rock saturated with fluids of thermal conductivity ranging from high to low. Many attempts have been made to obtain these values by measurement and by computation. Much of the data in the literature is inconsistent in that a mathematical or physical model developed by one author to explain the results of a particular set of experiments does not fit the results found by another author.

It is shown that much of this inconsistency can be removed if proper account is taken of some errors which are frequently, and reasonably, ignored for water-saturated rocks but become increasingly important for rocks saturated with low-conductivity fluids such as oil, air, or steam.

The experimental results are in reasonable agreement with a modified Maxwell model for thermal conductivity.

Electrical Exploration of Geothermal Systems in North Central Nevada

HARRY BEYER, H. FRANK MORRISON, AND ABHIJIT DEY

A program of geological, geochemical, and geophysical exploration of four geothermal areas in north central Nevada has been undertaken by the Lawrence Berkeley Laboratory and the University of California at Berkeley. Of primary importance to this program are electrical methods of exploration, which have demonstrated their usefulness in delineating geothermal reservoirs elsewhere in the world. Collinear telluric profiling and bipole-dipole resistivity have been compared and evaluated with regard to ease of data collection and ability to resolve areas worthy of more concentrated study. Over 65 line km of telluric measurements (with dipole lengths of 250 or 500 m) have been made in one of the areas alone, while the largest bipole-dipole survey has covered an area of 250 sq km with roving dipoles for two transmitter bipole locations. Areas of interest have been detailed with collinear dipole-dipole profiles using dipole lengths between 250 and 1000 m and dipole separations up to ten km. Two-dimensional modeling programs have been used to interpret these data. The telluric profiles appear to be as useful as the bipole-dipole but allow considerable saving of field time.

Methods of Microearthquake Location and Magnitude Determination: A Comparative Study for Use in Geothermal Exploration

PAUL LARRY BROWN, KEN CARLSON, AND DAVID BUTLER

The utility of microearthquake detection in geothermal exploration has been established by others. This paper addresses the problem of location of these very small events when they are detected on 1 to 8 seismic stations in areas with poor velocity control. A comparative study of both the accuracy and precision of various location methods is given using examples from a Nevada geothermal survey funded by NSF.

A method of magnitude determination based on amplitude and duration was used to assess the seismicity of the area surveyed. The seismicity of an area can be established if a large number of events are recorded and if magnitudes are assigned to the events detected. When a commercial geothermal reservoir is found, careful monitoring of seismicity is necessary to establish the effect of fluid withdrawal and reinjection on the active tectonics of such regions.

Seismology and Geothermal Exploration

DAVID BUTLER, KEN CARLSON, AND PAUL LARRY BROWN

Economic geothermal resources occur in regions of current tectonism. One indicator of such geologically active areas is a high relative level of seismicity which manifests itself as a large number of small earthquakes. An array of ground-motion sensors operated at very high gains ($1 - 10 \times 10^6$) and with time resolution of milliseconds can be used to detect and locate seismic events of interest in geothermal exploration. Digital tape recording of the data allows cross-correlation of events and their precise location via a generalized inverse least-squares method. Funds provided by NSF have allowed the recording of microearthquake data near the Black Rock Descart area of Nevada. Results of the survey can be interpreted to indicate favorable areas for development of geothermal resources.

Investigations of the Geothermal Problem by Geoprobe EMR-14 and Dipole-Dipole Resistivity Measurements

MRINAL K. GHOSH, PHILIP G. HALLOF, AND BRUCE S. BELL

Geothermal zones are electrically very conductive due to the high temperature and salinity of the fluids and the high porosity of the enclosing rocks. Resistivity values are 0.1 to 5 ohm-m. The undisturbed medium has a resistivity between 5 to 1000 ohm-m. Geoprobe EMR-14, a multi-frequency EM induction system, and a dipole-dipole resistivity system were used for electrical resistivity measurements to detect geothermal energy sources in the southwestern U.S. The undisturbed medium was conductive clay containing brine solution. This restricted the depth of penetration, particularly in the dipole-dipole system. The depth and resistivity information obtained from the dipole-dipole survey was approximate because the ground had been averaged over a large electrode separation. The Geoprobe system was found to be very practical for investigating a large area for geothermal sources.

