Title
GEOTHERMAL STUDIES IN NORTHERN NEVADA

Author
Wollenberg, Harold A.

Publication Date
1976-06-01

To be presented at the Eleventh
Intersociety-Energy Conversion Engineering
Conference, Lake Tahoe, NV,
September 12 - 17, 1976

GEOTHERMAL STUDIES IN NORTHERN NEVADA

Harold A. Wollenberg

June 1976

Prepared for the U. S. Energy Research and
Development Administration under Contract W-7405-ENG-48

GEOTHERMAL STUDIES IN NORTHERN NEVADA*

Harold A. Wollenberg
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

Abstract

The Lawrence Berkeley Laboratory (LBL) and University of California (UCB), under the auspices of the U. S. Energy Research and Development Administration, are conducting field studies at potential geothermal resource areas in north-central Nevada. The goal of the LBL-UCB program is to develop and evaluate techniques for the assessment of the resource potential of liquid-dominated systems. Field studies presently being conducted in northern Nevada incorporate an integrated program of geologic, geophysical, and geochemical surveys leading to heat flow measurements, and eventually to deep (1.5-2 km) confirmatory drill holes. Techniques evaluated include geophysical methods to measure contrasts in electrical resistivity and seismic parameters. Geochemical studies have emphasized techniques to disclose the pathways of water from its meteoric origin into and through the hydrothermal systems. Geochemical and radiometric analyses also help to provide a baseline upon which the effects of future geothermal development may be superimposed.

INTRODUCTION

The Lawrence Berkeley Laboratory (LBL) and the University of California, Berkeley (UCB), under the auspices of the U. S. Energy Research and Development Administration, are conducting field studies at potential geothermal resource areas in north-central Nevada. This region, shown on the location map (Fig. 1), is characterized by higher than normal heat flow (Sass and Munroe, 1) where temperatures at depth within some geothermal systems exceed 150°C

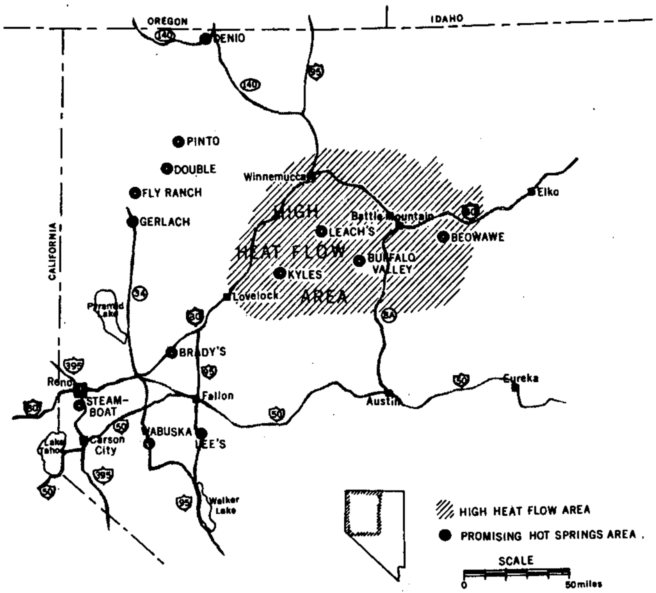

Fig. 1. Location map, northern Nevada, showing the region of high heat flow and sites discussed in the text.

(Mariner et al., 2). In contrast to many other geothermal resource areas, the central Great Basin of northern Nevada is not characterized by young siliceous volcanic rocks; rather, present-day hydrothermal systems are located on basin-and-range fault zones which penetrate deeply into areas of high geothermal gradient (>50°C km^{-1}) (Hose & Taylor, 3). The fault zones furnish permeable pathways for downward percolating, meteoric water to reach sufficient depth (4 to 5 km) where water is heated, then rises on the upward-flowing limb of a convection cell. Thus, fracture permeability, afforded by intersecting faults in sub-alluvial bedrock, is the mechanism by which waters can reach depths great enough for heating, and provides channelways for upward transport of hot waters. Geothermal reservoirs may be in fractured rock of fault zones, or in relatively permeable beds of Tertiary sedimentary deposits and Quaternary valley fill alluvium.

The goal of the LBL-UCB program is to develop and evaluate techniques for the assessment of the resource potential of liquid-dominated systems. Field studies presently being conducted in northern Nevada have been described in detail by Wollenberg et al. [4]. They incorporate an integrated program of geologic, geophysical, and geochemical surveys, heat flow measurements in holes up to 300 m deep, leading eventually to drilling of deep (1.5-2 km) confirmatory drill holes.

Areas under examination (shown in Fig. 1) include Whirlwind Valley, containing Beowawe Hot Springs, Buffalo Valley Hot Springs; Leach Hot Springs in Grass Valley; and Buena Vista Valley in the vicinity of Kyle Hot Springs. Techniques evaluated include geophysical methods to measure contrasts in electrical resistivity, incorporating induced and natural currents and magnetotellurics, as well as the self potential method. Passive seismic techniques have been employed to locate and monitor microearthquakes, study ground noise spectra, and evaluate patterns in teleseismic compression-wave delays. Some of these geophysical techniques may be used to monitor a geothermal reservoir as production proceeds.

