SUMMARY OF WELL CONSTRUCTION, TESTING, AND PRELIMINARY FINDINGS FROM THE ALLIGATOR ALLEY TEST WELL, BROWARD COUNTY, FLORIDA

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SUMMARY OF WELL CONSTRUCTION, TESTING, AND PRELIMINARY FINDINGS

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ABSTRACT

A 2,811-foot deep test well, designated G-2296, was drilled during 1980 in The Everglades of south Florida along Alligator Alley (Interstate 75), as part of the Floridan Regional Aquifer-System Analysis (RASA) project. A 16-inch diameter steel casing was installed and grouted with cement from land surface to a depth of 895 feet, below which a nominal 8-inch diameter exploratory hole was drilled to a total depth of 2,811 feet. A 2-inch diameter steel monitor tube with perforations from 811 to 816 feet was grouted with cement in the outer annulus. Hydraulic packers were used to isolate selected zones for water sampling and measurement of water levels.

The Alligator Alley test well penetrated the surficial and intermediate aquifer systems and terminated in the Floridan aquifer system. The surficial aquifer system is about 180 feet thick and is composed chiefly of sandy limestone of the Tamiami Formation of Pliocene age. The intermediate aquifer system is composed of three artesian limestone aquifers and related confining beds and occurs between 180 and 770 feet in Miocene deposits.

The top of the Floridan aquifer system in the Alligator Alley test well is considered to coincide with the top of the Suwannee Limestone of Oligocene age at 770 feet on the basis of hydraulic head and water chemistry data. In U.S. Geological Survey Professional Paper 1403-B, published in 1986, Miller, in describing the regional hydrogeologic framework of the Floridan, placed the top of the Floridan at about 950 feet at this test well on the basis of apparent porosity changes within the Suwannee Limestone. This discrepancy of placing the top of the Floridan aquifer system at two different depths at this test well site is due to the difference in the criteria defined for the regional framework and for the area studies. For area studies, more refinements are needed than for a regional study.

About 67 percent of the total thickness of the Floridan aquifer system was penetrated by the well. The formations that comprise the Floridan aquifer system in the well (from shallowest to deepest) include the Suwannee and Ocala Limestones and the Avon Park and Oldsmar Formations.

The Floridan aquifer system is composed of many water-bearing zones that are chiefly horizontal solution zones in the limestone. The dominant water-bearing zones occur at about 1,030 feet near the top of the Ocala Limestone of late Eocene age and at about 2,560 feet in the Oldsmar Formation of early Eocene age. The 1,030-foot water-bearing zone (zone 3) contains brackish artesian water (chloride concentration of about 800 milligrams per liter), and the 2,560-foot water-bearing zone (zone 13) contains salty artesian water similar in composition to seawater (chloride concentration of about 19,000 milligrams per liter). The head in the 1,030-foot zone is about 59 feet above sea level (at prevailing density), whereas that in the

2,560-foot zone is about 7 feet above sea level (at prevailing density). However, a possibility exists that the head in the 1,030-foot zone is several feet higher than the measured value because of loss of head due to internal circulation when the well is shut-in. Pressure gradients in the well indicate a saltwater flow system and a freshwater flow system. The theoretical saltwater-freshwater interface, based on buoyancy and the pressure gradients, would occur at 1,918 feet. However, the salinity distribution shows a thick mixing zone between 1,600 and 2,200 feet that suggests a complex relation between the two flow systems.

A reverse geothermal gradient is indicated by the coldest water (24.5 °C) occurring at 2,811 feet (the bottom of the well). Radiocarbon activities measured in dissolved inorganic carbon species (unadjusted for fractionation and reactions during transit in the aquifer) indicate that the saltwater in the 2,560-foot zone (zone 13) in the lower part of the aquifer system is younger than brackish water in the upper part, and that brackish water in the 1,030-foot zone (zone 3) in the upper part of the aquifer system is relatively younger than that in the overlying and underlying zones. Comparison of the carbon-14 activity of the saltwater from the deep zone (zone 13) with that from wells of comparable depth at Fort Lauderdale and Miami, east of the test well, indicates that the carbon-14 activity of the saltwater increases (is younger) toward Fort Lauderdale and the Atlantic Ocean. The carbon-14 activity gradient indicates that seawater flows inland through the 2,560-foot zone. The potentiometric surface for the Upper Floridan aquifer indicates that brackish water moves seaward in the 1,030-foot zone.

INTRODUCTION

Purpose and Scope

In October 1978, the U.S. Geological Survey began a 4-year study of the Floridan aquifer system of the southeastern United States, as part of a national investigative program called RASA (Regional Aquifer-System Analysis). The objectives of the Floridan RASA project were to describe the hydrogeology, geochemistry, and flow in the Floridan aquifer system (Johnston, 1978).

Data for the Floridan aquifer system in south Florida are sparse because the system contains saline water and is of little use for supply, it occurs at relatively great depth (generally more than 500 feet), and adequate potable supplies are, for the most part, available from surficial aquifers. Variations in water quality, head, and temperature are known to occur within the limestones that comprise the aquifer system (Kohout, 1965; Meyer, 1971; Meyer, 1974), thereby suggesting a complex flow regimen. To obtain reliable data and fill in the gap between the eastern and western coasts of south Florida, an exploratory test well was drilled in the central Everglades, south of Lake Okeechobee (fig. 1).

After assessing the distribution of existing data (Smith and others, 1982), a drilling site was selected in west Broward County, about 5 miles east of the Broward-Collier County line and 0.4 mile north of mile post 54 on Alligator Alley (Everglades Turnpike, Interstate 75, State Road 84) (fig. 1). The site is on right-of-way of the South Florida Water Management District

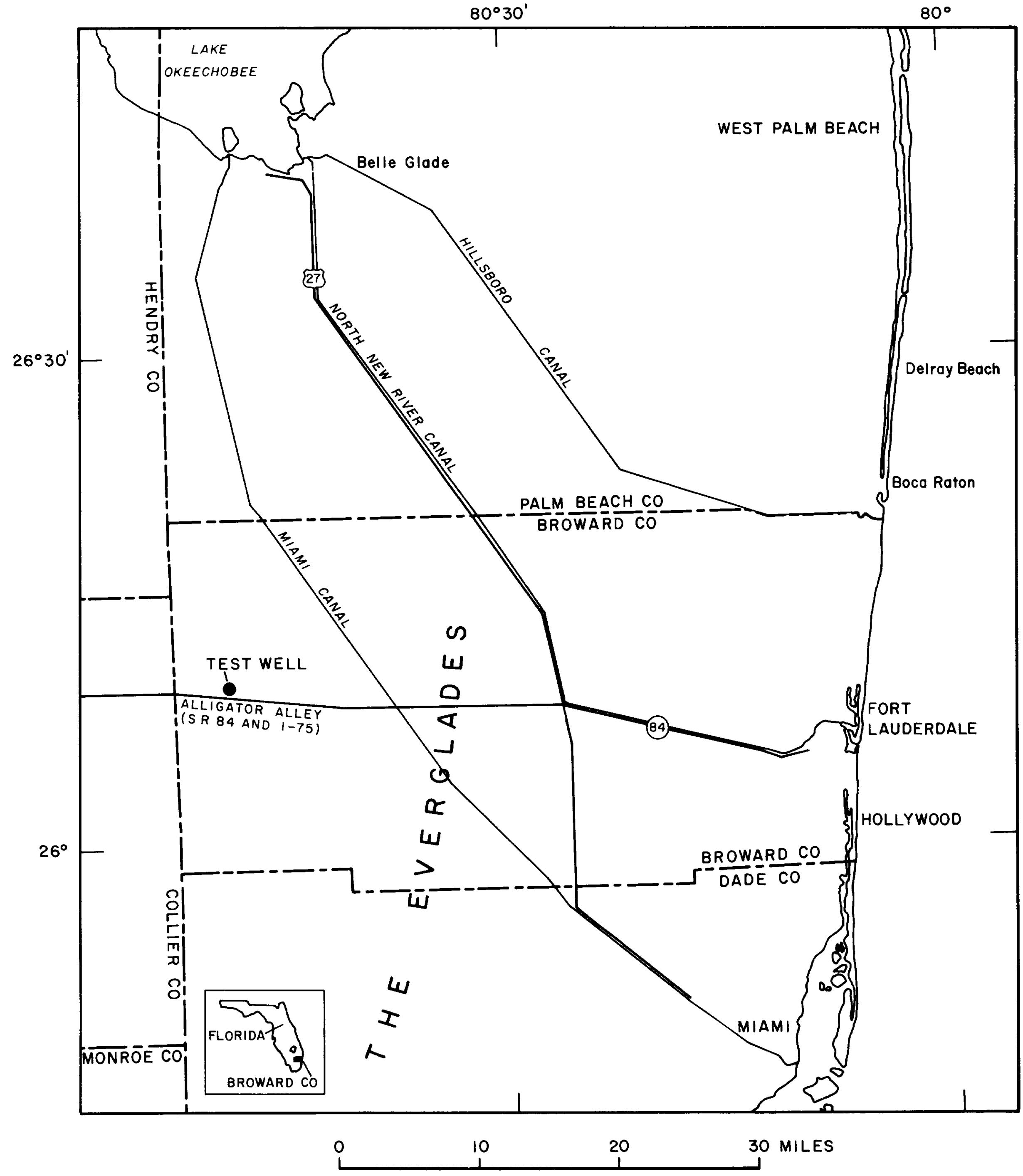

Figure 1.--Florida and Broward County showing location of the Alligator Alley test well.

(SFWMD) Canal 60, about 0.3 mile east of SFWMD pump station 140. Land surface at the site is 15.45 feet above sea level.

An identifier for national use, 261016080492601, and one for local use, G-2296, were assigned to the test well. The former is based on the well's latitude and longitude (26°10'16" N, 80°49'26" W). Plans and specifications were prepared in the spring of 1980 for a 2,800-foot test well that would tap a deep dolostone water-bearing zone in the Lower Floridan aquifer, called the Boulder Zone. The Boulder Zone is used chiefly as a receiving zone for injected liquid wastes along the southeastern coast of Florida. Construction of the well began in September 1980 and ended in November 1980, and testing began in March 1981 and ended in October 1981.

This report is a summary of data for the Floridan aquifer system collected as a result of the drilling and testing of the Alligator Alley test well. It includes information on construction, lithology, geophysical logs, water quality, and water levels, and summaries of sample descriptions, geophysical logs, comprehensive analyses of water samples, and photographs of the acoustic televiewer log from 895 to 2,811 feet are included in the appendixes. Interpretations of these data are also summarized in the report but are more fully described in a RASA project report approved for publication as U.S. Geological Survey Professional Paper 1403-G (F.W. Meyer, U.S. Geological Survey, in press, 1988).

Hydrogeologic Setting

South Florida is underlain by Cenozoic rocks to a depth of about 5,000 feet. These rocks are principally carbonates (limestone and dolostone) with minor amounts of evaporites (gypsum and anhydrite) occurring in the lower part and clastics (sand and clay) in the upper part. The movement of fresh ground water from inland areas to the ocean occurs chiefly through permeable parts of these rocks.

According to Miller (1986), evaporites in the rocks of Paleocene age are considered to be the base or lower confining bed of the active ground-water flow system. Overlying the evaporites are limestones and dolostones of the Floridan aquifer system (formerly the Floridan aquifer from Parker and others, 1955) that range from late Paleocene through Oligocene or early Miocene in age. Included in the Floridan aquifer system, in ascending order, are part of the Cedar Keys Formation, the Oldsmar and Avon Park Formations, the Ocala and Suwannee Limestones and part of the Tampa Limestone. Overlying the Floridan are alternating beds of sand, clay, marl, and limestone of Miocene age that contain the artesian intermediate aquifer system and that comprise the upper confining unit of the Floridan aquifer system. Above these beds are the surficial aquifers that range in age from Pliocene to Pleistocene and contain unconfined water.

Water in the Floridan aquifer system in south Florida generally is too saline for most uses. Therefore, the lower part, which contains seawater-like saltwater, is used primarily as a receptacle for liquid wastes; the upper part, which contains brackish water, is used primarily for limited industrial or agricultural supply. Artesian limestone aquifers in the overlying Miocene deposits of the intermediate aquifer system are important sources for supply in parts of southwest Florida. However, the surficial aquifers generally are the chief sources of potable water in south Florida. In southeast Florida, the surficial aquifer is called the Biscayne aquifer (Parker and others, 1955; Schroeder and others, 1958), and in southwest Florida it is called the "shallow aquifer" (McCoy, 1962).

Acknowledgments

The author thanks the following people whose efforts contributed to the success of the project: Russell J. Kerrn, Vice-President, Alsay-Pippin Corporation, Lake Worth, Fla.; Abe Kreitman (former chief of the ground-water section) and Leslie A. Wedderburn, South Florida Water Management District, West Palm Beach, Fla.; and Robert C. Buchmiller, Ellis Donsky, Gerald E. Idler, Lauralee Lidz, Harry C. Rollins, Robert J. Southwood, Craig L. Sprinkle, David C. Stanley, Henry J. Voegtle (deceased), Richard P. Volkman, and Stuart C. Williams, U.S. Geological Survey.

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WELL CONSTRUCTION

Construction of the Alligator Alley test well began September 15, 1980, with the arrival of the contractor's drilling equipment and supplies at the site and ended November 16, 1980, with their removal. Actual drilling occurred during 48 consecutive days (September 21 to November 7), of which 5 days were on standby for equipment shortage or breakdown (fig. 2). The work schedule consisted of two shifts of 12 hours daily, 7 days a week.

The unit used for drilling was a Skytop-Brewster 3AT[1] having a 6,000-foot depth capability and 275,000-pound hook load. The drill string consisted of 7-inch OD (outside diameter) API (American Petroleum Institute) drill pipe (6-inch inside diameter) having 10-inch drill collars (6-inch inside diameter). Circulation was through three 18,000-gallon steel tanks. Drilling from land surface to 934 feet was by the conventional hydraulic method (fluid movement down the drill pipe). Drilling from 934 to 2,811 feet was by the reverse-airlift method (fluid movement up the drill pipe).

[1]Use of the brand name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

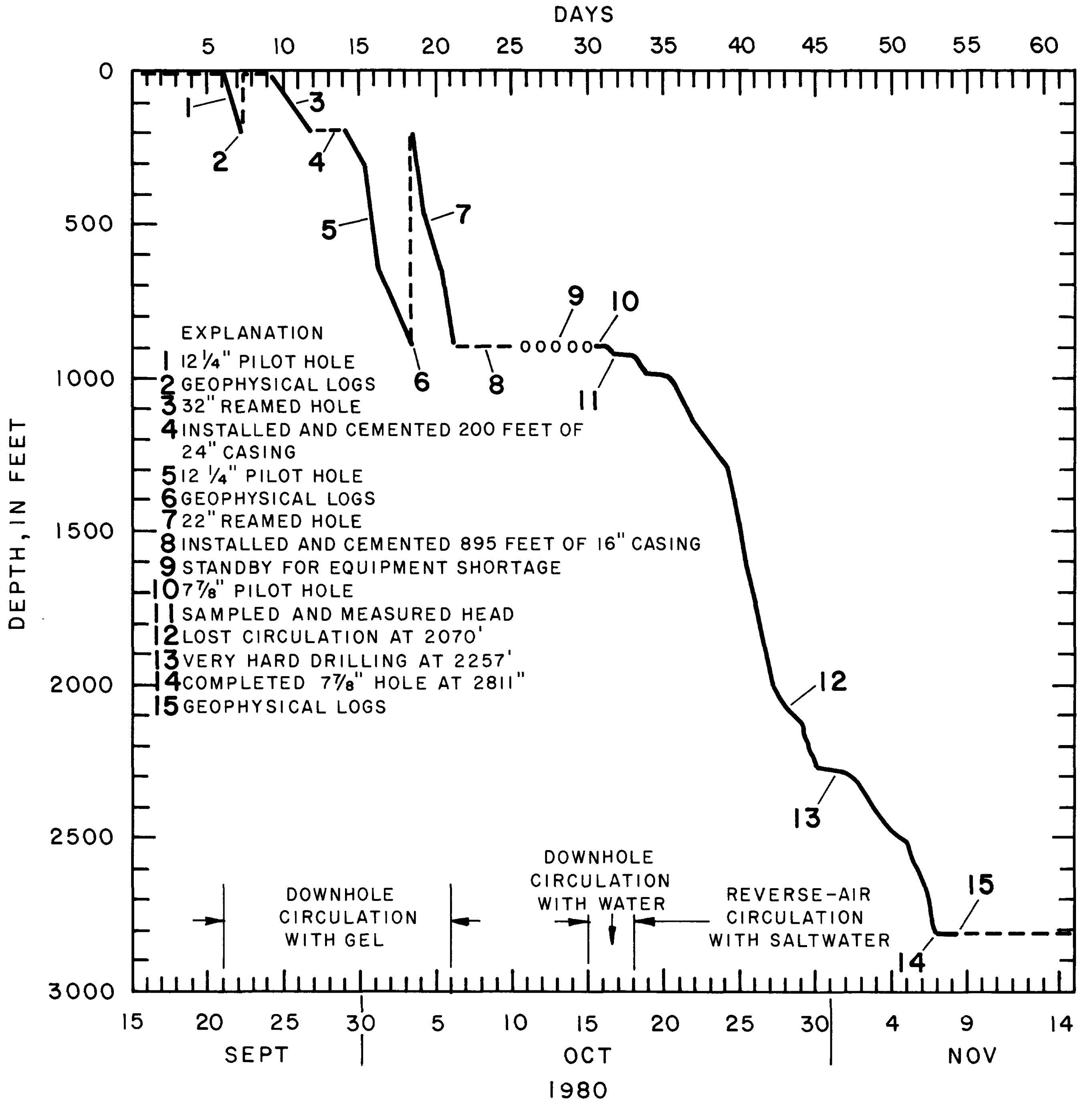

Figure 2.--Elements of well construction from September 15 to November 16, 1980.

Because of the potential for encountering strong artesian flows in the Floridan aquifer system, drilling fluids were circulated through the settling tanks back into the well to form a closed system. This procedure required the addition of large quantities of salt (sodium chloride) to the drilling fluid periodically to maintain the pressure head of the returned column of drilling fluid above that in the penetrated artesian water-bearing zones. At 2,389 feet, however, circulation problems occurred, and the well flowed out of control at a rate of several thousand gallons per minute and nearly undermined the drilling rig. A mixture of gel (bentonite drilling mud) and saltwater was pumped into the well to "kill" or stop the flow, and subsequent drilling proceeded by reverse airlift without returning the fluid to the well. About 1,450 sacks (58 tons) of salt were used during the entire drilling project.

Construction of the test well proceeded in three stages. The first stage involved drilling a 12¼-inch exploratory pilot hole through the surficial aquifer to a depth of 200 feet. Upon completion, the pilot hole was logged (see Appendix I for summary of geophysical logs) and then reamed to 32 inches in diameter to receive the 24-inch surface casing. A total of 200 feet of buttwelded 24-inch OD casing was installed in the reamed hole and cemented in place from the bottom of the casing to the surface with 350 sacks of API class B cement with 2-percent gel.

The second stage involved drilling a 12¼-inch exploratory pilot hole through the intermediate aquifer system to a depth of 900 feet in the Floridan aquifer system. Upon completion, the pilot hole was logged (see Appendix I) and then reamed to 22 inches to receive 16-inch OD casing. A 16-inch casing was selected for the final casing on the premise that the well would later be deepened and converted to a multiple-depth monitor well. A total of 895 feet of buttwelded 16-inch OD casing was installed in the reamed hole along with two strings of $2^7/^8$-inch OD steel casing (one 834 feet long and the other 330 feet long) on the outside of the 16-inch casing and cemented in place with 800 sacks of API class B cement with 2-percent gel. Later, on March 26, 1981, the deeper (834 feet) casing was directionally perforated from 811 to 816 feet for monitoring purposes. The shallower (330 feet) casing was not perforated because it failed to reach the intended depth of 567 feet in the Tampa Limestone of the intermediate aquifer system.

The third stage involved drilling a $7^7/^8$-inch exploratory pilot hole to a depth of about 2,800 feet in an attempt to penetrate the Boulder Zone, the deep dolostone that contains seawater-like water and locally receives liquid wastes. At 934 feet, drilling was suspended in the top of the Floridan aquifer system for several hours to obtain water samples for analyses and to measure the water level. A dolostone water-bearing zone, which resembled the Boulder Zone, was penetrated at about 2,450 feet, and drilling was terminated at 2,811 feet. Upon completion, the $7^7/^8$-inch hole was logged and later tested by installing inflatable, retrievable packers (see "Testing," next section). Conclusions reached later indicated that the well did not penetrate the target zone (which probably underlies the site at about 2,900 feet); however, data from deep coastal wells (J.I. Garcia-Bengochea, CH_2M Hill, Inc., oral commun., 1980) show that the 2,450-foot dolostone is hydraulically connected to the underlying Boulder Zone. A sketch of the completed well and geologic logs are shown in figure 3. Descriptions of the drill cuttings and geologic data are summarized in Appendix II.

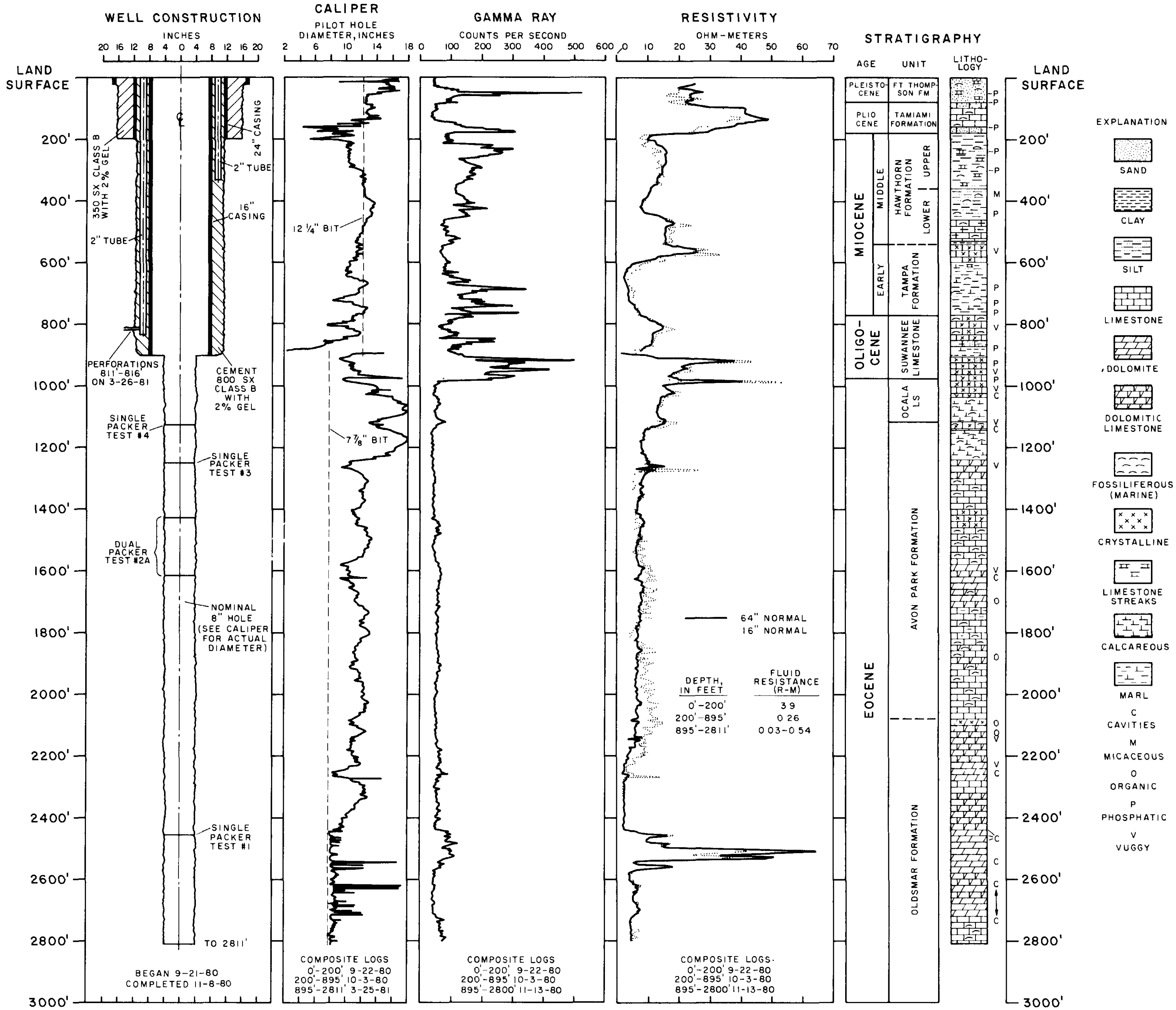

Figure 3.--Well construction and packer tests, caliper, gamma-ray, resistivity and lithology logs, and stratigraphy.

