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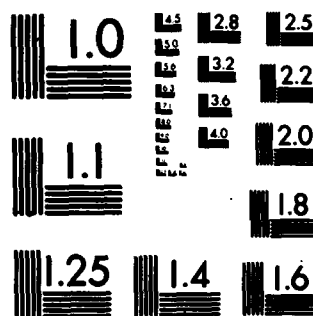
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Fallon Geothermal Exploration Project, Naval Air Station, Fallon, Nevada

Interim Report

by
James L. Brown
Geothermal Utilization Division
Public Works Department

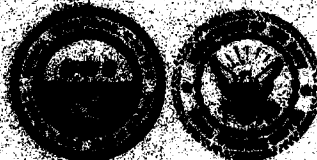
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FOREWORD

This is an interim report of a study conducted by the Naval Weapons Center's Geothermal Utilization Division. The work was performed during fiscal year 1979 and was sponsored by the Navy Civil Engineering Laboratory, under Project No. Z0840-SL.

The Fallon Exploration Project is part of a continuing program to determine the geothermal energy potential of Navy-controlled lands in order to plan for the orderly development of such resources in a manner consistent with the continuation of the Navy's mission.

This report was reviewed for accuracy by James A. Whelan and CDR Bruce L. Jackson.

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(U) The Fallon Geothermal Exploration Project was developed to determine which Navy-controlled lands near the Naval Air Station (NAS), Fallon, Nevada, had the highest potential for geothermal development. The project studied primarily NAS Fallon and Ranges Bravo 18 and Bravo 19. Some data (mercury study data for the ranges and temperature gradients for NAS Fallon) are incomplete and will later supplement this report. The areas having the highest geothermal development potential are (1) the southern portion of NAS Fallon, located over a fairly shallow thermal anomaly (300°F at a depth of 2400-3000 feet); and (2) the north-northwest portion of Range Bravo 19, with Lee Hot Springs and intersecting lineaments that could be conduits for geothermal fluids. A detailed regional geophysics study and a dipole-dipole resistivity survey could provide necessary data on the basin structure and other aspects of the Fallon area.

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CONTENTS

Summary	3
Introduction	4
Regional Geology	4
Lineament Analysis	11
Regional Geothermal Potential	14
Geology and Geothermal Potential of Selected Navy Properties . . .	19
NAS Fallon Main Base	20
Range Bravo 16	29
Range Bravo 19	31
Range Bravo 20	39
Conclusions and Recommendations	39
Bibliography	46
Appendix:	
A. Geothermometer Data	52
Figures:	
1. Locations Map	5
2. Regional Geologic Map	9
3. Composite Lineament Analysis Map	12
4. Major Lineament Map	13
5. Regional Geothermal Potential	15
6. Regional Geothermometer Map	17
7. Soda Lakes Geothermal Gradient Map	18
8a. NAS Fallon Wells and Heat Flow Holes--Location Map . . .	23
8b. NAS Fallon Heat Flow Holes Geothermal Gradients	24
8c. NAS Fallon Isothermal Cross Section (from footnote 1) . .	25
8d. NAS Fallon Mercury Study	27
9. Mercury Geochemical Study of Range Bravo 16	33
10a. Range Bravo 19 Heat Flow Hole Location Map	37
10b. Range Bravo 19 Heat Flow Hole Geothermal Gradients . . .	38
10c. Range Bravo 19 Mercury Study (Partial)	41
11. Mercury Study of Range Bravo 19	43

SUMMARY

The Naval Air Station (NAS), Fallon, Nevada, is located in one of the better geothermal potential areas in the western United States, west-central Nevada. The Fallon Exploration Project was developed to determine which Navy-controlled lands had the best potential for geothermal development. The areas studied in this project were primarily NAS Fallon and Ranges Bravo 16 and Bravo 19. The majority of the data analysis has been completed, but portions of the data relating to Ranges Bravo 16 and Bravo 19 (mercury study data) and NAS Fallon (temperature gradients) had not been completed at the time this report was being written. Thus, additional data will be added to this report as a supplement at a later date.

Those areas which appear to have the best potential for further geothermal development are the southern portion of NAS Fallon and the northwest and northern portions of Range Bravo 19. The southern portion of NAS Fallon appears to be located over or slightly north of a reasonably shallow thermal anomaly, 300°F at a 2400- to 3000-foot depth. Range Bravo 19 has a known geothermal system, Lee Hot Springs, just north of its northwest corner, and also has a northwest-trending lineament which cuts across Range Bravo 19 and intersects with a west-trending lineament at Lee Hot Springs. Thus, these lineaments could be conduits for geothermal fluids in this region.

A better understanding of the basin structures around NAS Fallon and Range Bravo 16 is needed. A regional geophysics study, including detailed gravity and aeromagnetism, and a dipole-dipole resistivity survey could provide these data and probably much more.

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INTRODUCTION

The Fallon Exploration Project was implemented to assess the geothermal potential of selected areas of NAS Fallon, Nevada. The objectives of the project were to analyze the existing data, collect and analyze new data supportive of the project, and then synthesize and organize these data into a viable information package from which new targets, showing the best potential for further study and development, could be selected.

Studies of NAS Fallon and associated ranges are continuing. The results of these studies will be published when complete.

NAS Fallon is located approximately 50 miles east of Reno, Nevada in the Carson Sink, a large playa in west-central Nevada. NAS Fallon is the support facility for six live target ranges which are within a 30-mile radius of the main facility (Figure 1). These target ranges are some of the few training and live air-to-ground target ranges in the western United States and are used continually by the various air units of the military. All of these ranges lie within or adjacent to the Carson Sink and its adjoining mountain ranges.

This report covers primarily the main air facility at NAS Fallon and target Ranges Bravo 16 and Bravo 19. Although Range Bravo 20 is covered briefly in this report, its remote location and surrounding land status have precluded serious study of the area for geothermal potential. The Electronic Warfare Range has not been included in the geothermal analysis because it is not included in the withdrawn land for NAS Fallon (it is being used by the Navy on a special land use permit from the Bureau of Land Management). Also, the Electronic Warfare Range is adjacent to Range Bravo 17, which was studied in a previous report along with the Shoal Site ranges;¹ these latter areas were determined to have little or no geothermal potential for further development.

REGIONAL GEOLOGY

NAS Fallon and its nearby targets are located within the Basin and Range province, which is a series of somewhat parallel uplifted mountain

¹Naval Weapons Center. *Evaluation of Geothermal Potential of Range Bravo 17 and the Shoal Site, Naval Air Station, Fallon*, by J. A. Whelan, C. R. Rodgers, J. Bown, and Jack Neffew. China Lake, CA, NWC, March 1980. (NWC TP 6142, publication UNCLASSIFIED.)

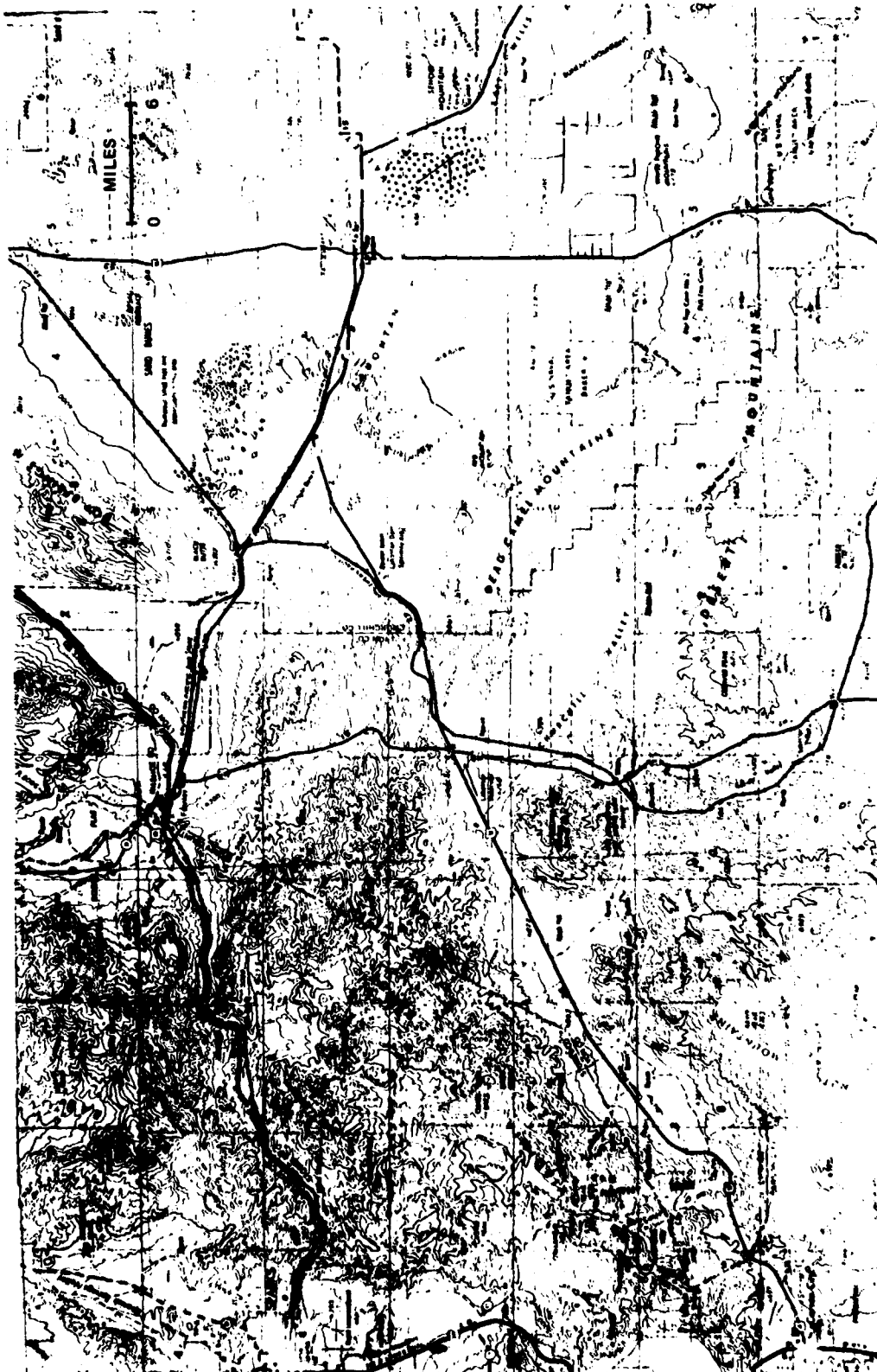


FIGURE 1. Locations Map

ranges (horsts) and downdropped valleys (grabens) trending in a north-to-northeast direction. Carson Sink is one of the largest grabens in the Basin and Range Province, extending approximately 60 miles in length and 20 miles in width. This northeast-trending graben is bounded on the west and east by northeast-trending horsts--the Hot Springs Mountains and West Humboldt Range on the west and the Stillwater Range and Lahontan Mountains to the east; on the south by a series of northwest to west-trending ranges--the Cocoon Mountains, Blow Sand Mountains, Dead Camel Mountains, and Desert Mountains.

The Carson Sink graben has three smaller northwest-trending grabens or structural lows branching off from it. In the southeast portion are the Salt Wells Basin and Bass Flats, and in the west-central portion is an extension of the Carson Sink between the northeast-trending Hot Springs Mountains and the West Humboldt Range.

The Carson Sink graben has been infilled with lacustrine and fluvial sediments. The lacustrine sediments are from pre-Pleistocene and Pleistocene lakes, of which the most recent is known as Lake Lahontan. Shorelines formed by Lake Lahontan can be seen several hundred feet up the flanks of many of the ranges bounding the Sink.