Geochemical studies have emphasized techniques to disclose the pathways of water from its meteoric origin into and through the hydrothermal systems. Included are analyses of waters, spring deposits, and country rocks by neutron-activation, x-ray fluorescence and radiometric methods. Abundances of elements in hot and cold springs are used to estimate the amount of mixing of near-surface cold waters with ascending hydrothermal waters. Geochemical and radiometric analyses also help to provide a baseline upon which the effects of future geothermal development may be superimposed.

The study of the Grass Valley area, where geophysical targets have been located near and away from Leach Hot Springs, illustrates the use of these techniques to locate sites for deep drilling.

GRASS VALLEY STUDIES

Geologic Setting. A potential geothermal resource area in Grass Valley is located in the vicinity of Leach Hot Springs, approximately 50 km south of Winnemucca. The Sonoma and Tobin Ranges bound the valley on the east, while the valley is constricted south of the hot springs by the Goldbanks Hills, locus of earlier mercury mining. Grass Valley is bounded on the west by the basalt-capped East Range. The distribution of major lithologic units in the region is illustrated on the geologic map (Fig. 2). The intricate fault and lineament pattern is shown on a separate map, Fig. 3, based strongly on interpretation of aerial photography provided by NASA. Paleozoic siliceous clastic rocks and greenstones are the oldest bedrock types in the region. In places in the Sonoma and Tobin Ranges, the Paleozoics are in thrust-fault contact with Triassic siliceous clastic and carbonate rocks. The Paleozoic and Triassic rocks have been intruded by granitic rocks, of probable Triassic age in the Goldbanks Hills; elsewhere the granitics are probably of Cretaceous age. Though not exposed in the Leach Hot Springs area, Oligocene-Miocene rhyolitic tuffaceous rocks are probably present in the subsurface. They are overlain by a sequence of interbedded sandstone, fresh water limestone and altered

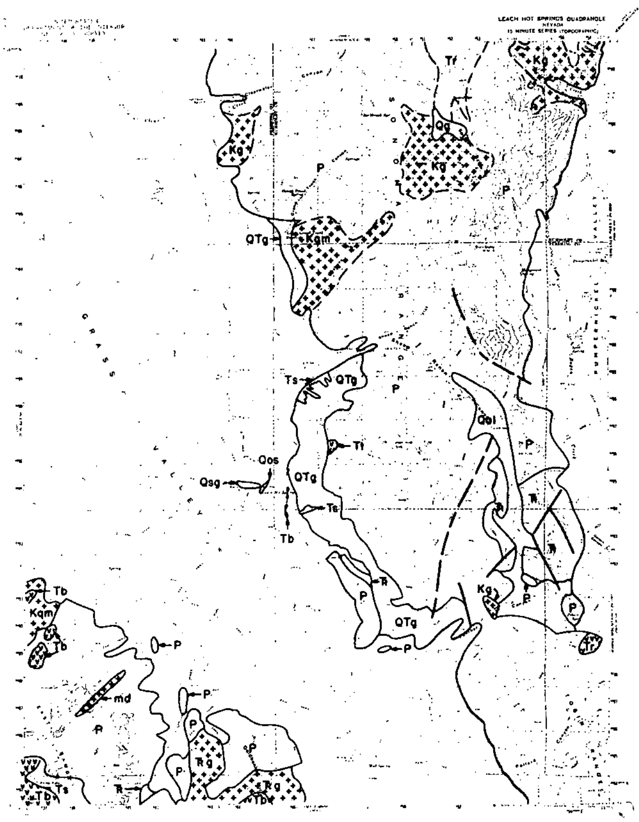

Fig. 2. Lithologic map, Leach Hot Springs area. Qal: alluvium, Qos: older sinter deposits, Qsg: sinter gravels, QTg: Quaternary-Tertiary gravels and fanglomerates, Tb: Tertiary basalt, Tr: Tertiary rhyolite, Tt: tuff, Ts: Tertiary sedimentary rocks, Kqm: quartz monzonite, Kg: granitic rock, md: mafic dike, TRg: Triassic granitic rocks, TR: undifferentiated Triassic sedimentary rocks, P: undifferentiated Paleozoic sedimentary rocks. Section squares are one mile on a side.

tuffs, which are in turn overlain by coarser conglomeratic sediments (fanglomerates) derived from mountain range fronts steepened by the onset of basin-and-range faulting. The fanglomerates are opalized sinter at Leach Hot Springs. The Tertiary sedimentary sequence is overcapped by predominantly basaltic volcanic rocks whose ages, dated by the potassium-argon method, range from 14.5 to 11.5 million years.

