Black Rock Desert - Gerlach

THE COLORADO SCHOOL OF MINES

NEVADA GEOTHERMAL STUDY

Progress Report No. 4 - For period

February 1 - October 31, 1975

NSF Grant GI 43866

Principal Investigators:

L. T. Grose
Dept. of Geology

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Dept. of Geophysics

December 1, 1975

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INTRODUCTION

This is the fourth in a series of reports that describe the progress of geological, geophysical, and geochemical exploration research for geothermal energy sources in a Basin and Range setting. The region of our investigation lies in the Gerlach-Hualapai Flat area in the southwestern part of the Black Rock Desert of northwestern Nevada (Plate I).

Included herein are preliminary presentations of results of field investigations carried out mainly during the summer of 1975 by graduate students and faculty of the Geophysics and Geology departments of the Colorado School of Mines. These studies consist of:

- 1) Geological mapping in the Gerlach-Hualapai Flat area.
- 2) Alteration studies at select hot springs.
- 3) Seismic, ground temperature, gravity, and time domain electromagnetic surveys.
- 4) Analysis of thermal infrared imagery.
- 5) Geochemical investigation of thermal and non-thermal waters.

Continuing studies include processing and interpretation of geophysical and geochemical data and water sample and petrologic and mineralogic analyses. More geologic field study is anticipated to augment geophysical and geochemical findings.

PLATE I. Index map of the Gerlach -
Hualapai Flat - Black Rock Desert
region of northwestern Nevada

CHAPTER I

GEOLOGICAL MAPPING IN HUALAPAI FLAT, FLY RANCH HOT SPRING AREA

INTRODUCTION

Field mapping of Hualapai Flat and adjacent areas was undertaken from May 15 through August 15, 1975, by Robert Sperandio. The objectives of the mapping were to delineate major rock types and structures, and to determine possible relations between geological structure, Tertiary volcanism, and hot spring activity, and ultimately to understand the geologic setting of the Fly Ranch geothermal system.

This report is preliminary. All petrographic descriptions are based on observations of outcrops and hand specimens. Correlations between volcanic flows and pyroclastic rocks northeast of Hualapai Flat (south Calico Mountains) with similar rocks north and northwest of Hualapai Flat are tentative, and confirmation awaits detailed petrographic analyses and further mapping to be accomplished next summer.

FORMATIONS

Permo-Triassic Metavolcanics and Metasediments

Metavolcanic and metasedimentary rocks which crop out in the Hualapai Flat area have tentatively been dated as Permo-Triassic by Bonham (1969) on the basis of a cast of Triassic ammonite and the correlation of these rocks with similar appearing Permo-Triassic

rocks in western Humboldt County (Happy Creek volcanic series of Willden, 1964). Neither the base nor the top of the metamorphic sequence is known in the area. Cretaceous granodiorite discordantly intrudes the sequence in the Granite Range. Although these rocks are mostly massive, local and rarely preserved bedding shows strikes ranging from $N20^{\circ}-70^{\circ}E$ and dips varying from $70N$ to $70S$.

Outcrops of metamorphic rocks are almost entirely confined to the south half of the map area (Plate II). The most common rock types are metamorphosed andesite and basalt (PTrvf) which are entirely massive and well-jointed. On a fresh surface they are green-black, but weather to a red-brown color. Near intrusive contacts with Cretaceous granodiorite, these rocks are phyllitic with foliation parallel to the contact. The bulk of the metamorphosed basalts and andesites have reached the actinolite-epidote-albite grade of thermal metamorphism; green amphibole and epidote are normally abundant. Near intrusive contacts epidote decreases and hornblende increases in amount.

A complex group of metamorphosed volcanic flows, flow breccias, and volcanoclastic sediments has been mapped together as one unit (PTrvb). The volcanic flows are aphanitic to highly porphyritic and are intermediate to basaltic in composition. The flow breccias are very similar to the volcanic flows but are autoclastically brecciated, monolithologic, unsorted, and unstratified. The volcanoclastic sediments include water-lain tuffs, and range from silt size to pebble size. The complex has been pervasively epidotized and actinolitized and it exhibits a dull green color on outcrop. Individual beds are thin and lenticular and cannot be traced from outcrop to

PROGRESS GEOLOGIC MAP OF THE AREA SURROUNDING HUALAPAI FLAT, NORTHWEST NEVADA

by Robert J. Sperandio
Colorado School of Mines
November, 1975

PROGRESS GEOLOGIC CROSS-SECTIONS IN HUALAPAI FLAT AREA, MODERATELY SCHEMATIC, VERTICALLY EXAGGERATED.

(FOR LOCATION INFORMATION AND FORMATION SYMBOLS, REFER TO PROGRESS GEOLOGIC MAP OF HUALAPAI FLAT AREA.)

by Robert J. Sperandio
Colorado School of Mines
November, 1975

outcrop.

A thick sequence of recrystallized limestone (PTRls) and metasiltstone (PTRss) occurs in the Granite Range (Plate II). The limestone is buff to blue-gray and is predominantly finely crystalline containing recrystallized clots and veinlets of sparry calcite. Interbedded with the limestone are relatively minor beds of metamorphosed calcareous sandstone and calcareous siltstone. The metasiltstone occurs stratigraphically between two thicker units of limestone. It is phyllitic, dark brown, and approximately 200 feet thick. The limestone-metasiltstone-limestone sequence is greater than 1000 feet thick in places.

Metasedimentary rocks also occur in the east part of the mapped area at the southern tip of the Calico Mountains. The sequence consists of interbedded cherts and limestones, totalling several hundred feet thick. Thin-bedded, red-brown cherty layers are interbedded with dolomitized limestone (PTRcls); the limestone beds are usually less than 5 feet thick.

Cretaceous Granodiorite

Granodiorite exposed in the south and southwest parts of the mapped area is part of a batholith which resembles other western U.S. Cretaceous batholiths of Buddington's (1959) mesozone bordering the Pacific basin. A potassium-argon isotopic age of $88.8 \pm 2.6 \times 10^6$ years (late Middle Cretaceous) is reported by Bonham (1969) for biotite from the granodiorite.

Cretaceous granodiorite is herein divided tentatively into two units: mafic "granodiorite" (Kgd_m) and felsic "granodiorite"

(Kgd_f). All of the granodiorite is hypidiomorphic-granular, medium-grained, containing plagioclase, K feldspar, quartz, biotite, and hornblende in various proportions. The bulk of the granodiorite has been mapped as Kgd_f, containing up to 20% biotite and hornblende. Kgd_m may be as mafic as a quartz diorite with up to 40% biotite and hornblende. Hornblende/biotite ratios appear to be greater in Kgd_m than Kgd_f.

Xenoliths of Permo-Triassic metavolcanics and metasediments are common in the granodiorite, and most abundant in the mafic phase. Many xenoliths have sharp contacts with Kgd_m, many have reaction rims, and some remain only as "ghosts." The large number of partially assimilated xenoliths in Kgd_m and the close spatial association of Kgd_m with PTRvf strongly suggest that assimilation of metabasalts and meta-andesites into the granodiorite melt caused parts of the magma to become relatively mafic. In a similar manner the composition of many plutons of northwest Nevada becomes more mafic towards bordering mafic country rock (Bonham, 1969).

Pegmatitic and aplitic veins of granitic composition cut Kgd_m, Kgd_f, and bordering country rock. They range in width from less than one millimeter to tens of meters, and are interpreted as being the product of late-stage differentiation of the Cretaceous granodiorite magma.

Tertiary Volcanic Flows, Tuffs, and Clastic Sediments

Tertiary volcanic flows, flow breccias, tuffs, and clastic sediments are generally easily distinguished from Permo-Triassic volcanics and clastics because the Tertiary rocks are fresh and

unmetamorphosed, they overlie older rocks, and they usually exhibit low dips.

Two Tertiary volcanic sequences are recognized: one in the north central and northwest, and one in the northeast (Calico Mountains). Stratigraphic relationships between them will be understood when mapping has extended into the Calico Mountains. Stratigraphic and lithologic data are summarized in columnar section (Figure 1) for the volcanic sequence northwest of Hualapai Flat. Intermediate flows, flow breccias and tuffs dominate the approximately 2000-foot thick section in the Hualapai Flat area. Basalt, lying locally with appreciable angular discordance on older volcanic units, is the youngest pre-Quaternary unit in the area. The whole volcanic pile is included within the South Willow Formation of Bonham (1969) who reports a minimum K-Ar age of 31.3 my (Middle Oligocene) for the formation. However, additional field investigation may well discover significantly younger volcanic rocks within the complex and heterogeneous assemblage, possibly structurally let down outliers of the Modoc lava field. We plan to date radiometrically a few critical samples from this section.

A possible volcanic center is recognized in the southern Calico Mountains. Wall rocks composed of Tertiary andesitic flows and overlying intermediate autoclastic breccias are discordantly cut by a bowl-shaped mass of very silicic air fall tuffs, tuffaceous sediments, bone-white autoclastic breccias, and rhyolitic flows (Tsf). The circular shape of this silicic mass is not apparent on Plate II due to incomplete mapping, but it is a striking

TERTIARY STRATIGRAPHIC COLUMN OF THE AREA NORTHWEST OF HUALAPAI FLAT

Figure 1

feature in the field. One must wonder if this possible volcanic center was the source of many of the tuffaceous beds of Tts in northwest Hualapai Flat; at any rate Tsf and Tts are in similar stratigraphic positions in relation to the intermediate volcanic flows and flow breccias of north Hualapai Flat.

Tertiary volcanic activity is not confined to the northern half of the mapped area. Intermediate flows and plugs are present in the southeast, and a volcanic dike of intermediate composition (Tid) cuts granodiorite for more than a mile in the most southerly part of the area. However, the spatial independence of these southerly volcanics precludes any assignment of a relative Tertiary age to any of them, although it is likely that they are associated in time with intermediate flows and flow breccias to the north.

Quaternary Deposits

Five Quaternary formations have been differentiated and mapped in the Hualapai Flat area (Plate II). Older alluvium (Qoa) and Lake Lahontan beds (Ql) are probably Late Pleistocene in facies relationship. Younger alluvium (Qya), playa deposits (Qp), and eolian dunes (Qd) are Holocene. Playa beds underlie most of the Black Rock Desert proper and also a larger area in the southern part of Hualapai Flat. Younger alluvium underlies the northern and central part of Hualapai Flat. Dunes are segregated along a low topographic-structural divide between the Black Rock Desert and Hualapai Flat. Locally, such as at Fly Ranch, Late Quaternary hot spring precipitates impregnate Quaternary deposits

and accumulate in low mounds on the ground surface.

STRUCTURE

The structural setting of the Hualapai Flat area is becoming clearer as mapping proceeds. The progress geologic map and cross sections (Plates II and III) depict the general structural framework of the area.

The oldest rocks in the area - the thick sequence of Permo-Triassic metavolcanic and metasedimentary rocks - strike northeasterly and dip subvertically. The relative consistency of structure in these rocks, which occur in isolated roof pendants scattered in an area of over 100 square miles, indicates that they were deformed prior to the invasion of Cretaceous granodiorite and that they have undergone little appreciable rotation since then. Prediction of their occurrence in the subsurface of Hualapai Flat and the Black Rock Desert depends upon irregularities of contact with granodiorite, preservation on pre-volcanic erosion surface, and offset on Cenozoic faults. The carbonate units within the Permo-Triassic section could provide excellent reservoir rocks for hot water and steam and therefore their location in depth is particularly important.

