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GEOTHERMAL EXPLORATION IN THE VICINITY OF LAKE ELSINORE, SOUTHERN CALIFORNIA

Brian N. Damiata and Tien-Chang Lee

Institute of Geophysics and Planetary Physics
University of California, Riverside, CA 92521

ABSTRACT

Geothermal exploration in the Lake Elsinore area has primarily focused near a cross fault which acts as a conduit for thermal water. Flow testing of an exploratory hole indicates an anisotropic aquifer with a maximum transmissivity axis oriented along the fault striking N 11° E. Thermal water migrates laterally throughout the downtown area along a zone of enhanced transmissivity associated with the fault. Thermal water is lower in total dissolved solids, depleted in Ca and Mg and enriched in SiO_2 and F as compared to non-thermal water. The difference in chemistry was used to develop a criterion for selecting future exploration targets based on: flow temperature $>$ 25°C, fluoride $>$ 1.2 mg/l and silica geotemperature $>$ 90°C. A conceptual model in which deep circulation of local meteoric water is proposed. Water derived from the Santa Ana Mountains descends to a depth of 2-2.5 km along major faults bordering Elsinore Trough. As the water descends, it is heated to a temperature of 90°C and then ascends along a fracture zone near the intersection of the Glen Ivy North and cross faults.

INTRODUCTION

Geothermal exploration near Lake Elsinore began in 1983 (Juncal et al., 1984). In 1985, three exploratory holes were drilled; one of which was completed as a production well to supply 50°C water to a retrofitted city-owned building. This report summarizes interpretations of data collected from temperature loggings in existing wells and new exploratory holes, and flow testing of one exploratory hole. In addition, a geochemical exploration criterion and a conceptual model are proposed.

REGIONAL SETTING

The study area occupies approximately 110 km^2 and is located about 100 km southeast of Los Angeles (Figure 1). Within the area, the Elsinore Trough lies between the Santa Ana Mountain and Perris tectonic blocks. Elsinore Valley represents the northwest surface expression of the trough. Topographic relief varies between 373 m in the valley to 1,736 m in the mountains.

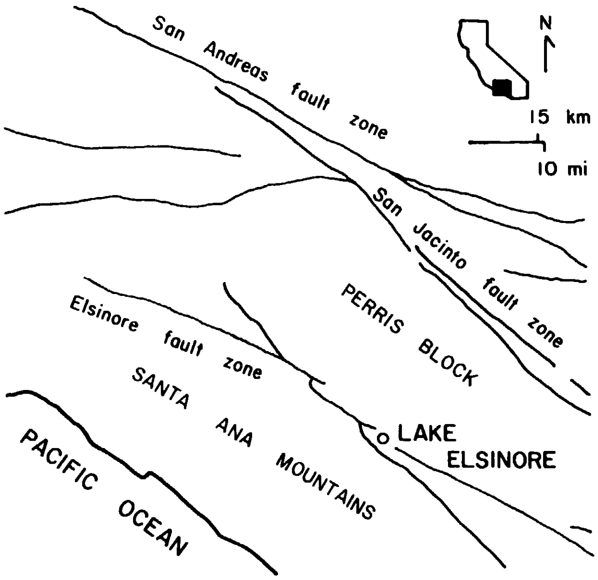

Figure 1. Location map of Lake Elsinore area.

Geology

Metasediments, metavolcanics and plutonics of Jurassic to Cretaceous age constitute the basement complex. These rocks form the Santa Ana Mountains, underlie the trough and define the northeast border of the trough. A thin veneer ($<$ 10 m) of alluvium overlies the basement complex within the downtown area.

Overlying portions of the basement complex along the western margin of the trough are alluvial fan deposits of Pleistocene to recent age (Weber, 1977). Within the trough are lacustrine, floodplain and valley fill deposits of late Miocene and younger ages. The estimated maximum thickness of these alluvial deposits is about 700 m (Harding-Lawson Associates, 1980).

Structure

The Elsinore fault zone represents a major branch of the San Andreas fault system in southern California. It dominates the structural features in the study area. Near Lake Elsinore, the zone is composed of several faults. The Glen Ivy North fault delineates the northeast boundary of the Elsinore trough (see Figure 4), characterized by right-oblique movement with the southwest side down relative to the northeast (Weber, 1977). The Wildomar and Willard faults delineate the southwest boundary of the trough. The former has a near vertical fault plane with > 4.8 km of right-lateral displacement (Kennedy, 1977). The latter is characterized by a high angle normal fault plane, dipping to the east (Engel, 1959).