The valley fill is considered to be about 3000 feet in thickness in the southern portion of the sink and in excess of 10,000 feet in the northern portion (data from a Standard-Amoco Oil Strat Test Well). The basin lithologic units include lacustrine and fluvial clays, sands, and silts; aeolian sands; and volcanic tuffs, tuffaceous sediments, and flows chiefly basaltic in composition.

The volcanic units which outcrop within the Carson Sink are primarily Quaternary in age and include Rattlesnake Hill, north of Fallon; Soda Lakes and Upsal Hogbacks, west and northwest of Fallon; and Lone Rock, located in the northwest portion of Range Bravo 20.

The surface geology of the Carson Sink can be divided into two sections. The northern half of the Carson Sink consists of a large playa extending 30 miles in length and averaging 15 to 20 miles in width. A few isolated dunes and silty to clayey berms rise a few feet above the playa. At the southern edge of the playa, where it is separated from the southern portion of the Sink by a large field of active and trapped sand dunes, is an area which appears to have undergone some slight uplift, as the material is well-sorted playa clays and silts which are thoroughly packed and compressed, but which have been dissected by erosion. The apparent uplifting of this small area, about 1/4 mile in width and apparently several miles in length, is only a few inches, but the region appears to be fairly young because the erosional dissection is not well advanced.

The southern half of the Carson Sink consists primarily of lacustrine and fluvial sediments, with overlain trapped blow and dune sand in places. The sand can hinder vehicle access. Much of this area has been under agricultural development since the early portion of the century, as the Carson River empties into this region, providing water for irrigation.

The absence of large alluvial fans in many places in the Sink to Mountain range transition zone indicates rather recent uplift of the ranges.

The nearby mountain ranges are composed of Mesozoic and Cenozoic rocks (Figure 2) in which Tertiary and Quaternary volcanic rocks dominate.

The Stillwater Range to the east is a typical uplifted horst and consists of primarily Jurassic and Triassic metasediments and sedimentary units overlain by Tertiary and Quaternary volcanic flows and volcanosedimentary tuffs. A few Jurassic-Triassic granites outcrop along the western edge of the range. The overlying Tertiary and Quaternary volcanic rocks are broken by northeast- and north-trending faults, indicating recent earthquake activity.

Across the Carson Sink to the west the West Humboldt Range is very similar to the northern portion of the Stillwater, and some correlation of rock limits across the basin is possible.

The other ranges, exclusive of the Sand Springs Range, are composed primarily of Tertiary volcanic rock and volcanosediments. These are the Hot Springs Mountains, Dead Camel Mountains, Desert Mountains, Blow Sand Mountains, Cocoon Mountains, Bunejug Mountains, and Lahontan Mountains. A small outcrop of Mesozoic granite occurs in the central portion of the Blow Sand Mountains, but other than this all of the ranges consist of Tertiary or younger volcanics. These ranges have not been uplifted as much as the Stillwater and West Humboldt Ranges have. Cenozoic volcanic activity appears to be greater in the southern portion of the Carson Sink area than in the north.²

The surface faults in these ranges are again usually northeast- and north-trending faults, except in the Dead Camel Mountains, where faults trend more easterly. The fact that these faults predominantly break the Tertiary and younger volcanic cap units indicates fairly recent movement.

The Sand Spring Mountains, which lie at the southeast end of Salt Wells Basin, consist primarily of Cretaceous granitic rocks and Tertiary sedimentary and volcanosedimentary rocks.

²Chevron Resources Company. *Evaluation of the Geothermal Potential of the Soda Lakes Area, Nevada. Dipole-Dipole Survey. 1973. (Unpublished data.)*

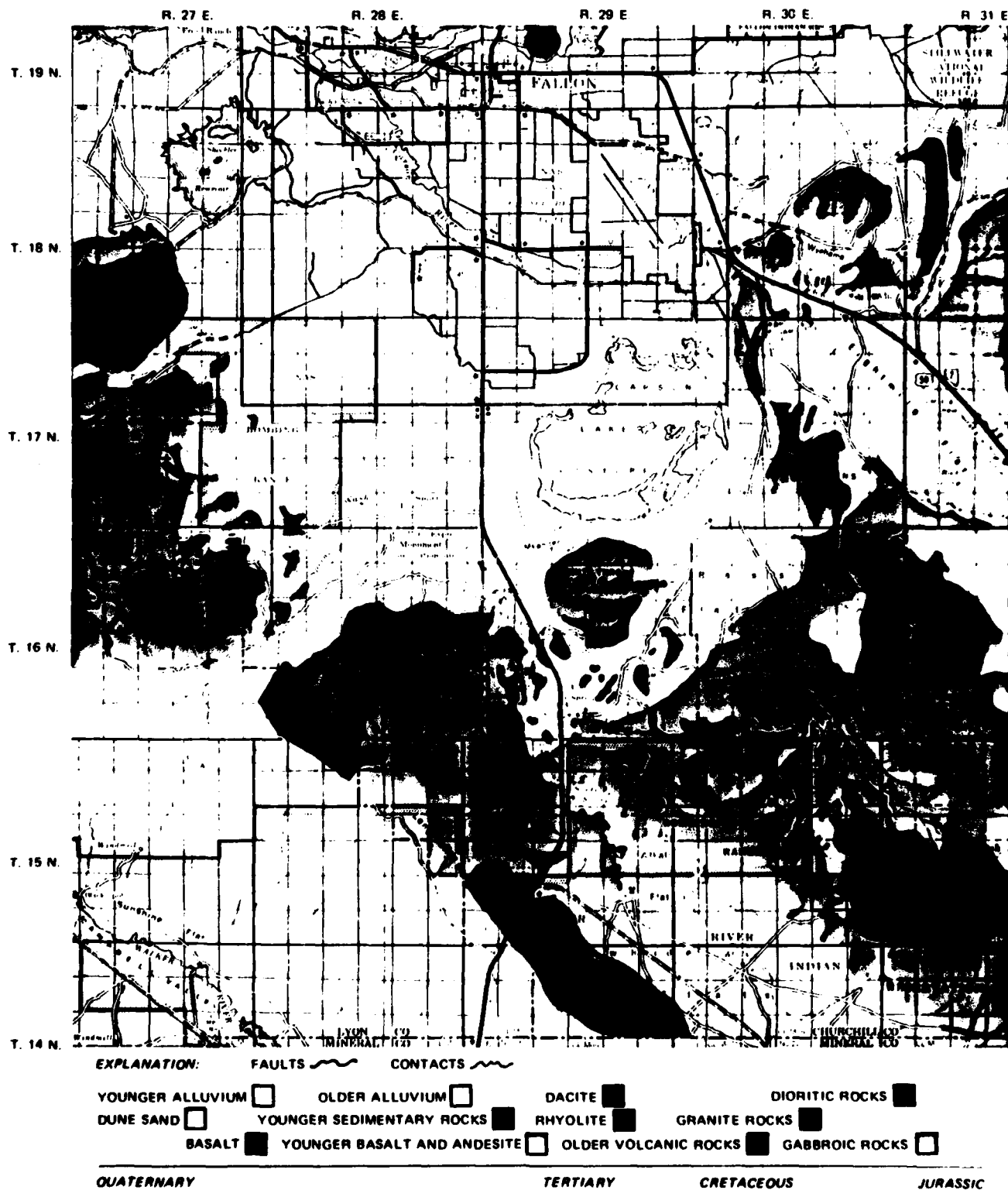


FIGURE 2. Regional Geologic Map

The overall geologic structure of the area indicates an early Cenozoic volcanic period during which volcanic units were deposited over Mesozoic sediments and metasediments, followed by mid- to late-Cenozoic crustal extension, during which the present-day Basin and Range structures were created. Concurrent to the crustal extension was additional volcanic activity of late Cenozoic age.

The Soda Lake-Upsal Hogback area of the Carson Sink is an interesting area for geothermal potential (a large amount of work has been done in the area). Both the Soda Lake uplift and the Upsal Hogback are Quaternary volcanic vents. Soda Lake has hot springs on the bottom of the lake which are producing 80°F+ fluids. Low electrical resistivity at a depth of 1000 to 3000 feet, as determined by a dipole-dipole resistivity survey run by Chevron Resources Company,² could be interpreted as either a large alteration zone in the sediments or a hot saturated aquifer or both. This coincides with the apparent trend of a possible shallow magma chamber which was shown by magneto-telluric studies.

LINEAMENT ANALYSIS

As part of the initial phase of the Fallon Exploration Project, a composite lineament analysis of the region was done. The composite lineament analysis combined lineament data from satellite photos, low-level aerial photos, regional aeromagnetic and gravity maps, and topographic maps (Figure 3). The result of this study was a regional structure-lineament map (Figure 4) on which were located structural features (faults and fracture zones) that were used to interpret the regional structure and regional geothermal potential.

Some of the structural features (i.e., lineaments) appeared to have a definite correlation with the geothermal systems in areas, while others did not correlate at all with known geothermal systems.

Those lineaments which correlate with areas of known geothermal potential include the intersection of two lineaments near Lee Hot Springs and Allen Spring north of Range Bravo 19. One of those lineaments bisects a portion of Range Bravo 19, and soil samples from this region are currently being analyzed for mercury. Another interesting lineament intersection is 1 to 2 miles southeast of NAS Fallon's southeast corner. Although these two lineaments are not well defined, they can be partially justified by mercury anomalies in soil samples and by radical changes in the thermal gradient of wells on opposite sides of the lineament.

