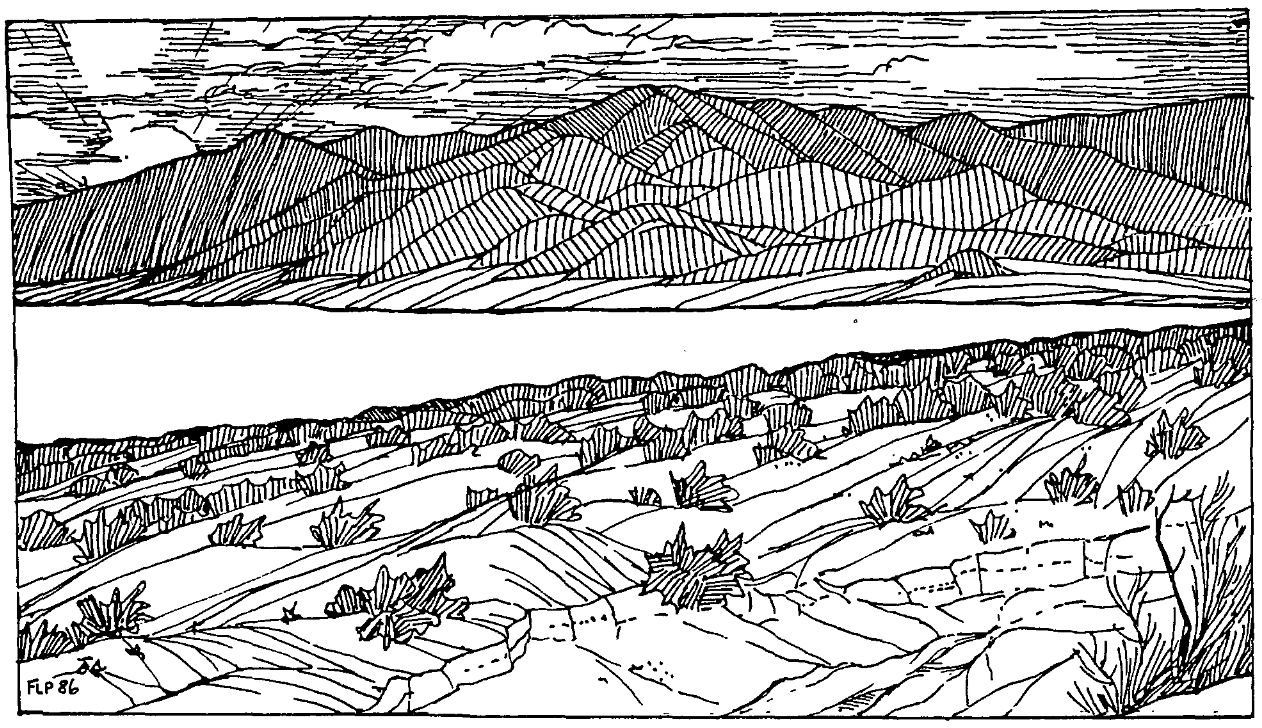
PRELIMINARY REPORT ON GEOPHYSICAL WELL-LOGGING ACTIVITY ON THE SALTON SEA SCIENTIFIC DRILLING PROJECT, IMPERIAL VALLEY, CALIFORNIA



U.S. GEOLOGICAL SURVEY
Open-File Report 86-544

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

PRELIMINARY REPORT ON GEOPHYSICAL WELL-LOGGING ACTIVITY ON THE SALTON SEA SCIENTIFIC DRILLNG PROJECT, IMPERIAL VALLEY, CALIFORNIA

Edited by Frederick L. Paillet

Contributors: F. L. Paillet, R. H. Morin, R. E. Hodges, L. C. Robison, S. S. Priest, J. H. Sass, and J. D. Hendricks, U.S. Geological Survey; P. W. Kasameyer, G. A. Pawloski, R. C. Carlson, A. G. Duba, J. R. Hearst and R. L. Newmark, Lawrence Livermore National Laboratory.

U.S. GEOLOGICAL SURVEY

Open-File Report 86-544

Denver, Colorado
1986

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary
U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information, write to:

U.S. Geological Survey
Water Resources Division
Mail Stop 403, Box 25046
Denver Federal Center
Denver, CO 80225

Copies of this report may be purchased from:

U.S. Geological Survey
Books and Open-File Reports
Federal Center, Bldg. 41
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To Obtain
Barrel per hour (bbl/h)	0.159	cubic meter per hour
Barrel (bbl)		
Cubic foot (ft^3)	0.02832	cubic meter
Foot (ft)	0.3048	meter
Foot per minute (ft/min)	0.3048	meter per minute
Pound, avoirdupois (lb)	453.6	gram
Inch (in.)	2.54	centimeter
Mile (mi)	1.609	kilometer
Pound per foot	1.488	kilograms per meter
Pound per hour (lb/h)	0.4536	kilograms per hour
Degree Celsius (°C)	F = 9/5°C + 32	degree Fahrenheit

PRELIMINARY REPORT ON GEOPHYSICAL WELL-LOGGING ACTIVITY ON THE SALTON SEA SCIENTIFIC DRILLING PROJECT, IMPERIAL VALLEY, CALIFORNIA

Edited by Frederick L. Paillet

Contributors: F. L. Paillet, R. H. Morin, R. E. Hodges, L. C. Robison, S. S. Priest, J. D. Hendricks, U.S. Geological Survey; P. W. Kassameyer, G. A. Pawloski, R. C. Carlson, A. G. Duba, J. R. Hearst and R. L. Newmark, Lawrence Livermore National Laboratory.

ABSTRACT

F. L. Paillet and R. H. Morin

The Salton Sea Scientific Drilling Project has culminated in a 10,564-foot deep test well, State 2-14 well, in the Imperial Valley of southern California. A comprehensive scientific program of drilling, coring, and downhole measurements, which was conducted for about 5 months, has obtained much scientific information concerning the physical and chemical processes associated with an active hydrothermal system. This report primarily focuses on the geophysical-logging activities at the State 2-14 well and is intended to provide early dissemination of geophysical data to other investigators working on complementary studies.

Geophysical-log data were obtained by a commercial logging company and by the U.S. Geological Survey. Most of the commercial logs were obtained during three visits to the site; only one commercial log was obtained below a depth of 6,000 feet. The commercial logs obtained were dual induction,

natural gamma, compensated neutron formation density, caliper, and sonic. The U.S. Geological Survey logging effort consisted of four primary periods, with many logs extending below a depth of 6,000 feet. The U.S. Geological Survey logs obtained were temperature, caliper, natural gamma, gamma spectral, epithermal neutron, acoustic velocity, full-waveform, and acoustic televiewer. Various problems occurred throughout the drilling phase of the Salton Sea Scientific Drilling Project that made successful logging difficult: (1) Borehole constrictions, possibly resulting from mud coagulation, (2) maximum temperatures of about 300°Celsius, and (3) borehole conditions unfavorable for logging because of numerous zones of fluid loss, cement plugs, and damage caused by repeated trips in and out of the hole. These factors hampered and compromised logging quality at several open-hole intervals. The quality of the logs was dependent on the degree of probe sophistication and sensitivity to borehole-wall conditions. Nevertheless, the geophysical logs obtained by the commercial logging company and by the U.S. Geological Survey, combined with the lithologic record derived from the mud log, provide a comprehensive data set for the State 2-14 well. Digitized logs presented in this report were processed on site and are presented in increments of 1,000 feet.

This report provides a relatively complete, although preliminary, listing of the log data that are available for analysis and interpretation through studies that are ongoing (1986) and that will continue for many months. A summary of the numerous factors that may be relevant to this interpretation also is presented.

INTRODUCTION

L. C. Robison, S. S. Priest, J. H. Sass, J. D. Hendricks, F. L. Paillet, and G. A. Pawloski.

The first deep well, State 2-14, of the U.S. Continental Scientific Drilling Program was drilled to a depth of 10,546 ft on the southeastern edge of the Salton Sea near Niland, California (fig. 1). State 2-14 well is located in the Salton Sea geothermal field in Sec. 14, T. 11 S., R. 13 E. at a ground elevation of 225.2 ft below National Geodetic Vertical Datum of 1920. Depths of all logs are relative to the kelly bushing which was at an elevation of -196.5 ft. The well was spudded on October 23, 1985. At intermediate casing points (fig. 2), geophysical logs were run prior to setting the casing. Temperature logs were also run prior to the first flow test which occurred between 6,000 to 6,227 ft. Total depth of 10,564 ft was reached on March 17, 1986. This was followed by a second flow test and a program of additional geophysical logging and downhole experiments that ended on April 1, 1986. The well presently is capped and will remain so for 6 months, during which time a succession of temperature logs will be run.

The well was drilled using standard oilfield technology with modifications for controlling the high temperatures at the bit face and in formation fluids. During the drilling, scientific objectives had priority over economic and engineering concerns, whenever safety and well integrity were not compromised.

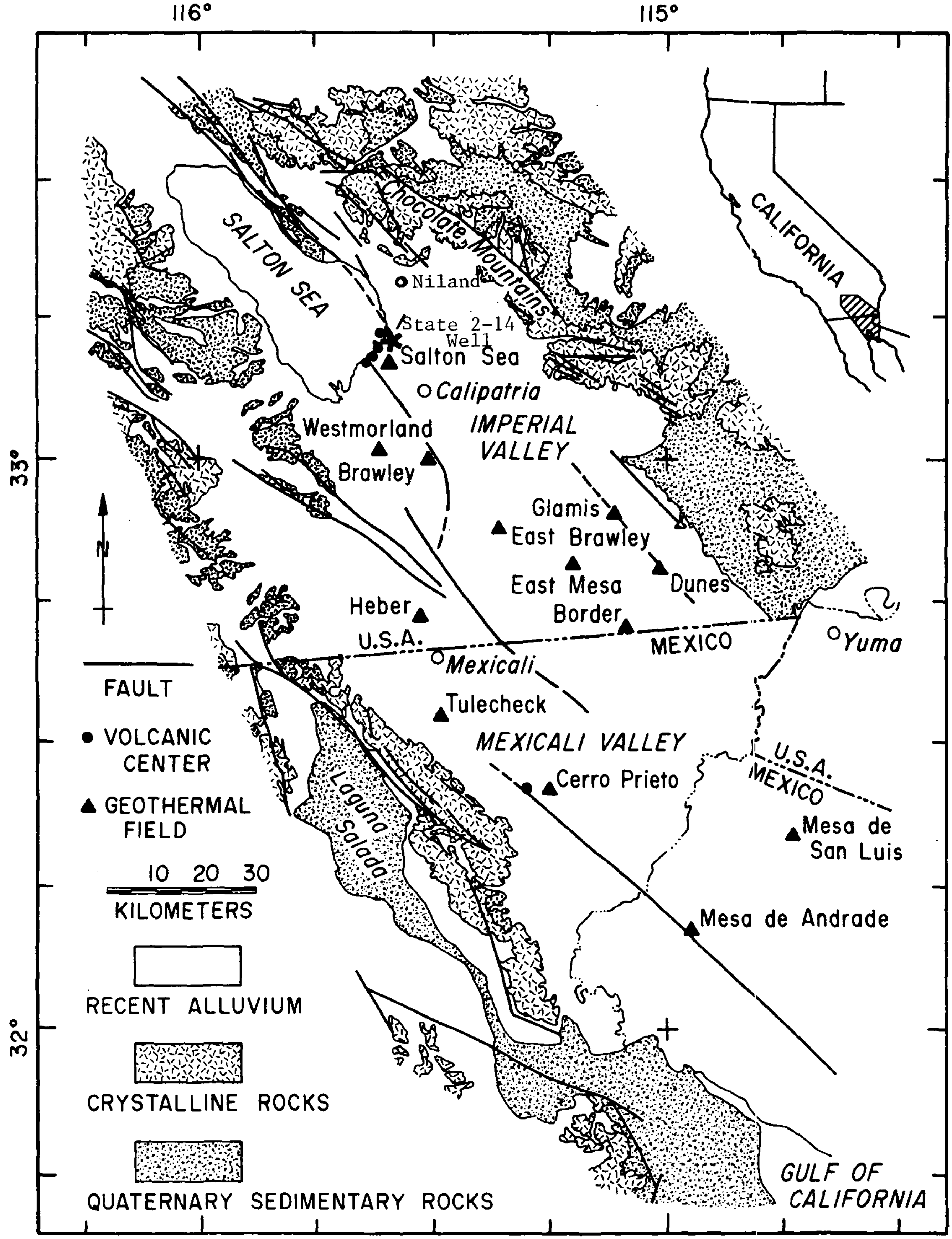


Figure 1.--Map showing location of State 2-14 well.

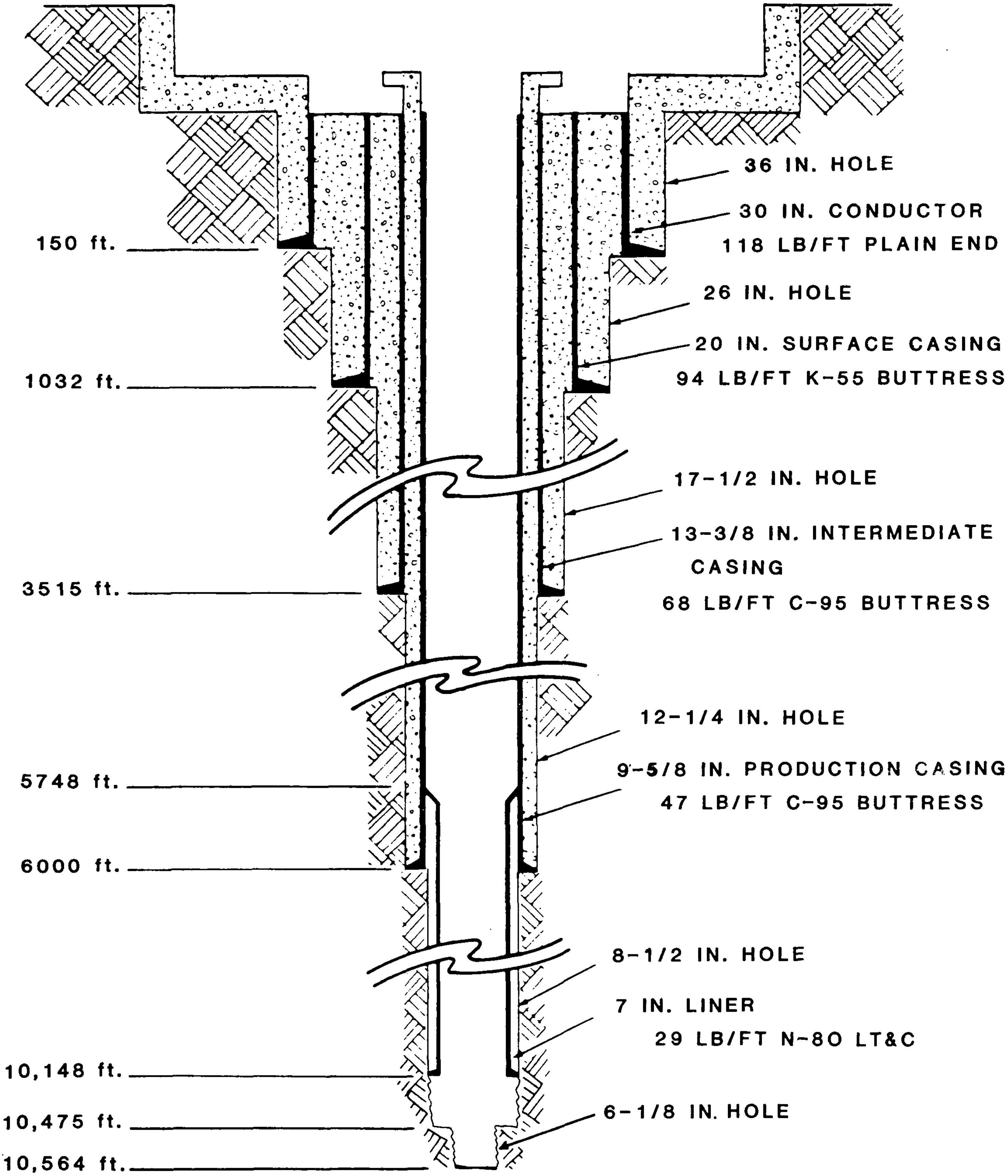


Figure 2.--Diagram showing casing configuration of State 2-14 well.

The primary scientific goals were to study active physical and chemical processes in a magmatic hydrothermal system. To achieve these goals, maximum data effort was focused in four areas: (1) Core recovery, (2) geophysical logs, (3) downhole experiments, and (4) sampling of formation fluids (Sass and Elders, 1986). All of these activities were coordinated and supervised by a science-management team from the U.S. Geological Survey. The purpose of this report is to present information relevant to the preliminary interpretation of data in the second category, geophysical logging. This objective addresses the need to provide early access to the geophysical data obtained from the State 2-14 well.

Geophysical logs were obtained from two sources: (1) A private geophysical logging company (Schlumberger, Inc.[1/]), and (2) the U.S. Geological Survey. There is one important difference between the commercial logs and the U.S. Geological Survey logs that potential users of the logs need to be aware of. The commercial well logs were obtained using standards and formats developed by the petroleum industry. The data produced are thus presented in units deemed more useful to that industry rather than in units used in geohydrology. For example, the units for neutron and gamma-gamma (density) logs are values of porosity and bulk density rather than count rates. This conversion requires assumptions about lithology, saturation, and so forth that may not be valid here. Also, field copies of logs made available at the site by the logging engineer list the data as calibrated values rather than actual measurements. However, some actual measurements were recorded on magnetic tape. In contrast, the U.S. Geological Survey

---

[1/] The use of trade and firm names in this report is for identification only and does not constitute endorsement by the U.S. Geological Survey.

logging program is based on the digital recording of actual measurements in the field, followed by subsequent analysis of those measurements in the laboratory. This approach retains the original measurements rather than only the interpreted values. This fundamental difference in approach was one justification for obtaining the otherwise redundant nuclear logs contained in this report. Calibration and tool-response curves are needed to interpret U.S. Geological Survey data. Several tools unique to each group also were used.

A well-log-analysis system, the Terra Station, was used to store, display, and manipulate the data at the well site in a timely fashion. This system was purchased by Lawrence Livermore National Laboratory; it represents the state-of-the-art in computerized analysis of well-log data. Before the well was drilled, a data base of information obtained from nearby boreholes was established for comparison with data to be collected in the well. When drilling commenced, the system was relocated to the well site. Lawrence Livermore National Laboratory and U.S. Geological Survey personnel entered the commercial and Survey log data into the data base at the well site shortly after each logging run. Lithologic data derived from the mud log (analysis of cuttings contained in the circulation drilling fluid) also was stored in the data base. The Terra Station and data base currently (1986) are at the Lawrence Livermore National Laboratory.

Summary of Activities During Drilling

Activities that occurred during the drilling program are listed in table 1 and summarized in figure 3.

Table 1.--Summary of activities during drilling of State 2-14 well

[ft, feet; in., inches; bbl, barrels; lb/h, pound per hour; core descriptions given by Mehegan and others, 1986]

Date	Depth (ft)	Activity
10/23/85	0	Drilled Spud 40-in. diameter hole
10/25/85	150	Set 30-in. diameter casing; drilled 17 1/2-in. diameter hole
10/28/85	1,032	Reamed to 26-in. diameter, set 20-in. diameter casing
10/31/85	1,553-1,578	Retrieved core 1, 24.6 ft, 98.4-percent recovery
11/01/85	1,983-2,013	Retrieved core 2, 29.2 ft, 97.3-percent recovery
11/02/85	2,448-2,478	Retrieved core 3, 30 ft, 100-percent recovery
11/04/85	2,970-3,030	Retrieved core 4, 59.6 ft, 99.3-percent recovery
11/05/85	3,028	Ran commercial and U.S. Geological Survey logs
11/05/85	3,028	Decided to extend casing point to 3,500 ft
11/08/85	3,080-3,089	Core 5 contained in 1-ft diameter junk basket, fished for cones
11/11/85	3,107-3,167	Retrieved core 6, 55 ft, 91.6-percent recovery
11/13/85	3,505	Ran commercial logs
11/12/85	3,470-3,505	Retrieved core 7, 34 ft, 97-percent recovery
11/15/85	3,515	Set 13 3/8-in. diameter casing; continued to drill 12 1/4-in. diameter hole
11/19/85	3,790-3,850	Retrieved core 8, 57 ft, 95-percent recovery
11/20/85	4,007-4,067	Retrieved core 9, 60 ft, 100-percent recovery
11/21/85	4,241-4,301	Retrieved core 10, 60 ft, 100-percent recovery
11/22/85	4,301-4,337	Retrieved core 11, 36 ft, 100-percent recovery
11/24/85	4,684	Conducted injection test
11/25/85	4,643-4,680	Retrieved core 12, 37 ft, 100-percent recovery
11/26/85	4,680	U.S. Geological Survey measured bottom hole temperature

Table 1.--Summary of activities during drilling of State 2-14 well--Continued

Date	Depth (ft)	Activity
11/26/85	4,680-4,686	Retrieved core 13, 2 ft, 33.3-percent recovery
11/27/85	4,710	Core 14, 5 ft, fished for stabilizer blades using 6-in. diameter junk basket
12/02/85	5,188-5,218	Retrieved core 15, 30 ft, 100-percent recovery
12/04/85	5,418	Conducted injection test; U.S. Geological Survey ran two temperature logs and measured bottom hole temperature
12/05-06/85	5,422-5,424	Fished for parted bottom hole assembly
12/07/85	5,574-5,591.5	Retrieved core 16, 17.5 ft, 100-percent recovery
12/08/85	6,000	Ran commercial logs
12/09-12/85	6,000	U.S. Geological Survey ran logs and measured bottom hole temperature
12/13-16/85	6,000	Set 9 5/8-in. diameter casing; continued drilling using 8 1/2-in. diameter bit
12/19/85	6,027-6,034	Retrieved core 17, 7 ft, 100-percent recovery; started directional drilling
12/23/85	6,227	Decided to conduct flow test; capped well
12/27/85	6,227	U.S. Geological Survey ran logs and measured bottom hole temperature
12/28-31/85	6,227	Conducted flow test, collected fluid samples and measured temperature, pressure, and flow rate at land surface; maximum flow estimated to be 600,000 lb/h
12/31/85-1/02/86	6,227	Capped well; U.S. Geological Survey collected downhole fluid sample and measured bottom hole temperature
01/02/86	6,227	Continued drilling 8 1/2-in. diameter hole
01/03/86	6,506-6,517	Retrieved core 18, 11 ft, 100-percent recovery
01/05/86	6,637	Lost circulation
01/06/86	6,758-6,771	Retrieved core 19 (blind), 8 ft, 61.5-percent recovery

Table 1.--Summary of activities during drilling of State 2-14 well--Continued

Date	Depth (ft)	Activity
01/06-10/86	6,771	Cemented lost circulation zone; waited on cement; continued drilling
01/11/86	6,820	Lost circulation, sealed off lost circulation zone with cement
01/14/86	6,880-6,889	Retrieved core 20 (blind), 3.5 ft, 38.8-percent recovery
01/16/86	7,100-7,109	Retrieved core 21, 7 ft, 77.7-percent recovery
01/18/86	7,300-7,313	Retrieved core 22, 11.5 ft, 88.5-percent recovery
01/19/86	7,547-7,577	Retrieved core 23, 28.5 ft, 95-percent recovery
01/20/86	7,708-7,738	Retrieved core 24, 30 ft, 100-percent recovery
01/22-27/86	7,737-7,781	Continued directional drilling
01/28/86	8,133-8,162	Retrieved core 25, 19 ft, 65.5-percent recovery
01/31/86	8,395-8,401	Retrieved core 26, 7 ft, 100-percent recovery
02/01/86	8,585-8,604	Retrieved core 27, 12 ft, 63.2-percent recovery
02/03/86	8,800-8,807	Retrieved core 28, 4 ft, 57.1-percent recovery
02/05/86	9,004-9,027	Retrieved core 29 (blind), 4.5 ft, 19.6-percent recovery
02/07/86	9,095-9,098	Retrieved core 30 (blind), 3 ft, 100-percent recovery
02/08/86	9,098	Lost circulation zone; waited on cement; continued drilling
02/10/86	9,248-9,254	Retrieved core 31, 3.5 ft, 58.3-percent recovery; well flowing at 9,254 ft, 400 bbl gain
02/11/86	9,453	Drill-bit button broken; ran junk sub to recover button; lost circulation; lost circulation material pumped in
02/13/86	9,453-9,458	Retrieved core 32, 2.3 ft, 46-percent recovery
2/14/86	9,458-9,473	Retrieved core 33, 5 ft, 33.3-percent recovery
02/15/86	9,473	U.S. Geological Survey ran temperature log

Table 1.--Summary of activities during drilling of State 2-14 well--Continued

Date	Depth (ft)	Activity
02/17-23/86	9,473	Lost circulation zone; waited on cement; injected cement in four stages using private contractor
02/23/86	9,473-9,475	Retrieved core 34 (blind), 1 ft, 50-percent recovery
02/25-27/86	9,517	Pipe stuck at 9,458 ft while running in hole; spot diesel; reconditioned well; continued drilling
02/28/86	9,694-9,698	Retrieved core 35, 3.5 ft, 87.5-percent recovery
3/02/86	9,907-9,912	Retrieved core 36, 0.75 ft, 15-percent recovery
3/03/86	10,000	Reached target depth
03/07/86	10,350	Film of multishot survey destroyed
03/08/86	10,475	U.S. Geological Survey ran temperature and caliper logs; lost circulation; sealed off lost circulation zone with mixture of drilling-mud additives and cement
03/10/86	10,475	Ran commercial dual-induction log
03/11-12/86	10,475	Rig up private contractor; waited on cement; drill pipe plugs with cement
03/12-13/86	10,475	U.S. Geological Survey ran logs
03/15-16/86	10,475	Injected cement; conditioned hole; set 7-in. diameter liner from 5,748 to 10,148 ft; drilled out cement
03/17/86	10,564	Reached total depth
03/19/86	10,564	Installed well-head valves
03/20-22/86		Conducted second flow test; maximum flow estimated to be 580,000 lb/h
03/22-25/86		U.S. Geological Survey ran Kuster temperature, pressure, and spinner; Los Alamos National Laboratory and Sandia Lab. ran downhole sampler; Leutert (sampler) run; U.S. Geological Survey and Lawrence Berkeley Laboratory conducted other downhole sampling

Table 1.--Summary of activities during drilling of State 2-14 well--Continued

Date	Activity
03/25-27/86	Reinjected brine
03/27-29/86	U.S. Geological Survey ran logs; Lawrence Berkeley Laboratory ran vertical seismic profile
03/30/86	Dia-Log ran casing caliper
03/30-31/86	Lawrence Livermore National Laboratory measured downhole gravity
04/01/86	U.S. Geological Survey ran temperature log; well was capped, beginning of shut in period.

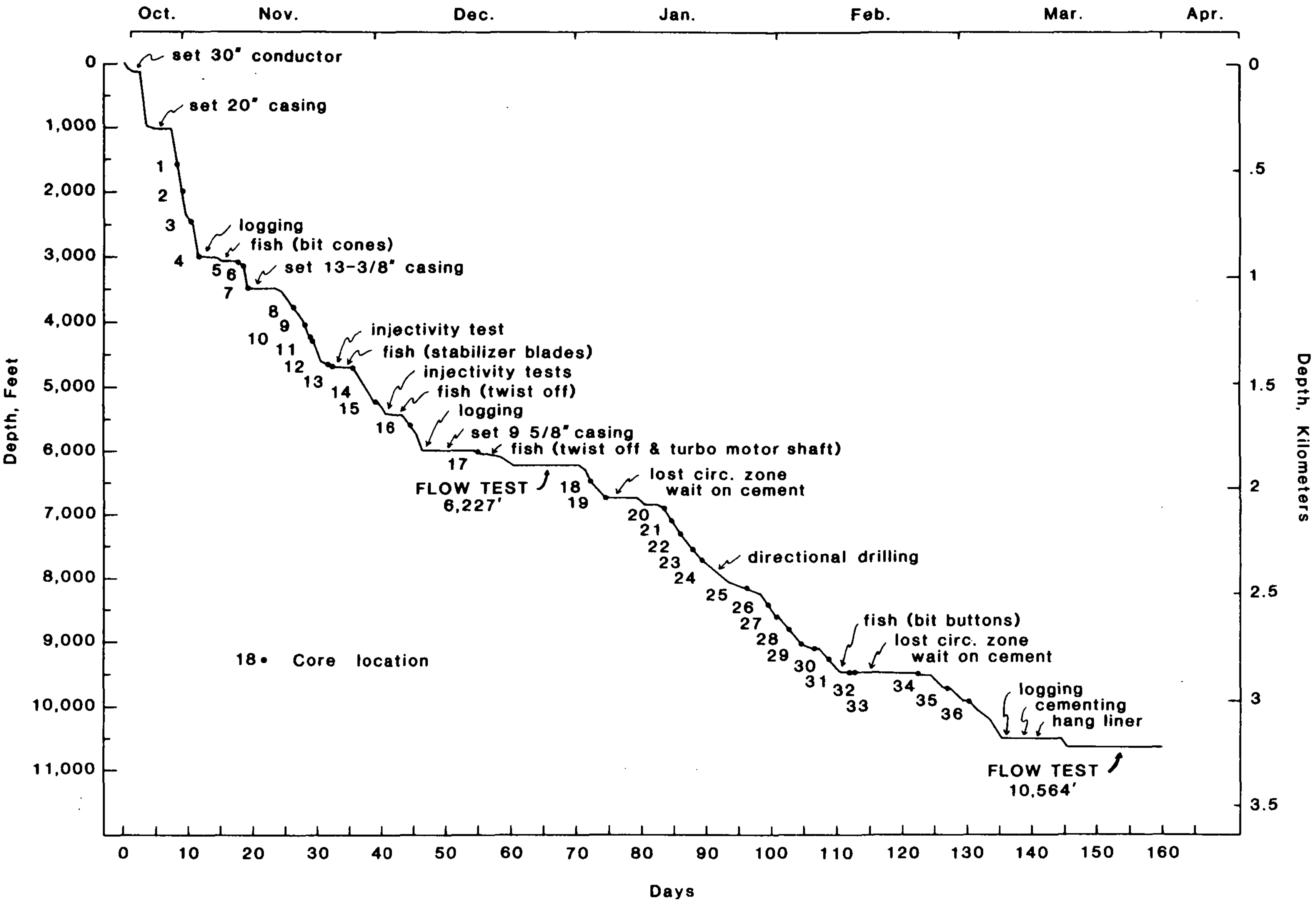


Figure 3.--Graph showing summary of activities during drilling of State 2-14 well plotted as a function of time versus depth.

