nostic technique for mapping shallow geothermal reservoirs, especially when the bipole source is not positioned over the target body.

Magnetotelluric Investigations at the Roosevelt Hot Springs KGRA and Mineral Mountains, Utah

Philip Wannamaker

During the summer of 1976 and 1977 and spring of 1978, 84 magnetotelluric sites were monitored by Geotronics Corp. and Francis X. Bostick with his crew, both of Austin, Texas. Amongst other MT functions, the transverse electric (TE) and transverse magnetic (TM) apparent resistivity and impedance phase data were provided for the frequency range 3 x 10^{-3} to 100 Hz.

Some 1-D inversion results for this area have yielded very low values of estimated true resistivity. Such values are unrealistic in light of established notions about conductivity mechanisms in earth materials. Furthermore, the assembly of such inversions to form a crude 2-D model has yielded a calculated 2-D pseudosection far removed from the observed pseudosection. Trial-and-error modeling has provided a better fit although strong differences between observed and modeled data remain and cannot be overcome by any purely 2-D model. The most noteworthy difficulty is the presence of exaggerated contrasts in apparent resistivity persisting to the lowest frequency of observation for both modes of wave excitation.

Single-conductor, 2-D, TE, and TM modeling may explain such problems in terms of 3-D effects. Discontinuities in electric fields from preservation of normal current density will result in the above-stated persistent apparent resistivity contrasts. This boundary condition must be obliged down to zero frequency. Three-dimensional integral equation modeling of conductors in a half-space strongly supports the procedure of surmising 3-D effects on the basis of such 2-D modeling. Three-dimensional anomalies persist through all frequencies and may superimpose themselves upon surrounding sites to yield false 1-D intrinsic resistivities and depths to interfaces. Three-dimensional gravity and plane-wave EM modeling indicate that the deep, conductive sediments of the Milford graben are the biggest distraction to interpreting deep crustal sounding in the resistive Mineral Mts.

Electrical strike estimation may be a meaningless endeavor in a strongly 3-D area. The total fields do not decompose into the standard principal modes (TE and TM) and H_z depends on horizontal derivatives of both electric field components. Multiple symmetry axes result in estimated strike directions depending upon where the observer is located. When derivatives of electric field are relatively small, noise may be the determining factor. The estimated strike directions for the Roosevelt stations are, however, quite consistent. The elongate resistive horst structure of the Mineral Mts. situated in conductive valley fill is felt to be the overwhelming reason for such a consistency.

Magnetotellurics with a Remote Magnetic Reference

Thomas D. Gamble, Wolfgang M. Goubau, and John Clarke

Magnetotelluric measurements were performed simultaneously at two sites 4.8 km apart near Hollister, California. Squid magnetometers were used to measure fluctuations in two orthogonal horizontal components of the magnetic field. The data obtained at each site were anlyzed using the magnetic fields at the other site as a remote reference. In this technique, one multiplies the equations relating the Fourier components of the electric and magnetic fields by a component of magnetic field from the remote reference. By averaging the various crossproducts, one can obtain estimates of the impedance tensor that are unbiased by noise, provided there are no correlations between the noises in the remote channels and the noises in the local channels. Even for data for which the E-E predicted coherencies were as low as 0.1, the apparent resistivities obtained from this technique were consistent with apparent resistivities calculated from high coherency data at adjacent periods. Apparent resistivities calculated by conventional analysis of the same data were biased by as much as two orders of magnitude. The estimated standard deviation for periods shorter than 3 sec was less than 5 percent and, for 87 percent of the data, was less than 2 percent. Where data bands overlapped between periods of 0.33 and 1 sec, the average discrepancy between the apparent resistivites was 1.8 percent.

With the remote reference measurements, one can calculate the noise power spectra for each measured field. The calculation of the noise spectra makes possible an accurate estimation of the confidence limits of each of the quantities derived from these fields. We will give examples of these calculations.

Borehole Geophysics Delineates Fractures in Geothermal Wells

W. Scott Keys

The U.S. Geological Survey has a research project on borehole geophysics as applied to groundwater hydrology. During the past several years, a major part of this effort has been to develop geophysical well-logging instrumentation and log-interpretation methods suitable for the hostile and unique geohydrologic environments found in geothermal wells.

