GL04059

FIELD TRIP #4

Reno to
Brady - Desert Peak - Humboldt House
Golconda - Getchell

19 - 20 May 1983

FIELD TRIP LEADER:
Joe Moore

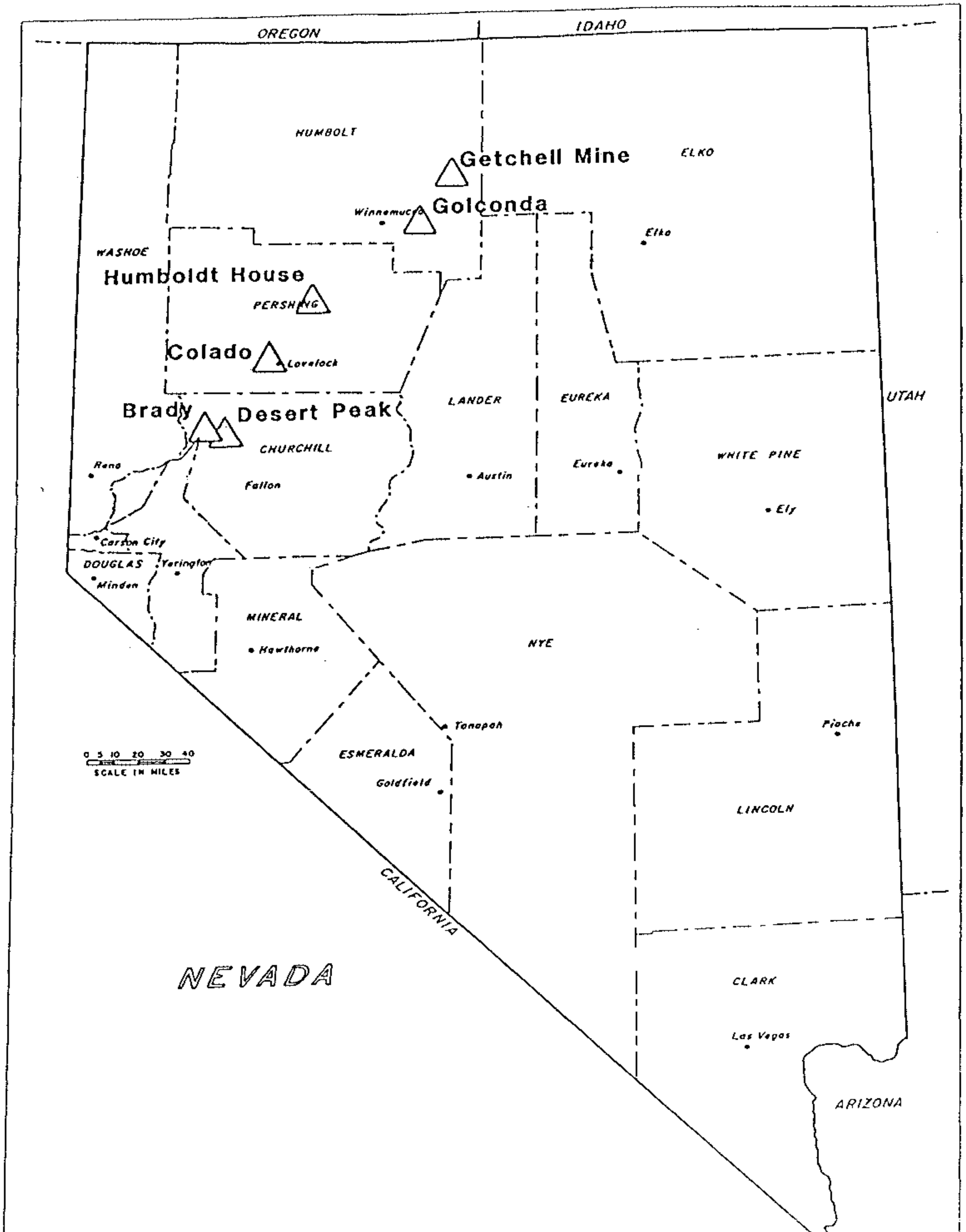
University of Utah Research Institute
Salt Lake City, UT

A Symposium on the Role of Heat
in the Development
of
Energy and Mineral Resources
in the Northern Basin and Range Province

16 - 18 May 1983

Reno, Nevada

TABLE OF CONTENTS



LOCATION MAP

ROADLOG - RENO TO WINNEMUCCA

PART I - RENO TO DESERT PEAK

by W. R. BENOIT

Interval Miles	Cumulative Mileage	
0	0	START - MGM GRAND, RENO, WEST ENTRANCE The hotel is located on a filled-in gravel pit. The Truckee River deposited an extensive sheet of gravel in this area. The fenced-in lake at the MGM is part of the gravel pit.
3.8	3.8	Junction of McCarran Boulevard with Interstate 80.
2.0	5.8	Vista Exit. This is the Truckee Meadows, a low marshy area along the Truckee River. The U.S. Army Corps of Engineers deepened the river channel in this area to lessen flood water effects and to lower the water table.

