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ASSESSMENT OF THE GEOTHERMAL RESOURCES OF CARSON-EAGLE VALLEYS AND BIG SMOKY VALLEY, NEVADA

FIRST ANNUAL REPORT
MAY 1, 1979 • MAY 1980

MASTER

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NEVADA BUREAU OF MINES AND GEOLOGY
UNIVERSITY OF NEVADA, RENO
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ABSTRACT

During the period 1 May 1979 through 31 May 1980 members of the Nevada Bureau of Mines and Geology under contract to the U. S. DOE as the state-coupled geothermal resource assessment team completed two geothermal investigations in three Nevada locations. The regions studied were selected from areas outlined as having direct utilization potential (Trexler and others, 1979) and included the Carson-Eagle Valley, Big Smoky Valley and Caliente. The Caliente investigations are discussed in a previously issued report dated March, 1980. Studies were organized around the completion of all or a selected group of tasks in each area. These tasks included:

Geologic Reconnaissance
Gravity Surveys
Aerial Photography
Fluid Sampling and Analysis
Shallow Depth Temperature Probe Surveys
Soil Mercury Surveys
Shallow Electrical Resistivity Measurements
Temperature Gradient Hole Drilling

Goals of the project were to provide regional information about the nature and extent of the resources and to offer a critical evaluation of the techniques employed.

Results from our work in the Carson-Eagle Valley demonstrate that geothermal fluids are meteoric waters heated by relatively deep circulation in the earth's crust. The dominant structural controls are high angle, large displacement, normal faults which provide conduits for fluid migration and dictate resource localization. Identification of these faults was accomplished by examining gravity data and abrupt changes in lithology and topography. The association of faults with thermal waters is substantiated by data obtained from two meter temperature probe studies and water well records which reveal linear isotherm patterns in the vicinity of geothermal manifestations. Distinctions between thermal and non-thermal fluids can be made on the basis of major and minor dissolved constituents while trace

elements are of limited utility. Thermal waters were not encountered in two temperature gradient wells drilled to depths of 240 ft. and 500 ft. in the area.

In the Big Smoky Valley a similar picture of fault-related, deep circulation of meteoric waters emerges. Gravity transects, low sun-angle photography, linear patterns in two meter probe isotherm configurations and soil mercury anomalies all aided in determining the location and orientation of important structural controls. Chemical composition, in terms of major and minor dissolved constituents details the similarities and distinctions between hot and cold waters throughout the study area while isotopic data demonstrate the probable high temperature (>150°C) history of fluids at the Darrough site. Integration of the results obtained from several techniques applied in the Darrough vicinity led to the siting and drilling of a 500 ft. well which encountered thermal fluid and extended the known resource limits.

Techniques used to accomplish the outlined exploration tasks are evaluated on a scale of 1-10. During evaluation consideration was given to parameters such as cost, time and manpower requirements, inter-regional applicability and the quality and quantity of data obtained. Methods receiving generally higher ratings include geologic reconnaissance, gravity, low sun-angle photography, 1-2 m temperature probes, fluid sampling and analysis and temperature gradient drilling. Intermediate rating is assigned to water well data and soil mercury surveys, and low rating is assigned to shallow resistivity.

Analysis of major, minor and trace constituents in fluids from Caliente, Nevada showed the compositions of hot and cold waters to be essentially indistinguishable. However, stable light isotopic data indicate that thermal fluids are derived from a distinct and homogeneous source.

ACKNOWLEDGEMENTS

We wish to express our sincere thanks to the many people whose cooperation and kindness played an important part in helping us complete our studies in the Big Smoky Valley and the Carson-Eagle Valley. In particular, we extend thanks to the Darrough familty - Luther, Lillian and Larry - of the Big Smoky Valley for providing us with useful information we might not have learned otherwise, for their permission to conduct surveys and drill test sites on their property and especially for their warm hospitality.

We also wish to thank another special group of people at the Frontier Tavern Motel near Austin, Nevada who, over several months, consistently provided us with delicious meals and comfortable lodging.

And finally, in the Big Smoky Valley, a special thanks go to Frenchy and Bill who were instrumental in helping us drill a well under trying circumstances, and Carl Haas who supplied us with necessary water for drilling.

In the Carson-Eagle Valley, much of the data were obtained thanks to the cooperation, assistance and encouragement of many more Nevadans including Harold Wilson along with friends at the Dangberg Farms, Mr. Richard Langson and and Mr. Craig Cedar at the Carson Hot Spring, Mr. Mike Filing of Walley's Hot Spring, Mr. Andy Hofer of Saratoga Hot Spring, Mr. John Asquaga and Mr. Noble Murray. Fluid composition data were obtained thanks to Mr. Lewis Nagy, superintendent of the Carson City Wastewater Treatment Plant and Mr. James Hadden of the Carson City Works. Special thanks also go to Mr. Harvey Whitecome of the Nevada Highway Department for providing aerial photographs and Mr. Cameron Covington who produced excellent graphics for this report.

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INTRODUCTION

In 1977 the U.S. Department of Energy Division of Geothermal Energy began to formulate a mission-oriented program for the development of geothermal resources. The program began with the western states which contain most of the geothermal resources in this country. The program consisted of integrating the cooperative efforts of participating "state teams", the U.S. D.O.E. Division of Geothermal Energy (DOE/DGE), the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA) and several other contractors which the DOE/DGE used in an administrative and technical consulting capacity.

The main objectives of the geothermal program were to (1) broaden the field of technical knowledge of geothermal resources by performing preliminary resources assessments, and (2) plan for the commercialization of the resources by creating area development scenarios using the most recent information supplied by the resource assessment teams. In Nevada the Nevada Bureau of Mines and Geology (NBMG) is responsible for resource assessment and the Nevada Department of Energy (NDOE) is responsible for commercialization.

The first objective of the resource assessment team was to define the geothermal resource potential on a regional scale by producing a 1:500,000 scale map of the state that showed the location of thermal springs and wells and ranked areas of highest potential for direct utilization.

In June, 1979, the NBMG completed a one-year regional assessment for the low- to moderate-temperature geothermal resources in Nevada. The 1:500,000 scale map entitled "Geothermal Resources of Nevada and their Potential for Direct Utilization " depicts both technical resource information for more than 300 springs and wells throughout the state and evaluates nearly 40 large areas with potential for geothermal development on the basis of a numerical scheme developed at NBMG.

A second objective of the resource team was to stimulate geothermal development by performing various geological, geophysical and geochemical surveys in favorably-assessed areas. These "Area Specific" studies were designed to:

1. expand the data base of the preliminary assessment
2. remove some of the risk in exploration by examining areas in more detail, and
3. develop and test scientific exploration methods for low- to moderate-temperature geothermal resources.

The area specific studies began in May, 1979, in two study areas: the Big Smoky Valley in central Nevada and the Carson-Eagle Valley in the western part of the state (fig. A1). These two areas were selected on the basis of their high potential for the development of industrial process heat and residential space heating, respectively. In November, 1979, a third study area, Caliente, was added to the program.

Baseline Data

The investigations began with a search and review of all pertinent literature including topographic maps, geologic reports, geologic maps, Bouguer gravity maps, theses, lithologic well logs and water resources reports. The compilation provided both a general understanding of the areas as well as an initial direction for the area specific study.

The following 7.5-minute topographic maps were used in the Carson-Eagle Valley study area: Carson City, New Empire, Genoa, McTarnahan Hill, Minden and Gardnerville. The Reno and Walker Lake 1:250,000 scale topographic sheets were also used.

In the Big Smoky Valley a combination of 7.5-minute series, 15 minute series and 2 degree maps was used. The 15 minute series maps included Austin, Spencer's Hot Springs, Millet Ranch, Wildcat Peak, Pete Summit Road, Hickson Summit and Diana's Punch Bowl. The 7.5-minute series maps consisted of Carvers, Carvers NE,

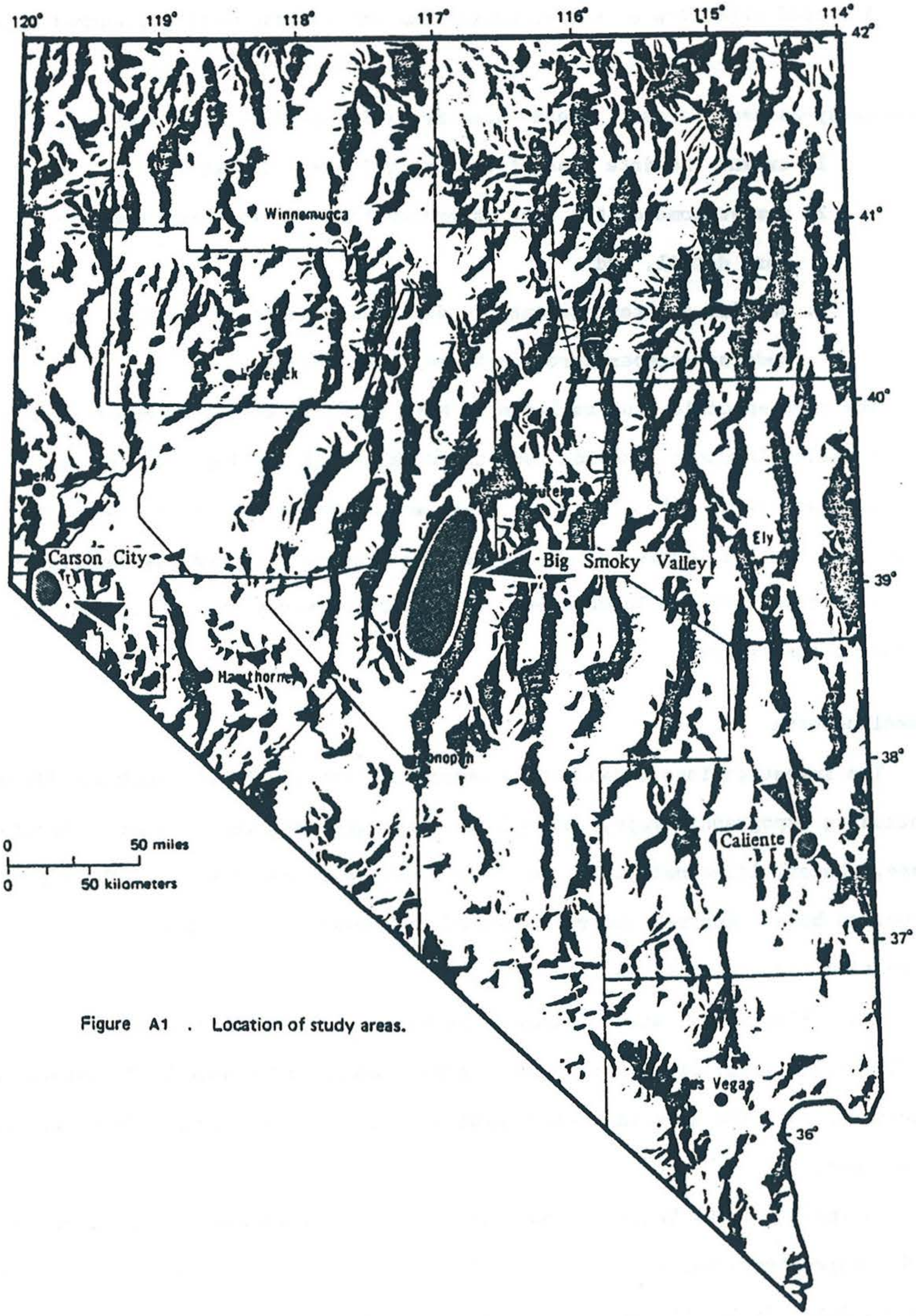

Figure A1 . Location of study areas.

Carvers SE, Carvers SW, Mt. Jefferson and Jet Spring. The Tonopah and Millet 2-degree sheets were also used.

Geologic maps were available in the Carson-Eagle Valley area at two scales. A 1:250,000 scale geologic map (Moore, 1969) provided a regional framework for the study. More detailed stratigraphic and structural information was obtained from the available 7.5-minute series geologic maps including Carson City (Trexler, 1977), New Empire (Bingler, 1977) and Genoa (Pease, 1979).

Most of the major geologic structures in the Big Smoky Valley could be identified on the 1:500,000 scale Geologic Map of Nevada (Stewart and Carlson, 1978). This map, however, was not particularly useful in the vicinity of thermal waters where smaller structures which are not mappable units at such large scales are generally the features of interest. Somewhat more detailed data were obtained from other geologic maps of the area including Kleinhampl and Ziony (1967), Means (1962) and McKee (1968). But an extensive portion of the Big Smoky Valley remains unmapped at a scale suitable for area specific studies.

Regional Bouguer and gravity data from the Reno (Erwin and Berg, 1977) and Walker Lake (Oliver and Robbins, 1973) 2-degree sheets were projected onto the 7.5-minute series base maps for the Carson-Eagle Valley study area. Since the contour interval for these data is 5 milligals, the technique helped to delineate some of the major geologic structures in the subsurface but failed to resolve the minor structural details.

In the Big Smoky Valley Bouguer gravity data were also available but the area included was limited to the region north of latitude 39° (Erwin and Bittleston, 1977). This map also failed to provide the information needed for the area specific study, and a full scale gravity program was planned to gather the necessary information.

Chemical analyses of both thermal and non-thermal waters were collected from several sources from both study areas. Garside and Schilling (1979) provided major and minor element chemical analyses for thermal springs and wells in both study areas. Additional water quality data were collected from the files of the Consumer Health Protection Services, a Division of the Nevada Department of Health, in Carson City. These data pertain mainly to non-thermal waters and included only the major dissolved constituents.

Lithologic logs for residential and agricultural water wells are available for public inspection in the Office of the State Engineer, Carson City. Although the quality of most of the logs is poor, they have been helpful in determining the distribution and depth of warm water aquifers. This is especially true in the Pinyon Hills area in Carson City. Oil and natural gas exploration has been focused on Railroad Valley in southeastern Nevada and data from that area are, unfortunately, of little value in this study. Also, the data from mineral and geothermal exploration holes remain largely proprietary.

Geologic Reconnaissance

The geologic reconnaissance consisted of identification of the important rock stratigraphic units and structures in the field. No large-scale geologic mapping was involved because of the need to complete the other items within the allotted time-frame.

Much of the reconnaissance was incorporated into other phases of the program such as the gravity and low sun-angle photo surveys. In the Big Smoky Valley several previously unmapped faults, which were identified on low sun-angle photographs, were verified during the geologic reconnaissance. Measurements of strike, dip and fracture and fault plane orientations were made in areas where a limited amount of geologic data were available. In addition, hydrothermally altered areas were examined for evidence of recent thermal spring deposits and cemented sediments.

Several representative samples of the major rock units were collected for petrographic examination, and the mineral assemblages were compared to thin sections of chips from the geothermal test holes. X-ray diffraction techniques were also used to identify several microcrystalline and water-soluble mineral phases.

Gravity

Gravity measurements were selected as a means of obtaining useful subsurface structural information. This choice was based in part on the results obtained by other investigators working the Basin and Range region.

One of the earliest studies was carried out in the Virginia City and Mt. Rose quadrangle areas, Nevada, by Thompson and Sandberg (1958). Their study combined gravity data with density measurements of the surrounding sedimentary, volcanic and metamorphic rocks. From their data the authors were able to calculate the thickness of the sedimentary rocks in several of the basins. A more regional survey was completed by Thompson (1959) in the area between Hazen and Austin, Nevada. These measurements depicted a series of north-south trending horsts and grabens bordered by normal faults along which several thousand feet of vertical displacement had occurred. Stewart (1971) also used regional gravity data to characterize the Basin and Range,horst and graben structures for several areas in north-central Nevada. He interpreted the steep gravity gradients which occur near the basin-range interface as an indication of normal faulting. Goldstein and Paulsson (1979) integrated gravity data with seismic and deep electrical resistivity survey data in Grass Valley and Buena Vista Valley, Nevada. They were also able to estimate a basement configuration, fault patterns and depth to the Paleozoic basement.

Additional reasons for using gravity measurements were the ready availability of the necessary equipment and the relatively high rating assigned to the technique by Goldstein (1977) for area-specific studies.

Approximately 400 stations were occupied in the two areas examined during our study. Readings were taken using a Worden gravimeter having a scale constant of 0.4656 milligals per division and a working range of 80 milligals. The instrument was allowed to thermally equilibrate (as judged by an unchanging reading over a five minute interval) for 15-20 minutes before making an initial measurement at the first station of a loop. A second reading was taken at the initial station as the termination measurement of the loop to establish instrument drift. Loop duration ranged from two to six hours with the smaller interval being used as frequently as conditions permitted.

Required elevation data were collected using a digital readout 30-power theodolite capable of measuring angles to the nearest three seconds of arc, combined with a 12-foot stadia rod. Control was established by tying in all measurements to U.S. Coast and Geodetic Survey and U.S. Geological Survey benchmarks. In general, the use of this equipment resulted in elevation measurement accuracy of approximately one foot over the horizontal distance covered.

Appropriate latitude and longitude data were computed for each station and combined with elevation data, raw measurements and instrument drift figures entered into a computer program for reduction to a simple Bouguer anomaly according to the formula adopted by the International Geodetic Commission in 1930. Reduction density was 2.67 grams per cubic centimeter. Terrain corrections were computed manually using the method of Hammer (1939) and applied to the "simple" data to obtain a "complete" Bouguer value.

The gravity data for all traverses conducted during this study are presented in Appendix II.

Aerial Photography

Three approaches were employed in the application of aerial photographic techniques to our study areas: a) examination of moderate to high altitude imagery, b) low altitude photography along selected flight lines and c) low sun-angle photography. Efforts under the first category were limited to scrutiny of LANDSAT RBV imagery at 1:250,000 scale and 1:78,000 scale black and white

U.S.G.S. aerial mapping photography. This imagery was used to check for the presence of regional trends which might be related to the location of geothermal occurrences within the area. Work within the second category involved the examination of black and white photographs flown at a scale of 1:12,000 along the same lines that were used in the gravity traverses. This was done to provide a means of searching for possible surface features related to subsurface changes as indicated by the gravity data. Low sun-angle photography was available at a scale of 1:12,000 for one of the study areas and was flown at a scale of 1:24,000 in the second area. An appropriate time of year was chosen to maximize sun-angle illumination and the photos were taken with 60% forelap and 20% sidelap to allow for stereoscope examination. Trexler and others (1978) demonstrated the usefulness of the low sun-angle photographic technique in studying geothermal occurrences in Nevada. The major use of the technique during our study was in delineating near-surface structural features associated with known geothermal manifestations.

Fluid Sampling

Thermal and non-thermal fluids were collected in each study area for analysis of major dissolved constituents, minor and trace dissolved species and oxygen and hydrogen stable light isotopic composition. The major goal of this segment of the study was to gather information on the nature and possible flow paths of fluids recharging the geothermal systems. This approach has been used with good results by several previous investigators as documented by White (1968), Ellis and Mahon (1977) and Cusicanqui and others (1975). Additional goals included providing a chemical data base compiled with uniform sampling and analysis procedures, and establishing a means of comparing the merits and drawbacks of each type of analysis on an area to area basis.

Sampling consisted of collection of a 250 ml raw unfiltered aliquot in screw-capped polyethylene containers for bulk and trace element analysis and 125 ml in a glass bottle for isotopic studies. In each case an attempt was made to "top off" the container with liquid to reduce interaction with trapped air. Additionally, isotopic sample caps were dipped in hot paraffin prior to application and the top portion of the vessel was immersed in the wax to form an airtight seal. Samples of selected thermal fluids were also taken for sulfide analysis. Preservation of the sulfide was accomplished by the addition of 2N zinc acetate to the fluid at the time of collection.

Subsequent to collection, the raw and isotopic samples were promptly shipped to outside laboratories for analysis. The results of these analyses are listed in tabular form in Appendix B. Values for SiO_2 are derived from an undiluted sample using an atomic absorption analysis technique. Reported sulfide figures represent total recoverable sulfide, i.e., all sulfur species capable of reacting with zinc acetate.

Temperature Probe Surveys

Temperature anomalies located near the surface of the ground can be mapped by using thermistor probes buried to a depth of 1 to 2 meters. These surveys have been most effective when probes are buried to depths at which diurnal effects are insignificant, approximately 1.5 m (Birman, 1969). However, temperature probes to a depth of 1 m have effectively delineated high temperature gradients in areas of known geothermal activity (Kintzinger, 1956; Olmsted, 1977). Seasonal temperature variations have been shown to be insignificant below a depth of approximately 6 m, but some temperature variations can still be measured at a depth of nearly 25 m.

Subsurface temperature surveys have been used to locate groundwater (Birman, 1969; Cartwright, 1966) to estimate thermal stresses on the walls of underground buildings (Singer and Brown, 1956) and to locate subsurface leaks in barge canals (Kappelmeyer, 1957).

In this study, temperature probes buried to depths of 1, 1.5 and 2 m were used to delineate areas of anomalous heat flow. Temperature measurements were made with a DIGITEC model 5800 series portable thermometer. General purpose, vinyl-tipped thermistor probes were used in conjunction with the thermometer. The probes are 3 m in length and are equipped with a standard phone-jack. The thermometer is battery operated with rechargeable batteries, and the entire unit can be operated in the field for up to 16 hours without the use of an external power source.

Small diameter holes (8 to 9 cm) were drilled to the various depths with a gasoline-engine powered auger and a thermistor probe encased in a 2 m section of pvc pipe was emplanted. The holes were then backfilled and the entire unit including the phone-jack was covered with soil. The phone-jack was wrapped in a small plastic bag prior to burial to protect it from moisture condensation. Spacing between probes varied from 100 to 400 m depending on the size of the area under investigation.

Field tests indicate that reliable temperature measurements may be taken within 24 hours of the installation. This short reading interval is applicable only to those areas where relatively unconsolidated materials permit drilling times of ten to fifteen minutes per hole or less. In general, the holes were allowed 2 to 4 days to equilibrate. After reading the temperatures the probes were removed for further use in other areas.

For large areas, and working with a limited number of probes, the survey consisted of a series of sub-surveys. The area of interest was subdivided into smaller areas which could then be probed as a single unit. Probes were emplanted into one subdivision, allowed to equilibrate, measured and removed for use in the adjoining subdivision. For internal consistency one probe from the initial survey was left in the ground as a standard for the duration of the survey. The new temperature measurements could then be related directly to the previous measurements.

The 2 m temperature probe survey was employed in the Carson-Eagle Valley study area at Saratoga Hot Springs in the Big Smoky Valley at Spencers's

McLeod Ranch and Darrough's Hot Springs and in the Caliente Study area. A 1 m temperature probe survey was employed in the Carson-Eagle Valley at the site of the geothermal test hole number one.

Soil Mercury Geochemistry Surveys

Soil mercury geochemistry is one of many types of soil surveys used in general geologic exploration. Soil mercury geochemistry has proved relatively reliable in geothermal energy exploration (Matlick and Buseck, 1975) and is a relatively simple exploration tool to use. The basic principle behind the method is that mercury is generally volatile above 80°C and since many geothermal systems are higher than 80°C at depth,mercury is released from the rock. The vaporized mercury then migrates upward until encountering absorbent clays, which capture the mercury. Many of these absorbent clays are found in the "B" or clayey horizon of soils.

Sampling this clayey soil layer provides the sample base for the analysis. After collection the samples are oven-dried at about 40-60°C to remove excess moisture. Then the samples are sieved to a minus 80 mesh (180 micron) fraction. These samples are then geochemically analyzed usually by an atomic absorption method or a Jerome gold film mercury detection machine (McNerney and others, 1972).

This data base is then analyzed and background values are determined. Anomalous regions are then studied to determine what relationship the soil mercury values have to the proposed geothermal system (i.e., structure controls, areal extent, etc.).

Resistivity Surveys

Electrical resistivity drilling surveys were carried out in several areas using a Geo-Western X-1 type prospecting instrument. This unit is designed primarily for traversing,and the self-contained 200-Watt converter supplies sufficient current output to achieve a 500-foot depth penetration under nominal conditions.

The transmitter and receiver are housed in a single unit with a 12-Volt D.C. external, sealed, rechargeable power supply. The instrument is used in conjunction with solid transmitter electrodes and porous plastic potential electrodes which are designed for use with a saturated copper sulfate solution.

A Werner array was employed in both study areas and the electrode spacings used were 10, 25, 50, 100 and 200 feet. An attempt was made to use a constant electrode spacing of 25 feet for an electrical mapping survey near the McLeod Ranch Hot Springs.

The apparent resistivity (ρ_a) was calculated using the formula:

$$\rho_a = \frac{2\pi \text{ "A" Delta V}}{I}$$

where,

"A" is the electrode spacing in feet

Delta V is the Impressed Potential in millivolts

I is the current in milliamperes

π is 3.14

The data were reduced by comparing the curves of electrode spacing vs. apparent resistivity plotted on 2 X 1 cycle logarithmic paper with two-layer model curves. The reduced data yielded a horizontal boundary layer between the surface and a second conducting layer located some distance below the surface.

Drill Site Selection Criteria

Locations for the slim temperature gradient holes were selected on the basis of numerous parameters. The sites were generally located within an area which showed anomalous values based on one or more of the field exploration techniques.

The primary parameters used in siting the holes were structural, proximity to known thermal anomalies, soil mercury anomalies, shallow temperature probe surveys and land availability. Land availability was a key factor in the Carson-Eagle Valley area because much of that area is fee simple land. Thus, drilling was conducted on fee land which would have the greatest benefit to the maximum number of people. The sites were located on Carson City School District property, hole CC-1, and the University of Nevada property, CC-2. It was felt that if a resource had been found at either location it would have benefited more people than if the holes had been drilled on land owned by an individual or group of individuals.

Temperature Gradient Drilling

Gradient drilling was implemented during the final quarter of the project as a technique to analyze selected areas for low- to moderate-temperature resources. The drill sites were selected from the data base which was developed from the field and analytical techniques described above, and on the availability of land and its potential use.

Five holes ranging in depth from 90 to 500 ft. were drilled. Cumulative footage was 1520 ft. which was 170 ft. more than originally planned. This additional footage was required because one of the original four holes, BSD-1, had to be abandoned due to drilling problems resulting from restrictions imposed on the drilling program by the BLM. All five holes were drilled according to the guidelines and regulations of the Geothermal Resource Operational Orders (GROO's) of the USGS.

General specifications for the holes were 6 1/2" surface casing to about 20 ft. with a 3" production casing string installed to total depth. Only three of the holes were completed to meet the general specifications due to problems or logistics which prevented the completion of the other two holes.

All five holes were drilled by the Rotary Division of Longyear, Inc. of Sedalia, Colorado. The drill rig was a Schramm Rotadrill Model CF 15 (fig. A2) with a 2565 Gardner Denver compressor and a 5"x6" two stage Gardner Denver mud pump. The bits used were a 7 1/2" tricone bit for the 6 1/2" surface casing and a 6" Ingersoll Rand downhole hammer or a 6" or 5 7/8" tricone bit for the remainder of the hole.

Of the five holes, four were drilled with air or partially with air and mud, and one hole was drilled with only mud. Drilling muds were primarily bentonite materials. Air drilling was augmented by the use of foam.

Generally, the data collected from the drilling and gradient tests made after the hole was completed were not encouraging. Only one significant temperature gradient was measured. This gradient was found in BSD-2 which was the third hole drilled in the Big Smoky Valley. Its gradient was 16.6° C per 100 meters. One of the holes in Eagle Valley was vandalized before gradient tests could be made. Thus, the end results of five holes were that only four could be tested and of these four only one provided enough positive data to predict the existence of a thermal anomaly.

The daily on-site drilling logs for each gradient hole are presented in Appendix III and completion diagrams are presented in Appendix IV.

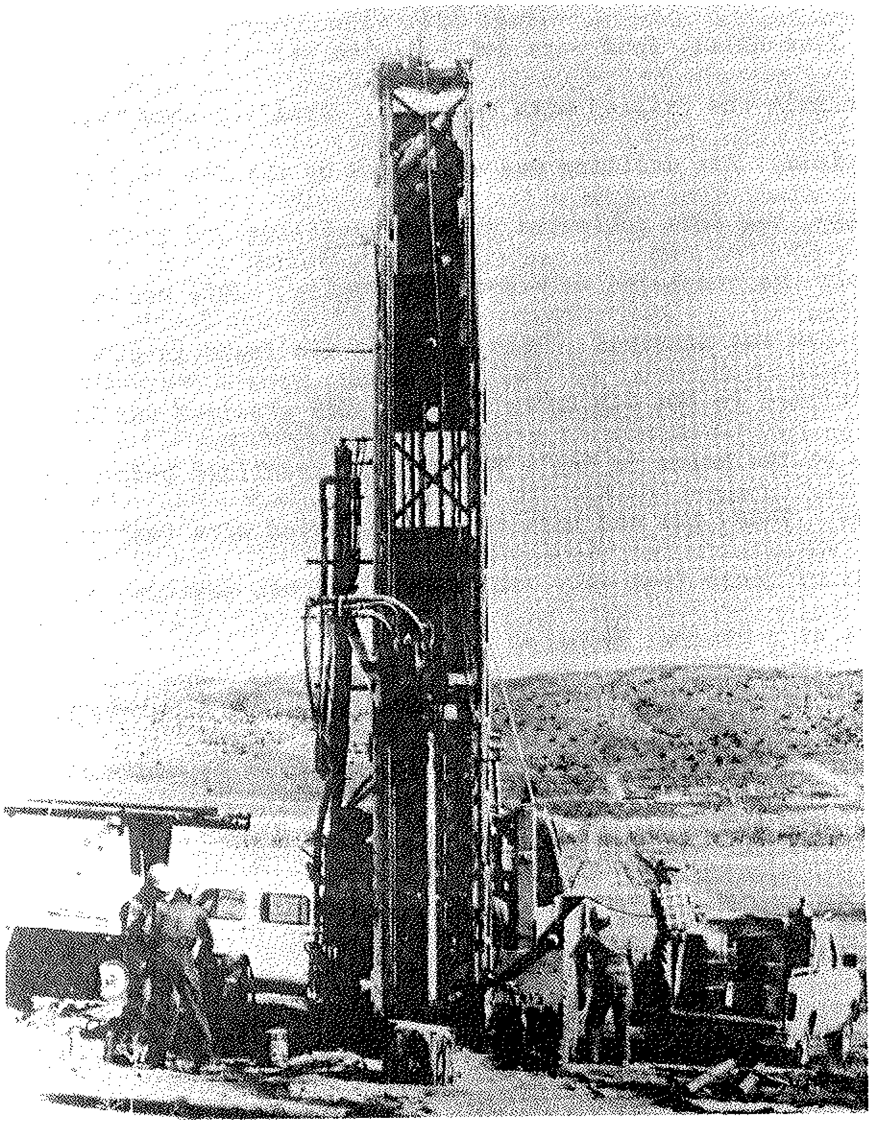

Figure A 2 . Photograph of Schramm Rotadrill CF 15 drill rig.

CARSON-EAGLE VALLEYS

Geographic Setting

The study area is located in west-central Nevada and occupies portions of Carson City and Douglas Counties (fig. A1). The 650-square-kilometer area is contained within two distinct valleys, Carson Valley and Eagle Valley.

Carson Valley, the larger of the two, trends north-south. It is approximately 32 km long and as much as 32 km wide. The elevation of the valley floor varies from 4600 to 5000 feet above sea level. Topographically it is bounded on the south by portions of the Sierra Nevada and the Pine Nut Range, on the west by the Carson Range, on the east by the Pine Nut Range and on the north by a low alluvial divide that separates it from Eagle Valley (fig. B1).

Eagle Valley is much smaller. It attains a maximum north-south dimension of 13 km and a maximum east-west dimension of only 10 km. The elevation of the valley floor varies from 4600 to 4800 feet. Eagle Valley is bounded by the Carson Range (Sierra Nevada) on the west, the Virginia Range to the north and by the northern extension of the Pine Nut Range to the east (fig. B1).

The north-flowing Carson River is the principal drainage for both valleys entering the southeast end of Carson Valley and exiting at the east end of Eagle Valley.

The major population centers in this area are Carson City, the state capital (pop. 36,712) located in Eagle Valley and Gardnerville-Minden (pop. 3045) located at the southern end of Carson Valley.

Geology

Historically the area has been indirectly involved in many geologic studies because of its proximity to the famous Comstock Mining District at Virginia City, Nevada. More recently, however, it has become the focus of attention for environmental geology and earthquake hazard studies. The principal cause of

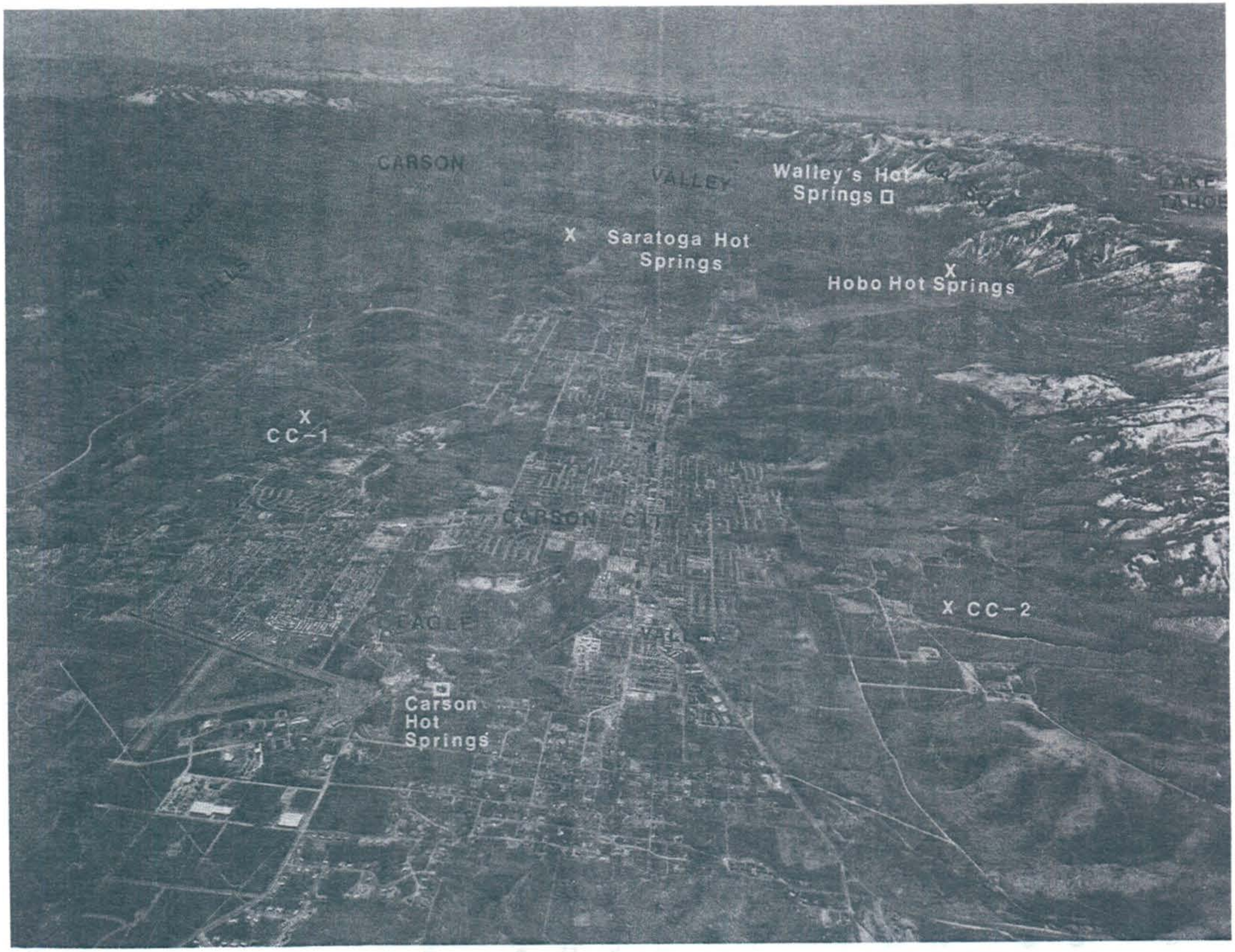

Figure B1 . Oblique aerial photograph of Carson–Eagle Valley study area showing principal physiographic features (photo courtesy of Har Whitcome, Nevada Highway Department).

this is the large-scale urban development which is currently underway in Eagle Valley. The result is a rather substantial data base for this study.

The entire area is underlain by rocks associated with the Mesozoic granodiorite batholith. There are no Precambrian or Paleozoic rocks exposed. The oldest exposures are Jurassic-Triassic metamorphic rocks, which appear as roof pendants in the granodiorite. Post Mesozoic deposits include a series of Tertiary volcanics that range in composition from andesite to rhyolite. Most of the Quaternary formations consist of fluvial and alluvial deposits but a very recent basaltic-andesite volcanic vent and its associated flows is exposed in the Virginia Range just north of Carson City.

Moore (1969) has compiled the most comprehensive report on the area. The report contains a 1:250,000 scale geologic map which was completed on the basis of reconnaissance geologic field work in the mountain ranges where the rocks are best exposed as well as some more detailed work in and near important mining districts. A structural interpretation based partly on aerial photograph interpretation is also included.

In addition to the 1:250,000 scale map, geologic maps at a scale of 1:24,000 have been completed for the New Empire (Bingler, 1977), Carson City (Trexler, 1977), and Genoa (Pease, 1979) 7.5-minute quadrangles.

The geology of the area can be roughly divided into 3 sections (fig. B2). The western section is the north-trending Carson Range, the central section is the alluviated Carson-Eagle Valley and the eastern section consists of the Pine Nut Range and the southern portion of the Virginia Range. Although the rock units in each of these sections are distinct the areas are also separated from one another by north-trending range-bounding faults.

The Carson Range consists of a relatively homogeneous mass of granodiorite although extensive exposures of early Mesozoic volcanic rocks do appear as roof pendants in the batholith. The granitic rocks in this area are mapped as

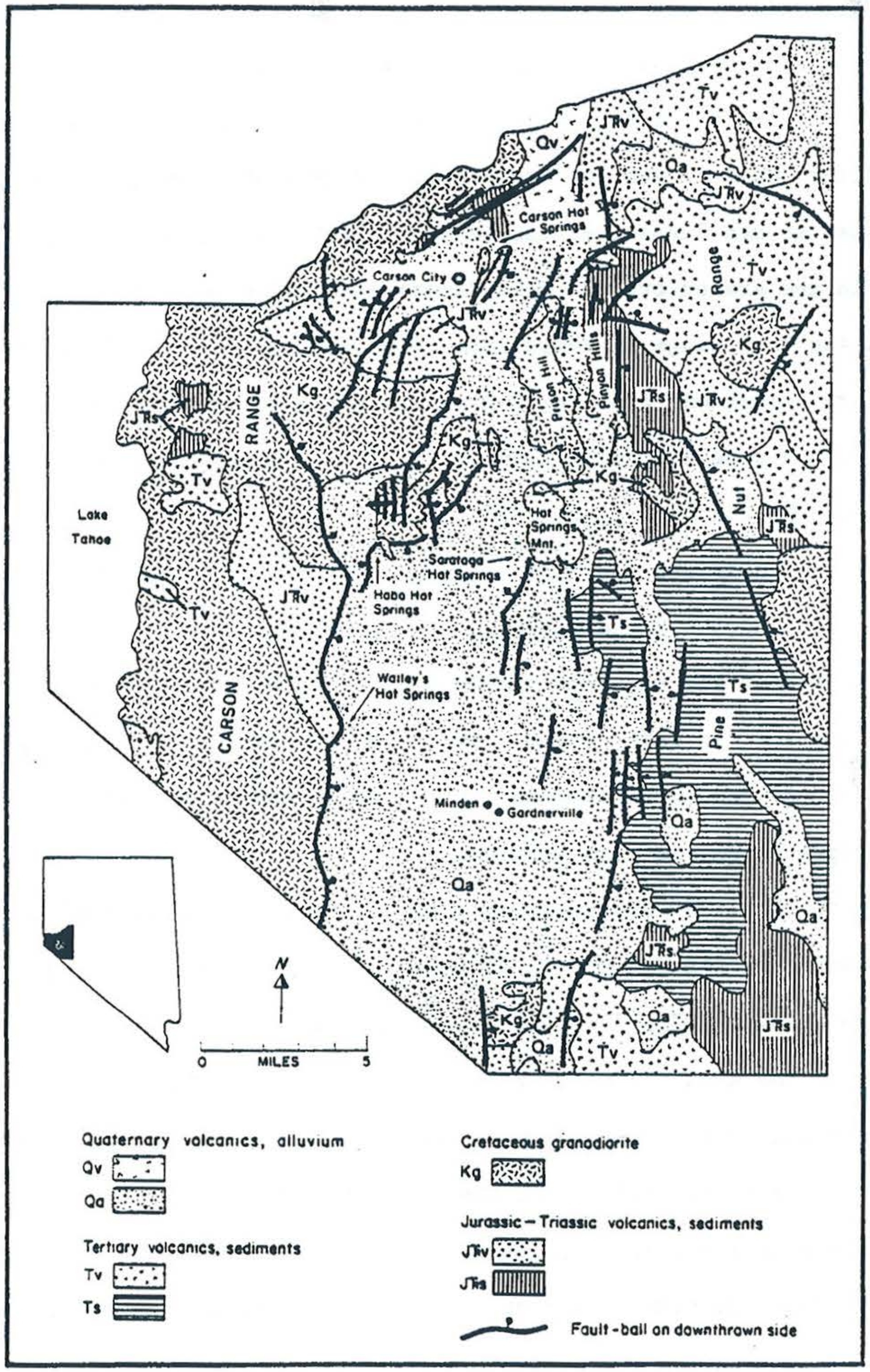

Figure B2. Generalized Geologic Map of Carson—Eagle Valley Study Area. (modified after Moore, 1969) undivided, non-porphyritic quartz monzonite and granodiorite (Moore, 1969). Similar rocks are exposed in the Pine Nut Range. The Carson Range is a horst-like structure and is bounded on the east by the Genoa fault. The displacement on this normal fault is greater than 1200 meters and a recent scarp is visible along the base of the range. This scarp is known to have existed since 1854 when the town of Genoa was first settled.

The Genoa fault extends from Walley's Hot Springs north and south along the range. To the north near Hobo Hot Springs the fault changes from a simple normal fault to a complex pattern of distributive faulting (fig. B3) (Moore, 1969). This pattern of distributive faulting may be the result of regional deformation that occurred during the Quaternary at the intersection of the northeast-trending Carson lineament (Shawe, 1965) and the north-trending Genoa fault. This abrupt change from north-trending to northeast-trending structures has been described as a "knee"-bend structure (Gilbert and others, 1968). In the area of the knee-bend the dominant style of deformation is block faulting although warping is also common.

The Pine Nut Range is a broad mountain block which is sharply upfaulted on the east and tilted westward (Moore, 1969). Metamorphic rocks of Triassic and Jurassic age and granodioritic rocks related to the Sierran Batholith are widespread in the eastern portion of the range. On the western side of the range extensive sections of Tertiary sedimentary and volcanic rocks as well as some Quaternary sediments overlie pre-Tertiary rocks.

The Pine Nut Range is separated from the Virginia Range directly to the north by a structural and topographic low (Moore, 1969). A complex sequence of interbedded Triassic and Jurassic sedimentary rocks including shale, limestone and gypsum crops out near the southern end of the Virginia Range. These rocks are also exposed in portions of the Pine Nut Range, and the limestones are the host rock for the skarn-type mineral deposits. Gypsum is presently being mined at a quarry near Mound House, 12 km east of Carson City.

Unlike the Carson Range the interface between the Pine Nut Range and the valley consists of an intricate series of north-trending horsts and grabens which are also tilted to the west. The Carson Valley itself has been interpreted as the alluviated backslope of the Pine Nut Range (Moore, 1969). The sediments consist of unconsolidated to slightly consolidated Quaternary deposits and include gravels, sands, silts and clays. The maximum thickness of these sediments has been estimated to be at least 1200 meters. Further north in Eagle Valley basement rocks are within 200 to 400 m of where the surface Quaternary deposits are considerably thinner.

In the Carson-Eagle Valley area thermal springs are located near or at the periphery of the alluviated basin, and surficial evidence of faulting can be recognized at most of the sites. In addition to thermal springs, faults are recognized by scarps, abrupt changes in lithology and topography, the occurrence of sag ponds and the alignment of cold springs.

Walley's Hot Springs occur over an area of several acres with an estimated discharge of 600 gpm and a temperature range of 60° to 70°C (Garside and Schilling, 1979). The springs are located at a salient in the Carson Range (fig. B2) and discharge from portions of the Genoa fault. In 1962 and 1963, 26 shallow holes were drilled to determine the area of maximum water temperature (Garside and Schilling, 1979). Temperature profiles obtained for several holes indicate that the hot water is confined to a narrow fault zone. The fault zone was penetrated several times. In each case, the water temperature increased in the vicinity of the fault and then rapidly decreased away from the fault. The highest temperature recorded in a drill hole was 83°C at 20 m.

Hobo Hot Springs consists of 6 to 8 small springs with a combined flow rate of 10 to 20 gpm that range in temperature from 30° to 50°C. They also occur over an area of several acres and their discharge appears to be directly related to several small faults (fig. B4) which have been mapped in that area (Moore, 1969; Pease, 1979).

At the Saratoga site a single spring issues from the base of Hot Springs Mountain (fig. B2) and flows at a rate of 100 to 200 gpm. The temperature of this spring is 50°C and several warm and hot wells have been reported to the south and east of the spring. The surrounding area is covered by a thick layer of eolian sand of Quaternary age, and many of the surface manifestations of faults have been obscured. Several faults terminate near the southern end of Hot Springs Mountain and have been mapped by Moore (1969).

There is no surface discharge of geothermal fluids in the Pinyon Hills area located 8 km southeast of Carson City (fig. B2). Nearly 50 shallow residential wells in this area have measured water temperatures that range from 25° to 40°C. The wells in this area which range in depth from 60 to 150 m were not drilled for their geothermal benefit. The water was intended to be used for drinking and bathing but its temperature and hardness all but precluded that possibility. Some residents are now considering using the geothermal fluids for space heating. Approximately 1 km north of the thermal area, Bingler (1977) has mapped a normal fault in the Mesozoic sedimentary rocks. If extended southward the fault trend would pass through the center of the thermal area.

Carson Hot Spring located north of Carson City (fig. B2) flows from the contact between an outcrop of Jurassic metavolcanic rocks and the Quaternary alluvium. Rogers (1975) has mapped several small faults in the area of the springs but none seems to be aligned with the point of discharge. A group of normal faults that trend northeast parallel to the Carson Lineament (Shawe, 1965) occur approximately 1.5 km southwest of the spring. Directly to the south several north-trending normal faults have also been mapped. Displacements on these faults have been reported to be as much as 2 m.

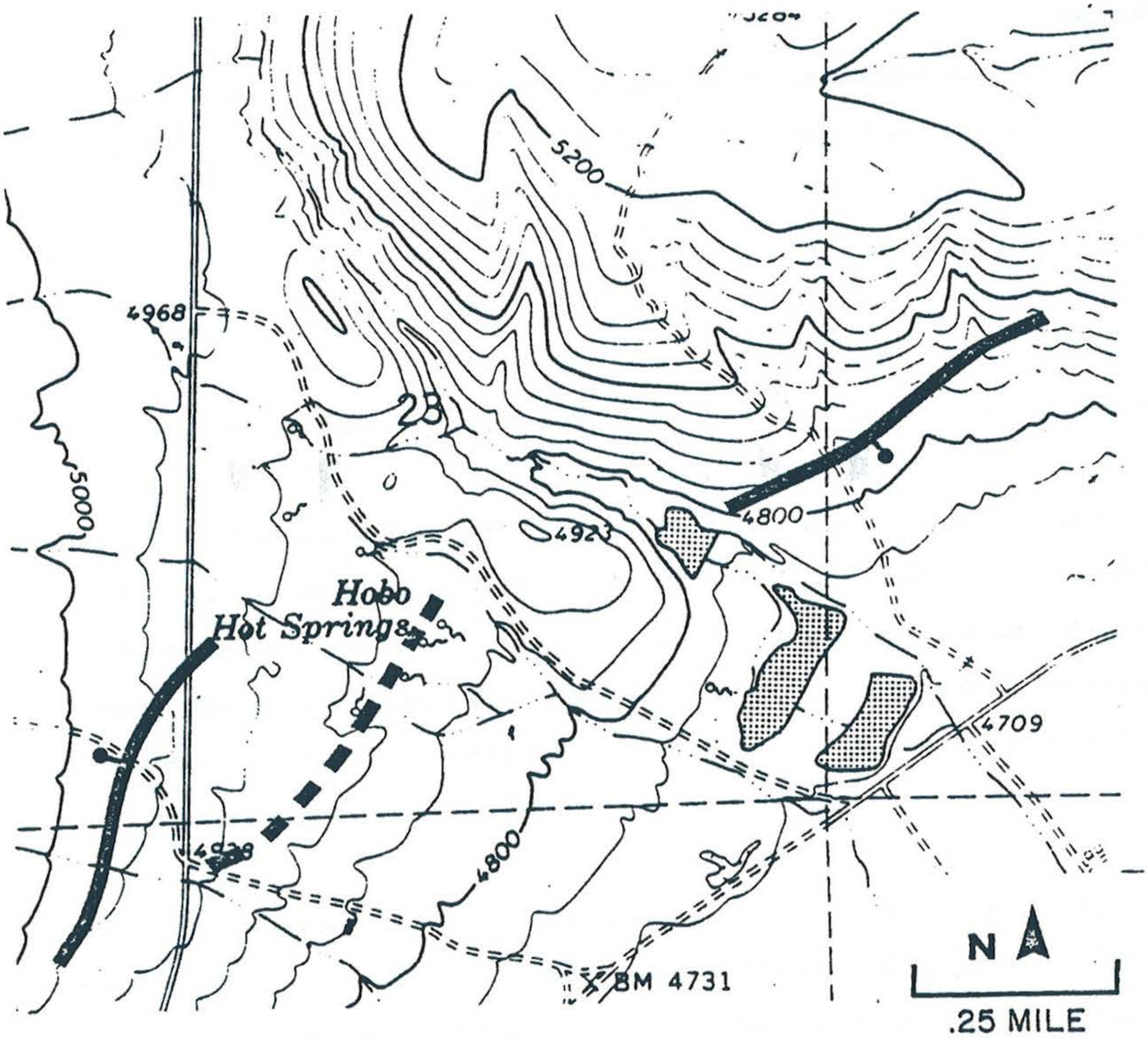

Figure B4. Spatial relationship between Hobo Hot Springs and nearby mapped faults (after Pease, 1979)

A small thermal spring flows near the site of the Nevada State Maximum Security Prison which is located at the north end of Prison Hill (fig. B2). The temperature of the water is 24°C and the discharge is very small. At the nearby Carson Sewage Plant a 60 m deep well produces water at a temperature of 32°C. Both of these thermal occurrences are associated with the normal fault that occurs at the northwest side of Prison Hill.

Gravity

Much of the study area is included in a regional gravity map of the Reno, Nevada 1° by 2° quadrangle (Erwin and Berg, 1977). This 1:250,000 scale map is a compilation of data from several sources including extensive work by the authors. The data are adjusted to U.S. Air Force base stations and the terrain-corrected results are presented in 5 milligal contour intervals.

In the southern part of the study area below latitude 39°N Oliver and Robbins (1973) have compiled a complete Bouguer gravity map of a portion of the Walker Lake, Nevada 1° by 2° quadrangle.

Taken together the maps indicate a large, deep depression in Carson Valley that narrows to the north in the vicinity of Hot Springs Mountain (fig. B5). A smaller and more shallow depression occurs in Eagle Valley just south of Carson City. A portion of the Carson Range, a prominent north-trending topographic high, extends to the northeast. The gravity contours indicate that it is joined with Hot Springs Mountain in the subsurface and forms a barrier between Carson Valley and Eagle Valley.

Although useful for examining regional geologic structures, maps at a scale of 1:250,000 cannot be successfully used to delineate those structures that are directly responsible for the control of geothermal fluid migration.

In order to further elucidate these structures and to supplement the existing gravity data base, gravity stations were established along three cross-valley traverses (fig. B6).

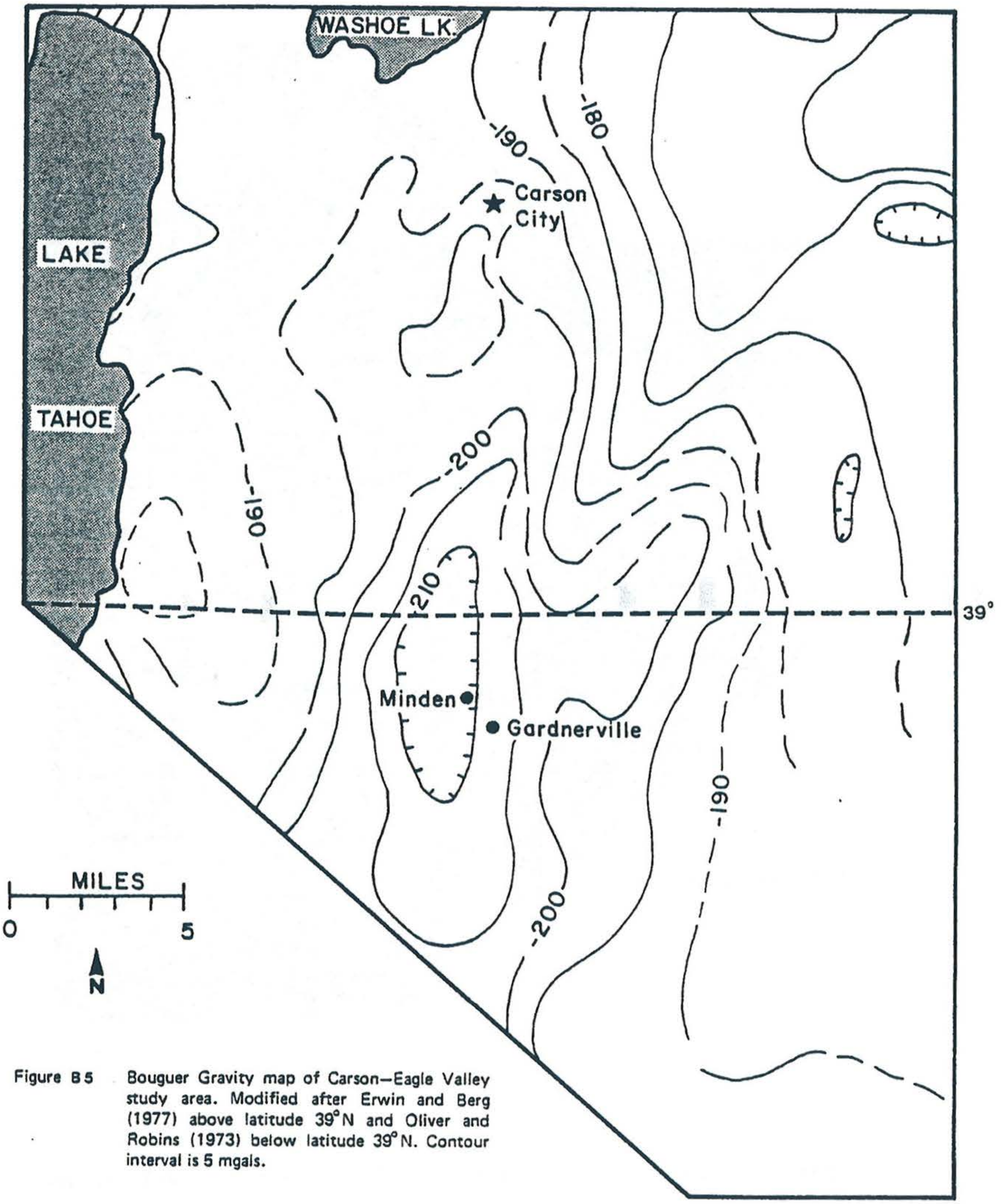

Figure B5 Bouguer Gravity map of Carson—Eagle Valley study area. Modified after Erwin and Berg (1977) above latitude 39°N and Oliver and Robins (1973) below latitude 39°N. Contour interval is 5 mgals.

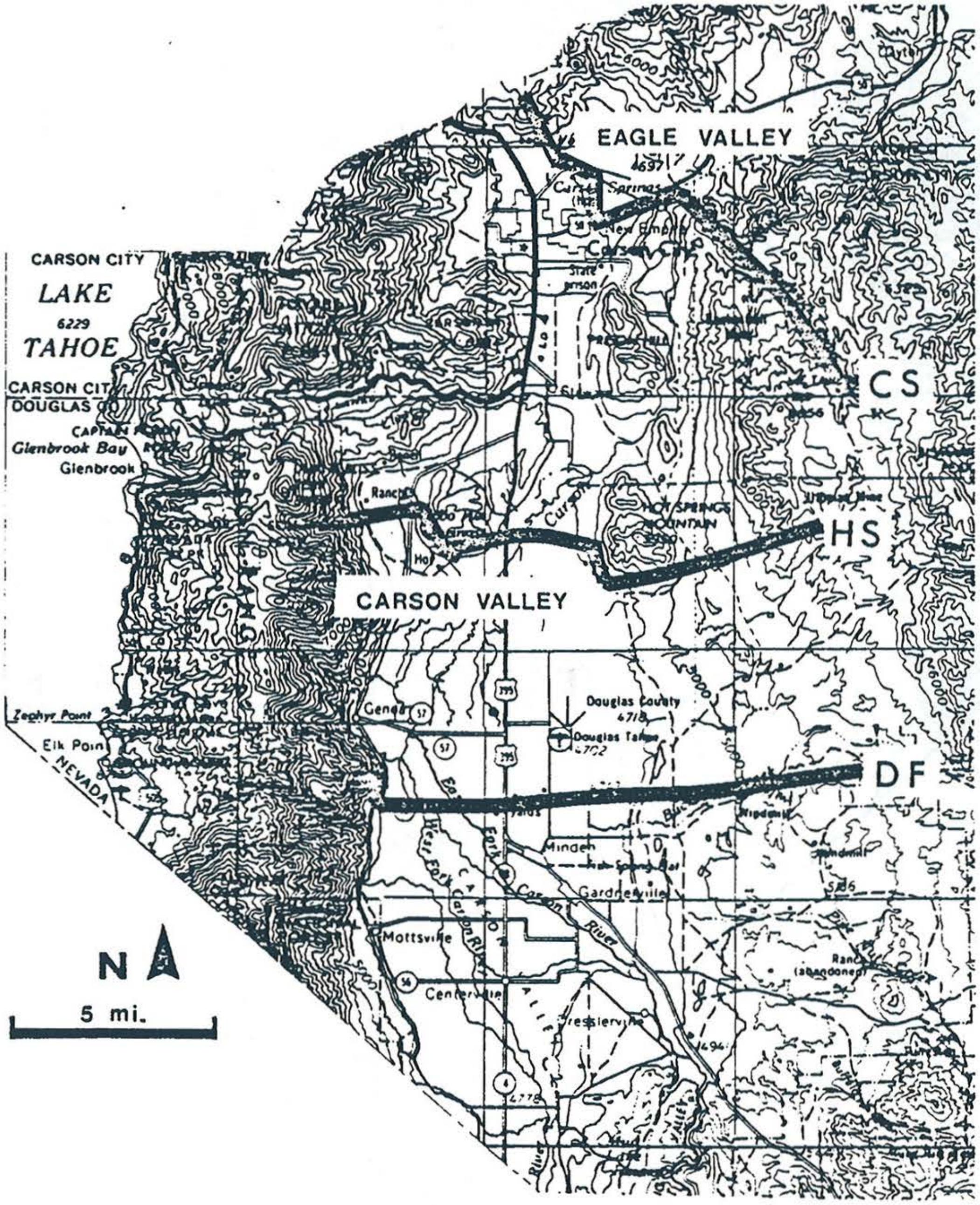

Figure B6. Location of gravity traverses CS, HS and DF in the Carson—Eagle Valley Area.

An attempt was made to locate as many bench marks as possible in order to supplement the leveled stations and to check the accuracy of the leveling technique. However, many of the monuments could not be located and were presumably removed during highway expansion or maintenance. The calculated elevations agree with the existing data which appears on the U.S. Geological Survey topographic maps for the area.

A total of 129 gravity stations were occupied in the Carson-Eagle Valley Study Area. All of the pertinent station data including latitude and longitude, elevation and gravity results are presented in tabular form in Appendix II.