Cretaceous granodioritic rocks, comprising part of the Granite Range pluton, crop out extensively in the southwestern and southern bordering areas of Hualapai Flat. The rock is essentially massive-directionless, although foliation is developed along narrow zones of contact with country rock. Generally

joints appear randomly in the granodiorite. However, several long zones of jointing of high density and preferred orientation indicate, together with other evidence, faulting. Major fracture patterns within and marginal to the granodiorite are being mapped locally and regionally. Geothermal fluids are restricted to permeable fracture zones within plutonic rocks. The importance of accurately predicting geometries of intersecting fracture zones in the granitic rocks of the area cannot be overestimated.

The Oligocene-Miocene-Pliocene (?) volcanic extrusive layers in the Hualapai Flat area record high-angle normal faulting and moderate tilting (Plates II and III). Most of the faults trend slightly east of north and have the eastern block downthrown. Most of them appear to occur along the western side of Hualapai Flat. Displacements appear to be dip slip and amount usually to several tens or hundreds of feet. However, several thousand feet of dip slip must occur between Tertiary volcanic rocks and Cretaceous granodioritic rocks along the southwest margin of Hualapai Flat. Prevailing block tilt direction is southwesterly toward the massive uplift of the Granite Range.

A large intrusive complex appears to exist in the Calico Mountains, and a north-south alignment of small plugs occurs several miles south. Structural significance of these features are not fully understood as yet.

Quaternary formations in Hualapai Flat record rifting, normal faulting and subsidence in Late Quaternary (Grose and

Keller, 1975). These features indicate extension of Hualapai Flat generally along a northwest-southeast axis.

The Cenozoic rocks and structures suggest the following events in the Late Cenozoic (largely post-volcanic) tectonic evolution of the Hualapai Flat area:

- 1) Southwestward tilting of volcanic terrain coeval with uplift at the Granite Range - Hualapai Flat basin not existent yet.
- 2) North-south faulting of volcanic and granitic terrain and beginning of formation of Hualapai Flat, north-south portion of Granite Range, and adjacent portion of Black Rock Desert.
- 3) Continuation of north-south faulting and beginning of northeast-southwest rifting and faulting within Hualapai Flat proper.
- 4) Development at Fly Ranch hot spring system favored by Late Quaternary extensional tectonic yield.

CHAPTER II

GEOLOGICAL MAPPING IN THE NORTHERN PART OF THE SELENITE RANGE

INTRODUCTION

Field mapping of approximately 70 square miles in the northern and northeastern extension of the Selenite Range was undertaken by A. Peter Smith from June 15 to August 15, 1975. This area lies along the southeastern margin of the Black Rock Desert and it extends northward from an area recently mapped by Crewdson (1973). The Gerlach hot spring system lies three miles west of the central part of the mapped area and Trego hot spring lies at the northeast end. The purpose of studying the geology of this area is to determine the boundary conditions of the Black Rock Desert on the southeast and to round out understanding of the geologic setting of several geothermal systems contained within the greater Black Rock Desert tectonic province.

This is a concise and preliminary edition of the forthcoming thesis on the area. Petrography and correlations await thin section study of samples collected in the Selenite Range and in the surrounding areas. Structural cross sections from the Selenite Range to the Granite Range and Hualapai Flat areas will be constructed and will, in part, be based on geophysical data currently being processed.

FORMATIONS

Paleozoic-Mesozoic Metavolcanic and Metasedimentary Rocks

The oldest rocks encountered include a large mass of metabasalt and meta-andesite occurring in the southcentral part of the area, and a 4000 foot thick section of fine-grained quartz-biotite schist at the northeast end of the Range (Plate IV). Neither top nor bottom of either sequence is preserved.

The metavolcanic mass appears to have internal foliation locally that trends usually north-south and that dips subvertically. The most common petrographic type is fine- to coarse-grained, massive to foliated, locally epidotized biotite-plagioclase amphibolite. This unit is not reliably correlatable with known rocks in the region. Less metamorphosed parts of the unit, however, do bear some lithologic resemblance to Permo-Triassic metavolcanic rocks in the Granite Range several miles to the northwest (Bonham, 1969; Sperandio, this report).

The fine-grained schist section is tentatively included within this large unit, because of field relationships and degree of metamorphism, while it is realized that this correlation is extremely tenuous. Layers in the isolated mass strike northeasterly and dip variously to the northwest. Major minerals in the schist are quartz and biotite, with lesser amounts of muscovite and calcite. Originally, the rock was probably a slightly calcareous siltstone.

GEOLOGY OF THE NORTH END
OF THE SELENITE RANGE,
NW NEVADA.

1:64,350

0 5000 10000 15000 feet

— geologic contacts

- - faults

2° strike & dip of bedding

10° foliation, strike & dip

contour interval = 200 ft.

MAP KEY

- Quaternary
 - Qal Quaternary Alluvium
 - Qplaya Quaternary Playa
 - Ql Quaternary Lake Sediment (Lake Lahontan)
- Tertiary
 - Tb Tertiary 'Basalt'
 - Tsu Tertiary Sedimentary Unit
- Mesozoic
 - Kgd Cretaceous 'Granodiorite'
 - Msr Nightingale Sequence
- Paleozoic
 - Pmvs Paleozoic Meta-Volcanics and Sediments

Plate IV

A. P. SMITH 1975

Nightingale Sequence

Metasiltstone, impure quartzite, and marble form a north-south, steep west-dipping, thick section that is herein assigned to the Triassic-Jurassic Nightingale sequence of Bonham (1969). These rocks occur only at the southern end of the area, but Crewdson (1973) mapped them farther south along the west flank of the Selenite Range.

Cretaceous Granodiorite

Most of the higher areas of the Selenite Range are sustained by granodioritic rocks that resemble those encountered in the Granite Range, radiometrically dated at about 89 million years (Bonham, 1969). They are equigranular, massive, medium-grained, locally porphyritic and containing mafic xenoliths. Contact with wall rocks usually displays foliation. The mode is plagioclase 50%, quartz and K-feldspar 30%, and biotite and hornblende 20%.

Tertiary Flows and Clastic Sediments

Tertiary rocks in the northern part of the Selenite Range are divided into two mappable units: 1) a lower sedimentary section up to 200 feet thick of fluvial gravels, sands, and silts, and lacustrine clays, and ashfall tuffs, and 2) an upper basalt and andesite flow sequence up to 300 feet thick (top is eroded). Both units occur in the central and southern part of the area, mainly west of the main granite mass, as tilted and faulted erosional remnants of what must have been originally an extensive

regional sequence.

The sediments lie on an irregular surface cut on granodiorite and older formations. The flows lie on the sedimentary sequence apparently conformably, and also higher in the Range they lie directly on granodiorite and older formations. Correlation of these units with other Tertiary flow and clastic rocks in the region awaits further study.

Quaternary deposits

Three Quaternary formations were delineated in the mapped area (Plate IV). They include: 1) Lake Lahontan clay, silt, and sand, 2) Holocene alluvium, and 3) modern playa clay. These deposits are restricted to the piedmont of the Range and the adjacent Black Rock Desert. Stable and active sand dunes occur between alluvium and playa at places in the northcentral and northeast part of the area. The Quaternary deposits are free of natural thermal manifestations except at Trego hot springs where hot water issues through reworked Lake Lahontan beds.

STRUCTURE

The rocks in the northern part of the Selenite Range reveal a fragmentary record of deformation which began in the Late Paleozoic or Early Mesozoic and which continued intermittently up to the present time.

The metavolcanic and metasedimentary succession strikes north-south where it occurs in the southern part of the area,

whereas in the northeast it strikes northeasterly. Although this oldest regional fabric is not extensively preserved in the Range, it does suggest a concordance with the overall bend in the Range from north-south to northeast-southwest and an adjacent similar bend in the Black Rock Desert depression. This further suggests the possibility of "basement control" on Late Cenozoic Basin and Range tectonic pattern, or vice versa, in this local area. However, Basin and Range patterns characteristically completely cut across all older fabric.

The Cretaceous granodioritic intrusive is essentially massive internally, and it discordantly cuts across layering and foliation of invaded rocks. Major faults displace the mass down to the northwest along the margin of Black Rock Desert; otherwise the granodioritic rocks appear remarkably unfaulted within the area mapped.

The Tertiary sedimentary unit occurs discontinuously at low and moderate elevations along the west side of the Selenite Range. It dips westerly and is cut by several north-south normal faults. Basalt and andesite flows conformably overlie this unit. In other parts of the area, however, at higher elevations and even on the east flank of the Range, the flows lie directly on granodiorite and older rocks. These flows dip about 20 degrees off both the west and east flanks of the higher parts of the Range.

The Quaternary formations and the modern land surface are cut by a fault scarp over 2 feet high one to three miles west and southwest of Trego hot spring along the northwest base of

Trego Mountain. Another fault zone, possibly active, is located in alluvium along the base of the Range where the large granodioritic mass occurs. It is manifest by a line of vegetation and cold springs. Elsewhere in the mapped area, no evidence of tilting or faulting in Quaternary formations was found.

The rocks within the northern part of the Selenite Range and those along the western piedmont (mostly alluvial fan) apparently escaped tilting and faulting of Quaternary age. No evidence for surface or near-surface thermal phenomena has been seen in these areas. However, Late Quaternary faulting is present toward the northeast, and it is in this area that a hot spring and shallow warm-water wells occur.

CHAPTER III
PRELIMINARY STUDY OF HYDROTHERMAL ALTERATION ASSOCIATED
WITH HOT SPRING ACTIVITY, GERLACH AREA

by S. B. Romberger
Assistant Professor of Geology

INTRODUCTION

In any natural system involving the activity of hot waters, a characteristic hydrothermal alteration of the rocks will be produced. This alteration can be observed in most recognized geothermal areas, as well as in areas containing common metallic mineralization. The alteration results from the fact that the hot waters percolating through fractures and pore spaces of rocks have a chemical composition which is far out of equilibrium with these rocks. Therefore, the chemical reactions taking place during hydrothermal alteration will be those which bring the chemical composition of the rocks closer to being in equilibrium with the solutions. However, it must be recognized that the rocks have as large an effect on the chemical composition of the aqueous solutions, as the latter has on the mineralogical composition of the rocks, and much of the dissolved material in the waters is derived from the alteration of these rocks. Broadly speaking, the types of chemical reactions involved are: conversion of anhydrous silicates to hydrous silicates, and therefore decrease in bulk density (increase in volume) of the rocks; solution of minerals present in small amounts in the altering solutions; and precipitation of minerals whose solubility has

been exceeded in the altering solutions.

The study of hydrothermal alteration in a geothermal system is far from simply academic. Such alteration has been used very successfully as an exploration tool in the search for mineral deposits, and there is no reason to believe it would not be helpful in the search and study of geothermal areas. In addition, knowledge of the chemical reactions common to a hydrothermal system would be very helpful in the engineering and design of recovery systems. These solutions are typically very reactive, and their mobilization during pumping could result in varying degrees of corrosion, scaling, or some other undesirable chemical change, perhaps resulting in the clogging of the aquifers or plumbing of the geothermal system. Such problems are well recognized in various geothermal fields.

With the above background material in mind, a preliminary investigation on the nature of the hydrothermal alteration associated with hot spring activity was carried out in the Black Rock Desert area, as part of a comprehensive study of the geothermal potential of this region. The objective was to determine the nature of the chemical reactions which might occur between the thermal aqueous solutions and the enclosing rocks.

