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THE MARYSVILLE, MONTANA GEOTHERMAL PROJECT

W. R. McSpadden and D. H. Stewart
Battelle-Northwest
Richland, Washington

J. T. Kuwada
Rogers Engineering Company, Inc.
San Francisco, California

Drilling the first geothermal well in Montana presented many challenges, not only in securing materials and planning strategies for drilling the wildcat well but also in addressing the environmental, legal, and institutional issues raised by the request for permission to explore a resource which lacked legal definition. The Marysville Geothermal Project was to investigate a dry hot rock heat anomaly. The well was drilled to a total depth of 6790 feet and many fractured water bearing zones were encountered below 1800 feet.

I. INTRODUCTION

The object of the Marysville Geothermal Project is to investigate a region of abnormally high geothermal heat flow near Marysville, Montana, about 20 miles northwest of Helena. The research should determine the nature and size of the resource, how the energy might be extracted, the potential monetary value of the energy, and how similar resources elsewhere might be located. The heat source was expected to be a granitic pluton or magmatic intrusion, 10,000 to 40,000 years old, with temperatures in the range of 300 to 500°C. Originally it was thought that the pluton was at relatively shallow depths, but at present its depth and exact location are unknown.

During the period from 1966 until the beginning of this project in 1973, Dr. David Blackwell, Associate Professor of Geophysics at Southern Methodist University (SMU), made extensive heat flow measurements in the vicinity of Marysville under the sponsorship of the National Science Foundation (NSF) and the U.S. Geological Survey. Heat flow data were obtained from 15 relatively shallow drill holes (less than 1000 ft) which existed in the area as a result of previous mineral explorations. The heat flow from the 15 sites ranged from 3.1 to 19.5 heat flow units (hfu) in $\mu cal/cm^2/sec$. (For comparison, the western Montana average is 1.9 hfu and the worldwide average is believed to be 1.5 hfu.) The maximum heat flow corresponds to a geothermal gradient of 240°C/km. In spite of these extremely high gradients there are no surface manifestations in the form of hot springs or geothermal activities within approximately 20 miles of the site. Consequently, this region is known as a blind geothermal anomaly.

In February 1973 Battelle-Northwest (BNW) submitted a proposal to investigate this anomaly to the NSF for a three-year research project at a cost of approximately $2,100,000. The project was funded in June 1973 by NSF, which allocated $265,000 for CY-73 and authorized $1,780,000 for CY-74.

During the summer of 1973, SMU conducted surveys of the geology, heat flow, gravity, magnetic field, and microseismic noise in the Marysville area. In addition, infrared aerial surveys were conducted by Battelle-Northwest. Heat flow measurements were made in nine additional shallow holes drilled under Dr. Blackwell's direction to obtain a better definition of the size of the heat flow anomaly. By October 1973 the results of these various field surveys enabled the team to pick a site for drilling a deep well. The site selected was approximately 1/4 mile downstream from the Empire Mine and about four miles west of Marysville on land administered by the Bureau of Land Management (BLM). On October 26, 1973 the NSF conducted a review meeting of the project in Helena, which was attended by members of the State and Federal Governments as designated by the NSF. A preliminary report provided to the reviewers at that meeting has now been superseded by a first annual report published in the spring of 1974. As a result of the review meeting, NSF authorized the next phase of the work which was undertaken in CY-74.

Once a decision was made to undertake the new work, Battelle-Northwest and Rogers Engineering Company prepared a draft environmental analysis for the BLM. Additional environmental analyses were conducted by BLM to cover 1974 work only (primarily the drilling of the deep well). BLM determined that no environmental impact statement would be required for CY-74 activities but that a new review would be required for activities beyond that time.

Following the site selection, Rogers Engineering Company prepared site engineering surveys and plot plans for the drilling operations. The necessary Use Permits were obtained from the Bureau of Land Management, the U.S. Forest Service, the Montana State Division of Water Use, and the Montana State Lands Department. Following these activities Rogers Engineering Company prepared specifications for the site construction and drilling of the deep well. For the site construction, the low bid was received from and the contract awarded to the William Miller Construction Company, Missoula, Montana, in April 1974. Similarly, the drilling contract was awarded to the Molen Drilling Company of Billings, Montana, in May 1974.