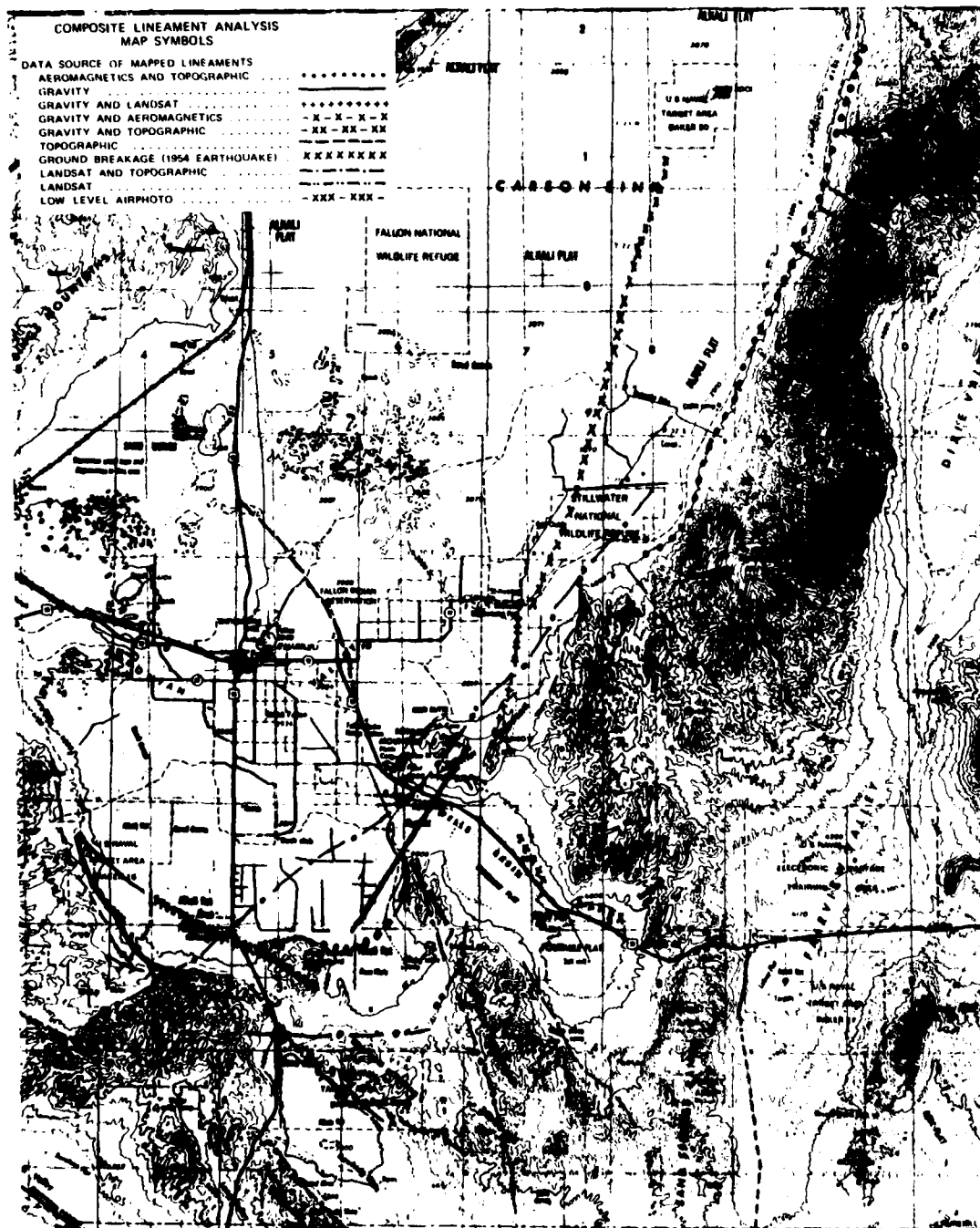


FIGURE 3. Composite Lineament Analysis Map

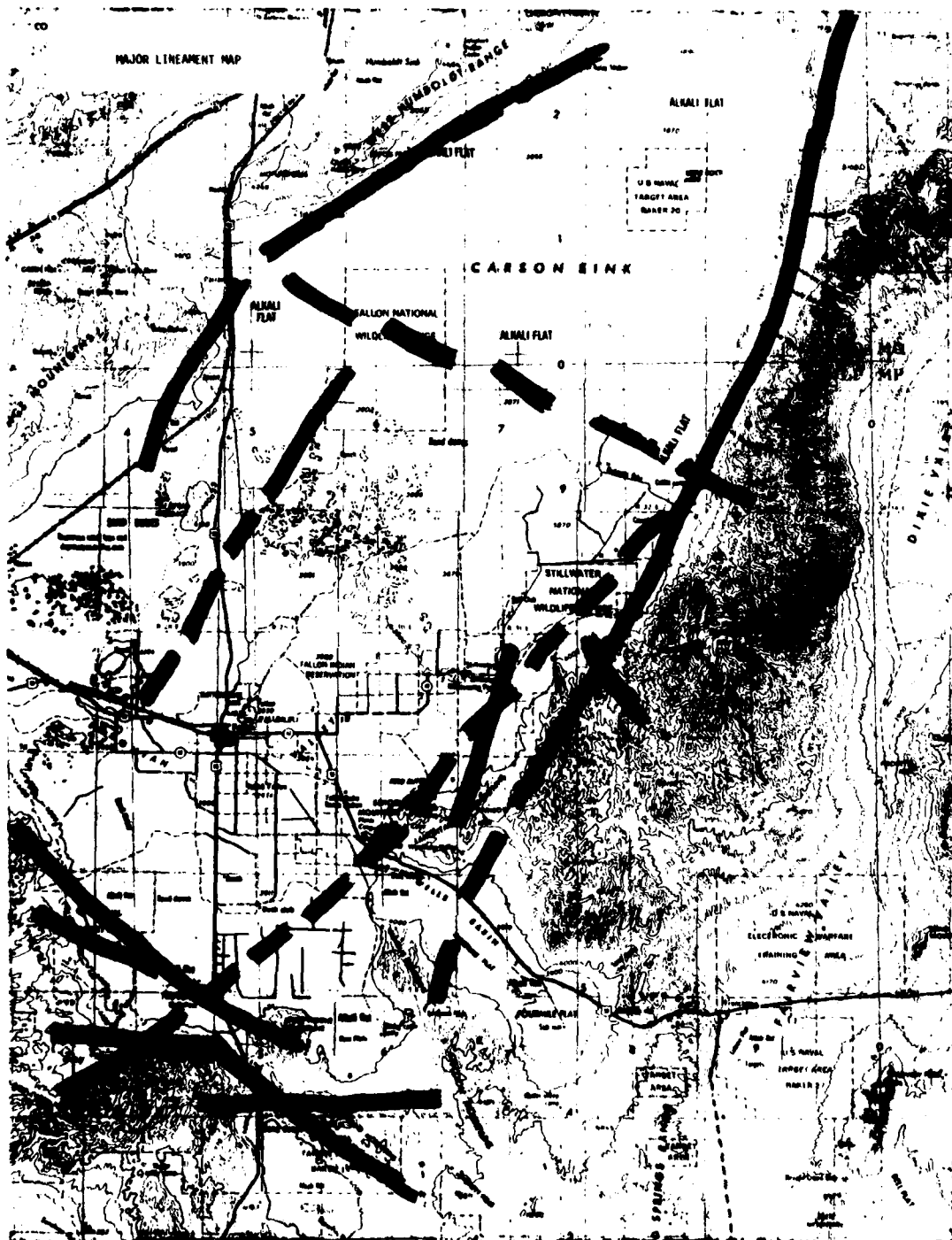


FIGURE 4. Major Lineament Map.

REGIONAL GEOTHERMAL POTENTIAL

West-central Nevada is one of the better geothermal resource areas of Nevada. Numerous near-surface thermal anomalies exist in the region, and many have surface expressions such as hot springs and alteration zones. Shallow water wells (only a few hundred feet deep) in many parts of the Carson Sink have encountered shallow thermal anomalies which have no surface expressions and are relatively warm ($>150^{\circ}\text{F}$).

The heat source for these near-surface thermal anomalies has not been fully understood or proved as to type of source. The two predominant theories are: (1) the geothermal systems in west-central Nevada are created by deep circulation of ground water along extensive faults and fracture zones; (2) a near-surface cooling intrusive body supplies the heat to the near-surface fluids. Owing to a possible shallow magma chamber existing in the Soda Lake region³ and the abundant late Cenozoic volcanics in the region, the second theory, of cooling magma bodies as the heat source, appears more realistic to the author than the deep circulating fluids theory. Only a small amount of deep geophysics work has been published on the region;⁴ thus, only limited data are available for interpretation.

Within the Carson Sink region of west-central Nevada exist five Known Geothermal Resource Areas (KGRAs) and several additional near-surface thermal anomalies not classified as KGRAs (Figure 5). These include the Brady-Hazen KGRA along the west side of the Hot Springs Mountains; the Dixie Valley KGRAs in Dixie Valley, east of the Stillwater Range; the Wabuska KGRA southwest of the Desert Mountains; the Stillwater-Soda Lakes KGRA north and northeast of Fallon; and the Salt Wells KGRAs southeast of NAS Fallon in the Salt Wells Basin. Thermal anomalies which are not classified as KGRAs include: portions of Four Mile and Eight Mile Flats in the Salt Wells Basin; the Lee Hot Springs and Allen Spring area, north of Range Bravo 19; the northern part of the Carson Lake pasture lands, about 2 miles south of the Fallon National Wildlife Refuge, in the Carson Sink; and the Desert Peak region, north of the Brady-Hazen KGRA in the Hot Springs Mountains. All of these non-KGRA thermal anomalies are identified by either hot water wells or high thermal gradients from drilled temperature gradient holes.

³Garside, L.J. *Geothermal Exploration and Development in Nevada through 1973*. Nevada Bureau of Mines and Geology Report 21, 1974.

⁴Chevron Resources Company. *Evaluation of the Geothermal Potential of the Soda Lakes Area, Nevada, 1973-1978*. (Unpublished data.)

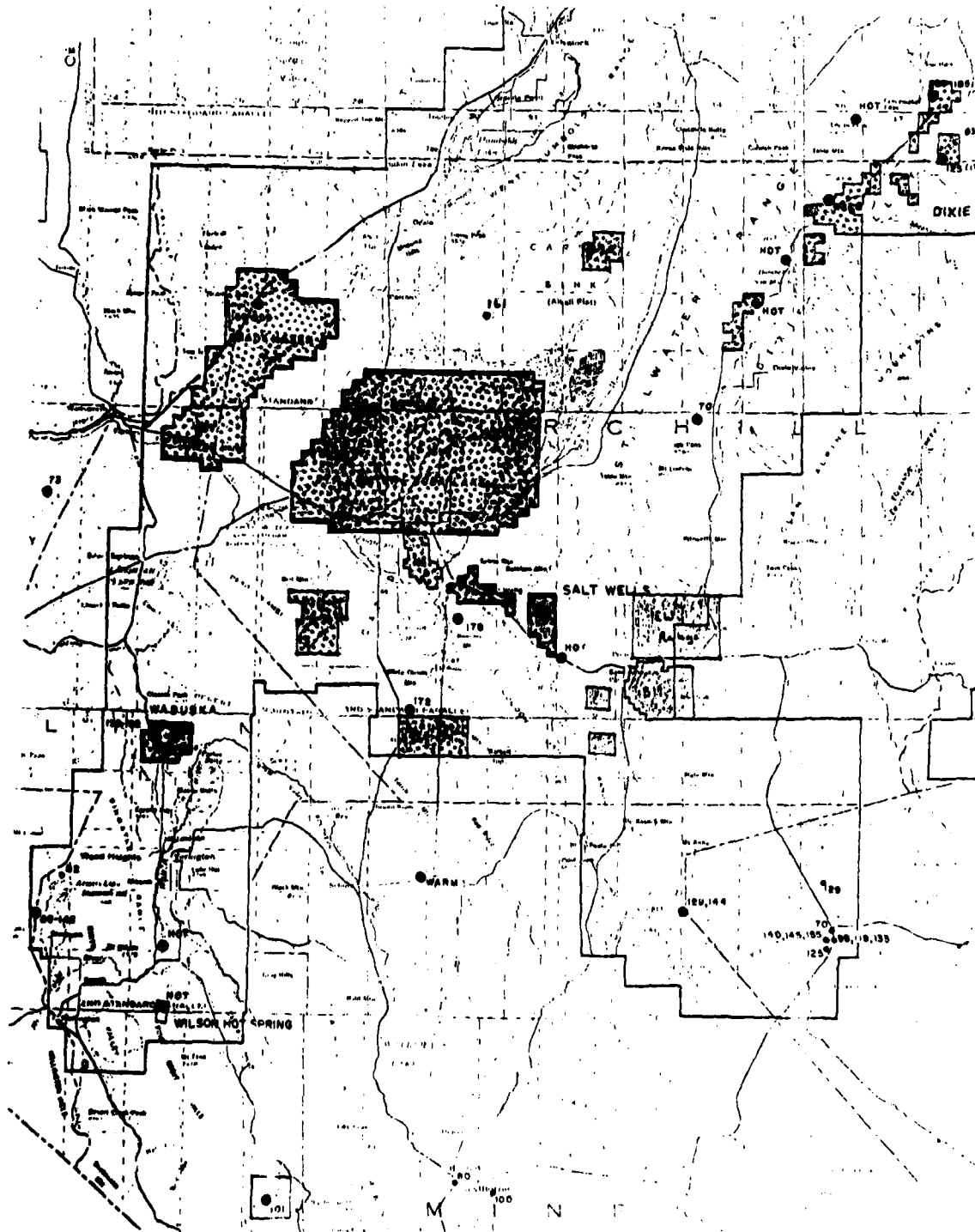


FIGURE 5. Regional Geothermal Potential

Analysis of the data dealing with the regional geothermal potential indicates a reasonable uniformity within the Carson Sink region. SiO_2 and Na-K-Ca geothermometers are reasonably constant across the region (Figure 6) and produce fairly reasonable geothermometer values (source temperature of the waters). SiO_2 values have an approximate range from 90 to 150°C, while Na-K-Ca values range from about 140°C to around 200°C. (Appendix A.)