Ahead is the upper end of the canyon that the Truckee River has cut through the Virginia and Pah Rah Ranges. The Pah Rah Range is north of the river and the Virginia Range is south of the river. In a very general way, this range is a large syncline. At both ends of the canyon metamorphosed volcanic and sedimentary rocks of the Triassic and/or Jurassic Peavine Sequence are exposed. Progressively younger volcanic rocks are found towards the central portions of the Virginia Range near the freeway. The volcanic rocks range in composition from basalt to rhyolite and their origin varies from intrusive plugs to ash-flow tuffs and extensive lava flows. The age of the volcanic rocks ranges from Oligocene to Pleistocene.

The Truckee River existed before warping and faulting uplifted the Virginia Range. As uplifting took place, the river apparently downcut at about the same rate, and no deep lake was formed in the Truckee Meadows area. The Truckee River drains Lake Tahoe and in turn flows into Pyramid Lake. The river is about 100 miles in length.

The Truckee Canyon has been used since the days of the 49ers as one of the main routes to and from California. The first transcontinental

		railroad, the Central Pacific (now the Southern Pacific Railroad) follows the canyon.
4.5	10.3	Mustang Exit. Nevada's premier pleasure palace, the Mustang Ranch is across the river. Pleistocene basalt and andesite flows in this area cover Miocene volcanic and sedimentary rocks.
6.0	16.3	On the south side of the freeway is the Tracy Power station. This plant contains three units which produce 53, 83 and 110 megawatts respectively. The 110 megawatt unit is used for base load while the other two are used principally for peaking. The Tracy Station uses both oil and gas for fuel. Gas is generally used during the summer and in the winter oil is the main fuel. The gas is supplied by the Southwest Gas Company from a pipeline which extends into Idaho.
2.2	18.5	The high voltage powerline crossing the road is Sierra Pacific Power Company's new 345,000 volt intertie to the North Valmy coal-fired generating station near Battle Mountain. This line will eventually extend to Hunt, Idaho.
1.7	20.2	At 3:00 o'clock the diatomite plant of Eagle-Picher Industries can be seen. The open-pit mines are about 7 miles to the east, and will be visible later. Diatomite (diatomaceous earth) is the white, glassy skeletal remains of microscopic organisms. It is used extensively as an absorbent filter material, insulation, and filler in many consumer products. The crushing, drying, calcining, and air-classification sections of this plant produce mostly absorbents ("floor-dry" materials) and fillers for domestic and foreign consumption.
5.0	25.2	High up at 2:00 o'clock are waste dumps at the Celatom mine which supplies the diatomite processed in the Eagle Picher plant and Clark Station. The white band in the canyon walls is volcanic tuff and ash, not the diatomite bed.
2.1	27.3	Painted Rocks. The rocks exposed in the road cuts are Early to Middle Miocene ash-flow tuffs which unconformably overlie Mesozoic rocks. Equivalent ash-flow tuffs are present in the Desert Peak area and may act as a caprock for the Desert Peak geothermal reservoir. Note the laminated Lake Lahontan sediments partially

		filling the gullies.
2.7	30.0	The remains of a 50 stamp mill are visible on the hillside north of the freeway. The mill was economically unsuccessful due to inadequate reserves in the nearby Olinghouse district and only operated for three months in 1906 and 1907.
1.4	31.4	Truckee River Bridge. For the pioneers on the California Trail the Truckee River here marked the end of the terrible Forty Mile Desert. From this point the Truckee River flows about 20 miles to the northwest where it empties into Pyramid Lake. Pyramid Lake is one remnant of Lake Lahontan, which once covered most of the valleys of northwestern Nevada.
1.2	32.6	Fernley Exit. To the left of the freeway lies a cement plant owned by the Nevada Cement Company. The limestone for the plant is mined in the hills south of Fernley and is visible on the right side of the freeway. The limestone is a Tertiary, fresh-water deposit.
1.2	33.8	To the right of the freeway is a diatomite plant owned by Cyprus Mines. The diatomite is mined about 20 miles north of Fernley.
1.4	35.2	Ahead lies the famous Forty Mile Desert. For forty miles there is no potable water. The freeway closely follows the Truckee River route of the California Trail. The Donner party passed this way in 1846 on their way to an historic encounter with the Sierra Nevada. This was truly rough country to travel in the mid 1800's. When Mark Twain passed this way, he reported there were 3000 abandoned wagons with $3,000,000 of abandoned property and one could walk almost the entire 40 miles on the carcasses of oxen. To the left of the freeway lies the Truckee Range. The visible part of this range is composed of basalts from two or three large shield volcanoes which are five to seven million years old. To the right of the freeway, the hills across the Alkali Flat are the southern part of the Hot Springs Mountains. These hills are composed of Tertiary basaltic rocks and some interbedded lacustrine sediments. Note the well developed shorelines which represent various stages of Lake Lahontan. Hazen Hot Springs are located near the south end of this range.