II. SUMMARY OF DEEP WELL DRILLING OPERATION

The drilling operation was scheduled to begin about June 1, 1974, after surface preparations were completed at the site. Ninety days of drilling were planned to achieve a target depth of 6000 ft. The actual drilling began on June 10 and continued until August 30, a period of 81 days ending at a total depth of 6790 ft, as shown in Fig. 1. Most of the drilling was done with aerated water at rates of 18 to 25 ft/hr. Two major formations were encountered. The upper formation of Empire Shale (metamorphosed shale and quartzite) extended to approximately 975 ft, and the remainder of the hole to depth was in the Empire Stock (quartz feldspar porphry). There is a gradual change in the Empire Stock with depth toward a granite, showing the effects of slow cooling.

The well profile and casing schedule are shown in Fig. 2 along with the 12 major fracture zones.

The Empire Stock is extensively fractured and contains a large volume of water. Water was first encountered at 1525 ft, and major water zones were found at 1912 and 3386 ft. However, the many fractures led to speculation that the water zones are interconnected. All of the fracture zones below 1000 ft appear to contain water, and in some cases we encountered flows in excess of 250 gallons/minute from upper fraction zones into the lower ones. It is not clear to what extent water was injected in lower formations during drilling. In view of all of the geophysical surveys that had been done at the surface, including electrical resistivity and magnetotellurics, large amounts of water had not been expected.

Schlumberger Well Services were contracted to log the hole before the middle-string casing was set to 1326 ft. Later they logged the remainder of the hole. Their logs include:

(1) Bore hole caliper (bhc), sonic, and gamma ray log, which measures the hole diameter, the acoustic velocity, and the natural radioactivity of the rock.

(2) Dual induction laterolog, which determines formation resistivity by eddy current induction and flow of a focused direct current.

(3) Formation density, gamma ray, and caliper log, which determines the formation density, hole diameter, and natural radioactivity.

(4) Compensated neutron log, which measures the formation porosity and hydrogen concentration by means of a neutron source.

(5) Electrical survey, which measures resistivity of the formation.

(6) A 4-arm digital dipmeter, which measures the dip angle and dip direction of fractures and bedding planes by correlating changes of formation electrical resistivity.

(7) Temperature logs with a platinum resistance thermometer.

(8) Water flow logs: open hole spinner, packer flowmeter, and radioisotope.

Results of these logs are now being analyzed.

Cutting of cores was undertaken 18 times during the drilling operations and produced 15 useful cores and 1 set of fragments. The depths at which the 15 cores were taken are shown in Fig. 2 on the left-hand side of the well profile. Despite the use of diamond coring bits, it was still difficult to obtain good cores. Costs for the coring operation were quite high, and we are now estimating approximately $11,000 per linear foot of recovered core. The cores have been cataloged and are now being cut, and scientific analysis is expected to begin soon.

The wellhead equipment, as shown in Fig. 3, is mounted on the 13-3/8-in. casing, which is cemented firmly to the formation to a depth of 1326 ft; in addition the 20-in. surface casing is cemented to a depth of 115 ft. The two gate valves on the wellhead can be opened to allow further scientific activities and measurements to proceed in the hole throughout the winter. In the event of a rapid hole heat-up and an increase in pressures, the 9-5/8 in. casing is free to expand upward into the spool; and the competent cementing jobs on the upper casings are entirely adequate to withstand high pressures. The 9-5/8 in. casing can be removed if the well should later be abandoned or it can be cemented in place if conditions so dictate.

III. WELL TEMPERATURES AND FLOW RATES

Rock temperature measurements were made with difficulty because of water flow in the hole throughout the entire drilling operation. In every case measured to date, the flow has been down the hole with the lower formations taking water from the upper ones. Flows in excess of 250 gallons/minute were encountered prior to setting the casing as shown in Fig. 4. The source of this large flow seemed to be the fracture zone between 3386 and 3410 ft. However, flows less than 50 gallons/minute were believed to originate from the upper parts of the hole, probably from the 1912- to 1936-ft zone. The open hole spinner test was not particularly sensitive to low flows in the large diameter hole, so accurate data above the 3400-ft level was difficult to obtain as indicated by the dotted line in Fig. 4. Data obtained near the bottom of the hole (not shown in Fig. 4) indicate that most of the 250-gallon/minute flow was going back into formation at the bottom of the hole in the fracture zone below 6723 ft. The hydrostatic pressure of this zone was apparently less than that of the upper zones, allowing the downflow of water. Whether the water flow was a local transient condition that would have stopped within a few days or a condition that might exist for a long period of time is unknown. However, the drill stem test did not show any large hydrostatic head difference between the lower and upper zones.

