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GEOPHYSICAL CHARACTERIZATION OF THE CARSON LAKE, NEVADA GEOTHERMAL RESOURCE

by

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ABSTRACT

Temperature-gradient studies have identified a shallow temperature anomaly on the eastern margin of Carson Lake that exceeds 21 km^2 (8 mi^2) in size. Deeper drilling here and on the nearby Fallon Naval Air Station has confirmed the presence of a moderate- to high-temperature geothermal system at depth. No natural surface thermal manifestations are present in the sands and silts of this part of the southern Carson Sink, but one shallow artesian thermal well is present. Public domain gravity and aeromagnetic data have been reprocessed and interpreted. When integrated with geologic mapping these provide a structural setting for the resource area. Self-potential (SP) surveys completed in the spring of 1992 and 1993 identified ten well-defined anomalies of limited extent within the area of the shallow thermal anomaly. Several of these anomalies occur near interpreted structures and structural intersections and may indicate upflow zones of thermal fluids to the near subsurface. Deep drilling is needed to prove the location and economic potential of the moderate-temperature geothermal reservoir.

INTRODUCTION

The Carson Lake geothermal prospect is located approximately 18 km (11 miles) southeast of Fallon, Nevada on the southeastern edge of the Carson Sink (Figure 1). The geothermal resource is adjacent to, and probably continuous with, a resource on the southeast limits of the Naval Air Station, Fallon (NAS, Fallon) which has been referred to as Mainside and described by Combs et al. (1995). This is an area of high regional heat flow (Lachenbruch and Sass, 1978) and several developed or known geothermal resources (Garside and Hess, 1994). The resource area is located in the southeastern

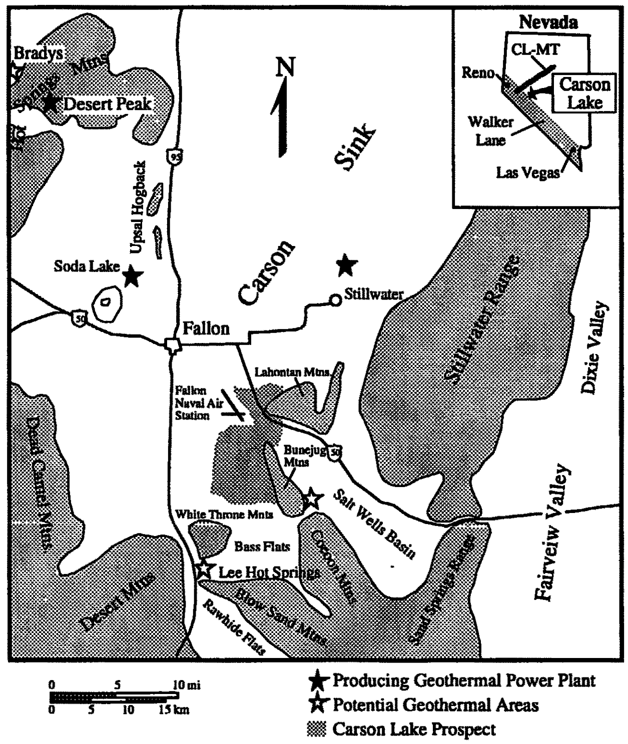

Figure 1. Location of the Carson Lake geothermal prospect on the southeastern side of the Carson Sink. CL-MT (index map) is the Carson Lineament-Midas Trench trend.

lowlands of the Carson Sink (elevation about 1200 m; 3900 ft), south and west of the Stillwater Range. Major high-temperature hydrothermal resources have been identified and developed at Soda Lake, Stillwater, and to the east in Dixie Valley (Benoit, 1996).

The Carson Lake geothermal anomaly was discovered by Phillips Petroleum Co. in 1973 (Dick Benoit, personal communication). Phillips drilled 28 temperature-gradient holes to a maximum depth of 152 m covering an area of about five townships, but discontinued exploration in favor of more attractive thermal anomalies. In 1980 and 1981 Unocal obtained five leases on BLM acreage east of the NAS, Fallon and performed a significant amount of exploration but abandoned the prospect after drilling a 881 m deep exploration hole, 72-7, in 1981. Oxbow Power Corporation later acquired the property and conducted additional shallow drilling which resulted in the delineation of a large, shallow thermal anomaly.

