POTENTIAL AND U.S. NAVY PLANS TO DEVELOP GEOTHERMAL RESOURCES AT NAVAL AIR STATION, FALLON, NEVADA

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ABSTRACT

In 1980 the U.S. Navy Geothermal Program Office initiated field studies to ascertain the geothermal potential of the Naval Air Station located at Fallon, Nevada. The studies included thermal gradient drilling, aeromagnetics, gravity, land magnetics, coring and deep observation holes.

Results of those studies indicate that there is a relatively shallow (5,000 ft.) depth to the 400 degree isotherm under the southeast portion of the Mainside facilities with temperature gradients in the range of 5 to 7 degrees Fahrenheit per 100 feet. Results of Na-K-Ca geothermometry studies show that maximum temperatures that can be anticipated at NAS-Fallon are in the range of 369°F to 399°F. Data indicate there is a moderate- to high-temperature resource at an exploitable depth in that vicinity.

BACKGROUND

Naval Air Station Fallon, Nevada is located approximately 100 km (65 mi) east of Reno at the southern end of the Carson Sink in Churchill County (see Figure 1). It consists of a mainside facility and several outlying "live" bombing ranges. The primary mission at NAS-Fallon is to maintain and operate facilities and provide services and material to support operations of aviation activities and units of the operating forces of the Navy and other activities or units as designated by the Chief of Naval Operations.

The facilities are located in the northern Basin and Range physiographic province characterized by north-south trending mountain ranges separated by intervening sediment-filled basins. In the immediate area of NAS-Fallon, the altitude is 1300 m (3900 ft) above sea level with the surrounding mountains rising as high as 2900 m (8790 ft) above sea level.

Mainside is located at the southern end of the Carson Sink in an area generally referred to as the Lahonton Valley. There are a number of lakes and irrigation canals immediately surrounding the facility, and the natural floral assemblage has almost exclusively been replaced by grasslands resulting from irrigation for farming and ranching. Alkali flats are common in the area.

Bravo 19 (B-19) is a bombing range located approximately 25 km (15 mi) due south of Mainside in the area of Lee Hot Springs. The northwest trending Blow Sand Mountains occupy the eastern one-half of the range while the western one-half is a low relief, alkali flat which is part of Rawhide Flats. Sand covers the vast majority of the 72.5 sq.km. (28 sq.mi) and attains thicknesses of several tens of feet making surface vehicular passage extremely difficult. The extreme western part of the range is relatively easily accessible and was the focus Navy geothermal investigations because of the proximity to known hot springs.

REGIONAL GEOTHERMAL

Grose and Keller (1979) divided the Great Basin into six distinct regions for the purpose of geothermal characterization. NAS-Fallon falls within the area they referred to as the northwestern Basin and Range which is characterized by a high frequency of hot springs, abnormally high regional heat flow, and abundant normal faults. All of the commercial geothermal development to date in Nevada has been in this region, and Grose and Keller (1979) estimate that the geothermal potential of the Basin and Range province could exceed 20,000 megawatts.

There are four areas immediately surrounding NAS-Fallon which have proven geothermal resources (see Figure 2): Desert Peak, Soda Lake, Stillwater, and Salt Wells. Dixie Valley located approximately 65 km (40 mi) to the northeast of Mainside on the eastern slope of the Stillwater Range is the site of a 55 MW electrical power generating facility owned and operated by Oxbow Geothermal, Inc. This is the largest single geothermal facility in Nevada at the present time.

GEOLOGICAL SETTING

Figure 3 shows the general geology of the Carson Desert area (after Hastings, 1979). The valley is a northeastward elongated triangular basin 100 km (65 mi) long and 14 km - 50 km (8 mi-30mi) in width. The basin itself is filled with as much as 3963 m (13000 ft) of Tertiary to recent sediments in the northern portion (Hastings, 1979). These sediments are a combination of fluvio-lacustrine, alluvial fan, and aeolian deposits laid down in ancient Lake Lahontan and the intervening dry periods. Basin sediments become thinner to the southwest reaching thicknesses of 675 m (2220 ft) in the area of southeast Mainside.

Carson Sink is surrounded by Mesozoic and Tertiary volcanics ranging from felsic to mafic intrusives and extrusives. There is evidence of at least two periods of major volcanic activity in the Basin and Range (see Davis, 1979): one in the late Cretaceous-early Tertiary (probably related to the Laramide orogeny; and the second in the middle Miocene (16-17 mybp). There is also evidence of a later volcanic episode during which time basalts were extruded over a fairly wide area of the Carson Sink (Willden and Speed, 1974). Rattlesnake Hill, Upsal Hogback, and the craters at Soda Lakes, composed of basalt and basalt lapilli tuffs, were all the result of this late tectonic activity.