Zones of Fluid Loss and Cementation

The major zones of fluid loss and gain encountered in the well are summarized in table 2. Above the 6,000-ft casing point, only one zone of fluid loss (depth of 3,107 to 3,200 ft) could have been considered a potential flow zone; however, fluid loss was minimal at 15 bbl/hr. At depths of 4,684 and 5,418 ft, injection tests were performed. These tests indicated a minimal potential for production, so no flow test was attempted above the 6,000-ft casing point. Below the 9 5/8-in. diameter casing (see casing diagram, fig. 2) the major zones of fluid loss may be viewed in the context of a temperature log obtained on February 15, 1986, shortly after circulation was lost at a depth of 9,473 ft (fig. 4). The zone associated with the first flow test was between the depths of 6,119 and 6,133 ft, where more than 6,000 bbl of brine were produced and reinjected into the well. The flow zone sealed after reinjection but had to be cemented off later. Four major loss zones occurred below this point at depths of 6,637 to 6,889 ft, 8,095 to 8,800 ft, 8,948 to 9,473 ft, and 10,475 to 10,564 ft (total depth).

In the first zone of fluid loss, complete loss of circulation occurred at a depth of 6,637 ft. Circulation was lost again at depths of 6,819 and 6,880 ft. Because the addition of additives to the drilling mud failed to restore circulation, the hole was cemented back to the 6,000-ft casing point and then drilled out. The cement did not effectively plug these zones and circulation was lost again. Two subsequent attempts to seal the zones, with cement were unsuccessful. Finally, cement was injected into the formation under pressure and circulation was temporarily restored.

Table 2.--Zones of fluid loss

[ft, feet; bbl/h, barrels per hour; bbl, barrels]

Date	Depth (ft)	Fluid-loss (bbl/h)	Remarks
11/11-12/85	3,107-3,200	-15	Only zone of fluid loss above 6,100 ft
12/22/85	6,119-6,133	-30 to -100	Mineralized zone with epidote fracture fill
12/28-30-85	6,227		Conducted first flow test
1/5-15/86	6,637-6,889	Total	6,637 ft: added additives to drilling mud 6,771 ft: set cement plug 6,850 ft: set second cement plug 6,889 ft: injected cement under pressure, regained circulation
1/16/86	7,030-7,090	-85	Added additives to drilling mud
1/27-29/86	8,095-8,160	Total	Well flowing at depth of 8,126 ft; added combination of drilling-mud additives and cement; regained circulation
2/1-3/86	8,580-8,800	Total	Well flowing at depth of 8,580 ft; plugged with combination of drilling-mud additives and cement
2/4-5/86	8,800-8,920	-100	Losing fluid, yet drilling with returns; well flowed while tripping
2/5/86	8,948-9,020	Total	Plugged with combination of drilling-mud additives and cement
2/7/86	9,098	Total	Plugged with combination of drilling-mud additives and cement

Table 2.--Zones of fluid loss--Continued

Date	Depth (ft)	Fluid-loss (bbl/h)	Remarks
2/10/86	9,254	Total	Well flowing, gained 400 bbl
2/11/86	9,450	Total	Plugged with combination of drilling-mud additives and cement
2/19-21/86	9,450		Cemented hole up to depth of 6,000 ft in four stages
3/9/86	10,450-10,460	-200	Plugged with combination of drilling-mud additives and cement by private contractor
3/9/86	10,475		Drilled without returns to total depth of 10,564 ft
3/17/86	10,564		Conducted second flow test

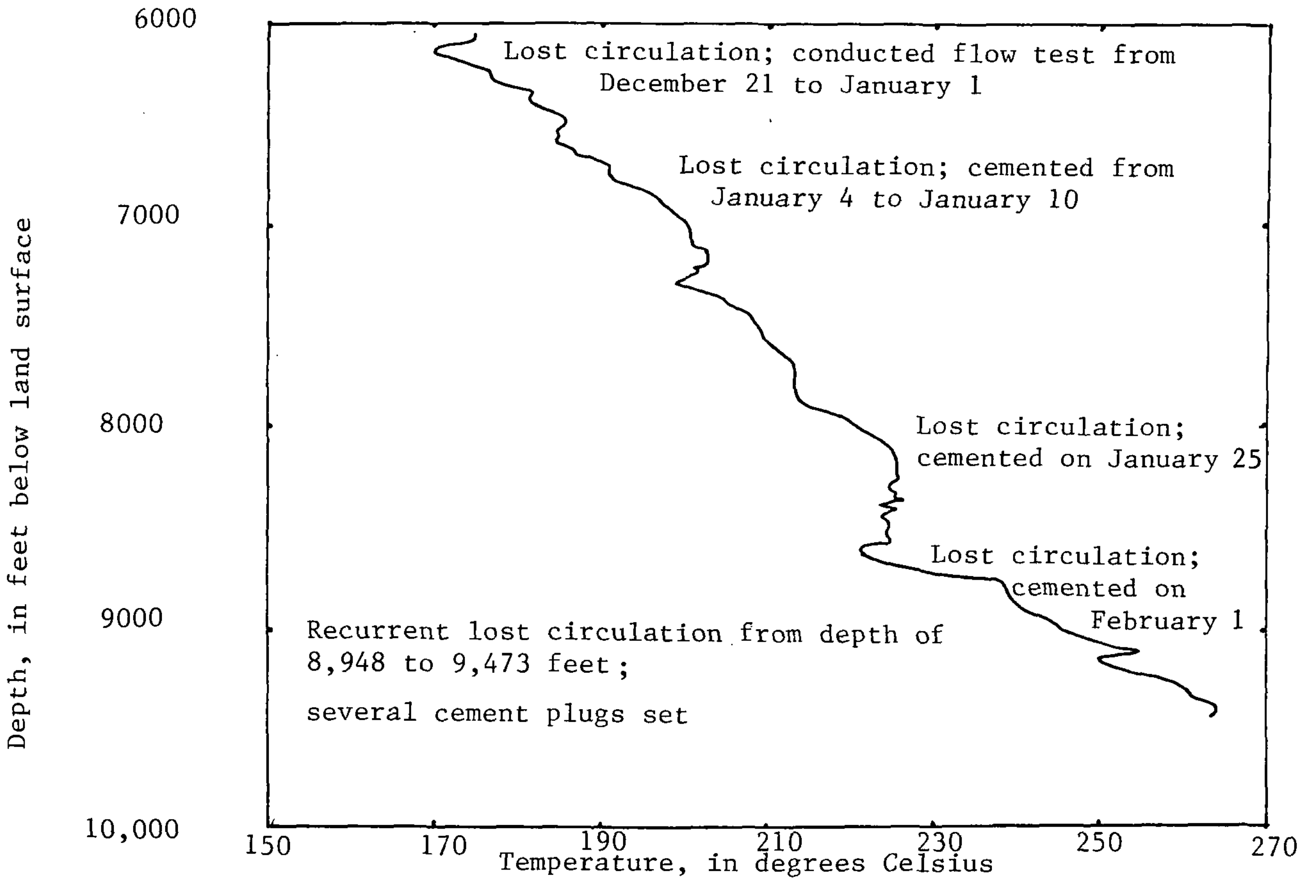


Figure 4.--U.S. Geological Survey temperature log, February 15, 1986.

At the second zone of fluid loss, from 8,095 to 8,800 ft, circulation was lost repeatedly and the well showed signs of flowing at depths of 8,126 and 8,580 ft. A plug consisting of a combination of drilling-mud additives and cement temporarily held, with 100-percent returns. However, it was not long before circulation was lost again. At the third zone of fluid loss, total loss of circulation occurred at depths of 8,948, 9,098, 9,450, and 9,473 ft. Numerous plugs consisting of a combination of drilling-mud additives and cement were set to regain circulation, but all attempts failed. The temperature log of February 15, 1986, indicated that several zones were indeed open up to the casing shoe. Cement was injected into those zones in four stages up to the 6,000-ft casing shoe and circulation was restored.

Finally, at a depth of 10,475 ft, total loss of circulation occurred that was not controlled by additives in the drilling mud. The total depth of 10,564 ft was reached while drilling without returns.

EQUIPMENT

R. E. Hodges, R. H. Morin, G. A. Pawloski, R. C. Carlson, A. G. Duba, and R. L. Newmark

Geophysical-Logging Equipment (U.S. Geological Survey)

All logging tools used by the U.S. Geological Survey at the well site were designed to operate at 260°C for 8 hours. Tools with active electronics sections were packaged in insulating dewar flasks. Other components were either specially modified for high temperature, or they were selected because of their superior temperature ratings. All tools, with the exception of the acoustic-televiewer and acoustic-velocity probes, functioned at borehole temperatures as high as 278°C. The caliper tool failed at temperatures in the range of 270°C to 300°C. The exact temperature is unknown, because the tool failed to respond after a run in which the maximum temperature was about 300°C. The televiewer and acoustic tools were only tested to 260°C, because of poor hole conditions. A list of pertinent logging tools and associated equipment follows, with a brief description of each tool and descriptions of field modifications, where appropriate.

Temperature

The temperature tool is 2 in. in diameter with a 500-ohm, platinum RTD (Resistive Thermal Device). Because this tool does not contain active electronics, it can be exposed to much higher temperatures than other tools. Limiting factors are pressure seals and cable strength.

Temperature-Caliper

The temperature-caliper tool also is 2 in. in diameter with a 500-ohm, platinum, RTD temperature sensor and a three-arm, single-action caliper. Single action refers to the spring-loaded mechanism that produces a single trace, giving the average of the deflections of the three caliper arms. Because of hole conditions, such as diameter, deviation, and mud weight, it was necessary to build a sleeve to slide over the tool to add additional weight and to ensure centralization.

Natural Gamma

The natural-gamma tool is a 2-in. diameter probe that contains a 3/4 X 2-in. long sodium iodide crystal. Because of the small size of the crystal and its location behind a heavy pressure housing and dewar flask, tool sensitivity is minimal. To obtain a quality log, a relatively slow logging speed of 15 ft/min and a long time constant were required.

Gamma Spectral

The gamma-spectral tool is a 3-in. diameter probe that contains a 1 X 4-in long sodium iodide crystal. Because of the larger crystal size, this is the preferable tool to use for gamma logs. It was used exclusively until the last run (March 29, 1986), when it failed to operate properly.

Epithermal Neutron

The epithermal-neutron tool is a 2-in. diameter probe that contains a 3/4 X 2 in. long lithium iodide crystal in conjunction with a 3-curie neutron source consisting of americium-232 and beryllium. No problems occurred in using this tool.

Acoustic Televiewers

The two acoustic televiewers are 4-in. diameter probes that normally have a 1.3-MHz (megahertz) crystal transducer. Because of the heavy mud used during drilling and other hole conditions, the frequency in one of the probes was changed to 600 kHz (kilohertz). This frequency provided greater penetrating capability; however, because of hole rugosity caused from repeated trips in and out of the hole in attempts to control lost circulation, redrill cement plugs, and emplace lost circulaton material, the resulting pictures are of poor quality.

Acoustic Velocity

The acoustic-velocity tool is a 4-in. diameter probe that consists of three receivers located 4, 6, and 7 ft uphole from a single, 15-KHz transmitter. The three receivers are selected in pairs to obtain 1-, 2-, or 3-ft spacings. This tool is used to obtain an acoustic-traveltime log and acoustic full-waveform recordings. Borehole centralization is critical for acoustic logs and the tool is centralized by means of four sets of rubber "fingers" perpendicular to the probe body. Difficult, irregular hole conditions and repeated attempts to get the tool below a depth of 7,000 ft resulted in the shearing off of the rubber fingers. The tool's centralizers could be redesigned to incorporate metal bowsprings with a hard rubber coating to minimize damage and noise that is inherent to this type of centralizer.

Cablehead

The cablehead is a modified 1 1/2-in. diameter Gearhart head. Modifications include: (1) Addition of 3 in. to its length in order to enable it to accept a larger volume of Krytox oil; (2) post-curing the seven-conductor bulkhead connector to obtain a higher temperature rating; and (3) manufacturing the head from MP35N instead of steel or stainless steel. MP35N is a corrosion-resistant material composed of 35 percent nickel, 35 percent cobalt, 20 percent chrome, and 10 percent molybdenum. Because of some concern for the integrity of this cable head and its ability to adequately support the weight of a tool and its associated drag, an actual pull-out test was conducted. Two tension-failure tests were performed. The first test used the same mechanical equipment and setup that was used during all logging at the State 2-14 well. The second test was conducted after remaking the mechanical part of the head. Both tests were run using a 10,000-lb dynamometer as the primary measurement and calibration device. For the first test, the measured pull-out force was 3,110 lb; for the second test, the measured pull-out force was 3,700 lb. Both test results are within the acceptable range for mechanical failure at the cable head.

Seven-Conductor Cable

The 15,000-ft geothermal cable was a special interagency purchase by the U.S. Department of Energy and the U.S. Geological Survey for this project. A cross section of the cable is shown in figure 5. All design specfications were for high temperature and corrosive environments. The conductors are 20-gage with a 27 percent nickel coating and Teflon-type insulation. Armoring is MP35N, with an actual cable break strength of 17,950 lb. It has a maximum temperature rating of 315°C.

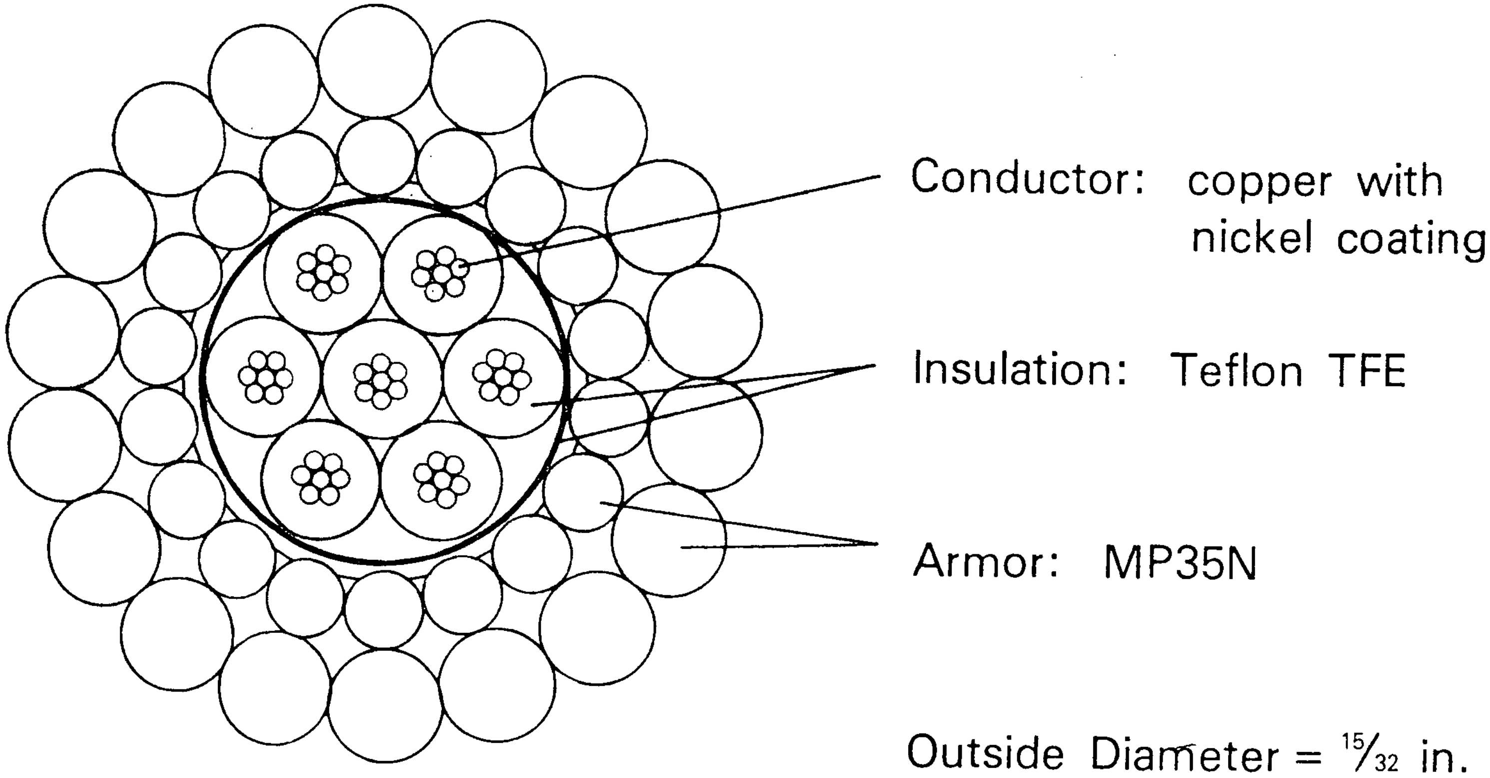


Figure 5.--Diagram of geothermal-cable cross section.

Data Management Equipment (Lawrence Livermore National Laboratory)

To provide capability for well-log analysis and data for decision making at the well site, Lawrence Livermore National Laboratory installed an IBM computer system, the Terra Station, which is based on a personal computer. The personal computer also was used for word processing and spread-sheet activities at the well site. The Terra Station consists of three major modes: BLISTR, TLOG, and TS. BLISTR reads industry-standard digital magnetic tapes and produces disk files readable by other programs. TLOG compiles the logs for a given well; it can provide borehole corrections, cross plots, and other standard log-analysis procedures, along with the ability to plot the data at any chosen scale, with any depth shifts. TS combines logs from many wells in an area, while keeping track of the depth and type of lithology on logs from each well. TS also provides the capability for correlation from well to well, and automatic drawing of cross sections through holes chosen from a map displayed on the color monitor or contour maps and perspective drawings of chosen lithologic surfaces or bed thicknesses.

Before the drilling of State 2-14 well, the Continental Scientific Drilling Program's Data Management Group at Lawrence Livermore National Laboratory (1) Generated a map of the northeastern Salton Sea area, with shoreline, rivers, section corners, and wells; (2) located and digitized available geophysical logs from nearby wells; (3) and entered lithologic data from the available logs and literature. These data could then be used for comparison with new data from State 2-14 well as they became available. Most new logging data were read directly from field-generated magnetic tapes or, in the case of the commercial logs, from tapes copied from those field tapes. Some data were entered manually, including the lithologic data obtained from mud-drilling samples and some temperature data when the logging digitizer was not functioning.

GEOPHYSICAL-LOGGING CHRONOLOGY

F. L. Paillet and R. H. Morin

Both commercial (Schlumberger) and U.S. Geological Survey geophysical logs were obtained during the drilling of State 2-14 well. The majority of the commercial logs were obtained during three visits to the site; only one log was obtained below a depth of 6,000 ft. Field copies of all commercial logs were retained at the site; these are listed in tables 3-6. The Survey logging effort consisted of four primary visits along with numerous ancillary visits that were scheduled for temperature logging and for specialty logging that needed to be coordinated with U.S. Geological Survey equipment; a chronological list of Survey logs is presented in table 7. Most of these logs were digitally recorded at the well site and are illustrated alongside complementary commercial logs later in this report. Most plots of logs presented in this report were generated by Lawrence Livermore National Laboratory's data-processing software. It should be noted that several additional temperature logs were run as part of the drilling program under less-than-ideal conditions. These logs were not digitized and are not listed in table 7.

An interesting phenomenon occurred in the test well at depths between 3,000 and 6,000 ft. Repeat caliper logs indicated that hole geometry was clearly changing with time during this logging period. The problem first became apparent when the relatively large (3-in. diameter) acoustic tool hung up as it was lowered below a depth of 5,500 ft. Subsequently, at several other depths, substantial cable tension was required to free the tool and pull it up the hole. After obtaining this sonic log, the caliper tool (3-in. diameter) and even the smaller temperature probe (2-in. diameter) could no longer be lowered to total depth. It was evident that the tools were consistently hanging up at certain depths.

Table 3.--Chronology of commercial (Schlumberger) logs, run 1

[in., inch; ft, feet; s, second; R_m , resistivity of drilling mud; h, hour; R_{mc} , resistivity of mud cake; R_{mf}, resistivity of mud filtrate; BHT, bottom hole temperature; lb/gal, pounds per gallon; ohm-m, ohm-meter; bbl, barrel]

Type of log	Figure number	Date logged	Time In (24-h time)	Time Out (24-h time)	Depth range (ft)
Type of service: Dual induction; side-focus log (2.5-in. standoff used)					
Deep induction	12,13	11-04-85	1740	1847	1,032-3,005
Spontaneous potential	14	do.	do.	do.	Do.
Natural gamma	13	do.	do.	do.	Do.
Type of service: Compensated neutron-formation density					
Nuclear porosity	15	11-04-85	1740	1847	1,032-3,005
Bulk density	23	do.	do.	do.	Do.
Compensation	23	do.	do.	do.	Do.
Natural gamma	13	do.	do.	do.	Do.
Type of service: Four-arm caliper					
Caliper	15	11-05-85	do.	do.	1,032-3,008
Type of service: Borehole compensated sonic					
Interval transit time	12	11-05-85	0003	0144	1,032-3,008

Casing diameter at 1,032 ft (casing logger) = 20 in.

Bit size at 3,000 ft = 17.5 in.

Bit size at 3,030 ft = 9.875 in.

Type of hole fluid = Gel/chemical

Fluid density = 9.4 lb/gal

Fluid viscosity = 42.0 s

Fluid pH = 10.2

Fluid loss = 14.2 bbl

R_m at measurement temperature = 0.764 ohm-m at 46.0°C

R_{mf} at measurement temperature = 0.657 ohm-m at 27.0°C

R_{mc} at measurement temperature = 1.080 ohm-m at 27.0°C

R_m at BHT temperature = 0.512 ohm-m at 79.5°C

Table 4.--Chronology of commercial (Schlumberger) logs, run 2

[h, hour; ft, feet; in., inch; ohm-m, ohm-meter; s, second; lb/gal, pounds per gallon; R_m , resistivity of drilling mud; R_{mc} , resistivity of mud cake; R_{mf} , resistivity of mud filtrate; BHT, bottom hole temperature]

Type of log	Figure number	Date logged	Time In (24-h time)	Time Out (24-h time)	Depth range (ft)
Type of Service: Dual induction; side-focus log (9.5-in. centralizing fins used)					
Deep induction	12,13,16,17	11-13-85	1120	1141	2,900-3,519
Spontaneous potential	14,18	do.	do.	do.	Do.
Natural gamma	13,17	do.	do.	do.	Do.
Type of Service: Compensated neutron-formation density					
Nuclear porosity	15,19	11-13-85	1359	1419	2,900-3,493
Bulk density	23	do.	do.	do.	Do.
Compensation	23	do.	do.	do.	Do.
Type of Service: Four-arm caliper					
Caliper	15,19	11-13-85	2213	2252	1,032-3,524
Type of Service: Borehole compensated sonic					
Interval transit time	12,16	11-13-85	1834	1904	2,900-3,525

Casing diameter at 1,032 ft. (casing logger) = 20 in.

Bit size at 3,000 ft = 17.5 in.

Type hole fluid = Pro-Temp

Fluid density = 9.3 lb/gal

Fluid viscosity = 40.0 s

Fluid loss = 12.6 bbl

Fluid pH = 10.6

R_m at measurement temperature = 1.110 ohm-m at 33.5°C

R_{mf} at measurement temperature = 0.665 ohm-m at 36.0°C

R_{mc} at measurement temperature = 1.070 ohm-m at 36.0°C

R_m at BHT temperature = 0.525 ohm-m at 94.5°C

Table 5.--Chronology of commercial (Schlumberger) logs, run 3

[h, hour; ft, feet; in., inch; lb/gal, pound per gallon; ohm-m, ohm-meter R_{mc}, resistivity of mud cake; R_{mf}, resistivity of mud filtrate; R_m, resistivity of drilling mud; BHT, bottom hole temperature]

Type of log	Figure number	Date logged	Time In (24-h time)	Time Out (24-h time)	Depth range, ft
Type of service: Dual-induction; side-focus log (2.5-in. standoff used)					
Deep induction	16,17	12-09-85	0740	0858	3,520-5,988
Spontaneous potential	18	do.	do.	do.	Do.
Natural gamma	17	do.	do.	do.	Do.
Type of service: Compensated neutron-formation density					
Nuclear porosity	19	12-09-85	0740	0858	3,520-5,980
Bulk density	23	do.	do.	do.	Do.
Compensation	23	do.	do.	do.	Do.
Type of service: Four-arm caliper					
Caliper	19	12-09-85	1112	1146	3,520-5,988
Type of Service: Borehole compensated sonic					
Interval transit time	16	12-09-85	1741	1843	3,520-5,988

Casing diameter at 3,520 feet (casing logger) = 13.375 in.

Fluid density = 9.1 lb/gal

Fluid viscosity = 34.0 s

Bit size = 12.25 in.

Fluid pH = 9.9

Type of hole fluid = Pro-Temp/Thermtrol III

Fluid loss = 12.4 bbl

R_m at measurement temperature = 0.658 ohm-m at 30.5°C

R_{mf} at measurement temperature = 0.916 ohm-m at 8.0°C

R_{mc} at measurement temperature = 1.690 ohm-m at 14.0°C

R_m at BHT = 0.206 ohm-m at 144.5°C

Table 6.--Chronology of commercial (Schlumberger) logs, run 4

[ft, feet; h, hour; in., inch; lb/gal, pounds per gallon; R_m, resistivity of drilling mud; R_{mc}, resistivity of mud cake; R_{mf}, resistivity of mud filtrate; BHT, bottom hole temperature; ohm-m, ohm-meter; s, second]

Type of log	Figure number	Date logged	Time In (24-h time)	Time Out (24-h time)	Depth range (ft)
Type of Service: Dual induction; side-focus log (1.5 in. standoff used)					
Deep induction	20	3-10-86	1408	1433	6,020-8,806
Spontaneous potential	21	do.	do.	do.	Do.

Casing diameter at 6,020 ft. (casing logger) = 9.63 in.

Bit size = 8.5 in.

