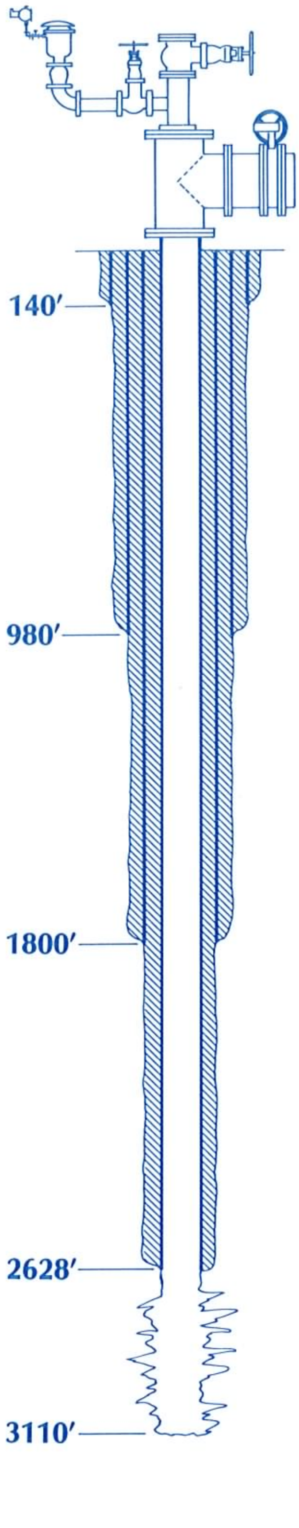


Summary of Engineering Report

DRILLING AND TESTING OF THE 8 INJECTION WELLS AND THE 3 MONITORING WELLS

for the South District Regional Wastewater Treatment Plant of the Miami-Dade Water and Sewer Authority

Dade County, Florida

MDWSA Contract No. S-154
EPA Contract No. C120377020

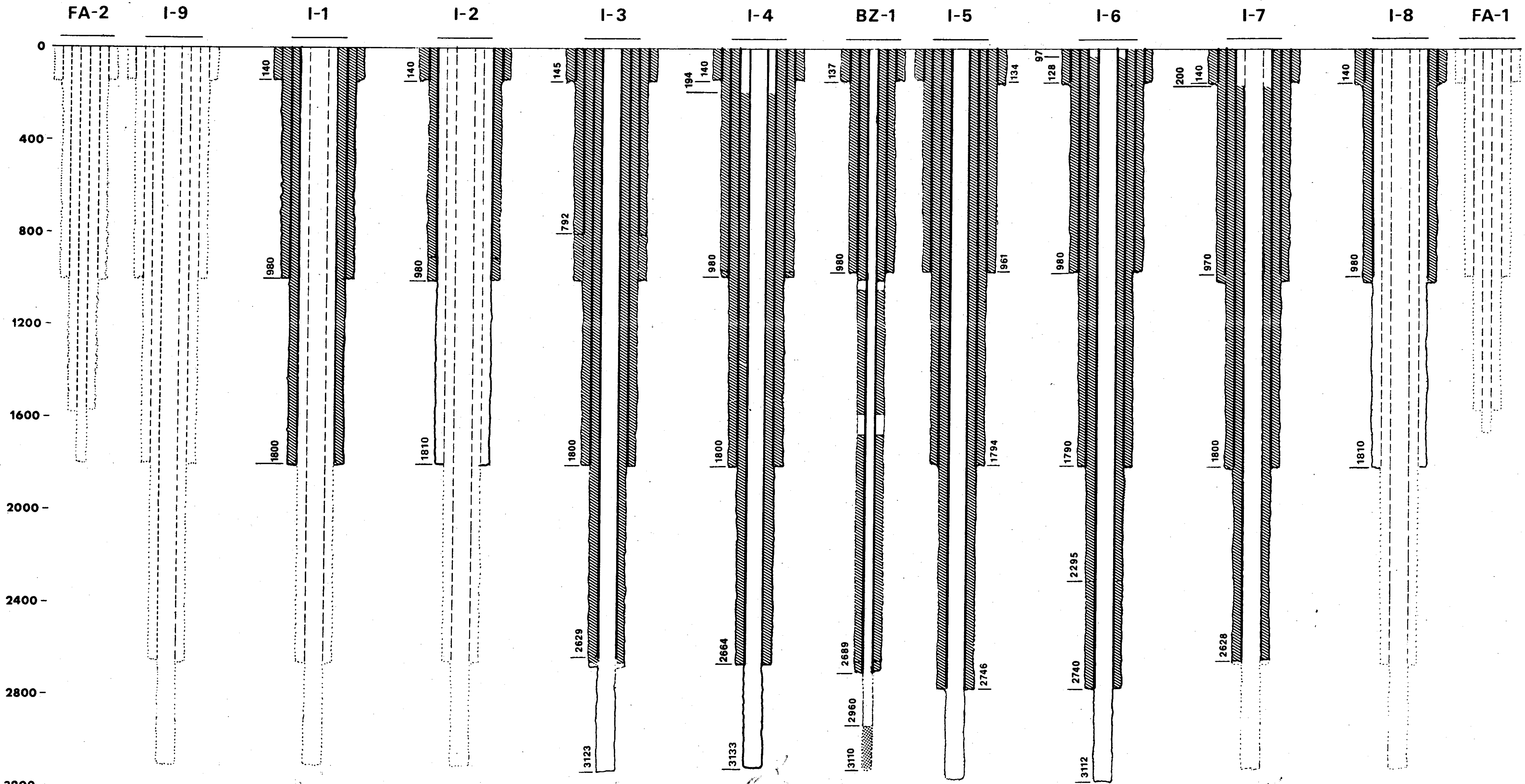
April 1981
BC 55900.92

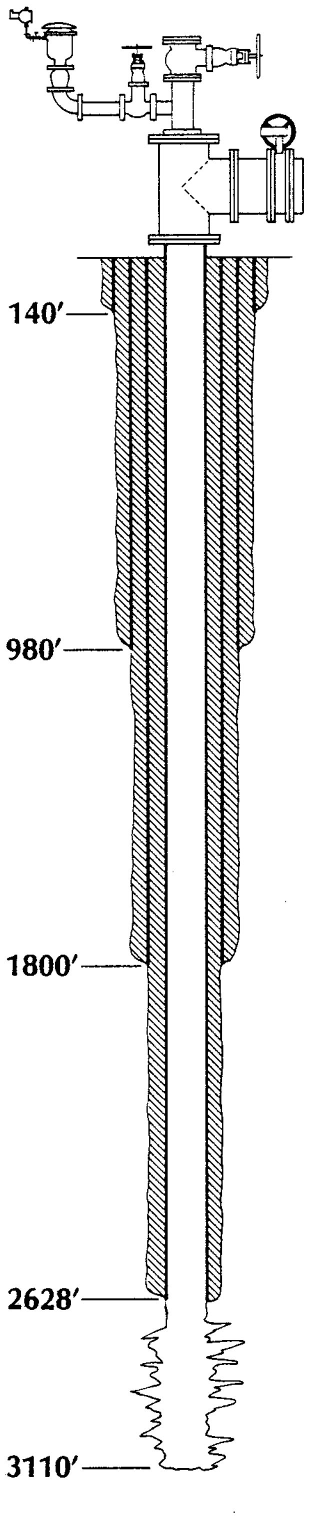
CH2M HILL

Miami-Dade Water & Sewer Authority   Project S-154

INJECTION & MONITOR WELLS

Progress as of 16 April 1980





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CH2M HILL

CH2M
HILL
engineers
planners
economists
scientists

May 20, 1981

BC55900.92

Mr. Garrett Sloan, Director
Miami-Dade Water and Sewer Authority
3575 South LeJeune Road
Miami, Florida 33133

Dear Mr. Sloan:

Subject: Drilling and Testing of Injection and Monitoring Wells for the South District Regional Wastewater Treatment Plant Your Contract S-154

It is with great satisfaction that we submit to you this engineering report covering the construction of the referenced project. This report is prepared in accordance with the requirements in paragraph 14 of the provisos included in the construction permits issued by DER, May 5, 1978 for each of the wells. Copies of the permits and the attached provisos for each of the types of wells are included in Appendix 4.A of the report.

Also included in the report is a chapter on the determination of the potentiometric surfaces of the Boulder Zone and the Upper Floridan aquifer and an injection model of the effects expected from the operation of the system at its design capacity. This is in accordance with the requirements of the letter from Mr. Warren G. Shrahm, DER, West Palm Beach, page 1, paragraph 4, dated December 23, 1976. On these two items, we have exercised our best professional judgment in view of the facts that this was the first time the determination of the potentiometric surface of the Boulder Zone has ever been attempted, that the zone starts at approximately 2,500 feet in depth, that it has the highest transmissivity that we have ever encountered (over 100 mgd/ft), that the slope of the surface is almost nil, and that this is an engineering rather than a research project.

We are proud to inform you that each of the injection wells was satisfactorily tested at a slightly higher rate than designed for (14 mgd), that their injection wellhead pressures are lower than anticipated (50 to 60 psi), and that the entire project was completed well within the 800 calendar

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In the Southeast, CH2M HILL was formerly known as Black, Crow and Eidsness.

days scheduled, slightly below the successful low bidder's total estimated cost, and below our estimated cost for construction of the project given to you in 1978.

It is our belief that such achievement was possible due to three main factors: (1) the close cooperation among the contractor, Alsay-Pippin Company of Lake Worth, Florida, the Technical Advisory Group (TAG), your staff, and our firm, (2) the dedication of the field personnel of the contractor, of your organization, and of ours, who kept the project running 24 hours a day, 7 days a week for approximately 2 years, and (3) the direction and guidelines you personally established at the inception of the entire project in 1976.

There are two persons on your staff who were involved in this project since it began and who contributed technically and administratively to its successful completion. They are Tom McCormick, resident inspector at the site, and Herb Kunen, consultants coordinator. To them, to Messrs. Jim Cowgill, Murray Grant, and George King, and to you personally, our sincerest thanks.

Sincerely,

J. I. Garcia-Bengochea, P.E.

gab

PREFACE

This report covers the construction and testing of eight deep injection, three multizone, and nine shallow monitoring wells for the South District Regional Wastewater Treatment Plant of the Miami-Dade Water and Sewer Authority (MDWSA), Dade County, Florida. The plantsite is located in south Miami, south of S.W. 232nd Avenue, north of Black Creek, and between S.W. 87th and 97th Avenues. The feasibility and final design of this system were developed from the I-5 test-injection well constructed in 1977 at the project site. The completed system encompasses nine injection wells, approximately 3,100 feet in depth, which provide 50 million gallons per day (mgd) average and 112 mgd peak disposal capabilities of secondary treated effluent from the South District plant. Subsurface monitoring is accomplished with three multizone and nine Biscayne aquifer monitoring wells.

Deep-well injection was the only feasible alternative to the effluent discharge from the South District plant. The presence of the Biscayne Bay Underwater National Monument between the mainland coastline and the coral reefs approximately 10 miles east prevented the discharge of effluent into the Bay or its tributaries. It also prevented the construction of an ocean outfall under the Bay to the Straits of Florida.

Funding for this project was provided through the Wastewater Treatment Works Grant Program of the State of Florida Department of Environmental Regulation (DER) and the U.S. Environmental Protection Agency (EPA) in cooperation with MDWSA.

Construction and testing of the wells was completed in accordance with "Contract Documents for Deep Injection and Monitoring Wells" for the South District Regional Wastewater Treatment Plant. Plans and specifications were prepared by CH2M HILL and issued by MDWSA in September 1978.

The Dade County Department of Environmental Resource Management (DERM) and the Florida DER issued the well construction permits consecutively numbered from UIC 13-5378 to UIC 13-5388 on May 5, 1978. Copies of these permits are contained in Appendix 4.A of this report.

At the onset of design and construction of this project, a Technical Advisory Group (TAG) was formed under the leadership of Mr. Roy M. Duke, Jr., of DER. This TAG included representatives of all the regulatory and advisory agencies concerned with the project: DER, DERM, SFWMD (South Florida Water Management District), EPA, U.S.G.S. (United States Geological Survey), and the COE (United States Army Corps of Engineers). TAG's participation in the project was a key factor in its successful completion within the budget and time schedule. Summaries of all the meetings held with TAG since the preconstruction meeting are included in Appendix 4.B. They contain the chronology of events and engineering decisions during construction of the project.

Construction of the eight injection and related monitoring wells was started February 19, 1979, and completed April 7, 1981. Total construction cost was $12,673,133.86.

ACKNOWLEDGEMENTS

Completion of this project within the pre-established cost estimate and time schedule was an outstanding accomplishment considering the nature of the project and the potential for unforeseen factors to be encountered while drilling 11 wells through cavernous limestones and dolomites, mostly under artesian conditions. Nine of the wells were drilled to approximately 0.6 mile in depth, and eight started with a hole diameter of 5 feet and tapered down to 2 feet. The accomplishment was made possible only by the close cooperation, coordination, and understanding of the many organizations and persons involved in the project. This was the result of continuous communication between the executors of the construction of the project and the Technical Advisory Group (TAG). Those who played a key role in this achievement included:

APCO (Alsay-Pippin Corporation): Messrs. Hubert L. Pippin, Russell J. Kerrn, and David N. Cabit.

COE (Corps of Engineers, U.S. Army): Messrs. James N. Hutchinson, William W. Brubaker, and Joseph E. Welsh

Deep Venture Diving Service: Messrs. Larry Hayden and Jim Hayden

DER (Department of Environmental Regulation, State of Florida): Mr. Roy M. Duke, Jr., (West Palm Beach), Chairman of TAG and Mr. Richard Knittel and Ms. Cathy Cash (Tallahassee)

DERM (Dade County Department of Environmental Resources Management): Messers. Bill Brant and Tony Sobrino

EPA (Environmental Protection Agency, U.S. Government): Messrs. Barry Amos, Gene Coker, and Stallings Howell

Halliburton Company: Mr. Gerald Badeaux

MDWSA (Miami-Dade Water and Sewer Authority): Messrs. Garret Sloan, Director; Herbert K. Kunen, Consultants Coordinator; Jim Cowgill, Chief Engineer; George A. King, Resident Engineer; Murray Grant; Tom McCormick; Dick Friberg; Robert V. Celette (retired); Armando Rubio, Joe Mazzarese; John Paxton; and Glen Yoemans

SFWMD (South Florida Water Management District): Messrs. Abe Kreitman, Leslie Wedderburn, and Paul Jakob

U.S.G.S. (U.S. Geological Survey, Water Resource Division, Miami Subdistrict): Mr. Fred W. Meyer

CH2M HILL: Messrs. J.I. Garcia-Bengochea, C.R. Sproul, Udai P. Singh, Jeffrey D. Lehnen, Frank Reynolds, and David G. Snyder

LIST OF REFERENCES

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2. Jacob, C. E., "Radial Flow in a Leaky Artesian Aquifer," Transactions, American Geophysical Union. Vol. 27, 1946.

