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THE HYDROTHERMAL SYSTEM ASSOCIATED WITH LEACH HOT SPRINGS IN SOUTHERN GRASS VALLEY, NEVADA

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ABSTRACT

Leach Hot Springs in southern Grass Valley, Nevada, appears to represent the surface expression of a high-temperature hydrothermal system with characteristics similar to other systems in the northern Basin and Range province. The hot springs discharge approximately 10 L/s of water at temperatures near boiling. Spring flow occurs along a basin-bounding fault at or near its intersection with a transverse normal fault. Southern Grass Valley is within the Battle Mountain heat-flow high, a region typified by heat flow greater than 120 mW/m^2. Chemical geothermometry indicates reservoir temperatures as high as 180°C for the Leach Hot Springs hydrothermal system. Only one deep well has been drilled into the system, approximately 1.2 km northwest of the springs and out into the basin; it reached a maximum temperature of about 125°C at a depth of 2,600 m. Heat and fluid flow modeling suggests that the flow system associated with Leach Hot Springs may be restricted to the basin-bounding fault zone and the adjacent mountain block in the Sonoma Range.

INTRODUCTION

Leach Hot Springs (LHS) is located 45 km south of Winnemuca, Nevada, within the southern part of Grass Valley (figure 1). The hydrothermal system associated with LHS is one of many such systems in northwestern Nevada located within the Battle Mountain heat flow high (BMH) as defined by Sass et al. (1971, 1981). Heat flows measured in this region commonly exceed 120 mW/m^2, as typified by results from five holes in the mountain ranges surrounding Grass Valley. Electric power developments are currently underway at six geothermal systems in this region, including Dixie Valley, Desert Peak, and Beowawe. At Leach Hot Springs, water at near-boiling temperatures discharges along a basin-bounding normal fault with significant vertical displacement, and chemical geothermometer temperatures for the hot-spring waters range from 150°-180°C. To date, however, only one deep well (Aminoil USA 11-36) has been drilled in southern Grass Valley and it encountered a maximum temperature of only 125°C at a depth of 2,600 m. The Aminoil well was drilled in 1980 at a site 1.2 km northwest of LHS, under a Department of Energy (DOE)-industry coupled funding program (UURI, 1981a). In this paper, we summarize the results of scientific studies conducted in Grass Valley by the U.S. Geological Survey and Lawrence Berkeley Laboratory and information now available from the Aminoil well. More detailed discussions of this information are given by Welch, et al. (1981) and Olmsted, et al. (in preparation, 1994). Although much has been learned about the LHS hydrothermal system, the existence of an exploitable, high-temperature geothermal reservoir is still in doubt.

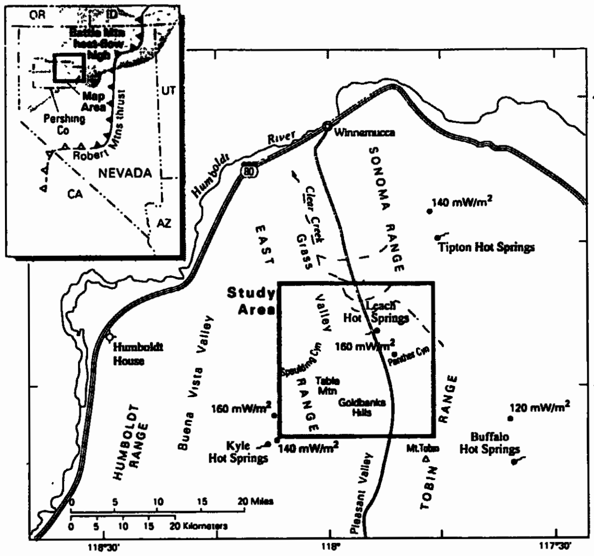

Figure 1. Map of Grass Valley, Nevada, and adjacent ranges and valleys showing study area discussed in this paper, wells with regional heat determinations (dots), a geothermal exploration well (open circle), hot springs, and the region of anomalously high regional heat flow in northwestern Nevada.