The area which appears to have the highest thermal values in the region is the Soda Lake-Upsal Hogback region, where thermal gradients ranging up to 341°C/100 meters are found (Figure 7). This area also has the most available geophysical data, and it shows interesting correlations of data. Besides the possible shallow magma chamber which would be shallowest (8000 feet) below Soda Lake and extends to the northeast to a depth of 34,000 feet, a large, shallow, northeast-trending, low-resistivity zone appeared in the dipole-dipole resistivity survey. This low-resistivity zone, averaging about 2 miles in width and 10 miles in length, but open on the southwest, is thought to be caused by a highly altered zone of basin fill and/or a hot, saturated, shallow aquifer. The depth of this zone varies from 1000 to 2000 feet, and it appears to be approximately 1000 feet thick.⁵

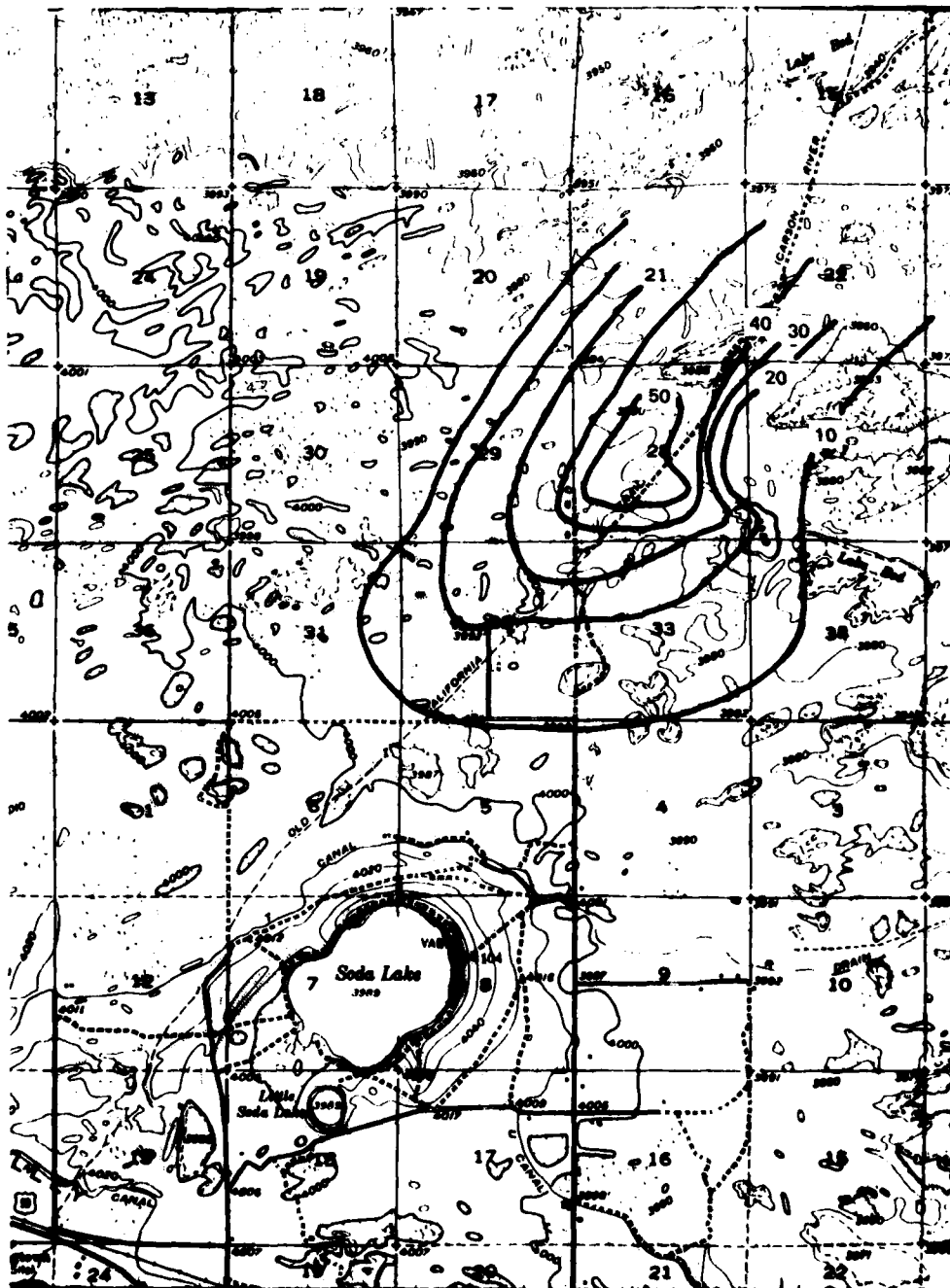
The subsurface structure of the Soda Lakes region is dominated by northwest-trending normal step faults which appear to be related to subsidence of the region immediately around Soda Lakes. Some of these faults are thought to be concentric in pattern, possibly indicating an older ring fracture system.⁶

Another high thermal anomalous area for which extensive geothermal exploration work has been done is the area around Stillwater, which is on the eastern edge of the Carson Sink. Most of the data in this region are still proprietary, but available data show a shallow thermal anomaly at about 200 feet which has fluids ranging from 190°F to greater than 200°F.⁶

Still another reasonably high thermal anomaly exists in an area near NAS Fallon. Southeast of the main facilities exists a shallow water well (163 feet deep) that is artesian and has a surface outflow of 162°F with a bottom hole temperature of 170°F. Geothermal gradients from wells on and around NAS Fallon show higher gradients to the southeast toward this well, indicating a possible 300°F resource at a depth of about 2500 to 3000 feet.

⁵Data compiled for Chevron Resources Company and released by a DOE/industry program through Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah.

⁶Garside, L.J., and J. H. Schilling. *Thermal Waters of Nevada*. Nevada Bureau of Mines and Geology Bulletin 91, 1979.



GRADIENT MAP (FROM FOOTNOTE 5); CONTOURS ARE °C/100 m

FIGURE 7. Soda Lakes Geothermal Gradient Map

One of the most interesting thermal anomalies exists in the playa of the Carson Sink. Here an apparent shallow well located approximately 6 miles out into the playa is flowing 161°F water at about 30 to 60 gal/min.⁶ The well is located along the eastern edge of the Fallon National Wildlife Refuge and appears to have been there a while. The water geochemistry analysis has not yet been completed.

GEOLOGY AND GEOTHERMAL POTENTIAL OF SELECTED NAVY PROPERTIES

As stated in the introduction, the analysis of Navy lands for geothermal potential at NAS Fallon was limited primarily to the airfield and Ranges Bravo 16 and Bravo 19. The geologic portion of the section has been derived primarily from published literature with some selected field reconnaissance.*

The evaluation of geothermal potential for NAS Fallon involves a series of studies and analyses of data. The primary path followed in evaluating Navy lands for geothermal potential is as follows:

Step I - Regional geologic and geothermal potential literature and field studies are made of the area. These studies look for recent volcanic activity or recent igneous intrusions, active or dormant hot springs or hot spring deposits, and high geothermal gradients or warm to hot water wells.

Step II - If Step I is favorable, then water samples for geochemical analysis are collected and available wells are temperature logged. The geochemical water analysis supplies the data necessary to derive the geothermometer values, and the temperature logs produce the geothermal gradients at the wells. Analysis of these data shows if a geothermal potential of reasonable scope exists and should be studied further.

Step III - A mercury anomaly study of soil samples is carried out, sometimes concurrently with Step II. The purpose of the mercury anomaly study is to locate areas of high mercury concentration in the subsurface nonorganic soils. These high mercury concentrations (anomalies) are sometimes associated with geothermal systems whose high heat has released mercury vapors which migrate upward and collect in the soil horizons near the surface. High concentrations of mercury in the soil may indicate that there is a heat source below, because free mercury vapors are released when the temperature exceeds 80°C. A problem with this type of

*The geologic studies of NAS Fallon and Ranges Bravo 16 and Bravo 19 were compiled by J. Bown of the Technical Branch of NWC's Geothermal Utilization Division. The short analysis of Range Bravo 20 was by the author.

study is that the mercury is soluble in water, meaning it can be transported by groundwaters, and that different soil materials absorb mercury at different rates (clays absorb more than sands). The mercury study for NAS Fallon has provided data relating to subsurface faulting, and some of the areas with high mercury constants correspond to known areas of higher geothermal potential.

Step IV - The drilling of heat flow/temperature gradient holes, which are of slim diameter and usually only about 500 feet deep, is done to measure the geothermal gradient in areas of high mercury or suspected high thermal gradient. Currently there are 12 heat flow holes existing on Main Base and Range Bravo 19.

Step V - If the thermal anomaly appears to be of such size and magnitude as to support development of the geothermal resource, then deeper observation holes and production size and depth test holes are drilled to begin testing the resource to see if it can be utilized for geothermal development.

Currently, Project Fallon is at the boundary between Steps IV and V for the airfield and Range Bravo 19 and at Step III for Range Bravo 16. The analyses of the data are included in the following subsections.

NAS FALLON MAIN BASE

NAS Fallon is located in the southern portion of the Carson Sink, about 6 miles southeast of the town of Fallon. Housing, offices, and air facilities are located here.

Geology

Previous Work. Several publications deal with the geology of the area which includes NAS Fallon. Russell's monograph (1885) is one of the earliest,⁷ but Morrison's work is of the most importance in understanding the geology of the base. (Morrison published works in 1952,^{8,9}

⁷Russel, I.C. *Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada*. United States Geological Survey, Monograph 11, 1885.

⁸Morrison, R.B., "Late Quaternary Climatic History of the Northern Great Basin (abs)." *Geological Society of America Bulletin*, Vol. 63, No. 12, Part 2 (1952), p. 1367.

⁹-----, "Stratigraphy of Lake Lahontan and Associated Quaternary Deposits in the Carson Desert Area, Near Ballon, Nevada (abs)," *Geological Society of America Bulletin*, Vol. 63, No. 12, Part 2 (1952), p. 1367.

1961,¹⁰ 1964,¹¹ and 1965.¹²) Wilden and Speed described the general geology of Churchill County in a Nevada Bureau of Mines bulletin in 1974.¹³ The data given below are abstracted from these publications.

Surface Geology. NAS Fallon is located in the southern part of the Carson Desert near Fallon. The Carson Desert contains Quaternary sediment that is probably more than 1000 feet thick in many places. The section is known to be at least 200 feet thick near Fallon. The whole section of sediments, both Quaternary and Tertiary, is known to be at least 3000 feet thick near Fallon. The basin occupied by the Carson Desert is one of the largest and deepest inundated by Lake Lahontan.

The exposed Quaternary deposits, exclusive of volcanics, comprise seven main units. A description of each follows in order from oldest to youngest: (1) lacustrine sediments of pre-Lake Lahontan age; (2) subaerial sediments and soil of late pre-Lake Lahontan age; (3) deep-lake sediments and minor amounts of intertonguing subaerial sediments of early Lake Lahontan age; (4) subaerial sediments, soil, and intertonguing subaerial sediments of mid-Lake Lahontan age; (5) deep-lake sediments and minor amounts of intertonguing subaerial deposits of Lake Lahontan age; (6) subaerial sediments and soil of early post-Lake Lahontan age; and (7) subaerial sediments and intertonguing shallow-lake sediments of post-Lake Lahontan age.¹¹

Two Quaternary formations are exposed within the present boundaries of NAS Fallon. These are the Turupah formation and the Fallon formation. In this area the Turupah is made up of alluvial sand and pebbly gravel in a former Carson River channel. The Fallon formation is shallow-lake sediments, aeolian sand, and alluvium.