2.8	38.0	The power line crossing the highway is an 800,000 volt D.C. line that runs from the Dallas hydroelectric station located near Portland to Sylmar, California, near Los Angeles.
8.2	46.2	To the right of the freeway lie the old vats of the Eagle Marsh Salt Works. The Eagle Marsh Salt Works probably produced over 500,000 tons of salt for use in treating ores from Virginia City and Humboldt County between 1870 and 1915. It is reported that on a good day one acre of vats could produce ten tons of salt. The brine came from springs located across the valley. These springs have essentially the same chemistry as water from the Desert Peak geothermal wells. The chemistry and temperature data in the area conclusively show that salt was the first commodity to be commercially extracted from the Desert Peak geothermal reservoir.
5.6	51.8	Leave the highway at the Hot Springs - Nightingale Exit and proceed east.
0.5	52.3	Geothermal Food Processors Plant. Continue east past the plant. This plant, which is the first U.S. vegetable dehydration plant to utilize geothermal energy, was dedicated November 3, 1978. Water at approximately 270°F is passed through a heat exchanger; the resulting warm air is used to dry vegetables. Onions are the main vegetable processed here.
0.2	52.5	STOP 1 - BRADY'S HOT SPRINGS.
		Discussion of early geothermal drilling and recent exploration leading to the Desert Peak discovery. From this stop, return to frontage road and turn left (south).
5.6	58.1	The brick building contains support equipment for a transcontinental telephone cable which crosses the area.
2.0	60.1	Well 29-1 is located on the left side of the road (Fig. 1).
1.5	61.6	Well B21-1, the discovery well, is located on the left side of the road.
.2	61.8	Well 86-21 is located on the left side of the road.

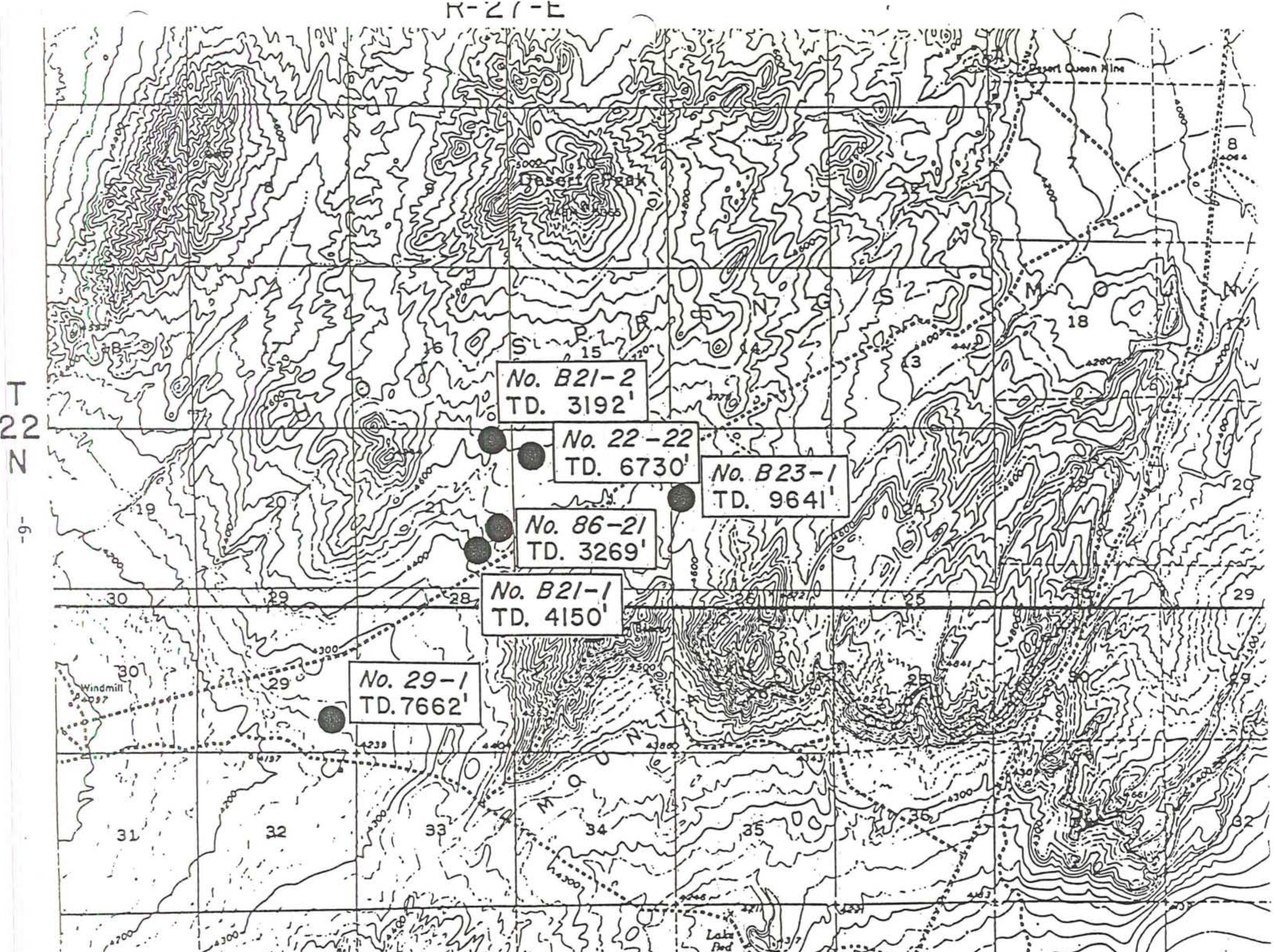

R-27-E
T 22 N
Desert Peak
Desert Queen Mine
No. B21-2 TD. 3192'
No. 22-22 TD. 6730'
No. B23-1 TD. 9641'
No. 86-21 TD. 3269'
No. B21-1 TD. 4150'
No. 29-1 TD. 7662'
Windmill
Lake Bed

Figure 1

0.7 62.3 STOP 2 - DESERT PEAK CONFIRMATION WELL (B21-2)

Discussion of Desert Peak geology and drilling results. Most of this discussion has been published by the Nevada Bureau of Mines and Geology as Bulletin 97.