Type of hole fluid = Pro-Temp/Thermogel

Fluid density = 8.75 lb/gal

Fluid viscosity = 44.0 s

Fluid pH = 11.7

R_m at measurement temperature = 1.140 ohm-m at 20.0°C

R_{mf} at measurement temperature = 0.980 ohm-m at 21.5°C

R_{mc} at measurement temperature = 1.480 ohm-m at 23.0°C

R_m at BHT temperature = 0.173 ohm-m at 252.0°C

Table 7.--Chronology of U.S. Geological Survey logs

[ft, feet; s, second; µs, microsecond]

Type of log	Date	Time In	Time Out	Comments	Figure
Interval logged: 1,032 ft to 3,000 ft					
Temperature	11-5-85	0900	1300	Before circulation	---
Natural gamma	11-5-85	2100	2300	2-s time constant	---
Temperature	11-6-85	0400	1000	After circulation	14
Caliper	11-6-85	0400	1000	Three-arm	---
Televiewer	11-6-85	1100	1300	No useful logs	---
Temperature	11-6-85	1300	1700	Many stationary readings	---
Caliper	11-6-85	1300	1700	---	15
Acoustic differential time	11-6-85	1800	2100	3-ft spacing	12
Acoustic differential time	11-6-85	2100	2300	2-ft spacing	---
Full waveform	11-7-85	0100	0300	2-µs sampling	---
Temperature	11-7-85	0400	0600	Stationary readings of temperature versus time	---
Natural gamma	11-7-85	0800	1130	---	13
Gamma spectral	11-7-85	0800	1130	Spectra at five depths	---
Temperature	11-7-85	1230	1430	Stationary readings at bottom	---
Temperature	12-4-85	2400	1400	Stationary readings at bottom	8

Table 7.--Chronology of U.S. Geological Survey logs-- Continued

Type of Log	Date	Time in	Time out	Comments	Figure
Interval logged: 3,515 ft to 6,000 ft					
Temperature	12-9-85	2115	0300	Stationary readings at bottom	---
Temperature	12-10-85	1400	1800	---	18
Caliper	12-10-85	1800	2000	---	19
Televiewer	12-10-85	2000	2000	No pictures below casing	---
Natural gamma	12-10-85	2200	0200	---	17
Gamma spectral	12-11-85	0200	0400	Analyzer failed after obtaining one spectrum	---
Single-point resistance	12-11-85	---	---	Burned up tool	---
Acoustic differential time	12-11-85	0500	1100	Poor analog record due to mud density	16
Full waveform 1	12-11-85	1100	1400	Total waveform	---
Full waveform 2	12-11-85	1400	1700	Magnified first arrival	---
Caliper	12-11-85	1700	1900	Tool hangs near 4700 ft	---
Temperature	12-11-85	1900	2400	Tool hangs near 5,100 ft	---
Caliper	12-12-85	1200	1500	---	---
Neutron	12-12-85	1500	1830	1-s time constant	19
Temperature	12-23-85	---	---	---	8
Temperature	12-29-85	---	---	---	8

Table 7.-- Chronology of U.S. Geological Survey logs--Continued

Type of Log	Date	Time in	Time out	Comments	Figure
		Interval logged:	6,000 to 10,000 ft		
Temperature	2-15-86	---	---	---	4,8
Temperature	3-12-86	1100	1400	Tool hangs at 8,600 ft	---
Televiewer	3-12-86	1600	2300	Logged from 6,600 ft up to casing	---
Full waveform	3-13-86	1800	0100	Logged from 7,000 ft up to casing	---
Natural gamma	3-29-86	1200	1700	Used tool with smaller detector, 5-s time constant	20
Neutron	3-29-86	2000	2400	---	20
		Interval logged:	total depth		
Temperature	3-8-86	2300	0400	Prior to flow test	8,21
Temperature	3-27-86	---	---	After first phase of re-injection	8
Temperature	3-31-86	---	---	---	---
Temperature	4-7-86	---	---	---	---

A composite of caliper and electric logs obtained during this time is depicted alongside the lithology record in figure 6. The second caliper log, obtained 26 hours after well circulation, shows the development of significant hole constrictions at several depths of less than 4,600 ft, where the caliper tool had originally hung up. Inspection of figure 6 indicates that the constrictions correlate with sand indicators on the spontaneous-potential log and also with sandstone intervals as defined from cuttings. It is hypothesized that hot pore fluid circulating through the more permeable sandstone intervals promoted additional heating of the wellbore adjacent to these zones and coagulated the drilling mud at specific depths. Coincident temperature logs tend to verify this explanation, because they indicate anomalously higher temperatures at depths that correspond with the appearance of sandstone (fig. 7). Although the higher temperature gradients can be partially attributed to the relatively low thermal conductivity of a porous sandstone, additional heating of the wellbore in the vicinity of the sandstone beds appears to have been the primary cause of these temperature-log signatures. It should be noted that both the first Geological Survey caliper log and the previous commercial caliper log indicate hole diameters 1 in. or more less than the bit diameter below a depth of 5,600 ft.

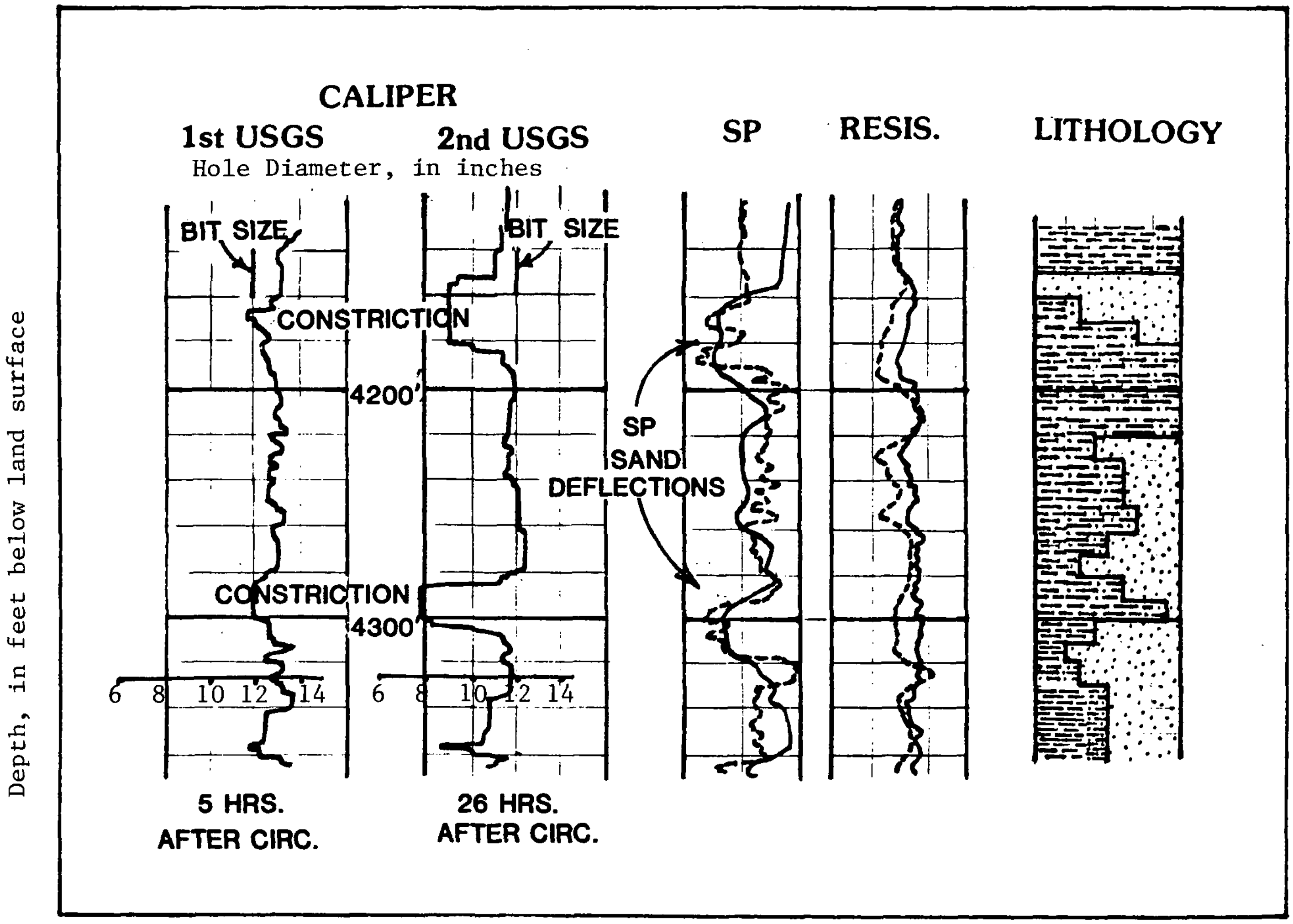


Figure 6.--Logs showing example of correlation of hole-diameter constrictions indicated on caliper logs with deflections.

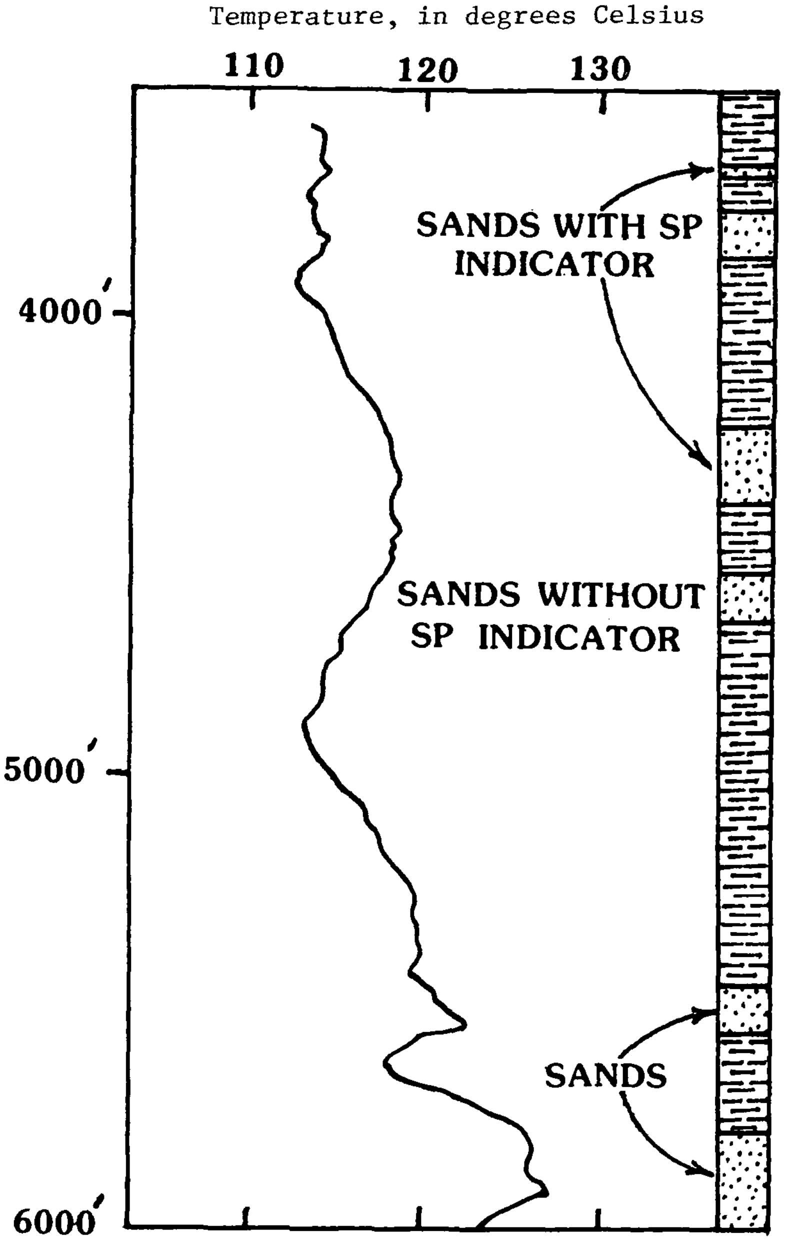


Figure 7.--Graph showing correlation of temperature log with lithologic log immediately after circulation showing association of temperature peaks with sandstone beds.

One more observation should be made here as a point of discussion before proceeding to examine the geophysical logs in greater detail. The generally poor condition of the borehole below a depth of 6,000 ft significantly hampered the success of the open-hole logging efforts in this lower section. Numerous lost-circulation zones and cement plugs, as well as repeated trips in and out of the hole, damaged the hole and caused severe enlargement. The condition and integrity of the borehole is of primary importance in determining the success or failure of those logs that require a fairly competent water-rock interface for accurate measurements. Correspondingly, the quality of the acoustic-televiewer and acoustic-waveform logs was substantially degraded. Response of the acoustic-waveform tool, for example, appeared acceptable while in casing, but deteriorated substantially below the bottom of the casing (depths below 6,000 ft) in the upper production zone with its associated washouts. More success was achieved in this bottom section with logs that are not as critically dependent on borehole condition, such as temperature, natural gamma, and neutron logs.

GEOPHYSICAL LOGS

F. L. Paillet, G. A. Pawloski, R. H. Morin, R. C. Carlson, L. C. Robison, S. S. Priest and J. H. Sass

The geophysical well logs obtained in the State 2-14 well are given in figures 12-23; these are presented in the "Supplemental Data" section at the end of this report. The data are divided into intervals corresponding to 1,000 ft of borehole. This depth interval was selected to provide a reasonable length of log on a single (8 1/2-in. by 11-in.) manuscript sheet, while retaining much of the resolution given on the full-sized field copies.

The logs in figures 12-19 have been depth shifted so that the lithologic contacts indicated on the various logs correspond to the same depths. Such shifts commonly are made in the geophysical-logging industry, because different degrees of cable stretch and different depth-measurement systems can produce depth errors (Hearst and Nelson, 1985). The depth adjustments made in figures 12-19 were identified by correlating the commercial and U.S. Geological Survey logs for the various logging sessions. Because the depth scale on U.S. Geological Survey logs gave depths that closely agreed with the nominal bottom of casing for both the 1,000- to 3,000-ft and the 3,500- to 6,000-ft logging runs, all logs in figures 12-19 are shown with depths corrected to correspond to the depth scale on U.S. Geological Survey logs. This adjustment required the subtraction of 6 ft from all commercial logs for the 1,000- to 3,000-ft depth interval, and the subtraction of 10 ft from all commerical logs for the 3,000- to 6,000-ft depth interval.

A similar depth adjustment might be required for optimal correlation between commercial and U.S. Geological Survey logs for the depth interval between 6,000 ft and total depth, but no obvious correlation between lithologic contacts could be determined because so few logs were obtained in the lower part of the borehole. An extended delay occurred between obtaining the commercial and U.S. Geological Survey logs during the final part of the logging program while efforts were made to control lost circulation. Extensive damage to the borehole wall was incurred during these efforts. Changes in borehole conditions between the commercial and U.S. Geological Survey logs further complicated the correlation of the two data sets. Therefore, the logs in figures 20 and 21 are given without a depth shift. Commercial and U.S. Geological Survey logs were obtained for four depth ranges (tables 3-7). Where data overlap the same depth interval, data from the latest run displace the earlier record and are represented in the figure. For example, for the deep-induction log shown in figure 12, data from the first run were collected to a depth of 3,005 ft. This data set is only displayed to a depth of 2,900 ft, however, because data from the next run begin at a depth of 2,900 ft and take precedent in the figure from a depth of 2,900 to 3,000 ft.

Commercial and U.S. Geological Survey interval-transit time logs are compared to the commercial deep-induction log in figures 12 and 16 for the 1,000- to 3,000-ft and 3,000- to 6,000-ft depth intervals. The commercial interval-transit time logs have been smoothed using proprietary algorithms to suppress cycle skips (Guyod and Shane, 1969). The U.S. Geological Survey interval-transit time log has been recorded with cycle skips retained in the record, but the same general trend in the two logs is apparent. Various lithologic changes also appear to be reflected in the commercial deep-induction log, indicating that formation resistivity probably depends on both conduction through pore spaces and the electrical conductivity of matrix minerals. Although interval-transit time logs were not obtained at depths below 6,000 ft, variations in apparent lithology are indicated by the commercial deep-induction log in figure 20. At least some of these variations may be related to borehole enlargements and washout zones associated with intervals of lost circulation so that the lowermost interval of induction log probably cannot be considered a straight-forward indicator of lithology. Note that the U.S. Geological Survey interval-transit time log is missing for the depth intervals 3,000 to 3,500 ft and 5,600 to 6,000 ft (the tool could not be lowered below a depth of 5,600 ft during logging).

The geophysical logs commonly associated with lithologic interpretation (commercial and U.S. Geological Survey natural gamma logs, and commercial deep induction log) are compared to the lithologic log reconstructed from cuttings in figures 13 and 17 for the 1,000- to 3,000-ft and 3,000- to 6,000-ft depth intervals. Extensive corrections have been made to account for the time required for cuttings to be transported from the drill bit to the land surface where they were identified, so that variations in lithology indicated in the figures generally correspond with changes in rock properties indicated on the logs. Both the commercial and U.S. Geological Survey natural-gamma logs are quite similar. However, the natural-gamma logs do not show a simple correlation with clay-mineral fraction indicated on the lithologic log even though the natural-gamma log commonly is used as the primary shale or clay-mineral-fraction indicator in the petroleum industry (Pirson, 1970). Variations in natural-gamma activity do appear to relate to changes in lithology, but the relation apparently is neither simple nor direct. The major and minor lithologic components are presented in figure 22.

U.S. Geological Survey temperature-gradient logs made within 6 hours of last circulation are given in figures 14 and 18 for the depth intervals 1,000 to 3,000 ft and 3,000 to 6,000 ft; they are compared to the commercial spontaneous-potential log and the lithologic log. Temperature data are presented in terms of temperature gradients, computed from data that were averaged for 20-ft intervals. Locally, large increases in the temperature gradient indicate depths at which heat is being transferred to the borehole fluid. These temperature-log anomalies can, in some instances, be related to points at which fluid is entering the borehole (Keys and MacCary, 1971), although interpretation of temperature logs is not always simple.

The commercial nuclear-porosity logs for the 1,000- to 3,000- ft and 3,000- to 6,000-ft depth intervals are compared to the U.S. Geological Survey epithermal-neutron log, where run, and to commercial and U.S. Geological Survey caliper logs in figures 15 and 19. Because only the U.S. Geological Survey natural-gamma and epithermal-neutron logs were run below a depth of 6,000 ft, these shallower intervals provide an important comparison between the U.S. Geological Survey data and the calibrated commercial logs. The commercial and U.S. Geological Survey logs apparently indicate the same features, but calibration of neutron count rate in units of sandstone porosity involves a relation between count rate and the logarithm of porosity. This nonlinear relation between count rate and porosity produces the observed suppression of minimal count-rate deflections in relating the U.S. Geological Survey log to the porosity units on the commercial log.

The U.S. Geological Survey epithermal-neutron and natural-gamma logs are compared with the commercial deep-induction log and the lithologic log for the depth interval 6,000 to 10,000 ft in figure 20. The U.S. Geological Survey temperature-gradient log for this same interval is compared with the commercial spontaneous-potential log and the lithologic log in figure 21. As in the case of figures 14 and 18, the log was run shortly after circulation ceased so that measured temperature gradients probably are quite different from the local geothermal gradients. Local anomalies in the differential temperature can correspond to points at which heated water is entering the borehole. The U.S. Geological Survey caliper tool failed during an attempt to log this lowermost part of the open hole; borehole-diameter information is, therefore, lacking for these depths. This is unfortunate because the possibility for large variations in borehole diameter, caused partly by severe washouts, could affect the interpretation of the logs in figures 20 and 21. Caution needs to be exercised in the quantitative interpretation of this geophysical data set.

A composite of U.S. Geological Survey temperature logs obtained at various times during drilling is given in figure 8. The variations in temperature profiles in the borehole fluid at different times during drilling operations reflect corresponding variations in the circulation history prior to measurement. Several attempts were made to seal off zones of lost circulation. The success of at least some of these efforts is indicated by the change in shape of measured temperature profiles before and after cementing. As pointed out earlier in this section, the location of anomalies in the temperature logs can indicate points at which fluids are entering or leaving the borehole. The log of March 27 is of particular interest in that it indicates that most of the cooled brine entered the formation behind the liner at a depth of about 8,600 ft.

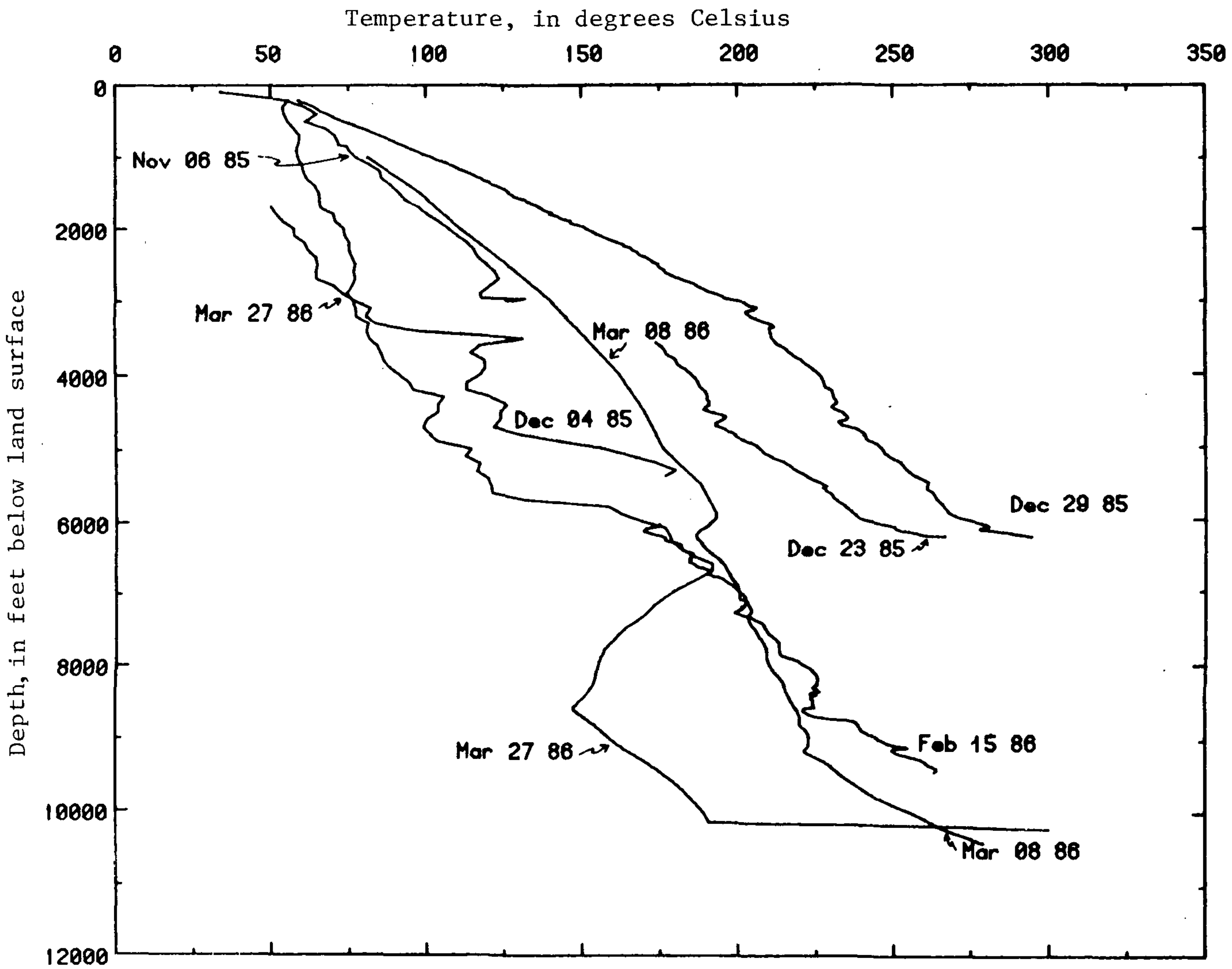


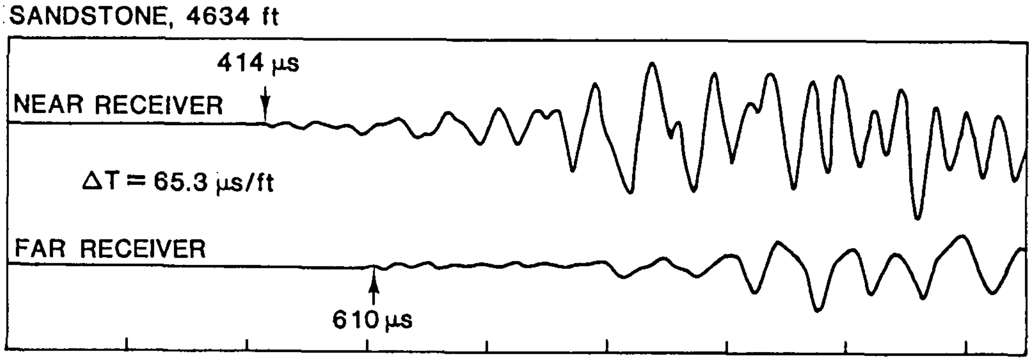
Figure 8.--Composite plot of temperature profiles at various stages during drilling.

ACOUSTIC-WAVEFORM LOGS

F.L. Paillet

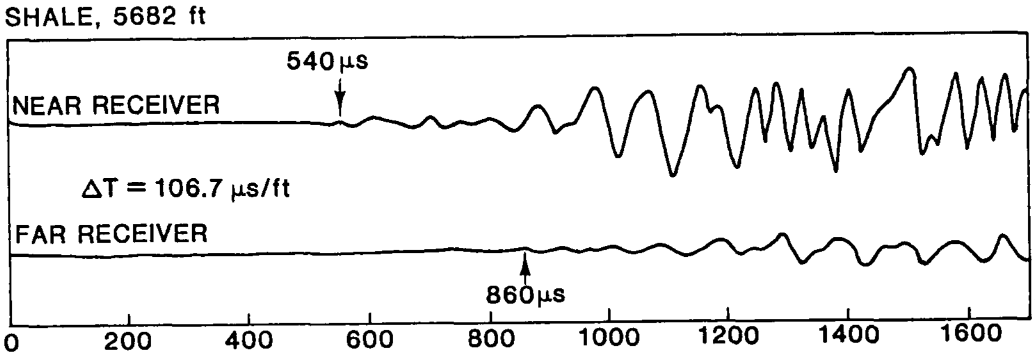
Acoustic-waveform logs were obtained in the State 2-14 well using the same logging system used to obtain the U.S. Geological Survey acoustic logs. Waveform data consist of the digitized pressure signals received at both receivers in the U.S. Geological Survey logging probe. Effective source frequencies were in the range of 12 to 16 kHz, and receivers were located 4 and 7 ft uphole from the source transducer. Waveforms were digitized using a 2μs sampling rate at 1-ft intervals. Waveforms were recorded for all of the uppermost depth intervals (1,000 to 6,000 ft), but only for the depth interval of 6,000 to 7,000 ft in the lowermost open hole. The limited data set for this lower interval may not be of good quality because of the extremely poor hole conditions, and because attempts to get the tool below a depth of 7,000 ft may have stripped the centralizers from the tool prior to logging.

Sample acoustic waveforms are illustrated in figure 9 for sandstone and in figure 10 for shale. These waveforms provide an example of waveform character in the two lithologies. The compressional velocity indicated on the sandstone waveform is consistent with transit times given on the acoustic logs. The compressional velocity indicated on the shale waveform is somewhat faster than that indicated by the acoustic logs. This discrepancy could be related to cycle skips in which the first energy arrivals at the far detector are too weak to trigger the acoustic logging system. Such cycle skips could be attributed to the greater intrinsic attenuation associated with the clay-mineral content in shale.



Time, in microseconds

Figure 9.--Diagram showing sample acoustic waveform for sandstone.



Time, in microseconds

Figure 10.--Diagram showing sample acoustic waveform for shale.

ACOUSTIC-TELEVIEWER LOGS

F.L. Paillet

Although the acoustic televiewer has been successful in characterizing fractures in geothermal boreholes (Keys and Sullivan, 1979), only limited use was made of televiewer logs at the State 2-14 well. Attempts to obtain televiewer logs in the borehole at depths above 6,000 ft were unsuccessful because the combination of large borehole diameter and heavy drilling mud attenuated the signals too severely. The televiewer with a low-frequency (600 kHz) source transducer did provide enough return signal strength at the highest gain settings at depths below 6,000 ft where the borehole diameter was about 9 in. However, hole conditions were so poor that no useful logs could be obtained in identified production zones. In those zones where the borehole wall was relatively unfractured, repeated trips of the drill string into a deviated well resulted in multiple grooves and gouges in the borehole wall that hampered fracture identification in relatively unfractured intervals where televiewer operation was effective.

Typical examples of televiewer logs from the State 2-14 well are given in figure 11. One of the highest-quality televiewer logs is illustrated in figure 11a. The darker patches in the figure may be gouges or enlargements in the borehole wall induced during or after drilling. The figure also shows some fine, irregular, near-vertical fractures. The strip of altered picture texture on the right side of the log is caused by electronic slip-ring noise in the system. Examples of somewhat poorer quality televiewer logs are given in figures 11b and c. The borehole gain had been increased to maximum level, accounting for the enhanced electronic noise evident in the figures. The logs also show gouges and steep-angle fracturing similar to those in figure 11a. A sample of televiewer log obtained in one of the zones of lost circulation is illustrated in figure 11d. All of the features in the figure are related to electronic noise in the system, because inspection of the actual televiewer output indicated that no measurable signal was being reflected from the borehole wall in this interval.

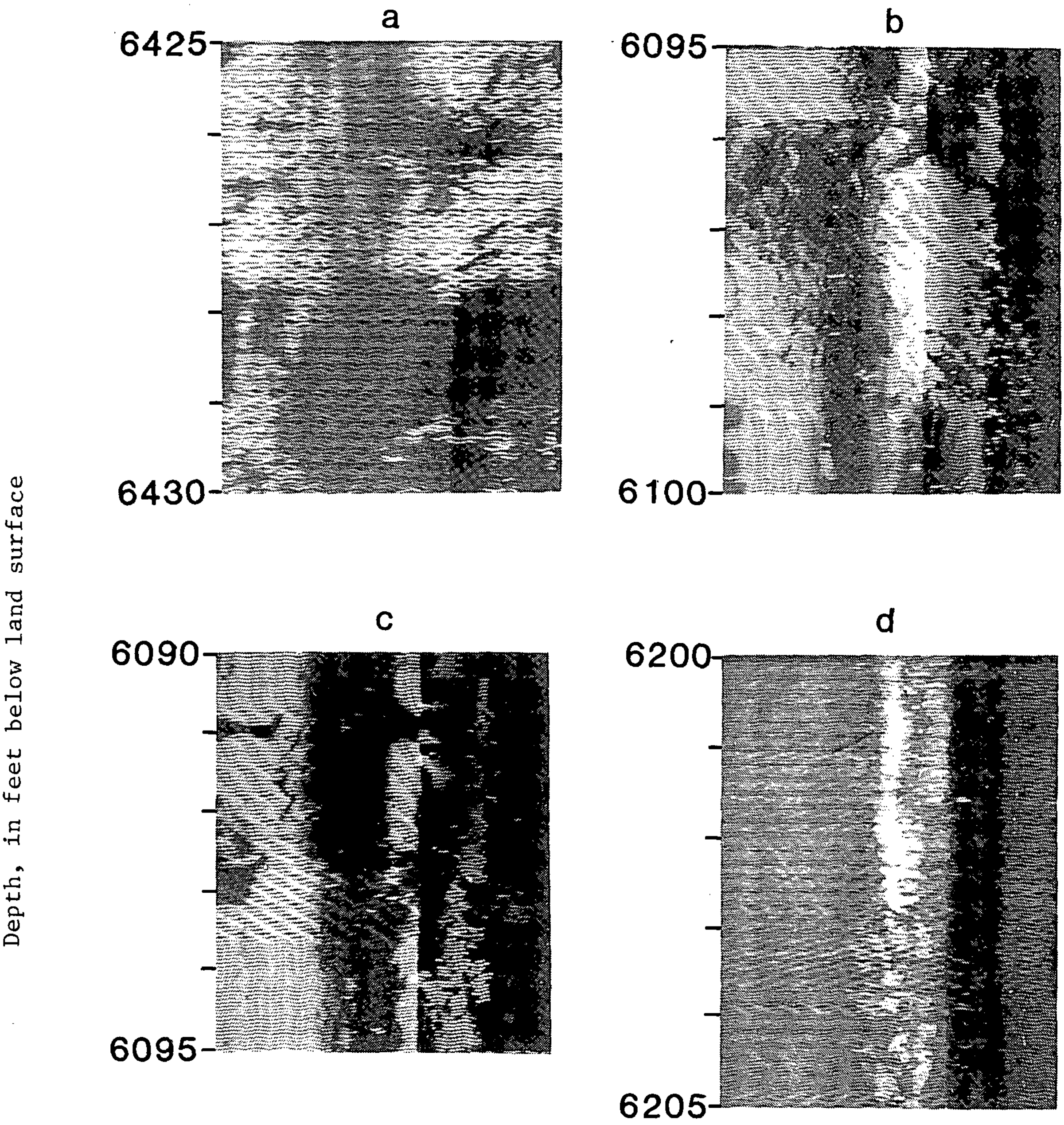


Figure 11.--Examples of televiewer logs from the State 2-14 well.