GERLACH HOT SPRING AREA

A reconnaissance investigation of the Black Rock Desert region suggests the present hot springs are associated with faults bounding the graben occupied by the Black Rock Desert. They occur in recent valley alluvium, and bedrock exposures in the immediate

vicinity of the active hot springs are sparse. In these areas it was not possible to study hydrothermal alteration changes. Therefore, a search was made for a bedrock area which might represent an uplifted and eroded remnant of a hot spring area. The most favorable area was a block of altered granodiorite and lake sediments about one mile northwest of the town of Gerlach, just to the west of the active Gerlach hot springs (Figure 2). This area was mapped in detail at a scale of one inch equals 200 feet (Figure 3). In addition to the alteration, this area is characterized by well preserved tufa cones, coatings, and fracture fillings on and in the bedrock. The tufa deposits and intense alteration lie astride a well developed N20E trending fault zone separating the Black Rock Desert block on the east and the uplifted Granite Range block on the west. A similarly altered area lies along strike about one mile to the northeast. Tufa deposits can be traced another $3/8$ of a mile along strike to the southeast. The area shown in Figure 3 appears to fall on the intersection of the northeast-trending fault zone with a lineament running N35W which topographically separates Granite Point from the main Granite Range block. This is consistent with the observation that the intersection of fault zones represent a more favorable plumbing for rising hydrothermal solutions than a simple fault plane. Both trends are represented in the area shown in Figure 3 by fracture sets consisting of brecciated altered granodiorite and distinct dikes of fragments of altered granodiorite in a fine-grained matrix (Figure 4). In Figure 3, the area of extensive tufa coatings and fracture fillings lies

Scale: 1" = 40'

FIGURE 4. Schematic diagram showing the brecciation along North-South fault zone (see Fig. 3 for location). Blocks not to scale.

right on the best developed fracture zone, which, in this area strikes nearly north-south (the change in strike of the fault zone in this area may be due to rotation on the northwest set).

The similarity of the structural setting of the tufa deposits and that of the active hot springs suggests that the area of Figure 3 is an uplifted and exposed expression of processes taking place under the present hot springs. The tufa deposits and fracture fillings of the former consist of fine-grained calcium carbonate similar to surface deposits around present hot springs. We have an additional dimension in that it appears that the north end of the area in Figure 3 has been eroded deeper, perhaps by a few tens of feet, than the southern end. Therefore, a study of the alteration in this area may give us an idea of the chemical processes taking place under the active hot springs.

NATURE OF ALTERATION

The unaltered granodiorite is medium to coarse grained, equigranular consisting primarily of plagioclase and orthoclase, with lesser amounts of biotite and hornblende. Younger pods, lenses, and dikes of granitic aplite and pegmatite are found, with one prominent strike direction of N50E. The rocks of Granite Point are relatively fresh; however, as the area of Figure 3 is approached from the west alteration begins to become apparent. Biotite and hornblende gradually become converted to chlorite, and epidote replaces plagioclase. This is the common propylitic grade of alteration observed in hydrothermal mineral deposits.

There is no sharp contact between the low-intensity propylitic alteration to the west, and the very intensely altered area of Figure 3. Transition between the two zones appears to take place over a distance of about 100 feet. In general, the rocks in the area shown in Figure 3 have been stained red, indicating the oxidation of iron. However, it is not clear if only the iron existing in the ferromagnesian minerals in the original granodiorite has been oxidized, or if additional iron has been introduced by the thermal waters. The only megascopically recognizable mineral from the original granodiorite is orthoclase. In the dikes of altered granodiorite breccia the matrix is considerably more oxidized than the fragments. Although hand specimens of granodiorite do not indicate silicification, petrographic study of thin sections should show this when they become available.

The lake sediments appear to show the same type of alteration as the granodiorite, and in places altered sediments are indistinguishable from altered granodiorite in hand specimen. In places, however, the former has been silicified to a very dense, hard, rock, particularly at the north end of Figure 3. In this same area originally flat-lying beds have been tilted up by movement along faults to the east.

There are two areas in Figure 3 worthy of special note. At the north end there is a zone of chlorite-epidote alteration running nearly east-west, and another less distinct zone about 400 feet south at the west edge. Here, the granodiorite has been altered to fine-grained clay, chlorite, and some epidote; the

proportions of the various phases varies from place to place. Where the east-west zone intersects the altered lake sediments, the latter are intensely silicified, and also include a fine-grained green mineral. Also in this area several branching and cross-cutting dikes of tufa-like material occur, indicating this area was one of active hot springs at one time. Small veins and dikes, from 1 to 4 inches wide, consisting of clay and chlorite occur with fracture fillings of tufa in the area of extensive tufa coatings and fracture fillings. These are cross-cut by the tufa fracture fillings. Where the argillic alteration occurs the red color of the altered granodiorite is bleached out, indicating either a reduction or the mobilization of the iron.

Although some general statements can be made on the nature of the alteration described above, a more complete chemical characterization should follow a petrographic study of thin sections of the rocks, when the latter become available. In general, the alteration is what would be expected when hot, slightly acid, aqueous solutions invade the rocks of this area. At this time no limits can be placed on the temperatures of the altering solutions. The low grade propylitic alteration is characterized by the addition of water, protons, and possibly carbon dioxide to the rocks, with the loss of very little. The slightly higher grade argillic alteration is characterized by the same additions, with the loss of alkali and alkaline earth elements, and the mobilization of silica. No evidence of higher grade alteration is found. No evidence of sulfides has been found, although these may be fine grained and picked up in microscopic inspection.

OTHER AREAS

A reconnaissance investigation was carried out on 2 additional occurrences of alteration that appear to have been a result of hot spring activity. The first is about 9 miles south of the town of Empire to the west of Highway 34. The altered areas appear to be aligned along a linear zone about one mile in length and trending north-south. Regionally, this zone is aligned with the west bounding fault of the Black Rock Desert to the north in the Gerlach area. The nature of the original rock has been obscured by the alteration, which megascopically consists of intense silicification and oxidation to a deep red color. Relict bedding suggests the rocks were originally sediments. The area is characterized by brecciation, together with coatings and fracture fillings of calcite and quartz. Although no tufa deposits were found, a remnant of a hot spring deposit was found which could have been subareal. This deposit consists of alternating layers of calcite and pale pink silica. In places, masses of coarsely crystalline black calcite was found.

The second area was at the southeastern edge of the Calico Mountains. The alteration and tufa deposits occur along a prominent north-south trending ridge of silicified rhyolite. The tufa deposits occur as coatings and fracture fillings in the rhyolite. Alteration associated with these deposits is not intense, however, brecciation is apparent and some chlorite and epidote were found. The deposits and brecciation appear to be aligned along a north-trending lineament on the east side of the Calico Mountain block.

CHAPTER IV
GEOPHYSICAL STUDIES IN THE GERLACH-HUALAPAI FLAT-
BLACK ROCK DESERT REGION

by R. A. Crewdson

INTRODUCTION

Geophysical field work on the Nevada Geothermal Project has been completed. The project covers approximately 1000 square miles as a regional study, as shown in Figure 5. This includes the Granite Range, Calico Mountains, Black Rock Range, and Selenite Mountain Range; the Black Rock Desert, and Northern Smoke Creek and San Emidio deserts; Hualapai Flat; and the Soldier Meadows, Double Hot-Black Rock, Trego, Gerlach, and Fly Ranch hot springs.

The geophysical studies have been concentrated on the Hualapai Flat-Fly Ranch Geothermal Prospect, Southern Black Rock Desert, and Gerlach Geothermal Prospect.

A geophysical crew of Mines' graduate students worked in the area during May, June, and part of July, 1975. The studies included about 19 miles of reflection seismic traverse, 200 miles of closely spaced gravity traverse, 223 one meter-deep ground-temperature measurements throughout the area, and a time domain electromagnetic survey (line-loop coupling). The bulk of the work is interpretive and remains to be done during the school year.

FIGURE 5
LOCATION MAP.

SEISMIC SURVEY

During May 1975 about 19 miles of reflection seismic traverse was run across the Black Rock Desert and Hualapai Flat (Figure 6). The purpose of the seismic survey was to derive data on the stratigraphic section in the Black Rock Desert and Hualapai Flat basins as well as information about the depth to crystalline basement. We expect to determine whether or not these basins contain thick sequences of lake sediments or volcanic flows. Additionally, we expect to determine the attitudes of the sedimentary layers and the configuration of the basement surface.

One traverse ran NNW from Trego to a point about 1 1/2 miles north of Steamboat Rock and then essentially due west across Hualapai Flat to bedrock exposures on the west. The second traverse, about 2 1/2 miles long, ran normal to the zone of high microseismicity as demonstrated by the microseismicity work (CSM Progress Rept., No. 1, 1974) of the previous summer (Figure 6). With the exception of 3 miles of 600% multiplicity common-depth-point shooting in the middle of the Black Rock Desert traverse, the seismic work was all split spread shooting at 1/4 mile shot spacings. Geophone arrays were at 110 ft spacings; each array consisting of 6 geophones at maximum separation to minimize low frequency ground roll. Signals were recorded as an analog signal on magnetic tape with a dry paper-galvo light camera used as a monitor. Filter settings were such to minimize original signal loss. The energy source was normally 2 1/2 # of seismic high-velocity dynamite at a depth of 11-14 ft.

Processing of this data will involve changing the analog tapes to a digital format and then computing a depth section using a Seismograph Service Corp. Phoenix processing package. The end result will be a velocity section and distance-depth reflection horizon section. This work is currently being carried out.

Mr. James Calloway, former employee of S.S.C. and presently a graduate student at Mines, supervised the data acquisition and is also doing all the data processing. Tables 1 and 2, prepared by Calloway, summarize the details of the data collection and processing procedures. Figure 7 is a time section along the three mile CDP coverage. It shows three reflecting horizons; one at .5 sec., 1.0 sec, and at 3.0 sec. The interval velocities for the layers from the surface downward are: 3425 ft/sec, 6575 ft/sec, and 16500 ft/sec. With these velocities, we obtain depths to these horizons as 856 ft, 2500 ft, and 18750 ft below the surface. The remainder of the processing will involve applying these parameters to the rest of the data, with adjustments as necessary and computing a depth section for the rest of the profile.

Table 1
Seismic Data Acquisition Field Parameters

24 Trace Split Spread
 2640 ft Spread Length
 55 ft Offset Trace 12, 165 ft Offset Trace 13
 110 ft Geophone Interval
 6 Geophones Per Station at 18 ft Spacing
 Open Filters
 Medium Rate AGC
 6 Fold on CDP Coverage

Table 2
Seismic Data Processing Procedure and Parameters

1. Analog to Digital Conversion of Field Data:
4 Seconds @ 2 ms. Sample Rate
2. Demultiplex to Convert From DFS Field Format to Phoenix Trace-Sequential Format
3. Filter and AGC on Raw Data:
Filters: 13/17 - 55/65 Hz
AGC Window: 400 ms.
4. Velocity Filter: 0-30 ms. Trace Pass Band
5. CDP Sort (where applicable)
6. Resample at 4 ms. with Alias Filter
7. Velocity Analysis:
 - a. Apply Results of Velocity Analysis
 - b. Compute Residual Statics on 3 Second Event to Minimize Residual NMO
 - c. Apply Residual Statics to Sorted Output
8. Velocity Analysis (After Residual Statics)
9. Apply 3 Level NMO Function Obtained From Step 8, and Application of Mute
10. Automatic Statics:
Pilot Trace .600 to 3.200 seconds
11. Stack and Apply 2 Second Window AGC
12. Apply Two-Dimensional Deconvolution:
32 Trace, 16-Trace Overlap.