Retrace route to Interstate 80 and proceed north towards Lovelock.

ROADLOG - RENO TO WINNEMUCCA

PART II - DESERT PEAK TO HUMBOLDT HOUSE AND WINNEMUCCA

by W. L. DESORMIER

Interval Miles	Cumulative Mileage	
10.0	72.3	Start - Desert Peak to Humboldt House and Winnemucca. Geothermal Food Processors Plant. Hot Springs - Nightingale Exit, Interstate 80.
4.3	76.6	The diatomite deposit on the left side of the freeway is occasionally mined. This diatomite is part of the Truckee Formation of Pliocene age. The mountains to the left of the freeway are the Trinity Mountains. These mountains consist of metamorphosed volcanic and sedimentary rocks of Mesozoic age overlain by Tertiary volcanic rocks.
4.0	80.0	The large valley to the right of the freeway contains the Carson Sink. This is the largest valley in northern Nevada. The Carson and Humboldt Rivers drain into this area from the crest of the Sierra Nevada and from northeastern Nevada. Tufa mounds deposited in and around Pleistocene Lake Lahontan are visible in this area, on both sides of the freeway.
7.8	88.4	The West Humboldt Range is located to the right of the freeway. This small but steep range consists predominantly of calcareous siltstone, shale, and argillite of the Auld Lang Syne Group of upper Triassic and lower Jurassic age. The hills at the southwest end of the range are called the Mopung Hills. Mopung is an Indian word for mosquito. The mosquitos must have been fierce here before the water was diverted for irrigation upstream. The brightly colored rocks in the Mopung Hills are rhyolitic ash-flow tuffs which are equivalent to those overlying the Desert Peak geothermal reservoir and those exposed at Painted Rocks in the Truckee River canyon. The Mopung Hills also contain exposures of gabbroic rocks from the very large Jurassic Humboldt Lopolith.
12.3	100.7	Toulon. The large building is the shell of a mill which treated ores from the tungsten mines at Nightingale.

		The layered units high in the Trinity Range are welded tuffs from the Early Pliocene eruptive center called Raggged Top.
12.7	113.4	Stoplight, Center of downtown Lovelock.
5.4	118.8	On the right about one mile up the alluvial fan is a large drill pad. This is where Getty Oil Company drilled a non-commercial geothermal well to a total depth of 7965 feet. The maximum reported temperature is 282°F at a depth of 7064 feet (Jones, 1982).
1.0	119.8	Colado Siding. To the left of the highway is the northern part of the Trinity Range, which consists mainly of granitic intrusives, metasedimentary rocks of the Auld Lang Syne Group and Quarternary-Tertiary volcanics. On the left side of the highway is another Eagle-Picher diatomite plant. Some of the largest diatomite mines in Nevada are located in Pershing County. A warm well is located near the diatomite plant. The Humboldt Range is to the right of the highway and consists mainly of Mesozoic carbonates and clastics, Quaternary-Tertiary volcanics, and some granitic intrusives. The rocks in this area were subjected to large-scale folding, thrust faulting, volcanism, and Basin and Range faulting. Several of the thrust faults are well exposed in this range. The abundant and diverse mineralization in the Humboldt Range consists of tungsten, copper, gold, silver mecury, lead, antimony, tin and fluorspar. Approximately $35 million dollars in tungsten ore was produced 1936 to 1956 in Pershing County.
7.2	127.0	Oreana. Ahead and to the right is one of the granitic intrusives of the Humboldt Range. The Canyon is aptly named Rocky Canyon. Tungsten, silver, lead and antimony came from Rocky Canyon and Rochester in the Humboldt Range (to the right of the highway) and from Arabia in the Trinity Range (to the left of the highway).
8.8	135.8	<u>Lunch Stop</u>. Exit freeway at Rye Patch Interchange. Turn left, proceed beneath the overpass and continue west to the reservoir.
1.7	137.5	Rye Patch Reservoir and picnic area on the right.

Figure 2

Humboldt House deep well location map.
Also shown is a line of cross-section.