3. Meyer, F. W., "Evaluation of Hydraulic Characteristics of a Deep Artesian Aquifer from Natural Water Level Fluctuations, Miami, Florida," Florida Bureau of Geology, Report of Investigation No. 75, 1974.

4. Millero, F. J. et al., "The Density of Seawater Solutions at One Atmosphere as a Function of Temperature and Salinity," Sears Foundation: Journal of Marine Research, Volume 34, No. 1, February 23, 1976.

5. Walton, W. L., Ground Water Resource Evaluation, 1970. McGraw-Hill Series in Water Resources and Environmental Engineering, New York.

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Figure

SUMMARY

Chapter 1.1
PROJECT DESCRIPTION

The South District Regional Wastewater Treatment Plant is located in the north half of Section 21, Township 56 south, Range 40 east, in Dade County, Florida, as shown on Figure 1.1-1. The plant has a design capacity of 50 mgd, with peak flow of 112 mgd of secondary treated municipal effluent. The treated effluent will be injected into a highly transmissive aquifer known as the Boulder Zone via eight of nine injection wells, the ninth used as standby. Thus, the peak flow per well will be approximately 10,000 gallons per minute (gpm). Monitoring of the injection zone and overlying aquifers is provided by a multizone well, BZ-1, in which the Boulder Zone is monitored (along with three other zones) using screened and gravel-packed tubes, two FA wells which are completed in the Floridan aquifer, and nine shallow wells in the Biscayne aquifer. The locations of the injection and monitoring wells are shown on Figure 1.1-2. A cross section of the wells showing casing depths, monitoring zones, and open hole intervals is shown on Figure 1.1-3. Important data and results from the construction and testing of the wells are summarized in Table 1.1-1.

DRILLING SITE PREPARATION AND MONITORING

Construction of the well pads began in February 1979, and drilling on the first well, I-6, began in early April of that year. Limestone fill was used to raise the ground surface at each well site to approximately 10 feet above mean sea level (msl). Concrete drilling pads 120 feet by 92 feet with curbs and sumps were constructed at each location to support the drilling rigs and to contain any fluid spills around the wells.

Four 20-foot-deep, 2-inch-diameter PVC monitoring wells were installed at each corner of the drilling pads. These wells were sampled weekly with a depth sampler during drilling operations to record the water quality of the Biscayne aquifer. Also constructed at each pad was an 8-inch water supply well drilled to approximately 40 feet below land surface. These wells were also sampled weekly, and are completed with a 2-inch cap above ground for future monitoring purposes. After construction was completed, the 2-inch wells were capped below land surface and finished such that they can be used in the future if needed.

The water quality in the Biscayne aquifer monitoring wells generally remained near background levels during the drilling of each well. The water supply well chloride levels were slightly higher than the levels in the unpumped 2-inch wells at some well sites, but this would be expected with brackish water near the bottom of the water supply wells (about 40 feet in depth).

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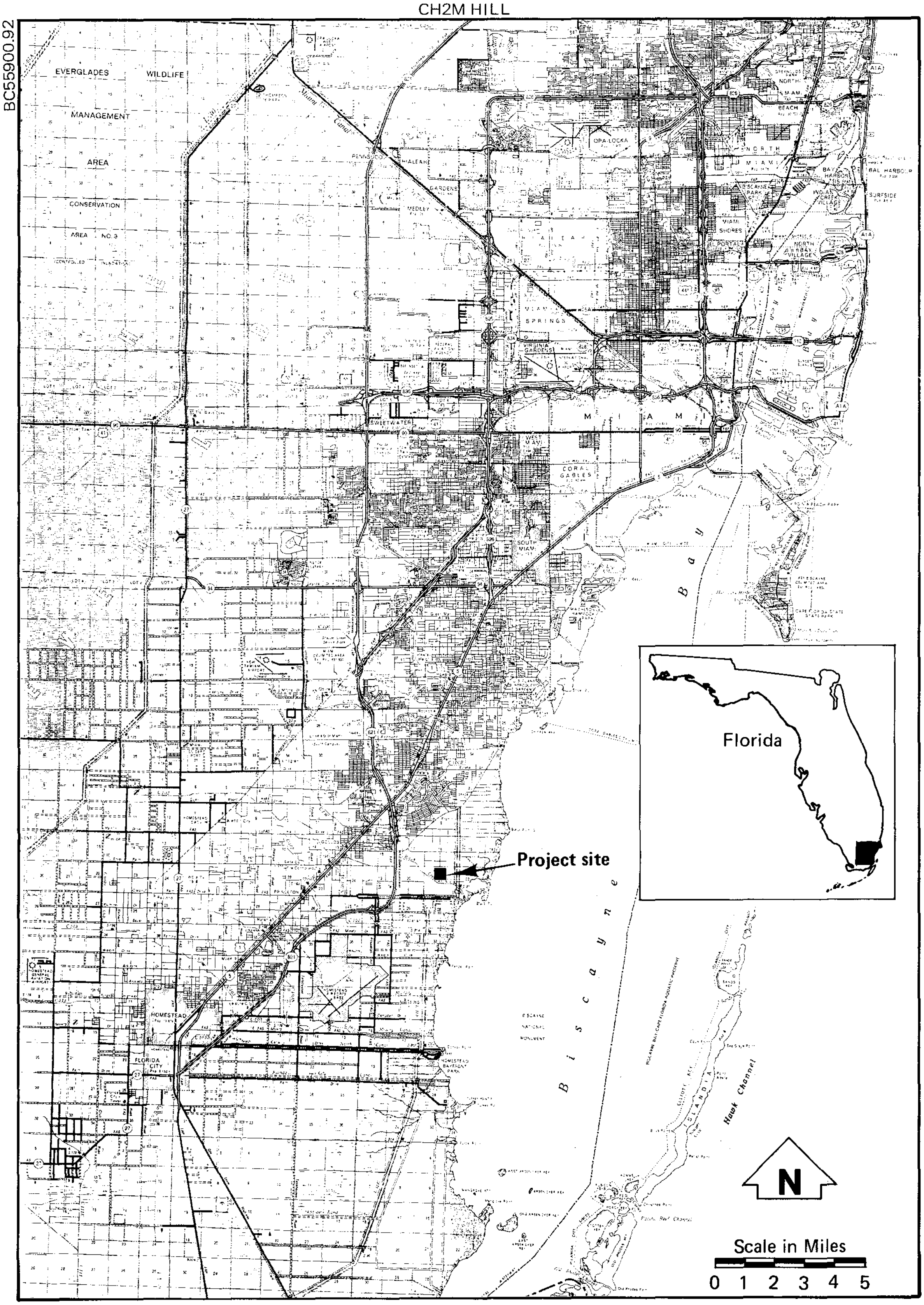


FIGURE 1.1-1. Project location.

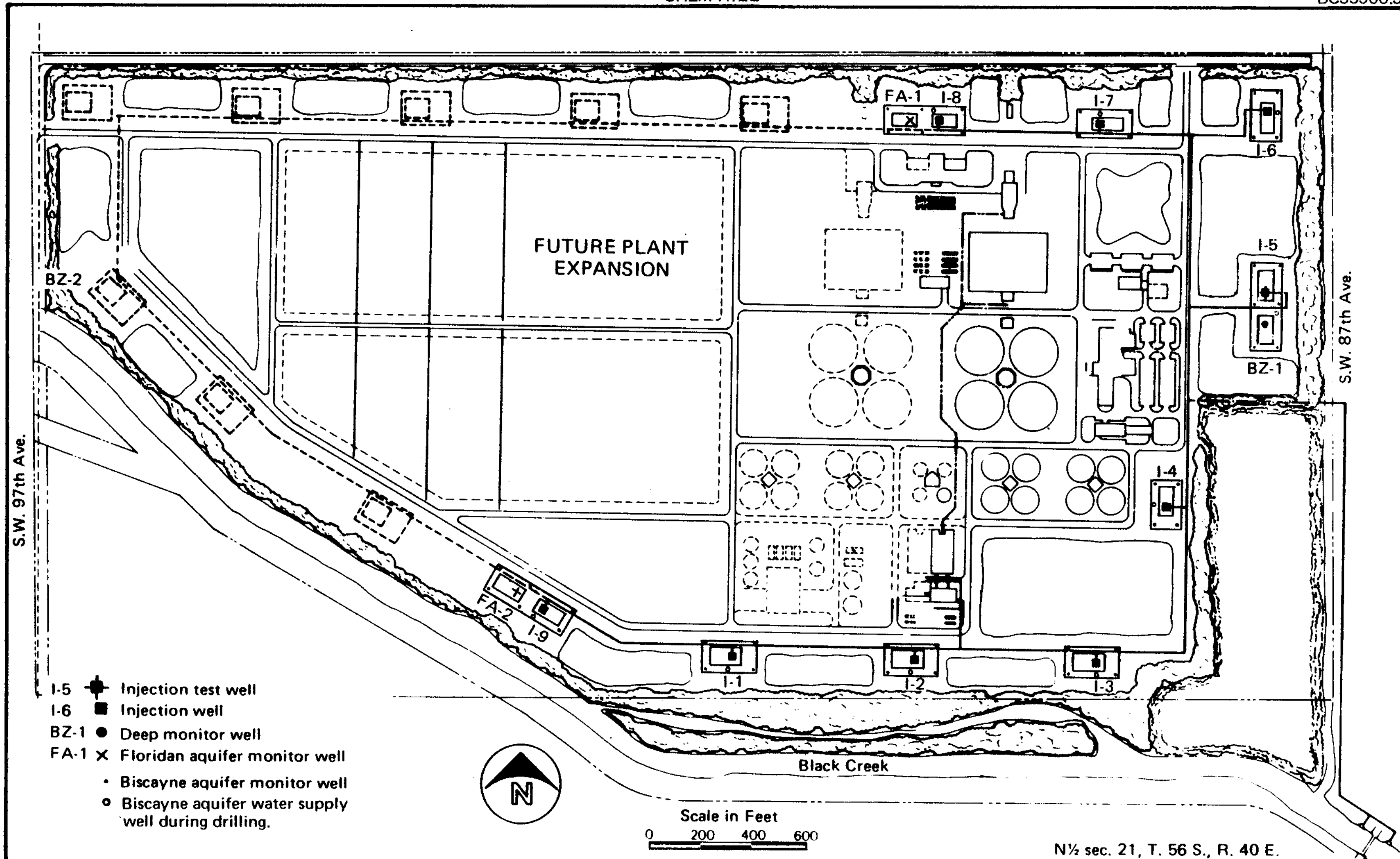
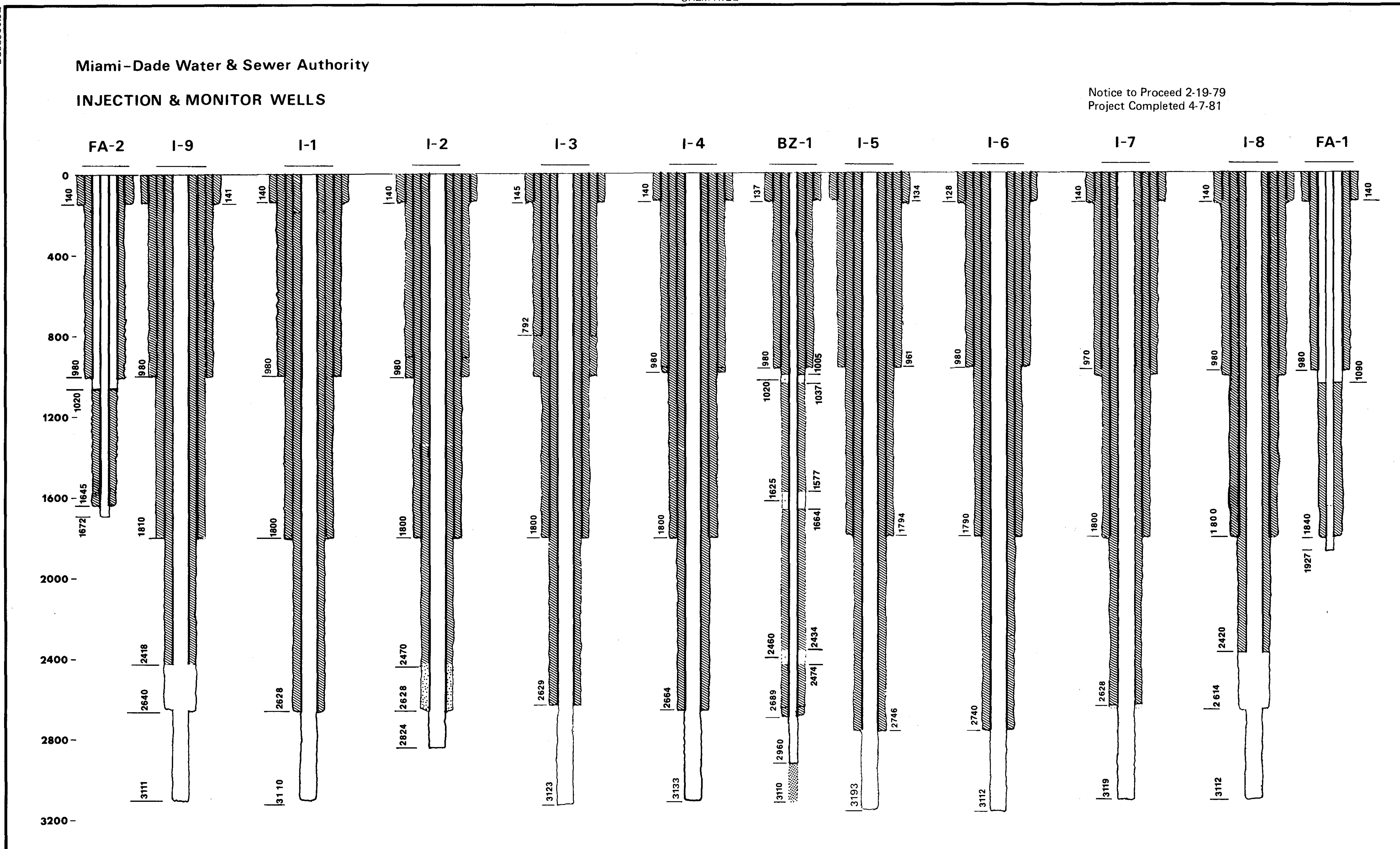


FIGURE 1.1-2. Injection and monitoring well field layout.