After the casing was set and the cement plug established in the bottom of the hole, flows were significantly reduced as shown in the lower part of Fig. 4. Approximately one gallon/minute is leaking through the perforations in the casing made for the second cement job and flows immediately beneath the casing increased to approximately 10 gallons/minute. Between September 10, when the packer flowmeter test was performed, and September 22, when the radioisotope test was done, an apparent equilibrium took place in a lower part of the hole since the flow at the 5700-ft level reduced from greater than 30 gallons/minute to approximately one gallon/minute. Below the 6000-ft level the flow is zero to the best of our ability to measure it with the isotope test. The last flow test, made on November 17, 1974 (not shown in Fig. 4) with the radioisotope instruments, shows a maximum flow of about one gallon/minute at about 4270 ft. Additional flow tests are planned to determine if further changes are taking place in the hole.

Downhole temperature measurements were made four ways: (a) using Dr. Blackwell's resistance element thermometer, which is limited to maximum depths of approximately 2500 ft and maximum temperatures of approximately 110°C; (b) using the Schlumberger platinum resistance thermometer; (c) a Kuster downhole temperature vs. time recorder; and (d) maximum reading mercury thermometers. Generally the data obtained by Blackwell in the upper part of the hole tends to complement the Schlumberger measurements shown in Fig. 5 and indicates cooling of the formation as drilling proceeded. The apparent erratic behavior of fine details is presumably caused by the in-flow of water from formations before and after the setting of the casing. The logging on September 10 (curve 2) occurred within a few hours after most of the cool water in the mud pit had been pumped back into the hole, and, consequently, cooler temperatures were recorded at that time. Also, two additional Schlumberger logs were made approximately 24 hours after the August 31 log (curve 1), and these agree quite closely with those of curve 3, which were obtained on September 21. Temperatures of curve 1 were obtained before the casing was in place and those of curves 2 and 3 afterwards. Water moving down the annulus between the 9-5/8-in. casing and the hole is affecting the temperature readings in the casing. Below the casing the water flows of approximately 10 gallons/minute are sufficiently high to prevent measurement of the ambient rock temperature, and generally this condition exists down to the 5700-ft level. Water temperatures slightly less than 200°F were obtained throughout this entire region. Maximum temperature thermometer readings over the same region read consistently 200 to 204°F and are probably the most reliable of the measurements. The Kuster instrument was left on the bottom of the hole for 44 hours between September 19 and 21, but it showed no temperature increase above 204°F. Since the flow rates in this region are believed to be zero or very low, it appears that the rock temperatures may not be greatly in excess of 200°F in the immediate vicinity of the hole. However, an additional period of perhaps one month will be required to allow the downhole temperatures to stabilize before valid conclusions can be drawn. Additional temperature measurements will be made throughout the winter months and flow in the bottom of the hole can probably be reduced to zero (if it is not at this time) by the use of wire line packers.

Numerous water samples have been taken throughout the drilling operation at various depths and are now undergoing chemical analyses at the SMU and BNW Laboratories. Although the water samples have been contaminated with soap and lubricants from the drilling operations, they show only 24 parts/million chloride content and, consequently, the water is not saline. Water samples from the upper part of the hole contained less than 1, 500 parts/million total dissolved solids in spite of contamination from the drilling operations. Geothermometer data from silica concentrations indicate a temperature of approximately 250°F, which seems to be consistent in nearly all of the water samples. The potassium, sodium, calcium ratios indicate a temperature of approximately 350°F. The effects of dilution of the underground water by surface water have not been determined. Work on the water samples is continuing and will tie in closely with the chemical analyses of the cores.

In conclusion, downhole temperature measurements made to date indicate temperatures of approximately 200°F, but the hole has not yet reached thermal equilibrium. Studies are planned throughout the winter months.

IV. GEOPHYSICAL SURVEYS, 1974

Geophysical surveys undertaken during the summer of 1974 included geologic mapping of heat flow to the south of the presently explored area and additional gravity, magnetic, and microseismic studies.* Work on these studies began in early May and by mid-June a crew of six scientists and graduate students were working at the field. Four additional shallow holes were drilled to the south in which additional heat flow measurements are being made. Data from all of these geophysical surveys are undergoing analysis at SMU, and conclusions are not yet available. Work on these data will continue throughout the winter months.