GROUND TEMPERATURE SURVEY

During the first two weeks of June 1975, 223 one-meter-deep ground temperature measurements were made in the Gerlach-Black Rock Desert-Hualapai Flat area (approximately 162 sq mi) (Figure 8).

The purpose was to survey a large area including known geothermal manifestations to see if these areas had characteristic ground temperature patterns that might also be diagnostic of geothermal areas without any other surface expression.

The study shows definite temperature patterns which may be roughly summarized by low temperature on the playas and low elevations and high temperature on the bedrock and higher elevations. The actual cause of this temperature distribution may be any of a number of factors which have yet to be studied: The temperature range in the vicinity of the hot springs is 18.6 to 33.8°C; The temperature range over the rest of the area is 10.1 to 22.8°C; The temperature range on the playas is 12-15°C. The higher alluvial and bedrock areas increase from 16°C near the playas to 18-21°C farther away.

When the results of this survey are compared to the one done in January 1975 (CSM Progress Report, no. 3, 1975), it becomes clear that there is a strong effect due to seasonal temperature and perhaps ground water flow. The playa temperatures have warmed only 2.5°C from January to June (from 9°C to 11.5°C) while the alluvial areas have warmed 12°C in the same time (from 5-6°C to 17-18°C). The Fly Ranch hot springs area shows about an 8°C warming from a range of 9-15°C to 18-23°C.

Interpretation of these data will be done during the spring semester, 1976.

GRAVITY SURVEY

During May and June 1975 about 200 traverse miles of 1/4 mile-spaced gravity readings were taken in the prospect area. The purpose of the survey was to give good definition of the sub-surface structural configuration of the Hualapai Flat and Black Rock Desert basins when interpreted along with the seismic and electrical data. Figure 9 gives the traverse locations.

Readings were taken with a Lacoste and Romberg thermostated gravity meter. Drift corrections and correction to standard absolute gravity were made by monitoring a U.S.C. and G.S. gravity station at the Gerlach railroad station for the duration of the survey. Elevations for all gravity stations were surveyed using a Wild T1 theodolite. Elevation was prolonged from elevation benchmarks which were surveyed in the area during the spring of 1975 by the U.S.G.S., Topographic Division. Processing of this data will involve making free air, simple bouguer and terrain corrections and regional removal. Rock samples have been taken from bedrock exposures and density analyses will be run. The final result will be a contoured map of residual gravity, and cross sections through the area. Model studies will be done to try to duplicate the data (inversion) and a realistic geologic model of the area will be the final result. Figures 10 and 11 show three simple Bouguer Residual Gravity Profiles which are labelled on Figure 9. Table 3 gives the equations and parameters

FIGURE 9
GRAVITY TRAVERSE
LOCATION MAP.

FIGURE 10
GRAVITY PROFILES.

FIGURE 11
GRAVITY PROFILE.

used for this preliminary calculation.

Table 3
Gravity Formulas and Constants

International Gravity Formula:

$$TG = 978049.0 (1.0 + \sin^2\phi(0.0052648 + 0.00002365 \sin^2\phi))$$

Free Air Correction:

$$FAC = H (0.09413 - 0.0001402 \sin^2\phi - 6.7 \times 10^{-9}H)$$

Bouguer Correction:

$$BC = 0.01278\sigma H$$

Bouguer Anomaly:

$$GB = MG - TG + FAC - BC$$

where: GB = Residual Bouguer Anomaly (mgal)

TG = Theoretical Gravity (mgal)

MG = Measured Gravity (mgal)

FAC = Free Air Correction (mgal)

BC = Bouguer Correction (mgal)

ϕ = Latitude

σ = Bouguer Slab Density (2.67 assumed)

H = Elevation (feet).

TIME DOMAIN ELECTROMAGNETIC SURVEY

During June 1975, a time domain electromagnetic survey was done over the Hualapai Flat and Central Black Rock Desert area (see Figure 12). The purpose was to give a complete depth picture of the geoelectric section throughout the area, define faults, etc. In addition to describing the limits of a possible geo-

thermal system, it is hoped that the survey will demonstrate the effectiveness of the method for 3 dimensional structural mapping.

Two orthogonal sources, each 2 kilometers long, were powered alternately with an asymmetric square wave of about 100 amperes peak to peak. A transient electromagnetic field is generated by the current step. The vertical component of this field is detected by a large area loop laid on the ground, and is recorded on a high speed chart recorder. A few examples of the received signals can be seen on Figure 13. Three hundred and thirty-six independent measurements were made.

Data processing will involve converting observed voltages, distances, and currents to a value of apparent resistivity. This is conveniently done only by computer and hence, not done in the field.

The geological evaluation cannot be made until the apparent resistivities have been calculated and mathematical models made to explain all the observed measurements. Nevertheless, considerable insight can be gained immediately from the shape and amplitude of the transient field records. Figure 9 shows some of the variations in signal types.

Vanyan and others (1967) have demonstrated that the voltage detected with a vertical-axis induction loop can be used to calculate an apparent resistivity with the formula

$$\rho_a = \frac{2\pi R^4}{3AIL \cos\theta} V$$

where A is the area of the loop, V is the voltage from the loop, R is the source to receiver distance, I is the source current, L

is the source length, and θ is the angle between the vector R and the normal to the vector L .

An initial interpretation method, then, is to scale off the maximum voltage and calculate a maximum resistivity for each receiver location. The accompanying map (Figure 14) is a maximum resistivity map calculated by this technique.

Vanyan's formula is precisely correct only for source-receiver separations which make the source appear to be a dipole and for $\theta = 0^\circ$. For each receiver location, we measure a signal from each of two sources separately. Since each source appears as a dipole, they may be added vectorially to give an equivalent single dipole whose moment and direction may be changed and rotated. Since the criterion for a dipole source is approximated, the equivalent rotating dipole may be rotated to a position such that the condition $\theta = 0^\circ$ is satisfied and Vanyan's formula is precisely applicable. Research on this new technique will be done along with the data processing phase.

CHAPTER V

ANALYSIS OF THERMAL INFRARED IMAGERY OF THE
BLACK ROCK DESERT GEOTHERMAL AREA

by Dr. Keenan Lee
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ABSTRACT

Airborne thermal infrared scanner imagery was flown over the Black Rock Desert area of Nevada to inventory known geothermal features and to detect unknown thermal effluents. Predawn flights produced imagery that shows all of the known thermal features, as well as many unreported hot springs. In addition to direct sensing of hot springs, the thermal imagery yields useful information on related fractures that may determine the discharge pattern of the thermal waters.

INTRODUCTION

An airborne thermal infrared scanner mission was subcontracted and flown in October, 1974. The primary objectives of the mission were to inventory the known thermal features of a large area (approximately 2500 square kilometers) around the Black Rock Desert near Gerlach, Nevada (Fig. 1), and to use the same thermal imagery to locate unknown thermal features and geologic structures associated with them.

The mission was flown as two separate flights between 0420 and 0730 hours local time on 20 and 21 October 1974. The thermal infrared imaging system used was the Daedalus Quantitative Scanning System, operating in the passband from 8.5-12 μm and recording data directly onto magnetic tape. This scanner has a 77° field of view and an instantaneous field of view of 1.7 milliradians. Most of the flights were conducted at altitudes of 2300 m above terrain, which produced an effective system ground resolution of approximately 4 m. Two low-altitude runs were made over the hot spring areas at Hualapai Flat and Soldier Meadows, at an altitude of approximately 750 m above terrain. More specific details on the mission parameters were discussed by Crewdson in an earlier progress report (1 Aug - 30 Oct 1974).

Data analysis and interpretation consisted largely of qualitative interpretation; no attempts were made to use the magnetic tape data in a quantitative mode. The data from some selected areas were quantized and color-coded to produce false-color facsimiles representing radiance levels, but these false-color images were in turn used for qualitative interpretation. Most interpretation was done on black-and-white positive paper prints at a scale of approximately 1:30,000, and interpretations were annotated directly onto the prints. Initial hydrologic and geologic interpretations were made without reference to published material and without detailed knowledge of the research area. The accuracy and completeness of the interpretation was then checked by comparison with published sources of information (both geology and hydrology) on the Black Rock Desert area and by subsequent field checking. The following examples of imagery interpretation, therefore, represent cases where surface features were first interpreted without prior knowledge of the surface phenomena and which were subsequently verified.

HOT SPRINGS

Gerlach Hot Springs (Line 7)

The hot springs system northwest of Gerlach images well on the nighttime thermal IR imagery (Figure 2). Of the ten main vents of this hot spring system, nine of the vents are apparent on the thermal IR imagery. The one orifice that does not appear on the imagery is in the area of granodiorite bedrock, the temperature of which exceeded the dynamic range of the imagery. All of the springs in the Gerlach system are above 38°C, and most are at temperatures near boiling. In addition to the recognized flowing vent areas, there are several light spots on the imagery that correspond to standing pools of hot water.

McClellan Ranch Hot Springs (Line 6)

Eighteen of the 21 known spring or flowing well occurrences at the McClellan Ranch are apparent on the thermal infrared imagery. Because of the close grouping of the discharge points there are probably more effluents that are below the spatial resolution of the scanner system. Information derived from the present residents of the ranch suggests that there are 19 hot springs and two cold springs, some of which may be flowing wells. The hot waters are reported to have temperatures of 41-43°C.

Figure 2. Predawn thermal infrared imagery at Gerlach, Nevada, showing hot springs and pools. (In this and all following figures: light = warm and dark = cool; scale is about 1:30,000 unless noted otherwise).

Figure 3. Numerous hot springs, hot pools and hot flowing wells of Hualapai (Fly Ranch) Hot Springs. Scale is about 1:10,000.

Trego Hot Springs (Line 6)

The single hot spring along the railroad tracks at Trego images clearly on the imagery. Temperature of the water at the vent is 84.0°C. The discharge point is obvious on the imagery, and its flow can be followed until after it crosses the railroad tracks through a culvert and has dissipated onto the playa.

Hualapai Hot Springs (Line 14)

It appears that all of the hot springs, wells, and hot water pools that are of sufficient size to be resolved can be clearly seen on the thermal infrared imagery (Figure 3). In all cases the thermal anomalies exceed the dynamic range setting of the scanner and are whited out on the imagery. In some cases, this whiteout has carried laterally across the scan line with the result that some objects that probably should have been resolved are not individually separable because of override.

The actual number of thermal features observable on the imagery is too great to warrant counting. Some very small thermal objects show up clearly on the imagery; one of these, which was field checked, has a diameter of only about 1 meter. The temperature of this feature, a spring pool, was measured at 25°C, so this particular feature probably represents well the approximate resolution capability of the

system. Temperature ranges of the springs and wells at Hualapai range from near normal ambient temperatures to superheated water.

Double Hot Springs (Line 11)

Three vents are apparent on the thermal infrared imagery at Double Hot Spring. Two of these were field checked and measured at 73°C and 77°C. The third apparent vent was inaccessible and may actually constitute ponding of the outflow of the two other springs.

Black Rock Springs (Line 10)

Three apparent springs are visible on the thermal infrared imagery (Fig. 4) south of the Black Rock Hot Spring, none of which has been reported in the literature. One of these three springs (Fig. 4,A) has a measured temperature of 41°C; the other two springs (Fig. 4,B&C) have not yet been field checked. Several hot springs between Black Rock Hot Spring and Double Hot Spring were not imaged because of improper flight navigation and resulting lack of sidelap.