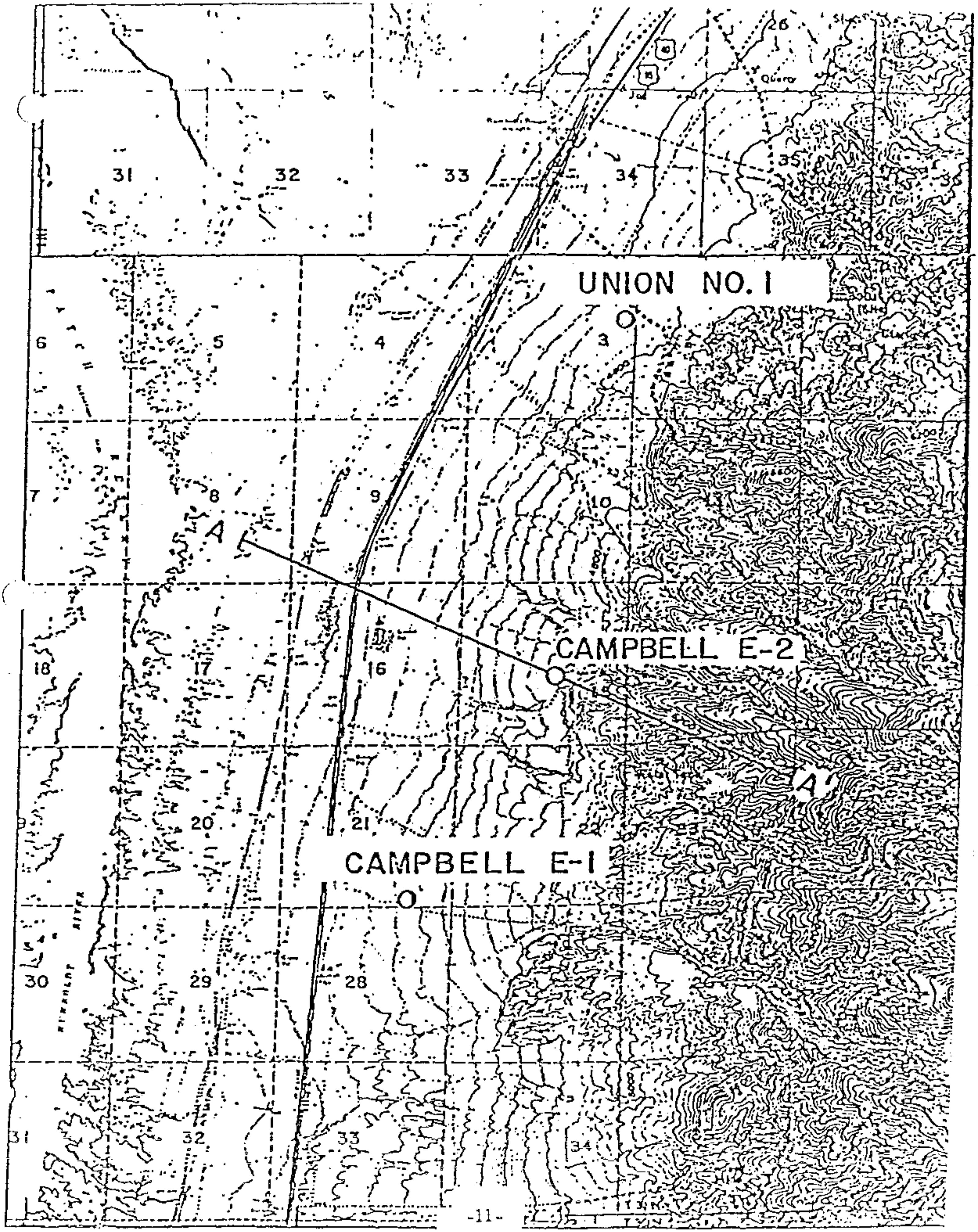

UNION NO. 1
CAMPBELL E-2
CAMPBELL E-1
A
A'
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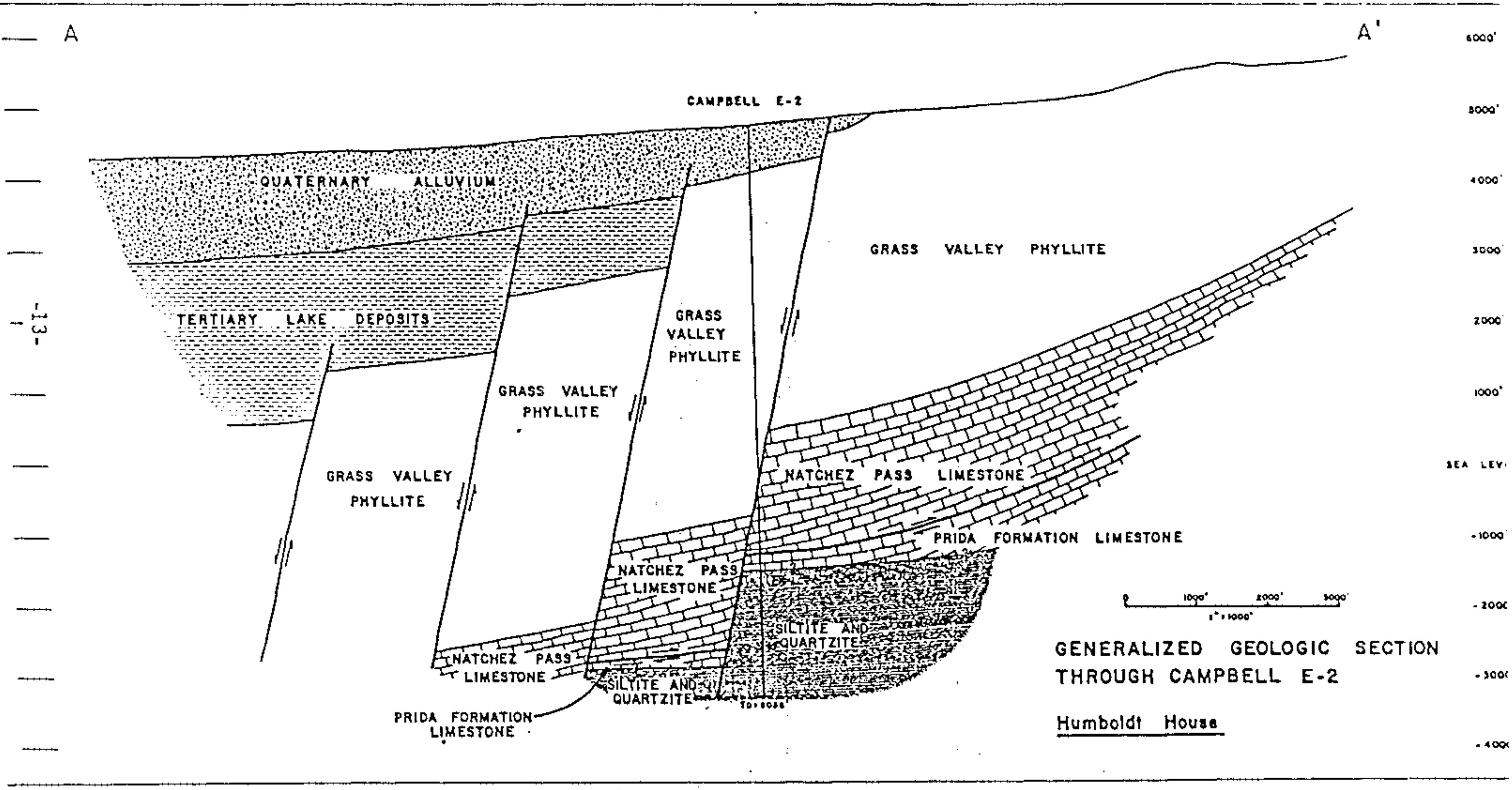
Figure 3