Survey personnel have used experimental equip-

ment for research logging at the following geothermal sites: Los Alamos, New Mexico; Raft River, Idaho; Long Valley and Imperial Valley, California; Roosevelt Hot Springs, Utah; and Marysville, Montana. Although equipment failures are common and interpretation of data is still preliminary, borehole geophysics has provided new knowledge on the character of geothermal reservoirs. Progress has been made on the identification of unique rock types and hydrothermal alteration and on the correction of porosity logs for these matrix effects. Borehole geophysics has also permitted the location, orientation, and characterization of producing and nonproducing fractures in several geothermal areas.

Geophysical well-logging equipment used for the USGS fracture studies includes the acoustic televiewer, caliper, temperature, impeller flowmeter, and dipmeter. The acoustic televiewer used for these studies is the only high-temperature version in existence. It has proved to be one of the most useful probes in geothermal wells and has clearly established the prevalence of fractures in all of the geothermal areas listed above except the Imperial Valley. Detailed studies of fractures underway at both Raft River and Marysville are described and examples of fractures at both sites are shown.

At Raft River, the acoustic televiewer and associated logs have demonstrated that hot-water producing fractures are present in altered sedimentary rocks, volcanic rocks and quartz monzonite. The temperature data digitized in the field were used to plot a differential log in the computer. This log indicates two zones of significant hot-water entry. The caliper log and two acoustic televiewer logs clearly show two fracture zones in altered sediments that coincide with the depths of water entry. Caliper and televiewer logs showed a fairly steep fracture dipping to the southwest at a depth of 1546.5 m and a relatively flat-lying fracture at a depth of 1642 m. Temperature logs suggest that both of these fractures, which are in quartz monzonite, produce hot water. Recently we have experimented with an acoustic caliper log at Raft River. The four oriented traces provide very high-resolution data on fractures.

The commercially available dipmeter log is widely run as a fracture finder in geothermal wells. The logs we have been able to analyze show no useful fracture information on the computer derived dipmeter log. At Marysville, we have been able to compare our acoustic televiewer logs with both the computed and analog field copies of dipmeter logs. The analog record contains anomalies that are apparently due to fractures clearly defined on the televiewer log. The orientation of fractures picked manually from the analog dipmeter record agree quite closely with the televiewer data. Acoustic wave forms recorded digitally in this well are also being analyzed for information related to fracture occurrence and orientation.

Mise-à-la-Masse Detection and Modeling of Hydraulic Fractures at LASL Geothermal Site

P. R. Kintzinger, G. R. Jiracek, G. A. Dorn, and F. G. West*

Electrical geophysical methods including mise-à-la-masse and self-potential (SP) for determination of hydraulic fracture characteristics have been used at Los Alamos Scientific Laboratory's Hot Dry Rock Geothermal Project.

Electrical and inductions logs indicated that the resistivity contrast between the granite and 200°C water at the 2926-m (9600-ft) depth is a factor of 1000 or more. Thus the water in a hydraulic fracture, formed to connect two adjacent deep holes, is a good conductor compared to the confining granite.

Model tank studies using the mise-à-la-masse electrical method have been used to study the response of subsurface platinum and aluminum disks, immersed in water, which simulate the possible hydraulic fracture systems of the LASL Hot Dry Rock Geothermal Project. Three-dimensional computer modeling has been used to compare with model tank results to define the capability of surface and downhole electrical methods to define hydraulic fractures. Computer modeling can aid in definition of limitations for these surface and downhole techniques.

Field mise-à-la-masse type measurements have been made to help determine the characteristics for hydraulic fractures formed in the LASL GT-2 and EE-2 goethermal holes. Mise-à-la-masse effects are obtained with the fracture pressurized both above hydrostatic and when depressurized to hydrostatic. This indicates that once the fracture has been created, enough natural propping exists that a conductive zone persists even when the fracture is deflated.

Geothermal Exploration of the Agua de Pau Massif, San Miguel, Azores, Portugal

Tsvi Meidav

A geotechnical survey was carried out in 1976 of the geothermal resources of the Agua de Pau massif, which is the central portion of the island of San Miguel in the Azorean island chain. The work was carried out with the active participation of the Institute of Geosciences of the Azores, and consisted of geologic, geochemical, and geophysical investigations.

Previous work had shown that the Azorean archipelago is located near the intersection of two tectonically active belts, the mid-Atlantic ridge and the east Azores fracture zone. The island of San

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