Soldier Meadows Hot Springs (Lines 11,12,13, and 15)

A large number of thermal features is present on the thermal infrared imagery in the Soldier Meadows area (Fig. 5).

Figure 4. Previously unreported hot springs south of Black Rock Hot Spring along same fault. "A" is hot spring at 41°C. Fault scarps shown by dashed lines.

Figure 5. Soldier Meadows Hot Springs. Imagery shows only a few of the many thermal features of the area. None of the springs at lower left has been reported previously.

These thermal features cannot be readily counted because many merge into adjacent thermal features, but within them, 49 distinct features appear to be points of issue of thermal waters. A wide range of temperatures was measured in these hot springs, but all seem to be bounded by bimodal temperatures at approximately 21°C and 52°C. Discharges from these springs vary from non-measurable seeps and areas where the total discharge is lost to phreatophyte transpiration to discharges (estimated) of about 30 l/s (~500 gpm). It is difficult to estimate the number of new thermal springs that are on the infrared imagery since the published hydrologic maps show little detail. Certainly there are some new thermal springs that appear on the imagery in an area where no published springs have been reported.

Miscellaneous Observations

An area of warm ground was imaged on Line 13. Field checking indicates no surface flow at this area, although the temperature anomaly no doubt is due to convective heat exchange near the surface of the ground. Soil temperatures were measured within and outside of the thermal anomaly at depths of 30 cm. The temperature inside the thermal anomaly was 23.5°C and just outside the warm ground area the temperature was 20.5°C. The possibility exists that during the time of the overflight (9 months prior to field check) this area of warm ground actually was an area of spring discharge.

It should be noted that some weakly thermal phenomena on the imagery cannot be uniquely interpreted to be hot springs. There exists, in many cases, the ambiguity in interpretation between thermal spring effluents and virile vegetation, particularly since the latter tends to occur along drainages in this environment. For example, Figure 6 shows several temperature anomalies near the Granite Ranch. Some of these anomalies, which are annotated, correspond to spring discharges, although the spring waters are not thermal. Some of the temperature anomalies, however, correspond to trees, in this case cottonwoods and willows.

Summary Comments

All known hot springs were imaged. Throughout the area covered by the thermal infrared imagery all hot springs that were previously known were imaged and are readily apparent on the thermal infrared imagery. Some individual springs cannot be seen separately on the thermal infrared imagery due only to lack of resolution capability of the scanner.

Many "new" hot springs have been interpreted from the thermal infrared imagery. Many more thermal spring effluents have been located on the thermal infrared imagery than have been reported in the hydrologic literature. Certainly some of this stems from the fact that many hot spring effluents were grouped together in the literature that are individually

Figure 6. Thermal anomalies that appear ambiguous on infrared imagery - "S" indicates a spring, "T" indicates a clump of willow trees, "TT" shows rows of cottonwood trees around ranch.

Figure 7. Nonstratified bedrock is granodiorite (Kgr) and dark areas are lacustrine sediments (Q₁).

resolvable on the infrared imagery, but there are many springs that have been located on the imagery that definitely have not been reported in the literature.

The thermal infrared imagery provides little information on the temperature of the hot springs. Because the dynamic range of the Daedalus scanner was gated at 20°C, almost all springs imaged above the dynamic range and show as saturated white on the imagery. Thus, the only information available on the temperatures of these springs is that they are discharging at greater than 20°C. As noted in the above comments, temperatures of the springs range from about 20°C to above boiling temperature (superheated).

The greatest utility of the thermal infrared imagery in this geothermal study lies in its ability to resolve individual spring effluents in an area of known hot springs. No new major hot spring areas were discovered in this area because the major systems have been known for many years. On the other hand, the thermal infrared imagery provides detailed information on the numerous small discharge vents in each hot spring area. Thus, the imagery provides detailed spatial information useful in sampling and measuring all spring discharges, and it helps in mapping the individual springs to determine an overall discharge pattern.

LITHOLOGIC DISCRIMINATION

The thermal infrared imagery in almost all cases provides excellent discrimination between bedrock and surficial unconsolidated deposits. Figure 7 shows a good example of the discrimination of such a contact. In this case the clear discrimination is between bedrock and Quaternary lacustrine sediments, with a narrow band of colluvial and alluvial material along the contact.

Discrimination within bedrock units on the thermal infrared imagery is poor. Generally the only discrimination that can be made with confidence is between non-stratified and stratified rocks. Figure 7 shows a typical example of non-stratified bedrock, in this case Cretaceous granodiorite-quartz monzonite.

Stratified bedrock is distinguished by parallel tonal variations. In the example shown (Fig. 8), the unit is interstratified Tertiary volcanics and volcanoclastic sediments. In the Black Rock Desert area, however, such parallel banding can also arise from landforms such as lacustrine shorelines (Fig. 18).

Figure 8. Tonal banding due to stratified Tertiary volcanic and volcaniclastic rocks.

Figure 9. Vegetation and soil moisture anomalies along fault.

STRUCTURE

The thermal infrared imagery of the Black Rock Desert area portrays well many structural features, especially fault structures. The surface phenomena associated with these faults are of different types and each images differently. Some of the surface features used to interpret faults are the same as those used in conventional aerial photointerpretation: the presence of aligned vegetation, aligned springs or seeps, differences in topographic texture, and stream drainage anomalies. There are, however, surface phenomena associated with some faults in arid regions that are capable of being sensed only with thermal infrared imagery: differences in thermal properties of materials and differences in soil moisture of the surface materials that are not manifest by vegetation.

Figure 9 shows thermal infrared imagery at the southern end of Hualapai Flat. The light dots immediately left of the indicated fault line represent phreatophytes growing along the fault. Immediately to the right of the fault trace, the dark tones represent areas of relatively high soil moisture. In predawn imagery such as this in arid areas, areas of high soil moisture tend to image cooler because of both higher thermal diffusivity and higher evaporative cooling.

Topographic differences remain one of the primary criteria for recognition of faulting, in the interpretation of both

thermal infrared imagery and air photographs. Figure 10 shows such a topographic texture difference, in this case differences in drainage developed on Quaternary lacustrine sediments as opposed to the drainage pattern developed on Quaternary alluvial fans. This texture difference produces a clear lineament, which in this case corresponds to a Holocene fault.

A variation on the use of topography for interpreting faults is the drainage pattern change induced by fault-line scarps and fault scarps. Figure 4 shows several examples of fault scarps that are readily recognizable by the change in drainage pattern along them.

Holocene faults that juxtapose bedrock with unconsolidated surficial deposits are recognized in this area most often by topographic differences. Figure 11 shows such a structural situation, but in this case the fault is recognizable not so much because of topographic differences as because of differences in thermal diffusivities of the juxtaposed materials. Because the bedrock forms an east-facing slope (north is at approximately 2 o'clock), the thermal differences portrayed cannot be attributed to differential solar heating induced by topography. The thermal diffusivity of the unconsolidated materials (mostly alluvial fan material) is considerably greater than the Permo-Triassic metasedimentary and metavolcanic rocks to the left of the fault.

Figure 10. Holocene fault recognized by differences in drainage developed on lacustrine sediments (Q1) and alluvium (Qaf).

Figure 11. Holocene fault that juxtaposes metamorphic bedrock (P_m) and Quaternary alluvium (Q_a).

Faulting within bedrock often can be recognized by tonal lineaments on the thermal infrared imagery. In cases where such faulting juxtaposes rocks of similar lithology, such as in Figure 12, the dark tonal lineament can be attributed indirectly to a topographic low produced by the faulting. This linear topographic low images relatively cool because of unconsolidated Holocene alluvium collected in the topographic low. In this case, again, the surficial deposits have thermal diffusivities that are several times greater than the bedrock, which in this case is Tertiary volcanic rocks.

Faults that occur within bedrock and that juxtapose rocks of differing lithologies also can be recognized clearly in some cases on the thermal infrared imagery. Figure 13 shows a normal fault in bedrock. Bedrock to the top of the fault is Cretaceous quartz monzonite-granodiorite, whereas the bedrock to the bottom of the fault is Permo-Triassic metasedimentary and metavolcanic rocks (the apparent stratification in this latter lithology is due to lacustrine shoreline terraces and is not actual stratification). A sag pond along the fault trace further aids in interpreting this fault.

Faults may sometimes be inferred from the thermal infrared imagery where distinct tonal lineaments occur in unconsolidated sediments. Figure 14 shows such a tonal change

Figure 12. Fault in Tertiary volcanic rocks.

Figure 13. Normal fault juxtaposes quartz monzonite (Kgr) and metamorphic rocks (P_m). Tonal contrast results from different thermal properties of the rocks.

Figure 14. Faulting inferred from linear tonal changes on imagery. Field evidence is not conclusive, because only alluvium is on both sides of the (apparent) fault scarp.

Figure 15. Sand dune field.

that is not explainable either in terms of topographic differences or contrasting thermal diffusivity values, since the material on both sides of the fault is Holocene alluvium and colluvium. The thermal differences across this fault may be interpreted to be due to differences in soil moisture caused by possible ground water damming along the fault. Such an interpretation would suggest that the water table upslope from the fault is deeper than the water table downstream from the fault. An alternative interpretation for the same phenomenon may suggest that upstream from the fault, bedrock is very close to the surface (perhaps a pediment situation), whereas downstream from the fault there is a greater depth to bedrock (implying the downstream block moved down). The unconsolidated deposits upstream from the fault would therefore image warmer because of the lower thermal diffusivity of the underlying bedrock. This interpretation best serves to explain the sharp contact north of the Gerlach Hot Springs (Fig. 2), which, along most of its length, does not correspond to known faulting.

LANDFORMS

Landforms generally appear on infrared imagery because of differences in topography and resulting orientation to solar heating. In addition to drainage anomalies, fault line scarps, and fault scarps discussed already, the primary landforms that show well on the thermal infrared imagery are sand dunes, playa surfaces, and shorelines.

Sand dunes were interpreted at several locations within the study area on the thermal infrared imagery. In a few cases, the dunes are grouped into dune fields, but in most of the area sand dunes are relatively isolated. Figure 15 is an example of a dune field northeast of Gerlach between Hualapai Flat and the Black Rock Desert proper. Very few barchan forms are seen on the imagery; most dune forms appear to be longitudinal. In some cases, the presence, location, and orientation of individual sand dunes is useful to interpret the location of faults. Figure 16 is an example of an area where a bounding fault is defined by the presence of aligned sand dunes. The occurrence of sand dunes along fault lines is not uncommon in desert environments, because ground water seepage along fault lines tends to support vegetation, which in turn tends to collect and stabilize blowing sand (the process seems to be self-propagating).

Figure 16. Oriented sand dunes, with individual dunes aligned along fault. Hot springs along fault show at left.

Figure 17. Playa surface at bottom appears relatively featureless. Old shorelines show above playa.

Playa surfaces image as relatively featureless areas similar to their appearance on aerial photographs. Figure 17 shows the easternmost part of Alkali Flat, a playa in the southern part of Hualapai Flat. The very large playa surface of the Black Rock Desert proper images warm on the predawn October thermal infrared imagery. One possible explanation for this may be that the water table under the playa is everywhere very shallow, often within a few inches of the surface and nowhere deeper than a few feet. This very shallow ground water table may act as a heat sink/source, keeping the playa surface relatively warm during the autumn nights.