GEOLOGIC SETTING AND GEOPHYSICAL CHARACTERISTICS

Grass Valley is bounded by north-trending mountain blocks and has ephemeral surface drainage. It is separated from Pleasant Valley to the south by an inconspicuous drainage divide. Hot springs occur in southern Grass Valley as well as in the adjacent valleys. Leach Hot Springs occur near the intersection of northward and northeastward-trending normal faults that are part of the east-side and transverse fault systems

(Noble, 1975; figure 2). Although the near-surface part of the LHS fault has a northeasterly trend, geophysical data and deep-drilling results indicate that the northeasterly trend characterizes only a short segment of a west-dipping buried basement escarpment having a more northerly trend and a throw of more than 800 m. The central graben fault system may have resulted from localized crustal extension at depth, although seismic profiling (Zoback and Anderson, 1983) indicates that the LHS fault zone separates the main part of the southern Grass Valley basin from an alluvium covered pediment on the east side of the valley and an east-dipping fault of smaller displacement underlying the western part of the basin (figure 3).

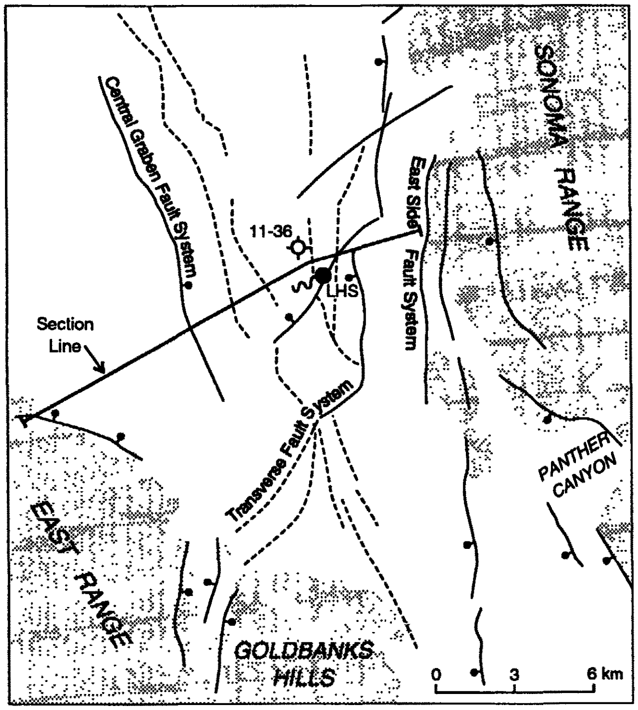

Figure 2. Map of southern Grass Valley, Nevada, and adjacent mountains showing fault systems identified from geologic mapping and air-photo interpretations (Noble, 1975), deep geothermal exploration well (Aminoil USA 11-36), and Leach Hot Springs (LHS).

Depth of the Cenozoic fill in the central part of the basin varies from about 1.4 to 2.0 km. The fill consists of Quaternary alluvium underlain by Tertiary sedimentary and volcanic rocks; Mesozoic and Paleozoic basement rocks exposed in the mountain ranges consist of slightly to moderately metamorphosed sedimentary, volcanic, and plutonic units. The 2.6 km deep Aminoil well penetrated 1.6 km of fill, including a relatively thick (0.7 km) sequence of Tertiary volcanic rocks, and encountered rhyolitic, granitic, and metavolcanic rocks in the Paleozoic basement section (figure 4).

Temperature gradients in the Aminoil well and in ~70 shallower heat-flow holes drilled in the study area indicate that conductive conditions prevail in the fill, but that zones of fluid circulation occur within the upper part of the basement section. Temperatures within these permeable basement zones are between 50°C and 120°C. The temperature profile shown for the Aminoil well was last of a series of three profiles run between 7 and 89 hours after circulation ceased on June 28, 1980. The series of profiles indicates that the temperatures shown in Figure 4 (89 hours) are close to equilibrium values. The measured profile within the Tertiary and Quaternary fill may be affected by a combination of upward flow in the borehole and in the adjacent rock. Borehole circulation seems unlikely, however, within the cased section of the hole (0-823 m). An extrapolation of the gradient measured in nearby shallow well DH7, which is probably influenced by lateral flow of thermal water from the Leach Hot Springs conduit, is shown for comparison. Within the basement section, two zones of nearly isothermal temperature may reflect permeable zones in the adjacent rock and/or vertical flow in the borehole. Below depths of about 2.4 km, the measured temperature profile is relatively conductive with an average gradient of about 50°C/km. For an estimated thermal conductivity of 3-4 $W/m^2/°C$ determined from core and cuttings of basement rocks in this region, the corresponding conductive heat flow would be 150-200 mW/m^2.