Topographic profiles and gravity profiles, including both simple Bouguer and complete Bouguer data are illustrated for the three traverses in Figures B7, B8 and B9. The gravity profile roughly approximate the basement configuration and each figure depicts one-half of the length of a particular traverse.

The gravity profile for the Carson Hot Springs area, traverse CS - figures B7A, B7B - is the least diagnostic of the three. The gravity profile does show a slight gradient in the vicinity of the spring which corresponds to a northeast-trending normal fault mapped nearby (Rogers, 1975). The bedrock in this area consists of a series of metamorphosed Mesozoic volcanic and sedimentary rocks which dip 30° to the south and strike east-west. Based on the lithologic logs from several water wells in the area the vertical displacement on this fault is approximately 10 to 15 m. In the vicinity of the traverse directional change, figure B7A, the gravity data also correspond with Rogers' (1975) interpretation of a thickening of the Quaternary deposits. Further to the southeast along traverse CS (Figures B7A, B7B) gravity values decrease and peak near the Carson River. This gravity high is interpreted to be the buried northern extension of Prison Hill. Continuing to the southeast the basement structure is obscured by a thick section of Tertiary volcanic rocks, but some displacements can be identified in the gravity profile. These displacements correlate well with north- and northeast-trending normal faults which are exposed at the surface to the south in Jurassic and Triassic sedimentary rocks.

The HS traverse, figure B8, was designed to pass through two geothermal areas, Hobo Hot Springs and Saratoga Hot Springs. The gravity profile for this traverse shows two prominent gravity highs coincident with two topographic highs separated by a gravity low. The topographic expression for the gravity low is the flat alluviated surface of the north end of Carson Valley.

At Hobo Hot Springs faults mapped on both sides of the topographic high (fig. B2) correlate well with the steep gradients in the gravity contours (fig. B8A). Similarly, at Saratoga Hot Springs the steep gravity gradient on the west side of the topographic high and the gravity low on the east side (fig. B8B) correspond to the faults which are exposed just to the south (fig. B2). At both geothermal sites the springs are directly associated with both the surface manifestations of faulting as well as the basement offset which was identified by the gravity profile.

The final traverse, DF, trends west-east from Walley's Hot Springs (fig. B6). The configuration of the gravity profile, figures B9A, B9B, seems to confirm the hypothesis for the basement structure proposed by Moore (1969) as a west-tilted fault block. The thesis further states that the west side of the valley has been filled with a thick section of alluvial deposits of Quaternary age.

The gravity profile near the hot springs shows an extremely steep contour gradient and indicates substantial offset along the fault (fig. B9A). The eastern section of the traverse delineates a gravity high which contains several irregularities. These irregularities are modest gravity gradients and are roughly coincident with the location of several north-trending normal faults (fig. B2); the irregularities in the profile probably represent offset along these faults in the subsurface. This configuration supports a second hypothesis for the basement structure in the Carson Valley, a slightly west-tilted asymmetrical

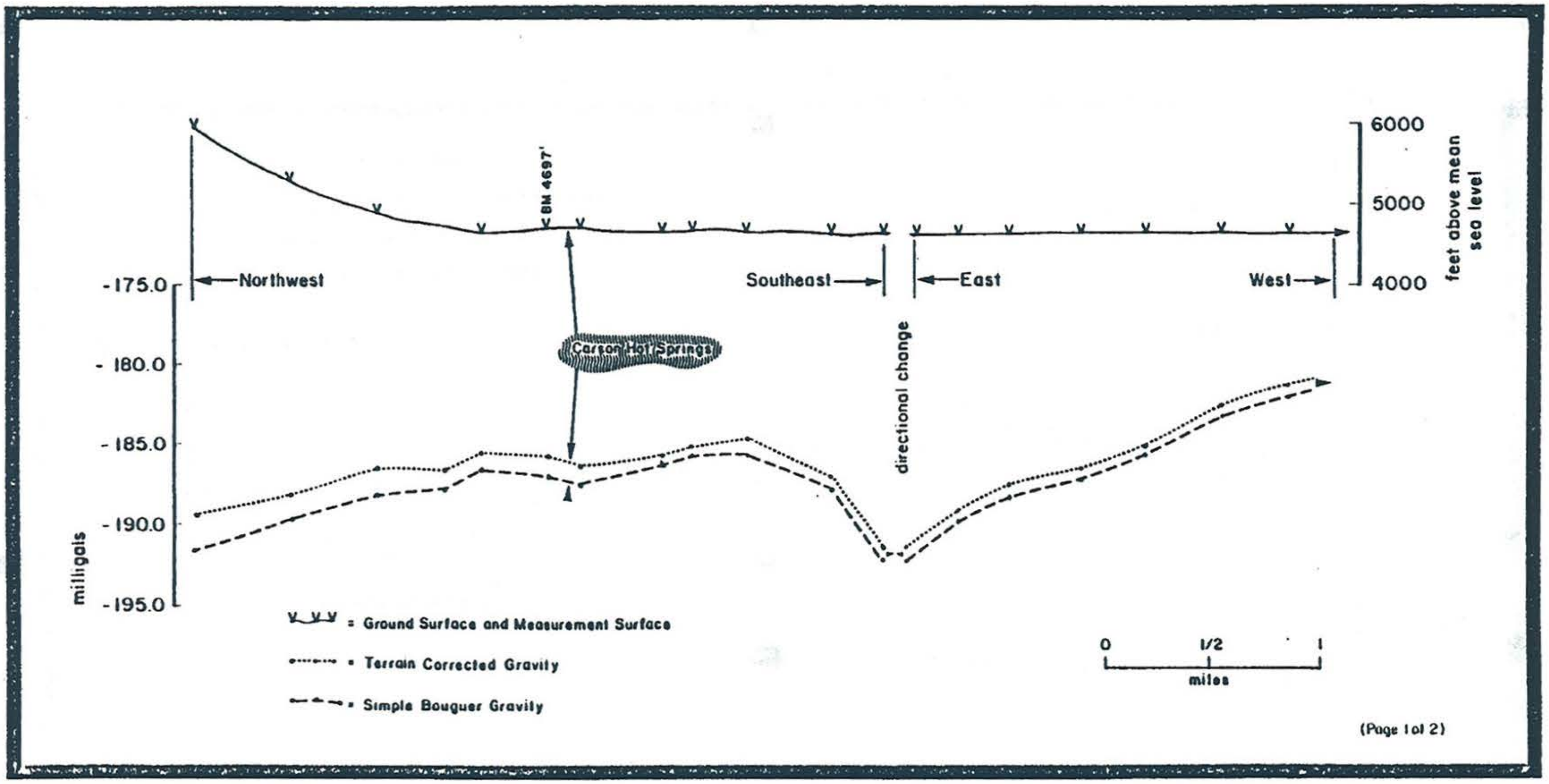

Figure B7a . CS gravity traverse, northwest section.

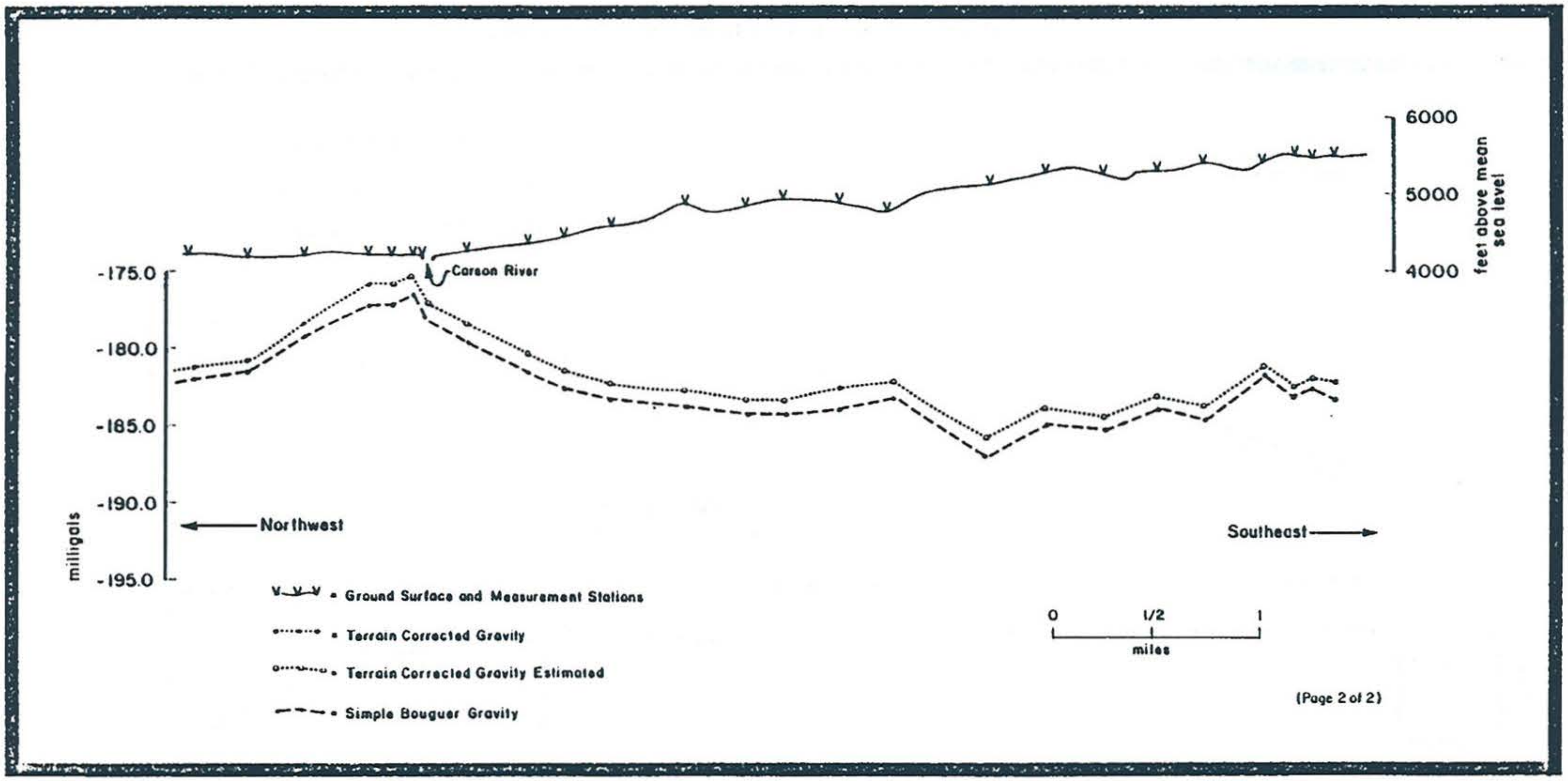

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Figure B7b . CS gravity traverse, southeast section.

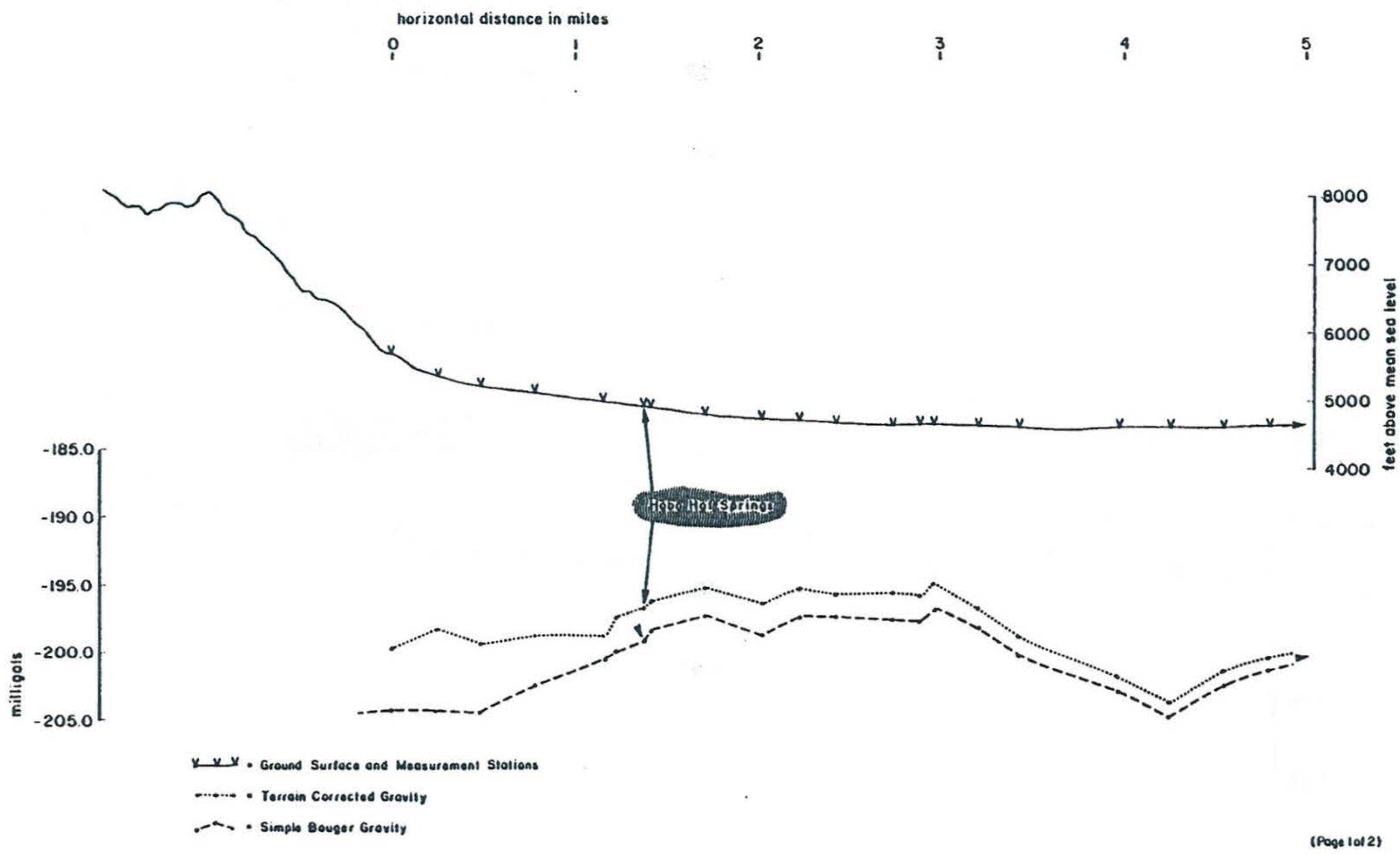

Figure B8a . HS gravity traverse, western section.

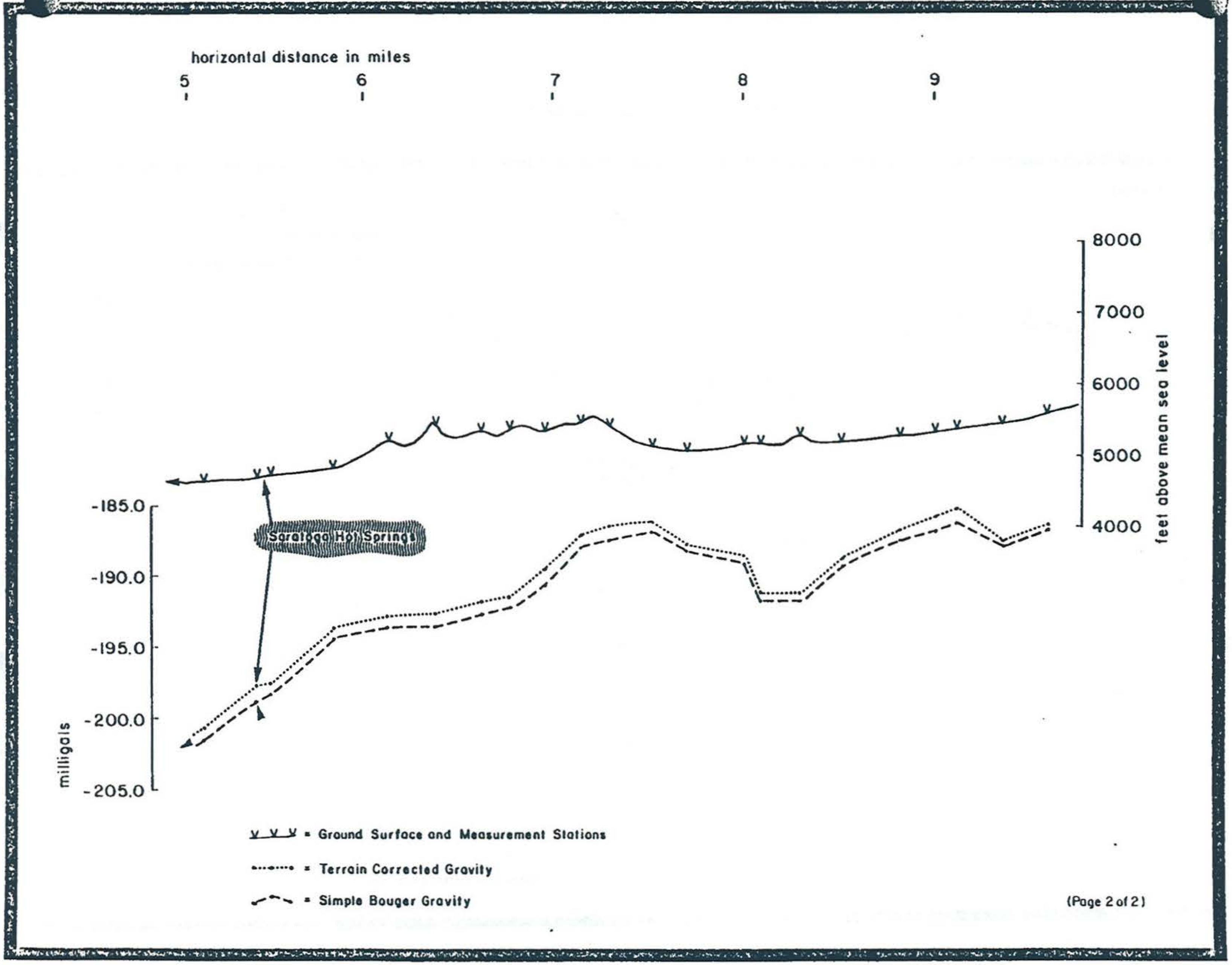

Figure B8b . HS gravity traverse, eastern section.

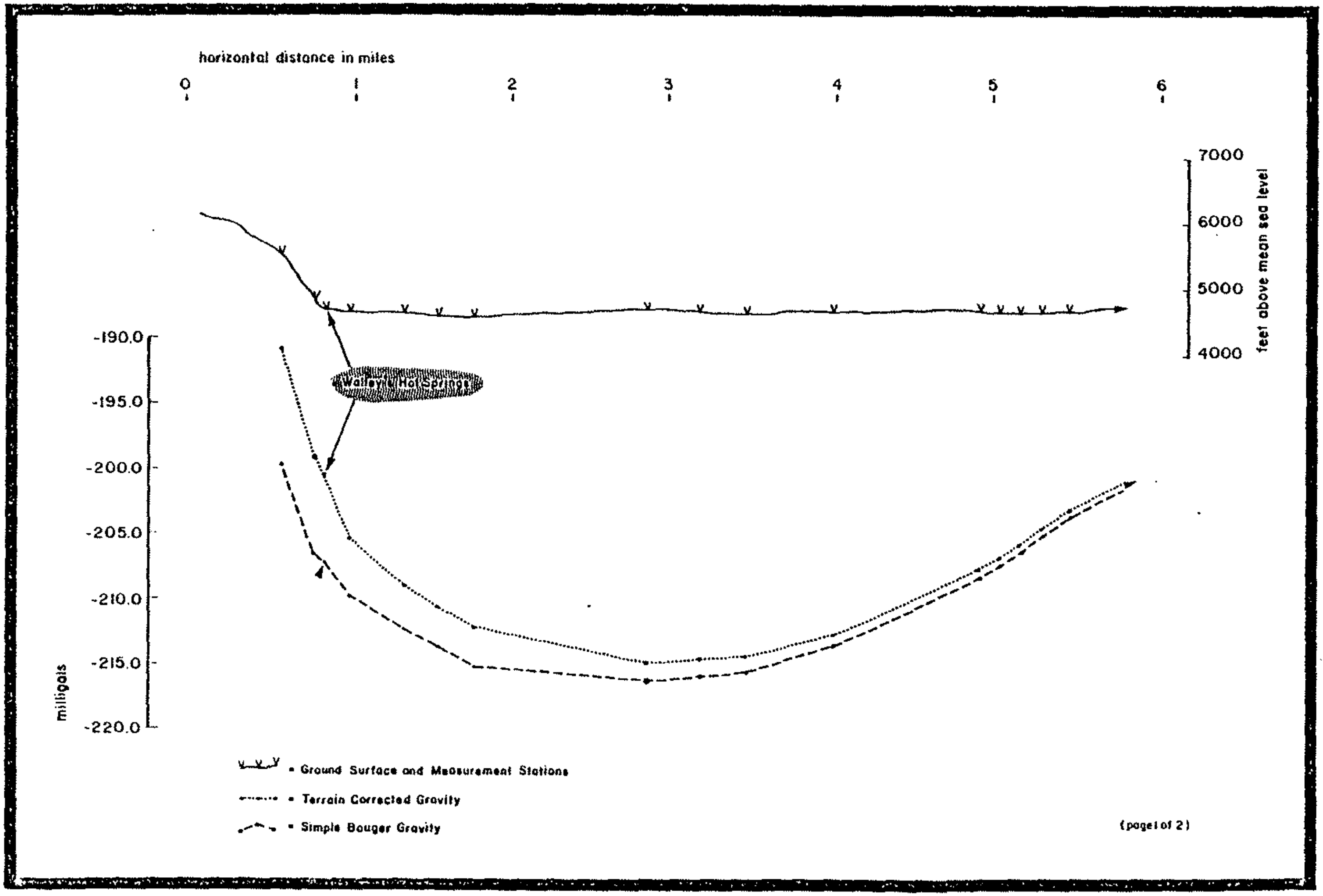

Figure B9a. DF gravity traverse, western section.

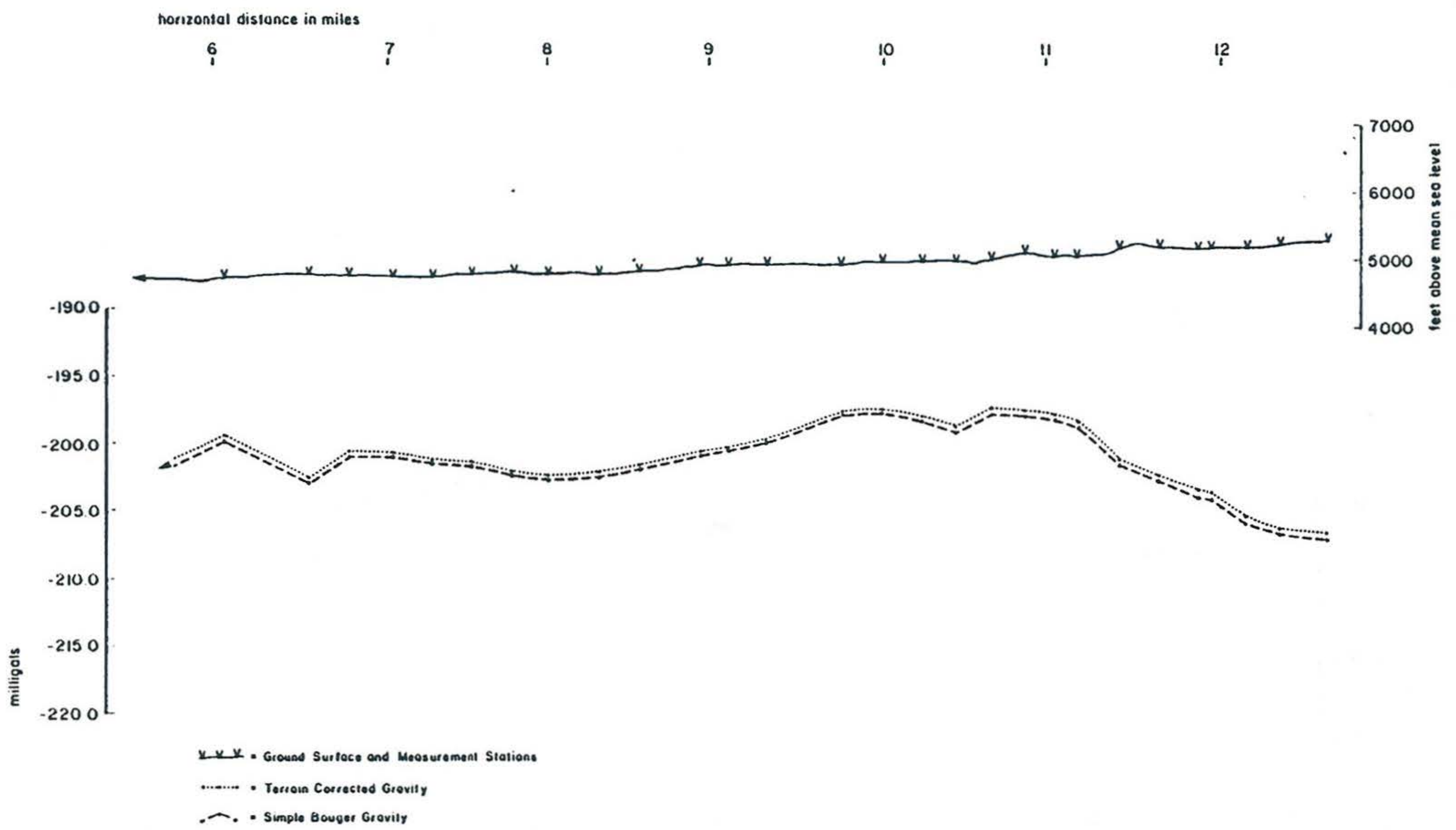

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Figure **B9b**. DF gravity traverse, eastern section.

graben. This graben is bounded on the west by the steeply dipping (60°-70°) Genoa Fault and on the east by a series of nearly vertical normal faults (fig. B2).

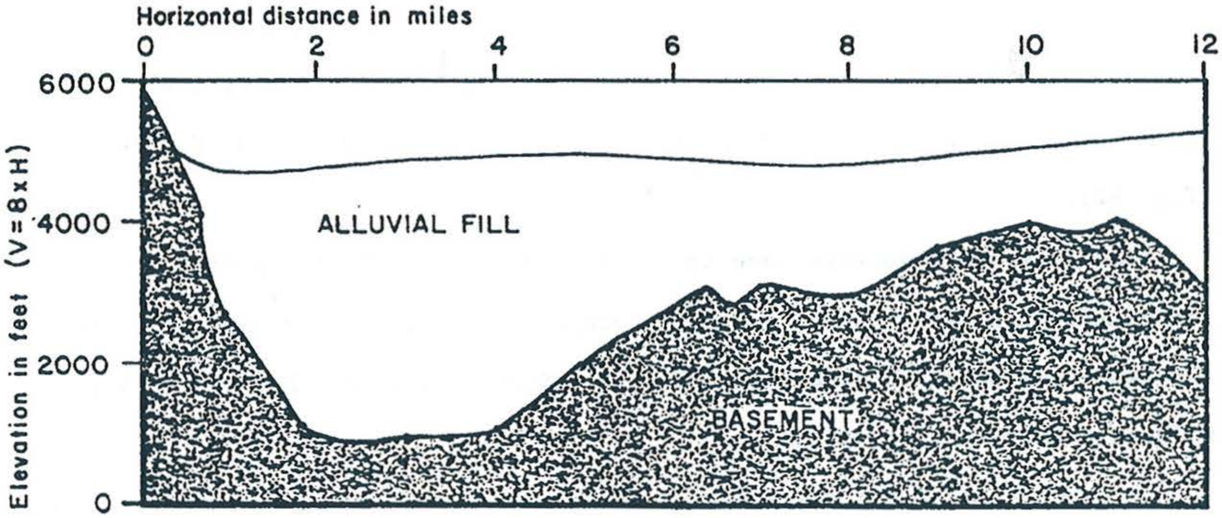
Similar gravity surveys have concluded that steep gravity gradients associated with range-bounding faults support the horst and graben hypothesis for Basin and Range structure (Thompson and Sandberg, 1958; Thompson, 1959; Goldstein and Paulsson, 1979).

An estimation of the thickness of the Quaternary alluvial sediments can be made using the formula $T = A/0.013S$ (Thompson and Sandberg, 1959) where T is the thickness of the sediments in feet, A is the difference between the regional gravity gradient and the local gravity anomaly and S is the difference in specific gravity between the sediments and the bedrock. The number 0.013 represents the attraction of an infinite slab in milligals per foot of thickness, and a value of 0.5 grams per cubic centimeter has been assigned to the contrast in specific gravity between bedrock and alluvium.

Figures B10A, B10B show the approximate configuration of the basement along traverses DF and CS, respectively. The figures indicate that the alluvial fill along both traverses may reach depths of 1.2 km (5000 ft) which is comparable to the topographic relief. In both figures the vertical scale has been greatly exaggerated so that minor irregularities in the basement surface which probably represent small displacements along faults can be more easily identified.

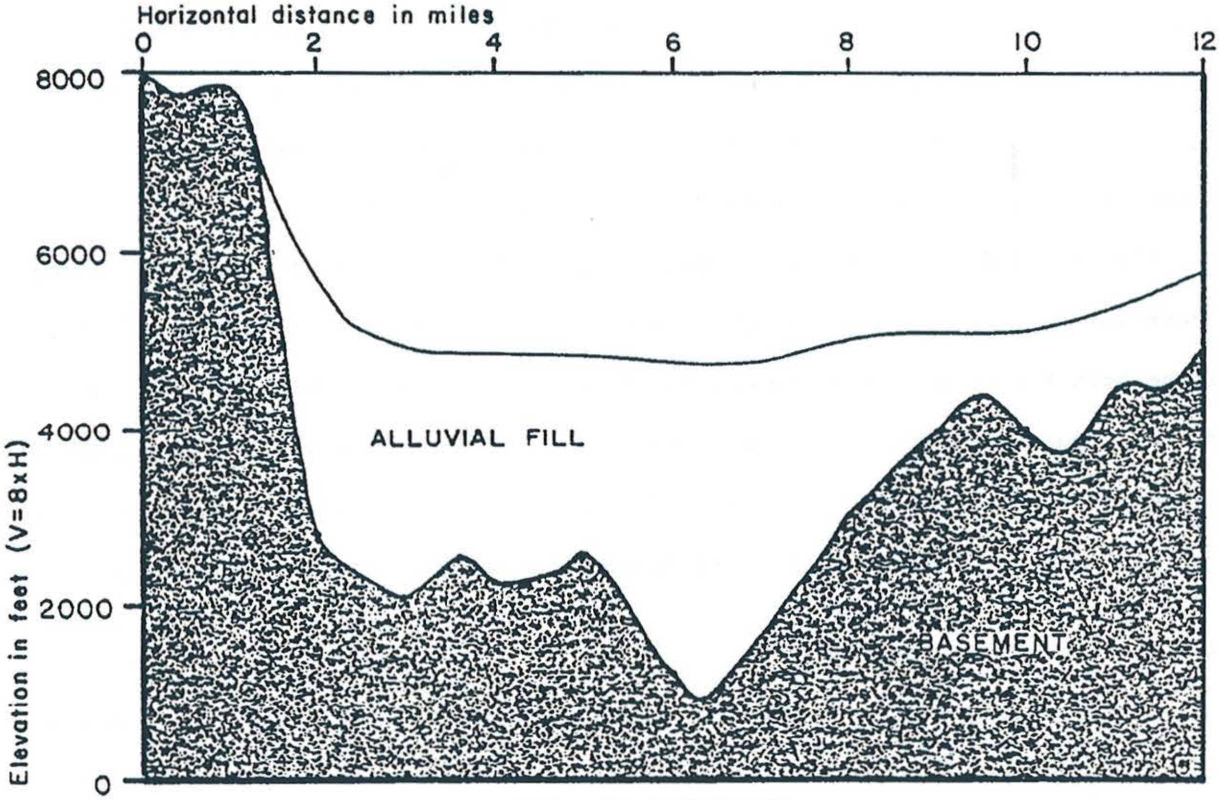
Aerial Photograph Interpretation

Aerial photographs were used to trace fault patterns at Walley's Hot Springs, Hobo Hot Springs and Saratoga Hot Spring. The imagery for this task included the use of black and white vertical photos (scale, 1:12,000), low-sun angle photos (scale, 1:12,000) and various scale oblique photos.



DF TRAVERSE
BASEMENT CONFIGURATION

A.



HS TRAVERSE
BASEMENT CONFIGURATION

B.

Figure B10.

Vertical and oblique air photos were flown along the lines of traverse used in the gravity survey (fig. B6). An attempt was made to correlate observable surface features with gravity anomalies.

The trace of the Genoa fault can be easily identified in the oblique air photo (fig. B11) as well as in the vertical photo (fig. B12). This is a recent scarp possibly less than 300 years old and can be traced for more than 20 km along the east side of the Carson Range. The displacement along this fault scarp varies from 2 to 5 meters and total displacement along the entire fault plane may be as much as 1200 meters. The springs at Walley's appear to emanate directly from the fault zone.

Further north at Hobo Hot Springs a series of less extensive faults branch out from the larger Genoa fault. In figure B13 as many as 4 hot springs can be identified flowing from the fault zone which trends to the northeast. Even though the fault can be traced at least 2 km to the northeast the hot springs flow only from the small area shown on the photo.

Although somewhat obscured by eolian sand deposits of Quaternary age the trace of a normal fault can be seen just to the south of Saratoga Hot Springs (fig. B14). The spring flows from a point along the fault zone.

Gravity survey data also correlate well with the surface manifestations previously discussed. Gravity profiles in the vicinity of the fault scarps shown near Saratoga, Hobo and particularly Walley's Hot Springs all show steep gravity gradients near the spring orifices.

Air photo interpretation is useful in areas that have not experienced extensive urban or agricultural development which may obscure fault scarps. In figure B15 which is a vertical airphoto of Carson Hot Spring, fault scarps cannot be clearly identified. The photo indicates that the housing developments surrounding the spring may have already obliterated the subtle topographic features which are used to identify recent faulting.

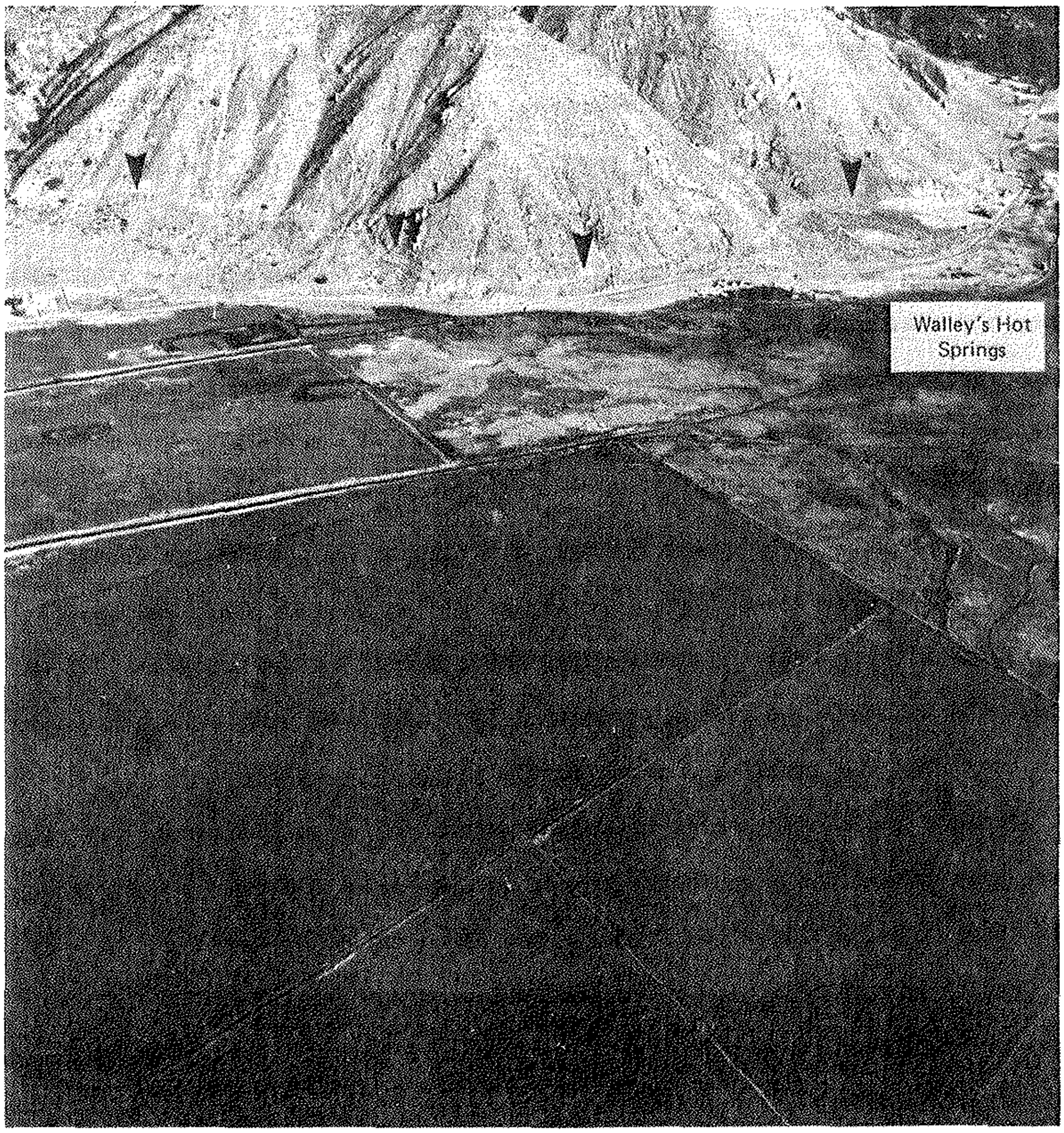


Figure B 11 . Oblique aerial photograph of Walley's Hot Springs area; arrows show location of Genoa fault.

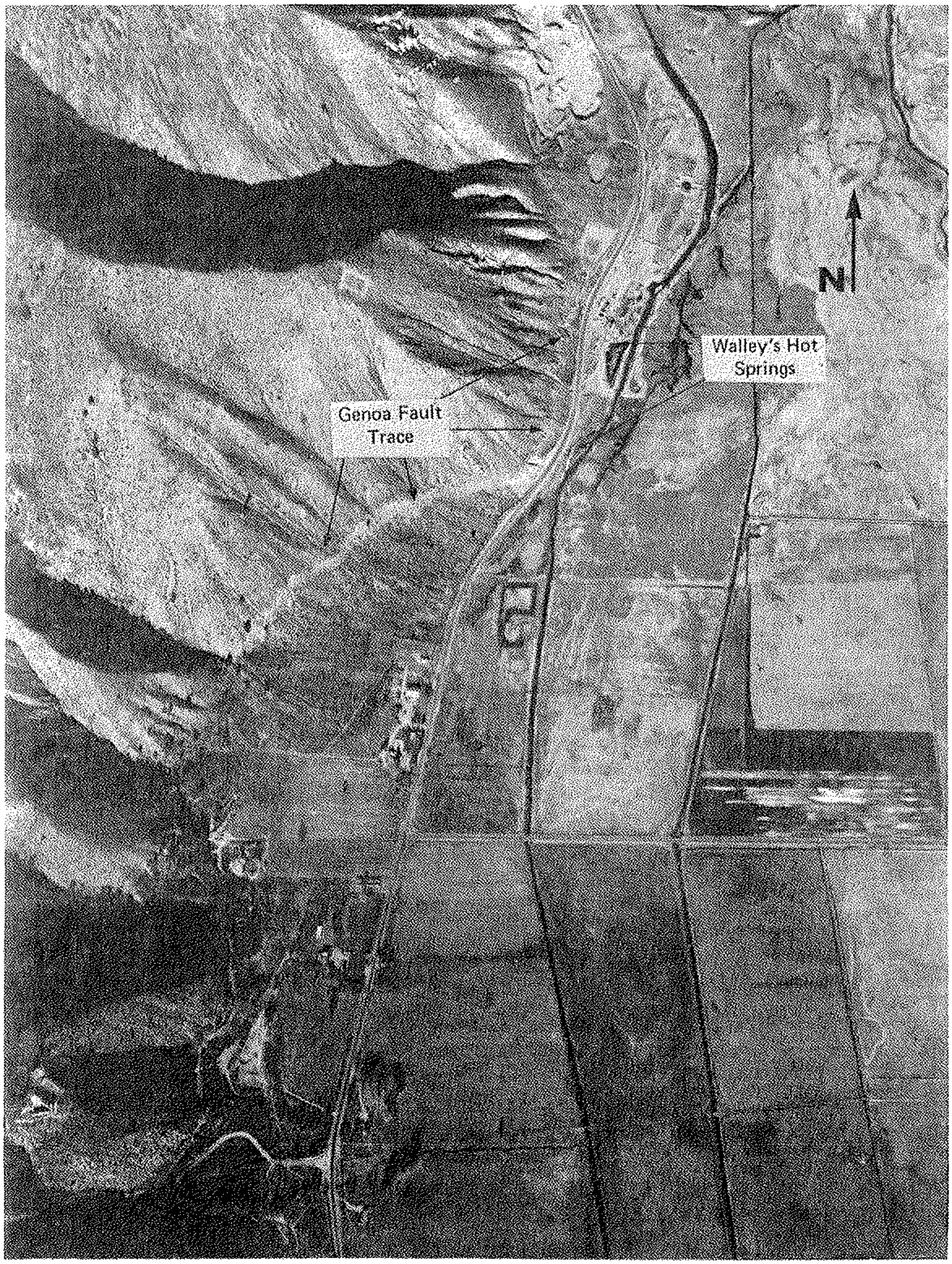


Figure B12. Genoa fault near Walley's Hot Springs. (Scale 1:12,000).

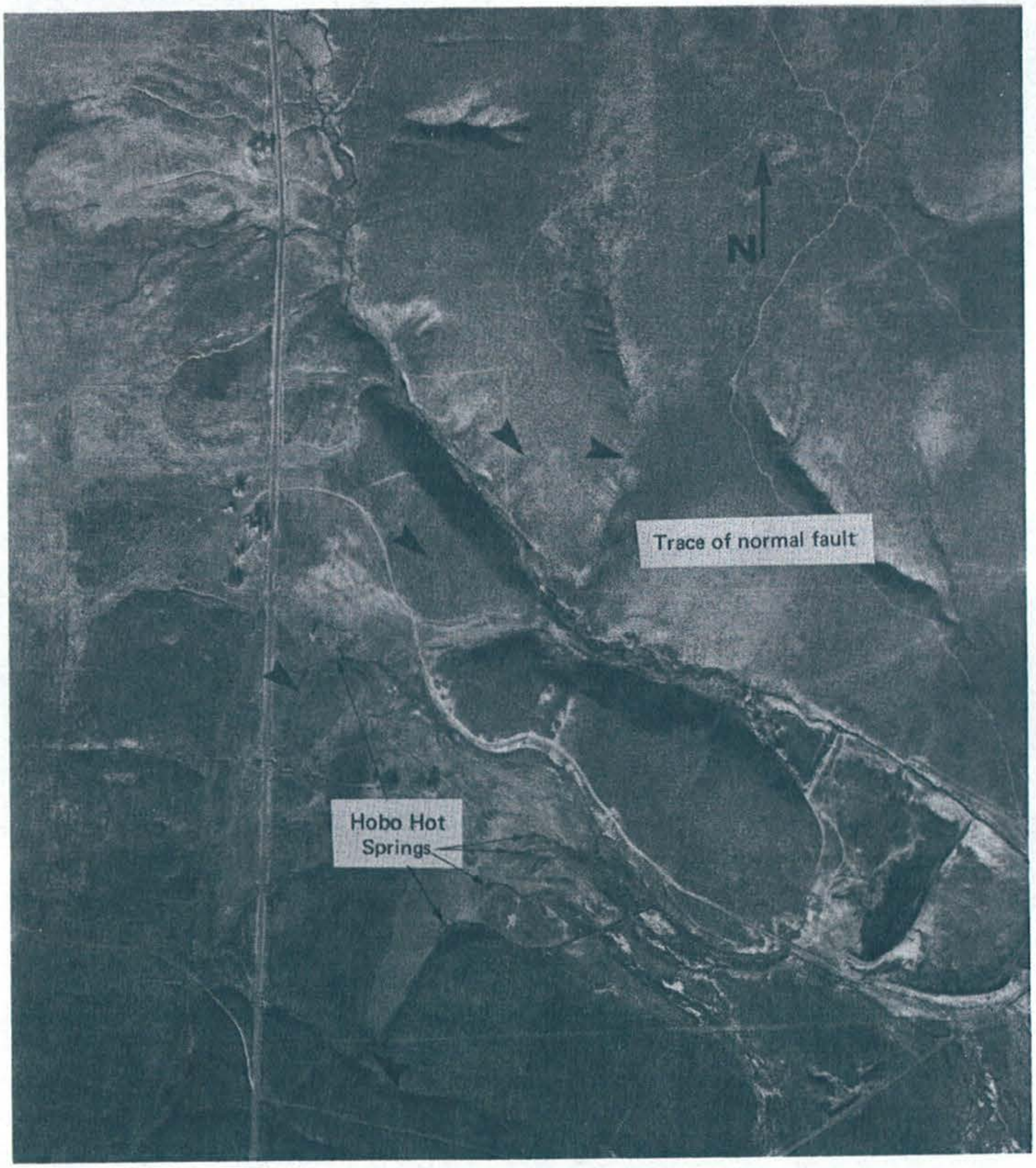


Figure B 13 . Faults near Hobo Hot Springs. (Scale 1:12,000).

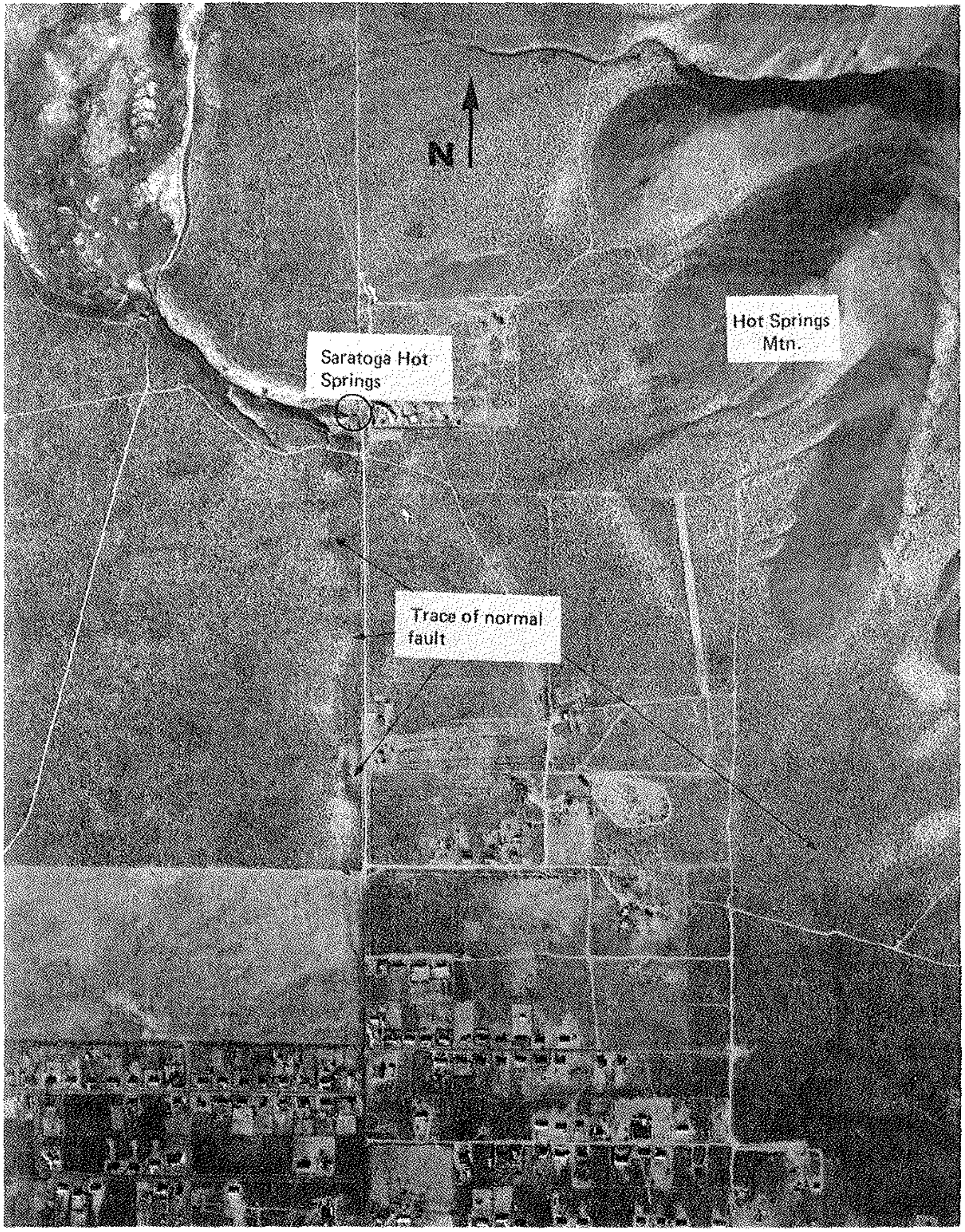


Figure B 14. Fault near Saratoga Hot Springs. (Scale 1:12,000).

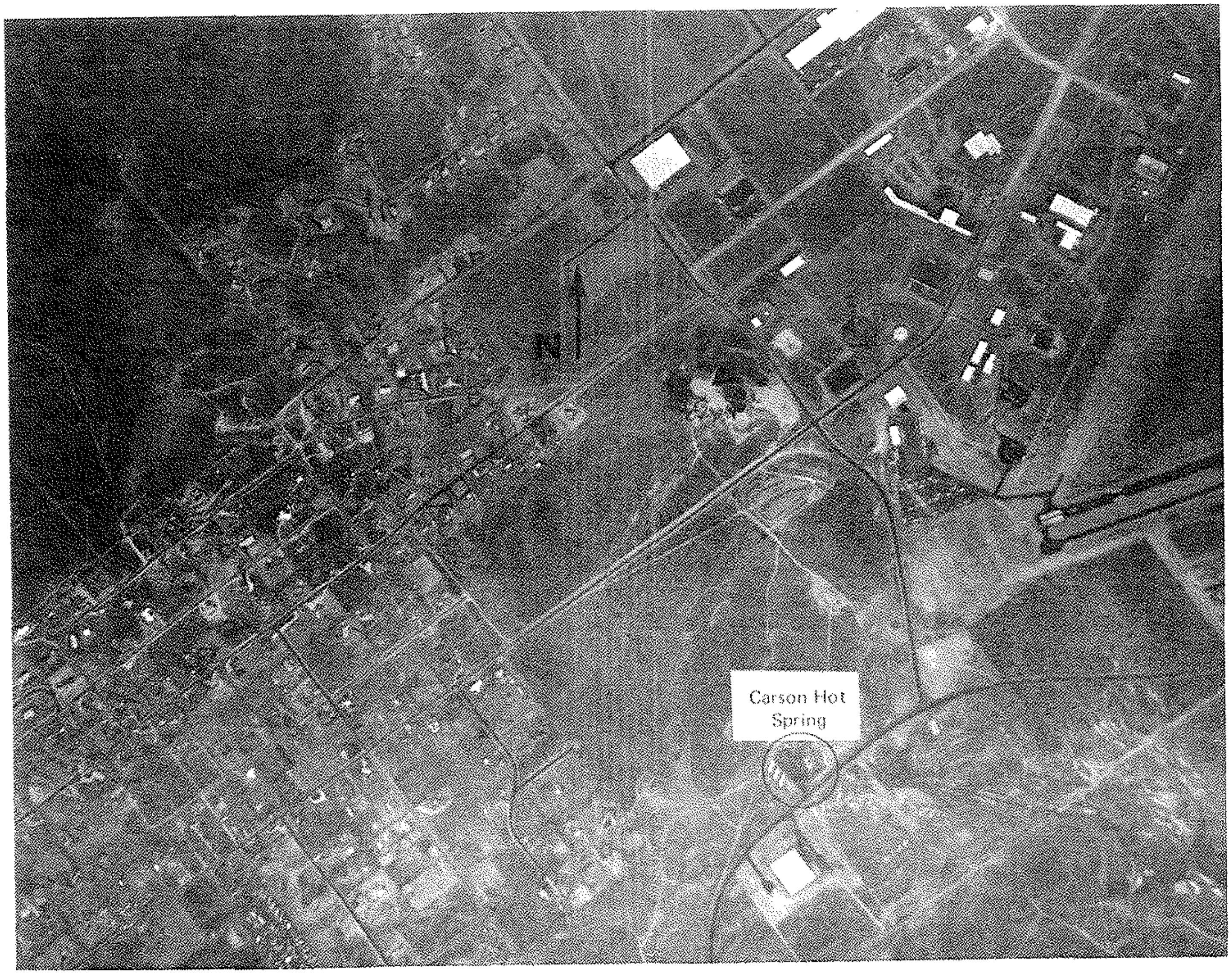


Figure B.15. Aerial photograph of the Carson Hot Springs area. (Scale 1:12,000).

The final oblique air photo (fig. B16) depicts the spatial and areal distribution of hot springs in the north end of the study area. Other important features such as the drill site CC-1, the Mound House gypsum mine and the Carson River are also shown.

Fluid Geochemistry

Chemical analyses of water samples from the Carson-Eagle Valley study area were obtained from several sources. Analyses from the files of the Nevada Department of Health Division of Consumer Protection included Ca^{+2}, Mg^{+2}, K^{+}, Na^{+}, SO_4^{-2}, Cl^{-}, HCO_3^{-} and CO_3^{-2}. The chemical analyses from this source pertained mostly to residential and commercial shallow-depth water wells. Many analyses of thermal waters were found during the initial literature search including Garside and Schilling (1979) who provide major, minor and trace element analyses for most of the thermal waters in the study area. In addition to published data 13 water samples from thermal and non-thermal sources were collected and analyzed for major, minor and trace elements plus stable isotopes of hydrogen and oxygen. Table B1 lists the source and location as well as all of the pertinent physical and chemical data for each sample collected. Data collected from the other sources are listed in Appendix I.

In general, the waters from the Carson-Eagle Valley study area can be divided into three groups based on the analyses of the major dissolved constituents which were listed above. The classification is illustrated in the trilinear diagram (fig. B17) which shows the anion, cation and average "total" compositions of the fluids (Piper, 1944).

In the trilinear diagram the anion (HCO_3^{-} + CO_3^{-2}, SO_4^{-2} and Cl^{-}) and cation (Ca^{+2}, Mg^{+2}, and Na^{+} + K^{+}) compositions are represented on the small triangles. Fluid composition for a particular sample is represented by either open circles (non-thermal fluids) or closed circles (thermal fluids). The

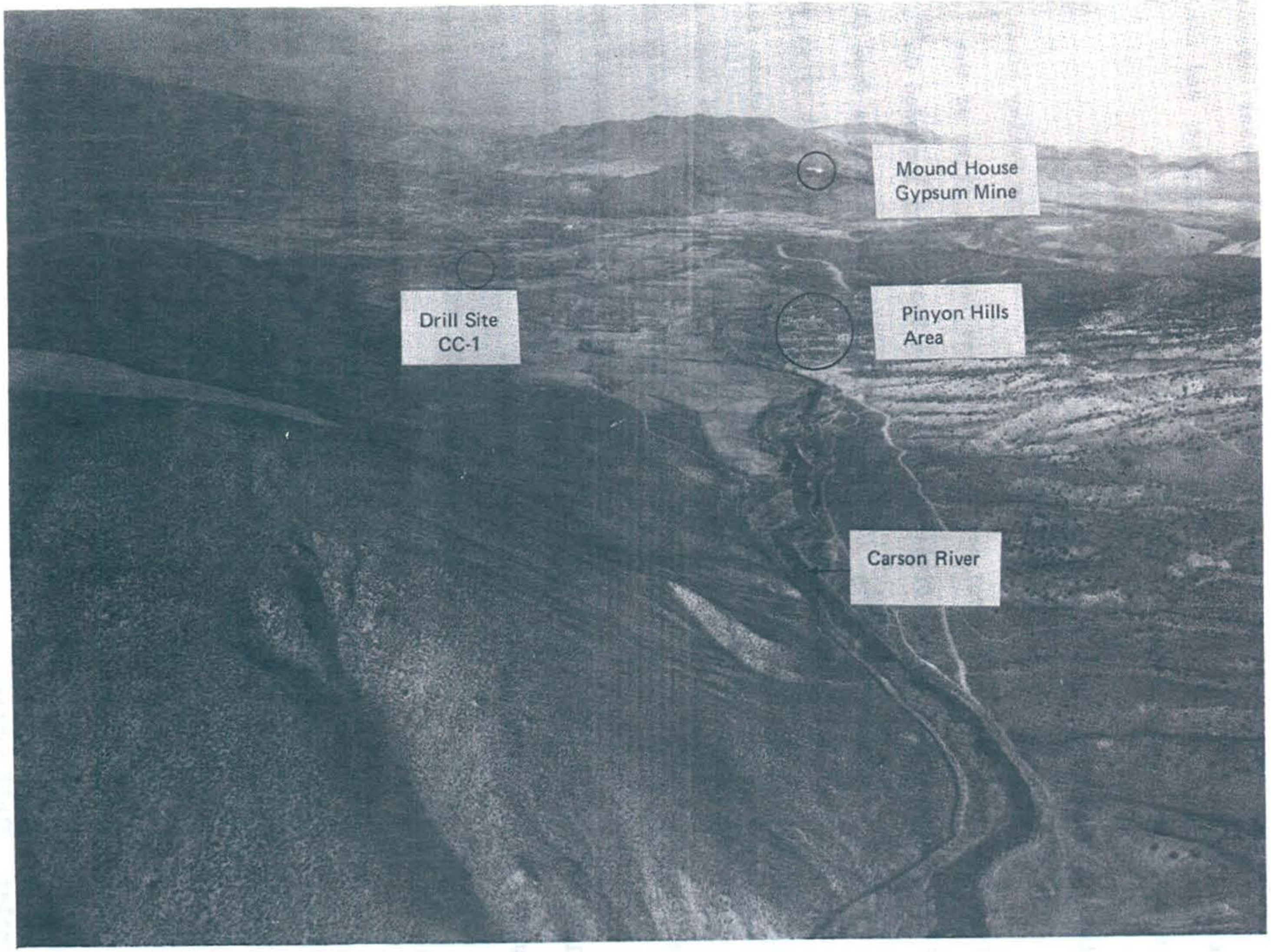


Figure B 16 . Oblique aerial photograph of Eagle Valley.

