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GEOELECTRICAL STUDIES NEAR SPRINGERVILLE, ARIZONA

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ABSTRACT

Evaluation of geothermal potential of lands near Springerville was conducted with d.c. resistivity and telluric current measurements. Geological, geochemical and geophysical evidence suggests a possible geothermal resource in the study area. We found:

1. Low d.c. resistivity values associated with known high total dissolved solids values north and south of Springerville.
2. A low d.c. resistivity zone near Greer, Arizona, that does not show up in the TDS data. This could be a deep high TDS or hot water zone.
3. A telluric current low southwest of Springerville near a Los Alamos Scientific Laboratory (LASL) magnetotelluric site, where conductive material is anomalously close to the earth's surface. The LASL station is on the edge of the telluric current low; both coincide roughly with a several-hundred-square kilometer gravity low. The region could be hot rock affecting deeply circulating groundwater which is detected as high TDS values to the north.

Introduction

This research was conducted to coordinate with geological and other geophysical studies to evaluate potential geothermal resources near Springerville, Arizona. The study area is located on an index map of Arizona in the corner of figure 1. The study area lies in a transition zone between the Colorado Plateau to the north and the Basin and Range Province to the south, and is in an area where three major lineaments intersect. Recent volcanics lie on these lineaments, possibly indicating large scale zones of crustal weakness, where deep partial melting is occuring, promoting high heat flow and anomalously high shallow temperatures.

The surface rocks in the mountainous southern part of the study area are predominantly volcanic, ranging from middle Tertiary to recent. Cinder cones, lava flows and travertine domes are abundant in the central part of the study area. In the flat land in the north, the surface rocks are mainly sedimentary, forming beds of late Paleozoic age, which dip gently to the south and probably to underly the volcanic rocks there. Groundwater flows from south to north in aquifers in these sedimentary rocks, recharged from greater rainfall in the southern mountains.

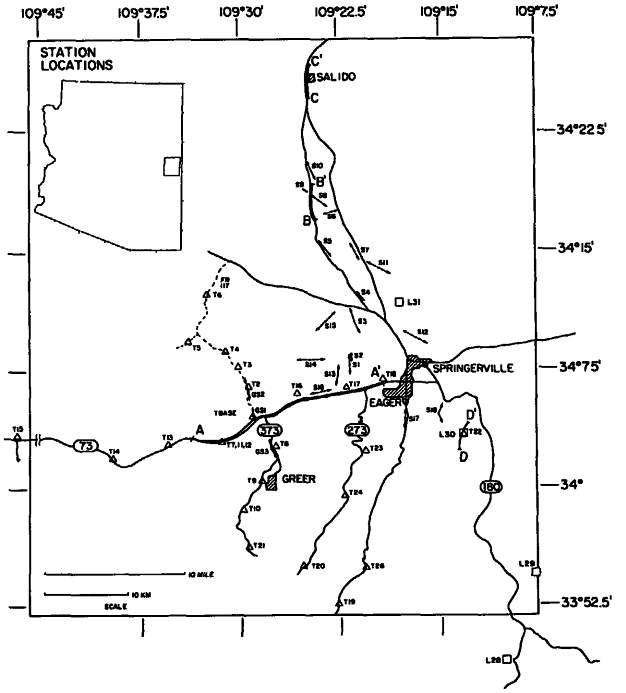

Fig. 1 Location of stations in study area. Triangles indicate telluric current stations. Double-ended arrows indicate Schlumberger soundings. Lines AA', BB', CC' and DD' are Schlumberger profiles, L28, L29, L30 and L31 are Los Alamos Scientific Laboratory magnetotelluric stations.

Heat remaining from the volcanoes is the potential geothermal resource. The resource may be hot dry rock, or heated circulating ground water. Evidence for the groundwater resource may be found in slightly high temperatures and dissolved solids in wells south of Springerville.

Gravity, magnetic and teleseismic P_n velocity data, reviewed by Stone in Hahman, 1979, also suggest a crustal hot spot in the study area. Los Alamos Scientific Laboratory (LASL) magnetotelluric data, below, agree with this prediction.

Los Alamos Scientific Laboratories is in the process of completing two large-scale deep-penetration magnetotelluric profiles across Arizona and New Mexico (Mark Ander, personal communication). The profile includes four stations along a north-south line passing through our research area. The stations are numbered L28, L29, L30 and L31 (shown on figure 1, along with our stations). Data are now available from stations L28 and L30.