TESTING

Six tests were performed at selected depths in the Floridan aquifer system to identify permeable zones and determine the quality of the artesian water and the pressure head. The tests included the use of production packers, perforating guns, and onsite tests during drilling operations. The tests were limited in number, duration, and complexity due to the high costs of rig time and equipment rental. Water-quality and water-level data from these tests are discussed in subsequent sections of the report.

The first test was performed on October 18, 1980, during drilling operations at a depth of 934 feet and after the 16-inch casing had been installed and cemented at 895 feet. The purpose of the test was to obtain a sample of the artesian water from the first permeable zone below the casing and to measure its water level. To accomplish this, the drilling fluid, cuttings, and soft cement were flushed from the casing by circulating freshwater down the drill string. The drilling then proceeded slowly through the cement plug in the bottom of the casing into the underlying Suwannee Limestone. Progress was stopped at 934 feet when the well began to flow at about 40 gal/min. The well was then permitted to flow for several hours until the water was clear, and the specific conductance had stablized at 4,600 μS/cm (microsiemens per centimeter). A sample of the water was collected for selected water-quality analyses at 0300 hours on October 13, 1980. An expandable seal was then inserted into the top of the 16-inch casing to measure the water level (head). The water level rose to a height of 36.6 feet above land surface (52 feet above sea level) at 0700 hours on October 18; however, slight leaks in the seal and insufficient recovery time prevented the water level from reaching its maximum height (static level).

Four packer tests were performed during March 2-9, 1981, using an inflatable, retrievable packer to isolate selected parts of the open hole between 895 and 2,811 feet (fig. 3). The packer, a single-set production-injection type, had a 66-inch long element capable of expanding from $7^3/_8$- to $12^3/_4$-in. OD. The packer was placed at selected depths (see fig. 3 for locations) by using a $2^7/_8$-inch API drill pipe and inflated hydraulically. Water samples and water-level measurements (figs. 3 and 4) were obtained above and below the packer.

Packer test 1 was performed during March 2-4, 1981 (fig. 4). A single packer was set at 2,457 feet below land surface (fig. 3) at the top of the middle dolostone of the Oldsmar Formation at 1430 hours on March 3. A sample of the water flowing from the 16-inch casing was collected at 1830 hours, and the sample represented the composite flow above the packer from 2,457 to 895 feet. A sample of the water from below the packer was collected at 0200 hours on March 4 by pumping, because the water level was below land surface. The specific conductance of the water from below the packer was 50,000 μS/cm, and it represented the composite flow from 2,463 to 2,811 feet. About 5 hours after pumping ceased, the water level in the zone below the packer from 2,463 to 2,811 feet rose to 8.4 feet below land surface (7.0 feet above sea level). An expandable seal was placed in the 16-inch casing at 0658 hours, and the water level in the zone from 895 to 2,457 feet rose to 35.7 feet above land surface (50.2 feet above sea level). The water level in the zone from 895 to 2,457 feet continued to rise at the end of the test,

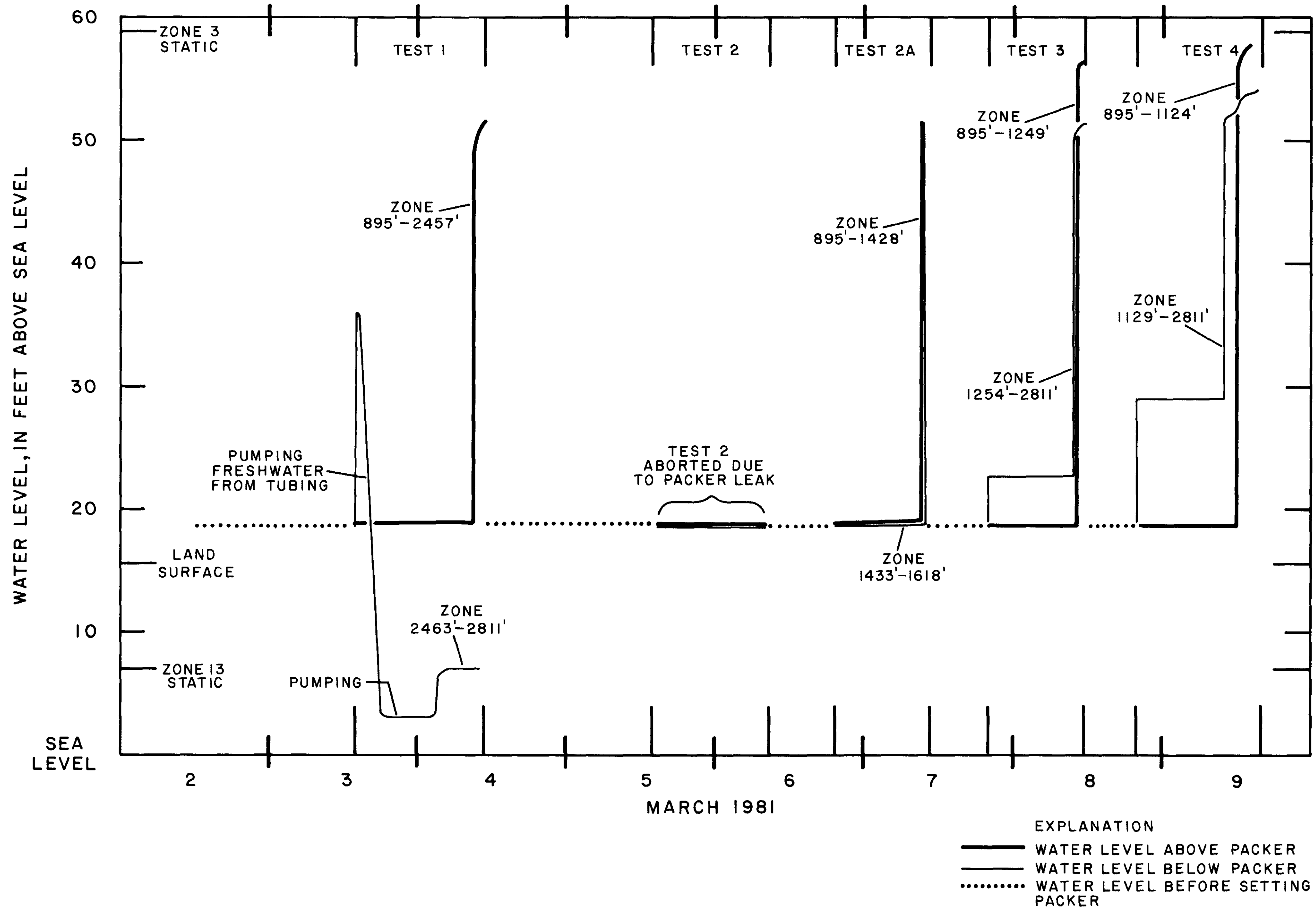

Figure 4.--Water-level measurements made during packer tests, March 2-9, 1981, compared with maximum measured water levels.

thereby indicating that a steady-state condition had not been reached. The water level in the zone from 2,463 to 2,811 feet, however, appeared to stabilize before the end of the test. Leakage across the packer was not indicated. The test demonstrated the effective confining capability of the rock where the packer was set. The water sample from the lower zones was, however, contaminated by residual drilling fluid that invaded the formation during drilling operations.

Packer test 2 was performed on March 5, 1981 (fig. 4). Two packers were positioned in the open hole at 1,408 feet and 1,638 feet in the Avon Park Formation. Attempts to inflate the packers were unsuccessful, and the test was aborted. Upon retrieval, one packer was found to be torn and leaking. No significant data were obtained for this test.

Packer test 2A was performed during March 6-7, 1981 (fig. 4). Two packers were set in the open hole at 1,428 feet (fig. 3) and 1,618 feet in the middle of the Avon Park Formation. Apparently, the 1,428-foot packer was insufficiently inflated due to a faulty shear pin (the pin sheared prematurely), and a crossflow occurred between the upper (895 to 1,428 feet) zone and the lower (1,433 to 1,618 feet) zone. The 1,618-foot packer effectively isolated the zone below the packer (1,623 to 2,811 feet), but the valve arrangement did not permit sampling or measurement of water levels below the 1,618-foot packer. Water samples were collected in the zone from 895 to 1,428 feet at 2355 hours on March 6, and in the zone from 1,433 to 1,618 feet at 0200 hours on March 7. The specific conductance of the water taken from the upper zone was 3,120 μS/cm, and that from the lower zone was 6,050 μS/cm. On March 7, an expandable seal was placed in the 16-inch casing to measure the static water level of the upper zone, and water levels in both zones responded, indicating previous leakage across the packer placed at 1,428 feet. The water level in the zone from 895 to 1,428 feet rose to 36.1 feet above land surface (51.6 feet above sea level), and that in the zone from 1,433 to 1,618 feet rose to 35.1 feet (50.6 feet above sea level). The expandable seal in the 16-inch casing was leaking badly during the measurements; therefore, the water levels measured for both zones are considered to be nonrepresentative. The water sample from 1,433 to 1,618 feet was probably diluted by flow from the overlying zone. Leakage across the 1,618-foot packer was not indicated.

Packer test 3 was performed on March 8, 1981 (fig. 4). A single packer was set in the open hole at 1,249 feet (fig. 3) in the upper part of the Avon Park Formation. Samples of the water from above and below the packer were collected for analyses. The specific conductance of the water from the upper zone was 3,150 μS/cm, and that from the lower zone was 10,450 μS/cm. The sample from above the packer represents the composite flow from 895 to 1,249 feet. However, the sample from below the packer does not represent the composite flow from 1,254 to 2,811 feet because some leakage occurred across the packer; therefore, proportionally less flow was contributed by the deep zone, of which part contains seawater-like saltwater. At 1012 hours, the water level in the zone below the packer was 36.5 feet above land surface (51.9 feet above sea level), whereas that in the zone above the packer was at about 3.0 feet above land surface (18.4 feet above sea level) while the well was discharging at about 1,000 gal/min. The head difference across the packer at that time was about 33.5 feet. At 1015 hours, the expandable seal was placed in the 16-inch casing. The water level in the zone from 895 to 1,249 feet rose from 3.0 to 41.2 feet above land surface (18.4 to 56.6 feet above sea level), and that in the zone from 1,253 to 2,811 feet rose from 36.6 to 36.8 feet (52.0 to 52.2 feet above sea level). Increasing the water level in the upper zone had slight but measurable effects on that in the lower zone, indicating that some leakage occurred across the packer. Leaks in the expandable seal and insufficient recovery time prevented the water levels from reaching the maximum (static level). At the end of the test, the water level in the upper zone was about 4.4 feet above that in the lower zone. The test demonstrated the confining capability of the rock at the point where the packer was set.

Packer test 4 was performed on March 9, 1981 (fig. 4). A single packer was set in the open hole at 1,124 feet (fig. 3) at the top of the Avon Park Formation. Water samples were collected from the zones above and below the packer. The specific conductance of the sample from the upper zone was 3,325 μS/cm, and that from the lower zone was 8,900 μS/cm. The sample from above the packer represents the composite flow from 895 to 1,124 feet; however, that from below the packer probably does not represent the composite flow from 1,129 to 2,811 feet. The water level in the zone below the packer at 1156 hours was 37.1 feet above land surface (52.5 feet above sea level), whereas that in the zone above the packer was at about 3.0 feet above land surface (18.4 feet above sea level) while the well was discharging at about 1,000 gal/min. The head difference across the packer was 34.1 feet. At 1200 hours, the expandable seal was placed in the 16-inch casing, and the water level in the upper zone rose from 3.0 to 42.3 feet above land surface (18.4 to 57.7 feet above sea level), whereas that in the lower zone rose from 37.1 to 38.7 feet (52.5 to 54.1 feet above sea level). Varying the head in the upper zone had measurable effects on that in the lower zone, indicating leakage across the packer. At the end of the test, the water level in the lower zone was 3.6 feet below that in the upper zone. Again, the test demonstrated the confining capability of the rock at the point where the packer was set.

The final test involved the use of a directional perforating gun. On March 26, 1981, a service company perforated the 834-foot 2-inch monitor tube (fig. 3) with 20 shots in the interval 811 to 816 feet below land surface at the top of the Suwannee Limestone. On April 21, the perforated zone was acidized which resulted in a flow of about 50 gal/min. On April 24, 1981, the water level was measured at 40.3 feet above land surface (55.7 feet above sea level), which was about 3.0 feet below that for the composite (between 895 and 2,811 feet) represented by the water-level measurement in the 16-inch casing. A sample of the artesian water was collected from the 2-inch monitor tube for analysis on October 19, 1981, and the specific conductance of the sample was 6,200 μS/cm. The difference in water levels indicates some degree of hydraulic separation of the perforated zone and the zone(s) below the 16-inch casing (below 895 feet).

GEOPHYSICAL LOGGING

Numerous geophysical logs were made during and after drilling operations to assist in interpreting the lithology and the water-bearing and water-quality characteristics of the rocks penetrated by the test well. The logs used primarily for lithologic interpretations were the natural gamma, electric (self-potential and resistivity), caliper, gamma-gamma (density), neutron (porosity), and acoustic (velocity). The logs used primarily for water-bearing characteristics were the caliper, flowmeter (fluid movement), fluid temperature, fluid resistivity, and acoustic televiewer.

Selected logs are shown with lithology and hydrogeology in figures 3, 5, and 6. A summary of the logs is presented in Appendix I. Composite photographs of the acoustic televiewer log are also presented in Appendix IV. Also used, but not included in the summary of logs, is a borehole television survey of the well from land surface to 2,811 feet. Full-scale copies of the geophysical logs and the video tape are available for inspection at the U.S Geological Survey office in Miami, Fla.

HYDROGEOLOGY

Three main hydrogeologic units are recognized in the strata penetrated by the Alligator Alley test well and include: (1) the surficial aquifer system; (2) the intermediate aquifer system (also referred to as the upper confining unit of the Floridan aquifer system); and (3) the Floridan aquifer system (fig. 5). The surficial aquifer system is composed of unconfined (or in some cases, poorly confined) aquifers that are more or less contiguous with land surface and lie above an areally extensive confining bed. The intermediate aquifer system is composed of one or more confined aquifers interbound with confining beds. The intermediate aquifer system as a whole greatly retards the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system. The Floridan aquifer system is an areally extensive and thick sequence of carbonate rocks of Tertiary age that are hydraulically connected in varying degrees. The Floridan is bounded above and below by areally extensive confining units. The upper confining unit is composed of clay or fine-grained calcareous sediments of early Miocene age. The lower confining unit (not penetrated by the test well) is composed of evaporite deposits of late Paleocene age.

Surficial Aquifer System

The surficial aquifer system is about 180 feet thick, of which the upper 60 feet is composed of unconsolidated shelly, quartz sand of Pleistocene age, and the lower 120 feet is composed of sandy, shelly limestone of the Tamiami Formation of Pliocene age. Phosphate containing uranium, which emits high rates of natural gamma rays, marks the top and bottom of the Tamiami Formation (fig. 3). The sand is chiefly fine-grained and yields only small quantities of water having high-organic content. The sand partially confines water in the underlying limestone. The limestone in the Tamiami is relatively permeable (fig. 5, water-bearing zone 1) and is capable of yielding large quantities of potable freshwater. In 1982, a sample of water from a zone between 50 and 150 feet in depth in shallow test well G-2329, located about 1¼ miles west of the Alligator Alley test well, had a chloride concentration of 120 mg/L and a specific conductance of about 1,000 μS/cm (Howie, 1987).

Intermediate Aquifer System

The intermediate aquifer system is about 590 feet thick and is composed of three confined limestone aquifers or water-bearing units and interlayered confining units (fig. 5, zones 1-3) of Miocene age. Water-bearing zone 1, the upper intermediate aquifer, ranges in depth from about 220 to 360 feet

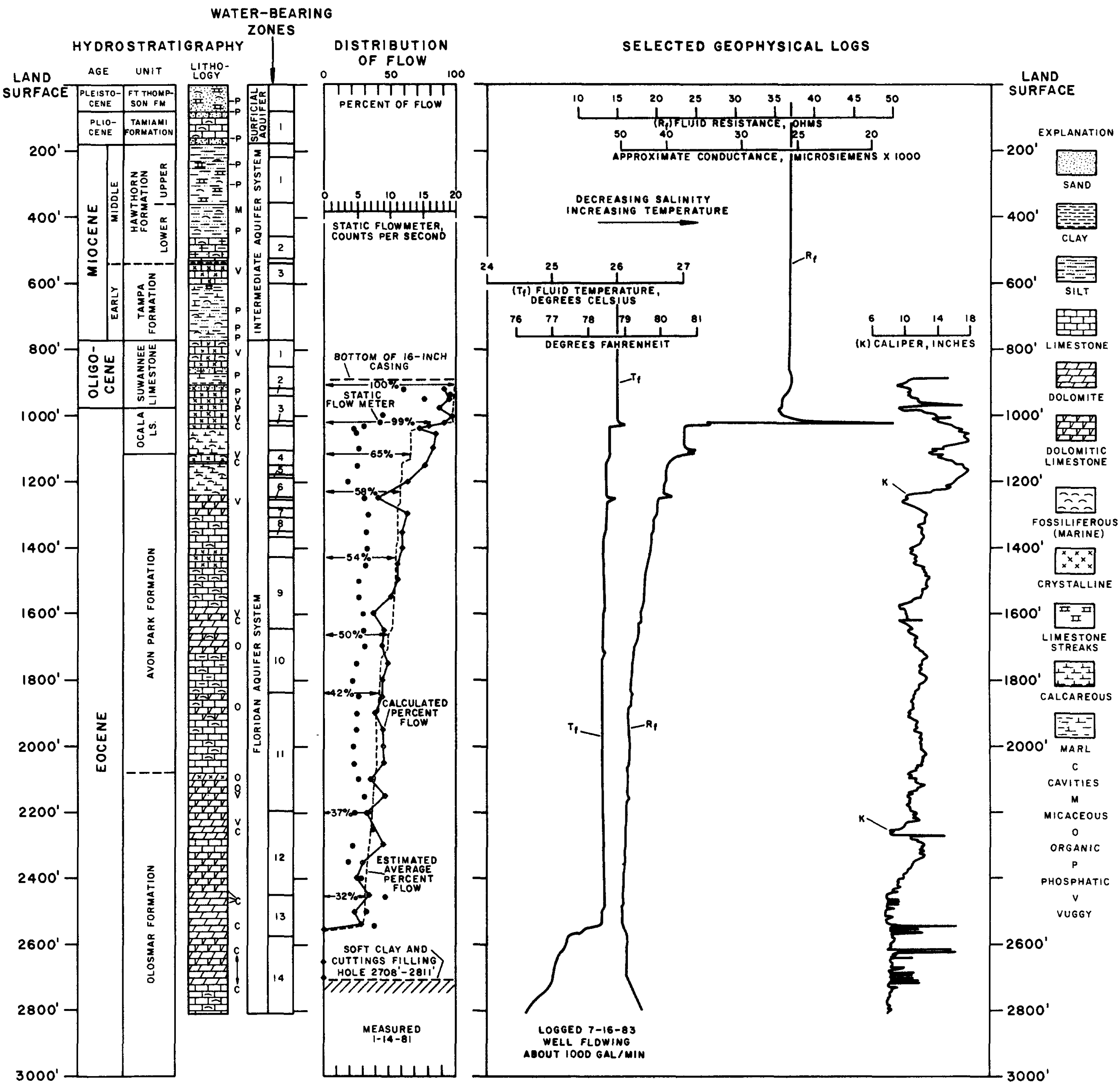

Figure 5.--Hydrogeology and distribution of flow with selected production logs, July 16, 1983.

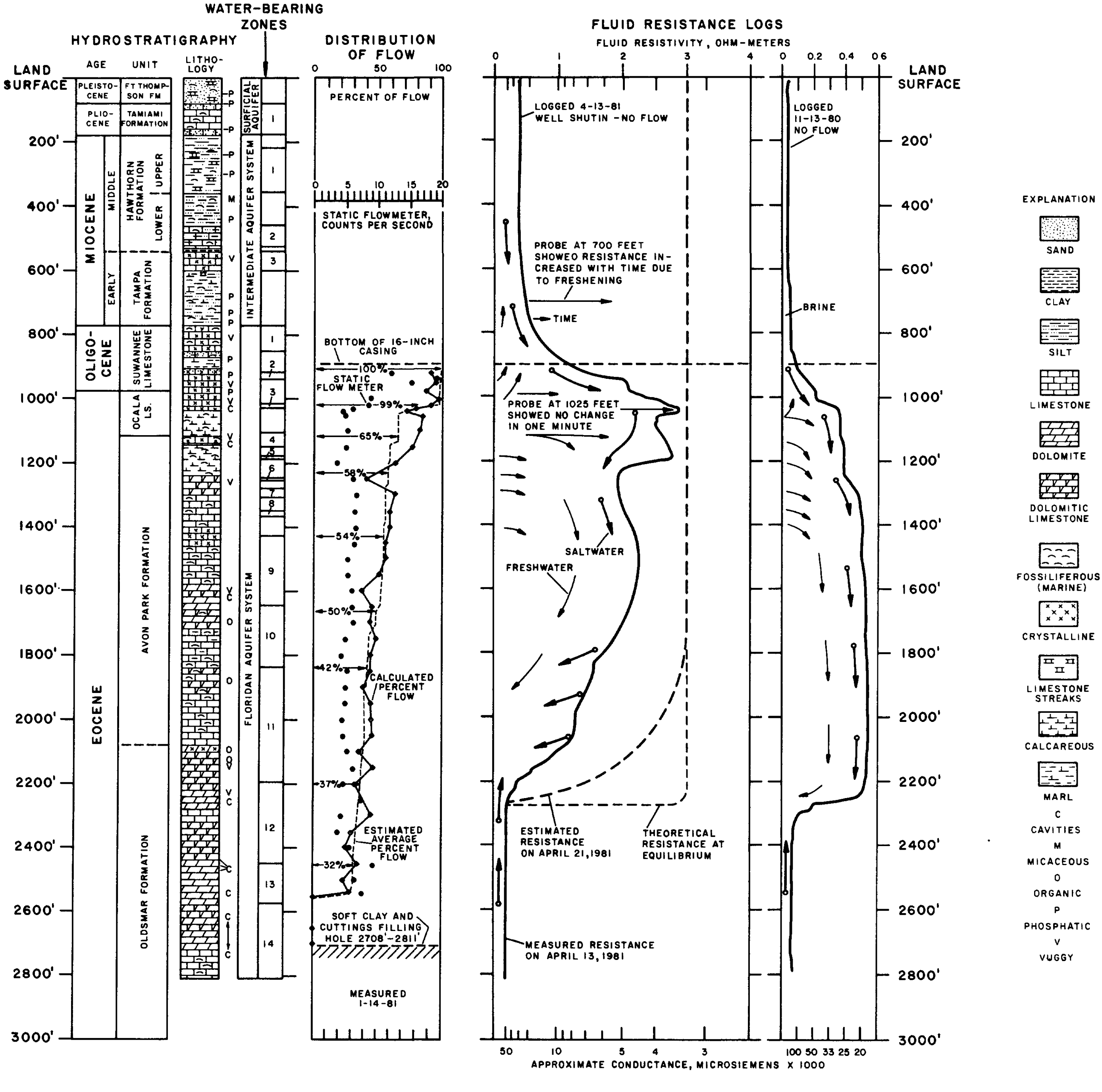

Figure 6.--Hydrogeology and distribution of flow with fluid resistance logs, November 13, 1980, and April 13, 1981.

and is composed of thinly bedded, gray, shelly limestone and interbedded sand and clay in the upper part of the Hawthorn Formation of middle Miocene age. The water-bearing and water-quality characteristics were not determined, but the rock type suggests that small quantities of brackish artesian water (less than 1,000 gal/min) can be obtained from wells that tap the entire thickness. Water-quality data are not locally available, but potable-quality water occurs in equivalent rocks in parts of Charlotte and Lee Counties on the Gulf Coast, west of Lake Okeechobee (Sutcliffe, 1975; Wedderburn and others, 1982). Zone 1 is confined above by a thick and extensive bed of silty, green clay of late Miocene age and below by thick and reportedly extensive beds of green, micaceous clay of middle Miocene age.

Water-bearing zone 2, the middle intermediate aquifer, ranges in depth from about 460 to 530 feet and is composed chiefly of sandy, shelly limestone in the lower part of the Hawthorn Formation of middle Miocene age. The water-bearing and water-quality characteristics of zone 2 were not determined in the test well, but the rock type compares to an aquifer in north-central Collier County (McCoy, 1962, p. 18), which in 1959, produced artesian water with a chloride concentration of 985 mg/L and a head of about 31 feet above sea level. Zone 2 is confined above by the previously described clay and below by a relatively thin (about 10- to 20-foot thick) bed of calcareous clay. The lower confining bed probably is not areally extensive and offers only local confinement.

Water-bearing zone 3, the lower intermediate aquifer, ranges in depth from about 540 to 600 feet and is composed of slightly sandy, shelly limestone of the Tampa Limestone of early Miocene age. The water-bearing and water-quality characteristics of zone 3 were not determined in the test well, but the rock type suggests that they compare with those of the overlying aquifer (zone 2). Zone 3 is confined above by the thin calcareous clay at the base of zone 2 and below by calcareous clay or calcilutite of early Miocene age. The lower bed of clay is the principal confining unit above the Floridan aquifer system and is easily recognized on the natural gamma-ray log (fig. 3) by high rates of gamma-ray emissions from uraniferous phosphate between 600 and 770 feet.

