GL00763

INTRODUCTION

by DENNIS TREXLER

INTRODUCTION

Geothermal resource assessment in Nevada was conducted by the State Assessment Team for the U.S. Department of Energy, Division of Geothermal Energy over the past three years. The first phase of this cooperative program focused on statewide evaluation of geothermal resources. In meeting these needs, a 1:500,000 scale map entitled "Geothermal Resources of Nevada and their Potential for Direct Utilization", NVO/1556-1 (Trexler and others, 1979), was prepared and published. The map depicts technical resource information for more than 300 springs and wells throughout the state and evaluates 40 large areas with potential for geothermal development based upon a numerical evaluation scheme.

The second phase of the cooperative program was a two year contract for area specific investigations to stimulate geothermal development. These area specific studies employ geological, geophysical and geochemical surveys and are designed to expand the data base of the regional assessment, provide more detailed resource information, and develop and test scientific exploration methods for low-to-moderate temperature geothermal resources.

The first year of area specific studies began in May, 1979 in two study areas: the Big Smoky Valley in central Nevada, and Carson-Eagle Valleys in west-central Nevada. The two areas were selected on the basis of their high potential for the development of industrial process heat and residential space heating, respectively. The results of these investigations were reported in the first annual report, "Assessment of the Geothermal Resources of Carson-Eagle Valleys and Big Smoky Valley, Nevada", Report No. DOE/NV/10039-2, May, 1980. An additional study area, Caliente, was added in November, 1979 at the request of DOE. Limited resource evaluation included geologic reconnaissance, two-meter depth temperature probe survey, soil

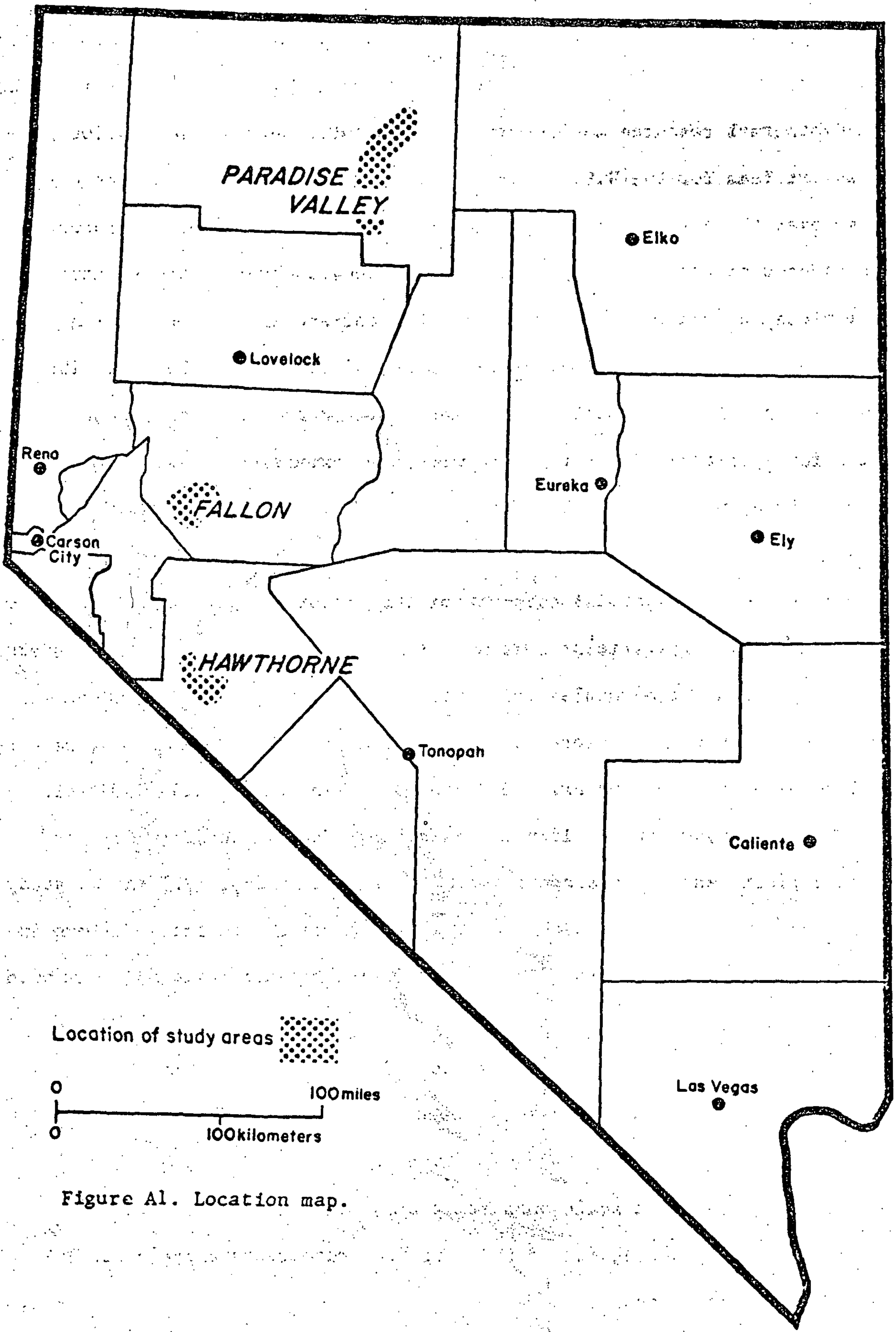


Figure A1. Location map.

mercury, and fluid geochemistry techniques. The results of this investigation and the selection of two sites for reservoir confirmation wells were reported in "Assessment of Geothermal Resources of Caliente, Nevada", DOE/NV/10039-1.

During the second year of area specific studies, three locations were investigated to determine their potential for low-to-moderate temperature geothermal resources. These areas are Hawthorne, located in west-central Nevada, Paradise Valley in north-central Nevada, and the Fallon Naval Air Station located in the southern Carson Sink of west-central Nevada. The Paradise Valley and Hawthorne study areas received the full compliment of exploration and assessment techniques, while less extensive investigations were performed in the Fallon area because of previous geothermal exploration work by the Navy. The location of the three areas is presented in Figure A1.

Regional definition of the nature of the resource, its extent, and controls on the extent are the primary objectives of the research. The program is organized around the completion of nine tasks that pertain to resource evaluation. Each of these work units is briefly described below.

1. Gather and examine existing information including geological, geophysical and hydrological literature, chemical data, lithologic and well completion logs, and appropriate aerial imagery.

2. Acquire relatively detailed information on the subsurface configuration through the use of gravity surveys employing station spacings of approximately 1/2 mile.

3. Collect and analyze soil samples for mercury content on regional (approximately one-mile spacing) and smaller grids.

4. Obtain low sun-angle photography at a scale of 1:24,000 for use in studying subtle geomorphologic manifestations, particularly faults.

5. Conduct shallow-depth temperature probe surveys to determine the

near surface thermal regime on both regional (1 mile grid) and smaller more localized grids.

6. Sample thermal and non-thermal groundwaters and, if possible, meteoric waters, and analyze for bulk chemical and stable light isotopic composition.

7. Collect and examine bulk rock samples for mineralogic composition. Analyze selected samples for whole rock chemical composition if appropriate. Compare rock mineralogic and chemical composition with the chemical composition and mineral equilibria of sampled fluids.

8. Based on the data obtained from 1-7 above, select sites for drilling three to five 100-250 meter temperature gradient holes. Determine lithology, temperature profile, and fluid chemical composition where possible.

9. Prepare a report detailing the results of the study.

In addition to the area specific resource tasks identified above, a tenth work element was initiated which included collecting and analyzing fluid samples, measuring physical and chemical parameters, and preparing input to the U.S. Geological Survey GEOTHERM data file for springs and wells lacking these data.

BASELINE DATA

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

Samples of thermal and non-thermal waters were collected from several sources in the study areas. Garside and Schilling (1979) provided chemical data for thermal springs and wells. 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 to non-thermal waters and include 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 most logs were difficult to read, they were helpful in determining the distribution and depth of many warm water aquifers. Data from oil and natural gas exploration in Railroad Valley in southeastern Nevada are, unfortunately, of little value in this study. Also, data from mineral and geothermal exploration holes are largely proprietary.

GEOLOGIC RECONNAISSANCE

Geologic reconnaissance consisted of identifying important rock stratigraphic units and structures in the field. No large-scale geologic mapping was required because most of this work has already been performed.

Much of the reconnaissance was incorporated into other phases of the program such as the gravity and low sun-angle photo surveys. In the Paradise Valley area, several previously unmapped faults were identified on low sun-angle photographs and verified during geologic reconnaissance. In addition, hydrothermally altered areas were examined for evidence of recent thermal spring deposits and hydrothermally-cemented sediments.

Several representative samples of the major rock units were collected for petrographic examination. Thin sections were used to investigate possible genetic affinities among various lithologies.

GRAVITY

Gravity measurements were taken to obtain useful subsurface structural information. This choice was based in part on the results of other investigators working the Basin and Range region.

One of the earliest studies was carried out in the Virginia City and Mt. Rose, Nevada quadrangles 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 sedimentary rocks in several 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 surveys 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.

An additional reason for using gravity measurements was the relatively high rating assigned to the technique by Goldstein (1977) for area-specific studies.

In the three study areas, 721 gravity stations were occupied. Readings were made with a Worden gravimeter with a scale range of 80 milligals. Vertical control was maintained to ±0.1 ft using an HP electronic transit. Station spacing ranged from 0.5 to 1.0 mile. 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 used as frequently as conditions permitted.

AERIAL PHOTOGRAPHY AND LANDSAT IMAGE ANALYSIS

Three aerial photographic techniques were used in the study areas: moderate to high altitude imagery, low altitude photography along selected flight lines, and low sun-angle photography. Landsat imagery at 1:250,000 scale, 1:120,000 U2 black and white photography, and 1:60,000 scale black and white U.S.G.S. aerial mapping photography were used under the first technique. This imagery identified regional trends possibly related to the location of geothermal occurrences within the area. Low sun-angle photography was flown at a scale of 1:24,000 along selected flight lines in the Paradise Valley and Hawthorne study areas, and low sun-angle photography at a scale of 1:40,000 was flown for the Fallon area. Aerial photography was flown in October to maximize sun-angle illumination; the photos were taken with 60% forelap and 20% sidelap to allow for stereoscope examination. In an earlier study, Trexler and others (1978) demonstrated the usefulness of the low sun-angle photographic technique in delineating near-surface structural features associated with known geothermal occurrences in Nevada.

FLUID SAMPLING

Samples of 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 isotopes. The goal 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 including White (1968), Ellis and Mahon (1977), and Cusicanqui and others (1975). A chemical data base was also compiled using sampling and analysis procedures which were uniformly applied to each area.

Two fluid samples were collected at each site; one contained a 250 ml aliquot and the second an 80-100 ml aliquot. The larger sample was topped-off to reduce atmospheric interaction, and preserved in a raw state for the analysis of anions. After filtration to remove particulate matter larger than 5 microns, a sufficient quantity of reagent grade nitric acid was added to bring the pH of the smaller sample to a value of approximately two. These steps were taken to insure reliable cation data. Additionally, a 125 ml sample was collected in glass bottles for isotopic analysis. 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.

Subsequent to collection, raw and isotopic samples were promptly shipped to laboratories for analysis. Values for SiO_2 are derived from an undiluted sample using an induction-coupled plasma or atomic absorption technique.

TEMPERATURE PROBE SURVEYS

Temperature anomalies located near the ground surface can be mapped using thermistor probes buried to a depth of one to two meters. These surveys are 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 effectively delineate high temperature gradients in areas of known geothermal activity (Kintzinger, 1956; (Olmstead, 1977).

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 1.5 - 2 m were used to delineate areas of anomalous temperature highs. General purpose, vinyl-tipped thermistor probes were used. The probes are 3 m in length and are equipped with a standard phone-jack.

Small diameter holes (8-9 cm) were drilled to various depths with a trailer-mounted gasoline-powered auger; a thermistor probe encased in a 2 m section of PVC pipe was emplanted. Spacing between probes varied from 0.25 - 1 mile 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 10-15 minutes per hole or less. In general, the holes were allowed two to four days to equilibrate.

SOIL-MERCURY SURVEYS

Soil-mercury surveys are reliable in geothermal energy exploration. The basic principle behind the method is that mercury is generally volatile above 80°C; since many geothermal systems are higher than 80°C at depth, mercury is released from the rock. The vaporized mercury then migrates upward untilit encounters absorbent clays which capture the mercury.

Sampling this clay 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. The samples are then sieved to a minus 80 mesh (180 micron) fraction, and analyzed with a Jerome gold film mercury detection machine. Background values are determined from this data base. Anomalous regions are then studied to determine the relationship of soil mercury values to the hypothesized geothermal system (i.e., structure controls, areal extent, etc.).

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. Drill sites were selected based upon the data gathered from field and analytical techniques, and also based upon the availability of land.

Three gradient holes were drilled in the Paradise Valley study area, each to a total depth of 132 m (400 ft). The holes were cased with 2" diameter schedule 40 PVC. Casing in GDS-1 was open, while PVC was capped and water was added during installation in the remaining two holes. Two gradient holes were drilled in the Hawthorne area, one to 265 m (800 ft), and a second to 132 m (400 ft). Both holes were cased using 3" pipe, and closed at the bottom to retain a column of water. A complete discussion of maximum temperatures and gradients is presented in the Paradise Valley and Hawthorne sections of this report.

HAWTHORNE STUDY AREA

by BRIAN A. KOENIG

INTRODUCTION

The Hawthorne study area is located in west-central Nevada approximately 40 miles from the California border. It encompasses an area of nearly 120 square miles and includes a large proportion of the land belonging to the U.S. Army Ammunition Plant as well as the communities of Hawthorne and Babbitt (fig. B1). The local population which exceeds 5000, and that of the Military Reservation make up a strong basis for geothermal energy development, particularly in the area of direct applications such as space heating and/or cooling.

No surface manifestations of geothermal activity have been identified in the study region to date. Information on the nature and distribution of the resource was obtained from several wells drilled within and near the city of Hawthorne. Thermal fluids were first discovered in the area during the 1940's and 1950's when wells were drilled on property which belonged to the Navy. Temperatures ranged from a minimum of 16°C along the range front near the southwest shore of Walker Lake to a maximum of 51.5°C in a hole two miles northwest of the city. A well drilled approximately one mile southwest of Hawthorne and 1/2 mile from a warm (34°C) city well encountered thermal fluids at 99°C. These temperatures were recorded within the past two years, indicating a strong resource potential in the area.

Representatives from both the government and private sectors have expressed interest in exploitation and development of geothermal resources over the past few years. DOE and private resource evaluation teams completed a cooperative study on engineering and economic feasibility of geothermal resources in the area. The study was initiated at the request of owners of the El Capitan Casino and the Mineral County Commissioners in a joint effort to utilize hot fluids produced from the well located on Casino-owned property.

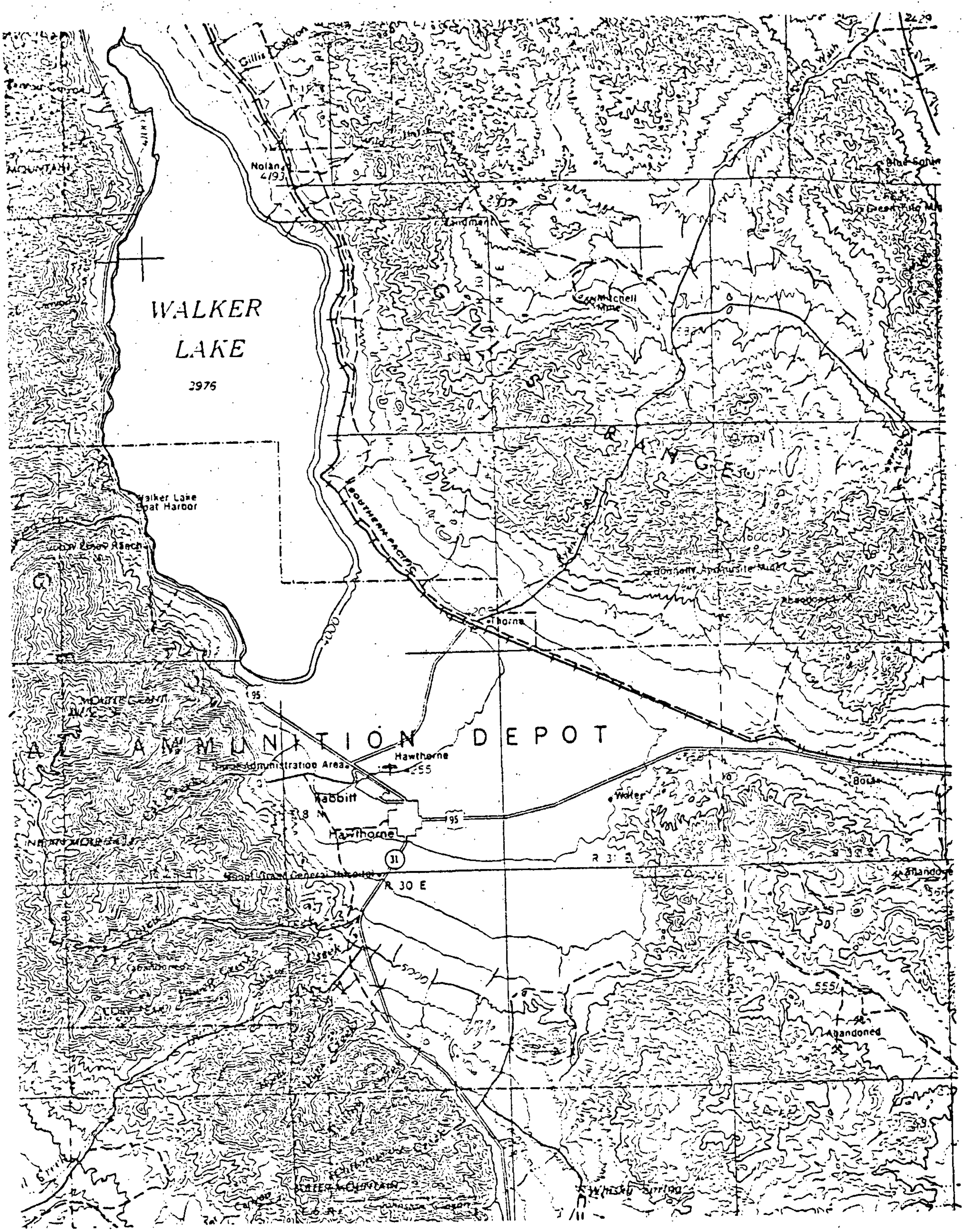


Figure B1. Hawthorne study area.

Personnel of the Hawthorne Army Ammunition Plant have also expressed an interest in utilizing geothermal resources as a result of the discovery of shallow depth (175 m), moderate temperature (90°C) fluids on Army land. Efforts are in progress to obtain funding for continued development and/or exploration in the Hawthorne area.

GENERAL GEOLOGY

The study area lies within the Walker Lake Basin. Although similar to other Basin and Range valleys, it is located in a zone of topographic discordance. Ranges to the south and west of the zone exhibit northwesterly trends while those north and east have northeast orientations. Within the zone, orientations are diverse and follow arcuate patterns. This zone was labeled the Walker Lane by Locke and others (1940). Some investigators interpret this feature to represent a zone of large scale right-lateral displacement. A discussion of various theories regarding the nature and timing of events within the zone is given by Stewart (1980, p. 86-87). Most characteristics discussed in the following paragraphs are presented graphically in a geologic map, Figure B2. It is a generalization from the maps of Ross (1961) and Stewart and Carlson (1978).

Rocks exposed within the area range in age from Triassic to Holocene, and a variety of lithologies is present. The Wassuk Range which forms the study area's western boundary is largely composed of intermediate intrusive rocks. Although compositions from diorite to granite are observed, the majority of rocks are granodiorite to quartz monzonite. The diorite rocks are directly associated with metavolcanic rocks of the Excelsior formation as defined by Muller and Ferguson (1936). Ross (1961, p. 28) suggests that the diorites are partly the result of assimilation of the metavolcanic rocks during intrusion

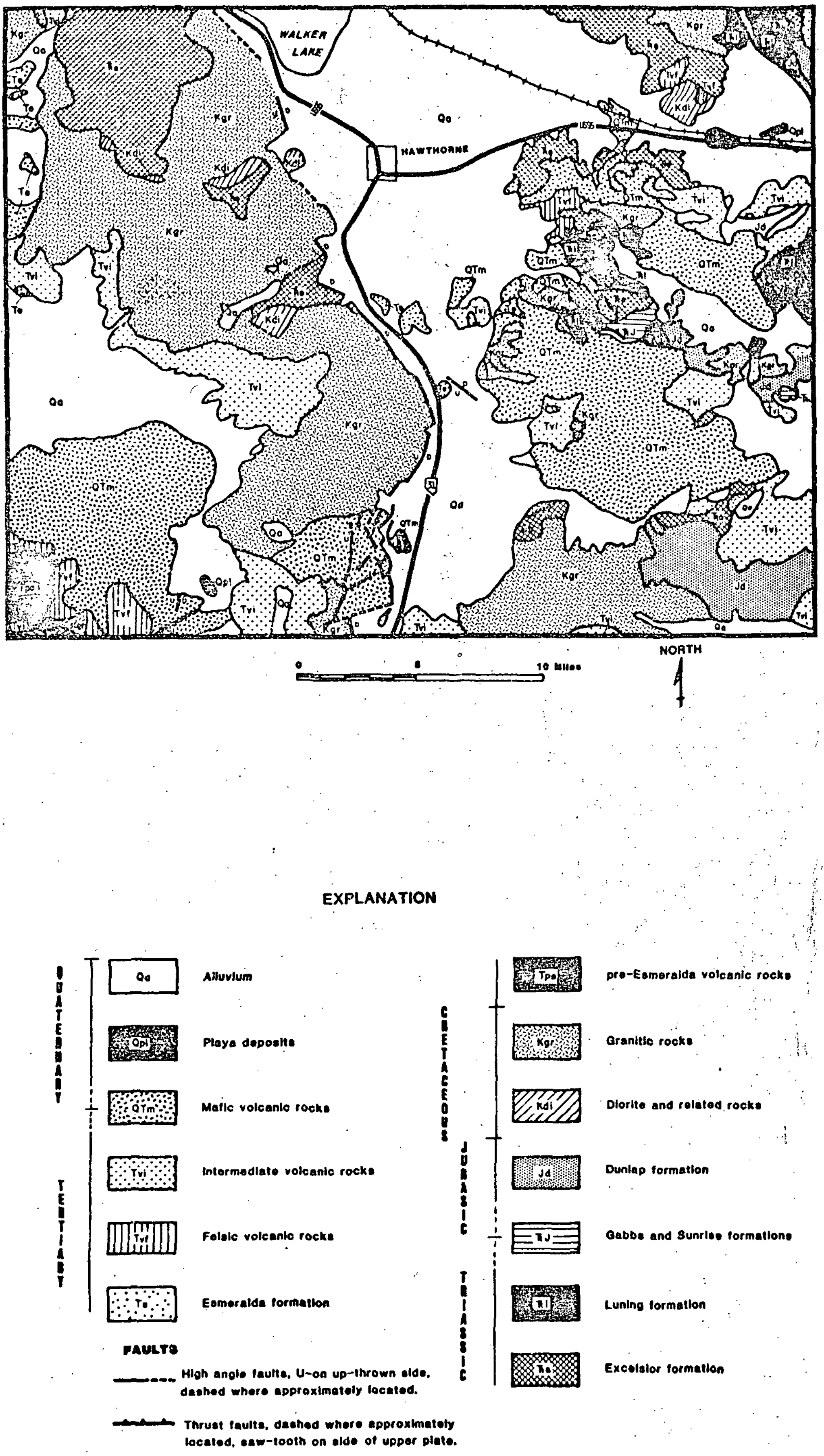


Figure B2. Generalized geologic map of the Hawthorne study area and surrounding region.

of the granites. He also proposes (Ross, 1961, p. 30) that the granitic rocks are probably related to the Sierra Nevada Batholith complex. The Excelsior formation rocks and associated diorites appear to be roof pendants on the granites. In the Lucky Boy Mine area, marble and phyllites are locally present in the Excelsior formation. These lithologies are probably the result of contact metamorphism during intrusion of granitic rocks. The western front of the Wassuk Range at the latitude of the study area is made up of intermediate volcanic rocks of Tertiary age. South of the primary study area, recent mafic volcanic rocks are present in the range. This rock type is found in the Aurora Crater and Mud Spring Volcano immediately west of the Wassuk Range. The former is dated at 250,000 years and the latter is determined to be even younger (Stewart, 1980, p. 109).

A group of low hills is located immediately north of Whiskey Flat in the southern portion of the study area. These hills are largely covered by Quaternary alluvium owing to their near central location in the valley, however, only limited outcrops are present. Ross (1961) labels these features as the Tertiary Esmeralda formation. Field checking confirms that the northern two groups of hills are composed of tuffaceous and lacustrine sediments as Ross' map suggests. The southernmost hill appears to be composed of a dark copper-bearing rock similar to the metavolcanic rocks of the Excelsior formation.