Wisconsinian Lahontan (and possibly pre-Lahontan) and Holocene lacustrine shorelines are ubiquitous throughout the study area. Many of these terraced areas are exhibited well on the thermal infrared imagery. Figure 18 shows an area of non-stratified bedrock; the parallel banding exhibited by this area is due to lacustrine shorelines. The succession of shorelines seen in this area ranges from the lowermost shoreline, representing the Holocene Upper Fallon shoreline at an elevation of approximately 3910 feet, to the uppermost Lahontan shoreline, corresponding to either the Wisconsinian Upper Seho or the Eetna maximum, at an elevation of approximately 4380 feet. The thermal banding represents both topographic differences due to the terrace profile and some lithologic differentiation by segregation of coarser and finer material along the old lacustrine wave-cut terraces.

Figure 18. Succession of lacustrine shoreline terraces superimposed on granodiorite.

CONCLUSIONS

The predawn aerial thermal infrared imagery proved useful in this geothermal study for providing basic geologic information on lithology, structure, and landforms. This basic geologic information is necessary to provide a reasonable framework for the hydrogeologic interpretation of any geothermal system.

Lithologic discrimination in the study area was restricted largely to the discrimination of bedrock from non-bedrock units. Discrimination in these cases was generally excellent. Discrimination within bedrock was generally rather marginal; the most reliable interpretations could be made differentiating stratified from non-stratified units only.

Geologic structural information interpreted from the imagery was restricted largely to fracture information; no folds were interpreted because of minimal stratified bedrock. Most of the major faults in the area that previously had been recognized were interpreted on the airborne thermal infrared imagery. Many lineaments were interpreted on the thermal infrared imagery in addition to known faults. Some of the lineaments interpreted from the imagery were faults. None were cultural features. Most lineaments picked on the imagery turned out to be probable, but still unverified, faults. In many cases, lineaments falling into this category were checked in the field, but field evidence was insufficient to determine

whether in fact there was or was not faulting. Some very recent (Late Fallon) faults of very subtle expression (fault scarps with less than two meters of relief) were detected.

Landform analysis was readily performed with the infrared imagery. Solitary sand dunes and dune fields, playa lake surfaces, fault line scarps, and fault scarps were the main landforms interpreted. Many of these landforms are directly related to the location of the hot springs.

Thermal features that were imaged directly are all interpreted to be manifestations of convected and advected heat. No thermal features were observed on any of the imagery that can be attributed to conductive heat phenomena. All known hot springs within the survey area that are of sufficient size to be resolved by the scanner system were in fact found on the thermal IR imagery. Numerous surface thermal features were found on the imagery that do not correspond with any known (published) thermal features.

The main utility of the thermal infrared imagery lies in its ability to show spatial relationships between the surface thermal discharges. The surface map aspects can be utilized for measuring and sampling the thermal discharges and for establishing relationships between them. No quantitative information is available on the surface temperatures of these springs, because in all cases the temperature of the thermal waters exceeded the dynamic range of the scanner system.

RECOMMENDATIONS

Despite the utility of the thermal infrared imagery for locating surface features associated with the Black Rock Desert geothermal system, it remains to be demonstrated that the use of such imagery is economically justified. Exclusive of subsequent labor costs for interpretation and field verification, the cost of the subcontract involved with obtaining the thermal infrared imagery was \$9,500. Since the thermal infrared mission covered approximately 2500 square kilometers, the cost breakdown is approximately \$3.80/km². The cost for color infrared photography at a comparable scale (1:30,000) would be about \$3.00/km².

In this type of desert environment, color infrared photography generally is admirably suited to providing the same types of information as that discussed from thermal infrared imagery. Basic geologic information of greater detail, of higher accuracy, and of less ambiguity probably could be derived from the CIR photography. Because all of the thermal hot springs have definite phreatophytic vegetation associated with them, it is probable that these springs would show clearly on the CIR photography.

Therefore, one major recommendation derived from this study would be that color IR photography should be flown over this or a similar area and the results compared to those from the thermal infrared study.

CHAPTER VI

PRELIMINARY REPORT OF GEOCHEMICAL INVESTIGATIONS OF
THERMAL AREAS IN THE GERLACH-HUALAPAI FLAT-
BLACK ROCK DESERT-SMOKE CREEK DESERT REGION

INTRODUCTION

This preliminary report includes a summary of basic geochemical data gathered to date by J. Anderson from the Gerlach and Fly Ranch hot spring systems in particular and from other thermal and non-thermal waters in the Black Rock-Smoke Creek desert region Plates V and VI. Reconnaissance of the region was undertaken in December 1974 and January 1975, and detailed investigations took place during the summer of 1975.

The data presented are being analyzed. Hence, significant conclusions which may be born from them will be forthcoming - probably by spring 1976 - in subsequent progress and final reports.

GERLACH THERMAL AREA

The Gerlach hot spring system lies one mile northwest and west of the town of Gerlach at the southeast and south end of the Granite Range along the northwest margin of the southwestern portion of the Black Rock Desert (Plate V, Figure 1). The system comprises two spring clusters: the Great Boiling springs on the northeast (Figure 2) and the Mud springs on the southwest (Figure 3). The springs issue from grassy areas covering Lake Lahontan

clay and silt. Fault scarps, inches to several feet high with usually the west side up, appear to extend control over the location of the two spring clusters.

The southern end of the Granite Range consists of relatively uniform medium-grained granodiorite which contains several scattered rather elongate (north-south) inclusions of amphibolite. At least three transverse fracture zones cross the range and project into the Great Boiling spring area (Figure 1). Joint attitudes are largely random as determined from 150 specific measurements.

An upfaulted block of altered granodiorite and lake beds is situated between the Great Boiling springs area and the Granite Range (Figure 1). This block is being studied in some detail (Romberger, this report), because it is believed to represent an exposed part of an ancestral Gerlach hot spring system.

The Great Boiling springs area (Figure 2) contains over 70 springs ranging in temperature from a few degrees above ambient to superheated. Individual spring temperatures (Table 1) measured in July 1975 are recorded and compared with temperatures recorded by Harrill in July 1973 (Harrill, 1973, in Olmstead and others, 1975). During the two year interval mud vent activity, ground surface cracking, and some spring temperatures have increased mainly in the northern part of the spring area and to a minor extent in the southwestern part. The mud vents have high silica and chloride content compared to the springs.

A mud vent near spring #23 (sample G-23 mv) departs from the "local" norm as far as the chemical makeup of the water is con-

LEGEND

Qp = playa

Qf = alluvial fan

Ql = Lake beds

Ql₂ = near shore dep.

Tb = basalt

Kgd = granodiorite

Kgdh = altered Kgd & alluvium

Kgdp = pediment

gi = amphibolite (gabbroic)

SCALE: 1" = 4800'

Faults - - - - -

lineations

Fig. 1 -- Geologic map of the Gerlach thermal area by J. Anderson during summer of 1975.

FIGURE 2.--Map of Gerlach Thermal area (Great Boiling Springs).

-based on work by Berry and Downs, 1966, by Harrill, 1973, in Olmstead and others, 1975, and field work done by J. Anderson in July, 1975.

Fig. 3. -- Map of the mud Springs (southwest of the Great Boiling Springs) based on work by Harrill, 1975 in Olmstead and others, 1975, and work by J. Anderson, June, 1975

GREAT BOILING SPRINGS

SPRING NUMBER (Fig. 2)	TEMPERATURE – JULY, 1975 (°C)	TEMPERATURE – JULY, 1973 (°C)	DIFF.
1	64.5	60.6	+ 3.9
2	49.0	40.0	+ 9.0
2M.V.	59.3	- - -	- - - -
3	64.1	49.4	+14.7
4	32.3	42.2	- 9.9
5	44.0	50.0	- 6.0
6	29.0	33.3	- 4.3
7	dry	36.7	- - - -
8	dry	43.3	- - - -
9	75.0	72.2	+ 2.8
10	69.8	50.5	+19.3
11	69.5	31.7	+37.8
12	- - -	33.9	- - - -
13	61.0	70.0	- 9.0
14	41.8	36.7	+ 5.1
15	30.0	35.6	- 5.6
16	47.5	36.7	+10.8
17	dry	57.8	- - - -
18	58.0	50.6	+ 7.4
19	90.0	96.1	- 6.1
20	38.3	48.3	-10.0
21	44.5	59.4	-14.9
22	55.3	40.6	+14.7
23	35.1	48.3	-13.2
24	93.5	33.3	+60.2
25	56.6	48.3	+ 8.3
26	62.8	61.7	+ 1.1
27	63.0	33.3	+29.7
28	95.5	42.8	+52.7
29	44.0	47.8	- 3.8
31	60.5	74.4	-13.9
35	32.0	27.2	+ 4.8
37	65.0	48.9	+16.1
39	48.5	52.2	- 3.7
40	31.8	35.6	- 3.8
41	72.8	58.9	+13.9
42	28.3	28.9	- 0.6
43	45.8	43.3	- 2.5
44	55.8	56.7	- 0.9
45	60.3	59.4	- 0.9
46	83.8	86.7	- 2.9
48	51.5	- - -	- - - -
49	42.0	- - -	- - - -
50	84.0	92.2	- 8.2
51	43.8	51.1	- 7.3
52	48.0	61.1	-13.1

TABLE # 1 Temperatures and differences with Harrill, 1973 observations – based on work by Harrill, 1973 in Olmstead and others, 1975, and field observations by J. Anderson, July, 1975.
– blank spaces are for new or dry spring.

SPRING NUMBER (Fig. 2)	TEMPERATURE – JULY, 1975 (°C)	TEMPERATURE – JULY, 1973 (°C)	DIFF.
53	76.8	60.0	+16.8
54	65.3	44.4	+20.9
55	53.0	34.4	+18.6
56	dry	70.0	- - - -
58	78.0	77.8	0
59	53.6	58.9	- 5.3
60	82.0	86.7	- 4.7
61	63.0	47.8	+15.2
62	56.3	43.3	+13.0
63	28.0	55.6	- 27.6
64	67.0	66.1	+ 0.9
65	69.8	73.3	- 3.5
66	51.0	67.8	- 16.8
67	43.3	57.7	- 14.4
69	52.8	32.2	+20.6

TABLE #1

MUD SPRINGS THERMAL AREA

SPRING NUMBER (Fig. 3)	TEMPERATURE – JULY, 1975 (°C)	TEMPERATURE – JULY, 1973 (°C)	DIFFERENCES (°C)	
1 pool	74.0	73.3	+0.7	3.5 l/sec flow
vent	62.3	86.7	- 24.4	
2	60.5	60.6	0	1.5 l/sec flow
3	65.5	65.6	0	
4	85.0	85.0	0	
5	72.5	72.8	0	
6	38.8	37.8	+ 1.0	
7	50.0	50.0	0	
8	52.0	51.1	+ 0.9	
9	84.3	84.4	0	
10	43.6	44.4	- 0.8	small flow
11	40.6	- - -	- - - -	vent in dug hole
12	44.0	44.4	0	
13	42.0	38.6	+ 3.4	
14	56.3	59.4	- 3.1	

TABLE #2 Temperatures of Mud Springs thermal area and differences compared to Harrill's observations of 1973 (Olmstead and others, 1975) – work done by J. Anderson in July, 1975.

cerned. This sample site consists of a small (2 in. diameter) pool (vent) in the center of recent mud vent activity. The temperature did not correspond to the high temperature found in the other mud vent areas, being only 35.1°C. The pH value of 4.45 also departs from the normal neutral values.

The silica content of this site is the same for the region in general being 174 mg/l. Conductivity increases from values around 7,600 to 27,600 microhms/cm. Other constituents which noticeably increase are: 1) Cl - from 2200 to 4950 mg/l; 2) SO₄ from 350 to 1350 mg/l; 3) Na from 1550 to 1900 mg/l; 4) K from 140 to 270 mg/l, and 5) Ca from 75 to 150 mg/l.