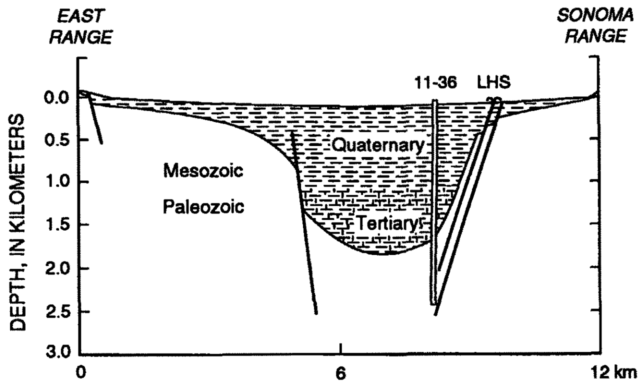

Figure 3. Geologic section (location shown in Figure 2) across Grass Valley, Nevada, showing geothermal exploration well 11-36 and Leach Hot Springs projected onto section.

Temperature gradients in drill holes define a heat-flow pattern in the basin that includes three areas of anomalously high heat flow, surrounded by areas of normal or below normal heat flow (figure 5). For the purpose of this discussion, we consider a heat flow close to 125 mW/m^2 as normal for this region. The heat-flow high around Leach Hot Springs would be expected as a result of conductive heat losses surrounding a zone of upward flow of thermal water. Elongation of the heat-flow pattern along a northwest-southeast direction suggests some combination of upflow along more than one fault or a long section of one fault and lateral flow of thermal water away from the upflow conduit. Regions of high heat flow to the southwest (near well QH3D) and to the southeast (near Panther Canyon) apparently result from circulation of warm water within the upper part of the basement sections in those areas. A permeable zone was encountered in well QH3D in a bedrock high (~400 m depth), where temperatures of 55°C were measured. In the vicinity of Panther Canyon, upward flow of thermal water at temperatures near 100°C along a section of the range-front fault may account for the anomalously high heat flow measured in the valley sediments.

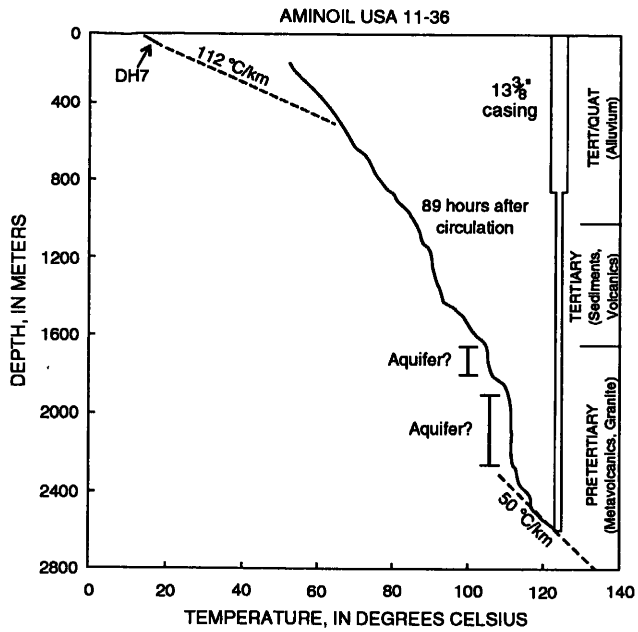

Figure 4. Temperatures measured in well Aminoil USA 11-36, 89 hours after circulation ceased on June 28, 1980. Also shown are the temperature gradient measured in nearby shallow well DH7, the extrapolation of this gradient to greater depths, and the distribution of major geologic units encountered in the well.