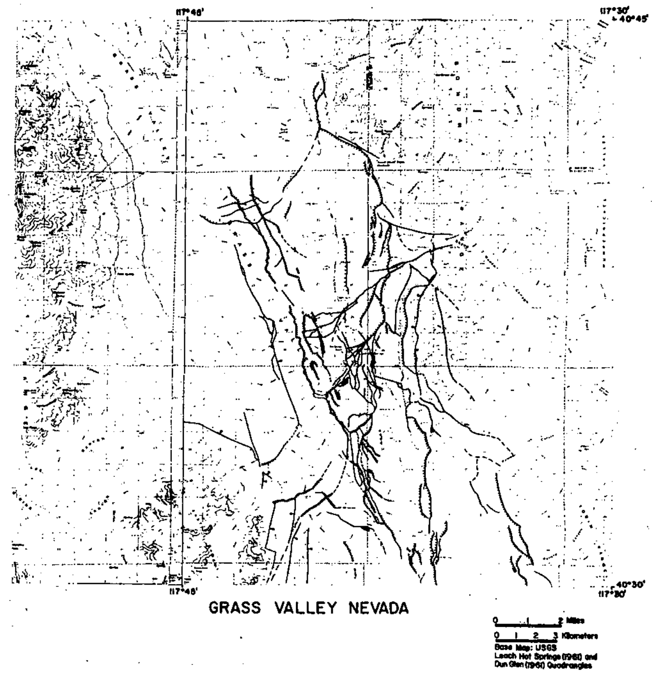

Fig. 3. Fault map of the Leach Hot Springs area. Hachured lines indicate down-faulted sides of scarplets; ball symbol indicates down-thrown side of other faults.

Characteristic of the hot spring systems observed in northern Nevada, Leach Hot Springs is located on a fault, strongly expressed by a 10- to 15-m-high scarp trending NE. Normal faulting since mid-Tertiary has offset rock units vertically several tens to several hundred meters. As shown on the fault and lineament map (Fig. 3), the present-day hot springs occur at the zone of intersection of the NE trending fault and the NNW-SSE trending lineaments.

Total surface flow from the Leach Hot Springs system has been measured at 130 ℓ min^{-1} (Olmsted, et al., 5). Surface temperatures of the springs reach 94°C, boiling at their altitude, and water temperatures at depth are estimated to be 155 to 170°C, based on silica and alkali-element geothermometers (Mariner et al., 2). Material deposited by Leach Hot Springs, presently and in the past, is predominantly SiO_2.

Geophysical Surveys. Geophysical efforts to delineate geothermal reservoirs in Nevada have concentrated on techniques to measure the electrical conductivity of an area and to determine its seismicity. The former is important because electrolyte in the pores of a rock increases in conductivity with increase in temperature, and because it has been observed that, in most geothermal occurrences worldwide, the reservoir is of higher conductivity than the surrounding cold rock. The seismic studies are important in determining the location of active faults which are believed to control fluid flow in geothermal areas. Auxiliary geophysical studies such as self potential and gravity have also been undertaken (Corwin, 6). These methods have provided valuable data for interpreting the geological structure of the area and some of these may prove to be useful for direct reservoir detection.

1. Electrical geophysical surveys, utilizing induced and natural earth currents, have been conducted to measure the resistivity at depth near and away from Leach Hot Springs. The most commonly used technique is to inject commutated dc current into the ground between two electrodes, and to measure the voltage difference produced between two distant electrodes. A reconnaissance version of this method, called bipole-dipole, consists of a large current transmitter with electrodes up to 2 km apart (the bipole), and voltages measured with a roving receiver array using electrodes 100 meters apart (the dipole). About 110 km^2 of the area initially selected for investigation in Grass Valley was surveyed by this method.

Methods using natural electromagnetic fields (telluric methods) have obvious advantages over the bipole-dipole resistivity method, in that a current source is not required, and a broad spectrum of energy is available. Therefore, the depth of exploration can be selected without the large arrays required in dc resistivity methods. A technique using natural low frequency earth currents has been developed which is particularly well suited for reconnaissance surveys. A leap-frogging array of three colinear electrodes spaced 500 m apart is employed to determine the ratio of the electric field (E) across the leading electrode pair to the lagging electrode pair. This E field ratio is proportional to the ratio of the ground resistivity beneath the electrode pairs. Successive ratios are referenced to the base, or starting, electrode pair so that a profile of a relative resistivity variation is produced.

The area encompassed by the bipole-dipole surveys was also covered by telluric surveys. 146 line-km were surveyed, with electrodes spaced at 500 m; frequencies of 0.05 and 8 Hz were recorded. Comparison of the results from the two methods indicates good correlation between them (Fig. 4 compares results of the methods along a profile line). Therefore, it is concluded that the telluric method can replace bipole-dipole surveys as a reconnaissance technique. Telluric measurements require simple portable equipment and only two men for operation, while bipole-dipole surveys require heavy high power generators, electrode emplacement, and a minimum of four men.