DENSITY INFORMATION

P.W. Kasameyer and J. R. Hearst

In geothermal systems in the Salton Trough, sediments have undergone substantial alteration and metamorphism. Several studies have used the increase of bulk density with depth to identify the degree of alteration, and to infer the maximum temperature to which the sediment was subjected (Seamount and Elders, 1981; Muramoto and Elders, 1984). Bulk-density information based on two surveys in the State 2-14 well is displayed in figure 23 (see Supplemental Data section).

The bulk-density trace is the output of a Schlumberger two-detector, formation-density log. The performance of this tool and the corrections required to determine the trace are discussed in Hearst and Nelson (1985). The electronic module in the logging truck compares the response of two detectors and computes a compensation trace that has been applied to the bulk-density trace. When compensation is large, or if the borehole well is so rough that the sonde is not parallel to the borehole surface, the value of the bulk density is suspect. The two traces have been shifted by 6 ft in the depth range from 1,000 to 3,000 ft, and by 10 ft in the depth range from 3,000 to 6,000 ft. This shift is based on correlations between commercial and U.S. Geological Survey logs, as described in the section discussing geophysical logs.

The solid line superimposed on the bulk-density trace is the gravimetric density, based on a survey conducted by EDCON, Inc., in the depth range from 3,370 to 5,700 ft at the direction of Lawrence Livermore National Laboratory. Because the gravimetric trace is obscured by the bulk-density trace, it has been duplicated with 1 g/cm^3(gram per cubic centimeter) subtracted. The survey began on March 30, 1986 at 2045 hours, after the well had been cooled by circulation for several hours, and was stopped at 1000 hours on March 31, when percolation in the well decreased meter stability. Attempts to make additional measurements were thwarted when a failure in the meter electronics occurred. A total of 46 readings was made at 36 different depth stations (table 8). The data were processed by EDCON, Inc., to correct for tidal forces and meter drift (based on repeated measurements at stations), and density was calculated using the theoretical free-air gradient formula given by Robbins (1981). Terrain corrections, slant-hole corrections, or depth shifts have not been applied. The layer densities shown on the track with bulk density were calculated using the theoretical free-air gradient. The mean difference between the gravimetric density and the well log is 0.02 g/cm^3. If the gravimetric density is matched to the zones where the bulk-density data are accurate, it provides an accurate representation of average density through the zones where the bulk-density data are inaccurate because of borehole roughness.

Table 8.--Drift-corrected, processed, borehole gravity meter data (not corrected for slant depth)

[ft, feet; mgal, milligals; g/cm^3, grams per cubic centimeter]

Depth interval (ft)	Slant delta Z	Deviation (degrees)	Delta G (mgal)	Density (g/cm^3)	80 percent confidence
5,700-5,660	40.00	0.0	1.001	2.627	0.007
5,660-5,610	50.00	.0	1.327	2.646	.007
5,610-5,520	90.00	.0	2.577	2.564	.005
5,520-5,450	70.00	.0	1.946	2.596	---
5,450-5,380	70.00	.0	1.944	2.598	---
5,380-5,290	90.00	.0	2.415	2.634	---
5,290-5,200	90.00	.0	2.454	2.617	.002
5,200-5,150	50.00	.0	1.349	2.628	.002
5,150-5,040	110.00	.0	3.184	2.551	.001
5,040-4,970	70.00	.0	2.032	2.548	---
4,970-4,880	90.00	.0	2.639	2.536	---
4,880-4,800	80.00	.0	2.317	2.550	---
4,800-4,730	70.00	.0	2.071	2.526	---
4,730-4,670	60.00	.0	1.737	2.551	---
4,670-4,580	90.00	.0	2.598	2.554	.000
4,580-4,520	60.00	.0	1.761	2.535	.000
4,520-4,460	60.00	.0	1.756	2.539	---
4,460-4,390	70.00	.0	2.000	2.565	---
4,390-4,330	60.00	.0	1.729	2.556	---
4,330-4,290	40.00	.0	1.194	2.515	.007
4,290-4,260	30.00	.0	.871	2.548	.005
4,260-4,220	40.00	.0	1.214	2.496	.003
4,220-4,165	55.00	.0	1.735	2.448	---

Table 8.--Drift-corrected, processed, borehole gravity meter data (not corrected for slant depth)--Continued

Depth interval (ft)	Slant delta Z	Deviation (degrees)	Delta G (mgal)	Density (g/cm^3)	80 percent confidence
4,165-4,090	75.00	0.0	2.144	2.565	---
4,090-4,030	60.00	.0	1.676	2.590	---
4,030-3,980	50.00	.0	1.458	2.543	---
3,980-3,885	95.00	.0	2.758	2.547	---
3,885-3,845	40.00	.0	1.194	2.515	---
3,845-3,780	65.00	.0	2.032	2.460	---
3,780-3,720	60.00	.0	1.796	2.512	---
3,720-3,660	60.00	.0	1.913	2.432	---
3,660-3,610	50.00	.0	1.554	2.467	0.002
3,610-3,550	60.00	.0	1.942	2.417	.001
3,550-3,470	80.00	.0	2.485	2.468	---
3,470-3,370	100.00	.0	3.086	2.476	---

The borehole gravity measurements can be used to detect lateral changes in density by calculating the gravimetric anomaly, or the difference between the borehole gravity and the bulk-density log. Because measurements stopped several thousand feet below the surface, the local free-air gradient was measured at the site. Values of gravity were measured at two elevations on the drill rig: (1) On the drill-rig floor 26.6 ft above the ground surface, and (2) on a major I-beam 79.9 ft above the drill-rig floor (table 9). The measured free-air gradient was 0.095337 mgal/ft (milligals per foot), which was 0.00123 mgal/ft greater than the theoretical value used to calculate the gravimetric density. Using the measured free-air gradient increases the calculated gravimetric density by almost 0.05 gm/cm^3. The borehole gravity anomaly, the difference between the gravimetric density and the average log density between measuring points, is the left-most curve in figure 23. The average log density was calculated after removing all points with a compensation greater than 0.07. The gravity-anomaly curve is dashed at depths where the log uncertainty is high.

Table 9.--Tide corrected gravimeter data determined on April 8, 1986, by using a U.S. Geological Survey G177 meter

[h, hour; ft, feet; mgal, milligals; mgal/ft, milligals per foot]

Time (24-h time)	Depth (ft)	Counter	Tide (mgal)	Tide correction counter	Gravity (mgal)
0700	26.60	3,207.115	-0.059	3,207.059	3,357.643
0722	106.50	3,199.834	-.045	3,199.791	3,350.035
0733	26.60	3,207.105	-.037	3,207.070	3,357.655
0743	106.50	3,199.814	-.030	3,199.786	3,350.029
0754	26.60	3,207.087	-.021	3,207.067	3,357.651
0805	106.50	3,199.798	-.012	3,199.786	3,350.029
0815	26.60	3,207.073	-.004	3,207.069	3,357.654
0823	106.50	3,199.792	.002	3,199.794	3,350.037
0832	26.60	3,207.065	.009	3,207.074	3,357.659

Average value at 26.6 ft = 3,357.652 mgal

Average value at 106.5 ft = 3,350.033 mgal

Average gravity = 7.619 mgal; Average depth = 79.92 ft

Free-air Gradient = 7.619 mgal/79.92 ft

Free-air Gradient = 0.095337 mgal/ft

CONCLUDING REMARKS

F. L. Paillet

This report presents the geophysical well log data obtained during and immediately after drilling of the State 2-14 well in the Imperial Valley of southern California. Geophysical logs provide a unique resource for researchers attempting to analyze the data and the core samples obtained during and after the drilling of the well. Perhaps the most important aspect of the well-log data set is the continuity of the log; the continuous depth scale provides the framework within which to address questions about the location of discontinuous core sections, and the properties of rocks in the intervals that were not cored. However, the usual problems associated with a large geotechnical project have affected the quality of the geophysical well logs. The high temperatures and the rigid drilling schedule imposed by the usual constraints on such a large, multidisciplinary project resulted in tool malfunction and deletion of time-consuming measurements from the program; therefore, the data set is incomplete. Borehole conditions and hole deterioration after drilling also seriously affected the quality of log data. The intent of this report is to present the geophysical log data that were collected, along with a summary of the numerous factors that may be relevant to the interpretation of those logs. Gaps in the data are indicated with the reasons for the occurrence of those gaps where they occur. Additional information will be available from ongoing and future studies after geophysical-well-log analysis is completed. In the meantime, this report provides a relatively complete listing of the log data that are available for analysis, along with a summary of conditions during and after drilling that affected the quality of that data set.

SUPPLEMENTAL DATA

This section contains figures 12-23. These figures are a compilation of the geophysical logs collected from the State 2-14 well.

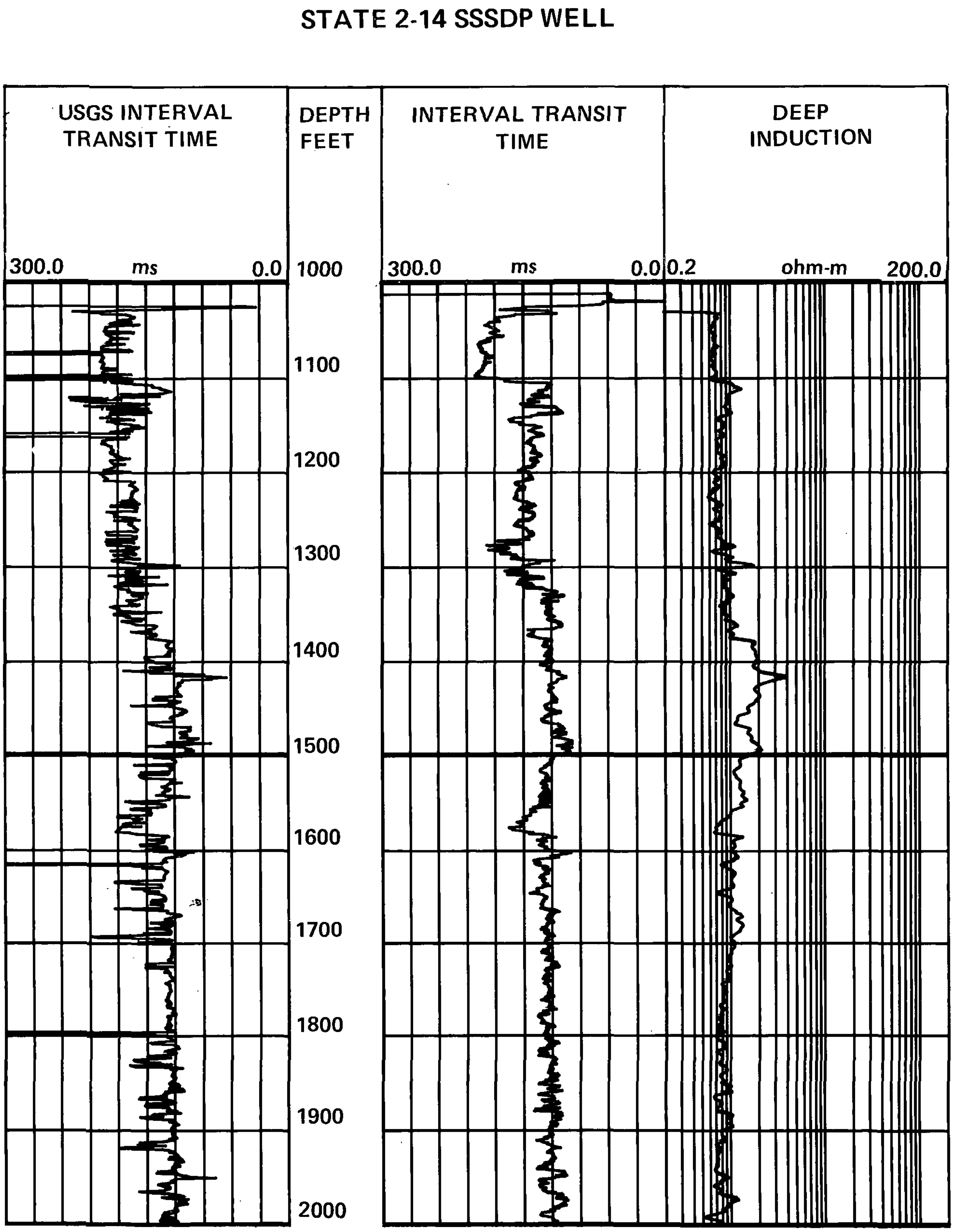
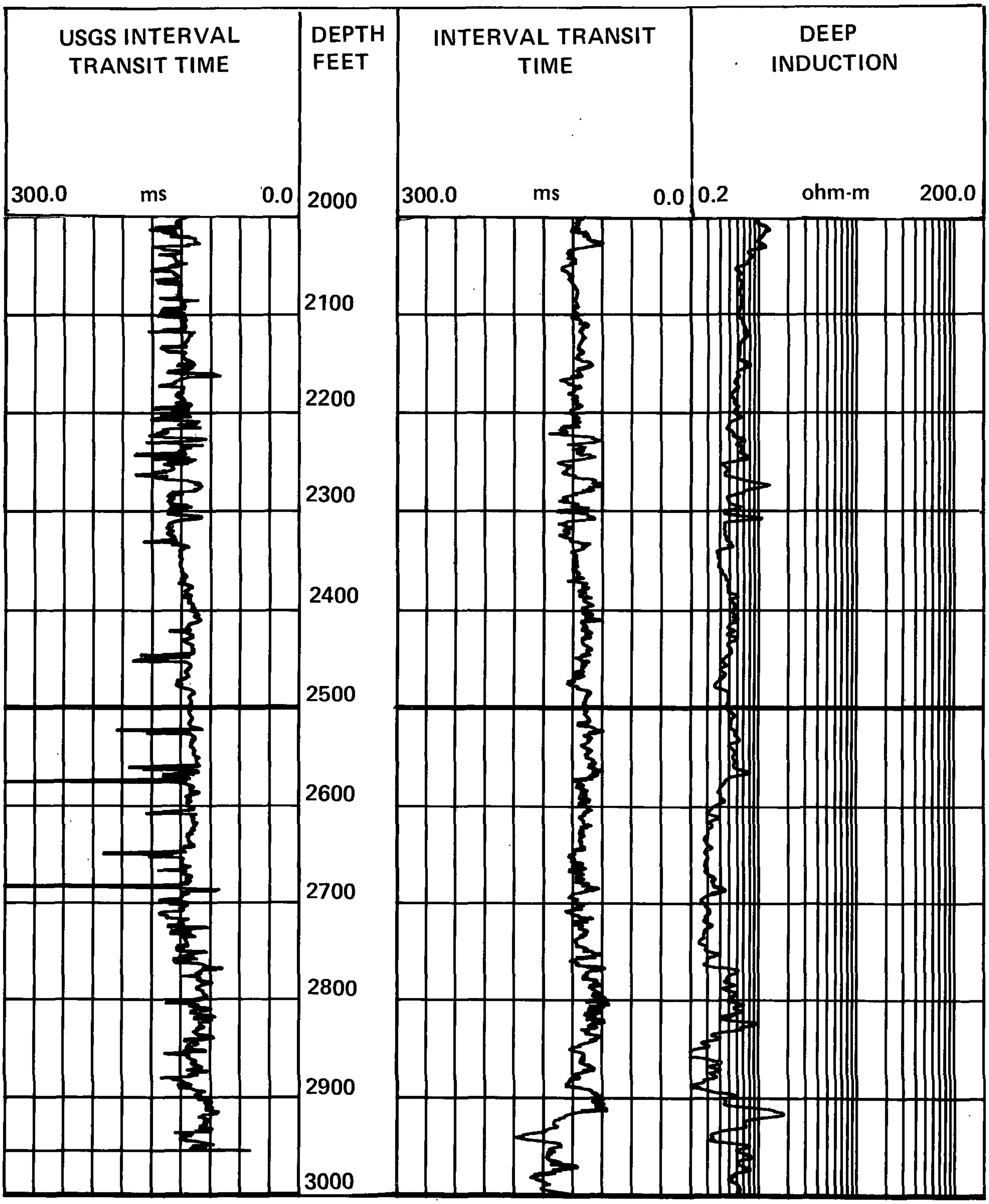
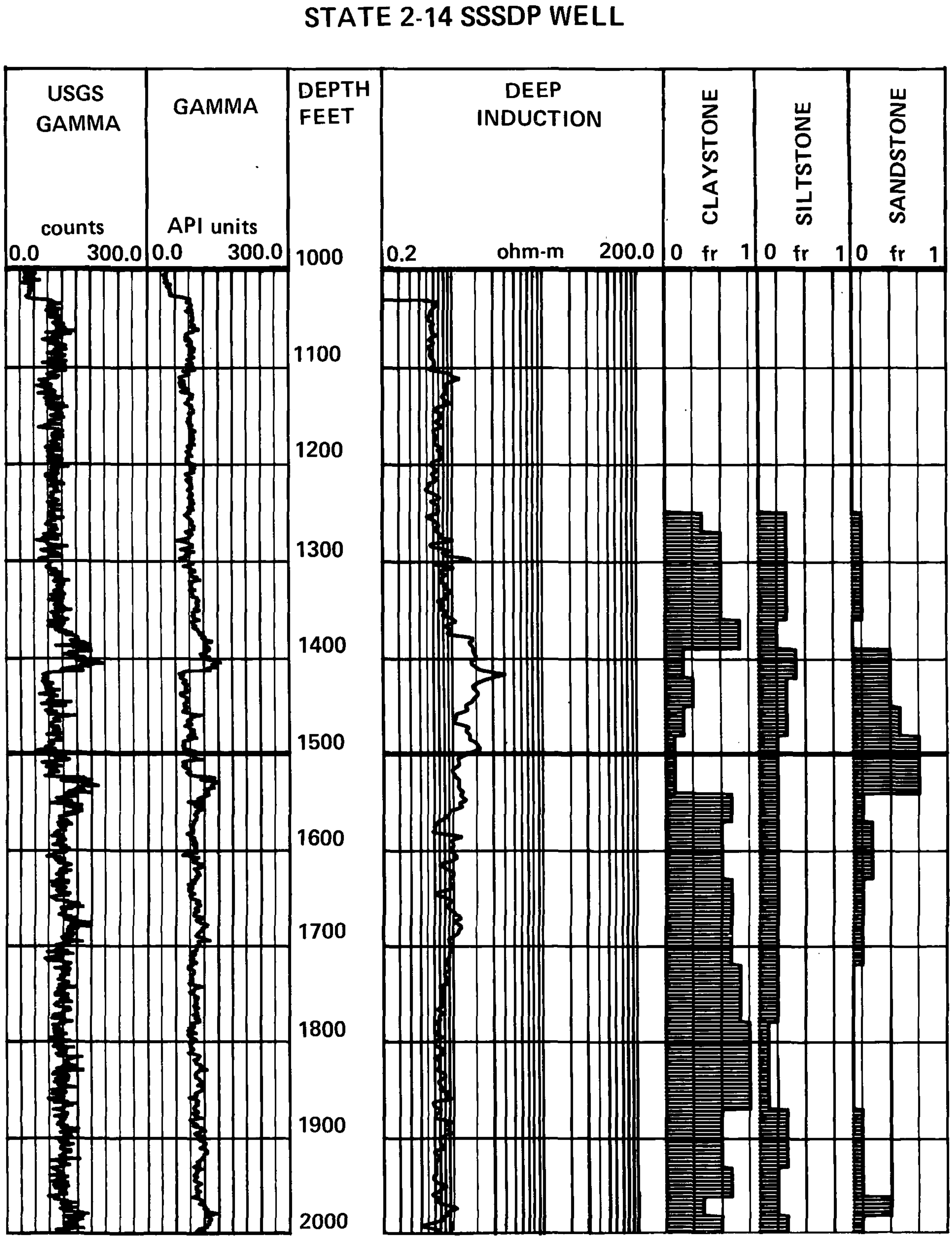


Figure 12.--U.S. Geological Survey interval-transit time log and commercial interval-transit time and deep induction logs; depth interval 1,000 to 3,000 feet.

STATE 2-14 SSSDP WELL

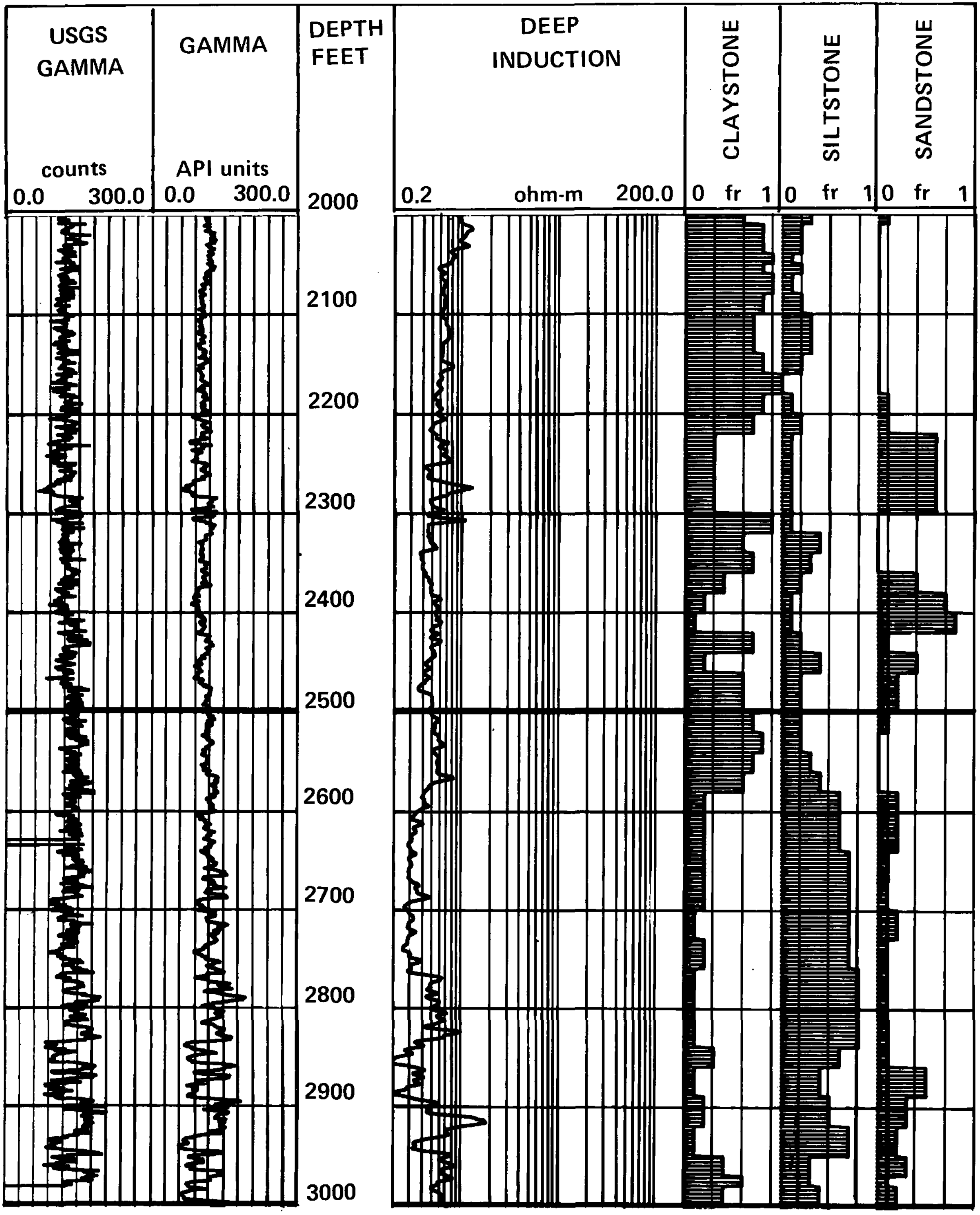




STATE 2-14 SSSDP WELL

Figure 13.--U.S. Geological Survey natural-gamma log, commercial natural-gamma and deep-induction logs, and lithologic log; depth interval 1,000 to 3,000 feet.