Oxbow suggested the area to the University of Utah Research Institute (UURI - now ESRI) as a challenging test of the self-potential survey method which had been used successfully in several low-to moderate-temperature hydrothermal areas in Utah and New Mexico (Ross et al., 1991;1995; Ross and Witcher, 1992). As the SP work progressed it became necessary to review other existing geological and geophysical data to aid in an understanding of the existing temperature and SP data. Observations from these studies have resulted in an interpreted geophysical setting for the hydrothermal resource area which is reported here.

GEOLOGIC SETTING

The Carson Lake geothermal prospect is located approximately 18 kilometers (11 miles) southeast of Fallon, Nevada on the southeastern edge of the Carson Sink (Figure 1). The geology of the area has been reviewed by J.L. Bruce (1981) and more recently by Combs et al.(1995). The Carson Sink is located in the western part of the Basin and Range province. Crustal extension during the late Cenozoic Era (Stewart, 1980) created this large basin which was then filled with more than a thousand meters of clastic sediments and volcanics. Mountain ranges surrounding the Carson Sink are mainly composed of Mesozoic sediments and metasediments and granitic intrusive rocks which have been covered by early Cenozoic volcanic rocks. In the vicinity of the Carson Lake geothermal area, intersecting structural trends create a complex of horsts and grabens, and Tertiary volcanic rocks are widespread (Bruce, 1981). Tertiary volcanic rocks range in composition from basalt to rhyolite and include olivine basalts 861 m thick at drill hole FOH#3 in the southern Carson Sink (Combs et al., 1995). Tertiary sediments, clastic debris and volcaniclastic flows, tuffs and ash falls fill the basin. Fine grain silts and sands were deposited in lakes and deltas during the late Pliocene and early Pleistocene ages. Sands and silts were carried into Lake Lahonton by the Carson River, and deposited in what is now the southern Carson Sink, including the geothermal prospect area. Wave cut terraces and gravel bars were left behind as Lake Lahonton receded. Broad alkali flats, some reclaimed as rangeland and some covered by sand and dune sand, form the ground surface in most of the prospect area.

Three regional structural trends occur in the Carson Sink area: the northwest-trending Walker Lane, the northeast-trending Carson Lineament-Midas Trench trend, and north-to-northeast trending Basin and Range structures (Rowan and Wetlaufer, 1973). Structures associated with these trends should provide ample permeable pathways for the deep circulation of thermal fluids.

Shallow Thermal Anomaly

Bruce (1981) summarized the results of early temperature gradient studies completed by the Naval Weapons Center, China Lake, in the Carson Lake area, primarily at the Naval Air Station Fallon. Oxbow Power Corporation has extended this work to the east and has defined a shallow (<100 m deep) temperature anomaly which exceeds 21 km^2 in area (Figure 2). Temperatures exceeding 100°C were observed in Unocal gradient hole

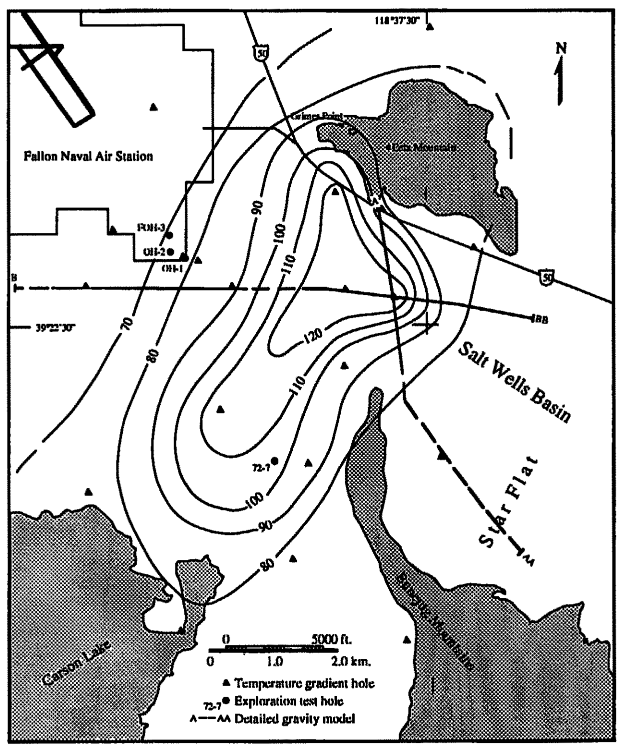

Figure 2. Shallow thermal anomaly as defined by temperature gradient holes. Contours indicate temperatures (°F) at a depth of 200 ft (60 m). Note the location of gravity profiles A- AA and B-BB.