Reconnaissance techniques then delimit areas to be examined in detail by dipole-dipole resistivity methods. Better resolution is achieved with the dipole-dipole array. Here the electrode pairs have equal spacing and are arranged colinearly; the separation between voltage receiver and current transmitter dipoles is an integer multiple of the dipole length.

Computer modeling of over 70 line-km of dipole-dipole resistivity profiles in Grass Valley has been accomplished (F. Morrison, private communication, 1976). Dipole spacings of 0.25, 0.5, and 1 km were used. A conductive anomaly (resistivity ∿ 3 ohm-meters) has been identified SSE of Leach Hot Springs. In the central part of Grass Valley--to the northwest, west, and southwest of Leach Hot Springs--modeling of the dipole-dipole data indicates a resistive surface layer approximately ½ km thick with the resistivity decreasing with depth over the range of 30 to 5 ohm-meters. Beneath this, along the north-south trending gravity low axis of the valley--the region of thickest sediments--is a more conductive zone which may be 0.75 km thick and 3 - 6 km wide. Modeling indicates that the resistivity of this region decreases from south to north, the direction of hydrologic flow. The resistivity appears to be about 4 ohm-meters southwest of Leach Hot Springs, and decreases to 1 - 2 ohm-meters west and northwest of the springs.

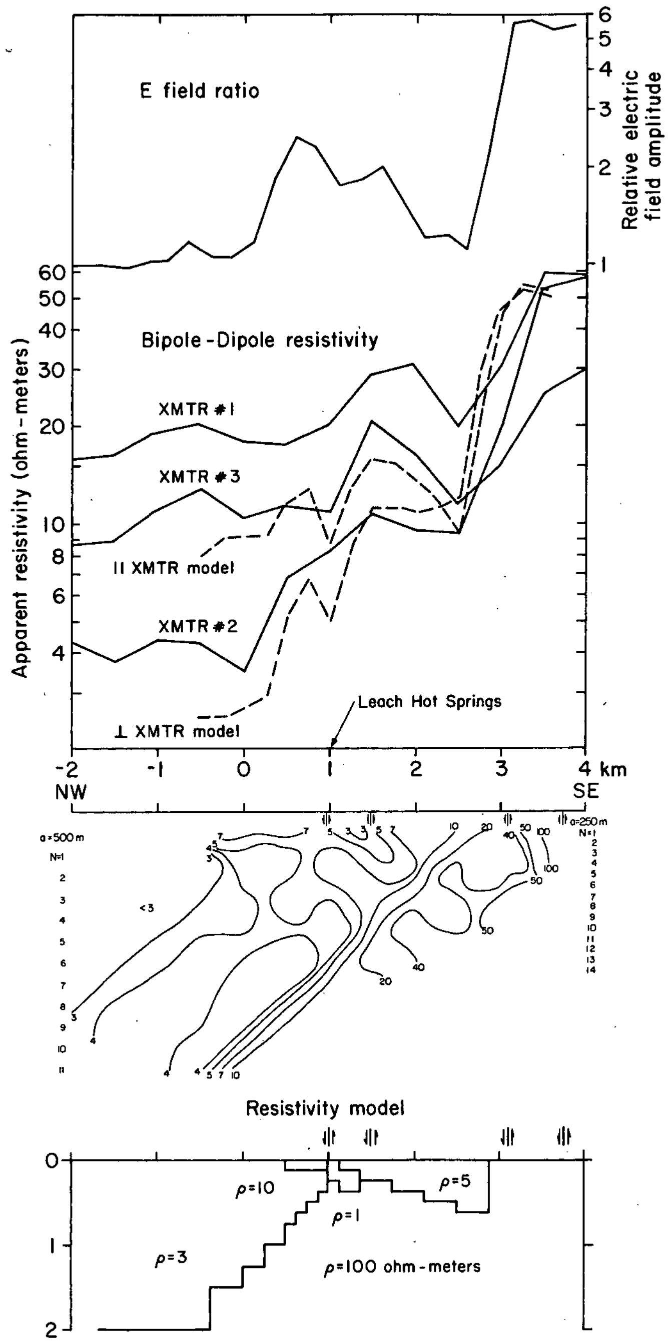

Fig. 4. Comparison of resistivity and telluric methods along a profile line transecting a portion of Grass Valley near Leach Hot Springs. XMTR# indicates curve for a specific current transmitter location.