STATE 2-14 SSSDP WELL



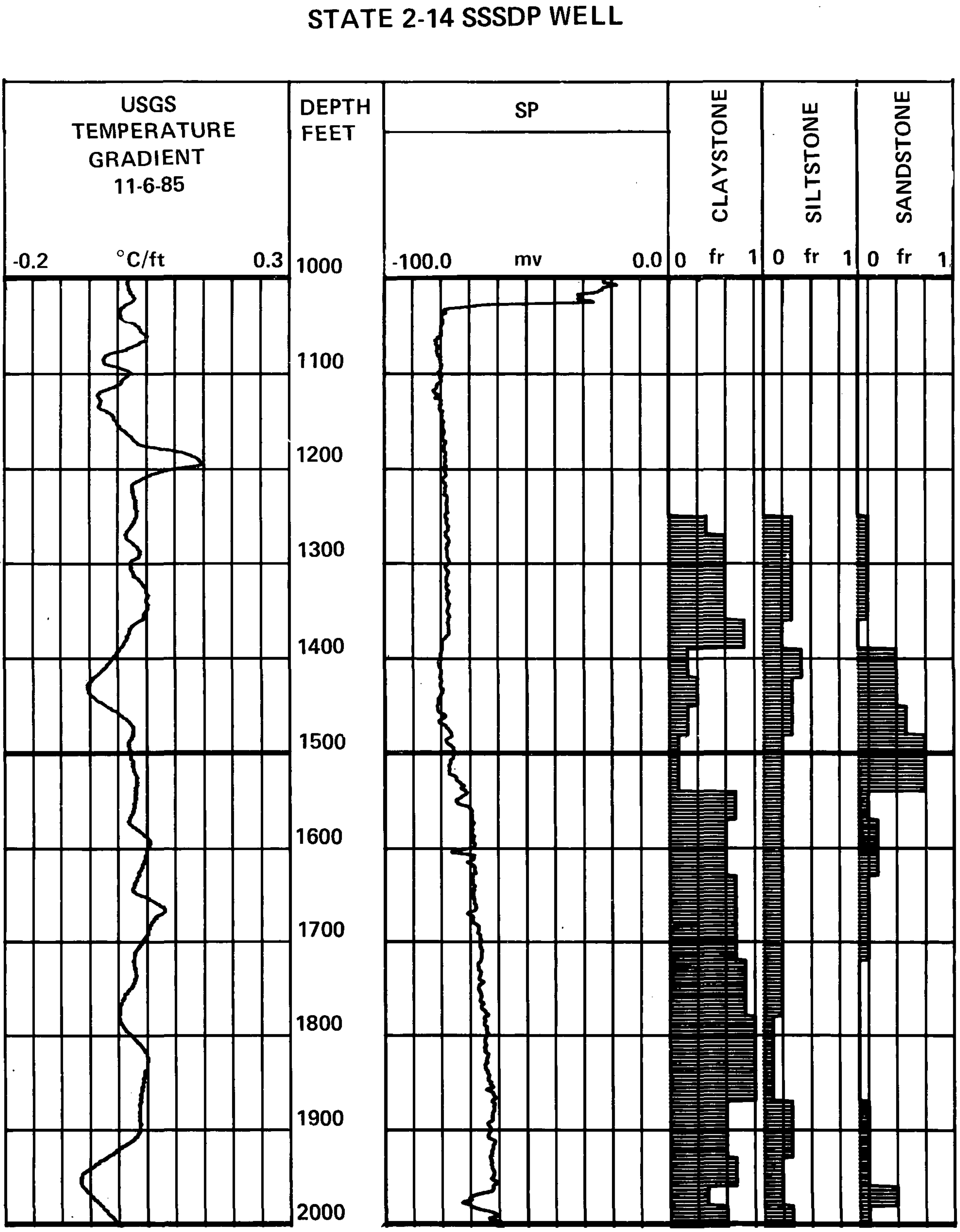
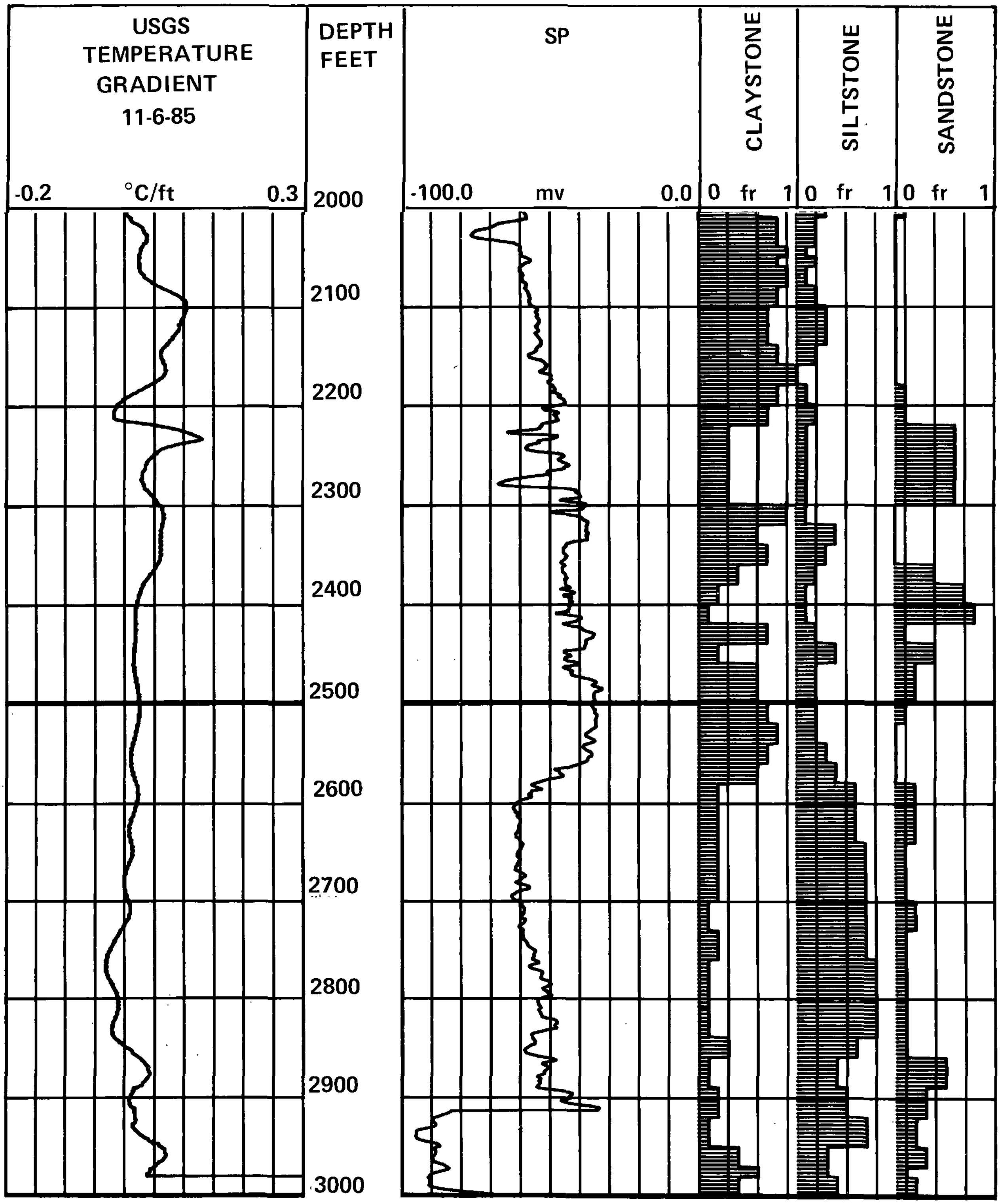


Figure 14.--U.S. Geological Survey temperature-gradient log, commercial spontaneous-potential log, and lithologic log; depth interval 1,000 to 3,000 feet.

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

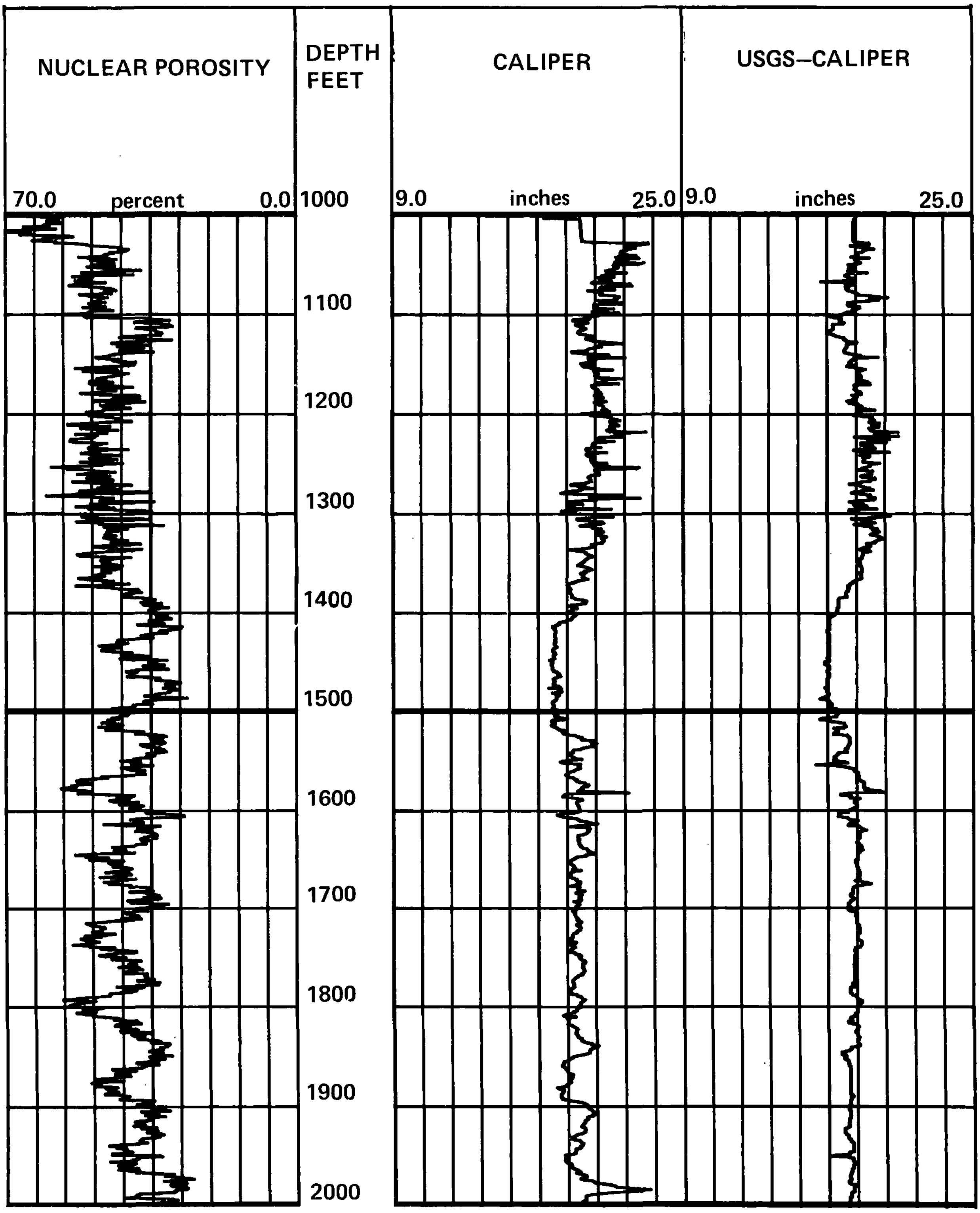
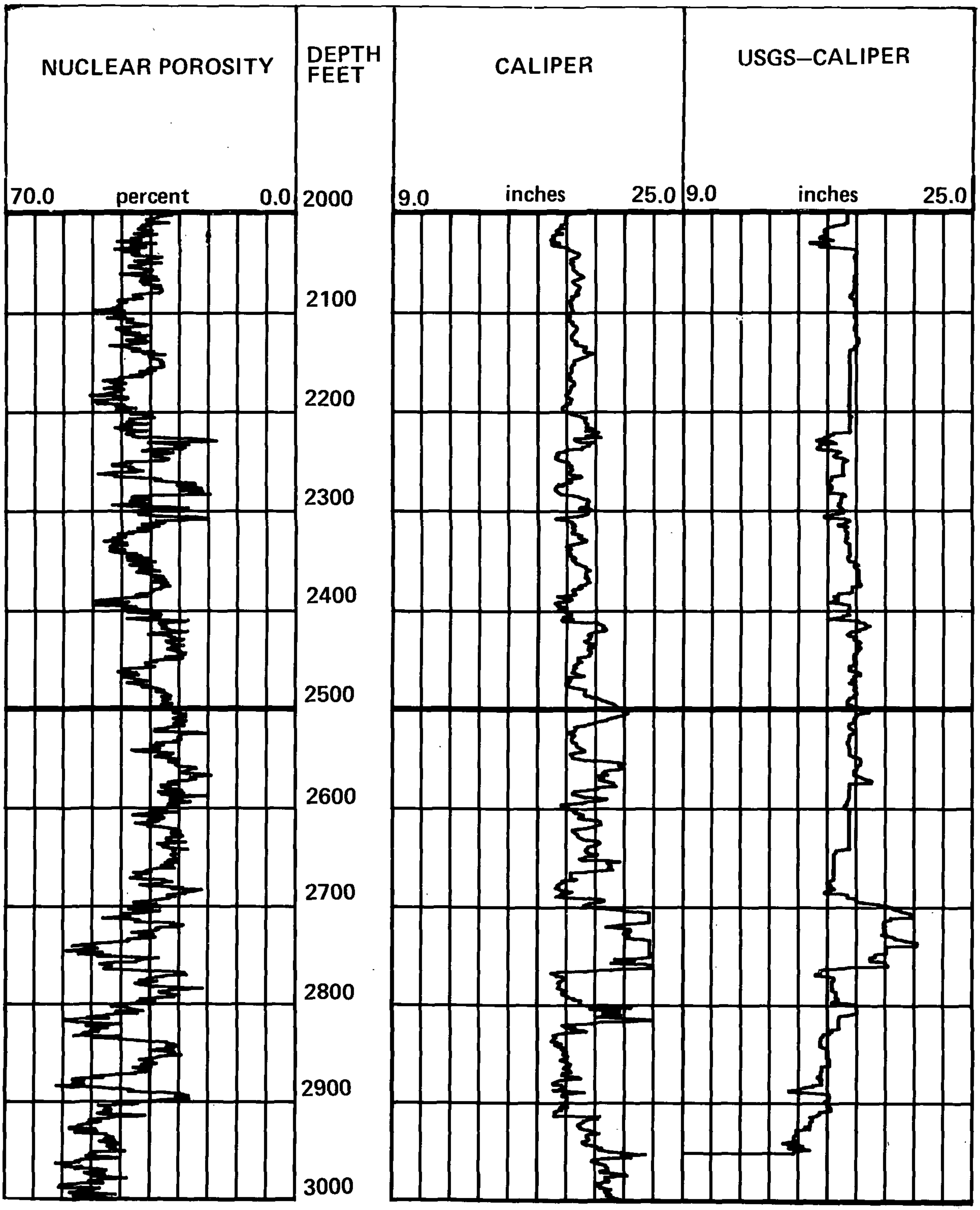


Figure 15.--Commercial nuclear-porosity and caliper logs, and U.S. Geological Survey epithermal-neutron and caliper logs; depth interval 1,000 to 3,000 feet.

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

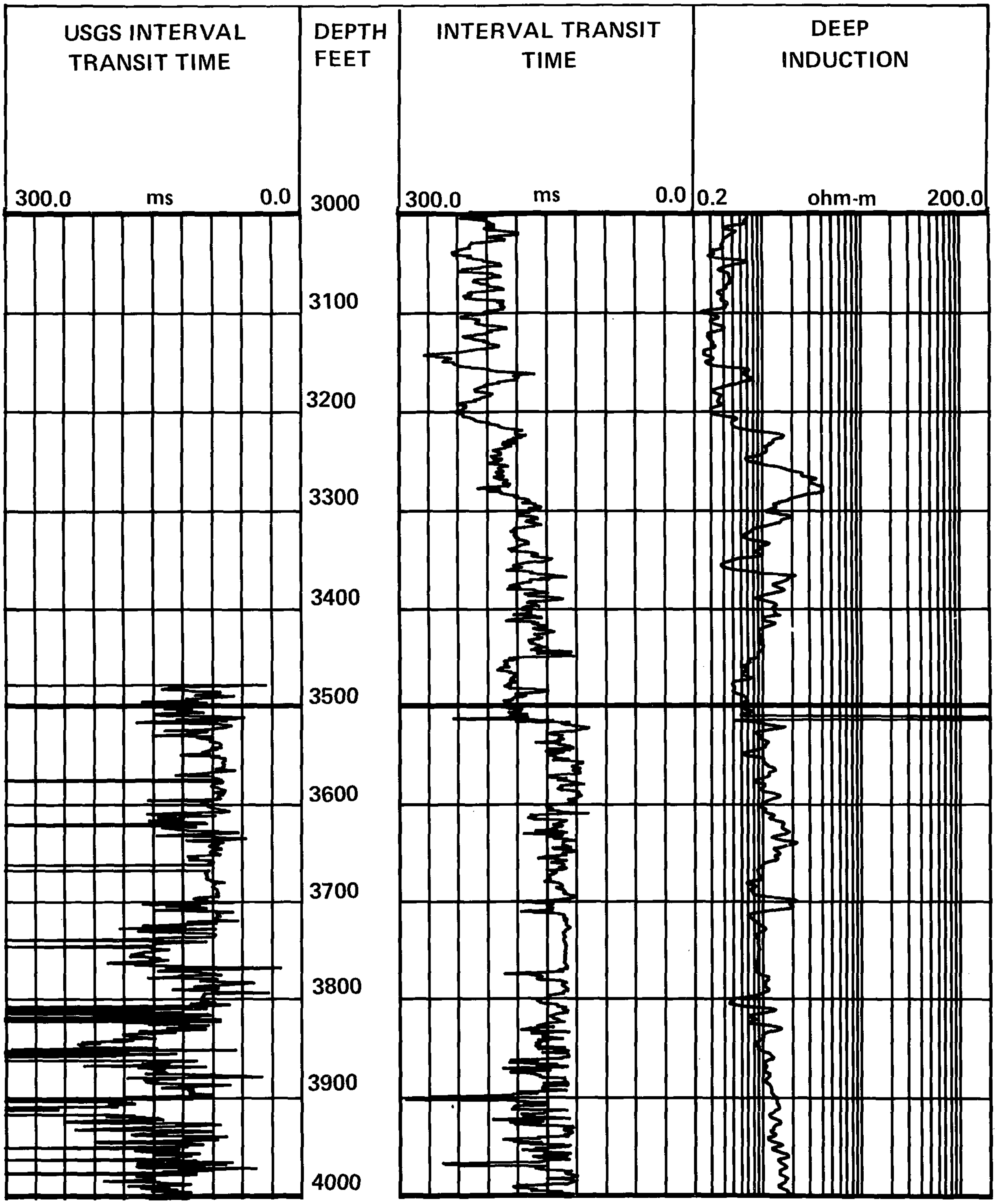
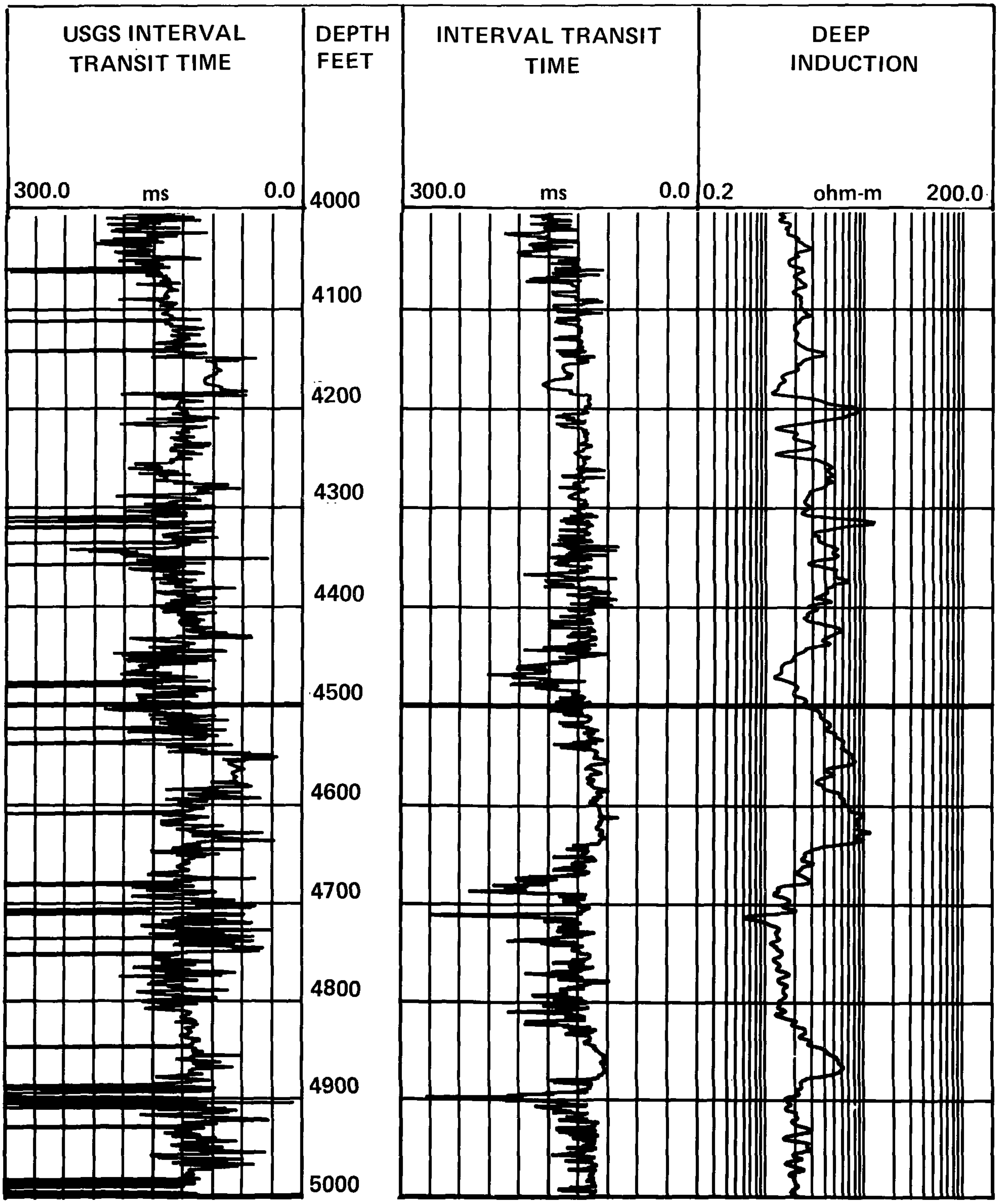


Figure 16.--U.S. Geological Survey interval-transit time log and commercial interval-transit time and deep-inducation logs; depth interval 3,000 to 6,000 feet.

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

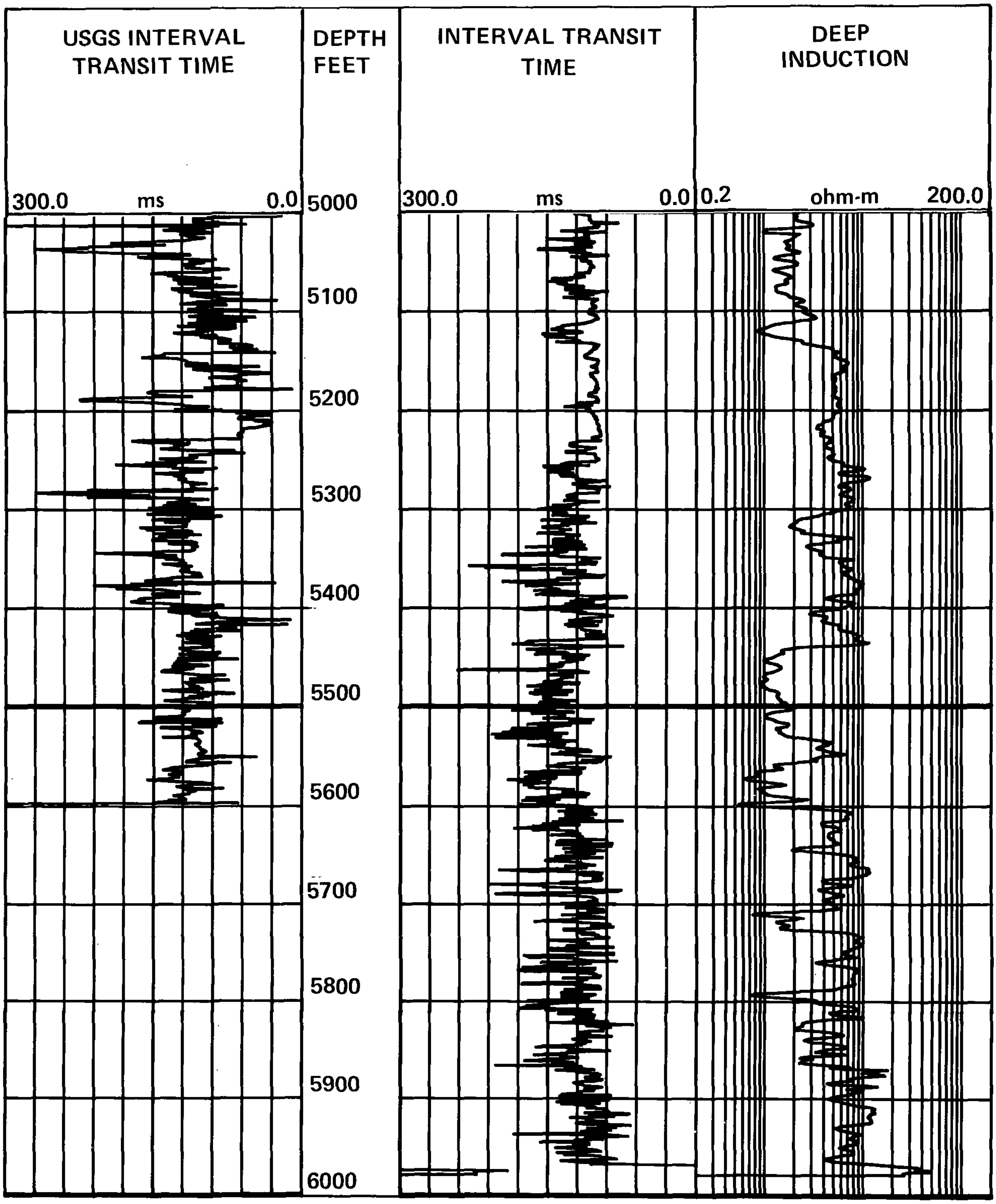


Figure 16.--U.S. Geological Survey interval-transit time log and commercial interval-transit time and deep-inducation logs; depth interval 3,000 to 6,000 feet. (Continued)

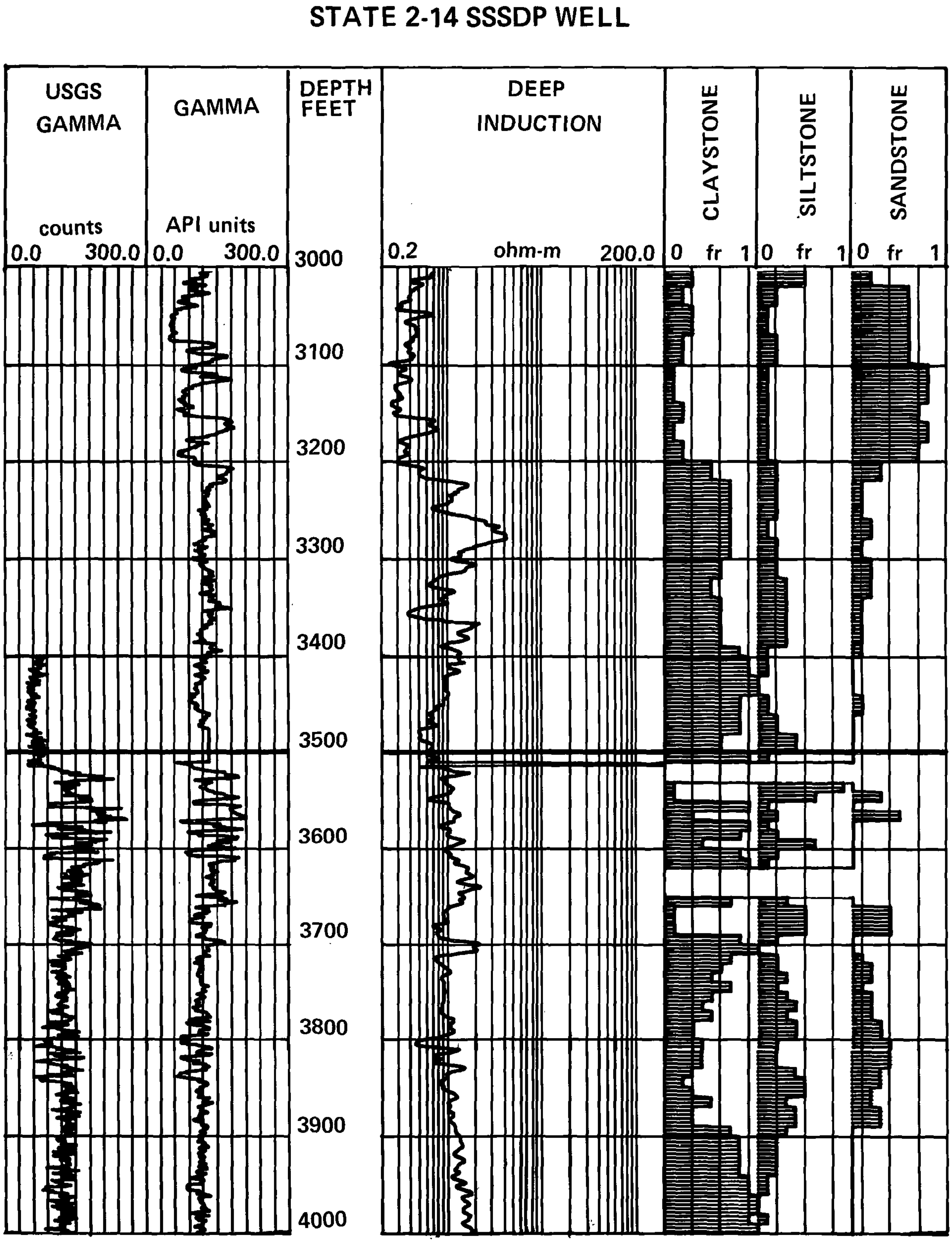
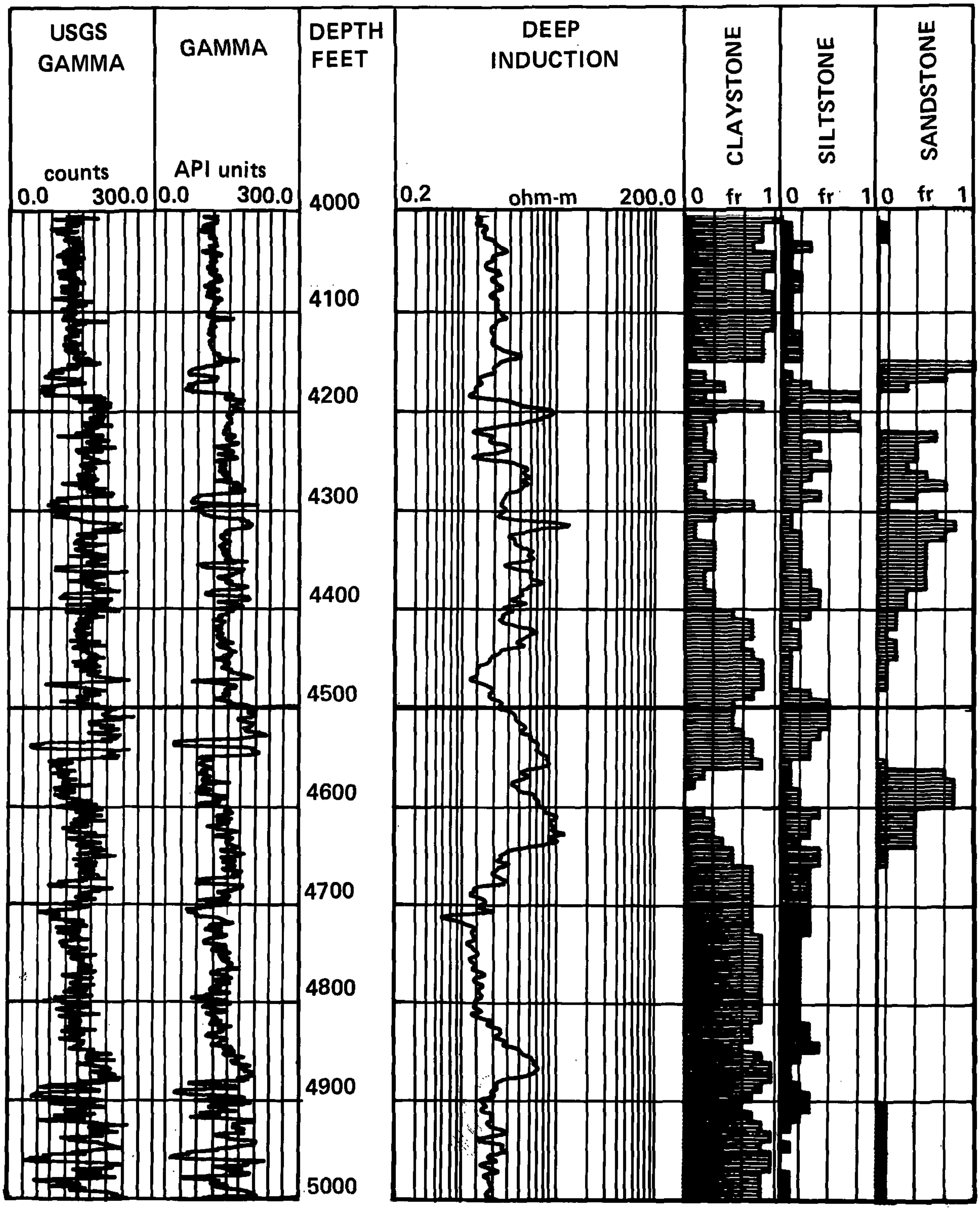


Figure 17.--U.S. Geological Survey natural-gamma log, commercial natural-gamma and deep-induction logs, and lithologic log; depth interval 3,000 to 6,000 feet.