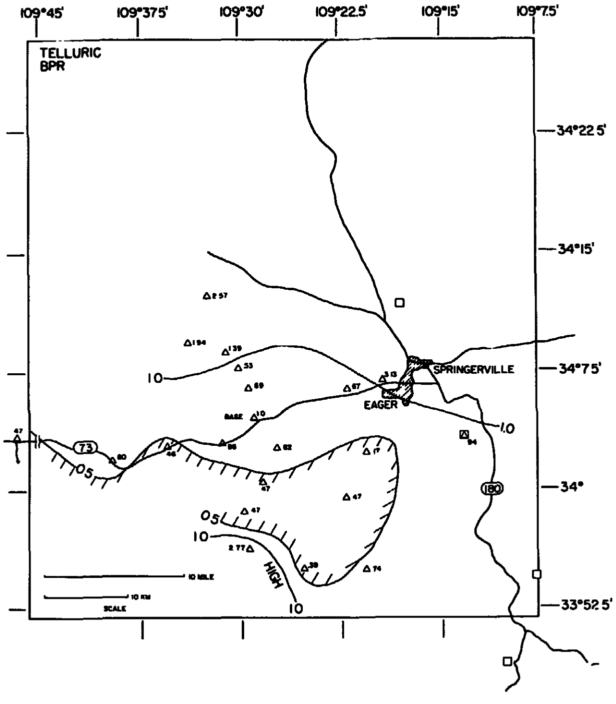

Fig. 2 Telluric current broadband voltage power ratios.

Preliminary modelling of site 28 data indicates resistive material over-lying a conductive half-space at a depth of about 12 km, however, the data are of too poor quality to indicate layer resistivities. The site 31 preliminary model has four layers:

1. a top layer of 119 Ω-m material 1 km thick,
2. a second layer of 18 Ω-m material 1 km thick,
3. a third layer of 1120 Ω-m material 22 km thick,
4. an underlying conductive half-space of 29 Ω-m material.

The significant difference between the two models is the shallower depth to the conductive layer at site 28 to the south, which agrees with our telluric current work described below. More detailed measurements of telluric currents and Schlumberger resistivity reported here have located deep and near surface conductors associated with this conductive layer.

Telluric Current Measurements

The Telluric Current Method measures natural alternating current voltages in the earth at a base and remote station to determine relative electric field strength over the survey area. The square-root of the ratio of electric fields is proportional to the ratio of magnetotelluric apparent resistivities at the base and remote sites. Thus, low telluric current voltages mean low resistivities at that site, relative to the base station. The data can also be analyzed to show direction of the earth currents at the base and remote sites, possibly showing current channeling in conductive bodies.

The depth of penetration of the telluric current signals is approximately equal to the skin depth of the electromagnetic wave being detected, that is, the depth at which the wave amplitude drops to 1/e or 37 percent of its value at the surface. Skin depth, δ, in meters, is calculated according to $\delta = 500\ (\rho/f)^{\frac{1}{2}}$, where ρ = resistivity of the rock in ohm-meters, f = frequency in Hz. The signals we recorded, with frequencies of .01 to .05 Hz, penetrate several kilometers.

Our data were analyzed by calculating broadband voltage power ratio (BPR): simultaneous base and remote records that exhibit high visual coherency are selected, several cycles are hand digitized and the power ratio between base and remote site are calculated by

$$\mathrm{BPR} = \frac{\sum_{j=1}^{N} [e^r_{xj} - \bar{e}^r_x)^2 + (e^r_{yi} - \bar{e}^r_y)^2]}{\sum_{j=1}^{N} [e^b_{xj} - \bar{e}^b_x)^2 + (e^b_{yi} - \bar{e}^b_y)^2]} \qquad (1)$$

where, for example e^r_{xj} refers to the j^{th} data point of the electric (x or NS) component recorded at the remote (r) site, $\bar{e}^r_x$ is the mean value of those data and N is the number of data sampled. The summation over squares is proportional to the square of the standard deviation of the data. Hermance, Thayer and Bjornsson (1975), show by example that the BPR values are just as effective as more complicated scalar data analysis techniques in locating low resistivity zones.

