logging crews regularly encountered problems which made it difficult to obtain reliable data. The results of both the major and minor logs are discussed in detail in other sections of the report.

The cutting of cores was undertaken 18 times during the drilling operations and produced 15 useful cores and one set of fragments. Of the 115 ft cored, 83 ft of useful cores were recovered. Despite the use of diamond coring bits, coring was difficult and expensive (about $1,636/ft recovered) in these formations. The cores were washed, color photographed and cut for analysis. One complete set of core sections is held in archives by SMU for future reference. The results of the core analysis show steeply dipping veins in both the Empire shale and Empire stock. Rock descriptions were obtained from a microscope study of the cuttings, petrographic studies of thin sections, x-ray diffraction analyses, and from studies of the logs. Detailed descriptions of the cores are given in both Sections C and E.

WELL TEMPERATURES AND FLOW RATES

Rock temperature measurements were made with difficulty because of water flow in the hole throughout the drilling operation. Generally 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 Figure A.4. The source of this large flow seemed to be the fracture zone between 3386 ft 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 ft 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 Figure A.4. Data obtained near the bottom of the hole (not shown in Figure A.4) indicates 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 zone and the 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 Figure A.4. Approximately 1 gallon/minute was leaking through the perforations in the casing made for the second cement job, and flows immediately beneath the casing were approximately 10 gallons/minute. Between September 10, 1974 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 1 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 flow test made on November 17, 1974 (not shown in Figure A.4.) with the radioisotope instruments showed a maximum flow of about 1 gallon/minute at about 4270 ft, which had reduced to about 0.1 gallon/minute by April 1975. *