Summary of well construction.

FIGURE 1.1-3.

Table 1.1-1
SUMMARY OF WELL CONSTRUCTION AND TESTING

Well No.	Casing Diameter (inches)	Casing Thickness (inches)	Casing Depth (feet)	Total Depth (feet)	Injection Test Results: Rate of of Flow (gpm)	Injection Test Results: Maximum Wellhead Pressure (psi)
I-1	54	0.500	140	3,110	10,100	39.8
	44	0.500	980			
	34	0.500	1,800			
	24	0.500	2,628			
I-2	54	0.500	140	2,824	10,650	38.5
	44	0.500	980			
	34	0.500	1,800			
	24	0.500	2,628			
I-3	54	0.500	145	3,123	10,200	41.0
	44	0.500	792			
	34	0.500	1,800			
	24	0.500	2,629			
I-4	54	0.500	140	3,133	10,700	40.3
	44	0.500	980			
	34	0.500	1,800			
	24	0.500	2,664			
I-5[a]	48	0.500	134	3,193	8,000	55.0
	40	0.625	961			
	30	0.500	1,794			
	20	0.500	2,746			
I-6	54	0.500	128	3,112	10,200	36.9
	44	0.500	980			
	34	0.500	1,790			
	24	0.500	2,740			
I-7	54	0.500	140	3,119	10,900	43.0
	44	0.500	970			
	34	0.500	1,800			
	24	0.500	2,628			
I-8	54	0.500	140	3,112	10,480	37.0
	44	0.500	980			
	34	0.500	1,800			
	24	0.500	2,420			
I-9	54	0.500	141	3,111	10,820	38.0
	44	0.500	980			
	34	0.500	1,800			
	24	0.500	2,418			

Table 1.1-1--Continued

Well No.	Casing Diameter (inches)	Casing Thickness (inches)	Casing Depth (feet)	Total Depth (feet)	Injection Test Results: Rate of of Flow (gpm)	Injection Test Results: Maximum Wellhead Pressure (psi)
BZ-1	30	0.500	137			
	20	0.438	980	2,960	--	--
	6	0.432	2,689			
FA-1	20	0.438	140			
	12	0.375	980	1,927	--	--
	6	0.280[b]	1,840			
FA-2	20	0.438	140			
	12	0.375	980	1,672	--	--
	6	0.280	1,645			

[a]Well I-5 drilled under separate contract (Test/Standby Well).
[b]Casing thickness is 0.280 inch to 1,646 feet and 0.432 inch to 1,840 feet.

In late June 1980, intensive dewatering operations began on the site under a separate contract for the clarifier tanks. It was estimated that over 30,000 gpm, with chloride concentrations of over 5,000 mg/l, were being pumped 24 hours per day in an attempt to keep the excavation dry. The water was discharged into two adjacent manmade lakes within the site. The first lake was immediately north of Injection Well I-3, and the second was between I-6 and I-5. The chloride concentration in the lakes increased rapidly to values of 5,000 mg/l in several months. The effect on the monitoring wells was a slight rise of chloride concentration at sites I-2 and I-8, and a significant alkalinity change in most of the wells being monitored at that time (sites I-2, I-8, I-9, and I-1). This alkalinity increase caused the chloride analysis to yield inaccurate values. The lab procedure was modified to yield accurate chloride values after the problem was identified.

DRILLING EQUIPMENT AND METHODS

The injection wells were constructed with three drilling rigs: a Skytop-Brewster model AT-3 with a rated hook load of 275,000 pounds; a TR-700 with a hook load of 300,000 pounds; and a TR-800 with a hook load of 410,000 pounds. Only the TR-700 and TR-800 rigs were capable of setting the 34-inch casings, and only the TR-800 could set the 24-inch casings. Therefore, nearly all the wells were constructed using at least two and, in some cases, three rigs successively.

The Boulder Zone monitoring well (BZ-1) was drilled with a Failing model 3,000 with a rated hook load of 100,000 pounds. The Floridan aquifer monitoring well (FA-1) was drilled with the AT-3, as was the second Floridan aquifer monitoring well (FA-2) to a depth of 1,651 feet. A Failing model 1,500 was used to drill out the open hole of FA-2.

Rotary drilling with conventional mud circulation was used to approximately 1,000 feet through the Biscayne aquifer and the Hawthorn Formation. The drilling method was then changed to reverse-air closed circulation through the Floridan aquifer, the confining beds, and into the Boulder Zone to total depth (T.D.). This method allowed for more accurate formation and water samples and for more efficient drilling.

The monitoring wells, except for FA-2, were drilled with the same method. On this well, conventional mud circulation was used to 1,000 feet; however, from there to 1,651 feet the well was allowed to flow by open circulation. Water samples were collected in an effort to identify the target zone with a specific conductance of at least 15,000 μmhos/cm. Water samples from the bottom section of the final monitor zone of the completed well have a specific conductance of 17,000 μmhos/cm.

WELL CASINGS

The injection and monitoring wells were constructed using a staged casing system. A small-diameter (8- to 12-inch) pilot hole was drilled to the estimated casing setting depth, and geophysical logs and other tests were performed to determine the final casing setting depth. The hole was then reamed to the appropriate diameter and depth, and the casing with centralizers was then installed and cemented. The pilot hole was then drilled to the next estimated casing setting depth and the process repeated. Finally, the open hole section of the well was drilled out after the innermost casing for that well had been set and cemented.

Surface Casing

The casing settings were chosen in accordance with environmental and construction considerations. The first casings, 54-inch on the injection wells and 30-inch or 20-inch on the monitoring wells, were set below the Biscayne aquifer at approximately 140 feet. The purpose of these casings is to shut off and protect the water in the Biscayne aquifer. The highly transmissive limestone associated with the Biscayne aquifer ends at about 100 feet, where the siltstone, clay, and limestone of the Hawthorn Formation occur.

Second Casing

The second casings, the 44-inch on the injection wells, and the 12-3/4-inch on the monitoring wells, are set near the top of the Floridan aquifer into the Suwannee limestone, at about 980 feet. These are primarily construction casings intended to sustain the clays and other friable material in the Hawthorn Formation.

Third Casing

The third casings of the injection wells were set at approximately 1,800 feet. This is below the brackish/saltwater interface where the total dissolved solids are above 10,000 ppm. These casings are 34-inch-diameter and case out the brackish waters of the Floridan aquifer. Three of the monitoring wells monitor the upper sections of the Floridan aquifer at approximately 1,000 feet in depth, two monitor the lower Floridan at approximately 1,650 feet, and the third monitors below the brackish/saltwater interface at approximately 1,900 feet.

Final Casing

The final casings, 24-inch-diameter, are set above the injection zone in each injection well. These casing settings vary from 2,740 feet to 2,418 feet across the site. During efforts to set the 24-inch casings as close to the top of the injection zone as possible, serious cementing problems were encountered on I-6, I-3, and I-2, i.e., the problems were the loss of cement in the cavernous formation in the upper sections of the Boulder Zone being too close to the hole reamed to set the final casing. The 24-inch casing on Well I-6 was set and cemented at 2,740 feet in depth. Due to fillup difficulties, subsequent 24-inch casings were set between 2,628 and 2,689 feet. I-2 was also set at 2,628 feet and again serious difficulties were encountered in cementing. Gravel had to be used to fill up between cement stages to 2,470 feet, where good cement fill was finally achieved.

Following the cementing difficulties on I-2, and after review of the pumpout test data on I-5, the lower monitoring zone (2,450 feet) was re-evaluated. A thorough evaluation of Well I-5 pumpout test data indicated that this zone (2,450 feet) does not appear to be separated from the injection zone. Based on these factors, it was decided to set the 24-inch casings on I-8 and I-9 above 2,500 feet to avoid potential cement fillup problems and subsequent costs. The 2,450-foot monitoring zone in BZ-1 therefore monitors the upper part of the injection zone.

GYROSCOPIC DIRECTIONAL SURVEYS

Early in the project, the addition of gyroscopic directional surveys to the geophysical logging program was required by the regulatory agencies. The initial funding was for three wells from 1,000 feet to 2,750 feet. Wells I-6, I-3, and I-4 were surveyed under this funding. After these wells were completed and the results reviewed for each well, CH2M HILL recommended the elimination of the gyro surveys in the construction program. The use of staged, multi-bit reamers make sidetracking of the pilot hole very unlikely. During these deliberations, Well I-7 was drilled and because funding approval for more surveys had not been received, no gyroscopic surveys were run. A decision was finally reached to run gyroscopic directional surveys only on the bottom section (from 1,800 to 2,650 feet) in Wells I-1, I-2, I-8, and I-9 .

The purpose of the surveys was to compare the well path of the pilot hole with that of the reamed hole at each site. The reamed hole well path needs to wipe out or at least intersect the pilot hole well path. If the reamer sidetracked the pilot hole, the surveys would indicate two holes drilled side by side which could prevent proper cementing and isolation of the injection zone from the overlying aquifers.

All of the pilot hole and reamed hole surveys run on the wells showed that the reamers tracked the pilot holes indicating the presence of only one hole at each site.

INCLINOMETER

In addition to the gyroscopic surveys, inclinometer surveys were made on the wells at least every 90 feet or every third drill pipe connection. This is a single-shot tool in which the inclination of the drill pipe near the bit, and therefore the hole, is measured. These surveys were made from the surface to T.D. in the pilot and reamed holes. The contractor was required to maintain less than 1° inclination throughout the drilling operations. For additional safety, an inclination of less than 30 minutes was maintained. The contractor did this to provide further assurance that during installation the casings would not become stuck above the specified setting depth.

PILOT HOLE DATA COLLECTION

Lithologic Samples

During the drilling of the pilot holes two sets of lithologic samples were collected every 10 feet from land surface to T.D. of each well. These samples were washed, analyzed, and described, and one set was sent to the State of Florida Bureau of Geology in Tallahassee and the other was kept for MDWSA.

The geology across the site is very consistent down to about 2,450 feet. From that depth to 2,800 feet, varying amounts of dolomitization and associated fracturing and cavity formation occur. This was the cause of the cement losses in these strata. In I-1, I-4, and I-7, no cavity large enough to cause cementing difficulties was encountered; however, on three wells, I-6, I-3, and I-2, large cavities were encountered. The casings for Wells I-8 and I-9 were then set above the 2,450-foot section. From 2,800 to 3,100 feet, the cavity development is fairly consistent throughout the site.

Water Quality

During drilling of the pilot hole for each casing below 1,000 feet, a water sample was collected from the drill pipe every 30 feet (at each pipe connection) to total depth. The purpose of these samples was to obtain representative water quality data from the bottom of the hole. Unfortunately, during normal drilling operations, large quantities of bentonite mud, soda ash, salt, and various other additives were mixed with the circulating fluid to maintain fluid circulation and to keep the wells from flowing. These additives cause the water quality analysis to be non-representative in most cases, though general water quality trends can be seen.

Drilling Rate

As a requirement of the contract, the contractor was required to provide a record of the pilot hole drilling rate. This was done using a continuous recording footage counter, which also recorded the weight on the bit and the torque on the drill string. This information is useful in determining formation changes, type of rock being drilled, and penetration rate. It also proved to be an important record of what was done on a particular work shift, thus enabling the next driller to understand the hole conditions being drilled in.

Geophysics

As each stage of the pilot hole was drilled, geophysical logs, gyroscopic surveys, television surveys, and any additional pumping tests were performed. The geophysical logs were run to evaluate the types of formation and to delineate transmissive zones. CH2M HILL and Schlumberger ran the geophysical logs, Eastman-Whipstock provided the gyroscopic directional surveys, and Deep Venture Diving Service did the underground television surveys.

The correlation of the geophysical logs shows very consistent bedding across the site. Although there are some apparent bedding thickness changes between some of the wells, this could be explained as the result of a karst-type surface in which sinkhole activity offsets the bedding in relatively short distances. Later, dolomitization can also occur at varying depths, sometimes obliterating the original bedding planes. In any case, the stratigraphic correlation through the Floridan aquifer and the confining beds is consistent with the regional pattern.

TV SURVEYS

Underwater closed circuit television surveys were made at various times during construction of the wells. The final survey inspecting the inner casing and open hole on each injection and monitoring well is summarized in Section 2, Well Construction, of the report. The borehole TV surveys provide a record of the integrity of the final casings as well as a subjective tool in evaluating the open hole. The highly transmissive zones are characterized by large cavities, fractures, and rough borehole walls. Non-producing zones typically have smooth borehole walls with occasional enlarging of the diameter over the bit size. This "overdrill" is caused by the soft, friable, chalky nature of this formation. The mechanical and hydraulic action as the bit drills through it causes the formation to wear away, thereby forming a large hole. This does not necessarily indicate transmissivity or permeability, because the hard, fractured rock is where the solution activity occurs, and the soft, homogeneous rock act as confining beds.

Copies of all the geophysical logs and directional surveys and the final TV surveys run on the injection and monitoring wells have been forwarded to the members of the Technical Advisory Group (TAG) for their records. This includes the following agencies: EPA (Atlanta), SFWMD, DER (West Palm Beach, except for TV tapes), DER (Tallahassee), and U.S.G.S. (Miami).