Floridan Aquifer System

The Alligator Alley test well penetrated about two-thirds of the estimated thickness of the Floridan aquifer system. The top of the aquifer system coincides with the top of the Suwannee Limestone of Oligocene age at 770 feet (fig. 5). The well terminated at 2,811 feet in the Oldsmar Formation of early Eocene age. According to Miller (1986), the base of the Floridan aquifer system occurs at about 3,800 feet in the Cedar Keys Formation of Paleocene age. The formations that comprise the system at the test well site are (from shallowest to deepest) the Suwannee Limestone of late Oligocene age, the Ocala Limestone of late Eocene age, the Avon Park Formation of middle Eocene age, and the Oldsmar Formation of early Eocene age.

Puri (1964, p. 107) noted that beds which were assigned to the Suwannee Limestone in south Florida differed faunally and stratigraphically from the typical Suwannee Limestone in north-central Florida and suggested that the beds in south Florida were deposited continuously during the Oligocene and early Miocene times. However, their stratigraphic position, fauna, and phosphate content suggest that they were deposited after a major period of erosion during mid-Oligocene time. Beds between 770 and 975 feet in the Alligator Alley test well are assigned to the Suwannee Limestone of south Florida.

Discrete water-bearing zones in the Floridan aquifer system are recognized in the test well by differences in permeability, pressure, water quality, and temperature. The zones are related chiefly to dissolution of the limestone and to the occurrence of fractured and cavernous dolostones. They generally occur at or near unconformities (ancient erosion surfaces) at formation boundaries. Permeability contrasts within the aquifer system suggest that locally, and perhaps regionally, some of the major water-bearing zones can be considered as distinct aquifers. Although the 16-inch casing penetrated most of the Suwannee Limestone (fig. 3), a 2-inch monitor tube with perforations from 811 to 816 feet provided data from the part that was inadvertently cased off. The test well flows naturally at about 1,000 gal/min from the interval between 895 and 2,811 feet and produces a blend of saline water that compares to about a 50-percent mixture of freshwater with seawater. Most of the water is produced from two major water-bearing zones, but many permeable zones are recognized. A reverse geothermal gradient is indicated, and the coolest water temperature occurs at the bottom of the well. The exact point of temperature reversal is not known because most of the fluid temperature logs were usually obtained while the well was flowing. A temperature log on April 10, 1981, while the well was shut-in, indicated the temperature reversal occurs at about 1,700 feet. The minimum temperature, however, occurs at a depth of about 2,560 feet.

Water Quality

As previously stated, water from the Floridan aquifer system in south Florida is too saline for most purposes. In the test well, the water having least salinity occurs in the Ocala Limestone and Avon Park Formation, whereas that having greatest salinity occurs in the Oldsmar Formation. The head in the Ocala Limestone and Avon Park Formation is sufficiently high to cause the well to flow naturally at rates between 1,000 and 2,000 gal/min. The salinity of the composite flow from all water-bearing zones, however, resembles a blend of about 50-percent seawater and 50-percent freshwater--a phenomenon related to the uphole movement of freshwater from the Ocala Limestone and saltwater from the Oldsmar Formation by reduced pressure in the borehole and dilution during free flow.

Water samples were collected during and after drilling operations with packers and thief samplers by pumping and free flows. Specific conductance, chloride concentration, and temperature were determined routinely on the samples to compare water quality from different zones (table 1). Comprehensive analyses of 13 water samples in table 1 are included in Appendix III.

Table 1.--Selected water-quality data

[μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; °C, degrees Celsius; gal/min, gallons per minute; min, minutes]

Date	Time	Depth (feet)	Specific conductance (μS/cm)	Chloride (mg/L)	Temperature (°C)	Remarks
10/16/80	1930	895-915	1,750	--	--	Airlifted sample during drilling. Diluted with fresh surface water.
10/17/80	0710	895-915	2,180	--	--	do.
	1310	895-925	2,520	--	27.0	do.
	1530	895-934	4,180	--	27.5	Airlifted sample during drilling. Uncontaminated.
	1630	895-934	4,200	--	27.0	Same as above. Slight H2S odor.
10/18/80	0300	895-934	4,600	1,200	26.5	Well flowing about 30 gal/min. Measured water level.
11/18/80	0730	0-895	5,750	--	--	Composite of casing water.
	0830	895-2,776	23,100	--	--	Collected at surface after flowing 30 min at about 2,000 gal/min. H2S odor.
	0900	895-2,776	25,800	--	--	Collected at surface after flowing 1 hour at about 2,000 gal/min. H2S odor.
	0930	895-2,776	25,800	--	--	Collected at surface after flowing 1½ hours. Flow decreasing to about 1,000 gal/min.
	1015	895-2,776	23,500	--	26.0	Collected at surface after flowing 2¼ hours.
	1200	895-2,776	25,800	--	26.5	Collected at surface after flowing 4 hours.
	1245	895-2,776	24,900	--	26.5	Collected at surface after flowing 4-3/4 hours.
	1355	1,027	14,600	4,800	--	Collected with thief sampler after flowing 5 hours, 55 min.
	1410	1,130	37,500	14,100	--	Collected with thief sampler after flowing 6 hours, 10 min.
	1440	1,220	41,000	15,800	--	Collected with thief sampler after flowing 6 hours, 40 min.
	1445	895-2,776	22,300	--	26.0	Collected at surface after flowing 6 hours, 45 min.
	1450	1,870	47,500	18,500	--	Collected with thief sampler after flowing 6 hours, 50 min.
	1510	2,690	48,500	19,200	--	Collected with thief sampler after flowing 7 hours, 10 min.
3/2/81	1420	895-2,811	29,500	--	26.0	Collected at surface after flowing 2 hours at about 1,500 gal/min. Affected by salt added to stop flow.
3/3/81	1830	895-2,457	13,500	4,600	25.1	Packer test 1. Well flowing at about 2,000 gal/min.
3/4/81	0200	2,463-2,811	50,000	19,500	24.7	Packer test 1. Pumped sample. Test zone would not flow.
3/5/81	1330	895-2,811	29,000	--	26.0	Packer test 2. Collected at surface. Packers at 1,408 and 1,638 feet not inflated. Well flowing.
3/6/81	0700	895-2,811	24,700	--	26.0	do.
	2355	895-1,428	3,120	800	26.0	Packer test 2A. Sampled at surface. Well flowing about 1,000 gal/min.
3/7/81	0200	1,433-1,618	6,050	1,800	25.9	Packer test 2A. Sampled straddled zone. Flowing 80 gal/min. Some leakage across top packer.
	0715	895-1,428	3,400	--	26.0	Packer test 2A. Sampled at surface. Well flowing about 1,000 gal/min.

Table 1.--Selected water-quality data--Continued

Date	Time	Depth (feet)	Specific conductance (µS/cm)	Chloride (mg/L)	Temperature (°C)	Remarks
3/7/81	0716	1,433-1,618	5,000	--	26.0	Packer test 2A. Sampled straddled zone. Flowing about 5 gal/min. Some leakage across top packer.
3/8/81	0630	895-1,249	3,150	800	26.2	Packer test 3. Well flowing about 1,000 gal/min
	1145	1,254-2,811	10,450	3,000	26.0	Packer test 3. Flowing about 50 gal/min. Rock partly blocking flow at 2,450 feet.
3/9/81	0730	895-1,124	3,325	850	26.2	Packer test 4. Flowing about 1,000 gal/min.
	1000	1,129-2,811	8,900	2,800	26.1	Packer test 4. Flowing about 50 gal/min.
3/26/81	1215	895-2,811	3,700	--	--	Collected at surface after flowing about 2 min at 2,000 gal/min. Casing water.
	1225	895-2,811	31,000	--	--	Collected at surface after flowing 12 min at 2,000 gal/min. Rock partly blocking flow at 978 feet.
	1328	895-2,811	25,500	--	--	Collected at surface after flowing 75 min at about 1,500 gal/min. Partial blockage at 978 feet.
4/1/81	0955	895-2,811	29,000	11,000	26.0	Collected at surface after flowing 1 hour at about 2,000 gal/min.
4/8/81	1239	1,020	26,000	9,350	--	Collected with thief sampler. Well flowing.
	1253	1,040	38,000	14,050	--	do.
	1308	1,260	42,700	16,050	--	do.
	1326	1,600	44,000	17,700	--	do.
	1349	2,250	50,000	19,350	--	do.
	1417	2,520	50,000	19,350	--	do.
	1445	895-2,811	26,200	9,400	--	Collected at surface. Well flowing.
	1447	2,600	50,000	19,350	--	Collected with thief sampler. Well flowing.
4/24/81	1015	811-816	5,400	--	26.0	Collected from perforated 2-inch monitor tube. Flowing about 50 gal/min.
	1100	811-816	6,400	--	--	do.
10/19/81	1030	895-2,811	3,700	1,100	--	Collected at surface after flowing 2 min at about 2,000 gal/min. From 1,030 feet.
	1230	811-816	6,200	1,600	--	Collected from perforated 2-inch monitor tube. Flowing about 62 min at 50 gal/min.
	1500	2,500	54,000	22,700	--	Collected with thief sampler. Well flowing 4½ hours at about 1,000 gal/min.

The specific conductance and chloride concentrations for 26 samples were used to establish a relation to estimate chloride concentrations for known values of specific conductance. The regression equation for the relation is:

$$Y = 0.399 X - 693, \quad (1)$$

where Y is chloride concentration, in milligrams per liter; and
X is specific conductance, in microsiemens per centimeter.

The correlation coefficient is 0.999, and the relation is used best for specific conductances between 4,000 and 50,000 μS/cm.

After the well had been shut-in for several weeks and then reopened, the flow from the well changed rapidly in quality and in quantity. For example, on March 26, 1981, the specific conductance increased from 3,700 to 31,000 μS/cm in about 10 minutes (table 1). At a rate of 2,000 gal/min, the water in the casing (about 8,490 gal) would be replaced in about 4 minutes, and the water in the open hole (about 9,310 gal) would be replaced in about 5 minutes. A rapid decline in flow rate from 2,000 to 1,000 gal/min is related to the increased density of the water column as saltwater from the lower part of the well was being blended with brackish water from the upper part of the well. A discussion of the phenomena is presented in sections about water levels and water movement.

The specific conductance of 14 samples of the composite flow (895 to 2,811 feet) after flowing at least 30 minutes ranged from 22,300 μS/cm at 1445 hours on November 18, 1980, to 31,000 μS/cm at 1225 hours on March 26, 1981; the average was 26,150 μS/cm. Variations in the specific conductance during free flow are probably related to variations in mixing. Samples obtained with a Foerst thief sampler at various depths while the well was flowing show that specific conductance generally increased with depth (table 1, samples on November 18, 1980, April 8, 1981, and October 19, 1981). The specific conductance of five samples from depths equal to or more than 2,250 feet ranged from 48,500 to 54,000 μS/cm, averaging 50,000 μS/cm, which is comparable to that for modern seawater. The specific conductance of samples from packer tests during drilling operations and from the perforated 2-inch monitor tube shows that the levels increase uphole from about 3,100 μS/cm at about 1,250 feet to 6,400 μS/cm at 811 feet and downhole from about 3,100 μS/cm at about 1,430 feet to about 50,000 μS/cm at 2,463 feet.

Fluid resistance and temperature logs show the cumulative effects of inflow from the water-bearing zones in the borehole. Superimposed on the fluid resistance logs is a scale showing the approximate conductance. Conductance and resistance are inversely related; that is, high resistance is low conductance. The fluid resistance and temperature logs of July 16, 1983 (fig. 5), were obtained after the well had flowed sufficiently for the water quality to stabilize. Both logs infer the presence of several water-bearing zones, but as previously mentioned, two are the most significant--a zone at about 1,030 feet, which contributes a significant amount of warm brackish water, and a zone at about 2,560 feet, which contributes cooler saltwater whose specific conductance compares with that of modern seawater. According to the fluid resistance log, the cumulative conductance of all the zones was about 26,000 μS/cm, which compares closely to the average specific conductance of 14 samples.

All temperature logs showed a reverse geothermal gradient that is related to the cooler saltwater in an underlying untapped water-bearing zone (Boulder Zone). The coldest temperature occurs at the bottom of the well, and the flow becomes progressively warmer uphole by contributions of warmer water from shallower zones. The cumulative effect of inflowing ground water uphole produces a blend that has a temperature of about 26.0 °C.

The temperature and fluid resistance logs (fig. 5) show that between 2,560 and 2,811 feet the temperature decreased from about 25.7 to 24.5 °C, and that concurrently there was an increase in fluid resistance. The temperature decrease could be related to very slight upward flow of cooler saltwater from a major untapped zone (Boulder Zone) that probably occurs at about 2,900 feet (Meyer, 1974; 1984) or to heat conduction to the underlying zone. The increase in fluid resistance near the bottom of the well is, therefore, temperature related and not an indication of inflowing freshwater.

The fluid resistance log of November 13, 1980 (fig. 6), was obtained 5 days after the completion of the well when drilling fluid (brine), which had been added to the well to suppress the artesian head (additives to prevent flow), was still in place. As previously described, the drilling fluid consisted of a mixture of salt and bentonite clay (gel). The fluid resistance log (fig. 6) shows the salty additives remaining in the top and bottom of the well. The resistance averaged about 0.03 ohm-meter (330,000 μS/cm) from land surface to a depth of about 1,000 feet and about 0.06 ohm-meter (167,000 μS/cm) from 2,260 to 2,800 feet. Between 1,000 and 2,250 feet, the resistance averaged about 0.5 ohm-meter (20,000 μS/cm), suggesting downhole movement of brackish water from the water-bearing zones in the upper part of the borehole to those in the lower part. It is possible that any residual drilling fluid that invaded the water-bearing zones may have influenced the chemical quality of the water sampled.

In addition to routine water-quality analyses, analyses of dissolved gases and bacterial populations were made on selected samples. The results of testing for dissolved gases and various aerobic and anaerobic bacterial organisms are listed in table 2. The low concentrations of oxygen and methane indicate that a reducing environment is present in most of the Floridan aquifer system at the test well. The highest dissolved oxygen level was measured in water collected with a thief sampler. Although the thief sampler was preflushed with industrial-grade nitrogen gas, trace amounts of oxygen could have remained in the sampler. Also, the high dissolved oxygen measured in the 1,428- to 1,618-foot sample (packer test 2A) may indicate contamination of the gas sampling tube with atmospheric gases; alternatively, the water sample itself may have been a composite of aquifer water and drilling fluids that contain residual oxygen. The presence of denitrifying and sulfate-reducing bacteria in every sample analyzed is an indication of the reducing conditions in the aquifer system. The high counts of total aerobes may be misleading as facultative organisms are also counted in that procedure.

Table 2.--Dissolved gases and bacteria in selected water samples

[ND, gas not detected; --, measurement not taken]

Date	Depth (feet)	Dissolved gases, pressure in atmosphere at indicated temperature[1]							Organisms per 100 milliliters			
		N_2	O_2	AR	CH_4	CO_2	He	H_2	Total anaerobes	Total aerobes	Denitrifiers	Sulfate reducers
3/4/81	2,463-2,811	0.98	0.002	0.015	ND	0.0027	--	--	10^2	10^6	10^4	10^2
3/7/81	1,433-1,618	1.16	.029	.013	.0008	.0009	--	--	10	10^7	10^3	10^2
3/8/81	895-1,249	1.20	.002	.015	.0012	.0017	--	--	10	10^3	10^4	1
3/9/81	895-1,124	1.22	.004	.018	.0014	.0017	--	--	10	10^5	10^4	10^2
10/19/81	811-816	1.23	.0007	.016	.0017	.0017	--	--	--	--	--	--
	895-1,030	1.22	.0032	.015	.0014	.0010	--	--	--	--	--	--
	2,500	[2]2.09	.076	.007	ND	.0022	--	--	--	--	--	--

[1]No corrections have been made for salting-out effects.

[2]Sample collected from an N_2-flushed thief sampler.

Water-Bearing Zones

Water-bearing zones in the Floridan aquifer system were identified primarily from flowmeter, fluid resistance, and fluid temperature logs (figs. 5 and 6). The percentage of the total flow (the discharge measured at land surface) was calculated at about 50-foot depth intervals from point velocities on the flowmeter log and from the cross sections (diameter) on the caliper log. Miscellaneous specific conductance measurements of water samples (table 1) were used to identify and evaluate the quantity and quality of water from each zone. The flowmeter-caliper calculations were augmented by calculations based upon the contributions (conductance load) of inflowing ground water from the water-bearing zones, and the cumulative conductance load was compared to the conductance of the fluid resistance log of July 16, 1983 (fig. 5). Acoustic televiewer photos (Appendix IV) and borehole television surveys also were used to identify the water-bearing zones. The water-bearing zones appear to be chiefly related to solution-riddled (in some cases cavernous) and fractured limestone. The water-bearing zones in the Floridan aquifer system as penetrated by the borehole are numerous, but at least 14 were identified and evaluated (table 3).

Zones 3 and 13 contributed about 66 percent of the total borehole flow. Zone 3 was the principal contributor (34 percent) of relatively fresh water (specific conductance of about 3,300 μS/cm) from the upper part of the aquifer system, and zone 13 was the principal contributor (32 percent) of salty water (specific conductance of about 50,000 μS/cm) from the lower part. The remaining 34 percent of the total flow was contributed by numerous less-permeable zones that were included in the remaining 12 zones. Zones 2 through 9, the interval from 895 to 1,645 feet, collectively contributed about 50 percent of the borehole flow with water whose composite specific conductance was about 5,000 μS/cm. Zones 10 through 14, the interval from 1,645 to 2,811 feet, collectively contributed about 50 percent of the borehole flow with water whose composite specific conductance was 45,500 μS/cm. Zones that contributed little or no water to the total borehole flow (for example, those that contributed 1 percent or less) probably constitute confining beds in the aquifer system. Zones 1 through 9, which contributed about 50 percent of the total flow, are within the Upper Floridan aquifer as delineated by Miller (1986). Zones 10 and 11, which contributed about 13 percent of the total flow, are within the middle confining unit of the Floridan aquifer system (Miller, 1986). Zones 12 through 14, which contributed about 37 percent of the total flow, are within the Lower Floridan aquifer (Miller, 1986).

The discussion of individual water-bearing zones that follows is keyed to the stratigraphy and lithology and to the estimates of flow and cumulative fluid resistance shown in figures 5 and 6. Zones 9 through 12 and 14 are discussed in minor detail because the contributions from these zones were less distinctive in quantity and quality.

Upper Floridan aquifer

Zone 1 is in the upper part of the Suwannee Limestone between 770 and 840 feet. It was cased off during construction, and therefore, did not contribute to the analysis based on borehole flow. However, data on water

Table 3.--Estimated distribution of flow and conductance

[µS/cm, microsiemens per centimeter; % x µS/cm, percent times microsiemens per centimeter]

Zone[1]	Depth (feet)	Per-cent of flow	Cumu-lative percent of flow	Esti-mated average conduc-tance (µS/cm)	Conduc-tance load (% x µS/cm)	Cumu-lative conduc-tance load (% x µS/cm)	Esti-mated cumu-lative conduc-tance (µS/cm)	Remarks
1	770-840	0	0	6,200	0	0	0	Zone cased off. Sampled from perforated monitor tube at 811 to 816 feet.
2	895-940	1	100	4,600	4,600	2,528,200	[2]25,300	Minor inflow from many cavities.
3	1,020-1,034	34	99	3,300	112,200	2,523,600	25,500	Major inflow from large cavities at 1,025 and 1,032 feet.
4	1,110-1,154	6	65	3,300	19,800	2,411,400	37,100	Major inflow from large cavities at 1,114, 1,120, 1,125, 1,127, and 1,132 feet.
5	1,180-1,192	1	59	2,500	2,500	2,391,600	40,500	Minor inflow from small cavities.
6	1,248-1,256	2	58	2,500	5,000	2,389,100	41,200	Minor inflow from small cavities at 1,248 and 1,256 feet.
7	1,280-1,310	1	56	3,300	3,300	2,384,100	42,600	Minor inflow from small cavities at 1,284, 1,286, 1,288, 1,304, and 1,308 feet.
8	1,350-1,370	1	55	3,300	3,300	2,380,800	43,300	Minor inflow from small cavities at 1,356, 1,360, 1,365, and 1,367 feet.
9	1,430-1,645	4	54	25,000	100,000	2,377,500	44,000	Major inflow from cavities at 1,642 feet. Minor inflow from small cavities at 1,430, 1,468, 1,476, 1,506, 1,570, 1,578, 1,592, 1,600, 1,606, and 1,610 feet.
10	1,645-1,840	8	50	35,000	280,000	2,277,500	45,500	Major inflow from cavities at 1,715 feet. Minor inflow from cavities at 1,625, 1,678, 1,690, 1,735, 1,754, 1,764, 1,793, and 1,809 feet.
11	1,840-2,200	5	42	36,900	184,500	1,997,500	47,600	Major inflow from cavities at 1,896, 2,070, and 2,172 feet. Minor inflow from cavities at 1,856, 1,874, 1,960, 2,028, and 2,126 feet.
12	2,200-2,457	5	37	42,600	213,000	1,813,000	49,000	Major inflow from cavities at 2,250 feet. Minor inflow from cavities at 2,228, 2,258, 2,308, and 2,340 feet.
13	2,457-2,580	32	32	50,000	1,600,000	1,600,000	50,000	Major inflow from cavities at 2,490 to 2,491, 2,544 to 2,546, 2,550 to 2,552, and 2,560 to 2,562 feet.
14	2,580-2,811	<1	1	50,000				Very minor inflow from cavities at 2,616, 2,635, 2,653, 2,672, 2,703, and 2,715 feet.

[1]Zones 1 to 9 represent the Upper Floridan aquifer, zones 10 and 11 represent the middle confining unit, and zones 12 to 14 represent the Lower Floridan aquifer.

[2]Average conductance of 14 samples collected at surface is 26,150 µS/cm.

quality, head, and yield of the zone were obtained from the perforated 2-inch monitor tube open to the interval 811 to 816 feet. The yield of the perforated zone suggests that this zone could contribute at least 1 or 2 percent to the total borehole flow with water that has a conductance of 6,200 μS/cm.

Zone 2 is in the lower part of the Suwannee Limestone between 920 and 940 feet. It contributed about 1 percent of the total flow with water having an estimated average conductance of about 4,600 μS/cm. The flow originates from many cavities that appear on the acoustic televiewer photos to be filled with soft material.

Zone 3 is in the upper part of the Ocala Limestone between 1,020 and 1,034 feet. It contributed about 34 percent of the total flow with water having an estimated average conductance of about 3,300 μS/cm. The flow from zone 3 originates from large cavities between 1,020 and 1,032 feet (fig. 7), which are related to the erosion surface at the top of the Ocala Limestone.

Zone 4 is at the top of the Avon Park Formation between 1,110 and 1,154 feet. It contributed about 6 percent of the total flow with water having an estimated average conductance of about 3,300 μS/cm. The flow from zone 4 originates from large cavities at 1,114, 1,120, 1,125, 1,127, and 1,132 feet, which are related to the erosion surface at the top of the Avon Park Formation.

Zones 5 and 6 are in the upper part of the Avon Park Formation between 1,180 and 1,192 feet and between 1,248 and 1,256 feet, respectively. They contributed about 3 percent of the total flow with water having an estimated average conductance of about 2,500 μS/cm. The flow from each zone originates from small cavities.

Zones 7 and 8 are in the upper part of the Avon Park Formation between 1,280 and 1,310 feet and between 1,350 and 1,370 feet, respectively. They contributed about 2 percent of the total flow with water having an estimated average conductance of about 3,300 μS/cm. The flow from each zone originates from many small cavities.

Zone 9 is in the middle of the Avon Park Formation between 1,430 and 1,645 feet. It contributed about 4 percent of the total flow with water having an estimated average conductance of about 25,000 μS/cm. However, the conductance of a water sample obtained by packer test 2A (table 1) on March 7, 1981, between 1,433 and 1,618 feet, was only 6,050 μS/cm. Leakage across the upper packer during test 2A was indicated; therefore, the sample was diluted with water of lower conductance from above 1,433 feet. The cumulative conductance of the borehole flow between 1,430 and 1,645 feet from the fluid resistance log suggests that the average level of 25,000 μS/cm is representative. Ground water having a total dissolved solids concentration of 10,000 mg/L (about equivalent to a specific conductance of 13,200 μS/cm) occurs in this interval. The flow from zone 9 originates chiefly from cavities at about 1,642 feet with minor inflows from many small cavities.