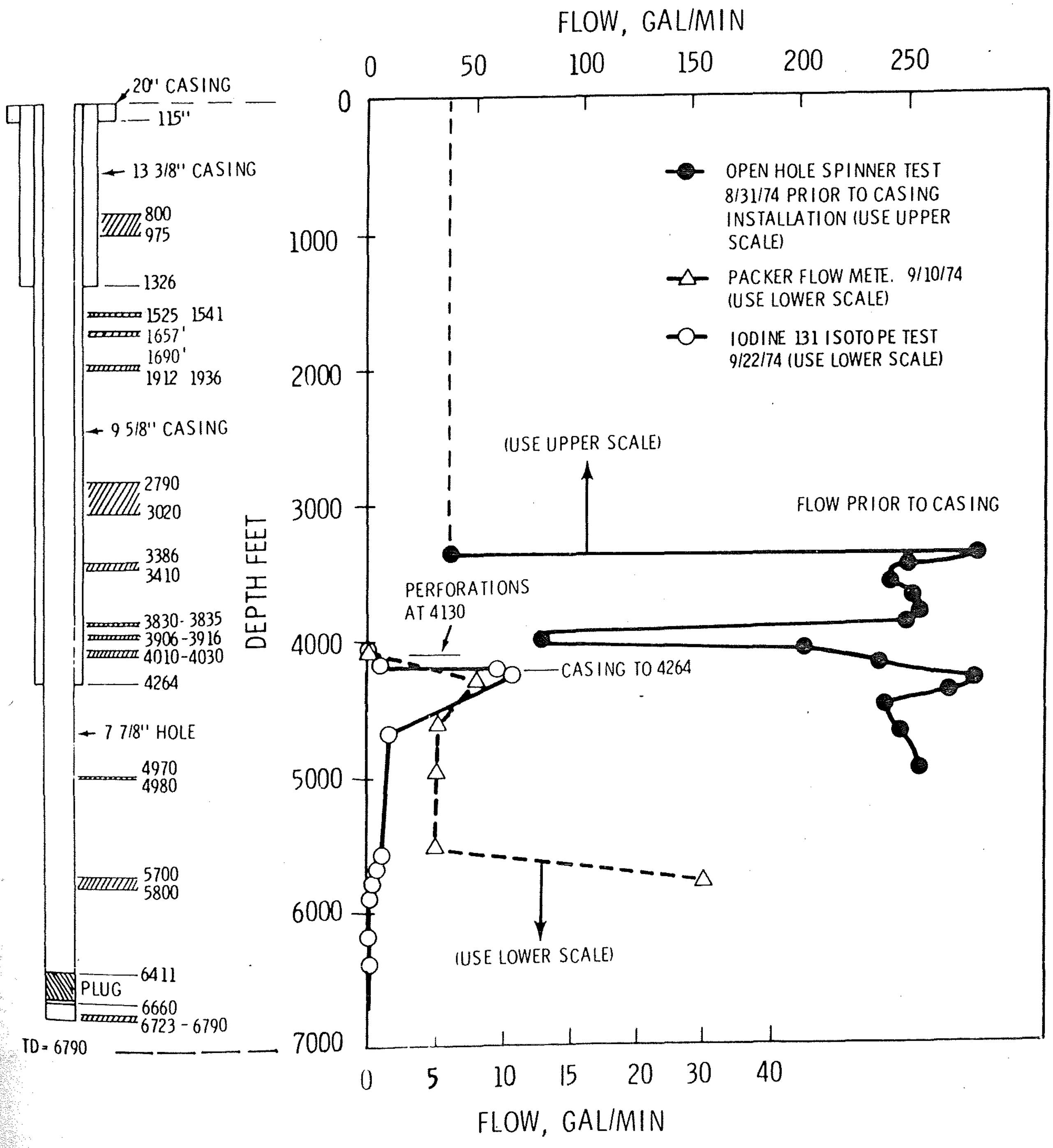

FIGURE A.4. Flow Rates, Well No. 1

The objective of this work was to produce a simulation code that could be run on a minicomputer for possible field implementation. The result was a code, THERMWEL, which was debugged and running at the termination of the project. Unfortunately time and funding limitations did not allow testing and field applications of the code.

The third thermodynamic study was an offshoot of the infrared survey conducted by BNW in September 1973. In that study it was noted that some of the trees over the geothermal anomaly appeared to be hotter than trees in comparable areas. Accordingly ground measurements were made in August 1974 which showed that the trees were indeed 1 to 2°C warmer than expected. Observation of the trees over a period of 12 months showed no significant sign of tree disease or insect infection which might account for the thermal anomaly. It is now surmised that the roots of the trees are obtaining slightly warmer water in the vicinity of the geothermal anomaly, and this difference is seen in the tree canopies. To our knowledge, this phenomenon of a geothermal anomaly has not been reported before, but it would be of interest to examine some of the known geothermal areas for this effect.

GEOPHYSICAL AND GEOLOGICAL SURVEYS

Analyses of the geological, geophysical, and drilling data show that the geothermal system consists of a hydrothermal circulation in fractures in the Empire stock. The reservoir is bounded on the sides by metamorphic rocks and by a Mesozoic granodiorite stock (the Marysville stock) around the Empire stock, and bounded on the top by a relatively unfractured portion of the Empire stock. The area lacks any surface manifestations, such as hot springs, at the hot water reservoir. Despite the circulating water system, it is a region of low ground noise and low seismicity. However, studies of regional seismic activity in 1973 and 1974 show a possible association of the geothermal anomaly and a zone of seismic activity extending toward the southeast approximately to Helena.

Despite the hydrothermal system, the geothermal region showed high electrical resistivity, as determined by the roving dipole method and the deeper penetrating audiomagnetotelluric survey. These results are rather surprising since known geothermal areas generally show low resistivities.

A negative gravity anomaly is associated with the high heat flow, but these are not associated with any magnetic anomaly. The Marysville stock to the northeast of the geothermal region does have a magnetic anomaly, however, which was useful in determining one boundary of the Empire stock.

An infrared survey conducted in September 1973 failed to show the geothermal anomaly. The aerial survey was conducted in two bands, 3-5μ and 8-14μ wavelengths, from an altitude of approximately 10,000 ft above the terrain. Under ideal conditions a heat flow of 20 hfu would produce a temperature rise of about 0.4°C. However, variations due to water vapor in the air, solar variations, changes in ground slope and the effects of trees and other vegetation produced a poor signal to noise ratio. As noted above, some vegetation was found to have a higher than normal temperature. The infrared survey was presented in detail in the First Annual Report (June 1974) and is not repeated here.