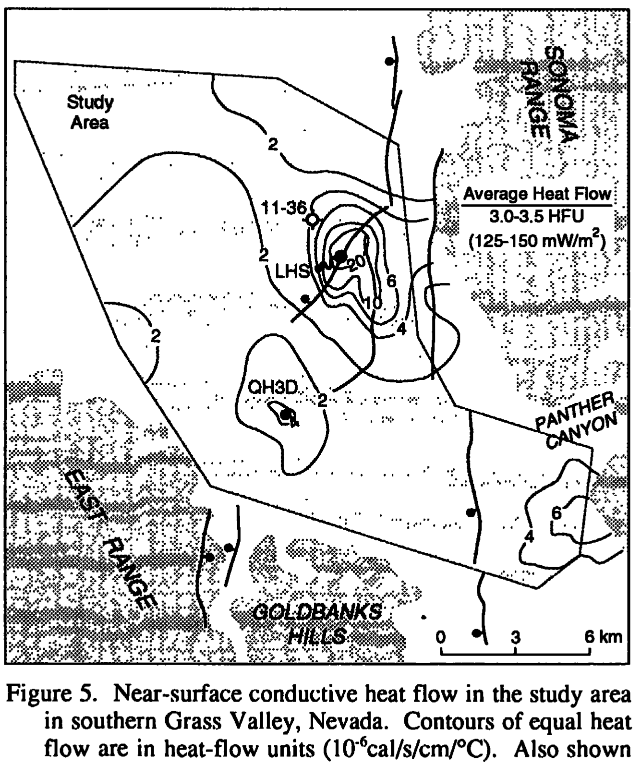

Figure 5. Near-surface conductive heat flow in the study area in southern Grass Valley, Nevada. Contours of equal heat flow are in heat-flow units (10^{-6}cal/s/cm/°C). Also shown are well QH3D, well 11-36, Leach Hot Springs (LHS), and principal normal faults.

Integrating these areas of above-average heat flow with areas of below-average heat flow yields an average conductive heat flow value for our study area of 120-150 mW/m^2. This result, along with similarly high heat flow values measured in drill holes within the broader BMH region, tends to confirm that southern Grass Valley and the hydrothermal system associated with Leach Hot Springs overlie a region of relatively high crustal heat flow. However, the occurrence of warm-water circulation in the upper part of the basement section makes is difficult to predict the thermal regime at depths of several kilometers or the depth to a source reservoir for the hydrothermal system from existing drill hole information.

Geophysical surveys conducted by Lawrence Berkeley Laboratory and private consultants and university groups funded by DOE have been useful primarily for delineating the geometry of the Grass Valley basin and bounding faults (Goldstein and Paulsson, 1977, 1978; UURI, 1981b). Subsurface control on interpretations of gravity and seismic data is limited, and the lack of significant density contrast between the deeper Tertiary rocks and the older crystalline rocks complicates determinations of the depth of fill. Electrical geophysical techniques (d.c. resistivity and telluric) were extensively compared in the basin (Beyer, 1977). Seven regions of differing electrical characteristics were outlined along the eastern and southern margins of the valley, including two shallow (< 1 km), low resistivity areas extending to the north and south of Leach Hot Springs and a third corresponding with the heat flow anomaly outlined in the Panther Canyon area. No evidence of a deep electrical conductor that might be associated with a high-temperature reservoir was found, either because none exists or because it was masked by the presence of a relatively thick section of conductive sediments.

HYDROLOGIC AND GEOCHEMICAL CHARACTERISTICS

Water-level measurements show evidence for regions of downward flow and upward flow within the valley fill. In general, head gradients for downward flow occur near the margins of the basin, whereas gradients for upward flow occur in the vicinity of Leach Hot Springs. No permeability measurements have been made for rocks within the study, including those penetrated by the Aminoil well, which was drilled with mud-rotary equipment. Considering the size and elevations of the potential recharge area for Leach Hot Springs, the measured rate of thermal water discharge from the LHS system (10 L/s) is relatively low. There may be significant flows of thermal water that do not reach the land surface, e.g. lateral subsurface discharge within the valley fill adjacent to the upflow conduit at LHS.

Thermal waters in southern Grass Valley are anomalous in that they contain relatively low concentrations of dissolved solids (500-620 mg/L) and lower concentrations of calcium, magnesium, and chloride than the nonthermal ground waters in the basin. Such thermal waters are encountered in LHS, in shallow wells around LHS, and in well QH3D. Water from the basement aquifer in QH3D is chemically and isotopically similar to the LHS thermal water, suggesting a common source reservoir or at least water-rock reactions with similar basement rock types. Source reservoir temperatures estimated from silica concentrations are close to 140°C, while those estimated from cation ratios and sulfate-oxygen-isotopes fall within the range of 150°-180°C. The hydrogen-isotope composition of the thermal waters is lighter by ~5‰ than that of the nonthermal spring and well waters sampled. The lighter composition of the thermal water could result from (1) recharge at sometime in past when the climate was colder than at present, (2) recharge from altitudes higher than those in the surrounding mountain blocks. We prefer the former explanation, which implies that the thermal water is at least 8,000 years old.