CEMENTING

The casings were cemented from the bottom up to pad level in one pumping operation on the first and second casings in each well by pumping cement down a drill pipe set near the bottom of the casing, out through the bottom, and up the annulus. The casing is sealed during this operation so that pressure can be maintained inside to prevent the casing from collapsing. Enough water is pumped after the cement to displace the cement below the drill pipe, and the cement is then allowed to set. The cement is circulated to the surface on the first and second casings; however, on the deeper casings, the first pumping did not circulate to the surface. The amount of cement and the length of time necessary to pump it requires that the deeper casings (the third and the final) be cemented by stages.

After the first pump or stage of cement on the deeper casings had set for 12 hours, a temperature log was run inside the casing to determine the top of cement outside the casing. The heat of hydration of the cement, detected inside the casing, is used to indicate the top of cement. The following stages are pumped down two tremie pipes set 180° apart in the casing annulus. These pipes are used to tag the top of the first and following stages on both sides before the next stage is pumped. The tag depths are compared to the temperature log and the cement retagged until they agree with the log. This prevents a space from being left uncemented between stages.

In all except the 140-foot surface casings, Class H neat cement was pumped at the bottom of the casings. Only after at least 200 feet of neat cement was placed were the cement mixtures changed to higher yield cement slurries. To aid in distributing the first stage evenly around the bottom of the 24-inch and 6-5/8-inch casings, 2-inch by 2-inch cement ports were cut at 90° around the casing near the bottom. Also, all the casings were centralized to provide open annuli for the cement to fill.

This method of cementing is probably the best assurance of good cement around the casings. In an effort to provide additional assurance of the integrity of the cement around the 24-inch casing in the injection wells and the 6-5/8-inch casing in the monitoring wells, cement bond logs were run. In order to provide a free pipe signal on which to reference the log, the upper 100 feet of the 24-inch casings was left uncemented. After the logs were completed, the casings were cemented to the surface. The cement bond logs were found to be limited in their use in evaluating the quality of the cement outside the casings. Their known limitation is that the tool response is unreliable in casings over about 16 inches in diameter. In most cases the difference between free and cemented casing was discernible, but little else was indicated.

It was for this reason that the U.S.G.S. ran several logs in I-4. Their logs showed the difference between free and cemented pipe also, but in a very subjective fashion. An attempt to gain more information was made by running Wave Train Display logs, but they too were uninformative.

PRESSURE TESTS

After the 24-inch and 6-5/8-inch casings were cemented, a pressure test was performed on each casing to prove that they were properly welded, not damaged or for any other reason leaking, the latter providing a possible short circuit of the confining or monitoring zones. The tests were conducted at 100 psi or greater for at least 1 hour. None of the casings had any measurable pressure loss in these tests.

AQUIFER TESTING

Injection Tests

After the injection wells were drilled to T.D., an injection test was run to determine the injectivity capacity of each well. A barge with two V-12 diesel engines and a turbine pump was used to pump lake water into the wells at approximately 10,000 gpm. The flow was measured with an inline propeller flowmeter and totalizer. The wellhead pressure was measured with a 12-inch precision double revolution, buordon-tube type gauge and the tests run for at least 10 hours. The maximum injection for each wellhead ranged from 85.2 feet of water to 99.4 feet of water, with an average of about 90 feet of water referred to the top of the concrete drilling pads.

Upon completion of each injection test and immediately after pump shutdown, the average residual freshwater head at each well was about 70 feet of water. This residual head was caused by the buoyancy of the fresh injected lake water on the native saltwater. Most of the difference between the injection head and static head is caused by pipe friction; thus the actual pressure at the injection zone is very low, on the order of less than 3 feet of water or 1.3 psi. Table 1.1-2 is a summary of the injection test results.

Table 1.1-2
SUMMARY OF INJECTION TEST RESULTS

Injection Well	Date of Test	Pumping Rate (gpm)	Test Duration (hr)	Maximum Injection Head (ft of water)	Elapsed Time to Reach Maximum Head (min)	Static Freshwater Head (ft of water)
I-1	08/21/80	10,100	10.6	92.0	7	50.2[a]
I-2	11/01/80	10,650	11.5	88.9	3	64.1
I-3	03/25/80	10,200	13	94.8	270	70.0
I-4	03/31/80	10,700	12	93.0	40	69.7
I-5[b]	10/26/77	8,000	10	127.0	25	72.0
I-6	02/13/80	10,200	32.5	85.2	7	66.0
I-7	06/11/80	10,900	12	99.4	7	69.0
I-8	01/03/81	10,480	12	85.5	10	65.1
I-9	01/09/81	6,685[c] 10,820	4.5[c] 7.5	87.7	12	64.7

[a] Standpipe valve open at end of test, static pressure not accurate.
[b] I-5 casing is 20 inches in diameter.
[c] Test run at 6,685 gpm for 4.5 hr, then at 10,820 gpm for 7.5 hr.

I-5 Withdrawal Test

After Injection Well I-6 and Monitoring Well BZ-1 were completed, a withdrawal test was performed on Injection Well I-5. The first test was a step-drawdown test pumping at 2,077, 3,855, and 5,875 gpm from Well I-5. The second test was at a constant rate of about 6,000 gpm from the same well. Wells BZ-1 and I-6 were used to measure drawdowns during this test. The report of the test was completed in March 1980. The test description and conclusions are presented in Chapter 3.1, and the data compiled during the test are included in Appendix 4.C.

POTENTIOMETRIC SURFACES

Upon completion of all the wells, the position of the potentiometric surface of the upper Floridan aquifer and the Boulder Zone was determined. The potentiometric surface of the lower Floridan could not be determined because of the differences in depth between FA-1, FA-2, and the lowest monitoring tube in BZ-1. These differences made surveying of the surface impossible. The potentiometric surface survey of the Boulder Zone is contained in Chapter 3.2, and the water density calculations are presented in Appendix 4.D. The potentiometric surface survey of the upper Floridan aquifer is contained in Chapter 3.3.

INJECTION MODEL

Upon completion of the project, an injection model of the effects of injection on the potentiometric surface of the Boulder Zone was prepared. This model encompasses the 30-year lifespan of the facility and is based on the average flow capacity of 50 mgd from the South District Wastewater Treatment Plant. Chapter 3.4 of the report presents the procedure used and the results obtained from the injection model.

Chapter 1.2
MONITORING PLAN

PURPOSE

Monitoring of the subsurface environment will be conducted using the monitoring wells installed for this project: Wells BZ-1, FA-1, and FA-2. These wells are multizone monitors, each discretely monitoring two or more zones. The wells are arranged in a triangular pattern as shown on Figure 1.1-2, Section 1, for a better determination of the potentiometric surface and the hydraulic characteristics of each zone.

The monitoring wells were constructed to provide a means by which to determine the effects of injection on the subsurface environment. The wells are designed to:

1. Determine the hydraulic effects of injection on the Boulder Zone.

2. Determine the thickness of the effluent lens and the water quality in the Boulder Zone after injection.

3. Detect any upward migration of the injected fluid.

4. Detect any change in the brackish/saltwater interface at the base of the Floridan aquifer.

5. Detect any change of water quality in the Floridan aquifer.

6. Detect any change of water quality in the Biscayne aquifer.

In addition, Well BZ-1 was used to evaluate the aquifer characteristics during the withdrawal test on I-5. All of the monitoring wells were disinfected and sampled after completion; the results are shown in Table 1.2-1. The monitoring zones are described below, along with the associated monitoring wells.

BOULDER ZONE

The top of the highly transmissive strata, known as the Boulder Zone, was thought to start at approximately 2,800 feet below the concrete drilling pads. Evidence from the withdrawal test on I-5 suggests that the original "2,500-Foot Zone," the first transmissive zone above the 2,800-foot depth, is communicated with the Boulder Zone. Further evidence was found in Well I-2 when cementing the 24-inch casing. Gravel had to be used to fill around the 24-inch casing up to 2,470 feet, because fill-up could not be accomplished with cement. This was an indication of extensive cavities up to that level.

Table 1.2-1
RESULTS OF WATER ANALYSES ON SAMPLES COLLECTED FROM
MONITORING WELLS AFTER COMPLETION AND THOROUGH FLUSHING

	FA-2	FA-1	BZ-1		FA-2	FA-1	BZ-1	
Depth Interval in Feet: Top	980	980	1,005	1,577	1,645	1,840	2,434	2,689
Bottom	1,020	1,090	1,037	1,664	1,672	1,927	2,474	2,960
Sample Collected: Date	12-08-80	12-08-80	12-08-80	12-08-80	03-26-81	12-08-80	03-16-81	03-16-81
Time	4:30 p.m.	4:05 p.m.	5:10 p.m.	5:05 p.m.	--	3:55 p.m.	3:40 p.m.	4:10 p.m.
Field Determinations: Water Temperature °C	20.5	21	22	22	21.5[b]	20	23	21.5
pH	7.2	8.15	8.2	7.85	7.35	7.75	7.95	7.60
DO (mg/l)	0.1[a]	0.1[a]	0.1[a]	0.1[a]	0.1[a,b]	0.10[a]	0	0.6[a]
Cl_2 Residual (mg/l)[c]	<0.02	<0.02	<0.02[d]	<0.02[d]	<0.02[b]	<0.02	<0.02[d]	<0.02[d]
Laboratory Determinations: BOD_5 (mg/l)	<1.0	<1.0	<1.0[d]	<1.0[d]	<1.0[d]	<1.0	<1.0[d]	<1.0[d]
Specific Conductance (μmhos/cm)	3,020	3,230	4,870	11,900	17,400	44,900	42,500	42,000
Total Dissolved Solids (TDS)	1,920	1,890	2,750	7,310	3,660	30,500	28,870	28,530
Turbidity, NTU	85[e]	70[e]	3.9[d,e]	2.2[d,e]	45[e]	46[e]	23[d,e]	29[e]
Alkalinity (mg/l as $CaCO_3$)	100	227	159	108[d]	127	122	118	121[d]
Total Hardness (mg/l as $CaCO_3$)	590	456	365[d]	1,440[d]	6,120	5,480	6,130	6,490
Calcium (mg/l)	175	85	52[d]	190[d]	340	460	475	452
Magnesium (mg/l)	37	59	57[d]	235[d]	1,280	1,050	1,200	1,300
Sodium (mg/l)	380	580	1,180[d]	2,260[d]	2,960	9,300	12,000[d]	11,300[d]
Potassium (mg/l)	8.8	20	21[d]	71[d]	94	290	370[d]	400[d]
Chloride (mg/l)	920	820	1,420	4,200	6,160	17,500	20,100	19,700
Sulfate (mg/l)	78	294	304	364	194	2,160	2,710	2,800
Iron (mg/l)	11.7	3.12	0.66[d]	0.38[d]	3.45	7.25	5.80[d]	9.85[d]
Nitrogen (as N): Ammonia	<0.02	0.11	0.10	0.14	0.11	<0.02	<0.02[d]	<0.02[d]
Nitrate and Nitrite	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.15
Total Kjeldahl	1.11	0.29	0.23	0.29	0.11	0.19	<0.02	<0.02
Total Phosphrous (mg/l as P)	<0.008	0.024	0.032	0.016	<0.008	<0.008	<0.008	0.016
Total Organic Carbon, TOC (mg/l)	3.5	6.0	6.0	2.5	2.5	2.5	4.5	4.0
CO_2 (mg/l as $CaCO_3$)	28	6,9	4.4	3.2	2.5	9.5	5.9	13
Hydrogen Sulfide (mg/l)	0.19	0.31	0.21	0.20	.65[b]	0.19	<0.20	<0.20
Coliform Colonies/100 ml	<1	<1	<1	<1	<1	<1	<1	<1
Pesticides (μg/l): Endrin	<0.06	<0.06	<0.2[d]	<0.2[d]	<0.06	<0.06	<0.2[d]	<0.2[d]
Lindane	<1	<1	<2[d]	<2[d]	<1	<1	<2[d]	<2[d]
Methoxychlor	<1.0	<1.0	<5[d]	<5[d]	<1.0	<1	<5[d]	<5[d]
Toxaphene	<2	<2	<3[d]	<3[d]	<2	<2	<3[d]	<3[d]
Herbicides (μg/l): 2, 4-D	<10	<10	<2[d]	<2[d]	<10	<10	<2[d]	<2[d]
2, 4, 5-TP Silvex	<2.0	<2.0	<2[d]	<2[d]	<2	<2	<2[d]	<2[d]
Trace Metals (mg/l): Arsenic	<0.002	0.003	0.002[d]	0.005[d]	0.004	<0.20	<0.20[d]	<0.20[d]
Barium	<0.2	<0.2	<0.2[d]	<0.2[d]	<0.1	<0.2	<0.2[d]	<0.2[d]
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005[d]	<0.0005[d]
Copper	<0.002	<0.002	<0.002[d]	<0.002[d]	<0.002	<0.002	<0.002[d]	<0.002[d]
Lead	<0.002	0.004	0.002[d]	<0.002[d]	<0.002	0.002	0.002[d]	0.002[d]
Manganese	0.98	0.105	0.023[d]	0.042[d]	0.029	0.170	0.310[d]	0.300[d]
Mercury	<0.0002	<0.0002	<0.0002[d]	<0.0002[d]	<0.0002	<0.0002	<0.0002[d]	<0.0002[d]
Selenium	<0.002	<0.002	0.002[d]	0.003[d]	<0.002	<0.20	<0.20[d]	<0.20[d]
Silver	<0.0005	<0.0005	<0.0005[d]	<0.0005[d]	<0.0002	<0.0005	<0.0005[d]	<0.0005[d]
Zinc	0.02	0.01	0.02[d]	0.02[d]	0.25	0.05	0.07[d]	0.04[d]
Chromium, Total	<0.002	<0.002	<0.002[d]	<0.002[d]	<0.002	<0.002	<0.002[d]	<0.002[d]

[a] Instrument reading should be equal to 0.
[b] Sample collected December 8, 1980.
[c] After disinfection.
[d] Sample collected November 21, 1980.
[e] Sample reddish cloudy-high iron.

Based on this evidence, the remaining 24-inch casings, I-8 and I-9, were set above the "2,500-Foot Zone." BZ-1 was essentially completed before the test results were available and construction difficulties were encountered; Well BZ-1 was therefore constructed as planned.

The open hole portion of BZ-1 is completed from 2,689 feet to 2,960 feet, and a screened and gravel-packed 2-inch monitor line is completed from 2,434 to 2,474 feet.