Since this spring site is close to the crack observed (Figure 2) it is possible that this site represents the true nature of the reservoir fluids. This mud vent area was no longer active, but increases in spring temperatures in this region could reflect an unstable condition. Therefore, it could be possible that this water is not in equilibrium, but saturated due to flashing at depth. This might explain the increase in temperature of nearby vents, and the increase in dissolved solids.

The Mud springs area (Figure 3) contains 14 springs aligned in an east-west direction. This spring area appears to have remained at fairly constant temperature (Table 2) and appears more stable than the Great Boiling spring cluster.

FLY RANCH THERMAL AREA

The Fly Ranch hot spring cluster lies along the western margin of Hualapai Flat 15 miles north of Gerlach (Plate V, Figure 4). The springs issue from a rather equidimensional mound nearly 2000 feet in diameter and bounded on the east side by a prominent east-facing fault scarp. The mound appears to be largely built up of hot spring deposits over the alluvium- and soil-veneered floor of Hualapai Flat. Bedrock of Permo-Triassic metavolcanics and Tertiary flows and volcanoclastics crop out about one mile west of the springs. A master north-south fault occurs between the springs and bedrock and it probably serves as the major subsurface conduit for the hot water. The spring cluster is located on a north-northeast trending intrabasin horst of Holocene age (Grose and Keller, 1975). Geological and geophysical features of the surrounding area are introduced in this and in other CSM Progress Reports.

The Fly Ranch hot spring cluster includes about 40 springs and two wells that range in temperature from near ambient to superheated (Figure 5, Table 3). The Western Geothermal, Inc. well, drilled in 1964 to a depth of about 1000 feet, still flows flashing superheated (96°C) water (Figure 5). At the Geyser well, water temperature dropped sharply after a week of rain, then slowly increased over a two-week period. About 5 miles south of the hot springs, Western Geothermal drilled an 800 ft deep well at Granite Creek Ranch. Shallow high temperature was encountered and the well blew out. In Hualapai Flat north of the hot spring area, many irrigation wells produce hot water.

Fig. 5 -- Hualapai Flat Thermal Area (Fly Ranch)

-by J. Anderson July, 1975, based on U.S.G.S. air photo GS-SWIR
1-9 and work by Berry & Downs, 1966

SPRING (Fig 5)	TEMPERATURE (JULY, 1975)	pH	REMARKS
H-1	32.4	8.4	
H-2	33.0	8.36	
H-3	35.0	8.4	
H-4	27.0	8.4	
H-5	31.0	8.2	
Geyser Well	86.0	8.4	Temp. after rain; 56°-3 days, 70°-8 days, 86°-14 days
H-8	43.0	7.5	
H-9	32.4	8.4	
H-10	35.0	8.4	
H-11	37.0	8.5	
H-12	39.0	8.28	
Western Well	96.0	7.2	Western Geothermal Well
H-14	34.0	8.6	
H-16	94.0	7.2	Well - travertine cone
H-17	32.0	8.15	
H-18	91.0	7.15	Well - travertine cone
H-19	34.6		
H-23	38.5		
H-24	29.0		
H-26	56.5	7.18	
H-27	31.5	7.9	
H-28	36.0	7.75	
H-29	35.0		
H-30	30.5	7.8	
H-31	35.0		
H-33	44.0		
H-34	33.0		
H-38	47.6		
H-41	33.5		
H-42	51.3		
H-45	40.0		
H-46	27.0		
H-47	28.0		
H-48	28.0		
H-49	32.0	7.95	
H-50	42.0	7.75	
H-54	38.3		
H-59	35.0	7.95	
H-61	47.9		
H-62	45.6		
H-63	82.0	7.15	Hottest sp. - trav. terrace
H-69	37.0	7.55	
H-70	35.3	7.5	
H-72	29.0	7.7	

Table 3 -- Temperature and pH data of Fly Ranch thermal area
-by J. Anderson, July, 1975

SPRING (Fig 5)	TEMPERATURE (JULY, 1975)	pH	REMARKS
H-76	29.3	7.7	
H-82	32.0	8.0	
H-83	30.0	7.7	
H-85	58.0	7.15	

Table 3 -- Temperature and pH data of Fly Ranch thermal area
-by J. Anderson, July, 1975

WATER ANALYSES

Water samples were collected for analyses in the region from Pyramid Lake on the south to Soldier Meadows on the north (Plate V). Most of the analyses are included in the Appendix.

The water samples were collected from the orifice of the spring or well, or as close to it as possible. Field determinations were made of water temperature, conductivity, pH, alkalinity, silica, sulfate, chloride, bicarbonate, carbonate, and hardness. Atomic absorption spectrophotometry was used to determine calcium and magnesium, and flame photometry was used to determine sodium, potassium, and lithium. Boron and fluoride were determined colorimetrically using a spectrophotometer.

On a regional basis it appears that the principal cation in all of the springs is sodium. Bicarbonate is the principal anion in the northern areas (Soldier Meadows, Double Hot, Pinto Mt., and Hualapai Flat), and chloride is the principal anion in the southern areas (Trego, Gerlach, and Pyramid Lake). A zone of bicarbonate chloride water with an increase of sulfate occurs

between Black Rock and Trego thermal areas and between Hualapai Flat and Gerlach thermal areas. Apparently the chloride concentration increases markedly in the deeper parts of the Black Rock Desert.

CHEMICAL THERMOMETRY

The chemical composition of thermal spring waters can be used to estimate thermal aquifer temperatures. Qualitative indicators of high subsurface temperatures are low Mg/Ca ratios, high Na/Ca ratios, high ratio of chloride to total carbonate, high Cl/F ratio, and the Ca and HCO_3 content of the thermal waters (Tonani, 1970).

Quantitative estimates of reservoir temperatures have been determined thus far for 8 thermal springs in the Black Rock region (Table 4). They were obtained using silica content, Na/K ratios, Na-K-Ca formula, and the silica correction method of Fournier and Truesdell (1970, 1974).

SPRING AREA	SURFACE TEMPERATURE	Silica	Na/K	Na/K-1/3Ca	Na/K-4/3Ca	Silica Corr.
GERLACH	30 to 97	175-200	175	205	230	
Fly Ranch	25 to 96	125	115	154	125	
Pyramid L.	60 to 82	140	175-225	210	177	195-213
Pinto Mt.	93	165	155	180	165	
Sold. Mea.	44 to 63	115	34	100	65	
Dou. Hot	77.6	140	65	130	115	
Bl. Rock	94.5	150	30	120	150	
Trego	86.0	128	50	120	112	

Table 4. - - Estimations of subsurface temperature using the various chemical geothermometers.
 - by J. Anderson July, 1975

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APPENDIX

This appendix is a record of 92 water sample analyses in the Black Rock-Smoke Creek Desert region (Plates V and VI). Twenty-one are from the Gerlach thermal area; 12 are from the Fly Ranch hot springs; 24 are from Hualapai Flat; and 35 are from other localities in the greater region from Pyramid Lake to Soldier Meadows.

The sample numbering system indicates the location from which the sample was taken by township/range-section and quarter section. For example, sample 34/27-9a was from T34N, R27E, sec. 9, NE 1/4. Letters a, b, c, and d refer to the NE, NW, SW, and SE section quarters respectively.

Sample designation beginning with G refers to Great Boiling spring cluster in the Gerlach area and the number refers to the specific spring shown on Figure 2. Samples beginning with MS refer to the Mud Spring group in the Gerlach area and the number refers to the spring shown on Figure 3. The Fly Ranch springs are prefaced by H with reference to Figure 5 for location. Many water samples collected at various places in the region are located on Plate V. Sample localities in Hualapai Flat (outside the Fly Ranch spring cluster) are illustrated on Plate VI.

All temperatures are in °C; conductivity is expressed in microhms/cm; and values of amounts of constituents present are indicated in mg/l.

LABORATORY REPORT
GROSS WATER ANALYSIS COLD WATER

DATE: JUNE, 1975

SAMPLE DESIGNATION	32/23-18 Godey-well	33/23-23 Bowen Ck	33/23-36 Playa W.	33/22-28 Deephole	34/23-25 Gran. Ck	39/27-30 Cain Sp.	33/25 Coyote Sp	36/24-11 Caine Sp	36/23-36 Negro Ck.	34/23-3b
pH	9.7	9.1	8.1	8.1	7.5	8.1	7.6	7.9	7.4	8.3
Temperature	20.0	26.0	17.0	13.0	26.0	23.5	22.0	23.0	23.0	19.0
TDS (20 °C)					135	136	3060	250	166	
Conductivity					229	264	5150	325	130	
HCO ₃	453	230	----	----	284	120	1210	107	75	200
CO ₃ ⁻	0	0	0	0	0	0	0	0	0	0
Cl ⁻	690	192	1680	106	21	12	1170	32	13	177
SO ₄ ⁻	280	52	10	38	9	15	5.8	24	12	55
Total Anions										
Na ⁺	1000	152	2050		18	55	1175	75	21	55
K ⁺	47	21	75	4.5	3.5	.6	17	10	7	8.5
Ca	1.9	.2	5.5	.2	19	7	12	23	8.5	18
Mg					3.8	.2	20	8.5	4.0	.2
Total Cations										
SiO ₂	20	45	61	50	18	36	58	74	64	59
F					.1	.3	1.5	.1	.1	.1
B					.1	.3	4.5	.1	.1	.1
CaCO ₃ hardness	618				63	17	109	95	38	170
Na/K Ratio										
H ₂ S	5									

COMMENTS:

LABORATORY REPORT

GROSS WATER ANALYSIS Pyramid Lake (needles) and cold water of the region

DATE: Aug, 1975

SAMPLE DESIGNATION	26/21-6 St. Ceyser	26/21-7 PL-1	26/20-12 PL-3	26/20-12 PL-4	PL-Lake	29/21-35c	23/22-9d	29/21-2	28/21-12	26/20-16b
pH	8.4	7.6	7.4	7.8	7.1	8.7	7.4	8.7	7.2	6.8
Temperature	66.0	65.6	82.0	60.3	22.0	19.6	18.3	19.6	17.0	17.3
TDS (20 °C)	4225	4680	4615	3770	5590	364	488	460	585	850
Conductivity	6500	7200	7100	5800	8600	560	750	710	900	1310
HCO ₃	22	100	50	110	580	110	150	110	130	160
CO ₃ ⁻	0	0	0	0	260	0	0	0	0	0
Cl ⁻	1880	1850	1950	1760	3250	40	50	50	68	18
SO ₄ ⁻	340	330	335	350	260	110	175	175	225	300
Total Anions										
Na ⁺	1100	1150	1040	1040	1460	32.5	50	34	40	325
K ⁺	160	200	120	120	112	7.4	8.2	10	7.6	3.4
Ca	260	315	163	198	651	58	81	95	77	109
Mg	.1	.4	.1	.3	1.7	.1	.2	.3	.2	.4
Total Cations										
SiO ₂	110	82	117	110	38	52	34	52	46	42
F	3.0						.9		1.0	.2
B	6.1									.1
CaCO ₃ hardness	450		460							
Na/K Ratio										
H ₂ S	0	2	0	2	0	0	0	0	0	0

COMMENTS:

LABORATORY REPORT
GROSS WATER ANALYSIS

DATE:

SAMPLE DESIGNATION	40/27-23b	37/25-9d	37/25-10d	37/27-8d	34/80-35c	33/23-26d	33/25-10b				
pH	7.7	7.3	7.8	8.1	7.4	7.4					
Temperature °C	15.6	15.5	36.0	15.8	15.5	16.0	20.0				
TDS (20°C)	290	324	324	2070	767	795	880				
Conductivity	376	451	446	3280	814	1104	1225				
HCO ₃ ⁻	151	148	165	1150	166	361	88				
CO ₃ ⁻	0	0	0	0	0	50	15				
Cl ⁻	28	42	32	500	120	160	272				
SO ₄ ⁻	21	32	45	95	65	80	165				
Total Anions											
Na ⁺	65	65	77	792	75	305	275				
K ⁺	11	5.5	11	15	1	10	9				
Ca	12	18	10	11	60	18	15				
Mg	2.5	7	3.0	5.6	14	5	4				
Total Cations											
SiO ₂	80	84	80	70	26	45	100				
F	.4	1	1.5	3.9	.3		.26				
B	.15	.1	.2	7.9							
CaCO ₃	37	74	35	50	78		58				
Na/K Ratio											

COMMENTS:

LABORATORY REPORT
GROSS WATER ANALYSIS

DIST.