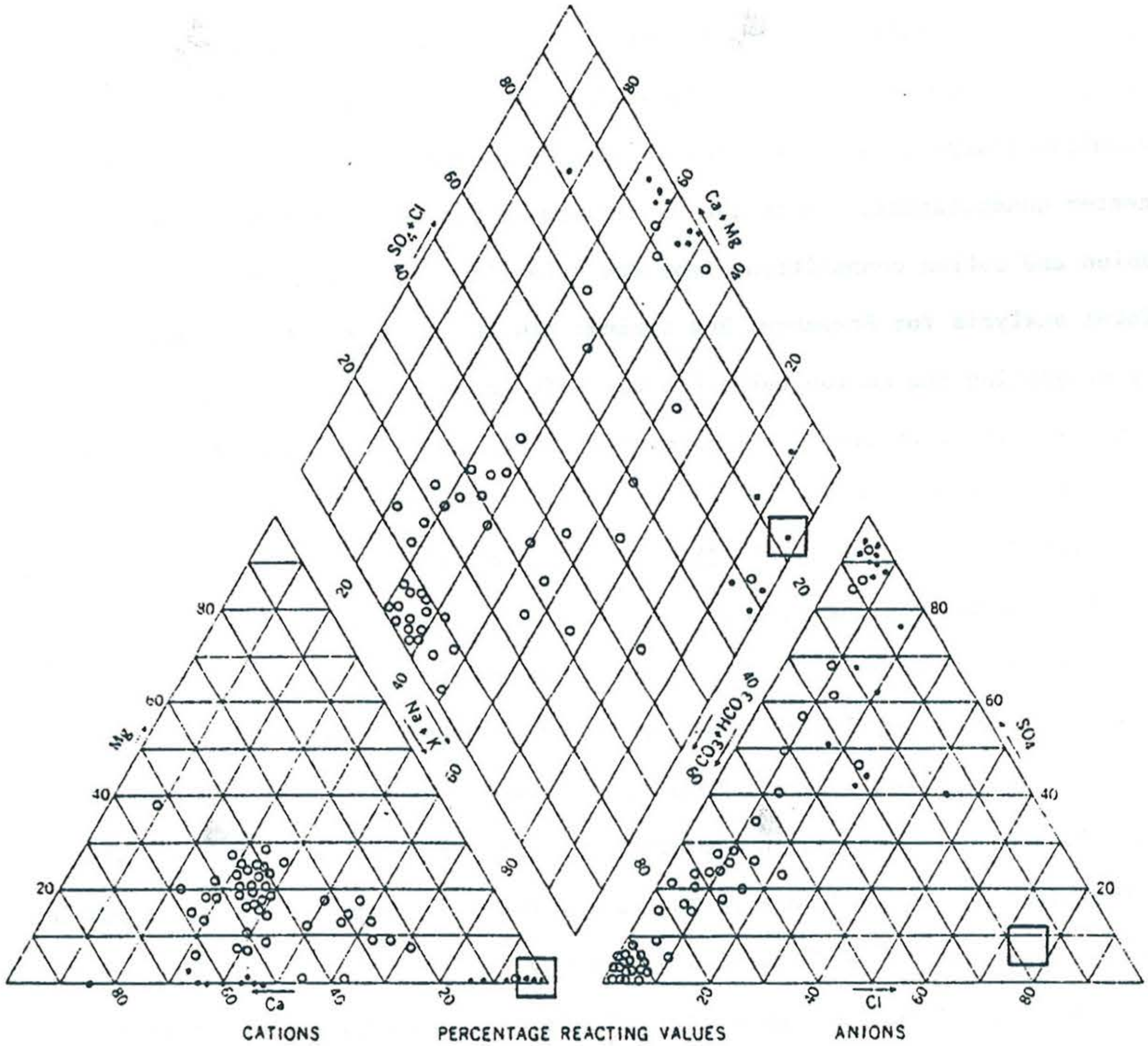
Table B1 . Chemical analyses of water from sampled sites:

Sample Name	Sample Number	Location	T°C	pH	SC µmhos	B ppm	Ca ppm	Mg ppm	K ppm	Na ppm	Li ppb
Hobo Hot Spring	CW1	SE¼,SE¼,Sec.23, T14N,R19E.	46	7.93	778	2.07	4.34	<0.05	1.64	142	350
Walley's Hot Spring	CW2	NW¼,NE¼,Sec.22, T13N,R19E.	58	9.08	778	1.55	9.81	<0.05	3.98	130	215
Job's Canyon stream	CW3	SW¼,SW¼,Sec. 14, T12N,R19E.	3	7.58	62	0.077	7.57	0.994	0.456	4.18	10.8
Carson River, south	CW4	NW¼,SW¼,Sec.31, T13N,R20E.	3.5	7.98	224	0.429	20	5.07	2.43	15.7	35.1
City of Minden well	CW5	SW¼,SW¼,Sec.29, T13N,R20E.	12	8.08	216	0.291	22	5.64	2.43	12.9	20.1
Unruh's well	CW6	SE¼,NW¼,Sec.33, T14N,R20E.	12	8.25	329	0.186	28.1	7.43	5.41	27.6	20.5
Saratoga well	CW7	SW¼,NW¼,Sec.28, T14N,R20E.	26	7.32	1847	0.125	168	<0.05	5.17	159	100
Saratoga Hot Spring	CW8	SE¼,SW¼,Sec.21, T14N,R20E	50	8.55	1857	1.37	166	0.10	5.03	161	95.5
Carson Sewage Plant	CW9	NW¼,SW¼,Sec.15, T15N,R20E.	32	7.83	501	1.19	11.6	<0.05	0.632	89.5	84.8
Noble Murray well	CW10	NE¼,SW¼,Sec.23, T15N,R20E.	41	7.26	2470	1.39	270	0.14	5.90	173	120
Carson Hot Spring	CW11	SE¼,NE¼,Sec.5, T15N,R20E.	50	8.84	515	1.48	2.16	<0.05	1.64	98.5	216
Carson River, north	CW12	SE¼,SW¼,Sec.23, T15N,R20E.	5	8.09	299	0.418	25.3	6.43	3.68	22.4	31.2
Dodd well	CW13	NE¼,SW¼,Sec.31, T,17N,R20E.	16	8.15	297	0.0515	31.9	6.62	2.13	18.3	5.0

Carson-Eagle Valley study areas.

Sample Number	Cl^- ppm	NO_3/NO_2 ppm	SiO_2 ppm	$SO_4/S^{=}$* ppm	CO_3/HCO_3 ppm	F^- ppm	As^{+4} ppb	Ba ppm	Fe^{+2} ppm	Rb ppb	Cs ppb	Sr ppb
CW1	91	<0.01	38.3	133/ .707	72.8	7.83	19.8	<0.1	0.04	13.2	<3	<200
CW2	45.5	0.06	72.3	205	42.6/ 1.90	4.66	167	<0.1	0.03	57	17.2	210
CW3	0.316	<0.01	21.8	6.15	28.4	0.208	<5	<0.1	0.167	<1	<3	<200
CW4	8.18	<0.01	24.6	25.4	82.4	0.185	14.9	0.08	0.192	109	4.2	298
CW5	4.94	1.34	33.8	16.3	100.1	0.110	<5	0.08	0.243	2.2	<3	298
CW6	7.46	2.55	77.9	34.6	140	0.364	20	0.16	0.03	<1	4.8	210
CW7	39.6	0.869	25.5	617/ .264	23.4	3.26	<5	<0.1	0.066	40.8	4.8	2520
CW8	39	<0.01	33	617/ .215	11.2/ 4.51	3.26	<5	<0.1	0.04	41.2	<3	2380
CW9	19.7	<0.01	35.5	132	47.4	6.42	50.3	0.08	0.447	2.2	4.2	<200
CW10	34.3	<0.01	43.9	843	26.4	4.14	<5	0.1	0.116	63.9	15.9	2950
CW11	27.4	<0.01	59.5	89.4	13.3/ 56.7	7.53	75.5	<0.1	0.03	32	24	<200
CW12	11.3	0.75	23.8	37.7	111	0.336	5.5	<0.1	0.192	8.4	5.5	350
CW13	3.19	13.4	34.7	18.3	137	0.217	<5	0.08	0.550	<1	4.2	350

*Measured and reported as total recoverable sulfide.



● Thermal Waters (T > 20°)

○ Non–Thermal Waters (T < 20°)

□ Average Chemical Composition of Steamboat Hot Springs Waters (Bateman and Scheibach, 1975)

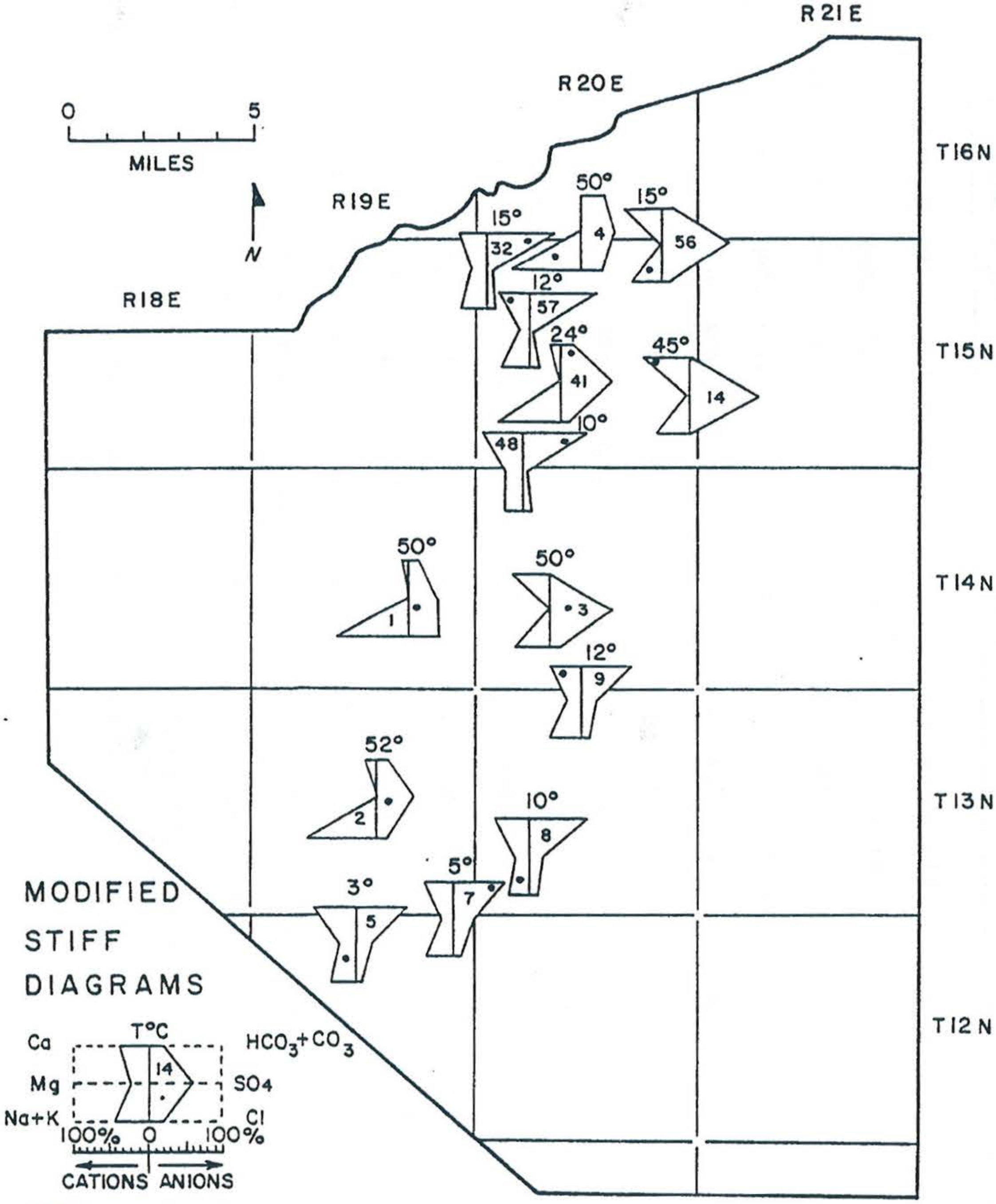
Figure B 17. Trilinear diagram showing the chemical characteristics of both thermal and non–thermal waters in the Carson–Eagle Valley study area.

apexes of the triangles represent 100 percent of the indicated dissolved species. The center of each triangle represents a fluid composed of essentially equal amounts of the species designated at the apexes. A 'total' chemical analysis for a particular fluid is represented by a point in the center quadrilateral which can be derived by projecting the association anion and cation compositions from the triangles into the quadrilateral. Total analysis for Steamboat Hot Springs fluids (open square) is obtained by projecting the cation value (in the left triangle) and the anion value (in the right triangle) into the quadrilateral along lines parallel to the quadrilateral coordinates.

Non-thermal waters ($T < 20^\circ C$) account for the majority of the plotted points, and these also show the largest variation in chemcial compositions. Most of the non-thermal waters show CO_3^{-2} + HCO_3 enrichment relative to Cl and SO_4^{-2}. Some fluids show SO_4^{-2} enrichment which is probably the result of mixing with sulfate rich thermal waters. None of the samples have Cl^- compositions higher than 25 percent. The cation compositions of the non-thermal waters is also widely distributed but most of the waters consist of approximately 40 percent Ca^{+2}, 40 percent $Na^+ + K^+$ and 10 percent Mg^{+2}.

The 'total' analysis shows two categories of thermal waters both of which are chemically different from the non-thermal waters. The Na^+-SO_4^{-2} waters include Walley's, Hobo and Carson Hot Springs, and plot near the open square that represents waters from Steamboat Hot Springs. The Ca^{+2}-SO_4^{-2} waters include samples from the Saratoga Hot Springs area and the Pinyon Hills area. These waters plot near the upper apex of the quadrilateral. Chemical variation between these two water types is small compared to the non-thermal waters.

Figure B18 shows the geographic distribution of both thermal and non-thermal waters throughout the study area. The name, location and chemical data for each of the symbols is listed in Table B2. The chemical similarity of the two types



HORIZONTAL AXES SHOW PERCENT REACTANCE OF RESPECTIVE IONIC SPECIES.

NUMBER INSIDE SYMBOL REFERS TO ANALYSIS OF SAMPLE IN TABLE B2. DOT SHOWS LOCATION OF SAMPLED FLUID.

PERCENT REACTANCE

$$= \frac{\text{ANION SPECIES (meq/L)}}{\text{SUM ANIONS (meq/L)}}$$

$$= \frac{\text{CATION SPECIES (meq/L)}}{\text{SUM CATIONS (meq/L)}}$$

Figure B18. Chemical Chacteristics of Waters from the Carson—Eagle Valley Area.

TABLE B2. Chemical Data (in milliequivalents per liter) for Symbols in Figure B18.

Sample Name	Sample Number	Ca meq/l	Mg meq/l	K meq/l	Na meq/l	SO_4 meq/l	Cl meq/l	F meq/l	HCO_3 meq/l	CO_3 meq/l	Data Source
Hobo Hot Springs	1	.217	0	.042	6.18	2.77	2.58	.412	1.19	0	A
Walley's Hot Springs	2	.490	0	.102	5.66	4.27	1.28	.245	0	1.42	A
Saratoga Hot Springs	3	8.28	.008	.129	7.00	12.9	1.10	.172	.074	.373	A
Carson Hot Springs	4	.108	0	.042	4.28	1.86	.773	.396	.929	1.372	A
Job's Canyon Stream	5	.378	.082	.012	.182	.128	.008	.010	.465	0	A
Carson River South	7	.998	.417	.062	.683	.529	.231	.009	1.35	0	A
City of Minden Well	8	1.10	.464	.062	.561	.340	.139	.005	1.64	0	A
Unruh's Well	9	1.40	.611	.138	1.20	.721	.210	.019	2.29	0	A
Bennett Well	14	13.98	.093	.139	9.60	22.0	1.01	.205	.360	0	C
Dickerson Well	32	.999	.576	.076	.869	.041	.197	.011	2.16	0	C
Maximum Security Prison Well	41	.674	.027	.051	3.56	3.08	.593	0	.785	0	B
Medium Security Prison Well	48	1.59	.576	.025	.652	.145	.254	.013	2.38	0	C
Bowland Well	56	16.98	2.30	.357	13.04	25.37	1.69	.097	2.88	0	C
Sullivan Well	57	1.04	.411	.051	.869	.020	.141	.007	1.91	0	C

Sources of Data: A. AMTECH LABS, this study
B. Trexler and others, 1979
C. Nevada Division of Health, public files

of thermal waters is preserved even for hot springs separated by as much as 25 km. The figure also indicates the chemical variations in the non-thermal waters especially near the Mound House gypsum mine in the northeast corner of the study area.

Trexler and others (1979) have shown that $Na^{+}-SO_{4}^{-2}$ rich fluids are the dominant thermal fluids in a region that extends north from the study area to Reno and southeast as far as Tonopah. Adjacent to this large region is an equally large area in which $Na^{+}-Cl^{-}$ type geothermal fluids are the dominant type. This area extends from the Steamboat Hot Springs area north approximately 120 miles to Winnemucca and as far east as Fallon. $Ca^{+2}-SO_{4}^{-2}$ type waters occur in both of these regions and include waters from Virginia City, Mound House, the Pinyon Hills area and the Saratoga Hot Springs area. The chemical similarities of these water types suggest that Triassic and Jurassic age deposits of gypsum and anhydrite which are presently being mined at Mound House extend from the mine site to the southwest along the west side of the Pine Nut Range. Geothermal fluids compositionally similar to the Steamboat Hot Springs fluids probably interact with the sulfate deposits in the subsurface and produce the characteristic $Ca^{+2}-SO_{4}^{-2}$ type fluids.

The investigation also included analyses of the following minor and trace elements: F^{-}, As^{+4}, Ba^{+2}, Fe^{+2}, Rb^{+}, Cs^{+}, and Sr^{+2}. Regrettably, these data were of comparatively little value for the investigation.

Fluoride (F^{-}) was the only minor element that showed any correlation to water temperature. The data are not conclusive but Figure B19 illustrates that thermal fluids contain significantly more F^{-} than non-thermal fluids.

Strontium values for most fluids analyzed (table B1) were 350 ppb or less with the exception of the two samples from the Saratoga Hot Springs area and the one from the Pinyon Hills. The strontium values for these fluids range from 2380 ppb to 2950 ppb. The characteristic strontium values for these moderately separated geothermal fluids (10 km at the surface) are probably due to the chemical

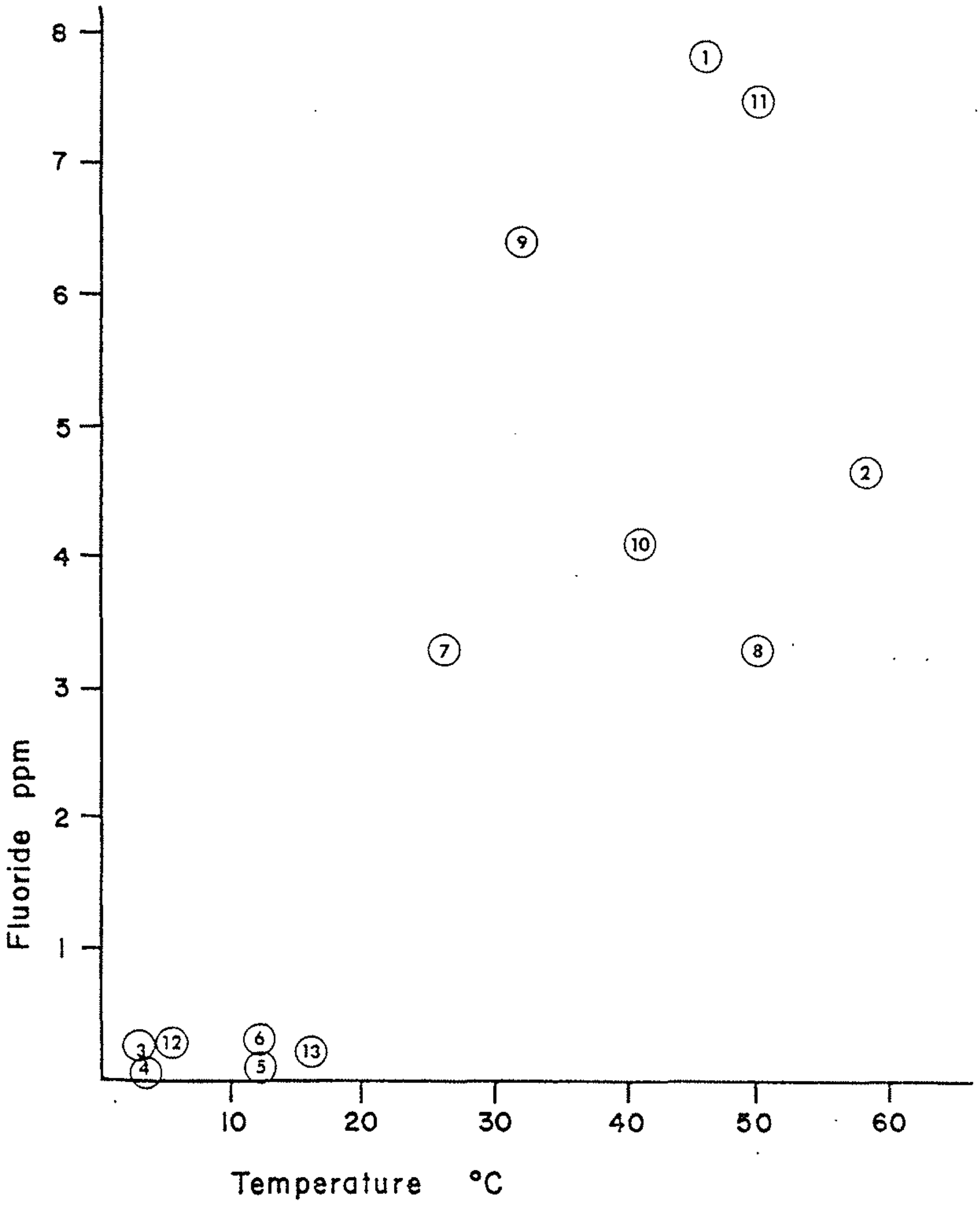


Figure B19. Relationship between temperature and fluoride concentrations for waters from Carson—Eagle Valley study area. Circled numbers refer to CW sample numbers in Table B1.

similarities between calcium and strontium. Calcium has an ionic radius of 0.99Å which is very close to that of strontium, 1.12Å. Strontium is also found in greatest amounts in calcium-rich minerals such as calcite ($CaCO_3$) or anhydrite ($CaSO_4$). Strontianite ($SrCO_3$) and celestite ($SrSO_4$) are usually associated with the respective calcium-rich minerals. The characteristic strontium values also indicate that thermal fluids are interacting with gypsum and anhydrite deposits in the subsurface.

The sampled fluids were also analyzed for deuterium (D) and ^{18}O which are the stable isotopes of hydrogen and oxygen, respectively. The results of these analyses are presented in Table B3. Figure B20 shows the isotopic compositions of the sampled fluids relative to the Worldwide Meteoric Line and some of the Steamboat Hot Springs fluids. The samples are essentially isotopically identical with respect to ^{18}O because the magnitude of the difference between the heaviest and lightest waters (1 and 2) is not significantly greater than the magnitude of the error bar (2 $^{o}/oo$). A small distinction does exist however in the samples with respect to D composition. Most of the thermal waters with the exception of sample number 1, have δD $^{o}/oo$ values of -119 or less. High negative values for D are generally attributed to fluids derived from snow which contains the isotopically lightest water. Nehring (1979) has shown waters sampled from the Virginia and Carson Ranges are isotopically lighter than surface and ground waters in the adjacent valleys. For these relatively dilute and neutral thermal waters it appears that a likely source or recharge fluids is the snow pack in the Sierras and, to a lesser extent, the Pine Nut and Virginia Ranges.

Chemical geothermometers can be useful for semiquantitative estimates of geothermal reservoir temperatures when certain assumptions regarding the chemical behavior of thermal fluids have been satisfactorily met. The common chemical geothermometers include the use of dissolved SiO_2, Ca^{+2}, Mg^{+2}, K^2 and

TABLE B3.

Hydrogen and Oxygen stable light isotope Analysis results - Carson-Eagle Valleys

Sample Name	Sample Number	$\delta D ^o/oo$	$\delta ^{18}O ^o/oo$	T^oC
Hobo Hot Spring	1	-115	-13.7	46
Walley's Hot Spring	2	-132	-16.3	58
Job's Canyon Stream	3	-117	-15.4	3
Carson River, South	4	-116	-14.6	3.5
City of Minden Well	5	-120	-14.8	12
Unruh's Well	6	-118	-15.4/-15.0	12
Saratoga Well*	7	-133	-16.0	26
Saratoga Hot Spring	8	-130	-16.2	50
Carson Sewage Plant	9	-123	-15.4	32
Noble Murray Well	10	-130	-16.2	41
Carson Hot Springs	11	-127/-128	-14.9	50
Carson River North	12	-121	-14.0	5
Dodd Well	13	-120	-14.2	16
Saratoga Well*	16	-133	-16.1	26

Values separated by a slash indicate duplicate runs on a single sample.
* Two samples collected simultaneously and submitted under different designations.

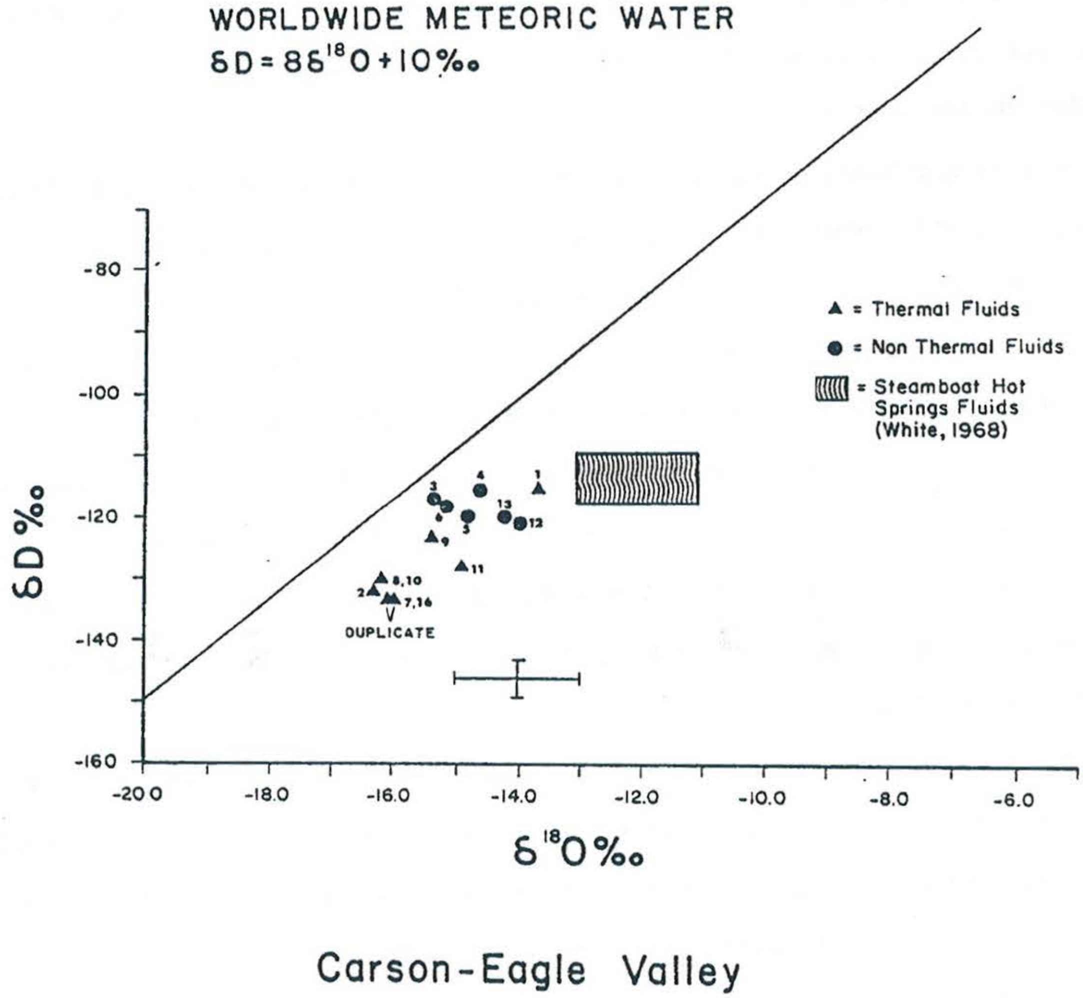


Figure B20. Stable light-isotopes of thermal and non-thermal fluids. Worldwide meteoric water line (after Craig, 1963). Numbers refer to samples in Table B3.

Na^+. The temperature estimate is based on the variations in the solubilities of the dissolved constituents as the fluid temperature is increased. One of the critical assumptions states that mixing of thermal and non-thermal fluids does not occur. The trilinear diagram (fig. B17) illustrates that some mixing of thermal and non-thermal fluids does occur in the study area and essentially rules out any serious consideration of chemical geothermometers for use in this portion of the study.

Silica geothermometers yield accurate results for neutral to slightly acid pH fluids (USGS, 1978). Fluids with pH greater than 8 such as some of those listed in table B1 may contain anomalously high concentrations of dissolved silica especially in granitic terrains. Table B4 illustrates the use of the chalcedony geothermometer assuming conductive cooling of the fluid.

Fournier (1979) has re-evaluated the Na/K geothermometer and the results of the use of the revised equation for thermal waters from the Carson-Eagle Valley study area are also presented in table B4. These temperature estimates ranging from 75°C to 134°C are presented only to demonstrate that there is considerable scatter in the data.

The data indicate that the range of temperature estimates from chemical geothermometers at Carson and Walley's Hot Springs is negligible compared with the other thermal fluids. These consistent data may accurately reflect maximum temperatures that can be expected at economical depths. The estimates at Walley's also concur with the maximum temperature measured in a 20 m deep well.

Shallow Depth Temperature Probe Surveys

Temperature probe surveys to depths of 2 m and 1 m were conducted at Saratoga Hot Springs and drill site CC-1, respectively. At the Saratoga site 23 2 m and 2 1 m holes were drilled. The thermistor probes were allowed to equilibrate for 24 to 72 hours. Eighteen thermistor probes were used at drill site CC-1 and they were allowed to equilibrate for 5 days.

Drilling at the Saratoga site was easy because most of the material consisted

Table B4.

Temperature estimate of thermal waters in Carson and Eagle Valleys

Location	$T^{o}C$	Depth (m)	Chemical geothermometers*	
			Chalcedony[1.]	Na/K[2.]
Hobo Hot Springs	46	surface	57	90
Saratoga Hot Springs	50	surface	50	134
Saratoga Hot Wells	55	61	39	110
Carson Hot Springs	50	surface	79	75
Walley's Hot Springs	58	surface	89	90
U.S. Steel Wells	83	30-365	(maximum temperature at 20 m intersected range-front fault)	

* Equations for geothermometers

1. Chalcedony, conductive cooling

$$t^{o}c = \frac{1015.1}{4.655-\log SiO_2} - 273.15$$

2. Na/K

$$t^{o}c = \frac{1217}{\log(Na/k)t1.483} - 273.15$$

of coarse- to medium-grained unconsolidated sand with some minor lenses of clay. These deposits belong to a Quaternary age sedimentary unit of eolian sand and are very common along the east side of Carson Valley. The material at drill site CC-1 consisted of a thin soil horizon (.5 m) which was underlain by a thick regolith that mantled the Mesozoic volcanic rocks. This material could not be penetrated to any significant depth with the hand-operated power auger; a jeep-mounted auger was used instead for drilling the 1 m holes in this area.

At the Saratoga site the measured temperatures range from 18°C to 35°C and the survey covered an area of approximately 25 square km. The highest recorded temperature was measured at a probe located nearly .8 km south of the hot spring. The spring itself discharges from a point 60 m northwest of its original orifice. It was moved several years ago during construction of a road.

The configuration of the isotherms (fig. B21) delineates a linear zone of high heat flow which is parallel to the nearby range-bounding fault. The data also show that the area of highest heat flow extends for only .8 to 1.2 km in a north-douth direction. Temperatures drop off even more rapidly west of the thermal high. The isotherms also reveal that the zone of highest heat flow is not coincident with the orifice of the hot spring.

These data suggest that geothermal fluids are rising along a selected portion of the fault and produce a linear isotherm configuration as they spread out near the surface. Although no fault scarp is exposed or mapped the abrupt topographic and lithologic change at the southern end of Hot Springs Mountain (fig. B21) suggest the presence of an east-west trending normal fault possibly related to a similar fault near Hobo Hot Springs four miles to the west. The intersection of such a fault with the existing north-trending fault correlates well with the location of the highest recorded temperatures in the 2 m probe temperature survey.

A shallow depth temperature probe survey was initiated at Carson Hot Springs but was not completed because of drilling difficulties. The area is also highly developed and many of the existing structures including several buildings, a

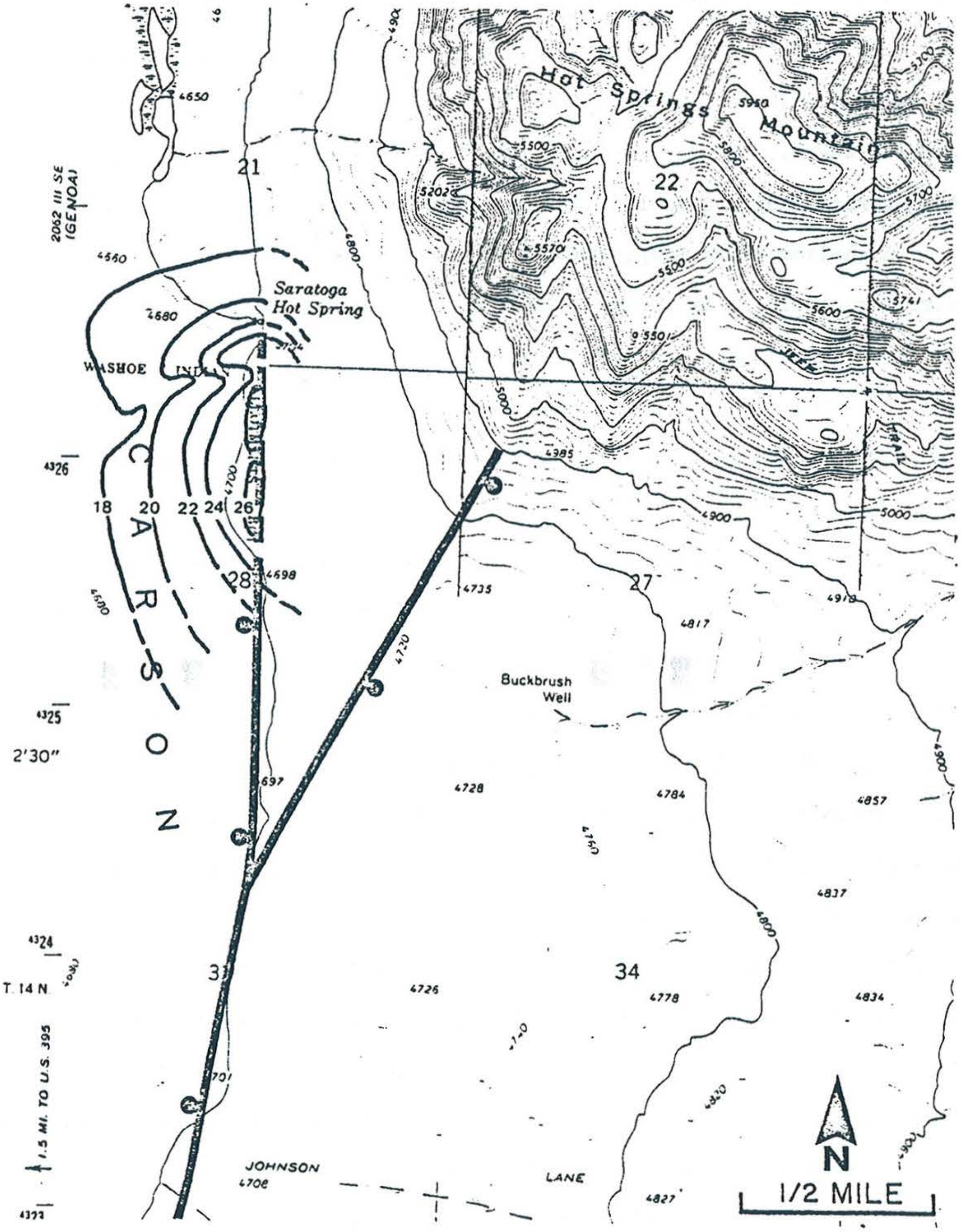


Figure B21. Spatial relationship between Saratoga 2 m. temperature probe isotherms and nearby fault (modified after Moore, 1979). Isotherm contour interval is 2°C; ball on downthrown side of fault.

swimming pool and a paved parking lot precluded the deployment of temperature probes in the vicinity of the hot springs.

The surface material at Hobo Hot Springs consists almost entirely of coarse gravel and alluvial fan conglomerates which cannot be drilled with gasoline-powered auger. The area is also a prime grazing pasture for cattle owned by the Stewart Indian School, and access was limited to reconnaissance activities.

A shallow depth temperature probe survey was also completed at the primary site for the 150 m temperature gradient hole, CC-1. At this site the temperatures ranged from 6.5° to 8.5°C (fig. B22) over an area that measured .4 km wide and .5 km long. There are no thermal springs associated with this site but the Pinyon Hills thermal area (fig. B2) is located across the valley 2 miles to the east.

The configuration of isotherms (fig. B22) outlines a small area of somewhat higher heat flow near the south end of the property. This thermal high is bounded on both the east and west by normal faults. The thermal area located on the horst was thought to be the result of thermal fluids percolating up one of the adjacent faults. Subsequent drilling, however, failed to locate thermal fluids; the highest temperature recorded in the well was 20°C. The temperature difference shown on the isotherm map may be the result of solar radiation warming the ground surface on the south end of the property.

No temperature probe survey was attempted at Walley's Hot Springs because the area surrounding the springs is a swamp. In 1962 and 1963 the Columbia Mining Co., a subsidiary of U.S. Steel, drilled 26 shallow holes in the area around Walley's Hot Springs (Garside and Schilling, 1979). The maximum temperature encountered was 83°C at 21 m depth.

Figure B23 is a shallow temperature gradient map of the Walley's Hot Springs area based on temperature logs of the 26 holes. The isothermal contours were derived using the formula:

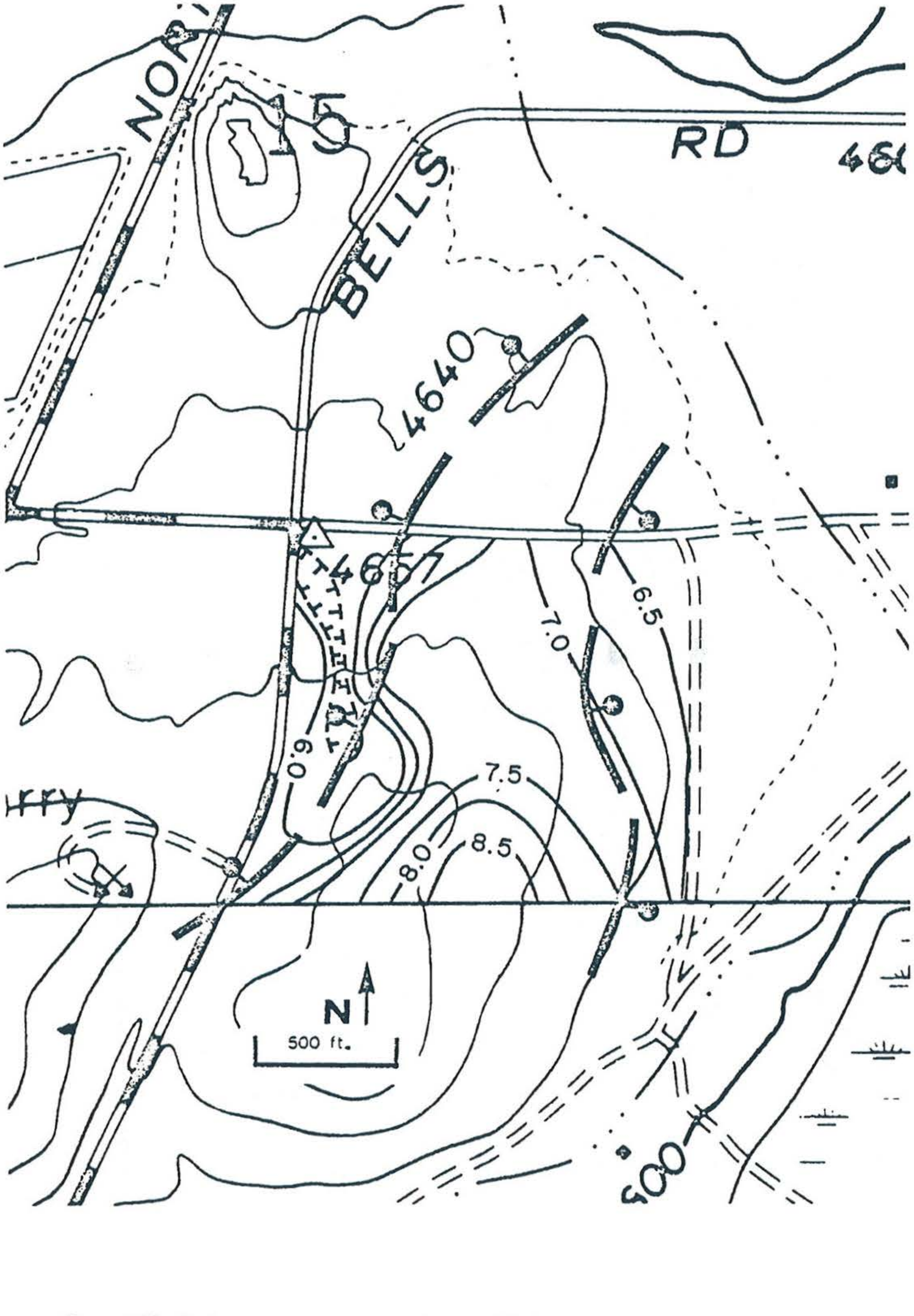


Figure B22. Shallow depth isotherms and mapped faults at drill site CC—1. Ball on downthrown side of fault. (after Bingler, 1978)

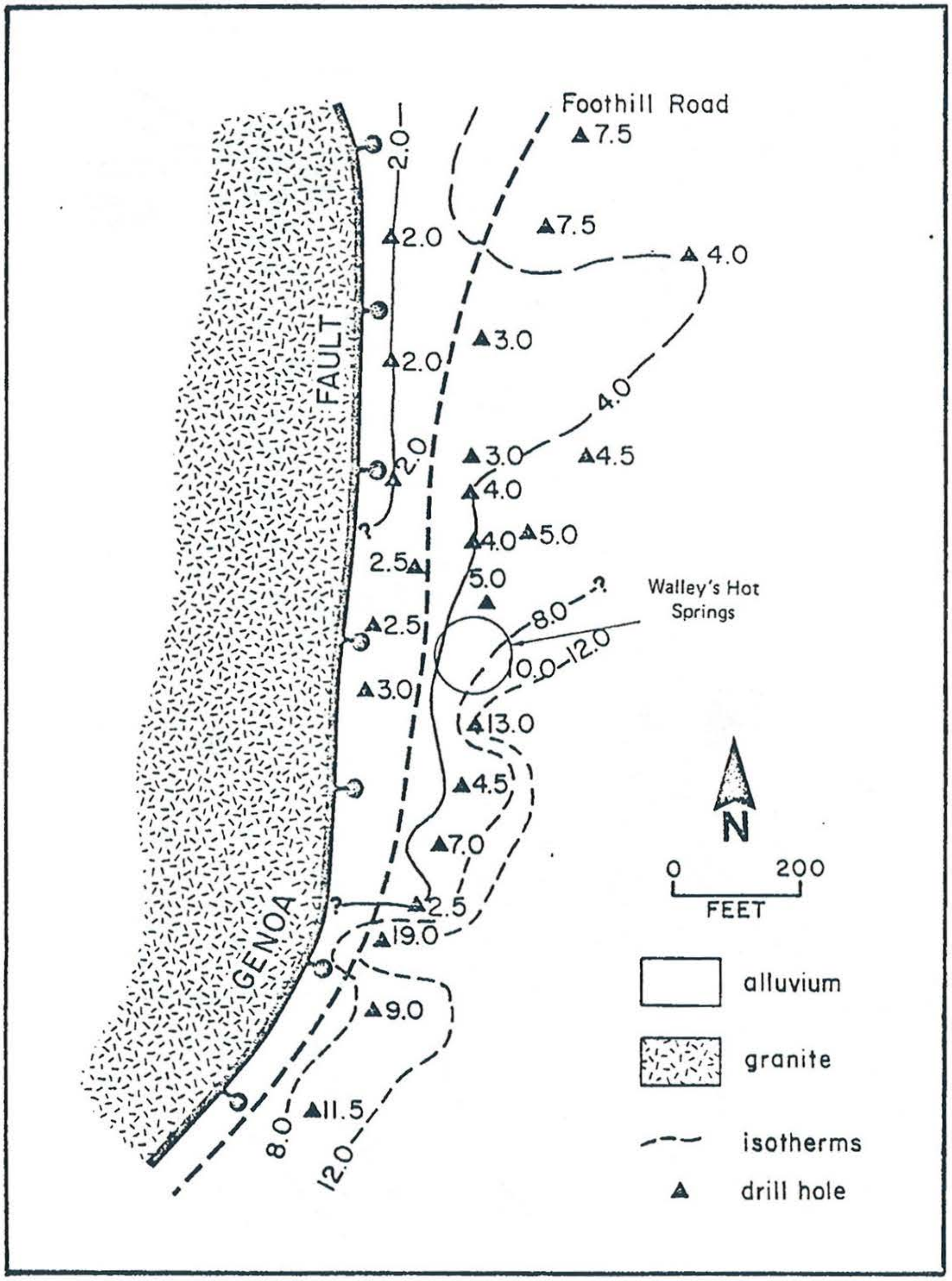


Figure 323. Spatial relationship between shallow temperature gradients and nearby mapped faults. See text for explanation. Ball on downthrown side of fault. (after Garside and Schilling, 1979)

$$T_{iso} = \frac{T_{max}-T_{amb}}{Depth_m}$$

where, T_{iso} is the isotherm temperature

T_{max} is the maximum recorded temperature

T_{amb} is the mean annual ambient temperature

$Depth_m$ is the depth of maximum temperature

It should be noted that all of the temperature profiles show reversals at various depths and the isothermal contours should not be extrapolated.

The data show that the highest water temperatures are limited to the fault zone not only in an east - west direction but also north and south. This observation supports the hypothesis that only a selected portion of the fault zone is being used to conduct rising geothermal fluids.

Figure B24 illustrates the shallow temperature gradients in the Pinyon Hills area and was constructed on the basis of existing water well data. A formula similar to that described for the Walley's Hot Springs area was used to derive the isotherms but the gradient is expressed in units of °C/100 m.

The data show that the isotherms form a linear configuration that is parallel to the range-bounding fault which is exposed just north of the area. The high-temperature isotherms show closure and are of limited areal extent suggesting that only a portion of the fault is currently conducting geothermal fluids.

Soil Mercury

Three soil survey traverses were established concurrently with the gravity traverses in the Carson-Eagle Valley area. Time and budget restrictions limited the extent of the soil geochemistry studies to the existing traverses although the northern traverse, CS, was expanded to cover a larger area.

In general, the data show anomalous mercury values adjacent to known thermal anomalies and the Sierran front indicating a possible thermal source at depth

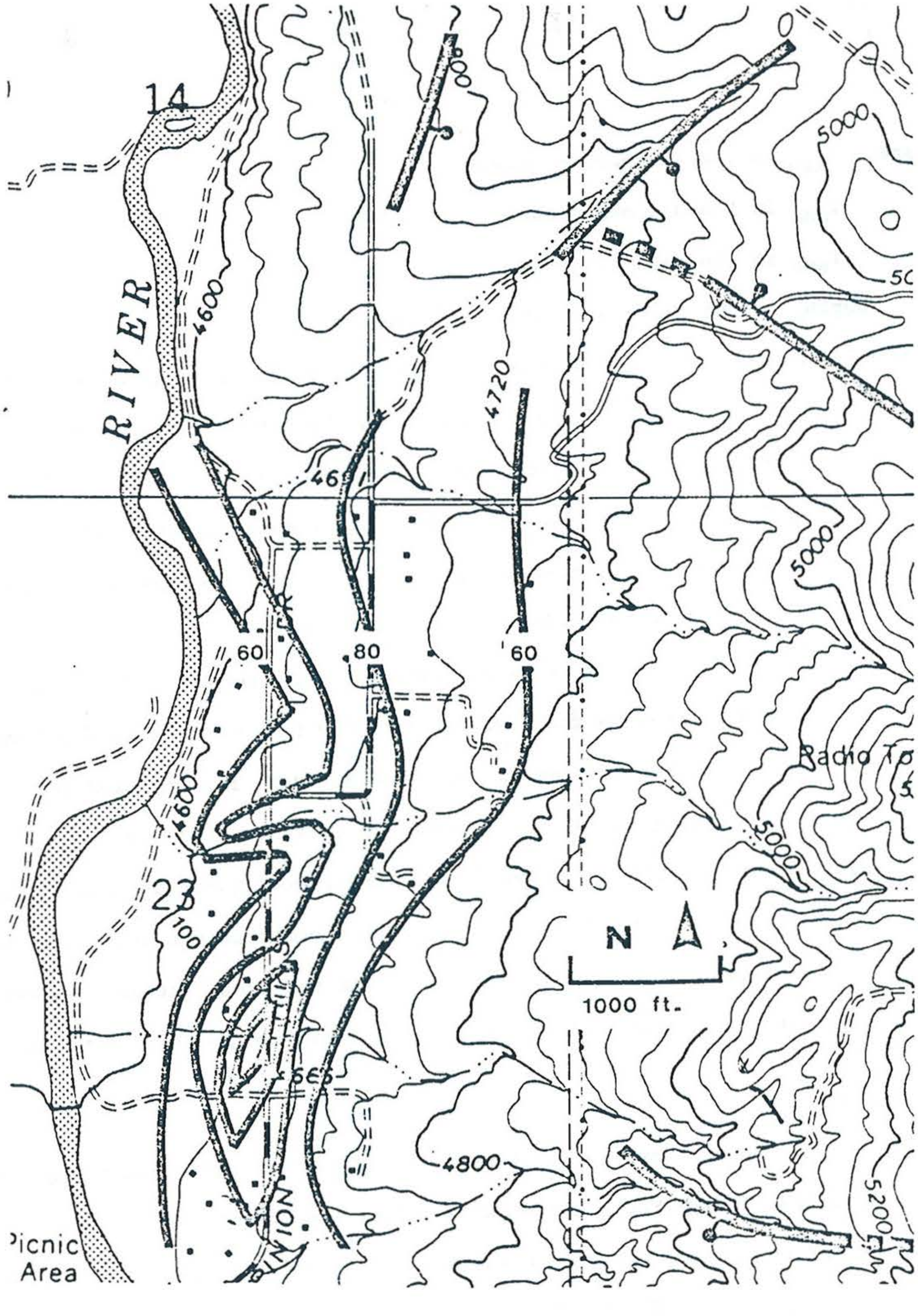


Figure B24. Spatial relationship between Pinyon Hills Wells shallow temperature gradient and nearby mapped faults. Contour interval is 20°C; ball is on downthrown side of fault (after Bingler, 1978) along the Sierran front. The highest anomalous values greater than 6000 parts per billion are located on the CS traverse along the northern Pinyon Hills. The closest geothermal anomaly is the Pinyon Hills area which is 2-3 km south of this mercury anomaly.

Further research of this anomalous area revealed that nearby is a site for several gold and silver mills operated during the mining of the Comstock Lode from approximately 1850 to 1900. These mills used mercury amalgamation to process the ore. Therefore, the anomalous mercury values for these soils is certainly artificial. Thus, this particular mercury soil geochemistry anomaly can not be directly related to a geothermal anomaly. Figure B25 shows the anomalous soil mercury areas in the Carson-Eagle Valley area.

A detailed soil mercury survey was conducted on the property selected for the location of one of the gradient holes, CC-1. Figure B26 shows the results of the survey. The northeast trending zone is subparallel to a fault trending north-northeast in the east central portion of the study area.

Electrical Resistivity Surveys

Using a Werner array for the electrode spacing which ranged from 3-60 m (10-200 ft), electrical resistivity drilling surveys were attempted at Carson Hot Springs and Hobo Hot Springs. The results were not very diagnostic. The data for the Carson area show a conducting layer at 13 m (42 ft) below the surface but this may simply be the top of the water table. Unfortunately, no large scale electrical mapping could be attempted due to the presence of many buildings and recreational vehicles on the property.

A similar experiment was attempted at the Hobo Hot Springs and a conducting layer was found at 15 ft. below the surface. Here, too, electrical mapping was not attempted.

This task was originally intended to aid in the location of unexposed faults. Unfortunately, the benefits of using electrical methods are not matched by the

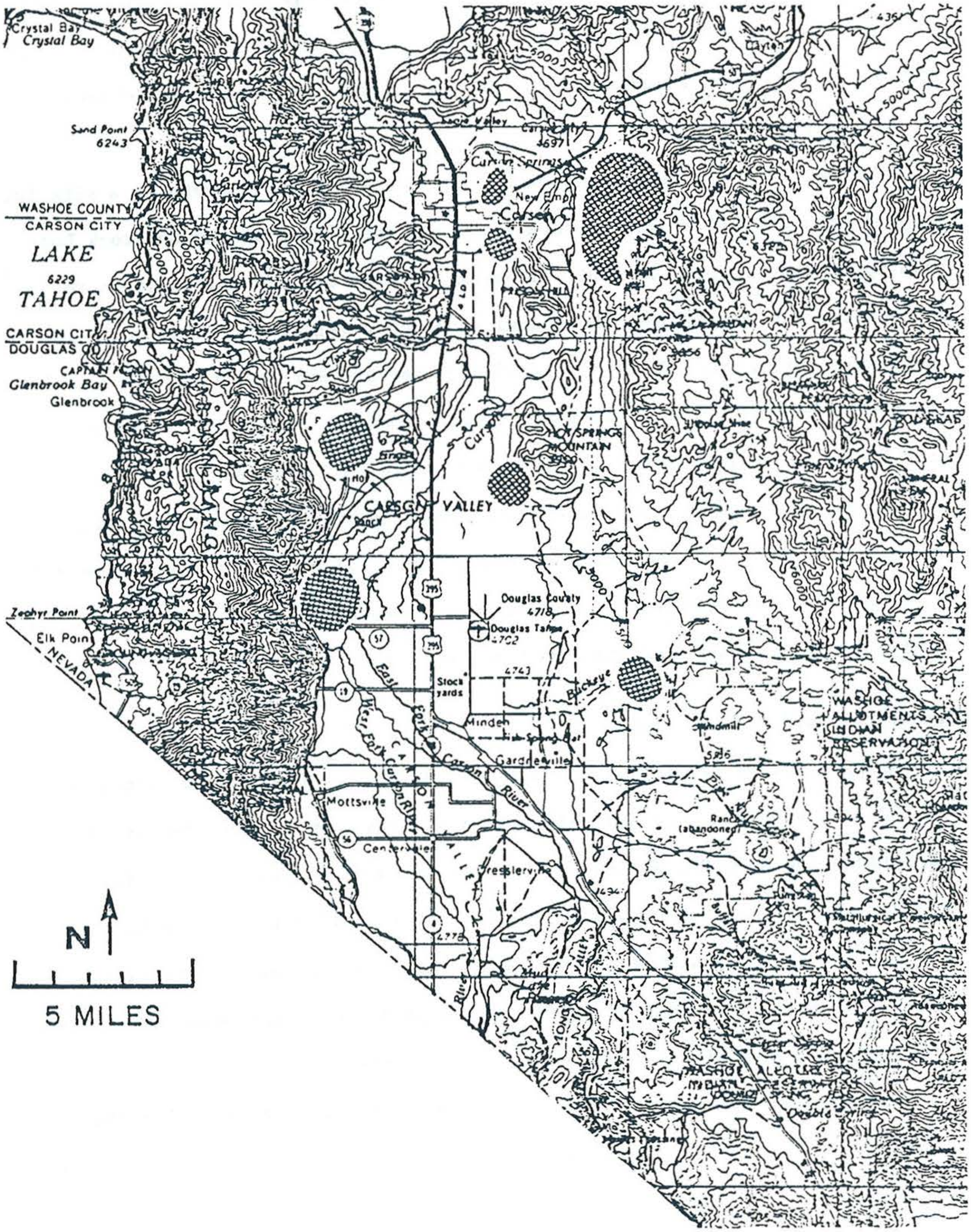


Figure B 25. Areas of anomalously high soil mercury values in the Carson—Eagle Valleys.

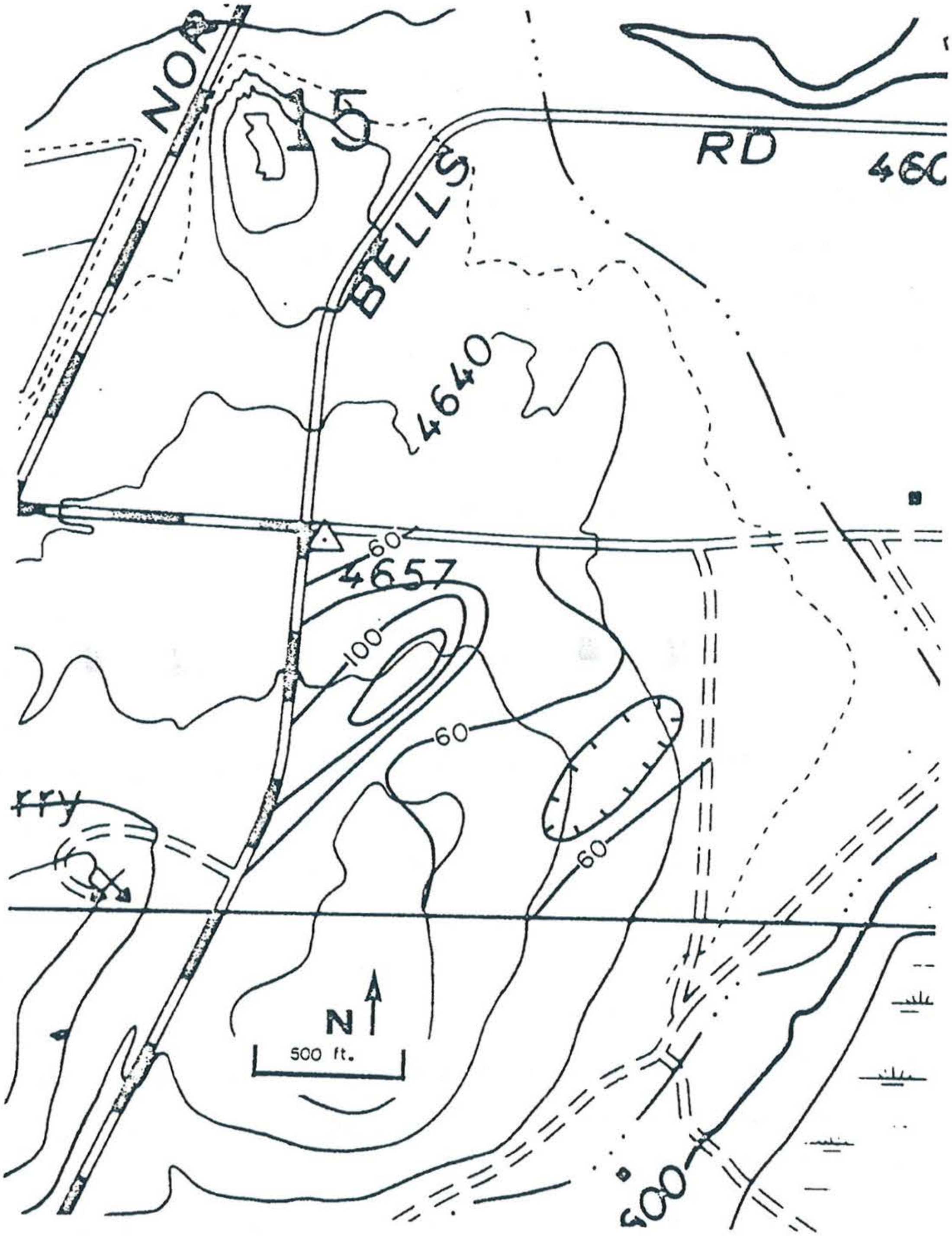


Figure B26. Contour map of mercury (concentrations in ppb) in soil sample at drill site CC–1.

cost of implementation. The method is time consuming and the results are ambiguous. Three other methods, air photo interpretation, soil analysis for mercury and shallow depth temperature probe surveys can be implemented more quickly and more economically over a wider range of conditions and produce results that are more unequivocal.

Drill Site Selection Criteria in Carson-Eagle Valley

The two gradient holes in the Carson-Eagle Valley area, CC-1, and CC-2 were located on the basis of land availability as well as geologic structure criteria. Much of the property in the area is fee simple land is owned by individuals. The holes were located on public land to avoid a possible conflict of interest. The possibilities for selection included properties owned by the Carson City School District, the Carson City municipalities and the State of Nevada.

The final site selections were based on several parameters. CC-1 was sited east of Carson City on property owned by the Carson City School District (fig. B27). This site is located between two known thermal anomalies, Pinyon Hills to the east and the Carson City Sewer Plant to the west and is also the location of a proposed new school building. The actual drill site was located on the basis of temperature survey combined with the presence of a soft, muddy zone surrounded by frozen ground.

CC-2 was selected on the basis of land availability and was located on property owned by the University of Nevada System near the Western Nevada Community College. This area also showed evidence of snow melt patterns indicating a possible high heat flow area and was situated in an area of recent faulting (fig. B3).

Other sites had been considered but they did not meet the requirements needed for a gradient hole site.