These late Quaternary basalts are not to be confused with the Pliocene/Early Pleistocene "capping" basalts of the Bunejug formation which are found throughout the southern part of the Carson Sink and in the adjacent mountains (Morrison, 1963). The capping basalts are primarily olivine basalts with some interlayered basaltic tuffs and volcaniclastics. They reach thicknesses of more than 600 m (2000 ft) in the Bunejug and Cocoon Mountains south of Mainside and are thought to play an important role in creation of economic geothermal reservoirs in this region (Grose and Keller, 1979). These basalts were encountered in the deep observation hole drilled by the Navy on the southeast corner of Mainside (Katzenstein and Bjornstad, 1987) although drilling did not go all of the way through the basalt layer.

There are two favored explanations for the abnormally high heat flow in the northwestern Basin and Range: a combination of high regional heat flow and radioactive decay in intrusive rocks; and, magmatic heating. Grose and Keller (1979) favor the non-magmatic origin of the heat mostly because of negative evidenct of recent widespread volcanism/magmatism. They state that, "most of the numerous sites of surface thermal activity in the Basin and Range do not reveal evidence in support of closely associated igneous intrusive activity" (Grose and Keller, 1979, p.366). They further contend that even though the crust in this area displays some anomalous geophysical properties, there are no "specific features" which could explain the kind of geothermal activity observed.

Davis (1979) favors the idea of crustal thinning in the Basin and Range resulting in the asthenosphere being nearer to the surface thereby creating high heat flow. Scholz, et al (1971) relate this crustal thinning to a back-arc phenomenon wherein there is a thermal plume rising over the leading edge of a subducting plate. There was a significant amount of interplate activity in the western U.S. during the middle Miocene when the Farallon and Juan de Fuca plates were impinging on the North American plate. This corresponds to at least one of the major episodes of volcanism in the western Basin and Range.

NAVY EXPLORATION EFFORTS AT FALLON

The Geothermal Program Office of the U.S. Navy conducted exploration efforts at NAS-Fallon from 1979 through 1987 during which time geological, geophysical, geochemical, and petrophysical data were acquired. These data were presented in three technical reports by Bruce (1980), Katzenstein and Danti (1982), and Katzenstein and Bjornstad (1987); additional gravity data will be acquired during 1989. These aforementioned data which form the basis for the Navy's geothermal resource estimates will be summarized and synthesized below. The reader is encouraged to obtain copies of the individual technical reports to review the raw and second-order forms of the data. The following discussion will focus on Mainside and B-19 because of their greater resource potential.

MAINSIDE GEOTHERMAL POTENTIAL

NAS-Fallon Mainside consists of approximately 3083 hectares (11.9 sq.mi) on which are located the aircraft runways, hangars, maintenance facilities, administrative buildings, and base housing. This complex is surrounded by open grasslands some of which are used for agricultural purposes through permit agreements.

There are no surface manifestations, i.e., hot springs, fumaroles, or related phenomena, on Mainside which would belie the fact that there is a geothermal resource under the base. However, during the evaluation of Navy facilities for geothermal potential, the Program Office became aware of a shallow thermal anomaly identified by high thermal gradients and a hot artesian well 50 m (163 ft) deep a few miles southwest of Mainside. Subsequent drilling of shallow thermal gradient holes (TGH) on the south side of the base (see Figure 4) yielded encouraging results. Holes HFH 24 (12.7°F/100 ft), HFH 26 (9.5°F/100 ft), and HFH 23 (5.6°F/100 ft) all showed higher gradients than the average for the Great Basin.

Concurrent with the TGH work, a trace mercury study was performed on, and around, Mainside the results of which were also encouraging. Figure 5 shows the data (plotted in parts-per-billion, ppb) which clearly delineate two linear trends which are more or less orthogonal. It was postulated by Bruce (1980) that these high Hg values resulted from upward migration of geothermal emanations through buried faults. At the time, he had no evidence to corroborate the existence of such features.

Further gravity and magnetic surveys at Mainside confirmed the presence of a series of faults trending northeast and northwest which coincided with the results of the trace mercury work. Figures 6 and 7 show the results of those efforts and clearly define a northeast-southwest fault over the southeast portion of Mainside and possibly an orthogonal fault intersection at that location (Katzenstein and Danti, 1980).