2. Passive seismic studies. There is evidence that geothermal reservoirs might be detected and located through the presence of microearthquakes, seismic ground noise, and variations in arrivals of

teleseismic compressional (P) waves. Seismic monitoring for microearthquakes (magnitude <<1) and teleseismic P-waves has been conducted in Grass Valley (Majer, et al., 7). The program is based on an 8-station geophone network (recently expanded to a 12-station network), whose signals are radio-telemetered to a central receiver station, and recorded by a 14-channel tape unit. Microearthquakes have been detected in three zones, aligned roughly ENE, several km SSE of Leach Hot Springs (their distribution is shown on Fig. 5). The $\sim$

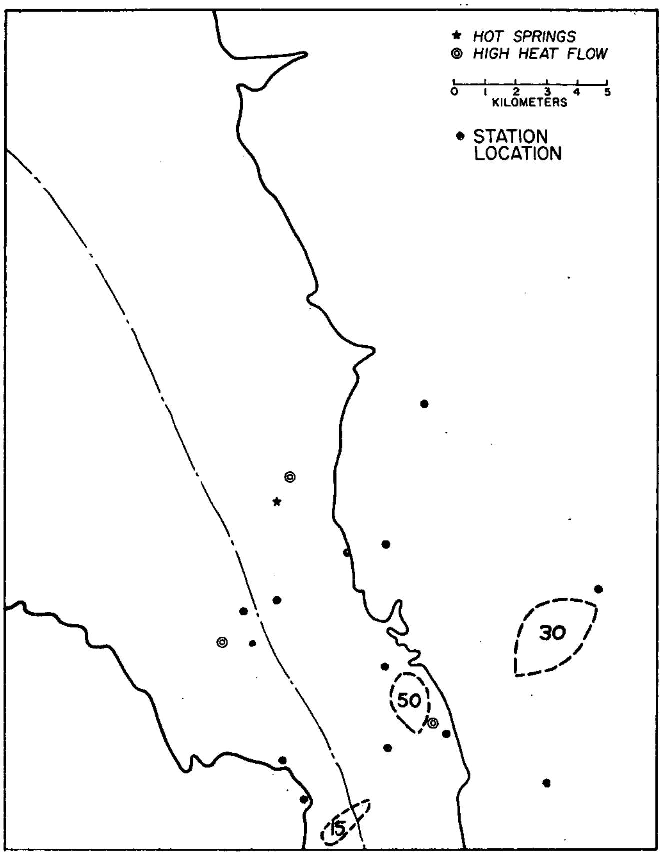

Fig. 5. Distribution and number of microearthquakes in southern Grass Valley, Nevada.

NE-SW orientation of the zones matches a general structural trend in northern Nevada which might reflect fracturing in the Precambrian-early Paleozoic crust (Rowan, 8).

Delays in arrivals of teleseismic P-waves were detected as expected, by stations on deep valley alluvium, in comparison to arrivals at stations on bedrock. However, P-waves were anomalously fast in the vicinity of Leach Hot Springs, suggesting densification of sediments there by deposition of material from the hydrothermal system. This densification is corroborated by a gravity survey encompassing the southern portion of Grass Valley (R. Grannell, private communication, 1976).

3. <u>Heat flow measurements</u>. On the basis of preliminary surface geophysical measurements, seven heat flow holes, 150 - 200 m deep, were drilled in cooperation with the U. S. Geological Survey; their locations are shown on Fig. 6. On completion of drilling the holes were cased with 1¼-inch-diameter pipe, plugged at the bottom, cemented-in and filled with water. Subsequently, downhole thermal gradients were measured, and combined with thermal

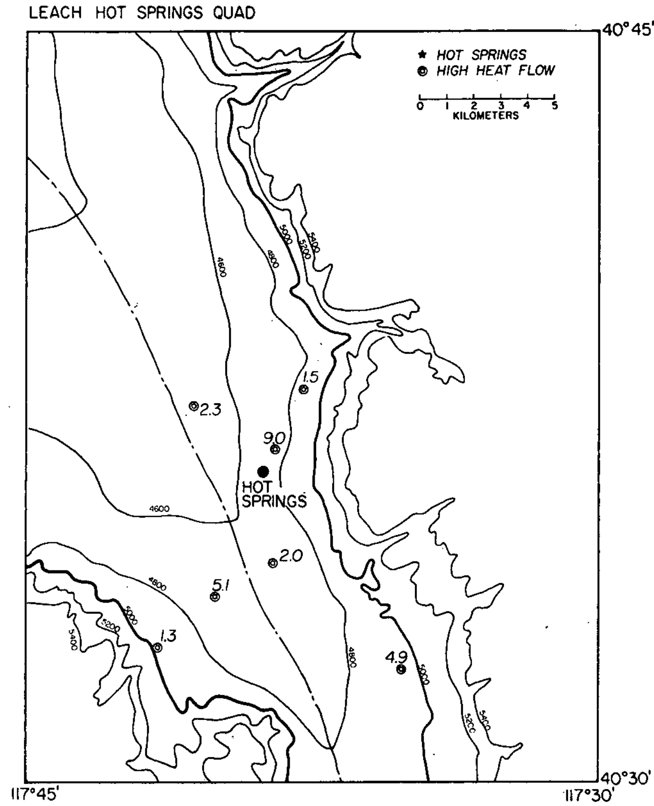

Fig. 6. Topography (elevations in feet) and conductive heat flow (in μcal cm^{-2} sec^{-1}) in southern Grass Valley, Nevada.

conductivities of core samples to yield conductive heat flow (expressed in heat-flow-units (hfu): μcal cm^{-2} sec^{-1}). Resulting heat flows (Sass et al., 9) are shown on Fig. 6; their distribution combined with earlier surveys by Olmsted et al.[5], indicates, besides the high heat flow associated with the hot springs, at least two anomalies (significantly above the regional background of 2.5 - 3.5 hfu) away from the hot springs. One anomalously high value is 5.1 hfu at a site $\sim$ 5 km SSW of the hot springs; another, 4.9 hfu $\sim$ 9 km SSE of the springs. Both are not associated with any surface hydrothermal manifestation, but are significant conductive thermal anomalies.