The purpose of the open hole of the BZ-1 monitoring well, completed in the injection zone, will be:

1. To provide a means of obtaining long-term data on water quality and hydraulic pressure in the injection zone.

2. To provide insight into the rate and direction of movement of the effluent and, therefore, the size of the effluent lens. This data will be supplemented with observations in unused injection wells during the early phase of system operation.

"2,500-FOOT ZONE"

As noted above, this zone was supposed to be the first transmissive stratum above the injection zone. Well BZ-1 was constructed to provide monitoring of this zone. However, since this zone seems to be part of the Boulder Zone and two of the injection wells are completed at about this zone, it no longer has a monitoring function for the upward migration of the injected fluid. Any water quality or pressure change detected could be attributed to either vertical or horizontal migration of the injected fluid in this zone. However, this zone could still be used to determine the thickness and change in water quality of the injected fluid in the Boulder Zone.

SALTWATER INTERFACE--BOTTOM

As a result of the construction modifications previously mentioned, Well FA-1 was deepened in order to monitor the first transmissive zone above the injection zone. This well is cased to 1,840 feet and has an open hole to 1,927 feet. The chloride concentration in this zone is 17,500 mg/l, as shown in Table 1.2-1.

This monitoring zone is the first one above the injection zone and would indicate any vertical migration of the injected fluid if it occurs.

SALTWATER INTERFACE--TOP

The water quality transition zone, or the brackish water/saltwater interface, occurs between 1,600 feet and 1,780 feet in depth at the site. The water quality in this interval changes from brackish (<10,000 mg/l TDS) to salty (>25,000 mg/l TDS), and Wells BZ-1 and FA-2 monitor this zone. There is a screened and gravel-packed 2-inch monitoring line in Well BZ-1 from 1,577 to 1,674 feet, and Well FA-2 is cased to 1,645 feet and has an open hole to 1,672. However, the chloride concentrations in the two wells are slightly different: 6,160 mg/l in FA-2 and 4,200 mg/l in BZ-1, as shown in Table 1.2-1. The fact that the screen is set from 1,620 to 1,630 feet in depth in BZ-1, or slightly higher than the open hole in FA-2 could be the reason for the water quality difference. Monitoring the interface top will detect any change in its position and will indicate upward migration of the injected fluid it if occurs.

FLORIDAN AQUIFER

The most productive and potentially useful zone of the Floridan aquifer is monitored at four locations at the site, extending from a depth of 980 feet to 1,090 feet. Wells FA-1 and FA-2 are completed with open annuli around the 6-5/8-inch inner casings and the 12-3/4-inch secondary casings at 980 feet. Well FA-1 is open from 980 feet to 1,090 feet, and FA-2 is open from 980 feet to 1,020 feet. Between the bottom of each interval and the inner casing bottoms, the annuli are filled with cement.

Wells BZ-1 and I-5 have a screened and gravel-packed 2-inch monitoring line completed from 1,000 feet to 1,037 feet and 1,007 feet to 1,056 feet in depth, respectively.

Monitoring in this aquifer will detect any changes in the artesian head or water quality resulting from injection or other pumping activity.

BISCAYNE AQUIFER

The Biscayne aquifer extends to about 100 feet at the site and contains freshwater to a depth of about 40 feet. Since this aquifer has been designated a sole source aquifer, water quality monitoring and prevention of saltwater intrusion are of paramount importance. After completion of the project, the nine water supply wells located at each drilling pad were completed with 2-inch steel caps. This allows a pump or depth sampler to be used to monitor the water quality at each pad.

During construction of the injection and monitoring wells, four 2-inch PVC wells were constructed to 20 feet in depth at the corners of each drilling pad. There were a total of 35 such wells installed as part of this project; all of which were sampled weekly during the drilling operations at each pad.

Upon completion of the project, these 2-inch wells were finished below grade and buried. If they are needed at a later date, they can be recovered and used.

These precautions are taken in spite of the fact that the project site is just downgradient of the 1,000-mg/l isochlor line established in the area which designates the bottom of the Biscayne aquifer.

OPERATIONAL MONITORING

The operational monitoring system involves the following: injection rate, injection pressure, effluent quality, aquifer pressures, and water quality. It is recommended that at least three complete water quality analyses be run (as shown in Table 1.2-1) immediately prior to system startup in order to provide more reliable background water quality data.

The injection system monitoring parameters are shown in Table 1.2-2, and the ground-water quality sampling schedule is presented in Table 1.2-3. The effluent quality sampling schedule is shown in Table 1.2-4. These monitoring parameters and frequencies are guidelines designed to evaluate the effects of injection on the subsurface environment. In the event of a change in parameters beyond the expected ranges of values, the monitoring plan (including sampling frequencies) may be modified to respond to that specific occurrence.

Table 1.2-2
INJECTION SYSTEM MONITORING PARAMETERS

Parameter	Sampling Point	Frequency
Injection Rate	Effluent pumping station Each injection well	Continuous Continuous
Injection Pressure	Each injection well	Continuous
Boulder Zone Pressure	BZ-1 monitoring well, inner casing[a]	Continuous
Upper Floridan Aquifer Pressure	Annuli of Wells FA-1 and FA-2	Continuous
	Monitoring tube in BZ-1 annulus	Continuous
Lower Floridan Aquifer Pressure, Top of Interface	Monitoring tube in BZ-1 annulus, inner casing of Well FA-2	Continuous
Lower Floridan Aquifer Pressure, Bottom of Interface	Inner casing of Well FA-1	Continuous
Total Volume Injected	Effluent pumping station	Daily

[a]Boulder Zone pressure will also be monitored continuously in Wells I-8 and I-9, both of which could be held out of service until needed.

Table 1.2-3
WATER QUALITY MONITORING PARAMETERS AND FREQUENCY

Monitoring Zone	Sampling Points	Parameter	Frequency
Boulder Zone	Inner casing of BZ-1	1. Basic hydrochemistry BOD_5 Total coliform Fecal coliform pH DO Specific conductance Turbidity Alkalinity Hardness Calcium Magnesium Sodium Potassium Chloride Sulfate Iron Nitrogen species Phosphate Organic carbon	Monthly
		2. Gases Nitrogen Methane CO_2 H_2S	Once per year
Lower Monitoring Zone in BZ-1	BZ-1 monitoring tube	Same as Boulder Zone 1 above	Monthly[a]
		Same as Boulder Zone 2 above	Once per year
Lower Floridan Aquifer (brackish to saline transition zone), top and bottom	BZ-1 monitoring tube	Same as Boulder Zone 1 and 2 above	Once per year
	FA-1 and FA-2 inner casings, BZ-1 monitoring tube	Specific conductance, chloride, temperature	Monthly
Upper Floridan Aquifer	FA-1 and FA-2 annuli, I-5 annulus tubing, and BZ-1 monitoring tube	Same as Boulder Zone 1 and 2 above	Once per year
		Specific conductance chloride, temperature	Monthly

Table I.2-3--Continued

Monitoring Zone	Sampling Points	Parameter	Frequency
Biscayne Aquifer	Nine Biscayne aquifer monitoring wells	Chloride, specific conductance	Monthly
Biscayne Aquifer	Biscayne aquifer monitoring wells; Sites I-8, I-5, and I-9	Basic hydrochemistry (same as Boulder Zone 1 and 2 above)	Once per year

[a]Until effluent is detected, then only once per year including Group 2 (gases).

Table 1.2-4
EFFLUENT QUALITY MONITORING PARAMETERS AND FREQUENCY

Parameter	Frequency
Specific conductance	Continuous
BOD_5	Daily
Suspended solids	
Chlorine residual	
Total coliform	
Fecal coliform	
pH	
DO	
Temperature	
Alkalinity	Monthly
Hardness	
Calcium	
Magnesium	
Sodium	
Potassium	
Chloride	
Sulfate	
Organic carbon	
Nitrate	
Phosphate	
Density	
Trace elements (metals)	Once per year
Pesticides	

FIGURES

BC55900.92

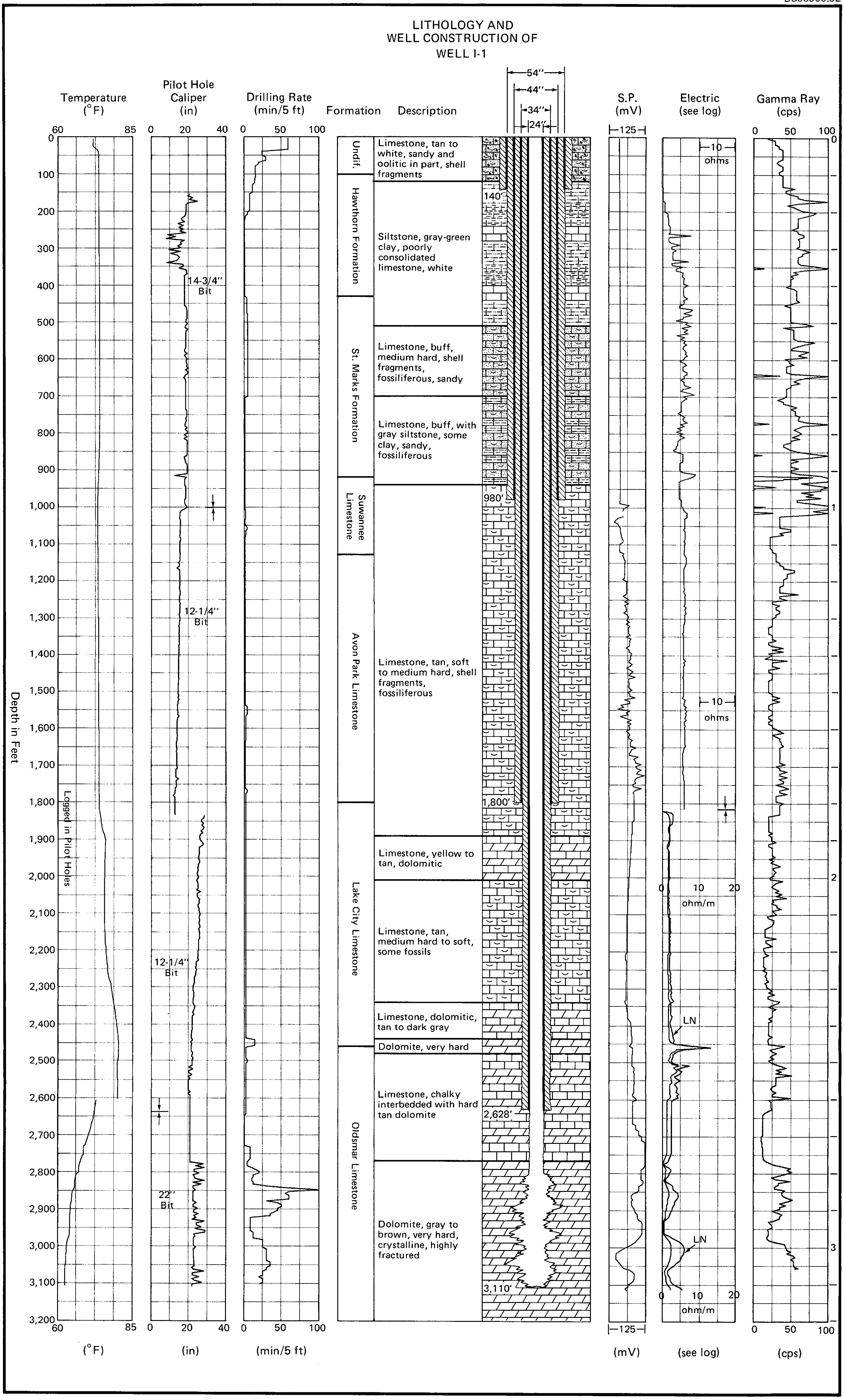


FIGURE 2.1-1.
Summary of drilling and logging data–Well I-1.