Two deep drill holes FOH-1 (617 m) and FOH-2 (1367 m) were drilled as observation holes in 1981 and 1986, respectively. The latter hole was also cored throughout its length. Results of those efforts further substantiated the presence of a geothermal anomaly of sufficient proportions to lead Navy to the conclusion that a power generating facility could be supported. Thermal gradients in FOH-1 and FOH-2 were 7.6°F/100 ft and 5.7°F/100 ft, respectively. The thermal gradient in FOH-2 was conductive at 5.1°F/100 ft at maximum depth in a thick sequence of Tertiary volcanics.

In FOH-2, 677 m (2223 ft) of sediments were found to overlie 689 m (2262 ft) of volcanics typical of the capping basalts in this area. These basalts were not totally penetrated so it is not certain whether there is a sedimentary column underlying these basalts as Morrison (1963) observed in surrounding mountains. There was an abundance of hydrothermally altered (pyritized) sediments in the hole along with sericite alterations and secondary calcite, opal, quartz and zeolites in vugs, fractures, and as pseudomorphic replacements of pyroxenes and hornblendes (Katzenstein and Bjornstad, 1987).

A broad, roughly circular magnetic high located under the center of Mainside may represent a doming of the basalts due to a local intrusive body beneath, or a thicker section of basalts. The gravity data do not strongly support the latter conclusion, but there is no independent evidence for the origin or nature of this feature.

Based on the thermal gradients, geophysical and geochemical data, it is estimated that the reservoir temperatures beneath NAS-Fallon Mainside should reach 369°F to 399°F comparable to those found at nearby Desert Peak. The 400°F isotherm is projected to lie between 1525 m (5000 ft) and 1829 m (6000 ft) beneath the capping basalts. Although neither of the deeper Navy wells were flow tested, it is believed based on results at nearby Salt Wells and Dixie Valley that availability of fluid should not be a limiting factor in development of the resource at Mainside.

Katzenstein and Bjornstad (1987) conclude that the geothermal system at southeast Mainside is very similar to that found at Desert Peak based on projected depth to reservoir, reservoir temperature (from geothermometry), and temperature gradients. They believe that the reservoir model is similar to that proposed by Grose and Keller (1979) for non-magmatic heat sources in the Basin and Range (see Figure 8). The buried Miocene (?) basalts are probably capping a deeper fluid reservoir which is recharged by water from surrounding mountain ranges. These fluids are heated over a particularly thin spot in the crust at this location thereby causing them to rise and to seep upward through the buried faults.

Direct evidence for the thinness of the crust in this area is sparse. Klemperer, et al (1986) interpret COCORP seismic lines in the northern Carson Sink as showing the crust being approximately 20 km (12 mi) thick which is half to one-quarter normal continental crustal thicknesses. The very broad nature of the southern Carson Sink, and the location of strong lineament sets in this area suggest that there may have been substantially more extension here than in adjacent basins, therefore leading to thinner crust. The absence of a higher heat flow anomaly here which would somewhat corroborate this conclusion, we believe is due to the insulating effect of both the large wedge of sediments and the buried basalts. Further investigation of this theory is planned.

BRAVO-19 GEOTHERMAL POTENTIAL

While present thinking about B-19 is that it does not have as much geothermal potential as Mainside, that conclusion is, in part, the result of very limited geological, geophysical, and geochemical sampling and analysis. Navy has drilled five shallow (150 m) temperature gradient holes on the west side of the range (see Figure 9) with some encouraging results in the northwest corner of the study area.

The highest temperature gradient measured was 5.2°F/100 ft. These holes were located without the benefit of any geochemical or geophysical data to justify their location, and the intent was merely to obtain some preliminary thermal gradient data for the range (Bruce, 1980).

Water samples were taken from HFH 22 the northernmost hole, Coyote Springs, and nearby Lee Hot Springs. Silica and Na-K-Ca geothermometer determinations were made results of which are shown below in Table 1. The data show that the underlying reservoir has reasonable geothermal potential not unlike that of Soda Lakes.

Table 1. Comparison of Geothermometry Data from B-19 and vicinity with data from Soda Lakes (*), adapted from Bruce (1980)

	SiO_2(°C)	Na-K-Ca(°C)
HFG 22	111	152
Lee Hot Springs	162	161
Coyote Springs	111	216
BRCDDH-14A *	158	141
CODH-30A *	143	158
CDDH-32A *	114	179

Results of geochemical and geophysical work were much more positive and in our opinion indicative of the geothermal potential of B-19. Figure 10 shows the results of the trace mercury analyses which clearly delineate northwest- and north-trending lineaments which appear to intersect just north of the boundary of the range. Although mercury values were substantially lower than those at Mainside, it is believed that this is an artifact of the high sand content of the samples. Mercury generally binds well to clays and organic material and poorly to sandy material. Thus, the absolute values may be somewhat misleading.