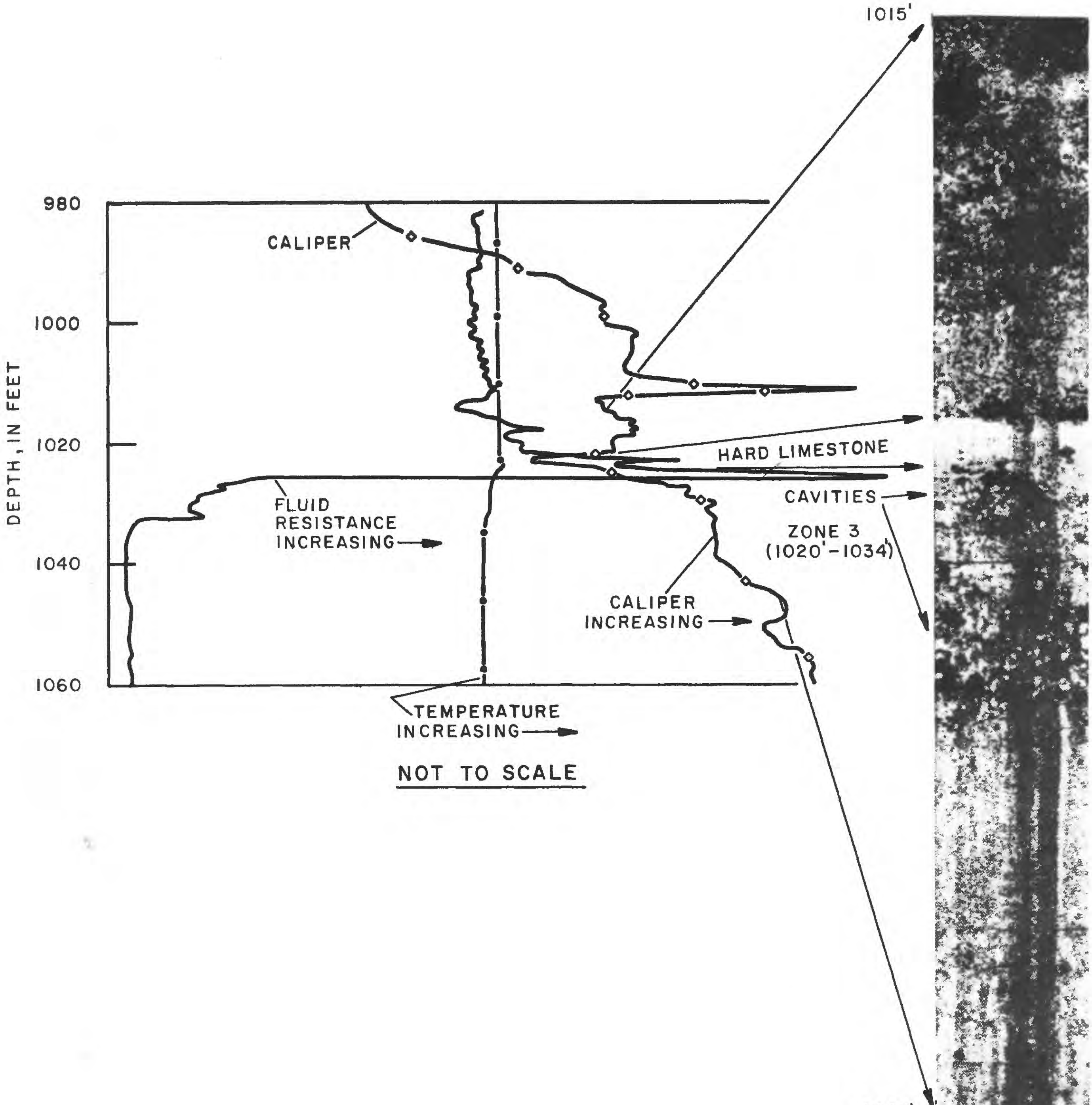

Figure 7.--Comparison between acoustic televiewer log of water-bearing zone 3, Upper Floridan aquifer, and production logs.

Middle confining unit

Zone 10 is in the lower part of the Avon Park Formation between 1,645 and 1,840 feet. It contributed about 8 percent of the flow with an estimated average conductance of 35,000 μS/cm. The flow originates chiefly from cavities at 1,715 feet with minor inflows from many small cavities randomly distributed throughout the zone. The cavities are probably related to an erosion surface near the middle of the Avon Park Formation (at the top of the former Lake City Limestone).

Zone 11 is in the lower part of the Avon Park Formation and the upper part of the Oldsmar Formation between 1,840 and 2,200 feet. It contributed about 5 percent of the flow with an estimated average conductance of about 36,900 μS/cm. The flow in zone 11 originates chiefly from cavities at 1,896, 2,070, and 2,172 feet. The cavities are probably related to an erosion surface at the top of the Oldsmar Formation.

Lower Floridan aquifer

Zone 12 is in the upper part of the Oldsmar Formation between 2,200 and 2,457 feet. It contributed about 5 percent of the flow with an estimated average conductance of about 42,600 μS/cm. The flow in zone 12 originates chiefly from cavities at about 2,250 feet. The cavities are related to the erosion surface at the top of the Oldsmar Formation.

Zone 13 is approximately in the middle of the Oldsmar Formation between 2,457 and 2,580 feet. It contributed about 32 percent of the flow with an estimated average conductance of about 50,000 μS/cm, which compares closely with that of modern seawater. The flow in zone 13 originates chiefly from large cavities at 2,544, 2,550, and 2,560 feet (fig. 8). Along the southeast coast of Florida, this zone was found to be hydraulically connected to an underlying zone of extremely high transmissivity--Boulder Zone (J.I. Garcia-Bengochea, CH_2M Hill, Inc., oral commun., 1980).

Zone 14 is in the middle of the Oldsmar Formation between 2,580 and 2,811 feet. It contributed insignificant amounts of the flow with an average conductance of about 50,000 μS/cm. No detectable velocity was measured with a flowmeter in the zone, although the temperature logs suggest a slight inflow of cool water. The temperature anomaly is probably related to heat loss to deeper and cooler permeable zones.

Water Levels

Water levels are indicators of the fluid potential or head in an aquifer or a water-bearing zone. Water movement occurs by the force of gravity and is from high- to low-fluid potential. Therefore, water-level measurements were an important and necessary element of the data-collection phase of the drilling project. Water levels were measured during the testing, as previously described, and at various times after completion of the well. Bourdon-tube pressure gages, calibrated to the nearest 0.2 foot of water, generally were used to measure water levels that were above land surface; and steel tapes,

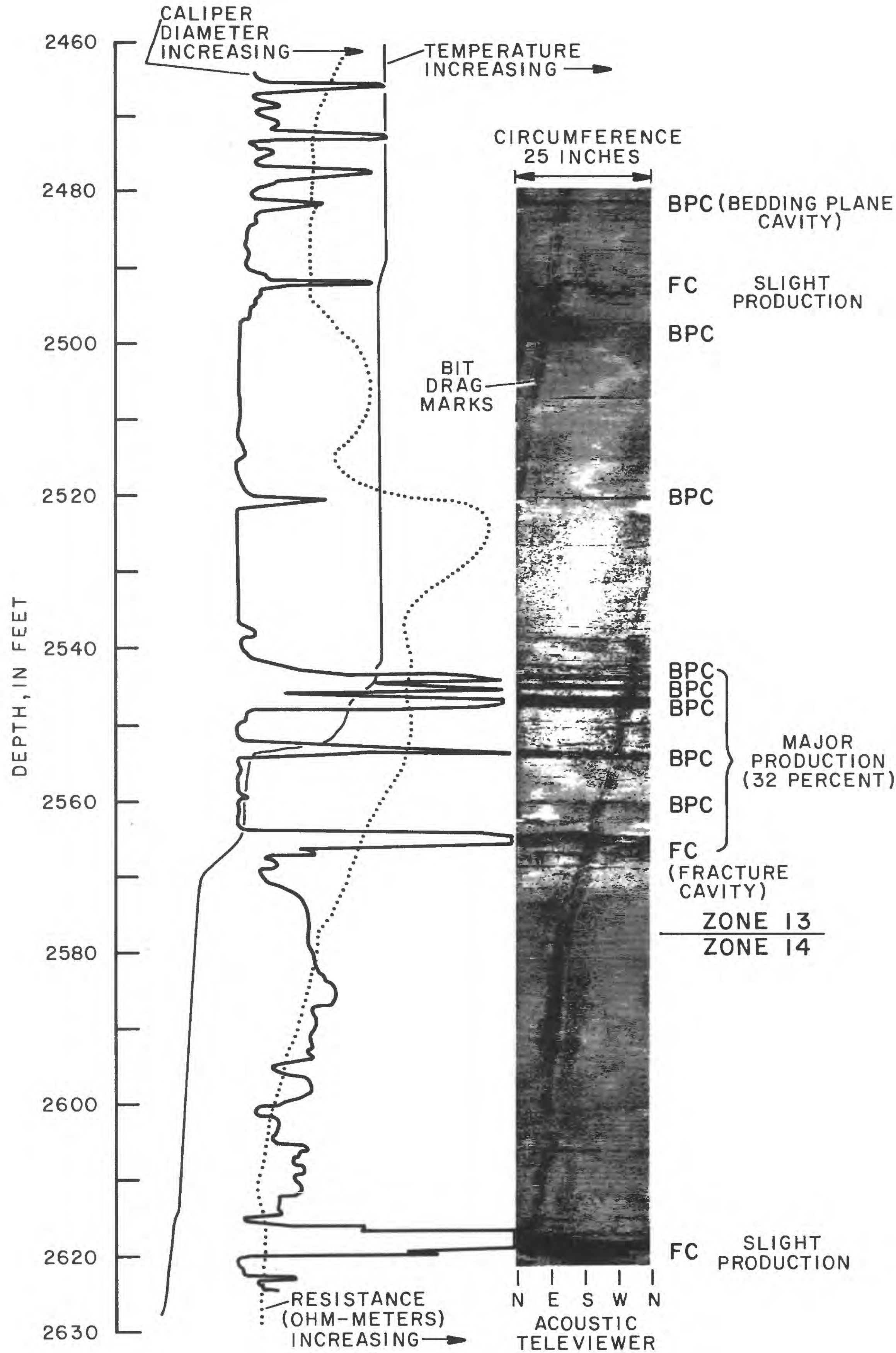

Figure 8.--Acoustic televiewer log from 2,480 to 2,620 feet with cavities in water-bearing zone 13, Lower Floridan aquifer.

calibrated to the nearest 0.01 foot, were used to measure water levels that were below land surface. For comparative purposes, the water levels were referred to the sea level datum.

Fluid potential (ϕ) and head (h) are related to fluid pressure and fluid density by the equations (Hubert, 1940):

$$\text{Fluid potential } (\phi) = gh \tag{2}$$

$$\text{Head } (h) = Z + \frac{P}{g\rho}$$

$$\phi = gh = gZ + \frac{P}{\rho}$$

where g is the acceleration due to gravity;

Z is elevation relative to a reference datum;

P is fluid pressure;

ρ is fluid density; and

P/ρ is pressure head.

At a given point in a body of liquid, the head is, therefore, an approximation of the fluid potential since the acceleration due to gravity is nearly constant in the vicinity of the earth's surface. Under hydrostatic conditions (no discharge), the pressure gradient (for example, the change in pressure per unit depth) is vertical, and pressure (P) is equal throughout the liquid body at the same depth (D). Under hydrodynamic (discharging) conditions, the pressure gradient (P/D) is deflected from the vertical by the force of the flow, and pressure at the same depth is lowest in the direction of flow. Therefore, comparisons of water levels and pressure gradients for segments of the fluid column in a well (borehole) can be used to evaluate fluid potentials and ground-water movement.

A summary of water-level measurements in selected intervals of the borehole are presented in table 4 with pertinent data such as fluid density, dissolved solids (salinity), temperature, specific conductance, and the water-bearing zones represented by the interval. The laboratory reported density values were determined gravimetrically, but they were found to be insufficiently precise to accurately determine pressure-head relations for sample depths greater than about 100 feet. For example, an error in density of 0.001 g/mL (grams per milliliter) would result in a 0.1-foot error in head at a depth of 100 feet, a 1-foot error in head at a depth of 1,000 feet, and a 3-foot error in head at a depth of 3,000 feet. Comparison of laboratory determined density at 20.0 °C with the dissolved solids showed inconsistencies in some values. For example, the same density (1.003 g/mL) was reported (table 4) for dissolved solids of 6,450 mg/L (measurement 7) and 5,290 mg/L (measurement 9). Also, a comparison of the laboratory determined density value of 1.024 g/mL for a dissolved solids concentration of 38,000 mg/L (measurement 3) with a calculated value of 1.02639 g/mL, based on a salinity of 37.11 parts per thousand from oceanographic tables (U.S. Navy, 1962), shows either an inconsistency in the laboratory determined value or an inconsistency

Table 4.--Summary of water-level measurements and other selected data

[Measured maximum water level shown in feet above sea level; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; g/mL, grams per milliliter]

Measurement number	Date (time)	Measured maximum water level	Depth interval (feet)	Water bearing zones	Specific conductance (µS/cm)	Temperature (°C)	Dissolved solids at 180 °C (mg/L)	Laboratory reported density (g/mL at 20 °C)	Calculated density[1] (g/mL)	Remarks
1	10/18/80 (0700)	52.0	895 to 934	2	4,600	26.5	2,670	--	0.99840	Test during drilling. Water level rising slowly at end due to density change.
2	3/4/81 (1009)	51.14	895 to 2,457	2-12	13,500	25.7	8,540	1.005	1.00380	Packer test 1. Water level rising slowly at end.
3	3/4/81 (0941)	6.97	2,463 to 2,811	13-14	50,000	[2]25.7	38,000	[3]1.024	1.02475	Packer test 1. Water level about static. Salinity of 37.11 parts per thousand.
4	3/7/81 (0916)	51.54	895 to 1,428	2-8	3,120	26.0	1,930	.999	.99770	Packer test 2A. 1,428-foot packer leaking; 1,618-foot packer not leaking.
5	3/7/81 (0916)	50.54	1,433 to 1,618	9	6,050	25.9	3,640	1.001	.99930	do.
6	3/8/81 (1052)	56.64	895 to 1,249	2-5	3,150	26.2	1,930	.999	.99770	Packer test 3. Slight leakage across 1,249-foot packer.
7	3/8/81 (1107)	52.44	1,254 to 2,811	6-14	10,450	26.0	6,450	1.003	1.00190	do.
8	3/9/81 (1330)	57.74	895 to 1,124	2-4	3,325	26.2	2,000	1.000	.99770	Packer test 4. Slight leakage across 1,124-foot packer.
9	3/9/81 (1338)	54.14	1,129 to 2,811	4-14	8,900	26.1	5,290	1.003	1.00080	do.
10	4/21/81 (1337)	58.84	[4]895 to 2,811	[4]2-14	3,100	26.0	--	--	.99770	Chiefly zone 3. Highest static level recorded.
11	4/24/81 (1100)	55.74	811 to 816	1	6,200	26.0	3,500	1.001	.99910	Perforated zone in 2-inch monitor tube. Static level.

[1]Calculated at ambient temperature.

[2]From temperature log.

[3]Compared to calculated density of 1.02639 g/mL at 20 °C, based on U.S. Navy oceanographic tables (1962).

[4]Represents zone 3 at 1,030 feet.

in the dissolved solids analysis (table 5). Because fluid density is related directly to salinity and pressure and related inversely to temperature, all density values used in this report were calculated from dissolved solids (salinity) concentrations and temperature measurements using the U.S. Navy oceanographic tables for highly saline samples and an estimated relation between dissolved solids, density, and temperature for samples whose dissolved solids compared to that of freshwater. The calculated density of the fluid for each measurment is also shown in table 4. Of the 11 water-level measurements (table 4), only measurements 3, 10, and 11 are considered to be representative of static water levels at the prevailing densities.

The recovery of water levels (for example, the rise in shut-in pressure after a period of flow or pumping) during the previously described tests indicated that leakage across packers and wellhead seals, changing density, and insufficient recovery time were the major problems in obtaining representative water levels. For example, data for measurements 2 and 3 (packer test 1 in figure 9A) showed that the head in the zone below the packer (2,463 to 2,811 feet) was virtually unaffected by the increase in head in the overlying zone that resulted from emplacing the wellhead seal in the 16-inch casing. However, the head in the overlying zone (895 to 2,457 feet) rose sharply, and the rate of rise was probably a result of decreasing density of the water column as fresher water from a high-pressure zone (probably zone 3) displaced saltier water in the upper part of the borehole. Data for measurements 5 and 6 (packer test 3 in figure 9B) showed that the head in the zone below the packer (1,254 to 2,811 feet) rose slightly as the head in the overlying zone (895 to 1,249 feet) rose sharply due to emplacing the wellhead seal in the 16-inch casing. Also, the decrease in the rate of rise of the head in the upper zone (895 to 1,249 feet) at about 7 minutes was chiefly a result of leakage of the wellhead seal. Data for measurements 7 and 8 (packer test 4 in figure 9C) showed that the head in the zone below the packer (1,129 to 2,811 feet) rose sharply as a result of emplacing the wellhead seal in the 16-inch casing, and the change in rate of rise (slope) of the head in the upper zone (895 to 1,124 feet) was chiefly a result of leakage across the packer.

Comparison of the water-level data from the short-duration packer tests in March 1981 with static water levels (fig. 4) showed that water levels above the packer generally increased as the packer was raised in the borehole and set closer to the bottom of zone 3 at about 1,030 feet. For example, the maximum water level for the recovery period during packer test 3 (table 4, measurement 6) at 1,254 feet was 56.64 feet above sea level, and that for packer test 4 (table 4, measurement 8) at 1,129 feet was 57.74 feet above sea level.

The maximum water level of 58.84 feet (table 4, measurement 10) was measured on April 21, 1981, about 13 days after the well was shut-in (fig. 10). The initial response of the water-level recovery (increase in shut-in pressure) was based upon a column of mixed salinity between depths of 895 and 2,811 feet, whose density probably ranged from about 0.998 to 1.025 g/mL. The average density of the water column was probably about 1.019 g/mL based on the distribution of saltwater indicated by the fluid resistance log of April 13, 1981 (fig. 6). By the end of the first day of recovery, the water level rose to about 47 feet above sea level. The slow rise in the water level during the

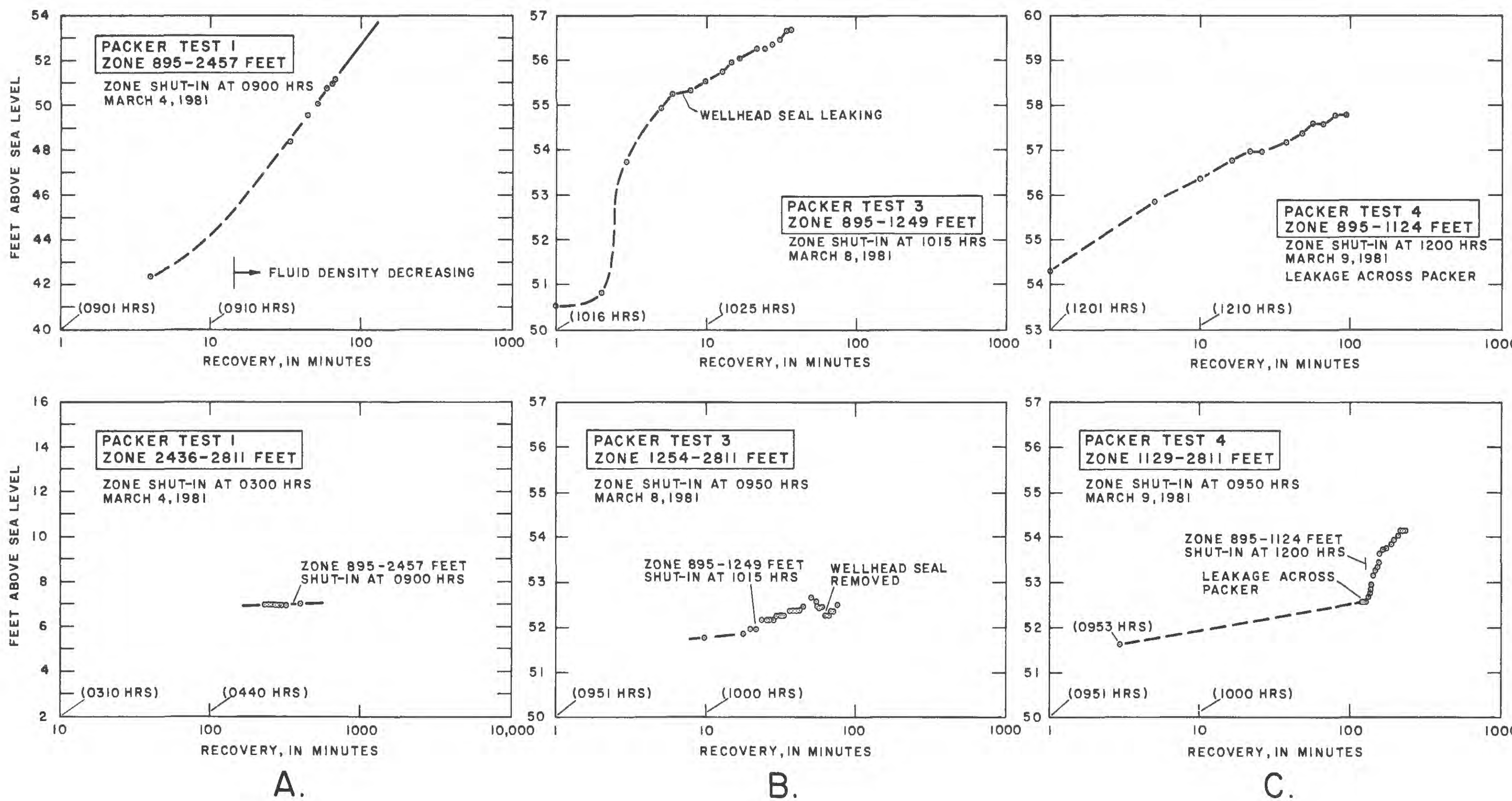

Figure 9.--Water-level recovery data for packer tests 1, 3, and 4.

Table 5.--Comparison of laboratory density with calculated density based on salinity-temperature relations

Type of density	Density (grams per milliliter)	Temperature (degrees Celsius)	Pressure (bars)
Laboratory[1]	1.024	20.0	0
Calculated[2]	1.02639	20.0	0
Calculated[2]	1.02475	25.7	0

[1]Density for measurement 3 shown in table 4.

[2]Density calculated from oceanographic tables (U.S. Navy, 1962), based on a dissolved solids concentration of 38,000 milligrams per liter or a salinity of 37.11 parts per thousand.

next 7 days chiefly was due to decreasing fluid density in the borehole as a result of the displacement (or replacement) of the saltwater in the fluid column by fresher, less dense, brackish water from the water-bearing zones near the top of the borehole. The displacement phenomenon is shown by comparison of the fluid resistance logs of April 13, 1981, and November 13, 1980 (fig. 6), during periods of rising pressure.

The fluid resistance log of April 13, 1981, obtained while the pressure was rising as shown in figure 10, confirmed that brackish ground water from water-bearing zones 3 and 4 (1,020 to 1,254 feet) flowed down the wellbore and displaced saltier water from the bottom of the borehole to a depth of about 2,250 feet. The residual saltwater that was trapped in the casing at the end of the flow period also flowed down the borehole as a density current and was replaced by fresher, less-dense water from water-bearing zones 2 and 3. The same phenomenon was observed upon completion of the well on November 13, 1980, except at that time the well had not been flushed of the brine-mud mixture used during drilling to prevent artesian flow. Prior to logging on November 13, the well had been shut-in and inactive since November 7. Again, the fluid resistance log showed that brackish water chiefly from zones 3 and 4 mixed with downward moving brine from the casing, and the mixture moved down the borehole to a depth of about 2,250 feet where the fluid left the borehole through cavities near the top of zone 12. Below the cavities, the borehole contained brine. Comparison of the two fluid resistance logs (fig. 6) suggests that given sufficient time the brackish water from zones 3 and 4 would have replaced the more dense fluids in the casing and in the borehole, and the shape of the log of April 13 would have eventually become more rectangular.

Figure 10 shows that the water level at the time of logging was about 6 feet below the maximum and rising slowly. The conductance of a miscellaneous sample of the water in the casing on April 17 (fig. 10) was about 3,100 μS/cm, which compared closely to that for zones 3 and 4. The measured maximum water level of 58.8 feet above sea level on April 21 could, therefore, be an intermediate but lower value than the true water level because some ground water was probably discharging from zones 3 and 4 down the borehole into zones with lower pressure. Flowmeter logs of the well while shut-in on November 13, 1980, and April 13, 1981, failed to show conclusively that downward flow of water actually occurred.

Pressure gradients for the 11 water-level measurements (table 6) were calculated from the estimated densities in table 4 and used to determine the pressures for each measurement at the representative depth. Measurements that have similar densities and pressure gradients (table 6, measurements 4, 6, 8, and 10) are generally representative of a common pressure system, and measurements that have dissimilar densities and pressure gradients (table 6, measurements 3 and 10) are generally from different pressure systems. The fact that static equilibrium conditions were reached only for measurements 3, 10, and 11 places some doubt upon the calculations of total static pressure for the other measurements.

