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A SCHLUMBERGER RESISTIVITY STUDY OF THE JEMEZ SPRINGS REGION OF NORTHWESTERN NEW MEXICO

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ABSTRACT

We are presenting the results of 33 Schlumberger resistivity soundings made in the Jemez Mountains of northwestern New Mexico, near the village of Jemez Springs. Using these data we identified three areas that have potential as low-temperature geothermal reservoirs. The areas are characterized by a localized zone of very low resistivity (<10 Ωm), which represents the extent of geothermal water and correlates with the location of hot springs or recent volcanic rocks. Resistivities increase rapidly toward the margins of the anomalies, which suggests either variable porosities or variable temperatures and salinities in the reservoirs.

INTRODUCTION

The Jemez Mountains are a well-known Miocene to Quaternary volcanic center in northwestern New Mexico which culminated in formation of the Valles Caldera 1.1 Myr ago (Smith and Bailey, 1968). This paper describes a detailed direct current resistivity survey involving 33 Schlumberger soundings recorded near the village of Jemez Springs (see Figs. 1 and 2). The purpose of our survey was to locate and determine the dimensions of near-surface geothermal aquifers that are warm enough for small-scale direct use.

GEOLOGY

The study area, which is slightly southwest of the Valles Caldera, contains a portion of the topographic rim of the caldera and recently dissected volcanic plateaus and mesas. The mesas are composed of extensive volcanic ashflow deposits (Bandelier Tuff) underlain by Miocene volcanics, Paleozoic sediments and Precambrian granite. The sediments outcrop in the bottoms of the deeper canyons.

The sediments are locally disturbed along a series of subparallel normal faults with as much as 300 m vertical displacement. These faults are part of the Jemez fault zone that extends from the Valles Caldera through our study area. Several splays of the fault zone cross the Jemez River in Cañon de San Diego north of Jemez Springs. Figure 3 shows a simplified geologic map of the area.

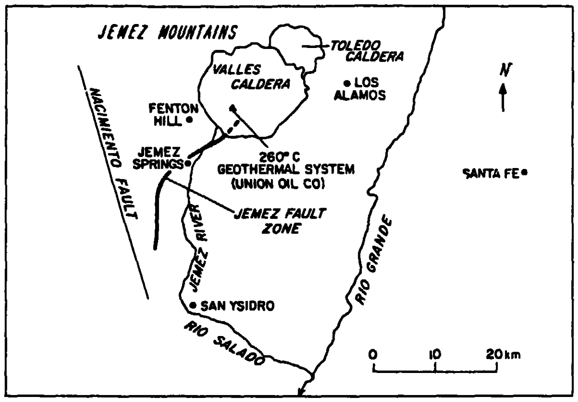


Figure 1. Sketch map of Valles Caldera region, New Mexico showing the location of Jemez Springs and Jemez fault zone (Goff et al., 1981).

The only major hot springs in our study area are Soda Dam and Jemez Springs which occur where these faults cross Cañon de San Diego. Geothermal waters discharging from these springs are derivatives of deep geothermal fluids within the Valles Caldera that flow to the springs through faults and fractures of the Jemez fault zone (Goff et al., 1981). A 250-m deep geothermal test hole, drilled recently near the town of Jemez Springs, intersected two low-temperature geothermal aquifers, one at a depth of 24 m and the other at a depth of 168 m. Surprisingly the upper aquifer contains water at ≥68°C, 8°C hotter than the lower aquifer and the chemistry of the upper aquifer is identical to the chemistry of overlying hot springs (Goff et al., 1981). The upper 24 m aquifer is particularly interesting because its shallow depth and relatively high temperatures may make it an economically attractive source for direct use applications. However, the extent of this geothermal resource is not known.