4. <u>Summary of geophysical surveys</u>. A concordance of electrical, seismic, gravity, and thermal data indicates the presence of a geophysical anomaly in the southern part of Grass Valley, centered roughly on the 4.9 hfu site, $\sim$ 9 km SSE of Leach Hot Springs. The anomalous zone is characterized by relatively low gravity, high conductive heat flow, low apparent resistivity and significant microearthquake activity. The high heat flow site (5.1 hfu) $\sim$ 5 km SSW of the springs is not accompanied by sharply anomalous values of other geophysical parameters, though gravity and resistivity data suggest the presence of a topographic high in the suballuvial basement rocks beneath the site. The zone of low apparent resistivity west and NNW of Leach Hot Springs, combined with teleseismic P-delay data, may be interpreted as reflecting the presence of a capped, hot-water reservoir in Tertiary and Quaternary sediments in that area. An equally valid interpretation is that of silicified hydrothermally deposited material overlying electrically conductive lakebed sediments

deposited in the late Tertiary-Quaternary.

Geochemical Studies. Geochemical sampling and analyses of waters and rocks in the Grass Valley area were part of a broader sampling program encompassing northwestern Nevada. Detailed descriptions of sampling methods, analytical techniques, and results are found in papers by Bowman et al. [10], Hebert and Bowman [11], and Wollenberg [12, 13].

Geochemical sampling encompasses country rock and hot and cold spring waters within hydrologic regions which may contribute waters to hot spring systems. By combining element analyses from these different sources, one may have sufficient data to trace the pathways of water from its meteoric origin, into and through the hydrothermal system. Incorporation of hot and cold spring chemistries and enthalpies into equations developed by Fournier et al. [14] permits estimates of the proportion of near surface cold water mixed with hot water from depth, as well as the temperature of the unmixed hot water. For example, at Leach Hot Springs, though quartz and alkali-element geothermometers indicate temperatures at depth within the range 150 to 170°C, mixing-model calculations estimate the temperature of unmixed hot water at 200 to 210°C.

1. Major and trace elements. Water samples are obtained for laboratory radiometry, x-ray fluorescence analysis for major elements (Si, Na, K, Ca, Al, Mg and S), and neutron activiation analyses for trace elements. Collection methods were devised to retain all solid material, including that which precipitates. At springs, a 1/4" diameter tygon tube is inserted directly into the flow, and water is drawn with a hand-operated vacuum pump. Instead of passing into a bottle, the water can also be drawn directly through a 0.45 micron cellulose acetate filter. Therefore, water can be introduced to the filter either directly from the spring, or by pumping from a bottle in the field or laboratory. Normally, 500 ml Nalgene bottles are used to collect and store the samples.

In the field or laboratory, drops of filtered water are evaporated onto a lexan disc, with a fixing solution, for subsequent x-ray fluorescence analysis. After the x-ray fluorescence analysis, the lexan can be irradiated, cleaned and etched for determination of the water's uranium content. For H_2S determinations, a silver disc is placed in an unfiltered aliquot of each water sample. The disc is later analyzed for sulfur by x-ray fluorescence.

Filtered samples for neutron activation analysis are obtained by evaporating the water directly from the Nalgene bottles (at 80°C) in the laboratory. The resulting residue is incorporated with a plastic binder into a pellet, and irradiated along with standards in a research reactor at the University of California, Berkeley. Nearly all elements in the samples have their counterparts in the standard, and the abundances were determined by comparing the activated gamma rays emitted from the unknowns and standards. This method is capable of quantatively analyzing in excess of 50 elements in a sample. In rock samples, more than two dozen elements can be determined with precisions of less than 5%, and a number of these are determined to better than 1% (Bowman, et al., 9).

The abundances of some of the trace elements show interesting contrasts between hot and cold waters. Tungsten and antimony contents are unusually high in the hot waters but not in cold, while conversely, uranium appears to be nearly absent in the hot waters. In two areas, uranium was detected at the level of ∿ 2 to 5 ppb in cold water and not detected in the hot spring waters. Attempts are being made to correlate the uranium abundances of hot and cold springs with measurements of radon and radium in the springs to determine the minimum age of the hot aquifer and the hot water flow rate.