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

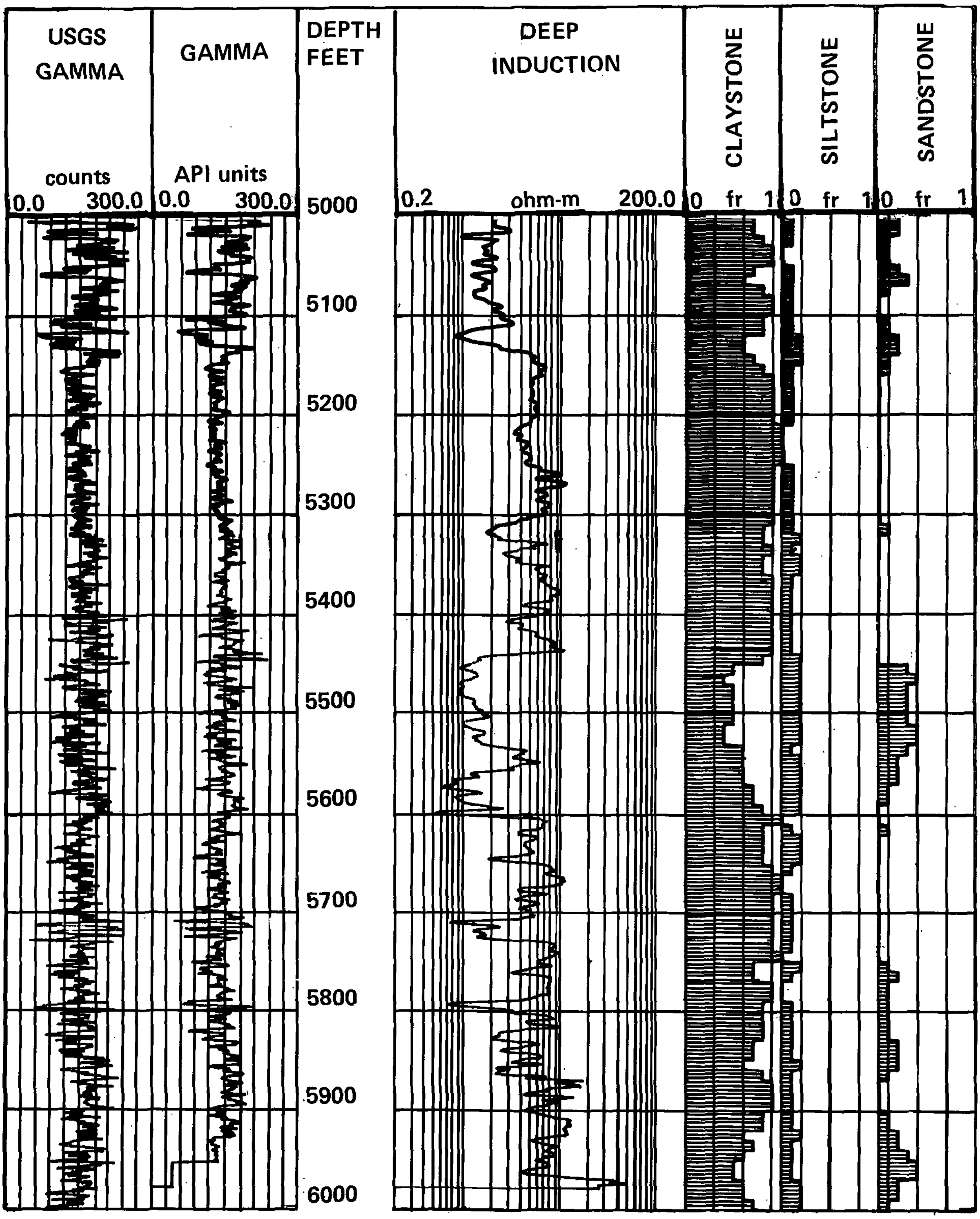


Figure 17.--U.S. Geological Survey natural-gamma log, commercial natural-gamma and deep-induction logs, and lithologic log; depth interval 3,000 to 6,000 feet. (Continued)

STATE 2-14 SSSDP WELL

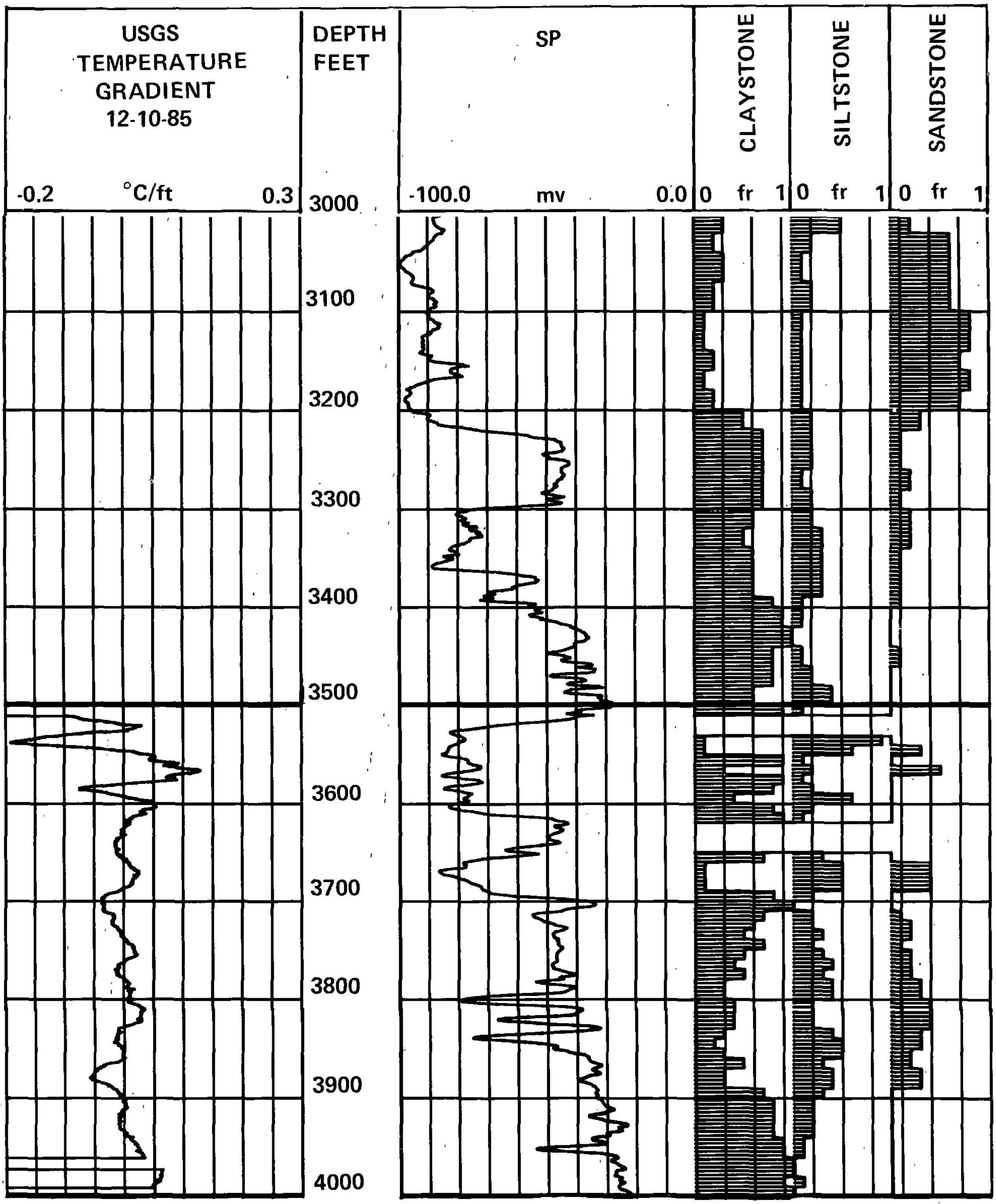
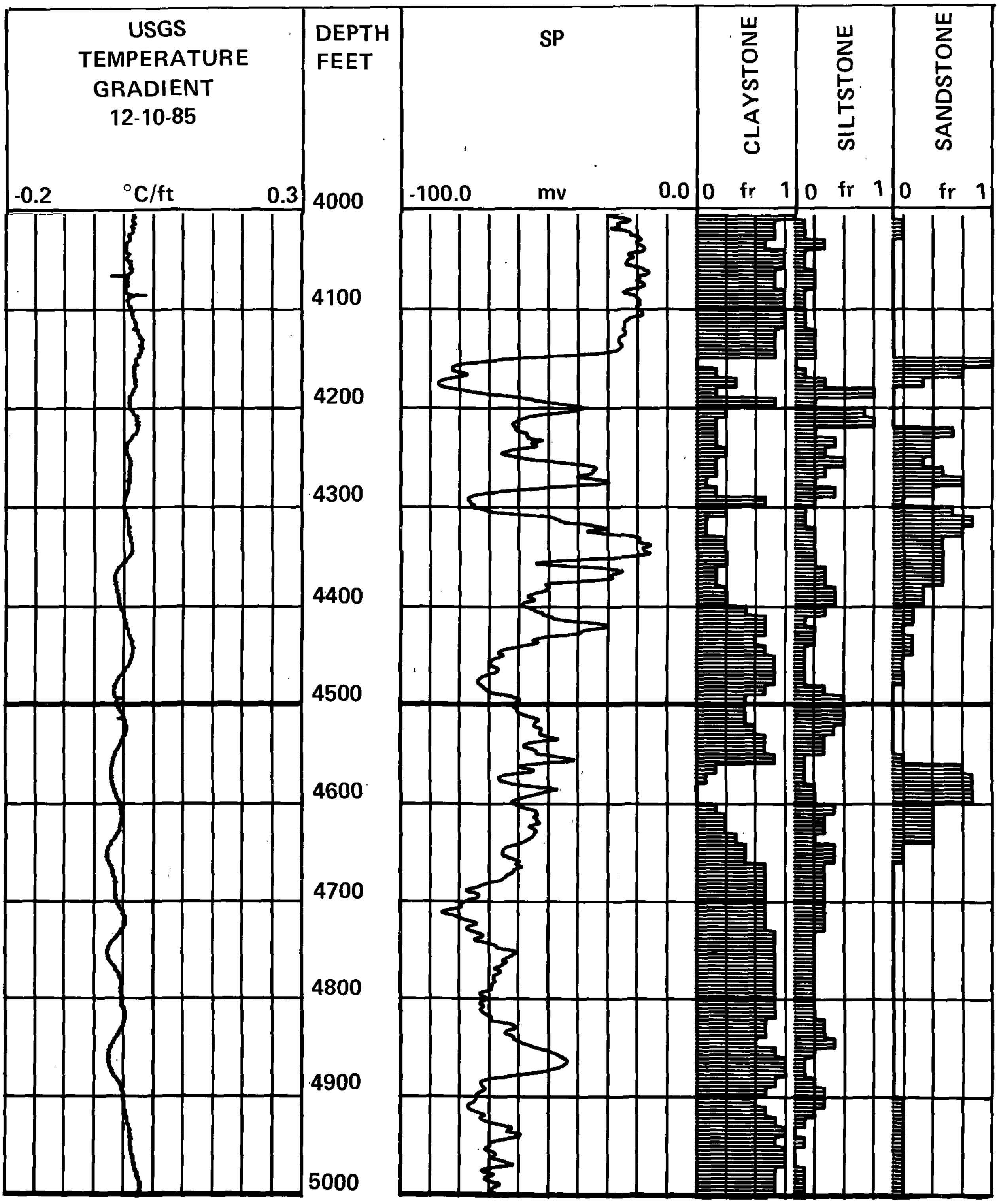


Figure 18.--U.S. Geological Survey temperature-gradient log, commercial spontaneous-potential log, and lithologic log; depth interval 3,000 to 6,000 feet.

STATE 2-14 SSSDP WELL



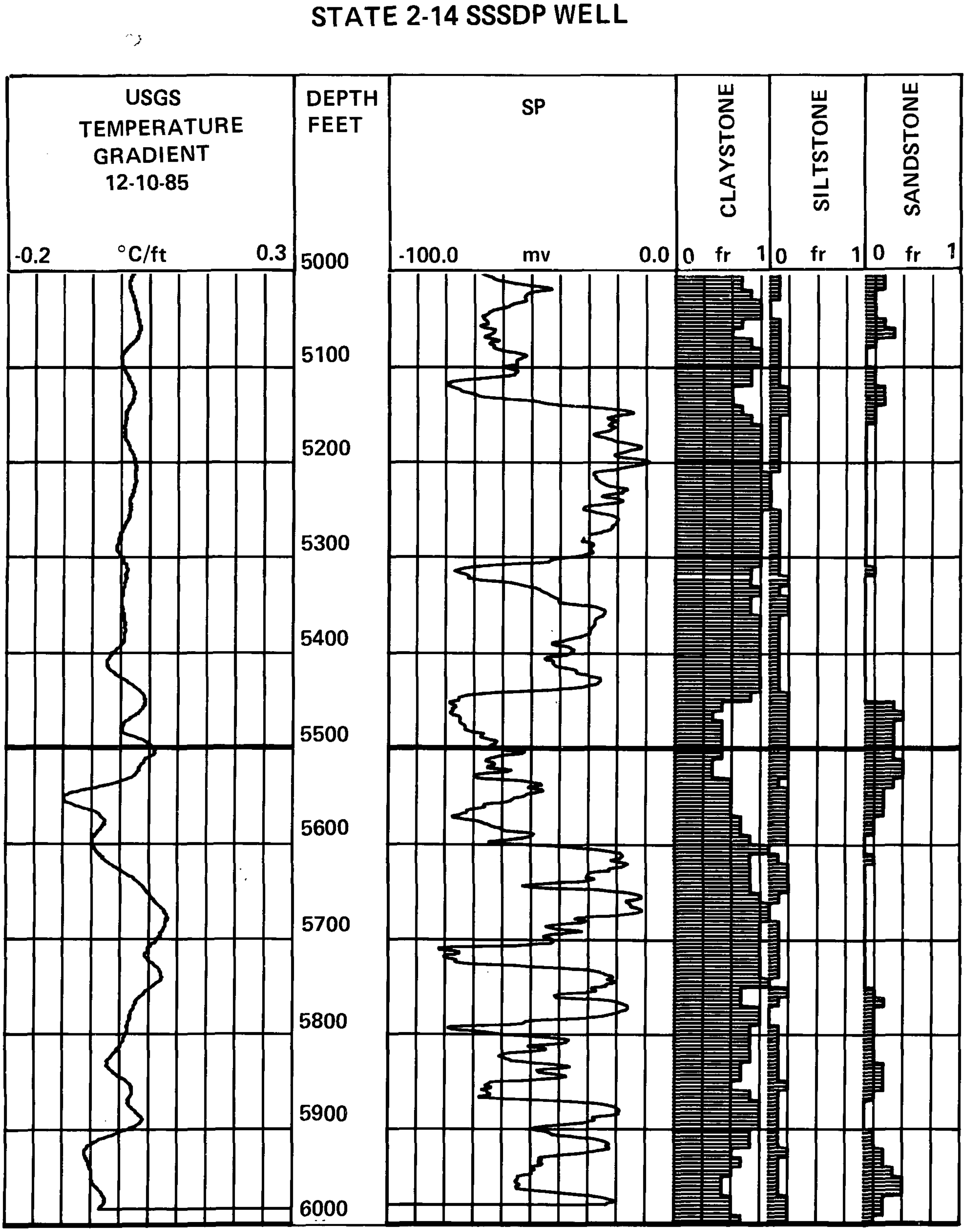


Figure 18.--U.S. Geological Survey temperature-gradient log, commercial spontaneous-potential log, and lithologic log; depth interval 3,000 to 6,000 feet. (Continued)

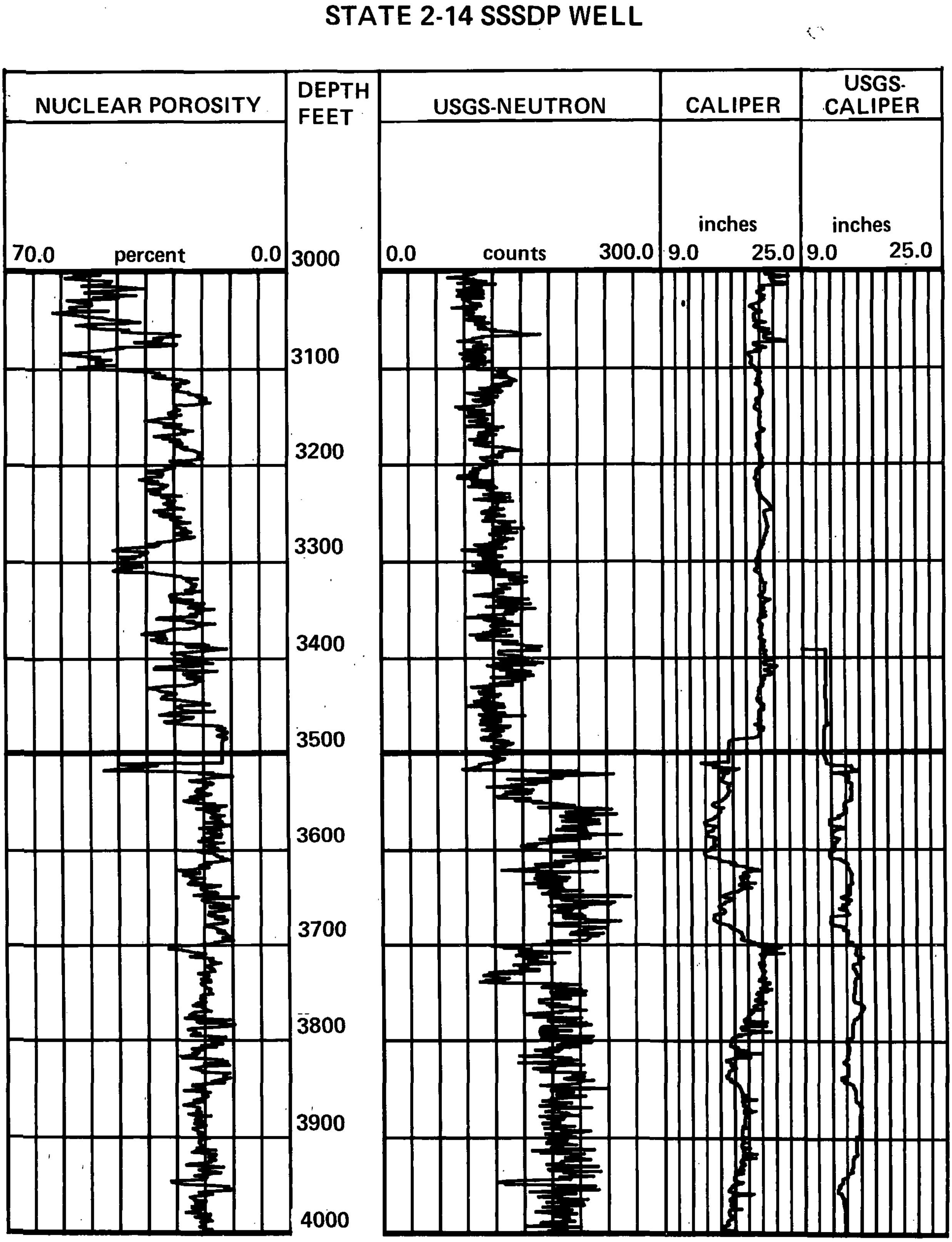
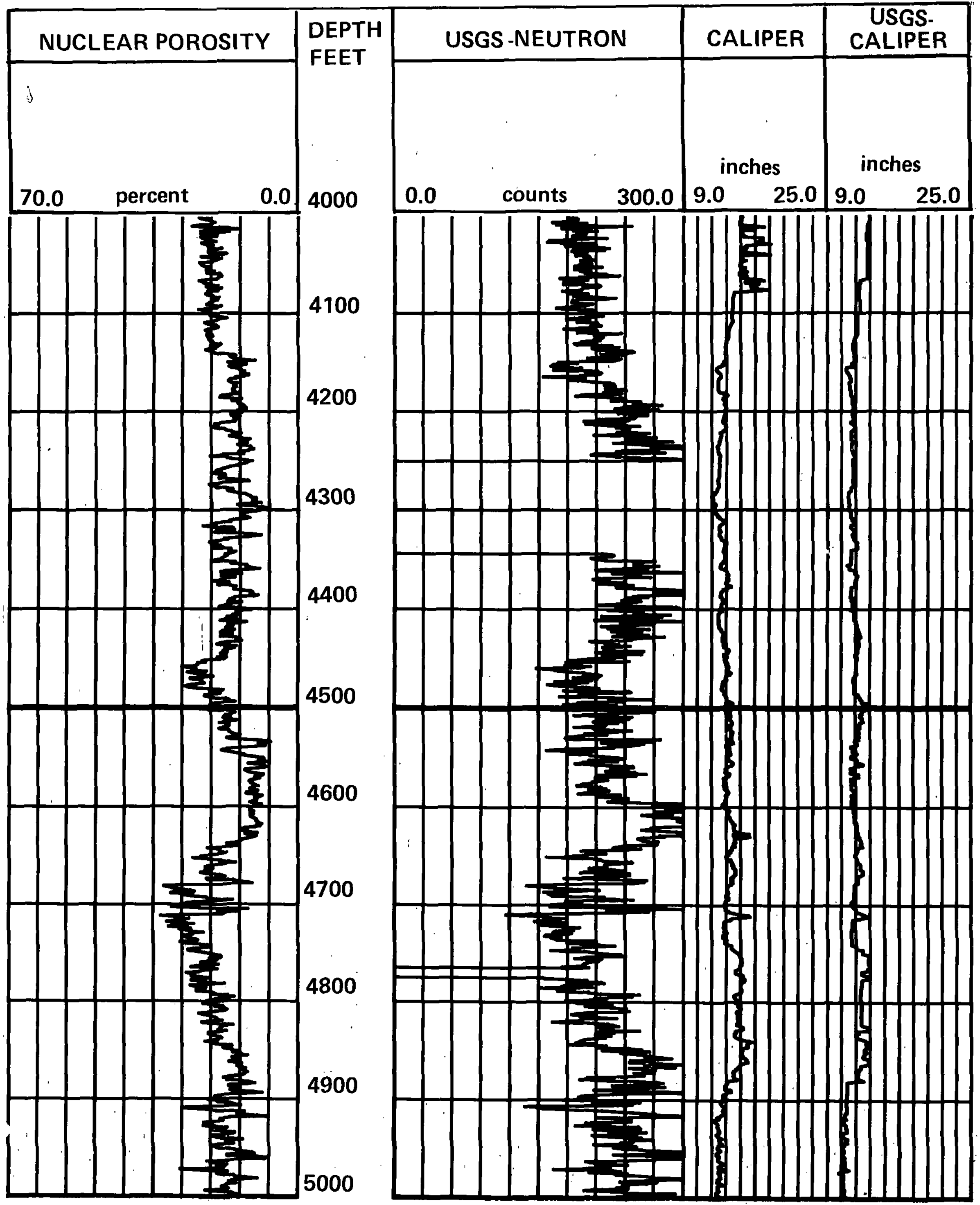


Figure 19.--Commercial nuclear-porosity and caliper logs, and U.S. Geological Survey epithermal-neutron and caliper logs; depth interval 3,000 to 6,000 feet.

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

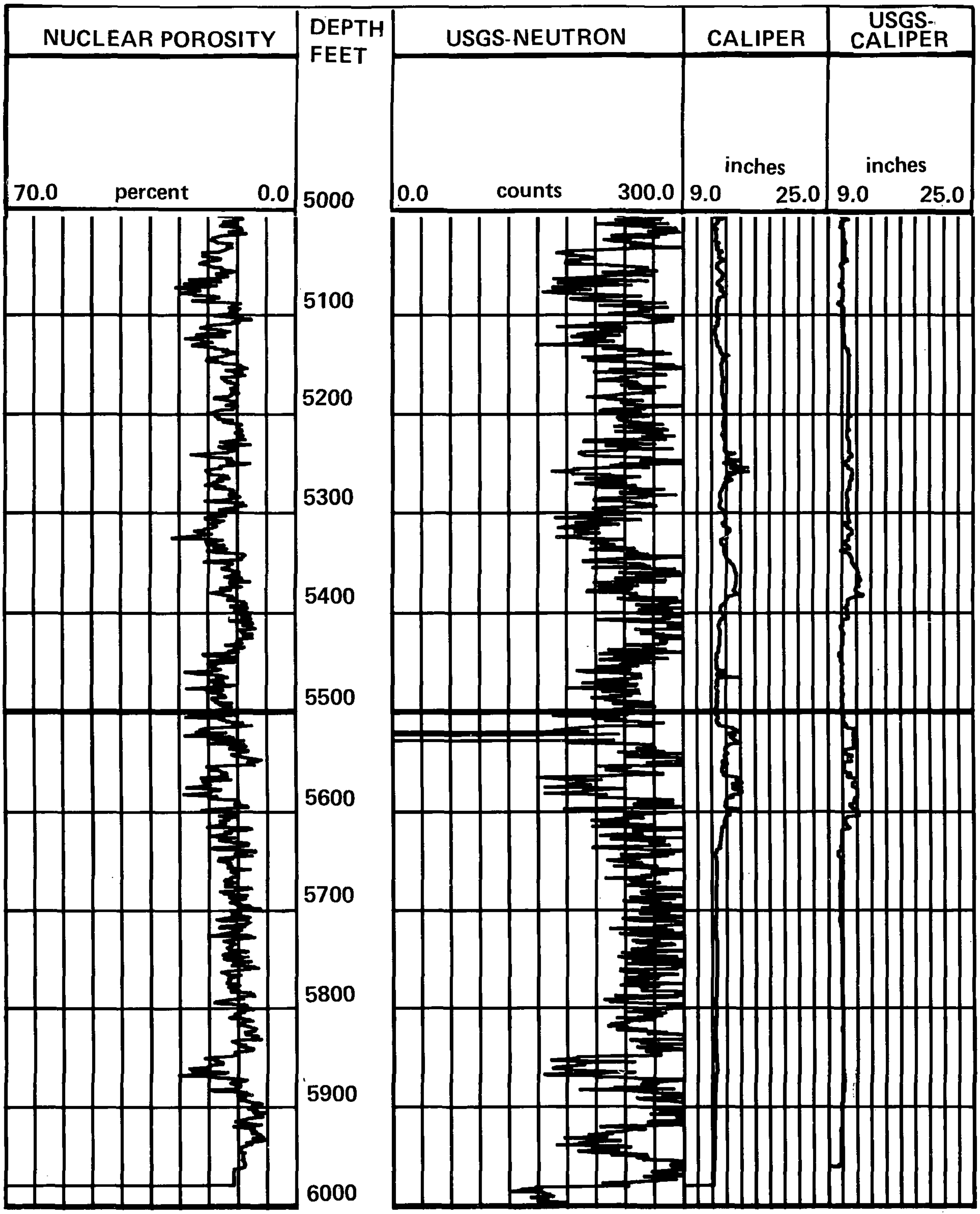
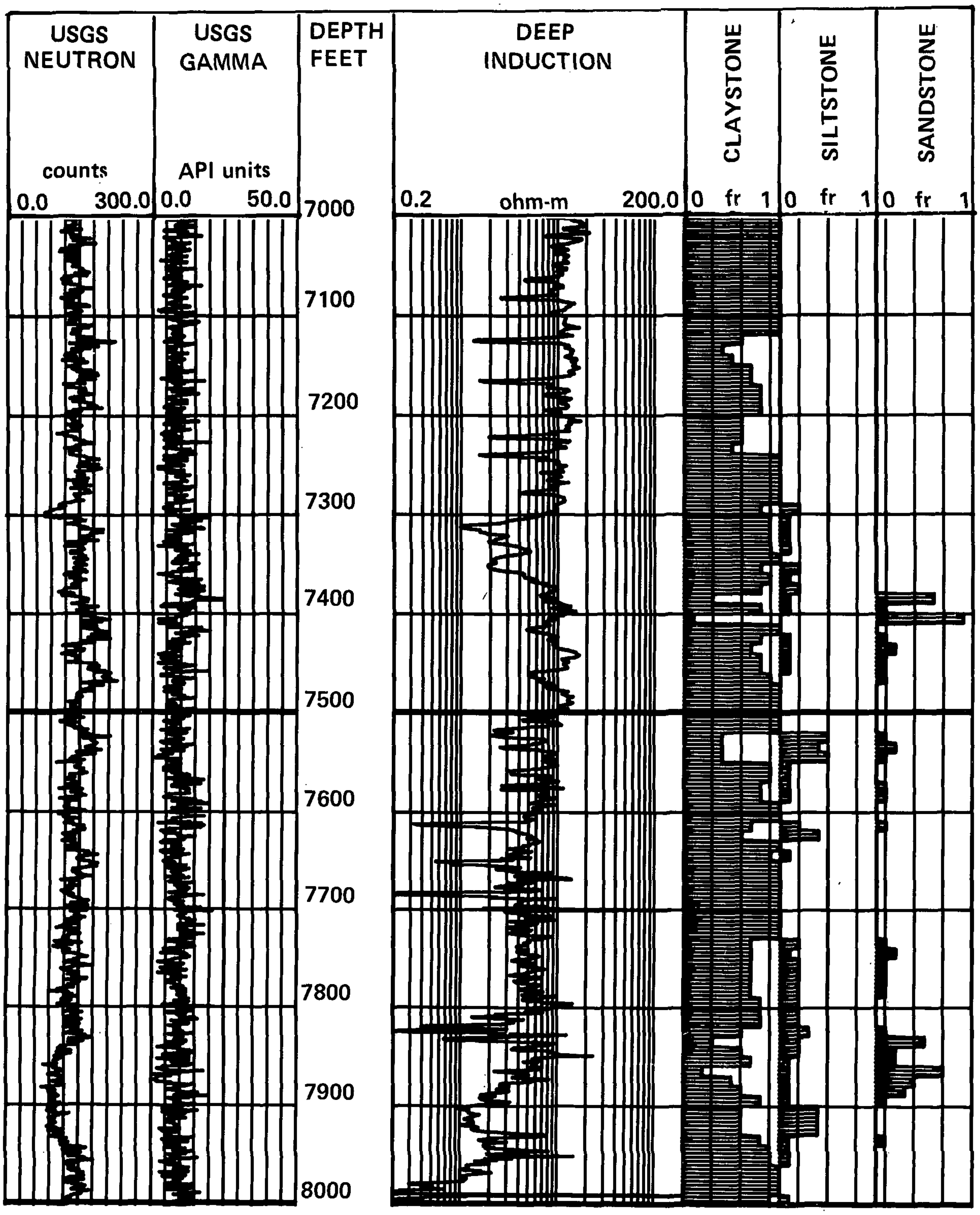