Thermal waters with Cl concentrations nearly as low as those at LHS are encountered at other geothermal areas in northern Nevada located to the east of LHS, e.g. Buffalo Valley Hot Springs, Tipton Hot Springs (Pumpernickel Valley), and Beowawe. In contrast, thermal waters issuing from Kyle Hot Springs and other areas to the west of LHS (e.g. Dixie Valley, Brady's Hot Springs, Desert Peak) contain much higher dissolved chloride. These differences may reflect the proximity and elevations of the geothermal systems relative to potential recharge areas containing evaporite deposits associated with the playas in northwestern Nevada, as suggested by Welch (1986). At Kyle Hot Springs, located in the valley immediately west of Grass Valley, Cl concentrations are over 700 mg/l. Similar Paleozoic rock types outcrop in the mountain blocks adjacent to Kyle Hot Springs (the East Range) and Leach Hot Springs (the Sonoma Range). A recent well drilled 1 mile to the south of Kyle Hot Springs encountered 80°C water with a small (2%) fraction of oil at depths of about 750 feet (Neumann, 1994). No such occurrences of oil have been found in drill holes in southern Grass Valley.

MODELING RESULTS

Geothermal exploration in the Basin and Range has delineated commercially viable production reservoirs at various geothermal systems, including some with and some without associated hot springs. At other areas, exploratory drilling has as yet been unsuccessful in this regard. Successful developments in the Basin and Range are for the most part tied to production zones in the upflow or lateral outflow parts of each system, frequently occurring in basin-bounding fault zones or structural highs associated with tilted fault blocks (Benoit and Butler, 1983; McNitt, 1994). In no case has the entire flow system from recharge area to discharge area been delineated, as pointed out over 10 years ago by Yeamans (1983), but still true today. Although such a delineation may not be necessary for establishment of commercial production in some systems, further understanding of the larger flow systems would be useful for several reasons. These include being able to determine the sustainable yield of developed systems and being able to establish guides for exploration drilling in unexplored areas or areas where initial drilling has been unsuccessful.

Mathematical or numerical modeling of fluid and heat flow in conceptual models of Basin and Range flow systems can provide useful constraints on possible hydrologic settings in this region. As discussed by Yeamans (1983), the hydrologic setting includes (1) the recharge zone, (2) the depth of circulation, (3) the aquifer, or reservoir, geometry, and (4) the discharge zone. Early attempts at modeling some or all of these components were described by Sorey (1975), Blackwell and Chapman (1977), Lowell (1979), Bodvarsson (1979), Nathenson, (1979), Welch et al. (1981), and Wheatcraft (1983). These studies involved two-dimensional descriptions of flow in vertical or horizontal sections, under steady-state and in some cases transient conditions. The simulations described by Welch et al. (1981) were the most comprehensive and showed that an important limiting constraint on geothermal systems with regional conductive heat flow input is attainment of basal temperatures estimated from chemical geothermometry. The controlling factors on basal temperature include the depth of circulation, the area over which conductive heat flow is absorbed, and the age of the system (transient or steady-state). In particular, the modeling showed that it is not possible to attain basal temperatures on the order of 180°C or greater by fluid circulation within a single fault zone unless either the depth of circulation is considerably greater than that indicated by the regional conductive gradient (say 3 km) or the system is relative young and is still mining heat from rocks at depth. Alternatively, flow systems that are not confined to single faults allow these type of constraints to be eased considerably. Such flow systems are three-dimensional in character and involve recharge from more distant sources in surrounding mountain blocks (figure 6).