V. WINTER 1974-1975 STUDIES

As previously indicated, logging of the well for temperature and flow studies will continue for some time as weather permits. Other studies, which are just now beginning, include: analyses of the cores, geochemistry studies, thermal equilibrium studies, and further analysis of the geophysical data from the surface surveys. Additional studies being considered at this time include regional hydrology, analysis of satellite data, and geophysical model development. If more drilling is contemplated in the region, an additional environmental analysis will be required.

Because many of the results obtained to date were not anticipated, despite extensive geophysical surveys, much information of scientific value is being generated. This information will undoubtedly be useful in the future to help reduce the risk factors in developing new geothermal energy resources.

VI. SPONSOR AND CONTRACTOR IDENTIFICATION

The sponsor of this research is the RANN Division of the National Science Foundation, and the project is under the direction of Dave Lombard. The project total cost is approximately $2,100,000 extending over a three-year period. The prime contractor for this work is Battelle-Northwest at Richland, Washington, under the direction of Donald H. Stewart, Manager of Geothermal Programs, and William R. McSpadden, Project Manager. Rogers Engineering Company of San Francisco, California, is the architectural engineering firm and is responsible for the deep well drilling operations and site construction work. Their work was under the direction of James T. Kuwada, Vice President, and W. F. Bott, Project Engineer. The geophysical surveys were performed by a team of scientists and graduate students from Southern Methodist University in Dallas, Texas, under the direction of David D. Blackwell, Associate Professor, Department of Geological Sciences. Thermal analysis and modeling have been done by Systems, Science and Software of La Jolla, California, under the direction of Russell E. Duff, Manager, Radiation and Fluid Physics Division.

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*For a more complete description of these surveys see the following paper in Session II: D. D. Blackwell, Assessment of the Geothermal Anomaly Near Marysville, Montana.

Additional information on the project can be obtained by writing to William R. McSpadden, Mathematics Building, Battelle-Northwest, Richland, Washington 99352.