Figure 19.--Commercial nuclear-porosity and caliper logs, and U.S. Geological Survey epithermal-neutron and caliper logs; depth interval 3,000 to 6,000 feet. (Continued)

STATE 2-14 SSSDP WELL



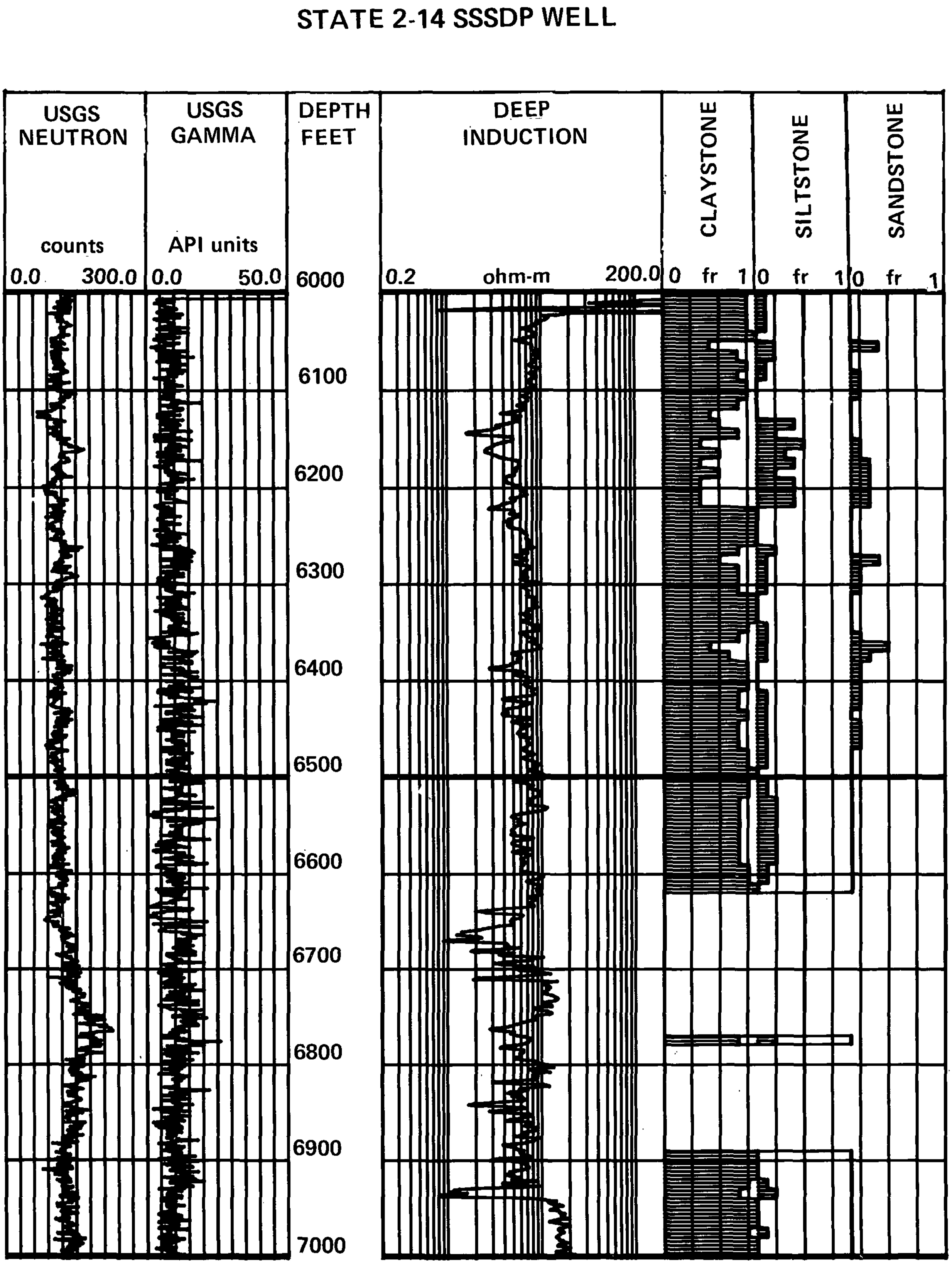
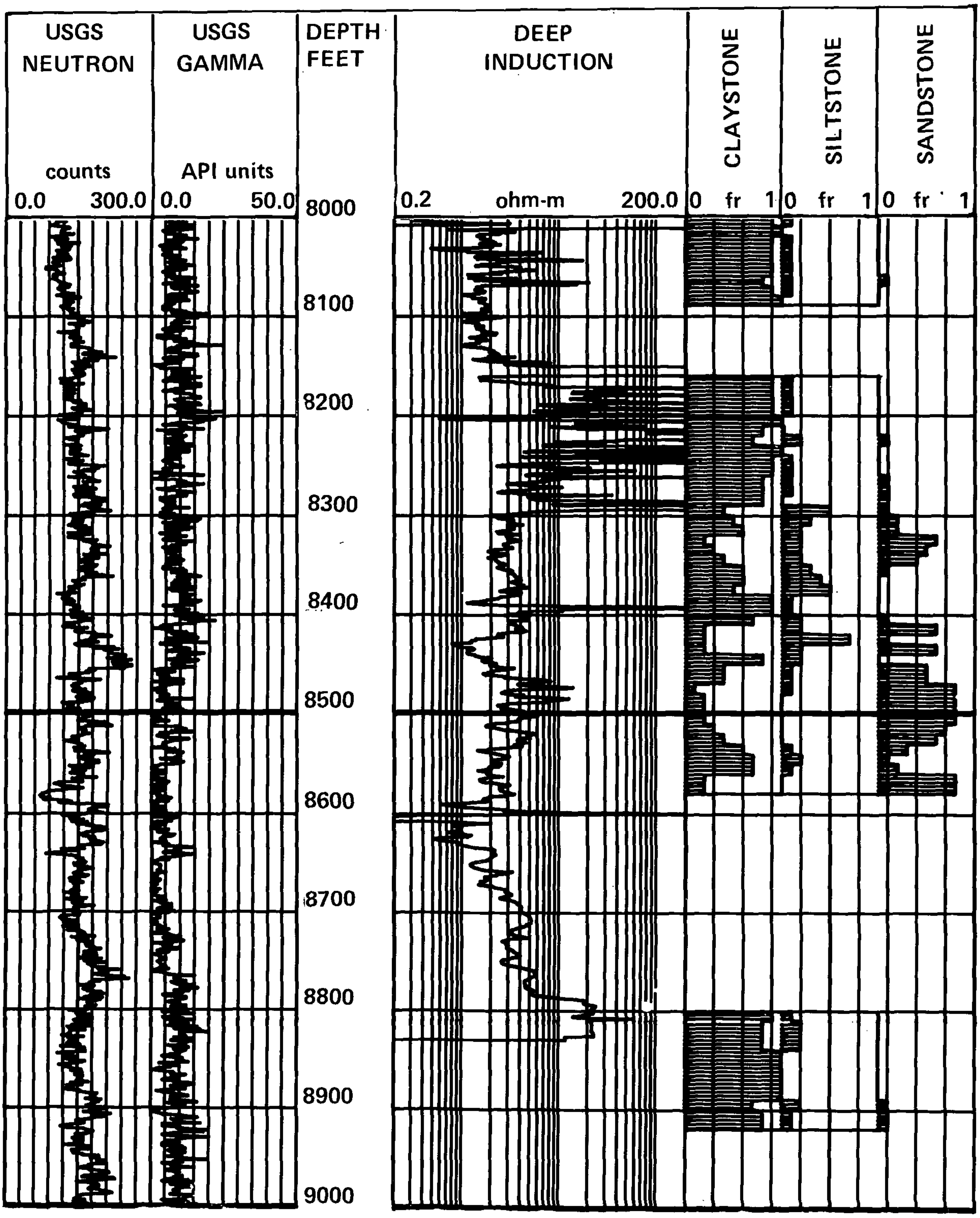


Figure 20.--U.S. Geological Survey epithermal-neutron and natural-gamma logs, commercial deep-induction log, and lithologic log; depth interval 6,000 to 10,000 feet.

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

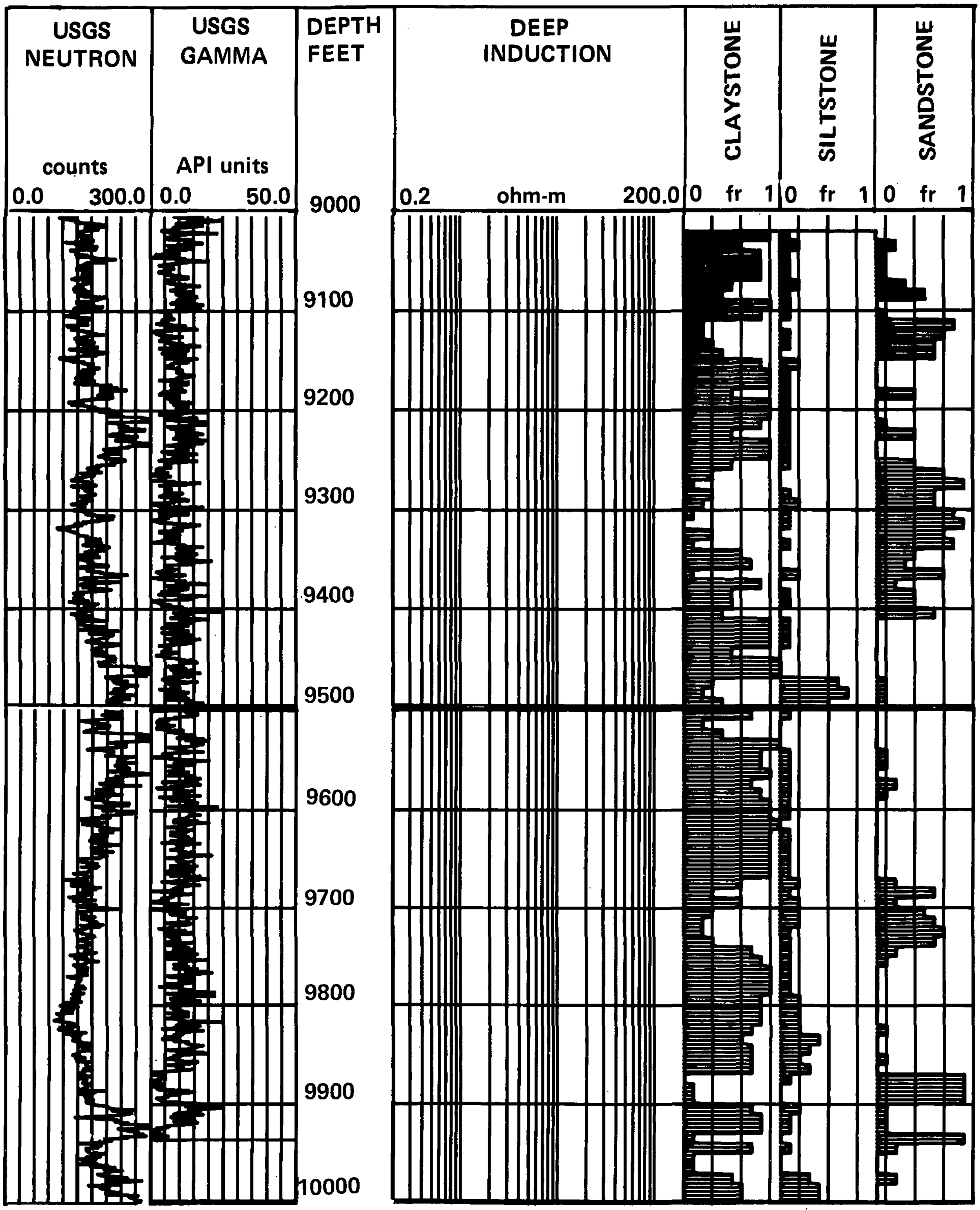


Figure 20.--U.S. Geological Survey epithermal-neutron and natural-gamma logs, commercial deep-induction log, and lithologic log; depth interval 6,000 to 10,000 feet. (Continued)

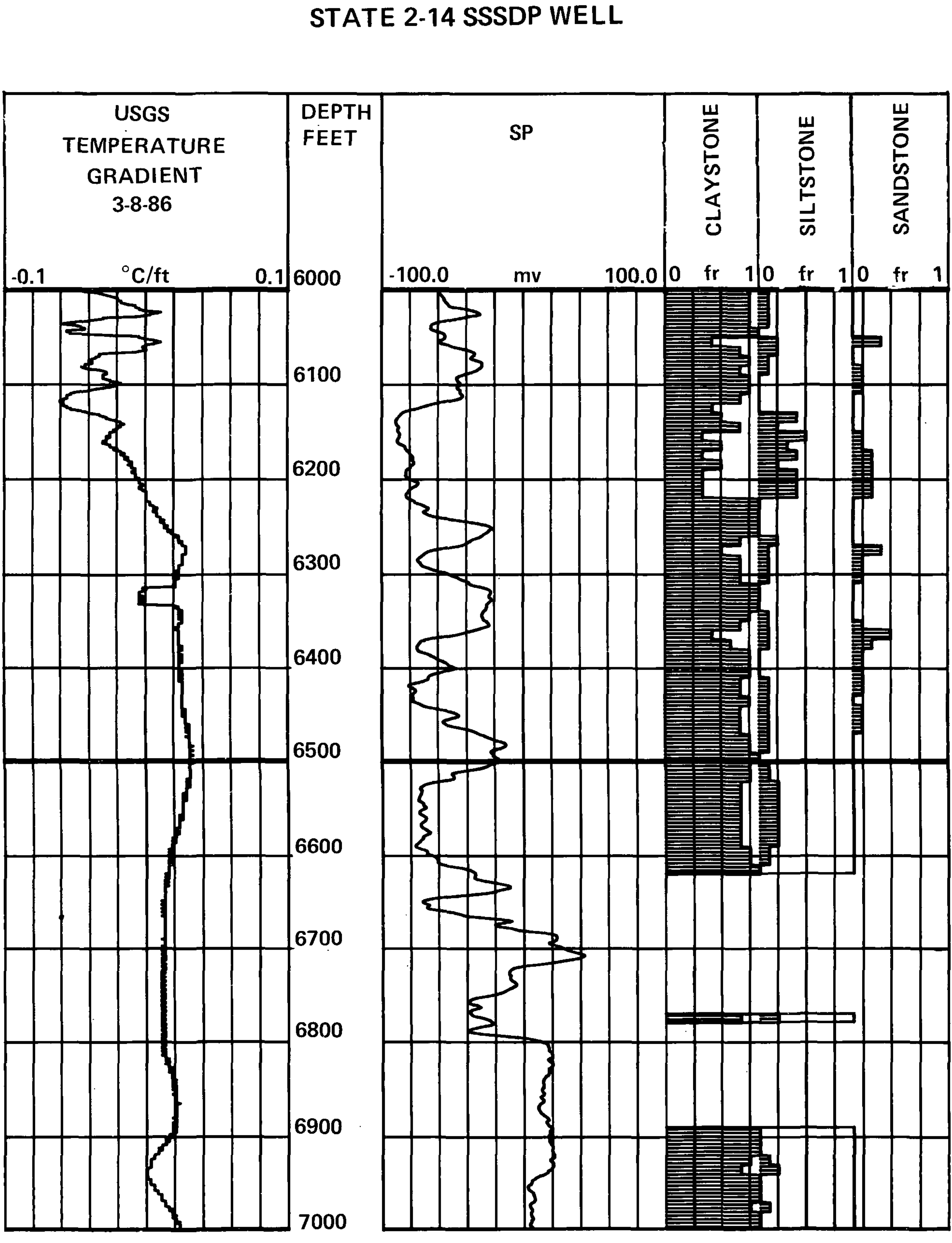
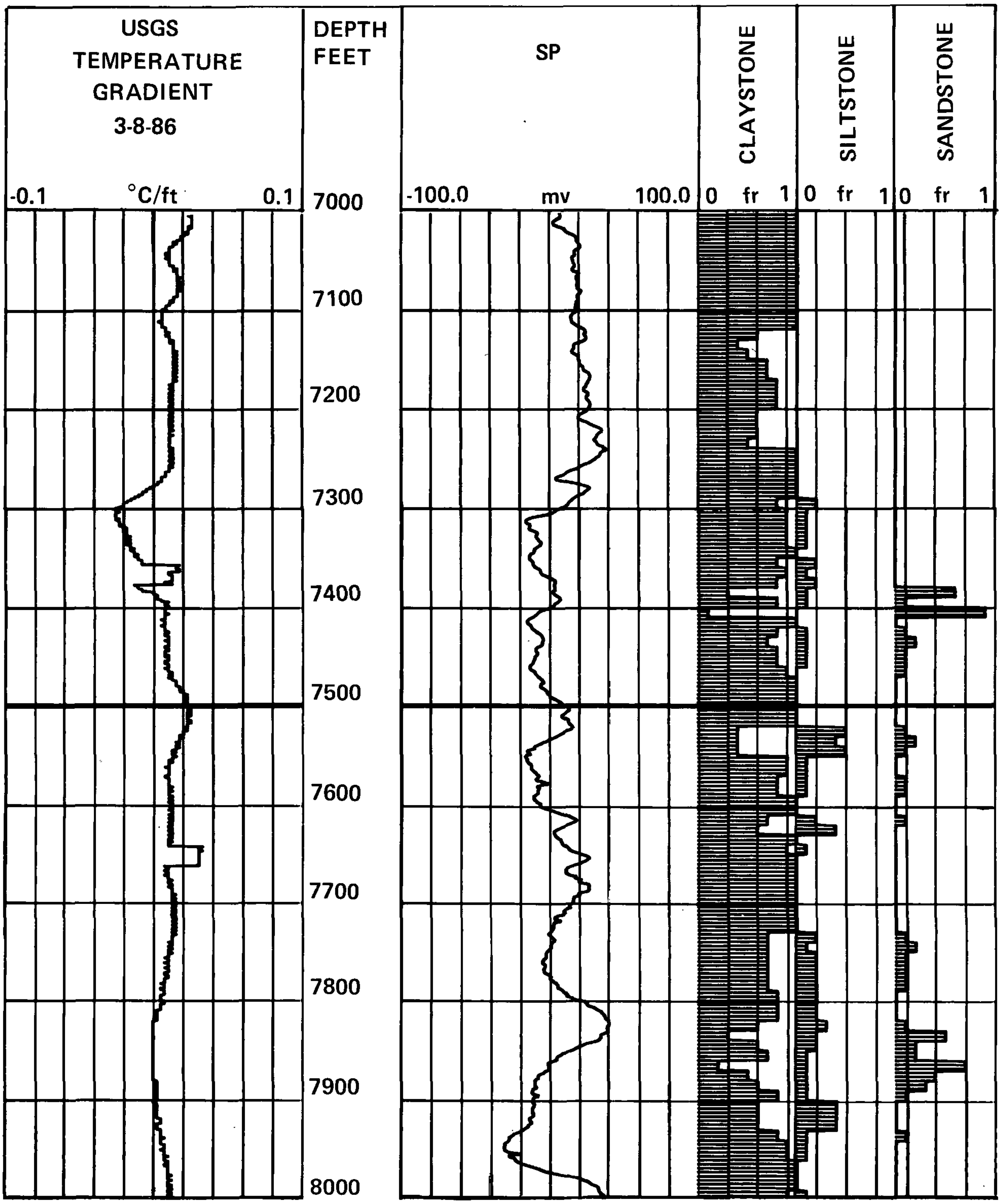


Figure 21.--U.S. Geological Survey temperature-gradient log, commercial spontaneous-potential log, and lithologic log; depth interval 6,000 to 10,000 feet.

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

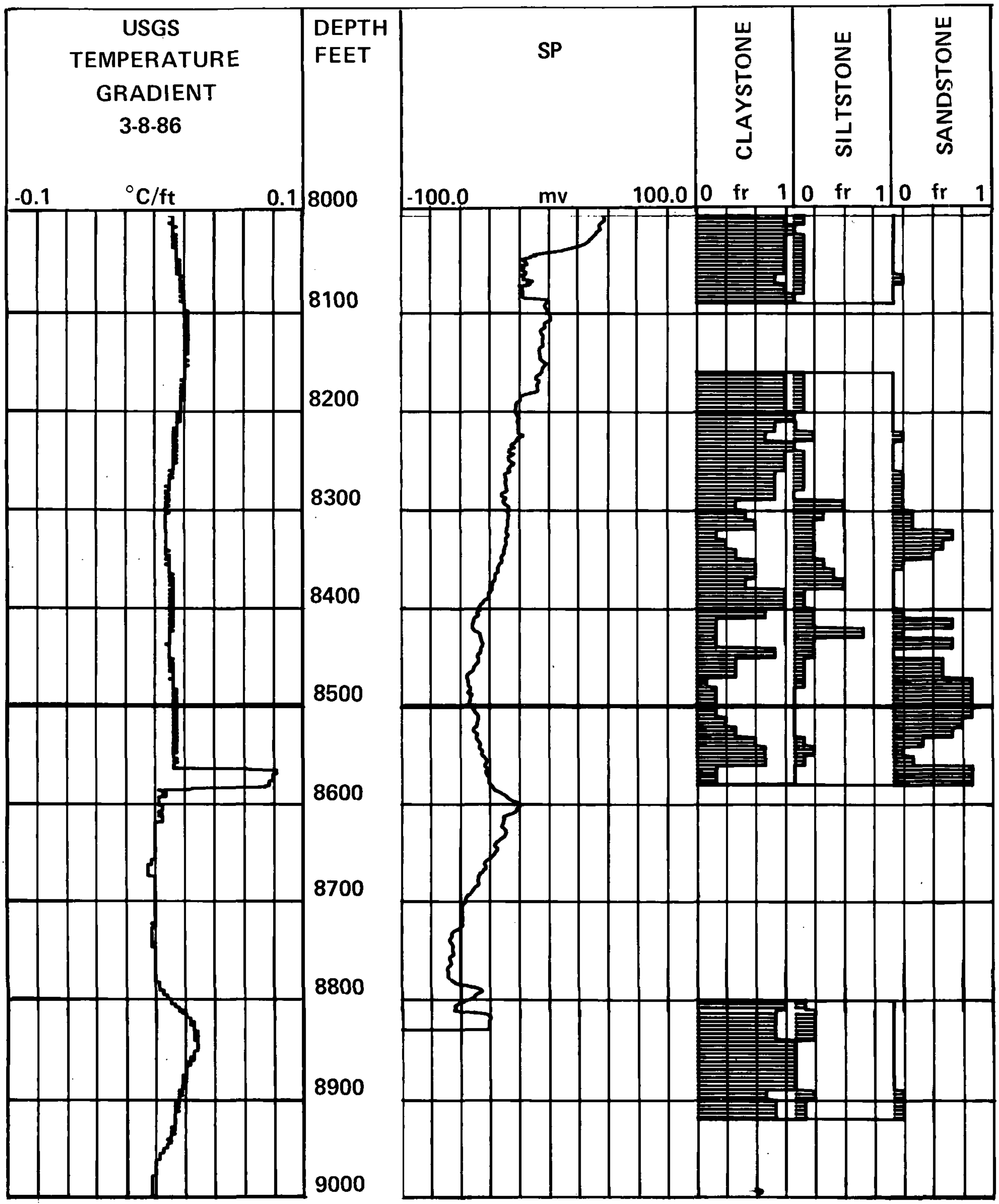
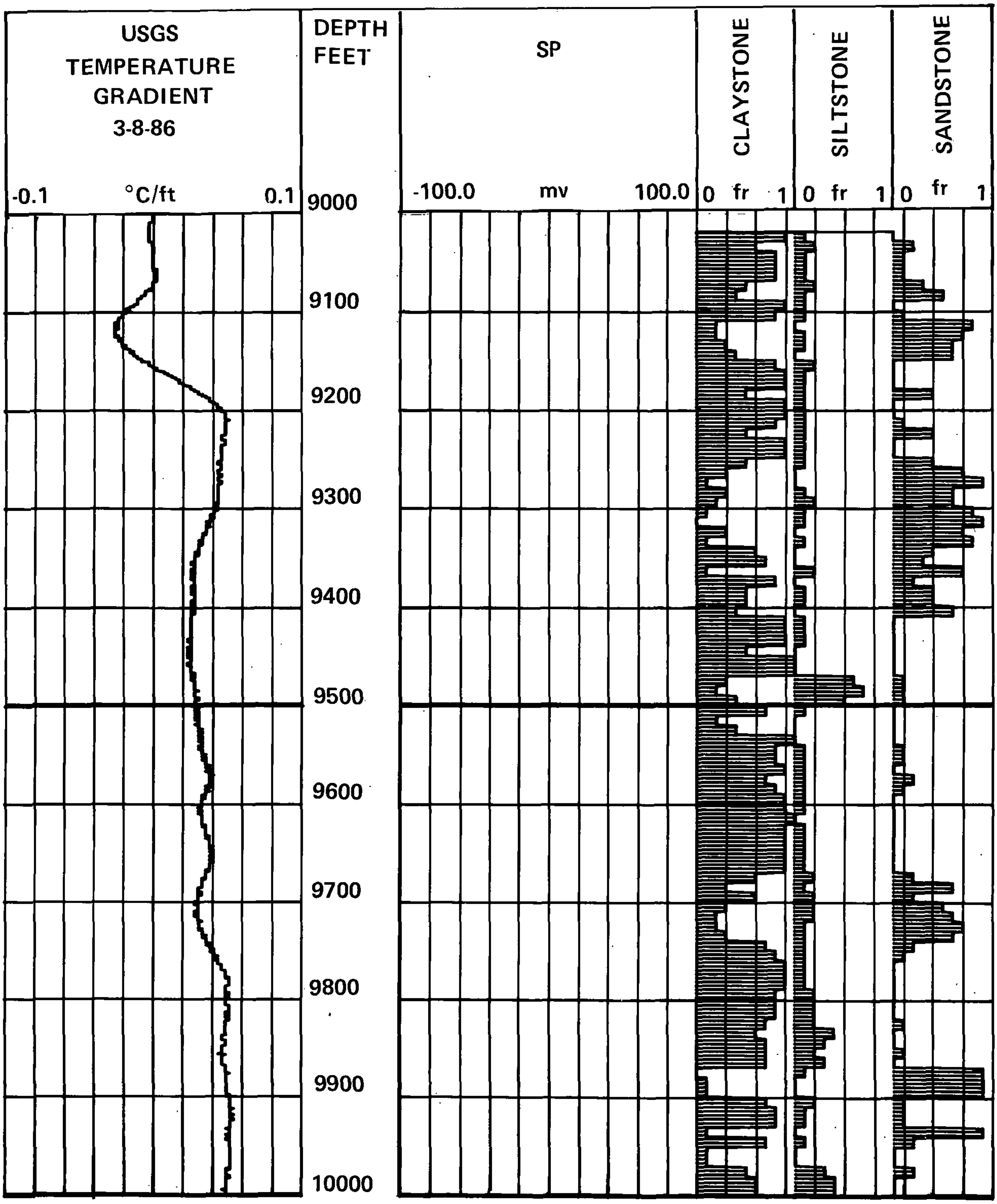