The eastern boundary of the study region is formed by the Garfield Hills. In their western extent, the mountains consist largely of the same units described for the Wassuk Range. However, volcanic rocks of Tertiary and especially Quaternary age dominate in this area. Only limited exposures of the Mesozoic granites are observed. Sizable outcrops of Excelsior formation rocks are present in the northwest part of the range. Rock units not seen in the Wassuk Range include limestone, shales, sandstones, and conglomerates of the Luning, Gabbs and Sunrise, and Dunlap formations of Mesozoic age and Tertiary felsic volcanic rocks. Quaternary alluvial deposits cover the valley floor and are occasionally found in topographic lows within the ranges.

Structurally, the Wassuk Range is similar to several other large mountain ranges in Nevada. Its eastern flank is well defined by frontal faults, particularly in the vicinity of Hawthorne. The eastern slope is steep and has deeply incised canyons. Elevation changes as much as 1500 feet per mile occur where Mt. Grant adjoins Walker Lake. Conversely, the western slope exhibits a notably more gentle grade with clearly defined frontal faults only locally evident. Recent faulting along the eastern front is evidenced by scarps cutting alluvium. Ross (1961, p. 56) notes that south of the study area in the vicinity of Powell Canyon, movement is distributed along several faults. Some of these faults are antithetic. Examination of low sun-angle photography suggests that a similar structural configuration exists in the study area (see section on "Aerial Imagery").

Structure of the Garfield Hills is documented in great detail by Ferguson and Muller (1949). A well-defined period of Mesozoic orogeny is recorded by the attitude and juxtaposition of beds in the Excelsior, Luning, and Dunlap formations. Types of documented orogenic events include folding, uplift, rapid erosion and deposition, thrust faulting, and intrusion. Following the Mesozoic intrusion, large volumes of Tertiary and Quaternary volcanic rocks were extruded, particularly in the western part of the range. Unlike the well-defined frontal fault patterns of the eastern slope of the Wassuk Range, range front scarps are essentially absent from the Garfield Hills. Relief of the range is subdued above the surrounding alluvium. Data supporting recent fault movement are not apparent.

AEROMAGNETIC DATA

An aeromagnetic survey was performed in 1967 for the U.S. Geological Survey. Two separate elevations, 9000 and 11,000 feet barometric were used in the aerial survey and both are found within the study area. Only a general discussion is appropriate since the survey was not flown drape and the effects of terrain were not taken into consideration. A segment of the map (U.S. Geological Survey, 1971) is reproduced as Figure B3.

From an overall perspective, the contours make up a collection of isolated closures and linear patterns. The most prominent feature of the area is the linear pattern which trends east-southeast within the Garfield Hills. This feature assumes a southeasterly orientation where it traverses the Walker Lake Basin. Position of the linear pattern compared with topographic and geologic maps indicates that it follows a depression primarily filled with alluvium. Regions of contour closure located north and south of the linear pattern tend to correlate with topographic highs and/or outcrops of mafic to intermediate volcanic rocks. Similarly, closure correlated with rock type are observed along the western front of the Wassuk Range. A more subtle pattern is observed in the vicinity of Mt. Grant, extending eastward to Hawthorne and southward to the vicinity of the Lucky Boy Mine. Relative differences between highs and lows are small within this region. A broad, rather non-descript zone is present west of Babbitt. These poorly-defined patterns may result from the large mass of relatively uniform granitic rocks which form the Wassuk Range.

Generally, information on this map provides little additional data compared to other sources such as topographic and geologic maps.

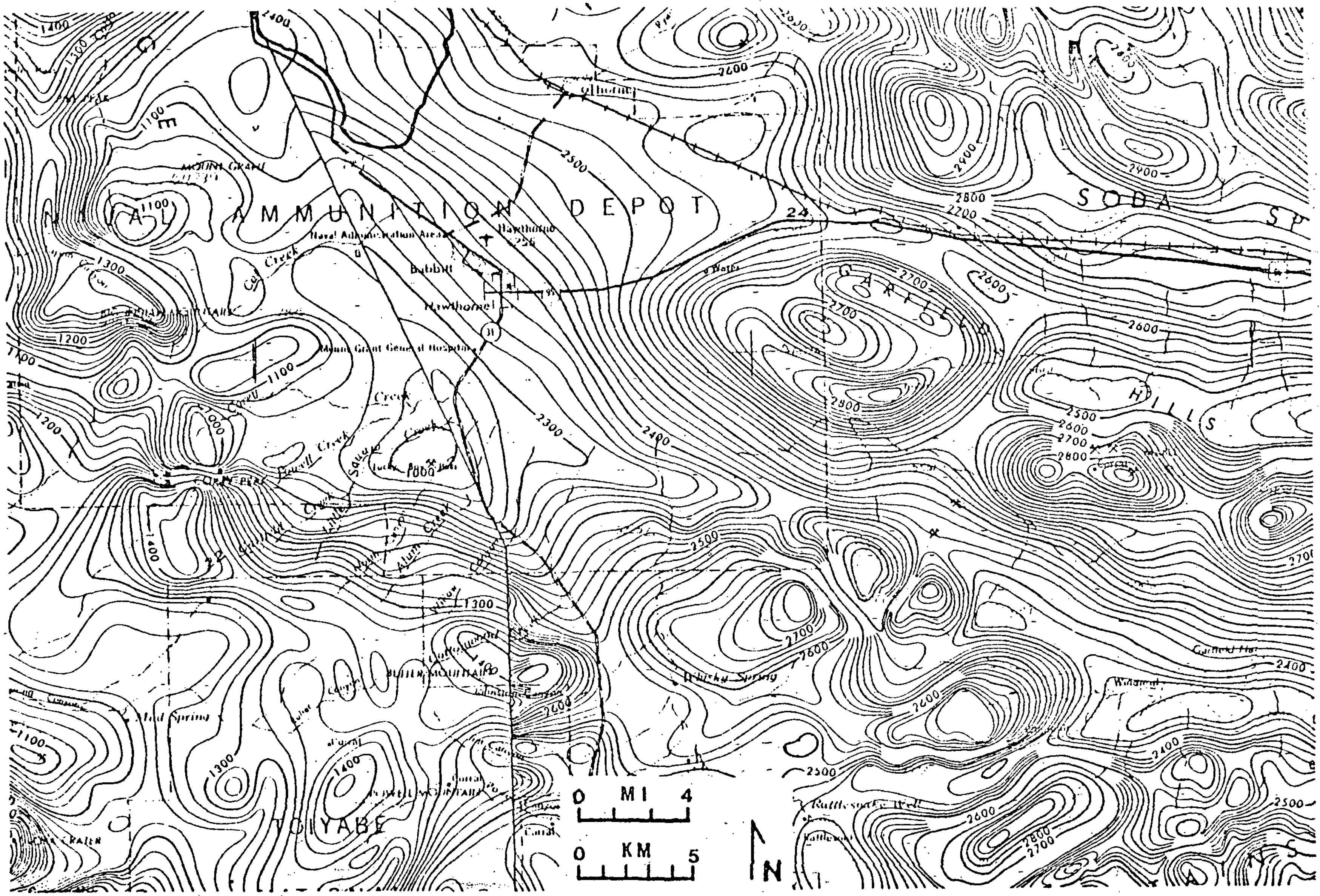


Figure B3. A portion of the U.S. Geological Survey aeromagnetic map (U.S. Geological Survey, 1971). Contours in Gammas.

LITERATURE SEARCH

Existing data sources were examined prior to commencement of field studies. Geology of the area is discussed in Ferguson and Muller (1949), Locke and others (1940), Muller and Ferguson (1936), Ross (1961), Speed (1977b), and Stewart (1980). Regional geophysical data for gravity is available in the form of a 1:250,000 scale map and accompanying tables (Healey and others, 1980). Aeromagnetic data in a 1:250,000 scale map is available from the U.S. Geological Survey (1971). Hydrology and hydrogeology are discussed in Everett and Rush (1967) and VanDenburgh and Rush (1975). A preliminary report on geothermal resources contains a compilation of fluid chemistry (Bohm and Jacobson, 1977). Further information on lithology and chemistry for wells located on the military reservation are available from records at the Ammunition Plant. Well records filed with the State Engineer's office were also examined.

SHALLOW TEMPERATURE SURVEY

Over 90 holes were drilled to an approximate depth of two meters, and thermistor probes were implanted. The probes remained undisturbed for a minimum of 24 hours before readings were taken. Previous work using this technique demonstrated that 24 hours is sufficient to obtain temperatures within 0.1°C of those recorded after the hole returns to a thermal equilibrium state. Locations of the probe holes are depicted in Figures B4 and B5 where the numbers correspond to those listed in Table B1.

This study was completed during three separate trips to the field in September, October and December, 1980. Therefore, the data represent measurements taken at three points along the changing curve of the annual wave, the effects of which penetrate to depths greater than two meters. To compensate

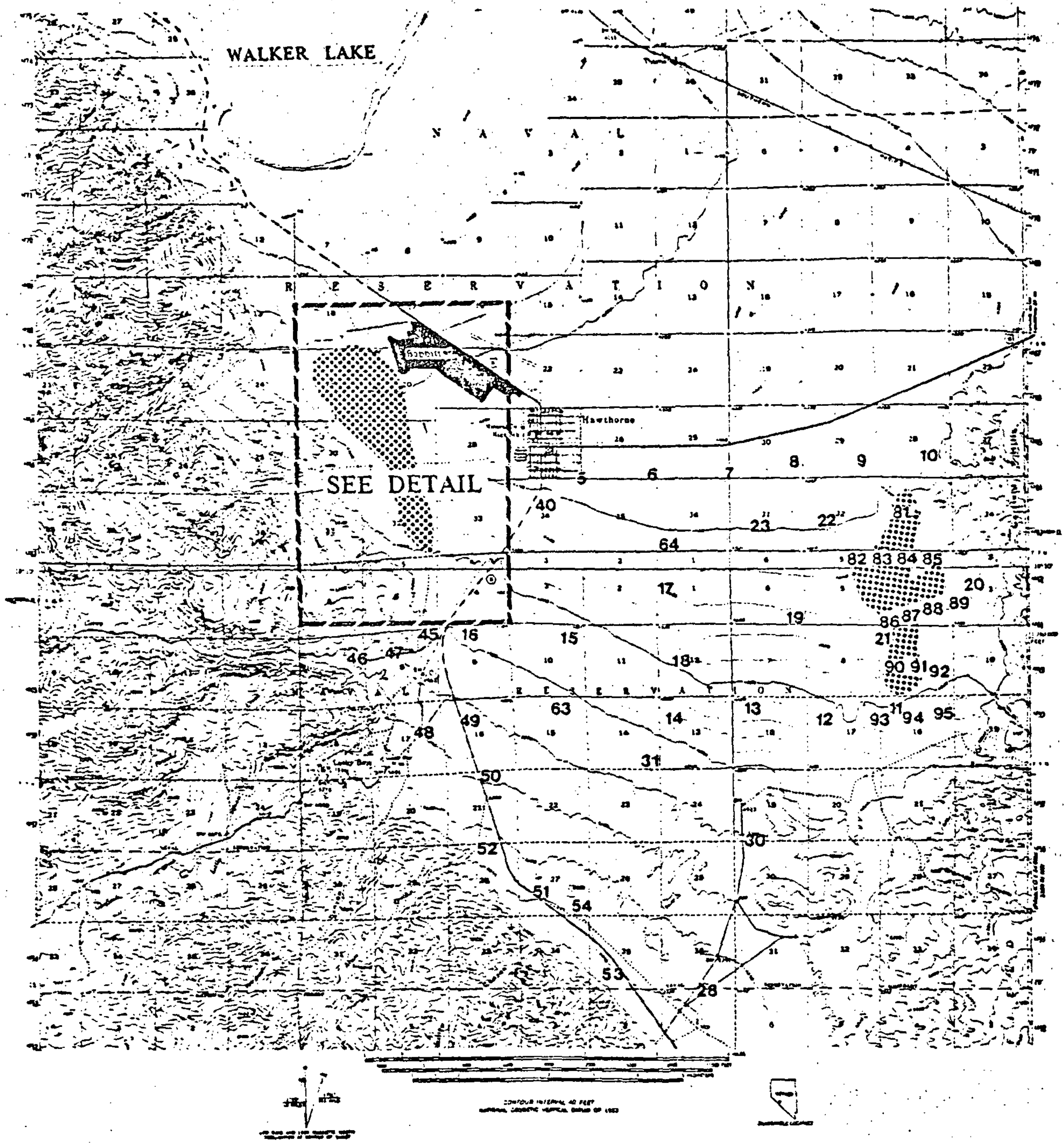


Figure B4. Two-meter temperature probe locations. Stippling indicates area of elevated temperatures. See Figure B5 for detail.

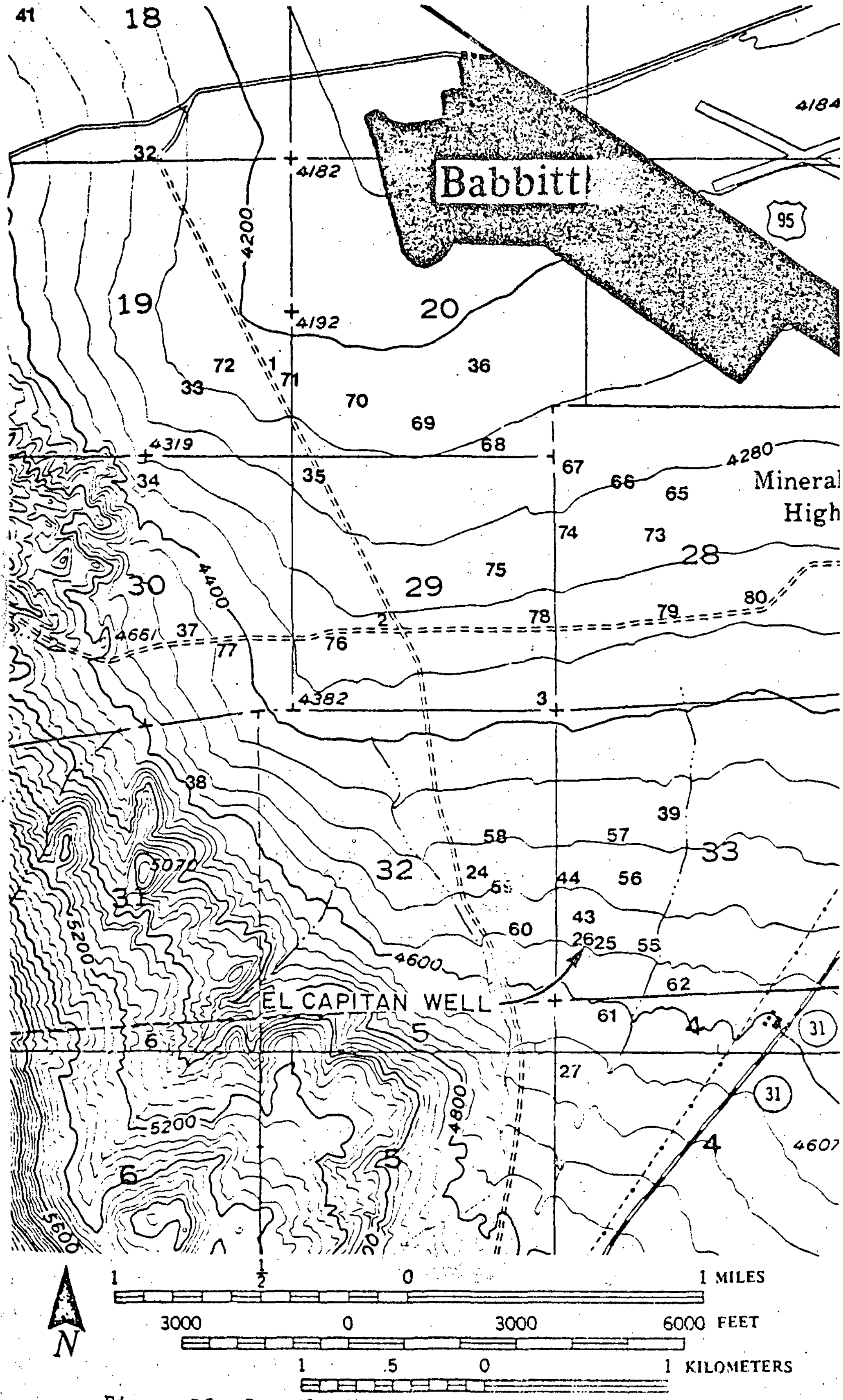


Figure B5. Detail of temperature probe locations.

Table B1. Temperature Probe Data

Probe #	Date of Reading	Measured Temp (^{o}C)	Correction Factor	Corrected Temp (^{o}C)
1	27 Sept.	22.8	N/A	N/A
2	27 Sept.	23.9		
2	1 Oct.	23.75		
2	17 Oct.	23.3		
2	3 Dec.	18.25		
3	27 Sept.	23.4		
4	27 Sept.	21.0		
5	27 Sept.	22.4		
6	27 Sept.	19.8		
7	27 Sept.	21.0		
7	1 Oct.	20.9		
7	17 Oct.	20.6		
8	27 Sept.	21.1		
9	27 Sept.	22.0		
10	27 Sept.	22.3		
11	27 Sept.	22.2		
12	27 Sept.	21.1		
13	27 Sept.	21.1		
14	27 Sept.	20.5		
15	27 Sept.	20.8		
16	27 Sept.	20.9		
17	27 Sept.	21.5		
18	27 Sept.	20.9		
19	27 Sept.	21.8		
20	27 Sept.	20.8		
21	27 Sept.	22.3		
22	27 Sept.	21.2		
23	27 Sept.	21.2		
24	27 Sept.	22.6		
25	27 Sept.	23.3		
26	27 Sept.	24.7		
27	27 Sept.	22.0		
28	27 Sept.	18.2		
29	27 Sept.	18.9		
30	27 Sept.	19.9	N/A	N/A
31	27 Sept.	Probe Damaged	-	-
31	18 Oct.	20.25	+0.5	20.75
32	17 Oct.	22.8	+0.5	23.3
33	17 Oct.	23.9	+0.5	24.4
34	17 Oct.	21.0	+0.5	21.5
35	17 Oct.	23.35	+0.5	23.85
36	17 Oct.	24.3	+0.5	24.8
37	17 Oct.	23.65	+0.5	24.15
38	18 Oct.	21.8	+0.5	22.3
39	18 Oct.	22.3	+0.5	22.8
40	18 Oct.	20.75	+0.5	21.25
41	17 Oct.	19.8	+0.5	20.3
42	No Station	-	-	-
43	18 Oct.	24.0	+0.5	24.5
44	18 Oct.	23.3	+0.5	23.8
45	18 Oct.	23.3	+0.5	23.8

Table B1. Temperature Probe Data (Cont.)

Probe #	Date of Reading	Measured Temp (^{o}C)	Correction Factor	Corrected Temp (^{o}C)
46	18 Oct.	18.8	+0.5	19.3
47	18 Oct.	19.2	+0.5	19.7
48	18 Oct.	19.95	+0.5	20.45
49	18 Oct.	20.7	+0.5	21.2
50	18 Oct.	20.7	+0.5	21.2
51	18 Oct.	17.15	+0.5	17.65
52	18 Oct.	19.3	+0.5	19.8
53	18 Oct.	18.7	+0.5	19.2
54	18 Oct.	18.75	+0.5	19.25
55	18 Oct.	21.6	+0.5	22.1
56	18 Oct.	22.55	+0.5	23.05
57	18 Oct.	22.75	+0.5	23.25
58	18 Oct.	23.2	+0.5	23.7
59	18 Oct.	23.1	+0.5	23.6
60	18 Oct.	23.6	+0.5	24.1
61	18 Oct.	24.95	+0.5	25.45
62	18 Oct.	21.1	+0.5	21.6
63	18 Oct.	20.2	+0.5	20.7
64	None	None	-	-
65	3 Dec.	16.7	+5.7	22.4
66	3 Dec.	17.7	+5.7	23.4
67	3 Dec.	18.5	+5.7	24.2
68	3 Dec.	17.3	+5.7	23.0
69	3 Dec.	16.8	+5.7	22.5
70	3 Dec.	17.3	+5.7	23.0
71	3 Dec.	16.4	+5.7	22.1
72	3 Dec.	18.5	+5.7	24.2
73	3 Dec.	18.75	+5.7	23.95
74	3 Dec.	17.8	+5.7	23.5
75	3 Dec.	17.0	+5.7	22.7
76	3 Dec.	17.2	+5.7	22.9
77	3 Dec.	17.6	+5.7	23.3
78	3 Dec.	18.3	+5.7	24.0
79	3 Dec.	18.6	+5.7	24.3
80	3 Dec.	15.9	+5.7	21.6
81	4 Dec.	17.95	+5.7	23.65
82	4 Dec.	17.0	+5.7	22.7
83	4 Dec.	17.0	+5.7	22.7
84	4 Dec.	16.5	+5.7	22.2
85	4 Dec.	17.15	+5.7	22.85
86	4 Dec.	17.3	+5.7	23.0
87	4 Dec.	17.9	+5.7	23.6
88	4 Dec.	18.7	+5.7	24.4
89	4 Dec.	17.9	+5.7	23.6
90	4 Dec.	17.5	+5.7	23.2
91	4 Dec.	16.0	+5.7	21.7
92	4 Dec.	17.4	+5.7	23.1
93	4 Dec.	16.4	+5.7	22.1
94	4 Dec.	16.9	+5.7	22.6
95	4 Dec.	17.4	+5.7	23.1

for this problem, selected probes were left undisturbed from one measurement period to the next. For example, probe number 2 was implanted at the inception of the two-meter temperature study and removed at the study's termination. Probe number 7 was in place for the first two measurement periods. Based on the recorded temperature differences between the probes remaining in place over time and the probes removed early, correction factors were calculated to permit comparison of all data. The modified data appear as corrected temperatures in Table B1.

This technique was systematically applied to the Hawthorne study area. Probes were first placed at intervals of one per square mile. The distribution of temperatures recorded during the initial phase provided a basis for selection of detailed study areas. Probe spacings as small as 250 meters (820 ft) were employed during the detailed study. This methodology established the presence of two regions of elevated temperature indicated by the stippled patterns in Figure B5. In addition, a trend of increasing temperatures exists, progressing from the southern extent of the study area to the central portion. Temperatures recorded in the immediate vicinity of a hot well in the study area (El Capitan Well - 99°C) were some of the highest measured during the study.

Isotherm configurations interpreted from temperature probe data are presented in Figures B6 and B7. Regions depicted in these figures approximately correspond to those delineated by stippling in Figure B4. The accuracy of interpreted isotherms is questionable in the western region (fig. B6). Patterns do not conform to linear arrangements which are usually associated with the upward flow of thermal fluids along fault zones. Instead, the data suggest broad zones with a limited temperature variation (3°C) and localized, irregularly shaped highs. In some locations within this region, measured temperatures varied abruptly over small distances. These characteristics make proper placement of isotherms problematical even with probe spacings as small as 250 m

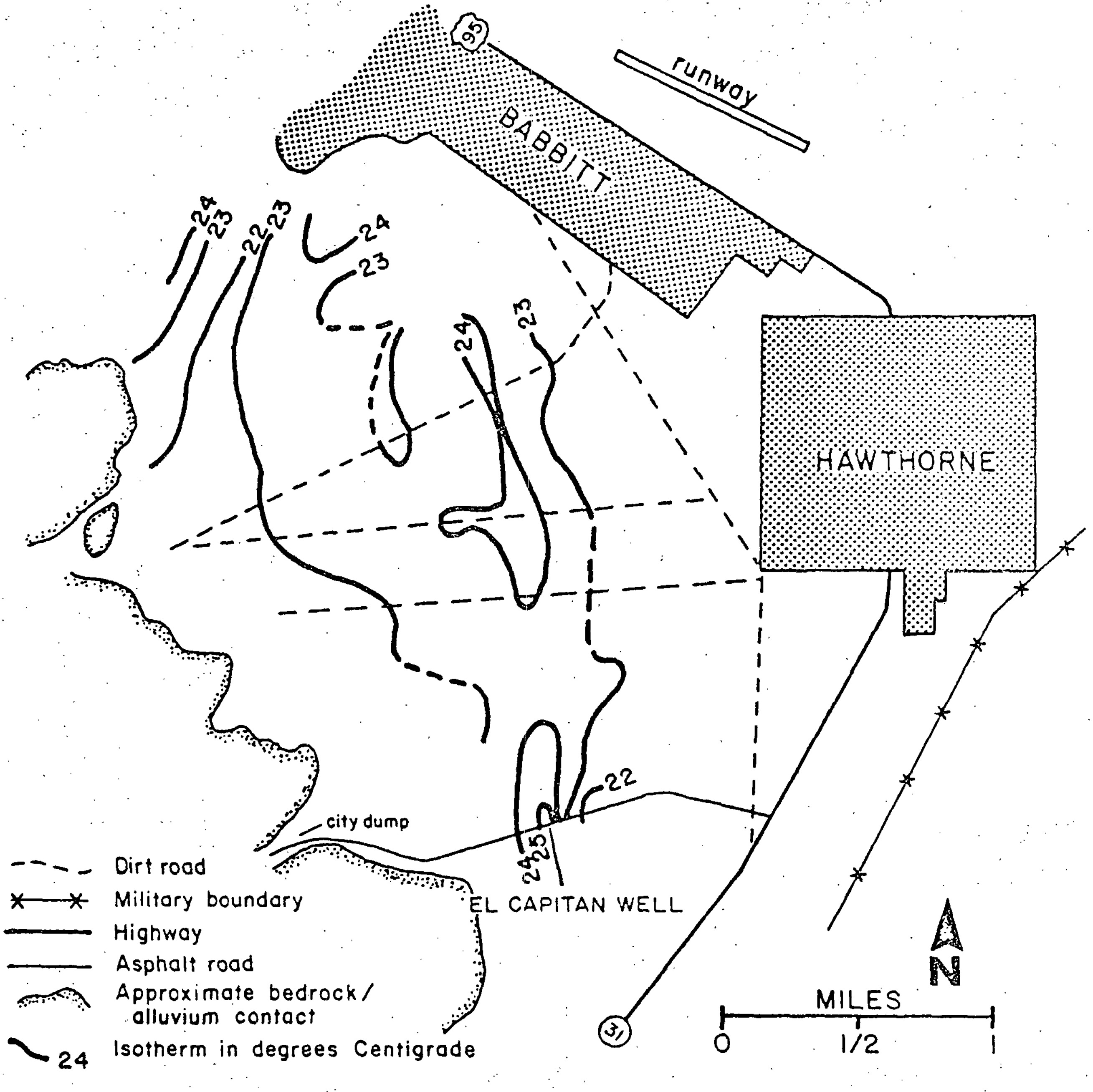


Figure B6. Possible isotherm configurations at a depth of two meters, see text for detail.