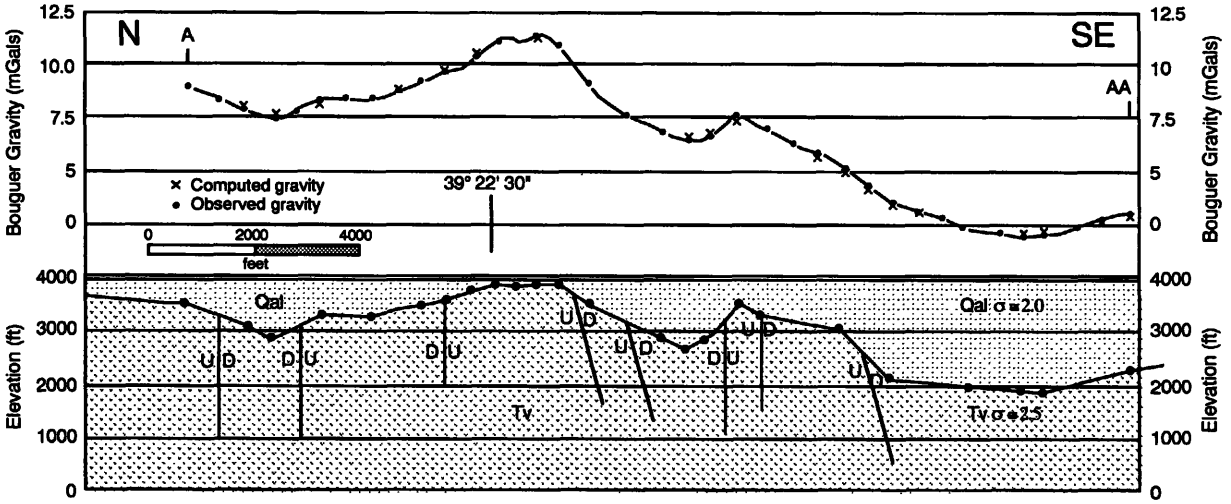

Figure 3. Gravity profile A-AA, numerical model, and interpretation. Computed and observed values are identical except as shown by x. Unit densitites (σ) are shown in gm/cm^3.

72-7 at depths greater than 305 m. Combs et al. (1995) report a maximum temperature of 191°C at depth in drill hole FOH#3 (total depth 2,119 m).

REGIONAL GEOPHYSICAL DATA

Two regional geophysical surveys completed by Unocal became available to Oxbow as public domain data. The data are valuable for the interpretation of subsurface geologic conditions and the possible relationship of interpreted geologic features to the geothermal system.

Gravity Survey

Unocal completed a detailed gravity survey of about 100 km^2 centered on the prospect area. The principal facts for these data were submitted to the Bureau of Land Management (BLM) and later replotted by ESRI at a scale of 1:24,000, appropriate for integration with other data. The typical station interval along several profiles is about 161 m (528 ft; 10 stations per section). The data were reduced to Bouguer gravity values using a density of 2.67 gm/cm^3. Terrain corrections were not applied but much of the area is of low relief and the relative error in Bouguer gravity values is generally small.

The residual Bouguer gravity map shows a general north-south contour trend with a 20 mGal decrease from the east (Eetz Mtn., Bunejug Mtns.) toward the center of the valley, the Carson Lake area, on the west. This trend indicates a rapid thickening of less dense alluvial and lake bed sediments west of north-trending basin border faults. Basin fill sediments beneath the Carson Lake bed are reported to a depth of 687 m in FOH#3 (Combs et al., 1995) and may exceed 1000 m elsewhere. Gravity values also decrease east of the Bunejug Mountains, for stations approaching and within the Salt Wells Basin. The residual gravity data generally contour smoothly and indicate a low level of geologic noise and relative station-to-station error. Locally steep horizontal gravity gradients are believed to indicate the location of buried faults, with an increased thickness of less dense basin fill or volcanics on the low gravity side.