Figure 7 shows the uranium content, determined by neutron activation, of hot and cold springs in the areas surrounding Kyle, Leach, Buffalo Valley, and Beowawe hot springs. The cold springs at Kyle and Leach have appreciable uranium, but uranium was not detected in the hot springs. In a carbonate-dominant hydrothermal system, this might be expected since uranium has a retrograde solubility in the carbonate form. Uranium can also be reduced from the +6 state to the +4 and precipitated in the presence of H_2S. From these uranium data along with assumptions based on the radium and radon measurements (Wollenberg, 15), one may be able to estimate the hot water subsurface flow rates or, conversely, the amounts of uranium accumulated at depths.

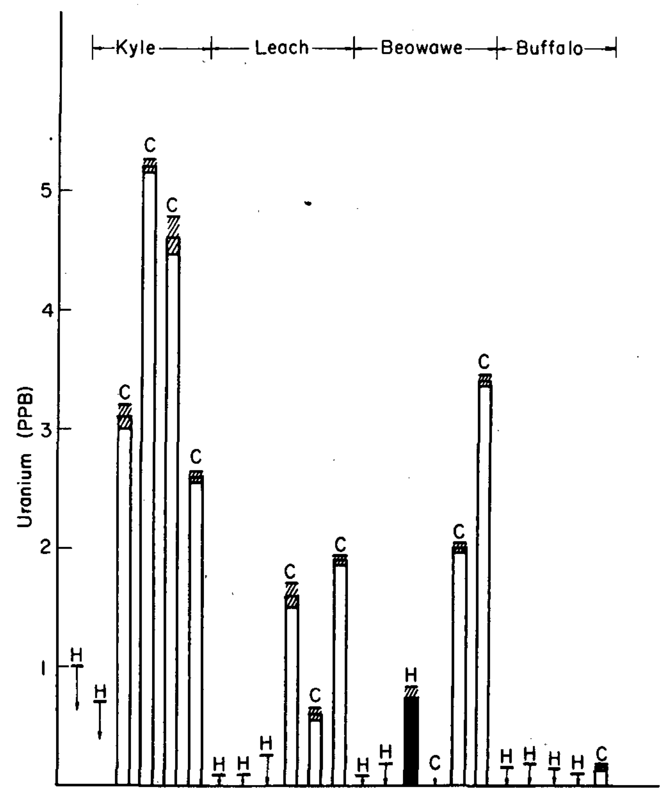

Fig. 7. Uranium content of hot (H) and cold (C) waters in areas surrounding Kyle, Leach, Buffalo Valley, and Beowawe Hot Springs. Arrows indicate values are below detection limits (horizontal lines).

Three warm pools were sampled at Leach Hot Springs; their analyses are shown in Fig. 8. Considerable variation was found. The hottest spring had the lowest abundances of Na, Cl, W, Br, Cs, and Rb. The variations observed here do not appear to be related to ground water mixing with the hot water system. Typical cold-spring elemental abundances in this area are: (Na (29 ± 1 ppm), Cl (56 ± 2 ppm), W (<3 ppb), Br (118 ± 2 ppb), Cs (0.23 ±.02 ppb), Rb (3.7 ± .6 ppb), Ba (75 ± 10), Mo (<2), and Sb (<0.2 ppb).

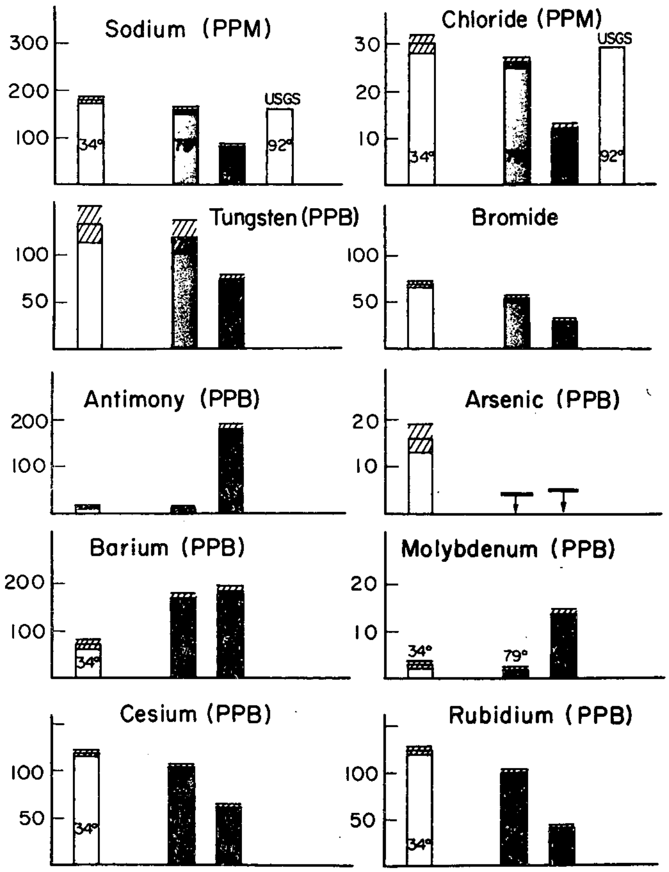

Fig. 8. Neutron-activation analytical results of trace element contents of some hot pools at Leach Hot Springs. Bar labeled USGS represents sample collected and analyzed by U. S. Geological Survey.