For comparison, the pressure versus depth data for each measurement in table 6 is shown in figure 11, a pressure-depth diagram. The plotted data suggest that two distinct relations are indicated by lines G_{FW} and G_{SW} that pass through the points for measurements 3 and 10. The slope of the lines

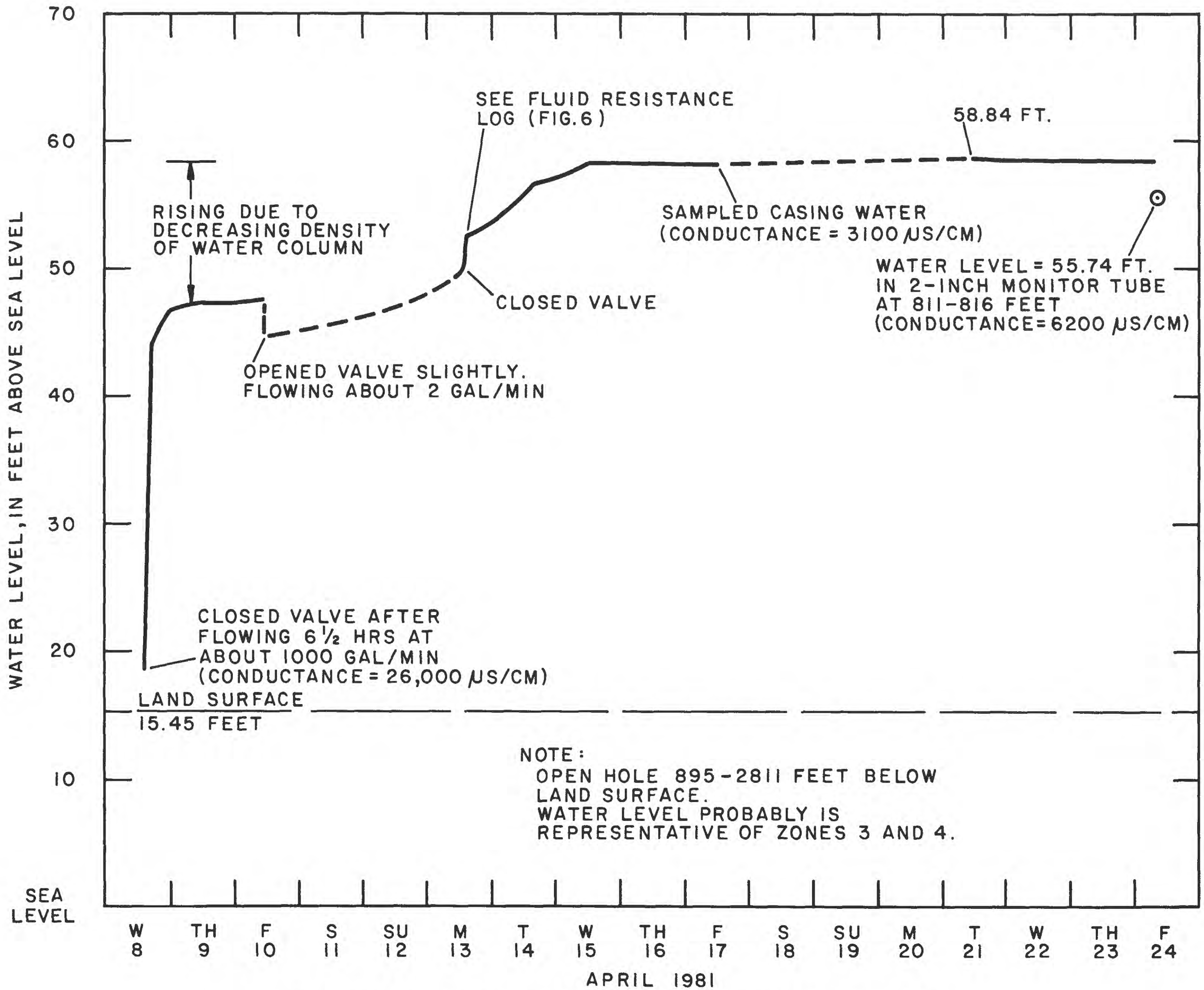

Figure 10.--Water-level measurements, April 8-24, 1981.

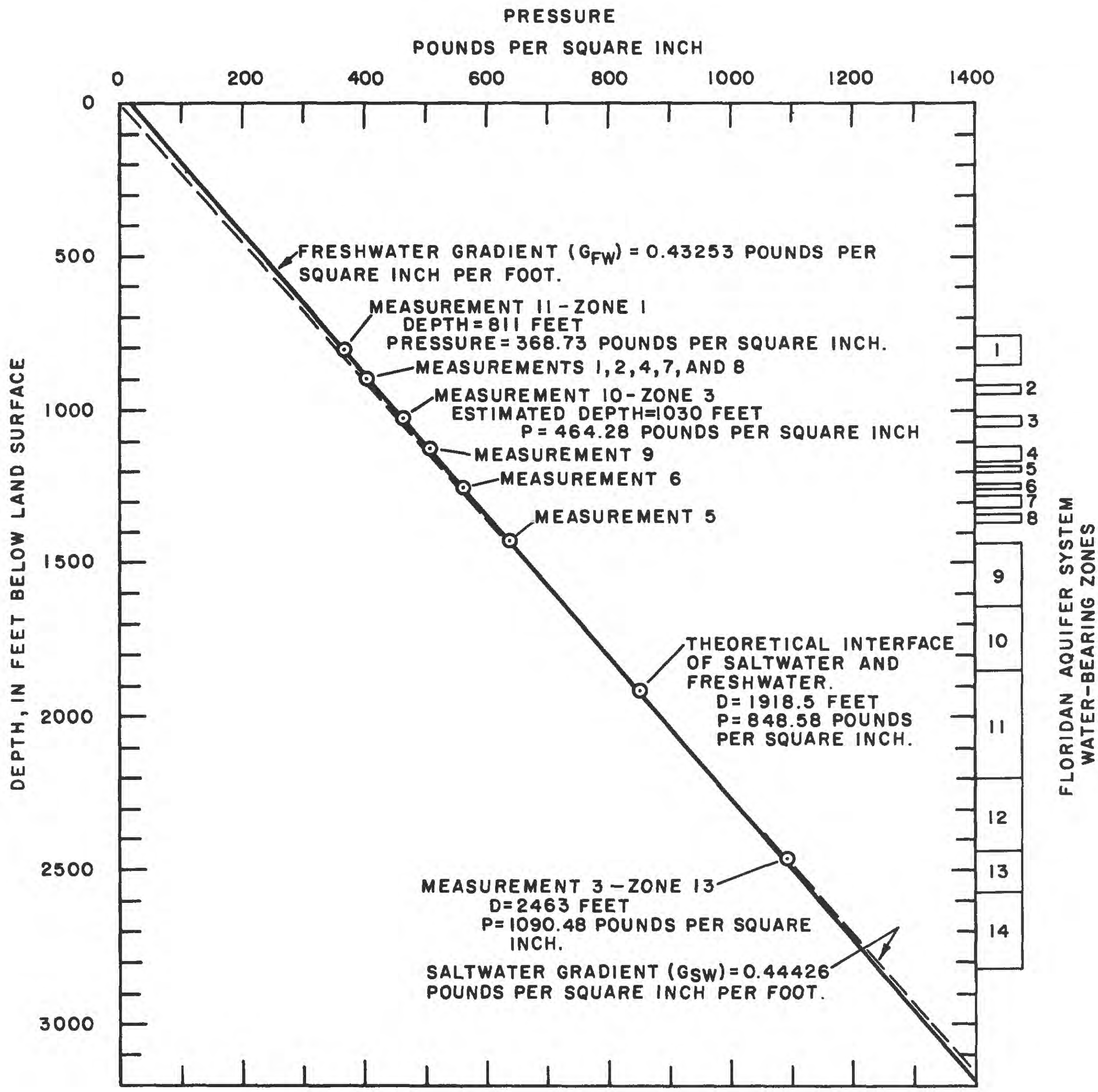

Figure 11.--Pressure versus depth for water-level measurements in the Floridan aquifer system.

Table 6.--Comparison of measured head with pressure gradients and pressures

[Based on measurements in table 4. Measured head shown in feet above sea level; estimated representative depth shown in feet below sea level. lb/in²/ft, pounds per square inch per foot; lb/in², pounds per square inch.]

Measurement number	Measured head	Depth[1] (feet)	Estimated pressure gradient (lb/in²/ft)	Estimated representative depth	Estimated pressure at depth (lb/in²)
1	>52.0	895-934	0.43284	879.6	403.23
2	>51.1	895-2,457	.43518	879.6	405.02
3	7.0	2,463-2,811	.44426	2,447.6	1,090.48
4	>51.5	895-1,428	.43253	879.6	402.73
5	>50.5	1,433-1,618	.43323	1,417.6	636.02
6	>56.6	895-1,249	.43253	879.6	404.93
7	>52.4	1,254-2,811	.43435	1,238.6	560.75
8	>57.7	895-1,124	.43253	879.6	405.41
9	>54.1	1,129-2,811	.43388	1,113.6	506.64
10	58.8	1,030-1,154	.43253	1,014.6	464.28
11	55.7	811-816	.43314	795.6	368.73

[1]Datum is land surface (15.4 feet above sea level).

through the points represents the respective pressure gradients for each measurement. The points for measurements 1, 2, 4 to 9, and 11 in the upper (brackish) part of the aquifer system (water-bearing zones 1-9) generally fall near or on the line (G_{FW}) represented by measurement 10, thereby suggesting that they are part of the same flow system (although minor variation in respective pressures and pressure gradients suggest the presence of local confining beds). Pressure at selected depths within the body of water in the upper part of the Floridan aquifer system can be reasonably estimated by the equation:

$$P = G_{FW} (D + 43.4), \qquad (3)$$

where P is pressure, in pounds per square inch;

G_{FW} is the pressure gradient of upper Floridan water, in 0.43253 pound per square inch per foot of depth represented by the water at depth of measurement 10, 1,030 to 1,154 feet at the test site;

D is depth below land surface, in feet; and

43.4 is the head above land surface of the water at depth of measurement 10 (58.8 feet - 15.4 feet = 43.4 feet).

Measurement 3 (tables 4 and 6), which represents the deeper seawater-like zones below a depth of 2,463 feet, plots above the downward extension of the line (G_{FW}) that represents the pressure-depth relation for the upper part of the system. Pressures in the deep saltwater part of the Floridan aquifer system can be reasonably estimated by the equation:

$$P = G_{SW} (D - 8.4), \qquad (4)$$

where G_{SW} is pressure gradient of saltwater, in 0.44426 pound per square inch per foot of depth;

D is depth below land surface, in feet; and

8.4 is the head below land surface of the water at the depth of measurement (15.4 feet - 7.0 feet = 8.4 feet)

The upward extension of the line G_{SW} representing the pressure-head relation for the saltwater part of the aquifer system intersects that for the freshwater part of the aquifer system at about 1,918 feet, the point of equal pressure. Two interpretations of the pressure data are possible: (1) the saltwater and freshwater systems are unrelated and function independently because of intervening confining beds; and (2) the two systems are interconnected and related by buoyancy, and the point of intersection (1,918 feet) of the lines G_{SW} and G_{FW} is the approximate freshwater-saltwater contact or interface.

The conductance or resistance of water that entered the borehole from all water-bearing zones (fig. 5 and table 3), while the well was flowing, suggests that the base of the freshwater part of the system occurs in zone 9, which ranges in depth from 1,430 to 1,645 feet, and that the top of the saltwater part occurs in zone 12, which ranges in depth from 2,200 to 2,457 feet. Between the upper freshwater zones and the lower saltwater zones are zones 10 and 11 which contain mixtures of both--much the same as the zone of diffusion in unconfined coastal aquifers such as the Biscayne aquifer (Cooper and others, 1964), except that the mixing zone in the Floridan is several hundred feet thick.

According to the fluid resistance log of July 16, 1983, while the well was flowing (fig. 5), there is no obvious indication that the saltwater-freshwater contact occurs at 1,918 feet as indicated by the buoyancy relation in figure 11. The fluid resistance logs of November 13, 1980, and April 13, 1981 (fig. 6), obtained while the well was shut-in (not flowing), suggest that the pressure in the upper freshwater part is sufficient to displace the saltwater in the borehole to a depth of about 2,250 feet. The maximum head for the upper zone was 43.4 feet above land surface or 58.8 feet above sea level on April 21, 1981, when the average density of the 2,250-foot fluid column was estimated to be 1.002 g/mL (based on the estimated fluid resistance log in fig. 6) at ambient temperature. Theoretically, given sufficient time, freshwater from zone 3 (the high-pressure upper zone) would have completely displaced the saltwater to about 2,250 feet with a freshwater column having a density of 0.998 g/mL. The freshwater head required for the displacement would, however, be about 9.2 feet higher than the maximum measured on April 21, 1981. Potentially, therefore, the head in zone 3 in the upper part of the aquifer system could be as high as 68 feet above sea level. If this were the case, then the buoyancy related contact between freshwater and saltwater would be deeper than 1,918 feet.

Comparison of the highest measured freshwater head (58.8 feet above sea level on April 21, 1981) in the well with the potentiometric surface map by Healy (1975) shows that the head estimated by the map at the well site was about 9 feet lower than the measured head. Recent maps by Johnston and others (1980; 1981) have incorporated the new head measurement of the Alligator Alley test well. As more detailed information on the vertical distribution of head in the Floridan aquifer system is obtained from other test wells in south Florida, the configuration of the potentiometric surface maps will no doubt change, particularly in the area between the Alligator Alley test well and the potentiometric surface high in central Florida.

The fact that zone 13 contributed a relatively large amount of saltwater to the well during natural free flow led to an early conclusion that the pressure head for zone 13 was higher than land surface. This early conclusion, however, proved to be incorrect when packer test 1 was performed, and the head was found to be 8.4 feet below land surface--a level that precluded natural flow under normal conditions. The phenomenon, therefore, had to be related to the inflow of freshwater from zone 3 at about 1,030 feet in depth.

The pressure-depth diagram (fig. 11) shows that during shut-in, the shut-in pressure for the saltwater column (extension of line G_{SW}) at 1,030 feet is lower than the shut-in pressure in zone 3. The pressure at 1,030 feet in terms of the saltwater gradient (G_{SW}) would be 453.86 lb/in^2. The fluid pressure at 1,030 feet in zone 3, therefore, would be 10.42 lb/in^2 greater than the fluid pressure at 1,030 feet in the static column of saltwater above zone 13. The difference in pressure is equivalent to about 24.1 feet of freshwater head. Because the borehole provides physical connection between the upper and lower zones, the fluid pressure in zone 3 is sufficiently high to displace the top of the saltwater column below the point of intersection (about 1,030 feet) to a depth of about 1,918 feet. During limited free flow when the head in zone 3 is lowered by 24 feet or less, the freshwater pressure is sufficient to displace the saltwater column below the major point of freshwater inflow at 1,030 feet, and little, if any, saltwater is entrained in the upward moving column of freshwater. However, if during unrestricted free flow the head in zone 3 is lowered by more than 24 feet, the freshwater pressure is insufficient to displace the saltwater column below the major point of freshwater inflow, and large amounts of saltwater are entrained in the upward moving column of freshwater. During maximum free flow, the head in zone 3 is lowered about 43 feet, and the freshwater pressure effect on depressing the saltwater column is minimal.

Natural Isotope Concentrations

Concentrations of natural carbon and uranium isotopes were determined in selected samples of ground water from the test well to assess their use as tracers. Dating of ground water by carbon-14 has been used with limited success in Florida to estimate rates and direction of water movement (Hanshaw and others, 1965; Pearson and Badden, 1975; Plummer, 1977). Conclusions reached by earlier investigators indicate that the apparent age of the water, based on carbon-14 activity, could not be construed as the absolute age because problems with fractionation or dilution by carbon-12 and carbon-13 are yet unresolved. Another major problem seemed to be a lack of understanding of the flow regimen because the water samples used for analyses were generally obtained from wells which tapped several water-bearing zones in the aquifer system. The distribution of flow, both horizontally and vertically, and the amount of mixing between zones were and still are poorly known. However, the consensus was that relative differences in age between samples from the same general area are sufficient for estimating rates and direction of flow (Hanshaw and others, 1965, p. 495).

With these limitations in mind, nine water samples of water were obtained at various depths in the test well for radiocarbon analysis (table 7). Samples 1 through 8 were analyzed by the U.S. Geological Survey Laboratory in Denver, Colo., and sample 9 was analyzed by the Tritium Laboratory, University of Miami, Coral Gables, Fla. The carbon-14 activity (uncorrected for fractionation) and chemical reactions in the samples ranged from 4.7 to 38.9 percent of modern, and the $\delta^{13}C$ (carbon-12/carbon-13 stable isotope ratio) ranged from -1.2 to -3.8 o/oo (per mill). Samples 1 through 6 represent the upper brackish water part of the Floridan aquifer system (Upper Floridan aquifer). The uncorrected carbon-14 activity ranged from 4.7 to 17.3 percent of modern. This compares with reported values by Pearson and Badden (1975) of 5.6 and 4.3 percent for water samples collected in 1971 at depths of 1,290 and 1,924 feet during drilling of a deep disposal well (site I.D. 25412408024530.01) near Miami. The $\delta^{13}C$ for samples 1 through 6 ranged from -1.2 to -2.6 o/oo.

Samples 7 and 8 were from the deep saltwater part of the system (Lower Floridan aquifer) but were slightly contaminated by a mixture of brackish artesian water from the uppermost water-bearing zones and sodium chloride

Table 7.--Analyses of carbon-14 in selected water samples

[Carbon-14 apparent age, years before present, based on half life of 5,568 years (uncorrected for fractionation). μS/cm, microsiemens per centimeter; years B.P, years before present.]

Sample number	Depth (feet)	Date (time)	Specific conductance (μS/cm)	Carbon-14 activity (percent of modern)	Carbon-14 apparent age (years B.P.)	C-13/C-12 stable isotope ratio (per mill)	Remarks
1	811-816	10/19/81 (1230)	6,200	7.3	21,000	-1.8	Collected from perforated 2-inch monitor tube in upper part of Suwannee Limestone. Zone 1.
2	895-934	10/18/80 (0300)	4,600	17.3	14,000	--	Sampled during drilling in lower part of Suwannee Limestone. Zone 2. Probably not representative.
3	[1]895-2,811	10/19/81 (1030)	3,770	11.9	17,100	-1.2	Collected at surface after flowing 2 minutes. Casing water. Probably represents flow from zone 3.
4	895-1,124	3/9/81 (0730)	3,325	4.7	24,500	-2.4	Packer test 4. Poor yield of benzene for counting. Zones 2 and 3.
5	895-1,249	3/8/81 (0630)	3,150	5.8	22,900	-2.6	Packer test 3. Zones 2 to 5.
6	1,433-1,618	3/7/81 (0200)	6,050	4.7	24,500	-1.6	Packer test 2A. Probably not representative. Zones 8 and 9.
7	[2]2,463-2,811	3/3/81 (2100)	50,000	30.3	9,600	-3.8	Packer test 1. Slight contamination suspected. Zones 13 and 14.
8	2,500	10/19/81 (1500)	54,000	7.6	20,700	-3.7	Thief sample. Poor yield of benzene for counting. Contamination suspected. Zones 13 and 14.
9	2,520	7/7/83 (1040)	50,000	[3]38.9	[3]7,600	-2.1	Thief sample. Probably representative. Zones 13 and 14.

[1]Sampled casing water, which probably represents from 895 to about 1,034 feet.

[2]Probably sampled from 2,463 to about 2,562 feet.

[3]Preliminary results from University of Miami, Tritium Laboratory, Miami, Florida, August 16, 1983.

which was added to the well during drilling and testing as discussed earlier. Sample 9, obtained by a Foerst thief sampler at 2,520 feet (zone 13) on July 7, 1983, has an uncorrected carbon-14 activity of 38.9 percent of modern, or an apparent age of 7,600 years B.P. (before present) and a $\delta^{13}C$ of -2.1 o/oo. Sample 9 is considered to be representative of the lower part of the system that contains younger, seawater-like saltwater.

The distribution of carbon-14 activity by depth in the test well suggests a complex flow system in which two (or more) flow systems are evident: (1) an upper flow system containing a mixture of brackish water (a mixture of bicarbonate and chloride type water) that conveys relatively old freshwater from the recharge areas in central Florida to the sea; and (2) a lower flow system through which moves relatively younger cooler saltwater that is similar in quality to seawater. Within the upper flow system, the carbon-14 activity (11.9 percent of modern) in sample 3 from near the most productive zone (1,030 feet) is relatively higher (younger) than that either above or below. This indicates that water probably moves faster through zone 3, the most productive zone. The absolute age of sample 3 is probably younger than the apparent age because the water while moving from the recharge area has reacted with carbonate minerals within the aquifer and lost the isotopically heavy carbon (both $\delta^{14}C$ and $\delta^{13}C$) during transit. The loss of carbon-14 would cause the carbon-14 activity to decrease and the water to appear older.

The carbon-14 activity of sample 9 from the deep saltwater part of the system is about 38.7 percent of modern and, therefore, is relatively younger than all other samples. A sample of saltwater obtained on April 28, 1983, from about 3,000 feet in a deep disposal well at Fort Lauderdale, about 45 miles east of the Alligator Alley test well, yielded a carbon-14 activity of 65.9 percent of modern and a $\delta^{13}C$ of -2.4 o/oo; and a sample of saltwater from about 2,700 feet in a deep disposal well near Miami yielded a carbon-14 activity of 41.2 percent of modern and a δ^{13} of -5.3 o/oo. The data suggest inland flow of seawater through the Lower Floridan aquifer as postulated by Kohout (1965). This conclusion does not, however, consider possible errors in activity due to the gain or loss of carbon-14 in transit or to variations in past carbon-14 production.

Uranium isotopes have also been used as tracers for determining flow patterns in the Floridan aquifer system. Cowart and others (1978) compared $^{234}U/^{238}U$ alpha-activity ratios of water samples from three deep (about 3,000 feet) injection wells in southeast Florida with those for the ocean and concluded that the variations in uranium concentration and alpha-activity ratios indicate inland movement of seawater. A sample of saltwater from 2,520 feet (zone 13) in the test well on July 8, 1983, yielded a $^{234}U/^{238}U$ alpha-activity ratio of 1.20 ± 0.03 and a uranium concentration of 2.44 ± 0.07 μg/L (micrograms per liter) which compares to the worldwide average values of 1.14 ± 0.01 and 3.30 ± 0.14 μg/L for seawater (J.B. Cowart, Florida State University, oral commun., 1983). The alpha-activity ratios usually increase during transit while the concentration decreases.

SUMMARY

A 2,811-foot deep test well was drilled during 1980 in The Everglades of south Florida along Alligator Alley (Interstate 75), as part of the Floridan Regional Aquifer-System Analysis (RASA) project. A 16-inch diameter steel casing was installed with cement grout from land surface to a depth of 895 feet, below which a nominal 8-inch diameter exploratory hole was drilled to a depth of 2,811 feet. A 2-inch diameter steel monitor tube was grouted with cement in the outer annulus and later perforated in the interval 811 to 816 feet. Hydraulic packers were used to isolate selected zones in the well in order to collect samples of water and measure water levels.

The well penetrated the surficial and intermediate aquifer systems and most of the Floridan aquifer system. The surficial aquifer system is about 180 feet thick and is chiefly composed of sandy limestone of the Tamiami Formation of Pliocene age. Three artesian limestone aquifers and related confining beds occur in the intermediate aquifer system between 180 and 770 feet in Miocene deposits. The top of the Floridan aquifer system occurs at 770 feet and is confined by the overlying Miocene deposits. About two-thirds of the total thickness of the Floridan aquifer system was penetrated by the well. The formations that comprise the aquifer system (from shallowest to deepest) at the well site include the Suwannee and Ocala Limestones and the Avon Park and Oldsmar Formations. The well did not penetrate the Cedar Keys Formation, the lowermost unit in the system.

The Floridan aquifer system is composed of many discrete water-bearing zones that are chiefly horizontal solution zones in the limestone. Major water-bearing zones occur at about 1,030 feet near the top of the Ocala Limestone and at about 2,560 feet in the Oldsmar Formation. The 1,030-foot zone contains brackish artesian water (chloride concentration of about 800 mg/L), and the 2,560-foot zone contains seawater-like artesian water (chloride concentration of about 19,000 mg/L). The water level in the well when open to the 1,030-foot zone is about 59 feet above sea level (freshwater head), whereas that when open to the 2,560-foot zone is about 7 feet above sea level (saltwater head). Pressure gradients for the two flow systems suggest that the theoretical freshwater-saltwater contact based on buoyancy should occur at a depth of 1,918 feet. However, a wide mixing zone occurs between depths of about 1,600 and 2,200 feet.