Numerical modeling was completed for two well-controlled gravity profiles, A-AA and B-BB, located on Figure 2. Each profile was modeled using program G-REGION which simulates three-dimensional geometries with finite strike-length (2-1/2 D) bodies (Nutter, 1982). Profile A-AA (Figure 3) trends south, then southeast, from the southern edge of Eetz Mountain across the shallow temperature high and then across Star Flat. An average density contrast of 0.5 gm/cm^3 was chosen to represent the contrast between Tertiary volcanics (Tv) and lake sediments-alluvium with minor volcanic units. The top of the Tv is modeled as a variable sloping surface with many vertices corresponding to gravity station locations. Depth-to-volcanics data available for a few drill holes formed the initial model, but depths were allowed to vary to reach the better solution to the gravity data. The modeled steeply-sloping surfaces are believed to be the result of offset and erosion along steeply dipping normal faults which trend northeasterly to easterly.

Profile B-BB (Figure 4) extends easterly from the center of the Carson Basin just south of wells OH-2 and OH-1, to the Salt Wells Basin. The depth to volcanics in these wells, and well 72-7 projected to the

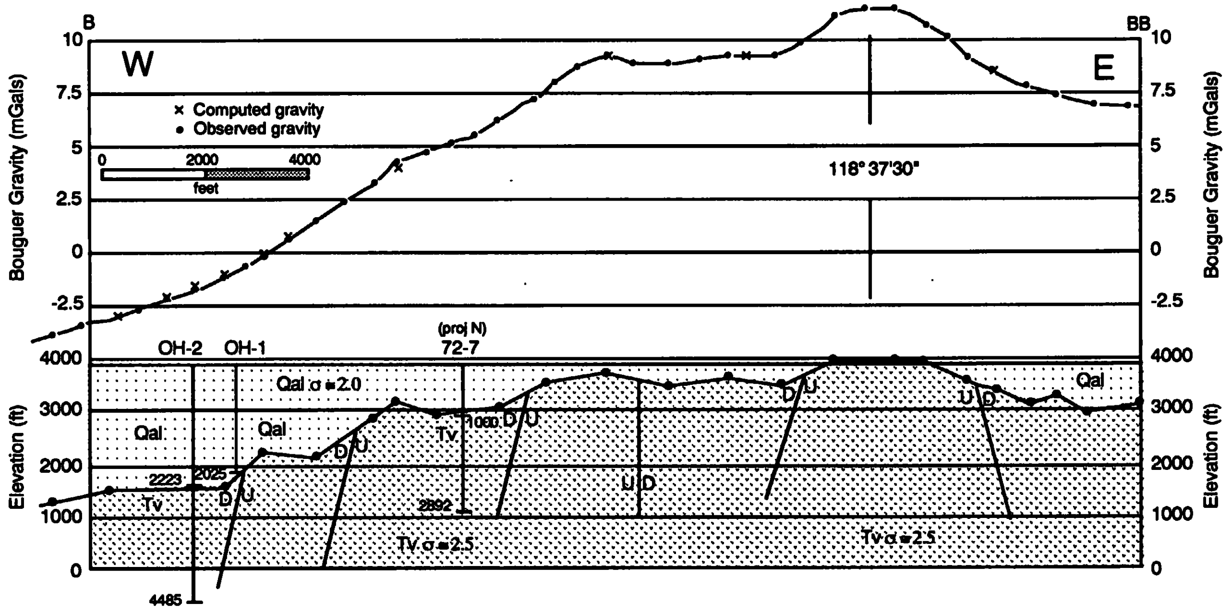

Figure 4. Gravity profile B-BB, numerical model, and interpretation. Computed and observed values are identical except as shown by x. Unit densities (σ) are shown in gm/cm^3.