Figure 1 shows the locations of all the geoelectric stations. The Schlumberger stations will be discussed later.

Figure 2 shows the BPR ratios. The lowest values are within the 0.5 contour, approximately 20 kilometers southwest of Springerville. The highest values are generally north of the base station. Since these signals penetrate several kilometers, the low voltages south of Springerville could represent a several-kilometer-deep, low resistivity zone, in general agreement with the Los Alamos magnetotelluric data, discussed above. If one considers the earth beneath the telluric current stations to be a resistive layer (cold rocks) over a conductor (hot rocks), then the low telluric current voltages represent either a decrease of second layer resistivity or a reduction of first layer thickness, or both.

Schlumberger Resistivity Measurements

Vertical Electric Soundings determine the resistivity and thickness of layers within the earth. Four electrodes are set up in a line on the earth's surface, direct current of a few amperes or tenths of amperes is introduced through the outer two electrodes, and the resultant voltage is measured at the inner two electrodes. One can calculate the apparent resistivity of the earth from the voltage and current readings and the electrode spacings. Deeper penetration is achieved by increasing the separation between the outer two current electrodes. The set of resistivities thus obtained for a set of increasing current electrode spacings, called a vertical electric sounding curve, is compared with handbook or computer-generated models to determine the thickness and resistivity of layers beneath the sounding site. We do cut-and-try modelling with an interactive APL language program on an Amdahl 470. The program is an APL translation of a BASIC language program from Sternberg, 1977, based on the convolution filtering technique of Ghosh, 1971.

The depth to which a sounding can detect layers depends on the layers present, and is always less than AB/2, half the distance between the outer two electrodes.

In addition to Schlumberger soundings, we also carried out Schlumberger profiling. In profiling, apparent resistivities are measured at only one or two electrode spacings along a survey line. Although it is not possible to construct layered models from these data, it is possible to map changes in subsurface resistivity, and roughly estimate the depth of these resistivities. If the AB/2 spacing is equal to the station interval, it is possible to "leap-frog" along a survey line. We used AB/2 = 800 m and 100 m and spaced our stations 800-m apart, obtaining penetration of hundreds of meters and covering several kilometers per day of profiling.

The location of Schlumberger soundings are shown as double-ended arrows, and the profile locations are shown as lines A-A', B-B', C-C' and D-D' on figure 1. A summary of sounding models and profile data is given in figure 3. Most Schlumberger soundings show:

1. high resistivity surface layers,
2. a low resistivity middle layers, presumably an aquifer,
3. a high resistivity electrical basement.

The low resistivity middle layer is of the greatest interest in the present study. In figure 3, alongside the circles marking the Schlumberger stations, there are three numbers separated by slash marks showing

1. the layer resistivity of the aquifer in ohm-m,

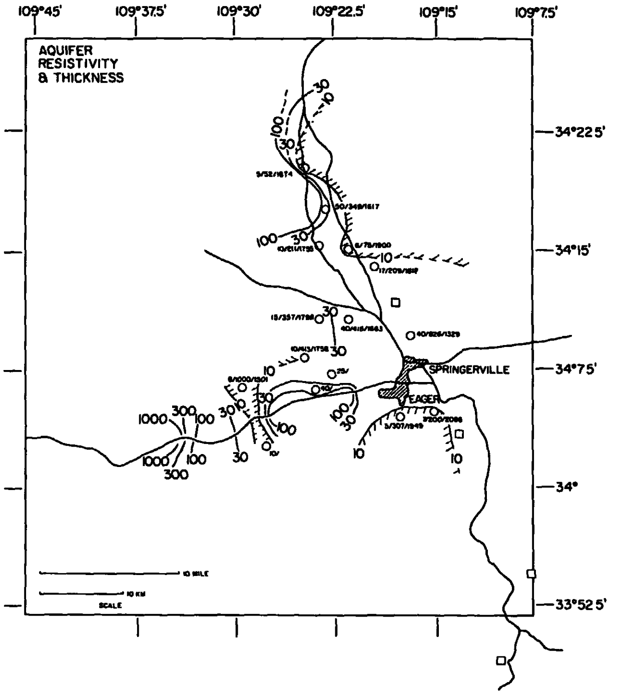

Fig. 3 Aquifer thickness and resistivity data. See text for key to numbers.