A reverse geothermal gradient is indicated with coldest water (24.5 °C) occurring at the bottom of the well (2,811 feet). Radiocarbon activities (unadjusted for fractionation and dilution by carbon-12 and carbon-13) of several water samples suggest that the seawater-like water in the 2,560-foot zone is younger than brackish water in the 1,030-foot zone, and that brackish water in the 1,030-foot zone in the upper part of the system is relatively younger than that in adjacent zones. Comparison of the carbon-14 activity of the saltwater from the 2,560-foot zone with that from wells of comparable depth at Fort Lauderdale, about 45 miles east of the test well, and at Miami indicates that the carbon-14 activity of the saltwater increases eastward toward Fort Lauderdale and the Straits of Florida, thereby suggesting that the saltwater is younger at the coast, and that the direction of flow is inland. Uranium isotope data also indicate an inland gradient.

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Appendix I.--Summary of geophysical logs

Log number	Date	Depth (feet)	Log type	Remarks
1	9/22/80	0-200	Electric	Run 1, SP, 16-inch normal, 64-inch normal; logged in 12¼-inch pilot hole filled with drilling fluid.
2	9/22/80	0-200	do.	Run 2; same as above.
3	9/22/80	0-200	Acoustic velocity	Interval transit time; logged in 12¼-inch pilot hole filled with drilling fluid.
4	9/22/80	0-200	Natural gamma	Counts per second, not American Petroleum Institute units; in 12¼-inch pilot hole filled with drilling fluid.
5	9/22/80	0-200	Caliper	Logged in 12¼-inch pilot hole filled with drilling fluid.
6	10/3/80	190-894	Electric	SP, 16-inch normal, 64-inch normal; logged in 12¼-inch pilot hole filled with drilling fluid.
7	10/3/80	190-887	Focused resistivity	Two scales: a 2R-m/inch, 10R-m/inch; logged in 12¼-inch pilot hole filled with drilling fluid.
8	10/3/80	0-890	Natural gamma	Logged down; in 12¼-inch pilot hole filled with drilling fluid.
8a	10/3/80	0-896	Caliper	Logged up; same as above.
9	11/13/80	800-2,798	Temperature	Logged down; in 8-inch pilot hole with mud cap and saltwater to suppress flow; no flow at surface.
9a	11/13/80	800-2,795	Caliper	Logged up; same as above.
10	11/13/80	890-2,805	Electric	SP, 16-inch normal, 64-inch normal; logged in 8-inch pilot hole; casing filled with drilling fluid; no flow at surface.
11	11/13/80	890-2,795	Focused resistivity	Logged in 8-inch pilot hole; same as above.
12	11/13/80	0-2,811	Natural gamma	do.
13	11/13/80	0-2,795	Fluid resistivity	do.
14	11/13/80	0-2,798	Fluid temperature	do.
15	11/13/80	880-2,770	Acoustic velocity	do.
16	11/13/80	960-2,740	Flowmeter	Two runs for internal flow; casing filled with drilling fluid; no flow at surface.
17	11/13/80	800-2,793	Sidewall neutron	Logged in 8-inch pilot hole; same as above.
18	11/13/80	800-2,786	Sidewall gamma gamma.	do.
18a	11/15/80 11/16/80	890-2,770±	Acoustic televiewer	Well flowing; logged in 8-inch pilot hole.
19	11/18/80	790-2,776	Fluid temperature	do.
19a	11/18/80	790-2,776	Caliper	do.
20	11/18/80	10-2,730±	Fluid resistivity	Same as above; thief samples at 1,027, 1,130, 1,270, 1,870 and 2,670 feet.
21	11/18/80	800-2,696	Flowmeter	Run 1, logged up; well flowing at surface.
21a	11/18/80	800-2,696	Caliper	do.
22	11/18/80	780-2,730	Flowmeter	Run 2, logged down; well flowing at surface.
23	11/18/80	800-2,730	do.	Run 3, logged up; well flowing at surface.
23a	11/18/80	800-2,730	Caliper	do.
23b	11/18/80	Calibrations	for logs 21 and 22	Apparently filled with soft mud from 2,710 to 2,811 feet.
24	1/14/81	600-2,700	Fluid velocity	Logged by South Florida Water Management District; logged down; well flowing at surface.

Appendix I.--Summary of geophysical logs--Continued

Log number	Date	Depth (feet)	Log type	Remarks
25	1/14/81	800-2,695	Static velocities and calibrations.	Logged by South Florida Water Management District; logged down; well flowing at surface.
3/2-9/81--Packer tests; hole was cleaned to 2,811 feet on 3/1/81. 3/19-81--Television survey 0 to 2,449 feet; blockage at 2,449± feet prevented survey to 2,811 feet.				
26	3/24/81	0-832.6	Natural gamma	Logged in western 2-inch monitor tube; no flow.
26a	3/24/81	50-331	Temperature	Logged in eastern 2-inch monitor tube; no flow.
27	3/25/81	10-2,812	do.	Run 1, logged down; well flowing.
28	3/25/81	900-2,811	do.	Run 2, logged up; well flowing.
28a	3/25/81	900-2,811	Caliper	do.
3/25/81--Partial acoustic television survey of bottom (2,450 to 2,811± feet).				
29	3/26/81	811-816	Directional perforations.	Schlumberger perforated western 2-inch monitor tube with 20 shots.
3/26/81--Television survey discovered loose rock covering hole at 978 feet; postponed survey.				
30	3/26/81	0-2,811	Fluid resistivity	Run 1, logged down; passed rock at 978 feet; well flowing.
31	3/26/81	0-2,811	do.	Run 2, logged up; shows pulse effect of blockage; well flowing.
32	3/26/81	900-2,811	Caliper	Run 2, loose rock at 978 feet.
33	4/13/81	0-2,811	Fluid resistivity	Well not flowing; logged through wiper; partial blockage.
34	4/7/81	160-2,800	Flowmeter	Run 2, logged up; well flowing.
34a	4/7/81	160-2,800	Caliper	do.
35	4/7/81	170-2,800	Flowmeter	Run 1, logged down; well flowing.
4/8/81--Television survey completed to bottom; thief samples at 1,020, 1,040, 1,260, 1,600, 2,250, 2,520 and 2,600 feet.				
36	4/10/81	0-2,816	Temperature	Run 1, logged down; well not flowing; wiper used.
37	4/10/81	0-2,816	do.	Run 2, logged up; same as above.
38	4/10/81	900-2,780	Flowmeter	Logged up; well not flowing; wiper used.
38a	4/10/81	2,300-2,780	Caliper	do.
39	4/10/81	500-2,780	Flowmeter	Run 1, logged up; well not flowing; wiper used.
39a	4/10/81	500-2,780	Caliper	do.
4/13/81--See log 33, fluid resistivity. 10/19/81--Sampled at 2,500 feet for carbon-14 analysis.				
40	7/6/83	0-2,811	Temperature	Run 1, logged down; well flowing.
41	7/6/83	900-2,811	do.	Run 2, logged up; well flowing.
41a	7/6/83	900-2,811	Caliper	do.
7/7/83--Sampled at 2,520 feet for carbon-14 analysis.				
42	7/8/83	0-2,811	Fluid resistivity	Ohm-meters; logged up; well flowing.
43	7/8/83	890-2,811	Electric	SP, 16-inch normal, 64-inch normal; logged down; well flowing.
44	7/8/83	0-2,811	Fluid resistivity	Ohms; logged down; well flowing.
44a	7/8/83	0-2,811	Fluid temperature	Logged down; well flowing.
45	7/16/83	0-2,811	Fluid resistivity	Ohms; logged down; well flowing.
45a	7/16/83	0-2,811	Fluid temperature	Logged down; well flowing.

Appendix II.--Generalized description of lithology

Depth (feet)	Description
0-60	Sand, white to light-gray, quartz, fine to coarse grained; with fine carbonate sand, mollusk shells, light-gray, fine-grained limestone, and traces of phosphate. Probably Pleistocene to Holocene age.
60-180	Limestone, light-gray, sandy; with many mollusks and echinoids (Encope sp.); very sandy and phosphatic from 60 to 80 feet and from 160 to 180 feet. Tamiami Formation, Pliocene age.
180-220	Clay, dark-olive-green, silty, slightly phosphatic; with mollusks. Probably Hawthorn Formation, late Miocene age.
220-360	Clay, gray-green, sandy, diatomaceous; with alternating beds of white calcareous clay, dark-gray shelly limestone, and coarse-grained quartzose and phosphatic sands. Shark teeth are common. Hawthorn Formation, late Miocene age.
360-390	Clay, gray-green, slightly sand, micaceous; with barnacles and shark teeth. Hawthorn Formation, middle Miocene age.
390-460	Clay, olive-green; with white, calcareous, clay galls; slightly phosphatic. Contains Globoratalia mayeri and Orbulina saturalis. Hawthorn Formation, middle Miocene age.
460-510	Limestone, white to gray, sandy, shelly (barnacles and oysters), slightly phosphatic; with alternating beds of calcareous clay. Hawthorn Formation, limestone facies, middle Miocene age.
510-540	Limestone, light-gray, very sandy, fine to very coarse grained; with quartzose and phosphatic sand and calcareous clay. Hawthorn Formation, limestone facies, middle Miocene age.
540-600	Limestone, light-gray, shelly, microcrystalline, vuggy, hard, slightly phosphatic and sandy. Fossil molds and casts are common. Archaias floridanus is rare. Tampa Limestone, early Miocene age.
600-660	Clay, light-gray, calcareous, slightly phosphatic, silty; with white, chalky, clay galls; and minor limestones as in 540 to 600 feet. Contains Globoratalia mayeri, Globigerina juvenilis, and Globogerinoides obliquus. Clay facies of Tampa Limestone, early Miocene age.
660-770	Clay, light-gray, calcareous, slightly shelly; with phosphate increasing in size and prominence near base. Clay facies of Tampa Limestone, early Miocene age.
770-850	Limestone, white, hard, fine-grained, fossiliferous, vuggy. Casts and molds of mollusks and calcite crystals are common. Dictyoconus cookei and Miogypsina sp. are rare. Suwannee Limestone, Oligocene age.
850-880	Limestone, white, as in 770 to 850 feet; alternating with beds of calcareous clay and gray to tan, sandy, phosphatic limestone. Suwannee Limestone, Oligocene age.
880-900	Clay, gray, sandy, calcareous; interbedded with limestone as in 850 to 880 feet. Clay-claystone facies of Suwannee Limestone, Oligocene age.
900-975	Limestone, tan to gray, phosphatic; and white, hard microcrystalline limestone with fossil molds and casts which probably is interbedded with the phosphatic limestone. Suwannee Limestone, Oligocene age.
975-1,040	Limestone, white, hard fossiliferous; chiefly microcrystalline with vuggy porosity. Lepidocyclina ocalana floridana is common. Ocala Limestone, late Eocene age.
1,040-1,115	Limestone, cream, fossiliferous, fine-grained, soft; with Camerina sp. and Lepidocyclina sp. Ocala Limestone, late Eocene age.
1,115-1,140	Limestone, cream, fossiliferous, medium hard, fine-grained to crystalline; trace of fine-grained phosphate. Avon Park Formation, late middle Eocene age.
1,140-1,240	Limestone, tan, fine-grained to crystalline; with many Dictyoconus sp., miliolids, Lituonella floridana, and Fabularia vaughani. Avon Park Formation, late middle Eocene age.
1,240-1,290	Limestone, tan to gray, dolomitic, chalky, fossiliferous, vuggy; with coarse crystalline dolomite, 1,250 to 1,260 feet. Avon Park Formation.
1,290-1,400	Limestone, cream to tan, fine-grained, fossiliferous; with many Dictyoconus sp. and fragments of mollusks. Avon Park Formation.
1,400-1,460	Limestone, cream to tan, hard; with sparry, calcite-filling vugs. Avon Park Formation.
1,460-1,570	Limestone, tan, fossiliferous, fine-grained, medium hard, sparry; with many Dictyoconus sp., miliolids, fragments of small echinoids and mollusks. Trace of green, silty, phosphatic clay (probably cavings). Avon Park Formation.

Depth (feet)	Description
1,570-1,600	Limestone, tan, fossiliferous; with calcite and vugs. Contains Dictyoconus sp., miliolids, and small echinoids. Also, some brown crystalline dolomite, white calcareous clay, and gray-black stained fossiliferous limestone. Avon Park Formation (formerly the Lake City Limestone).
1,600-1,620	Limestone, tan, fossiliferous; and fine-grained, brown, dolomite. Avon Park Formation (formerly the Lake City Limestone).
1,620-1,670	Limestone, tan, fine-grained, fossiliferous; with gray dolosand and brown to gray dolomite. Noted one Dictyoconus americanus. Avon Park Formation (formerly the Lake City Limestone).
1,670-1,720	Limestone, tan, fossiliferous; and brown, organic-calcareous, clay. Noted one Dictyoconus americanus. Avon Park Formation (formerly the Lake City Limestone).
1,720-1,820	Limestone, tan, fossiliferous, medium hard to soft; with many Dictyoconus americanus. Avon Park Formation (formerly the Lake City Limestone).
1,820-1,920	Limestone, tan to cream, fine-grained; with many Dictyoconus sp. and organic-rich layers. Avon Park Formation (formerly the Lake City Limestone).
1,920-2,070	Limestone, cream argillaceous, fine-grained; with many Dictyoconus sp. (including cookei, americanus, and gunteri). Avon Park Formation (formerly the Lake City Limestone).
2,070-2,120	Dolomite, brown, coarsely crystalline, carbonaceous or lignitic, cherty; and tan, fine-fine-grained limestone. Noted many very large Dictyoconus americanus. Probably Oldsmar Formation, early Eocene age.
2,120-2,140	Limestone, tan, fine-grained. Probably Oldsmar Formation.
2,140-2,180	Dolomite, dark-brown to dark-gray, crystalline, vuggy; with organic-rich laminae and cream, fine-grained limestone. Probably Oldsmar Formation.
2,180-2,230	Limestone, cream, chalky, fine-grained; and tan dolomite. Dictyoconus sp. is common. Probably Oldsmar Formation.
2,230-2,250	Limestone, cream to light-gray; with dark-gray to brown, sucrosic, dolomite and a trace of quartz crystals. Probably Oldsmar Formation.
2,250-2,270	Dolomite, tan to light-brown, hard, microcrystalline to medium-grained; black calcite and dogtooth spar; and cream to tan, fine-grained limestone with dolomite rhombs. Probably Oldsmar Formation.
2,270-2,340	Limestone, cream to light-gray, chalky, massive, dolomitic (dolomite rhombs floating in matrix); and dark-brown to tan, sucrosic to microcrystalline dolomite. Noted one Miscellanea nassauensis in samples from 2,320 to 2,330 feet. Oldsmar Formation.
2,340-2,430	Limestone, tan to cream, fine-grained, dolomitic; and tan to brown, sucrosic dolomite. Dictyoconus sp. common. Oldsmar Formation.
2,430-2,450	Dolomite, dark-brown to dark-gray, vuggy, coarsely crystalline, organic or carbonaceous; and blue-gray, massive, fine-grained limestone with crystals filling porosity. Oldsmar Formation.
2,450-2,540	Dolomite, dark-brown to dark-gray, hard, crystalline, massive; and a trace of cream, fossiliferous limestone. Oldsmar Formation.
2,540-2,570	Dolomite, brown to dark-brown, hard, massive, vuggy; and trace of white, fossiliferous limestone with miliolids (possibly cavings). First noticeable cavities encountered. Subrounded pebbles noted from 2,492 to 2,494 feet. Oldsmar Formation.
2,570-2,620	Limestone, cream to gray, fine-grained, chalky, dolomitic, fossiliferous; and brown, crystalline to sucrosic dolomite. Oldsmar Formation.
2,620-2,720	Dolomite, brown, crystalline to sucrosic, vuggy; and white, chalky, fossiliferous, fine-grained limestone. Oldsmar Formation.
2,720-2,811	Limestone, white, fine-grained, hard, fossiliferous; and some brown, coarsely crystalline dolomite. Oldsmar Formation.

Appendix III.--Summary of comprehensive water analyses

[Station number 261016080492601; °C, degrees Celsius; Pt-Co, platinum-cobalt; μS/cm, microsiemens per centimeter; pci/L, picocuries per liter; g/mL, grams per milliliter; mg/L, milligrams per liter; μg/L, micrograms per liter]

Date of sample	Time	Elevation of land surface datum (feet above sea level)	Depth of well, total (feet)	Depth to top of sample interval (feet)	Depth to bottom of sample interval (feet)	Temperature (°C)	Color (Pt-Co units)	Specific conductance (μS/cm)	pH (units)	pH lab (units)
10/18/80	0300	15.45	2,811	895	934	26.5	3	4,600	7.9	7.9
3/3/81	1830	15.45	2,811	895	2,457	25.1	<5	13,500	7.7	8.0
3/3/81	2100	15.45	2,811	2,463	2,811	24.7	<5	50,000	7.8	7.8
3/6/81	2355	15.45	2,811	895	1,428	26.0	<5	3,120	7.9	7.9
3/7/81	0200	15.45	2,811	1,433	1,618	25.9	<5	6,050	8.2	7.9
3/8/81	0630	15.45	2,811	895	1,249	26.2	<5	3,150	7.8	8.0
3/8/81	1145	15.45	2,811	1,254	2,811	26.0	<5	10,450	7.9	7.8
3/9/81	0730	15.45	2,811	895	1,124	26.2	<5	3,325	7.8	7.8
3/9/81	1000	15.45	2,811	1,129	2,811	26.1	<5	8,900	8.0	7.8
4/1/81	0955	15.45	2,811	895	2,811	26.0	5	29,000	7.5	7.4
10/19/81	1030	15.45	2,811	895	2,811	26.0	1	3,770	8.3	7.9
10/19/81	1230	15.45	2,811	811	816	26.0	2	6,200	8.2	8.1
10/19/81	1500	15.45	2,811	2,500	2,500	24.7	1	54,000	7.7	7.6

Date of sample	Concentrations shown in milligrams per liter							
	Alkalinity field (CaCO3)	Bicarbonate fet-fld (HCO3)	Nitrogen, dissolved (N)	Nitrogen, organic dissolved (N)	Nitrogen, ammonia dissolved (N)	Nitrogen, nitrite dissolved (N)	Nitrogen, nitrate dissolved (N)	Nitrogen, ammonia + organic dissolved (N)	Nitrogen, NO2 + NO3 dissolved (N)
10/18/80	--	--	0.53	0.05	0.470	0.000	0.01	0.01	0.52
3/3/81	104	--	--	--	--	--	--	--	--
3/3/81	121	--	.64	.37	.180	<.010	--	.09	.55
3/6/81	--	--	--	--	--	--	--	--	--
3/7/81	110	--	--	.00	.300	<.010	--	<.01	.21
3/8/81	100	--	.32	.00	.290	<.010	--	.05	.27
3/8/81	--	--	--	--	--	--	--	--	--
3/9/81	100	--	--	.00	.290	<.010	--	<.01	.25
3/9/81	110	--	--	--	--	--	--	--	--
4/1/81	105	128	.29	.08	.180	<.010	--	.03	.26
10/19/81	--	--	--	.25	.330	<.010	<.05	<.01	.58
10/19/81	--	--	--	.00	.630	<.010	--	<.01	.60
10/19/81	115	--	--	.32	.180	<.010	<.05	<.01	.50

Date of sample	Concentrations shown in milligrams per liter								
	Phosphate, ortho, dissolved (PO4)	Phosphorus, dissolved (P)	Phosphorus, ortho, dissolved (P)	Carbon, organic total (C)	Carbon, inorganic total (C)	Sulfide total (S)	Hardness (CaCO3)	Hardness, non-carbonate (CaCO3)	Calcium, dissolved (Ca)
10/18/81	0.00	0.010	0.000	6.0	--	1.9	680	580	87
3/3/81	--	--	--	--	--	--	1,300	1,300	135
3/3/81	.06	.060	.020	.9	23	1.9	6,400	6,400	420
3/6/81	--	--	--	--	--	--	530	410	76
3/7/81	--	<.010	<.010	4.1	26	1.4	570	460	72
3/8/81	--	<.010	<.010	2.6	25	2.8	540	430	78
3/8/81	--	--	--	--	--	--	1,300	1,200	120
3/9/81	--	<.010	<.010	4.7	24	3.6	550	460	79
3/9/81	--	--	--	--	--	--	840	740	97
4/1/81	--	.020	<.010	--	--	--	3,400	3,300	240
10/19/81	--	<.010	<.060	--	--	--	560	--	72
10/19/81	--	<.010	<.010	--	--	--	790	--	100
10/19/81	--	.050	<.060	--	--	--	6,500	--	420

Appendix III.--Summary of comprehensive water analyses--Continued

Date of sample	Magnesium, dissolved (Mg)	Sodium, dissolved (Na)	Sodium adsorption ratio	Percent sodium	Potassium, dissolved (K)	Chloride, dissolved (Cl)	Sulfate, dissolved (SO4)	Fluoride, dissolved (F)	Silica, dissolved (SiO2)
	Concentrations shown in milligrams per liter								
10/18/80	110	630	11	66	33	1,200	410	1.9	9.4
3/3/81	240	2,800	32	80	83	4,600	730	1.4	9.6
3/3/81	1,300	11,000	60	78	420	19,500	2,800	.8	2.3
3/6/81	81	500	9.5	66	22	800	430	1.5	11
3/7/81	92	1,100	20	80	29	1,800	450	1.7	9.8
3/8/81	82	500	9.4	66	21	760	380	.3	13
3/8/81	240	1,700	21	73	81	3,000	680	1.5	11
3/9/81	83	500	9.4	66	23	850	400	1.5	11
3/9/81	140	1,700	26	81	43	2,800	520	1.6	9.8
4/1/81	680	6,100	46	78	220	11,000	1,700	1.1	7.3
10/19/81	90	670	12	72	23	1,100	400	1.7	9.0
10/19/81	130	790	12	67	38	1,600	500	3.0	15
10/19/81	1,200	13,000	59	77	430	22,700	2,700	.7	2.6

Date of sample	Arsenic, dissolved (As)	Arsenic, suspended total (As)	Arsenic, total (As)	Barium, dissolved (Ba)	Boron, dissolved (B)	Cadmium, dissolved (Cd)	Cadmium, suspended recov-erable (Cd)	Cadmium, total recov-erable (Cd)	Chromium, dissolved (Cr)
	Concentrations shown in micrograms per liter								
10/18/80	0	0	0	--	--	0	0	0	10
3/3/81	--	--	--	--	--	--	--	--	--
3/3/81	0	0	0	--	--	0	0	0	50
3/6/81	--	--	--	--	--	--	--	--	--
3/7/81	0	0	0	--	--	0	0	0	<10
3/8/81	0	0	0	--	--	0	0	0	<10
3/8/81	--	--	--	--	--	--	--	--	--
3/9/81	0	0	0	--	--	0	0	0	10
3/9/81	--	--	--	--	--	--	--	--	--
4/1/81	0	0	0	--	--	2	0	0	20
10/19/81	--	--	--	<50	480	--	--	--	--
10/19/81	--	--	--	<50	710	--	--	--	--
10/19/81	--	--	--	<100	3,000	--	--	--	--

Date of sample	Chromium, suspended recov-erable (Cr)	Chromium, total recov-erable (Cr)	Cobalt, dissolved (Co)	Cobalt, suspended recov-erable (Co)	Cobalt, total recov-erable (Co)	Copper, dissolved (Cu)	Copper, suspended recov-erable (Cu)	Copper, total recov-erable (Cu)	Iron, suspended recov-erable (Fe)
	Concentrations shown in micrograms per liter								
10/18/80	20	30	0	4	4	0	0	0	1,500
3/3/81	--	--	--	--	--	--	--	--	--
3/3/81	0	50	0	0	0	1	1	2	0
3/6/81	--	--	--	--	--	--	--	--	--
3/7/81	--	10	0	1	1	0	1	1	280
3/8/81	--	10	0	1	1	0	1	1	50
3/8/81	--	--	--	--	--	--	--	--	--
3/9/81	10	20	0	3	3	0	7	7	150
3/9/81	--	--	--	--	--	--	--	--	--
4/1/81	0	20	3	0	0	0	1	1	40
10/19/81	--	--	--	--	--	--	--	--	4,700
10/19/81	--	--	--	--	--	--	--	--	0
10/19/81	--	--	--	--	--	--	--	--	0

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Appendix III.--Summary of comprehensive water analyses--Continued

Date of sample	Concentrations shown in micrograms per liter: Iron, total recoverable (Fe)	Iron, dissolved (Fe)	Lead, dissolved (Pb)	Lead, suspended recoverable (Pb)	Lead, total recoverable (Pb)	Manganese, suspended recoverable (Mn)	Manganese, total recoverable (Mn)	Manganese, dissolved (Mn)	Strontium dissolved (Sr)
10/18/80	1,900	370	0	14	14	10	60	50	6,500
3/3/81	--	--	--	--	--	--	--	--	17,000
3/3/81	4,700	5,000	1	15	16	0	160	190	6,800
3/6/81	--	--	--	--	--	--	--	--	9,300
3/7/81	750	470	2	0	1	20	110	90	13,000
3/8/81	100	50	0	1	1	0	10	10	9,400
3/8/81	--	--	--	--	--	--	--	--	11,000
3/9/81	190	40	0	10	10	10	20	10	9,300
3/9/81	--	--	--	--	--	--	--	--	22,000
4/1/81	420	380	0	7	7	30	40	10	5,800
10/19/81	4,800	100	--	--	--	--	20	<10	11,000
10/19/81	1,100	1,100	--	--	--	0	10	10	6,400
10/19/81	400	400	--	--	--	60	120	60	7,900