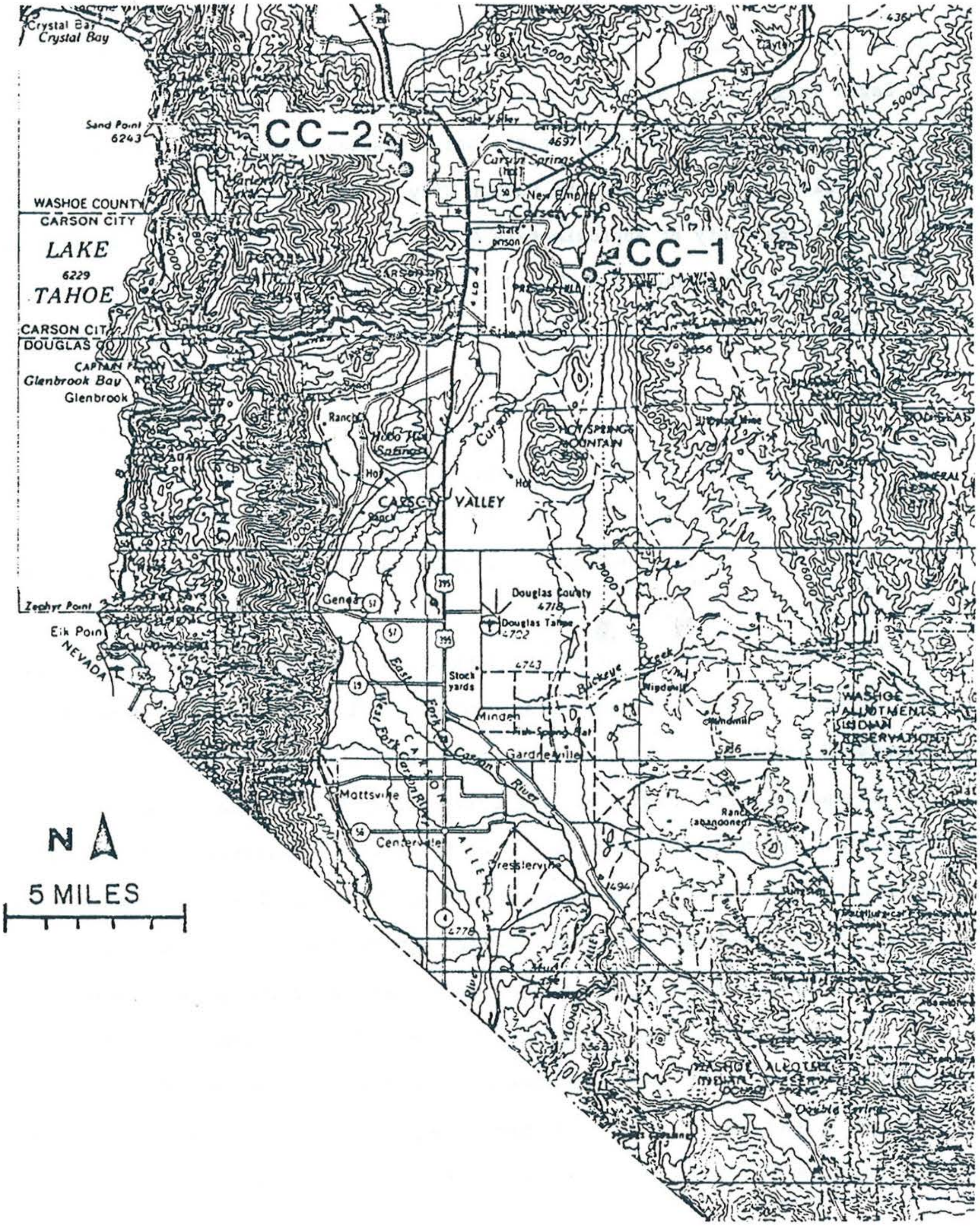


Figure B27. Locations of temperature gradient holes CC–1 and CC–2 in the Carson–Eagle Valley.

Carson-Eagle Valley Gradient Drilling

The first two gradient holes of the project were drilled in Eagle Valley during the month of February, 1980. The holes were located on opposite sides of Eagle Valley (fig. B27) and were designated CC-1 and CC-2.

CC-1 was located between two thermal anomalies within Eagle Valley, Pinyon Hills to the east and the Carson City Sewer Plant to the west. Drilling began on 12 February at approximately 4:30 p.m. using a 7 1/2" tricone bit to drill a large enough hole for the 6" surface casing. Drilling was carried out by a single crew on a 12-hour shift with project personnel on hand to monitor the return temperatures and log the cuttings during the entire shift.

A single joint (22 ft) of 6" casing was installed in the hole on the morning of the 13th. The 7 1/2" tricone bit was replaced with a 6" Ingersoll Rand downhole hammer which was used to drill the remainder of the hole. Drilling continued at a moderate rate until the 15th when the drill string became stuck in the hole due to caving.

Only minor rotation, one to two turns, and a few inches of vertical movement were obtainable. This movement continued all day but resulted in an overheated hydraulic system which had to be shut down to cool.

At approximately 6:00 p.m. the drill string began to work free and by 10:30 p.m. the entire string was out of the hole. Unfortunately, the hammer had twisted off at an internal joint leaving the hammer box sub still attached to the string. A decision was made to try fishing the tool out the next day.

The first attempts to recover the hammer were made on the morning of the 16th using the string to try to fish the tool out and by washing out the hole with air. These methods were unsuccessful, and a decision was made to switch to mud to clean out the hole and then attempt to recover the tool. Additional parts were needed to convert the rig to mud drilling. A decision was made to take the next day off while the parts were shipped via air freight from Denver, Colorado.

Drilling began again on the 18th using a tricone bit and washing the hole out with mud. Some circulation was lost but was regained by adding lost circulation material, LCM, to the mud. The operation was stopped near mid-shift because of inclement weather. Very low temperatures, high wind and rain mixed with snow produced unsafe working conditions.

With improved weather conditions washing of the hole continued on the 19th. By 9:45 a.m. the drilling string had reached the top of the hammer and the hole appeared stable. The string was tripped out and the bit was replaced with the hammer sub. An attempt to spear the hammer with its own sub was made and the hammer was recovered on the first effort and slowly removed from the hole. The bit was put back on the string and drilling continued.

The target depth of 500 ft. was reached at 2:00 p.m. on the 20th, and casing was prepared for installation on the 21st.

Prior to installing casing on the 21st the hole was flushed with Barafos to break down the drilling mud. The casing operation was started and was nearly complete when logistic problems caused a 24 hour delay in the casing operation. Following the correction of the problems, the casing operation was routinely completed on the 22nd at about 1:00 p.m.

CC-2 was located in the western Part of Eagle Valley (fig. B27) on property owned by the University of Nevada. The drill site is situated in an area of recent faulting. There are reports of rapid snowmelt in that area as well.

CC-2 was spudded in at 7:30 p.m. on February 22 after improvements on the road leading to the site were made. These improvements allowed the drill rig to reach the site. Drilling rates with the 7 1/2" tricone bit were rapid because the material consisted of decomposed granitic rock. At the end of the first day of drilling the depth of the well was 95 feet. Drilling was stopped because the surface casing had not arrived on site.

Drilling resumed at 12:00 p.m. on the 23rd after 97 feet of 6" surface casing had been installed. A 5 7/8" tricone bit and an air-foam medium were used in this drilling operation. A total depth of 240 feet was reached at about 2:00 p.m. and the gradient casing string was installed by 4:30 p.m. Drilling progress charts for both CC-1 and CC-2 are shown in figure B28.

Results of Temperature Gradient Drilling

Soon after completion of CC-1 a temperature profile was completed using a DIGETEC temperature sensor attached to a 1000 foot cable for down-hole measurements. The results of the temperature log are illustrated in figure B29. The diagram on the left shows the actual measured temperature as a function of depth. The gradient is positive but the maximum temperature recorded was only 20°C at 500 feet. The diagram on the right illustrates the change in the geothermal gradient with increasing depth. This diagram indicates that normal geothermal gradient for this area was perterbated between the 300 and 400 foot interval. This was the result of large volumes of cold ground water which were encountered at all intervals during drilling.

No warm water intervals were encountered during or after the drilling of CC-1. There appeared to be some indication that warm or hot water was encountered during the final phases of drilling. Unfortunately, a wet thermistor probe connection was found to be the cause of the anomalously high temperatures.

The lithologic log for CC-1 is illustrated in figure B30. Most of the drilled material consisted of slightly metamorphosed (greenschist facies) volcanic breccias and mudflows of Triassic and Jurassic age. These rocks are among the oldest exposed in this study area and have been described as roof pendants in the granodioritic batholith which underlies the entire area.

DRILLING PROGRESS CHART FOR CC-1 AND CC-2

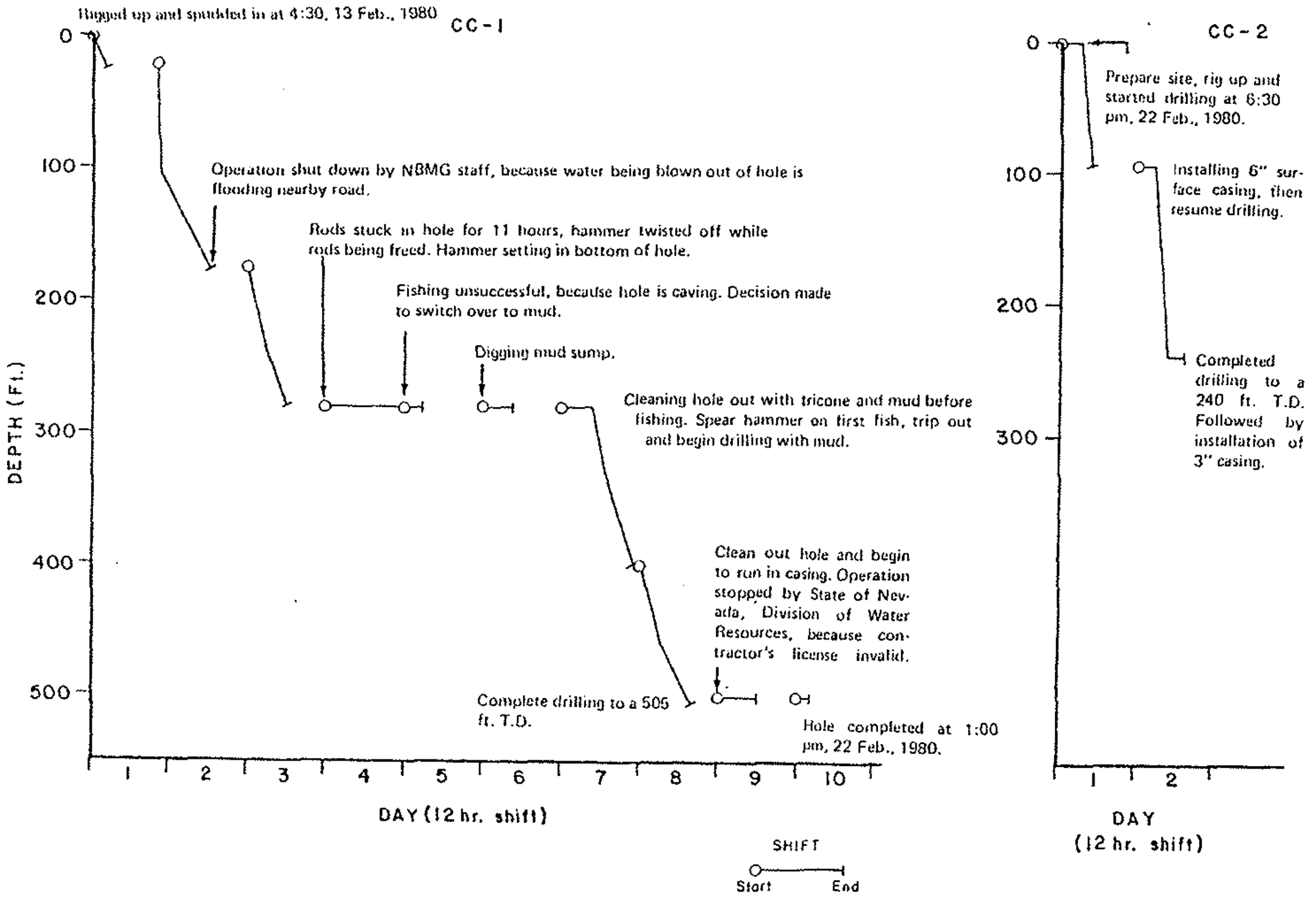
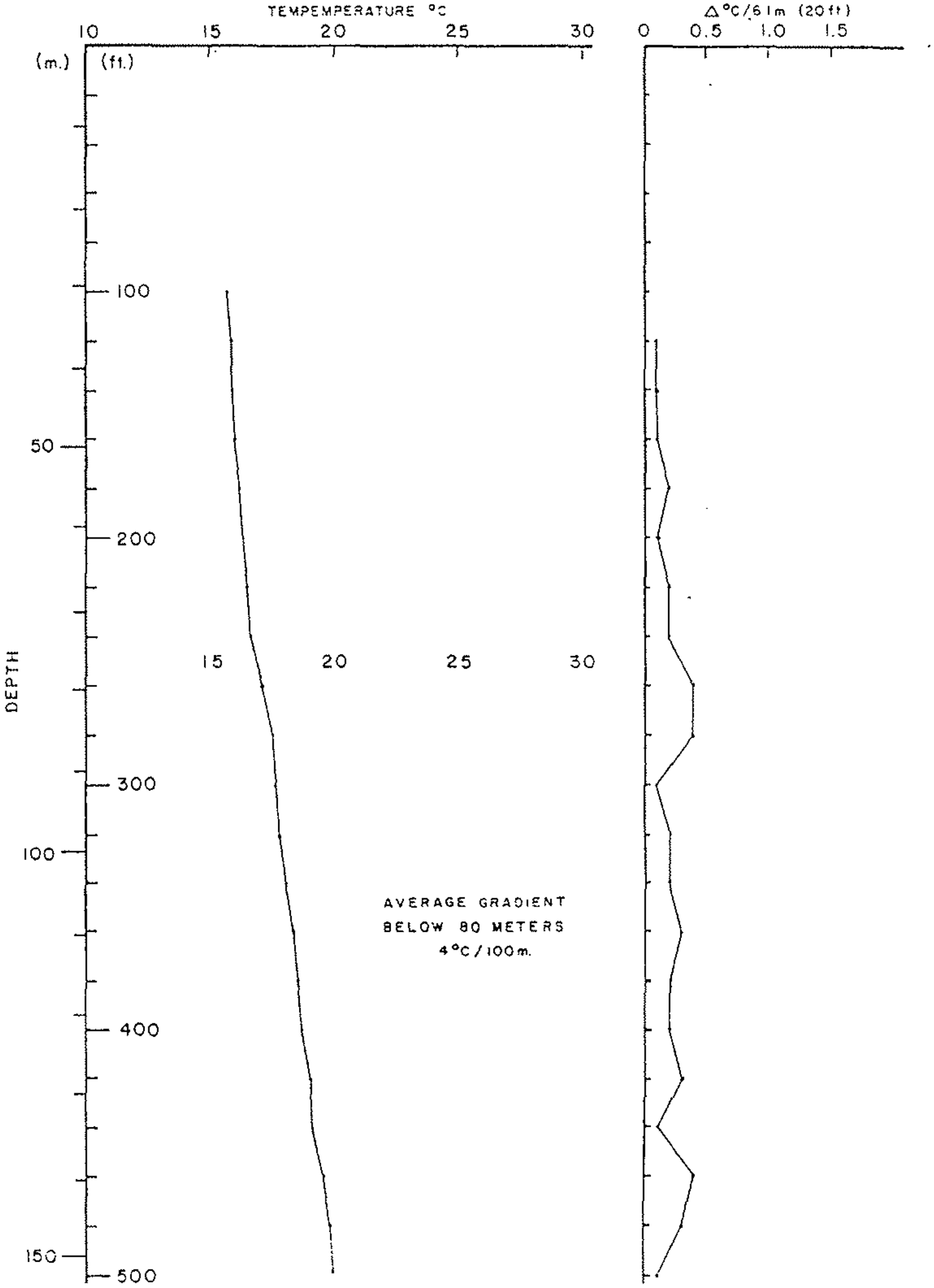


Figure B28

Figure B29.

TEMPERATURE GRADIENT PLOTS FOR CC-1



GENERAL LITHOLOGIC LOG
CC-1

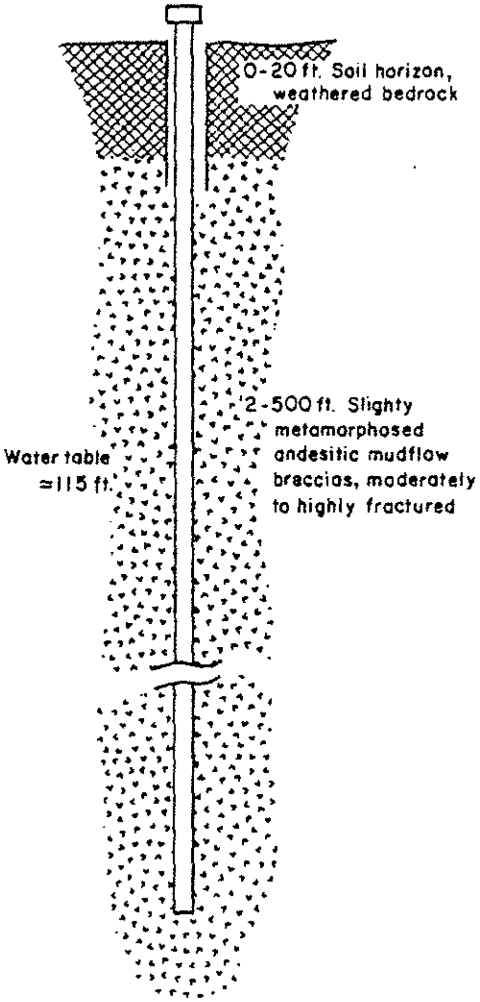


Figure 8 30.

Samples of the drill chips from several intervals were examined with a polarizing microscope and X-ray diffraction equipment. The petrographic analyses revealed a fine- to medium-grained highly altered and highly variable mineral assemblage. The original rock appears to have been of volcanic origin containing micro-phenocrysts of plagioclase and pyroxene in various stages of alteration and obliteration. Many of the samples showed a vuggy texture, and these voids were often filled with calcite and quartz. Sericite, chlorite and epidote are widespread in all the samples and probably reflect the alteration episode prior to and during emplacement of the granite batholith. Minor minerals included magnetite, biotite and potassium feldspar. The mineralogic composition was consistent throughout the 500 foot interval and there is no indication that the contact between the lower Mesozoic metamorphic rocks and the upper Mesozoic intrusive rocks was reached.

No temperature gradient profiles could be measured in CC-2 because the hole was vandalized shortly after it was completed. The locked cap on the well bore was destroyed and the well bore was filled with debris. An attempt was made to remove the clog with a small cable tool but the hammer could not dislodge the obstruction. Apparently the hole had been filled with sand to a level 60 feet below the surface.

During the drilling a small amount of cold water was encountered but the level of static water was not measured.

The lithologic log for hole CC-2 is presented in figure B31. This diagram shows granite bedrock overlain by almost 200 feet of alluvial material, primarily a decomposed granite. The alluvial material is mineralogically identical to the basement material. Both units contain abundant plagioclase, quartz and perthitic potassium feldspar. Accessory minerals include biotite, hornblende, magnetite and sphene. Small volumes of more mafic mineral assemblages were

GENERAL LITHOLOGIC LOG
CC-2

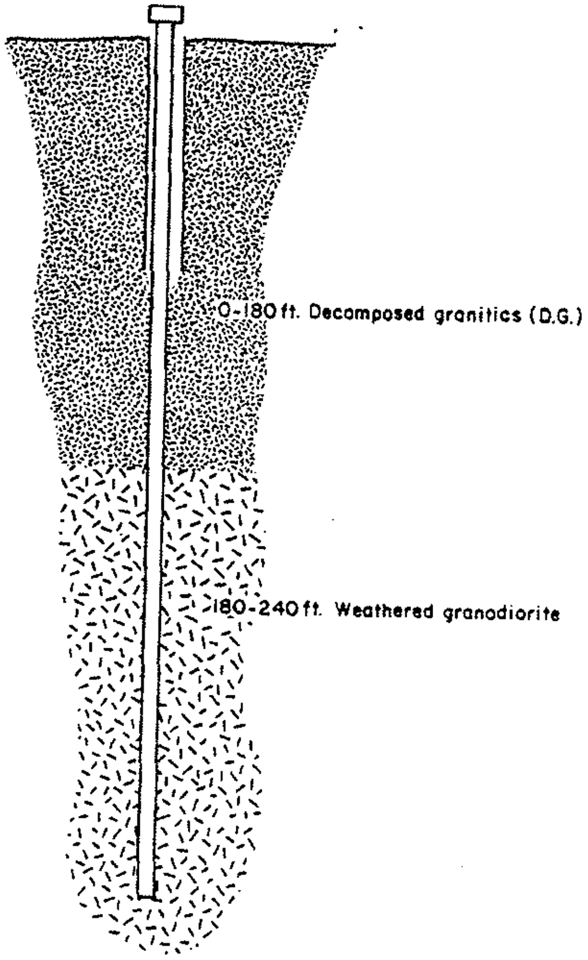


Figure B31.

present in the drill chips and these were probably parts of xenoliths which are widespread in the batholith.

Summary and Conclusions

Normal faults associated with Basin and Range style deformation are the major structural controls for geothermal fluids in the Carson-Eagle Valley study area. These faults can be identified on the surface by abrupt changes in topography and lithology and can also be seen in gravity profiles along traverses normal to the strike of the fault. Total displacement along these faults appears to be at least 1.5 km and may be as much as 3 km. Portions of these fault zones are presently conducting rising geothermal fluids to the surface. Lineament analysis supports previous interpretations which suggest that the orthogonal intersections of faults along major range fronts in the Basin and Range and the Sierra Nevada Front provide major zones of weakness in the upper crust (Trexler and others, 1978; Trexler, 1979). In many cases only one of the orthogonal fault patterns reaches the surface. This fault plane intersection may be a zone of enhanced permeability which provides the initial conduits for rising thermal fluids. A model of this hypothesis is illustrated in Figure B32.

Near-surface temperature measurements from 2 m probes and shallow depth water wells reveal a linear isotherm configuration in the area surrounding the rising geothermal fluids. The lineation is probably the result of thermal fluids that spread out along the zone of most recent faulting.

Chemical analyses of fluids from the study area indicate significant compositional differences in major dissolved constituents between thermal and non-thermal fluids. Non-thermal fluids show greater chemical variation and appear to be mixing with the two varieties of thermal fluids in this area. Chemical geothermometers are of little value for these fluids,and maximum reservoir temperatures based on direct measurements in shallow wells probably range from 90°C to 100°C. Stable isotopes of hydrogen and oxygen indicate that the thermal

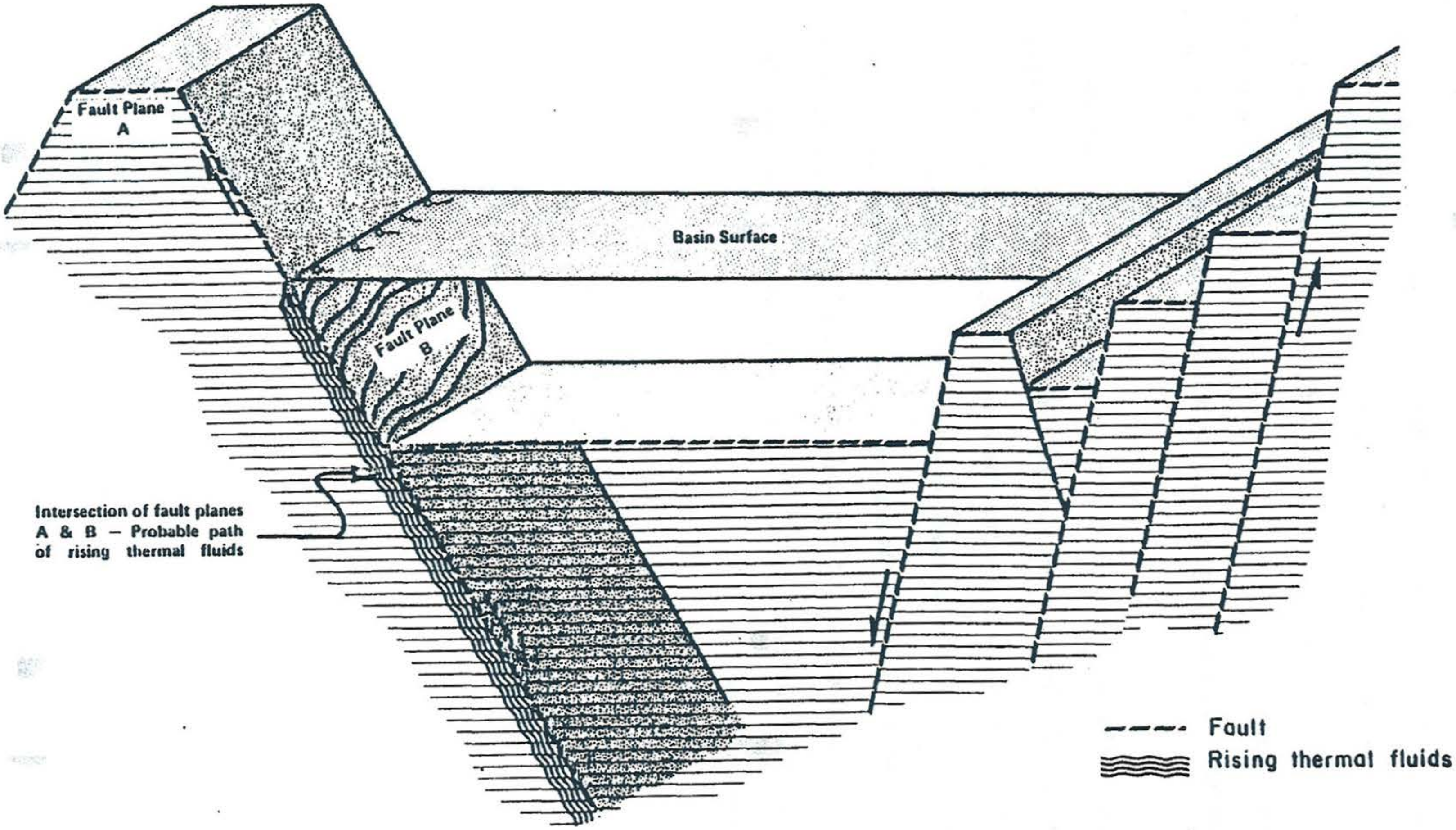


Figure B32. Graphic model showing the inferred structural controls on the upwards migration of geothermal fluids in the Carson–Eagle Valley study area.

fluids are compositionally similar to the non-thermal fluids and are ultimately derived from meteoric waters. Some of the thermal fluids are, however, slightly isotopically lighter than the non-thermal fluids and these are probably derived from the snow-pack in the nearby Carson, Virginia and Pine Nut Ranges.

No thermal fluids were encountered in the two temperature gradient holes. Based on shallow, warm water wells and a 2 m depth temperature probe survey the geothermal reservoirs in this area appear to be narrow zones of limited areal extent.

Although the geothermal resources in this area are low- and moderate-temperature and are of limited extent commercial development is currently underway at Walley's Hot Springs. Plans have also been made to use the thermal waters at Saratoga Hot Spring for space-heating in a new residential subdivision. The Carson Hot Spring is currently being used as a spa but may be tapped to heat a new commercial office complex. The Pinyon Hills area geothermal resource is now being used to heat some residences. There are no planned uses for Hobo Hot Springs at the present time.

BIG SMOKY VALLEY

INTRODUCTION

The Big Smoky Valley is situated in central Nevada. It begins at a point 12 miles east of the town of Austin and extends approximately 100 miles in a southwesterly direction to reach a southern terminus near Coaldale Junction some 40 miles to the west of Tonopah. Hydrologically and topographically the valley is divided into northern and southern sections by a physiographic high near the mining community of Round Mountain. Our study area was limited to the northern section (fig. A1) and contains three geothermal resources located at the points labeled Darrough's, McLeod and Spencer's in figure C1. The area was chosen for study based on its "high" potential rating for industrial process heat direct utilization (Trexler and others, 1979).

Geologically the region is complex with a lithologic history extending from the pre-Cambrian to the Holocene. Rocks comprising the Toiyabe Range which forms the valley's western boundary within the study area include Pre-Cambrian and Paleozoic siliceous, argillaceous and calcareous sediments and metasediments, Paleozoic lavas, Mesozoic intermediate to acidic intrusives, Tertiary lavas, tuffs and sediments. The Toquima Range forms the valley's eastern limit and contains Paleozoic siliceous, argillaceous and calcareous sediments and metamorphic rocks, Mesozoic intermediate intrusives and Tertiary intermediate flows and silicic ash flow tuffs. Quaternary to recent alluvial, fluvial, lacustrine and playa deposits form the valley floor.

Structural features of the region are also indicative of a long and complex history. Evidence can be found for regional metamorphism folding from a scale of near invisibility to several tens of feet in amplitude, large scale low angle faulting related to the Robert's Mountain Thrust, large displacement high angle faulting largely associated with the Basin and Range tectonics, small to moderate scale faulting in alluvial materials and numerous intrusive events.

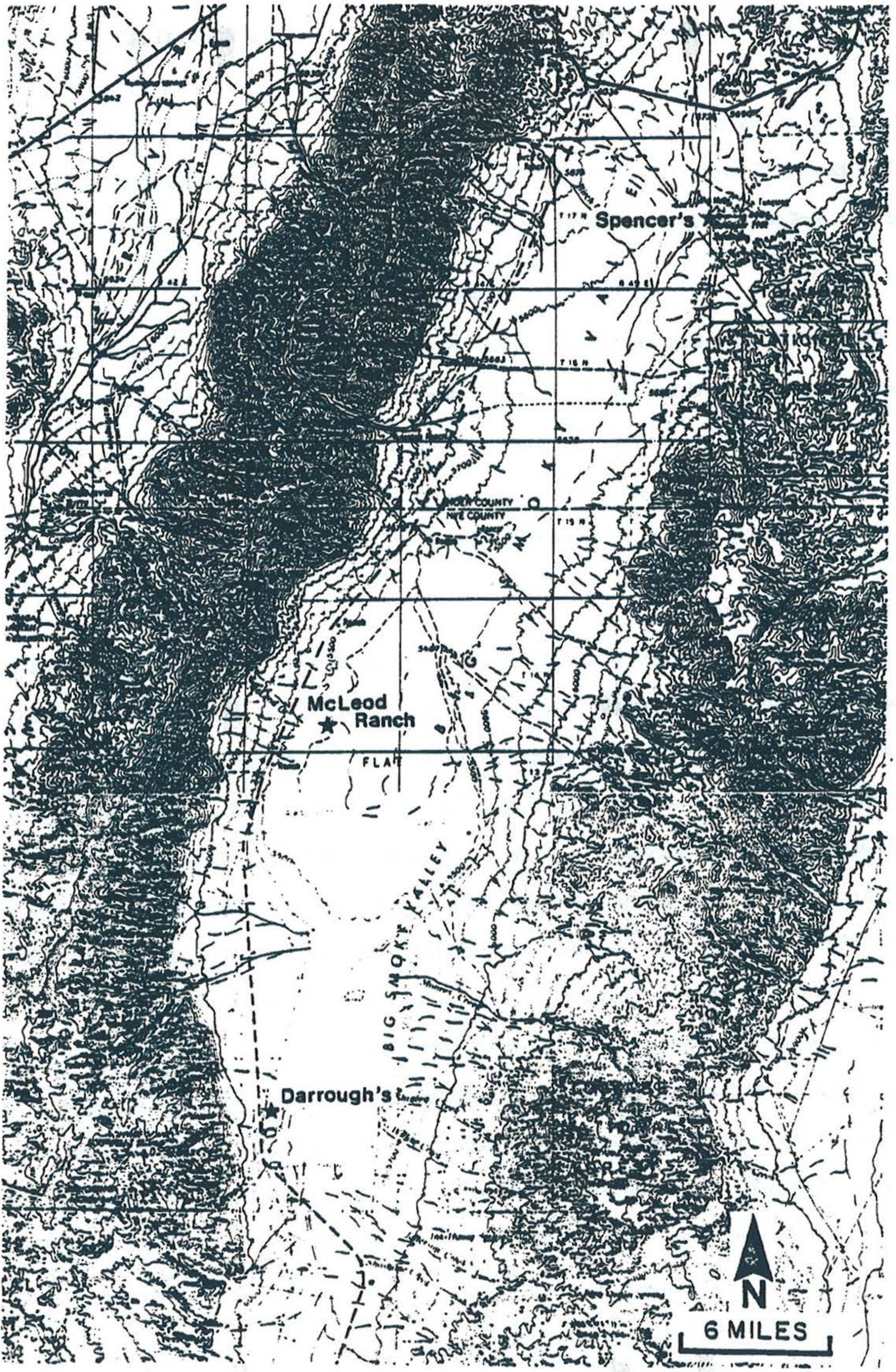


Figure C1. Location of Big Smoky Valley geothermal resources investigated during this study.

Generalized geologic maps (figs. C2, C3) outline the distribution of some of the lithologies and structural features of the study area. More detailed information is available in Ferguson and Cathcart (1954), Kleinhampl and Ziony (1967), Means (1962), Meinzer (1917), McKee (1968), McKee (1972), McKee (1976), Speed and McKee (1976) and Stewart and Carlson (1978).

GEOTHERMAL RESOURCE INVESTIGATION

The techniques and equipment used to conduct the investigation of the geothermal resources within the Big Smoky have been described in the introduction of this report. This section reviews the data gathered, discusses the specifics of and problems associated with the application of the techniques in this study area and presents possible interpretations of the results.

Geological Reconnaissance

Because of limited accessibility and time considerations our study was devoted to field stratigraphic and structural examination in this area. Samples of some of the major rock types were collected in the range near the geothermal occurrences and were made into thin sections for study. This was completed as a preliminary step in choosing appropriate samples for whole rock chemical analyses for use in determining possible fluid recharge paths (by comparing whole rock chemistry to that of the thermal fluids). Unfortunately, because of problems associated with the fluid analyses which will be discussed under a separate heading no whole rock analyses were performed.

An area of altered rocks along the range front of the Toiyabe Range and in the vicinity of the McLeod Ranch hot springs was also visited. Examination of the rocks revealed no currently active or recent geothermal phenomena, that the rocks were highly altered tuffs which have been placed in the present position by block faulting and that the alteration is probably the result of pre-Quaternary hydrothermal processes.

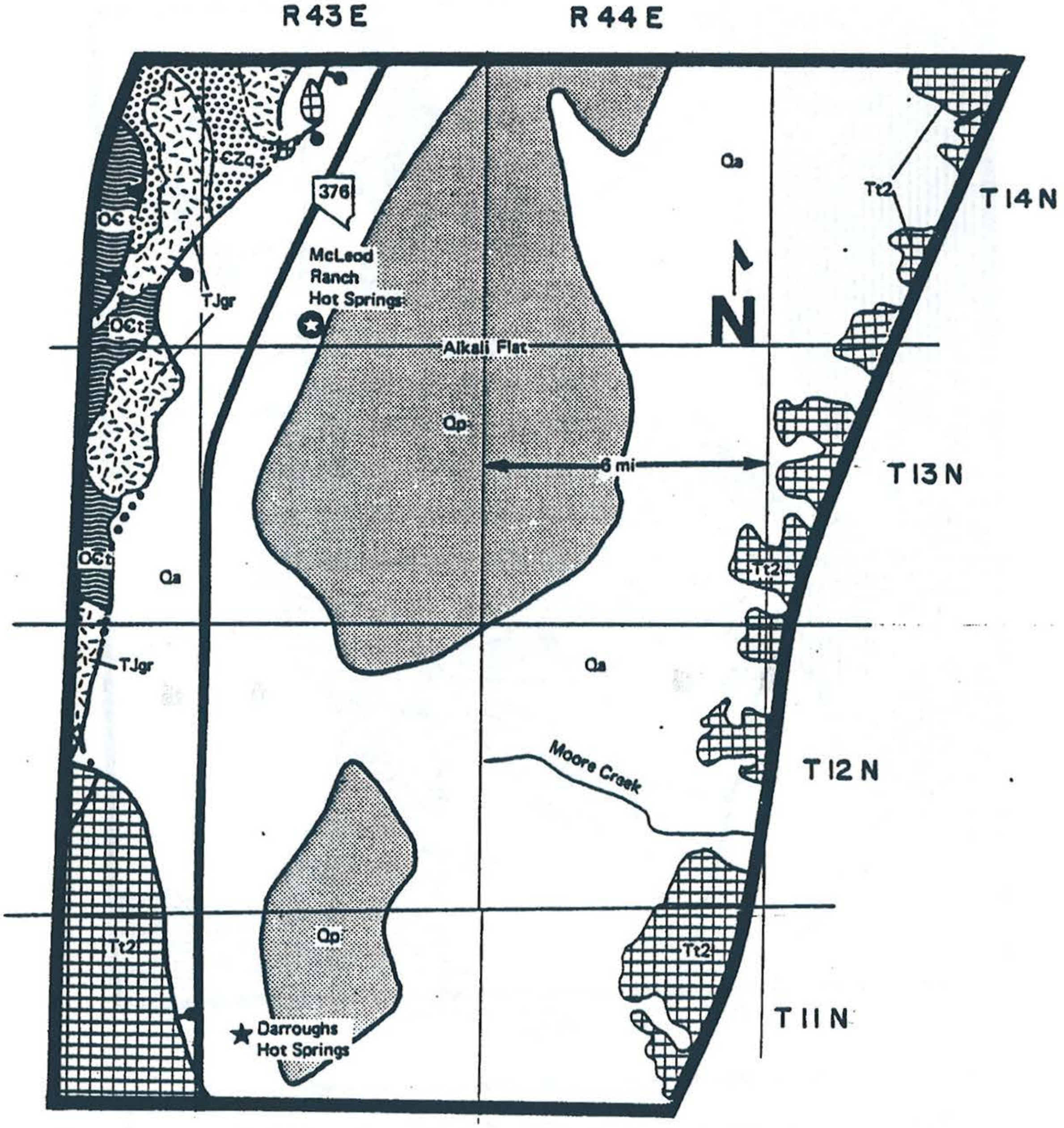


Figure C2. Generalized geology of central Big Smoky Valley. After Stewart and Carlson (1978).

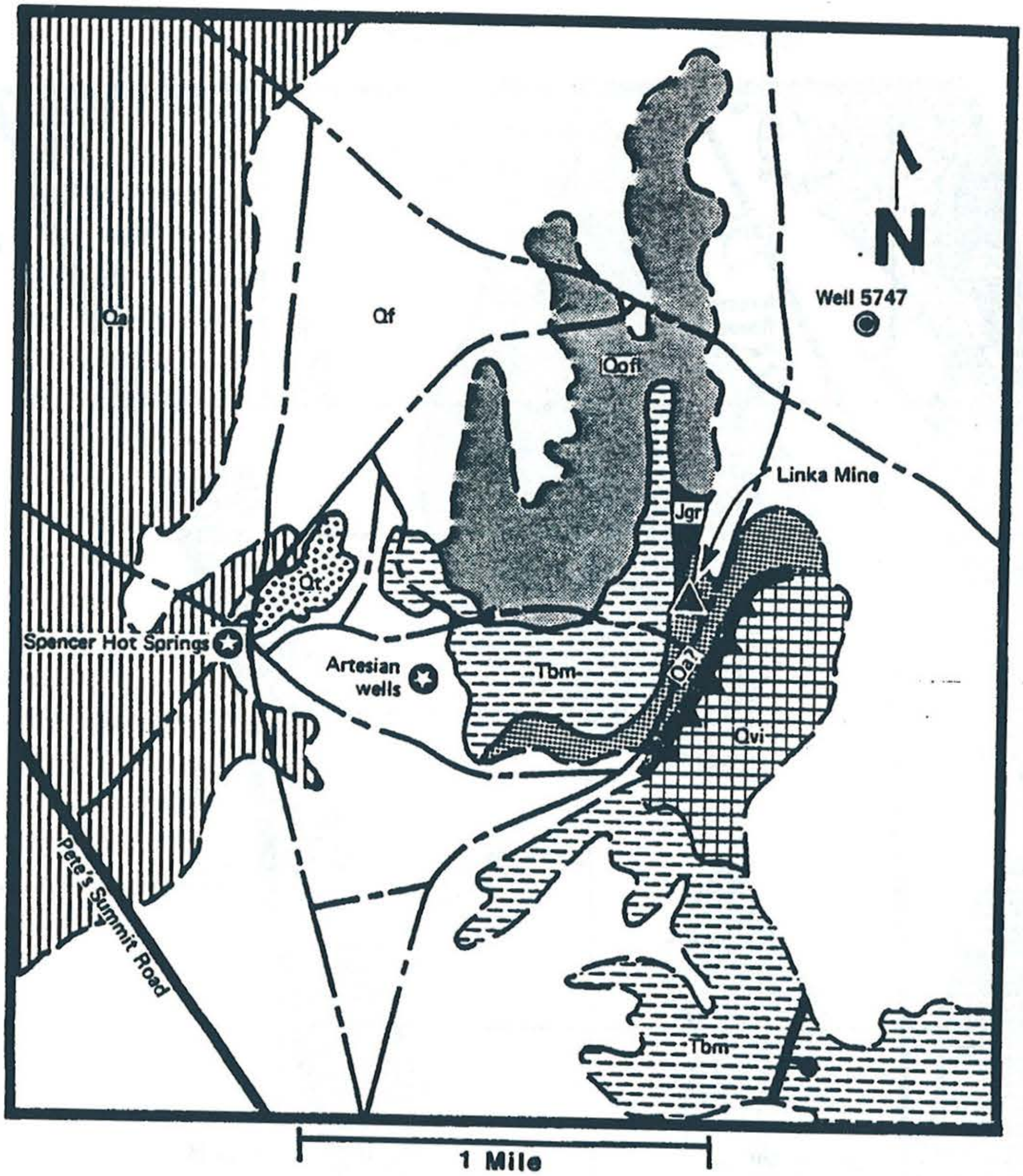


Figure C3 . Generalized geology of Spencer Hot Springs. After McKee (1968).

Qof	Quaternary old fan deposits	Tbm	Tertiary tuff
Qa	Quaternary alluvium	Jgr	Jurassic granite
Qf	Quaternary alluvial fan	Ovi	Ordovician chert and quartzite
Qt	Quaternary tuff	Oa	Ordovician limestone

Alluvial processes along the range fronts bounding the valley have remained active over a considerable period of recent geologic time. This activity has essentially eliminated any clear definition of fault plane dips in the area. Thus,no attempt was made to measure these angles. The orientation of faults and their relationship to the present geothermal occurrences are more easily studied using aerial photographic techniques and will be discussed under that topic.

Gravity

Prior to our study only a limited amount of gravity data was available for the area in the form of a 1:250,000 scale Bouguer gravity map by Erwin and Bittleston (1977). This map provides regional trends for the section of the study area from the McLeod Ranch northward. In general, their data indicate a basin with the western side dipping more steeply than its eastern counterpart and the deepest segment occurring along the valley's central axis. The five milligal contour interval used on the map does not provide sufficient detail to accurately define the location of range bounding faults. For this reason and the complete lack of data for the study area's southern portion, a series of traverses were completed with emphasis on the data-deficient area.

Approximately 250 stations were occupied along six traverses. Four of the traverses were oriented approximately normal to the valley's central axis while the remaining two maintain a nearly north-south direction (fig. C4). Station spacing varied from 0.4 to 0.54 kilometers which provided both a practical working distance for theodolite measurements and a sufficient data density for our purposes. A short description of the individual traverses follows. <u>Traverse S</u> (Spencer's) the "simple" and "complete" Bouguer anomaly curves are plotted with the corresponding topography in Figures C5a and C5b. Evidence of the western range bounding fault system is seen as a group of inflections in the curve at and to the left (northwest) of the point labeled BM6034 in Figure C5a. From BM6034

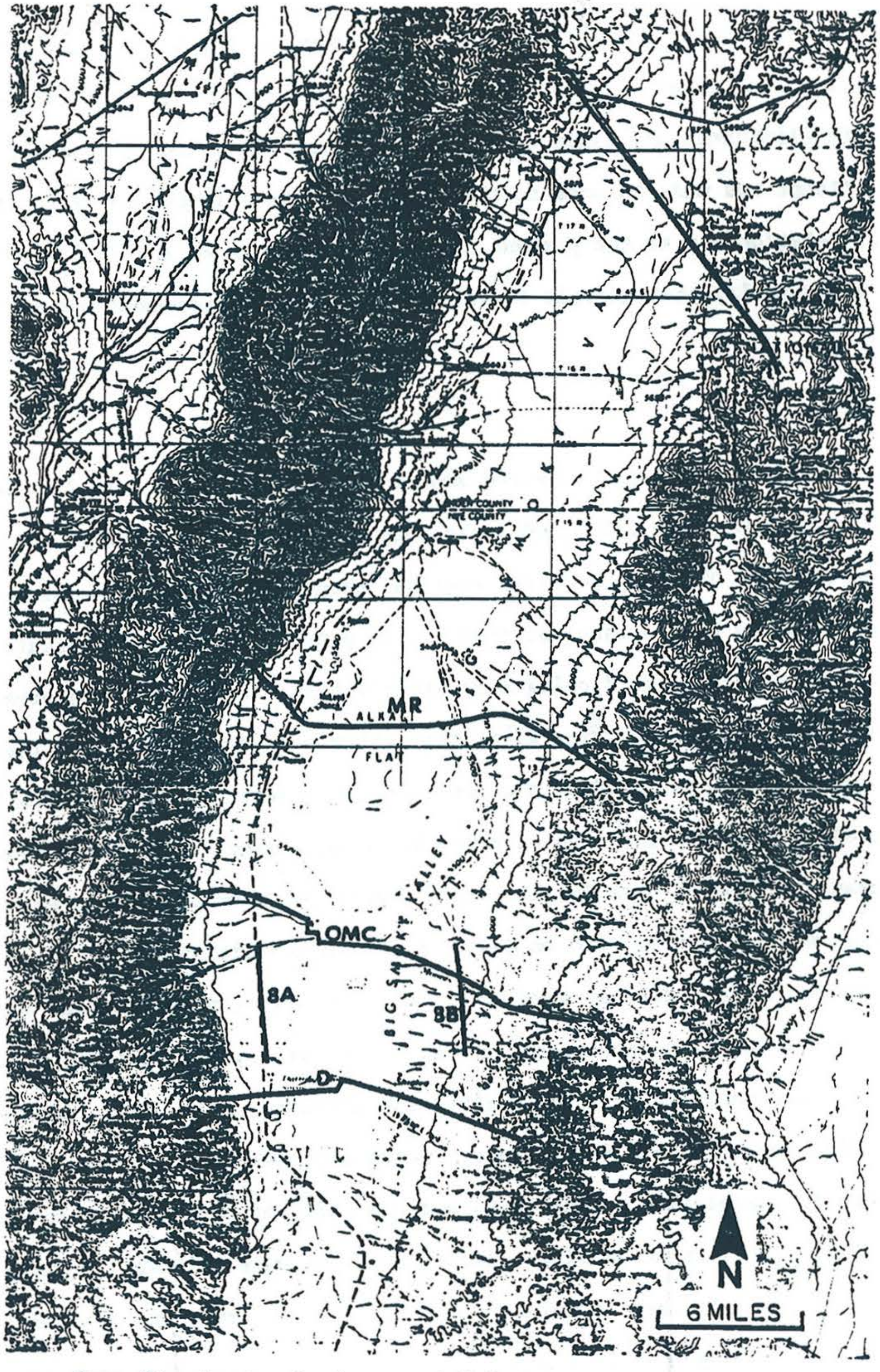


Figure C4 . Locations of gravity traverses in Big Smoky Valley.

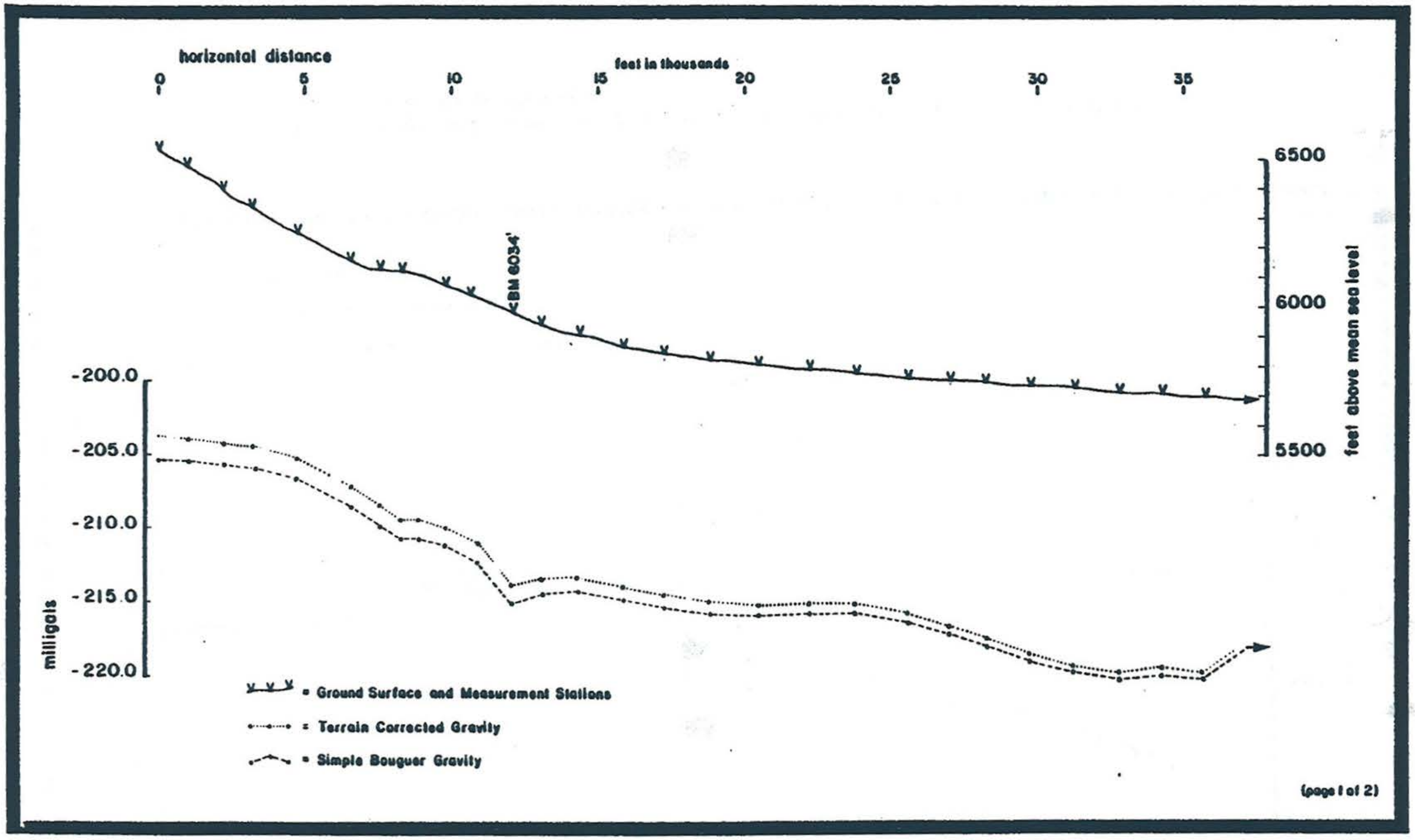


Figure C5a . Simple and complete Bouguer anomaly, and topography of the western segment of the S (Spencer's) gravity traverse.

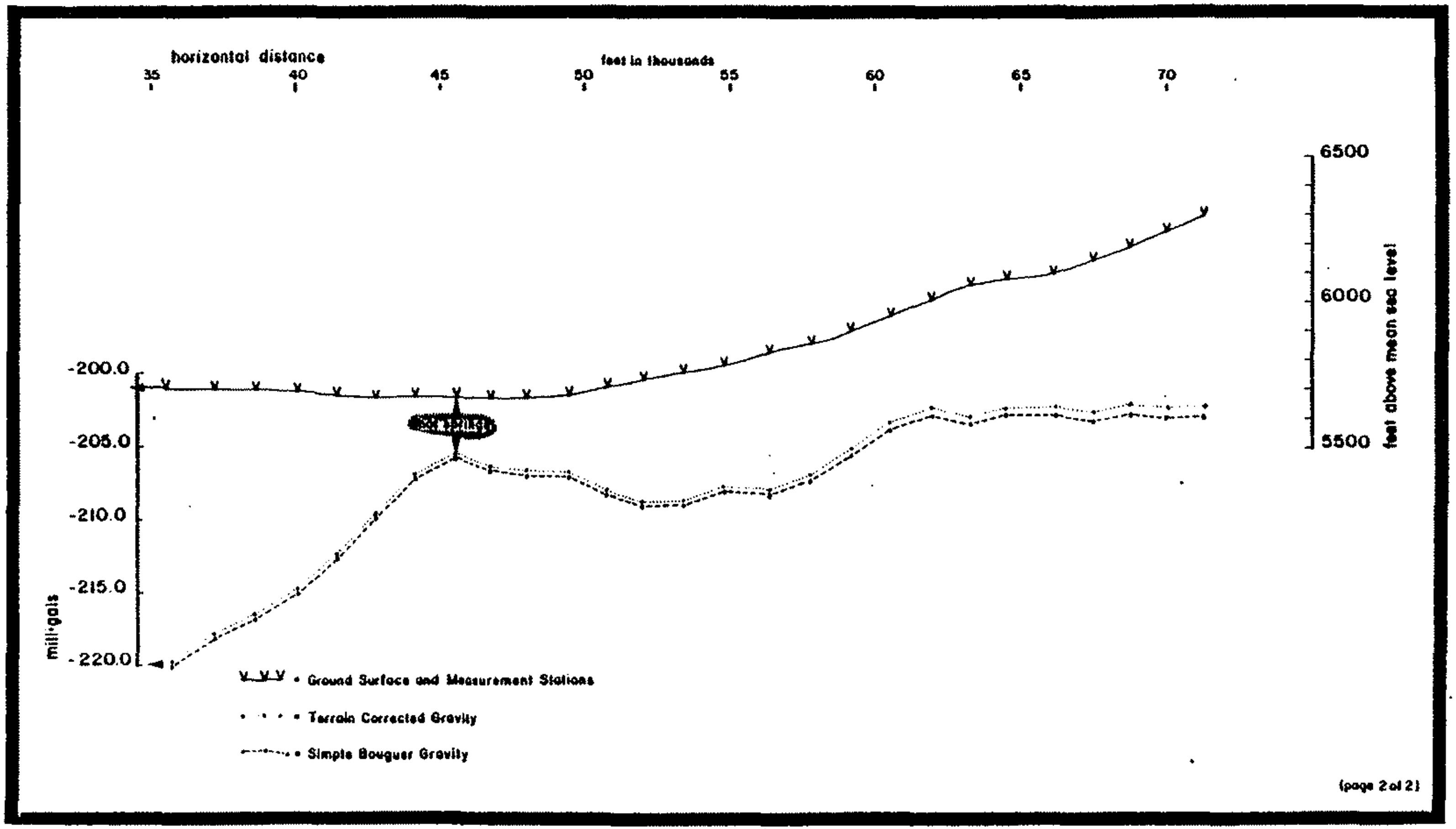


Figure C5b. Simple and complete Bouguer anomaly, and topography of eastern segment of the S (Spencer's) gravity traverse.

moving to the right (southeast) the subsurface slopes downward in two gentle approximately linear segments to a point about 35,000 feet from the beginning of the traverse. This point appears to be the location of the greatest thickness of valley fill encountered on the traverse. For comparison purposes the thickness of the alluvial materials can be roughly estimated using the formula of Thompson and Sandberg (1958) with a density contrast of $0.5 g/cm^3$ (2.7 bedrock, 2.2-alluvium). Applying the formula to that density contrast and the 15 milligal difference in gravity between the regional value and this locality yields a thickness of approximately 2300 feet. Proceeding southeastward the subsurface configuration takes a rapid rise towards the surface to a local high in the vicinity of Spencer's Hot Springs (fig. C5b). At this point the valley fill thickness estimated using the same formula is only 460 feet. It should be noted that the traverse line does not pass directly through the surface geothermal expression at Spencer's. It is displaced approximately one half mile to the southwest. However, this same trend is apparent on the regional map and it does substantiate the presence of a subsurface structural feature which is likely related to the localization of the hot springs. Continuing southeastward the gravity data indicate a graben structure which rises into an undulating segment of bedrock.

Traverse MR - The line of this traverse passes within 100 meters of the geothermal springs and therefore provides an on site picture of the subsurface configuration (figs. C6a, C6b). Gravity data indicate a very well defined, large displacement fault on the valley's western edge. Moving eastward (to the right) three approximately linear segments are present in the curve from 6,000-14,000 feet, 14,000-18,000 feet and 18,000-23,000 feet. It is likely that these segments represent a series of step-faulted blocks whose long axes parallel the current range front trends. At approximately 23,000 feet the curve takes a steeply inclined dip that correlates with the location of the thermal springs.

From this point eastward the curve becomes nearly linear and level reaching its lowest point at approximately 41,000 feet after a slight change in slope. Applying the previously used formula the depth of valley fill is computed to be approximately 5100 feet. Following the curve to the east (fig. C6b) a series of slope changes are apparent and probably related to a series of blocks formed by tectonic activity acting on rocks of the Northumberland caldera complex. The origin of the feature at 81,000 feet is not clear but it may result from a tilted block or buried body of higher density. It is apparent that along this traverse the valley's western boundary dips notably more steeply than does that of its eastern edge.

Traverse OMC - Traverse OMC does not pass in the vicinity of any known surface or subsurface geothermal activity and was conducted to determine the nature of the subsurface configuration between the Darrough's and McLeod Ranch resources. As was the case along MR, the western side of the valley is defined by rather steep changes in slope. However, at this location these changes occur in only three approximately linear segments (0-4,000, 4,000-12,000 and 12,000-22,000 feet) (fig. C7a). The direction changes shown are the result of available road configurations. Maximum computed depth of valley fill along this traverse is approximately 4,100 feet and occurs in the vicinity of 37,000 feet horizontal distance (fig. C7b). The subsurface configuration resembles that of MR in its more gentle slope and step faulted nature as the Toquima Range front is approached.

Traverse D - In the vicinity of Darrough's Hot Springs the closure of the northern segment of the Big Smoky Valley is evidenced by the nearly six mile shorter transect distance compared to traverses MR and OMC (figs. C8a, C8b). This traverse passes through the area of known surface and subsurface geothermal expressions at this location and its subsurface configuration closely resembles those of MR and OMC. Like MR the location of the hot springs correlates well with a steeply dipping slope change on the gravity curve which is most likely the

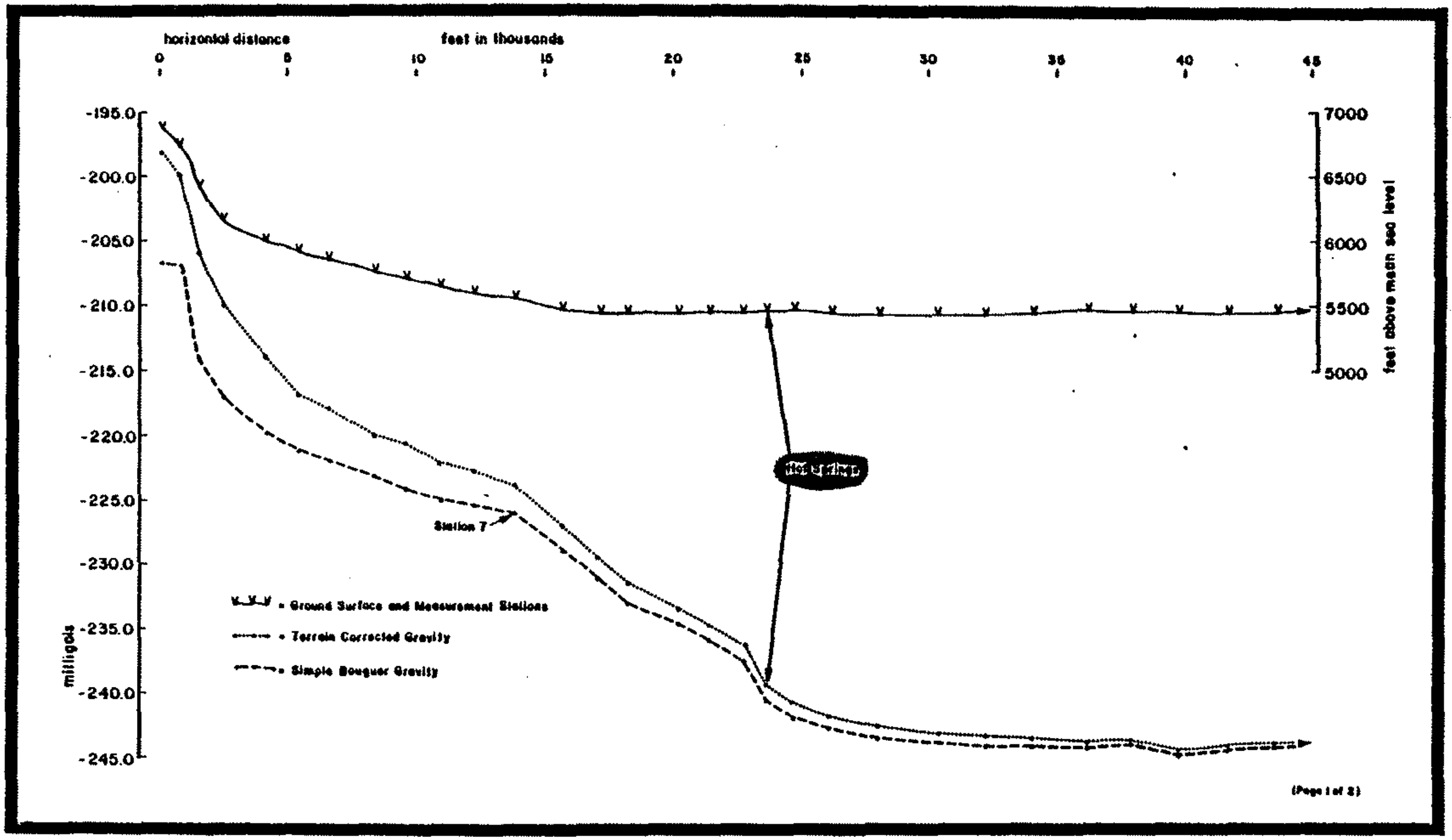


Figure C6a. Simple and complete Bouguer anomaly, and topography of the western segment of the MR (McLeod Ranch) gravity traverse.