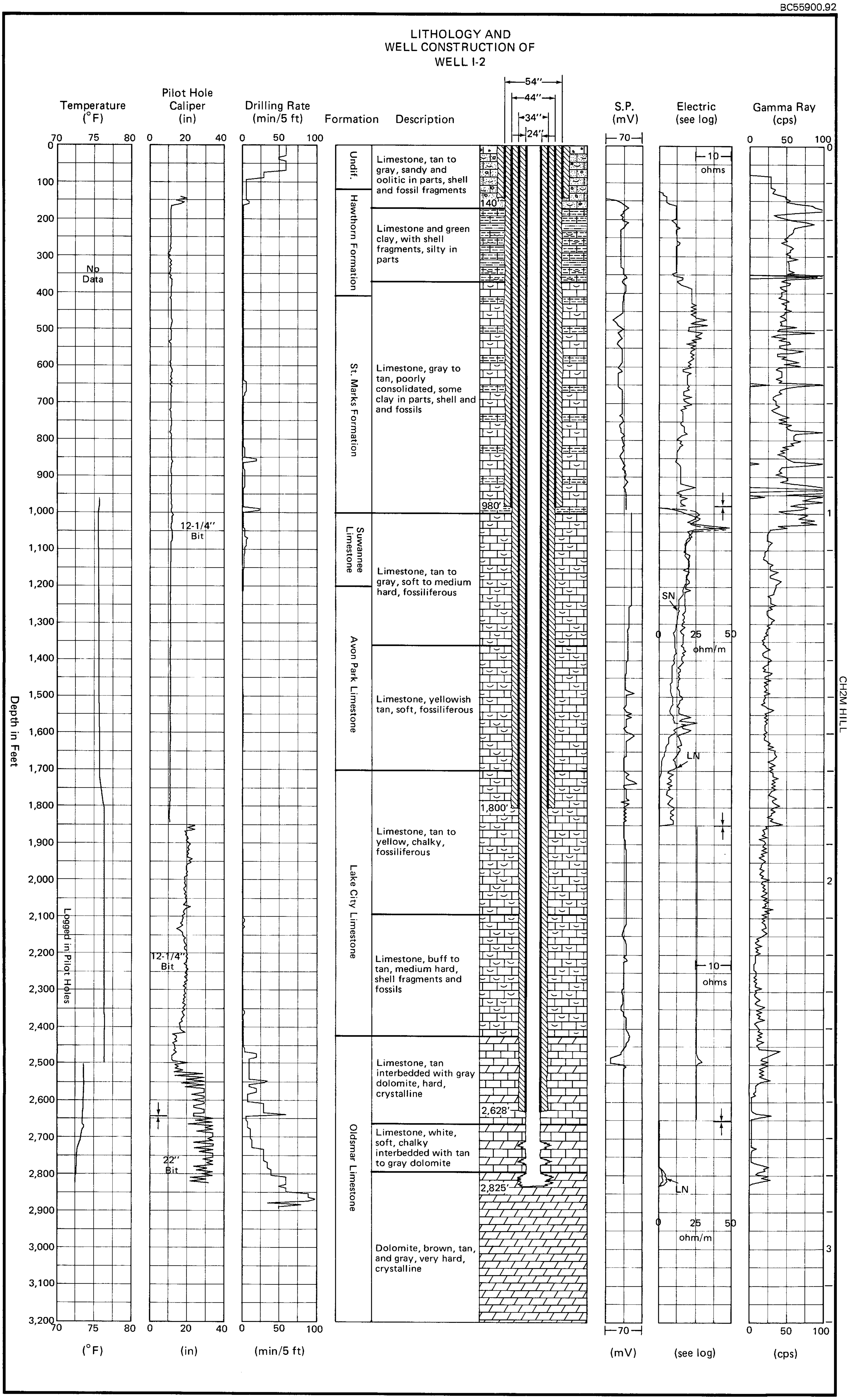
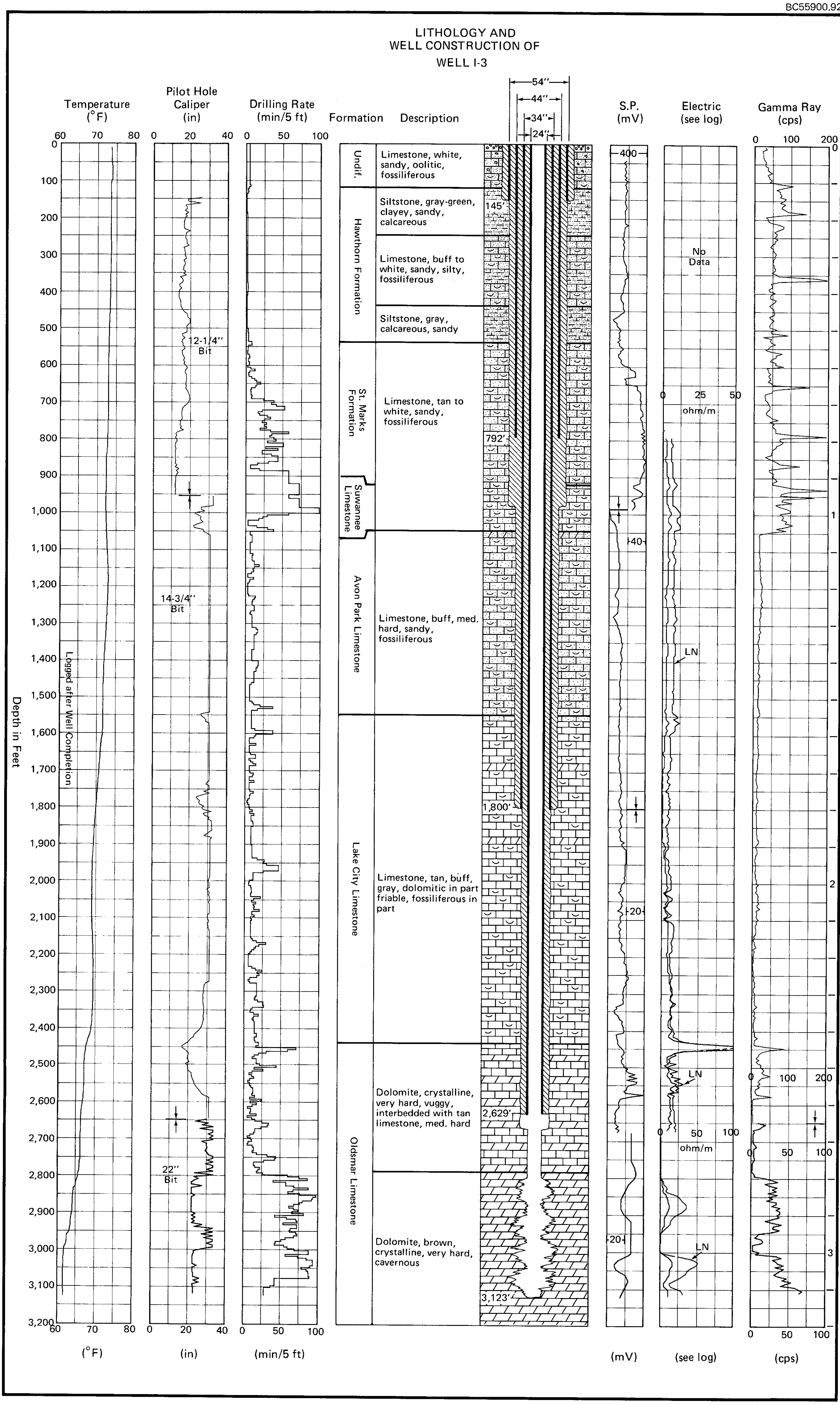


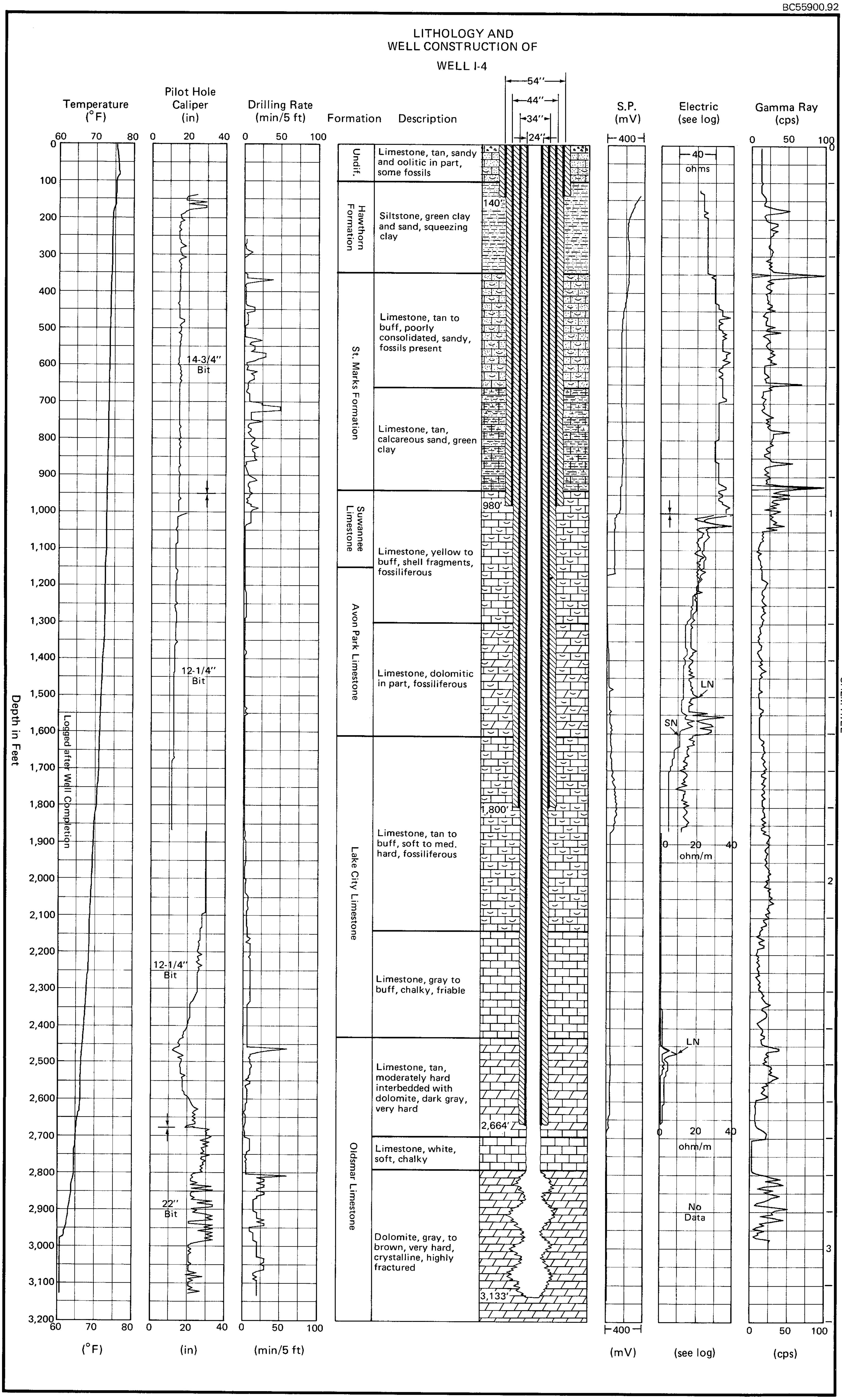
FIGURE 2.2-1.
Summary of drilling and logging data—Well I-2.



Summary of drilling and logging data—Well I-3.

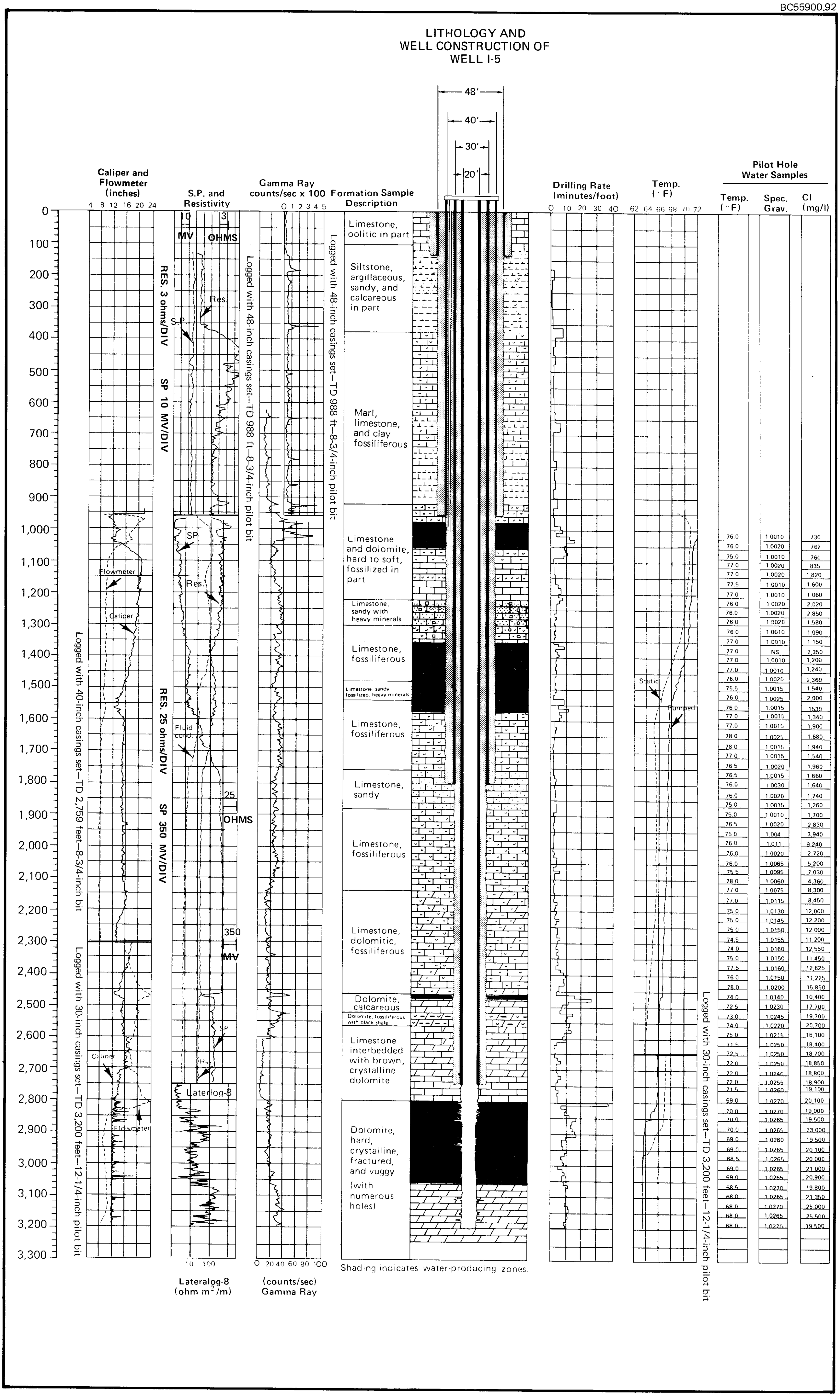
FIGURE 2.3-1.

BC55900.92



Summary of drilling and logging data—Well I-4.

FIGURE 2.4-1.



Pilot Hole Water Samples

Temp. (°F)	Spec. Grav.	Cl (mg/l)
76.0	1.0010	730
76.0	1.0020	762
75.0	1.0010	760
77.0	1.0020	835
77.0	1.0020	1,820
77.5	1.0010	1,600
77.0	1.0010	1,060
76.0	1.0020	2,020
76.0	1.0020	2,850
76.0	1.0020	1,580
76.0	1.0010	1,090
77.0	1.0010	1,150
77.0	NS	2,350
77.0	1.0010	1,200
77.0	1.0010	1,240
76.0	1.0020	2,360
75.5	1.0015	1,540
76.0	1.0025	2,000
76.0	1.0015	1530
77.0	1.0015	1,340
77.0	1.0015	1,900
78.0	1.0025	1,680
78.0	1.0015	1,940
77.0	1.0015	1,540
76.5	1.0020	1,960
76.5	1.0015	1,660
76.0	1.0030	1,640
76.0	1.0020	1,740
75.0	1.0015	1,260
75.0	1.0010	1,700
76.5	1.0020	2,830
75.0	1.004	3,940
76.0	1.011	9,240
76.0	1.0020	2,720
76.0	1.0065	5,200
75.5	1.0095	7,030
78.0	1.0060	4,360
77.0	1.0075	8,300
77.0	1.0115	8,450
75.0	1.0130	12,000
75.0	1.0145	12,200
75.0	1.0150	12,000
74.5	1.0155	11,200
74.0	1.0160	12,550
75.0	1.0150	11,450
77.5	1.0160	12,625
76.0	1.0150	11,225
78.0	1.0200	15,850
74.0	1.0140	10,400
72.5	1.0230	17,700
73.0	1.0245	19,700
74.0	1.0220	20,700
75.0	1.0215	16,100
71.5	1.0250	18,400
72.5	1.0250	18,700
72.0	1.0250	18,850
72.0	1.0240	18,800
72.0	1.0255	18,900
71.5	1.0260	19,100
69.0	1.0270	20,100
70.0	1.0270	19,000
70.0	1.0265	19,500
70.0	1.0265	23,000
69.0	1.0260	19,500
69.0	1.0265	20,100
68.5	1.0265	20,000
69.0	1.0265	21,000
69.0	1.0265	20,900
68.5	1.0270	19,800
68.0	1.0265	21,350
68.0	1.0270	25,000
68.0	1.0265	25,500
68.0	1.0270	19,500

Summary of data from drilling and related operations—I-5.