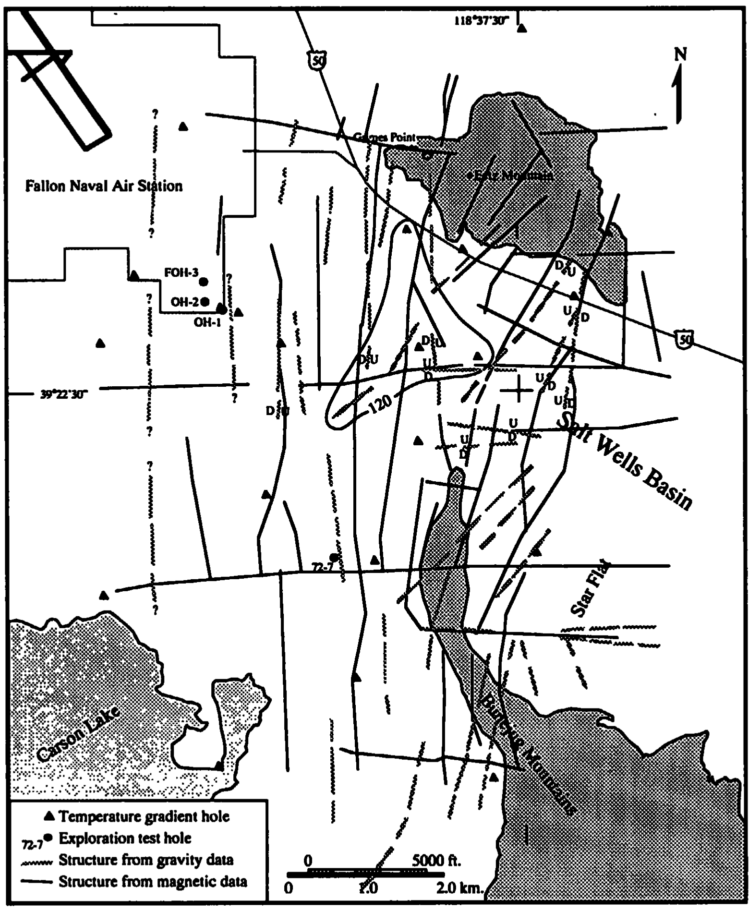

Figure 5. Integrated structural interpretation map showing probable faults interpreted from gravity and aeromagnetic data. 120°F at 200 ft contour shown for reference.

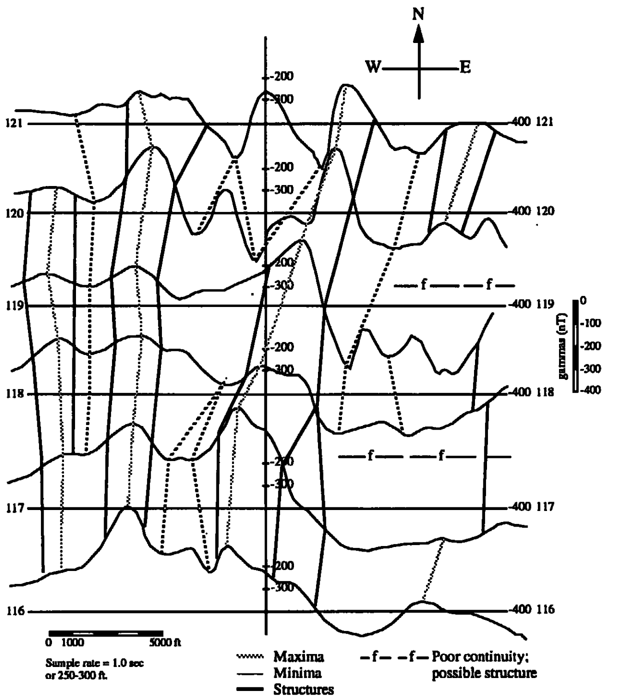

Figure 6. Correlation of detailed (east-west) aeromagnetic profile plots and structural interpretation.

north, provided initial control for the model. The modeled volcanic surface shows several areas of steep slopes which probably include fault offsets.

Figure 5, a generalized structural interpretation map, shows a number of north and northeast-trending linear features interpreted from the gravity data, many of which are probably faults bounding the Bunejug Mountain block. East-west faulting is suggested in the central and southern part of the area. Many inferred structures coincide with continuous, sharp magnetization contrasts indicated by the magnetic data. At a minimum, the gravity models present a good first approximation to the configuration of the buried Tertiary volcanic surface and indicate the more likely faults along the two gravity profiles.