The trends in the mercury data are substantiated by the gravity data acquired by Katzenstein and Danti (1982). The residual Bouguer anomaly map shown in Figure 11 clearly shows both north- and northwest-trending lineaments coinciding with the mercury anomalies.

It is the opinion of the U.S.Navy that like southeast Mainside, these data delineate pathways for migration of geothermal fluids from deeper reservoirs and there is some potential for producible geothermal fluids. However, before any firm conclusions can be reached regarding the geothermal potential of B-19, substantially more exploration work will have to be done.

EXPLORATION CONCLUSIONS

1. There is a moderate- to high-temperature (369°F to 399°F) geothermal resource located beneath southeast Mainside. This resource lies at a commercially exploitable depth and should be able to support an electrical power generating facility.

2. The resource lies at depths in excess of 1370 m (4500 ft) and is likely overlain by "capping" basalts. Reservoir rock type is not known but could be sedimentary (as seen beneath the basalts in the Bunejug Mountains) or igneous (as at Desert Peak).

3. The confluence of three sets of lineaments in the area of southeast Mainside is important in the evaluation of the producibility of the reservoir. It is likely that such extensive faulting will have resulted in a highly fractured reservoir and will allow greater transmissivity of the fluids (Katzenstein and Bjornstad, 1987).

4. Bravo-19 has a much more speculative geothermal potential than Mainside. This is due for the most part to the scant amount of exploration work done to date on that site. Results of such efforts have provided some encouragement, but much more work is required before definitive pronouncements about the geothermal resource can be made.

U.S. NAVY PLANS FOR DEVELOPMENT OF GEOTHERMAL RESOURCES AT NAS-FALLON

After eight years of data acquisition and evaluation, the U.S. Navy has made the decision to proceed with plans to develop the geothermal resources beneath NAS-Fallon. This decision is principally based on the encouraging results of the scientific investigations described in this paper, but they are also influenced by the success realized at the Coso geothermal area located on the Naval Weapons Center. Many legal, institutional, and operational hurdles have been overcome in the development of the Coso geothermal field, and the groundwork for additional Navy-sponsored alternate energy projects has been successfully laid.

As a necessary first step in the Fallon development project, Navy has undertaken the preparation of an environmental impact statement (EIS) which is scheduled for release in draft form early in the first quarter of 1990. A final EIS should be available by May of the same year.

Simultaneous with the EIS effort, Navy is preparing a formal solicitation package in which bids will be requested from prospective operators interested in developing geothermal resources at NAS-Fallon. The Navy will evaluate, among other things, the bidders' technical expertise, business plan, and financial capability to undertake the project. It is presently anticipated that this solicitation package will be available in October 1989 with an award being made in early summer 1990.

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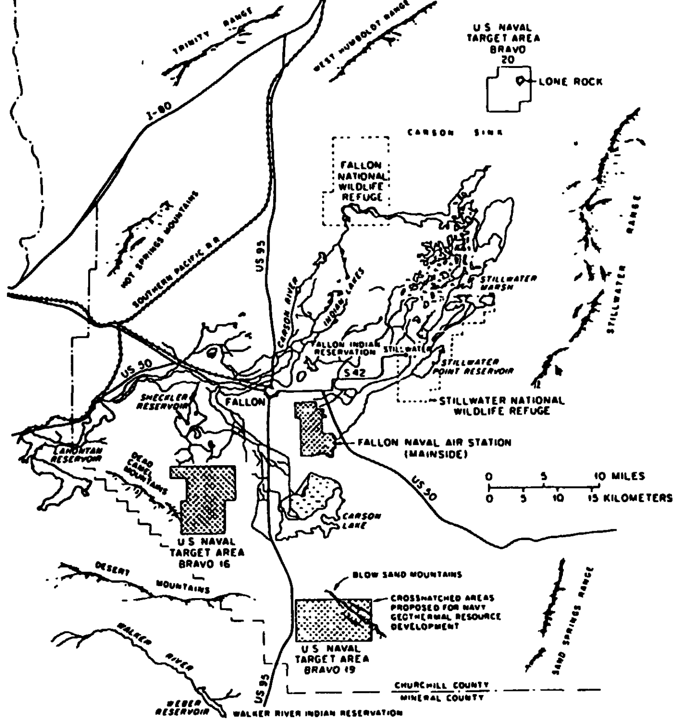

Figure 1. Location of Facilities at NAS-Fallon.