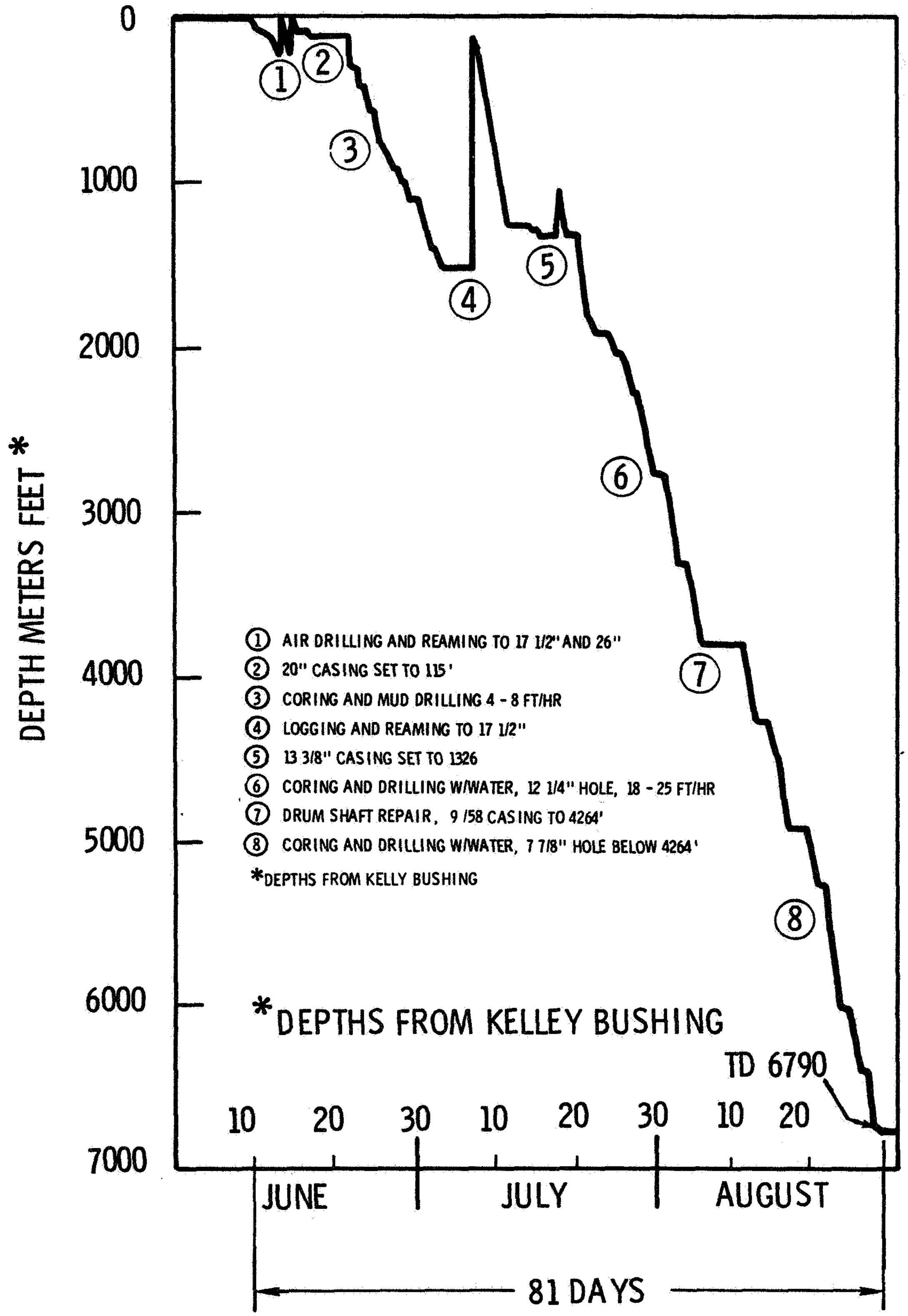

Fig. 1. Marysville Geothermal Project drilling record, well No. 1