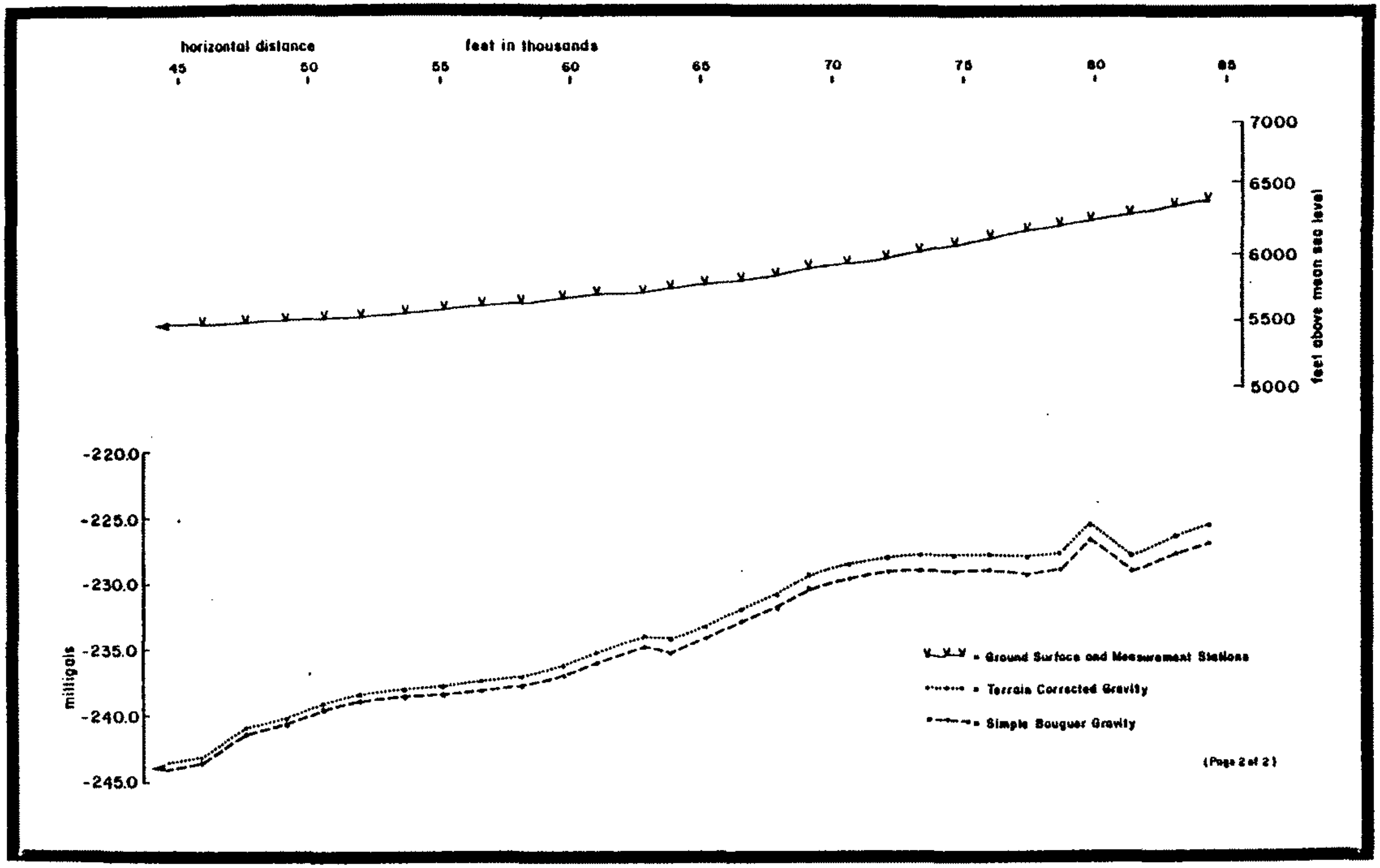


Figure C6b. Simple and complete Bouguer anomaly, and topography of the eastern segment of the MR (McLeod Ranch) gravity traverse.

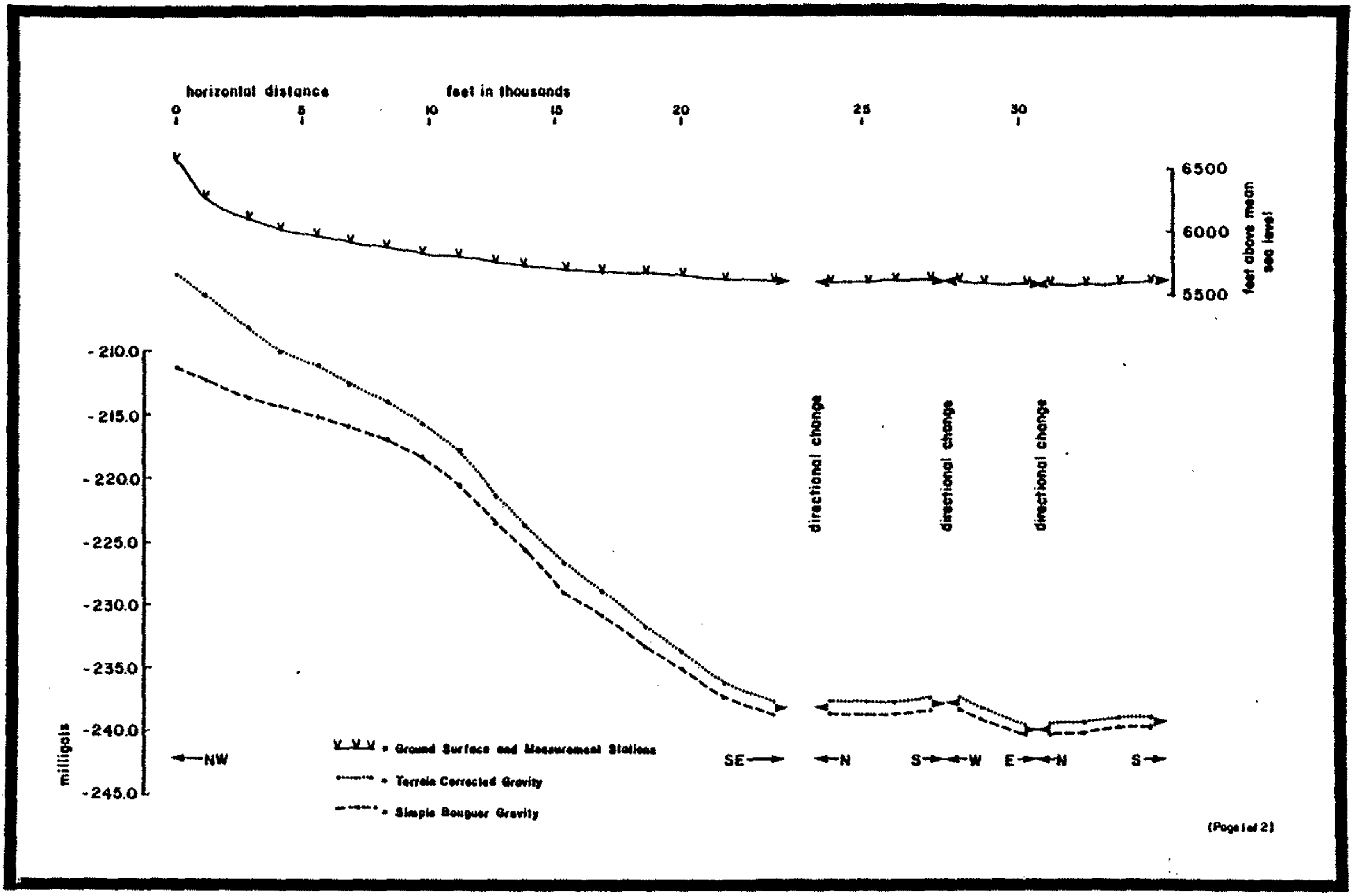


Figure C7a. Simple and complete Bouguer anomaly, and topography of the western segment of the OMC (Ophir-Moores Creek) gravity traverse.

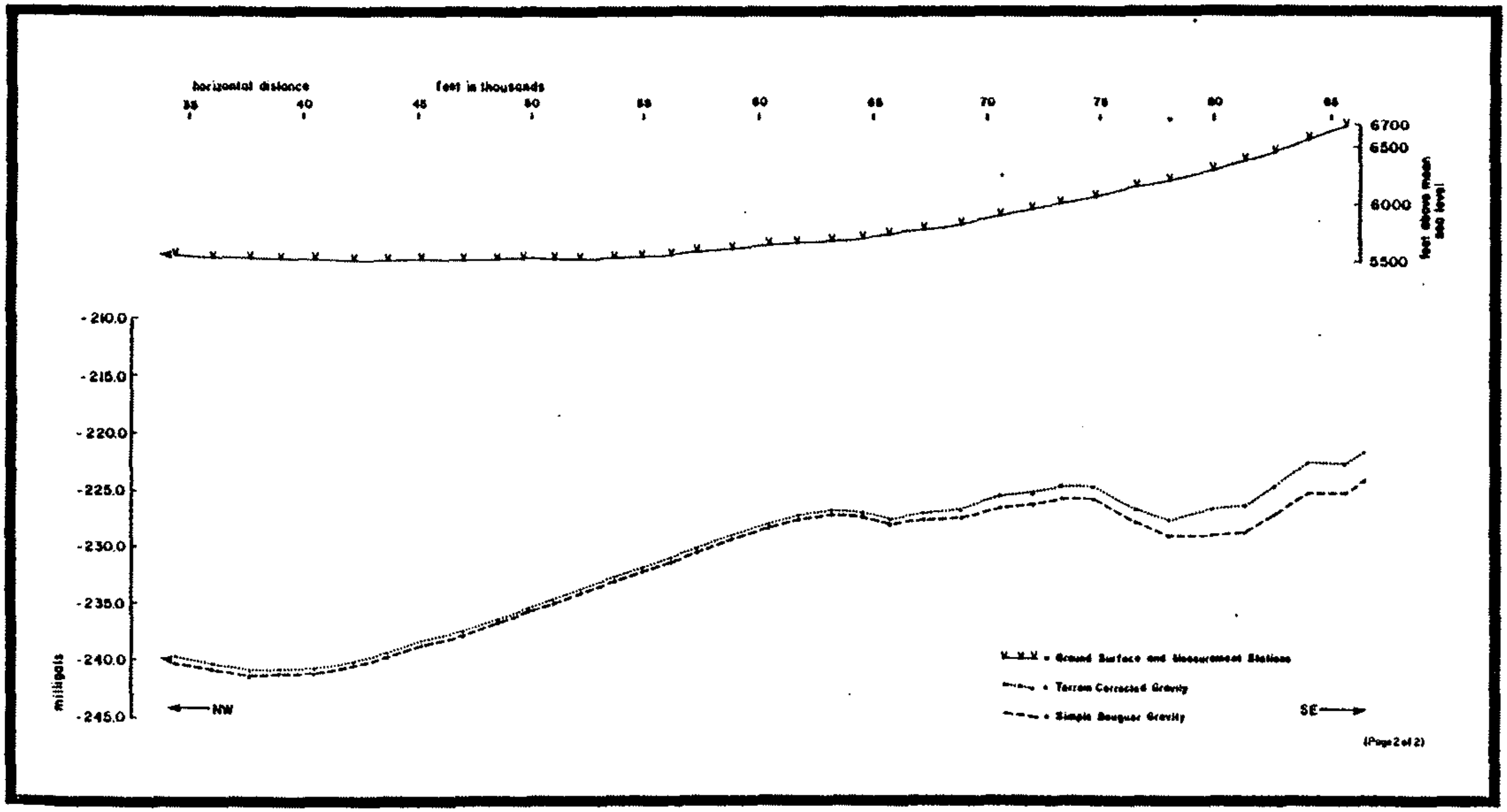


Figure C7b . Simple and complete Bouguer anomaly, and topography of the eastern segment of the OMC (Ophir-Moores Creek) gravity traverse.

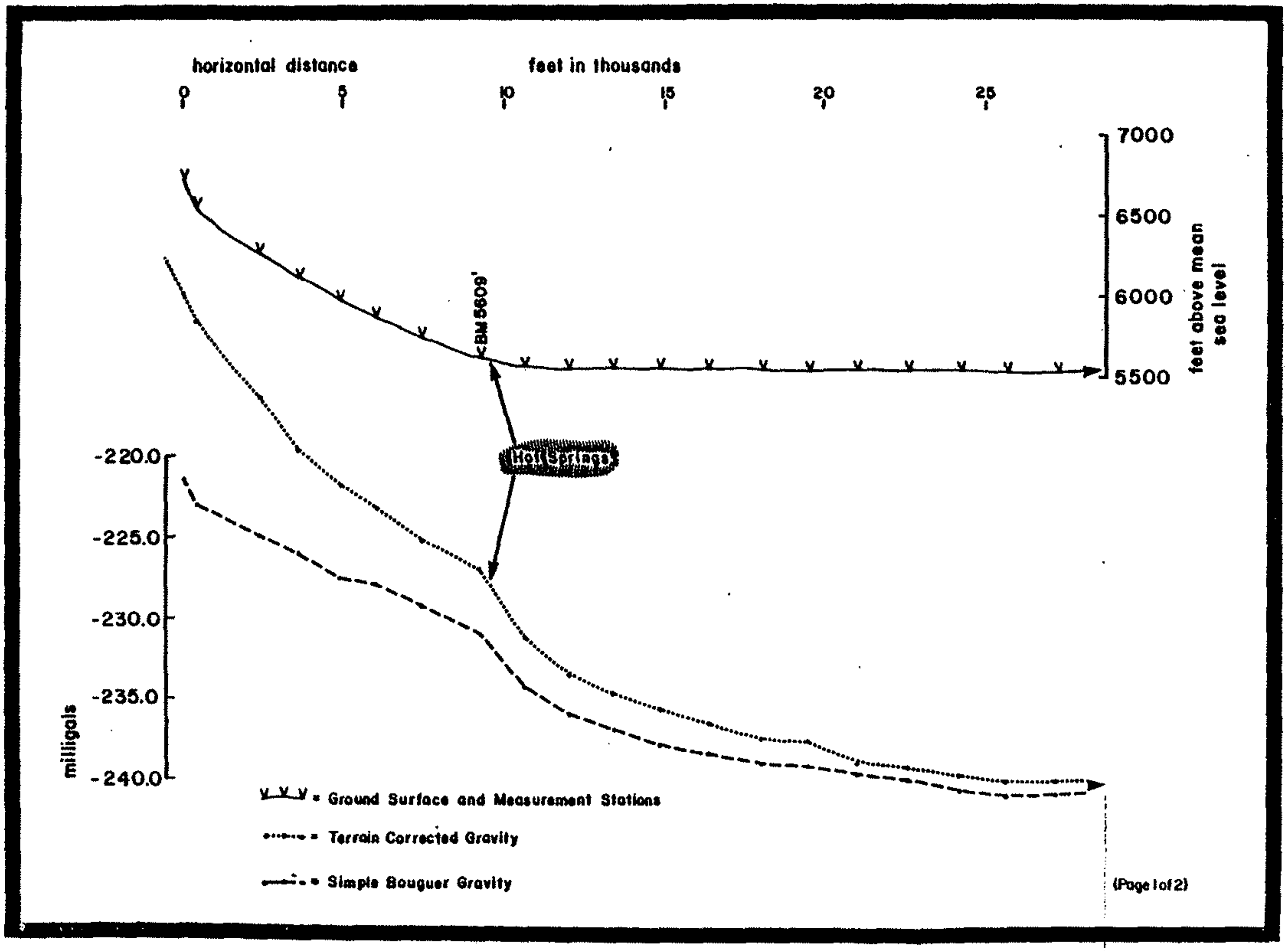


Figure C8a. Simple and complete Bouguer anomaly, and topography of the western segment of the D (Darrough) gravity traverse.

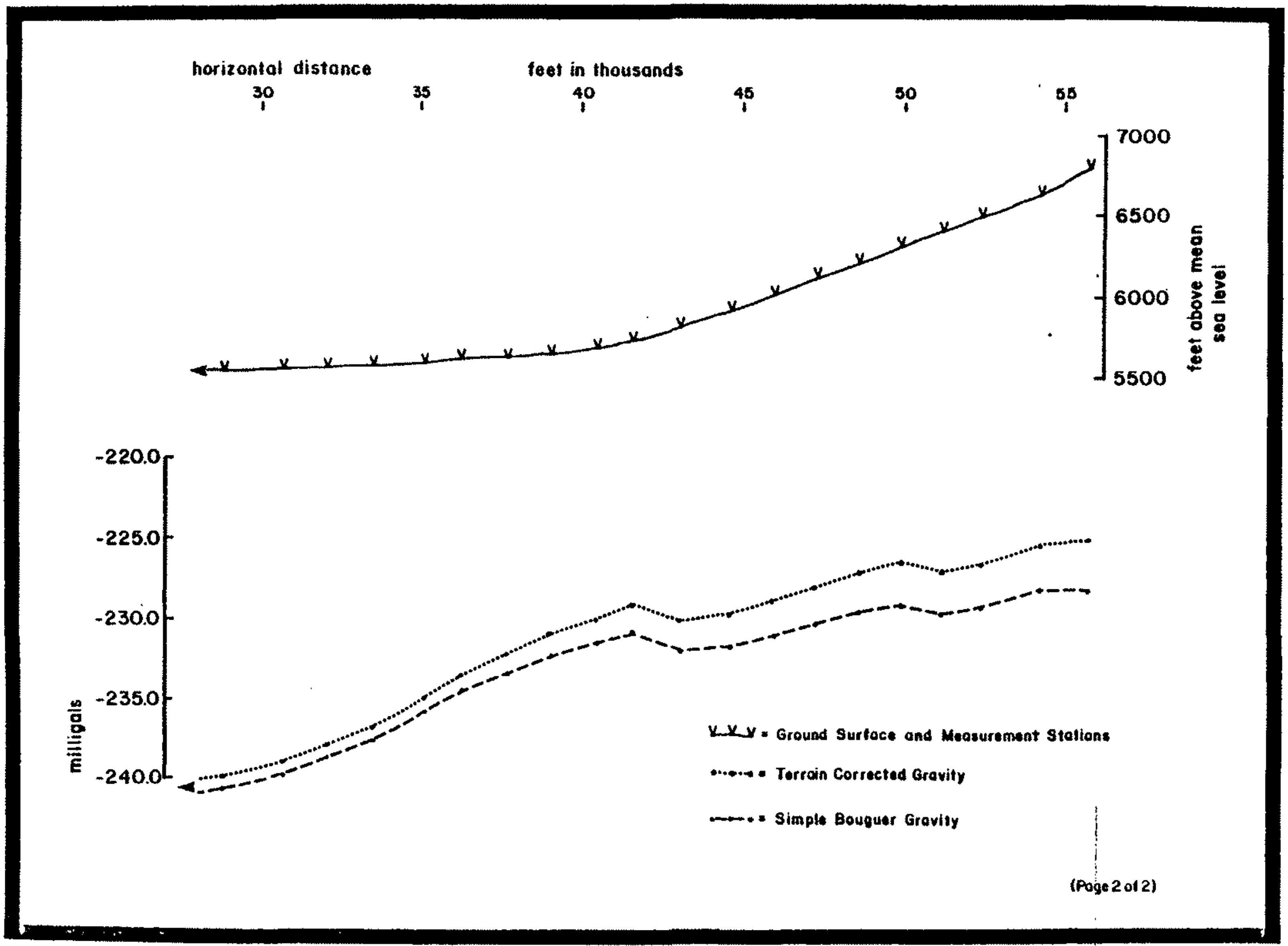


Figure C8b. Simple and complete Bouguer anomaly, and topography of the eastern segment of the D (Darrough) gravity traverse.

result of large displacement on a fault at this point. Computed maximum valley fill thickness occurs in the vicinity of 27,000 feet horizontal distance and has a value of approximately 3,800 feet. This figure also tends to indicate subsurface closure of the valley.

Traverses 8A and 8B - The purpose of these lines was to test for the presence of a subsurface structure which might be related to the Pritchards Station Lineament described by Ekren and others (1976). North-south orientations were used to accomplish this objective. Traverse 8A (fig. C9) possesses a single well defined inflection point while 8B (fig. C10) has two and possibly three slope changes. Consideration of the overall pattern produced by contouring at a five milligal interval using data from OMC, 8A, 8B and D does not show any relation between the inflections on 8A and 8B. The slope changes on 8B appear to be a function of the step faulted nature of the valley's eastern boundary while the single inflection along 8A seems to be a local anomaly.

Summary

Gravity data indicate the presence of subsurface structural features associated with all three of the known geothermal resources in the study area. In the north (Spencer's) this feature occurs along the valley's eastern boundary while in the central (McLeod Ranch) and south (Darrough's) the structures are located along the steeply dipping frontal faults of the Toiyabe Range. Additional information includes the assymetrical nature of the subsurface in the central and southern portions of the area and the subsurface closure of the valley as it approaches Round Mountain.

Aerial Photography

Imagery used to examine the Big Smoky study area included: 1:250,000 RBV LANDSAT, 1:78,000 9"x9" B&W, 1:24,000 low sun-angle 9"x9" B&W and 1:12,000 9"x9" B&W along gravity traverse lines. The LANDSAT and 1:78,000 scale photos were available through the EROS DATA CENTER while the remaining work was flown

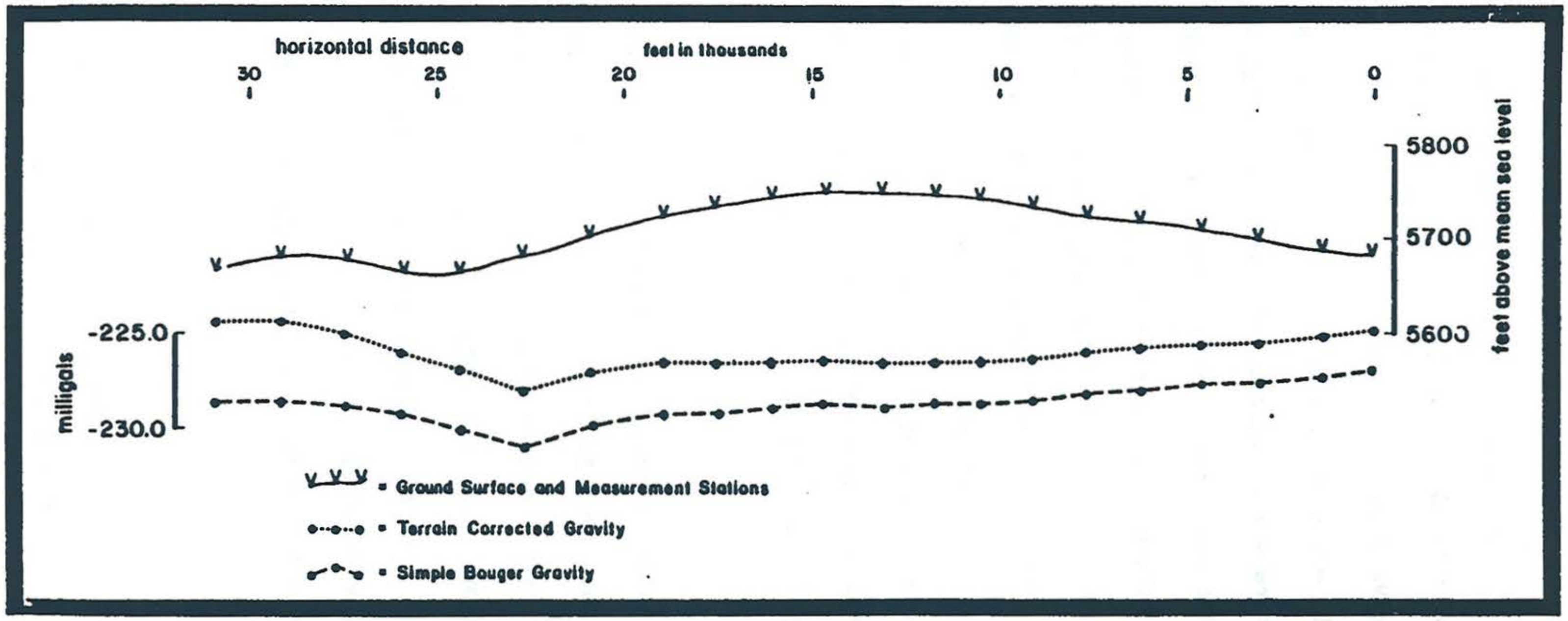


Figure C9. Simple and complete Bouguer anomaly, and topography of gravity traverse 8A.

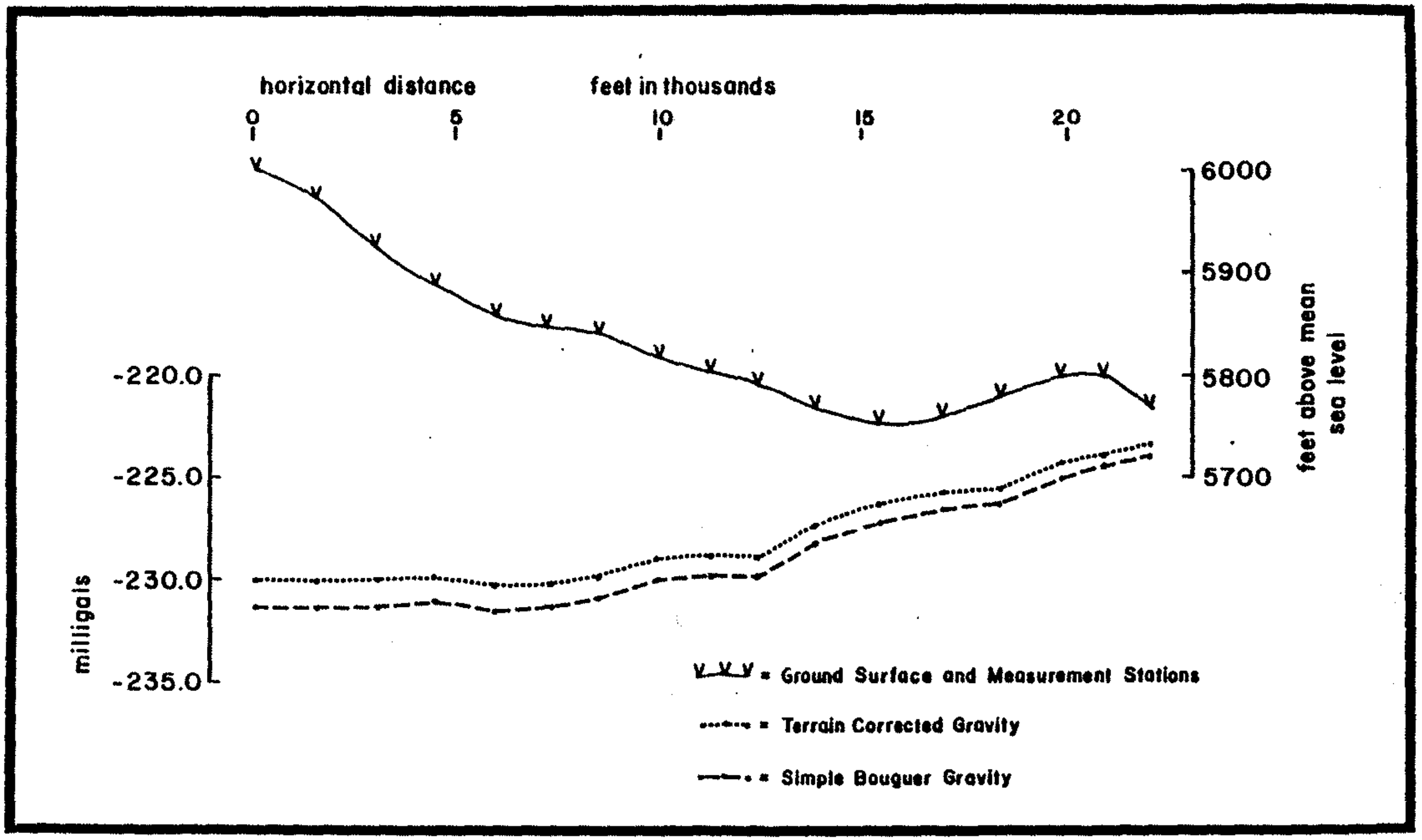


Figure C 10. Simple and complete Bouguer anomaly, and topography of gravity traverse 88.

during the course of our investigations. RBV LANDSAT images proved to be of no use in determining hot spring localization. This was in large part due to poor image quality and the presence of snow during the mid-May flyover. Photography at 1:78,000 helped to a limted degree by providing a base for regional trend investigation and allowing the possible relationship between large scale (longer than 5 km) linear and curve-linear features and geothermal occurrences to be examined. However, the most useful aerial imagery technique applied during our work was low sun-angle photography (LSAP). Regions flown using LSAP are labeled "A" and "B" in figure C11. The missions were conducted late in the year (December) to increase available flight time, and between 5 and 18 degrees solar elevation to maximize light-shadow contrast as indicated in Walker and Trexler (1977). Forelap and sidelap were incorporated to aid stereoscopic study. These restrictions combined with the selected scale of 1:24,000 which permitted detection of small displacement alluvial fault scarps resulted in the successful application of this technique to the study area.

Examination of the low sun-angle imagery revealed information on both the physiographic expression of the geothermal occurrences and the presence of local structural features which appear to be related to resource localization. For example, figure C12 is a frame taken over the Spencer's Hot Springs area. Ground study has shown the springs and wells to be located in a region of undulating topography which is related to the deposition of calcareous sinter. The areal extent of this sinter is clearly defined in the photograph and stereoscopic study points out the generally raised nature of this feature. No fault traces are seen which can be related to the geothermal phenomena. Fault traces and lineations which appear to be related to hot spring localization as well as a distinctive physiographic expression are revealed in LSAP taken in the vicinity of the McLeod Ranch occurrence. The bounding faults in the Toiyabe Range approximately one mile south and four miles west of the hot springs possess a

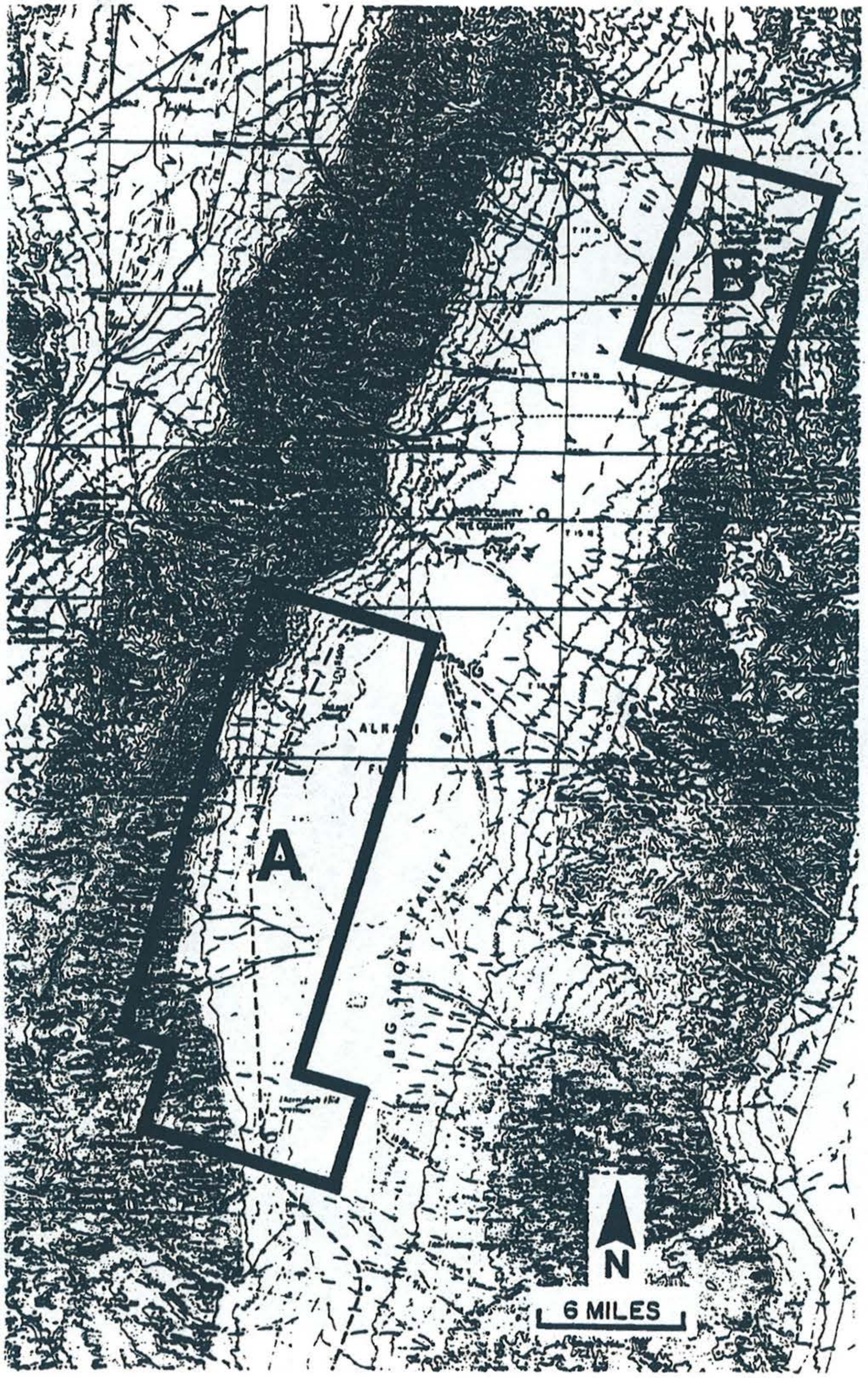


Figure C11. Low sun-angle photography areas in Big Smoky Valley.

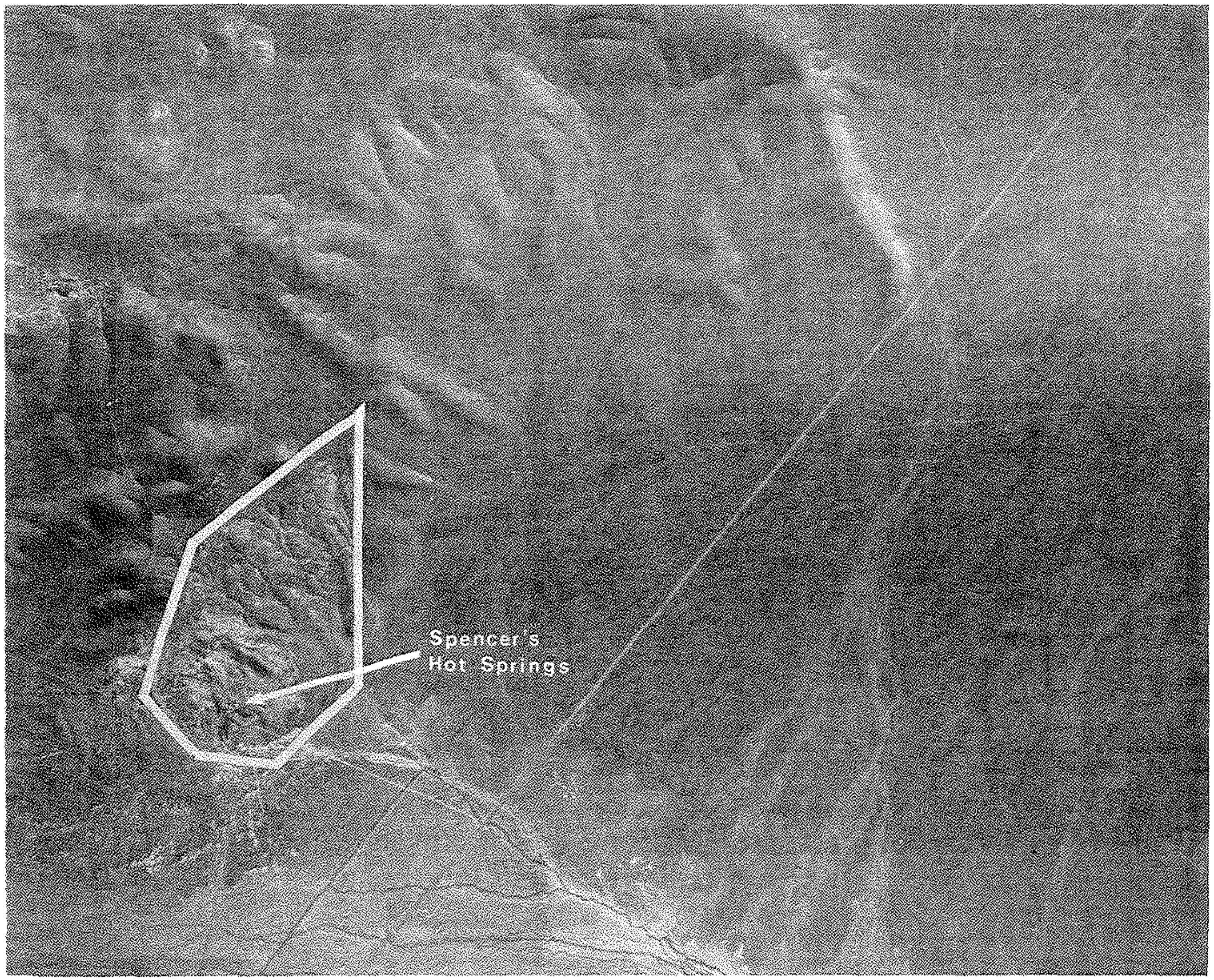


Figure C12 . Low sun-angle photography over Spencer's Hot Springs area, scale 1:24,000.

notable sawtooth appearance (fig. C13) and this pattern is repeated though somewhat distorted in nearby alluvial materials. The approximately orthogonal nature and spatial orientation of these faults is duplicated in the shallow probe isotherm configuration and will be referenced in the discussion of that technique. Moving northward along the range front a strong N45°W lineation is observed in the orientation of canyons and rock fracture patterns. The extension of this lineation from one of its major expressions as depicted in figure C14 passes directly through the surface geothermal manifestations. This linear also parallels one of the faults depicted in figure C13 and thus appears to represent a definite local structural trend. Topographically the McLeod Ranch occurrence possesses a readily distinguishable roughly circular expression as shown in figure C15. Surface examination has shown this feature to be a large diameter low profile tuffa mound.

The geothermal manifestations at the Darrough site are developed in alluvial fan materials and do not exhibit a distinctive physiographic expression. LSAP flown over the resource does demonstrate the presence of a structural feature which is likely related to the localization of the thermal fluids. If the trend of the range bounding fault visible in the left portion of figure C16 is extended northward a colinear fault scarp is encountered in alluvial fan materials. Further extension of this line in the same direction, as depicted in figure C17 shows that it passes through the zone of known surface and subsurface geothermal occurrences. This same line correlates well with the distinct inflection in the gravity curve discussed earlier and defines a trend which parallels that found in the two meter probe isotherm configuration (discussed in a later section).

Black and white 9"x9" format photography was flown along gravity traverse lines to check for surface features which could be associated with subsurface changes in gravity profiles or areas of anomalous high mercury as determined during soil sampling. This effort did not prove useful. Scale of the imagery

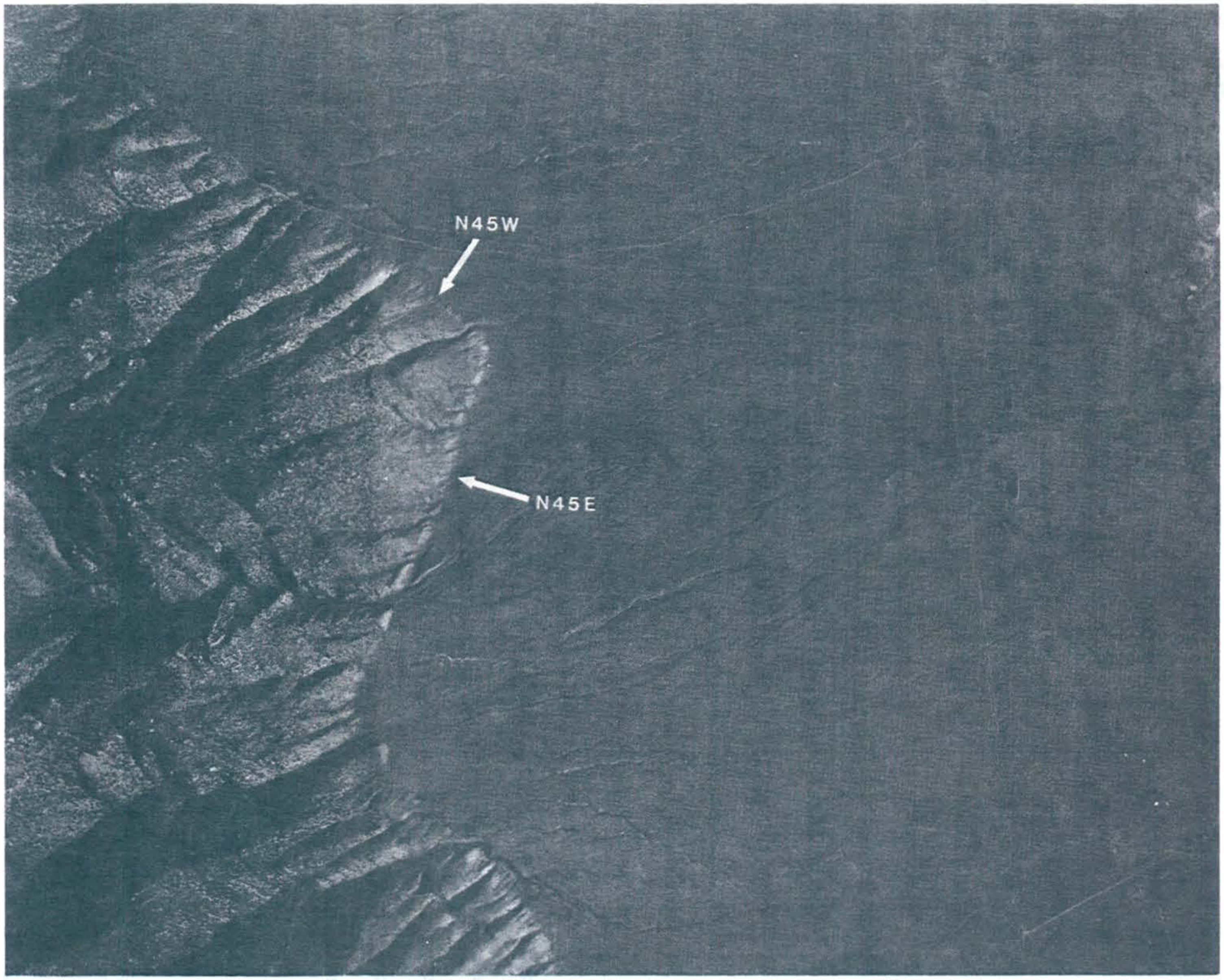


Figure C13 . Range bounding faults southwest of McLeod Ranch Hot Springs area. Low sun-angle photography, scale 1:24,000. Note N45° W orientations.

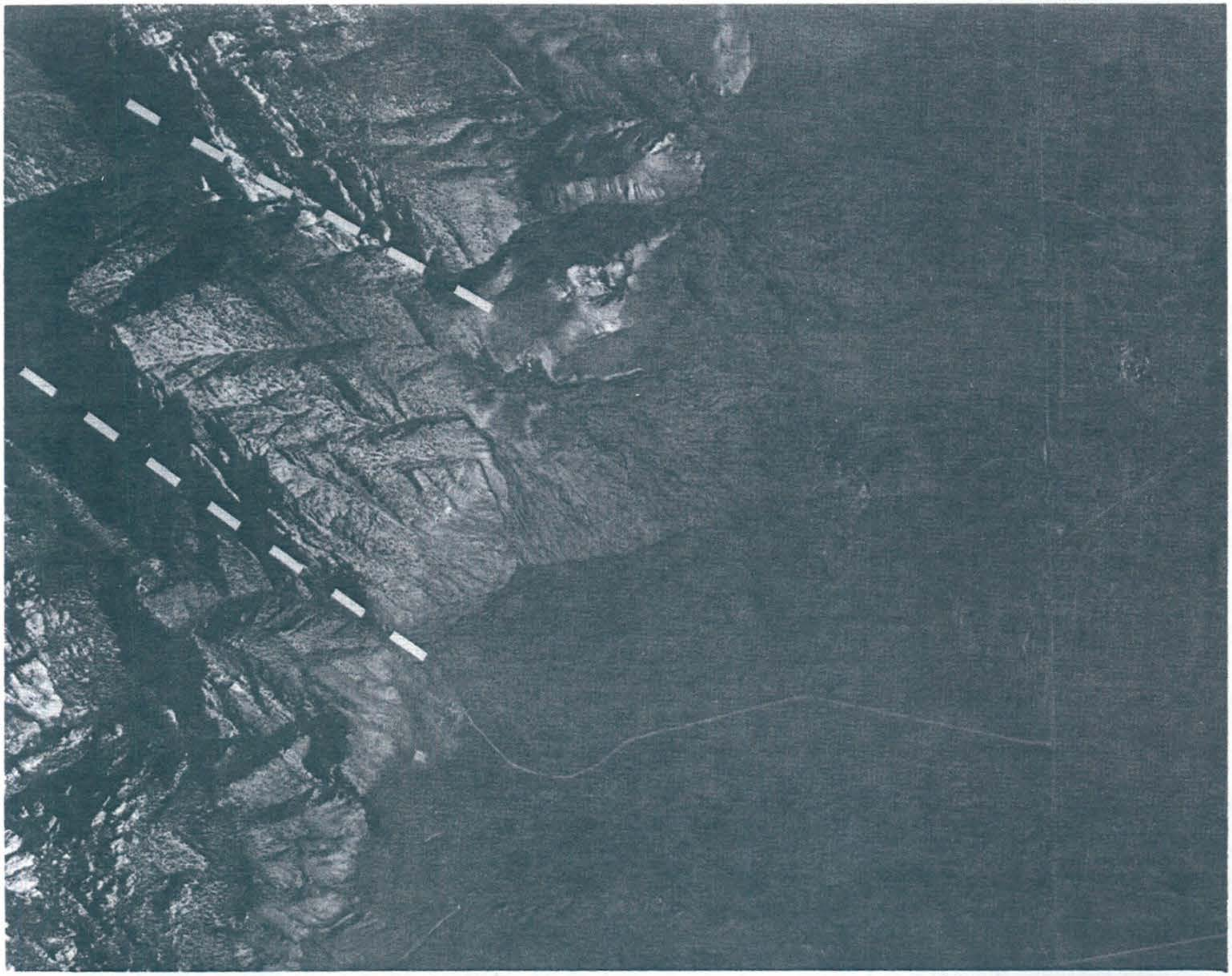


Figure C14 . Lineaments described by canyons and fracture patterns immediately northwest of McLeod Ranch resource. Extension of upper dashed line to lower right (southeast) passes directly through geothermal springs.

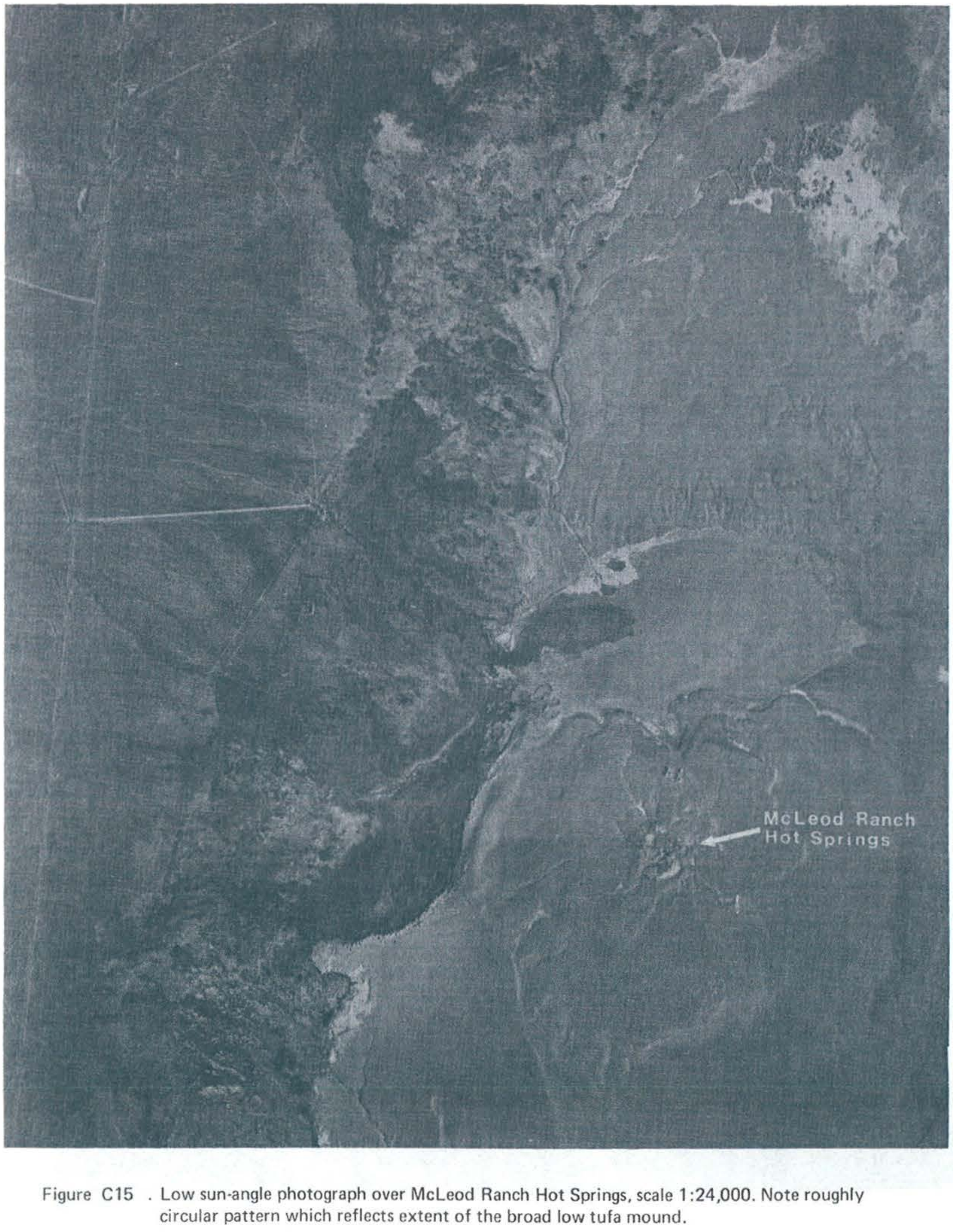


Figure C15 . Low sun-angle photograph over McLeod Ranch Hot Springs, scale 1:24,000. Note roughly circular pattern which reflects extent of the broad low tufa mound.

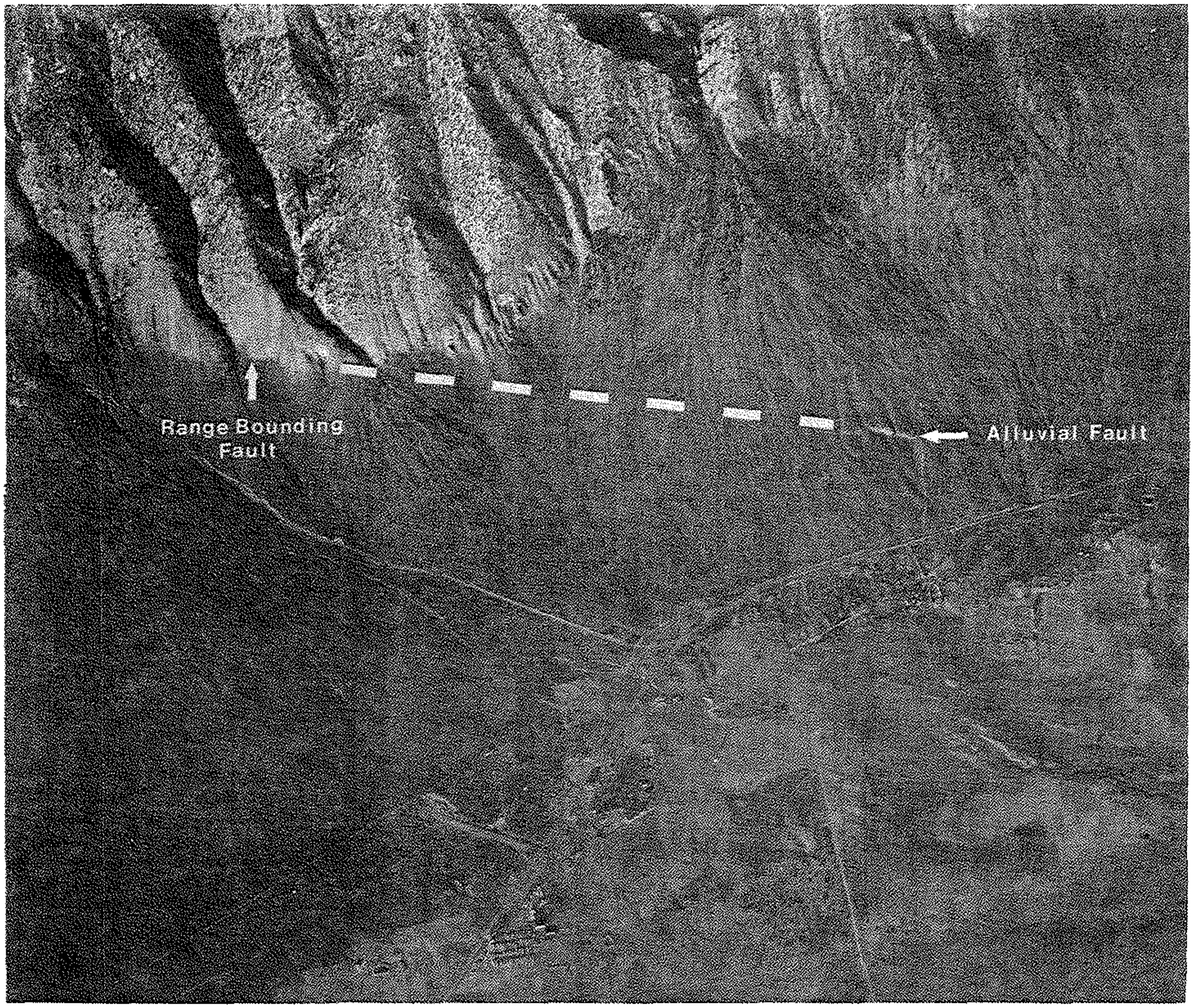


Figure C16 . Low sun-angle photography of range bounding and alluvial fault traces southwest of Darrough's Hot Springs, scale 1:24,000. Note colinear trend as shown by dashed line.

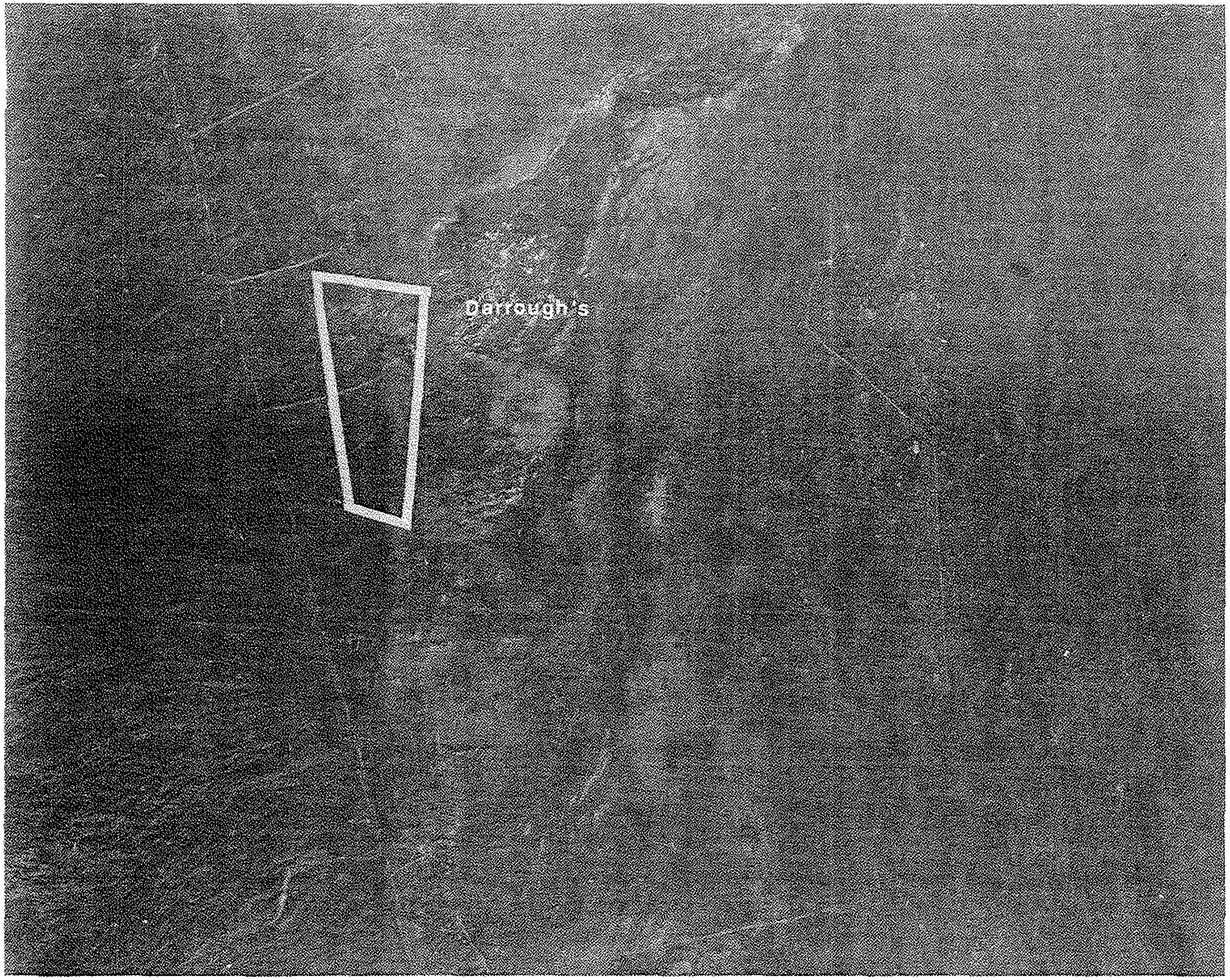


Figure C17 . Low sun-angle photograph over Darrough's resource area, scale 1:24,000. Alluvial fault of Figure C16 is visible in lower left.

was 1:12,000 but it did not provide additional information when compared to that flown at 1:24,000.