Other important faults bordering the trough include the North Elsinore fault and a cross fault. The North Elsinore has been traced from surface ruptures formed in response to the 1918 San Jacinto earthquake (Engel, 1959). Fault displacement is primarily strike-slip along a near vertical fault plane. The cross fault between the North Elsinore and Glen Ivy North faults was first hypothesized by Juncal (1984) and confirmed in this study.

Within the trough, the fault structure is complex. Ford and Mido (1981) suggest the presence of eight en echelon fault blocks whose characteristics are poorly known.

EXPLORATION

Downtown Lake Elsinore

Geothermal exploration was conducted in the downtown area. Due to a high level of cultural activity, surface geophysical methods have not been employed in this area. Most of our effort was concentrated on exploratory drilling, temperature loggings and flow testing.

Figure 2 depicts the temperature profiles for three exploratory holes. Hole GW #1, located near the southwestern end of the cross fault, encountered dioritic basement at 10 m depth. A bottom hole temperature of 40°C was measured at a depth of 148 m. Hole GW #3, located near the northwestern end of the cross fault, was drilled into metasediments and metavolcanics. A maximum temperature of 29.4°C was measured at a depth of 183 m. Hole GW #2 was drilled into a fracture zone in the dioritic basement. The well is 213 m deep, cased to 146 m and perforated from 79 to 140 m. A maximum temperature of 50°C was measured in this hole.

Two flow tests were conducted on GW #2 to determine hydraulic properties of the thermal aquifer. Test #2 lasted for about 95 hours. A flow rate of 2,840 l/min as determined from a flow meter on the well head was maintained throughout the test. Well head temperatures declined slightly during the test from 49.3°C at the beginning to 48.7°C at the end. Figure 3 depicts the effects of anisotropy on the drawdown distribution around the pumped well as deduced from 8 observation wells. The iso-drawdown contours are ellipses with their major axes aligned in the direction of greatest transmissivity. Based on a two-dimensional flow

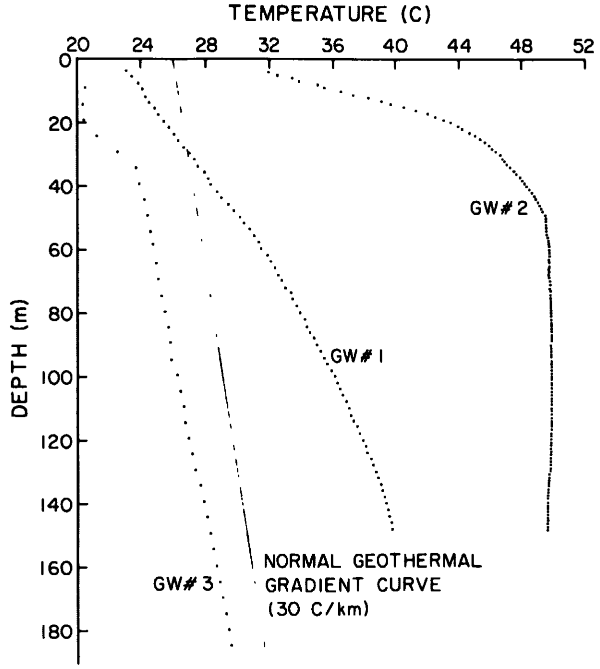

Figure 2. Temperature profiles for exploratory holes (see Figure 4 for locations).

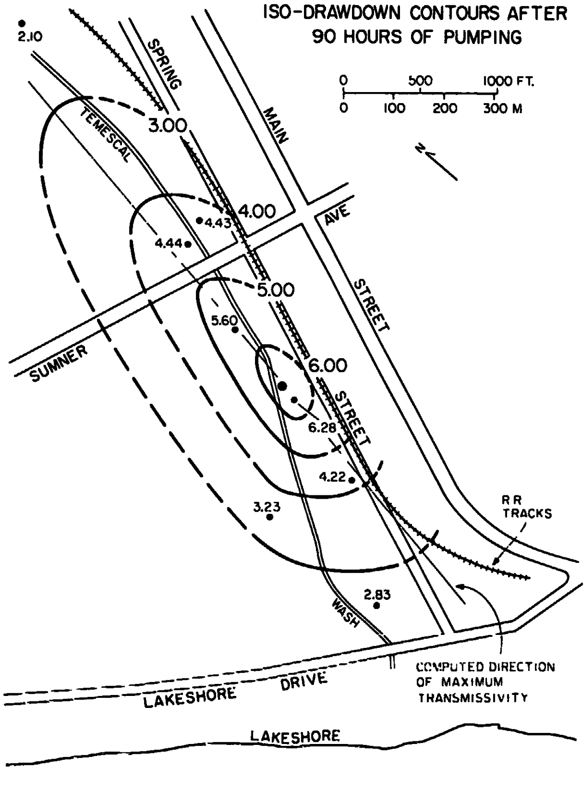

Figure 3. Iso-Drawdown contours during flow test of GW #2.

model for a homogeneous anisotropic aquifer (Papadopulos, 1967), the principal transmissivities are 2.3 x 10^{-2} m^2/s (N 11° E) and 5.4 x 10^{-4} m^2/s (N 79° W) (at a prevailing temperature of 49°C). Although the orientations of the fractures are not known, they are by no means horizontal. Thus, the determinations should be regarded as apparent values.

The origin of the cross fault is attributed to a "tear" between two primarily right-lateral faults: the Glen Ivy North and North Elsinore faults. For two predominately right-lateral faults trending in approximately the same direction, differential displacement between the faults may result in a high angle vertical fracture which intersects the wrench axis at an angle between 70 and 90° (Wilcox et al., 1973). Assuming the two faults are oriented between N 60° W and N 30° W in this vicinity, the qualitative assessment is consistent with the calculated direction of maximum transmissivity.

Interpretations of temperature data for wells located in the downtown area (data not shown) are also consistent with the idea of a cross fault. Wells located near the zone of maximum transmissivity have the highest measured temperatures and observed temperature gradients. Based on the extent of wells affected by flow testing and the location of other known thermal wells, the fracture zone has a width between 0.3 and 0.5 km. Within the zone, the geometric mean storativity is about 1.4 x 10^{-3}.

Elsinore Valley

Over 360 water analyses from 61 wells were compiled to examine trends in geochemistry and classify thermal and non-thermal waters. Stiff diagrams (Figure 4) were constructed to facilitate rapid comparison of analyses. Table 1 depicts several chemical analyses for thermal and non-thermal waters.

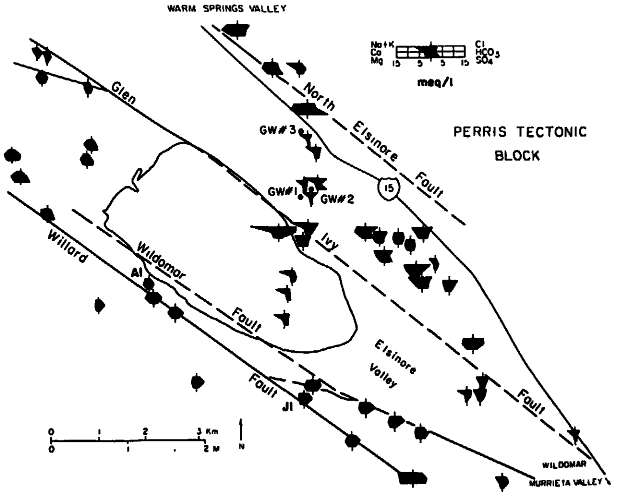

Figure 4. Stiff diagrams for waters near Lake Elsinore.

TABLE 1. CHEMICAL ANALYSES

SAMPLE	65/4W-19J1	65/5W-14A1	GW#2
Well Depth (m)	35	shallow	145
Measured Temp. (°C)	20	20	48.1
pH	7.4	8.1	9.4
TDS	408	316	359
Na	54	31	92
K	2	0.6	7.8
Ca	49	49	0.0
Mg	22	11	0.0
SiO_2	37	--	85
CO_3	0.0	0.0	66
HCO_3	231	163	43
SO_4	45	40	41
Cl	60	29	64
F	0.6	0.5	4.6

concentrations in mg/l

Several distinct geochemical trends are observed. Groundwater in the Lucerne area is calcium sulfate ($CaSO_4$) and calcium bicarbonate $Ca(HCO_3)_2$-rich. Groundwater at the base of the Santa Ana Mountains is $Ca(HCO_3)_2$-rich. A distinct change in water chemistry is observed south of the North Elsinore fault where known thermal water occurs. In general, the thermal water is lower in total dissolved solids, depleted in Ca and Mg and enriched in SiO_2 and F with respect to non-thermal water. The North Elsinore fault may act as an effective groundwater barrier thus, defining the northern extent of thermal water in this area.

Using geochemistry, a criterion was developed for selecting future exploration targets. The method is based after Swanberg and Alexander (1978). The general approach in establishing the criterion is to prepare histograms of various geothermal indicators from which the

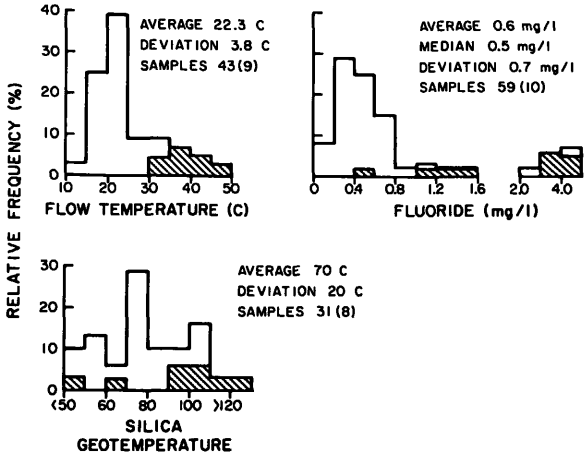

Figure 5. Histograms of flow temperature, fluoride concentration and silica geotemperature. The shaded portions represent thermal waters which are not included in the calculation of means and standard deviations.

mean (or median) and standard deviation are calculated. For an indicator which has a normal distribution, a water which plots beyond one standard deviation is considered anomalous. Figure 5 depicts the three indicators used for waters in the vicinity of Lake Elsinore.

Flow Temperature

Flow temperature is an obvious geothermal indicator. However, interpretation is complicated by insufficient well completion data. Thus, it is not always possible to distinguish between thermal water and non-thermal water which has been sampled from a deeper well in a normal geothermal gradient area. Using the one-deviation condition, flow temperatures greater than 25°C are considered anomalous as compared to a mean ground temperature of 17°C. All known thermal waters (9 samples) are anomalous.

Fluoride

Fluoride is concentrated in thermal water and is used as a geothermal indicator. The corresponding histogram is skewed to the right. However, excluding known thermal waters results in a normal frequency distribution. Because low concentrations are involved, one standard deviation from the median value was used. Using the one-deviation condition, fluoride concentrations in excess of 1.2 mg/l are considered anomalous. All but two known thermal waters are anomalous.

Silica Geotemperature

The histogram for silica geotemperatures yields a cutoff temperature of 90°C. Five of seven known thermal waters are anomalous.

A water which is anomalous for two or more indicators is considered potential thermal water and suggests an area warranting further exploration. All known thermal waters pass the criterion.

A CONCEPTUAL MODEL

The thermal anomaly near Lake Elsinore can be characterized by a low temperature geothermal convection system driven by deep circulation of meteoric water. Recharge water in the Santa Ana Mountains is heated as it descends along faults bordering Elsinore Trough. After heating, the water ascends by free convection due to density differences and by forced convection due to a regional hydraulic gradient. The thermal water rises to shallow depths via deep fractures along the northeast margin of Elsinore Trough. Near surface upflow is localized along a zone of enhanced transmissivity near the intersection of the Glen Ivy North and cross faults. Some leakage of thermal water occurs across the Glen Ivy North fault into permeable formations within Elsinore Valley.

SiO_2 geothermometry applied to known thermal waters (data not shown) yields a potential reservoir temperature of 90°C. Assuming an average groundwater temperature of 22°C and a normal geothermal gradient of 30°C/km results in a circulation depth of 2.3 km. Thus, the model requires that fractures within Elsinore Trough extend to at least this depth. This condition is reasonable considering microseismic activity extends to a depth of 5 km (Langenkamp and Combs, 1974).

Higher SiO_2 and F concentrations in thermal water are attributed to elevated temperatures and circulation through the basement complex. A possible explanation to account for the depletion of Ca and Mg ions is that as descending recharge water is heated, the ions are depleted by the precipitation of carbonates. The slight increase in Na does not offset the depletion of Ca and Mg resulting in slightly lower total dissolved solids for thermal water as compared to recharge water. However, loss of CO_2 at the sampling site may have an appreciable effect on the chemical analyses for thermal water. In particular, pH and Ca, Mg, CO_3 and HCO_3 concentrations may be significantly affected. Thus, caution must be exercised in interpreting thermal water analyses.

ACKNOWLEDGEMENTS

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