¹⁰ United States Geological Survey. "Lake Lahontan Stratigraphy and History in the Southern Carson Desert (Fallon) Area, Nevada," by R. B. Morrison. *Short Papers in the Geologic and Hydrologic Sciences*, U.S. Geological Survey Professional Paper 424-C, 1962, pp. D111-D114.

¹¹ ----- . *Lake Lahontan: Geology of Southern Carson Desert, Nevada*, by R. B. Morrison. U.S. Geological Survey Professional Paper 401, 1964.

¹² Nevada Bureau of Mines and Geology. *Correlation of the Middle and Late Quaternary Successions of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), Southern Great Plains, and Eastern Midwest Areas*, by R. B. Morrison and J. C. Frye. Nevada Bureau of Mines and Geology Report 9, 1965.

¹³ ----- . *Geology and Mineral Deposits of Churchill County, Nevada*, by Ronald Wilden and Robert C. Speed. Nevada Bureau of Mines and Geology Bulletin 83, 1974.

Only one igneous formation is encountered under NAS Fallon. This is the Quaternary basalt of Rattlesnake Hill. The basalt is mostly black to dark-grey flows with low outward dips from the hill. The crater is underlain by locally exposed reddish basaltic agglomerate. The flows are cut by wells at several points within or near NAS Fallon.

Most faults exposed in the area date from two periods, the first in late Pliocene or early Quaternary and the second also in early Quaternary. Both were in existence long before Lake Lahontan was formed. During the period between fault formation, extensive pediments formed at the edges of nearby mountains. The main faults were repeatedly active, and as for most bounded mountains relief increased to a maximum at the end of the second episode of faulting. Subsequent erosion lowered the mountains and filled the basin. Some faulting has continued into the present.

Geothermal Potential

NAS Fallon is located only a few miles northeast of a shallow thermal anomaly identified by high thermal gradients and a hot artesian well 163 feet deep with a bottom hole temperature of 170°F (well 6). The heat flow holes (HFH) that are located along the southern portion of NAS Fallon, HFH 23 and HFH 26, both have geothermal gradients above average for the Basin and Range Province. HFH 24, which was mistakenly drilled on private property, is $\frac{1}{4}$ mile closer to the hot well, and has an even higher geothermal gradient (Figures 8a and 8b). The isotherm cross section of this NAS Fallon area (Figure 8c) shows the isotherm lines at shallower depths to the south. The northern portion of NAS appears to be cooled by the inflow of groundwater from the south dipping basalt aquifer which exists at a depth of between 500 and 1000 feet.

A mercury geochemical study for NAS Fallon, which has been completed, delineates some interesting trends (Figure 8d). Three lineated anomalous highs cross the area of NAS Fallon. The southwest to northeast high parallels a probable lineament which appears to be 1 to 2 miles to the south. A second high trends northward along the east edge of NAS Fallon and intersects the northeast-trending high at the southeast corner of the base. This intersection has a geothermal gradient above regional average, which increases southward along the north-trending high. A third northwest-trending high crosses the northern portion of NAS Fallon and has the highest mercury concentration values of any of the highs, greater than 1300 parts per billion (ppb). This northwest-trending high is currently being monitored, as four new heat flow holes have been drilled in this region. Temperature logs for these holes have not been taken, as the holes have only been recently completed and they have not stabilized thermally.