Summary

Photo imagery used to examine the Big Smoky Valley consisted of black and white prints ranging in scale from 1:250,000 (LANDSAT) to 1:12,000. LANDSAT imagery was of poor quality and lacked necessary detail. Large scale linear and curvelinear and other regional features were examined using available 1:78,000 scale photos. The greatest amount of useable data was derived from 1:24,000 scale low sun-angle photography. It provided pertinent information on local structural features which show likely relationships to thermal spring locations as well as physiographic distinctions associated with the occurrences. Photography at 1:12,000 scale did not prove useful.

Fluid Sampling and Analysis

Sixteen fluid samples were collected in the Big Smoky Valley area during the study. Two thermal wells and six thermal springs were sampled. In addition, six non-thermal springs and two non-thermal wells were sampled. Results of chemical analyses for major, minor and trace constituents are listed in Table C1 along with a sample designation and temperature measured at collection. Values for pH represent measurements made in the laboratory during analysis. Figure C18 depicts the generalized chemical composition of the sampled fluids using modified Stiff diagrams. The data depicted in the figure demonstrate a marked compositional difference between thermal and non-thermal fluids in the Darrough's and McLeod Ranch regions while sampled hot and cold waters in the Spencer's Hot Springs area possess notable similarities. A more detailed discussion of these relationships follows.

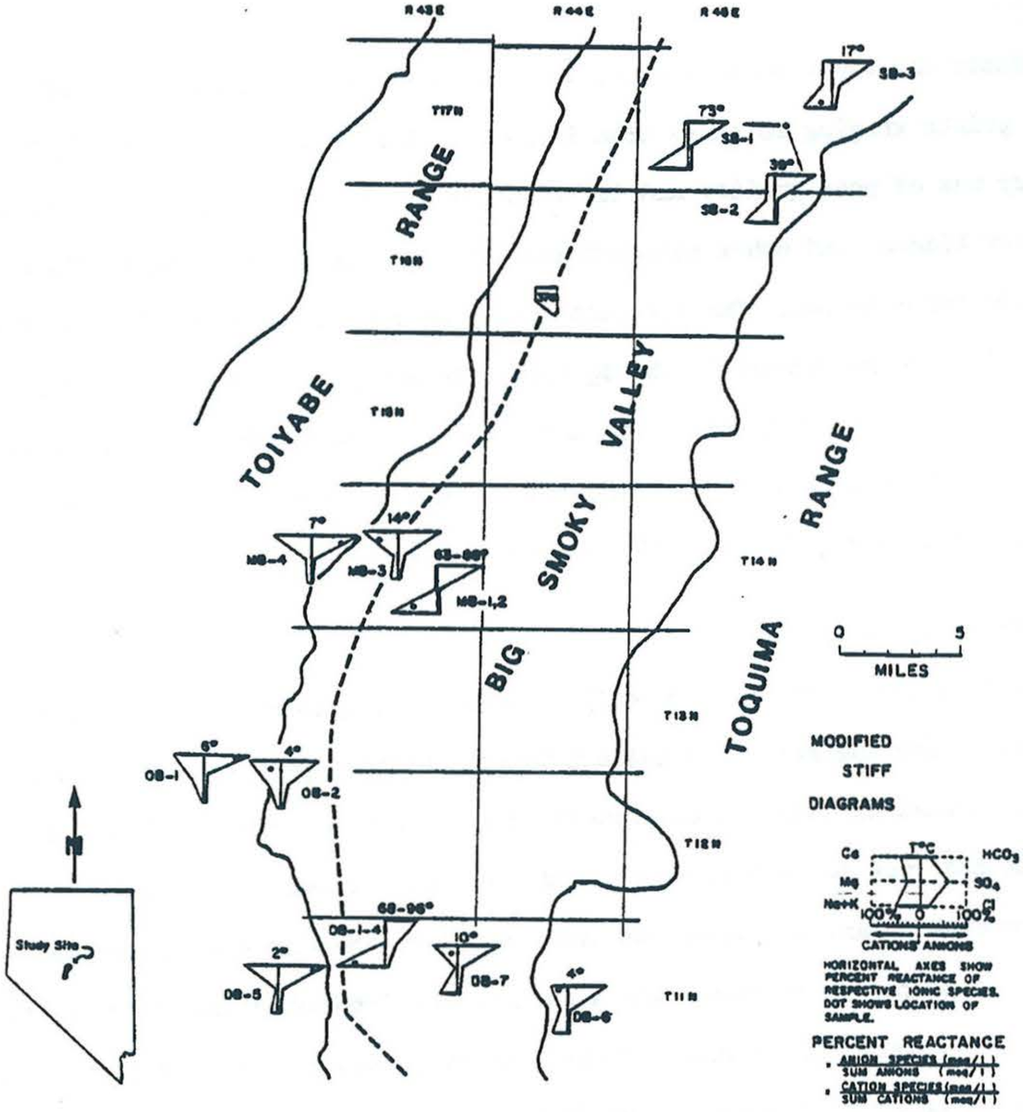


Figure C18. Chemical characteristics of waters from the Big Smoky Valley study area.

Table C1. Chemical analyses of fluids from Big Smoky Valley.

Sample Name	Sample Number	Location	T°C	pH	SC µmhos	B ppm	Ca ppm	Mg ppm	K ppm	Na ppm	Li ppb
Darrough's well (800 ft)	DB1	SW¼SE¼SE¼Sec.7 T11N,R43E	90.5	8.77	432	0.700	1.12	<0.05	3.30	98.8	349
Darrough north spring	DB2	SW¼SW¼SW¼Sec.8 T11N,R43E	71.2	8.72	444	0.575	1.35	<0.05	2.72	94.2	324
Darrough south spring	DB3	SE¼SE¼NE¼Sec.18 T11N,R43E	68	8.68	440	0.590	1.44	<0.05	2.20	91.1	309
Darrough's pool	DB4	SW¼SW¼SW¼Sec.8 T11N,R43E	95.5	8.85	465	0.630	1.24	<0.05	3.00	98.2	328
Aqueduct stream	DB5	NE¼SE¼NW¼Sec.13 T11N,R42E	1.8	7.75	125	0.060	20.1	1.42	0.683	5.29	5.5
Barker Creek	DB6	SW¼SE¼SW¼Sec.15 T11N,R44E	3.9	7.69	102	0.077	11.8	1.98	0.646	8.08	2.94
Jake's well	DB7	NE¼SW¼SE¼Sec.24 T11N,R43E	10	7.83	175	0.113	20.5	1.81	1.40	15.4	13.2
Spencer 73	SB1	NE¼NE¼NE¼Sec.24 T17N,R45E +	72.5	8.14	1021	3.33	14.9	9.06	36.6	181	1810
Spencer-39 Dead Burro	SB2	NE¼NE¼NE¼Sec.24 T17N,R45E +	38.8	7.89	848	1.46	25.2	16.5	22.4	100	594
well north of Linka Mine	SB3	NW¼ Sec.18 T17N,R46E +	-	8.22	808	1.39	30.4	17.5	18.0	95.4	464
Upper Ophir Creek	OB1	NW¼SW¼Sec.33 T13N,R42E	5.8	8.05	249	0.136	34.3	8.84	1.20	4.31	2.83
Lower Ophir Creek	OB2	SW¼SW¼SE¼Sec.34 T13N,R42E	3.7	8.21	289	0.077	40.4	9.15	1.38	5.37	4.13
McLeod 88 Spring	MB1	SE¼NE¼SW¼Sec.34 T13N,R43E +	87.9	8.59	2318	3.47	10.4	2.49	38.3	525	1670
McLeod 63 Spring	MB2	SE¼NE¼SW¼Sec.34 T13N,R43E +	62.7	8.17	2466	3.61	18.4	9.02	40.2	537	1780
Fault Spring	MB3	SW¼NW¼SW¼Sec.16 T14N,R43E	13.6	7.97	177	0.204	28.5	2.45	0.796	6.80	2.08
Decker Bob Creek	MB4	SW¼SW¼NE¼Sec.18 T14N,R43E +	6.7	8.11	187	0.082	36.8	3.00	0.796	4.84	3.9

*Measured and reported as total recoverable sulfide.

+Unsurveyed area - township and range location estimated.

Sample Number	Cl^- ppm	NO_3/NO_2 ppm	SiO_2 ppm	$SO_4/S^{=*}$ ppm	CO_3/HCO_3 ppm	F^- ppm	As^{+4} ppb	Ba ppm	Fe^{+2} ppm	Rb ppb	Cs ppb	Sr ppb
DB1	12.2	0.13	122	47/ 0.439	21.1/ 119	14.2	86.4	<0.1	0.03	25.3	58.8	<200
DB2	11.8	0.07	112	52.9/ 1.37	16.7/ 125.9	13.7	78.8	<0.1	0.04	19.8	44.7	<200
DB3	11.6	0.07	108	49.4/ 0.464	11.2/ 125.7	13.1	41.5	<0.1	0.04	16.5	41.7	<200
DB4	13.5	0.04	114	50.7/ 0.910	22.3/ 108	14.2	58.6	<0.1	0.091	21.5	49.8	<200
DB5	1.10	0.36	9.91	3.56	71.9	0.106	<5	<0.1	0.066	2.1	4.2	298
DB6	2.02	<0.01	25.5	2.71	57.3	0.129	<5	<0.1	0.04	2.0	3.6	<200
DB7	3.82	0.85	35.5	7.44	86.1	0.264	-	0.08	0.04	2.7	3.6	210
SB1	22.9	<0.01	93.5	35.8/ 0.249	525	0.466	28.7	0.344	0.167	250	209	848
SB2	13.3	0.06	46.7	35.0/ 0.273	444	2.10	38.7	0.21	1.78	100	50.8	1500
SB3	15.2	1.03	58.6	48.8	390	1.94	26.5	0.16	0.04	83.5	7.31	866
OB1	1.71	0.03	11.7	7.53	143	0.119	5.3	0.21	0.03	<1	3.6	298
OB2	2.38	0.06	11.7	17.9	155	0.145	6.0	<0.1	0.04	<1	4.8	316
MB1	48.2	<0.01	107	64.7/ 0.345	40.1/ 1380	11.7	149	0.344	0.14	449	216	419
MB2	48.2	0.25	162	64.5/ 0.361	1420	13.1	163	0.252	0.04	374	171	333
MB3	3.05	1.20	17.2	9.27	93.6	0.192	<5	0.08	0.066	<1	<3	316
MB4	1.39	0.71	20.9	3.71	143	0.264	<5	<0.1	0.066	<1	<3	402

Table C1. Chemical analyses of fluids from Big Smoky Valley.

Sample Name	Sample Number	Location	T°C	pH	SC umhos	B ppm	Ca ppm	Mg ppm	K ppm	Na ppm	Li ppb
Darrough's well (800 ft)	DB1	SW¼SE¼SE¼Sec.7 T11N,R43E	90.5	8.77	432	0.700	1.12	<0.05	3.30	98.8	349
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Aqueduct stream	DB5	NE¼SE¼NW¼Sec.13 T11N,R42E	1.8	7.75	125	0.060	20.1	1.42	0.683	5.29	5.5
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[*] Measured and reported as total recoverable sulfide.

[+] Unsurveyed area - township and range location estimated.

Major and Minor Dissolved Components

The composition of Big Smoky fluids plotted as percent equivalent per million of major cations and anions is shown in figures C19, C20 and C21. Sample designations in these figures correspond to those used in Table C1 in figure C18. In some instances compositions of several fluids from a given area are so similar that plotting them as individual points is not practical. Where this occurs a larger symbol with a compound designation such as "MB1,2" or "DB-1 - DB-4" is used. Points with designations such as "Sec. 12" represent results obtained from records of the Nevada State Department of Health. The number represents the section in which the water source is located. "Sec. 12" is a well from T11N,R34E and "Sec. 30" is also a well in the same township.

Similarities and contrasts in fluid cation characteristics for the system Ca^{+2}-Mg^{+2}-Na^{+} can be studied in figure C19. The hottest Spencer's thermal fluid sampled (72.5°C) is labeled SB-1 in the figure. A second sample of thermal water collected at the same site (SB-2, 38.8°C) along with a non-thermal fluid from that area (SB-2, approximately 17°C) lie along a straight line extending from SB-1 to the midpoint of the Ca^{++}-Mg^{++} join. This straight-line relationship suggests that the composition of SB-2 may result from mixing SB-1 and SB-3 type fluids. Disregarding SB-3, the remainder of the non-thermal liquids sampled and those analyzed by the Department of Health are grouped in the upper half of the diagram and are relatively calcium rich. A distinction between cold waters from the vicinity of the Toquima Range and those near the Toiyabe Range can also be made. The former (DB-7, DB-6, Sec. 12) are notably more sodium rich while the latter (DB-5, MB-3, MB-4, Sec. 30, OB-1,)B-2) are relatively more calcium and magnesium (Sec. 30, OB-1, OB-2) rich. Shifting to the system Ca^{+2}-K^{+}-Na^{+} (fig. C20) similar distributions are observed. However, the range in variation with respect to potassium content is distinctly more limited. Once again OB-1 and OB-2 are part of a distinct grouping. The anomalous Mg^{+2} values of OB-1 and OB-2 are likely related to dolomite and greenstone rocks through which this creek

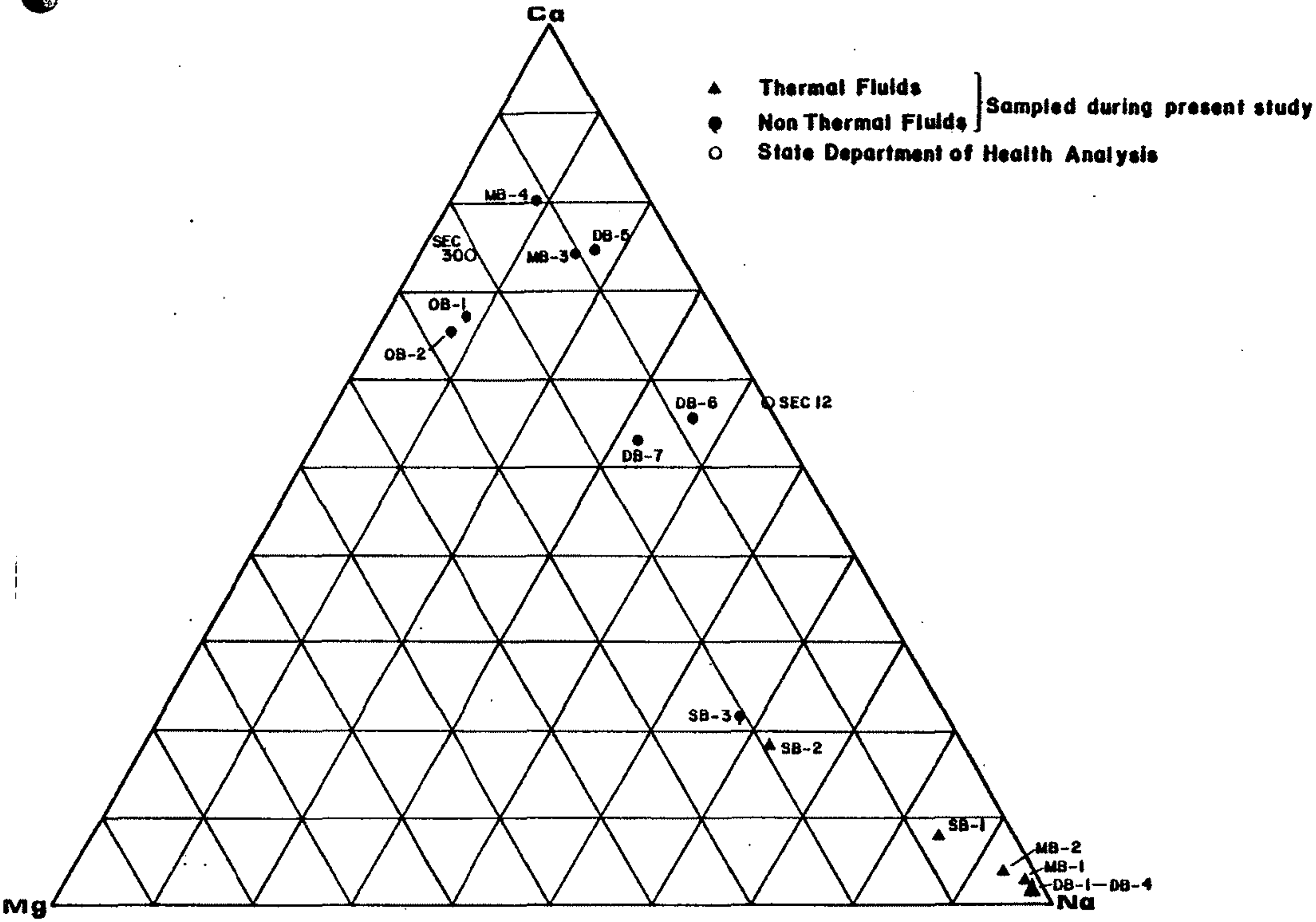


Figure C 19. Distribution of thermal and non-thermal fluids with respect to Mg-Ca-Na cations in the Big Smoky Valley. Points are plotted as percent equivalents per million of the sum for the species.

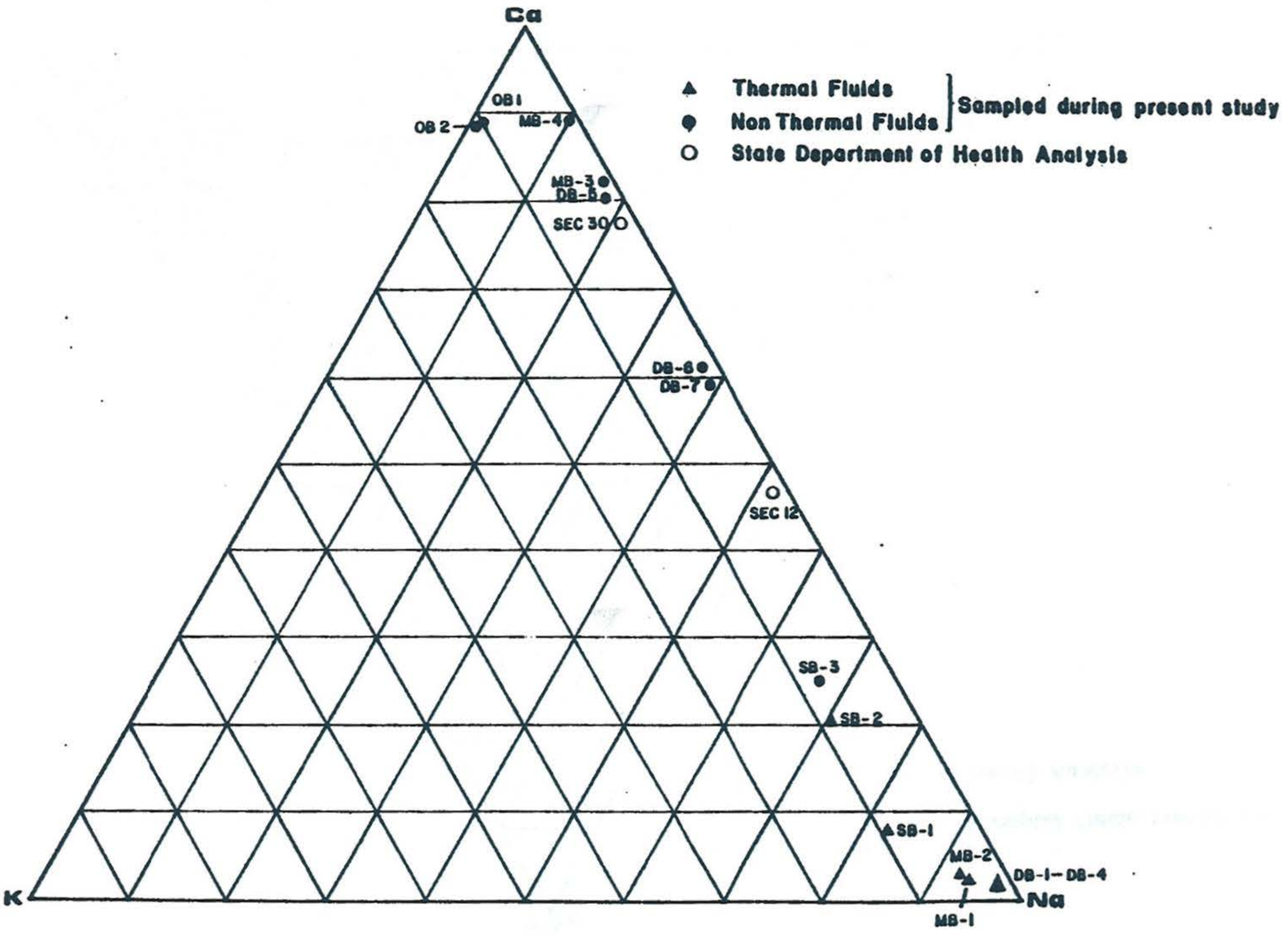


Figure C 20. Distribution of thermal and non-thermal fluids with respect to K–Ca–Na cations in the Big Smoky Valley. Points are plotted as percent equivalents per million of the sum for the species.

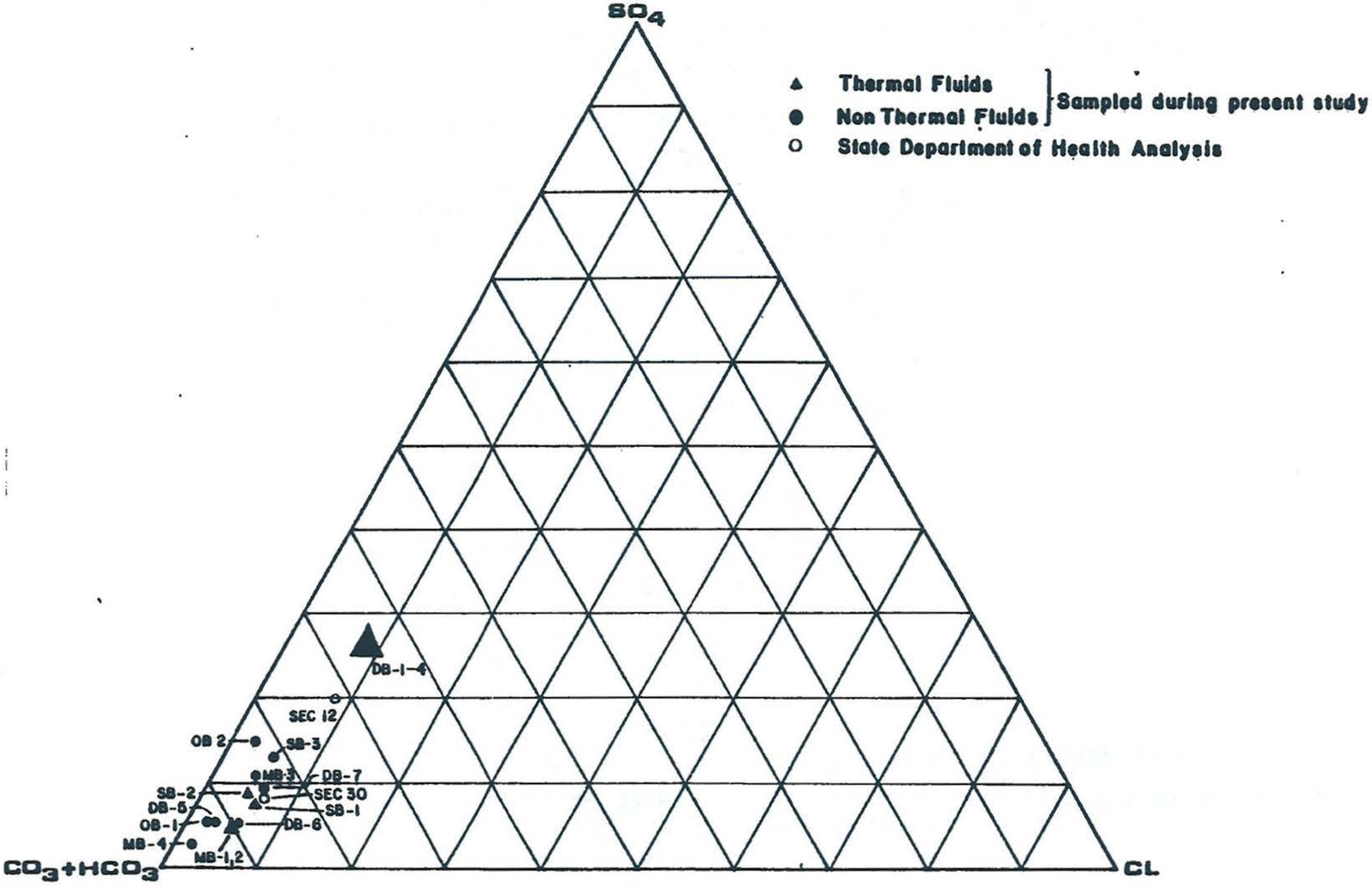


Figure C 21. Distribution of thermal and non-thermal fluids with respect to CO_3 + HCO_3–SO_4–Cl anions in the Big Smoky Valley. Points are plotted as percent equivalents per million of the sum for the species.

passes. No ready explanation is apparent for the relatively high potassium content of these samples.

Geothermal fluids when plotted in terms of the anions SO_4^{-2}-CO_3^{-2}+HCO_3^{+}-Cl^{-} do not possess the uniform distribution apparent in the cation plots (fig. C21). Hot waters from McLeod Ranch and Spencer's are found mixed within a grouping of cold waters near the CO_3^{+2}+HCO_3^{+} apex. Thermal fluids from the Darrough site, however, display a distinct displacement from other waters and are in relative terms decidedly more sulfate and somewhat more chloride rich. This unique character of the Darrough hot waters will also be apparent in their isotopic characteristic.

Silica is an important nonionic constituent of geothermal fluids. Frequently it is used to estimate reservoir temperatures using a chemical geothermometer developed by Fournier and Rowe (1966). No attempt will be made to apply this technique to fluids sampled during our study because we feel that the assumptions necessary to obtain meaningful results cannot be adequately demonstrated to hold in our systems. However, it is interesting to study the silica content in terms of the solubility of various polymorphs. This can be accomplished by plotting the values obtained from analysis on a graph whose axes are log molality SiO_2 and temperature. The assumption is made that the activity coefficient for this species is unity and therefore that activity equals molality. For convenience the solubility curves are also plotted (fig. C22). These curves are drawn from the data given by Walther and Helgeson (1977).

All of the fluids sampled plot above the curve for alpha-quartz and are thus saturated with respect to this phase. The majority of the points fall between the curves for alpha-cristobalite and beta-cristobalite. Exceptions to this are MB-2 and SB-3 which fall between beta-cristobalite and amophous silica. Silica content does not appear to be simply a function of temperature. In certain cases it may be possible to explain the silica levels of various fluids from a given

Log $m_{SiO_2(aq)}$ vs. T. FOR SiO_2 PHASES

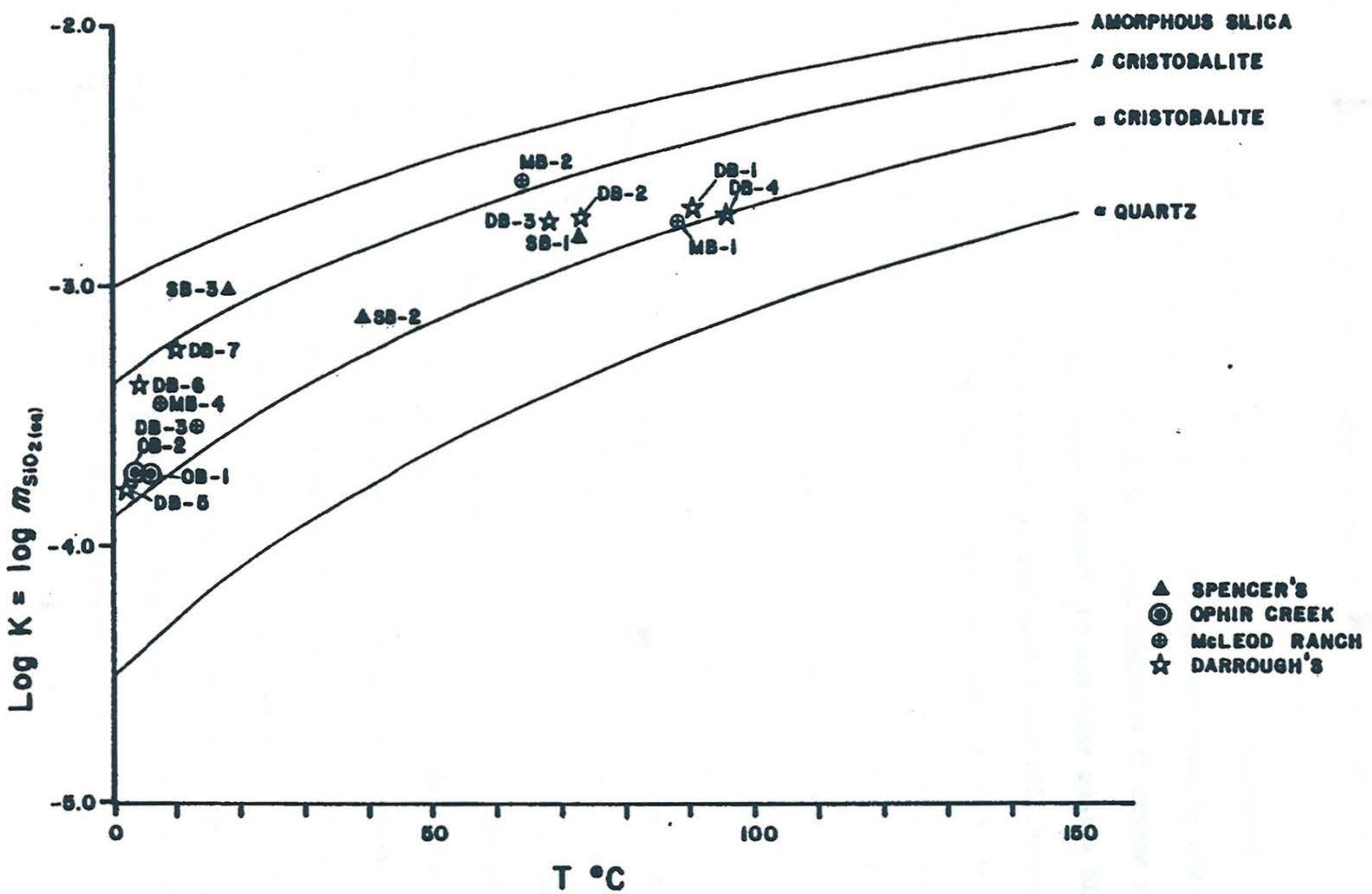


Figure C22.

area as heating or cooling of solutions with little or no change in SiO_2 content (e.g. SB-1, SB-2, SB-3, or DB-1, DB-2, DB-3, DB-4). However, this explanation does not hold for MB-1, MB-2 where the higher silica is associated with the lower temperature. More detailed study would be required to determine the possible source or sources which contribute to the distribution of silica in the fluids sampled.

Trace Constituents

Nine elements are grouped into the trace category although their levels may equal or exceed those of some of the components discussed under the major and minor heading. Included in this subdivision are B^{+3}, Li^{+}, F^{-}, As^{+3}, Ba^{+2}, Fe^{+2}, Cs^{+}, Rb^{+} and Sr^{+2}. Analytical results for these elements are given in Table C1.

Some relationships associated with the distribution of these elements are reasonably straight-forward while others are not clear from the data available from this study. A comparison of the levels of these elements in thermal versus non-thermal fluids is presented in Table C2. The information presented in the table does indicate that concentrations of certain trace constituents could be used to distinguish hot from cold water on a local basis e.g., Darrough's or Spencer's. Care should be exercised in applying this approach because levels of these constituents in thermal fluids vary considerably from one location to another while their concentrations in cold waters throughout the study area are similar. The nature of trace element concentration with respect to temperature

Table C2. Relative change when comparing thermal to non-thermal fluids (E=enrichment, B=both enrichment and depletion occur, N=approximately equal level in both.)

Element	As^{+3}	B^{+3}	Ba^{+2}	Cs^{+}	F^{-}	Fe^{+2}	Li^{+}	Rb^{+}	Sr^{+2}
Relative Change	E	E	B	E	E	B	E	E	B

varies both with location and the element being considered. For example, Rb^+ levels at Spencer's and Darrough's both increase with increasing fluid temperature. However, Spencer's concentrations of this element are as much as an order of magnitude greater than those at Darrough's even though the latter has measured temperatures nearly 23°C greater than those recorded at the former. Consideration of the information in Table 1 demonstrates that in the thermal fluids sampled, arsenic levels are generally higher in lower temperature fluids. The above relationships indicate that fluid trace element chemistry is significantly variable throughout the study area. It should be noted that the geothermal sites are located within (McLeod), or near (Darrough's, Spencer's) playa deposits which may explain some of this complexity.

Stable Light Isotopes

Fourteen of the sixteen fluids sampled within the Big Smoky were submitted for analysis of hydrogen and oxygen stable light isotopic composition with the aim of using the results to aid in understanding the nature and possible paths of recharge within the geothermal systems. Analysis results are listed in Table C3 and plotted along with a worldwide meteoric water line in Figure C23. A cross present in the lower center of the figure depicts error bars constructed from data supplied by the analysts. The data plotted in Figure C23 indicate within analytical error limits that thermal fluids at Spencer's and McLeod Ranch are heated meteoric waters with a possible slight oxygen shift resulting from interaction with carbonate rocks which are present in the respective areas. Calcium carbonate (tuffa and calcareous sinter) are being deposited at both of these sites from thermal fluids further substantiating this hypothesis. Clayton and others (1968) have presented data demonstrating oxygen shifts in fluids in equilibrium with carbonates in the Salton Sea system at temperatures as low as 100°C. Fluids from Spencer's also lie along an approximately straight line indicating the possibility of mixing discussed earlier. It is also

Table C3. Hydrogen and oxygen stable light isotope Analysis results - Big Smoky Valley

Sample Name	Sample Number	δD°/oo	δ^{18}O°/oo	T°C
Darrough's well	DB-1	-131	-8.4	90.5
Darrough's north spring	DB-2	-130	-6.7	71.2
Darrough's south spring	DB-3	-128	-15.1/-15.0	68
Darrough's pool	DB-4	-129	-8.1	95.5
Aqueduct stream	DB-5	-123/-122	-10.8	1.8
Barker Creek	DB-6	-125	-15.9/-15.2	3.9
Spencer 73	SB-1	-141	-15.4	72.5
Spencer 39 Dead Burrow	SB-2	-143	-15.9	38.8
Well north of Linka Mine	SB-3	-141/-141	-17.8	-
Upper Ophir Creek	OB-1	-132	-16.0	5.8
Lower Ophir Creek	OB-2	-126	-11.2	3.7
McLeod 88 Spring	MB-1	-132	-17.7	87.9
McLeod 63 Spring	MB-2	-125	-16.3	62.7
Fault Spring	MB-3	-132	-15.1	13.6

Values separated by a slash indicate duplicate runs on a single sample.

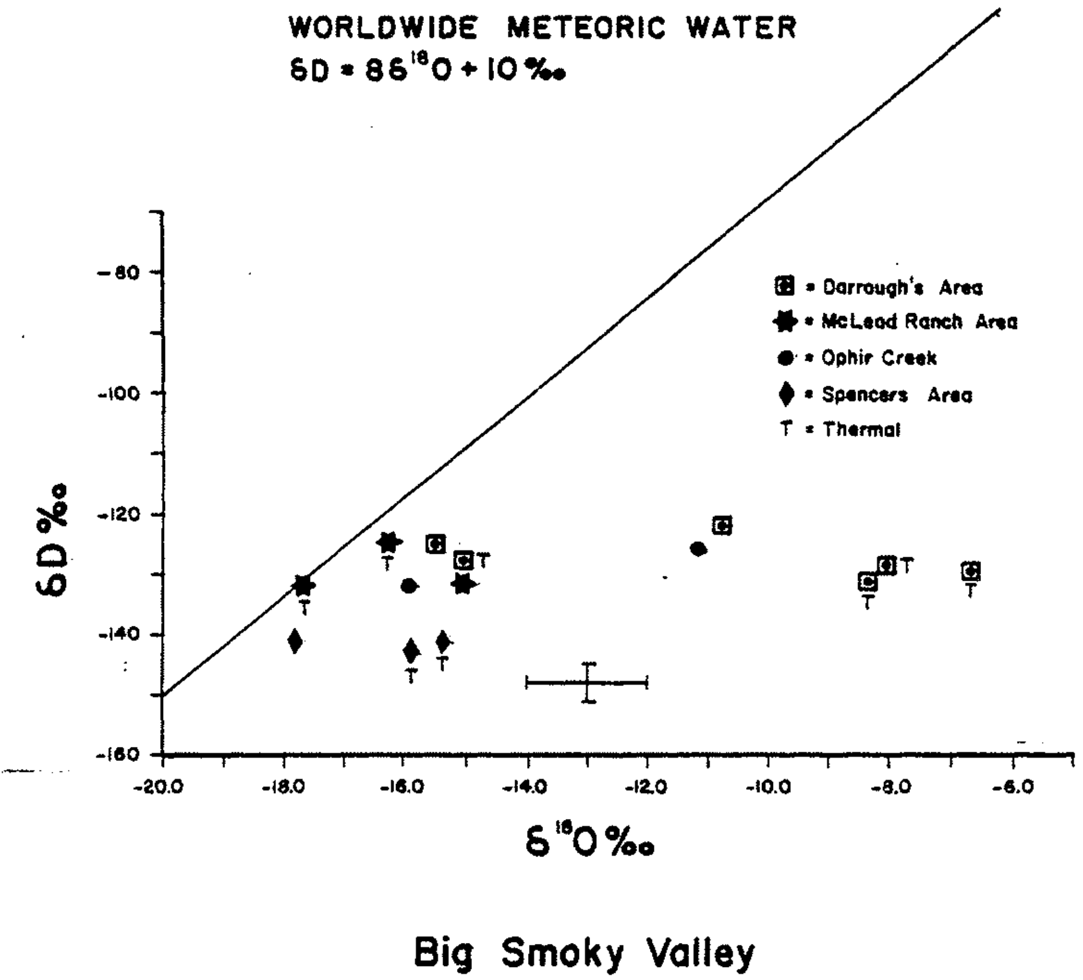


Figure C23. Oxygen and hydrogen stable light isotopic composition of thermal and non-thermal fluids from the Big Smoky Valley study area. Worldwide meteoric water line after Craig (1963).

interesting that Spencer waters possess distinctly lower deuterium concentrations than fluids sampled farther south in the valley. This may result from higher recharge elevations or a greater component of snow melt but no data is available upon which definite conclusions can be drawn.

Data from the Darrough's Hot Spring area appear to represent a more complex scenario. Three of the four thermal fluids sampled at Darrough's exhibit an oxygen shift of seven to nine per mil. Although a minor amount of carbonate rocks are present in the Toiyabe Range near the Darrough's surface geothermal site, chemical analysis has shown the fluids to be deficient in calcium by more than an order of magnitude compared to non-thermal fluids in the area. In addition, these springs are not depositing tufa. Based on these facts and the magnitude of the oxygen shift it seems reasonable to postulate that these fluid isotopic compositons are the result of a relatively high temperature thermal history. Comparable isotopic shifts are present in the Salton Sea system (Ellis and Mahon, 1977, Figure 3.1) where Clayton and others (1968) determined isotopic equilibrium with fine-grained silicates to have occurred at fluid temperatures in excess of 150°C). Such temperatures at the Darrough's location are not improbable as one of the fluid samples (DB-1) comes from a well with a recorded temperature of 129°C at a depth of 800 feet. One of Darrough's thermal fluids exhibits an isotopic composition falling within the meteoric range. This is thought to be the result of recharge which occurs along a relatively shallow path possibly in alluvial materials where it is heated by conduction.

Two non-thermal fluids exhibit oxygen isotopic shifts with a magnitude of about one half or two thirds that was found in the Darrough's thermal waters (fig. C23). Chemically these cold fluids are similar to other non-thermal waters sampled (the two points labeled Ophir Creek were collected from different elevations along the same stream). Both of the samples displaying the shift were taken at points along the bounding faults of the Toiyabe Range approximately six miles apart. In consideration of the above it is suggested that the isotopic composition of these fluids results from the mixing of a fluid similar to the shifted thermal fluids at Darrough's, with those of a type resulting from precipitation in the range. Thermal fluids migrating upward along the range bounding fault could dissipate heat via conduction with minimal chemical alteration because their recharge path keeps them in contact with the same rock types encountered in their downward migration.

Summary

Analyses of major and minor dissolved constituents demonstrate the distinctive nature of the Darrough's resource compared to other Big Smoky geothermal locations. It is also noted that all thermal fluids sampled exhibit relative calcium depletion when compared to local cold waters. Silica content of all fluids indicates saturation with respect to quartz and most values lie between the solubility of alpha- and beta-cristobalite. No simple relationship between SiO_2 content and temperature is readily apparent.

Trace element chemistry shows certain elements to exhibit increasing levels as temperatures increase for all thermal fluids at a given site while others appear to have random temperature associations. Levels of these trace constituents vary widely from one location to another but are generally enriched in the thermal fluids when compared to local meteoric and groundwater values.

Isotopic analysis of thermal and non-thermal fluids indicate that waters which recharge the geothermal systems are of meteoric origin. Darrough's fluid isotopic compositions show large oxygen shifts which are likely related to a relatively high temperature recharge history. And finally, samples collected along the bounding faults of the Toiyabe Range suggest mixing of meteoric and thermal fluids where meteoric waters cross the faults.

Shallow Depth Temperature Probe Surveys

The distribution of temperatures at a depth of two meters was determined for all three of the resource areas in the Big Smoky Valley. Initially a series of two meter holes was attempted at the Spencer's location, but this endeavor met with limited success due to the presence of a layer of calcareous sinter at approximately 1.3 meters depth and a poor design of cutting bit for use in such material. Only five holes were completed in the vicinity of surface geothermal manifestations and they seemed to indicate a rapid drop in temperature as one proceeds laterally away from a surface thermal expression. In addition to the five holes in the vicinity of the thermal springs and wells at Spencer's, three other holes were drilled at distances of approximately 1 and 2 1/2 miles (1.6 and 4 km) from the area of known geothermal occurrences. These holes exhibited temperatures comparable to those recorded in holes drilled as close as 300 ft. (91.5 m) from thermal springs and wells at the Spencer's site. This limited work was completed during mid-October.

A second two meter depth temperature study was undertaken in the Spencer's Hot Springs area in mid-November. Use of a more effective bit design permitted the completion of 15 holes. The location of the majority of the holes and the isotherm constructed from the data obtained are depicted in figure C24. Background temperatures determined during this investigation were 6-8°C lower than those recorded in mid-October. This difference likely reflects seasonal ambient changes. Daily highs for the first study period averaged 15°C while those of mid-November fell to -1°C. Information from this study generally supports the earlier observation of rapid decrease in temperature with short lateral movement from the location of a thermal spring or well. This phenomenon combined with the sample point spacing resulted in the limited nature of the isotherm configuration shown in figure C24. Based on the available data it can be concluded that the

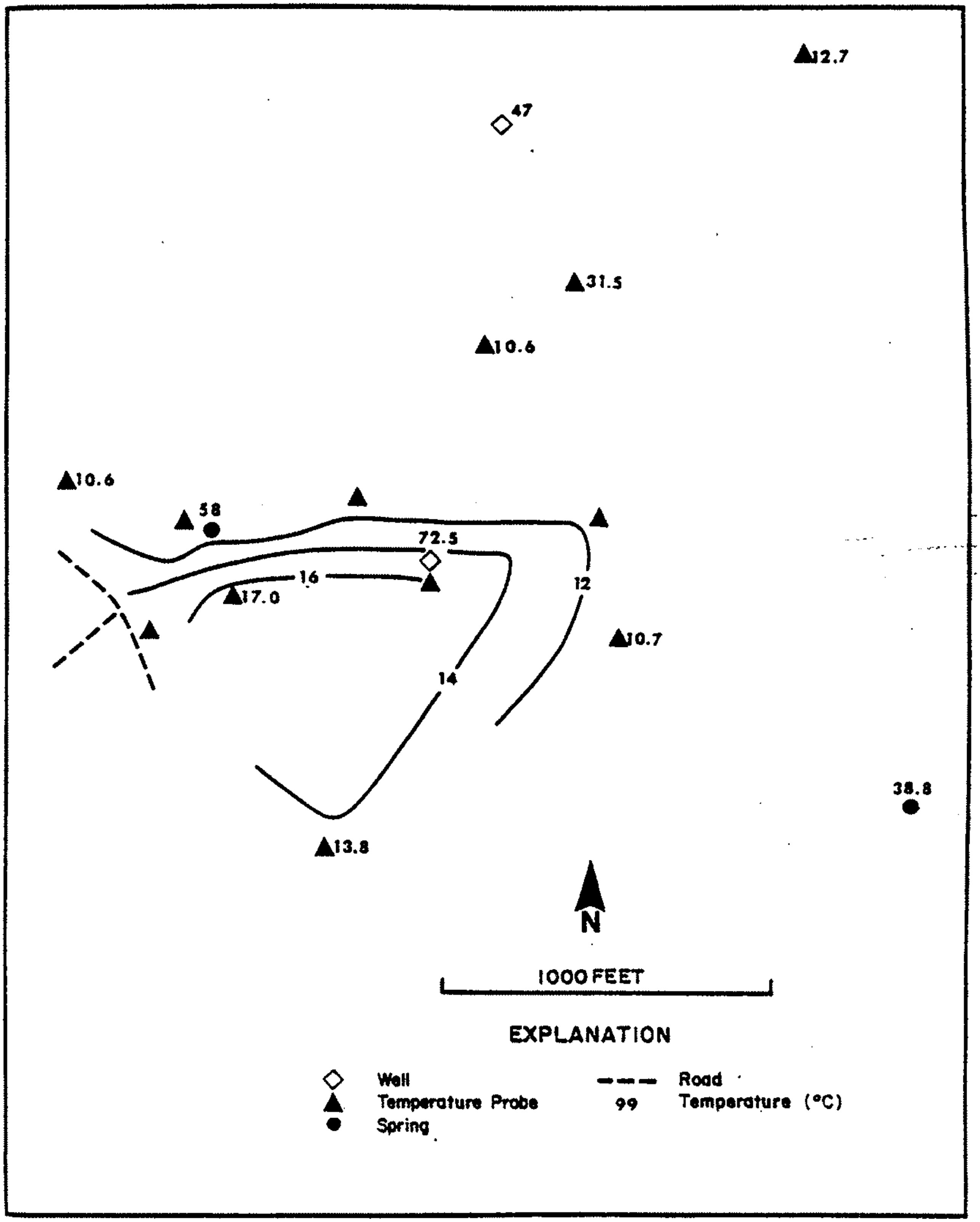


Figure C 24. Two meter probe isotherm configuration at Spencer's Hot Springs.

near surface thermal manifestations at Spencer's occur as relatively localized phenomena which appear to be separated from one another and not related to any (as yet discernible) trend.

The sample point labeled 31.5°C in figure C24 is approximately twice the magnitude of the next highest temperature recorded during the study but is not associated with a spring or well. Probe hole location is within a few feet (3 meters) of a topographic high, covered with an anomalous amount of foliage which could be suspected of being a former spring in a tufa mound. The temperature recorded seems to substantiate this hypothesis and indicates a potential usefulness of the shallow depth probe in delineating buried near surface thermal phenomena within a local study area.

A total of 16 holes of two meter depth were drilled on a rectangular grid pattern with 800 foot (244 m) spacing between points at the McLeod Ranch Hot Springs. All of the holes were drilled and the probes implanted within a single day. Temperatures were measured shortly after sensor implantation and at times approximately 16, 24 and 36 hours after implacement. It was found that temperatures became stable to within 0.1°C (as detected by our sensors) after a period of 24 hours. This agrees with stabilization times determined during the limited work done at the Spencer's location during mid-October.

A diagram of the interpreted isotherm configuration based on the two meter study at McLeod Range is presented in figure C25. The material drilled was largely playa silt with varying amounts of clay. Mud was frequently encountered at a depth of 1-1.5 m and standing water was encountered in one hole at a depth of 1.3 m. Based on these observations it can be concluded that the isotherm patterns are derived from measurements taken in water rich to saturated materials and are not representative of a strictly conductive temperature distribution. Examination of the isotherm configuration reveals two interesting phenomena: the two meter depth thermal highs are not coincident with surface geothermal

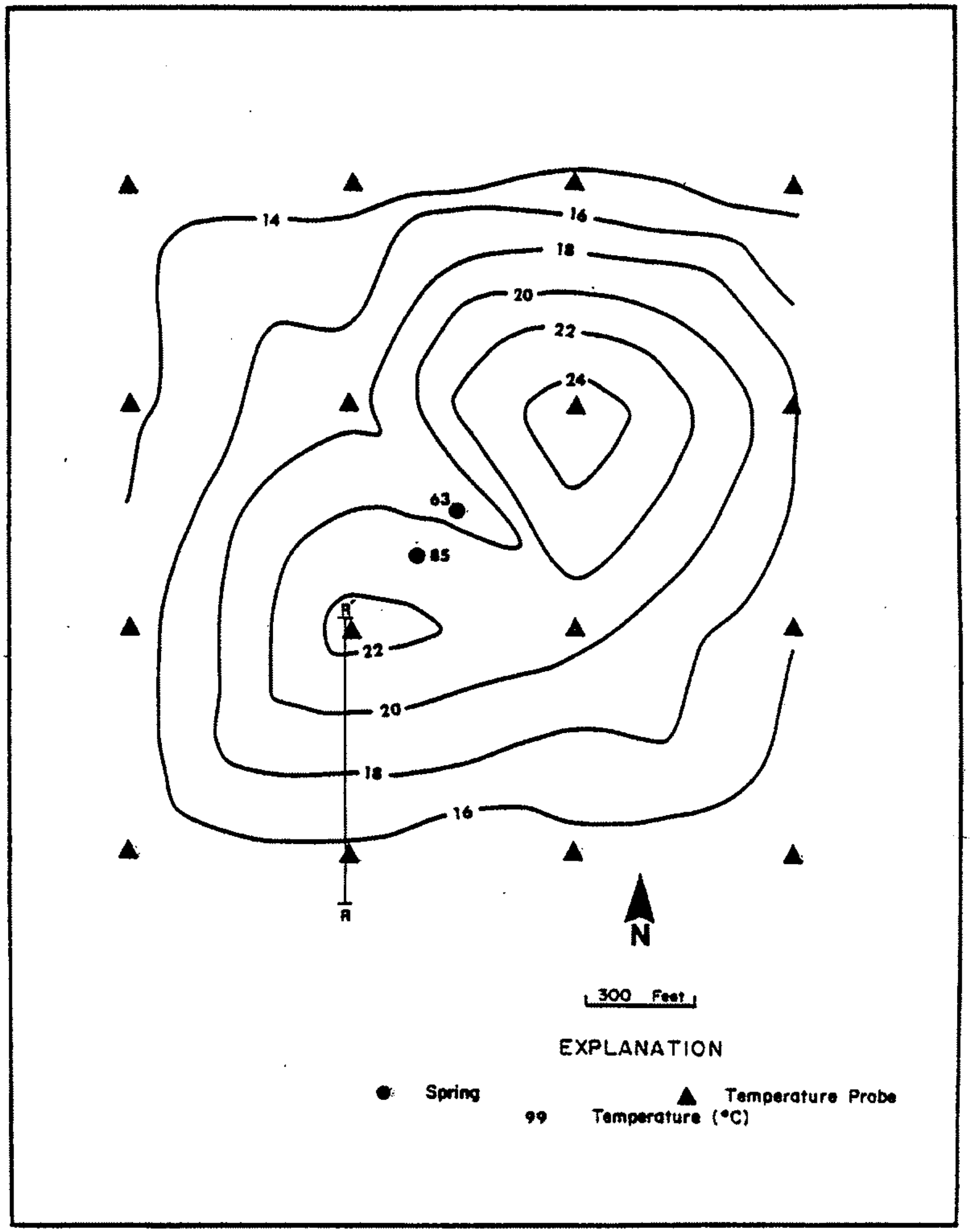


Figure C 25. Two meter probe isotherm configuration at McLeod Ranch Hot Springs. Line R-R' represents the path used during shallow resistivity study (see text under shallow resistivity heading for discussion).

manifestations (shown by solid circles in fig. C25) and the presence of two linear trends. No explanation of the displaced highs is readily apparent from our study. However, the linear features do correlate with other data previously discussed. The two linears alluded to are described by (1) the colinear arrangement of the subsurface thermal highs and surface hot springs-orientation approximately N45°E, and(2) the distortion of the isotherm pattern along an approximately N45°W direction. These features parallel the directions noted in the section describing low sun-angle photography over this location. On-site examination indicates the presence of a 25°C spring within 10 feet (3 m) of the hot spring labeled "63" in figure C25. This information combined with the nature of the distorted pattern indicates the possibility of a fault allowing non-thermal fluids to enter the hot spring site along a N45°W trend.

A relatively detailed shallow-depth temperature probe study involving 29 two-meter holes was completed at the Darrough's Hot Springs site. The isotherm configuration prepared from the accumulated data is shown in figure C26. Study of the patterns in the figure indicates that the thermal fluids migrate in the near-surface along distinct paths which extend eastward from the approximate locations of the springs labeled "71" and "68". These paths may be former channels in the alluvial materials through which the hot springs surface. The pattern extending from the 68°C source is rather well defined while that from the 71°C spring is noticeably more irregular. This is interpreted to be the result of the influx and mixing of non-thermal fluids in the near surface environment. Non-thermal fluids were present as a standing body of water in a region surrounding the 8°C isotherm during the study. Temperatures within this region were the lowest recorded.

In addition to the eastward pattern caused by fluid migration, a second linear feature is described by closure of the isotherm pattern about an axial high. The presence of alluvial materials containing cobble- and boulder-size

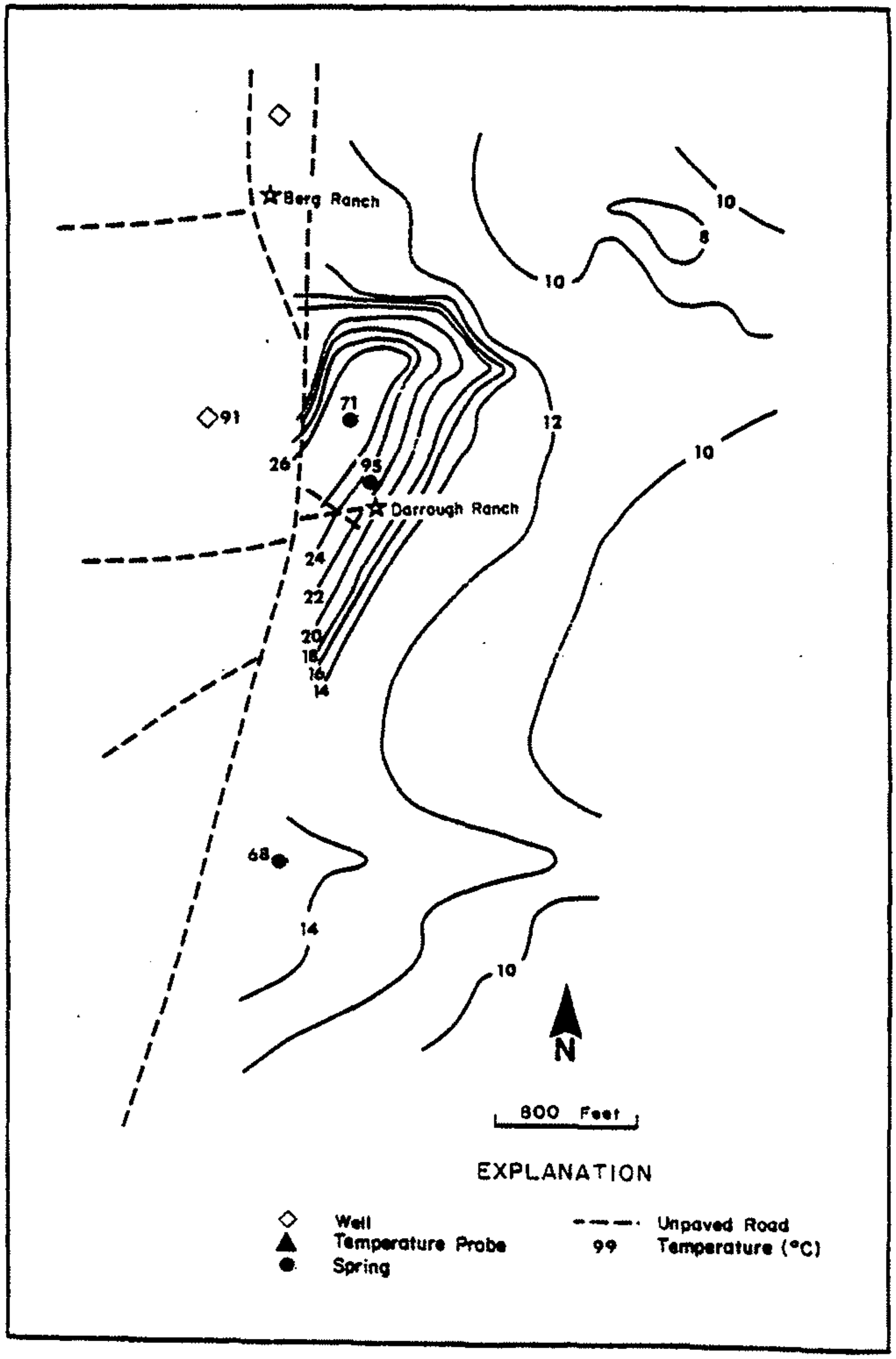


Figure C 26. Two meter probe isotherm configuration at Darrough's Hot Springs. Scale of the figure prohibits probe locations from being depicted.

rubble prohibited drilling in the area to the west of the road (indicated by the dashed line) which in turn results in the abrupt termination of the isotherms. However, a sufficient amount of data are available to assign a general orientation to the axial high of between N15°E and N20°E. A marked inflection in the slope of the gravity curve derived for this location is coincident with the lineation axis. Furthermore, if this axial trend is extended to the southwest it is seen to be the same trend described by the range-bounding fault and alluvial faults discussed under the section devoted to low sun-angle photography.

Summary

Two-meter depth temperature probe studies at the location of the three known geothermal resource sites in the Big Smoky Valley have indicated the usefulness of the technique in defining the distribution of the resource in the near surface environment. Isotherm configurations at the Darrough and McLeod ranch sites can be related to structural features present in the Toiyabe Range and nearby alluvial materials. At the Spencer's location no structural correlation could be determined but the isolated nature of the individual springs is demonstrated and a subsurface thermal high is located in a mound which may have been developed by a formerly active thermal spring. It was found that alluvial materials and calcareous sinter can present formidable obstacles to drilling when using a handheld power auger.

Soil Mercury

Six soil survey traverses were established concurrently with the gravity traverses in the Big Smoky Valley area. Due to time and budget restrictions sampling was limited to the gravity traverses and short extensions beyond the traverse limits. Lithologic variations along the traverses and poor sampling control due to the lack of developed soil horizons caused widespread variations in the mercury values. Several samples show mercury concentrations less than 1 ppb, which is probably related to insufficient sampling depth. In addition, several point anomalies had to be disregarded because samples collected on either side of these anomalies did not exhibit sufficient mercury levels to establish the area surrounding the points as an anomalous region.

In general, areas of high Hg concentrations did correlate with known thermal anomalies. Many of these areas are in close proximity to slope changes along gravity profiles substantiating the postulated structural control of the thermal anomalies. A definable northwest trending linear anomaly is outlined in the eastern portion of the OMC traverse. However, correlation with gravity profile inflection in the vicinity is uncertain. The interesting fact about this northwest trend is its parallel and subparallel relationship to several surface lineations in the mountain ranges on either side of the valley. A similarly oriented linear pattern defines a structural direction which appears to play a major role in the localization of the McLeod Ranch Hot Springs. Figure C27 shows the anomalous regions found in the Big Smoky Valley.