Generalized geologic cross-section along line A-A' (Figure 1) for the Humboldt House area.



GENERALIZED GEOLOGIC SECTION THROUGH CAMPBELL E-2

Humboldt House

Rye Patch Reservoir has a capacity of approximately 180,000 acre-feet. The water is used almost exclusively to irrigate about 44,000 acres of land in the Lovelock area. Irrigation wastewater and any other Humboldt River flow below the dam ultimately discharge into the Carson Sink.

The range to the east is the Humboldt Range. The highest point in the range is Star Peak at 9834 feet. The Humboldt Range consists primarily of Mesozoic sedimentary and volcanic rocks. These rocks have been highly deformed by normal faulting, thrust faulting and folding and have undergone low grade regional metamorphism.

Return to the highway.

1.4	138.9	Rye Patch interchange. Turn left and proceed east on Interstate 80.
2.4	141.3	To the right of the highway is the Standard Gold Mine. Leaching on a small scale was conducted here a few years ago.
1.9	143.2	To the right of the highway is Phillips Petroleum Company's Campbell E-1 drill pad and reserve pit.
1.1	144.3	To the immediate right of the highway is a road going up the alluvial fan. This is the access road to Phillips Petroleum Company's Campbell E-2. The drill pad and reserve pit are about 1-1/2 miles up the alluvial fan but are not easily visible from the highway.
2.7	147.0	To the right of the highway in the lowermost hills is a large area of argillic alteration. This altered area has been explored by numerous drill holes and was the site of a small leaching operation several years ago. Just below the altered rocks is Union Oil Company's Campbell Number 1 drill pad and reserve pit.
5.4	152.4	STOP 3. HUMBOLDT HOUSE OVERVIEW AND CAMPBELL E-1 (Figs. 2 and 3).

Phillips Petroleum Company has one production well (Campbell E-1), one dry hole (Campbell E-2), six stratigraphic tests and many shallow temperature-gradient holes at Humboldt House. Phillips also has gathered a large quantity of geological, geochemical and geophysical data in the area. Additionally, Union Oil Company has drilled in the area and has one deep test (Campbell Number 1).

The exploration results show that a thermal anomaly of significant size and geothermal fluids of good quality exist, and suggest that a geothermal reservoir of commercial quality exists at depth.

During 1974 Phillips drilled shallow temperature-gradient holes in order to evaluate Southern Pacific land along the Humboldt River Basin. Several of the holes in the area near Humboldt were found to be anomalous. Additional drilling delineated the thermal anomaly.

Following the drilling in the area of the thermal anomaly several related geothermal phenomena were noted, such as deposits of siliceous sinter, tufa, and sulphur. A mineral exploration hole drilled into hydrothermally altered rocks on the west flank of the Humboldt Range was later also found to discharge hot water.

Phillips completed the Campbell E-1 geothermal well in 1977 to a depth of 1835 feet. Fluid can only enter the well through the uncased lower 82 feet. The geothermal fluid is under pressure and can only flash to steam at the surface. During the initial (17-hour) flow test this well produced approximately 800,000 pounds per hour of fluid at a temperature of 350°F.

In 1978, Union Oil Company drilled the Campbell Number 1 well to a depth of 6825 feet. The well is located in the NE-1/4 of section 3 T31N-R33E. The well is reported to be a non-commercial producer.

In 1979, Phillips completed the Campbell E-2 well to a depth of 8036 feet. A report on this well is available to the general public through the DOE (Phillips Petroleum Company, 1979). The well is not capable of producing geothermal fluids.

Return to frontage road and proceed north.

5.0	157.4	Proceed east through gate.
0.8	158.2	Union Oil Company's Campbell Number 1 drill pad and reserve are on the right.

0.3	158.5	STOP 4 - Alteration-Mines Area.

Argillic alteration is present along the western flank of the Humboldt Range in Sections 1, 2, and 11, T31N-R33E. The alteration is highly visible because of the bleaching and iron staining that has occurred here. The alteration occurs within the thermal anomaly and is probably related to the heat that produces the anomaly. Some kaolin was mined in the altered rocks approximately 1/4 mile north of the mouth of Florida Canyon.