In addition, there are two hot springs on the west side of the Cañon de San Diego that issue from the base of recent (≤0.4 Myr) rhyolite flows in the south moat of Valles Caldera. While these rocks do not extend east of the Jemez River, it suggests that another shallow geothermal aquifer exists in the moat zone of the caldera. Geothermal waters of the moat zone are extremely dilute

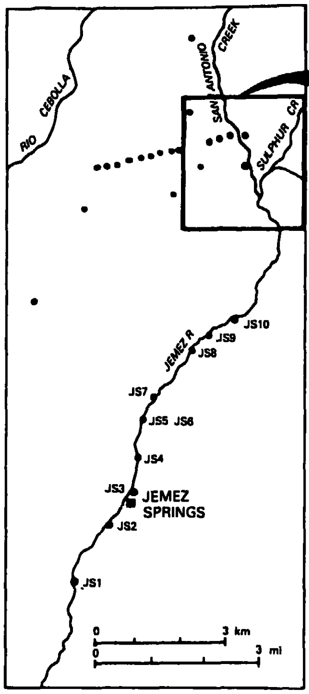


Figure 2. Location map of our Schlumberger soundings.

compared to other thermal/mineral waters of the Jemez Mountains.

DATA AQUISITION AND INTERPRETATION

A Schlumberger array consists of four co-linier electrodes, in which two closely spaced potential electrodes are centered between two current electrodes. A Schlumberger survey is conducted by increasing the current electrode separation between readings while leaving the potential electrodes fixed. During each reading we record the current between the outer electrodes and the potential drop between the inner electrodes. We then calculate apparent resistivities, which physically are a normalized measure of the earth's resistivity after the effects of changing electrode spacings have been removed (Keller and Frischhnect, 1966). If the earth is horizontally layered, variations in effective resistivity as a function of current electrode separation can be used to infer resistivities as a function of depth below the array. We interpreted the data using a well-known computer program developed by Zohdy (1974). Figure 4 shows two sample Schlumberger sounding curves.

INTERPRETATION

We found several electrically conductive zones in the Cañon de San Diego that may indicate low temperature geothermal aquifers at moderate depth. Near the center of Jemez Springs we discovered a very low resistivity layer at a depth of 24 m that we identified as a shallow geothermal aquifer using data from the nearby geothermal test

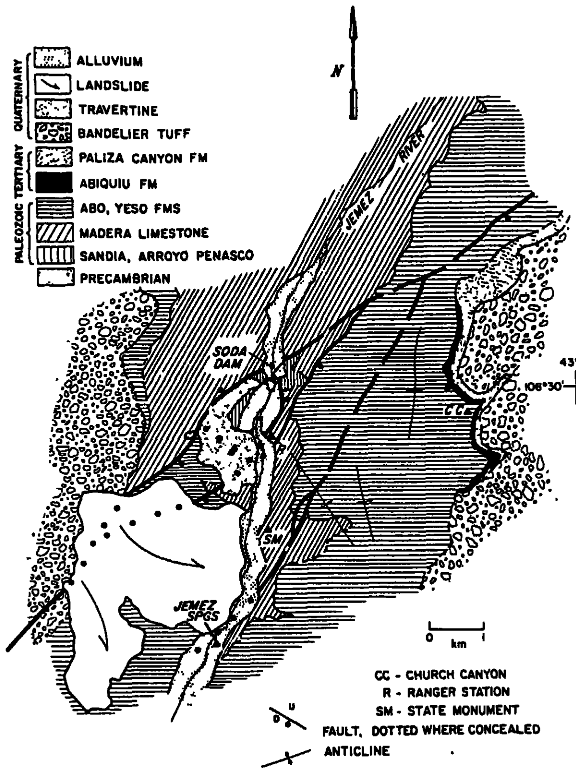


Figure 3. Simplified geologic map of the region near Jemez Springs (Goff et al., 1981).

hole as control. Figure 5 shows our interpretation of the resistivity data. We were able to trace the aquifer several km north and south of Jemez Springs; however, aquifer resistivities are lowest near Jemez Springs and increase with distance both to the north and south. This may indicate that the shallow geothermal aquifer is fed by geothermal water from a splay of the Jemez fault zone, which is also responsible for the nearby hot springs.

We found a second highly conductive layer slightly to the north of the Soda Dam Hot Springs, 2 km north of Jemez Springs. Once again the formation resistivities increased north of the dam. Surprisingly, JS5, which was 150 m closer to the hot springs than JS6, also detected higher formation resistivities. This may be caused by sheared (low permeability) sandstones faulted against granite (Fig. 3) or by precipitation of $CaCO_3$ from geothermal fluids, which reduce porosity and thus the formation resistivity. North of our JS7 sounding, the geothermal aquifer seems to disappear completly, although our northernmost station JS10 did detect a highly conductive zone that may represent yet another localized area saturated with hot water. The Soda Dam reservoir has limited lateral extent and may represent a pool of geothermal water dammed by upfaulted granite slightly to the south (Fig. 3).