Date of sample	Zinc, dissolved (Zn)	Zinc, suspended recoverable (Zn)	Zinc, total recoverable (Zn)	Aluminum, dissolved (Al)	Selenium, dissolved (Se)	Selenium, suspended total (Se)	Selenium, total (Se)	Tritium total (pci/L)	Solids, residue at 180 °C dissolved (mg/L)
10/18/80	10	0	10	--	0	0	0	--	2,670
3/3/81	--	--	--	--	--	--	--	--	8,540
3/3/81	30	0	30	30	2	0	2	1.0	38,000
3/6/81	--	--	--	--	--	--	--	--	1,930
3/7/81	10	0	10	10	0	0	0	<2.0	3,640
3/8/81	10	0	10	10	0	0	0	3.0	1,930
3/8/81	--	--	--	--	--	--	--	--	6,450
3/9/81	10	750	760	10	0	0	0	.0	2,000
3/9/81	--	--	--	--	--	--	--	--	5,290
4/1/81	20	0	20	10	2	0	2	--	20,300
10/19/81	--	--	--	20	--	--	--	--	2,400
10/19/81	--	--	--	100	--	--	--	--	3,500
10/19/81	--	--	--	10	--	--	--	<1.0	36,700

Date of sample	Solids, sum of constituents dissolved (mg/L)	Solids, dissolved (tons per acre-feet)	Density (g/mL at 20 °C)	Concentrations shown in milligrams per liter: Nitrogen, ammonia dissolved (NH4)	Nitrogen, nitrate dissolved (NO3)	Nitrogen, nitrite dissolved (NO2)	Bromide, dissolved (Br)	Mercury, dissolved (µg/L as Hg)
10/18/80	2,550	3.6	--	0.61	0.04	0.00	--	0.2
3/3/81	7,090	--	1.005	--	--	--	10	--
3/3/81	31,100	--	1.024	.23	--	--	68	.1
3/6/81	1,880	--	.999	--	--	--	2.3	--
3/7/81	3,400	--	1.001	.39	--	--	2.5	.1
3/8/81	1,740	--	.999	.37	--	--	2.0	.1
3/8/81	5,830	--	1.003	--	--	--	8.7	--
3/9/81	1,990	--	1.000	.37	--	--	2.2	.1
3/9/81	5,310	--	1.003	--	--	--	10	--
4/1/81	20,100	--	1.012	.23	--	--	60	.1
10/19/81	2,440	--	1.001	.43	--	--	3.3	--
10/19/81	3,260	--	1.001	.81	--	--	10	--
10/19/81	37,200	--	1.023	.23	--	--	66	--

Date of sample	Mercury, suspended recoverable (µg/L as Hg)	Mercury, total recoverable (µg/L as Hg)	Specific conductance lab (µS/cm)	Alkalinity lab (mg/L as CaCO3)	Hardness noncarbonate (mg/L as CaCO3)	Potassium 40 dissolved (pci/L as K40)
10/18/80	0.0	0.1	4,380	97	--	25
3/3/81	--	--	13,600	93	--	60
3/3/81	.0	.1	40,200	100	--	310
3/6/81	--	--	3,070	93	--	16
3/7/81	.0	.1	6,100	100	--	22
3/8/81	.0	.1	3,000	93	--	16
3/8/81	--	--	9,580	100	--	60
3/9/81	.0	.1	3,250	93	--	16
3/9/81	--	--	8,920	100	--	32
4/1/81	.0	.1	29,000	100	3,300	160
10/19/81	--	--	4,020	99	460	--
10/19/81	--	--	5,580	110	680	--
10/19/81	--	--	48,800	120	5,900	--

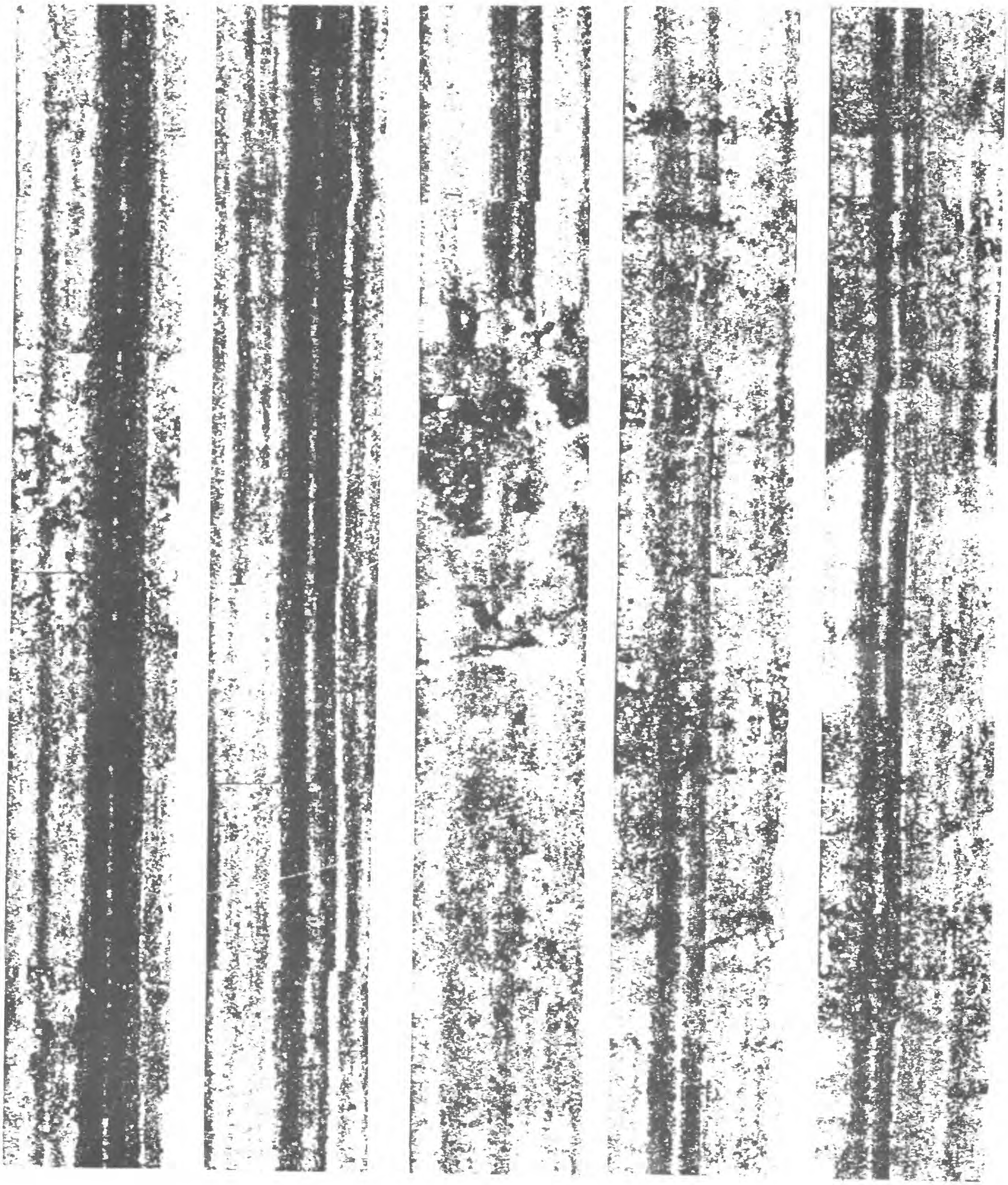
Date of sample	C-13/C-12 stable isotope ratio (per mill)	H-2/H-1 stable isotope ratio (per mill)	O-18/O-16 stable isotope ratio (per mill)	S-34/S-32 stable isotope ratio (per mill)	Carbon 14 percent modern	Carbon dioxide, dissolved (mg/L as CO2)
10/18/80	--	-13.5	-2.2	--	17.5	--
3/3/81	--	--	--	--	--	--
3/3/81	-3.8	-.5	-.3	--	30.3	--
3/6/81	--	--	--	--	--	--
3/7/81	-1.6	-14.0	-2.3	--	4.7	--
3/8/81	-2.6	-9.5	-2.6	--	5.8	--
3/8/81	--	--	--	--	--	--
3/9/81	-2.4	-12.0	-2.6	--	<4.7	--
3/9/81	--	--	--	--	--	--
4/1/81	--	--	--	--	--	5.8
10/19/81	-1.2	-12.0	-2.2	23.1	11.9	--
10/19/81	-1.8	-9.5	-1.8	--	7.3	--
10/19/81	-3.7	3.5	-.2	19.4	<7.6	--

