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Authors
Wilt, M.J.
Goldstein, N.E.

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Lawrence Berkeley Laboratory
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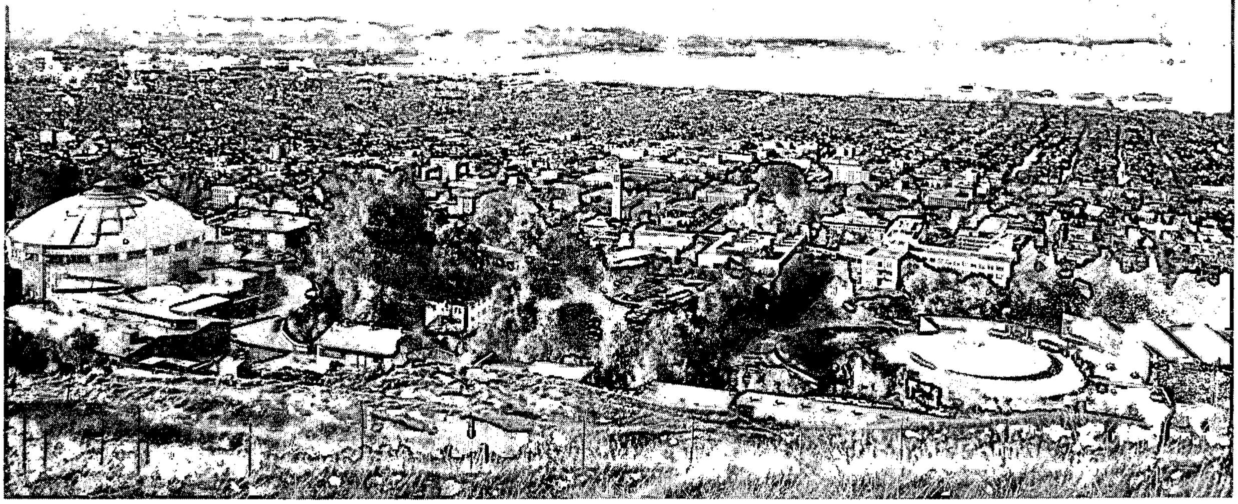

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DISCLAIMER

ELECTROMAGNETIC SOUNDINGS FOR GEOTHERMAL RESOURCES IN DIXIE VALLEY, NEVADA

M.J. Wilt and N.E. Goldstein

Earth Sciences Division
Lawrence Berkeley Laboratory, University of California
Berkeley, CA 94720

ABSTRACT

An electromagnetic (EM) sounding survey was performed over a region encompassing the Dixie Valley geothermal field to map the subsurface resistivity in the geothermal field and the surrounding area. The EM survey, consisting of 19 frequency-domain depth soundings made with the LBL EM-60 system, was undertaken to explore a narrow region adjacent to the Stillwater Range to a depth of 2 to 3 km.

Lithologic and well log resistivity information from well 66-21 show that for EM interpretation the section can be reduced to a three-layer model consisting of moderately resistive alluvial sediments, low resistivity lacustrine sediments, and high resistivity Tertiary volcanics and older rocks. This three layer model was used as a starting point in interpreting EM sounding data. Variations in resistivity and thickness provided structural information and clues to the accumulation of geothermal fluids.

The interpreted soundings reveal a 1 to 1.5-km-deep low-resistivity zone spatially associated with the geothermal field. The shallow depth suggests that the zone detected is either fluid leakage or hydrothermal alteration, rather than high-temperature reservoir fluids. The position of the low-resistivity zone also conforms to changes in depth to the high resistivity basal layer, suggesting that faulting is a control on the location of productive intervals.

INTRODUCTION

During the summer of 1982, an electromagnetic sounding survey was made over a geothermal field located in the northern part of Dixie Valley, Nevada. Nineteen electromagnetic soundings were obtained using the Lawrence Berkeley Laboratory EM-60 system (Morrison et al., 1978; Wilt et al., 1983). The soundings were designed to explore to a depth of 2 km over a zone adjacent to the Stillwater Range and encompassing the known geothermal field. The purpose of the survey was to help define the geothermal field boundaries and the possible structural controls on the geothermal system.