Gold and silver mineralization is present within the area of alteration and may also be related to the geothermal activity that produces the thermal anomaly. Considerable mineral exploration has been conducted in this area.

Gold, fluorspar, mercury and sulfur have been mined elsewhere in the vicinity, but outside the area of alteration mentioned above.

In the west central part of Section 2, T31N-R33E there are several outcrops of cherty rock. These outcrops are thought to be "fossil" hot springs deposits. The chert was probably deposited by ascending hot water.

The most prominent outcrop of chert in this area has the appearance of a dike and lies parallel and adjacent to the main range-front fault. The chert is resistant to erosion and some of the denser masses now stand several feet above the surrounding rocks. The present topographic expression of the chert deposits suggests that a relatively long period of erosion has taken place since the deposition of the chert.

Return to the frontage road.

1.0	159.5	Proceed through the gate, beneath the overpass and head south along the western frontage road.
1.3	160.8	Turn right, cross over the railroad tracks and turn north along the pipeline road.
0.8	161.6	STOP 5. HOT SPRINGS DEPOSITS.

In addition to the chert deposits seen at Stop 4, there are other hot spring deposits. In this area there are tufa mounds, and deposits of siliceous sinter and silicified sediments.

The tufa mound located in the south central part of Section 33, T32N-R33E is associated with deposits of siliceous sinter and silicified sediments and may be the result of late stage hot spring activity. The mound is composed mainly of coarsely crystalline calcite with some gypsum and sulfur.

There are several pits and shallow shafts in the tufa mound which are the result of sulfur mining. Some sulfur was produced from the area as early as 1869 and eight carloads were produced in 1936.

Turn around and head south along the pipeline road.

0.4	162.0	Turn right (west).
0.5	162.5	STOP 6. "HOT SPRINGS".

At the present time, there are no active hot springs in the area, however, there is one mineral-exploration hole that is presently flowing hot water. The hole is located in the SE 1/4 of Section 32, T32N-R33E and was drilled by a company called "Estoril." Depth of the hole is not known.

Sodium chloride water at 168°F flows from this hole at a rate of about five gpm. The water has a conductivity of approximately 9000 μhos and is quite similar chemically to water obtained from Campbell E-1 and from other test holes. The silica and the Na-K-Ca geothermometers give predicted reservoir temperatures of 450-490°F, and these data combined with information from temperature-gradient holes encouraged additional, more detailed exploration work.

Drive ahead to safe turn-out.

0.3	162.8	Turn around and return to highway.
2.2	165.0	Humboldt Interchange. Proceed east on Interstate 80.
16.8	181.8	To the left of the highway are the Eugene Mountains and the mining town of Tungsten. The town was named after the main ore produced from the district. However, substantial deposits of gold, silver, copper and lead were also found. Tungsten was again mined for a six month period beginning early in 1982. When prices fell the

"Springer" mine shut down. The rocks consist mainly of Mesozoic metasedimentary rocks of the Auld Lang Syne Group, granitic intrusives and Quaternary-Tertiary volcanics.

To the right of the highway is the East Range. The rocks of the East Range were subjected to large-scale folding and thrust faulting, and later to volcanism and Basin and Range faulting. The rocks consist mainly of Paleozoic and Mesozoic sedimentary and metasedimentary rocks, granitic intrusives and Quaternary-Tertiary volcanics. Gold was the main ore produced from the mining districts in this range.

15.6	197.4	Directly left of the highway is Winnemucca Mountain and left of this is Blue Mountain. The rocks are mainly Mesozoic sedimentary and metasedimentary rocks, Tertiary volcanics and a few small intrusives. Silver and gold were the main ores produced from these mountains.
		To the right of the highway is Grass Valley. Leach Hot Spring is located here. Considerable geothermal studies and exploration have been conducted in this area.
6.9	204.3	Winnemucca.

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GEOLOGY AND GEOCHEMISTRY OF THE COLADO GEOTHERMAL AREA
PERSHING COUNTY, NEVADA

by

Bruce S. Sibbett

Odin D. Christensen

and

Michael J. Bullett

Introduction

The Colado geothermal area is located about 8 miles northeast of Lovelock in south-central Pershing Co., Nev. The geothermal field straddles the western flank of the West Humboldt Range. In the eastern portion of the thermal area, antimony, precious metals and copper were mined from deposits of the Willard District. High temperatures and steam encountered in precious metal exploration drill holes and trenches were in part responsible for arousing the recent interest in the geothermal potential of this area.

The presence of anomalously warm temperatures at shallow depths in the Colado area has, however, been known for some time. Christen (1920) reported water so hot at a depth of 10 meters in a shaft (NE 1/4 SE 1/4 S27, T28N, R32E) that the shaft had to be abandoned (Osterling, 1960). Other warm domestic wells occur in the Lovelock area and an industrial well drilled at Colado encountered water with a temperature of 66°C (Garside and Schilling, 1979).

During 1979-80, 18 shallow and 2 intermediate depth temperature gradient holes were drilled (Figure 1) by Getty Oil Company in cooperation with the Division of Geothermal Energy of the U. S. Department of Energy. Geologic, geochemical and geophysical investigations were conducted by the Earth Science Laboratory under the Industry Coupled Program. The paper summarizes results of the geologic and geochemical investigations.