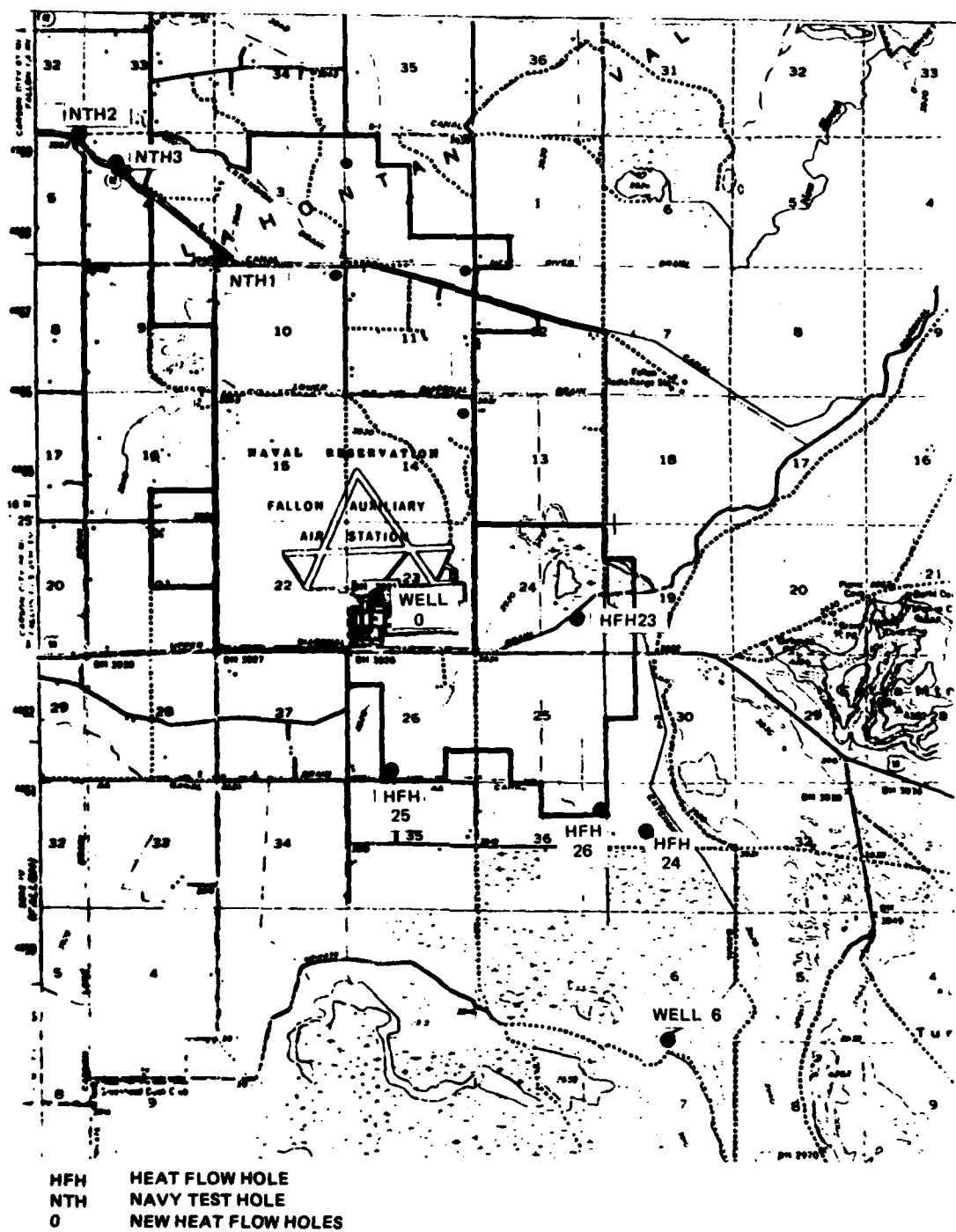


FIGURE 8a. NAS Fallon Wells and Heat Flow Holes--Location Map

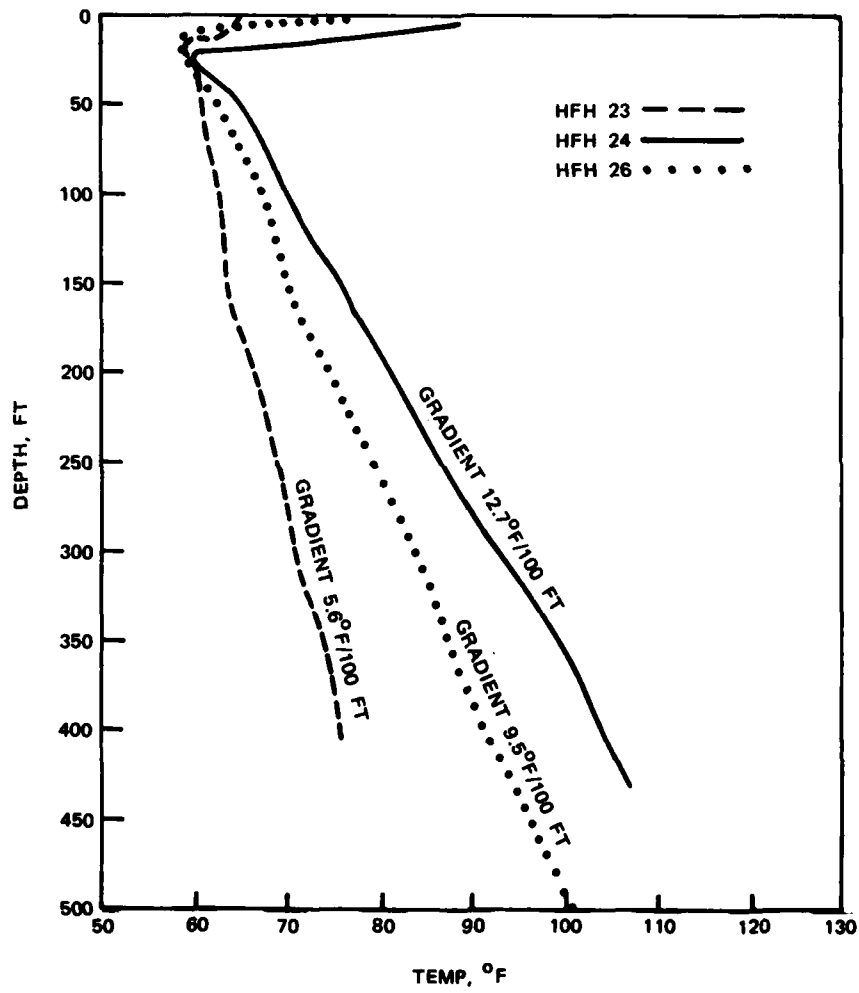


FIGURE 8b. NAS Fallon Heat Flow Holes Geothermal Gradients

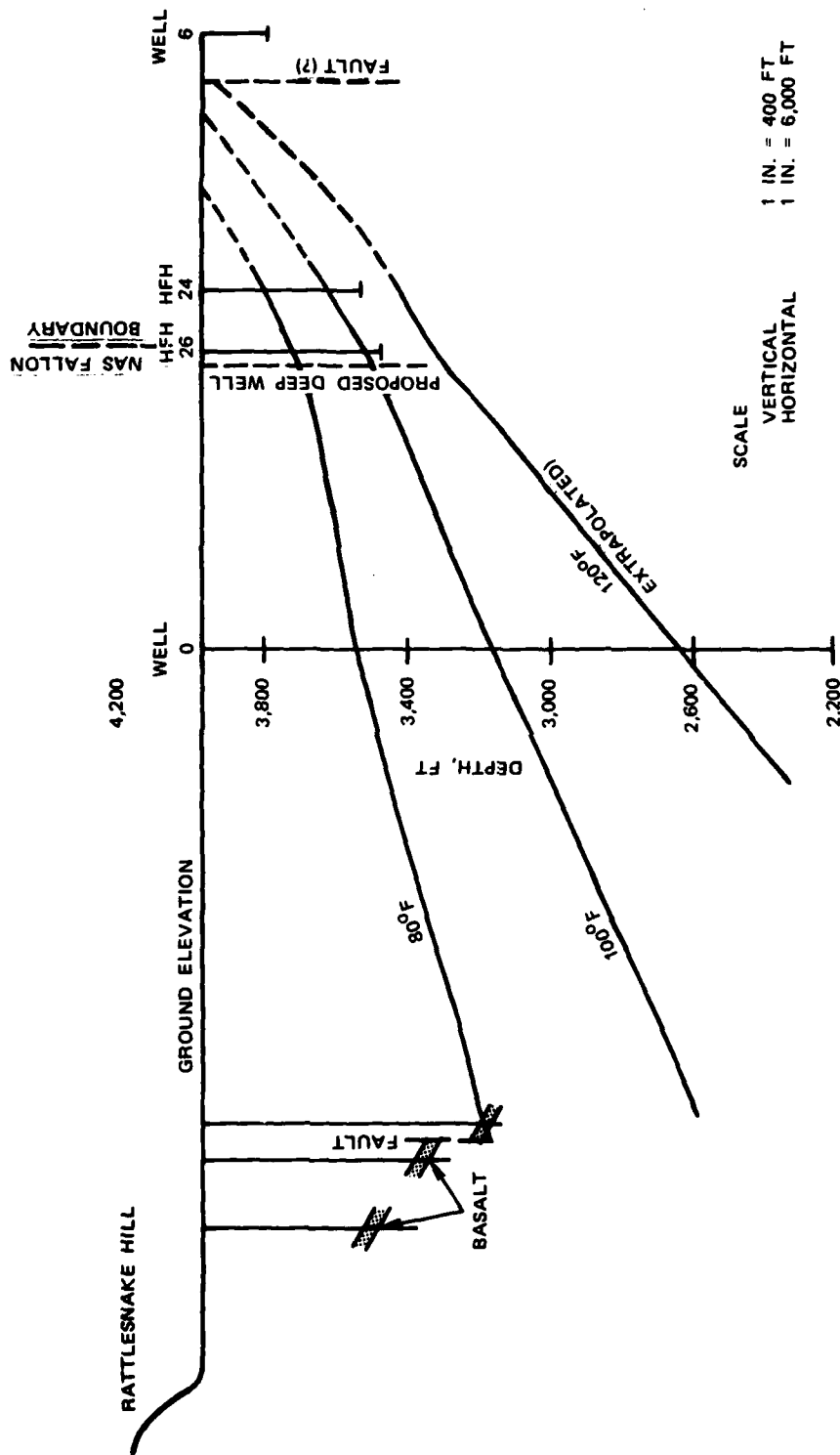


FIGURE 8c. NAS Fallon Isothermal Cross Section (by J. Whelan, 1978)



FIGURE 8d. NAS Fallon Mercury Study

The best potential for a shallow geothermal resource on NAS Fallon still appears to be along the southern edge, unless the four new heat flow holes in the north provide higher gradients than those to the south. Also, the southern region is slightly closer to the majority of the facilities which would benefit from the development of geothermal energy.

RANGE BRAVO 16

Range Bravo 16 is located approximately 12 miles southwest of NAS Fallon and is situated along the southwestern edge of the Carson Sink. The range is used for practice air-to-ground bombing using primarily small practice bombs. The range is monitored during operations by three spotting towers which have been modified for remote video operation.

Geology

Previous Work. Very little earlier work deals with the geology of Range Bravo 16. Axelrod's report (1956) describes the geology of an area around Red Mountain just to the northwest of the Range.¹⁴ A publication by Morrison on Lake Lahontan has described the Quaternary formations exposed at the Range.¹¹ The Nevada Bureau of Mines published a description of the geology of Churchill County in 1974.¹³

Surface Geology. A description of the geology of Range Bravo 16 can be separated into two parts: one on the Dead Camel Mountains, and the other on the valley fill to the east.

DEAD CAMEL MOUNTAINS. An excellent description of the Dead Camel Mountains is found in Wilden and Speed.¹³ The range lies along the southwest border of Churchill County extending south from the Lahontan Reservoir. Local relief amounts to no more than 1300 feet, with most of the range showing even less. Much of the southern part of the range is covered with blow sand.

Stratigraphy: The oldest rocks exposed in the Dead Camel Mountains are the Miocene, Old Gregory Formation. According to Axelrod,¹⁴ this formation consists of rhyolite tuffs, breccias derived from nearby vents, and siliceous shales. Apparently the Old Gregory Formation rests on granitic and metamorphic rocks. Resting conformably on the Old Gregory is the Chloropagus Formation. This unit consists chiefly of biotite-andesite and basalt, with siliceous shales and rhyolite tuffs

¹⁴University of California. "Mio-Pliocene Floras from West-Central Nevada," by D. L. Axelrod. *University of California Publications in the Geological Sciences*, Vol. 33 (1956), pp. 1-322.

subordinate in the section. The lower member of this formation consists primarily of siliceous shales with minor basalt and basalt tuff. The upper member includes thinly bedded siliceous shales, soft lacustrine sediments, basalt tuff, and rhyolite tuff.

Structure: At least in the northern end, the Dead Camel Range has a northeasterly trending structural pattern. The formations strike northeasterly, and the folds and faults generally parallel them. Axelrod¹⁴ considers the structure of the range to be broadly synclinal, with the axis of the fold under Red Mountain. Apparently the whole section was gently folded prior to faulting. The principal faults all appear to be high angle with most dipping nearly vertically. The chief exception is a large fault east of Red Mountain which dips northwest 65 degrees. Although the principal set of faults trends northeasterly, a second less important set trends northwesterly.

EASTERN PART OF RANGE BRAVO 16. The eastern portion of Range Bravo 16 is characterized by unconsolidated Quaternary sediments. Formations present include the Fallon, the Sehoo, the Indian Lakes, the Wyemaha, and the Eetza.

Stratigraphy: All of the formations in the eastern part of Range Bravo 16 are part of the Lahontan Valley group mentioned by Morrison.¹¹ This unit, of late Pleistocene age, consists of lake sediments deposited in Lake Lahontan and interfingering and immediately overlying subaerial sediments. The Eetza in this area is lake gravel, mainly boulder gravel, with some pebble and cobble gravel. The Wyemaha in the area is represented by two members. The first member is aeolian sand with some associated alluvium and colluvium. The other member consists of shallow-lake and subaerial sediments. Most of the material is lake sand with minor silt and clay. Two intertonguing formations are next in the column. The Sehoo Formation is primarily deep-lake sediments. Locally it consists of clay, silt, and some sand. Two other members are primarily sand and gravel. The Indian Lakes Formation consists of subaerial sediments. These consist of alluvial sand, pebbly sand in former channels of the Carson River, and alluvial gravel of highland washes. The youngest formation is the Fallon Formation, which consists of shallow-lake sediments and alluvium.

Structure: The structure of the area is relatively simple. All of the formations are basin fill. Several faults cut these formations. All of the faults seem to be part of the same arcuate trend paralleling the edge of the basin called the Wildcat Fault Zone.

Geothermal Potential

The geothermal potential for Range Bravo 16 has not been fully analyzed to date. One mercury geochemical study, which is currently being completed, can supply only a limited amount of data. No heat flow

holes have been drilled yet; plans for at least four were implemented this year, but drilling was postponed due to funding difficulties.

The mercury geochemical study of Range Bravo 16, which has been completed, gives inconclusive results (Figure 9). No definite linear trends such as those existing around NAS Fallon exist in the area of Range Bravo 16, although the three areas of greatest mercury concentration are aligned in a rough eastwest trend. These three areas are very localized. In addition, the mercury values of these areas are not actually very high, being in the range of 50 to 80 ppb mercury. The highest value is about 78 ppb mercury.

It appears that the mercury concentrations in the soil are related to the soil type or the nearness of outcropping bedrock. Along the north part of the west boundary of the range, mercury concentrations decrease toward the west as bedrock is approached, if it is basaltic or andesitic in composition. Unfortunately, due to the complete lack of data from the southwest corner of the range, it is not apparent whether or not this trend continues. The one rhyolite outcrop in the area is associated with a moderate high. In conclusion, the mercury data for this range indicate a rather low geothermal potential. Also on this range, the finer material contains lesser amounts of mercury, differing from NAS Fallon.

RANGE BRAVO 19

Range Bravo 19 is located approximately 18 miles south of NAS Fallon, south of the White Throne Mountains. The range is located in the Blow Sand Mountains and the northwestern portion of Rawhide Flats. It is a live air-to-ground bombing range and has a large impact region. This range is also monitored by two remote video spotting towers.

Geology

Previous Work. Russell's monograph⁷ on Lake Lahontan appears to be the earliest work to cover the area containing Range Bravo 19. During the 1940s and 1950s, Axelrod studied the Mio-Pliocene floras of west-central Nevada.¹⁴ During the 1960s Morrison studied the Quaternary history of the Carson Sink located just to the north of Range Bravo 19.¹¹ The Nevada Bureau of Mines published a bulletin on the geology of Churchill County in 1974.¹³

Surface Geology. Five rock types were examined in the study area. These include Tertiary rhyolite, younger Tertiary basalt, older Quaternary alluvium, young Quaternary alluvium, and Quaternary sand.

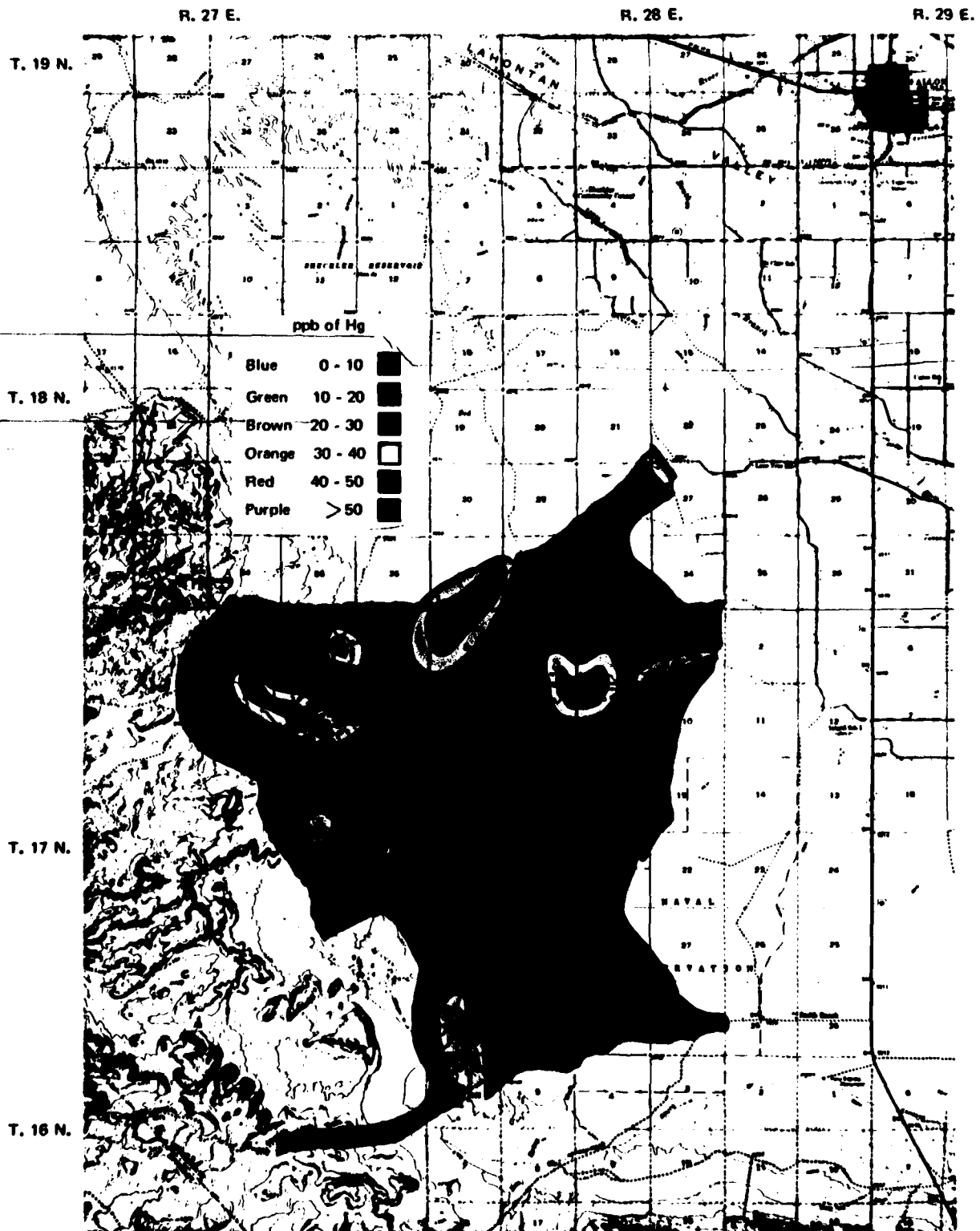


FIGURE 9. Mercury Geochemical Study of Range Bravo 16

A small outcrop of rhyolite was visited during sampling. This type of unit is very widespread in Churchill County. The unit includes flows, welded tuffs, tuff, and some intrusive bodies. Very thin sedimentary beds are interlayered with the rhyolite. This unit is assigned a Miocene age because it is overlain in places by Pliocene rocks and because Miocene plant fossils have been found in sedimentary formations believed to be equivalent. The outcrop is a low ridge which extends north from the main body of the Blow Sand Mountains. At the north end of the ridge is a shallow shaft located on a steeply dipping silicified zone.²

The most abundant bedrock on the range is younger Tertiary basalt. The unit, which is a sequence of basalt and andesite flows with interlayered sediments, includes the Pliocene and Pleistocene Bunejug Formation.¹¹ The unit is several hundred feet thick. Olivine basalt is the most common lithologic type, but andesite is also rather common. The age of the unit is based on two radiometric dates and on the age of interlayered fossiliferous sediments. These give a span of ages from later Miocene to late Pliocene. The basalt underlying Range Bravo 19 is rust red or black with a vesicular structure. At the west end of the mountains thin beds of fossiliferous lake sediments are interlayered with the basalt.