GEOLOGIC SETTING

Dixie Valley, a north-northeast-trending basin in central Nevada, is about 80 km long and 15 km wide at its widest point (Figure 1). The region is known for its high seismicity (Ryall and Vetter, 1982) and numerous active hot springs (Sass et al., 1971) and is thought to be a locus of crustal spreading in northern Nevada (Wallace, 1977). Regional geologic mapping has been done by Page (1965), Speed (1970), and Willden and Speed (1974). Regional geophysical studies, including passive and active seismics, gravity, and magnetics, are reported by Smith (1968), Thompson and Burke (1974), Wallace (1977), and Ryall and Vetter (1982).

Much of the lithologic information for rocks underlying Dixie Valley has been derived from exposures in the Stillwater Range (Figure 1). The range is capped by Tertiary basalt and andesite flows and breccias overlying several deformed Mesozoic units (mainly sandstones, volcanic breccias, and thin limestones) separated by thrust faults. The range is also the center of a large Mesozoic complex of mafic igneous rocks called the Humboldt gabbroic complex (Speed, 1970). The Stillwater Range is a horst bounded by normal faults with large vertical displacements; normal faults with smaller displacements cut across the axis of the block. The Stillwater Fault is the main fault system in Dixie Valley. It bounds the Stillwater Range on the southeast, dips 50 to 60° at the surface and trends N36°E from Dixie Meadows, which is immediately south of the survey area, into Pleasant Valley, just north of the survey area.

Dixie Valley, situated to the east of the Stillwater Range, is an eastward-tilted basin filled predominantly with Quaternary alluvium and lacustrine sediments (Smith, 1968; Speed, 1970). The valley is a complex graben bounded by high-angle normal faults typical of the Basin and Range Province. The Tertiary section underlying the Quaternary valley fill is similar to that observed in the adjacent Stillwater and Clan Alpine Ranges: mainly basalt and andesite flows and breccias, rhyolitic tuff, and associated sedimentary interbeds. The Tertiary section probably attains a maximum thickness of 1 km. Underlying the Tertiary rocks and crossing beneath the northern part of the