Figure 21.--U.S. Geological Survey temperature-gradient log, commercial spontaneous-potential log, and lithologic log; depth interval 6,000 to 10,000 feet. (Continued)

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

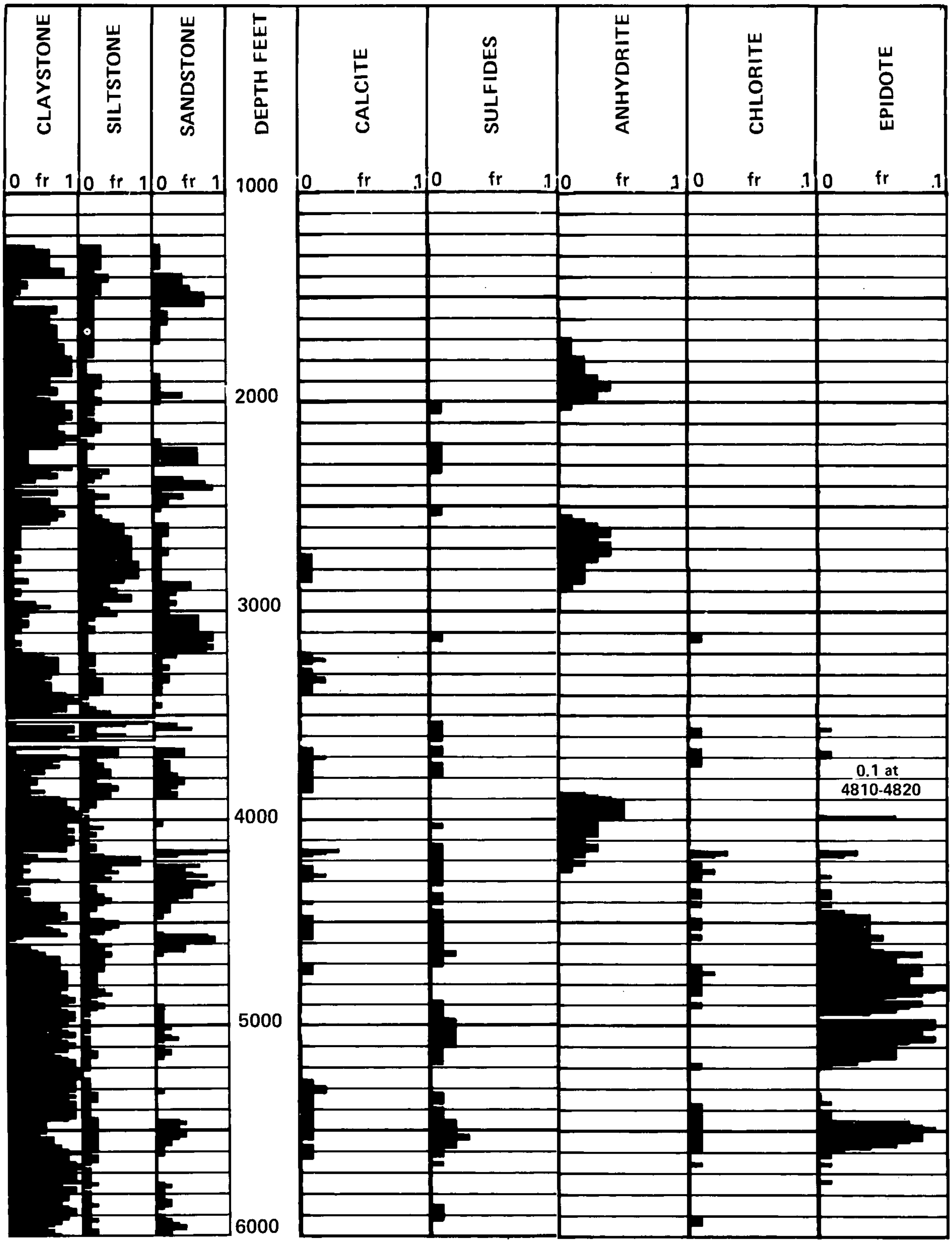
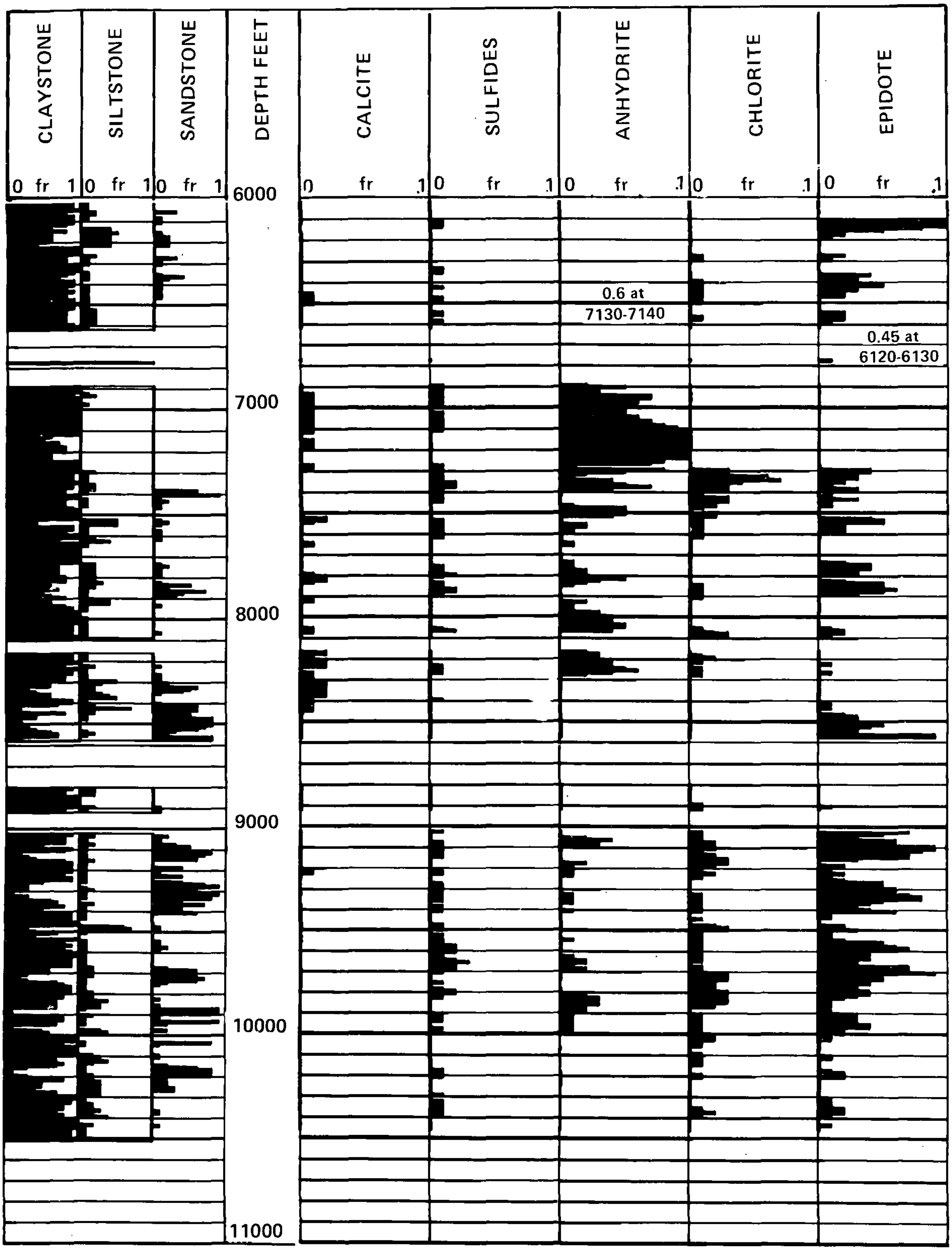


Figure 22.--Log of major and minor lithologic components; depth interval 1,250 to 10,465 feet.

STATE 2-14 SSSDP WELL



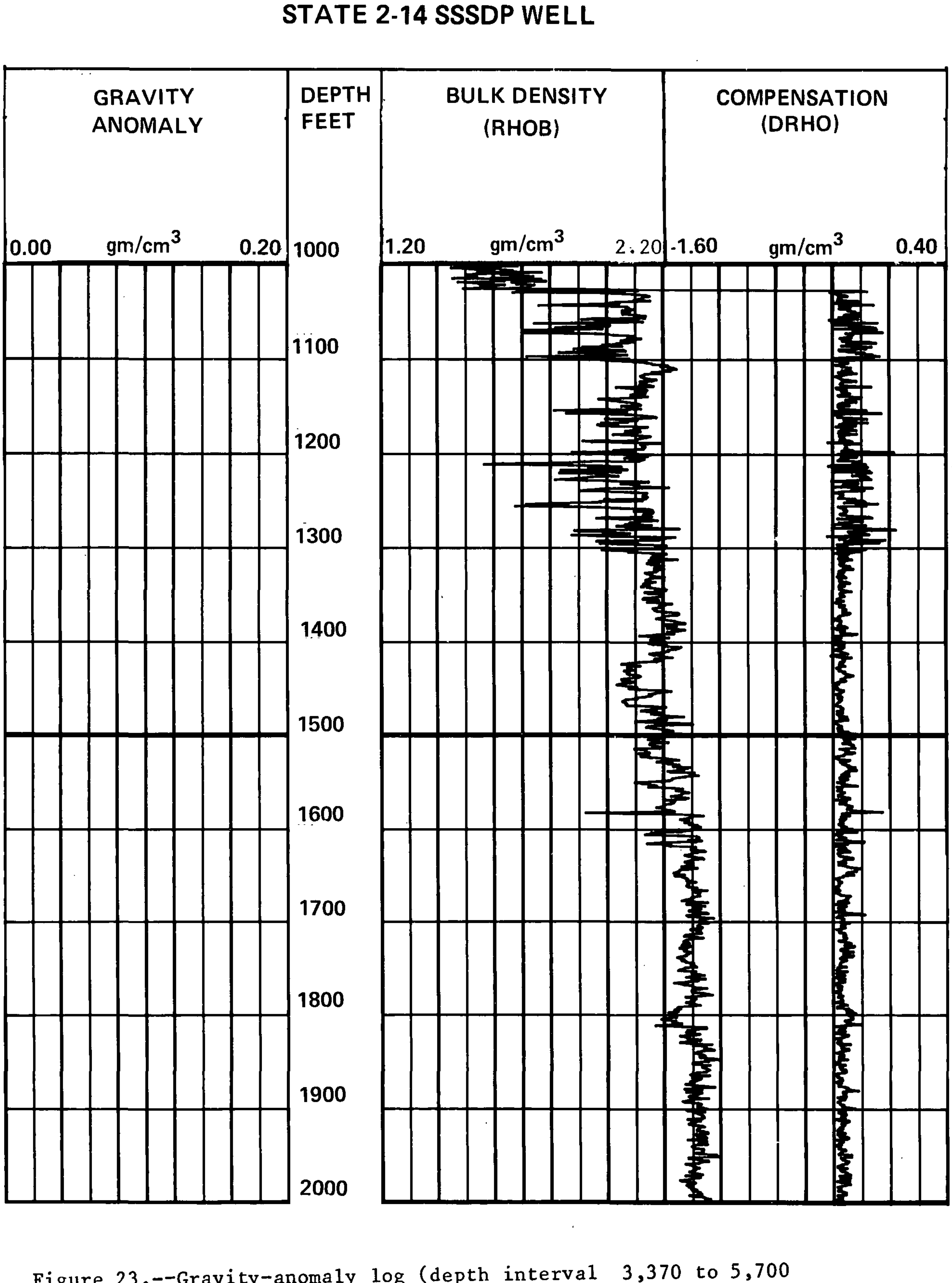
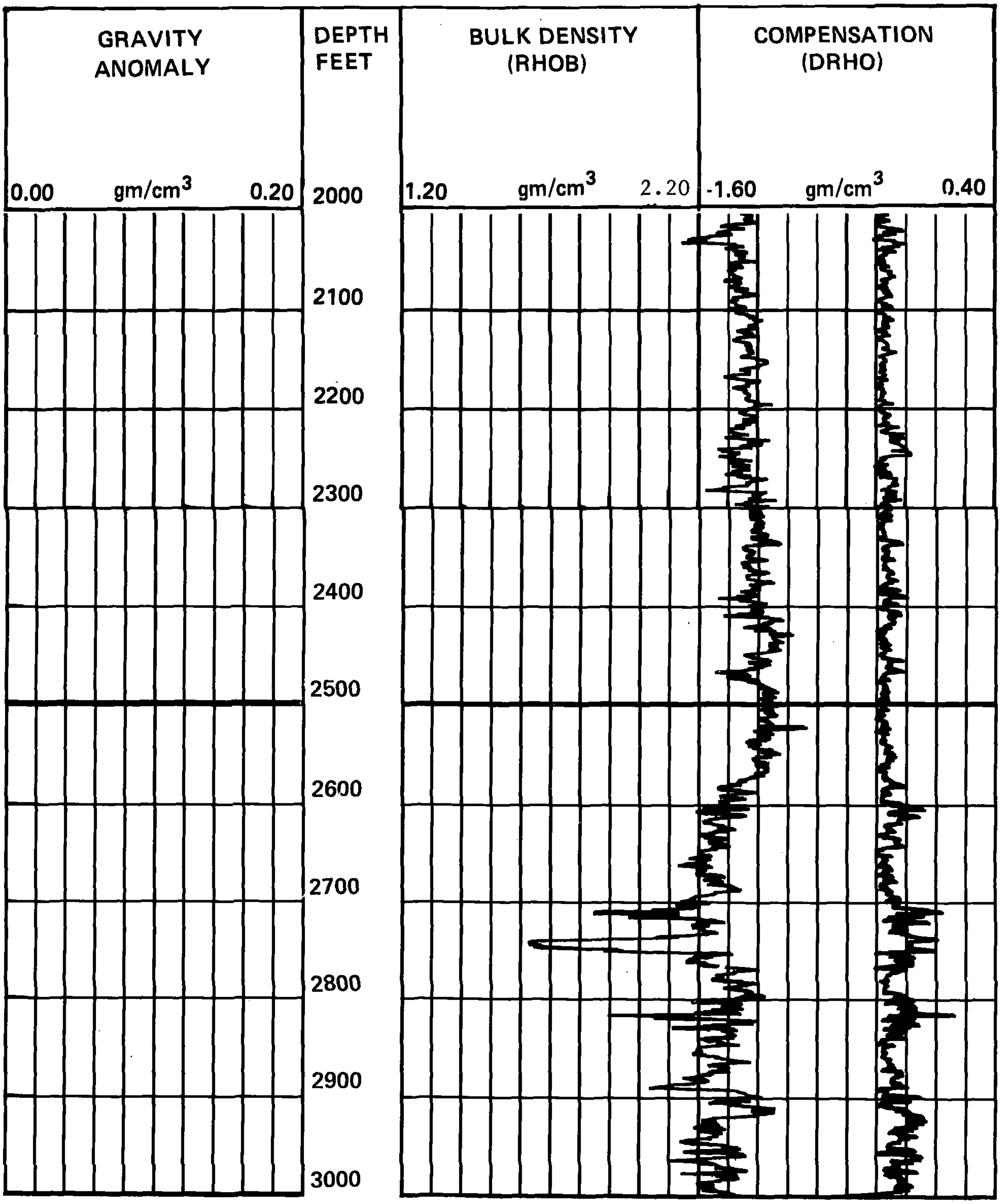


Figure 23.--Gravity-anomaly log (depth interval 3,370 to 5,700 feet) and commercial bulk-density and compensation logs (depth interval 1,000 to 6,000 feet).

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

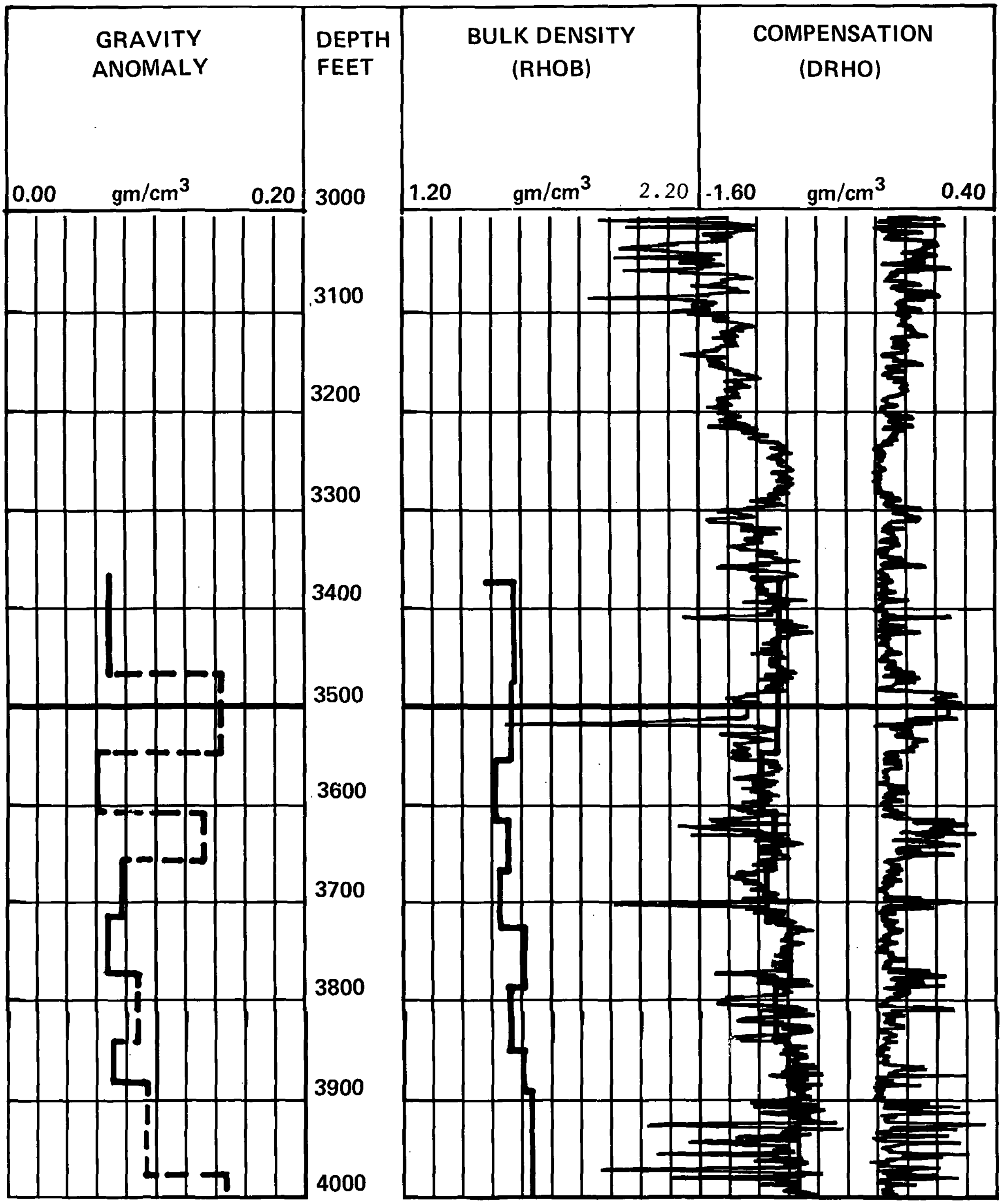
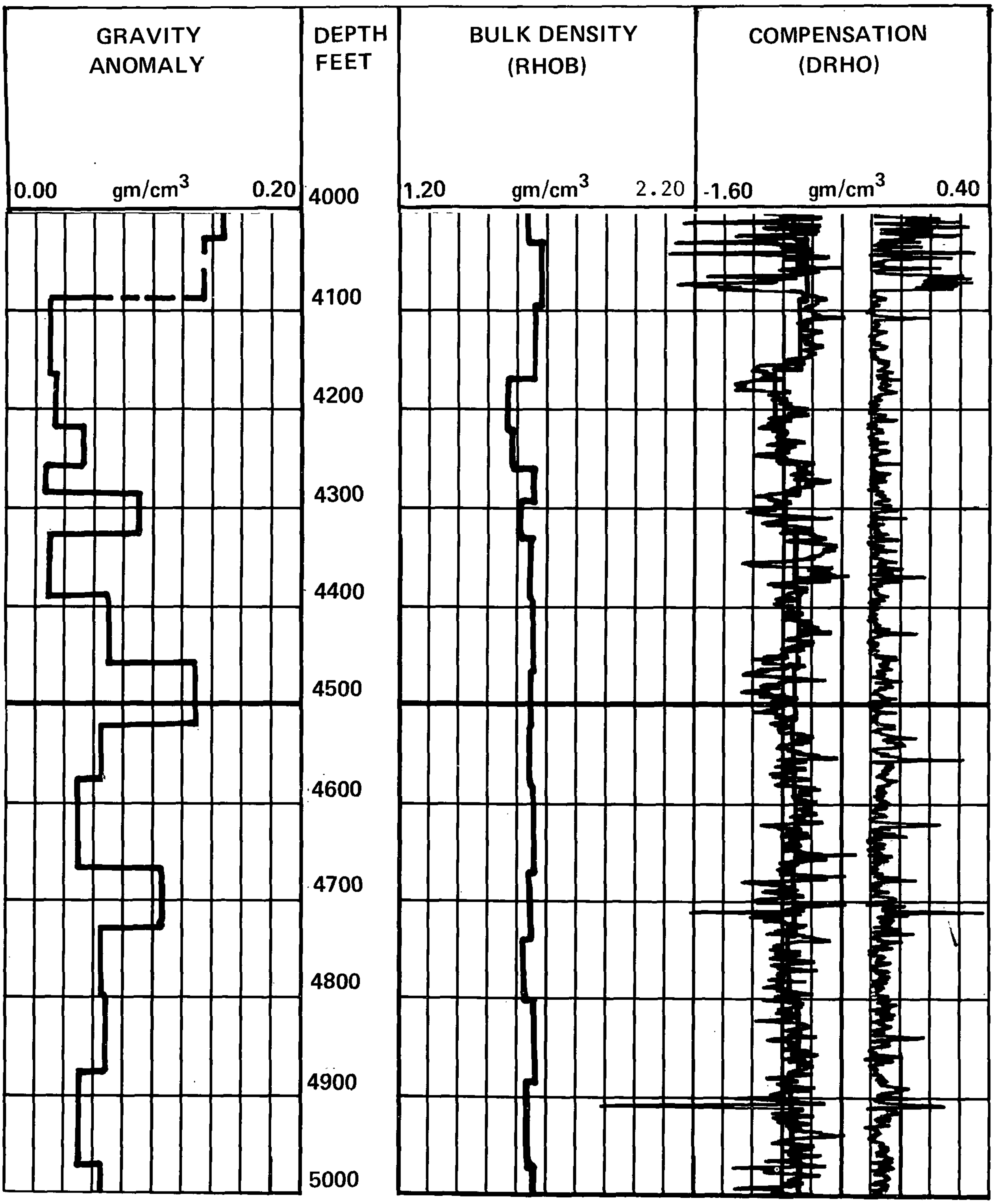


Figure 23.--Gravity-anomaly log (depth interval 3,370 to 5,700 feet) and commercial bulk-density and compensation logs (depth interval 1,000 to 6,000 feet). (Continued)

STATE 2-14 SSSDP WELL



STATE 2-14 SSSDP WELL

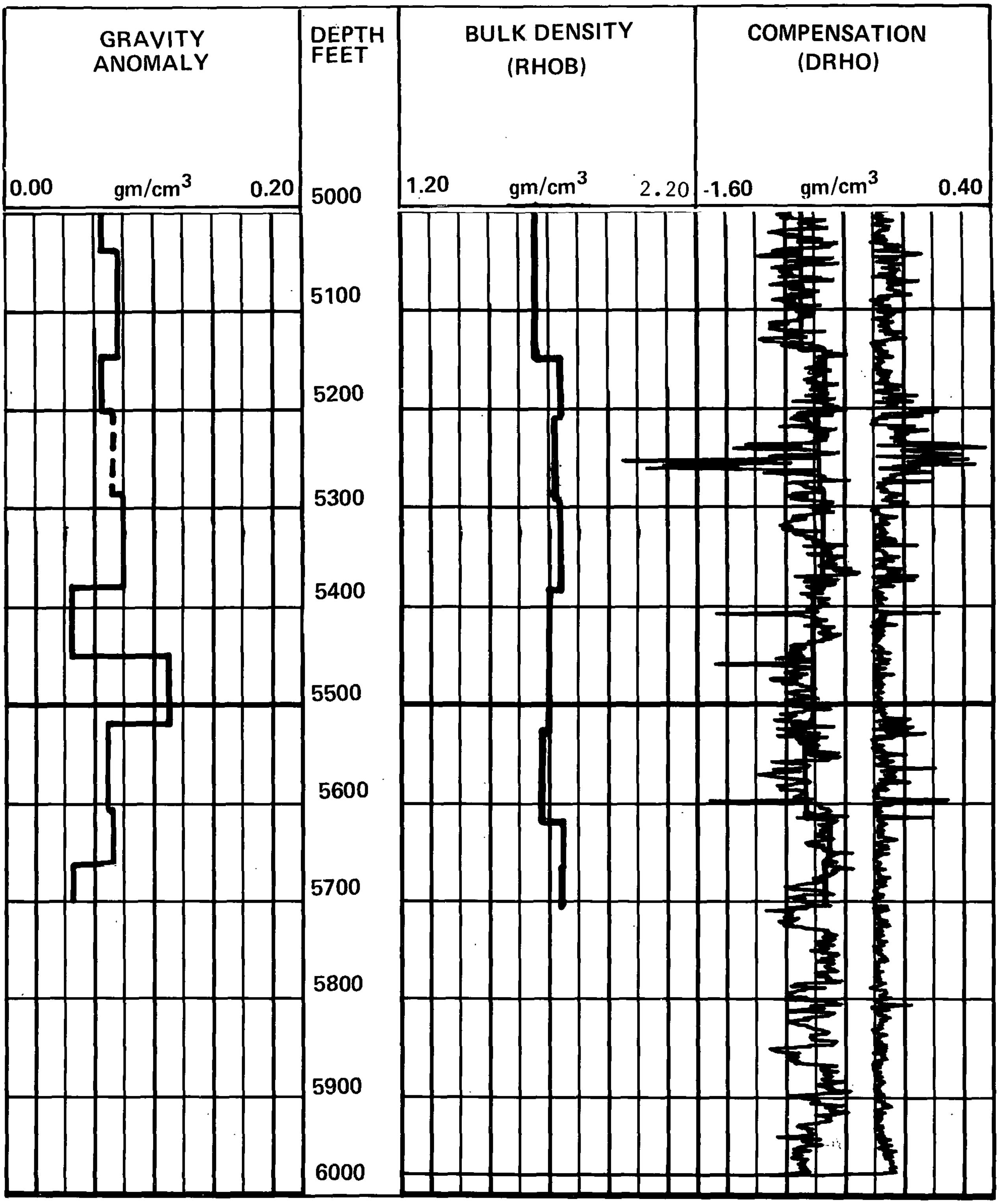


Figure 23.--Gravity-anomaly log (depth interval 3,370 to 5,700 feet) and commercial bulk-density and compensation logs (depth interval 1,000 to 6,000 feet). (Continued)

REFERENCES CITED

Guyod, Hubert, and Shane, L.E., 1969, Geophysical well logging--Introduction to geophysical well logging; acoustical logging: Houston, Hubert Guyod, v. 1, 256 p.

Hearst, J.R., and Nelson, P.H., 1985, Well logging for physical properties: New York, McGraw-Hill, 571 p.

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

Keys, W.S., and Sullivan, J.I., 1979, Role of borehole geophysics in defining the physical characteristics of the Raft River geothermal reservoir, Idaho: Geophysics, v. 44, no. 6, p. 1116-1141.

Mehegan, J.M., Herzig, C.T., and Sullivan, R.M., 1986, SSSDP, California State 2-14 well, visual core descriptions, v. 1: University of California Riverside Publication UCR/IGPP-86/1, 221 p.

Muramoto, F.S., and Elders, W.A., 1984, Correlation of wireline log characteristics with hydrothermal alteration and other reservoir properties of the Salton Sea and Westmorland geothermal fields, Imperial Valley, California: Los Alamos National Laboratory Publication LA-10128-MS, 100 p.

Pirson, S.J., 1970, Geologic well log analysis: Houston, Gulf Publishing Co., 370 p.

Robbins, S.L., 1981, Reexamination of the values used as constants in calculating rock density from borehole gravity data: Geophysics, v. 46, no. 2, p. 208-210.

Sass, J.H., and Elders, W.A., 1986, Salton Sea Scientific Drilling Project: Scientific Program, Geothermal Resources Council Meeting, Palm Springs, Calif., 1986, Transactions, v. 10, p. 473-478.

Seamount, D.T., and Elders, W.A., 1981, Use of wireline logs at Cerro Prieto in the identification of the distribution of hydrothermally altered zones and dike locations and their correlation with reservoir temperature: Third Symposium on the Cerro Prieto Geothermal Field, Baja California, Mexico, 1981, Proceedings, Lawrence Berkeley Laboratory Publication LBL-11967.

*U.S. GOVERNMENT PRINTING OFFICE: 1987-0-774-523/65088