Aeromagnetic Survey

Unocal purchased a regional aeromagnetic survey of the area in 1980 and this later became available as public domain data from the BLM. Applied Geophysics, Inc. flew the survey with east-west flight lines 0.5 miles (0.8 km) apart approximately 120 m above ground level. A preliminary interpretation of the aeromagnetic contour map was completed for an area of about 260 km^2 (100 mi^2) including the Carson Lake prospect. Magnetic source positions and geometries, and discontinuities were inferred with reference to magnetic model anomalies appropriate for this field inclination (64°) and declination (16°E), but no specific modeling was undertaken. It became apparent that the high-frequency magnetic field variations in the vicinity of the Carson Lake geothermal prospect were not adequately represented by the coarse grid used in the map compilation. Oxbow contracted with Applied Geophysics, Inc. to prepare a number of detailed profile plots of total magnetic intensity, terrain clearance, and horizontal position. The profile plots were interpreted to upgrade the structural interpretation in the main area of interest. The dominant north-south structural grain facilitated correlation of magnetic highs and lows, and bounding structures of magnetic sources, and permitted a much more detailed interpretation than with the aeromagnetic map alone. Figure 6 illustrates the data and correlation process for east-west profiles 116-121, at a reduced scale. Reversely magnetized volcanic units were also identified by joint terrain clearance-magnetics correlation.

Figure 5 compares structural features interpreted from gravity and aeromagnetic data. Structures interpreted from the aeromagnetic data correspond closely with four north-trending and two northeast-trending structures interpreted from gravity data, within the thermal anomaly area. Furthermore, four east-west trending structures can be inferred which present the possibility of intersections with other structures, and hence favorable zones for up welling fluid migration.

SELF-POTENTIAL DATA

Self-Potential Survey

The initial self-potential (SP) survey was completed during March and April 1992. Approximately 760 observations were made at 630 stations totaling 37.2 line-km of profiles. About 100 of the observations (an additional 4.3 line-km) were required for base station ties and repeat coverage. The survey was extended and several lines repeated in April 1993 when an additional 10.7 line-km of data (240 stations) were recorded. The basic station interval along profiles was 60 m with selected stations at 30 m. The total area surveyed is about 10.9 km^2. The result is a fairly detailed SP survey although the data density varies (Figure 7). The survey was conducted using a high-impedance digital voltmeter and copper-copper sulfate porous pot electrodes connected by a spooled 1290 m light weight single-conductor copper wire. A basic radial or "spoke" survey technique was used as described by Ross et al. (1991).