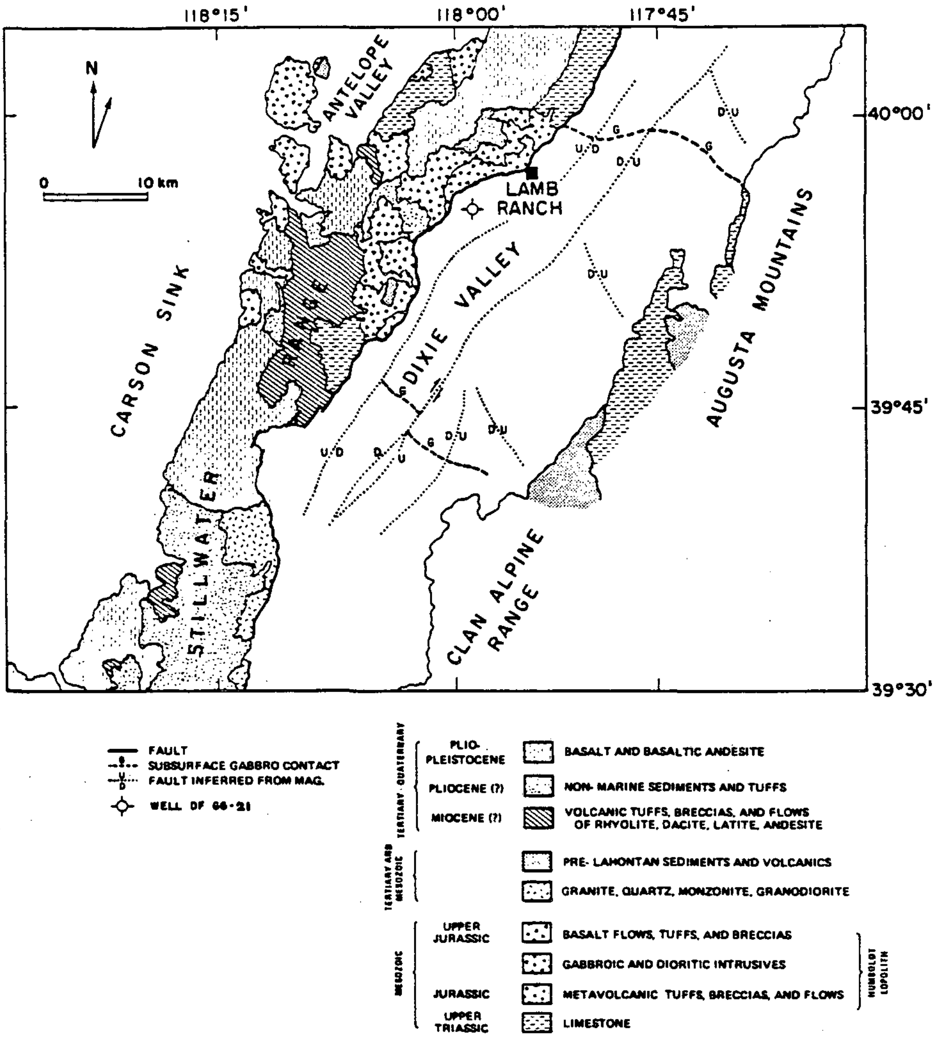

Figure 1. General geologic map of northern Dixie Valley (after Speed, 1970).

Dixie Valley is the downfaulted extension of the Humboldt gabbroic lopolith. The subsurface position of this igneous intrusive has been determined by interpreting aeromagnetic data (Smith, 1968; Speed, 1970). Gravity and magnetic evidence in the northern part of Dixie Valley suggests a concealed north-northeast-trending central graben where sediments attain a maximum thickness of about 1.8 km (Speed, 1970; Smith, 1968).

In Figure 2 lithologic, temperature, and deep induction log resistivity data are given for well Dixie Federal 66-21, located about 3 km south of the known geothermal field. The well was drilled by Thermal Power Inc. in 1979 and encountered high temperatures at depth but did not produce fluid.

The well provides a benchmark resistivity vs. lithology section with which to compare sounding interpretations. The resistivity log from 66-21 can be reduced to a 3 or 4 layer section. The upper layer consists chiefly of alluvial outwash sediments with a resistivity of 3-15 ohm·m. EM soundings show that the resistivity of this unit is higher at higher elevation and towards the northern part of the valley. At depths from 200-400 meters the outwash sediments grade into silts and clays with resistivity from 1-3 ohm·m. These more lacustrine deposits probably represent an earlier northward expansion of the Humboldt Salt Marsh. The low resistivity is probably mainly due to high salinity pore fluid. The Tertiary section, encountered in well 66-21 at a depth of 1400 m, is marked by an increase in resistivity to 10 ohm·m. The resistivity increases with depth to more than 100 ohm·m as the Mesozoic granites and metamorphic rocks are penetrated. As production in the Dixie Valley geothermal field is thought to originate in fractures within the Tertiary and underlying rocks, we expect that the resistivity of deeper layers would be much lower where geothermal fluids are present. The goal of the EM survey is to map variations in these layers in order to map structure and locate concentrations of geothermal fluids.

FIELD SURVEY

Electromagnetic sounding measurements were made with the frequency-domain EM-60 system developed at Lawrence Berkeley Laboratory (Wilt et al.,

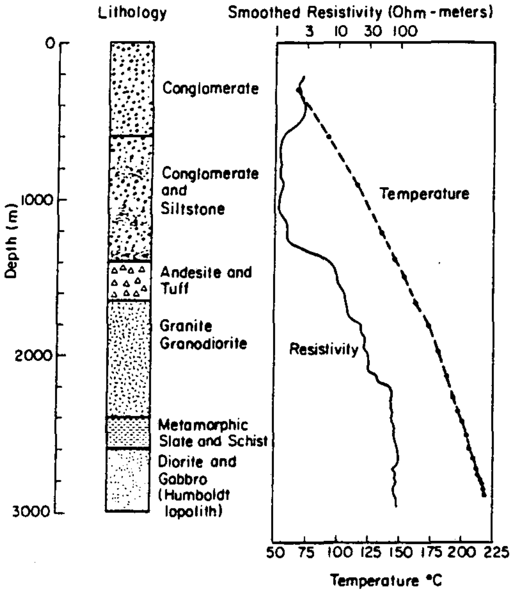

Figure 2. Generalized lithology, well log resistivity and temperature for well Dixie Federal 66-21.