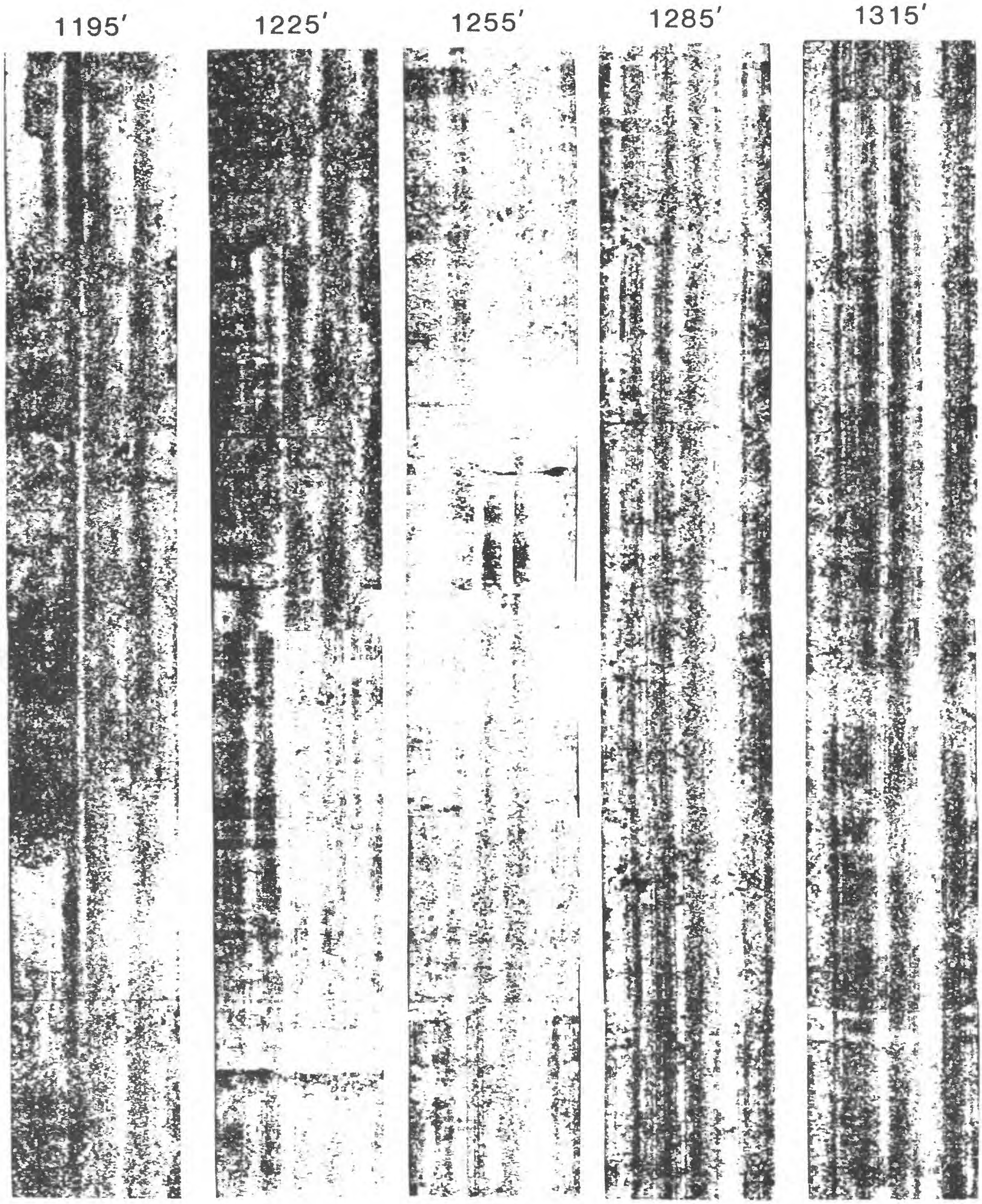
APPENDIX IV

ACOUSTIC TELEVIEWER LOG FROM 895 TO 2,811 FEET

ALLIGATOR ALLEY TEST WELL
BROWARD COUNTY G-2296

1045′	1075′	1105′	1135′	1165′

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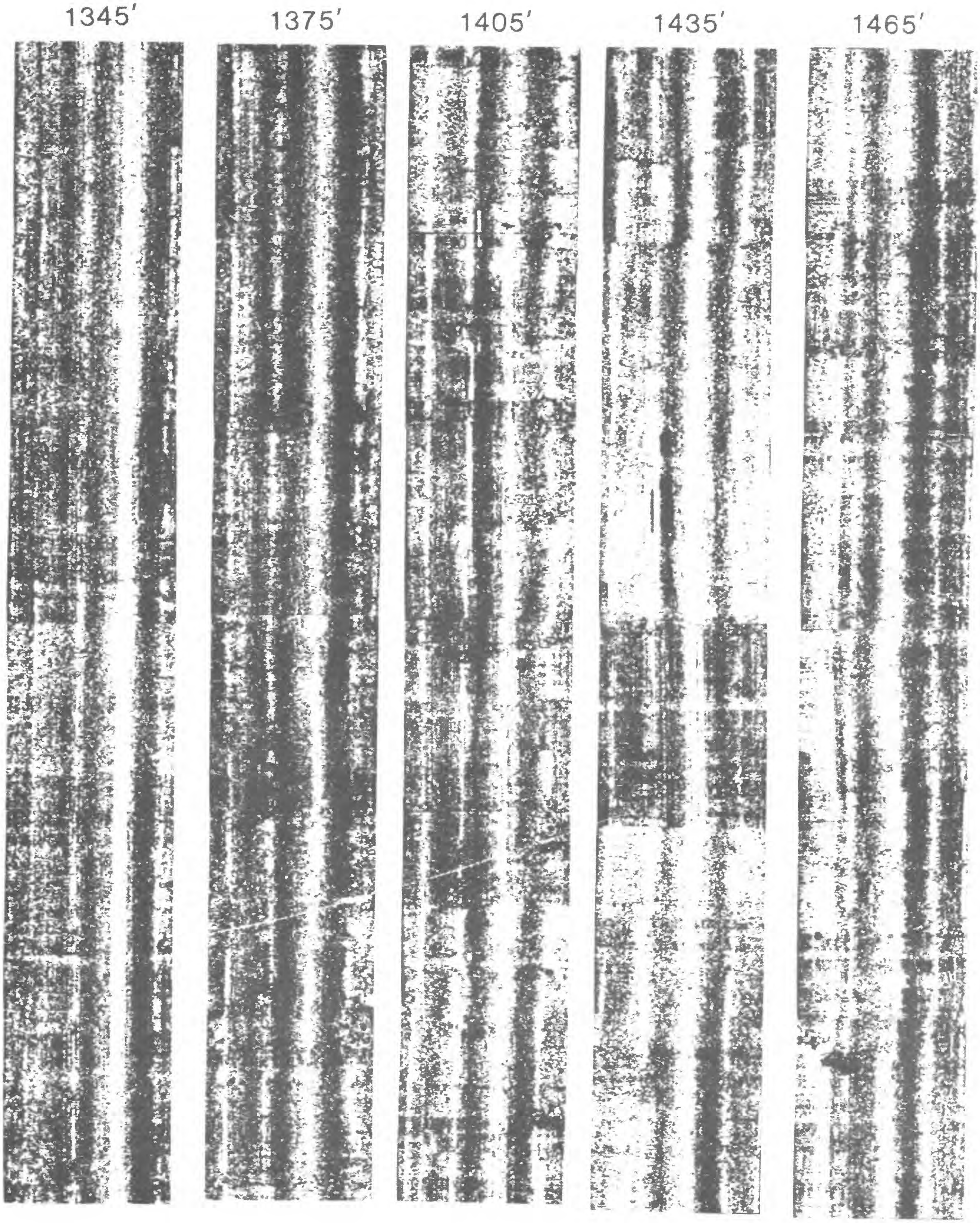
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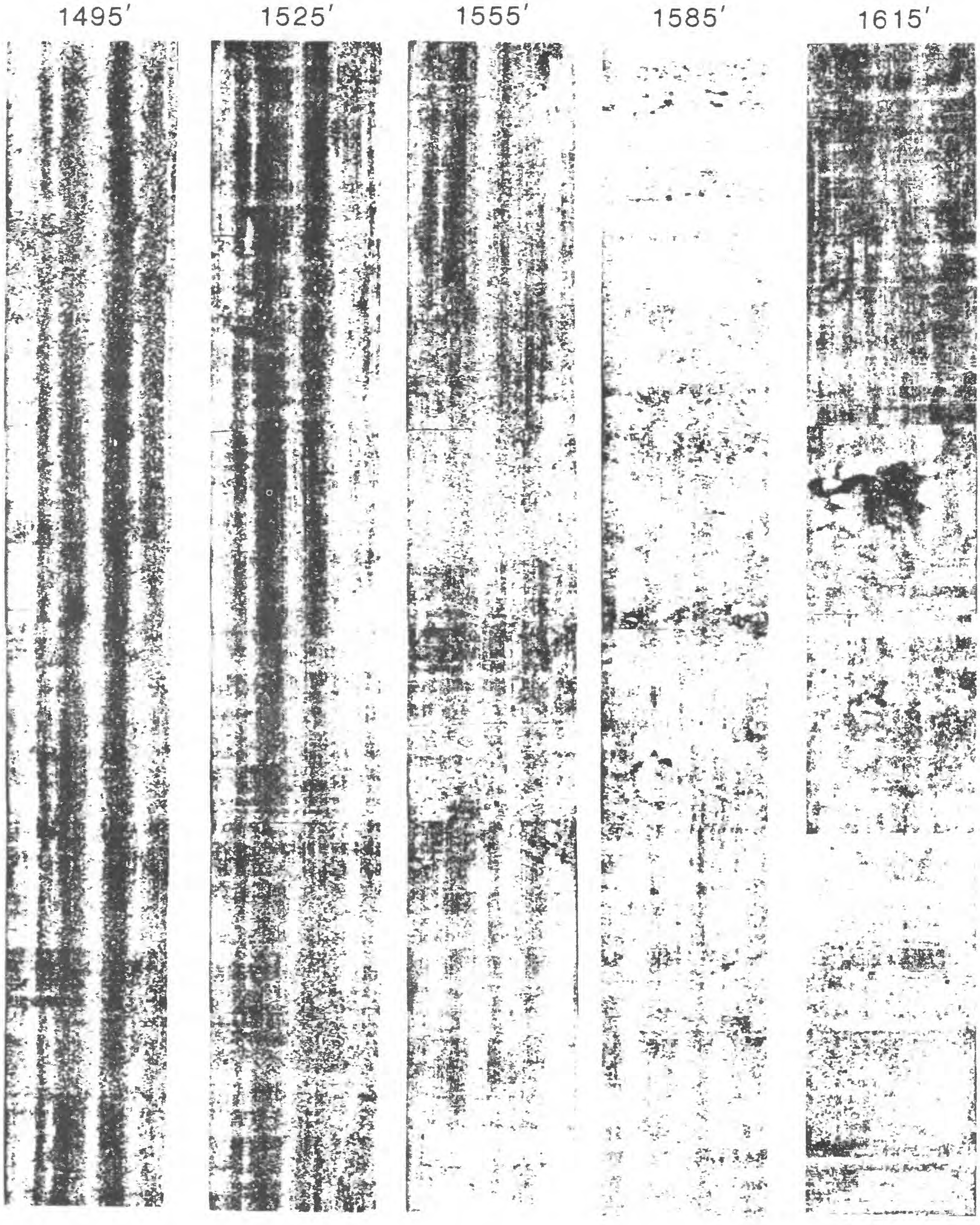
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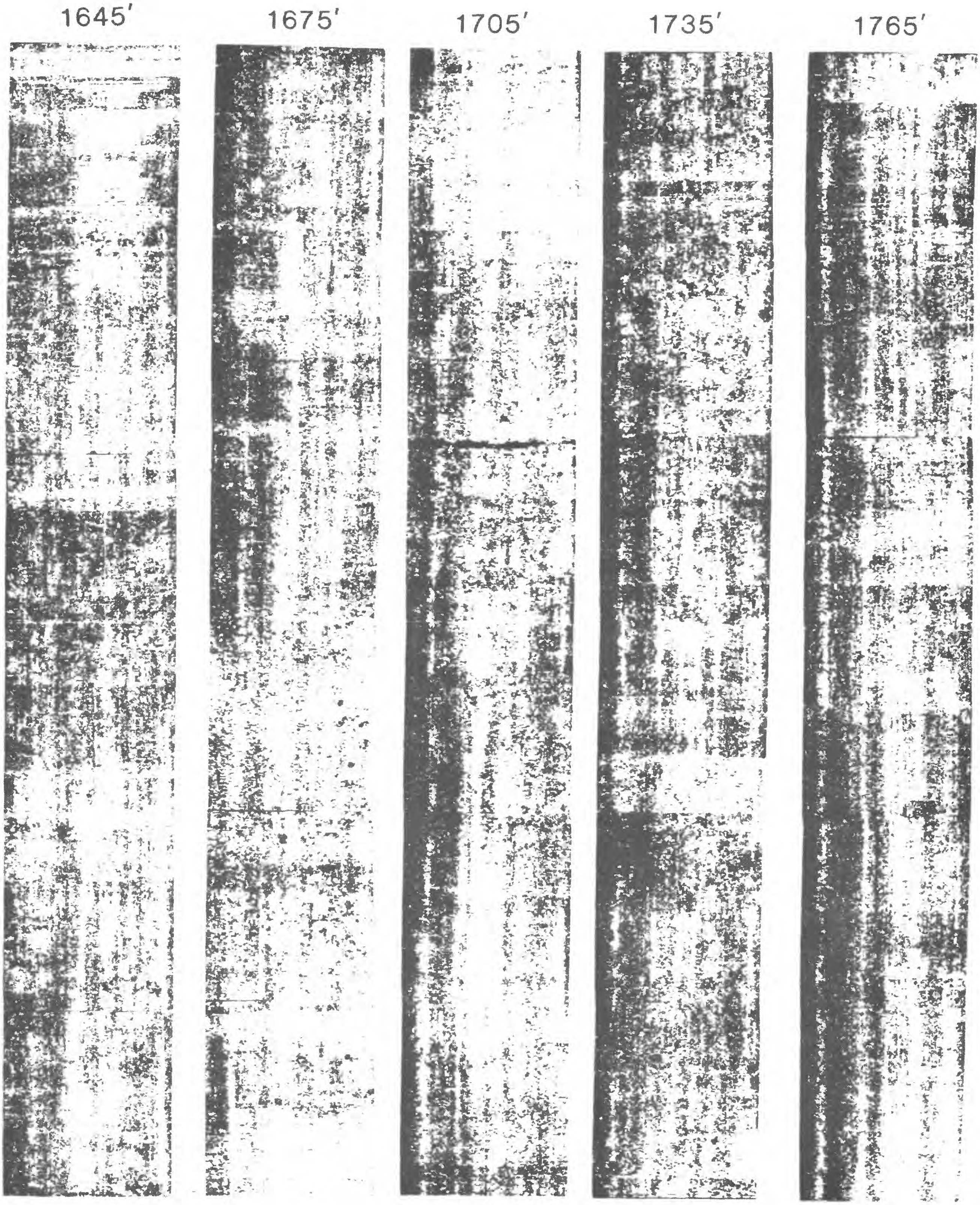
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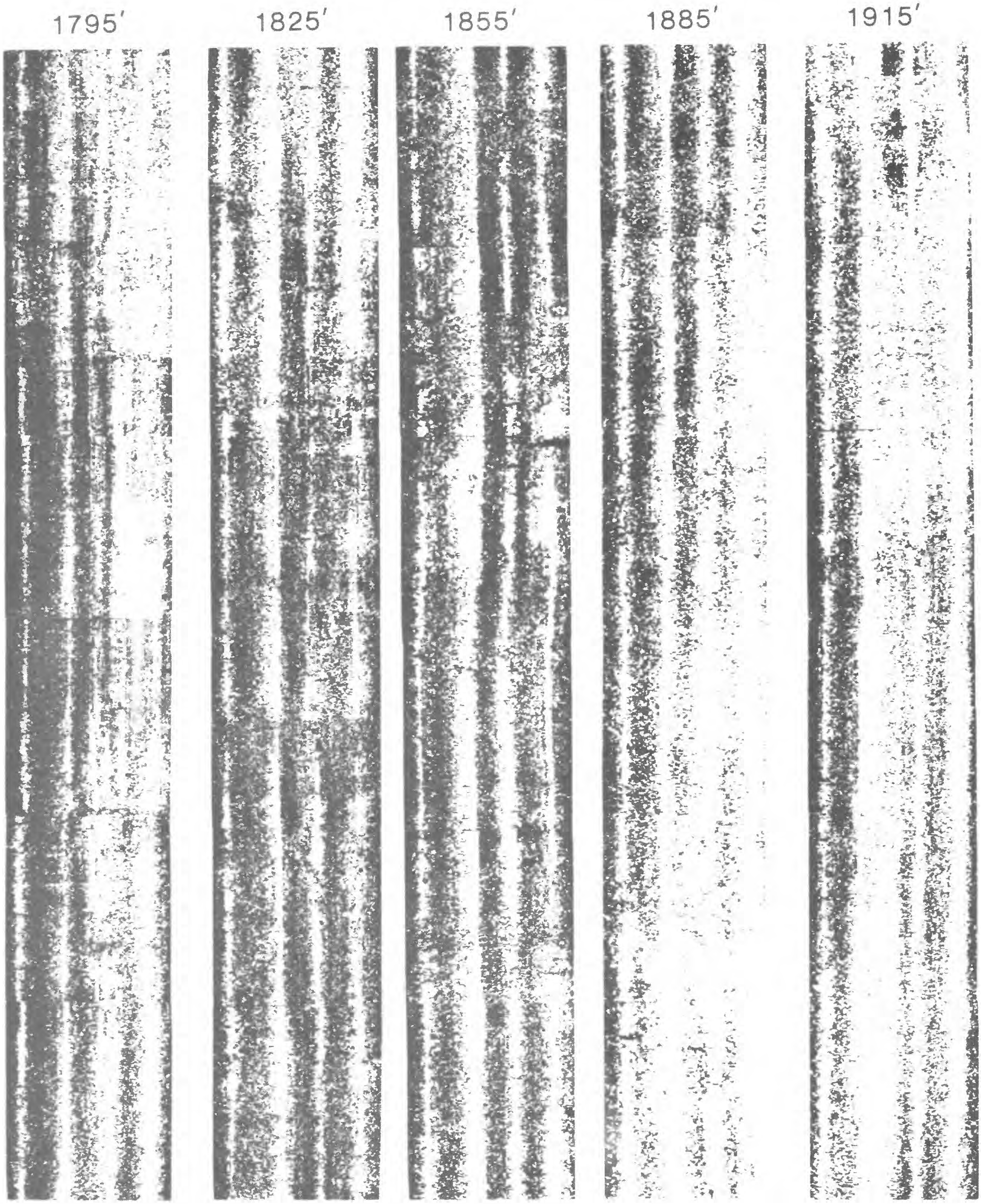
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1885'
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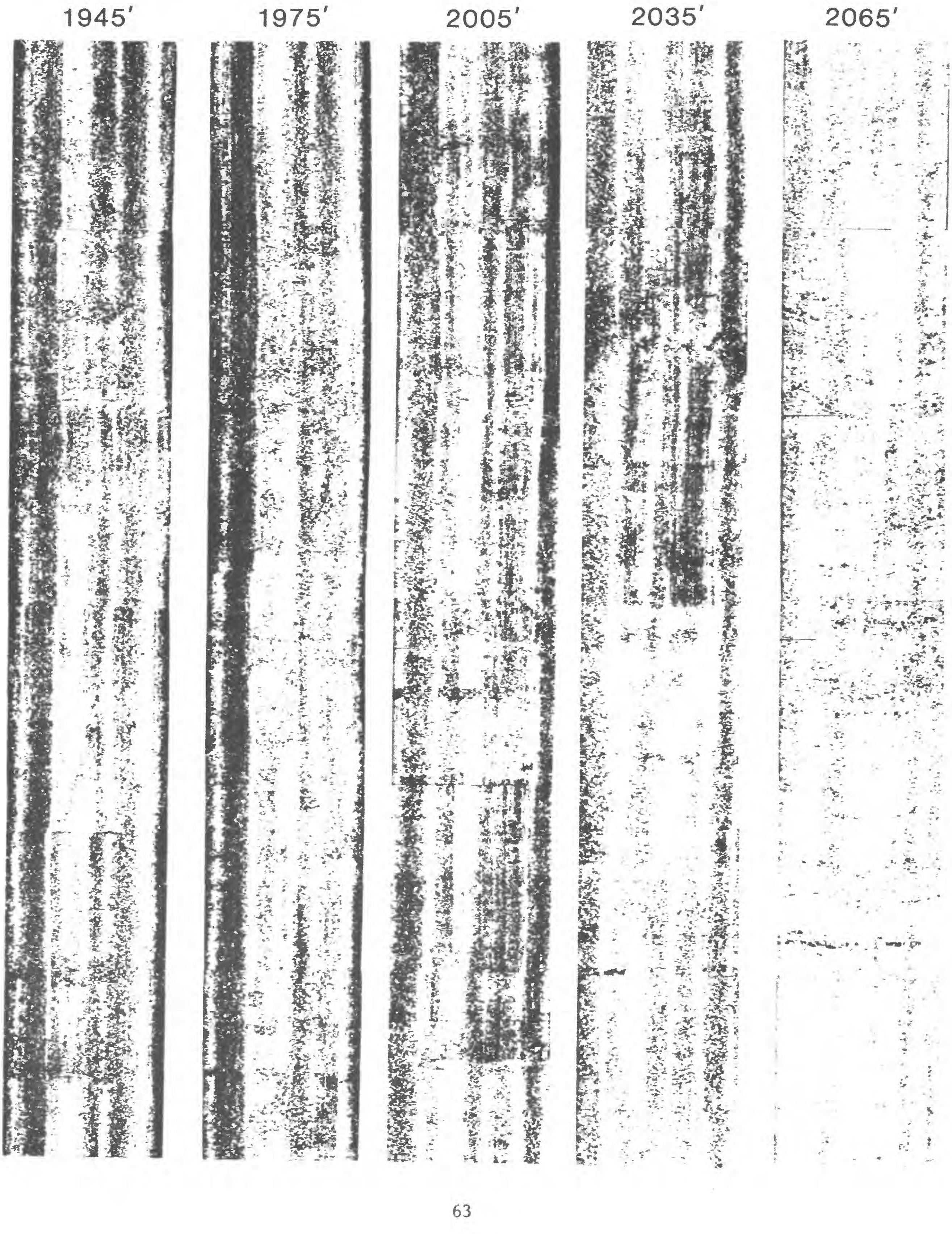
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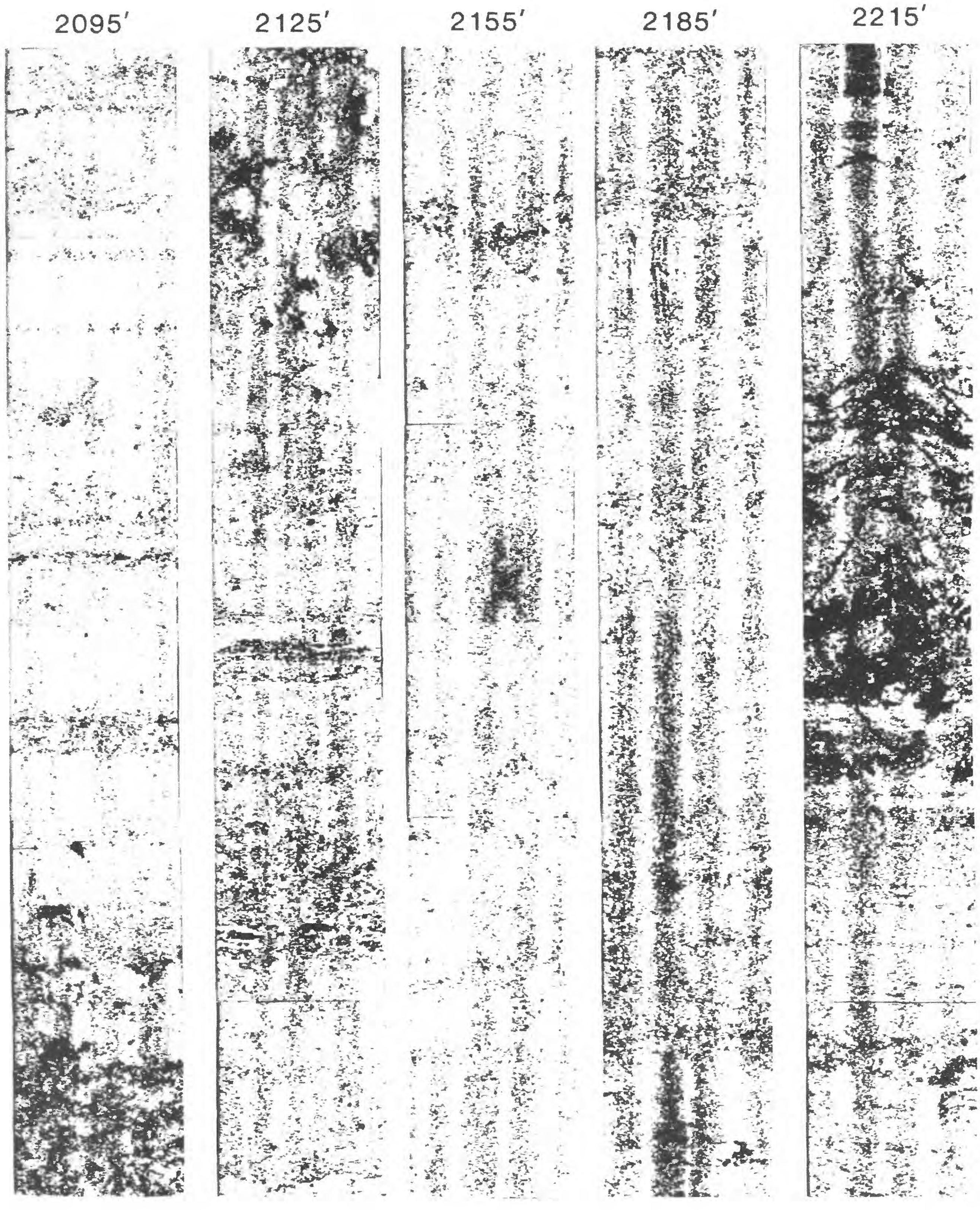
2065′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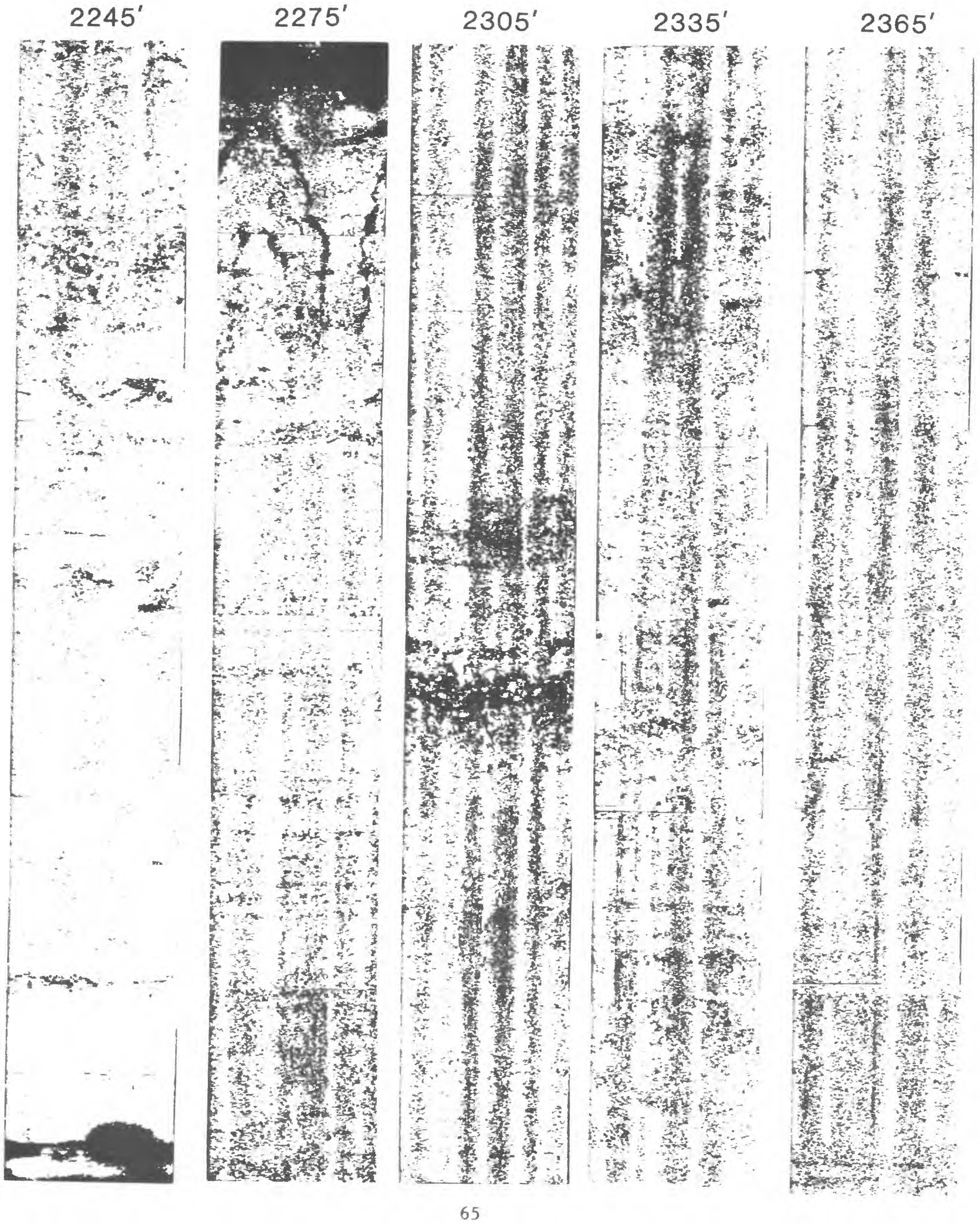
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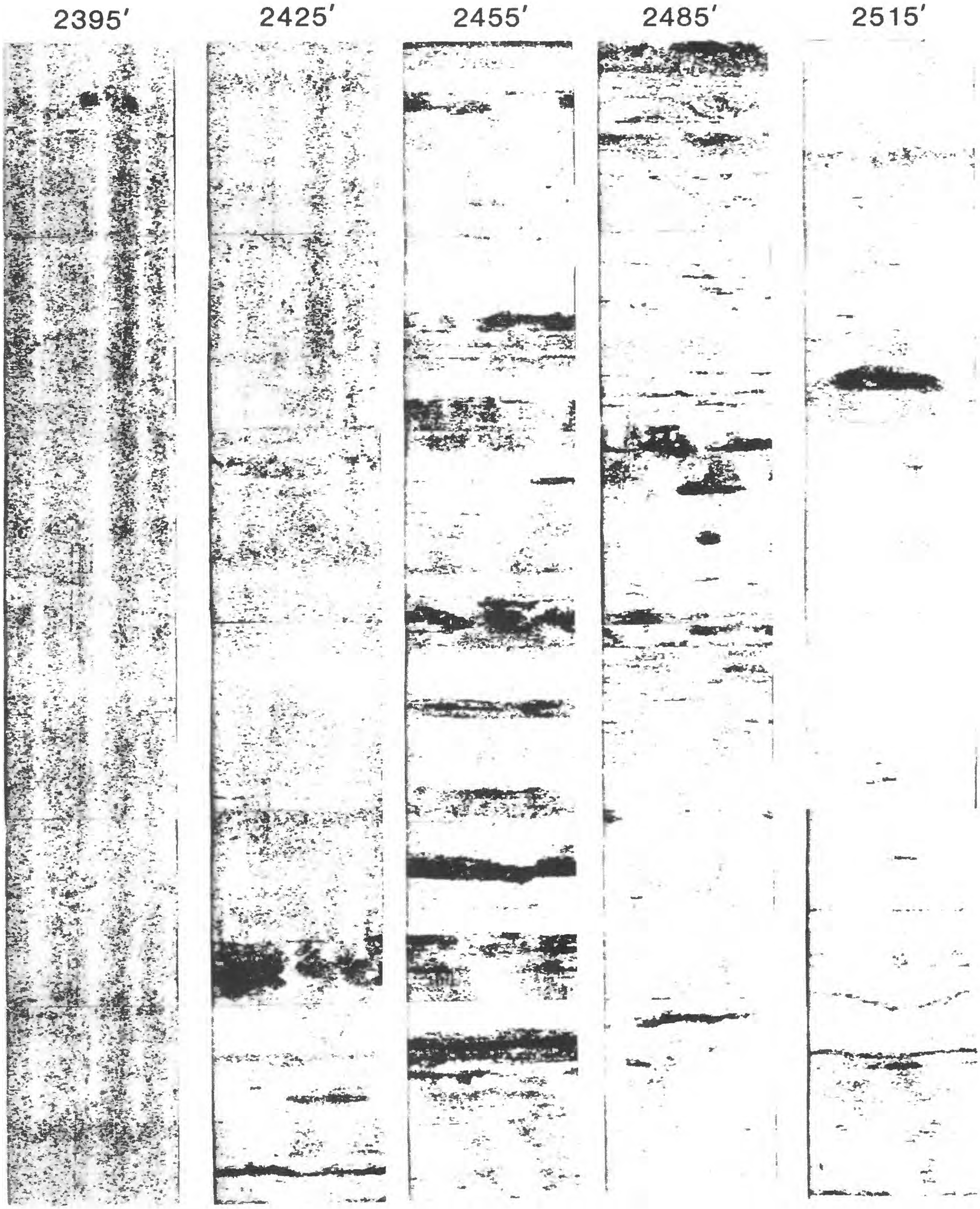
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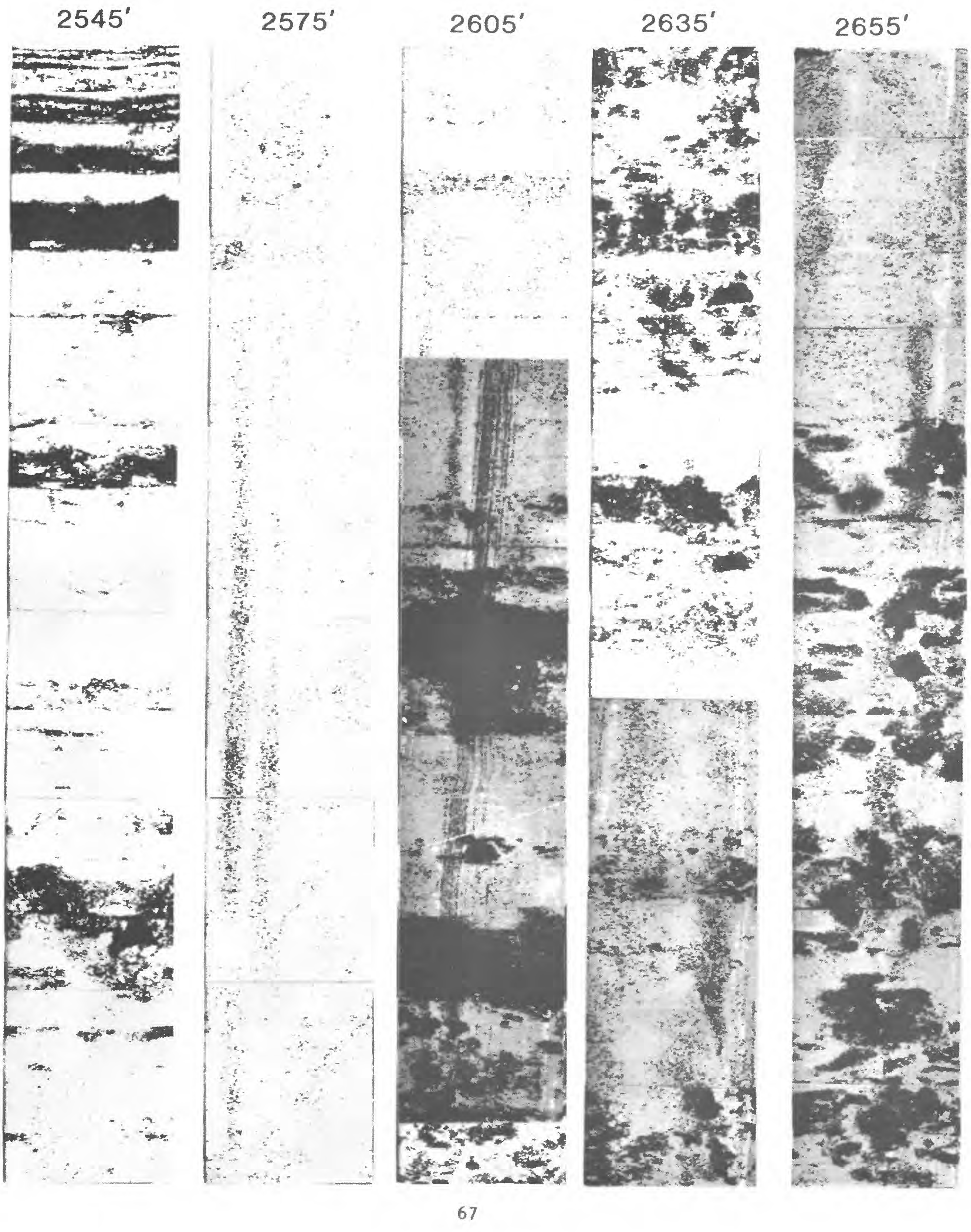

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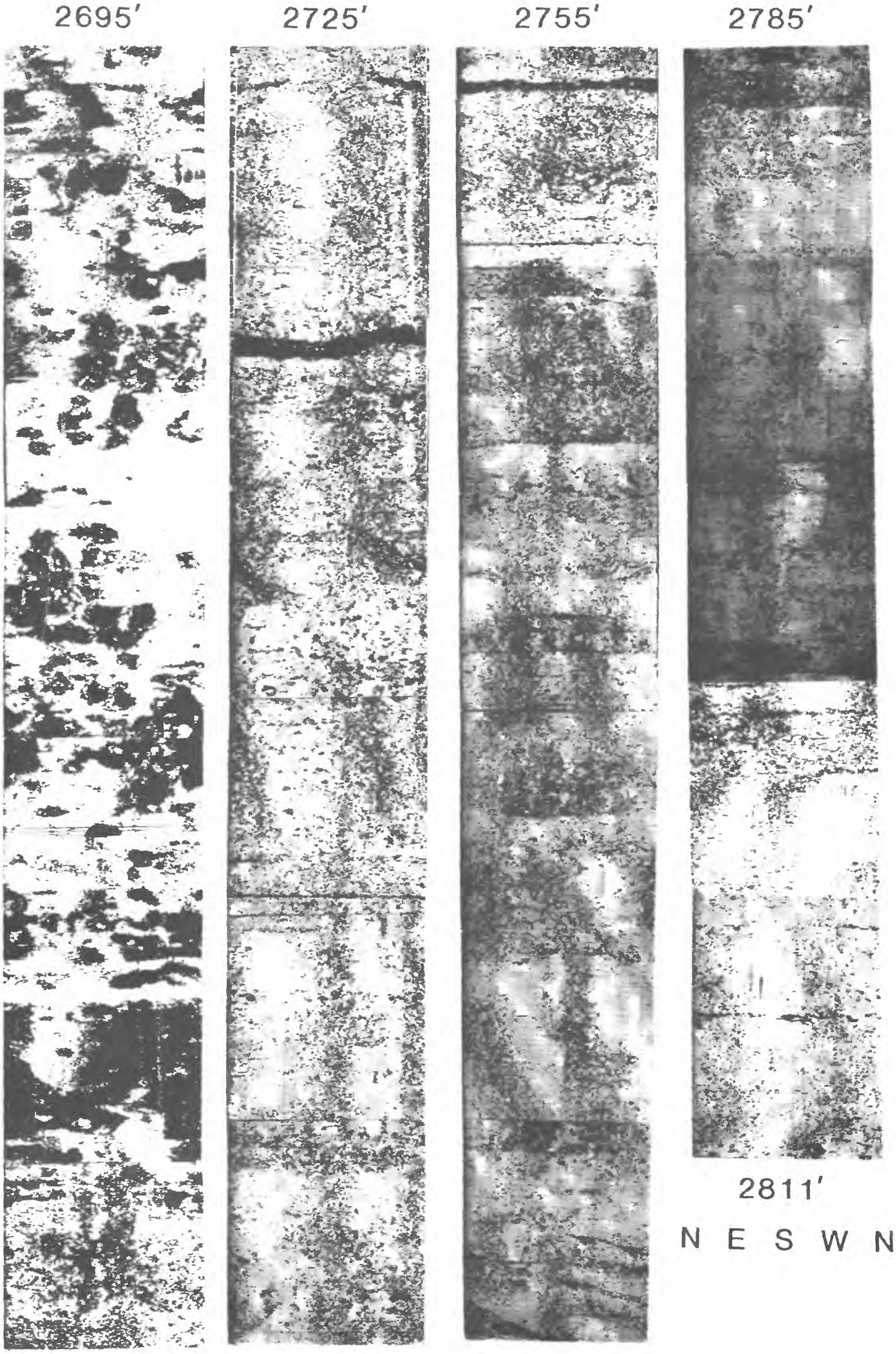
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