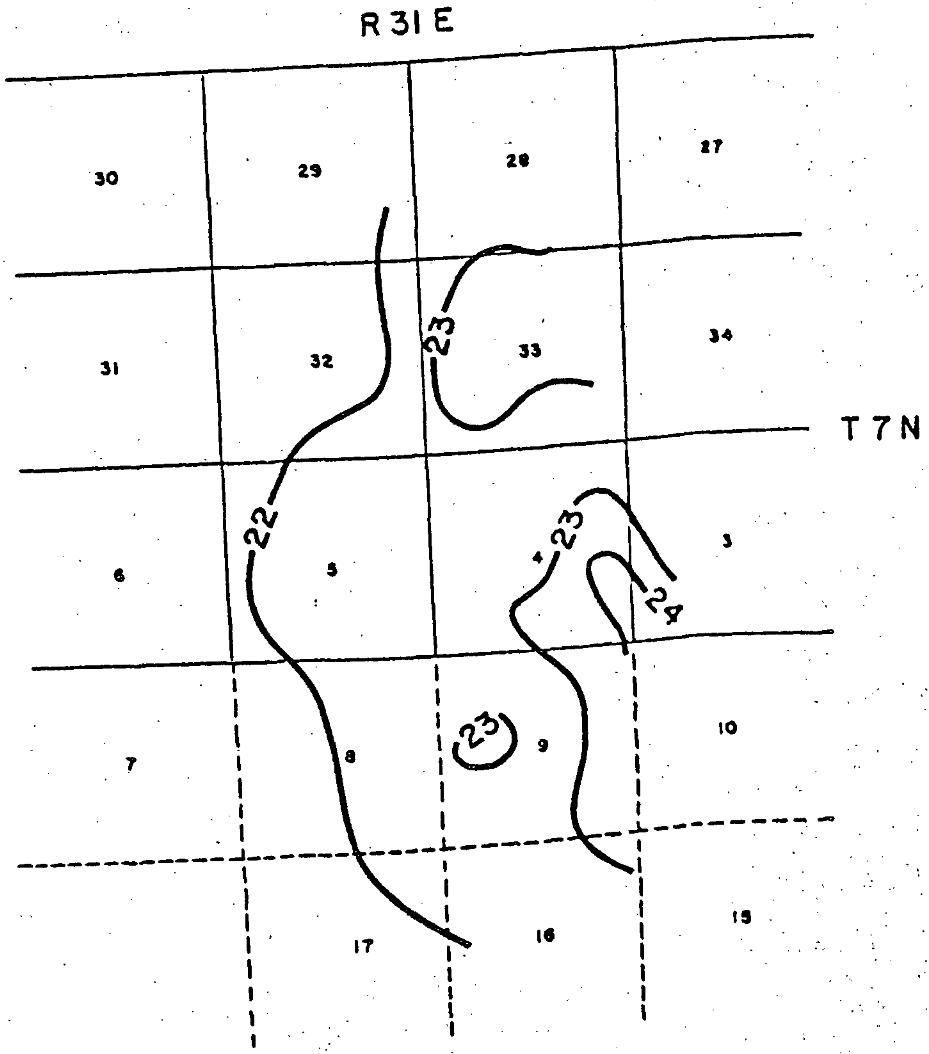


Figure B7 Two-meter isotherm configuration interpreted from two-meter depth temperature probe study, eastern segment of study area.

(820 ft). The irregular shape and localization of areas with elevated temperatures may be partially due to interpretation. It should also be noted that the accuracy of individual probes is ±0.5°C.

Figure B7 details the inferred two-meter depth isotherms for the eastern region. Characteristics of the patterns here are similar to those observed to the west. Well-defined linears are absent, and isolated irregularly-shaped zones of elevated temperature are once again present. Abrupt temperature variations over short distances were not detected, however, sampling-density was lower for this area.

Despite limitations outlined above, the shallow-depth temperature probe study clearly delimits regions of elevated temperature in the study area. This is particularly meaningful in Hawthorne since there are no surface manifestations of geothermal resources. The selection of test hole drill sites was largely based upon data obtained from this technique.

PHOTO IMAGERY

Imagery used to examine the Hawthorne study area ranged in scale from 1:24,000 to 1:250,000. Two forms of 1:250,000 scale color imagery, false color computer-enhanced Landsat, and natural color Skylab were employed. Black and white photography included U-2, Army Map Service Missions, and a low sun-angle mission flown for our study. Scales of the three sets of photographs are 1:120,000, 1:60,000 and 1:24,000, respectively. The smaller scale photographs were used to search for regional structural features and to examine the areal distribution of rock types. Fault locations and linear and curvilinear features were investigated on the larger scale imagery.

Examination of Skylab and Landsat photographs reveals only a limited

number of regional-scale linear features surrounding the study area. The most conspicuous linear alignment occurs along the trend of the Walker Lane (Locke and others, 1940) and is particularly apparent in the Gillis and Gabbs Valley ranges. Range front boundaries on the eastern slope of the Wassuk Range are also clearly visible. An analysis of lineaments (Rowa
concluded that there are few regional features in the
there was little correlation between photo image linea
Steward and Carlson (1974). Ekren and others (1976) d
regional linear which they name the Pancake Range Line
verses the Garfield Flat and Whiskey Flat and passes s
area. The feature is actually an S-shaped curvilinear
fore, does not present a single orientation. Late Tert
trusive rocks may mask the presence of regional-scale l

Low sun-angle photography was flown over most of the area bounded by U.S. Highway 95 to the north and a topographic rise separating Walker Lake Basin from Whiskey Flat to the south. The Garfield Hills and Wassuk Range are the eastern and western boundaries, respectively. This imagery provided the greatest amount of detailed information on the location and direction of offset along faults, as well as the nature and orientation of other features in the area.

Linear and curvilinear features interpreted from low sun-angle photographs are shown in Figure B8. The majority of these linears represent traces of faults or suspected faults; however, some depict drainage paths or topographic features which do not appear to be directly related to faulting. All features appear to fall into one of three general orientations: a NW-SE trend defined by the bounding faults of the eastern flank of the Wassuk Range and other

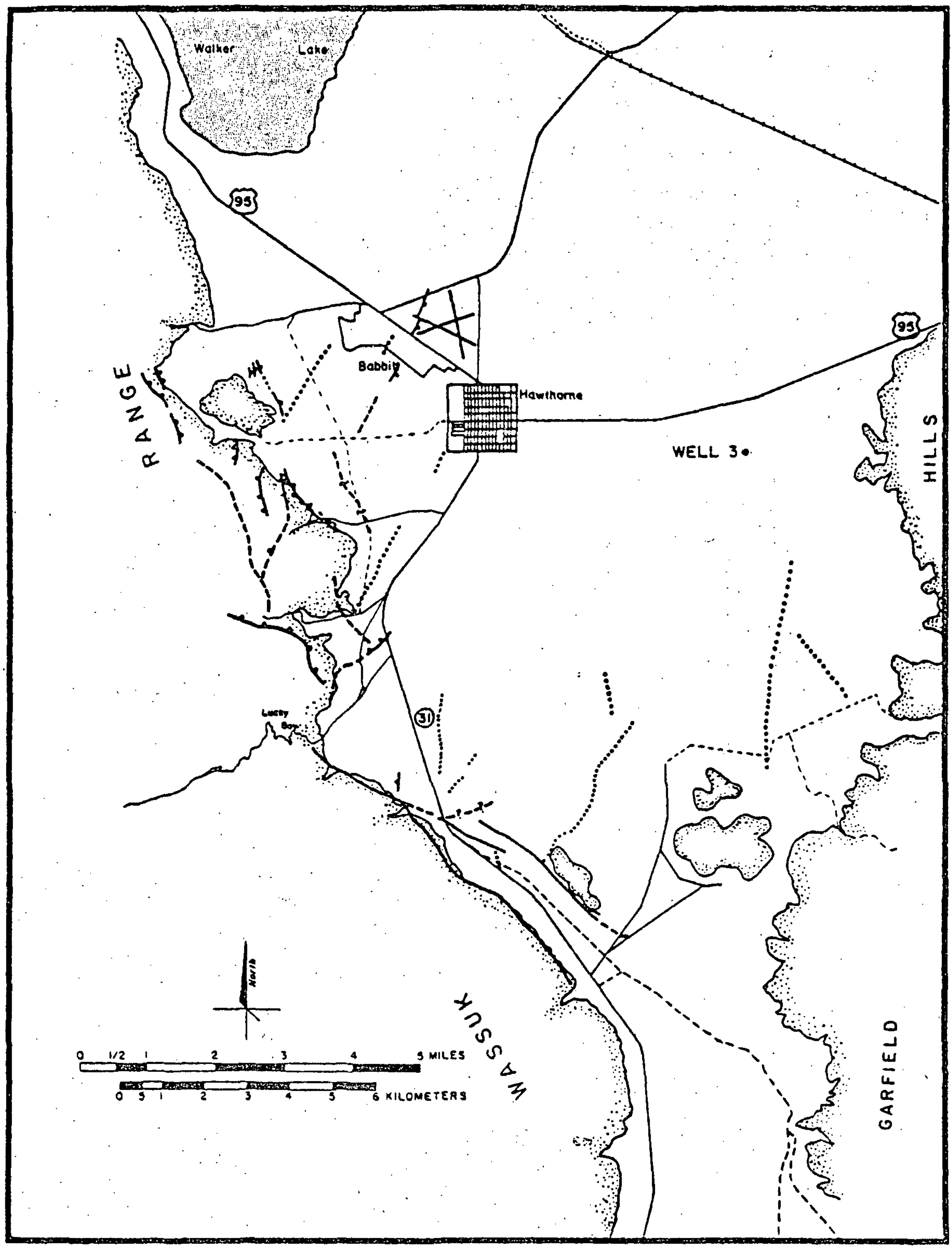


Figure B8. Linear and curvilinear features interpreted from low sun-angle photography in the Hawthorne study area.

subparallel faults; a NE-SW attitude exhibited by faults and drainages in the valley's western area; and a N-S textural grain represented in the south-central portion of the valley. Range front fault traces and escarpments are notably absent in alluvium along the western front of the Garfield Hills.

The eastern frontal zone of the Wassuk Range exhibits well-defined fault traces unlike the western front of the Garfield Hills. These faults are both present in bedrock and alluvium. There are good examples of scarps in alluvium in the region between the mouth of Cat Creek and the airfield runways east of Babbitt (figs. B9, B10). It is likely that some movement has taken place following the last high stand of Lake Lahontan approximately 12,000 years B.P., since some of these scarps lie below this level. Fault scarps are not co-located with wells containing thermal water with one exception where the well was deliberately sited along the fault trace.

A large number of faults in bedrock and alluvium is present along the Wassuk front approximately three miles west of Hawthorne. A complex of horsts and grabens appears to be present within this zone. Faults with blocks down-thrown toward the range and the valley are a phenomenon also observed in the vicinity of Powell Canyon (Ross, 1961, p. 56).

U-2 and AMS photography provided little additional information. In certain instances, 1:60,000 scale AMS imagery aided in delineating contacts between certain rock units.

TEMPERATURE PROFILING OF WELLS

Measurements of temperature as a function of depth were completed in four wells in the Walker Lake Basin. Two profiles were taken from existing holes at the Army Ammunition Plant, and the remaining pair was acquired from geothermal test wells. A third profile in one of the Army Plant wells was abandoned when

Figure B9. Fault scarps in alluvium west of Hawthorne; star indicates location of test well HHT-1.

Figure B10. Fault scarps bounding the eastern front of the Wassuk Range west of Hawthorne.

the probe became entangled. Data from the two thermal wells formerly on Navy land are presented in Table B2. Fluids in both wells are essentially isothermal and are around the same temperature. These holes are separated by a distance of nearly 11 km (7 mi) and are located near opposite sides of the Walker Lake Basin (fig. B11, HAAP5 and HAAP 3).

Two geothermal test wells drilled and cased with three-inch diameter threaded pipe were filled with water for the purpose of temperature profiling. Their designations are HHT-1 and HHT-2; their locations are shown in Figure B11. Leaks developed at threaded pipe couplings causing water loss. At HHT-1 which is drilled to a total depth of 255 m (800 ft), temperature profiling was limited to the interval between approximately 73 m (240 ft) and TD. Only the bottom 17 m (55 ft) of the 120-meter (395 ft) HHT-2 contained fluid at the time of profiling.

Three separate temperature profiles were completed on test well HHT-1. The first was performed one week after well completion and is labeled "23 April 81" in Figure B12. Three intervals, each with a lower gradient than the overlying interval, were found at 82-98 m (270-320 ft), 98-122 m (320-400 ft), and 122-146 m (400-480 ft). From 146-177m (480-580 ft) temperatures were essentially isothermal and attained the maximum temperature recorded in the well. A distinct temperature reversal occurs below 177 m (580 ft). Although the temperature probe was calibrated before use, it would not stabilize for some readings due to a leak in the cable shield. In spite of these problems it is believed that temperatures recorded during profiling were within ±5 degrees centigrade of those actually present. Furthermore, the shape of the curve is accurate.

A second set of profiles was performed on HHT-1 three weeks following completion. The first of these labeled "6 May 18" in Figure B11 represents conditions in the well before the addition of 416 liters (110 gal) of water.

Table B2. Temperature data from Hawthorne Army Ammunition Plant, wells 3 and 5.

HAAP well No. 3* 4 Dec. 1980

Depth in ft.	Temperature °C
260	39.7
280	40.0
300	40.1
320	40.0
340	39.9
360	40.1
380	40.2
400	40.3
420	40.3
440	40.3
452	40.3

*well pumped immediately prior to measurement

HAAP well No. 5 2 Dec. 1980

Depth in ft.	Temperature °C
210	40.3
220	40.5
240	40.7
260	40.8
280	40.8
300	40.8
320	40.8
340	40.8
360	40.8
380	40.8
400	40.8

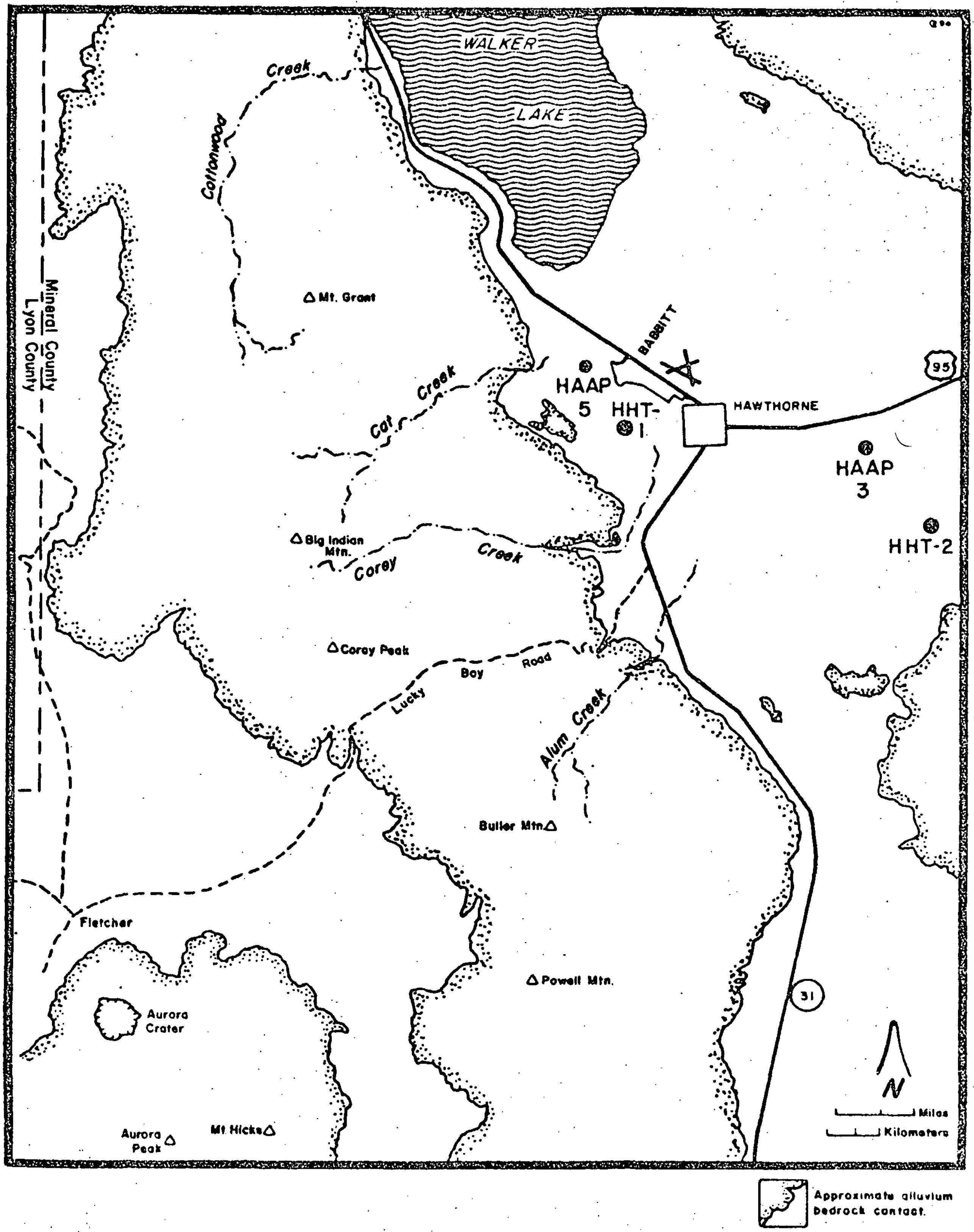


Figure B11. Location of wells profiled for temperature.

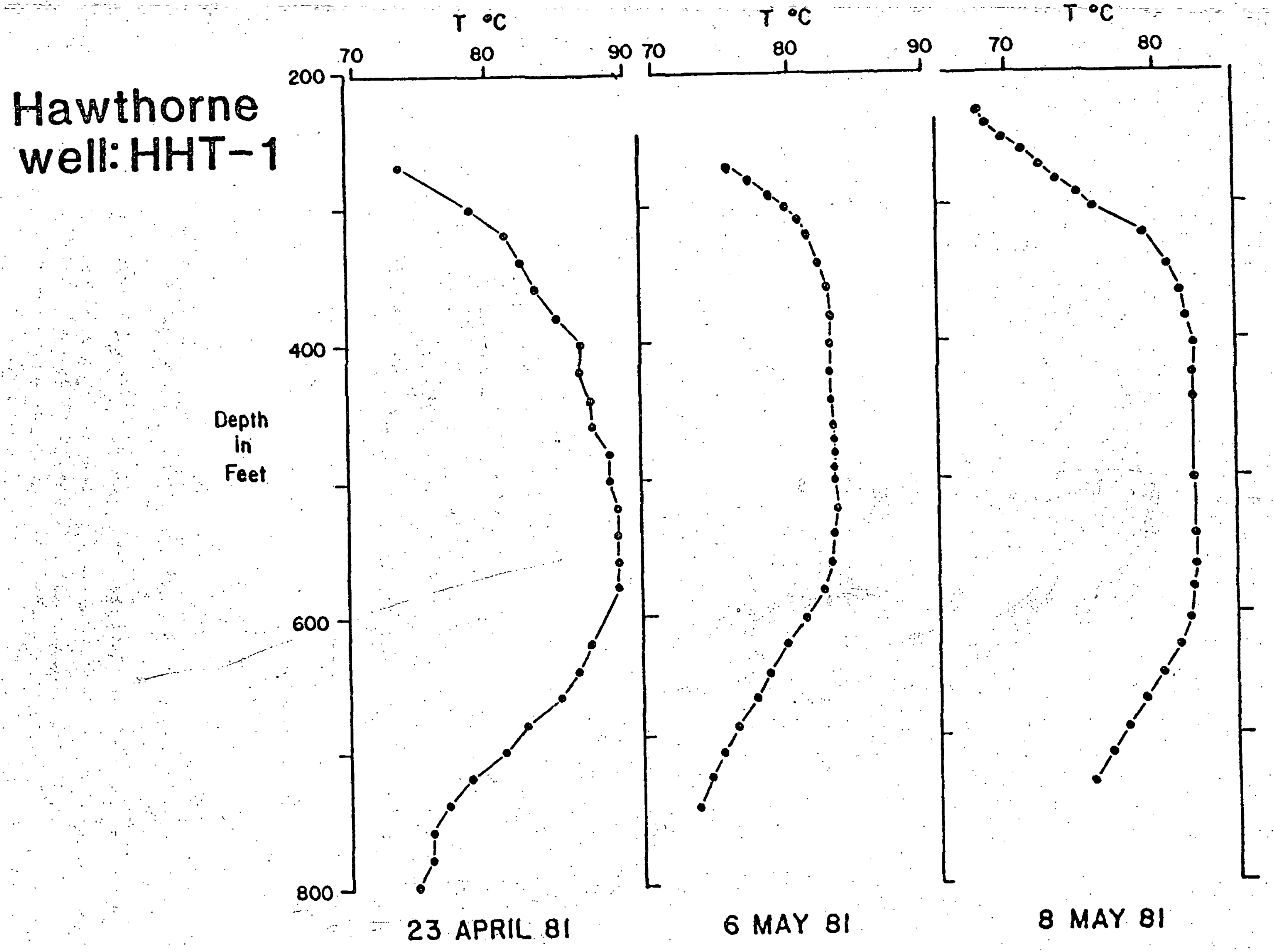


Figure B12. Temperature profiles of test well HHT-1.

A second curve labeled "8 May 81" was drawn from data collected 24 hours after the addition of water. The level of well water was increased only 11m (36 ft) after this addition.

General characteristics of all three profiles are similar. Each has a zone of positive gradient, an isothermal layer, and a segment in which the temperature decreases with depth. There are, however, certain notable differences. Isothermal zones of the second and third curves are approximately twice the thickness of that encountered during the first measurement period. Gradients in the zones where temperature decreases with increasing depth are lower for the 6-May and 8-May curves. Maximum temperatures encountered during the first profile are 6°C greater than those of subsequent measurements. And lastly, the shape of the profile above isothermal layers of the latter curves is convex as opposed to the linear-to-concave shape of the same region of the 23 April plot.

A combination of factors is probably responsible for changes between the profiling periods. Poor transfer between thermal and non-thermal fluids and the well casing is perhaps the most influential factor. HHT-1 was drilled using mud to prevent caving of alluvial materials. During drilling, the mud became noticeably thicker due to high temperatures. It is likely that the mud formed a relatively impermeable wall cake after standing since it was not flushed before insertion of the casing. The steel casing is a second important factor. If exposed to a hot zone such as that which appears to be present in HHT-1, the casing tends to conduct heat in both directions, particularly if external thermal sources or sinks were insulated by the mud cake suggested above. Thickness of the isothermal layer tends to increase and the magnitude of the negative gradient decreases. These changes follow the pattern observed in HHT-1 over time. Other influential factors include the upward migration of heat via well-bore convection, and the lack of cold shallow groundwater as noted during the drilling of HHT-1. The lack of cool groundwaters at levels less than 63 m (200 ft) is documented in well logs from the surrounding area.

One profile was completed on test hole HHT-2, and the data are plotted in Figure B13. Water loss problems were severe at this site limiting the length of the profile. Little can be deduced about temperature-depth relationships at this location due to limited data. Because the temperature is over 60°C at less than 122 m (400 ft) below the surface and the gradient is definitely positive, deeper drilling at this site may be warranted.

SOIL-MERCURY SURVEY

Sixty-four soil samples were collected for analysis of soil-mercury content in the Hawthorne study area. Samples were collected from an average depth of 25 cm (2 ft) and dried at 30°C (54°F) before being analyzed on a gold-film apparatus. The analytical results are listed in Table B3. Collection locations and sample numbers used in the table correspond directly to those used for two-meter temperature probes (see figs. B4 and B5).

Variations in the data are due to several factors. The highest measured value, 127 ppb, is suspect. It occurred at sample location 30, an area of possible contamination. Also, errors associated with operation of the analytical apparatus, and sample in homogeneities limit precision at any selected site to ±15%. If the 127 ppb value is excluded based on contamination, the statistical parameters for the remaining data are $\bar{X} = 18$ ppb, $\sigma = 8$ ppb. Since 3σ represents 99.7% of the area under a normal distribution curve, it is reasonable to adopt the mean plus or minus 3σ as the bounds for "normal" values. Using this formula and excluding the previously discussed high value, 43 ppb becomes the minimum for anomalous points.