Older Quaternary alluvium occurs in the extreme southwest corner of the range. This outcrop is an alluvial fan, and as such the material is poorly sorted and relatively coarse.

The younger Quaternary alluvium occurs mostly in playa deposits. Most of the younger alluvium is fine sand, silt, or clay. Various evaporite minerals are locally important. Where this is true a white crust of various salts forms on the surface of drying lakes.

Recent dune sand is very common in and around the range. Except for the playas and areas of exposed bedrock, Range Bravo 19 is totally covered with sand. Part of the sand is stabilized by vegetation but much is not. The covering ranges from a few feet on the western side of the range to deep, large dunes over parts of the eastern side of the range. The sand is generally well rounded and composed of quartz and lesser amounts of feldspars, chert or opal, olivine, magnetite, and various other minerals.

Two other lithologic types which were not examined occur in the vicinity of Range Bravo 19. These are a rhyolite intrusion to the east of the Range in the Barnett Hills and a Jurassic diorite intrusion north of Lee Hot Springs.

Very little has been published on the geologic structure of Range Bravo 19. Basalt is unconformable on both dacite and rhyolite. Also the basalt and rhyolite are offset by high angle faults.

Subsurface Geology. As part of an effort to determine the geothermal potential of Range Bravo 19, three heat flow holes were drilled on the western edge of the Range. A lithologic log and a rudimentary gamma ray log were produced for each hole. In addition, each hole was temperature logged at least once. The three holes penetrated a mixture of marl, sand and gravel, and basalt flows. The marl is present only near or at the surface in HFH 20 and 22. Present in HFH 21 and 22 is a series of thick basalt flows. These holes are in marl and have higher thermal gradients than HFH 20. The sand and gravel are composed primarily of basalt and quartz grains to boulders.

Mines and Prospects. Two groups of named prospects occur just east of Range Bravo 19. The Bimetal Group is on quartz veins in granodiorite. The Cinnabar Hill Group is $1\frac{1}{2}$ miles north of the Bimetal Group. These groups of prospects are located on the east side of a hill on the northwest end of the Barnett Hills. Development consists of several shafts and adits on shear zones in altered rhyolite tuffs. The shaft with the largest dump is on a shear zone which trends N85W and dips 75N. The altered rock in the zone is stained with iron and manganese oxides, and a sample contained 140 ppb of mercury. Some mercury was produced at this mine. Several other pits and shallow shafts occur in the area on similar features. Samples from these contain up to 100 ppb of mercury.¹³

Geothermal Potential

The geothermal potential of this region does not appear as promising as that of NAS Fallon, but the northwest corner of the range and the southern front of the Blow Sand Mountains appear to have the best possibilities. The southern front of the Blow Sand Mountains is controlled by a northwest-trending lineament (Figure 4) which intersects with a west-trending lineament in the vicinity of Lee Hot Springs and Allen Springs, north of the northwest corner of the range.

Three heat flow holes exist along the western boundary of Range Bravo 19 in the lowlands, but none of them had a gradient higher than 50°F/100 feet. These holes were not located on any known thermal anomaly or mercury anomaly, but were located to test the gradients in these areas (see Figures 10a and 10b).

Two small springs exist in the central portion of the west boundary. Water samples were geochemically analyzed from Stinking Springs, Coyote Springs, and Lee Hot Springs. The geothermometer values indicate a reasonable geothermal potential (see Appendix A).

Early results from the mercury geochemical study of Range Bravo 19 show some interesting trends. The absolute values of mercury (ppb) on Range Bravo 19 are generally less than those of NAS Fallon by a factor

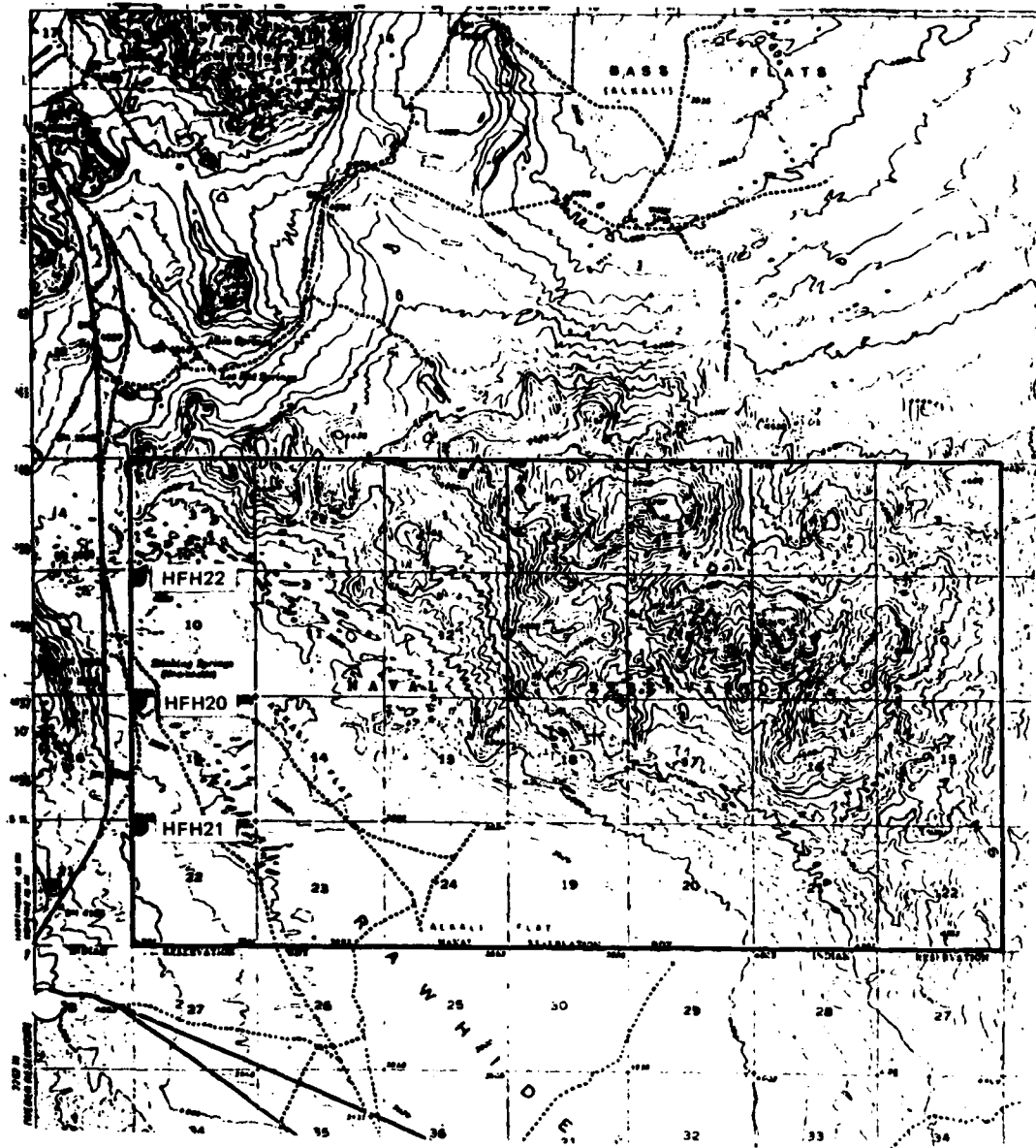


FIGURE 10a. Range Bravo 19 Heat Flow Hole Location Map

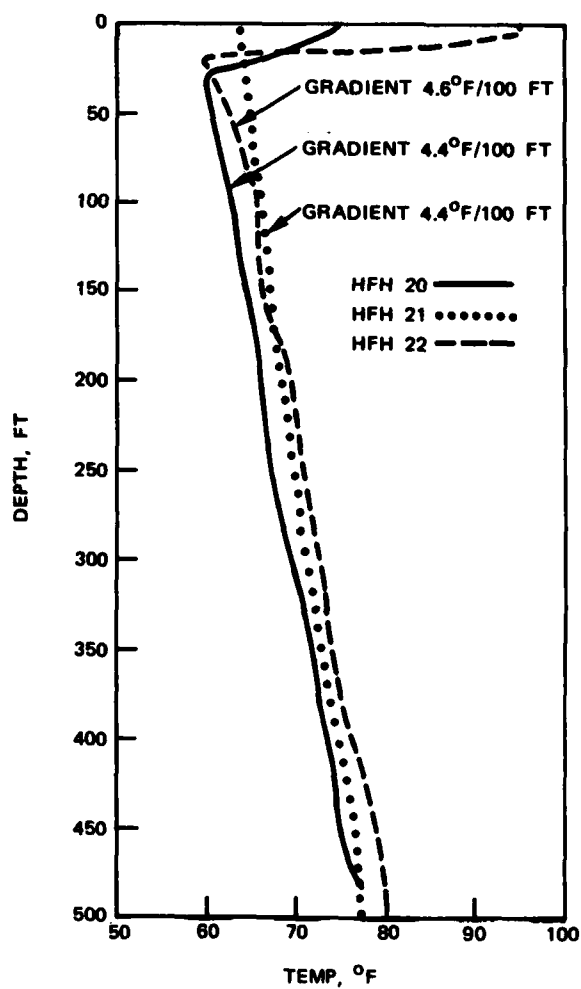


FIGURE 10b. Range Bravo 19 Heat Flow Hole Geothermal Gradients

of 10, but this can be explained by a greater portion of sand grains in the Range Bravo 19 samples. The NAS Fallon samples are more silty and clayey. The two lineaments which intersect at Lee Hot Springs are well defined in the current mercury data, and additional samples are being analyzed from sample lines which cross the lineaments further east (Figure 10c).

The mercury study of Range Bravo 19 has been completed (Figure 11). The additional data tend to support the original conclusions mentioned above, with a few minor exceptions. With the addition of the new data several new highs have been delineated. A linear high which exactly parallels U.S. 95 exists just to the west of the range. To the northeast of Lee Hot Springs an area of very high values is present. Also, to the east of the range there is a high centered around a small cinabar prospect. In fact, a sample taken at the prospect gave a value of about 1000 ppb of mercury. The prospect is not a hot springs deposit. The other highs that were mentioned commonly have values up to 200 ppb of mercury. One troubling fact is the closeness of the western anomaly to U.S. 95. In conclusion, it still appears that the highest geothermal potential in the area is in the northwest corner of the range.