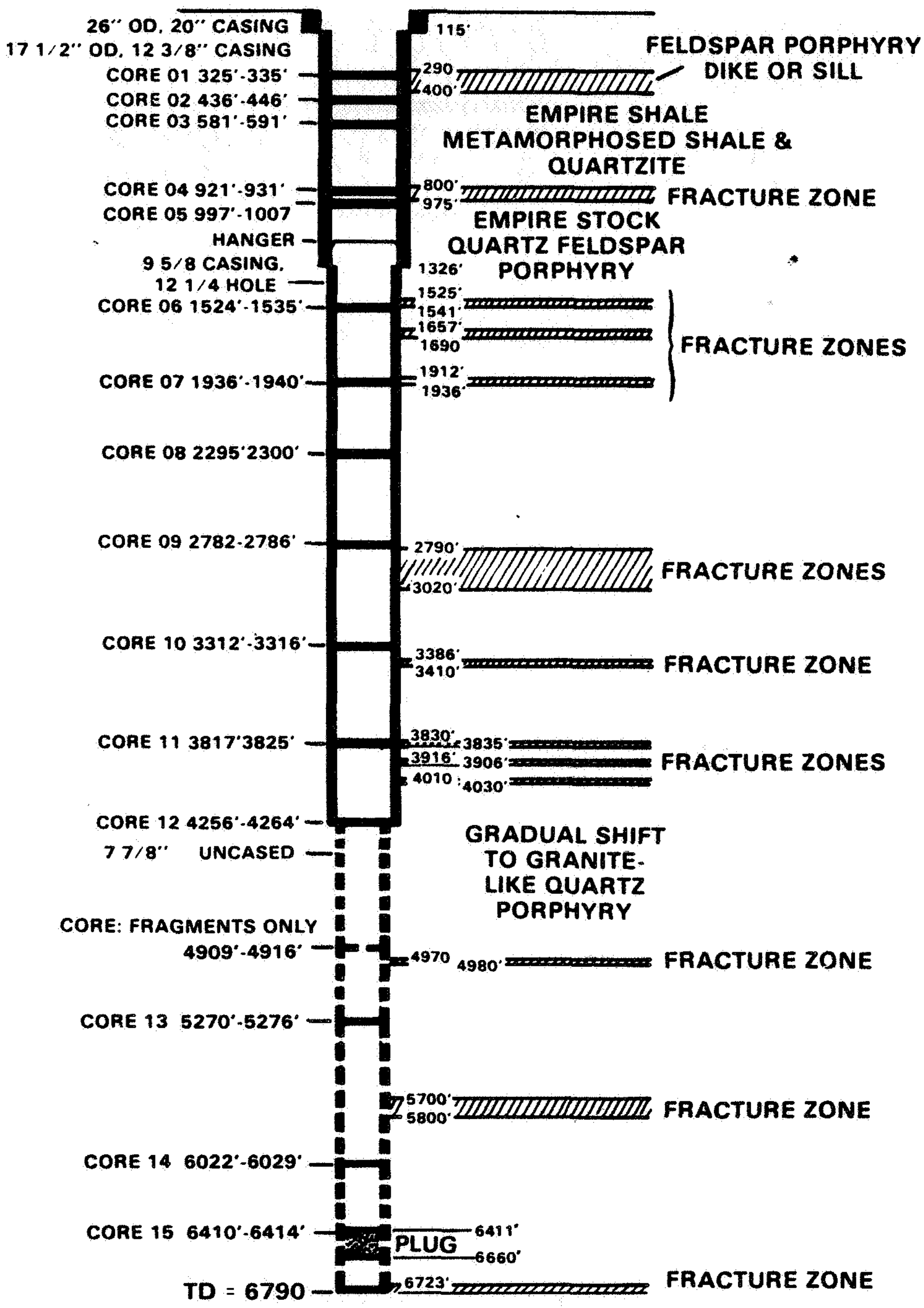

Fig. 2. Casing, coring, and formation data, well No. 1