FIGURE 2.5-1.

BC55900.92

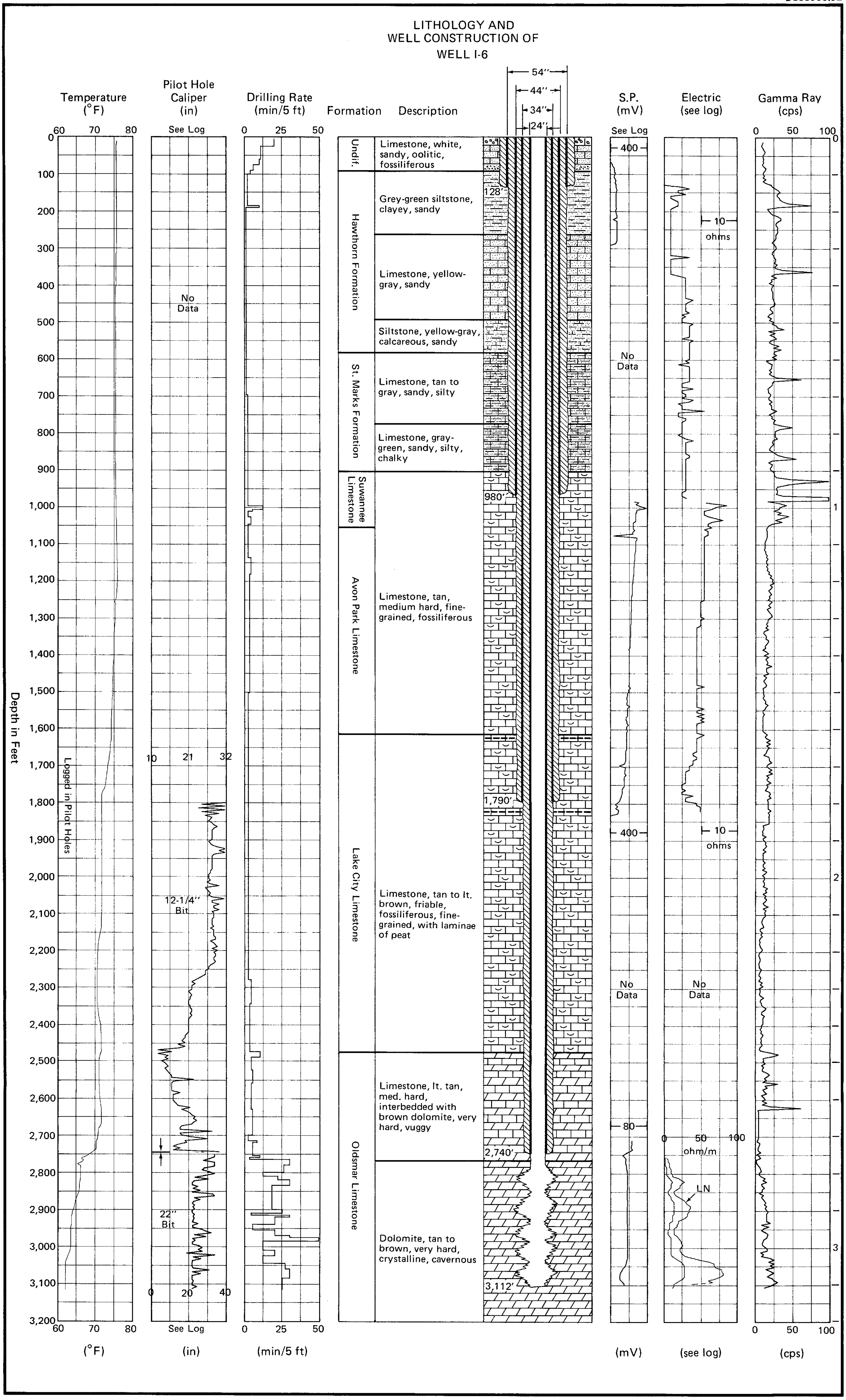
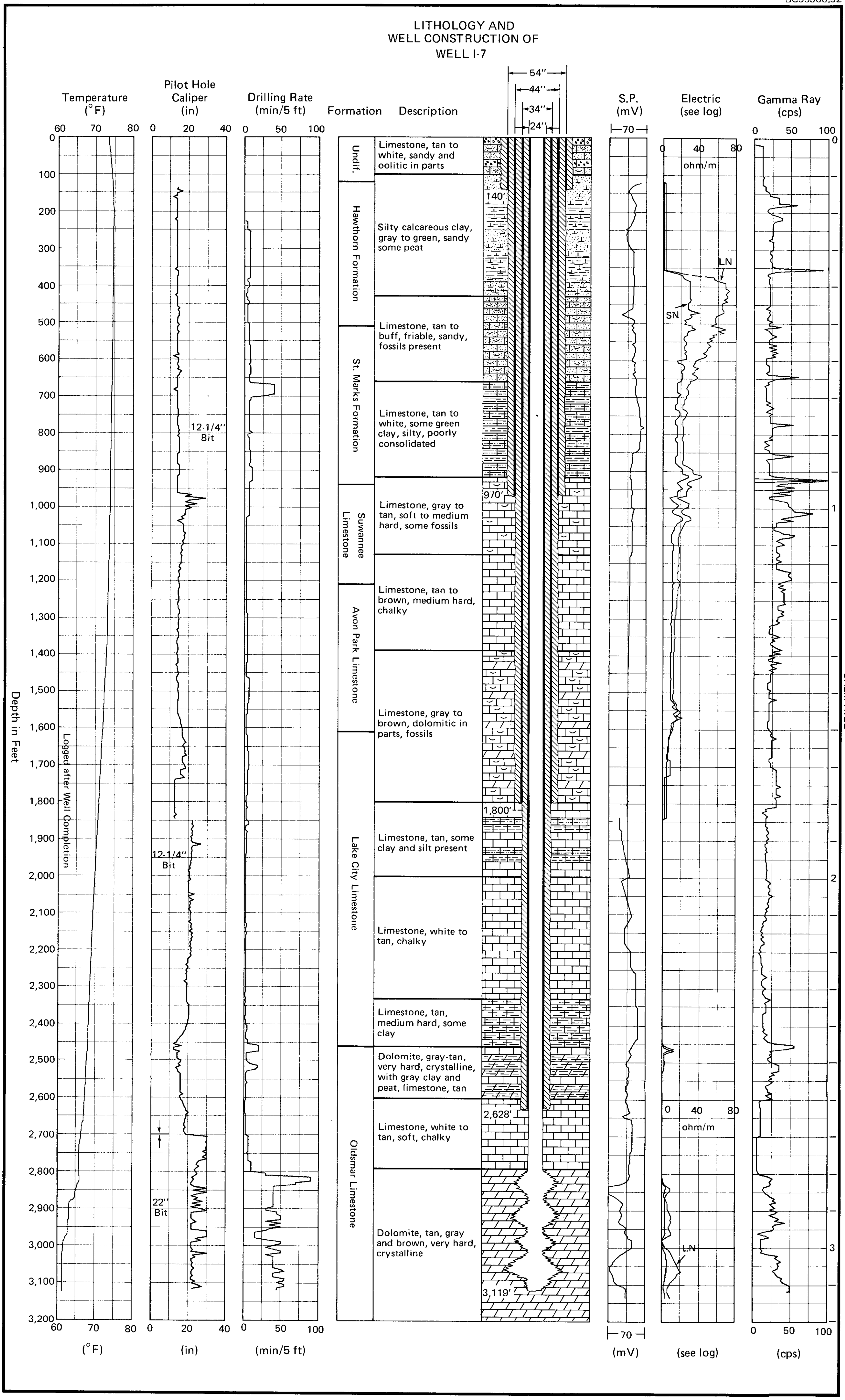


FIGURE 2.6-1. Summary of drilling and logging data—Well I-6.

BC55900.92

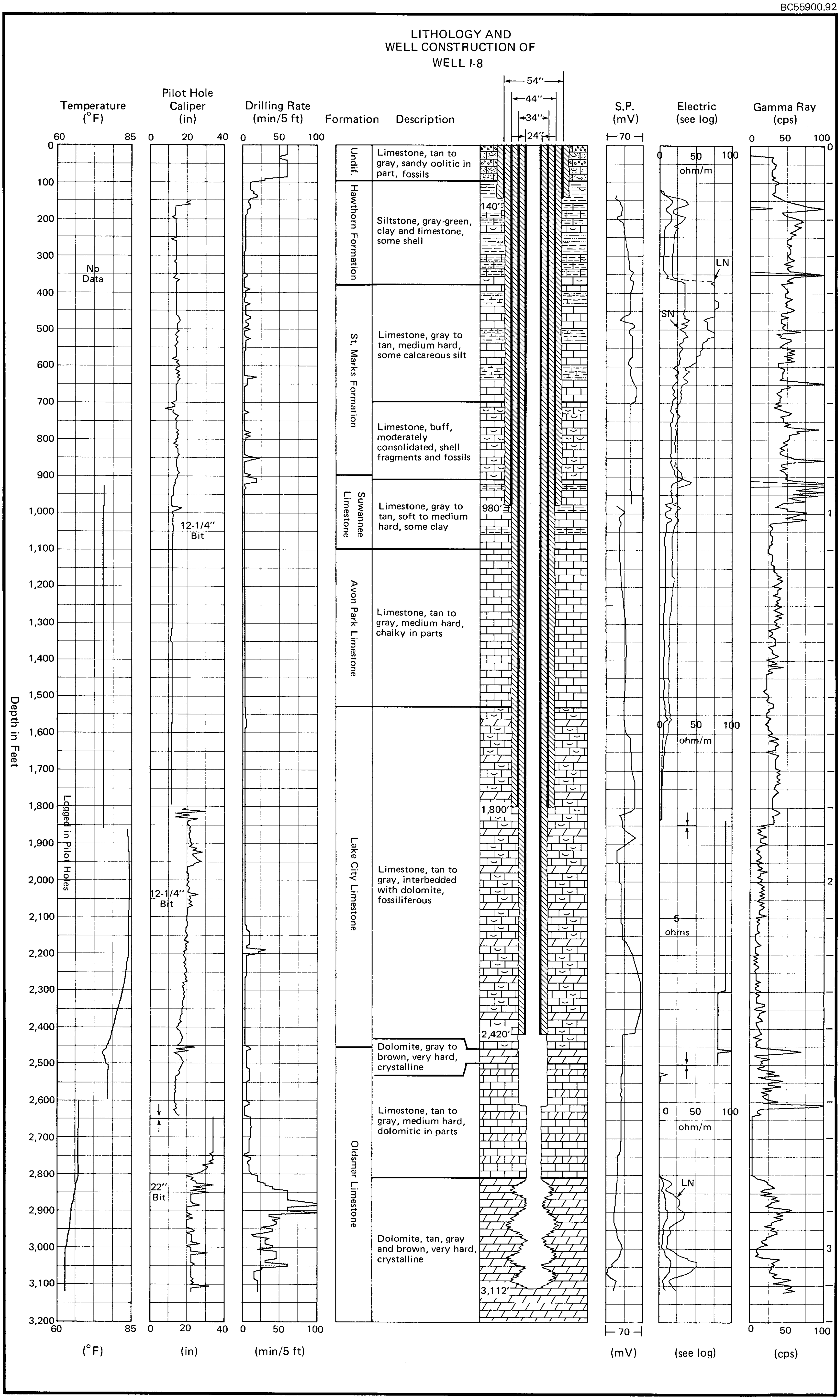


Summary of drilling and logging data—Well I-7.

FIGURE 2.7-1.