RANGE BRAVO 20

Range Bravo 20 is located approximately 30 miles northeast of NAS Fallon, in the northern Carson Sink. Very little geothermal evaluation has been carried out in this region because of its remote location and distance from NAS Fallon, and because an 11,000-foot oil stratigraphy test well drilled by Standard Oil and Amoco in 1974, near the northeast corner of Range Bravo 20, had a bottom hole temperature below 300°F.

The geology of Range Bravo 20 is primarily basin and playa sediments and Quaternary volcanics (Lone Rock). The possibility of a shallow hot water aquifer, which was not noted in the data from the oil stratigraphy test, has developed with the discovery of the "shallow" hot artesian well in the Fallon National Wildlife Refuge 12 miles southeast of Range Bravo 20.

A limited mercury geochemical study could be carried out to further assess the geothermal potential of Range Bravo 20.

CONCLUSIONS AND RECOMMENDATIONS

The Fallon Exploration Project was initiated to assess the geothermal potential of selected areas at NAS Fallon and to recommend further work to be scheduled for these areas. Although portions of the analysis

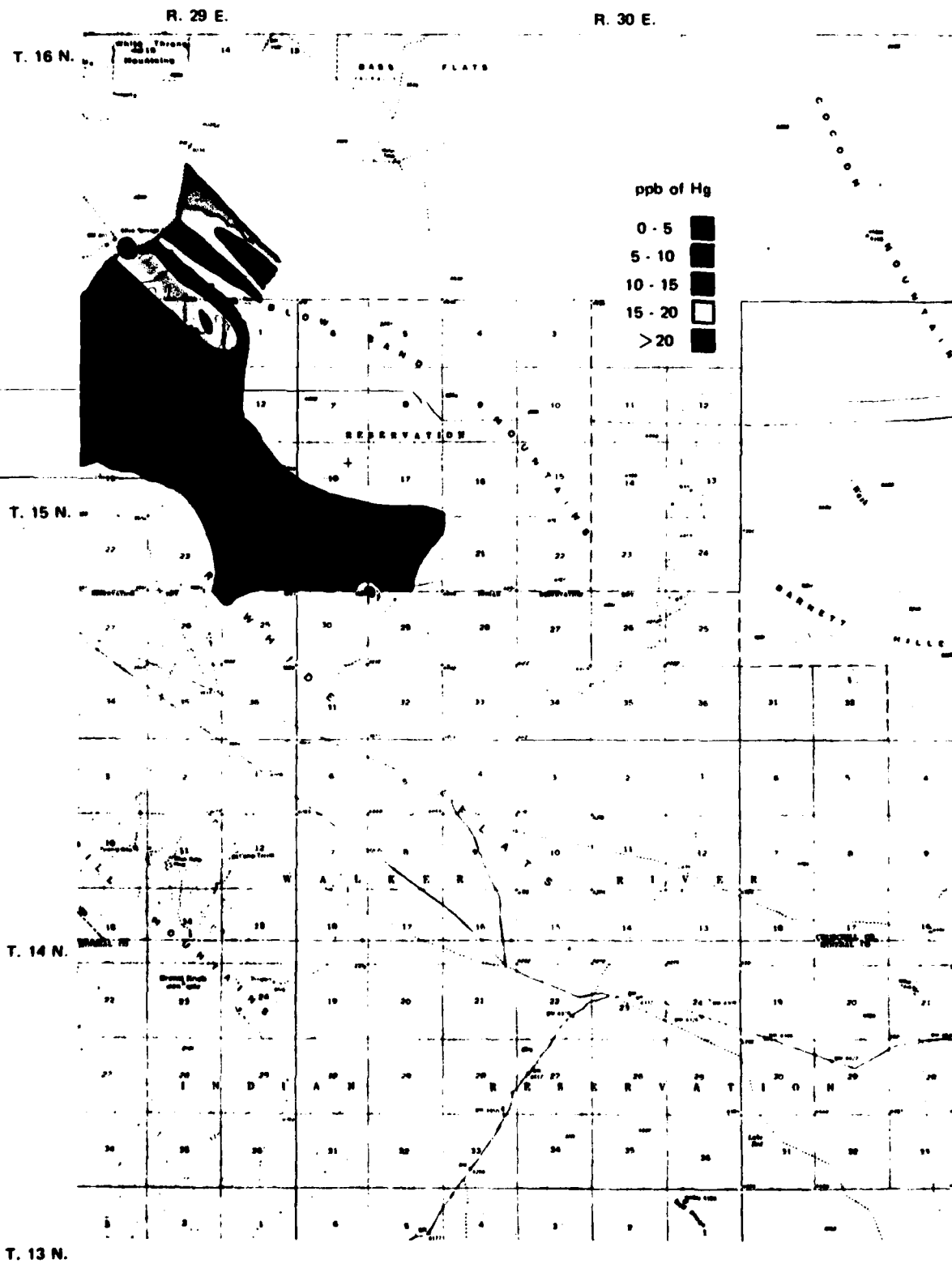


FIGURE 10c. Range Bravo 19 Mercury Study (Partial)

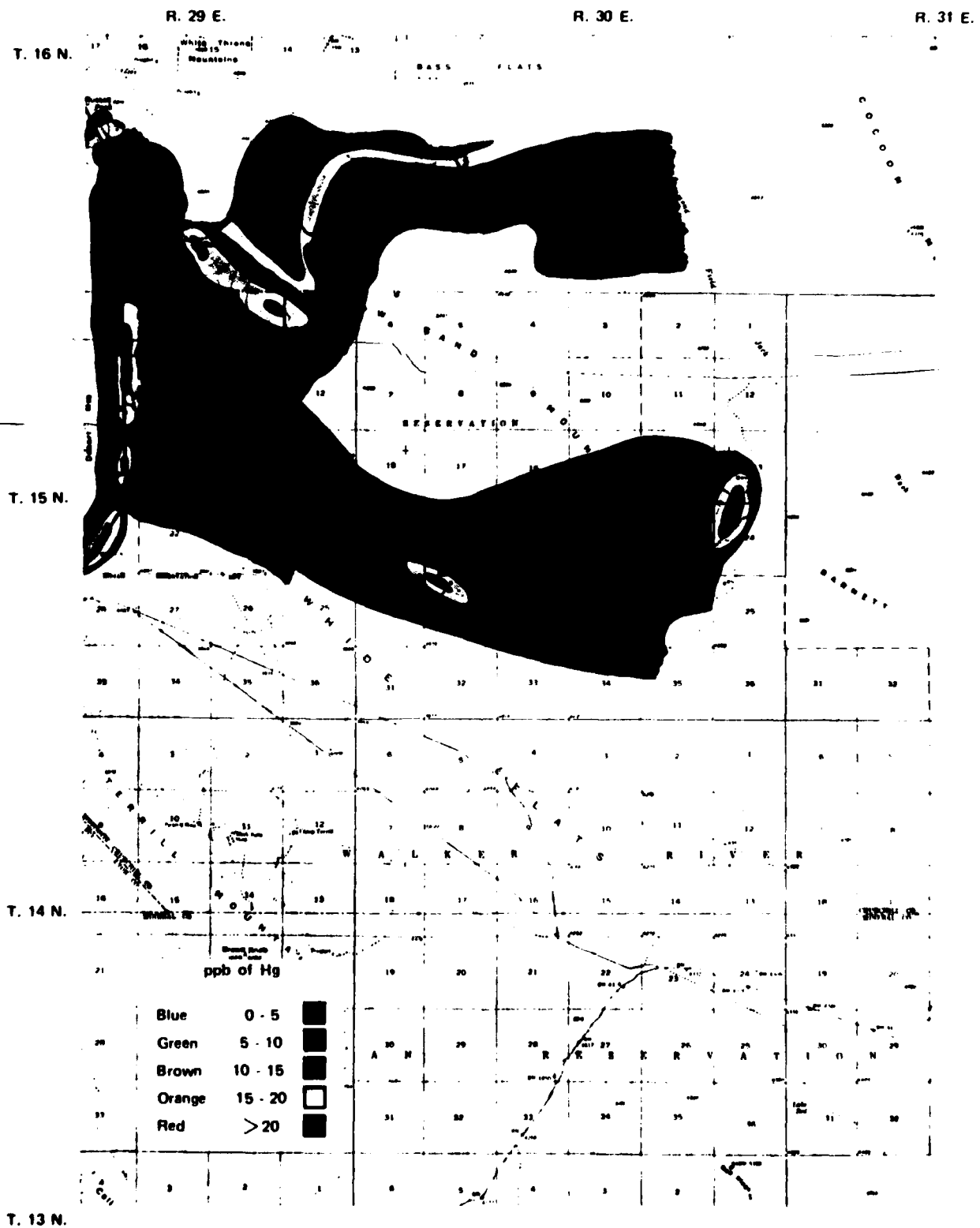


FIGURE 11. Mercury Study of Range Bravo 19

are incomplete at this time, enough data were analyzed to provide additional target areas to be studied.

The area which shows the best potential for geothermal development, based on current data, is the southern portion of NAS Fallon. Here a high mercury anomaly exists, paralleling a probable buried fault (lineament), and the area also has a high geothermal gradient (up to 9.5°F/100 feet). This could indicate a 300°F resource may exist at depths of 2500 to 3000 feet.

Additional work which could provide more data to the complete project would be a regional geophysical study incorporating detailed gravity and aeromagnetic analysis and a dipole-dipole resistivity study. Areas to be covered by this study would be NAS Fallon and Range Bravo 16 and possibly Range Bravo 19. The study would provide needed data on the structure of the basin fill and depth to bedrock. From these data the probable system boundaries and hot water aquifers could be located.

The best geothermal potential of Range Bravo 19 exists along the northern edge, primarily in the northwest corner. Geothermal gradients from the three existing heat flow holes, south of the northwest-trending lineament, are not particularly high. If a thermal anomaly is present it probably exists north of this west-trending lineament, or north of the west-trending lineament which intersects with the northwest-trending lineament at Lee Hot Springs (200 to 212°F surface waters). There appears to be little heat transfer southward to the area of the heat flow holes.

The study of Range Bravo 16 is not yet complete. Additional laboratory analysis on the soil samples is needed before the mercury geochemical study can be completed. Once this study has been completed, the data can be used to site heat flow holes for Range Bravo 16. The heat flow holes will probably have to be sited down on the playa or on the northern half of the mesa area (western portion), because the southern portion of the mesa area and southern edge of Range Bravo 16 are composed of very loose sand and weathered diatomaceous earth. Vehicle travel is thus very difficult.

Range Bravo 20 does not appear to have a good geothermal potential. The deep Standard-Amoco test well had a very low gradient. Also, the remoteness of the area means power generation temperatures would have to be reached in order to make the area economically feasible. An interesting possible shallow, low-temperature resource may exist if the "shallow" resource which supplies the hot artesian well (161°F) in the Fallon National Wildlife Refuge extends that far to the northeast. A reconnaissance mercury anomaly study of the range would provide additional data on the area's potential and probably could be accomplished in 1 or 2 days.

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Appendix A

GEOTHERMOMETER DATA

Area sampled	SiO ₂ , °C	Na-K-Ca, °C
Coyote Springs	111	216
Stinking Springs	24	164
Lee Hot Springs	162	161
HFH 22	111	152
HFH 24	100	158
Well 0	96	178
Well 6	142	204
B16 Well	108	148
Navy Well - Section 7 T18N R29E	155	144
Soda Lakes Region:		
CDDH-31	79	189
CDDH-32A	114	179
BRCDDH-14A	158	141
CODH-30A	143	158
CDAH-37	-	190
CDAH-2A	105	214

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