SAMPLE DESIGNATION	40/24-23 SOLD. MEA	40/24-23 SOLD. ME.	40/28-19 W. Pinto	40/28-21 E. Pinto	36/26-4 Deu. Hot	36/26-76 D.H.-2	36/26-76 D.H.-3	36/26-21 D.H.-4	36/26-33 Bl. Rock	35/23-10 D.H.-7
pH	8.55	7.6	7.7	7.2	7.98	7.25	6.95	7.10	7.50	8.1
Temperature °C	54.0	48.0	93.3	94.0	77.6	68.5	73.5	68.5	50.5	94.5
TDS (20 °C)	275	272							1330	
Conductivity microhms/cm	360	360	1500	1560	910				2050	6650
HCO ₃ ⁻	90	96	280	500	250	230	275	280	902	952
CO ₃ ⁻	3	0	2	1	2	0	0	0	0	0
Cl ⁻	18	21	160	160	80	110	120	120	180	790
SO ₄ ⁻	35	39	190	120	120	120	140	135	130	290
Total Anions										
Na ⁺	74	76	325	325	225	230	260	265	570	1500
K ⁺	1	1.3	26	26	4.5	4.5	5.6	10	12	20
Ca	3.5	2.6	5	19	15	17	15	18	24	36
Mg	1.1	1.4	.1	.3	.1	.1	.15	.19	.19	4
Total Cations										
SiO ₂	63	65	162	155	105	130	112	86	70	120
F	12	10	15.0	14	10	10	9.4	10	9	14
B	.5	1.0	7	7	2.0	2.1	2.0	1.8	2.8	4
CaCO ₃	11	12			230	230			52	
Na/K Ratio										
Li			.5	.5	.65					.25

COMMENTS:

LABORATORY REPORT
GROSS WATER ANALYSIS

34/22-18

all values in mg/l

DATE:

SAMPLE DESIGNATION	New sp.	Squaw Ck.	H-1	H-3	H-Geyser	H-5	H-8	H-West.	H-16	H-18
pH	7.8	34/22-18	8.4	8.4	8.4	8.2	7.52	8.4	7.2	7.15
Temperature °C	29.0	10.0	32.4	35.0	84.0	31.0	43.0	96.0	94.0	91.0
TDS (°C)										
Conductivity microhms/cm								1800		
HCO ₃ ⁻			446	458	484	450	456	458	486	452
CO ₃ ⁻	0	0	0	0	0	0	0	0	0	0
Cl ⁻	28	26	250	240	260	240	245	275	250	245
SO ₄ ⁻					260		250	46		
Total Anions										
Na ⁺	25	298	380	380	456	424	405	386	405	400
K ⁺	7	4	17	17	17	17	16	17	17.5	18
Ca	32	30	28	24	32	22	18	22	22	28
Mg			.2	.2	.18	.15	.2	.2	.19	.2
Total Cations										
SiO ₂	86		88	89	90	88	84	90	90	88
F								7		
B								2		
Na/K Ratio	6.0	126.6	37.9	37.9	40	42.4	43	38.6	39.3	37.7

COMMENTS:

LABORATORY REPORT
GROSS WATER ANALYSIS

DATE:

SAMPLE DESIGNATION	H-82	H-41	H-50	H-63
pH	8.0	7.9	7.95	7.15
Temperature °C	32.0	33.5	32.0	82.0
TDS (°C)				
Conductivity				
HCO ₃	440	448	452	456
CO ₃ ⁻	0	0	0	0
Cl ⁻	245	260	250	255
SO ₄ ⁻	368	380	380	390

Total Anions

Na ⁺	400	440	430	405
K ⁺	17.5	16	15	14.5
Ca	20	18	17	24
Mg	.2	.2	.2	.2

Total Cations

SiO ₂	82	90	82	86
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F

B

Na/K Ratio	38.8	46.7	48.7	47.5
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COMMENTS:

LABORATORY REPORT
GROSS WATER ANALYSIS

DW 31

SAMPLE DESIGNATION	33/25- T-200	33/25- McC -1	33/25- McC -2	G-3	G-9	G-18	G-22	G-23mv	G-24	G-27
pH	8.13	8.6	8.4	7.70	7.58	8.30	8.2	4.45	7.60	7.80
Temperature °C	86.0	36.3	33.5	64.1	75.0	58.0	55.3	35.1	93.5	63.0
TDS (20 °C)			1410							
Conductivity microhm/cm	2300	2150	1930			7,600		27,600	7,800	
HCO ₃ ⁻	188	102	93	83	90	84	83	10	66	82
CO ₃ ⁻	0	14	15	0	0	0	0	0	0	0
Cl ⁻	280	290	275	2430	2100	2230	2400	4950	2080	2180
SO ₄ ⁻	86	141	156					1350	360	
Total Anions										
Na ⁺	345	315	310	1800	1560	1560	1800	1900	1590	1590
K ⁺	10	21	12	150	110	135	128	270	135	148
Ca	25	21	14	80	73	73	75	150	73	75
Mg	.2	.2	.4	2.3	2.0	2.5	2.5	12.2	2.0	2.2
Total Cations										
SiO ₂	85	86	94	186	178	186	180	174	172	176
F	5.0	2.7	2.8	5.0						
B	9			10						
CaCO ₃	154	35	35	70	74			8.2	54	
Na/K Ratio										
H ₂ S	5.0							.5		

COMMENTS:

LABORATORY REPORT
GROSS WATER ANALYSIS GERLACH AREA

DATE:

SAMPLE DESIGNATION	G-28	G-19	G-37	G-43	G-46	G-55	MS-1	MS-2	MS-9	MS-13	
pH	7.20	7.40	7.75	6.80	7.65	7.0	8.29	8.15	6.95	7.15	
Temperature °C	95.5	98.0	65.0	45.8	83.8	78.0	74.0	60.5	84.3	42.0	
TDS (°C)											
Conductivity	7620				7600						
HCO ₃	156				83						
CO ₃ ⁻	0	0	0	0	0	0	0	0	0	0	
Cl ⁻	2180	2100	2340	2230	2350	2130	2075	2100	2130	2400	
SO ₄ ⁻	410			356	400	360			290		
Total Anions											
Na ⁺	1560	1610	1420	1760	1360	1600	1540	1530	1470	1600	
K ⁺	134	140	133	130	136	140	134	135	143	131	
Ca	68	95	70	69	96	73	174	75	73	50	
Mg	2.4	1.0	2.2	2.3	2.3	2.3	2.5	2.8	2.4	2.3	
Total Cations											
SiO ₂	172	174	192	172	172	180	172	172	165	172	
F					4.8						
B					10						
CaCO ₃	128										
Na/K Ratio		19.5			17			19			

COMMENTS:

LABORATORY REPORT
GROSS WATER ANALYSIS GERLACH AREA

DATE:

SAMPLE DESIGNATION	MS-Well	Borax P	32/23-15a	32/23-10a						
pH	9.05	8.2	7.6	7.73						
Temperature °C	19.0		63.0	97.0						
TDS (20 °C)										
Conductivity microhms/cm										
HCO ₃ ⁻	74		74	84						
CO ₃ ⁻	0	0	0	0						
Cl ⁻	65	2100	1915	2150						
SO ₄ ⁻		367	356	386						
Total Anions										
Na ⁺	40	1560	1380	1440						
K ⁺	4	134	130	121						
Ca	72	78	74	73						
Mg	6.2	1.3	1.0	2.2						
Total Cations										
SiO ₂	26	174	282	184						
F										
B										
Na/K Ratio	17	19.8								

COMMENTS:

LABORATORY REPORT

GROSS WATER ANALYSIS Cold Water of Hualapai Flat region

DATE: JUNE, 1975

SAMPLE DESIGNATION	34/23-35a	34/23-3b	35/23-23a	35/23-24a	35/23-26a	35/24-6c	35/24-17c	34/23-1a	34/23-10a	34/23-25b
pH	8.2	8.4	8.2	8.3	8.2	8.1	7.6	7.6	7.2	7.3
Temperature	14.0	15.0	24.0	24.5	24.0	26.0	14.0	19.0	22.0	13.0
TDS (°C)										
Conductivity	840	4200	440	420	480	430	790	435	775	703
HCO ₃	244	548	174	172	202	166	237	173	223	220
CO ₃ ⁻	0	45	0	0	0	0	0	0	0	0
Cl ⁻	128	762	43	38	43	44	102	35	93	86
SO ₄ ⁻	76	390	61	56	62	77	67	18	67	41
Total Anions										
Na ⁺	114	796	121	42	53	82	126	46	54	109
K ⁺	26	23	16	17	13	39	41.8	7.5	9.6	2.3
Ca	41	18	34	31	39	1.8	7.5	30	72	30
Mg	13	17	13	13	14	1.0	1.0	8.5	21	10.0
Total Cations										
SiO ₂	65		34		35		68	67	89	36
F								.1	.1	.1
B								.1	.1	.1
CaCO ₃ hardness	154	114	140	132	154	8	22	110	265	114
Na/K Ratio										

COMMENTS: Locations on Plate XI

LABORATORY REPORT
GROSS WATER ANALYSIS

Hualapam Plats. (cold waters)

DATE:

SAMPLE DESIGNATION	34/24-66	35/23-11d	35/23-13d	35/23-25d	35/24-31d	36/23-26d	35/24-36d				
pH	7.9	7.1	7.8	7.3	7.7	7.2	8.8				
Temperature °C	16.0	17.0	18.4	21.0	17.0	13.0	15.5				
TDS (20 °C)	290	275	245	329	266	357	499				
Conductivity microhms/cm	409	380	339	509	366	560	776				
HCO ₃ ⁻	175	159	148	178	160	205	257				
CO ₃ ⁻	0	0	0	0	0	0	20				
Cl ⁻	27	29	23	46	20	35	62				
SO ₄ ⁻	20	22	16	37	16	67	47				
Total Anions											
Na ⁺	38	45	32	35	33	40	172				
K ⁺	8.8	8	5	9	7	5	12				
Ca	30	21	25	44	26	46	3.6				
Mg	10	8.8	9	12	10	20	1.2				
Total Cations											
SiO ₂	69	65	61	60	66	42	65				
F	.1	.2	.2	.1	.2	.1	1.4				
B	.1	.1	.1	.1	.2	.2	.5				
CaCO ₃	116	88	100	168	104	198	13				
Na/K Ratio											

COMMENTS: Locations on Plate VI