2. the depth from the surface to the bottom of the aquifer in meters,
3. the elevation above sea-level of the bottom of the aquifer, in meters.

Most soundings show an aquifer that is several hundred meters thick. The layer resistivities are contoured along with apparent resistivities for profile data for AB/2 = 800 m. Even though this seems like mixing two kinds of data, the combination is useful in indicating trends in subsurface resistivity. The contours should indicate changes in water quality, rock permeability, temperature, or all three.

Groundwater total dissolved solids (TDS) data from the U.S. Geological Survey WATSTORE file give a clue to the interpretation of the low resistivities in figure 3. High TDS values, which give rise to low resistivity, are present both north and south of Springerville. However, the narrow north-south zone of low resistivity west of Springerville has TDS values generally less than 75 ppm. It is surprising that there would be a zone of low TDS and low resistivity. The only explanation that comes to mind is that the well water samples all come from shallow wells which are recharged with low TDS rainwater, while the resistivity values represent deeper, more conductive, hot or higher TDS water. We made three Schlumberger soundings in this low resistivity zone. only one detected the bottom of the zone at a depth of 1024 meters. In fact, the bottom may be deeper, since a Schlumberger sounding can register a false electrical basement due to resistive material off the side of the sounding. We know from the profile data that highly resistive material does exist off to the side, so, is possible that the low resistivity zone extends deeper than the measurement can detect.

Conclusions

Using telluric current measurements, we have found a low resistivity zone, which could be as much as several kilometers deep. This could be a crustal scale hot-spot which heats water and causes high geochemical temperatures and high dissolved solids values. Further deep penetration electrical work, either tellurics or magnetotellurics, would be desirable to map the zone more accurately and to determine the depth to the hot material.

The DC resistivity measurements found a low resistivity layer present on all the soundings which we interpreted as an aquifer. The resistivity of this layer generally correlates well with total dissolved solids data. We found one low resistivity region which did not correlate with TDS values, which could be deep hot or high TDS water.

Combined telluric, resistivity, and gravity data are shown in figure 4. The telluric and gravity lows are overlapped and may indicate a structural feature which is a deep source of heat. Groundwater may flow through or above this deep heat source and move north and north-westward and come near the surface at the locations identified by low d.c. resistivities. A more complete interpretation will be possible when the heat flow data are available.

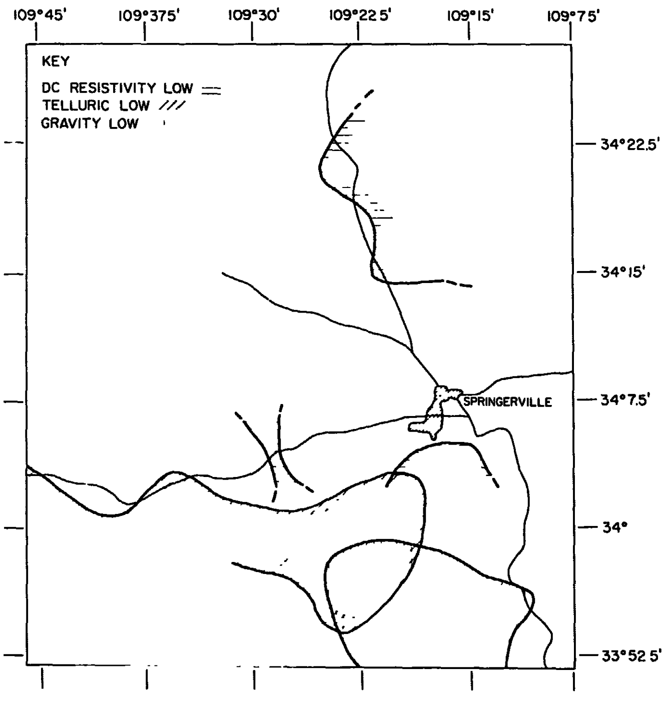

Fig. 4 Resistivity, telluric current and gravity data summary. 1) D.C. resistivity low, from figure 2, showing contour of aquifer resistivity or apparent resistivity at AB/2 = 800 m. Values less than 10 Ω-m. 2) Telluric current low, from figure 3, showing contour of remote station broadband voltage powers ratios less than .5. 3) Bouger gravity low, from Hahman, 1979, showing -30 miligal contour.

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