2. Radon and radium. Radioactivity anomalies associated with hot spring systems in Nevada have been studied by Wollenberg [13]. Both radium-226 and radon-222 are observable in some of the hot waters, especially in spring systems where $CaCO_3$ is the predominant material being deposited. Systems where silica predominates, such as Leach Hot Springs, are relatively low in radioactivity. This is explained by the fact that radium-226, in some chemical environments, may be completely separated from its parent uranium-238, transported in bicarbonate-rich waters, and deposited with $CaCO_3$ on spring walls.

SUMMARY AND CONCLUSIONS

The evaluation of techniques to assess geothermal resources in the northern Great Basin is presently underway in northern Nevada. The program is exemplified by the geoscience disciplines employed in discerning the magnitude and quality of the potential geothermal resource in the southern portion of Grass Valley. Geophysical, geochemical and heat flow surveys have delimited three areas of potential: the Leach Hot Springs thermal anomaly, and two sites several km SSE and SSW of the springs. Follow-up heat flow surveys have recently been conducted, based on sufficient holes of adequate depth to permit contouring of heat flow over the region surrounding and between the thermal anomalies. From this information, sites for at least two deep confirmatory drill holes (1 to 2 km) will be chosen. Subsequent drilling, lithologic studies, and downhole geophysical surveys will enable comparison of subsurface physical and chemical properties with models inferred from surface surveys. From this information, the nature of the resource, i.e., fractured basement rock, permeable fault plane, Tertiary-Quaternary sedimentary reservoir, or a combination of these, will be discerned. The work recently completed in Grass Valley places the status of the project near the milestone of drill site location. It is planned that, funds permitting, confirmatory drilling will follow in a timely fashion, furnishing data for a case history report.

FOOTNOTE AND REFERENCES

* This report was done with support from the United States Energy Research and Development Administration. Any conclusions or opinions expressed in this report represent solely those of the author and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the U. S. Energy Research and Development Administration.

1. Sass, J. H. and Munroe, R., "Basic Heat Flow Data from the United States," U. S. Geological Survey Open File Report 74-9, 1974.

2. Mariner, R. H., et al., "The Chemical Composition and Estimated Minimum Thermal Reservoir Temperatures of the Principal Hot Springs of Northern and Central Nevada," U. S. Geological Survey Open File Report, 1974.

3. Hose, R. K., and Taylor, B. E., "Geothermal Systems of Northern Nevada," U. S. Geological Survey Open File Report 74-271, 1974.

4. Wollenberg, H. A., et al., "Geothermal Energy Resource Assessment," Lawrence Berkeley Laboratory Report UCID-3762, 1975.

5. Olmsted, F. H., et al., "Preliminary Hydrogeologic Appraisal of Selected Hydrothermal Systems in Northern and Central Nevada," U. S. Geologocial Survey Open File Report 75-56, 1975.

6. Corwin, R., "Use of the Self Potential Method for Geothermal Exploration," Lawrence Berkeley Laboratory Report LBL-3235, 1975.

7. Majer, E., Liaw, A., and McEvilly, T. V., "Seismological Investigations Near Leach Hot Springs, Nevada," Abs. Amer. Geophys. Union Fall Meeting, 1975.

8. Rowan, L. R., "Application of Satellites to Geologic Exploration," Amer. Sci., 63, July-August, 393 (1975).

9. Sass, J. H., et al., "Geothermal Data from Test Wells Drilled in Grass Valley and Buffalo Valley, Nevada," U. S. Geological Survey Open File Report 76-85, 1976.

10. Bowman, H. R., et al., "Trace, Minor and Major Elements in Geothermal Waters and Associated Rock Formations (North-Central Nevada)," Proc. Second United Nations Symp. on the Development and Use of Geothermal Resources, San Francisco, May 1975.

11. Hebert, A., "Non-Dispersive Soft X-Ray Fluorescence Analyses of Rocks and Waters," Proc. Second United Nations Symp. on the Development and Use of Geothermal Resources, San Francisco, May 1975.

12. Wollenberg, H. A., "Sampling Hot Springs for Radioactive and Trace Elements," Proc. U. S. Environmental Protection Agency Workshop on Sampling Geothermal Effluents, 1975; Lawrence Berkeley Laboratory Report LBL-4422.

13. Wollenberg, H. A., "Radioactivity of Nevada Hot Spring Systems," Geophys. Res. Lett., 1, no. 8, 359 (1974).

14. Fournier, R., et al., "Geochemical Indicators of Subsurface Temperature," U. S. Geological Survey J. of Res., 2, no. 3 (1974).

15. Wollenberg, H. A., "Radioactivity of Geothermal Systems," Proc. Second United Nations Symp. on the Development and Use of Geothermal Resources, San Francisco, May 1975.

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