Toward Estimating a Regional Geothermal Resource Base for Iceland: A Status Report

JOHN F. HERMANC
AND AXEL BJORNS

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Deep Electrical-Resis with "Dry" Geoth Mexico

GEORGE R. JIRA
PAUL R. KINTZI

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JOHN F. HERMANCE, RICHARD THAYER, AND AXEL BJORNSSON

The exploitation of geothermal resources on a regional scale should hinge on the fundamental question of how surficial manifestations of hydrothermal activity such as hot springs and steam fields are related to deep-seated thermal processes in the crust and upper mantle beneath tectonically active regions. This report summarizes the status of a joint research program of Brown University and the National Energy Authority of Iceland which is focused on studying this question. Iceland occupies a tectonic setting where processes related to crustal spreading at mid-ocean ridge crests are currently active, hence this research may serve as a guideline for similar programs elsewhere.

In particular, we have developed the following strategy in attacking this problem from the geophysical viewpoint: *first*, to estimate the regional variance of electrical resistivity in the crust and upper mantle through broad-scale, regional electrical surveys; *second*, to employ the regional resistivity interpretation for assessing the regional geothermal resource base (defined as the total heat energy stored in the crust); and *third*, to investigate the manner in which the *regional* geothermal resource *base* becomes concentrated in *localized*, exploitable hydrothermal *reservoirs* through placing *geometrical constraints* on the subsurface boundaries of representative hydrothermal reservoirs.

This paper contains a review of reconnaissance field methods employed and aspects of our current electrical resistivity interpretation which have a direct bearing on estimating the regional variance of the geothermal resource base; in essence, we review the status of the *first* stage of our strategy. The status of the third stage of our strategy is summarized in another paper presented at this meeting (Thayer and Hermance). The authors describe progress in modeling crustal features associated with what, from surficial indications, appears to be a highly productive hydrothermal reservoir in north-central Iceland.

Deep Electrical-Resistivity Investigations Coupled with "Dry" Geothermal Experiments in New Mexico

GEORGE R. JIRACEK AND PAUL R. KINTZINGER

A deep electrical-resistivity survey was conducted in the Jemez Mountains of New Mexico in conjunction with the hot dry-rock geothermal test well drilled by Los Alamos Scientific Laboratory. The 1935.5-m well penetrated a sequence of volcanic and sedimentary rocks overlying Precambrian basement which was encountered at 733 m. Bottom-hole temperature was approximately 140°C. Resistivity reconnaissance in the vicinity was accomplished by use of the bipole-dipole technique with a source located 5 km from the drill site. Dipole-dipole surveys were also carried out along two traverse lines which intersected the drill site and extended 3 km on either side of it. Shallow Schlumberger soundings were centered at transmitter and receiver electrode locations 500 m apart along these lines. Deep-resistivity soundings were modeled from the shallow measurements and borehole resistivity logs obtained from the drillhole. Final interpretation of the field results was achieved by use of generalized inversion techniques. The sedimentary section of over 650 m thickness is characterized by resistivity averaging less than 20 ohm-m, whereas the Precambrian section is highly resistive, with average values of about 1000 ohm-m. Repetitions of the deep-resistivity measurements were used in an attempt to detect the subsequent formation of water-filled, hydraulically produced fractures in the Precambrian section.

Drilling at the Summit of Kilauea Volcano

GEORGE V. KELLER

A borehole has been drilled to a depth of 1262 m beneath the summit of Kilauea Volcano on the island of Hawaii. The purposes were two-fold: to obtain engineering information related to the possible occurrence of geothermal energy in a basaltic volcano and to obtain scientific information about the internal nature and workings of Kilauea Volcano. Because the location of the borehole is within Hawaii Volcanoes National Park, the drilling could not have the production of steam as its objective. Accordingly, the drilling program was carried out in a manner intended to minimize the chance of a steam eruption and maximize the chances of gathering scientific information. The fact that the borehole was drilled without encountering any significant difficulties is in itself a measure of success. It was found that the interior of the volcano was not nearly as inhospitable an environment as some people anticipated. In fact, the only difficulties met in drilling were related to the remoteness of the location from normal sources of supply. Although there are numerous occurrences of very hot surface rocks close to the drillsite, the borehole penetrated only cool rocks until the water table was entered at a depth of 490 meters. From this level to nearly sea level, at a depth of 1102 m, a complicated temperature profile was observed, with temperatures varying between 60°C and 90°C. The groundwater in this zone appears to have a salinity roughly equal to that of sea water. It is thought that a convection system exists over this interval. At greater depths, the permeability of the rock is markedly reduced, though the porosity and water content remain high, in the range from 20 to 25 percent. The bottomhole temperature is 137°C, and the gradient over the last 100 m of hole is about 400°C per kilometer. If the hole were located in an area where production of geothermal energy could be undertaken, it is possible that production of commercial-quality