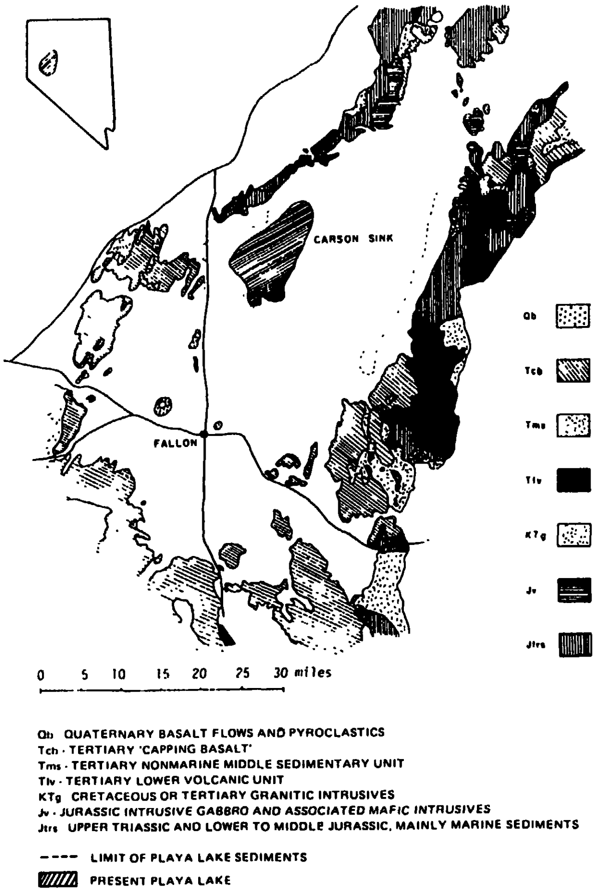

Figure 3. Generalized Geologic Map of the Carson Desert Area (modified from Hastings, 1979).

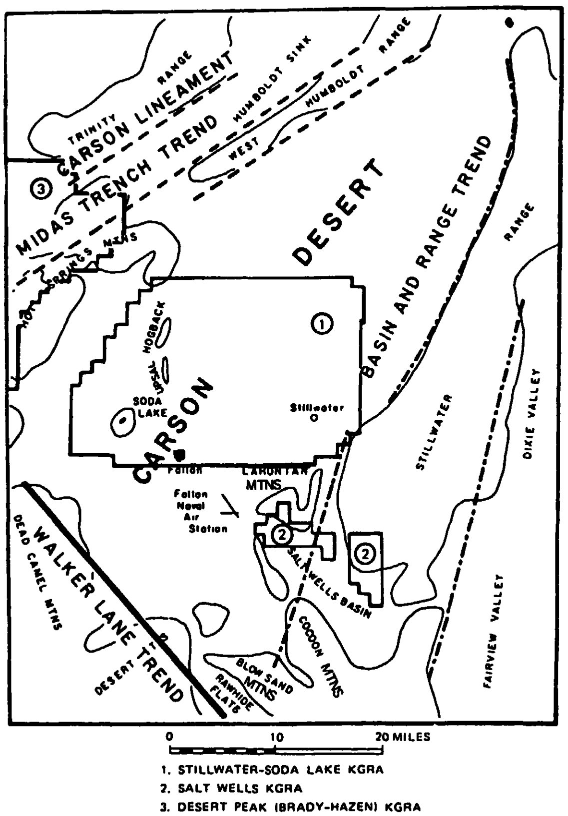

Figure 2. Known Geothermal Resource Areas in, and around the Carson Sink, Nevada (after Katzenstein & Danti, 1982).

