Proceedings Seventh Workshop Geothermal Reservoir Engineering
Stanford, December 1981. SGP-TR-55.

GEOTHERMAL RESERVOIR ENGINEERING: THE ROLE OF THE U.S. GEOLOGICAL SURVEY

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Introduction The U.S. Geological Survey has a legislated mandate to assess and inventory the Nation's geothermal resources. Accordingly, principal objectives of the Survey's Geothermal Research Program are: (1) to determine the geologic, geochemical, geophysical, and hydrologic characteristics of all types of geothermal systems; (2) to improve and develop techniques of exploration for and assessment of geothermal resources; (3) to characterize the seismicity, ground deformation, and hydrologic changes that may be induced by the production of geothermal fluids and their subsequent injection back into the subsurface; and (4) to determine the amount of geothermal energy that exists as a national resource and periodically to update this assessment as new information becomes available. Research that addresses objectives 1, 2, and 3 is designed to provide information that permits an increasingly accurate assessment of the Nation's geothermal resources.

Reservoir-Related Research Since its formal establishment in 1971, the Survey's Geothermal Research Program has supported field, laboratory, and theoretical studies in geology, geophysics, geochemistry, and hydrology. Duffield and Guffanti (1981a,b) have recently sumnarized the history of the program from 1971 through 1980. The program's broad-based, multidisciplinary character reflects the fact that any comprehensive understanding of geothermal systems requires studies of rocks, fluids, and a host of canplex interactions between the two. If reservoir engineering, the subject of this workshop, is defined in a broad sense to include all studies that either directly or indirectly help to characterize a geothermal reservoir, most of the research of the Survey's Geothermal Research Program addresses some aspect of today's topic.

Some of the Geological Survey's geothermal research is quite directly related to reservoir engineering. Laboratory experiments, development of theory, and computer-assisted numerical modeling have attempted to describe the characteristic behavior of a vapor-dominated hydrothermal system; computer-assisted numerical modeling has also been applied to hot-water and two-phase hydrothermal systems. Precise measurement of ground deformation at The Geysers, California, has suggested a correlation between steam production and subsidence. Similarly, precise measurements of gravity at The Geysers have suggested a correlation between steam production and changes in the strength of the gravity field. Research in well-logging equipment has resulted in development of an acoustic televiewer that can map the size, orientation, and position of fractures in high-temperature geothermal boreholes. Laboratory measurements of the electrical and magnetic properties of rocks under simulated geothermal conditions help constrain all modeling of geothermal reservoirs.

Geologic studies of the Survey's Geothermal Research Program have provided information on the nature of the heat source, the lithology of reservoir rocks, and the inferred nature of permeability for several geothermal systems. Several geoelectric techniques have been used to map the electrical conductivity of the crust and upper mantle; relatively deep probing techniques have provided information on heat sources, and shallower probing techniques have helped to outline the size and position of geothermal reservoirs themselves. Research using active and passive seismic techniques has identified crustal zones of low seismic velocity that may reflect the presence of magma, has outlined structures important to delineating geothermal reservoirs, and has discovered apparent anomalies in the elastic properties of rocks that may constitute geothermal reservoirs. Monitoring of seismicity at The Geysers has shown a correlation between areas of steam production and small-magnitude earthquakes. Measurements of temperature gradient and thermal conductivity in crustal rocks have delineated several broad regions of characteristic and differing heat flow and have provided considerable information on the thermal budget of specific hydrothermal convection systems. Hydrologic studies have defined the water budget of some geothermal areas and, coupled with chemical analyses of waters, have provided a powerful tool for defining the origin and tracing the general path of fluids in hydrothermal systems.

Geochemical study of fluids probably has been the most fruitful single area of research for characterizing hydrothermal systems; many widely used geochemical techniques have been pioneered by the Geological Survey. The chemistry of surface fluid samples has been used to discriminate between vapor-dominated and hot-water systems, to estimate subsurface temperatures, to constrain the possible origins of fluids and their recharge areas, and to estimate the residence time of fluids in many hydrothermal systems. In recognition of their cost-effective exploration potential, a variety of chemical geothermometers are used in the early stages of geothermal evaluation worldwide. Techniques have also been developed to adjust geothermometer temperatures for dilution of thermal water with cool shallow ground water during convective flow to the surface. Analyses for deuteriun, oxygen-18, and tritium commonly are used to estimate the origin and residence time of hydrothermal fluids. Current research holds some promise for developing additional means of estimating residence time, through analysis of various radionuclides in hydrothermal fluids. Moreover, geochemical monitoring of fluids from areas under production--for example, at Larderello, Italy, and Cerro Prieto, Mexico--has provided considerable insight into the functioning of geothermal reservoirs; time-dependent changes in the composition of produced fluids, especially when considered together with such more traditional production data as temperature and pressure, provide information critical to successful long-term exploitation strategies of such reservoirs. Duffield and Guffanti (1981a,b) have sumnarized the findings of other Geological Survey research that addresses various aspects of geothermal reservoirs.

Research Trends Field-oriented studies of geothermal reservoirs may conveniently be grouped into surface (including shallow heat-flow drilling) and subsurface categories. With rare exception, the Geological Survey's geothermal research has been of the surface variety. Recent research drilling, however, reflects program policy to seek opportunities to make measurements in and study samples from boreholes. Geological Survey research drilling funded by the U.S. Department of Energy demonstrated in July 1981 a potential geothermal resource for nonelectrical use in the vicinity of Mount Hood, Oregon; a pumping test produced 380 L/min from an 80°C aquifer at about 1,200-m depth. At Newberry caldera, Oregon, research drilling funded and carried out by the Geological Survey in 1981 discovered a 265% permeable zone in the bottom few meters of a 932-m-deep borehole; a 20-hour flow test from this zone produced a sample of geothermal fluid whose chemical analysis should provide considerable information on the composition and thermodynamic state of the reservoir fluid. The recovery of nearly continuous core from the Newberry hole provides abundant opportunities for studies of the reservoir and overlying rocks.

Such sampling of reservoir fluids and rocks is the most direct way to test inferences made from surface studies. The Survey's Geothermal Research Program is philosophically comnitted to seeking opportunities for research drilling that make this type of direct sampling possible. The Survey plays an active role in promoting the goals of the Continental Scientific Drilling Committee of the U.S. National Academy of Sciences, specifically the proposal of this organization's Thermal Regimes Panel to drill into the roots of a hydrothermal system at roughly 500°C and 6- to 7-km depth. Research drilling into increasingly hotter and deeper parts of geothermal reservoirs may be the tool needed for major advances in our understanding of hydrothermal systems.

References

Duffield, W. A., and Guffanti, Marianne (1981a), The Geothermal Research Program of the Geological Survey: U.S. Geological Survey Open-File Report 81-564, 108 p.

------ (1981b), The Geothermal Research Program of the Geological Survey: U.S. Geological Survey Circular, in press.