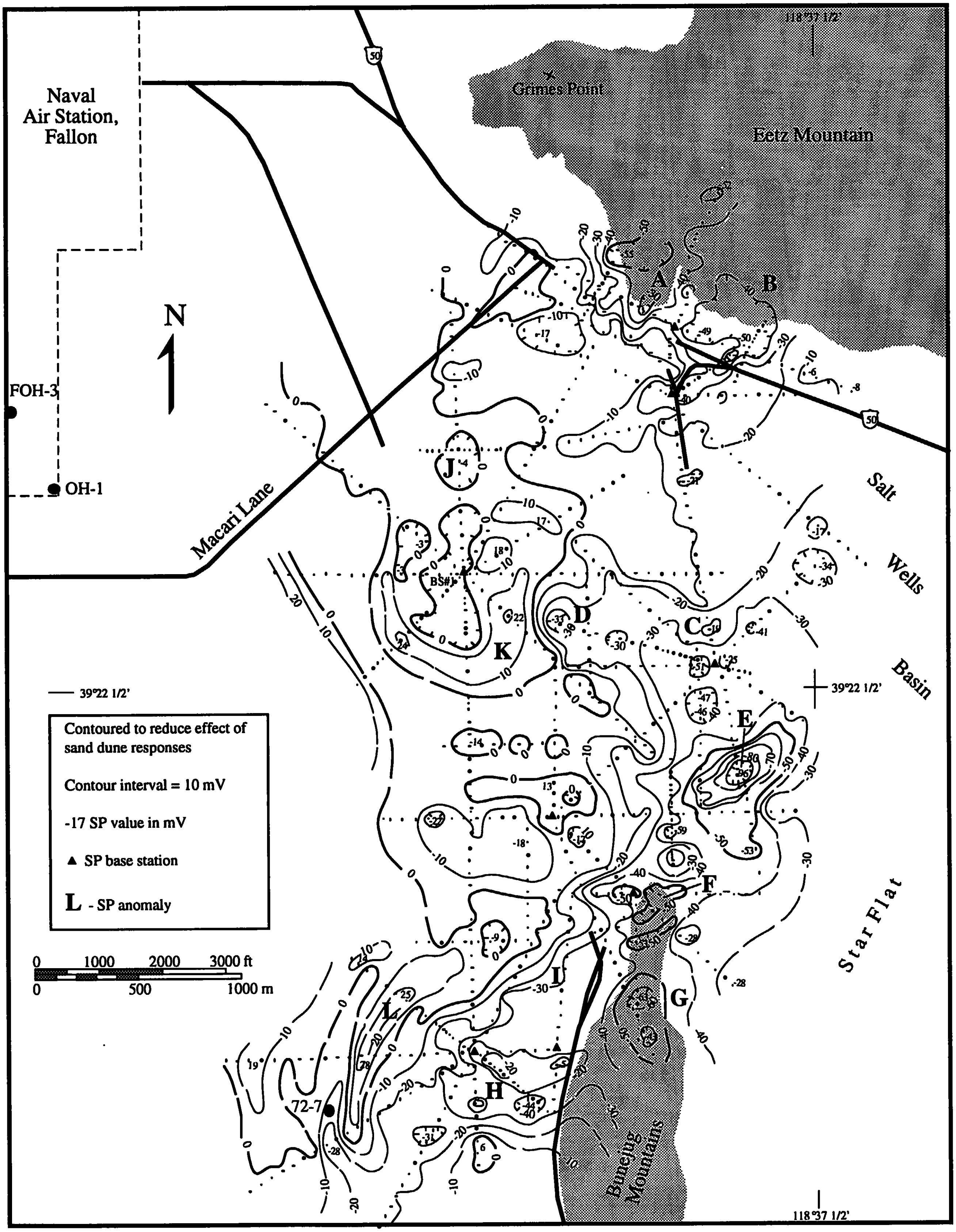

Figure 7. Self-potential survey map completed in 1992 and 1993. Contour interval is 10 mV.

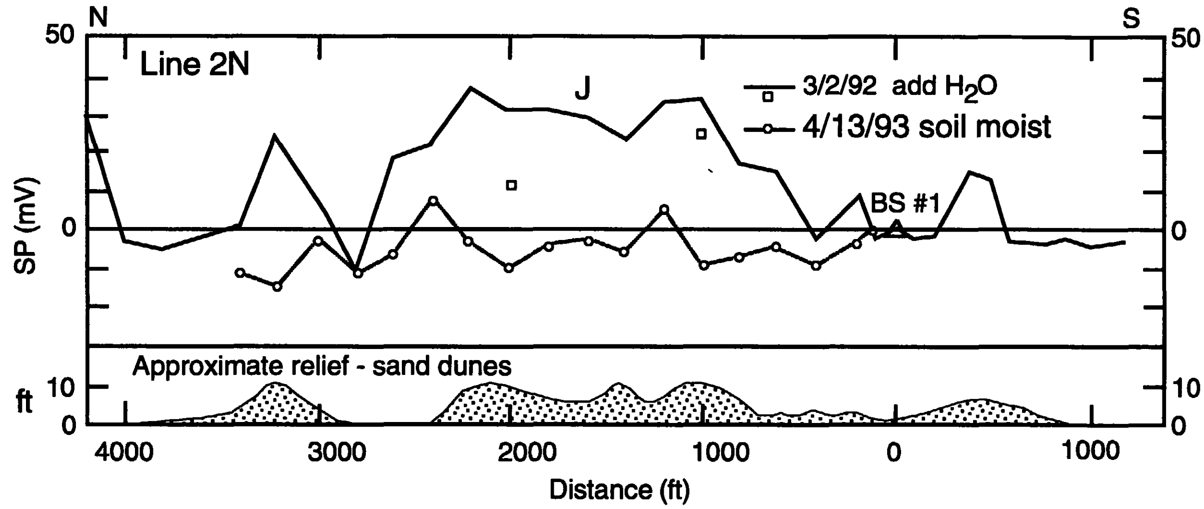

Figure 8. SP profile 2N comparing March 1992 (very dry) and April 1993 (moist subsurface) SP data across sand dune topography.