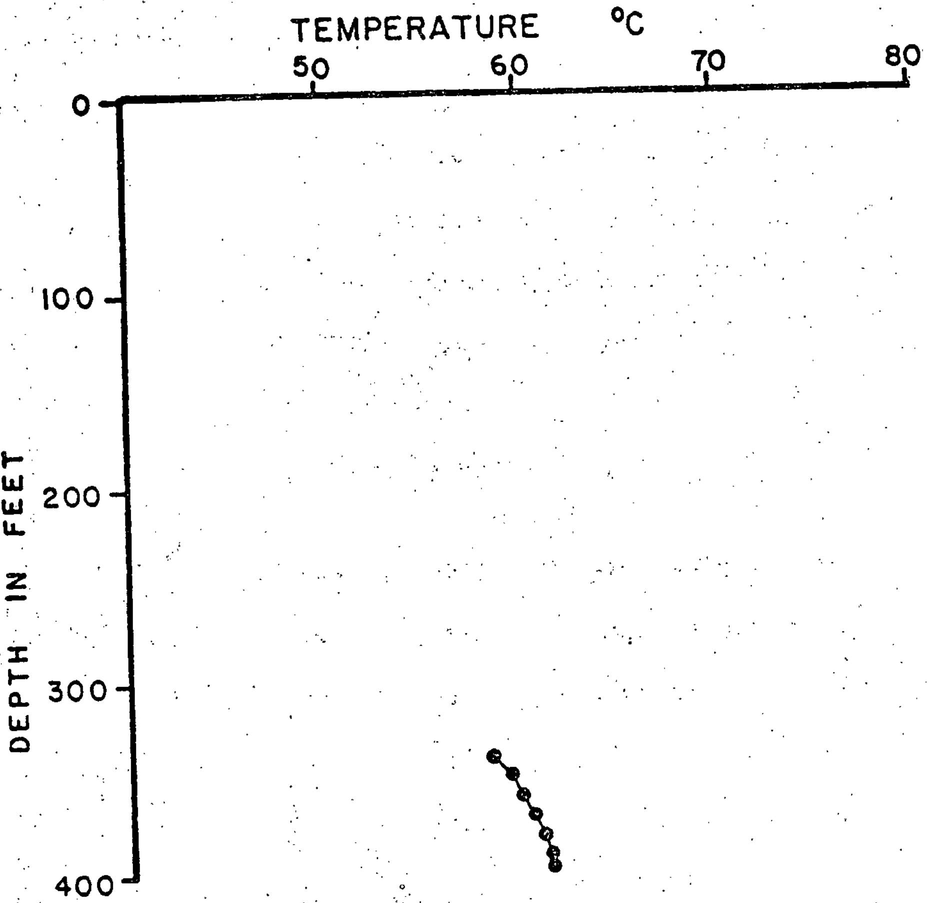


Figure B13. Temperature-depth relationships in test hole HHT-2, profiled May 7, 1981.

Table B3. Results of Hawthorne soil-mercury survey.

Sample #	Mercury Conc. (ppb)	Sample #	Mercury Conc. (ppb)
1	38	28	15
2	18	29	13
3	22	30	127
4	19	31	16
5	38	36	14
6	22	38	16
7	13	39	28
8	16	40	24
9	23	41	19
10	17	43	18
11	20	44	14
12	19	45	15
13	16	46	19
14	17	47	20
15	14	49	12
16	16	51	9
17	12	52	18
18	12	53	11
19	13	54	21
20	13	55	17
21	24	56	27
23	58	57	12
24	14	58	11
25	13	59	14
26	18	60	15
27	15	63	17
		64	20

The soil-mercury data confirm that this technique is not useful for resource exploration in the Hawthorne study area. Only one data point is considered both valid and anomalous (fig. B14). Rather than suggesting trends which define regional anomalies, the data reflect a relatively narrow range of background values. In addition, neither the anomalous point or even the high "normal" values are co-located with points of elevated temperature recorded during the shallow-depth temperature probe study. Finally, data gathered on a small grid spacing, approximately 244 m (800 ft) in the immediate vicinity of the 99° C El Capitan well, are essentially all at background levels. One of the lowest recorded values occurs adjacent to the well.

FLUID GEOCHEMISTRY

Fifteen water samples were collected and analyzed for bulk chemistry and oxygen and hydrogen-stable light isotopic composition to help explain the nature of thermal fluids and flow and/or recharge paths. Results of the analyses for major and minor dissolved constituents are presented in Table B4. Data reported for samples taken during the present study are designated using the letters "HAW" followed by a one or two digit number. Data taken from literature sources are indicated by other appropriate alphanumeric combinations.

Two problems are associated with the analyses results for the HAW series. Silica concentrations reported by the analysts of the HAW series are consistently lower than those reported in the literature although both samples were taken from the same fluid source. For example, two measurements of silica made on fluid extracted from the same location, HAW-6, in May and August, 1980 revealed values of 78 and 74 ppm, respectively. Our sample taken in October, 1980 contained only 40.8 ppm according to the results reported to us. The problem again is apparent when comparing reported values in the two SiO_2

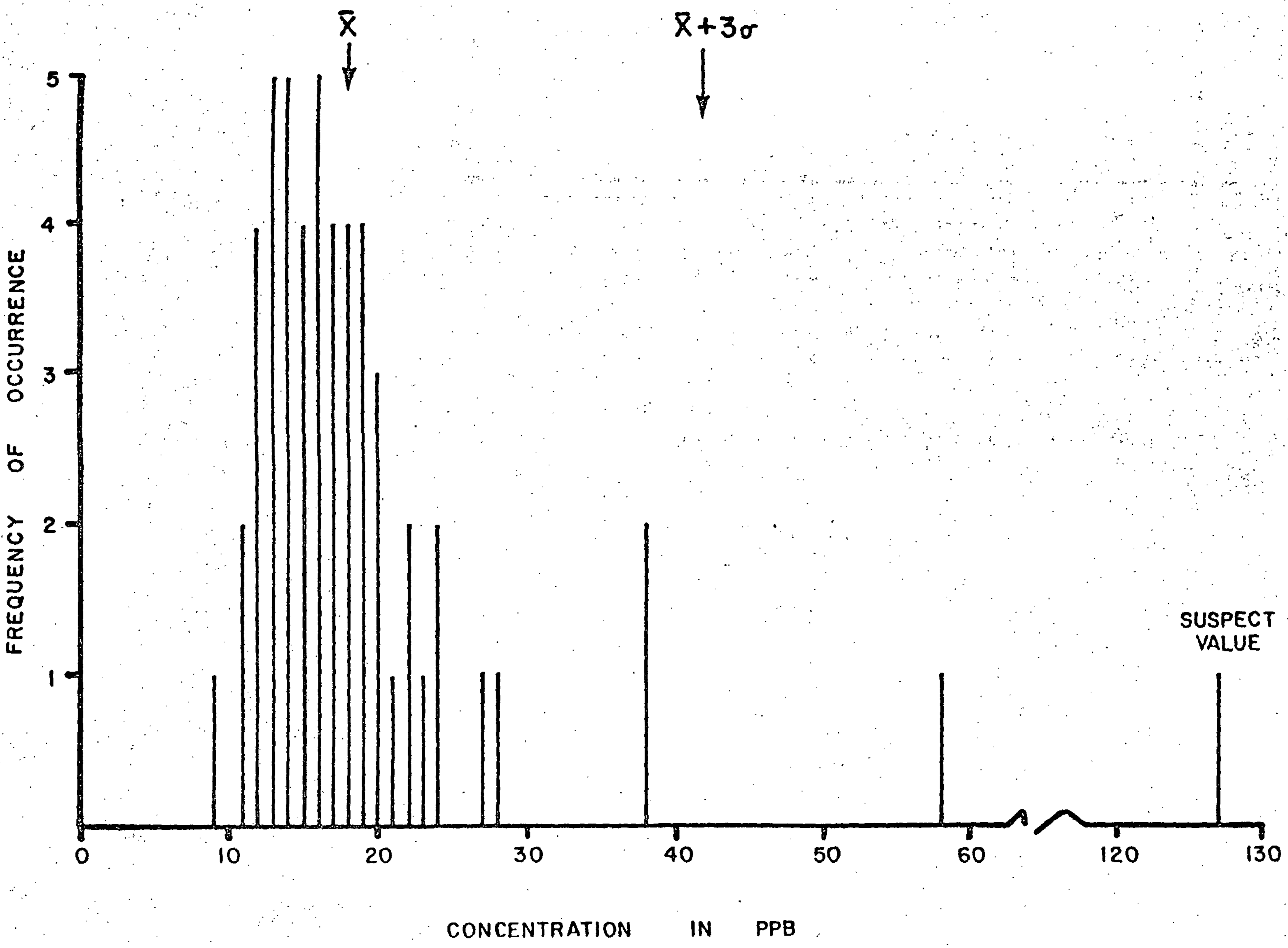


Figure B14. Frequency of occurrence vs. soil-mercury content in ppb.

Table B4. Fluid Chemistry in the Hawthorne study area.

Sample Designation	Temp. C°	pH	Ca	Mg	Na	K	Li	Sr	Al	Cl	SO_4	CO_3	HCO_3	NO_3	F	B	SiO_2 This Study	SiO_2 Other Study	Cation/ Anions (Equiv.)
HAW-1 (HAAP #1)	42/51	7.4	66.9	4.33	185	8	0.17	1.03	<0.3	68.9	384	0	43.9	0.24	1.96	1.12	18.8	31.8‡	1.12
HAW-2 (HAAP #5)	41	7.4	42.9	0.41	276	10	0.60	1.11	<0.3	89.2	491	0	51.2	0.10	7.48	2.27	32.3	50HAAP	1.10
HAW-3 (HAAP #6)	/24	7.3	87.0	17.9	165	7	0.04	0.555	<0.3	85.8	369	0	85.4	0.41	1.61	1.59	13.9	23.8‡	1.17
HAW-4 (HAAP #3)	40.8/	8.1	42.3	4.74	242	16	0.22	0.426	<0.3	105	350	0	117	<0.05	5.15	2.79	38.1	54‡	1.11
HAW-5 (HAAP #4)	/23	7.5	128	26.3	95	6	0.03	0.160	<0.3	95.5	325	0	100	0.96	0.747	1.40	16.3	30‡	1.15
HAW-6 (El Cap)	97/	7.4	40.4	0.08	260	11	0.50	1.46	<0.3	85.2	436	0	95.2	<0.05	7.28	2.19	40.8	76DRI	1.02
HAW-7 (Alum Cr)	6.5/	3.2	186	91.3	26	3	0.06	0.553	109	6.8	1390	0	0	1.34	1.89	0.112	39.0		1.02
HAW-8 (Cottonwood Cr) 4800'	9.7/	7.4	40.2	8.06	18	2	<0.01	0.208	<0.3	6.0	34.1	0	109.8	<0.05	0.315	0.049	14.2		1.29
HAW-9 (Cottonwood Cr) 7500'	6.9/	7.5	35.1	6.85	12	1	<0.01	0.126	<0.3	3.63	12.0	0	100	<0.05	0.097	0.036	10.9		1.42
HAW-10 (Cottonwood Cr) 9000'	3.1/	7.3	28.6	6.81	9	2	<0.01	0.140	<0.3	3.06	4.51	0	102.5	1.15	0.085	0.027	15.4	39HAAP	1.20
HAW-12 (Coreyville)	5.7/	7.1	24.9	4.13	13	3	<0.01	0.170	<0.3	5.88	10.2	0	90.3	<0.05	0.092	0.041	12.4		1.19

Table B4. Fluid chemistry in the Hawthorne study area (Cont.)

Sample Designation	Temp. C°	pH	Ca	Mg	Na	K	Li	Sr	Al	Cl	SO_4	CO_3	HCO_3	NO_3	F	B	SiO_2 This Study	SiO_2 Other Study	Cation/ Anions (Equiv.)
HAW-13 (Cottonwood Spr)	14.7/	7.9	160	27.8	69	6	0.02	0.957	<0.3	45.8	177	0	390.4	<0.05	0.710	0.131	18.5		1.17
HAW-14 (HUD 5)	35.0/	7.4	99.4	13.4	82	6	0.02	0.987	<0.3	21.4	272	0	136.6	1.59	0.179	0.103	14.9	25‡	1.14
HAW-15 (Corey Canyon Well)	11.1/	7.5	87.4	14.1	28	4	0.02	0.669	<0.3	16.0	96.9	0	180.6	1.54	0.163	0.067	9.5		1.03
HAW-16 (Walker Warm Spr)	34.5/	7.2	27.9	0.66	212	3	0.40	1.23	<0.3	4.44	68.2	0	43.9	0.18	7.89	1.83	21.3		1.29
BLM* (Whiskey Flat Windmill)	/43	--	6.0	0.9	116		--		--	64	109	9	47	0.1	4.8	--		37	--
6/31 b2 * (Whiskey Flat Irrigation)	/11	8.1	30	13	44		--		--	38	93	0	90	--	--	--		--	--
NAD2‡	/27.5	7.5	82	9.7	187.5	11.9	--	--	--	85.6	405	0	134	--	1.09	--		58.4	--
NAD7‡	/21	8.6	18.2	0.25	135	4.4	--	--	--	60.4	204	0	61	--	3.35	--		136	--
NAD8‡	/26.5	7.4	74	8.4	137.5	7.4	--	--	--	52.9	193	0	259	--	2.85	--		43.9	--

* = Data from Everett, D.E. and Rush, F.E. (1967)
‡ = Data from Bohm, B.W. and Jacobson, R.L. (1977)
HAAP = Data from Hawthorne Army Ammunition Plant records.
DRI = Data from files of Desert Research Institute, University of Nevada System, Reno.

Data preceded by a slash were extracted from a source independent of our work.

columns in Table B4. Lengthy discussions with the analysts together with reanalysis of several samples failed to produce any satisfactory explanation of this problem. Due to this unusual situation, all silica concentrations from our study should be considered suspect.

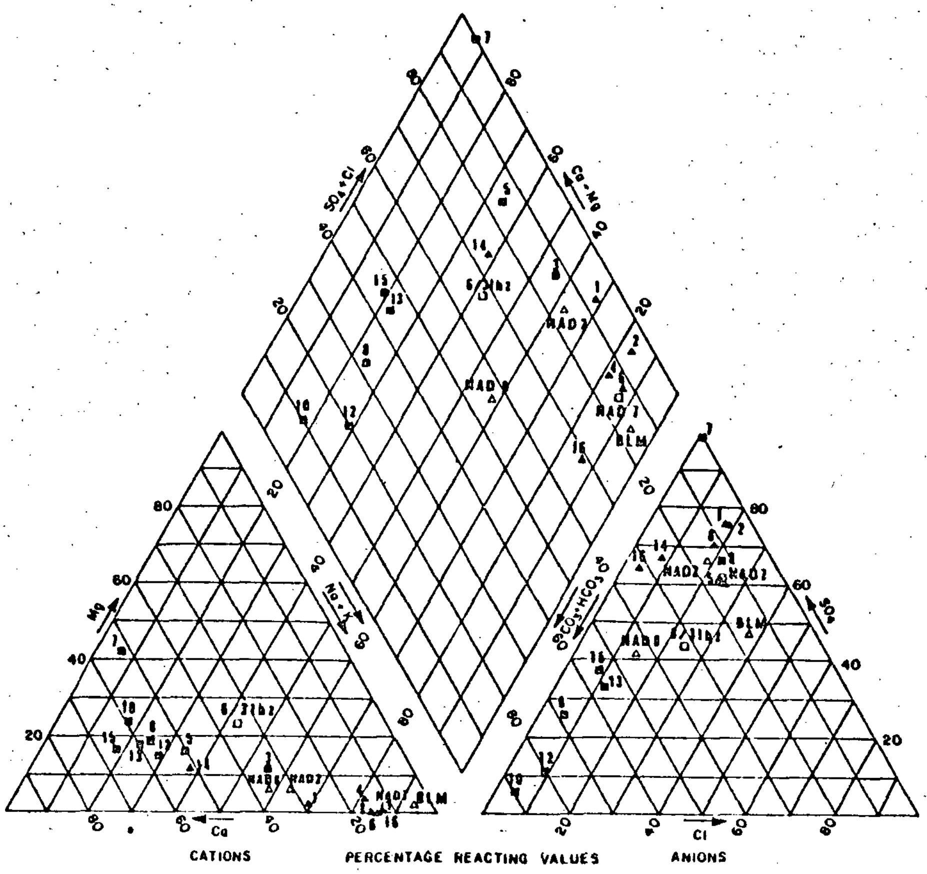
In addition to low silica values, several analyses from the HAW sample series exhibit relatively poor ionic balances. Ordinarily this would imply that an important species was omitted from the analysis suite. However, the analysis suite was comprehensive. The completeness of the analytical suite and the composition of probable source rocks for dissolved constituents argue strongly against omission error. Reanalysis of several samples produced similar values. Literature data describing the same fluid sources indicate lower calcium and higher bicarbonate values than our analyses. Such differences bias the ionic balances toward the cation side, which is also the nature of the imbalance observed in our data.

The sampling program design makes it possible to trace changes in fluid composition moving down the hydrologic gradient. For example, samples HAW-10,HAW-9, HAW-8 were collected at elevations of 2743 m (9000 ft), 2286 m (7500 ft), and 1463 m (4800 ft) along Cottonwood Creek. Data presented in Table B4 indicate that concentrations of most dissolved constituents increase with decreases in elevation for Cottonwood Creek waters. Sample HAW-12 represents meteoric surface water collected near the source of Corey Creek. HAW-15 and HAW-13 are groundwaters from progressively lower elevations. Once again, decreasing elevation corresponds to higher concentrations of dissolved constituents. These trends suggest that significant increases in the concentration of dissolved species take place simply with migration down the hydraulic gradient. It is also generalized from Table B4 that groundwaters contain notably higher levels of dissolved constituents than surface fluids at the same elevation.

Gross chemical characteristics of fluids in the study area and surrounding region are shown in the form of a trilinear plot in Figure B15. The cutoff for designation as a thermal fluid is arbitrarily set at 25°C. Sample compositions tend to fall into one of three groups with respect to cations. One of these assemblages is located near the Na+K apex and includes samples 2, 4, 5, 16, NAD7, and BLM. A second more calcium and magnesium-rich collection is defined by numbers 1, 3, NAD8, and NAD2. And finally, samples 5, 8, 10, 12, 13, 14, and 15 constitute a third group. The latter group consists primarily of cool surface waters and groundwaters. If anions are used for comparison, waters can be described as those which lie above the 50% SO_4 line, and those which fall below it. Decreasing elevation apparently correlates to decreasing relative CO_3 + HCO_3 content as demonstrated by meteoric surface waters (10, 12, 8) and groundwaters that are probably directly related to these surface fluids (13, 15). This phenomenon is also partially a result of increasing SO_4 content as elevation decreases.

The colinear arrangement of selected points in Figure B15 suggests that some water compositions may result from mixing. Samples 1, NAD2 and 8 define one line. In addition to being colinear, the relative spacing of the points and their sequence along the line is maintained in all three segments of the plot. This further substantiates the mixing hypothesis. The same situation also exists for samples 6, NAD8 and 12. A further test of the hypothesis could be made if stable light isotopic data were available for all samples. Unfortunately, samples from sites NAD2 and NAD8 could not be obtained during the study period.

Modified Stiff diagrams provide a method of depicting areal variations of bulk chemistry. This format is used in Figure B16. The shape of the symbols in Figure B16 suggests that certain waters are similar. For example,



1- HAAP well no. 1
2- HAAP well no. 5
3- HAAP well no. 6
4- HAAP well no. 3
5- HAAP well no. 4
6- 11 Cap. well
7- Alum Creek
8- Cottonwood Cr. 4800'
10- Cottonwood Cr. 9000'
12- Coreyville
13- Corey Canyon - Cottonwood Springs
14- HUD well no. 5
15- Corey Canyon well (HUD no. 4 ?)
16- Walker Warm Springs
BLM Whiskey Flat Well
6/31b irrigation well Whiskey Flat
NAD 7
NAD 8
NAD 2

■ COLD (Less than 25 degrees Centigrade)

▲ HOT (Greater than 25 degrees Centigrade)

OPEN TRIANGLES AND SQUARES REPRESENT
DATA EXTRACTED FROM THE LITERATURE.

Figure B15. Chemical characteristics of thermal and non-thermal fluids in the Hawthorne study area. Numbers refer those in Table B4.

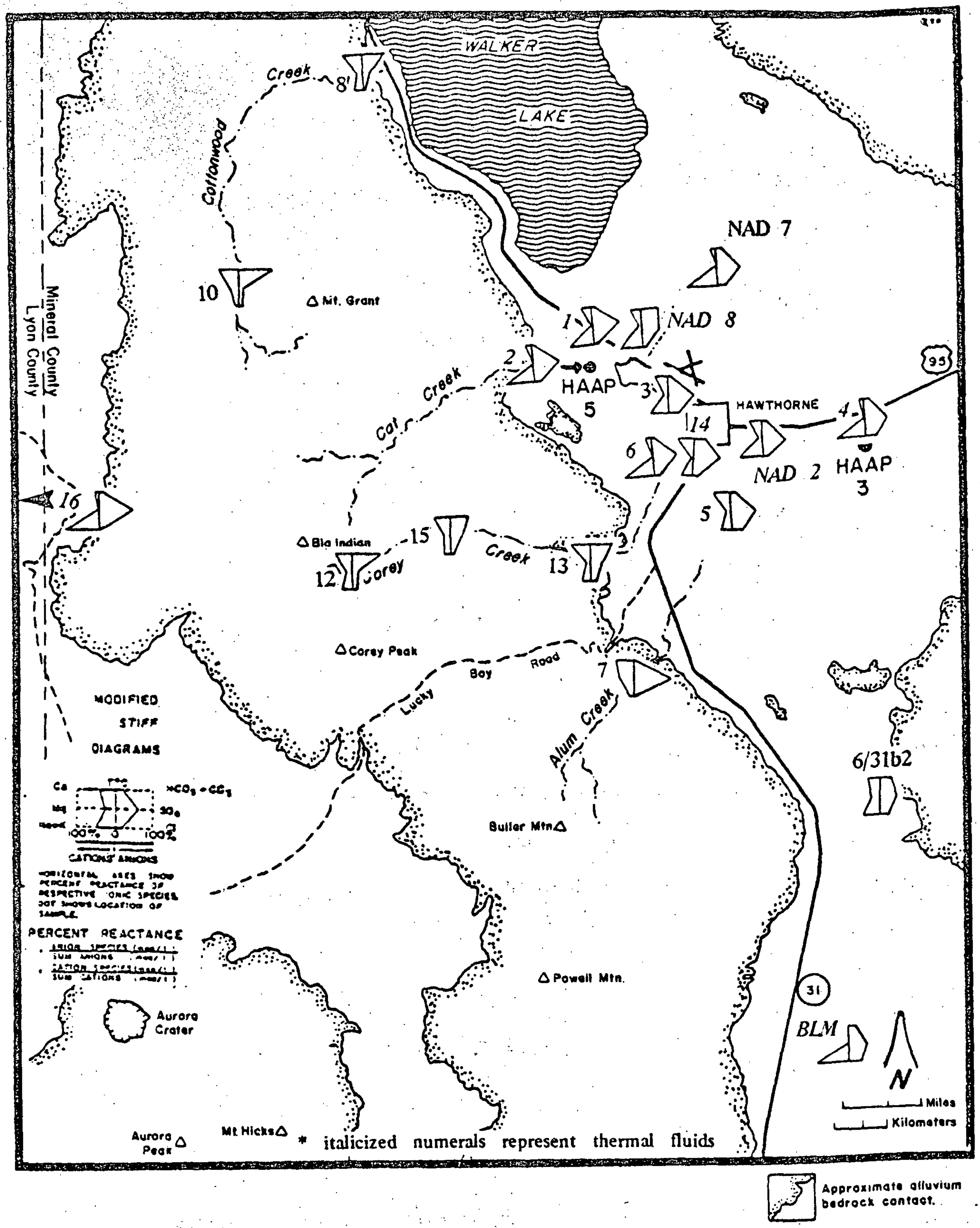


Figure B16. Chemical variations in fluids sampled throughout the Hawthorne study area. Numbers refer to those in Table B4.

samples 2, 4, 6, 16, and NAD7 exhibit marked parities although they are widely spatially distributed. Differences between groundwaters in the Wassuk Range and those of the Whiskey Flat are delineated by comparing symbols 13 and 15 to number 6/31b2. Lastly, the anomalous composition of surface waters in Alum Creek is indicated by symbol 7. Field examination of the rocks through which Alum Creek flows demonstrates that a zone of intense hydrothermal alteration exists near the headwater. Clay minerals are present in large quantities and sulfides are also found in the altered rocks. The low pH (3.2) and high aluminum content of the stream waters probably result from acids released during sulfide weathering.

Trace Constituents

Trace element concentrations may be useful to a limited extent as a tool to distinguish thermal from non-thermal fluids in the Hawthorne area. Concentrations of boron, fluoride, lithium, and strontium are plotted for most samples in Figure B17. Lithium maintains a clear distinction between concentration level in hot versus cold waters. For boron, fluoride and strontium, cold water concentrations are present which approximate or exceed those of hot fluids. Sample 14 is noteworthy because levels of all four trace constituents are comparable to those observed in cold fluids, even though a temperature of 35°C was measured at the sample site.