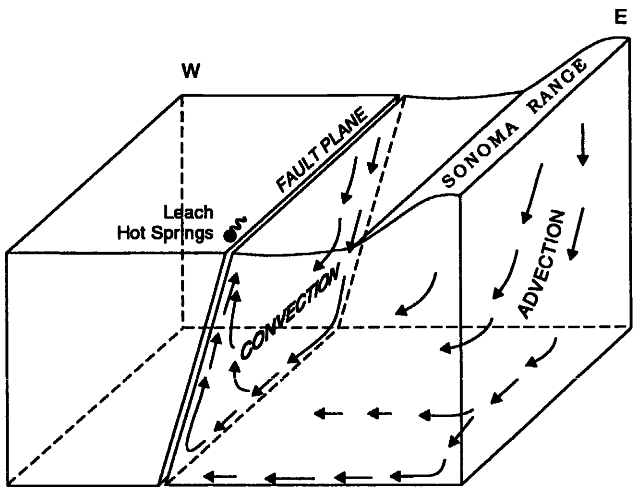

Figure 6. Conceptual model of possible fluid circulation in the hydrothermal system associated with Leach Hot Springs, showing regions dominated by advective heat transfer (in the mountain block) and convective heat transfer (in the fault zone).

More recent modeling studies reported by Pottorff (1988) and Lopez et al. (1994, this volume) provide generalized three-dimensional descriptions of Basin and Range flow systems. These studies indicate that the simplest systems satisfying the constraints posed by regional heat flow, basal system temperatures, and steady-state conditions are those involving a combination of circulatory fluid convection within a basin-bounding fault zone and fluid advection through the adjacent mountain block (figure 6). The driving forces for such fluid flow include both density differences between thermal and nonthermal water and hydraulic head gradients associated with topographic relief.

DISCUSSION

The results of scientific studies and geothermal exploration by private industry in southern Grass Valley provide considerable information on the characteristics of the shallow part of the Leach Hot Springs hydrothermal system. However, this information cannot be easily used to delineate the extent of any high-temperature reservoir at depth or to assess whether or not the system can be commercially developed for electric power. Additional exploratory drilling is obviously needed to address these issues. There are, however, several factors that should be considered as guides to future exploration of this and other systems in the Basin and Range.

Results from the 2.6 km deep Aminoil USA 11-36 well demonstrate that future exploratory drilling must be selective and aimed at specific structural or geophysical targets in order to be successful. Temperature measurements in 11-36 suggest that the basal heat flow in this region is relatively large (>125 mW/m^2), but that circulation of warm water within the upper section of the basement can result in significant depression of conductive isotherms down to depths of several kilometers at distances of only 1-2 km from the upflow conduit feeding the hot springs. Limited lithologic data obtained from 11-36 do not allow a determination to be made of possible intersections with faults of the transverse or east-side systems.

Targets for future drilling in Grass Valley include (1) the upflow conduit feeding LHS, (2) the basin-bounding fault responsible for the ~800 m bedrock offset west of LHS, (3) the intersection of major faults of the transverse and east-side systems, (4) permeable stratigraphic units within the bedrock block on the upthrown side of the basin-bounding fault, and (5) the area of anomalously high heat flow adjacent to Panther Canyon. Targets 1-3 could prove to involve the same structure. The Panther Canyon anomaly could reflect a combination of upflow of thermal water along a fault zone and lateral leakage into the valley sediments. McNitt (1994) argues for the existence of high-temperature reservoirs within structural bedrock highs, commonly associated with tilted fault blocks. The Grass Valley experience, however, indicates that where such features occur near the bedrock-fill interface, they are too cool for commercial development.

REFERENCES CITED

Benoit, W.R., and Butler, R.W., 1983, A review of high-temperature geothermal developments in the northern Basin and Range province: Geothermal Resources Council, Special Report No. 13, p. 57-80.

Beyer, J.H., 1977, Telluric and d.c. resistivity techniques applied to the geophysical investigation of Basin and Range geothermal systems, part III: the analysis of data from Grass Valley, Nevada: Lawrence Berkeley Laboratory Report LBL-6325 3/3, 115 p.

Blackwell, D.D., and Chapman, D.S., 1977, Interpretation of geothermal gradient and heat flow data for Basin and Range geothermal systems: Geothermal Resources Council, Transactions, v. 1, p. 19-20.

Bodvarsson, G., 1979, Convection and thermoelastic effects in narrow vertical fracture spaces with emphasis on analytical techniques: final report on U.S. Geological Survey Grant No. 14-08-001, 111 p.