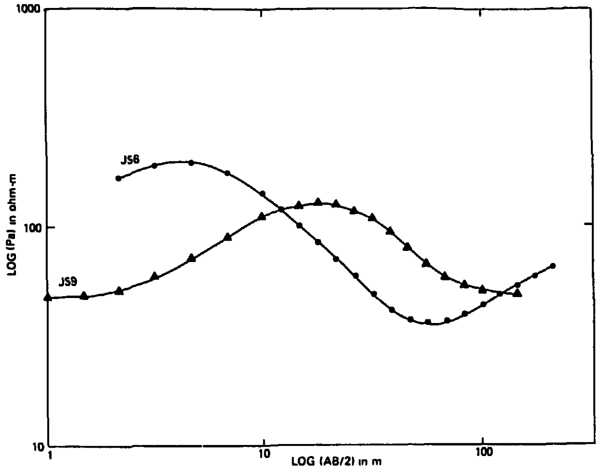


Figure 4. Two sample Schlumberger sounding curves. JS6 was conducted over a highly conducting zone, which is a potential geothermal aquifer; JS9 was not.

We identified a third area 12 km north near the village of La Queva that may have some limited geothermal potential. The easternmost station LC4 is underlain by comparatively recent rhyolite flows and the 4 Ω m layer beneath this station probably represents a geothermal aquifer. While stations LC1-LC3 are situated on unconsolidated alluvium, moderately low resistivity (12-18 Ω m) layers here may be caused by various geothermal waters in localized aquifers. In fact, water wells in La Queva have struck warm, relatively dilute water (Sharon Crane, La Queva Lumber Co., personal commun., 1981). None of our other stations provided any evidence for near-surface geothermal reservoirs underlying the mesas and canyons west of the Jemez River valley.

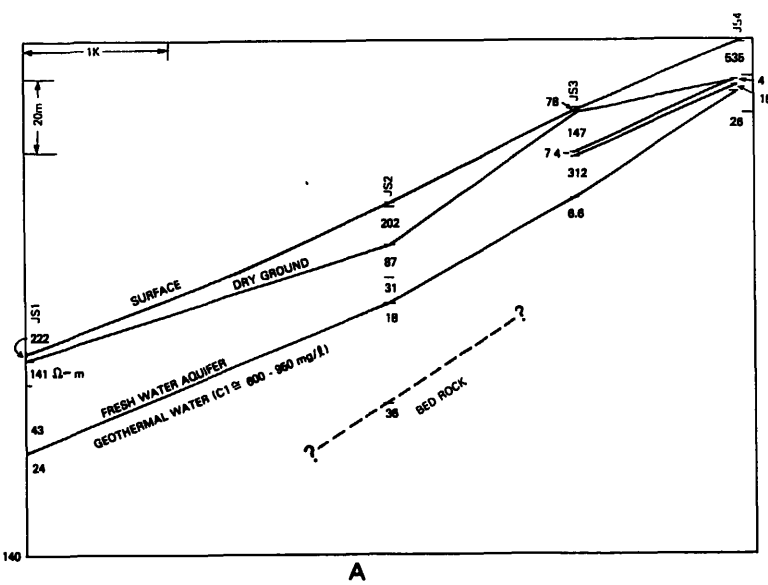
AQUIFER PROPERTIES

The formation resistivity ρ_F of a geothermal aquifer is related to the water resistivity ρ_W and the porosity ϕ by Archie's (1942) equation

$$\rho_F = 0.62\ \phi^{-2.15}\ \rho W. \quad (1)$$

If we have samples of the pore water from the aquifer and can measure ρ_W, we can use Eq. 1 to estimate the porosity. We calculated ϕ in this manner for the highly conductive zones underneath JS3, JS6, and LC4 by using water resistivities from nearby hot springs for ρ_W (see Table 1).