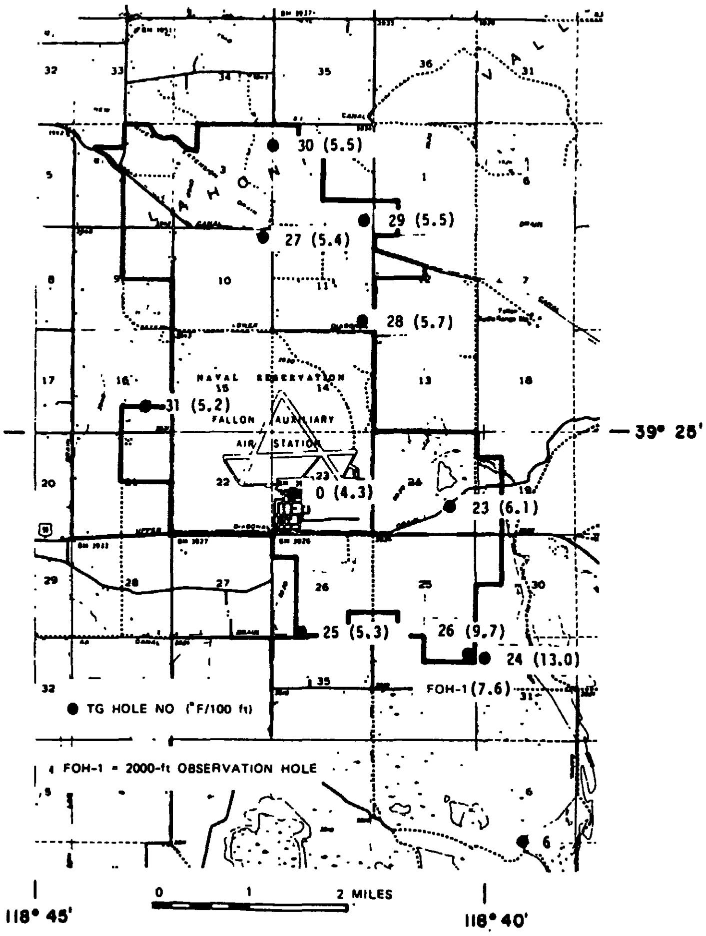

Figure 4. Locations of Thermal Gradient Holes and Deep Observation Holes at Mainside, NAS-Fallon. Values in Parentheses are Temperature Gradients in °F/100 ft.

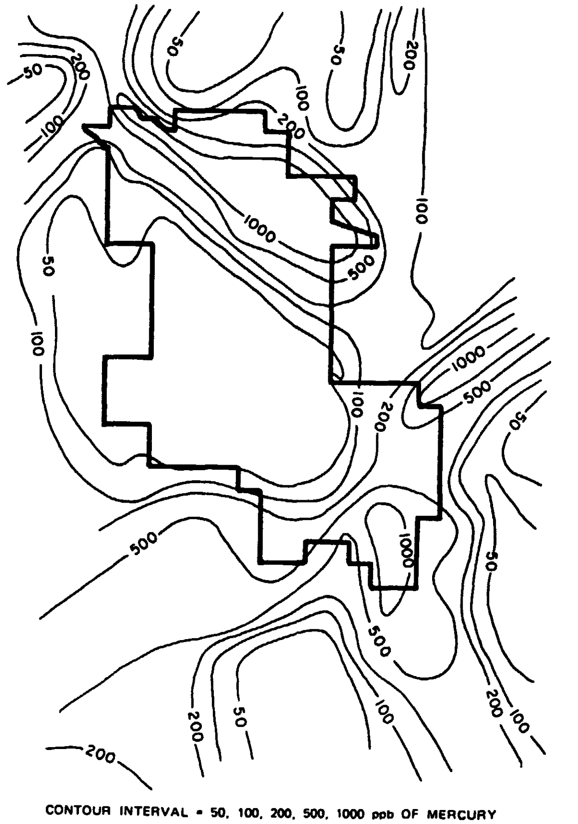

Figure 5. Results of Trace Mercury Study at Mainside, NAS-Fallon. All values are in parts-per-billion. (from Katzenstein & Danti, 1982).