Goldstein, N.E., and Paulsson, B., 1977, Interpretation of gravity surveys in Grass and Buena Vista Valleys, Nevada: Lawrence Berkeley Laboratory Report LBL-7013, 43 p.

Lopez, D., Smith L., and Sorey, M.L., 1994 (this volume and/or Geothermics paper in preparation).

Lowell, R.P., 1979, The onset of convection in a fault zone: effect of anisotropic permeability: Geothermal Resources Council, Transactions, v. 3, p. 377-380.

McNitt, J.R., 1994, The fault block theory for the migration of geothermal fluid in non-volcanic systems, a model for exploration in extended terrains: Geothermal Resources Council, Bulletin, v. 23, No. 2, p. 55-61.

Nathenson, M., Urban, T.C., and Diment, W.H., 1979, Approximate solution for the temperature distribution caused by flow up a fault and its application to temperatures measured in a drillhole at Raft River Geothermal Area, Cassia County, Idaho: Geothermal Resources Council, Transactions, v. 3, p. 477-480.

Neuman, W., 1994, Oil shows in mineral exploration hole KHS-1, Buena Vista Valley, Pershing County, Nevada [abs.]: Nevada Petroleum Society Meeting April 14, 1994, in Reno, Nevada.

Noble, D.C., 1975, Geologic history and geothermal potential of the Leach Hot Springs area, Pershing County, Nevada: Preliminary report to the Lawrence Berkeley Laboratory.

Olmsted, F.H., Welch, A.H., Sorey, M.L., and Schaefer, D.H., 1994, The geothermal hydrology of Southern Grass Valley, Pershing County, Nevada: U.S. Geological Survey Professional Paper, 1044-X, (in preparation).

Pottorff, E.J., 1988, A new approach for simulating heat transfer and groundwater flow in the Leach Hot Springs hydrothermal system, Pershing County, Nevada: Master's Thesis, University of Nevada, Reno, 153 p.

Sass, J.H, Lachenbruch, A.H., Munroe, R.G., Greene, G.W., and Moses, T.H., Jr., 1971, Heat flow on the western United States: Journal of Geophysical Research, v. 76, p. 6376-6413

Sass, J.H., Blackwell, D.D., Chapman, D.S., Costain, J.K., Decker, E.R., Lawver, L.A., and Swanberg, C.A., 1981, Heat flow from the crust of the United States, in Y.S. Touloukian, W.R. Judd, and R.F. Roy, ed.: Physical Properties of Rocks and Minerals, pp. 503-548, McGraw-Hill, New York.

Sorey, M.L., 1975, Numerical modeling of liquid geothermal systems: U.S. Geological Survey Professional Paper 1044-D, 25 p.

University of Utah Research Institute, 1981a, Gravity survey data and interpretations: Salt Lake City, University of Utah Open-FIle item Leach Hot Springs (LCH)-2, 16 p.

University of Utah Research Institute, 1981b, Geology and geothermal regime, geothermal test well USA #11-36, Grass Valley: Salt Lake City, University of Utah Open-FIle item Leach Hot Springs (LCH)-7, 14 p.

Wheatcraft, S.W., 1983, Numerical simulation of the geothermal reservoir in the Leach Hot Springs area, Grass Valley, Nevada: University of Nevada, Desert Research Institute, Water Resources Center, Publication No. 41089, 40 p.

Welch, A.H., Sorey, M.L., and Olmsted, F.H., 1981, The hydrothermal system in southern Grass Valley, Pershing County, Nevada: U.S. Geological Survey Open-File Report 81-915, 193 p.

Welch, A.H., and Preissler, A.M., 1986, Aqueous geochemistry of the Bradys Hot Springs geothermal area, Churchill County, Nevada, in Subitzky, Seymour, ed., Selected papers in the hydrologic sciences 1986: U.S. Geological Survey Water-Supply Paper 2290, p. 17-36.

Yeamans, F.L., 1983, Basin and Range geothermal hydrology: An empirical approach: Geothermal Resources Council, Special Report No. 13, p. 159-175.

Zoback, M.L., and Anderson, R.E., 1983, Style of basin and range faulting as inferred from seismic reflection data in the Great Basin, Nevada and Utah: Geothermal Resources Council, Special Report No. 13, p. 363-381.