CH2M HILL

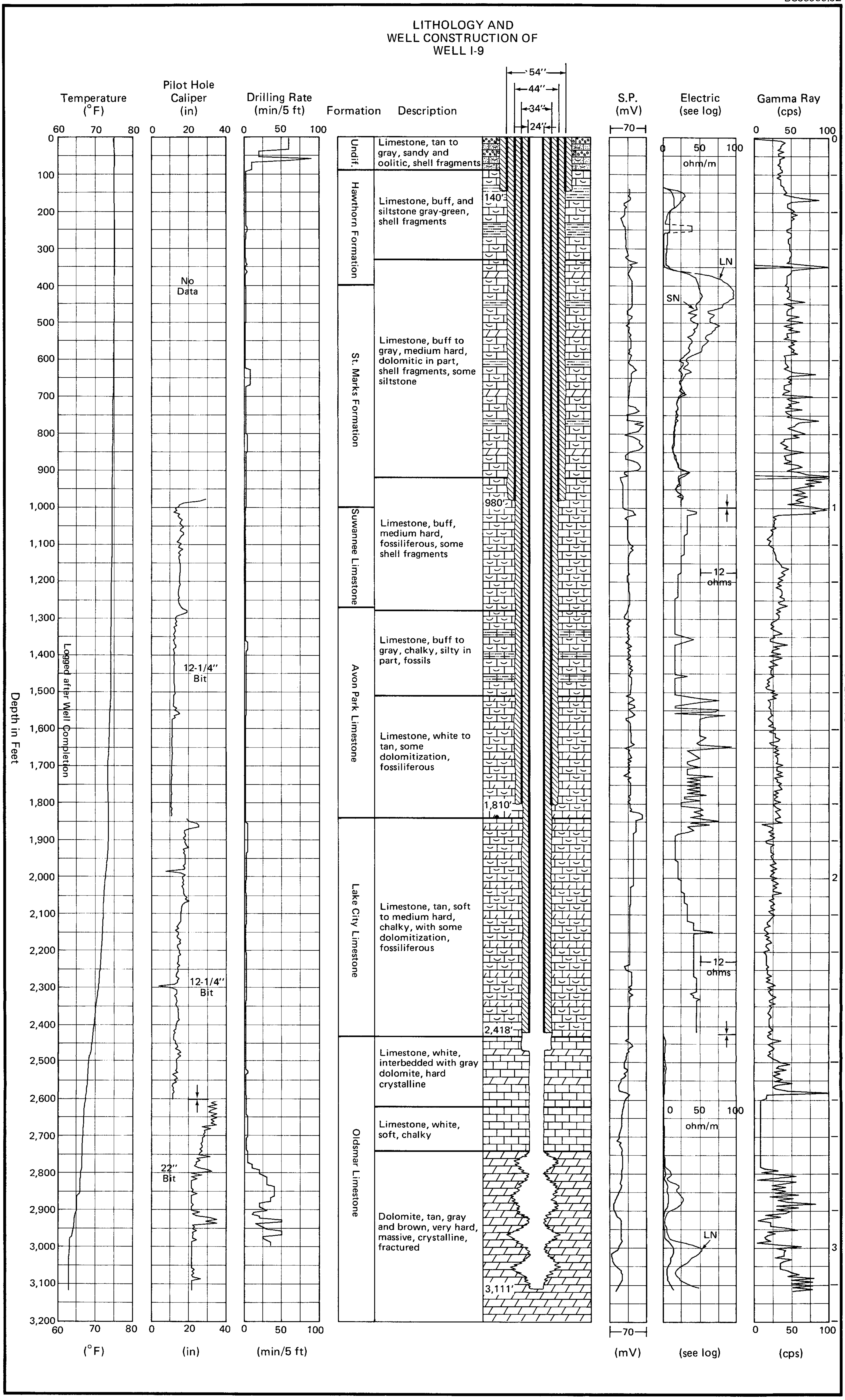
BC55900.92



Summary of drilling and logging data—Well I-8.

FIGURE 2.8-1.

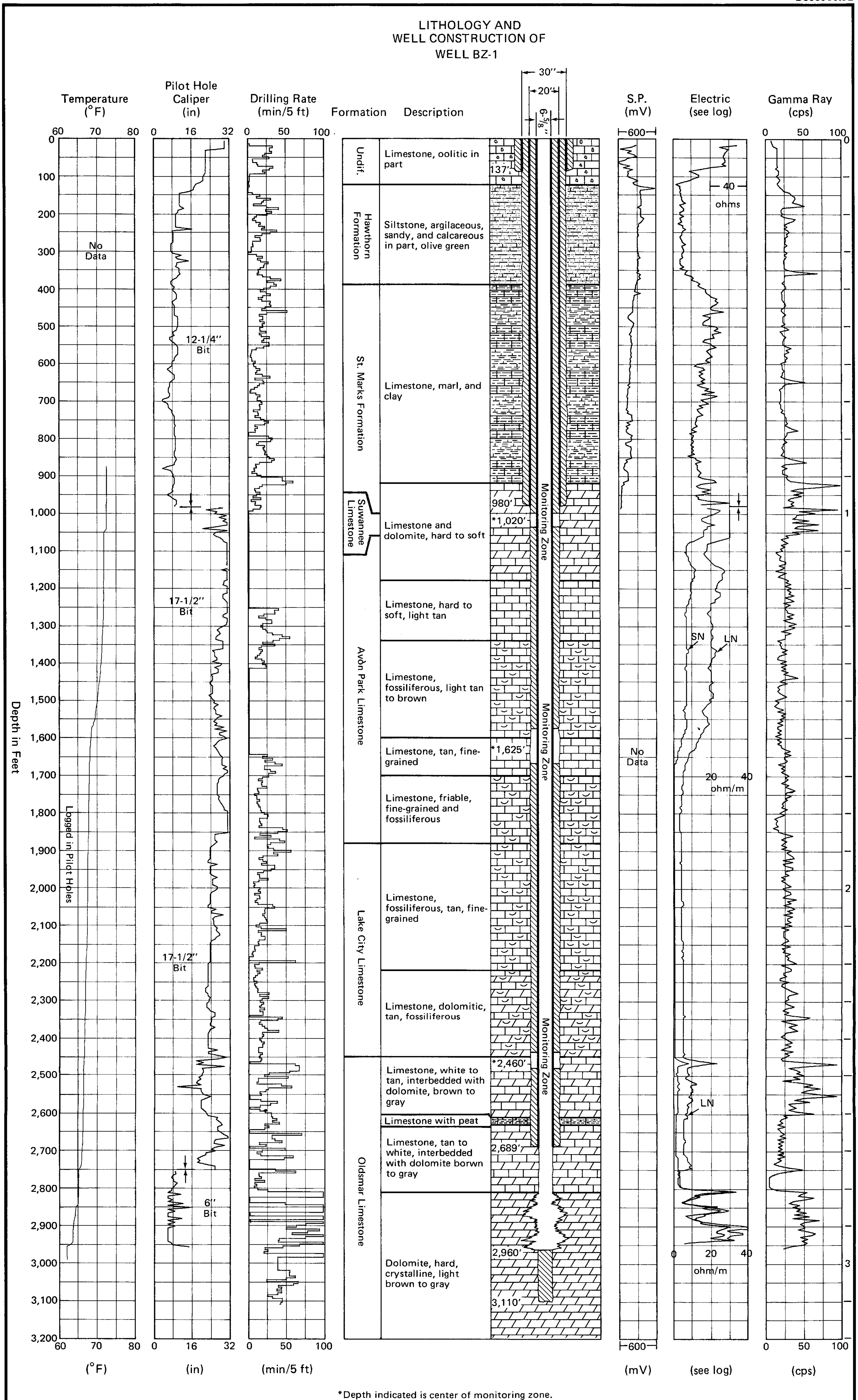
BC55900.92



Summary of drilling and logging data—Well I-9.

FIGURE 2.9-1.

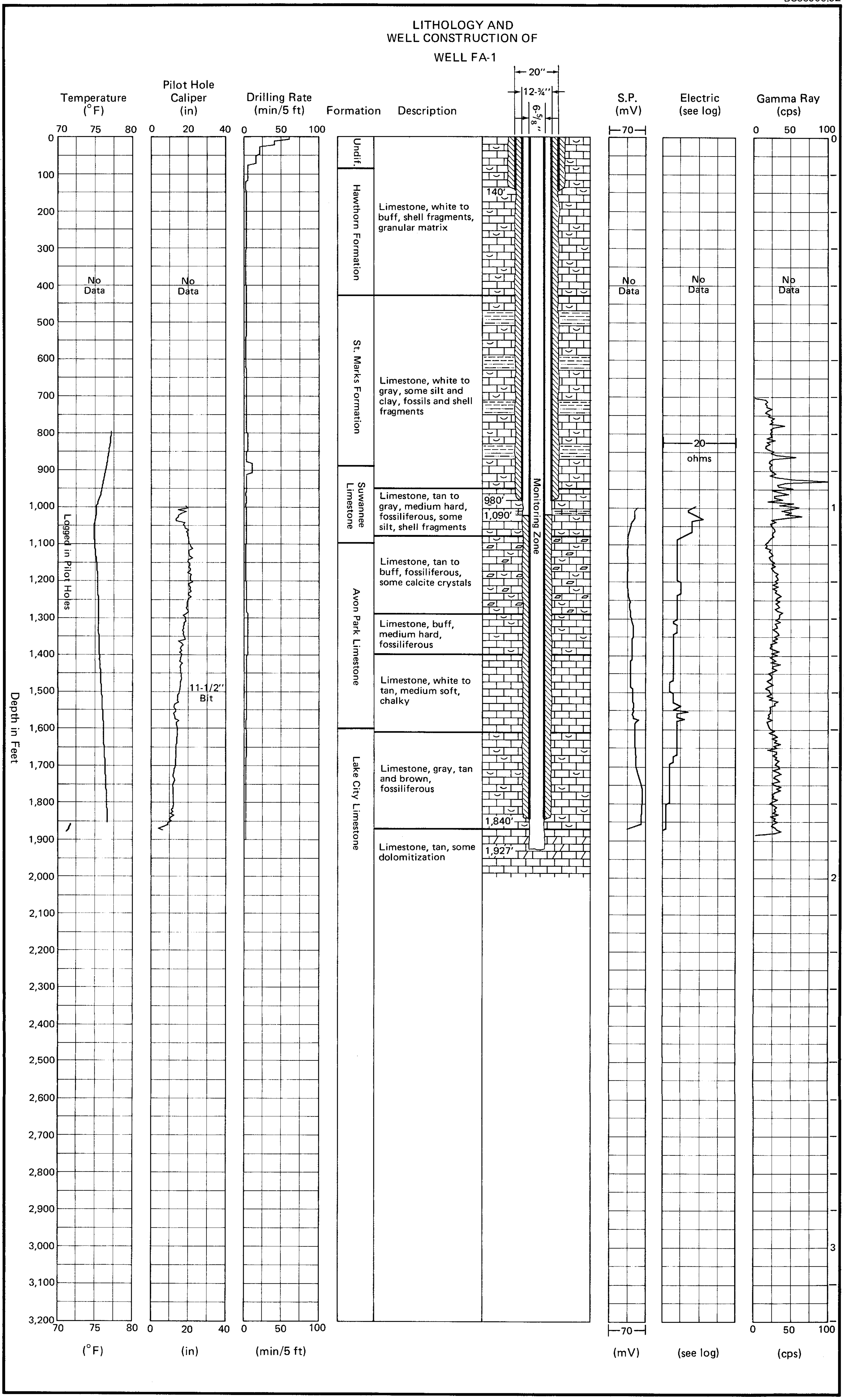
BC55900.92



Summary of drilling and logging data—Monitoring Well BZ-1.

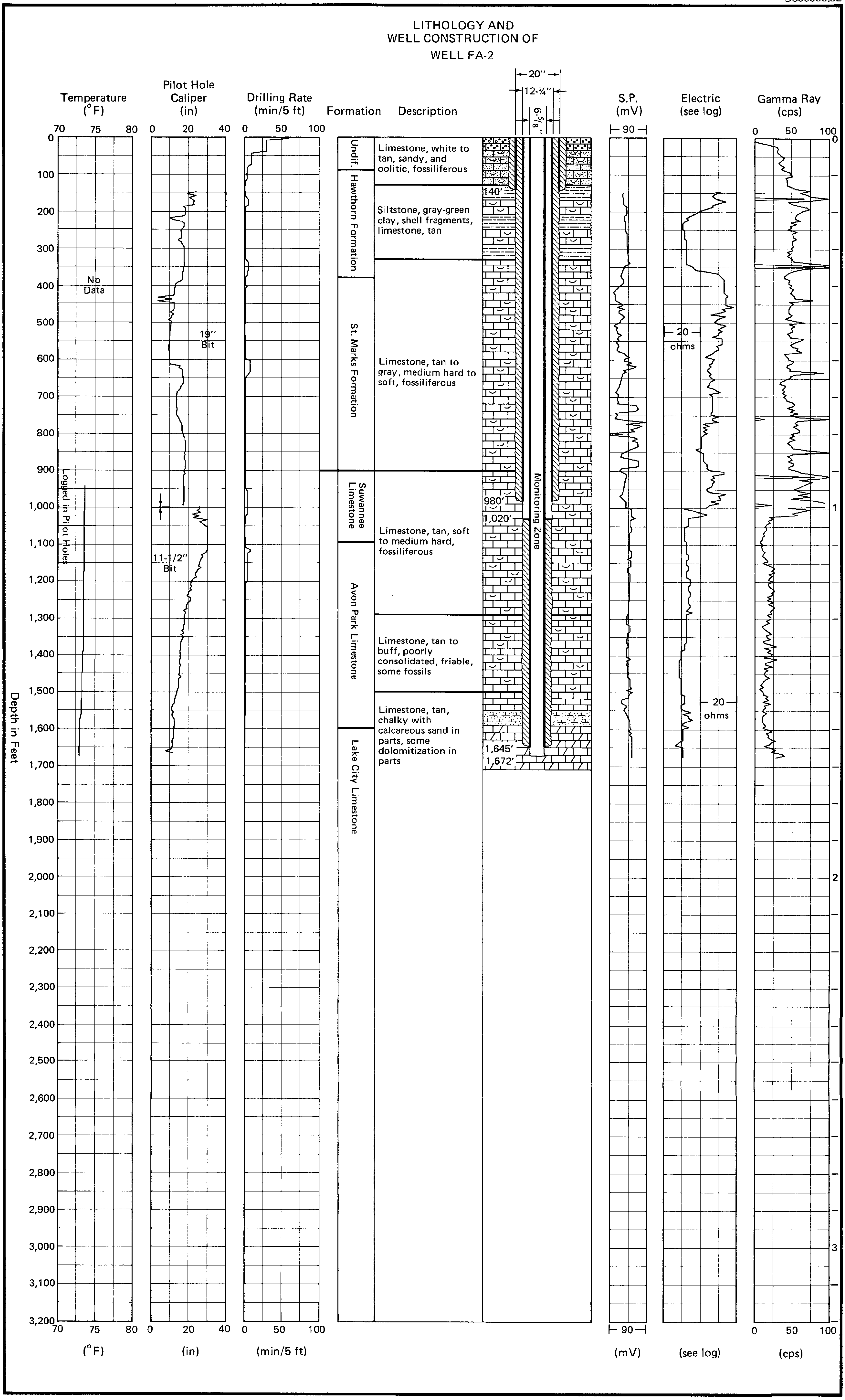
FIGURE 2.10-1.

BC55900.92



Summary of drilling and logging data—Monitoring Well FA-1.

FIGURE 2.11-1.



Summary of drilling and logging data—Monitoring Well FA-2.

FIGURE 2.12-1.