Stable Light Isotopes

Data on the hydrogen and oxygen stable light isotopic compositions for 15 study area fluids are listed in Table B5 and plotted in Figure B18. The point labeled "3" in Figure B18 exhibits a relatively large ^{18}O shift relative to the meteoric water line and compared to other samples. This shift is not the result of water-rock interaction; it was caused when the sealed

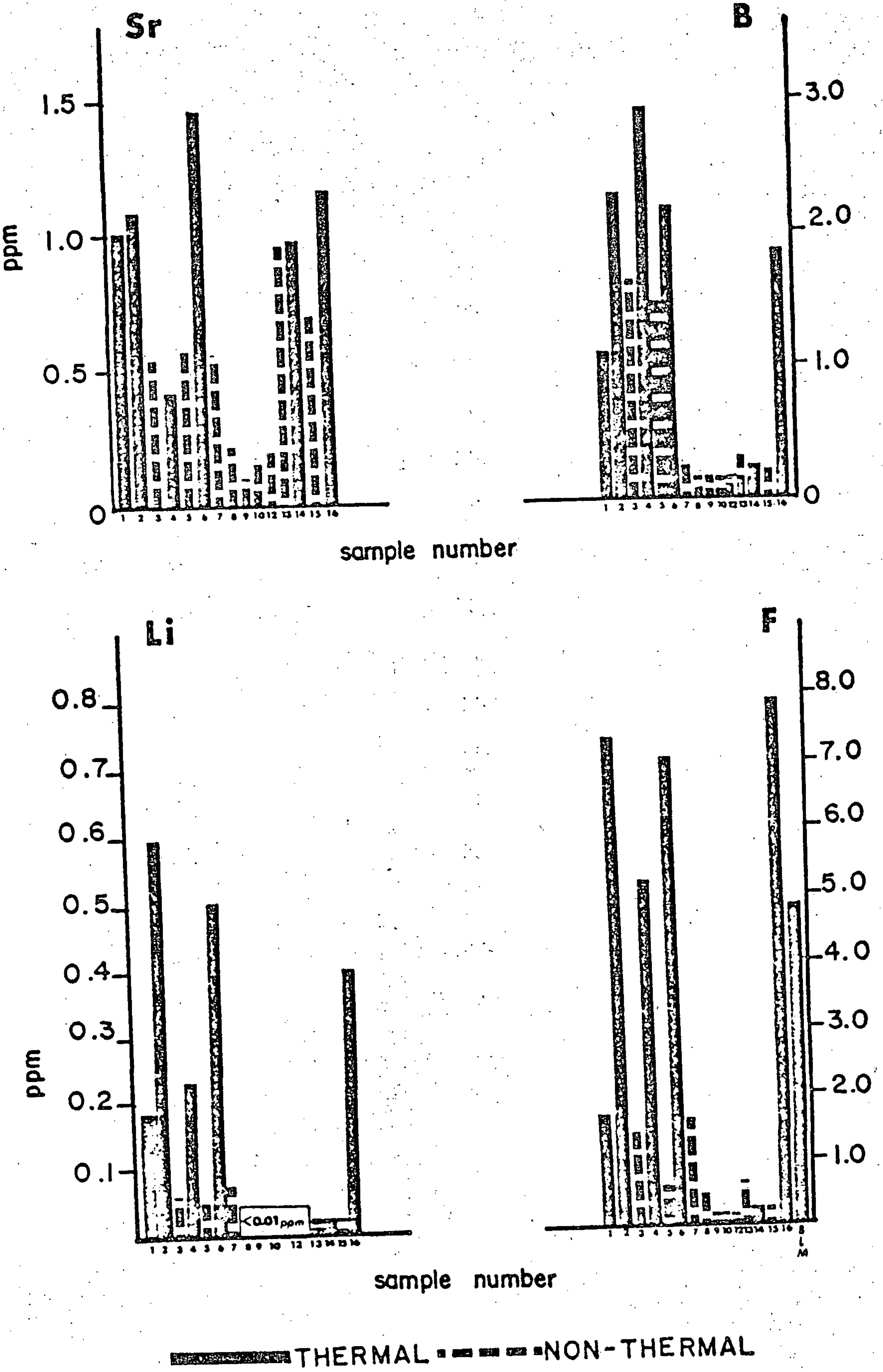


Figure B17. Trace element compositions of samples from the Hawthorne area.

Table B5. RESULTS OF FLUID ISOTOPIC ANALYSIS, HAWTHORNE AREA

SAMPLE DESIGNATION	$\delta^{18}O$ °/oo	δD °/oo
HAW-1	-15.2	-126.
-2	-15.3	-127.
-3	-13.6	-124.
-4	-15.6	-123.
-5	-15.3	-132.
-6	-15.4	-130.
-7	-14.8	-116./-117.*
-8	-15.2	-119.
-9	-15.3/-15.5*	-115.
-10	-16.1	-124.
-11	-16.2	-127.
-12	-15.7	-119.
-13	-15.1	-123.
-14	-15.2	-122.
-15	-15.2	-124.
-16	-16.2	-133./-131.*
-17	-15.8	-124.

* Values separated by slashes represent duplicate analyses of a single sample.

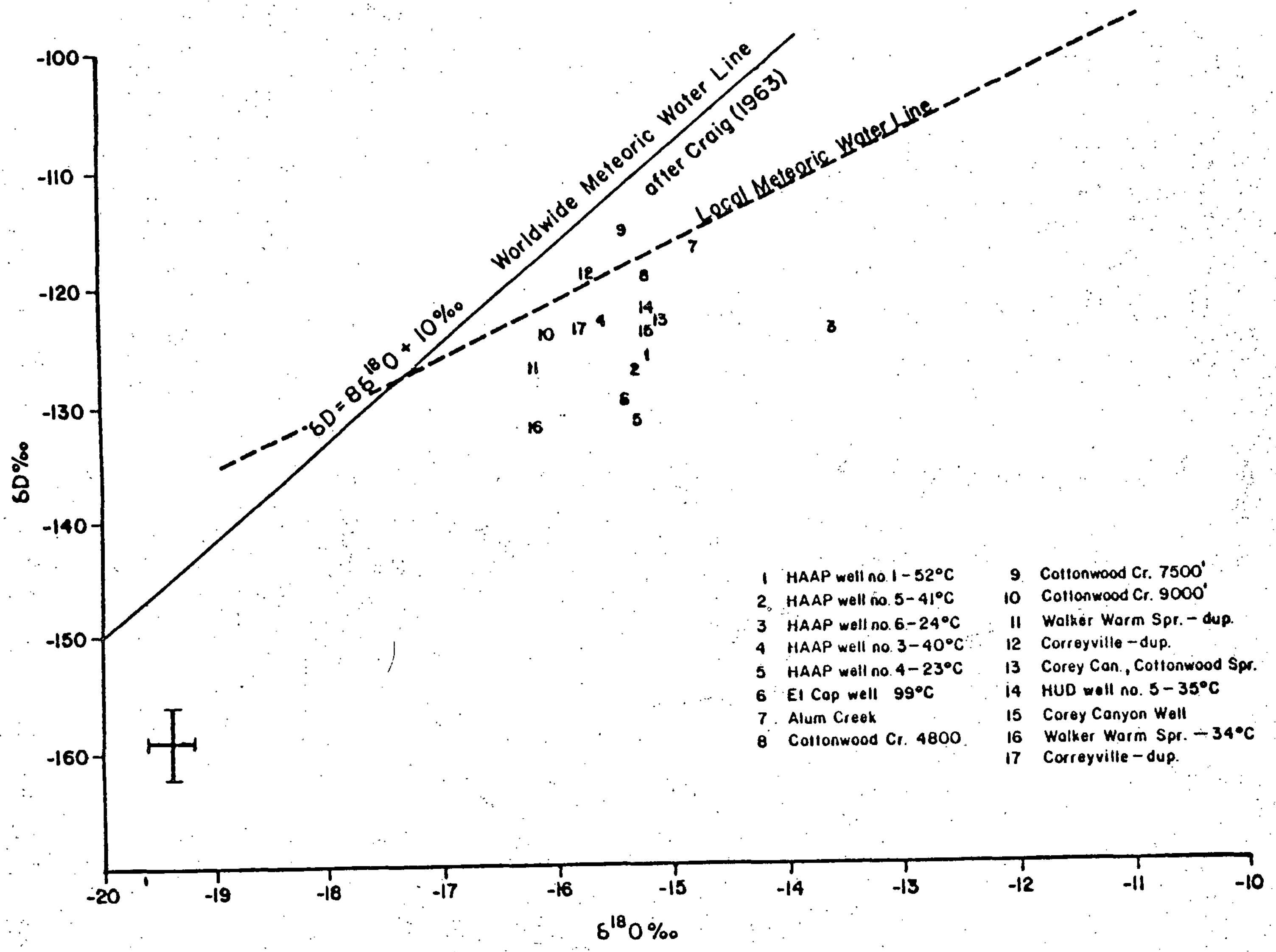


Figure B18. Stable light isotopic composition of Hawthorne area waters - reference SMOW.

sample bottle cracked before analysis and exposed the fluid to atmospheric oxygen. Since the deuterium value should not be significantly affected by this process, it may be used for discussion purposes. Error limits reported by the analysts are ±3°/oo for deuterium and ±0.2°/oo for oxygen. These limits are depicted to scale in Figure B18 as a cross in the lower left-hand corner of the plot.

In general, the location of points in Figure B18 shows a relatively small variation among many of the waters, and the deviation shrinks even further when analytical error limits are considered. Samples 11 and 16, and samples 12 and 17 are analyses of duplicate aliquots collected during a single visit. Waters 7, 8, 9, and 10 are taken from surface streams with 8, 9 and 10 representing different elevations along the same water body. Number 10 was collected at the highest elevation 2744 m (9000 ft) and exhibits the isotopically lightest signature. However, samples 8 and 9 are indistinguishable within analytical error limits even though they differ by approximately 823 m (2700 ft) in collection-point elevation. This situation may reflect the nature of infeed waters at different elevations along the main creek.

Data derived from samples of meteoric surface waters in the Hawthorne area suggest that the slope of the worldwide meteoric water line given by Craig (1963) may not be appropriate for use in this region. A line with a slope calculated from linear regression of the Hawthorne data (samples 7, 8, 9, 10, 12, and 17) is shown in Figure B18 as the "local meteoric water line". This line has a slope approximately equal to 5 indicating that the local system may be a "closed basin" with respect to meteoric water cycles. Craig (1963) found similar slope lines for meteoric waters collected in Africa. The slope is the result of a complex isotopic exchange process that occurs in areas with high evaporation rates. Because Hawthorne area meteoric surface waters can be correlated with such a well-defined line, the "local" line will be used for discussion purposes.

Most of the waters sampled during the study period appear to be isotopically directly related to local meteoric waters of the type sampled in the Wassuk Range (fig. B18). However, a few fluids do stand apart. The isotope data of Table B5 have been plotted in terms of δD-Cl plots (fig. B19) as a means of highlighting the similarities and differences between sampled fluids. One of the most striking features of the plot is the clear distinction in chloride content between various sample groups. Samples 1, 2, 3, 4, 5, and 6 taken from wells drilled in alluvium contain notably higher chloride levels than other fluids. This implies that the well waters obtain chloride from an alluvial source or follow a different recharge path than other area groundwaters. Sample 14 was collected from a well drilled in alluvium located approximately 1 km east of the sample 6 site. Its Cl content places it in a relatively low level group similar to other groundwater (sample 15). These relationships support the hypothesis that different recharge paths are responsible for the high chloride values of samples 1-6. Sample 13, a spring water from Corey Canyon, possesses an intermediate chloride level possibly derived from a recharge path similar to that which feeds the wells of the high chloride group.

Deuterium values for the 15 waters do not appear to be systematically related to chloride content (fig. B19). Changes in the heavy hydrogen isotope can be correlated with variations in recharge elevation. Waters collected from elevations less than 2300 meters (samples 7, 8 and 9) have δD values less than $120^{o}/oo$ and are labeled "group I" in Figure B19. Samples 12, 17 and 10 collected at 2400 and 2700 meters are placed into a second group (II, fig. B19) along with related groundwaters and well waters. An

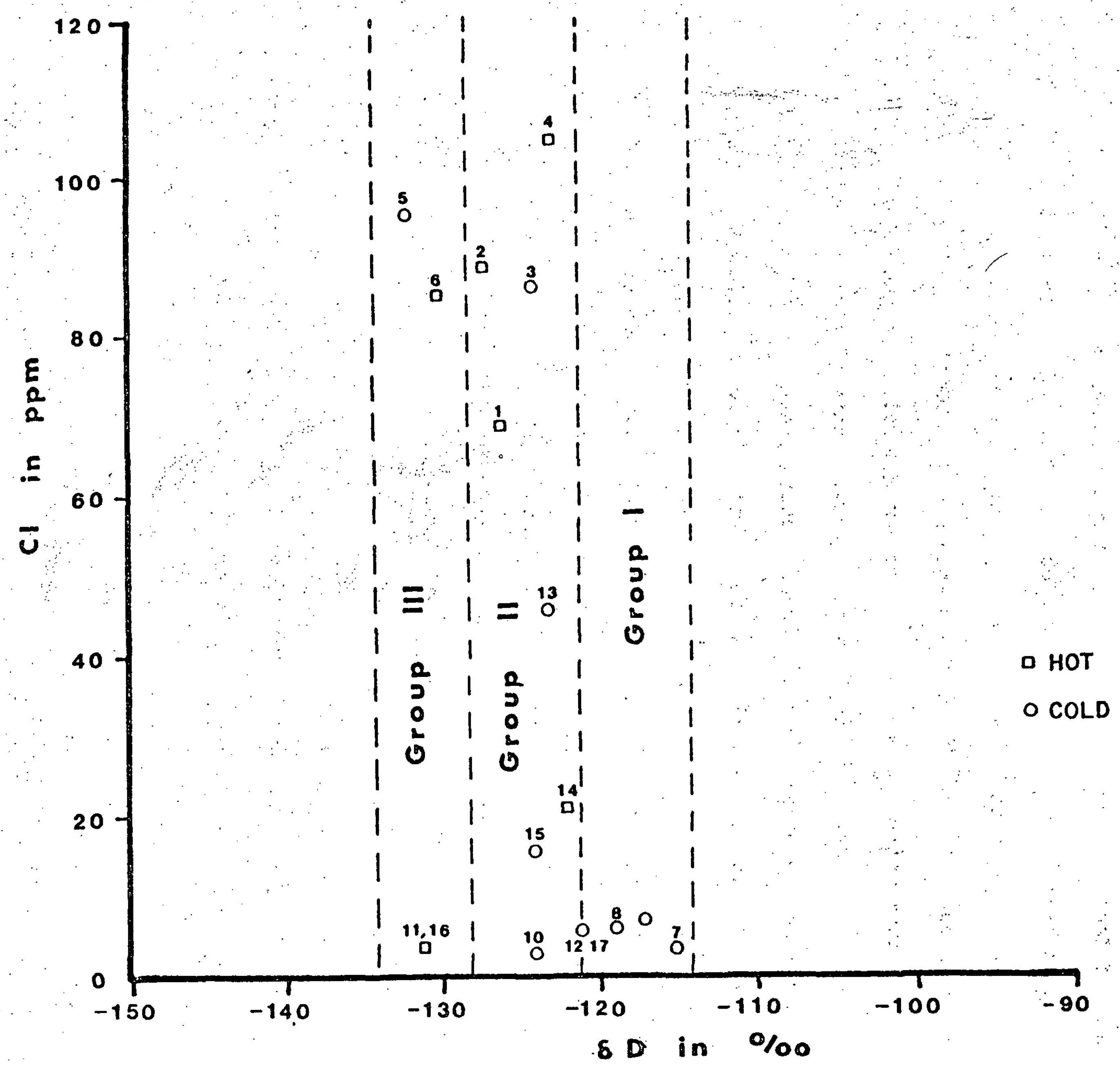


Figure B19. δD-Cl diagram for selected regional fluids.

elevation functional relationship identifies a third group in which isotopically lighter recharge is occurring. Samples 11, 16, 6, and 5 (fig. B19) define this group. Elevations greater than 2700 meters are limited to relatively small portions of the Wassuk Range and the Sierra Nevada which are several kilometers to the west of the study area. Thus, possible recharge regions are areally restricted and may be the same for fluids collected from spatially widely distributed sources. Fluid $^{18}0$ compositons fall into a relatively narrow range spanning only 1.4^{o}/oo (fig. B18). Maximum "oxygen shifts" occur for samples 5 and 6 and are approximately 2.5^{o}/oo if the plotted values are true values. However, if analytical error limits are taken into consideration, the apparent shift may be as little as 1.6^{o}/oo. Sample 6 was collected from a well that produces fluids with a temperature greater than 99°C. Therefore, the "shift" may represent that expected for area thermal fluids. Carbonates are present in the regional section but only to a very limited extent in the vicinity of the Lucky Boy Mine. It is possible, although unlikely, that they contribute to the oxygen "shift" since this would require a recharge path which opposes the regional hydrologic gradient.

There is no clear definition of recharge and/or reservoir processes due to the limited range of isotopic compositions, uncertainties introduced by analytical error limits, and general lack of well-defined trends in isotopic compositions. All fluids appear to be related to meteoric recharge from the Wassuk Range. The limited "oxygen shift" observed in a few fluids could result from short circulation times, relatively low temperature (<150°C) water-rock interaction, high water/rock ratios, or a combination of these factors.

Chemical Geothermometers

Many approaches to predict subsurface fluid temperatures use fluid composition and the temperature dependence of specific reactions. Perhaps the most widely known and universally applied of these chemical geothermometers are those developed by Fournier and Rowe (1966) and Fournier and Truesdell (1973). Values calculated from concentrations of silica, sodium, potassium, and calcium using the equations given by Fournier in Rybach and Muffler (1980, p. 13) are shown for selected study area fluids in Table B6. Historical data for silica were used for computation purposes because of analytical uncertainties previously discussed. Samples HAW-4 and BLM each have two values for the cation geothermometer. Numbers following the slash are computed with a magnesium correction factor after the procedure developed by Fournier and Potter (1979).

The most conspicuous feature of the data in Table B6 is the generally moderate maximum temperatures indicated by both the silica and cation geothermometers. Nine of the ten samples listed have calculated maximum temperatures below 125°C. Sample NAD7 is the only exception. Fluids from this well contain the highest silica level of any recorded for the entire region. Silica concentration in NAD7 is nearly a factor of two greater than that recorded in the hottest well (HAW-6, 99°C) in the area. There are three possible explanations of this phenomenon: the historically reported silica value is erroneous; the silica phase which controls the concentration is not quartz; and the silica value is real and regulated by quartz equilibrium. The first explanation must be considered since no other data are available to substantiate or refute it. Furthermore, samples taken during the study which generated the NAD7 value notably disagree with silica data acquired during other investigations. Table 3

Table B6. Calculated Geothermometers for fluids in the Hawthorne Study Area.

Sample Designator	Quartz No. Steam Loss	Quartz Maximum Steam Loss	Chalcedony	Amorphous Silica	Na-K-Ca	Measured Temperature	-Cristo-Balite	B-Cristo-Balite
HAW-1	81.8	85.2	50.6	-30.9	71.8	51	32.0	-13.5
HAW-2	101.8	102.6	71.9	-14.0	93.6	41	51.4	4.7
HAW-3	70.1	74.9	38.3	-40.6	61.2	24	20.7	-23.9
HAW-4	105.4	105.7	75.8	-10.9	158.8/112*	41	55.0	8.0
HAW-5	79.4	83.1	48.1	-32.9	44.6	23	29.6	-15.6
HAW-6	122.4	120.2	94.2	3.8	97.7	97	71.8	23.9
HAW-14	72.0	76.6	40.3	-39.0	47.8	35	22.5	-22.2
BLM	88.3	90.8	57.4	-25.5	152.5/107*	43	38.2	- 7.7
NAD 2	109.2	108.9	79.8	- 7.7	80.3	28	58.7	11.5
NAD 7	155.1	147.7	130.5	33.2	77.0	21	100.0	55.5
NAD 8	95.8	97.4	65.5	-19.1	64.3	27	45.6	- 0.8

*Na-K-Ca Value with Magnesium Correction of Fournier and Potter (1979) of Bohm and Jacobson (1977) under the heading NAD1 offers an example of this. The contention that quartz does not control silica level in NAD7 is supported by the large discrepancy between the quartz and the cation geothermometer temperatures. No evidence supports the hypothesis that the reported value for NAD7 is real and quartz-controlled.

If the data in Table B6 are considered with respect to agreement between silica and cation geothermometer temperatures, the samples fall into two groups. Group one contains samples HAW-1, HAW-2, HAW-3, HAW-4, and BLM and shows closest agreement between quartz and Na-K-Ca temperatures. Samples HAW-5, HAW-6, HAW-14, NAD2, and NAD8 form a second collection. Comparison of chalcedony and cation numbers yields the smallest disparity between calculated temperatures for the second group. NAD7 does not fall into either assemblage which casts greater doubt on the validity of the reported silica value. The significance of the groups is not clear, however, it is interesting to note that both the chalcedony and cation temperatures for HAW-6 are within 5°C of temperatures measured during pumping at a rate of 2500 l/min (660 gpm). This may suggest that the two groups are the result of different recharge paths, one controlled by chalcedony and another regulated by equilibria with quartz.

Source for $SO_4^=$.

Sulfate is a major dissolved constituent in all study area groundwaters. The highest measured level, 1390 ppm, occurs in a sample collected from Alum Creek. This correlation may indicate the source for the constituent in area waters. Field examination of the rocks through which Alum Creek flows demonstrates that a highly altered zone is present in granitic rocks near the headwater. The zone contains disseminated sulfides. When placed in contact with oxygenated surface waters, these minerals react to produce sulfuric acid and release iron. Rock minerals, particularly feldspars, are then attacked by the acid, releasing aluminum and calcium into the solution. This mechanism accounts for the high calcium, aluminum and sulfate content and low pH observed in Alum Creek waters. Although not shown in Table B4, the iron content of the creek is also at least two orders of magnitude higher than any other water sampled. High iron content further substantiates the oxidation-acid production hypothesis. Similar zones containing sulfides may exist at other locations below the surface in granitic rocks of the Wassuk Range.

Granitic rocks are not the only lithologic type known to contain sulfides. Disseminated pyrite is present in a hand specimen collected near the mouth of North Canyon. Lithologic type is metavolcanic, and the rocks are part of the loosely-defined Excelsior formation discussed by Ross (1961). This rock type is also present over much of the study region as roof pendants on Mesozoic granites. Its presence in the subsurface is unconfirmed although suspected based upon areal distribution.

Buried evaporites or oxidation of H_2S are other possible sources for the sulfates. A gypsum deposit is present along the western slope of the Wassuk Range approximately 48 km (30 mi) north-northwest of Hawthorne. Similar deposits may be present along the recharge path of sampled groundwaters. Calcium-to-sulfate mole ratios calculated from analysis of thermal fluids are notably different from 1. This suggests that gypsum or anhydrite is not likely to be a major source of $SO_4^=$. Hydrogen sulfide is not present as a detectable odor in any sampled fluid. In addition, the pH of all area groundwaters is neutral to basic. Therefore, it is highly unlikely that near-surface oxidation of the gas is a source of sulfate. Deep subsurface sulfate contributions from H_2S oxidation are indeterminate.

GRAVITY SURVEY

A detailed gravity survey using a grid spacing of approximately 0.8 km (0.5 mi) was conducted in the Southern Walker Lake Basin to obtain subsurface structural information. Existing data in the form of a 1:250,000 scale map contoured with a 5 milligal interval (Healey and others, 1980) was not useful. Data from the survey conducted for this project is shown as a complete Bouguer contour map in Figure B20. The subcontractor performing the work failed to tie his work into any known gravity base stations in the area. The values selected for contouring were chosen with regard to the reduction program. These limitations permit only relative changes to be discussed and prohibit correlation with regional absolute gravity data.

Several prominent characteristics are noted on the regional scale map depicted in Figure B20. A strong north-northwesterly linear trend does not parallel the Walker Lane described by Locke and others (1940) and instead, corresponds to the general attitude of the contours seen on the 1:250,000 scale map by Healey and others (1980). It may represent a second or third order phenomenon related to Walker Lane tectonics or the imprint of a later tectonic event upon Walker Lane trends. This trend ends at a point which is the convergence of a south-southwesterly and southeasterly trend located in the southern extent of the study area. The southeasterly direction parallels the Walker Lane. The contours also define a relatively broad region of limited variation and localized highs and low closures. The region of limited variation covers most of the basin. General assymetry of the valley is suggested by steep gradients found along the eastern front of the Wassuk Range which contrast with gradual gradients bounding the western Garfield Hills.