1983) (Figure 3). The transmitter is a horizontal loop, usually two turns of #6 welding cable, laid out in a square 100 m on a side. The EM-60 impresses a square wave current of more than 60 A into the loops at frequencies from .05 to 500 Hz. The waveform is controlled by one of a pair of synchronized quartz clocks; the other clock, located at the receiver truck, is used for phase reference between transmitter current and detected fields.

Receiver sites were located at distances ranging from 1 to 5 km from the transmitter. The depth of investigation is a function of both frequency and transmitter-receiver separation, the closer sites provide a shallow depth of investigation and the more distant sites provide information to greater depths. As a general rule, the depth of investigation varies from one-half to one times the source-receiver separation.

At each receiver site three orthogonal components of the magnetic field were measured with SQUID magnetometers oriented to obtain vertical, radial and tangential fields with respect to the loop. Data were taken over the frequency range .05 to 500 Hz at two sites simultaneously. Signals from one magnetometer ("local") are brought to the processing van via a 100-ft cable. The other magnetometer ("remote") is located 1 to 3 km from the van and linked to the van via FM radio telemetry; background geomagnetic fields are simultaneously measured for the purpose of noise cancellation. Sites for background measurements were located 15 km or more from the transmitters and the signals sent to van with FM telemetry. Field data were processed on site, in real time, by an HP 9835 desktop computer. Field processing resulted in initial EM parameter estimates, data quality evaluations and apparent resistivity calculations. One dimensional (layered model) resistivity vs depth sections are obtained for each station by fitting observed field spectra to computer generated data by iterative least-squares inversion.

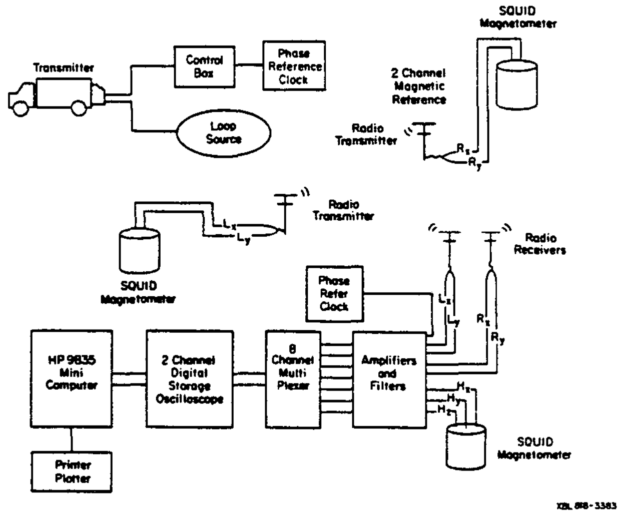

Figure 3. Schematic diagram of the EM-60 system.

INTERPRETATION

The locations of the three loop transmitters and 19 receiver sites used in the EM survey are given in Figure 4. The stations form a narrow belt 10 km long along the western margin of the valley that encompasses the known geothermal field. Resistivity interpretations are presented in a NE-SW profile and two contour plots of specific parameters (Figure 5-7).

A three-layer starting model, obtained from the resistivity log in well 66-21 was taken as a first guess for the 1-D inversions. The starting model is a surface layer of resistivity 20 ohm·m and thickness 200 m, a middle layer of resistivity 3 ohm·m and thickness 500 m, and a basal layer of resistivity 100 ohm·m and infinite thickness. Most field soundings could be fitted to this type section, although the individual layer parameters varied from sounding to sounding. For several soundings, a two-layer model was more appropriate; the receivers were either too close to the transmitter to provide information on the bottom layer or too far from the transmitter to resolve the top layer. For other soundings, particularly those taken within the geothermal field, the basal layer was less resistive. A good fit was achieved between observed and calculated field values at all sounding locations.

Figure 5 is a NE-SW profile of interpreted resistivities and depths for stations located along the western margin of the valley. Layered model resistivity sections are plotted at a position halfway between the transmitter and receiver. The resistivity values are plotted in the center of each layer; values for the bottom layer are plotted 100 meters below the upper surface of the layer.

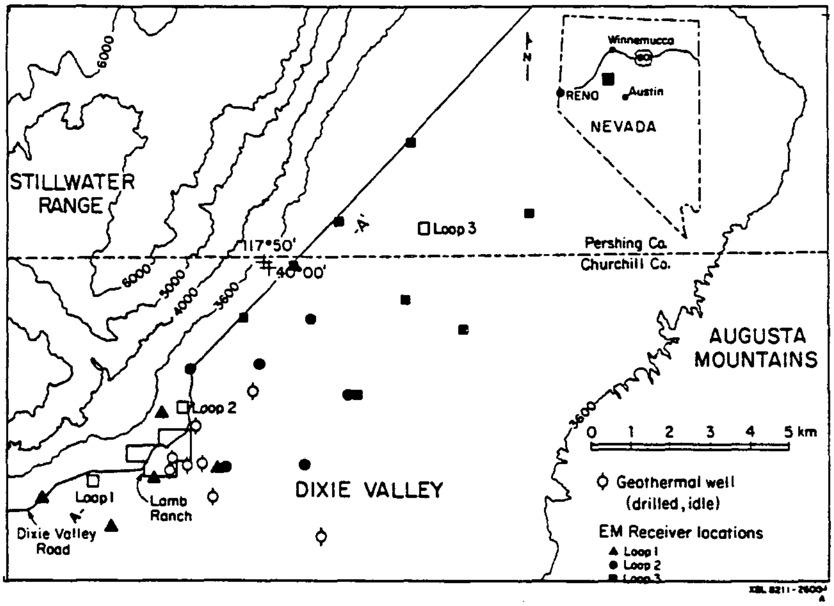

Figure 4. Transmitter and receiver locations for the EM survey in Dixie Valley.

The profile presents a fairly consistent section from sounding to sounding of a type similar to the well log section. In the area of producing wells the profile indicates a low resistivity zone at a depth of about 1 km. As this is only half of the reported production depths, the low-resistivity zone is probably a manifestation of fluid leakage along the plumbing system or hydrothermal alteration, rather than the high-temperature reservoir itself. The depth to the basal resistive layer increases from about 1 km at the southern edge of the profile to 1.5 km towards the north. The transition from shallow to deeper basal high resistivity also correlates with the low resistivity anomaly. This suggests that the low resistivity zone may also be a porosity effect, related to an increase in fracture density caused by changes in strike or dip of the Stillwater fault system or the existence of cross faults.

Figures 6 and 7 are contour plots of the cumulative thickness of the upper two layers and the resistivity of the basal layer. The thickness contours show a steep dropoff in the depth to the basal layer from the Stillwater Range eastward into the valley (Figure 6). The depths increase from about 400-600 m to 1.5 km or more over a distance of about 1.5 km. The steep dropoff aligns well with the interbasin graben proposed by Smith (1968) and Wallace (1977). The western edge zone of steep dropoff trends roughly parallel to the range front throughout the survey area. It may represent the basinward extension of the range front faulting.

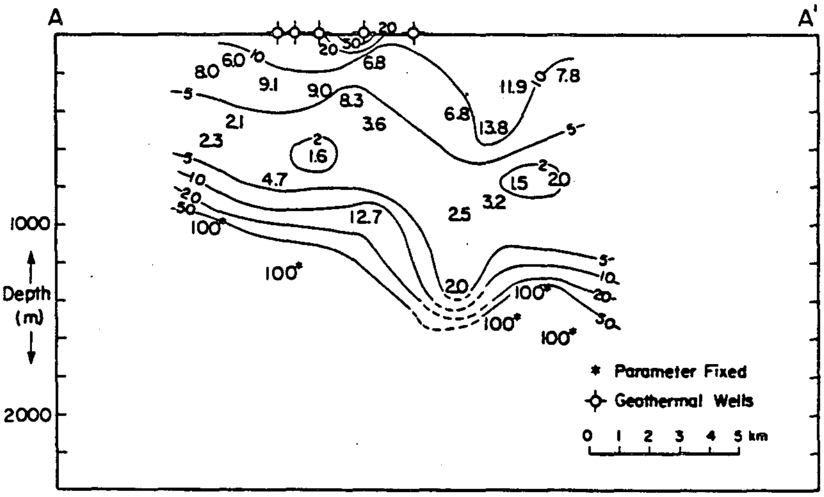

Figure 5. Resistivity vs depth cross-section for profile A-A'. Sounding parameters are plotted halfway between transmitters and receivers.

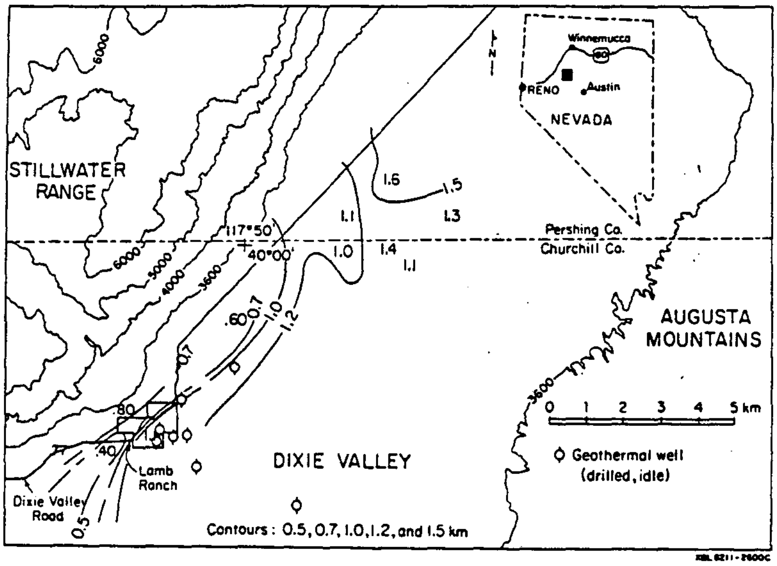

Figure 6. Thickness of the upper two (sedimentary) layers.

Figure 7 shows the resistivity of the basal layer. This map indicates a narrow, elongated region of low resistivity in the basal layer stretching from the Lamb Ranch northward along the Stillwater Range front for almost 5 km. Resistivities in this anomalous zone range from 2 to 50 ohm·m. Outside this belt the basal layer is more resistive. Figures 6 and 7 show that the low-resistivity region also correlates with the western margin of the graben described by Smith (1968) and Speed (1970), hence it is likely that the graben faults are important in providing fluid conduits and permeability for the system. The existence of a clay-rich middle layer may locally provide a sealing cap for the system.

SUMMARY AND CONCLUSIONS

Electromagnetic sounding measurements were used in mapping the subsurface resistivity distribution in the northern part of Dixie Valley to a depth of about 1.5 km. Based on well log information a three-layer model was used to help interpret the sounding curves. The upper layer represents alluvial sediments; the middle layer, lacustrine deposits; and the basal layer, Tertiary and older rocks. Variations in resistivity and thickness of these layers for individual soundings provided structural information and clues to the distribution of geothermal fluids.

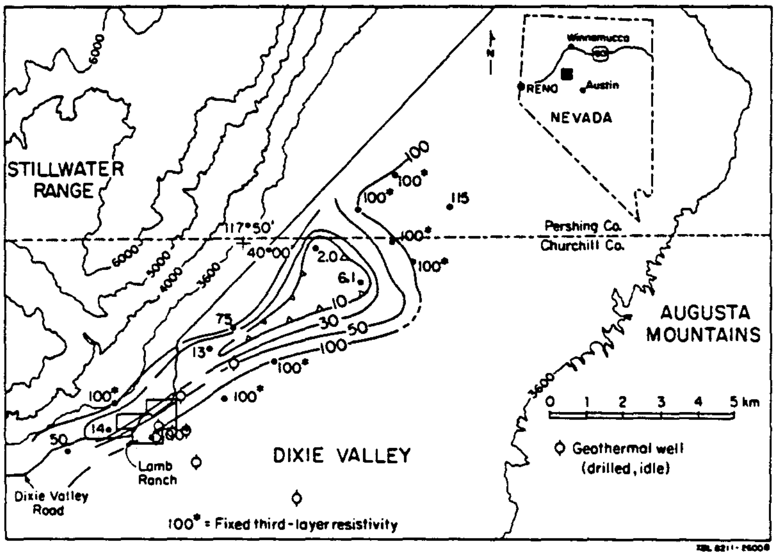

Figure 7. Resistivity of the basal layer (ohm·m).

A 1 to 1.5-km-deep low-resistivity zone is spatially associated with the known geothermal field. Because known fluid production comes from a deeper interval, this zone is probably due to leakage and/or hydrothermal alteration. The location of the low resistivity zone also correlates with change in the depth to the high resistivity basal layer, suggesting that fault induced fracturing may play an important role in fluid production.

ACKNOWLEDGEMENTS

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TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720