Heat flow, correlated with other geophysical surveys, proved one of the most useful techniques for this project. As noted in the paragraph on FY 1974 activities, heat flow was measured at 15 sites prior to 1973, at nine sites drilled in 1973 and at four new sites drilled in 1974. Heat flow and geothermal gradient data were corrected for terrain variations and found to vary from 19.5 hfu (240°C/kilometer) to 3.2 hfu (43°C/kilometer) with rather sharply defined boundaries on the north and east sides (abutting the Marysville stock). Values on the south and west sides diminished more gradually, as did the gravity anomaly. Additional areas of high heat flow may exist to the south, but time and money limitations prevented further exploration here.

Geologic mapping in 1973 and 1974 proved very significant in providing a framework for understanding the geothermal anomaly. These studies consisted of structural geology, metamorphic petrology, neutron activation analysis of the igneous rocks and identification of lithologic units of the Precambrian Belt Series and the plutonic and volcanic igneous rocks. There are at least four major normal faults which may have played a part in the emplacement of the geothermal source. These are generally east-west faults dipping to the south. The mapping identified a dome-like structure that correlates approximately with the high heat flow. The petrology studies indicate that the Empire stock was much larger than suspected and perhaps underlies most of the dome southwest of the Marysville stock.

COST SUMMARY

The total expenditures for the Marysville Geothermal Project to date (September 1975) are $2,240,000, which are detailed in Table A.1. This includes an obligation of approximately $50,000 for plugging and abandonment of the hole at some future date. Site restoration costs are included in this latter figure.

The total footage drilled, including 1556 ft of reaming the upper levels for large size casing, was 8346 ft. Since the direct drilling costs were $633,993, the average linear drilling cost is $76/ft. However, coring costs were high because of very slow cutting rates (0.5 to 4.0 ft/hr) of the diamond coring bits. The 82.5 ft of recovered core cost an average of $1,636/ft.

RECOMMENDATIONS

It is highly probable that other geothermal systems like Marysville exist in the western part of the United States and elsewhere, some of which can be expected to have temperatures high enough for commercial exploitation. Because so much data are available on the Marysville system, it can serve as a testing and research area to help locate and understand similar systems. Accordingly, it is recommended that (a) pump tests be made to determine reservoir production characteristics, (b) additional heat flow wells be drilled to the south of the anomaly to close the heat flow contours and complete the study, and (c) the existing well be held open for research and equipment testing.

With respect to geothermal exploration and national resource assessment programs, many additional wildcat wells will be drilled in the next 10 years. If we use the oil industry's success ratio of about one successful well in 10 tries for

TABLE A.1. Cost Summary of the Marysville Geothermal Project

Geosciences Surveys, Core Analysis and Data Reduction	$ 332,786
Site Preparation and Field Office Operations	107,751
Direct Drilling Costs	633,993
Coring Costs	134,970
Casing, Cement and Wellhead Equipment	196,759
Well Logging and Testing	52,664
Engineering and Drilling Supervision	178,051
Thermodynamic Studies and Infrared Survey	81,924
Environmental Analysis, Fracture Analysis, Logging Analysis	158,866
Project Management	211,700
Drilling Arbitration Costs	33,648
Miscellaneous Other Costs	66,888
Plugging and Abandonment (Estimate)	50,000
Project Total	$2,240,000

geothermal estimation, we can expect a very high ratio at nonproductive wells. Accordingly, research should be pursued to reduce the cost of locating and assessing new geothermal areas. A national program could produce refined geophysical exploration techniques, new drilling and coring techniques, and use of existing slim hole drilling technology as an exploration technique. Better logging service at high temperatures is needed, and the integration of modern computer technology for rapid data reduction in the field should be undertaken. The need for all of these techniques and services was experienced on the Marysville Geothermal Project.

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