Figure B21 suggests several relationships between thermal well locations, surface fault traces, and subsurface configuration defined by gravity. Fault

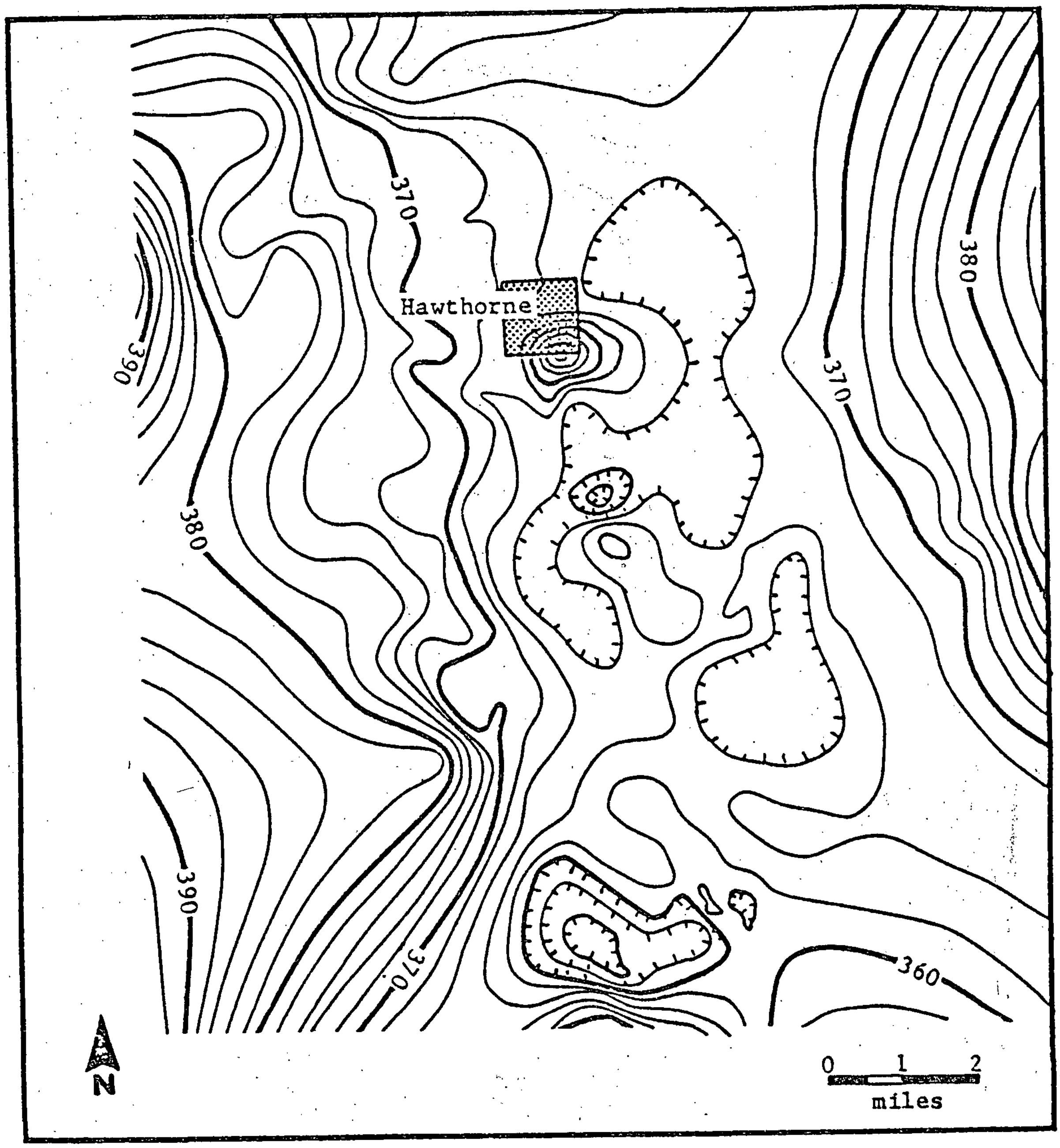


Figure B20. Complete Bouguer gravity map for the Hawthorne study area.

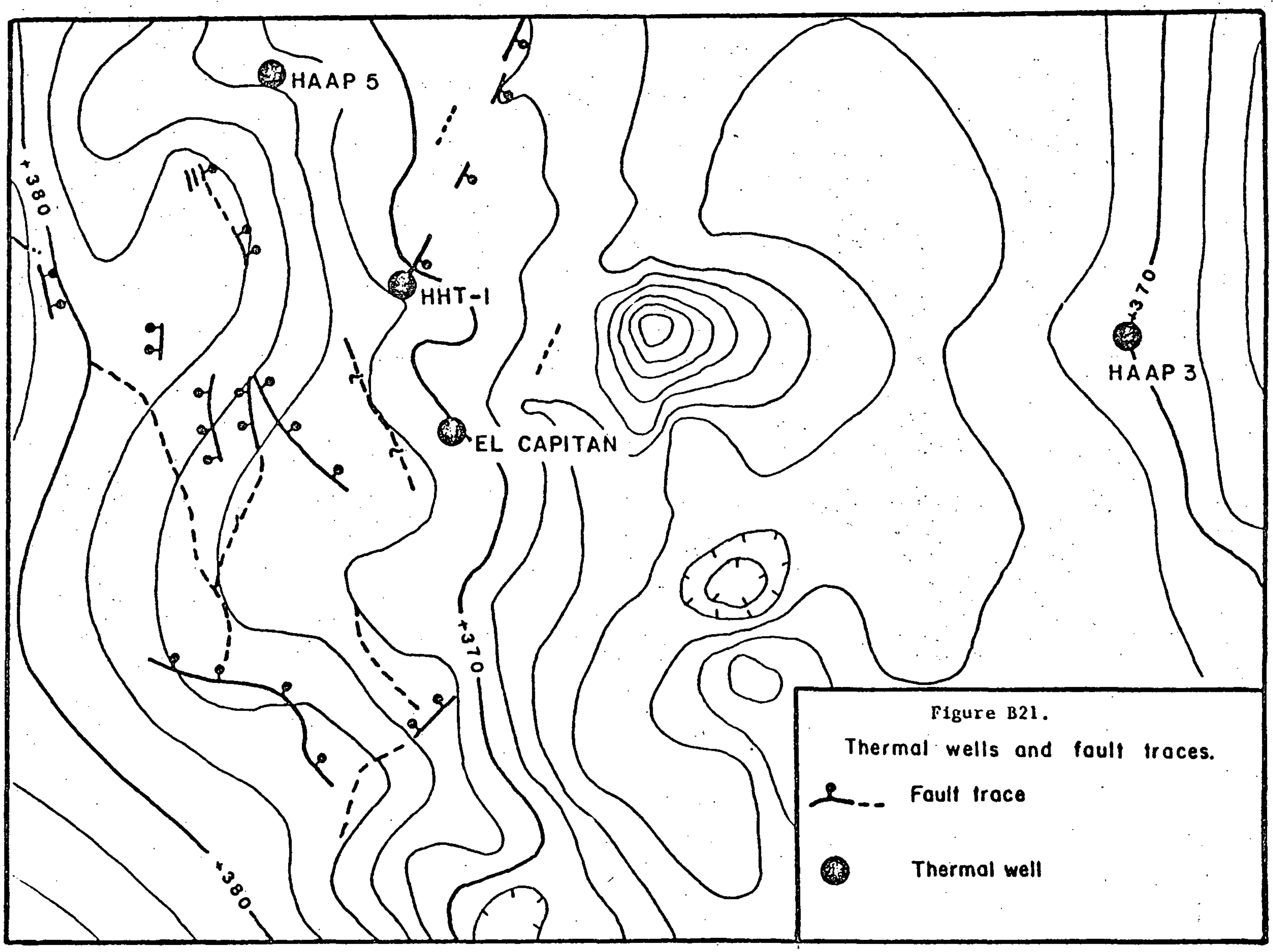


Figure B21.
Thermal wells and fault traces.

and suspected fault traces shown in the figure are those observed on low sun-angle photographs. Although several traces parallel or subparallel gravity contours, others cross gravity lines at angles between 45 and 90 degrees. This suggests that these contours are probably controlled by subsurface topographic changes in bedrock materials as opposed to vertical fault displacement. The hottest test hole, HHT-1, is sited in a location where these circumstances exist. On the other hand, the El Capitan well (99°C) is sited along contours which are subparallel to traces of a fault and a suspected fault. This is in direct opposition to the situation described for HHT-1. Both wells are located in a region of gradual change in gravity between Hawthorne and the steep front of the Wassuk Range. A third well containing thermal fluids is shown in Figure B21 (HAAP #5). It is located in an area where gravity contours have a marked inflection which is not co-located with any surface fault traces. These inflections appear to be correlated with the location of thermal fluids, and are one of the criteria for siting the second test well, HHT-2.

A high closure occurring in the southeast corner of Hawthorne is one of the most curious features on the contour map shown in Figure B21. This feature is unlike any other observed in the region of the gravity survey. A dense object of limited areal extent is inferred. The magnitude of this relative high is equal to values measured at elevations of 1768 m (5800 ft) along the Wassuk front. Possible explanations for the phenomenon include an erosional or tectonic remnant of bedrock, an intrusive igneous body in the valley fill, a buried mafic volcanic center, or densification of allivium by deposition related to hydrothermal activity. A two-meter depth temperature probe implaced near the southeast corner of the city measured a higher temperature than other probes in the area. However, a 183 m (600 ft) city well which is nearly co-located with the center of the gravity high produces cold groundwaters. The relationship of this feature to area geothermal phenomena, if any, is uncertain.

TEST HOLE DRILLING

A total of 366 m (1200 ft) of 15 cm (6 in) hole was allotted for the test hole drilling program in the southern Walker Lake Basin. A variable-depth drilling program was developed based upon the general absence of shallow groundwaters (100 m/328 ft) and the known depth to thermal fluids in the El Capitan well (180 m/590 ft). Under this program, two or three holes would be drilled depending on the temperatures observed during drilling.

The full 244 m (800 ft) length allotted to drilling in the area west of Hawthorne was expended in a single hole. Drilling a 122 m (400 ft) hole near the Garfield Hills used up the remaining footage. Locations of the test holes are NW¼, NE¼, SE¼, Sec. 29, T8N, R30E (HHT-1, 244 m) and SW¼, SE¼, Sec. 4, T7N, R31E (HHT-2, 112 m) (fig. B22).

Site selection involved the following considerations in order of decreasing importance: comparison of data generated from different exploration techniques, land status for acquiring permission to drill, and site accessibility. In choosing a location for test hole HHT-1 a comparison was made between the two-meter isotherm patterns and fault scarps in alluvium west of Hawthorne (fig. B23). An irregular, somewhat linear segment of 24°C line forms an intersection with a fault trace in the alluvium approximately 1.6 km west of the city limit. Chemical similarity of fluids taken from thermal wells was another factor in drill site selection. These parities are shown in Figure B24 by modified Stiff diagram symbols labeled"2" and "6". A simple Bouguer gravity contour map indicating a distinct inflection in gravity contours was also used in the site selection process. Permission

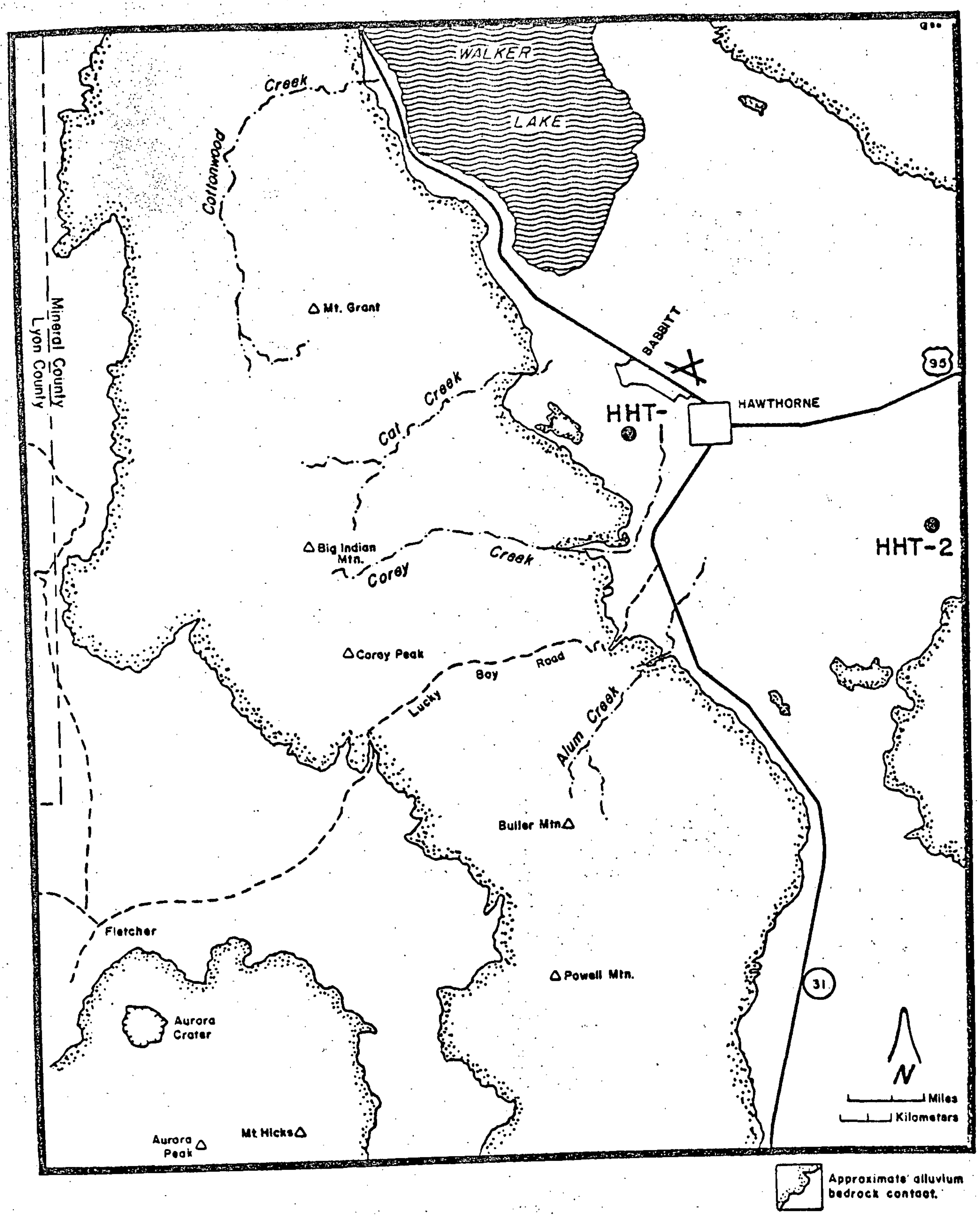


Figure B22. Location of test hole drill sties.

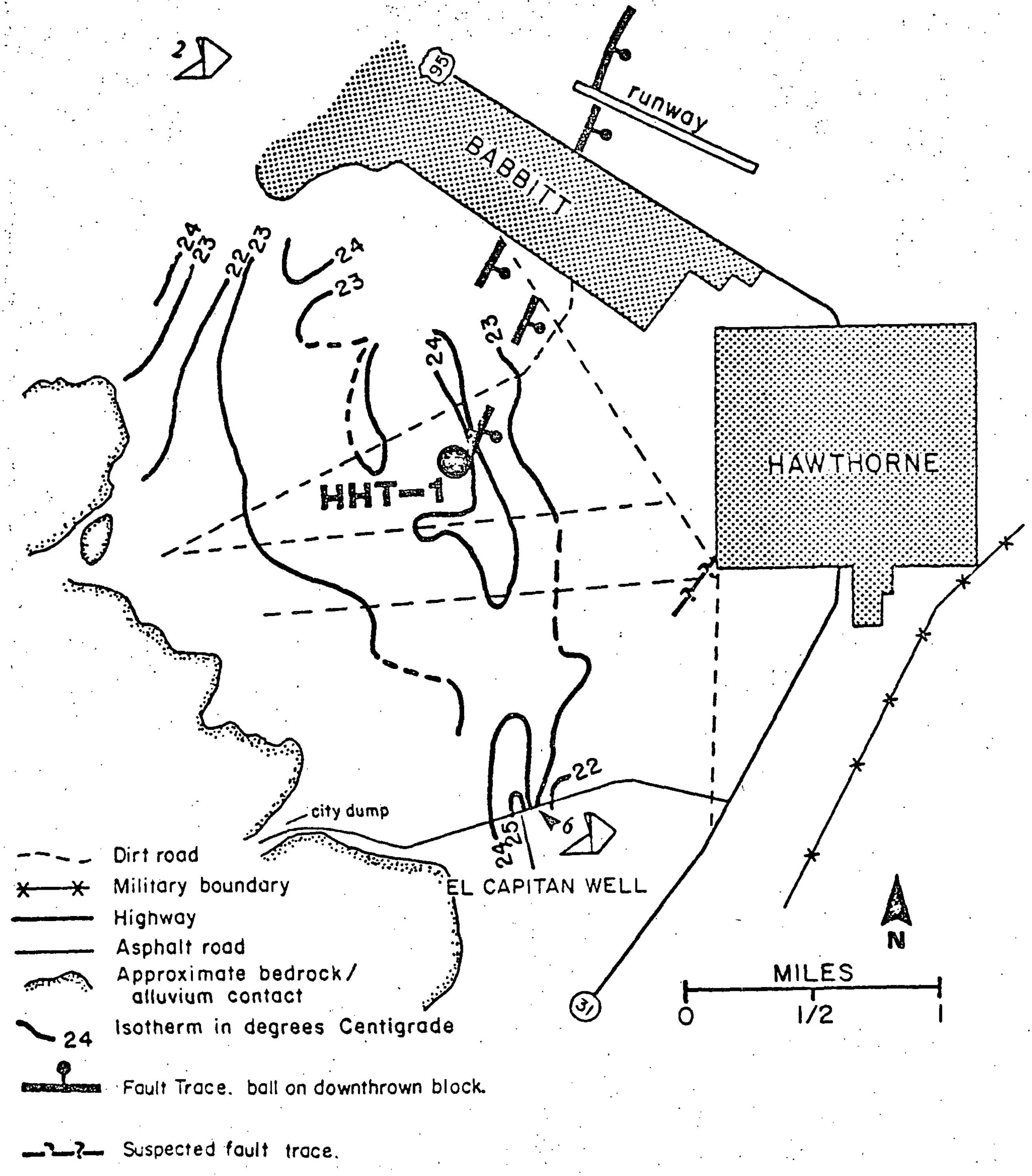


Figure B23. Correlation of isotherm high with fault trace in alluvium.

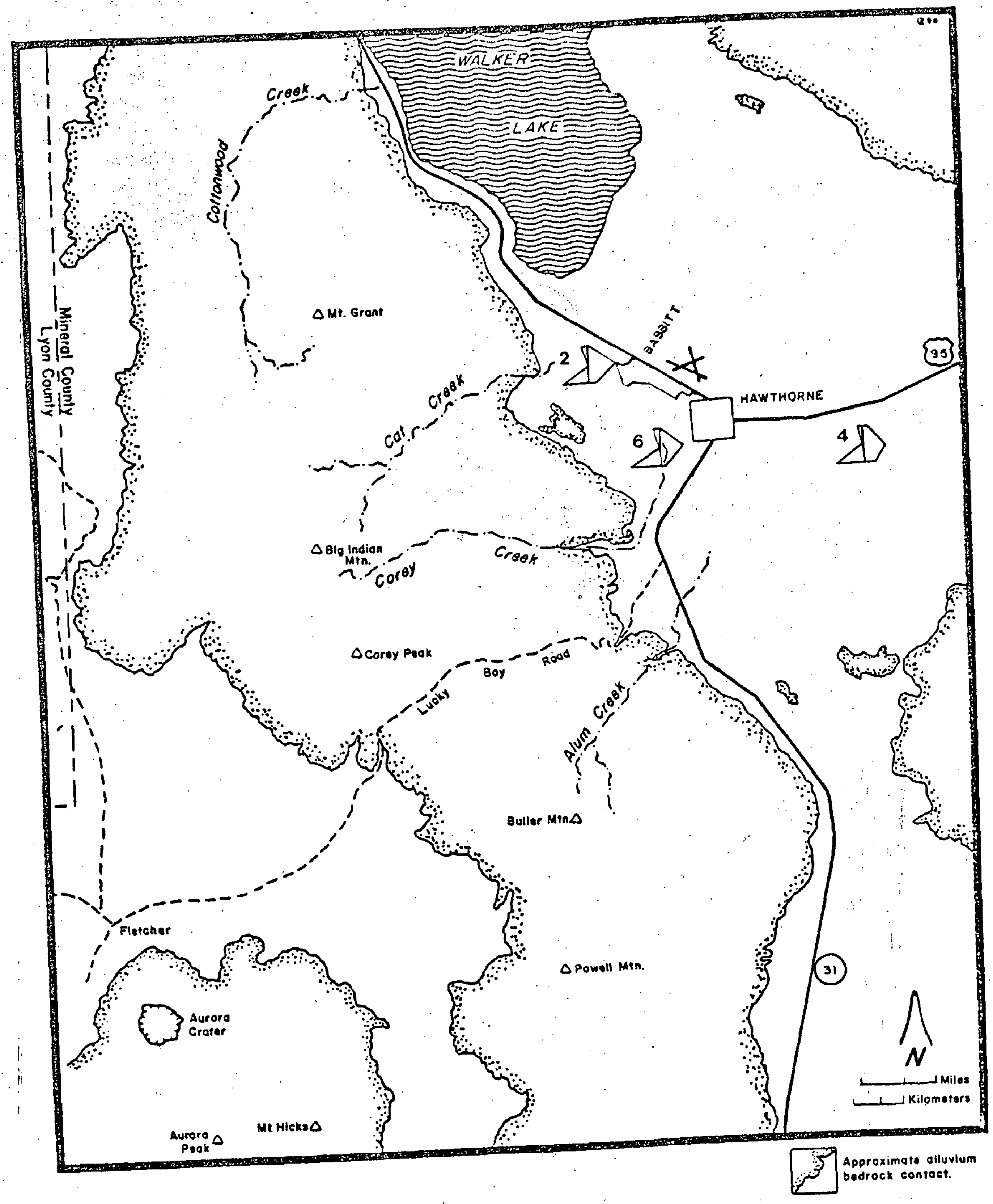


Figure B24. Chemical similarities between thermal wells.

to drill on U.S. Army property was obtained prior to site selection, and a network of dirt roads provided easy access.

Site selection for test hole HHT-2 relied heavily upon two-meter isotherm patterns and marked inflections in the gravity contours. Chemical evidence for a possible thermal fluid source is given by the similarity of fluid composition between western thermal wells such as numbers 2 and 6, and the eastern thermal well 4 on Figure B24. This site is also located on U.S. Army property, and is accessible via a paved road.

Both test holes encountered thermal fluids. A discussion of temperature depth relationships in these wells is given in the section titled "Temperature Profiling of Wells."

Return Temperatures

Two probes capable of measuring 100°C were used to monitor input mud temperatures (mud pit) and outlet mud temperatures (surface casing perimeter) as drilling progressed. Temperature records generated from this procedure were used to construct the return temperature-versus-depth profiles shown in Figures B25 and B26. Temperature measurements were taken primarily for drilling safety since no blow-out preventer was used. A return temperature of 75°C was chosen as a cutoff. Because this temperature was never attained, it was assumed that fluid temperatures above the cutoff were not encountered, however, this assumption was incorrect. Temperature profiles measured in the wells after casing (figs. B12, B13) indicate that return temperatures are from 32° - 40°C lower than maximum recorded temperatures.