Observations of surface and soil conditions and correlations with SP values were made throughout the survey. Approximately 90 percent of the SP stations were located between elevations of 1190 and 1205 m, where surface types included alkali flats (dry surface), flat sandy soils, sand dunes, and meadowlands. Dry sand dune sites often recorded SP values 5 to 30 mV higher (more positive) than adjacent or nearby stations in flat sandy soils, alkali flats, and meadowland in the 1992 surveys, but some exceptions to this generalization were noted. Alkali flat areas were generally negative (0 to -20 mV) with respect to sandy base stations. The 1992 surveys were performed during a severe, six-year drought. Any precipitation immediately before the survey amounted to little more than surface wetting, but some moisture was observed below 15 cm depth in some sandy and playa locations. All stations were prewatered to minimize near-electrode soil moisture differences. One purpose of the April 1993 survey was to compare selected data from 1992, recorded after a six-year drought, with observations after a wet spring and winter which left the near-surface quite moist and provided a better electrical continuity with the subsurface. In addition, new detail was obtained for several anomalies identified in the 1992 survey.

Figure 8 compares 1992 and 1993 data along profile 2N which originally recorded a coherent SP high (J) closely associated with a sand dune area south of Eetz Mountain. The strong correlation between the SP high (20-36 mV) and sand dune topography of about 3 m had suggested a near-surface origin for the anomaly. The 1993 survey recorded typical background values of +8 to -10 mV across the previously anomalous area, confirming that the dry sand effectively decoupled the surface voltage regime from adjacent areas. Repeat traverses over other sand dune anomalies showed similar results. Confirmed sand dune anomalies have been eliminated from the final contour map, Figure 7.

The SP contour map (Figure 7) shows voltage differences in millivolts (mV) with respect to Base Station #1, located in the northwest part of the survey, east of Macari Lane. The SP map is complex, with several minima (-30 to -98 mV) and a few weak maxima. Table 1 describes the location and amplitude of the more significant anomalies. All anomaly sources appear to be quite shallow, within a few station intervals (60-180 m) depth as judged from anomaly gradients.

Table 1. Carson Lake, Nevada Self-Potential Anomalies.

Anomaly	Location on map	Amplitude (mV)	Description
A	North	-50 to -55	NE trend from alkali flat across US 50 to Eetz Mtn. Independent of surface. Along NE faults.
B	Northeast	-40 to -50	NE trend cuts across alkali flat, sand and dunes. Along NE-trending fault.
C,D	East center	-30 to -51	E-trending low across alkali flat, sand and dunes. Along E-W structures, intersecting faults.
E	East center	-70 to -96	Mainly over alkali flat and Tv. Along intersecting E-W, NE faults?
F,G	Southeast	-50 to -63	Over Tv and gravel. Along NE-trending faults.
H,I	South	-20 to -46	Over sand, dunes, alkali flat. Along NE faults.
J	North center	+10 to +36 -10 to +8	Positive anomaly when sand dunes were very dry. Background level values after wet season.
K	North center	+10 to +24	Weak high over sand, sand dunes, meadow. Along NE, E faults. Possible dipolar high.
L	South	+10 to +28	Mainly over alkali flat, meadow. Along N-S faults. Dipolar high of H,I?

SUMMARY

The Carson Lake geothermal system is a blind or covered hydrothermal system with no significant thermal manifestations. Exploration drilling has defined a large, shallow thermal anomaly and has indicated a moderate- to high-temperature system at depth. An interpretation of available gravity and aeromagnetic data indicates a complex area of north and northeast-trending faults cut by east-west structures, beneath the area of the shallow temperature anomaly. Thus a number of structures and structural intersections are available to act as conduits which carry thermal fluids to shallow depths. Several of the more significant SP minima, A, B, C, D, E, F, G, H, and L occur near structural intersections inferred from the gravity and aeromagnetic interpretations. Thermal fluids probably rise to the near surface at several of these locations and this probably accounts for the multiple SP anomalies and the broad thermal plume. Further interpretation is necessary to identify the location of the thermal reservoir at depth. Deep thermal gradient drilling in the northern part of the thermal anomaly will be required to site a successful production well.

ACKNOWLEDGEMENTS

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