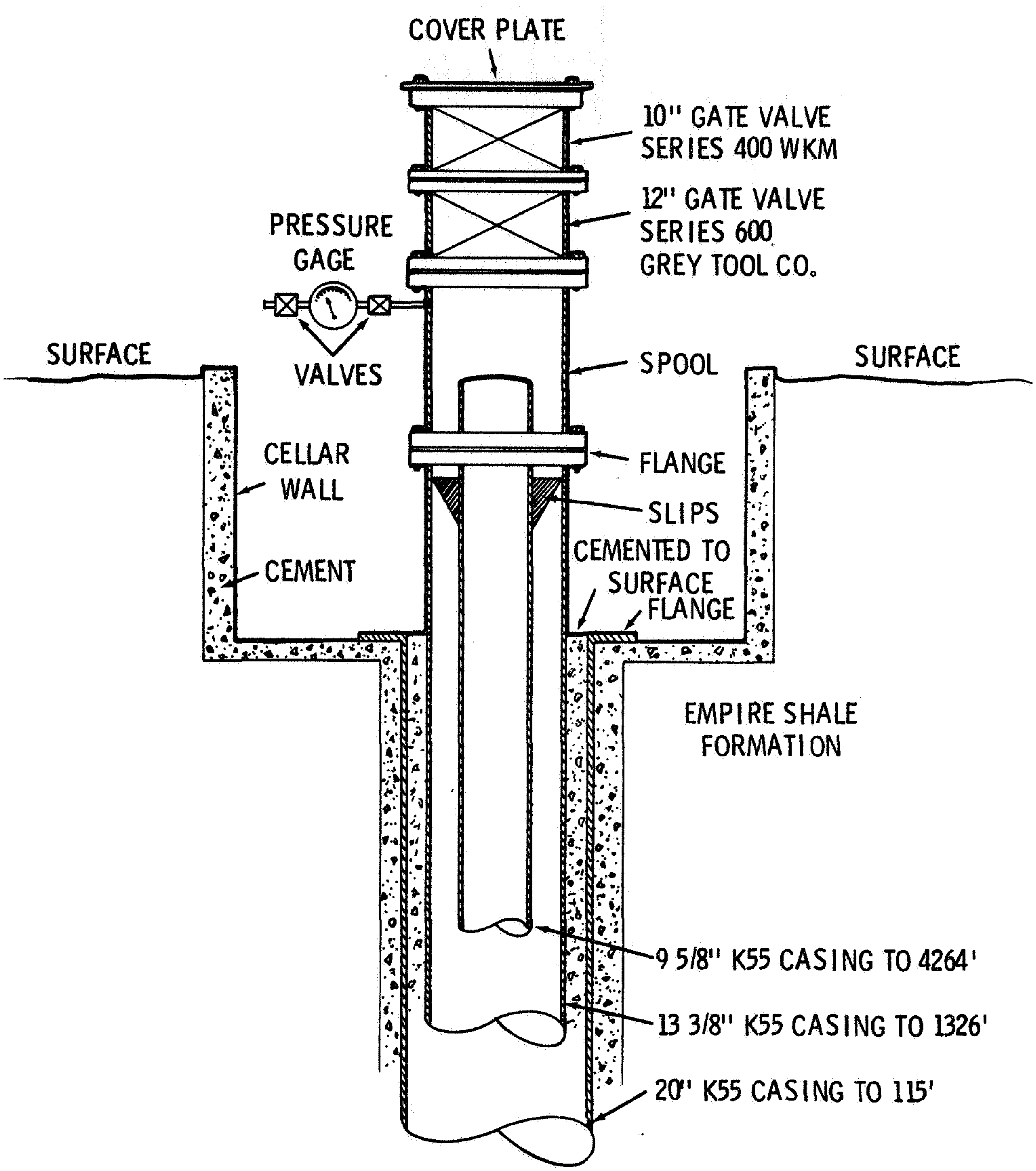

Fig. 3. Wellhead equipment, September 1974

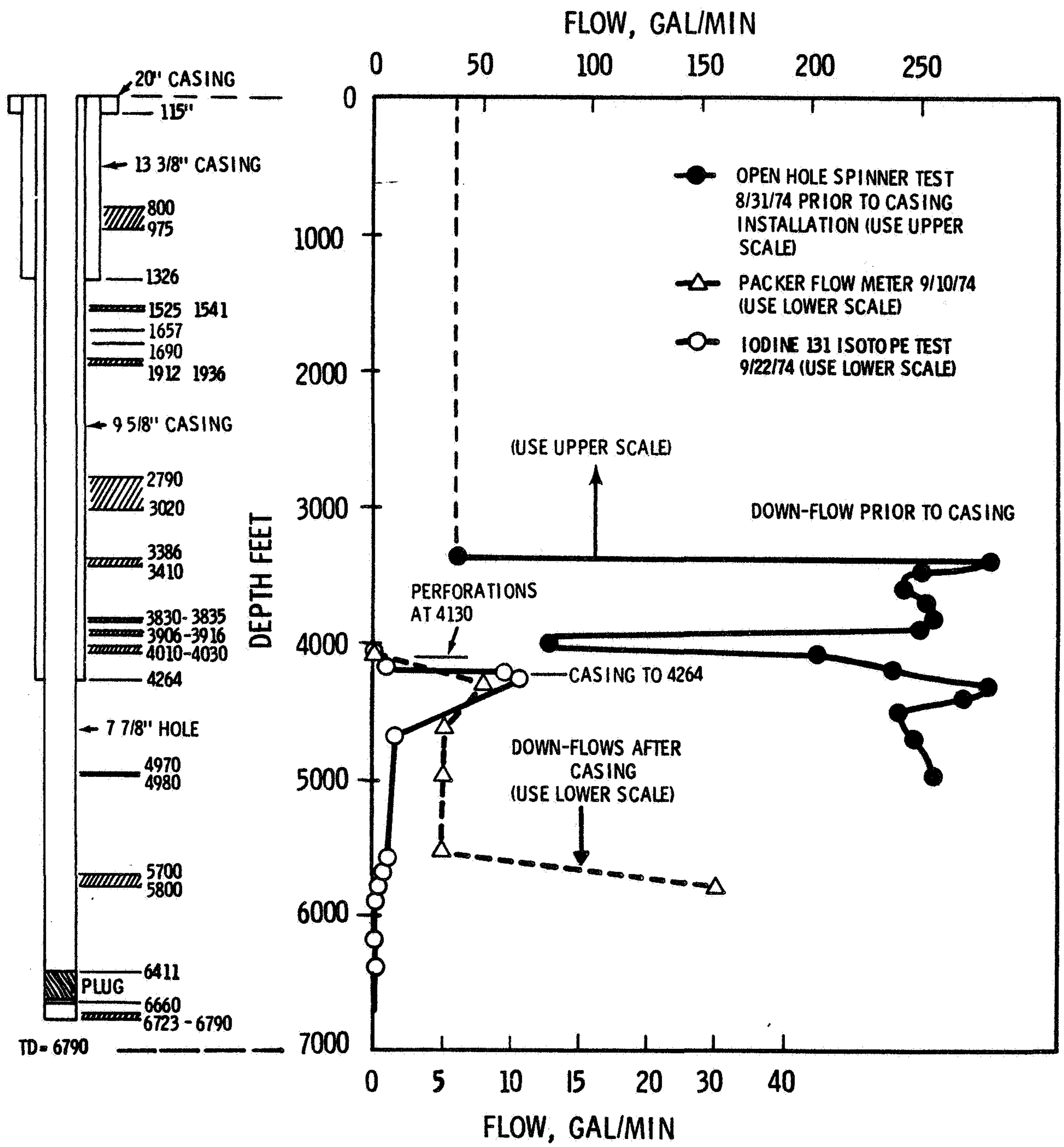