Lithologic Descriptions

Both HHT-1 and HHT-2 were completed to total depth in alluvium. The rock types which compose the alluvial fill vary somewhat from one side of

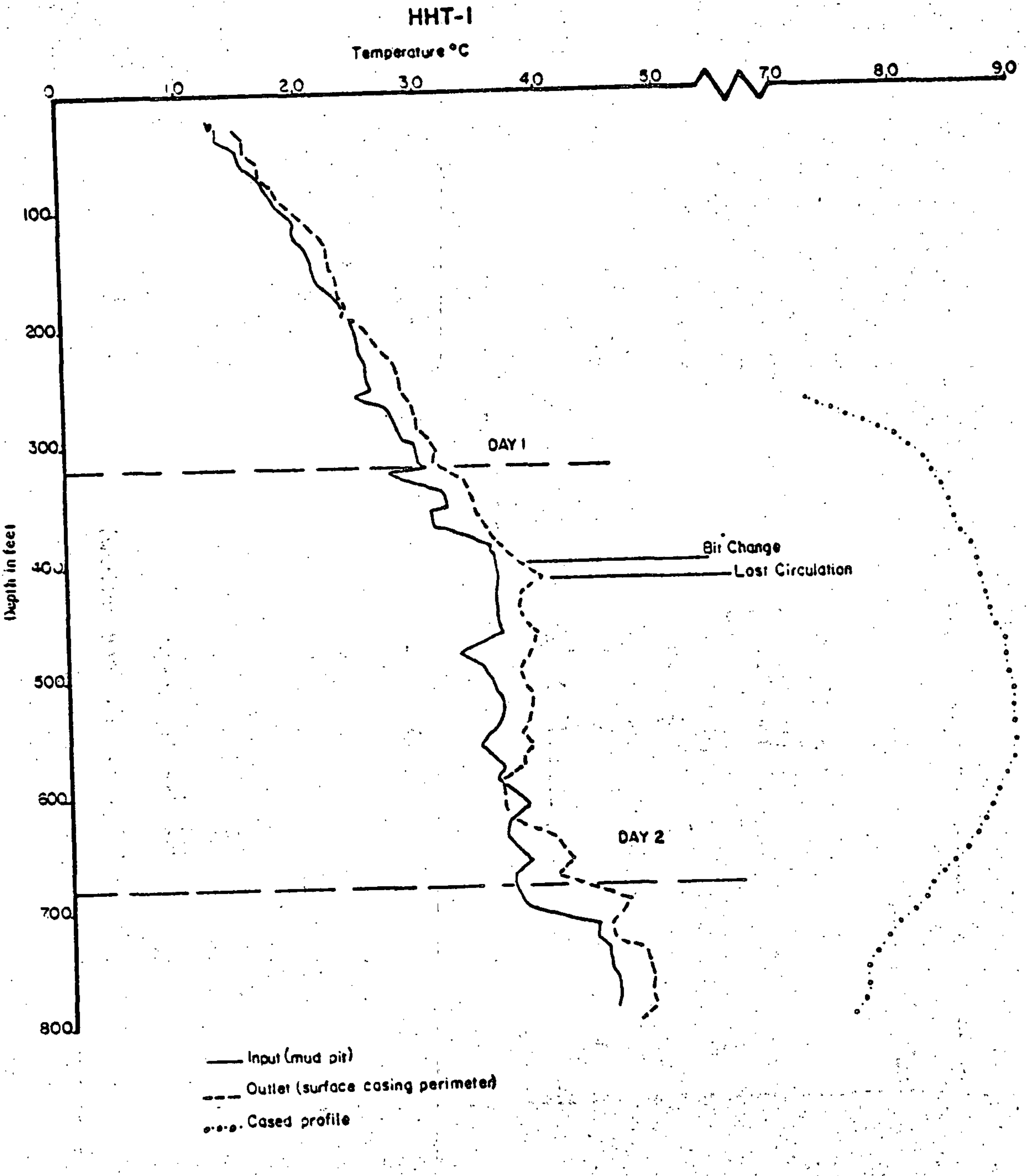


Figure B25. Return temperatures vs. depth of drilling

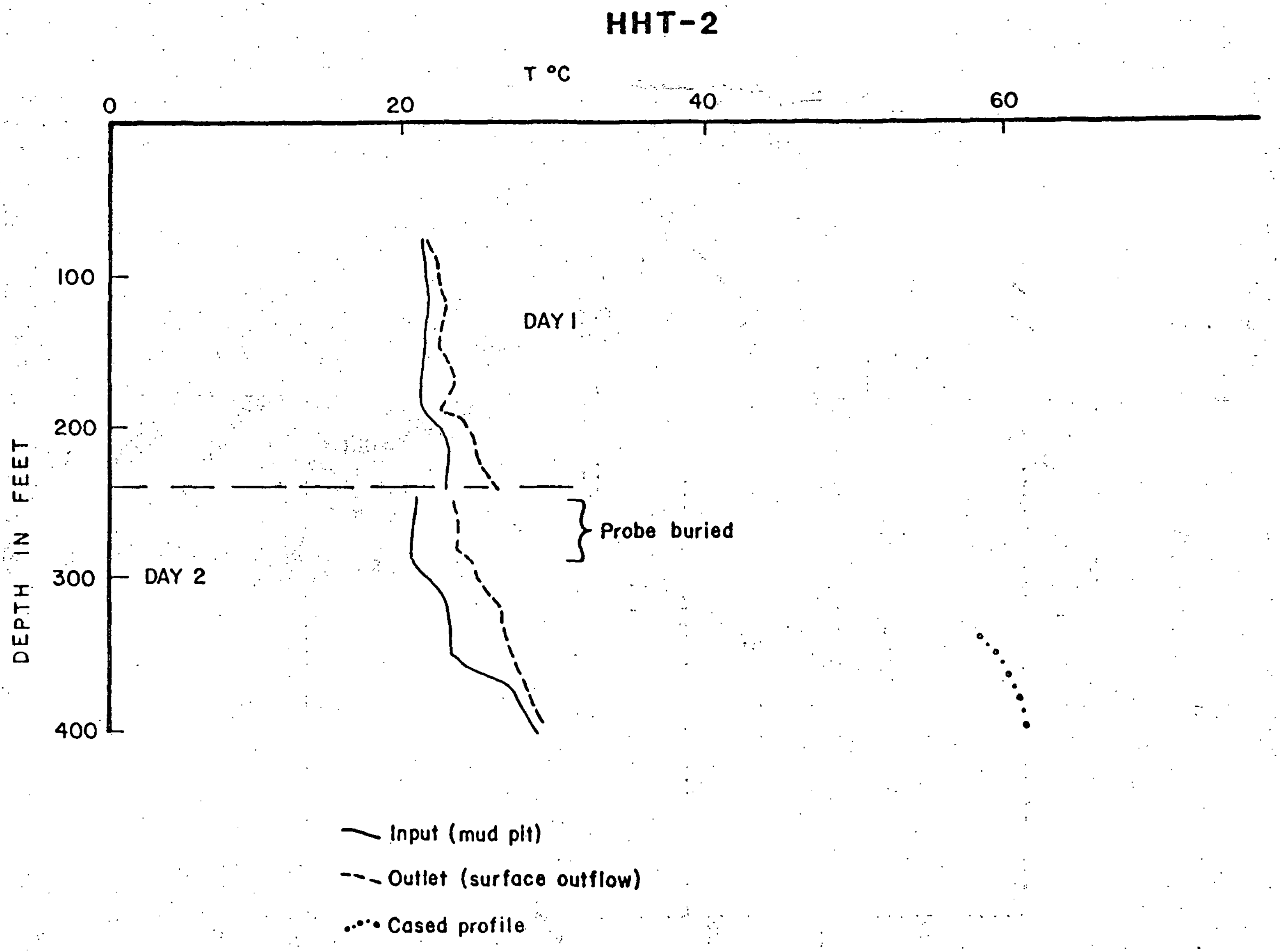


Figure B26. Mud return temperatures vs.drilling depth.

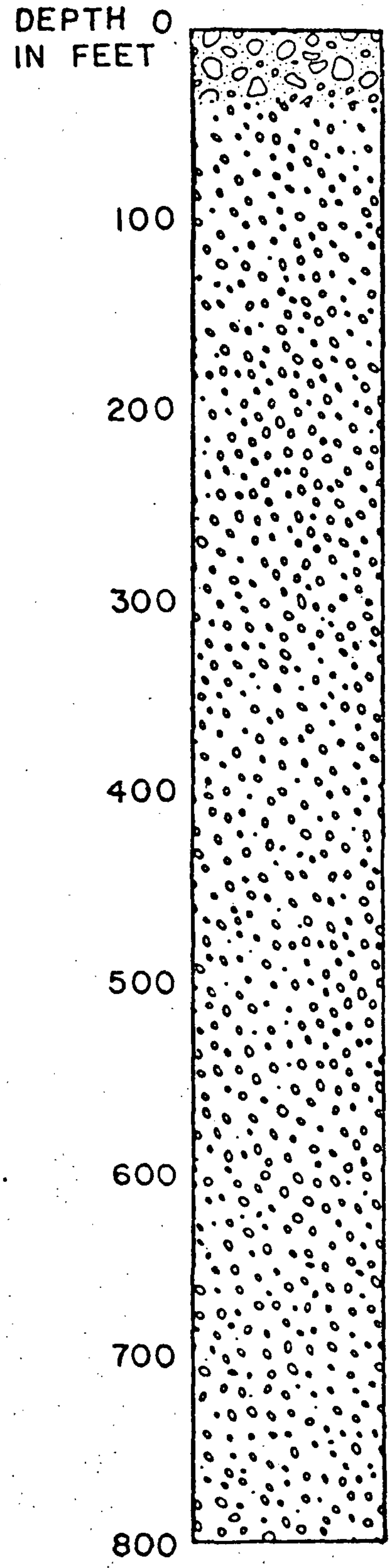
the valley to the other (figs. B27 and B28). This reflects that differing source regions supply the materials. Rock types from HHT-1 can be directly related to the intermediate intrusive and metavolcanic rocks of the Wassuk Range. Lithologies present in HHT-2 are rich in basic to acidic flow rocks and tuffs and tuffaceous sediments.

An interesting correlation is noted if clay content is plotted versus depth in the two test holes (fig. B29). In both cases, clay content is less than or equal to five percent to a depth of approximately 67 m (220 ft). Beyond this point, a marked increase occurs to approximately 76 m (250 ft) where both curves begin a rapid decrease. A second zone of relatively high clay content is found in both holes between 92 and 122 m (300-400 ft). At approximately 122 m, a zone in which both white and brown cohesive clays is observed in HHT-1 and HHT-2. These correlations suggest a uniform depositional environment in the basin. Unfortunately, no other sufficiently detailed lithologic descriptions are available for comparison.

SUMMARY

General Geology

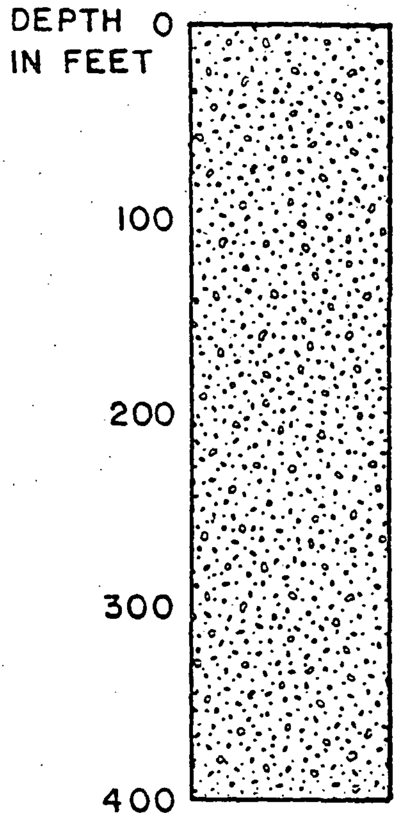
The study area lies within a region of physiographic and structural discordance termed the Walker Lane by Locke and others (1940). Its eastern boundary is the Garfield Hills which record an intense period of orogeny during the Mesozoic era. The Wassuk Range forms a western boundary and is a west-dipping tectonically-tilted block. Ages of rocks exposed within the area vary from Triassic to Holocene,and a variety of lithologies is present. Rock types include intermediate intrusive, metavolcanic, limited marble and phyllite, mafic to intermediate flows, intermediate to felsic tuffs,



HHT-1

Alluvial materials consisting of: Angular to subangular fragments of decomposing intermediate intrusive rocks containing - quartz, plagioclase, k-feldspar, biotite and/or hornblende; fragments of more mafic intrusives probably diorite; fragments of basic rock such as diabase (probably the result of mixing during intrusion of the granitic rock); epidote color mineral; and fragments of metavolcanic rocks from Excelsior formation of the Wassuk Range. Many of the intermediate intrusive fragments are heavily iron stained from mafic mineral decomposition. Size of the fragments is variable from <1-30 mm above 40' and generally <5 mm from 50' to TD. Between 780' and 800' all material was <2 mm. Clay content was variable from <5% up to >70% by visual volume estimate. Occassional cobble to boulder size fragments encountered during drilling.

Figure B27. Lithologic log and description - test hole HHT-1.



HHT-2

Alluvium, angular to subrounded fragments composed in varying proportions of: quartz, k-feldspar, DG, mafic volcanics (basalt?), light colored fine-grained tuff containing biotite flakes, fine grained poorly sorted tuffaceous sediment, reddish-purple aphanitic volcanics (andesite), red porphyritic rhyolite, green and brown chert, and epidote. Above 30 ft. some pebble size frags, from 30-220 ft. 2 mm-10 mm, 220-400 ft.<5 mm. Occasional cobble and/or boulder size material encountered during drilling. Clay content variable from 5% to >70% by visual estimate.

Figure B28. Lithologic log and description - test hole HHT-2.

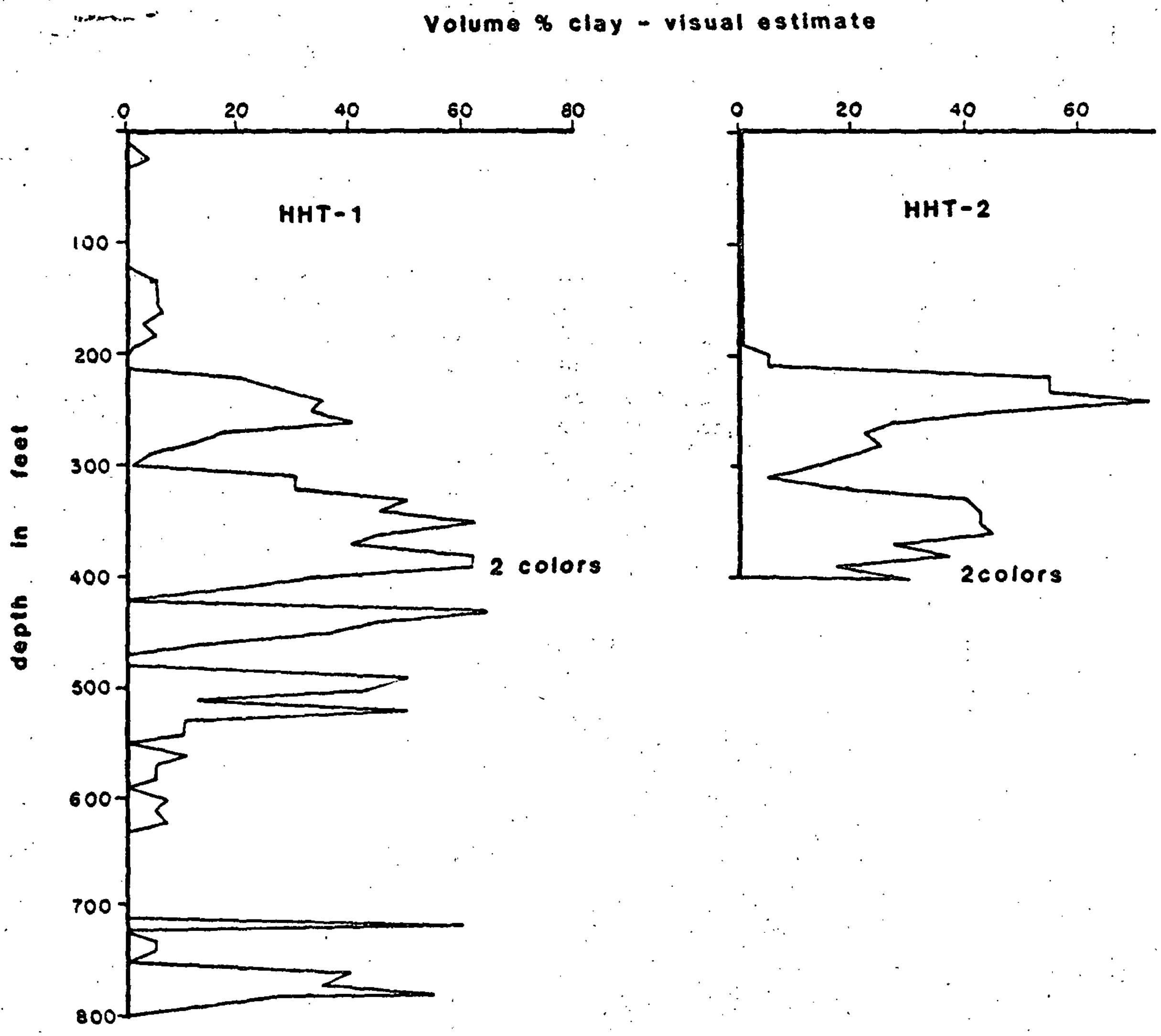


Figure B29. Clay content as a function of depth, HHT-1 and HHT-2.

tuffaceous sediments, and clastic sediments.

Aeromagnetic Map

High and low closures on the map generally follow the outcrop patterns of volcanic rocks or topographic features. This is probably in part an effect of the non-drape method of data collection. Within the vicinity of the city of Hawthorne, the contour patterns record only subtle changes.

Shallow Depth Temperature Survey

This study involved the emplacement of over 90 two-meter probes on both regional and reduced scales. Two regions of elevated temperatures were delineated. They are located in the Hawthorne vicinity along the eastern front of the Wassuk Range and western front of the Garfield Hills, respectively. The regions are composed of broad zones of limited temperature variation and contain irregular non-linear localized highs as indicated by isotherm configurations.

Photo Imagery

Both B & W and color imagery were examined. Scales from 1:24,000 to 1:250,000 were used. Identified regional features are limited to Walker Lane linears and frontal structures of the eastern Wassuk Range. Low sun-angle photography proved most useful. It demonstrated the presence of three general linear trends: NW-SE, NE-SW and N-S. There is also a lack of fault traces and escarpments along the western front of the Garfield Hills.

Soil-Mercury Survey

This technique was not useful for exploration in the Hawthorne area. No trends were observed and only a single anomalous value was measured. Low background values were recorded in the immediate vicinity of the El Capitan well which contains 99°C fluids.

Temperature Profiling of Wells

Two previously existing wells and two test holes drilled for this study were profiled. The two existing wells proved to be essentially isothermal over vertical distances of 60 meters. They are separated by nearly 11 km and have nearly identical temperatures. Temperature depth relationships in our 244-meter test hole HHT-1 demonstrate the presence of three distinct zones at increasing depths: a positive gradient zone, an isothermal zone, and a negative gradient zone.

Gravity Survey

A relatively closely spaced grid of 0.8 km was employed during data collection. Several features are distinguishable. Many area attitudes follow a strong NNW trend. This trend does not follow the Walker Lane but does correspond to the general orientation of contours shown on the 1:250,000 scale regional map of Healey and others (1980). A Walker Lane trend is present within the southern portion of the survey. Like the aeromagnetic patterns, gravity contours indicate a region of subtle variations in the vicinity of Hawthorne. Some of the gravity contour trends parallel surface fault traces while others are clearly discordant. Hot well locations correspond to both of these circumstances. Hot well locations also correspond to inflections in contours. Finally, an area of high closure exists under Hawthorne which may be explained by an erosional or tectonic bedrock remnant, an igneous intrusive, a buried mafic volcanic center, or densification related to mineral deposition.

Fluid Geochemistry

Fifteen samples were collected and analyzed for bulk chemical and stable light isotopic composition. Numerous functional relationships can be described from the data. Concentrations for the majority of dissolved constituents increase when moving down the hydrologic gradient. Groundwaters contain higher total dissolved solids than surface waters collected at the same elevations. Waters tend to fall into several groups based upon cation or anion relative percents. Certain spatially widely separated fluids exhibit marked chemical similarities. There is a distinction between cold groundwaters in the Wassuk Range and those in Whiskey Flat. Lithium content may also be useful for distinguishing thermal and non-thermal fluids.

Isotopically, the fluids exhibit a limited compositional range. Most waters seem to be related to meteoric recharge in the Wassuk Range. Only limited ^{18}O "shifts" are observed. This could result from short circulation times, a temperature <150°C for water-rock interaction, a high water to rock ratio, or a combination of these factors. Geothermometers suggest an upper limit of 125°C for equilibration temperatures.

High sulfate content of thermal fluids is probably related to the oxidation of sulfide minerals found in granitic and/or metavolcanic rocks within the area.

Test Hole Drilling and Associated Lithologies

Two test holes were drilled to test for the presence of geothermal fluids and to determine temperature-depth relationships. Thermal fluids were encountered in both wells. HHT-1 in the area west of Hawthorne shows a maximum temperature of 90°C, and HHT-2 near the Garfield Hills shows a maximum of 61°C. Each well is completed in alluvium. They have similar clay content versus depth relations, and both possess a two-color clay zone at approximately the same level. These similarities suggest a uniform depositional history for alluvium on both sides of the valley.

CONCLUSIONS

Four important parameters characterize geothermal resources in the Hawthorne study area. Greater knowledge of these parameters will aid resource exploration and development in the future. They are:

1) areal distribution of thermal fluids,
2) recharge paths and associated fluid chemical variations,
3) subsurface controls on fluid flow, and
4) heat source.

These variables are all part of a complex system and are not independent.

Waters with anomalous heat content are found over a wide area in the southern Walker Lake Basin and surrounding region. The majority of these fluids occurs in wells drilled in alluvium; however, HAW-16 is an exception. It occurs as a thermal spring of low flow rate in a narrow canyon along the Walker River west of the Wassuk Range. This location places the spring approximately 18 km to the west of the "cluster" of thermal fluids found in wells of the Army Ammunition Plant. Another hot water labeled "BLM" is also widely separated from the "cluster". Like the fluids farther north, it is a well-water in alluvium although it is located nearly 18 km from the main grouping of thermal waters. Some of these fluids exhibit notable chemical similarities in addition to above-normal temperatures. Similarities between mode of occurrence, measured temperatures, and bulk and isotopic composition suggest that some of the thermal fluids may be related to a common and possibly widespread source.

Concordance and discordance are both evident when comparing bulk chemical compositions and measured temperatures of thermal waters. These similarities and contrasts are probably the result of differing recharge paths of various fluids. For example, if fluid HAW-6 (99°C) represents a relatively unchanged sample of the geothermal fluid source, then waters such as HAW-2 (41°C) and

HAW-4 (41°C) are probably from the same source. This conclusion is based upon the chemical similarity of fluids from three wells. Recharge to this group probably occurs along very similar lithologic paths. Temperature disparities could result from simple conductive cooling. Fluids areally distributed between the waters discussed above, such as HAW-3 and NAD2, are relatively enriched in calcium and magnesium, and relatively depleted in sodium. However, their anion compositions are comparable to those of HAW-6, HAW-2 and HAW-4. The majority of wells in the "cluster" around Hawthorne follow a similar pattern of consistency in anionic composition coupled with variable calcium, magnesium and sodium concentrations. If HAW-6 is a parent fluid, it seems reasonable that the relative enrichment of Ca and Mg in other fluids is a function of water-rock interaction along different recharge/flow paths within the alluvium. The mixing of various fluids might also explain the compositional variations. However, lack of a well-defined end member which could produce such changes argues against this hypothesis.

Parameters which govern fluid movement and distribution in the near surface (<500 m) environment of the Hawthorne geothermal resource cannot be clearly deduced from available data. As previously discussed, the resource appears to be present over a large region although, with one exception, it does not exhibit any surface manifestations. No direct correlations between range front faults and geothermal fluids are demonstrated within the detailed study area. Orientations of fault scarps in alluvium in the area west of Hawthorne do not correlate with isotherm patterns from the two-meter probe study. Also, there are no anomalously high soil-mercury concentrations or trends related to fault locations. Reliable temperature profiles from thermal wells where they were completed indicate relatively thick (60 m) zones of hot fluids. These facts all support a type of control on fluid distribution which is not primarily high-angle faults. Rather, it is postulated that lateral movement along permeable zones within the alluvium is the primary control. A possible scenario might include initial movement upward along range-bounding or subparallel faults driven by forced convection; rising thermal fluids contacting a zone within which lateral permeability exceeds that in the vertical direction; followed by lateral transport down the hydraulic gradient. Parameters which govern permeability within alluvium are presently indeterminate. One possible explanation is movement of fluid in the vicinity of the alluvium-bedrock interface. This hypothesis is based upon two observed phenomena. The temperature-depth profile in test hole HHT-1 possesses a reversal from positive to negative gradient near the 180 m (600 ft) level. This may be the result of drilling into a relatively impermeable bedrock layer. However, owing to the similarities between alluvium and bedrock apparent in chip samples, this cannot be demonstrated in the lithologic log. Secondly, there is a marked contrast in temperatures and chemistries between samples HAW-6 and HAW-14. The wells are nearly identical in depth, apparently completed to total depth in alluvium and located within 1 km of each other along an east-west line. HAW-14 might not be deep enough to reach hotter fluids found in HAW-6 due to increasing depth to the interface of valley fill and bedrock when moving toward the center of the valley. No further confirming evidence can be cited due to a lack of detailed lithologic logs for the area, and the uncorrelated nature of gravity data.

Many low-to-moderate temperature geothermal systems in Nevada seem to be related to deep circulation of meteoric waters in a region of normal or above normal crustal gradient. This may also be valid for Hawthorne area fluids although other heat sources are possible. The presence of relatively young (<250,000 yrs) extrusions of mafic rock in the area of Aurora Crater suggests that subsurface igneous bodies may also supply heat. It is inferred from chemical evidence that Hawthorne fluids are probably moderately-heated (<150°C) meteoric waters that have not experienced extensive high temperature water-rock interaction. If this assumption is correct, then rocks which transfer heat to the Hawthorne fluids are probably, in turn, heated by conductive and or convective processes associated with relatively remote igneous bodies in the subsurface. There is geophysical evidence for the existence of igneous bodies. Van Wormer and Ryall (1980) determined that the configuration P-wave residuals in the vicinity of the Adobe Hills is consistent with a region of partial melting in the crust. This region extends to the northeast. The authors also postulate an upper mantle source below the Excelsior Mountains. Phenomena of this magnitude could easily provide elevated subsurface temperatures necessary to produce heating with limited circulation of fluid at depth. It would also explain the extensive areal distribution of geothermal fluids.

The remote possibility of an intrusive igneous body in the valley fill is suggested by certain patterns in the detailed gravity survey. Presently there are insufficient data to refute or confirm such a hypothesis.

Suggestions for Further Study

A considerable amount of information has been compiled from this study regarding the nature and distribution of geothermal resources in the Hawthorne area. A better understanding of the distribution of thermal fluids in the near surface (<600 m) is of primary importance in siting future production wells for direct applications. Depending upon funding availability, several approaches could be taken including accurate temperature-depth profiles of all accessible wells, drilling a deeper test hole (600 m) with accurate and detailed lithologic and borehole logging, and completing a deep electrical resistivity survey that may provide a 3-dimensional picture of the distribution of hot waters.