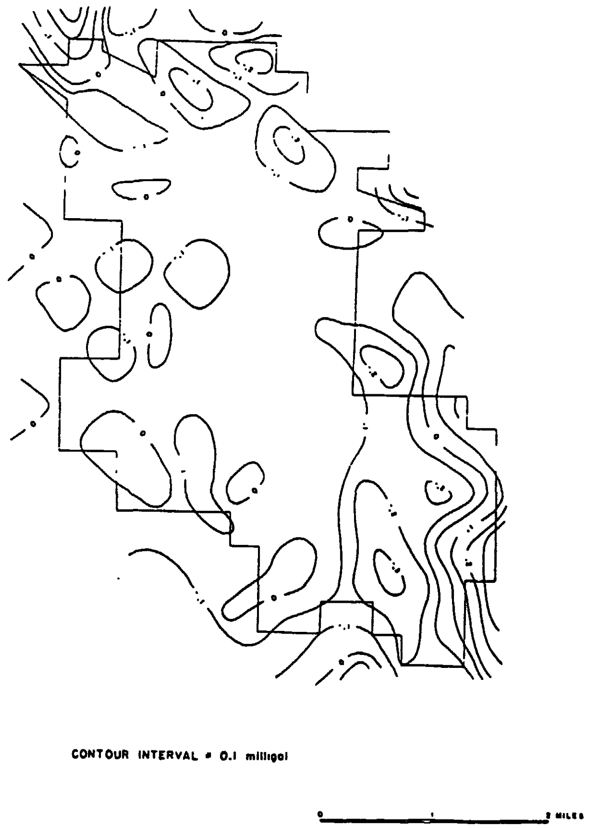

Figure 6. Residual Gravity Map, Mainside, NAS-Fallon Contour interval is 0.1 milligal (from Katzenstein & Danti, 1982).

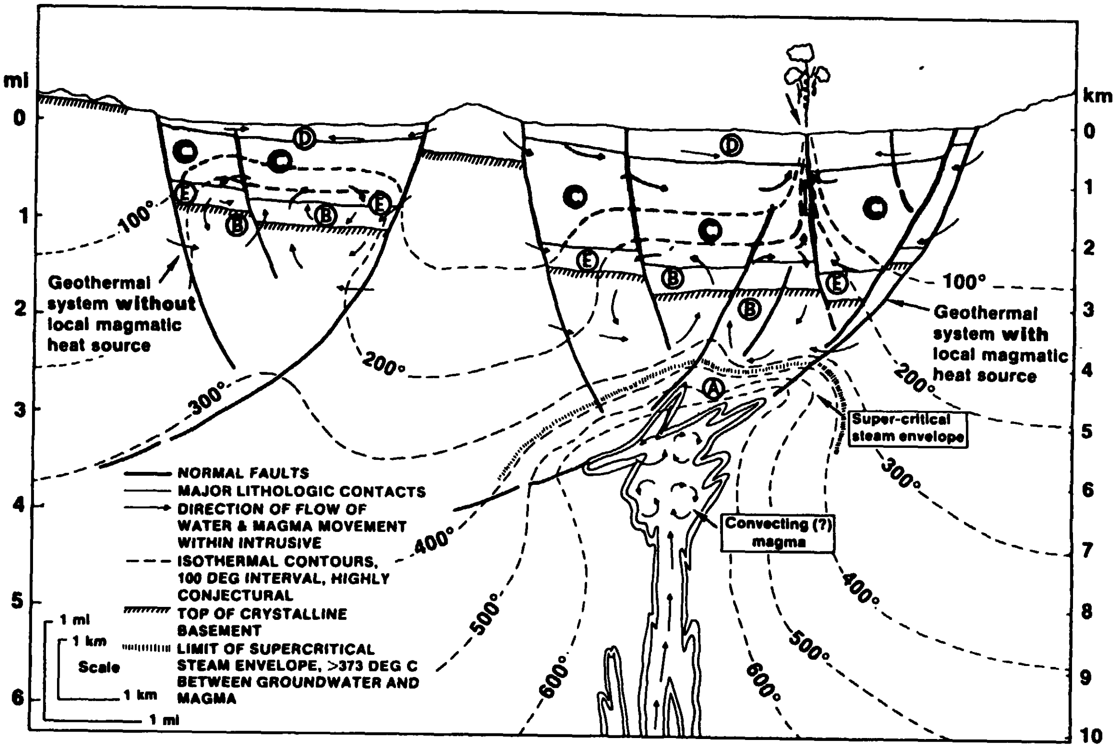

Figure 8. Conceptual Model of Geothermal Reservoir Believed to Be Similar to that Underlying Mainside, NAS-Fallon (from Grose & Keller, 1979).

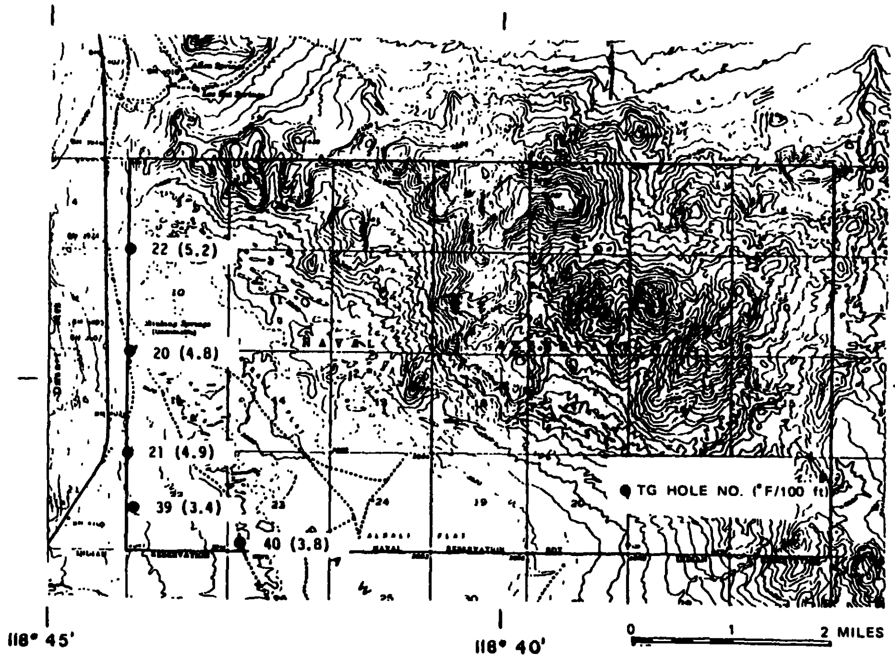

Figure 9. Locations of Temperature Gradient Holes at Bravo-19. Values in Parentheses are Temperature Gradients in °F/100 ft.

Figure 7. Total Intensity Land Magnetic Map, Mainside, NAS-Fallon (from Katzenstein & Danti, 1982).

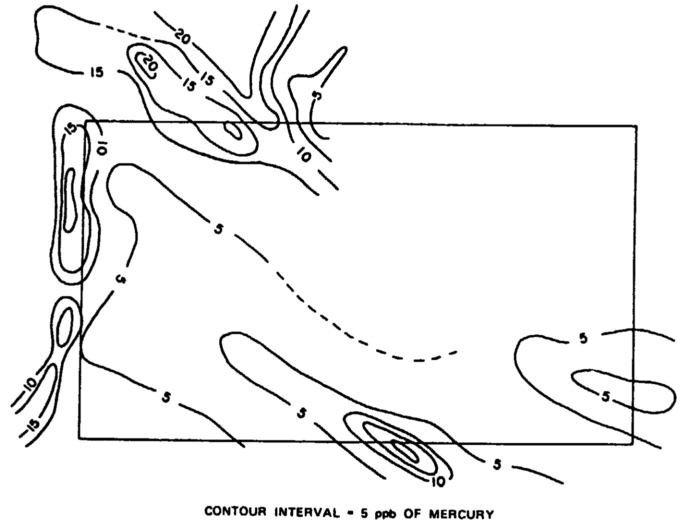

Figure 10. Results of Trace Mercury Study at Bravo-19. All Values are in parts-per-billion (from Katzenstein & Danti, 1982).

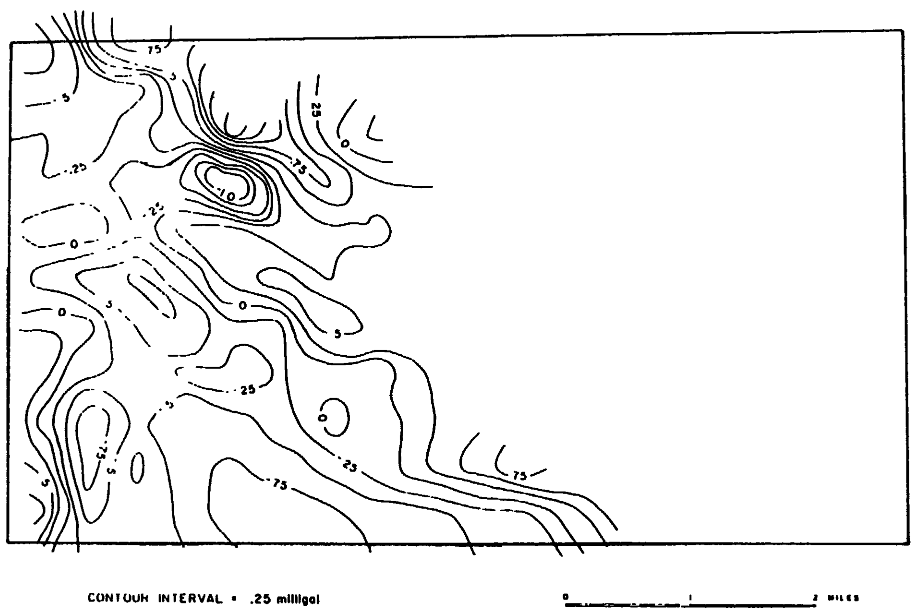

Figure 11. Residual Gravity Map, Bravo-19 (from Katzenstein & Danti, 1982).