Shallow Electrical Resistivity

Shallow resistivity measurements were conducted only at the McLeod Ranch site in the Big Smoky. The survey consisted of a Wenner array with an electrode spacing of 25 feet (7.6 m) used for mapping and 10, 25 and 50 feet (3.05, 7.6 and 15.2 m) for vertical electrical sounding (VES). Because the survey was undertaken after the two meter temperature study some knowledge of near surface material, composition and distribution was available. R-R' on figure C28 shows the location of the mapping line. A VES at point R with electrode spacings of 10, 25 and 50 feet (3.05, 7.6, 15.2 m) indicates a highly conductive layer between depths of penetration of the 25 and 50 (7.6 and 15.2 m) spacings. The layer was so conductive that our equipment could not supply a sufficient amount of current to register a potential. Assuming this conductive layer to

Figure C27. Areas of anomalously high soil mercury values in the Big Smoky Valley.

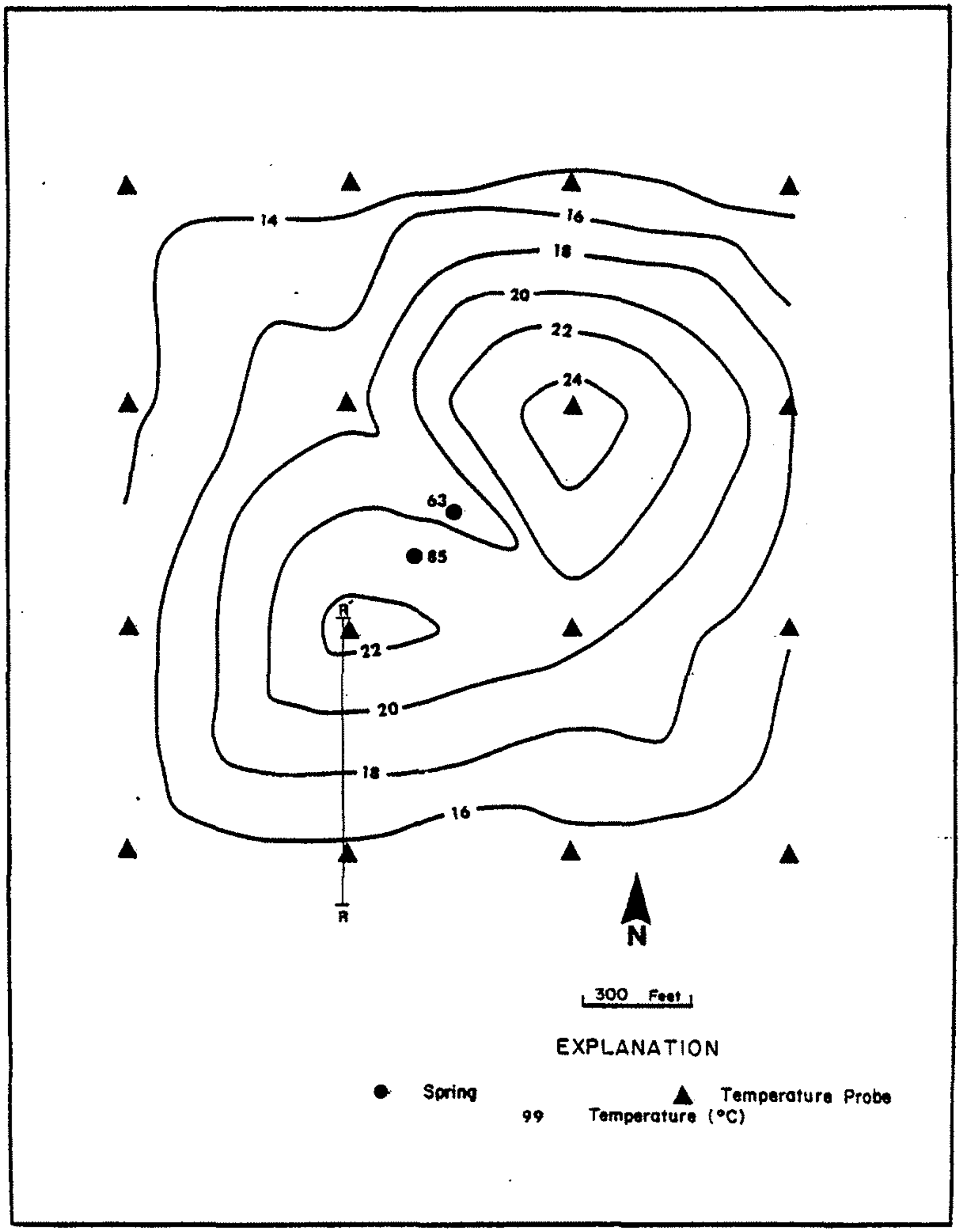


Figure C 28. Line (R-R') used during shallow resistivity study. Station spacing 100 feet. See figure 25 and accompanying text for temperature study.

represent a water saturated zone, mapping was conducted with a 25 foot (7.6 m) electrode spacing in a northerly direction towards R'. It was hoped that the resistivity would drop significantly in the vicinity of R' which is known from drilling to be nearly saturated at a depth of 1.5 m. No notable decrease was noted. An electrode spacing of 50 feet (15.2 m) near R' failed to penetrate the conductive layer encountered at R and the survey was discontinued.

Results of the study were at best indeterminate and the time expended in gathering the information excessive in view of the results. To use this method to locate near surface but buried faults would require 6-8 mapping-lines each requiring two man-days. The information obtained would be from a distinctly limited area, and if similar highly conductive materials were encountered the effort would likely be wasted.

Summary

A shallow resistivity study was conducted at only one geothermal resource site in the Big Smoky-McLeod. The survey produced ambiguous results and required too much time to be considered an effective exploration method when bounding in highly conductive layers found at this location.

Temperature Gradient Drilling

One primary and two alternative sites were selected prior to the commencement of drilling in the Big Smoky. Primary status was assigned to the Darrough's area while second and third choices were Spencer's and the Ophir-Moores Creek region respectively. Several criteria were used to make the selection as described below. Highest priority was assigned to the location we felt had the greatest potential of extending the limits of a known resource.

The decision to site the hole in the primary (Darrough's) area was made after consideration of the numerous complimentary lines of evidence discussed previously. To review, these include 1) a distinct inflection in the gravity profile below the known surface and subsurface manifestations,(2) an area of anomalously high soil-mercury levels in the same position,(3) the linear pattern of shallow temperature isotherms and its colinear orientation with(4) the lineation described by the range-bounding fault trace and alluvial fault trace to the southwest of the geothermal expression. Also considered was the relatively high (129°C) temperature recorded from the 800+ foot well situated within the area defined by the hot springs.

Fewer positive and supportive criteria were available to aid in choosing secondary sites. The Spencer's site was selected on the basis of the coincidence in location of a soil-mercury high and a relatively high shallow temperature probe measurement. Additionally, a slight inflection in the gravity profile was noted in the vicinity. A northwest trend of soil mercury anomalies combined with steep changes in the slope of the gravity profile led to the choice of the Ophir-Moores Creek alternate.

Drilling activities in the Big Smoky Valley study area were carried out during the last week of March and first week of April, 1980. A decision was made to apportion the remaining footage on the contract (610 ft.) between the Darrough's (BSD) and Spencer's (BSS) sites (fig. C30). In keeping with the restrictions discussed above, drilling at BSD-1 began with air although a limited capacity portable sump was available. A chronological description of drilling operations and their associated problems follows.

A significant problem with drilling was encountered at location BSD-1 which resulted in the drilling of a second and successful hole at nearby BSD-2 (fig. C29). The problem revolved around restrictions imposed by the Bureau of Land Management (BLM) because chipping fragments were found during site examination by a BLM geologist. These restrictions included a prohibition against the digging of a mud sump. In accordance with their request, BSD-1 was drilled using air and foam in thick alluvial fill. This endeavor ended in failure

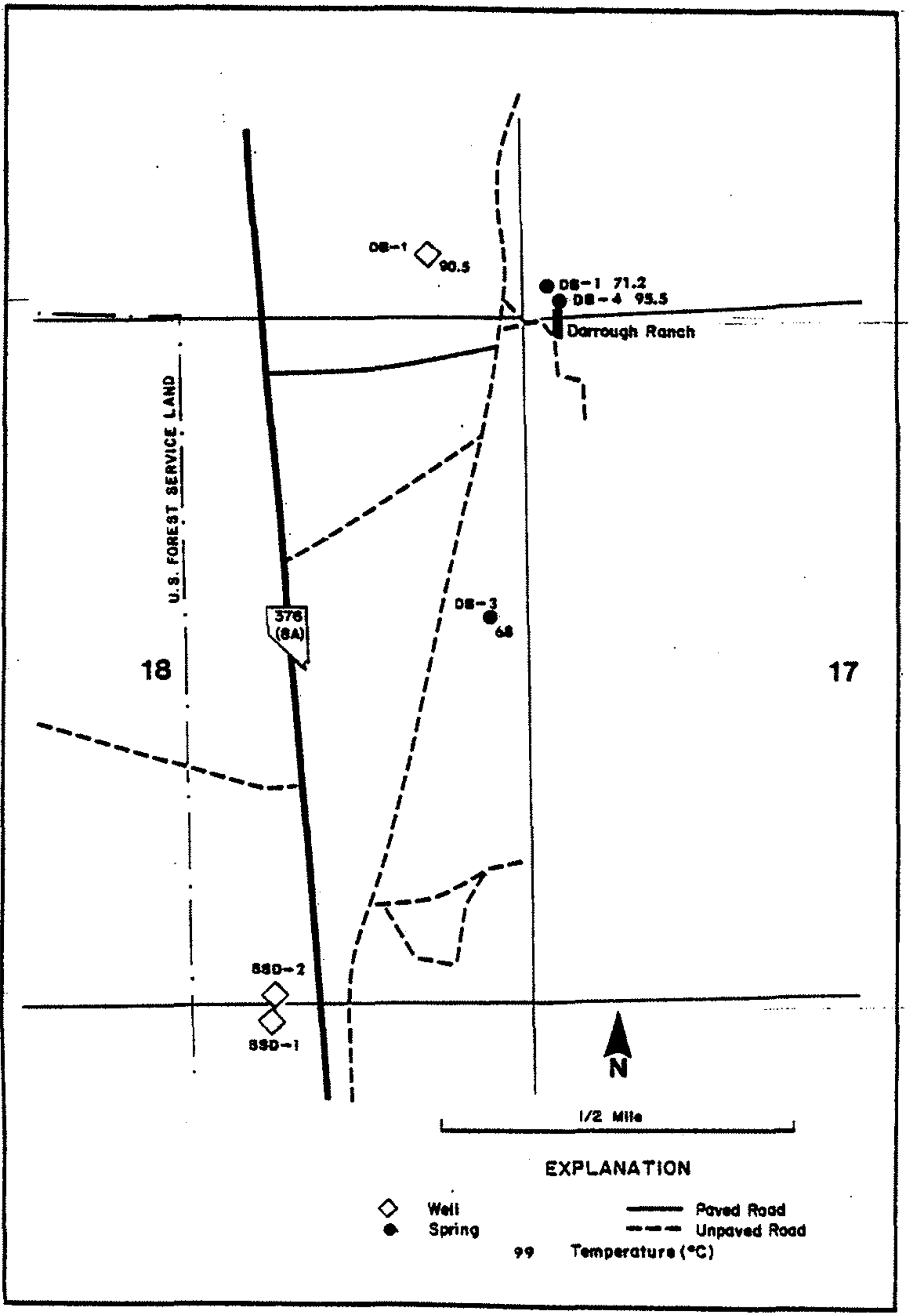


Figure C29. Location of drill sites BSD-1, BSD-2, and thermal springs and well in the vicinity of Darrough's Hot Springs.

and was abandoned after the five day effort produced a caving hole less than 200 feet in depth. Seeking to avoid future BLM limitations, permission to drill on private land was acquired from a landowner, and approval of this approach was obtained from DOE. Using mud, a successful 500-foot hole was completed in similar materials in three days.

29 March - BSD -1 spudded in at 1300 with a 7 7/8" tricone bit. Very coarse alluvial cover: difficult drilling. Operations terminated at 16:30 - water truck requires filling.

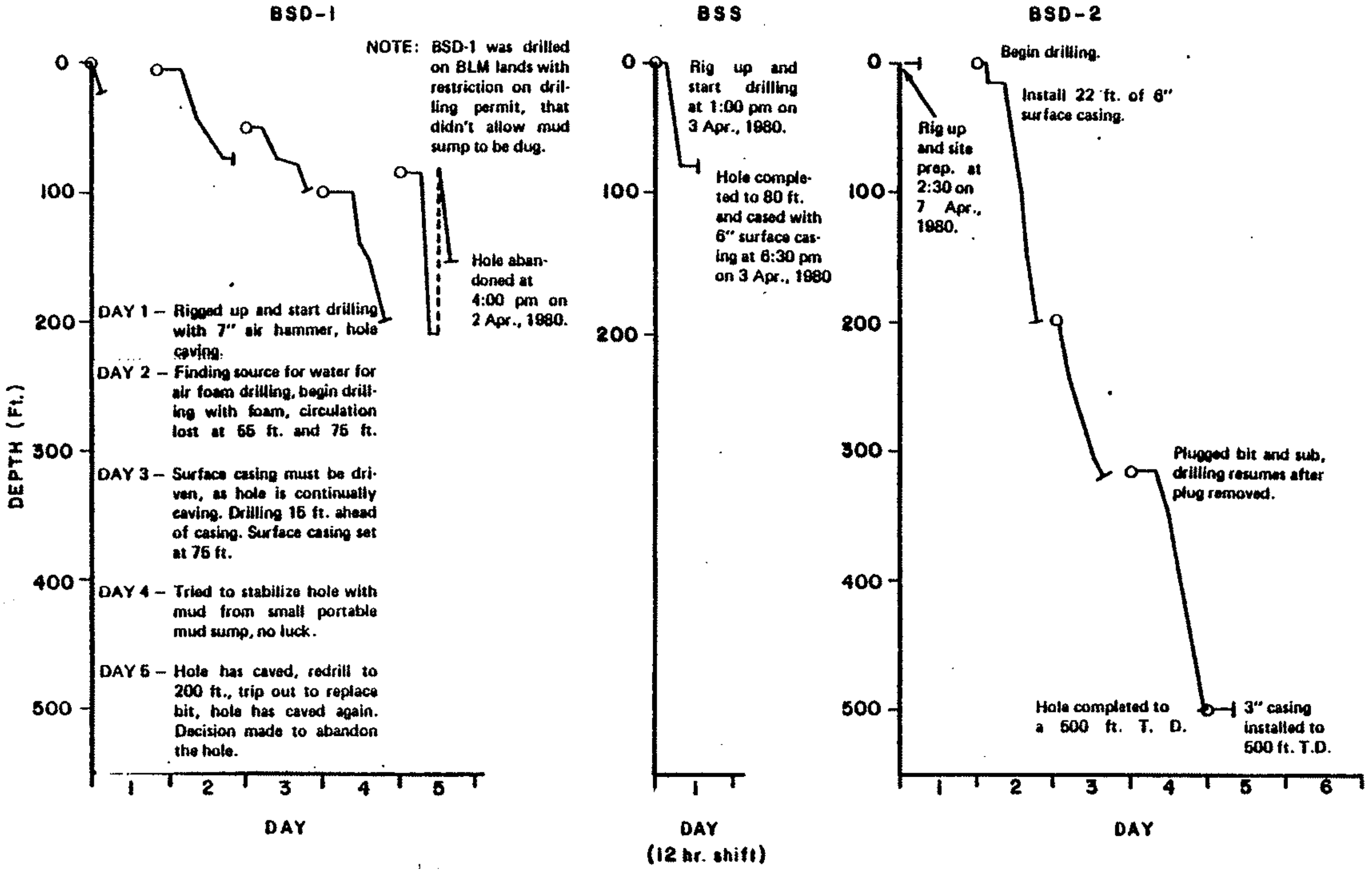
30 March - Owner of a local ranch agrees to supply water to the drilling contractor. Drilling is resumed at 11:30 and progresses slowly. All circulation is lost between 50 and 75 feet and only partial fluid recovery occurs above this interval. At the 75 foot level the drill string is tripped out and preparations made to install a 6" surface casing. A blockage is encountered at 50 feet which prevents further movement of the casing. It is decided to cease operations and drill ahead of the casing the following day.

31 March - Activity begins with the installation of a 5 7/8" bit which is run down the hole inside the casing. It is hoped that drilling ahead of the casing with the smaller diameter bit will permit the casing to be driven with the top head drive unit (kelley). The casing is finally set to 75 feet at 16:30 and drilling continues with the 5 7/8" bit. Attempts to maintain a heavy foam consistency are hampered by significant groundwater influx. Drilling stopped at 100 feet because of excessive caving. Mud and portable tank will be used the following day.

1 April - The morning is used to rig up for mud drilling. Over 400 gallons of mud are pumped downhole without returns. Lost circulation material is pumped downhole but returns are not gained. Drilling with an air-foam-mud mixture begins at 12:50 and continues until 18:00 at which time a 200 foot depth is attained. The drill string is tripped up into the cased section of the hole and operations terminated for this day.

Figure C30. Locations of temperature gradient holes BSD–1, BSD–2, and BSS, in the Big Smoky Valley.

DRILLING PROGRESS CHART FOR BSD-1, BSS, AND BSD-2



NOTE: BSD-1 was drilled on BLM lands with restriction on drilling permit, that didn't allow mud sump to be dug.

Hole abandoned at 4:00 pm on 2 Apr., 1980.

DAY 1 – Rigged up and start drilling with 7" air hammer, hole caving.

DAY 2 – Finding source for water for air foam drilling, begin drilling with foam, circulation lost at 55 ft. and 75 ft.

DAY 3 – Surface casing must be driven, as hole is continually caving. Drilling 15 ft. ahead of casing. Surface casing set at 75 ft.

DAY 4 – Tried to stabilize hole with mud from small portable mud sump, no luck.

DAY 5 – Hole has caved, redrill to 200 ft., trip out to replace bit, hole has caved again. Decision made to abandon the hole.

Rig up and start drilling at 1:00 pm on 3 Apr., 1980.

Hole completed to 80 ft. and cased with 6" surface casing at 6:30 pm on 3 Apr., 1980

Rig up and site prep. at 2:30 on 7 Apr., 1980.

Begin drilling.

Install 22 ft. of 6" surface casing.

Plugged bit and sub, drilling resumes after plug removed.

Hole completed to a 500 ft. T. D.

3" casing installed to 500 ft. T.D.

Figure C31

2 April - Rig requires recentering and string must be tripped out for replacement of a bit with a defective bearing. Drilling resumes at 14:00. Caving occurs and progress is severely hindered. At 15:30 a decision is made to abandon the effort before the string becomes jammed in the hole. During string removal continued caving of coarse material occurs. The string is out at 16:30 and mobilization to BSS site is ordered.

3 April - BSS is spudded in at 14:00 using a 7 7/8" tricone bit. Drilling proceeds rapidly in the fine alluvium and playa silts reaching a depth of 78 feet by 16:00. Casing of 6" diameter is run to total depth by 17:40 and the string is tripped into the hole and daily activity terminated.

4 April - Activities at BSS are halted while discussions are carried out with DOE Nevada Operations and the owner of the private land immediately north of BSD-1 regarding the prospect of drilling a second hole in the primary target area. The dialogue results in a decision to return to the Darrough area and drill on private land using mud.

5 April - BSS is abandoned and the drill crew leaves the area to obtain additional supplies required for the new hole. Drilling is scheduled to be resumed on 7 April. A rider is added to the original footage allowed in the contract to permit a total depth of 500 feet at the new location.

7 April - Operations at site BSD-2 with the digging of a mud pit and erection of the rig.

8-11 April - Drilling begins at 09:00 on 8 April. A single length of 6" surface casing is set to a depth of 22.5 feet and drilling continued using a 5 7/8" tricone bit. Progress is rapid and problems minimal. A comparison of drilling rates for BSD-1 and BSD-2 (fig. C31) demonstrates the marked increase in efficiency of the mud method in the alluvial materials. Total depth - 500 feet is attained at 19:30 on 10 April and the hole cased the following day using 3" steel pipe.

Results of Temperature Gradient Drilling

Of the three gradient holes drilled in the Big Smoky Valley study area only one, BSD-2, had a good gradient and bottom hole temperature. Figure C32 is a plot of the gradient for BSD-2. As can be seen from the diagram, this hole has an excellent gradient, 14.3°C/100 m, and a maximum bottom hole temperature of 28.8°C was recorded at 471 feet approximately one month after the hole was completed. Additional gradient measurements after this showed no major changes in the gradient.

The results of this gradient hole helps expand the known extent of the Darrough's resource as no subsurface evidence had indicated that the resource extended west of the highway (see figure C29).

Figures C33, C34 and C35 are the general lithologic logs for gradient holes BSD-1, BSS and BSD-2, respectively. Holes BSD-1 and 2 were drilled along the alluvial boundaries of the valley, whereas BSS was drilled in the north central portion of the valley in the playa silts and fine sands. Drilling rates with air were best in the finer playa silts and sands (BSS) whereas drilling rates with mud were much better than drilling rates with air in the alluvial material of BSD-1 and 2.

TEMPERATURE GRADIENT PLOTS FOR BSD-2

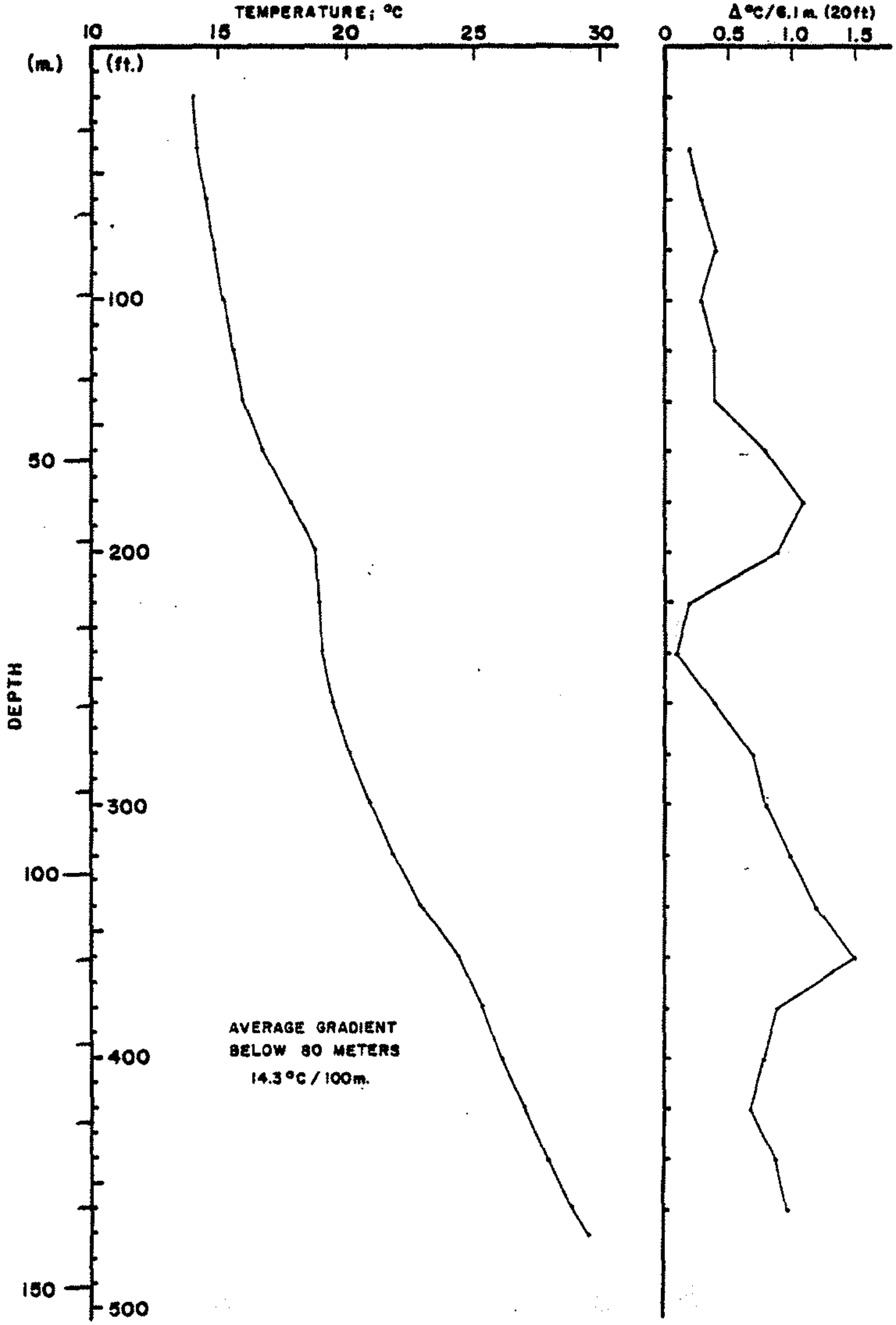


Figure C32.

GENERAL LITHOLOGIC LOG
BSD—I
(ABANDONDED)

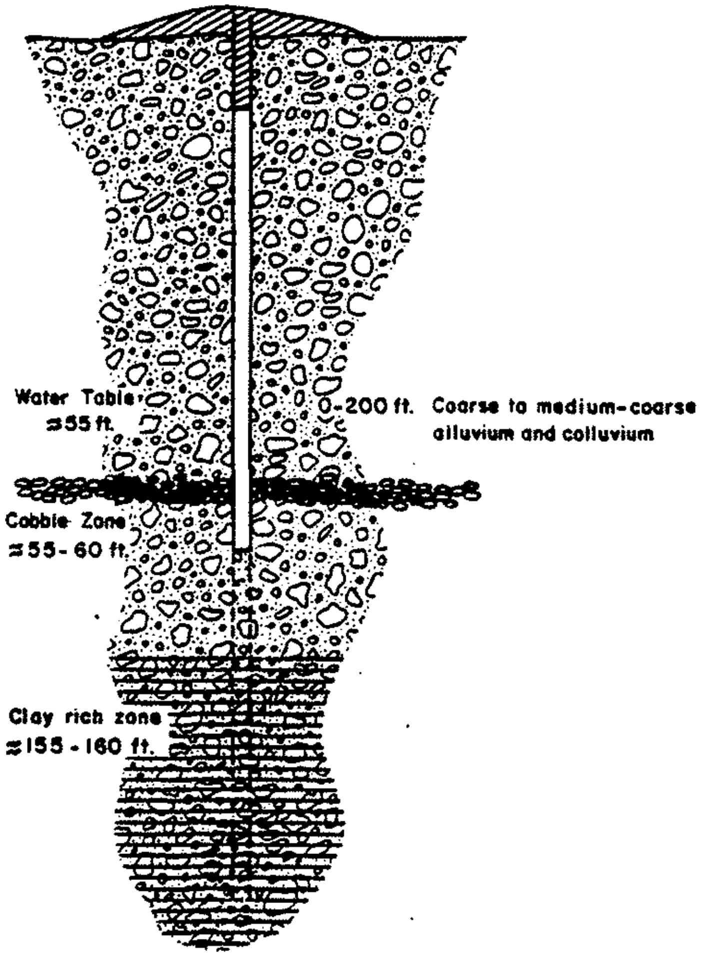


Figure C33.

GENERAL LITHOLOGIC LOG
BSS

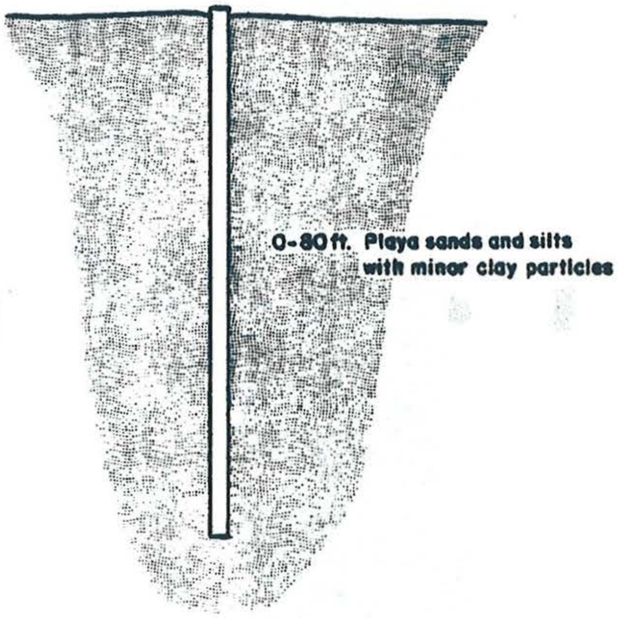


Figure C34.

GENERAL LITHOLOGIC LOG

BSD-2

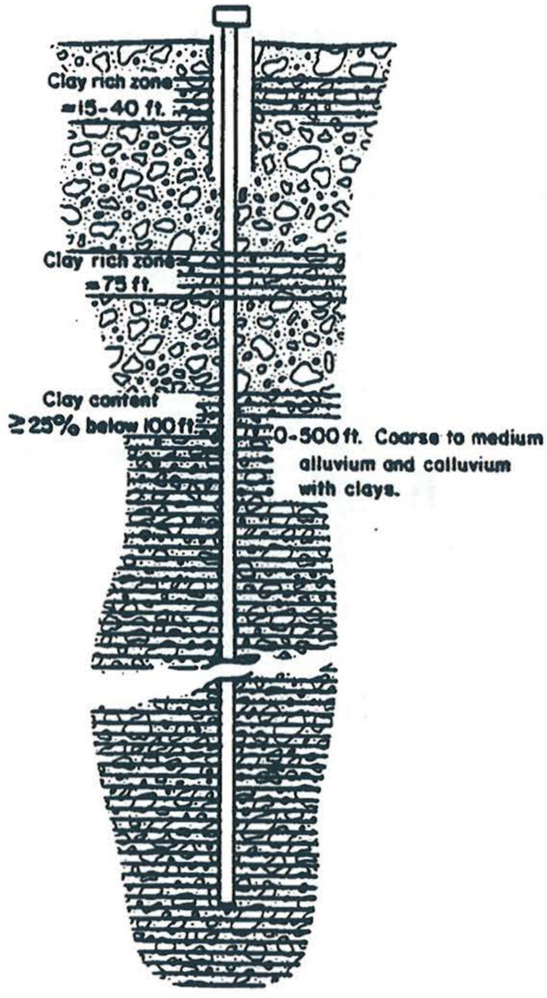


Figure C35.

SUMMARY

Evaluation of Exploration Strategy

In addition to the geothermal resource assessment of three areas in Nevada, the techniques employed in each area were evaluated on the basis of useful data derived from the methods. The evaluation (table D1) considers the applicability of the contractual tasks to only low- and moderate-temperature geothermal resource exploration. Exploration programs for potential high-temperature electricity producing resources may employ some of these techniques but generally rely heavily on extensive drilling.

The tasks for this study are rated on a scale of 1 to 10 for each area studied. The rating system is somewhat subjective and is strictly related to the areas studied. Appropriate comments for each task are included.

In general, tasks that provided abundant information for little time, effort or money expended have the highest ratings. Those tasks that could be integrated with other parts of the program to facilitate data interpretation are also favorably evaluated. The lowest ratings are awarded to time-consuming tasks that provide little or dubious data.

Review of geologic literature includes published reports, maps and thesis studies and constitutes one of the most essential tasks in any exploration program. The moderate to high ratings for this task reflect the quality and availability of geologic data. The scale of the available data should, however, be closely matched to the scale of the project. Regional geologic maps at a scale of 1:250,000 are adequate for regional geothermal assessments but should be supplemented by more detailed work in a site-specific program.

Properly conducted gravity surveys can furnish abundant data at low cost. The surveys conducted during this study did provide abundant data but required nearly 6 man-months to complete the field work alone. An additional 5 man-months were consumed during data reduction and interpretation. Although the cross-valley traverses were useful for a regional interpretation, a grid-like pattern would be much more effective especially for a site-specific effort. Also, data extrapolation between distant traverses may lead to erroneous interpretations. The resultant data from gravity surveys are easily integrated with existing gravity data and can be very valuable if depth to bedrock is known from either well-log data or seismic surveys.

Low sun-angle photographic surveys represent a component of imagery analysis that is particularly well suited to geothermal exploration programs. Economically attractive geothermal resources in the Basin and Range are generally associated with recent faulting. Subtle topographic features such as fault scarps are easily identified on air photos and greatly facilitate mapping and structural interpretation. However, ground verification of any linear feature is essential. Ground-disturbing activities such as agriculture, surface mining and urban activities may destroy parts or all of the target fault scarps. Natural erosion and deposition may also conceal the faulted topography.

Direct measurements of geothermal resources provide the most valuable data in any assessment program. Drilling is the most reliable method of obtaining subsurface temperatures but high drilling costs can limit the number and depth of planned holes. Drill-hole siting becomes a critical factor when funds are limited.

Shallow depth temperature probes have been used in this study to outline near-surface temperature anomalies. Temperatures measured 2 m below the ground surface are usually not affected by diurnal temperature variation. The effects of the annual temperature variation can be minimized if the reading interval for the temperature survey is small. Temperature corrections may be necessary, however, in areas where extreme inhomogeneous conditions occur in the soil, shade-cover, moisture content or topography. Holes may be hand-augered or drilled with a truck-mounted rig in clay-rich or cobbly soils. The technique is applicable to regional studies but may be most helpful for locating wells in site-specific program.

Collecting existing water well data broadens the data base and helps to reduce the costs of fluid analysis programs. This is true only in areas for which reliable data are available. Although very little useful data was available for the Big Smoky Valley area principally due to the small population, there was a tremendous amount of useful data for the Carson-Eagle Valley area. The available data include water chemical analyses, temperature measurements and lithologic logs. These data should be thoroughly evaluated prior to use in the assessment.

Shallow resistivity surveys received the lowest rating because the time required to implement the task was high and the resultant data was dubious. The technique is especially useless in the vicinity of hot springs where conductive saline brines saturate near-surface layers and show no resistance at all. This technique was eliminated from the program and was replaced by the soil-mercury sampling task.

Soil samples collected along the gravity traverse lines generally showed high concentrations of mercury in the vicinity of faults. These faults were identified by geologic mapping and air photo interpretation and generally corresponded to the location of steep gravity contour gradients. This technique also requires considerable evaluation; mercury anomalies can also be caused by analyzing soils with an above average clay fraction and may lead to erroneous interpretations. Low mercury values may also arise from a remobilization of soils.

The fluid sampling task was used to distinguish the chemical characteristics of thermal and non-thermal waters. In general, the major dissolved constituents provided the required data but trace and minor dissolved constituents were also used in the final interpretation. Isotopic analyses revealed a meteoric source for most of the sampled fluids, but fluids from Darrough's Hot Springs in the Big Smoky Valley appear to be chemically and isotopically different from local meteoric waters and probably represent a more complex heating history. Chemical geothermometers have been reliable indicators of subsurface temperatures in fluids that demonstrate little or no mixing with non-thermal fluids. Most of the fluids sampled here, however, have probably been mixed with shallow, cool, ground water. It should also be noted that commercial analytical laboratories may not provide reliable results for all samples and care must be exercised in laboratory selection.

Temperature gradient holes were drilled in the study areas to obtain reliable subsurface temperature information, to possibly identify new sources of thermal fluids and to obtain reliable lithologic data. The data from the drill holes support the hypothesis that the geothermal fluids are limited in areal extent. The thermal fluids apparently rise along portions of faults and fault plane intersections.

Problems associated with drilling included the site-selection process and drilling fluids used. Although drilling permits for test holes can be easily obtained, primary drill sites in urban areas can raise conflict-of-interest problems and may result in law suits. Drilling on public land requires bonding and permitting procedures. Drilling with air is advantageous for eventual downhole fluid sampling, but mud is often needed to support the wellbore walls in unconsolidated material. Mud-drilled wells should be thoroughly flushed prior to sampling and fluid disposal may become problematic on both private and public land. Despite the logistical and technical problems, drilling represents the ultimate test of the assessment program.

Table D1. Evaluation of Exploration Techniques.

	Regional Studies				Site-Specific Studies	
	Carson-Eagle Valley		Big Smoky Valley		Caliente	
Task	Rating	Comments	Rating	Comments	Rating	Comments
Geology	9	Regional data used in conjunction with gravity and air photos. Small scale data used to aid in structural and stratigraphic interpretations near thermal anomaly sites.	6	Geologic information available on a large scale only. The study area is too large to examine in the detail necessary for reliable structural and stratigraphic interpretations.	7	Useful for structural and stratigraphic interpretations. For a small area, 1:250,000 scale maps are not appropriate.
Gravity	8	Yields information on basement configuration, total displacement along faults, and depth of alluvial fill.	9	Subsurface configuration indicates faulting associated with location of geothermal resources. Study on a grid pattern, rather than transect pattern, would be more valuable to study.	N/A	N/A
Low Sun-Angle	6	Delineated subtle topographic features of older fault scarps. Not especially useful in ground-disturbed areas-urban and agricultural.	8	Particularly useful in vicinity of Darrough's Hot Springs for defining co-linear arrangement of range-bounding faults and alluvial fault traces with geothermal occurrence. Recommend scale of 1:24,000 for regional studies.	N/A	N/A
1-2 m depth temperature probe survey	7	Outlined areas in which the absolute measured temperature is high, relative to background. Configuration of isotherms reflects structural controls. Hand-augering holes becomes problematic in clay-rich and cobble-rich areas. No temperature corrections were applied to data.	8	Very useful in delineating near-surface thermal anomalies and patterns associated with them. Applied only on a site-specific basis (less than 1 sq. km).	8	2-m. probe survey results were nearly identical to data obtained from down-hole temperature measurements of warm water wells in the same area.

	Regional Studies				Site Specific Studies	
	Carson-Eagle Valley		Big Smoky Valley		Caliente	
Task	Rating	Comments	Rating	Comments	Rating	Comments
Water well data	8	Where available and reliable, may be used to identify both thermally and chemically anomalous areas.	3	Very limited availability combined with selectively useful chemistry in the Big Smoky Valley study area.	N/A	N/A
Shallow Resistivity	1	Time-consuming technique that yields dubious results	2	Requires excessive time and yields indeterminate results. Especially useless in saline brine-saturated materials in the vicinity of hot springs.	N/A	N/A
Soil mercury	6	Best when sampled on a grid system and in an area of undisturbed ground. The technique is quick and simple.	5	Requires consistent sampling techniques to produce meaningful results.	7	Data obtained should be evaluated on the basis of original deposition favorability and probability of remobilization.
Fluid sampling	8 5 8	Major ion concentrations can be used to distinguish thermal waters from non-thermal waters. Minor and trace ion concentrations may not always be diagnostic. Isotopes are very useful for identification of sources of fluids.	9 4 9	Most meaningful approach obtained through consideration of combined isotopic and major ionic data. Trace elements useful only on a site specific basis.	8 4 3	Although thermal and non-thermal fluids were chemically indistinguishable, their isotopic composition was different.
Temperature gradient drilling	6	Identified geothermal gradient but failed to locate thermal fluids. Confirmed structural interpretation in drilled areas.	9	Particularly useful in delimiting the areal extent of the resources.	N/A	N/A

Caliente Study Area

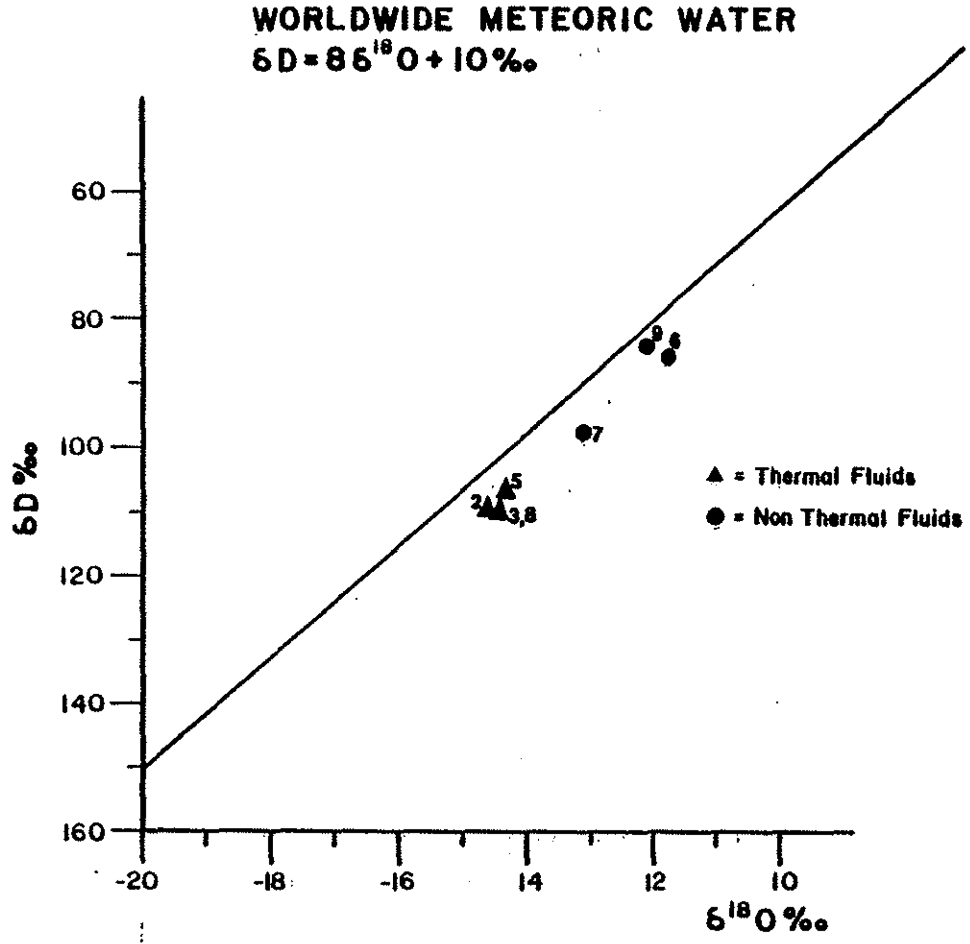
In addition to the major efforts conducted in the Carson-Eagle and Big Smoky areas, a smaller scale investigation was completed in the city of Caliente, Nevada and its immediate surroundings. The results from the majority of the techniques applied are detailed in a report published earlier this year (Trexler and others, 1980). However, data from isotopic analysis of fluids were not available at publication time. These data and their interpretation are discussed below.

Although major, minor and trace chemical constituents of thermal and non-thermal fluids do not show any clear distinctions, the hydrogen and oxygen-stable, light, isotopic data presented in Table D2 and plotted in Figure D1 indicate a prominent contrast. Thermal fluids are clearly grouped separately and within analytical error, present identical signatures. From their position in relation to the meteoric water line (Fig. D1) it seems reasonable to assume they are derived from meteoric water precipitated at a higher elevation than local non-thermal fluids and probably recharge from a single source. It is interesting to note that cold waters 9 and 6 form a distinct set. These fluids were collected in the southern portion of the area and display a similar distinct grouping in terms of major and minor dissolved constituents. Sample 7 which lies isotopically between the 9, 6 and thermal groups is chemically similar and may represent a mixing of these two types of waters. Because no isotopic data are available from fluids surrounding the Caliente area, no conclusions as to the source of the recharge can be drawn at this time.

Table D2. Hydrogen and oxygen-stable light Isotopic analysis results - Caliente

Sample Name	Sample Number	$\delta D^{o}/oo$	$\delta^{18}O^{o}/oo$	T°C
Wallis Well	CW-2A	-109	-14.6	67.0
Hospital reinjection well	CW-3A	-109	-14.4	29.2
Hot Springs Motel well	CW-5A	-106	-14.3	45.0
Clover Valley Wash	CW-6A	-88/-84	-11.7	12.0
Meadow Valley Wash	CW-7A	-97	-13.1	5.0
Van Kirk Well	CW-8A	-109	-14.4	42.8
Caliente City Well	CW-9A	-84	-12.1	15.0

Values separated by a slash indicate duplicate runs on a single sample.



CALIENTE STUDY AREA

Figure D 1. Oxygen and hydrogen stable light isotopic composition of thermal and non-thermal fluids from the Caliente area, Lincoln County, Nevada. Worldwide meteoric water line after Craig (1963).

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Appendix I

Chemical Analyses of Water from Thermal and Non-thermal Sources: collected from the files of the Nevada Department of Health, Division of Consumer Protection Services.

Table i . Chemical data for water in Pinyon Hills area. Source Nevada Division of Health.

Name	Location	T°C	pH	Depth m.	Ca ppm	Mg ppm	Na+K ppm	Cl ppm	F ppm	CO_3/HCO_3 ppm	SO_4 ppm	TDS ppm
Bennett well no. 1	T15NR20E Sec. 23	44	8.03	39	280	1.14	214	36	3.9	0/22	1056	1554
Bennett well no. 2	T15NR20E Sec. 23	44	8.14	-	277	7	105	34	4.3	0/32	840	1552
Bennett well no. 3	T15NR20E Sec. 23	39	7.81	37	280	0	226	37	4.2	0/29	1090	1529
Bennett well no. 4	T15NR20E Sec. 23	38	7.98	37	264	10	113	34	4.2	0/32	840	1517
Brown well	T15NR20E Sec. 23	43	8.43	49	272	5	150	33	4.4	6/37	913	1614
Everson well	T15NR20E Sec. 23	29	8.33	28	181	26	196	33	4.0	0/37	873	1501
Hackett well	T15NR20E Sec. 23	27	7.95	-	296	5	231	38	3.7	0/51	1120	1662
Hurin well	T15NR20E Sec. 23	43	8.31	48	277	12	90	34	4.3	6/41	820	1606
Lagliamonte well	T15NR20E Sec. 23	45	8.22	46	277	2	147	33	4.3	2/29	913	1563
McKinzie well	T15NR20E Sec. 23	42	8.1	-	269	12	110	32	4.0	0/34	859	1554

Table 1 . Chemical data for water in Pinyon Hills area. Source Nevada Division of Health.

Name	Location	T°C	pH	Depth m.	Ca ppm	Mg ppm	K pmm	Na ppm	Cl ppm	F ppm	CO_3/HCO_3 ppm	SO_4 ppm	TDS ppm
Merrimac well #1	T15NR20E Sec. 2	C	7.97	–	49	17	8	85	43	.61	0/259	66	453
Merrimac well #2	T15NR20E Sec. 2	C	7.70	21	65	21	4	50	28	.52	0/273	57	432
Merrimac well #3	T15NR20E Sec. 2	C	7.95	–	48	14	4	38	15	.52	0/220	37	297
Mills well #1	T15NR20E Sec. 2	C	7.82	21	87	24	10	71	42	.54	0/154	276	661
Mills well #2	T15NR20E Sec. 2	C	8.07	59	35	4	6	28	9	.74	0/61	78	255
Bowers well	T15NR20E Sec. 2	C	7.65	27	33	10	6	27	13	.44	0/117	57	234
Bowland well	T15NR20E Sec. 2	C	8.00	27	340	29	14	300	60	1.86	0/176	1218	2325
August well	T15NR20E Sec. 2	C	7.75	30	94	27	18	242	64	1.15	0/439	425	1101
Schreinert well	T15NR20E Sec. 2	C	7.52	30	630	60	18	544	195	.92	0/222	2786	4338
Maximum security prison well	T15NR20E Sec. 16	W	8.8	–	13.5	.33	2	82	21	–	0/48	148	–
Burgess well	T15NR20E Sec. 23	W	8.6	61	265	0	5	173	33	4	8/10	889	1587
Matthews well	T15NR20E Sec. 23	H	7.31	30	262	1	4	176	34	3.2	0/12	1036	1546

C: Cold; W: Warm; H: Hot; TDS: Total Dissolved Solid

Table 2 . Chemical data for water in Saratoga Hot Springs area. Source Nevada Division of Health.

Name	Location	T°C	pH	Depth m.	Ca ppm	Mg ppm	K ppm	Na ppm	Cl ppm	F ppm	CO_3/HCO_3 ppm	SO_4 ppm	TDS ppm
Imer well	T14NR20E Sec. 28	H	8.5	25	170	0	4	182	40	3.42	4/2	707	1175
Hofer well	T14NR20E Sec. 27	H	7.76	-	177	0	4	177	41	3.2	0/15	600	1193
Seaman well	T14NR20E Sec. 33	C	8.14	33	19	5	4	41	8	1.5	0/144	36	247
McGowan well	T14NR20E Sec. 33	C	7.9	-	117	1	5	152	28	3.6	0/24	553	926
Hickman well	T14NR20E Sec. 33	C	7.75	34	19	4	5	69	28	1.54	0/139	54	284
Quirk well	T14NR20E Sec. 33	C	7.8	-	18	4	4	53	9	1.75	0/146	38	254
Cave well	T14NR20E Sec. 33	C	7.8	-	65	1	4	121	25	3.08	0.107	267	602
Ford well	T14NR20E Sec. 33	C	8.1	35	21	6	4	41	8	1.58	0/134	43	245
Kuperus well	T14NR20E Sec. 33	C	7.6	-	20	4	6	52	17	1.3	0/102	70	269
Longstrom well	T14NR20E Sec. 33	W	8.8	60	14	0	1	132	35	4.72	10/17	202	461
Pierce well	T14NR20E Sec. 33	C	7.7	-	19	7	4	45	8	1.4	0/159	35	235
Medium security prison well	T14NR20E Sec. 4	C	7.73	107	32	7	1	15	9	.26	0/146	7	118

Table 3 . Chemical data for water in Carson Hot Springs area. Source Nevada Division of Health.

Name	Location	T°C	pH	Depth m.	Ca ppm	Mg ppm	K ppm	Na ppm	Cl ppm	F ppm	CO_3/HCO_3 ppm	SO_4 ppm	TDS ppm
Carson Hot Spring	T15NR20E Sec. 5	50	9.41	-	3	0	1	103	30	8.1	32/7	98	307
Carson well	T15NR20E Sec. 5	C	8.87	18.3	7	0	1	96	27	8.1	10/67	94	307
Odum well	T15NR20E Sec. 6	C	7.58	27.5	19	8	2	19	4	.22	0/132	1	142
Thoreson well	T15NR20E Sec. 5	C	7.64	-	27	10	2	19	5	.12	0/144	11	168
Stanley well	T15NR20E Sec. 5	C	7.46	31.4	26	5	1	27	4	.19	0/137	10	182
Dickerson well	T15NR20E Sec. 8	C	7.25	-	20	7	3	20	7	.22	0/132	2	148
Pagliaro well	T15NR20E Sec. 5	C	7.9	-	17	6	2	15	0	.14	0/95	2	107
Brockuche well	T15NR20E Sec. 5	C	7.89	-	16	5	1	12	2	.15	0/100	0	105
Frisbee well	T15NR20E Sec. 5	C	7.72	-	16	4	2	14	1	.13	0/95	0	95
Barker well	T15NR20E Sec. 5	C	7.70	-	18	4	2	16	3	.13	0/105	1	119
Fitts well	T15NR20E Sec. 5	C	8.13	55	17	6	2	17	2	.2	0/102	1	106
Rudolph well	T15NR20E Sec. 5	C	8.09	34.7	15	3	2	22	0	.19	0/102	4	144

Table cont.

Name	Location	T°C	pH	Depth m.	Ca ppm	Mg ppm	K ppm	Na ppm	Cl ppm	F ppm	CO_3/HCO_3 ppm	SO_4 ppm	TDS ppm
Hubert well	T15NR20E Sec. 5	C	7.81	50	18	5	4	15	2	.14	0/98	6	138
Roulette well	T15NR20E Sec. 6	C	7.65	45.7	15	6	2	17	0	.21	0/102	2	125
Ruby well	T15NR20E Sec. 5	C	8.11	-	20	6	2	20	5	.16	0/124	3	122
CCWD No. 7 well	T15NR20E Sec. 6	C	8.16	170.7	16	2	2	17	1	0.05	0/105	4	98
Schoenfelder well	T15NR20E Sec. 5	C	8.03	24	22	5	2	14	3	0	0/110	1	128
Sullivan well	T15NR20E Sec. 7	C	7.89	42	21	5	2	20	5	.15	0/117	1	125

Appendix II

Gravity data from traverses in Carson-Eagle Valley and Big Smoky Valley study Areas

GRAVITY DATA OF SPENCER TRAVERSE

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
BM 6034	39 24.13	116 56.44	6034	9801 27.48	9795 53.22	-212.22	-211.0
S 1	39 24.31	116 56.52	6073	9801 27.74	9795 52.16	-211.20	-210.0
S 2	39 24.35	116 56.73	6114	9801 27.80	9795 50.30	-210.66	-209.4
S 3	39 24.37	116 56.84	6125	9801 27.83	9795 49.63	-210.70	-209.4
S 4	39 24.42	116 56.98	6133	9801 27.90	9795 50.16	-209.77	-208.4
S 5	39 24.54	116 57.11	6159	9801 28.08	9795 50.02	-208.52	-207.2
S 6	39 24.86	116 57.20	6243	9801 28.55	9795 47.42	-206.55	-205.3
S 7	39 25.04	116 57.46	6333	9801 28.82	9795 42.94	-205.90	-204.4
S 8	39 25.12	116 57.67	6394	9801 28.94	9795 39.60	-205.70	-204.2
S 9	39 25.27	116 57.89	6480	9801 29.16	9795 35.00	-205.36	-204.0
S 10	39 25.43	116 58.00	6535	9801 29.39	9795 32.04	-205.25	-203.7
S 11	39 24.93	116 56.40	5986	9801 28.66	9795 54.41	-215.09	-213.9
S 12	39 23.78	116 56.26	5937	9801 26.96	9795 56.25	-214.49	-213.4
S 13	39 23.61	116 56.10	5911	9801 26.71	9795 57.73	-214.32	-213.4
S 14	39 23.38	116 55.87	5873	9801 26.37	9795 59.01	-214.98	-214.0
S 15	39 23.18	116 55.69	5846	9801 26.07	9795 59.87	-215.44	-214.5
S 16	39 22.95	116 55.47	5824	9801 25.74	9795 60.55	-215.74	-215.0
S 17	39 22.71	116 55.26	5812	9801 25.38	9795 60.76	-215.90	-215.3

S 18	39 22.46	116 55.03	5793	9801 25.01	9795 61.62	-215.81	-215.1
S 19	39 22.24	116 54.83	5778	9801 24.69	9795 62.26	-215.75	-215.4
S 20	39 22.00	116 54.60	5763	9801 24.33	9795 62.15	-216.41	-215.7
S 21	39 21.79	116 54.42	5752	9801 24.03	9801 61.76	-217.14	-216.7
S 22	39 21.62	116 54.24	5742	9801 23.77	9795 61.24	-218.02	-217.5
S 23	39 21.42	116 54.04	5732	9801 23.48	9795 60.57	-218.99	-218.5
S 24	39 21.23	116 53.88	5724	9801 23.20	9795 60.09	-219.67	-219.3
S 25	39 21.00	116 53.66	5718	9801 22.86	9795 59.56	-220.22	-219.7
S 26	39 20.79	116 53.46	5706	9801 22.55	9795 60.27	-219.92	-219.5
S 27	39 20.61	116 53.28	5700	9801 22.29	9795 60.17	-220.12	-219.9
S 28	39 20.38	116 53.09	5693	9801 21.95	9795 62.11	-218.26	-219.0
S 29	39 20.20	116 52.89	5687	9801 21.68	9795 63.64	-216.83	-217.6
S 30	39 19.98	116 52.71	5686	9801 21.36	9795 65.18	-215.02	-214.8
S 31	39 19.79	116 52.56	5678	9801 21.08	9795 67.85	-212.55	-212.3
S 32	39 19.61	116 52.36	5673	9801 20.81	9795 70.70	-209.73	-209.5
S 33	39 19.43	116 52.19	5671	9801 20.55	9795 73.23	-207.06	-206.8
S 34	39 19.24	116 52.02	5669	9801 20.27	9795 74.50	-205.63	-205.4
S 35	39 19.06	116 51.85	5669	9801 20.00	9795 73.36	-206.51	-206.3
S 36	39 18.89	116 51.69	5669	9801 19.75	9795 72.76	-206.85	-206.5
S 37	39 18.68	116 51.50	5685	9801 19.44	9795 71.42	-206.92	-206.7

S 38	39 18.50	116 51.33	5708	9801 19.18	9795 68.55	-208.15	-208.0
S 39	39 18.32	116 51.17	5735	9801 18.91	9795 65.92	-208.90	-208.6
S 40	39 18.14	116 50.98	5763	9801 18.65	9795 64.25	-208.79	-208.6
S 41	39 17.94	116 50.80	5792	9801 18.35	9795 63.25	-207.94	-207.6
S 42	39 17.72	116 50.59	5843	9801 18.03	9795 59.68	-208.12	-207.6
S 43	39 17.52	116 50.39	5865	9801 17.73	9795 59.01	-207.18	-206.9
S 44	39 17.31	116 50.22	5913	9801 17.42	9795 57.50	-205.50	-205.1
S 45	39 17.10	116 50.03	5970	9801 17.11	9795 55.57	-203.71	-203.3
S 46	39 16.90	116 49.84	6027	9801 16.82	9795 52.83	-202.73	-202.2
S 47	39 16.73	116 49.67	6069	9801 16.57	9795 49.35	-203.44	-202.9
S 48	39 16.53	116 49.51	6083	9801 16.27	9795 48.91	-202.74	-202.3
S 49	39 16.31	116 49.28	6117	9801 15.95	9795 46.55	-202.74	-202.3
S 50	39 16.12	116 49.11	6168	9801 15.67	9795 42.79	-203.16	-202.6
S 51	39 15.95	116 48.96	6217	9801 15.42	9795 40.09	-202.67	-202.0
S 52	39 15.76	116 48.79	6253	9801 15.14	9795 37.38	-202.93	-202.3
S 53	39 15.57	116 48.61	6301	9801 14.86	9795 34.27	-202.89	-202.0

GRAVITY DATA OF TRAVERSE OMC

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
OMC-1	38 52.15	116 59.13	6581	9800 80.41	9794 60.44	-225.10	-222.5
OMC-2	38 52.13	116 59.43	6468	9800 80.38	9794 65.30	-227.00	-224.5
OMC-3	38 52.09	117 09.22	6400	9800 80.32	9794 67.75	-228.57	-226.3
OMC-4	38 52.18	117 09.51	6310	9800 80.45	9794 73.03	-228.82	-226.5
OMC-5	38 52.33	117 09.85	6223	9800 80.67	9794 78.42	-228.88	-227.5
OMC-6	38 52.55	117 09.98	6174	9800 81.00	9794 82.87	-227.68	-226.5
OMC-7	38 52.82	117 01.18	6084	9800 81.39	9794 90.71	-225.64	-224.5
OMC-8	38 52.99	117 01.37	6022	9800 81.64	9794 94.83	-225.49	-224.4
OMC-9	38 53.08	117 01.59	5966	9800 81.77	9794 97.73	-226.08	-225.3
OMC-10	38 53.19	117 01.87	5906	9800 81.94	9795 01.14	-226.43	-225.3
OMC-11	38 53.31	117 02.19	5845	9800 82.11	9795 04.09	-227.32	-226.5
OMC-0	38 52.12	116 09.28	6697	9800 80.36	9794 53.42	-225.12	-222.6
OMC-1A	38 52.15	116 09.12	6713	9800 80.41	9794 53.57	-224.06	-221.5
OMC-12	38 53.47	117 02.47	5795	9800 82.35	9795 07.22	-227.43	-226.8
OMC-13	38 53.57	117 02.77	5755	9800 82.49	9795 09.42	-227.77	-227.4
OMC-14	38 53.66	117 02.97	5729	9800 82.63	9795 11.83	-227.06	-226.9
OMC-15	38 53.77	117 03.23	5709	9800 82.79	9795 13.25	-226.99	-226.7
OMC-16	38 53.86	117 03.50	5687	9800 82.92	9795 14.31	-227.39	-227.0
OMC-17	38 53.93	117 03.75	5661	9800 83.02	9795 15.24	-228.12	-227.7
OMC-18	38 54.03	117 04.07	5627	9800 83.17	9795 16.47	-229.08	-228.8