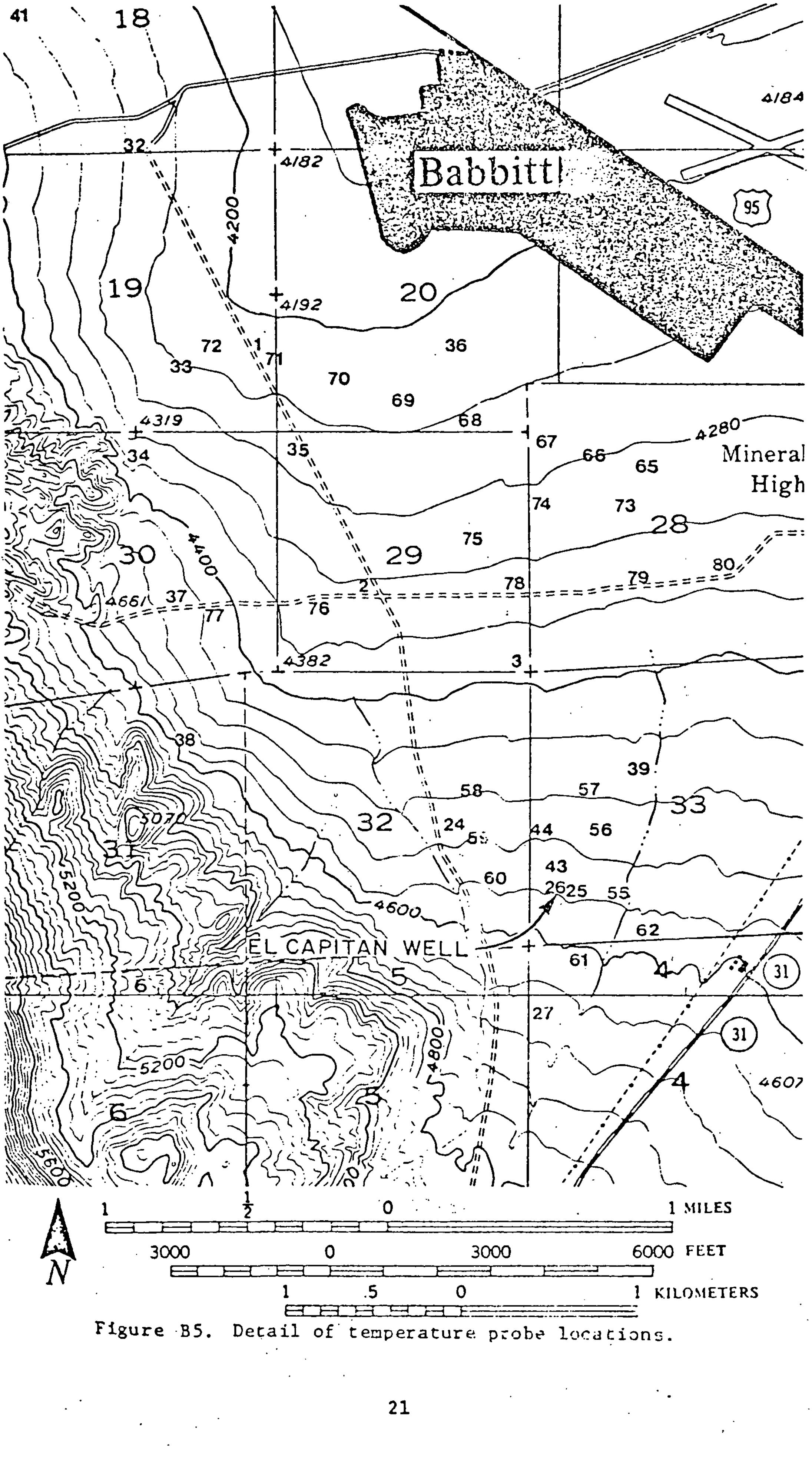


Figure B5. Detail of temperature probe locations.

Table B1. Temperature Probe Data

Probe #	Date of Reading	Measured Temp (°C)	Correction Factor	Corrected Temp (°C)
1	27 Sept.	22.8	N/A	N/A
2	27 Sept.	23.9		
2	1 Oct.	23.75		
2	17 Oct.	23.3		
2	3 Dec.	18.25		
3	27 Sept.	23.4		
4	27 Sept.	21.0		
5	27 Sept.	22.4		
6	27 Sept.	19.8		
7	27 Sept.	21.0		
7	1 Oct.	20.9		
7	17 Oct.	20.6		
8	27 Sept.	21.1		
9	27 Sept.	22.0		
10	27 Sept.	22.3		
11	27 Sept.	22.2		
12	27 Sept.	21.1		
13	27 Sept.	21.1		
14	27 Sept.	20.5		
15	27 Sept.	20.8		
16	27 Sept.	20.9		
17	27 Sept.	21.5		
18	27 Sept.	20.9		
19	27 Sept.	21.8		
20	27 Sept.	20.8		
21	27 Sept.	22.3		
22	27 Sept.	21.2		
23	27 Sept.	21.2		
24	27 Sept.	22.6		
25	27 Sept.	23.3		
26	27 Sept.	24.7		
27	27 Sept.	22.0		
28	27 Sept.	18.2		
29	27 Sept.	18.9		
30	27 Sept.	19.9	N/A	N/A
31	27 Sept.	Probe Damaged	-	-
31	18 Oct.	20.25	+0.5	20.75
32	17 Oct.	22.8	+0.5	23.3
33	17 Oct.	23.9	+0.5	24.4
34	17 Oct.	21.0	+0.5	21.5
35	17 Oct.	23.35	+0.5	23.85
36	17 Oct.	24.3	+0.5	24.8
37	17 Oct.	23.65	+0.5	24.15
38	18 Oct.	21.8	+0.5	22.3
39	18 Oct.	22.3	+0.5	22.8
40	18 Oct.	20.75	+0.5	21.25
41	17 Oct.	19.8	+0.5	20.3
42	No Station	-	-	-
43	18 Oct.	24.0	+0.5	24.5
44	18 Oct.	23.3	+0.5	23.8
45	18 Oct.	23.3	+0.5	23.8

Table B1. Temperature Probe Data (Cont.)

Probe #	Date of Reading	Measured Temp (°C)	Correction Factor	Corrected Temp (°C)
46	18 Oct.	18.8	+0.5	19.3
47	18 Oct.	19.2	+0.5	19.7
48	18 Oct.	19.95	+0.5	20.45
49	18 Oct.	20.7	+0.5	21.2
50	18 Oct.	20.7	+0.5	21.2
51	18 Oct.	17.15	+0.5	17.65
52	18 Oct.	19.3	+0.5	19.8
53	18 Oct.	18.7	+0.5	19.2
54	18 Oct.	18.75	+0.5	19.25
55	18 Oct.	21.6	+0.5	22.1
56	18 Oct.	22.55	+0.5	23.05
57	18 Oct.	22.75	+0.5	23.25
58	18 Oct.	23.2	+0.5	23.7
59	18 Oct.	23.1	+0.5	23.6
60	18 Oct.	23.6	+0.5	24.1
61	18 Oct.	24.95	+0.5	25.45
62	18 Oct.	21.1	+0.5	21.6
63	18 Oct.	20.2	+0.5	20.7
64	None	None	-	-
65	3 Dec.	16.7	+5.7	22.4
66	3 Dec.	17.7	+5.7	23.4
67	3 Dec.	18.5	+5.7	24.2
68	3 Dec.	17.3	+5.7	23.0
69	3 Dec.	16.8	+5.7	22.5
70	3 Dec.	17.3	+5.7	23.0
71	3 Dec.	16.4	+5.7	22.1
72	3 Dec.	18.5	+5.7	24.2
73	3 Dec.	18.75	+5.7	23.95
74	3 Dec.	17.8	+5.7	23.5
75	3 Dec.	17.0	+5.7	22.7
76	3 Dec.	17.2	+5.7	22.9
77	3 Dec.	17.6	+5.7	23.3
78	3 Dec.	18.3	+5.7	24.0
79	3 Dec.	18.6	+5.7	24.3
80	3 Dec.	15.9	+5.7	21.6
81	4 Dec.	17.95	+5.7	23.65
82	4 Dec.	17.0	+5.7	22.7
83	4 Dec.	17.0	+5.7	22.7
84	4 Dec.	16.5	+5.7	22.2
85	4 Dec.	17.15	+5.7	22.85
86	4 Dec.	17.3	+5.7	23.0
87	4 Dec.	17.9	+5.7	23.6
88	4 Dec.	18.7	+5.7	24.4
89	4 Dec.	17.9	+5.7	23.6
90	4 Dec.	17.5	+5.7	23.2
91	4 Dec.	16.0	+5.7	21.7
92	4 Dec.	17.4	+5.7	23.1
93	4 Dec.	16.4	+5.7	22.1
94	4 Dec.	16.9	+5.7	22.6
95	4 Dec.	17.4	+5.7	23.1

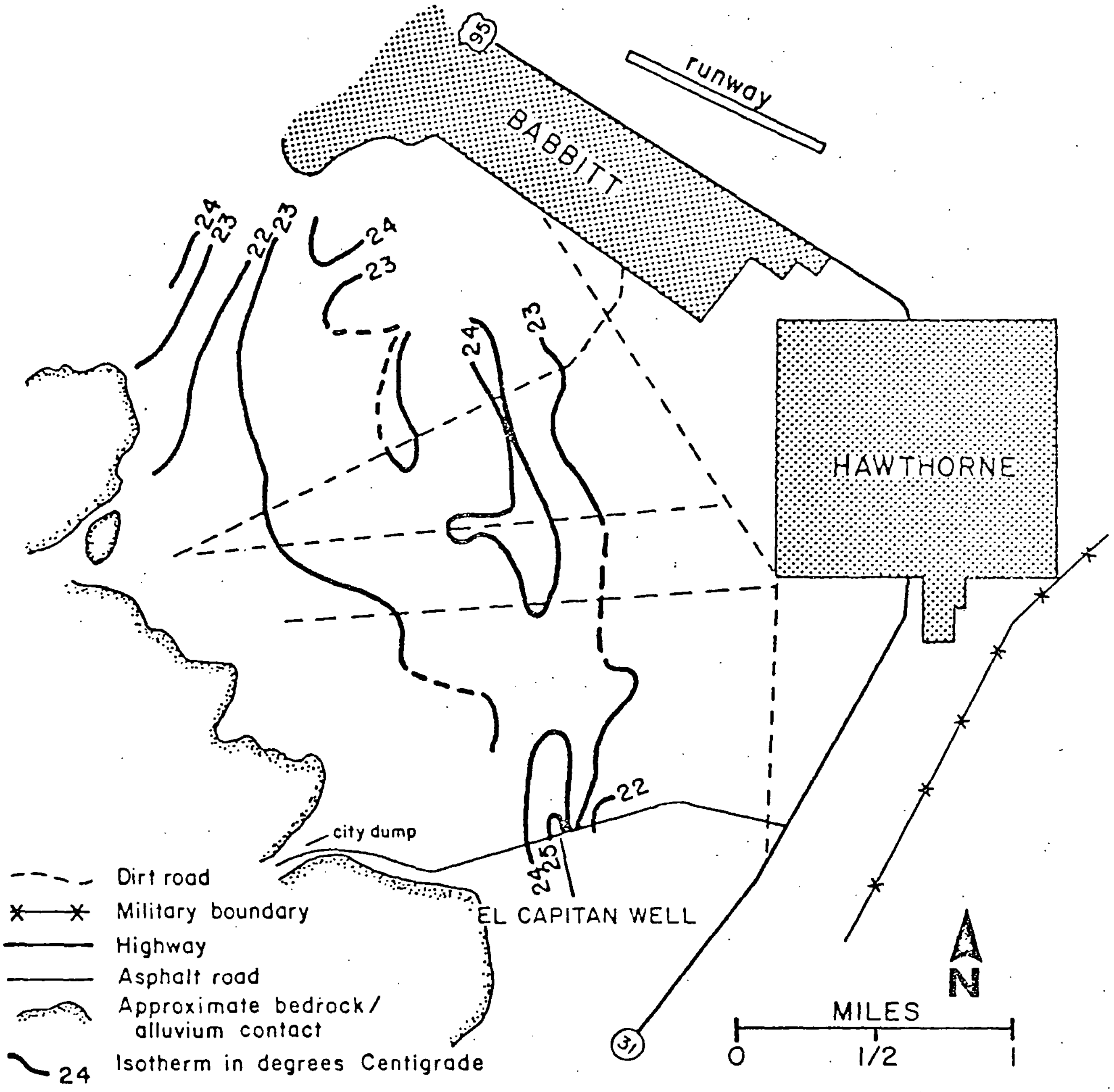


Figure B6. Possible isotherm configurations at a depth of two meters, see text for detail.

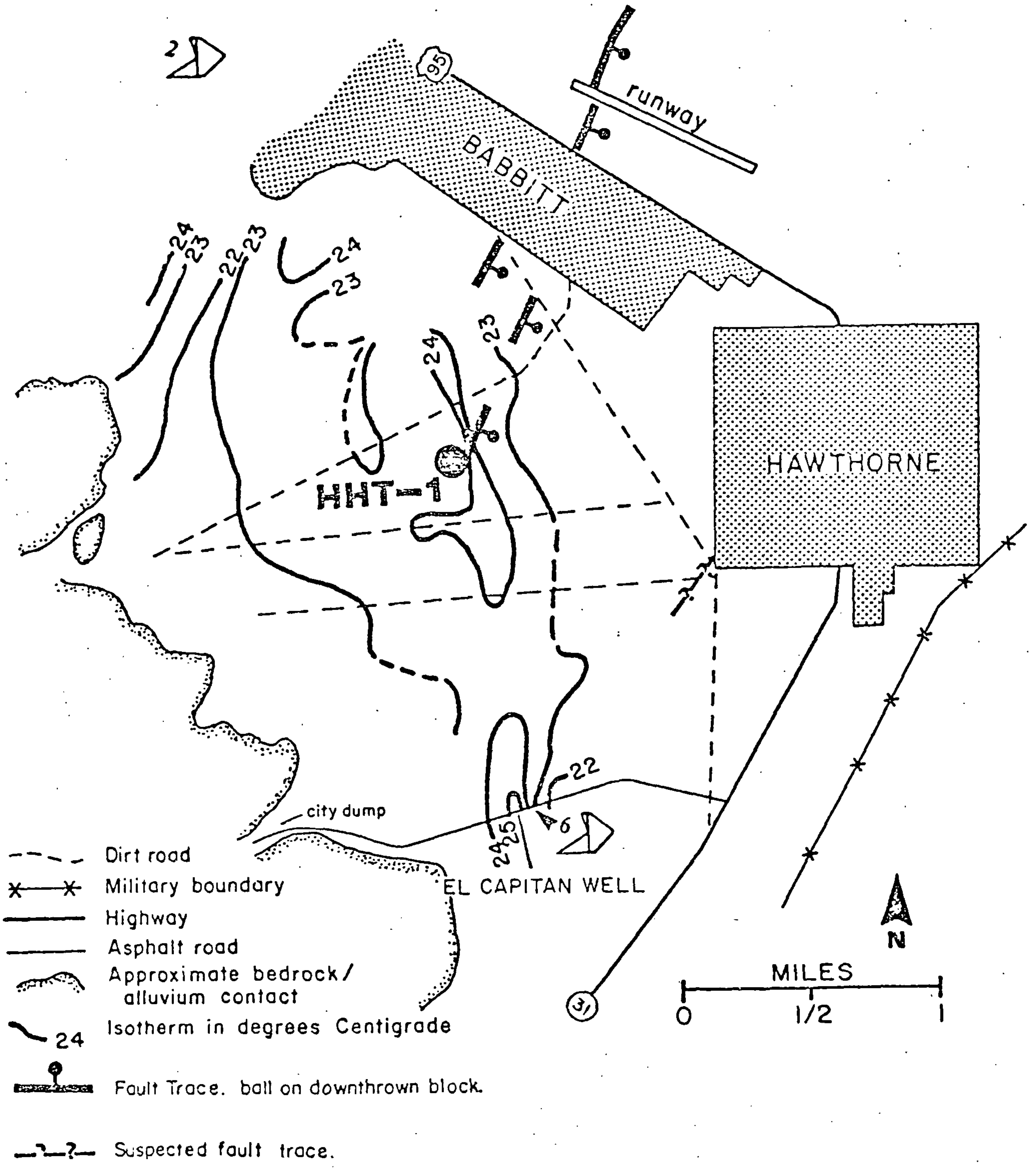


Figure B23. Correlation of isotherm high with fault trace in alluvium.

The following comments concerning geothermal resource exploration at Hawthorne Army Ammunition Plant are based on the Supplemental Scope of Work contract DACA05-81-C-0122. Tasks and paragraphs cited below are referenced to the 9 June 1982 edition of the SOW.

Three options are identified by the Army for geothermal resource definition and assessment. In addition to these, a fourth option suggested herein could also be considered.

The first two options (4.2.3.3.1.5 and 4.2.3.3.1.6) are straightforward drilling and hydrologic testing of the resource identified by the Nevada State Coupled Program Geothermal Resource Assessment Team in their thermal gradient drilling. No geologic exploration is required for these options; stepping out from the existing thermal gradient hole should permit adequate resource testing. Economic rather than geologic considerations should be applied in determining between the smaller diameter well of Option 1 and the larger well of Option 2.

Option 3, identified by the Army (4.2.3.3.2), and our suggested Option 4, both require additional geologic studies. Option 3 is designed to provide geothermal resource assessment within a small area adjacent to the ordinance portion of the facility. Option 4, which would be dependent upon the allocation of additional funding, would expand the study to look at the entire facility for resources. Geoscientific tools for Options 3 and 4 would be similar; only the area of study would expand.

Geothermal Resource Assessment

Studies performed by the Nevada Resource Assessment Team in the Hawthorne area would be extended under Option 3 to include the area of greatest direct use potential near the community of Babbitt and, under Option 4, near other potential sites. The following tasks are a suggested exploration approach, modified after Nevada team reports.

Geology

Geologic studies should emphasize identification of fault trends and channels for the circulation of hydrothermal fluids. Low-sun-angle aerial photography has defined several northeast trending linear features near Babbitt, which have been interpreted as recent faults crosscutting alluvium. Field checking of these features should be done to verify their existence and determine, if possible, their exact tract and amount and direction of displacement. More detailed surface geologic mapping of alluvial deposits, based upon recently completed studies by the U.S. Geological Survey (Stewart et al., 1981) should be accomplished within the area between Hawthorne, Babbitt and the Wassuk Range front to the west. This mapping would be expanded under Option 4. Intrusive formations within the Wassuk Range, peripheral to the study area, should be mapped with emphasis on faulting and fracture or joint orientations, which could be used to aid interpretation of buried geological structures under the valley. Alluvial deposits within the valley should be mapped with emphasis on geomorphic features that may be related to Quaternary faulting, and identification of any zones of hydrothermal alteration. Variations in surficial deposits (if any) and surface alteration should be noted from material encountered during drilling of the suggested 60 2m test holes (Option 3) for shallow thermal studies.

Geochemistry

If appropriate wells in addition to those sampled by the Nevada Team can be located in the study areas of Option 3 or 4, fluid samples should be collected, analyzed, and the results integrated into the hydrothermal system model.

Geophysics

A 2m temperature probe survey consisting of approximately 60 stations (Option 3) at selected spacings within the study area should be completed as originally proposed in the SOW, in order to augment similar studies already performed by the Nevada RA team. A greater number of 2m test holes would be required if Option 4 is selected. Detailed gravity studies might help in defining subsurface geologic structures.

A deep resistivity survey could be used to define the thermal aquifer. It could be referenced to wells that penetrate the aquifer. Approximately ten line miles of survey within the Option 3 study area should be designed to cross suspected buried geologic structures and penetrate to depths from 1000 to 2000 feet. This study could be expanded to cover more of the valley if Option 4 is identified.

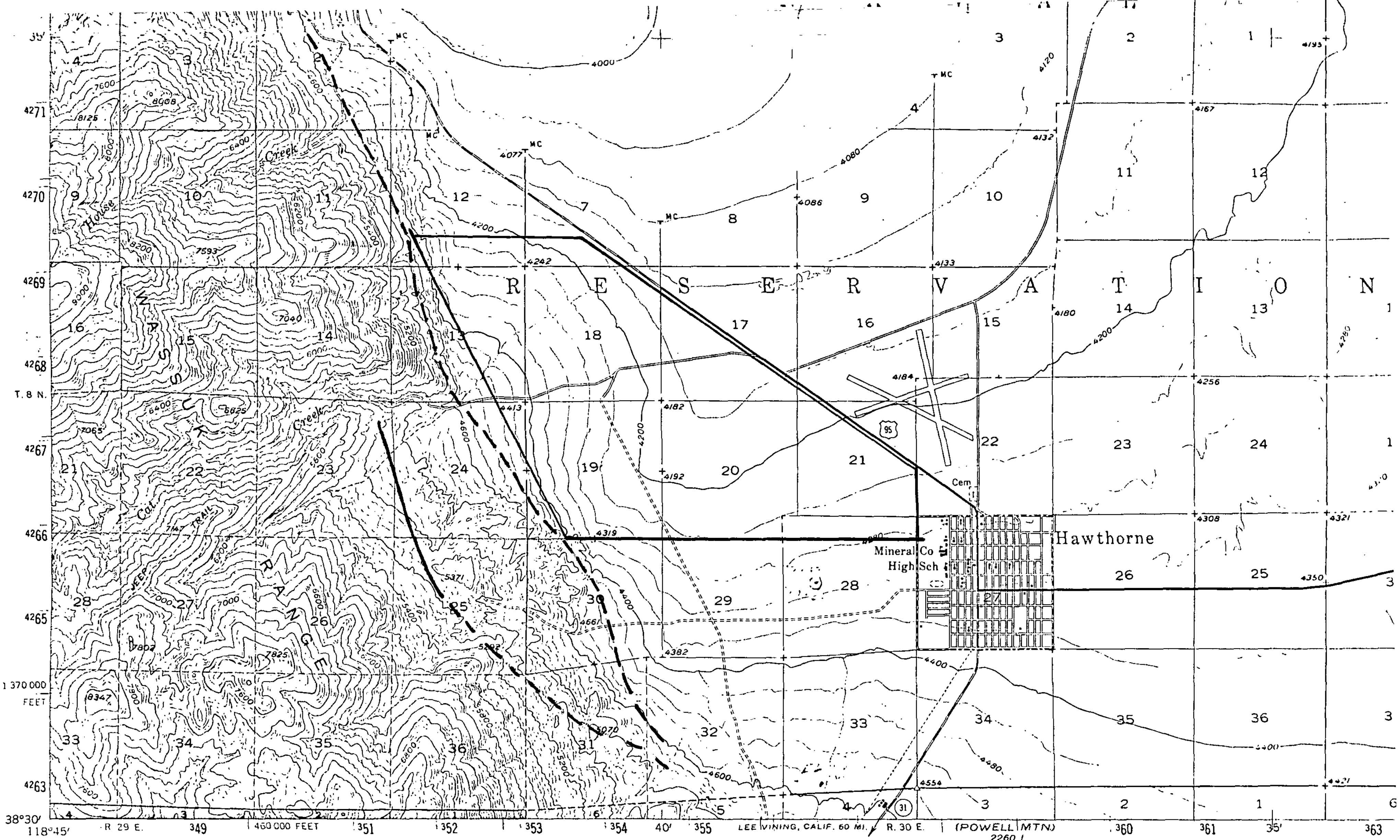
Test Drilling

Deep thermal and hydrologic regimes should be evaluated by one or more deep test holes. The Nevada RA team has proposed upder Option 3 additional testing by drilling 600 m (approximately 1970 ft.) to obtain pertinent data related to the geothermal system. Multiple wells might be desirable under Option 4. The exact location(s) of the deep test well(s) will depend on the results of the previous geological and geophysical studies. Detailed lithologic logs should be compiled from the cuttings and analysed in conjunction with a standard suite of downhole geophysical surveys. Test holes ideally should be completed in a manner such that thermal gradient as well as hydrologic data can be obtained.

Model Development

All data should be integrated to develop a conceptual target model for the geothermal resources of the study area. Stratigraphic and/or structural controls of the geothermal system should be defined by the proposed exploration methods such that design and location of production and injection wells can be facilitated.

Geologic programs for Option 3 and Option 4 could be scoped in area and cost to accommodate available funding. Additional exploration techniques are probably not required, but more thermal gradient holes and deep resource test wells could be drilled if more funding were available.



(AURORA)
2260 IV

Mapped, edited, and published by the Geological Survey

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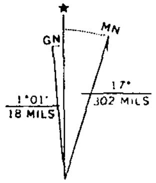
Topography from aerial photographs by multiplex methods
and by planetable surveys 1955. Aerial photographs taken 1954

Polyconic projection. 1927 North American datum
10,000-foot grid based on Nevada coordinate system, west zone

Red tint indicates areas in which only
landmark buildings are shown

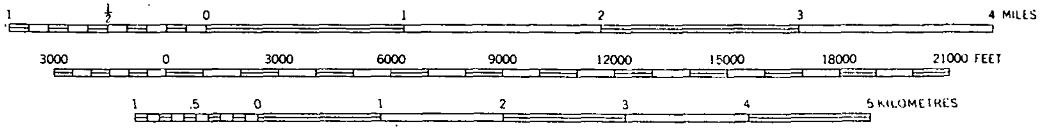
Dashed land lines indicate approximate locations

1000-metre Universal Transverse Mercator grid ticks,
zone 11, shown in blue



UTM GRID AND 1955 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1:62500



CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRAN

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST