GEOPHYSICAL STUDIES OF THE LASSEN KGRA, CALIFORNIA

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ABSTRACT

During the summer of 1979, the U.S. Geological Survey conducted a geophysical study of the Lassen Known Geothermal Resource Area (KGRA) in northern California.

The only data available before this study were a regional geological map and gravity surveys of the Susanville 2° sheet. As part of the USGS work, audio-magnetotelluric (AMT) and magnetotelluric (MT) soundings were made in this area, along with E-field ratio telluric and self-potential traverses.

Data obtained with the four techniques used correlated quite well and delineated two major areas of low resistivities within the KGRA.

INTRODUCTION

The U.S. Geological Survey conducted a geophysical study of the Lassen KGRA in 1979. Data already available included a regional gravity survey of the Susanville 2° sheet (Griscom and Oliver, 1980) and regional geologic mapping of the 2° sheet (Lydon et al, 1960). A detailed magnetic survey was flown in the spring of 1980 by Oregon State University, but results are not yet available.

As part of the USGS study, audio-magnetotelluric (AMT) and magnetotelluric (MT) surveys were made in the area, along with self-potential and E-field ratio telluric traverses.

LOCATION AND GEOLOGY

The Lassen KGRA covers approximately 324 square kilometers (125 square miles) immediately south of Lassen Volcanic National Park and about 50 kilometers (31 miles) west of Susanville in northern California. Elevations in the KGRA range from about 1400 to 2300 meters. The KGRA lies at the southern edge of the Cascade Mountains section. Mesozoic and Paleozoic rocks of the Sierra Nevada section extend to within about 10 kilometers southeast of the area.

Lassen Peak, lying about 7 kilometers north of the KGRA in Lassen National Park, is the southernmost volcano in the Cascade Range. It was last active in 1914-1917 when explosions and lava flows occurred at the peak. Numerous hot springs, hot pools, and steam vents lie just north of the KGRA boundary in Lassen Park and are most prominent in the Sulphur Works and Terminal Geyser areas. Thermal manifestations (hot springs, and mud pots) are present in the western part of the KGRA at Morgan and Growler Hot Springs.

Almost all of the exposed rock units in the KGRA are Cenozoic volcanics. The oldest rocks are small exposures of Miocene pyroclastics. Most of the area is covered by Pliocene and Pleistocene rhyolites, andesites, basalts, and pyroclastics. Several Pleistocene dacite domes are exposed in the western half of the KGRA. There are minor exposures of Holocene basalt, Pleistocene fanglomerate, and Quaternary glacial deposits. Quaternary alluvium exists as valley fill. Post-Pleistocene faulting occurred mostly in the eastern part of the KGRA and to the north with a west to northwest trend.

GRAVITY

Regional gravity coverage is available from the Bouguer gravity map of the Susanville 2° sheet (Griscom and Oliver, 1980).

A regional gravity gradient, caused by isostatic compensation (thicker crust under higher topographic areas), was removed from the complete Bouguer anomaly map to obtain a better look at local gravity features, which otherwise may have been obscured by sharp gradients on the Bouguer map. This adjustment was made by subtracting a value of 0.9 mgal/10 meters of elevation over a smoothed topographic map from the complete Bouguer map. The resulting gravity map (fig. 1) shows residual gravity anomalies ranging from +25 to -35 mgals. The borders of Lassen KGRA and Lassen Volcanic National Park are located approximately on the map.

The broad, northwesterly trending high (0 to +25 mgals) in the southwest part of the sheet and the more circular high in the middle of the sheet (-10 to +20 mgals) are believed to represent an extension of the Sierra Nevada composed of metasediments and metavolcanics (Griscom and Oliver, 1980). The highs are separated from the Lassen area by steep gravity gradients (apparent on both maps), which perhaps result from faulting or lithology change (as the volcanics thicken and become prominent near Lassen and to the north).

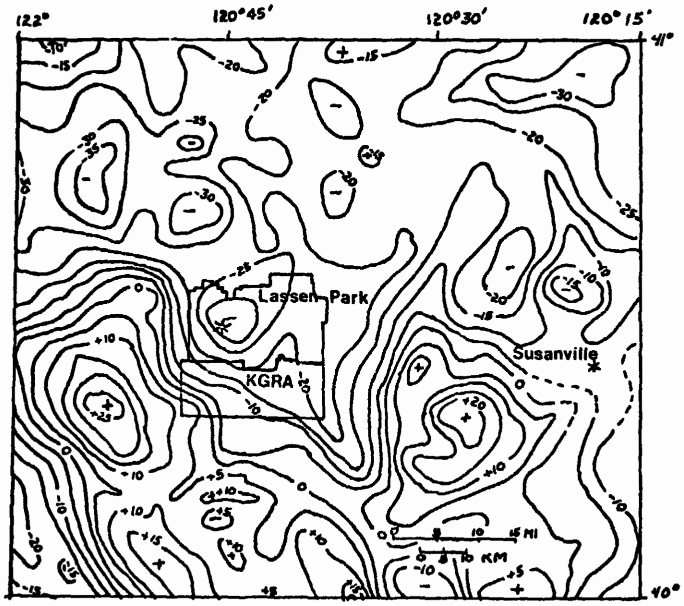

Fig. 1. Residual Gravity Map, Lassen KGRA vicinity California. 5 mgal contours.

The volcanics of the Lassen area and those to the north are characterized by residual gravity contours of -15 to -30 mgals. The low values are due, in part, to the lower density of the volcanics compared to the metamorphics of the Sierra Nevada.

In the area of Lassen Peak, the residual anomaly is -30 mgals, about -10 mgals different from the average for the volcanic region. The most recent interpretation (Griscom and Oliver, 1980) attributes the low to local subsidence of 1000 meters or more near Lassen Peak or to a possible intrusion of lower density rocks beneath the park.

The regional gravity contours in the KGRA show no detailed structure but do indicate a subtle northeast trend through the middle of the area which coincides with some trends of electrical data. No detailed gravity data are available for the Lassen area, but would probably be useful.

AUDIOMAGNETOTELLURIC SURVEY

Sixty-eight audio-magnetotelluric (AMT) soundings were made in and near the Lassen KGRA at nine frequencies between 7.5 hertz and 18,600 hertz (Christopherson et al, 1980). The 7.5 hertz data were log-averaged for the two E-line orientations and are plotted in fig. 2.

The skin depth (approximate depth of penetration) of electromagnetic waves at 7.5 hertz ranges from about 600 meters in 10 ohm-meter material to about 2000 meters in 100 ohm-meter rock. In volcanic rocks, low resistivity values can result from alteration or from the presence of geothermal or saline waters. In the Lassen area, low values can perhaps denote older volcanics in which more fracturing and alteration has occurred or regions of more extensive geothermal activity and alteration.

The 7.5-hertz map (fig. 2) provides the deepest information. It is complex, yet it points to some interesting results. The two areas of modern geothermal activity included in the survey, Sulphur Works and Terminal Geyser, are designated by low (less than 18 ohm-meter) apparent resistivity values. The other geothermally active area, Morgan and Growler Hot Springs, was inaccessible.

There are seven other areas of relatively low apparent resistivity compared to background values of 40 to 100 ohm-meters in the KGRA and greater than 100 ohm-meters near the KGRA and park borders. These low values range from 14.40 ohm-meters (near Wilson Lake) to about 11.0 ohm-meters south of Willow Lake. Most of these low resistivity stations lie in the middle of the KGRA, to the south and southwest of Willow Lake extending to the south and east of Childs Meadows. The resistivity differences seem unrelated to topography or surficial lithology. The low values occur mostly in areas with surface exposures of Pleistocene and Pliocene andesites and basalts, within which the apparent resistivity values can vary by more than one order of magnitude. This area also coincides with magnetotelluric soundings of low to intermediate resistivity (James O'Donnell, written commun., 1980).

A northeast-trending low-resistivity zone through Childs Meadows and Terminal Geyser is apparent on all AMT maps, but is more obvious at 7.5 hertz. Although the cause of this zone is unknown, it does coincide with a gravity trend and is probably quite important.

One of the more interesting areas is southwest of Willow Lake, where the log-averaged 7.5-hertz resistivity values at two stations are 20.0 and 21.0 ohm-meters. A magnetotelluric sounding in this area shows decreasing resistivity to a depth of investigation of about 10 kilometers. Seven other magnetotelluric soundings in the KGRA show increasing resistivity at depth with the lowest values centered at about 7.5 hertz.

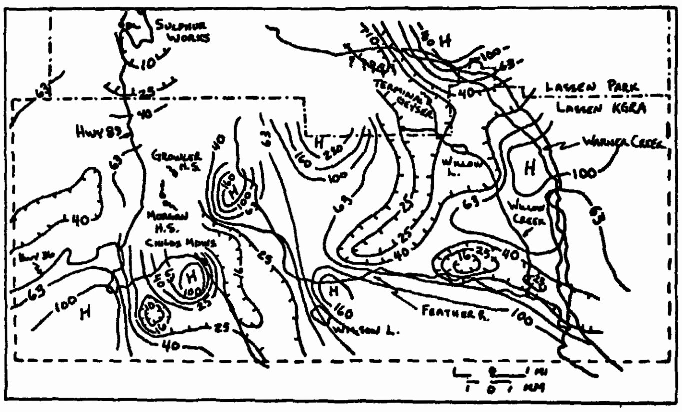

Fig. 2. Audio-magnetotelluric (AMT) Apparent Resistivity Map at 7.5 hertz (log-averaged). Logarithms contours in ohm-meters.

TELLURIC AND SELF-POTENTIAL SURVEYS

Two E-field ratio telluric and self-potential traverses were made in the Lassen KGRA (fig. 3), one near Childs Meadows and one southeast of Terminal Geyser (Christopherson et al, 1980).

Traverse 1 (fig. 4) was run east-west from southern Mill Creek Valley to the eastern flank of Wild Cattle Mountain. The large increase in self-potential voltage between stations 4 west and 3 west occurs where the traverse moves from the southern end of Morgan Mountain into Mill Creek Valley and can probably be explained by the drop in elevation and by changes in ground-water content or lithology. The self-potential voltage then varies from station 3 west to 7 east due to more subtle geologic changes. The decrease in potential from stations 7 to 12 (with the lowest value occurring on the ridge of Wild Cattle Mountain) probably is the result of a self-potential gradient caused by elevation increase.

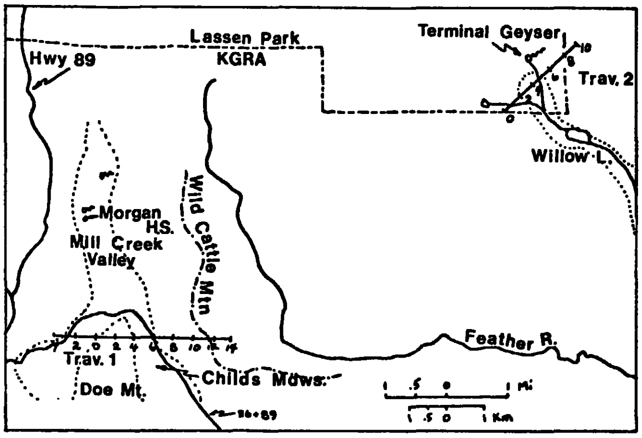

Fig. 3. Telluric and Self-Potential Profiles Location Map.

The telluric voltage drops east of station 2 west where the profile crosses Mill Creek Valley, possibly indicating faulting. The voltage then increases slightly as the traverse moves onto Doe Mountain (station 0 to 1 east). The telluric response is varied between 1 east and 4 east. Between stations 4 east and 7 east the resistivity (proportional to the voltage squared) drops sharply when the traverse crosses Childs Meadows and starts up Wild Cattle Mountain. The telluric voltage remains at a relatively low level as the traverse crosses over Wild Cattle Mountain, signifying a major resistivity contrast between the western and eastern halves of the profile. This low coincides with an AMT low, suggesting that the low-resistivity zone is continuous from a fairly shallow depth to several kilometers; rough one-dimensional modelling substantiates this continuity.

Traverse 2 (fig. 4) was run from southwest to northeast near Terminal Geyser in the northern part of the KGRA. The most significant change in both self-potential and telluric voltages occurs near stations 5 and 6; the self-potential voltage drops nearly 70 millivolts between stations 3 and 5 and then increases by 25 millivolts between stations 6 and 7. The telluric voltage quadruples between stations 5 and 6 (relative to its value between stations 4 and 5) and then drops to approximately its previous level.

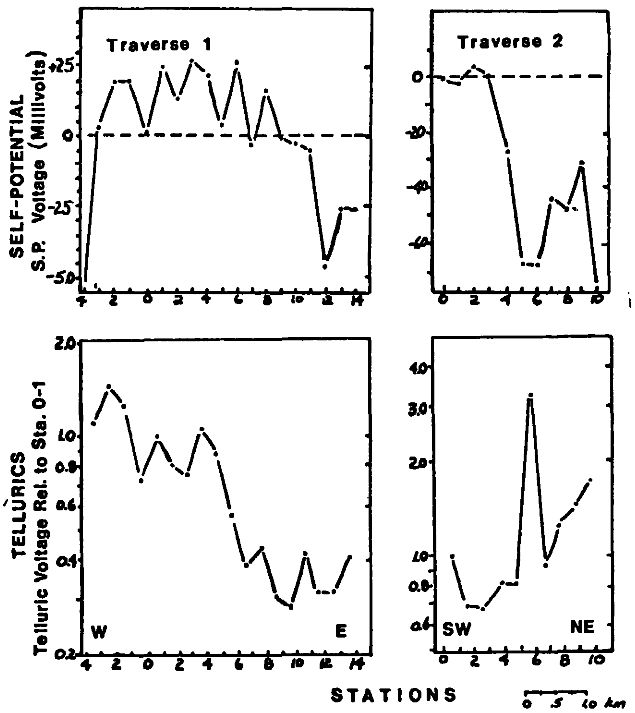

Fig. 4. Telluric and Self-Potential Profiles.

This peak reveals a narrow, highly resistive zone, less than one-half mile southwest of Terminal Geyser, that could be indicative of an intrusive (ring dike?) trending to the northwest. No such structure was detected by the other geophysical methods, probably because of low station density, but the traverse lies within a low-resistivity (less than 40 ohm-meter) AMT region.

MAGNETOTELLURICS

Eight magnetotelluric (MT) soundings were made in the Lassen KGRA at frequencies ranging from .01 to 10 hertz (James O'Donnell, written commun., 1980). The soundings were done at or near previous AMT stations, and their locations are shown in figure 5. The MT data were combined with the AMT data at each station and plotted as frequency vs. resistivity. A smoothed curve was fit to the data, and the data were then inverted (Bostick, 1977) to obtain resistivity vs. depth; the resistivities from the inversion curves for depths of 1, 5, and 10 kilometers are listed in fig. 5. For sounding 1, three sets of curves were generated (for both the field data and inversions), because a split between the two modes resulted in one curve for each mode and an intermediate curve.

The lowest resistivity values trend east-northeast between stations 1 and 5. Stations 6, 7, and 8 have relatively higher resistivities (indicative of fresher, unaltered rock) to a depth of 10 kilometers. The lowest value, 6 ohm-meters at a depth of 5 kilometers at station 3, is probably quite significant as this is very low resistivity for volcanic rock, even with severe alteration. Stations 2, 4, and 5 are of moderate resistivity at all depths, probably signifying a fair amount of alteration. The split in the curves at station 1, some being low and some moderate, indicates that station 1 is located near a pronounced lateral change in resistivity.

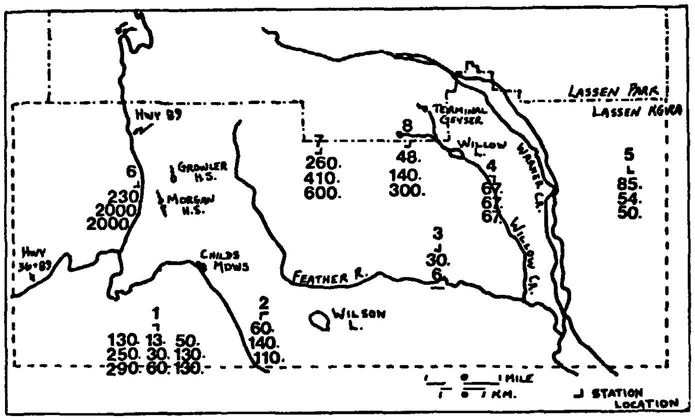

Fig. 5. Magnetotelluric Station Location Map. Station number (above station) and resistivity in ohm-meters at depths of 1, 5, and 10 km (below station).

CONCLUSION

The Lassen KGRA is identified by a complex geophysical signature reflecting lithologic contrasts within the volcanic province associated with complicated changes in alteration, porosity, permeability, and other factors affecting the electrical conductivity of the volcanics. The KGRA lies just south of Bouguer and residual gravity lows, the implications of which are not fully understood. It is inferred from these lows of that a deficiency of mass exists at depth, although the cause of it is still debatable. The other geophysical methods seem to correlate well in mapping areas of low resistivity in the KGRA.

The AMT results point to two major areas of low resistivity within the KGRA; one near Childs Meadows and one south and north of Willow Lake, both covering at least 50 square kilometers. These low-resistivity areas coincide with low relative voltages on the telluric traverses and low to intermediate MT resistivity values. The low values do not coincide with changes in topography or lithology; the AMT resistivity values within one rock type can vary by more than one order of magnitude. Both of the main low-resistivity zones seem prospective and worthy of further study. The area near Childs Meadows lies south of Growler and Morgan Hot Springs (the only surface geothermal manifestations within the KGRA). The AMT resistivity contours at Childs Meadows appear to trend toward the Growler and Morgan Springs area, indicating perhaps the same geologic environment. This trend appears to follow the edge of a major andesite body along Wild Cattle Mountain.

The low south of Willow Lake is very interesting, as it is unmarked by surface indications of any geothermal activity and yet shows very low MT resistivity at 5 kilometers depth (6 ohm-meters at station 3). It is also worth noting that, in the area of this MT station, resistivity decreases with depth from more than 40 ohm-meters at 7.5 hertz (AMT) to 30 ohm-meters at 1 kilometer (MT) and is along a subtle northeast trend seen in all geophysical data.

This area also lies south of the postulated ring dike located near Terminal Geyser (shown by telluric traverse #2). The dike appears to follow a geologic trend northwest-southeast. Considering the clustering of low resistivities in the middle of the KGRA, this trend could be indicative of a large, older volcanic collapse structure bounded roughly by Willow or Warner Creek on the east and Highway 89 on the west.

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