OMC-19	38 54.12	117 04.38	5601	9800 83.30	9795 16.99	-230.25	-230.0
OMC-20	38 54.18	117 04.58	5578	9800 83.39	9795 17.66	-231.05	-230.8
OMC-21	38 54.26	117 04.83	5561	9800 83.51	9795 17.86	-231.99	-231.6
OMC-22	38 54.33	117 05.08	5549	9800 83.61	9795 17.78	-232.89	-232.5
OMC-23	38 54.40	117 05.37	5537	9800 83.71	9795 17.51	-233.98	-233.6
OMC-24	38 54.48	117 05.58	5535	9800 83.83	9795 16.88	-234.85	-234.5
OMC-25	38 54.55	117 05.80	5534	9800 83.93	9795 16.34	-235.56	-235.3
OMC-26	38 54.60	117 06.08	5531	9800 84.01	9795 15.52	-236.63	-236.2
OMC-27	38 54.55	117 06.42	5521	9800 83.93	9795 14.87	-237.80	-237.3
OMC-28	38 54.53	117 06.80	5511	9800 83.90	9795 14.61	-238.63	-238.3
OMC-29	38 54.53	117 07.12	5507	9800 83.90	9795 13.78	-239.71	-239.3
OMC-30	38 54.55	117 07.43	5506	9800 83.93	9795 13.18	-240.39	-240.0
OMC-31	38 54.41	117 07.77	5510	9800 83.73	9795 12.02	-241.11	-240.6
OMC-32	38 54.37	117 08.08	5514	9800 83.67	9795 11.65	-241.18	-240.6
OMC-33	38 54.32	117 08.36	5518	9800 83.60	9795 11.14	-241.37	-240.8
OMC-34	38 54.30	117 08.70	5532	9800 83.57	9795 10.96	-240.68	-240.2
OMC-35	38 54.28	117 09.05	5558	9800 83.54	9795 09.90	-240.16	-239.5
OMC-36	38 54.43	117 09.10	5557	9800 83.76	9795 10.83	-239.50	-238.7
OMC-37	38 54.63	117 09.10	5552	9800 84.05	9795 11.49	-239.44	-238.7
OMC-38	38 54.88	117 09.12	5544	9800 84.42	9795 11.87	-239.91	-239.3
OMC-39	38 55.12	117 09.13	5540	9800 84.77	9795 12.24	-240.13	-239.3
OMC-41	38 55.15	117 09.52	5555	9800 84.81	9795 12.58	-238.94	-238.0
OMC-42	38 55.15	117 09.70	5566	9800 84.81	9795 12.77	-238.09	-237.2

OMC-43	38 55.38	117 09.73	5561	9800 85.15	9795 13.01	-238.49	-237.5
OMC-44	38 55.58	117 09.73	5560	9800 85.45	9795 13.33	-238.51	-237.5
OMC-45	38 55.82	117 09.73	5554	9800 85.80	9795 14.04	-238.52	-237.5
OMC-46	38 55.92	117 10.10	5570	9800 85.95	9795 14.60	-237.15	-236.0
OMC-47	38 56.00	117 10.45	5589	9800 86.06	9795 15.93	-234.79	-233.7
OMC-48	38 56.07	117 10.75	5607	9800 86.17	9795 16.47	-233.28	-233.5
OMC-49	38 56.15	117 11.08	5622	9800 86.28	9795 18.24	-230.72	-228.8
OMC-50	38 56.22	117 11.38	5633	9800 86.39	9795 19.34	-229.07	-226.7
OMC-51	38 56.30	117 11.72	5664	9800 86.50	9795 21.03	-225.63	-223.7
OMC-52	38 56.35	117 11.95	5689	9800 86.58	9795 21.77	-223.47	-222.4
OMC-53	38 56.42	117 12.25	5725	9800 86.68	9795 22.69	-220.49	-217.6
OMC-54	38 56.48	117 12.57	5767	9800 86.77	9795 22.45	-218.30	-215.7
OMC-55	38 56.55	117 12.86	5807	9800 86.87	9795 21.56	-216.89	-214.0
OMC-56	38 56.63	117 13.15	5856	9800 86.99	9795 19.75	-215.88	-212.6
OMC-57	38 56.70	117 13.40	5900	9800 87.09	9795 18.01	-215.08	-211.0
OMC-58	38 56.68	117 13.72	5965	9800 87.06	9795 14.84	-214.33	-210.0
OMC-59	38 56.63	117 13.95	6047	9800 86.99	9795 10.55	-213.62	-208.2
OMC-60	38 56.45	117 14.32	6205	9800 86.73	9795 02.07	-212.35	-205.5
OMC-61	38 56.47	117 14.57	6507	9800 86.75	9794 84.99	-211.34	-204.0

GRAVITY DATA OF MCLEOD RANCH TRAVERSE

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
MR 7	39 2.56	117 9.95	5564	9800 95.71	9795 35.96	-225.91	-223.8
MR 9	39 4.05	117 12.04	6882	9800 97.90	9794 78.24	-206.74	-198.3
MR 8	39 4.14	117 12.15	6753	9800 98.03	9794 85.99	-206.86	-200.0
MR 10	39 4.00	117 11.87	6419	9800 97.83	9794 98.50	-214.19	-205.9
MR 11	39 3.87	117 11.73	6145	9800 97.64	9795 11.77	-217.16	-210.0
MR 12	39 3.69	117 11.48	6003	9800 97.37	9795 17.35	-219.84	-214.0
MR 13	39 3.54	117 11.29	5934	9800 97.15	9795 19.84	-221.27	-217.0
MR 14	39 3.40	117 11.10	5867	9800 96.94	9795 22.97	-221.95	-217.9
MR 15	39 3.19	117 10.84	5776	9800 96.64	9795 26.87	-223.21	-220.2
MR 16	39 3.05	117 10.60	5719	9800 96.43	9795 29.27	-224.02	-220.6
MR 17	39 2.94	117 10.36	5660	9800 96.27	9795 31.65	-225.01	-222.1
MR 18	39 2.76	117 10.18	5619	9800 96.00	9795 33.38	-225.48	-222.8
MR 22	39 1.82	117 9.93	5492	9800 94.62	9795 36.19	-228.91	-227.0
MR 23	39 1.72	117 9.66	5471	9800 94.47	9795 35.13	-231.08	-229.5
MR 24	39 1.64	117 9.41	5462	9800 94.36	9795 33.61	-233.02	-231.5
MR 25	39 1.54	117 8.96	5465	9800 94.21	9795 31.72	-234.59	-233.4
MR 26	39 1.55	117 8.70	5459	9800 94.22	9795 30.83	-235.85	-234.6
MR 27	39 1.52	117 8.38	5462	9800 94.18	9795 28.92	-237.54	-236.3

MR 28	39	1.52	117	8.18	5473	9800 94.18	9795 25.25	-240.55	-239.4
MR 29	39	1.46	117	7.95	5476	9800 94.09	9795 23.63	-241.90	-240.7
MR 30	39	1.44	117	7.74	5463	9800 94.06	9795 23.54	-242.74	-241.8
MR 31	39	1.47	117	7.22	5442	9800 94.11	9795 24.07	-243.51	-242.5
MR 32	39	1.50	117	6.70	5438	9800 94.15	9795 23.99	-243.88	-243.2
MR 33	39	1.49	117	6.29	5449	9800 94.13	9795 23.08	-244.12	-243.4
MR 34	39	1.49	117	5.87	5452	9800 94.13	9795 22.95	-244.06	-243.5
MR 35	39	1.49	117	5.41	5455	9800 94.13	9795 22.64	-244.19	-243.8
MR 36	39	1.50	117	5.01	5459	9800 94.15	9795 22.66	-243.95	-243.6
MR 37	39	1.51	117	4.60	5463	9800 94.16	9795 21.56	-244.83	-244.5
MR 38	39	1.52	117	4.19	5467	9800 94.18	9795 21.75	-244.40	-244.0
MR 39	39	1.53	117	3.81	5466	9800 94.19	9795 22.05	-244.18	-243.9
MR 40	39	1.54	117	3.27	5476	9800 94.21	9795 21.93	-243.71	-243.2
MR 41	39	1.58	117	2.88	5490	9800 94.27	9795 23.47	-241.39	-241.0
MR 42	39	1.58	117	2.54	5499	9800 94.27	9795 23.67	-240.65	-240.3
MR 43	39	1.59	117	2.23	5512	9800 94.28	9795 23.96	-239.60	-239.2
MR 44	39	1.59	117	2.23	5528	9800 94.28	9795 23.69	-238.91	-238.4
MR 45	39	1.69	117	1.57	5554	9800 94.43	9795 22.70	-238.49	-238.0
MR 46	39	1.83	117	1.26	5584	9800 94.63	9795 21.16	-238.43	-237.8
MR 47	39	1.96	117	.91	5614	9800 94.83	9795 19.93	-238.06	-237.4
MR 48	39	2.10	117	.67	5642	9800 95.03	9795 18.81	-237.71	-237.0

MR 49	39 2.24	117 .37	5674	9800 95.24	9795 17.86	-236.94	-236.3
MR 50	39 2.36	117 .14	5701	9800 95.41	9795 17.36	-235.99	-235.3
MR 51	39 2.51	116 59.80	5733	9800 95.63	9795 16.87	-234.78	-234.0
MR 52	39 .45	116 56.06	6419	9800 92.61	9794 80.60	-226.86	-225.5
MR 53	39 .57	116 56.28	6387	9800 92.78	9794 81.90	-227.66	-226.4
MR 54	39 .69	116 56.61	6318	9800 92.96	9794 84.90	-228.98	-227.8
MR 55	39 .87	116 56.90	6264	9800 93.22	9794 90.72	-226.67	-225.5
MR 56	39 .98	116 57.10	6224	9800 93.38	9794 91.07	-228.88	-227.7
MR 57	39 1.13	116 57.31	6179	9800 93.61	9794 93.52	-229.34	-228.0
MR 58	39 1.27	116 57.54	6128	9800 93.81	9794 97.22	-228.91	-227.7
MR 59	39 1.41	116 57.76	6080	9800 94.02	9795 00.19	-229.03	-227.8
MR 60	39 1.56	116 57.98	6035	9800 94.24	9795 03.26	-228.88	-227.8
MR 61	39 1.69	116 58.19	5996	9800 94.43	9795 05.67	-229.00	-228.0
MR 62	39 1.84	116 58.42	5948	9800 94.65	9795 08.20	-229.57	-228.5
MR 63	39 1.99	116 58.69	5902	9800 94.87	9795 10.47	-230.28	-229.3
MR 64	39 2.10	116 58.95	5862	9800 95.03	9795 11.56	-231.75	-230.7
MR 65	39 2.19	116 59.20	5821	9800 95.16	9795 13.05	-232.86	-232.0
MR 66	39 2.29	116 59.41	5789	9800 95.31	9795 13.86	-234.12	-233.7
MR 67	39 2.40	116 59.60	5755	9800 95.47	9795 14.96	-235.21	-234.3

GRAVITY DATA OF TRAVERSE 8A

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
8A-2	38 58.38	117 11.57	5747	9800 82.21	9795 08.48	-228.91	-226.6
8A-3	38 53.12	117 11.57	5746	9800 81.83	9795 08.32	-228.75	-226.4
8A-4	38 52.90	117 11.55	5740	9800 81.51	9795 08.12	-228.99	-226.5
8A-5	38 52.65	117 11.53	5732	9800 81.14	9795 07.98	-229.24	-226.5
8A-6	38 52.40	117 11.52	5722	9800 80.77	9795 08.10	-229.36	-226.5
8A-7	38 52.08	117 11.52	5703	9800 80.30	9795 08.24	-229.88	-227.0
8A-8	38 51.80	117 11.52	5682	9800 79.89	9795 07.97	-231.01	-228.0
8A-9	38 51.52	117 11.50	5664	9800 79.48	9795 09.55	-230.09	-226.9
8A-10	38 51.25	117 11.48	5662	9800 79.09	9795 10.07	-229.29	-226.0
8A-11	38 51.00	117 11.48	5678	9800 78.72	9795 09.19	-228.85	-225.0
8A-12	38 50.72	117 11.47	5678	9800 78.31	9795 08.97	-228.66	-224.4
8A-13	38 50.43	117 11.45	5665	9800 77.88	9795 09.30	-228.68	-224.3
8A-14	38 53.62	117 11.58	5745	9800 82.57	9795 09.19	-228.68	-226.5
8A-15	38 53.83	117 11.58	5741	9800 82.88	9795 09.78	-228.63	-226.5
8A-16	38 54.07	117 11.60	5732	9800 83.23	9795 10.80	-228.51	-226.4
8A-17	38 54.28	117 11.62	5724	9800 83.54	9795 12.00	-228.10	-226.0
8A-18	38 54.53	117 11.63	5719	9800 83.90	9795 12.77	-227.99	-225.7
8A-19	38 54.80	117 11.63	5709	9800 84.30	9795 14.07	-227.70	-225.5
8A-20	38.55.07	117 11.65	5698	9800 84.70	9795 15.26	-227.55	-225.4
8A-21	38 55.30	117 11.67	5689	9800 85.04	9795 16.46	-227.23	-225.1
8A-22	38 55.52	117 11.68	5683	9800 85.36	9795 17.47	-226.91	-224.8

GRAVITY DATA OF TRAVERSE 8B

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
8B-1	38 51.05	117 02.66	6001	9800 78.79	9794 87.28	-231.45	-230.0
8B-2	38 51.30	117 02.64	5973	9800 79.16	9794 89.39	-231.39	-230.1
8B-3	38 51.54	117 02.68	5921	9800 79.51	9794 92.89	-231.36	-230.1
8B-4	38 51.77	117 02.68	5887	9800 79.85	9794 95.56	-231.07	-229.9
8B-5	38 52.02	117 02.73	5859	9800 80.22	9794 97.11	-231.57	-230.3
8B-6	38 52.23	117 02.73	5849	9800 80.53	9794 98.20	-231.39	-230.3
8B-7	38 52.43	117 02.75	5840	9800 80.82	9794 99.47	-230.95	-229.9
8B-8	38 52.67	117 02.78	5819	9800 81.17	9795 02.00	-230.03	-229.0
8B-9	38 52.88	117 02.75	5804	9800 81.48	9795 03.36	-229.88	-228.9
8B-10	38 53.07	117 02.77	5790	9800 81.76	9795 04.50	-229.86	-229.0
8B-11	38 53.32	117 02.78	5768	9800 82.13	9795 07.81	-228.23	-227.4
8B-12	38 53.82	117 02.73	5762	9800 82.86	9795 10.60	-226.54	-225.0
8B-13	38 54.02	117 02.73	5779	9800 83.15	9795 10.07	-226.35	-225.6
8B-14	38 54.27	117 02.73	5792	9800 83.52	9795 10.92	-225.08	-224.4
8B-15	38 54.43	117 02.75	5794	9800 83.76	9795 11.63	-224.48	-223.9
8B-16	38 54.62	117 02.68	5767	9800 84.04	9795 14.06	-223.95	-223.3

GRAVITY DATA OF DARROUGH'S RANCH TRAVERSE

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
D 2	38 49.17	117 12.83	6728	9800 76.03	9794 50.91	-221.44	-210.0
D 1	38 49.16	117 12.75	6536	9800 76.02	9794 60.82	-223.03	-211.7
D 3	38 49.28	117 12.10	6106	9800 76.19	9794 83.84	-226.00	-219.6
D 4	38 49.25	117 12.34	6253	9800 76.15	9794 76.05	-224.92	-216.4
D 5	38 49.25	117 11.83	5974	9800 76.15	9794 90.19	-227.52	-228.7
D 6	38 49.27	117 11.57	5856	9800 76.18	9794 97.02	-227.80	-223.7
D 7	38 49.27	117 11.27	5743	9800 76.18	9795 02.41	-229.19	-225.3
D 9	38 49.32	117 10.61	5559	9800 76.25	9795 08.37	-234.34	-231.3
D 10	38 49.34	117 10.32	5549	9800 76.28	9795 07.45	-235.89	-233.5
D 11	38 49.37	117 10.03	5548	9800 76.32	9795 06.57	-236.87	-234.6
D 12	38 49.39	117 9.72	5544	9800 76.35	9795 05.88	-237.83	-235.7
D 13	38 49.42	117 9.41	5543	9800 76.40	9795 05.52	-238.30	-236.5
D 14	38 49.46	117 9.06	5542	9800 76.46	9795 05.01	-238.93	-237.5
D 15	38 49.49	117 8.70	5541	9800 76.50	9795 04.92	-239.12	-237.6
D 16	38 49.58	117 8.34	5539	9800 76.63	9795 04.70	-239.59	-238.9
D 17	38 49.82	117 8.22	5536	9800 76.99	9795 04.90	-239.93	-239.3
D 18	38 49.76	117 7.88	5538	9800 76.90	9795 04.05	-240.57	-239.7
D 19	38 49.70	117 7.57	5538	9800 76.81	9795 03.67	-240.86	-240.0

D 20	38 49.64	117 7.26	5542	9800 76.12	9795 03.42	-240.78	-240.0
D 21	38 49.57	117 6.92	5548	9800 76.62	9795 03.13	-240.61	-239.8
D 22	38 49.49	117 6.53	5550	9800 76.50	9795 03.73	-239.77	-239.0
D 23	38 49.41	117 6.25	5559	9800 76.38	9795 04.19	-238.65	-237.9
D 24	38 49.33	117 5.96	5572	9800 76.27	9795 04.28	-237.66	-236.9
D 25	38 49.28	117 5.62	5591	9800 76.19	9795 04.93	-235.80	-235.0
D 26	38 48.32	117 1.48	6769	9800 74.78	9794 39.91	-228.73	-223.6
D 27	38 48.40	117 1.81	6636	9800 74.90	9794 48.62	-228.13	-225.4
D 28	38 48.47	117 2.18	6494	9800 75.00	9794 56.12	-229.25	-226.6
D 29	38 48.51	117 2.44	6398	9800 75.06	9794 61.50	-229.68	-227.0
D 30	38 48.54	117 2.70	6305	9800 75.11	9794 67.63	-229.18	-226.5
D 31	38 48.59	117 2.98	6205	9800 75.18	9794 73.32	-229.56	-227.1
D 32	38 48.68	117 3.24	6104	9800 75.31	9794 78.72	-230.35	-228.0
D 33	38 48.79	117 3.48	6007	9800 75.47	9794 83.98	-231.08	-228.9
D 34	38 48.91	117 3.71	5908	9800 75.65	9794 89.48	-231.69	-229.8
D 35	38 48.99	117 4.02	5805	9800 75.77	9794 95.40	-232.07	-230.2
D 36	38 49.06	117 4.32	5745	9800 75.87	9795 00.36	-230.81	-229.2
D 37	38 49.10	117 4.53	5694	9800 75.93	9795 02.74	-231.55	-230.0
D 38	38 49.13	117 4.83	5650	9800 75.97	9795 04.65	-232.33	-231.0
D 39	38 49.19	117 5.10	5623	9800 76.06	9795 05.25	-233.43	-232.4
D 40	38 49.24	117 5.38	5601	9800 76.13	9795 05.66	-234.41	-233.5

GRAVITY DATA OF TRAVERSE CS

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
CS-1	39 07.15	119 37.87	5272	9801 02.46	9795 75.63	-183.21	-182.18
CS-2	39 07.37	119 37.87	5667	9801 02.79	9795 80.12	-182.64	
CS-3	39 07.42	119 38.06	5644	9801 02.86	9795 80.99	-183.23	
CS-4	39 07.68	119 38.43	5598	9801 03.24	9795 85.74	-181.62	
CS-5	39 07.87	119 38.63	5487	9801 03.52	9795 89.70	-184.60	
CS-6	39 08.07	119 38.75	5422	9801 03.82	9795 94.56	-183.93	
CS-7	39 08.29	119 38.84	5352	9801 04.14	9795 97.63	-185.39	
CS-8	39 08.58	119 38.91	5215	9801 04.57	9796 06.70	-184.96	
CS-9	39 08.78	119 39.15	5123	9801 04.86	9796 10.54	-186.94	
CS-10	39 09.13	119 39.39	5073	9801 05.38	9796 17.39	-183.61	
CS-11	39 09.23	119 39.72	5008	9801 05.52	9796 21.07	-183.97	-182.76
CS-12	39 09.36	119 39.97	4985	9801 05.71	9796 22.33	-184.28	
CS-13	39 09.48	119 40.13	4922	9801 05.89	9796 26.34	-184.23	
CS-14	39 09.62	119 40.47	4892	9801 06.10	9796 28.91	-183.67	
CS-15	39 09.81	119 40.81	4777	9801 06.38	9796 36.55	-183.21	
CS-16	39 09.97	119 40.96	4807	9801 06.61	9796 35.38	-182.81	
CS-17	39 10.18	119 40.95	4712	9801 06.92	9796 42.61	-181.59	
CS-18	39 10.33	119 41.27	4657	9801 07.14	9796 47.97	-179.75	
CS-19	39 10.54	119 41.31	4602	9801 07.45	9796 53.24	-178.09	
CS-20	39 10.69	119 41.09	4596	9801 07.67	9796 55.43	-176.49	

CS-21	39 10.86	119 41.12	4606	9801 07.92	9796 54.37	-177.20	
CS-22	39 10.84	119 41.34	4633	9801 07.89	9796 52.73	-177.18	-175.85
PUMPHS-23	39 10.84	119 41.67	4612	9801 07.89	9796 52.06	-179.11	
CS-24	39 10.99	119 41.73	4614	9801 08.11	9796 51.90	-179.37	-178.56
CS-25	39 11.13	119 42.01	4646	9801 08.32	9796 47.96	-181.60	-180.89
CS-26	39 11.32	119 42.13	4647	9801 08.60	9796 47.79	-181.99	-181.27
CS-27	39 11.22	119 42.46	4620	9801 08.45	9796 47.96	-183.29	-182.58
CS-28	39 11.08	119 42.83	4622	9801 08.25	9796 45.05	-185.88	-185.17
CS-29	39 10.94	119 43.2	4632	9801 08.04	9796 42.76	-187.36	-186.59
CS-30	39 10.81	119 43.45	4636	9801 07.85	9796 41.25	-188.44	-187.57
CS-31	39 10.69	119 43.73	4640	9801 07.67	9796 39.37	-189.91	-189.16
CS-32	39 10.59	119 43.94	4642	9801 07.52	9796 36.43	-192.57	-191.74
CS-33	39 10.86	119 43.93	4657	9801 07.92	9796 40.45	-188.05	-187.22
CS-34	39 11.15	119 43.93	4672	9801 08.35	9796 42.36	-185.67	-184.89
CS-36	39 11.43	119 44.18	4687	9801 08.76	9796 41.57	-185.97	-185.05
CS-37	39 11.41	119 44.48	4683	9801 08.73	9796 41.19	-186.56	-185.68
BM R316	39 11.60	119 44.90	4704	9801 09.01	9796 39.19	-187.58	-186.51
BM 4697	39 11.57	119 45.23	4697	9801 08.97	9796 40.17	-186.98	-185.89
CS-38	39 11.90	119 45.24	4745	9801 09.45	9796 38.10	-186.65	-185.56
CS-39	39 11.91	119 45.57	4729	9801 09.47	9796 37.86	-187.87	-186.69
CS-40	39 12.22	119 45.63	4899	9801 09.92	9796 27.82	-188.16	-186.37
CS-41	39 12.58	119 45.75	5279	9801 10.45	9796 03.97	-189.75	-188.14
CS-42	39 12.89	119 46.08	5970	9801 10.91	9795 61.06	-191.65	-189.57

GRAVITY DATA OF TRAVERSE HS

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
HS-1	39 03.76	119 50.00	4931	9800 97.47	9796 01.63	-199.98	-197.28
HS-2	39 03.82	119 49.87	4905	9800 97.56	9796 03.97	-119.29	-196.67
HS-3	39 03.66	119 49.85	4874	9800 97.33	9796 06.48	-198.40	-196.12
HS-4	39 03.49	119 49.60	4820	9800 97.08	9796 10.60	-197.28	-195.13
HS-5	39 03.34	119 49.33	4690	9800 96.86	9796 16.75	-198.70	-196.41
HS-6	39 03.47	119 49.16	4710	9800 97.05	9796 16.96	-197.48	-195.36
HS-7	39 03.56	119 48.96	4701	9800 97.18	9796 17.19	-197.93	-195.76
BM 4653	39 03.95	119 48.28	4653	9800 97.75	9796 20.42	-198.15	-196.7
HS-8	39 03.68	199 48.08	4647	9800 97.36	9796 18.31	-200.22	-198.97
HS-9	39 03.74	199 48.48	4753	9800 97.44	9796 15.53	-196.73	-194.97
HS-10	39 03.62	119 48.54	4656	9800 97.27	9796 20.26	-197.64	-195.88
HS-11	39 03.62	119 48.68	4701	9800 97.27	9796 17.69	-197.52	-195.68
HS-12	39 04.37	119 40.03	5694	9800 98.37	9795 69.85	-186.88	-185.61
HS-13	39 04.45	119 39.77	5840	9800 98.49	9795 61.52	-186.57	-185.3
HS-14	39 04.25	119 40.26	5591	9800 98.19	9795 77.58	-185.16	-184.08
HS-15	39 04.07	119 40.43	5452	9800 97.93	9795 84.98	-185.83	-184.87
HS-16	39 04.01	119 40.63	5390	9800 97.84	9795 88.01	-186.43	-185.76
HS-17	39 03.99	119 40.97	5302	9800 97.81	9795 91.31	-188.38	-187.74

HS-18	39 04.04	119 41.23	5245	9800 97.89	9795 92.34	-190.85	-190.25
HS-19	39 03.91	119 41.48	5187	9800 97.69	9795 95.64	-190.83	-190.23
HS-22	39 03.53	119 41.92	5070	9800 97.14	9796 05.48	-187.45	-186.81
BM 5136	39 03.56	199 41.58	5136	9800 97.18	9796 00.95	-188.07	-187.55
HS-23	39 03.35	119 42.12	5058	9800 96.87	9796 07.40	-185.99	-185.12
HS-24	39 03.23	119 42.38	5076	9800 96.69	9796 05.59	-186.54	-185.51
HS-25	39 03.04	119 42.56	4965	9800 96.41	9796 11.53	-186.98	-186.17
HS-26	39 02.92	119 42.77	4917	9800 96.24	9796 11.58	-189.64	-188.65
HS-27	39 02.80	119 42.97	4859	9800 96.06	9796 13.20	-191.32	-190.59
HS-28	39 02.83	119 43.18	4824	9800 96.11	9796 14.94	-191.73	-190.81
HS-29	39 02.83	119 43.40	4788	9800 96.11	9796 16.23	-192.60	-191.60
HS-30	39 02.83	119 43.72	4746	9800 96.11	9796 18.76	-192.59	-191.88
HS-31	39 02.93	119 44.05	4737	9800 96.25	9796 18.59	-193.45	-192.70
HS-32	39 02.91	119 44.42	4693	9800 96.22	9796 17.38	-197.26	-196.58
HS-33	39 03.65	119 50.86	5317	9800 97.31	9795 73.99	-204.30	-198.16
HS-34	39 03.52	119 51.08	5570	9800 97.12	9795 58.70	-204.22	-194.63
HS-35	39 03.75	119 50.65	5164	9800 97.46	9795 83.22	-204.40	-199.28
HS-36	39 03.80	119 50.39	5056	9800 97.53	9795 91.78	-202.39	-198.79
HS-37	39 03.83	119 50.01	4944	9800 97.58	9796 00.43	-200.50	198.22
HS-38	39 02.99	119 44.51	4696	9800 96.34	9796 15.39	-199.19	-198.55

HS-39	39 03.15	119 44.50	4697	9800 96.58	9796 16.37	-198.38	-197.59
HS-40	39 03.43	119 44.50	4697	9800 96.99	9796 17.46	-197.71	-196.64
HS-41	39 03.48	119 44.82	4670	9800 97.06	9796 16.29	-200.58	-199.62
HS-42	39 03.45	119 45.15	4655	9800 97.02	9796 16.45	-201.27	-200.52
HS-43	39 03.42	119 45.45	4650	9800 96.97	9796 15.61	-202.36	-201.29
HS-44	39 03.48	119 45.78	4642	9800 97.06	9796 13.93	-204.61	-203.52
HS-45	39 03.49	119 46.10	4634	9800 97.08	9796 16.26	-202.77	-201.66

GRAVITY DATA OF TRAVERSE DF

Station	Latitude	Longitude	Elevation (Feet)	Theoretical Gravity (mg)	Observed Gravity (mg)	Simple Bouguer (mg)	Complete Bouguer (mg)
DF 30	38 58.80	119 50.28	5475	9800 90.18	9795 61.76	-199.92	-190.94
BM 4694W	38 58.77	119 50.00	4694	9800 90.14	9796 01.23	-207.27	-199.93
BM 4685	38 58.52	119 50.18	4685	9800 89.77	9796 02.10	-206.56	-199.96
BM 4676	38 58.27	119 49.83	4676	9800 89.40	9795 98.96	-209.88	-205.73
DF 32	38 58.27	119 49.48	4680	9800 89.40	9795 98.16	-212.44	-209.21
DF 31	38 58.26	119 49.28	4679	9800 89.39	9795 94.99	-213.66	-210.55
BM 4678	38 58.27	119 49.03	4678	9800 89.40	9795 93.58	-215.14	-212.14
BM 4688	38 58.26	119 47.91	4688	9800 89.39	9795 91.66	-216.45	-215.09
DF 33	38 58.25	119 47.56	4690	9800 89.37	9795 91.97	-216.00	-214.67
DF 34	38 58.25	119 47.28	4695	9800 89.37	9795 92.11	-215.56	-214.38
BM 4698	38 58.23	119 46.70	4698	9800 89.34	9795 93.53	-213.93	-213.01
BM 4694E	38 58.57	119 46.68	4694	9800 89.84	9795 94.39	-213.81	-212.89
DF 2	38 58.57	119 45.75	4711	9800 89.84	9795 98.62	-208.56	-207.96
BM 4714	38 58.57	119 45.59	4714	9800 89.84	9795 99.59	-207.41	-206.82
DF-1	38 58.57	119 45.47	4715	9800 89.84	9796 00.46	-206.52	-205.93
DF-3	38 58.57	119 45.32	4718	9800 89.84	9796 01.58	-205.18	-204.64
DF-4	38 58.58	119 45.16	4721	9800 89.86	9796 02.78	-203.81	-203.29
BM 4743	38 58.56	119 44.47	4743	9800 89.83	9796 05.57	-199.68	-199.38
BM 4767	38 58.56	119 43.93	4767	9800 89.83	9796 01.09	-202.72	-202.45

DF 5	38 58.56	119 43.69	4779	9800 89.83	9796 02.29	-200.80	-200.54
DF 6	38 58.57	119 43.42	4790	9800 89.84	9796 01.49	-200.95	-200.76
DF 7	38 58.57	119 43.15	4805	9800 89.84	9796 00.22	-201.32	-201.13
DF 8	38 58.57	119 42.92	4820	9800 89.84	9795 99.14	-201.50	-201.30
DF 9	38 58.57	119 42.63	4832	9800 89.84	9795 97.65	-202.28	-202.28
DF 10	38 58.49	119 42.43	4836	9800 89.72	9795 97.08	-202.49	-202.32
DF 11	38 58.46	119 42.10	4861	9800 89.68	9795 95.72	-202.30	-202.15
DF 12	38 58.43	119 41.83	4882	9800 89.64	9795 94.97	-201.75	-201.59
DF 13	38 58.41	119 41.47	4895	9800 89.61	9795 94.96	-200.94	-200.75
DF 14	38 58.38	119 41.29	4904	9800 89.56	9795 94.86	-200.46	-200.27
DF 15	38 58.42	119 41.05	4916	9800 89.62	9795 94.67	-200.00	-199.75
BM 4962	38 58.56	119 40.57	4962	9800 89.83	9795 94.19	-197.91	-197.61
DF 16	38 58.62	119 40.33	4975	9800 89.91	9795 93.81	-197.60	-197.23
DF 17	38 58.62	119 40.08	5005	9800 90.00	9795 91.38	-198.32	-197.95
DF 18	38 58.75	119 39.83	5018	9800 90.11	9795 89.98	-199.05	-198.22
DF 19	38 58.83	119 39.62	5031	9800 90.22	9795 90.67	-197.70	-196.82
DF 20	38 58.92	119 39.41	5043	9800 90.36	9795 89.78	-198.00	-197.35
DF 21	38 59.02	119 39.24	5082	9800 90.50	9795 87.21	-198.38	-197.97
DF 22	38 58.93	119 39.08	5107	9800 90.37	9795 85.15	-198.80	-198.39
DF 23	38 58.98	119 38.83	5123	9800 90.44	9795 81.42	-201.65	-201.23
DF 24	38 59.05	119 38.59	5150	9800 90.55	9795 79.12	-202.42	-201.98
DF 25	38 59.11	119 38.33	5213	9800 90.64	9795 73.62	-204.24	-203.75
DF 26	38 59.14	119 38.25	5223	9800 90.68	9795 73.15	-204.15	-203.66

DF 27	38 59.27	119 38.04	5248	9800 90.87	9795 69.93	-206.06	-205.58
DF 28	38 59.27	119 37.82	5290	9800 90.97	9795 66.75	-206.82	-206.31
DF 29	38 59.32	119 37.52	5390	9800 90.94	9795 60.26	-207.28	-206.70

Appendix III

Daily on-site drilling logs of
CC-1, CC-2, BSD-1,
BSS, BSD-2

13 Feb 80

Carson City, NV

School Site Well CC #1

Longyear Co., Drilling Contractor-Sedilia, CO
Crew:

NBMG Personnel
J. Bruce, D. Trexler, T. Flynn

Comment: Longyear crew arrived in Carson City on 12 Feb and set up rig at approximately 1630 hrs.

13 Feb

0700 Longyear crew arrives (0800 CO time)
Set up and used tricone bit to set 22 ft of hole for surface casing.

0801 J. Bruce arrives site

0805 T. Flynn arrives.

0810 J. Bruce, T. Flynn discuss project with Gil Speaker, Longyear Tool pusher.

0815 Drill crew putting on hammer

0835 Trexler arrives on site with equipment

0845 First sample taken at 20 ft with hammer

0850 Start drilling with hammer

0900 Pause in drilling to install temporary probe

0905 Start drilling again. Move Carryall to front of rig for equipment set up. Return air temperature 10.0°C @ 25 ft. Sample taken.

0910 30 ft depth sample taken. Return Temperature.

1000 Drilling slows down a bit. Been taking samples at 5 ft intervals. Up to the 90 ft interval now.

1010 Temperature probe is buried in chips

1015 Depth 100' dry

1030 TD 110 still dry - trouble with chips not coming out of the hole - water truck not here yet.

1034 112' chips moist

1040 Well starts to make water

13 Feb 80

Carson City, NV

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1535 Tripping out of hole

1545 Rod binding in trip out during last two joints

1555 Rods out of hole

1600 Discussed with Gil Speaker what time backhoe will arrive for work. Approximately 9:00 AM.

1615 Secure site and depart for office.

Day #2 14 Feb 80

0800 Bruce arrives at site. H.P. & Greg (Longyear) already on site prepping rig for drilling. Greg brings in full load of water. John (H.P.) mentions he heard press release on morning TV news, story associated with public hearings in Sparks today.

0805 Trexler arrives

0815 Flynn arrives - backhoe should arrive approximately 9 AM this morning to dig sump.

0845 Rig prepped and ready to drill, waiting for backhoe. Check hole visually - no water visible, but appears to be bridge at about 40 ft.

0930 Move water truck to off load drill pipe. Truck stuck in mud, still no backhoe.

1000 Trexler and Flynn go into town for errands. Move water truck out of mud and place off tail end of rig.

1005 Begin transferring rod off truck.

1010 Truck getting stuck in mud again, stopped offloading rod.

1030 Backhoe arrives.

1045 Unloading backhoe down by 5th St. construction.

1130 Trexler to Reno

1200 Backhoe working on water pit - drill stem is being lowered into hole.

1215 One rod apparently plugged as no air return coming up annulus. Changed rod.

1224 HH water at approximately 130-135 ft. Blowing water with each joint now.

1230 Sump almost complete. Blowing lots of water, depth 160 ft.

1235 Reach TD begin drilling. Koenig arrives.

1255 180 ft sample taken some chips - soft - chlorite rich? Gray-Green.

FB= 1.4
C=32.5

1308 185 ft sample taken. Soft green material as vein filling in grey green fine to medium grain metavolcanic.

1330 Drilling with heavy foam reached 200 ft level. Sample taken.

1415 Continued use of heavy foam.

C=38.7
FB= 4.5
T=17.5

1430 Reached 220 ft interval - still drilling with foam. Aids the chip lift.

1445 New stem. Heavy foam.

C=43.8
FB= 5.8
T=16.5

1500 Sample taken at 225. Shows two rock types. Formation providing lots of water. Heavy foam still being used. Gary Ferguson shows up at site (Longyear, Denver).

1520 Still much water in formation - heavy foam. Reached 230' level.

1530 Sample taken at 235' level. Same stuff - John Woods suggests may have to use tri-cone bit to get water and chips out of hole.

C=43.8
T=16.8
FB= 4.2
EP=16.8
Envirolab probe in sump.

1545 Sample taken at 240' interval. Mixed bag - formation still producing mucho water - sump pit filled to top with foam - about 1/2 way with water.

1600 FB= 6.8
C=44.2
T=16.2

1615 Reach 250' level. Sample taken. Same stuff - still lots of water.

1625 FB= 7.9
C=44.2
T=17.3

1635 Sample at 255'. Same materials - very small amount of sample.

1650 Sample at 260'. Same rock types plus what appears to be a piece of quartz from a vein.

FB= 7.2°C
C=40.2°C
T=16.9°C
EP=17.2°C

1705 Sample taken at 265'. Similar materials to inverval above.

1712 EP probe 17.1°C (downstream in return flow).

1720 Sample taken at 270'. Same materials but smaller fraction of friable rock.

1730 EP - 16.6°C

1750 Sample taken at 275'. Same materials

1755 EP=17.2
FB= 8.2
C=44.3
T=13.9 (in air)

1803 Reached 280' level.

EP=17.0

1820 Begin to close down shift.

FB= 9
T=18
C=45

1830 Begin to secure rig for shift end.

Day 3 15 Feb 80

0725 Trexler arrives at site. No crew, water level 15 in. below top of Berm.

0740 Flynn arrives at side. No crew. Set up temperature probes, water bucket.

0800 Crew arrives; Ken, John, Craig.

0810 Ken begins backhoe work to expand sump. Crew readies rig for drilling.

0830 Foam barrel (FB)=10°C
Truck (T)=11°C
Collar (C)=20°C

0835 Set up Envirolab probe in return water chanel. No temperature recorded.

0930 Drill stem stuck in hole - due to caving.

0955 Gary Ferguson arrives at site.

1015 Drill stem still stuck in hole. John goes for fuel. Gary Ferguson says it looks grim!

1050 Ken shuts down rig for fuel filter replacement.

1055 Ken starts up rig agin.

1130 Craig goes for more water.

1255 Rig still stuck. Moved up about 18". Gary digging supplemental sump.

1305 Craig back with water truck.

1330 Jim Bruce arrives - still stuck in hole. Trexler back to Reno.

1430 Forest King shows up for a 10 minute chat. Very happy we are drilling here.

1445 John Hancock shows up to see what is happening. Still stuck.

1500 Shut down rig to let hydraulic cool down - getting too hot to be effective.

1550 Ken Taylor, 2460 Pinyon Hills, C.C., stopped by to check on well condition. He just had well drilled by Forest King. Having problems with Forest King. Tom Flynn going over to temperature log Mr. Taylor's well.

1605 Start rig up again to try to free string. Still Stuck. Rotation a little less now.

1610 George Ghusn arrives.

1620 Ken (driller) starts enlarging sump.

1640 Ken takes over on rig trying to free string.

1715 Flynn returns from Pinyon Hills. Probe cable gets tangled. He will try again tomorrow.

1740 Ferguson arrives with casing 30' lengths. Rig capabilities can handle 24' length.

1815 Rods unstuck and pulled up 3'. Still binding, but looks good.

1835 Rods still binding and stuck but about 8' out of hole now.

1845 Ghusn leaves site.

1900 First joint free, ready to disconnect. Need one more foot to disconnect, still binding about 19' off bottom.

1908 First joint free, but crooked.

1916 First joint in rod rack.

1955 32' off bottom and still stuck, but gradually coming out.

2002 Second joint out of hole.

2005 Third joint out of hole. Joint really tight, doesn't want to break.

2008 Third joint out; fourth joint out but tight. Appears that hole is free. Binding part appears to be about 40' off bottom.

2010 Joints coming out good now, but highly torqued up.

2040 Out of hole, but hammer twisted off probably at bottom of casing. Hammer wedged about 50' down.

2100 Secure site.

16 Feb 80

0900 Bruce arrives, crew just beginning to run down rods trying to fish out rod which is about 30' off bottom; wash out hole as they go down to try to clean around tool.

0945 Tom and Pat arrive.

0955 Tom and Pat depart to measure Ken Taylor's well.

1005 Gary Ferguson arrives. About 18' off bottom.

1015 Tripping out of hole to switch over to mud parts for mud drilling. Should be at airport around noon.

Del Landing, President of Carson City School Board drops by. Asked how operation was going. He is familiar with drilling as he owns a portion of an oil and gas rig.

Day #5 18 Feb 80

0800	Bruce arrives at site, crew prepping rig for operation, no work on 17 Feb. Tool still in hole, converting rig to drill with mud and try to retrieve tool.
0815	Greg arrives with water truck.
0830	Gary Ferguson arrives with parts for mud drilling.
0945	Put tricone bit on to clean out hole, and running in to clean out hole with mud to fish out hammer.
0950	Adding LCM (cottonseed) directly down the hole, loosing circ, added about 1/2 bag.
1000	Mixing more mud. Have used all mud in mud pit 12'x6'x4' deep, adding 5 bags bentonite.
1015	Hipres. pop-off valve on compressor keeps blowing off.
1045	Replace gasket on regulator.
1110	Running string into hole and washing out.
1115	2nd joint added. 25' returns gained. LCM seems to be working.
1130	Mud pump intake clogs, have to clean.
1135	3rd joint added.
1145	4th joint added.
1155	5th joint added.
1202	6th joint added, 120'.
1209	8th joint added, 160'
1215	9th joint added.
1240	11th joint added. Shutting down due to weather.

Day 6 19 Feb 80

0900 Flynn arrives. Drilling with mud approximately 2 in over the bit which is at the 280' interval (± 2'). The drillers plan to wash out the hole over the bit and will attempt to recover it with a custom-made friction socket. This will be further described when it is fabricated. Ken, John and Craig have been at site since 0800.

0915 Jim Bruce arrives.

0920 Gary Ferguson arrives with casing for friction socket.

0945 Drillers start tripping stem to begin fishing operation. Carryall get stuck in mud behind rig.

1015 We get carryall unstuck.

1040 Tricone bit is being removed from stem, replaced with hammer sub.

1045 Drillers are attempting to spear bit with sub.

1120 Final drill stem is being lowered into hole. Getting ready to spear bit.

1125 On top of hammer, working rod up and down on hammer.

1128 Appear to have snagged hammer, slowly rotating trying to screw into hammer.

1130 Both Ken and John feel its been snagged. Begin pulling out of hole. Rod binding at about 4' off bottom, same spot as when we were stuck. John feels that this is where the tool came off before.

1140 About 6' of bottom coming up very slowly, still some binding.

1225 Running back in hole with tricone bit.

1300 On bottom and ready to drill.

1305 Drilling. Install temperature probes; one at intake end of mud pit; one at return end of mud pit, and one in casing still.

1318 290'. No sample.

1340 300'. Sample taken. John into town for diesel. Raining cats and dogs plus wet snow. Mud samples have very fine cuttings and a lot of cottonseed shells. Drilling rate pretty good.

1350 305' sample.

Cr	19.5	returns
Mp	11.4	mud pit
Cc	19.0	collar

Raining and cold winds from southwest.

1405 Drilling proceding quite well. Still using mud. Chips too fine to identify in field. Weather continues to be bad. Down to 315' interval.

Mp 13.0
Cr 19.8
Cl 21.8

1430 Drilling at 325' mark.

Cr 21.8
Cc 21.8
Mp 11.6

Unable to make field description due to fineness of cuttings and cottonseed content.

1450 Down to 335' interval. No recovery at 330'.

1500 Cr 21.8
Mp 12.3

1505 Collected sample at 340' level. Still impossible tosee any chips for identification. They are very small, black, and obscured by both mud and cottonseed. The weather continues to be very cold, windy, and very rainy. Drilling continues at a good pace with mud.

1520 Samples recovered at 345' are black- fine-medium grained metavolcanics. Some felsic material present. Slight break in weather. Still windy and cold.

1530 Mp 11.2
Cr 23.1 Temperature of return beginning to rise at 350' level.
Cc 21.9

1550 Sample recovered at 355' interval. Looks like same stuff - still very fine grained - using sump pond to remove mud and cottonseeds. Clouds are breaking up overhead, but some rain is still falling from clouds to southwest. Rig continues to drill with mud, but more slowly now.

1600 Cr 24.2
Mp 11.0 Return mud continues to increase in temperature.
Cc 22.2 Drilling is slow - about 357' mark.

1630 Sample at 360' mark. Forest King shows up.

1645 Cr 24.1
Mp 11.6 At 365' mark sample taken. Forest King gone.
Cc 22.4

1700 Sample taken at 370' level same stuff. The weather had held off, rain wise, until now. Rainy again, but looks like it might stop soon. Drilling continues with some hard spots.

1705 Sample taken at 375' level same stuff.

1715 Sample taken at 380' same stuff. Gary Ferguson leaves site.

Cr 24.0
Mp 12 In stream flow - not in mud pit.
Cc 22.8

Temperatures seem to be holding steady.

1730 Sample collected at 385' level. Looks like same stuff - possibly more andesitic but hard to tell with all the mud.

1745 Sample taken at 390' level.

Cr 23.3
Mp 12.5 Things have cooled a bit.
Cc 23.1
1750 Sample taken at 395' mark same stuff.

1800 Sample at 400' - begin to wash out to trip stem.

Cr 28.0 and falling
Mp 12.7
Cc 22.5

1845 All 400' of stem tripped out of hole. Tricone looks good - Rig down.

Day 7 20 Feb 80

0815 Flynn arrives at site, Ken, John and Craig are putting drill stem into hole. Weather is clear and cold

0820 Temperature probes set up at

Collar Cc
Mud Pit Mp No temperatures taken yet.
Mud Return Cr
Forest King was here for 10 minutes. Told Flynn about some geothermal projects he has going with P. Langston at Carson Hot Springs and a possible project at Wabuska. He now has a portable unit to measure ΔT at known flow rates in a hot well bore.

John says a gentleman reporter from the Appeal was here - asked if anything positive had been found - Ken told him about the 72°F mud returns - John told him to come back later to chat with Flynn.

0900 All 400' of stem in hole, drilling begins.

Cr	25.1
Mp	9.3
Cc	21.5

0915 Samples at 405' and 410' - same black stuff.

0930 Small sample taken at 415'. Flynn asked Ken to move bucket closer to the hole in order to catch a larger sample. Drilling goes well.

Cr	22.9
Mp	12.0
Cc	22.1

0935 Good sample taken at 420' . Chips are coarser and rock looks like a medium-fine grained basic rock - no visible alteration - many chips mud stained.

0945 Sample taken at 425' level. Looks like the same stuff. Weather getting bad - snow and wind.

0955 Sample taken at 435' level - same stuff.

Cr	25.8
Mp	17.7
Cc	22.3

1010 Sample taken at 440'. Looks the same - black-white grains in this bag. Medium-fine grained-muddy. Weather has cleared. Drilling smooth. Took some photos of mud drilling and catch bucket - also of Ken and John.

1023 Sample taken at 445' level. Some grains show medium-grained black-white (salt/pepper) mineralogy. Drilling still smooth, weather OK

Cr 27.2
Mp 18.8
Cc 24.7

1035 Sample taken at 450' level. Sample resembles grabs - black-white medium grained. Difficult to see any alteration. Drilling still smooth, weather holding.

1045 Sample taken at 455' level. Sample continues as fine-medium grained black-white rock. Gary Ferguson arrives at site. Weather holding. Drilling smooth.

1100 Gary Ferguson says mud flow rate is 250 GPM. Drilling looks like is tougher now.

Cr 26.3
Mp 19.2
Cc 24.2

1105 Sample taken at 460' level. Rock looks the same. Fine-medium grained black and white minerals - Gary says that hole will be chemically cleaned with LFN-OX (lignite). We plan to perforate 10' intervals to the water table, leave the top 6" casing and cement to 20' level.

1130 Sample taken at 465' level. No lithologic change. Gary backs up casing truck to drill rig. Temperature holding steady. Drop here - steady.

Cr 26.3
Mp 15.8
Cc 24.5

1145 Sample taken at 470' level. Lithology unchanged

1200 Sample taken at 475'. Lithology unchanged.

1215 Crew preparing casing for hole. Fitting couplings on tubes.

Cr 26.8
Mp 17.5
Cc 24.6

1220 Sample recovered at 480' level. Lithology unchanged; crew still working on casing cooling. Weather is blowy and colder.

1240 Sample taken at 485' level. Lithology unchanged. Crew still working on casing couplings.

Cr 26.6
Mp 15.0
Cc 25.1

1250 Sample taken at 490' level. Lithology unchanged. One more 15' drill stem to go. Crew continues to work on casing.

1300 Last 15' section of drill stem now being rigged in.

1305 Drilling continues smoothly on last drill stem.

Cr 27.5
Mp 19.4
Cc 25.5

1320 Sample collected at 495' level. Lithology unchanged. Gary starts work on perforating casing at 10' intervals. Ken says they will trip the stem when hole is completed, change to a slightly smaller bit, go back and flush hole.

1330 Jim Bruce arrives at site.

Cr 28.3
Mp 19.2
Cc 25.5

Gary will cut slots from 320'-500'.

1350 Reach 500' level. Sample taken. Lithology unchanged.

Cr 32.0
Mp 20.8
Cc 25.5

Based on jump in temperature, Jim told drillers to go another 5'.

1400 Tom runs into town, to bank and for coffee.

1415 Reach 505'. Use as T.D.

Cr 33.0
Mp 20.6
Cc 25.5

1415 Prepping for tripping out of hole, then will run in and clean hole out with Barfos (cleans out mud by breaking it down). Circulating to clean out hole.

1425 Still circulating about 1' off bottom.

Cr 32.8
Mp 20.6
Cc 25.6

1430 Beginning to trip out of hole.

1515 Flynn returns. Gary and Bruce talk about casing hole. Gary wants to shut down after tripping out and Barfos the hole tomorrow, because otherwise the crew would probably not finish casing the hole until late tonight.

1535 Out of hole with string.

1600 Rig down and secure site.

Day 8 21 Feb 80

0930 Bruce and Flynn arrive at site. 6 inches of snow on ground and still falling. We pulled two cars out of ditch in Washoe Valley. Crew here since about 0800 includes Gary, Ken, John, Craig. All 500' of drill stem in hole. Draining mud pit into water sump in preparation for chemically washing the hole. Saw short article and photo in Nevada Appeal about our drilling. KOLO ran the TV interview last night.

1000 Circulating with Barfos.

1020 Mud out of hole only Barfos returns. Now getting ready to trip out.

1030 Cleaning temperature probe and other equipment in truck. Tripping out. Bruce and Gary go to check other site.

1150 Bruce and Gary return, second site inaccessible due to over 12" of snow. Will probably have to get a blade to clear road.

1150 Out of hole and breaking bit off rods, and stacking rods on truck. Getting ready to run casing.

1200 Running casing into hole, 189' of slotted casing will be put in hole first.

1255 Tenth joint of casing in the hole, all 9 joints which are slotted are in the hole.

1330 Dick Wiliford showed up and asked to see the driller's license. Nobody has a driller's license and the operation is shut down until we can get a licensed driller on site.

Day 9 22 Feb 80

1210 Crew arrives.

1215 Casing setting begins

1257 Last segment of casing bottoms in hole. Ten 23' sections with couplings were used to complete the hole.

Carson City, NV

Community College Site Well - CC#2

Longyear Co., Drilling Contractor, Sedalia CO.

Crew - Ken Dfaart
John Woods
Greg ?
Darrel Nfkuda

NBMG Personnel - T. Flynn
B. Koenig
J. Bruce
D. Trexler
G. Ghsun

CC#2 22 Feb 80

1500 Begin to grade road for rig.

1600 Set up rig at site.

1630 Bruce leaves.

1720 No drilling yet. Koenig and Flynn check out.

1830 Start drilling.

1930 Shut down drilling at 95'. Some caving, most material is decomposed granite.

2000 Rig down.

Day 2 23 Feb 80

0830 Flynn and Bruce arrive. No drillers yet; at CC#1 picking up vehicles.

0900 John and Ken arrive, Greg sick, bring backhoe with them.

0910 John and Ken return to CC#1 to pick up casing truck.

0940 George Ghusn arrives. Bruce and Flynn setting up temperature probes.

0950 John and Ken return with casing truck, waiting on Gary Ferguson who is picking up 7" casing to case hole as DG wants to cave.

1015 Trexler arrives. Drillers reached 95' level last night and quit. Need more casing. Lithology is D.G. all the way down. Some large cobbles in some samples. No water yet.

1045 Gary and Darrel arrive with casing, buttress joint casing, so we will have to weld joints.

1050 Start up rig. Ready to run casing.

1100 Running first joint casing.

1105 Welding first joint casing.

1115 Two joints in the hole.

1125 Third joint in the hole.

1145 Fifth (last) joint casing in the hole, 97' (2' exposed. Will try to clean out hole bottom with tricone and are going to let casing settle the exposed 2'.

1150 Getting ready to clean out hole.

1155 Running rods into hole, new tricone bit on, will work out hole with air till water volume increases.

1210 Depth 100'. Running sixth rod in hole. Drilling rat - 1'/25 sec. = 25'/minute. Material appears to be G.D.

1213 Cutting window into casing. Refueling.

1219 Dennis and Tom set up temperature sensor. Drilling underway again.

1223 -105 sample taken (ST)
Barrel Temperature (B) 12.5°C
Return Temperature (R) 21.0°C

1225 - 110 ST

1226 - 115 ST

1227 Fitting 7th rod in hole.
ST At 120'

1234 ST - 125'

1236 ST - 130'

1238 ST - 135'

1240 ST - 140'
7th rod

1245 Reach water table, or water seam at 140', water volume decreased below 140'.
ST - 145'

1246 ST - 150'

1247 ST - 155'
Lith - D.G.

1250 ST - 160'
Lith - D.G.
8th rod down hole

1255 ST - 165'
Lith - D.G.

1257 ST - 770'
Good OL D.G.

1300 B=5.5°C R=12.0°C Depth 175'
Sample taken same D.G. - 180'.

1302 Hit something hard at almost -180'.

1306 ST - 180'
Lith D.G. + chips of bedrock or boulder.
9th rod down hole

1311 ST - 185'

1313 ST - 190'

1315 ST - 195'

1318 ST - 200'
10th rod down hole

1321 11th rod being installed.

1322 B=5.3°C R=16.2°C Very little fluid coming up. Depth 205'.

1324 ST - 205'
Lith - D.G.

1333 ST - 210'

1335 ST - 215'
Lith - some aplite, in D.G.

1337 ST - 220'
11th rod down hole

1347 Drilling resumed.

1350 ST - 225'

1352 ST - 230'

1354 ST - 235'
R=17.3°C at 235' B=5.8°C

1355 ST at 240' - last one.
Begin to flush hole.
Some epidote in aplite dikes.

1408 Drillers tripping out.

1425 Last drill stem tripped out of hole.

1435 Casing truck has been moved into position for unloading. Crew begins to case the hole. Bottom casing is plugged. No casing will be perforated. George goes to CC-1 to change locks.

Preliminary Temperature Profile at CC-1 25 Feb 80

1000 Arrive at site - nobody around. Hole has not been cemented. 2'x2' space dug out around casing. 3'-4' - Begin to set up Envirolab cable.

1010 Cable in place - probe at 100' level. Allowing 3-5 minutes for equilibration.

1025 Drill crew arrives to cement hole. Break down probe.

1045 Out of hole. Cementing begins.

DEPTH	TEMP	TIME
100'	15.6	1015
150'	15.9	1020
300'	17.8	1030
400'	19.1	1033
459'	19.6	1036

29 Mar 80

Big Smoky Valley Drilling Project

Darrough's Site - Hole BSD

NBMG Personnel: J. Bruce, B. Koenig, G. Ghusn

Comments: Begin drilling 1: pm. Hole begun in alluvial material, no water, air only.
Sample 1 10' 0.5 cm frags appear to be Darrough Felsite in fine grained (0.5-1 mm) matrix
Hole blown @ ≈12', cobbles of grey chert and Darrough Felsite (DF) came to surface.
Drilling stopped @ 1:45 pm hole caving - depth before caving ≈15'
3:07 pm drilling restarted using foam-water-mud-thickener.

0900 Meet drill crew @ site, begin search for H_2O for drill rig.

1000 Wine Glass Ranch will allow water to be taken from their pond (owner - Carl Hass (sp?)).

1115 Water truck @ rig, start up rig to warm up. Putting new 7 7/8" tri-cone bit, #201.

1134 Begin drilling.

1157 1st 20' regular rod mounted, drilling continues.

1203 20' sample taken, many rock types of varicolored cherts, colors vary from black to reddish purple.

1235 50' sample, samples have been collected @ 5' intervals, mostly coarse-med coarse alluvium. Rough going at 50'.

1240 Losing circulation @ 50'. Return temp 15°C.

1243 Circulation regained.

1250 New 20' section added.

1303 60' sample taken, losing circulation, chips now average 0.2 cm size

1304 55' lost circulation.

1325 65' sample still small chip size.

No sample between 65'-75'

30 Mar 80

1340 New 20' rod added, circulation lost @ 75'.

1358 Newly added rod pulled, foam in compressor, attempting to regain circulation.

30 Mar 80 cont.

1413	Second 20' rod removed.
1427	3rd rod removed.
1433	4th removed (a string being pulled to inspect the bit).
1448	String being reinserted, groundwater in hole @≈55' (former zone of lost circulation).
1543	Circulation established to 75', string being removed for placement of surface casing.
1615	String out.
1700	Casing movement blocked @ 50', operations suspended for this day.

31 Mar 80

0800	Arrive on site, surface casing in to a depth of ≈50', stopped by an obstruction.
0830	Water being circulated to clear the hole.
0850	Casing cut and drilling within casing with smaller bit begun.
0935	String being pulled, one joint pulled.
1000	Tilt mast to slide cut casing back over the string.
1010	Rewelding casing together, now have 61 ft of casing string.
1025	Driving casing & blowing out annulus. Casing down to about 53 ft. Blowing approximately 40 gpm of water from the formation.
1040	Driving casing by blowing cuttings out below casing and then forcing casing down with rod tong on top of casing. Casing depth 54.5 ft.
1120	Cut a notch in the casing to act as a blooey line and are cleaning out the hole and driving the casing with the power head, best method to date.
1200	Casing beginning to drive better because added an 18" sub to the string, thus cleaning the hole at a greater distance ahead of the casing.
1245	Casing down to 58 ft driving casing seems to be going much easier.
1255	New rod on - switched to foam.
1305	Sample taken @ ≈75'.
1312	Sample taken @ ≈80'.
1330	Change from 20 ft joint and replaced with a 15' joint so bit is not as far ahead of the casing. Added a 10 ft section of casing.

31 Mar 80 cont.

1350 Welding casing together, total casing string 71 ft. Approximately 58 ft in the hole.

1405 Begin driving casing again, by 1410 have driven 2 ft more.

1530 70 ft of casing in the hole, changing the 15 ft joint and replacing with a 20 ft joint. Adding 7' more to the casing string (total casing string 78') will try to drive 5 more feet of at casing.

1550 Begin driving casing again.

1610 Surface casing set to 759 - blowing hole using air.

1635 New 20' section being added, hole @ ≈ 80'.

1640 Foam added, drilling continuing.

1720 100' depth achieved. 100' sample may not be representative - material averages 1-2 mm, no large chips.

1740 Rig shut down for the day, hole sluffed about last 5 feet.

1 Apr 80

0750 Arrive at site.

0800 Rigging up for mud drilling to prevent hole collapse.

0854 New tri-cone bit installed

0930 Hook up mud pump and begin to mix mud. Valve on mud pump is leaking. So shut down & begin repair of valve.

1050 Hole being filled with mud.

1115 ≈400 gal of mud pumped but no returns.

1121 Switching to air to unplug hole plus mud being mixed in water truck.

1250 Start drilling with air-mud mix @ 105'. Temp is 10.2C. Sample taken @ 105' - rock frags contain a previously unseen rock which appears to be a poorly sorted subangular white sedimentary rock (a quartzite) and possibly contains feldspar frags.

1255 110' sample taken, same materials.

1300 115' sample taken, same materials.

1305 120' sample taken, same rock types. Size of frags avgs. 0.3 cm (smaller than previous 5 samples (2).

1310 New 20' rod added.