Potential geothermal aquifers identified in Cañon de San Diego show increasing formation resistivities with distance from the source of the geothermal water. One possible explanation is that $CaCO_3$ deposited in sediment pore spaces decreases the permeability during CO_2 discharge from fluid. Assuming that ρ_W does not change, we can calculate porosities from the formation



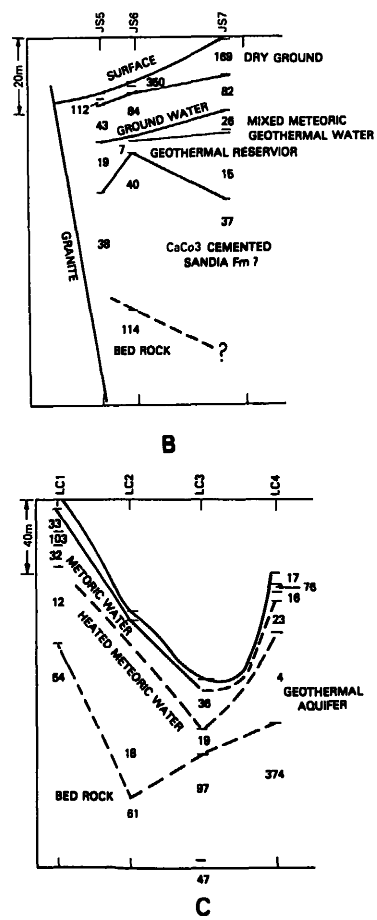


Figure 5. Interpretation of Schlumberger soundings conducted near (a) Jemez Springs, (b) Soda Dam, and (c) La Queva, New Mexico.

Table 1. Porosities estimated from the formation resistivity using Archie's Equation.

Station	Formation Resistivity Ωm	Water Resistivity Ωm	Porosity %
JS 3	6.6	1.1	35
JS 6	7.2	0.9	30
LC 4	4.0	0.9	40

resistivities using Eq. 1 (see Table 2). These calculations show that the reservoir has quite variable porosity which is usually highest near the center and comparatively low near the margins.

A second explanation is that the water resistivity at the margins of the geothermal aquifer increases due to dilution with meteoric water. We estimated the change in ρ_W needed to cause the changes in the formation resistivity by assuming that the formation factor in Eq. 1 was constant throughout each of the three geothermal aquifers. We then estimated the amount of mixing with pure 10°C water necessary to produce these changes in ρ_W using nomographs relating ρ_W temperature and salinity (Schlumberger log interpretation charts, 1979). Results of these calculations are summarized in Table 2 reported as percent geothermal water in aquifer. Clearly either a decrease in porosity or a decrease in water temperature due to mixing may cause the increasing aquifer resistivities that we observed during this survey and both mechanisms are probably important. However, these studies emphasize the importance of careful investigations before drilling because regions containing high temperatures and high permeabilities are probably quite localized.

CONCLUSION

We identified three low-temperature geothermal reservoirs that have potential for direct use applications. Two of these reservoirs are near the town of Jemez Springs and both are probably fed by geothermal waters discharging along strands of the Jemez fault zone. The southern aquifer in Jemez Springs has a large lateral extent and we were able to trace it nearly 4 km south of Jemez Springs. The second reservoir, near Soda Dam, is much more confined and may represent a small pool of geothermal water dammed by an upfaulted granitic block lying slightly downstream. The third reservoir, 12 km north near La Queva, is probably composed of heated meteoric water circulating in local aquifers of the caldera moat. All three aquifers have highly variable resistivities suggesting that the temperatures, salinities, and/or the formation porosities are also variable.

ACKNOWLEDGMENTS

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Table 2. Porosities and reservoir temperatures estimated from formation resistivities.

Station	Porosity %, assuming no mixing	Percent geothermal water in the aquifer; assuming no porosity changes	Calculated temperature °C
JS 1	19	44	37
2	22	54	43
3	35	100	72[a]
4	18	42	36
5	19	51	29
6	40	100	48[a]
7	21	61	33
LC 1	24	48	33
2	20	36	27
3	19	35	27
4	40	100	58

[a]Temperatures given are known temperatures of hot springs fed by underlying aquifers.

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