Fig. 4. Flow rates, well No. 1

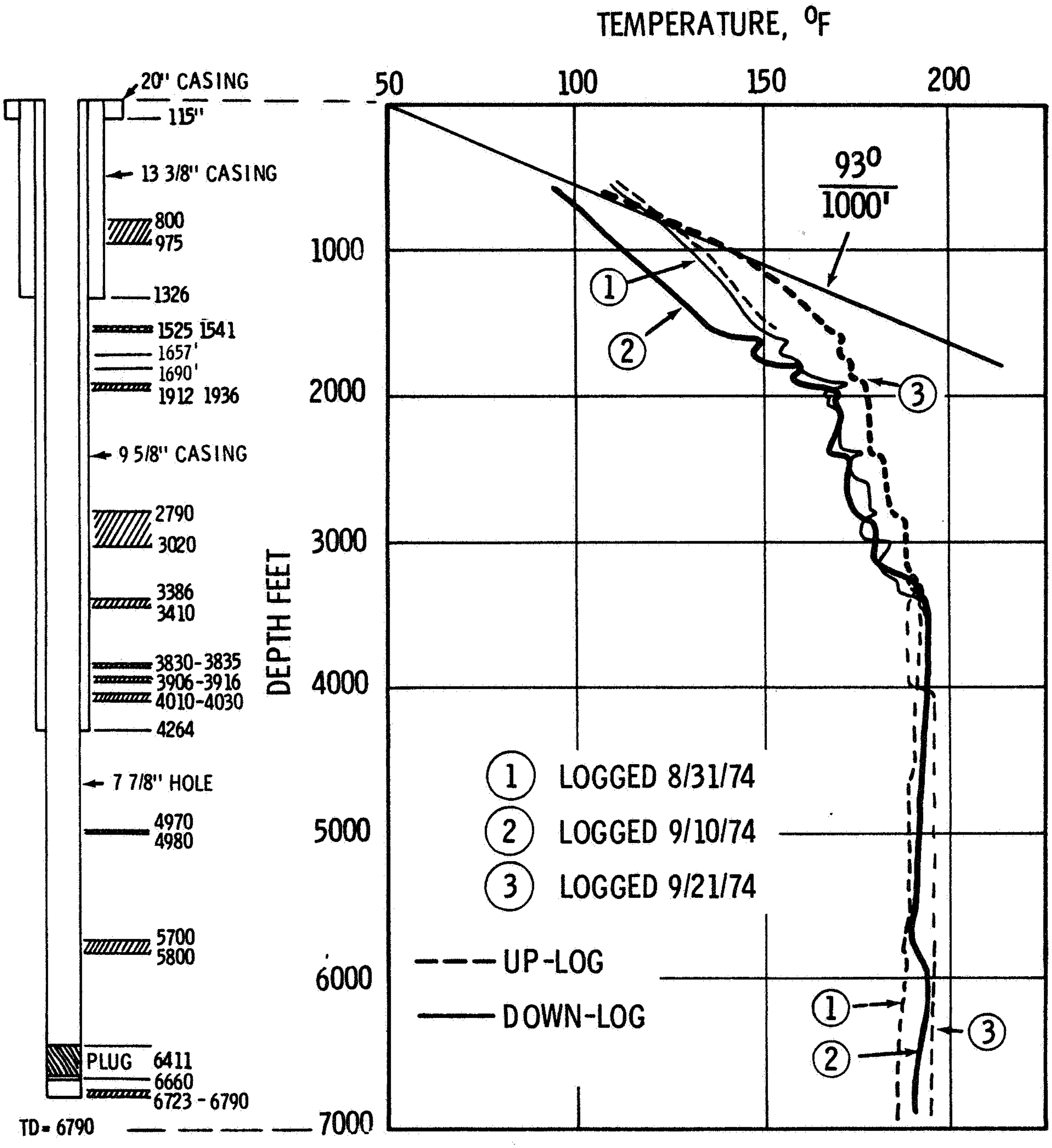

Fig. 5. Well temperatures, well No. 1