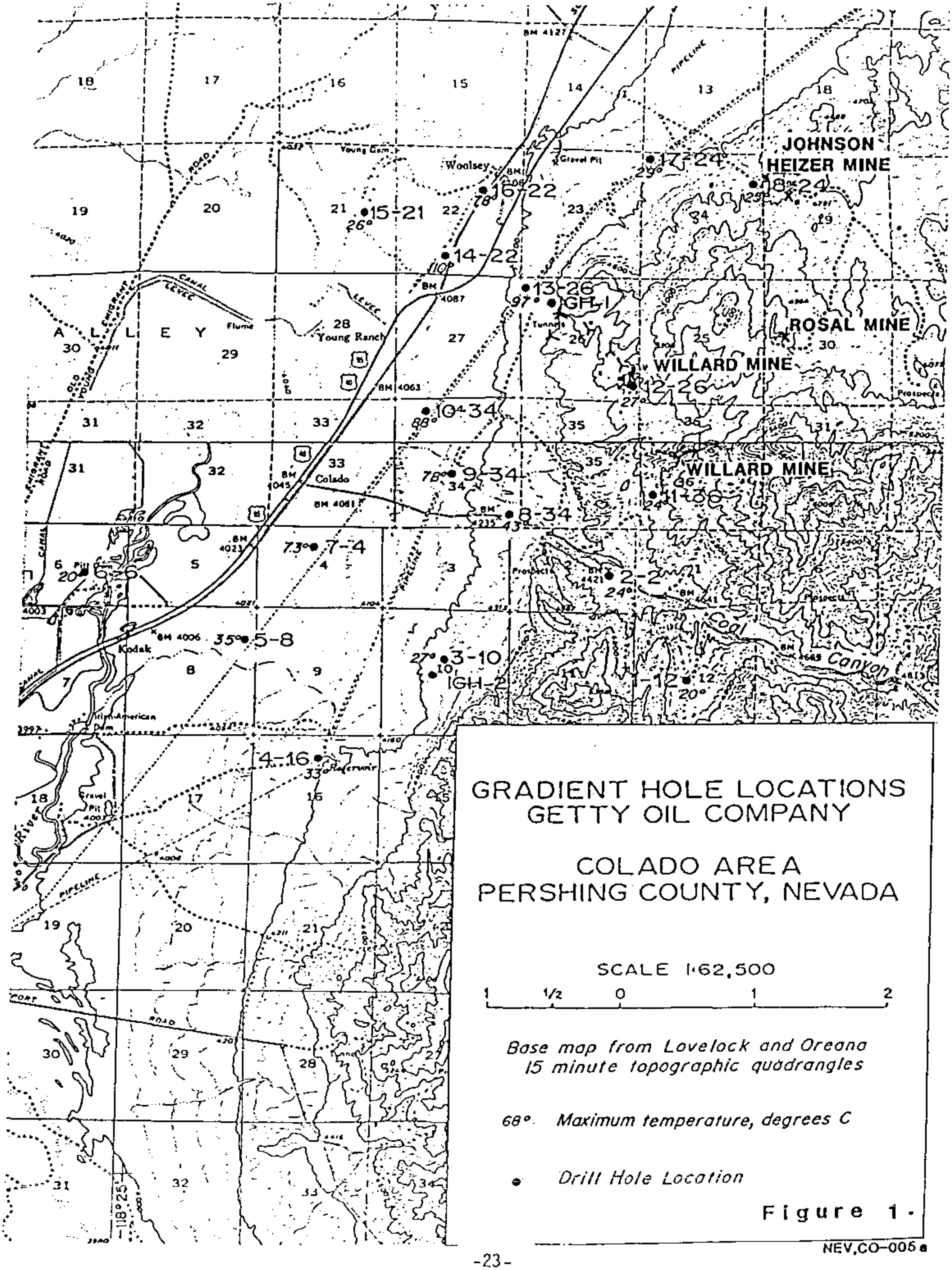
Details of this work have been presented by Christensen (1980), Christensen and others (1981), Mackelprang (1980), Sibbett and Bullett (1979), and Sibbett and Bullett (1980).

Geologic Setting

The Humboldt Valley is a northeast-trending graben in the western part of the Basin and Range Province. Normal step faults form the structural boundary between the valley graben and the horst of the West Humboldt Range. The central part of the valley is covered with Quaternary Lake Lahontan sediments. The gentle slopes near the range front consist of alluvium.

The West Humboldt Range consists mainly of a thick sequence of weakly metamorphosed pelites of lower Mesozoic, eugeosynclinal origin (Figure 2). These monotonous, fine clastic rocks and a few limestone beds in the upper part of the section were thrust to the east during Jurassic time. The surface exposures are considered to be a succession of thrust sheets (Speed, 1976).

The clastic rocks are part of the Triassic to Jurassic Auld Lang Syne Group (Burke and Silberling, 1973); the exposed section may be Grass Valley or Raspberry Formation. Previous investigators have not assigned formation names to the clastic rocks in the area and stratigraphic correlation is beyond the



GRADIENT HOLE LOCATIONS
GETTY OIL COMPANY

COLADO AREA
PERSHING COUNTY, NEVADA

SCALE 1:62,500

1 — 1/2 — 0 — 1 — 2

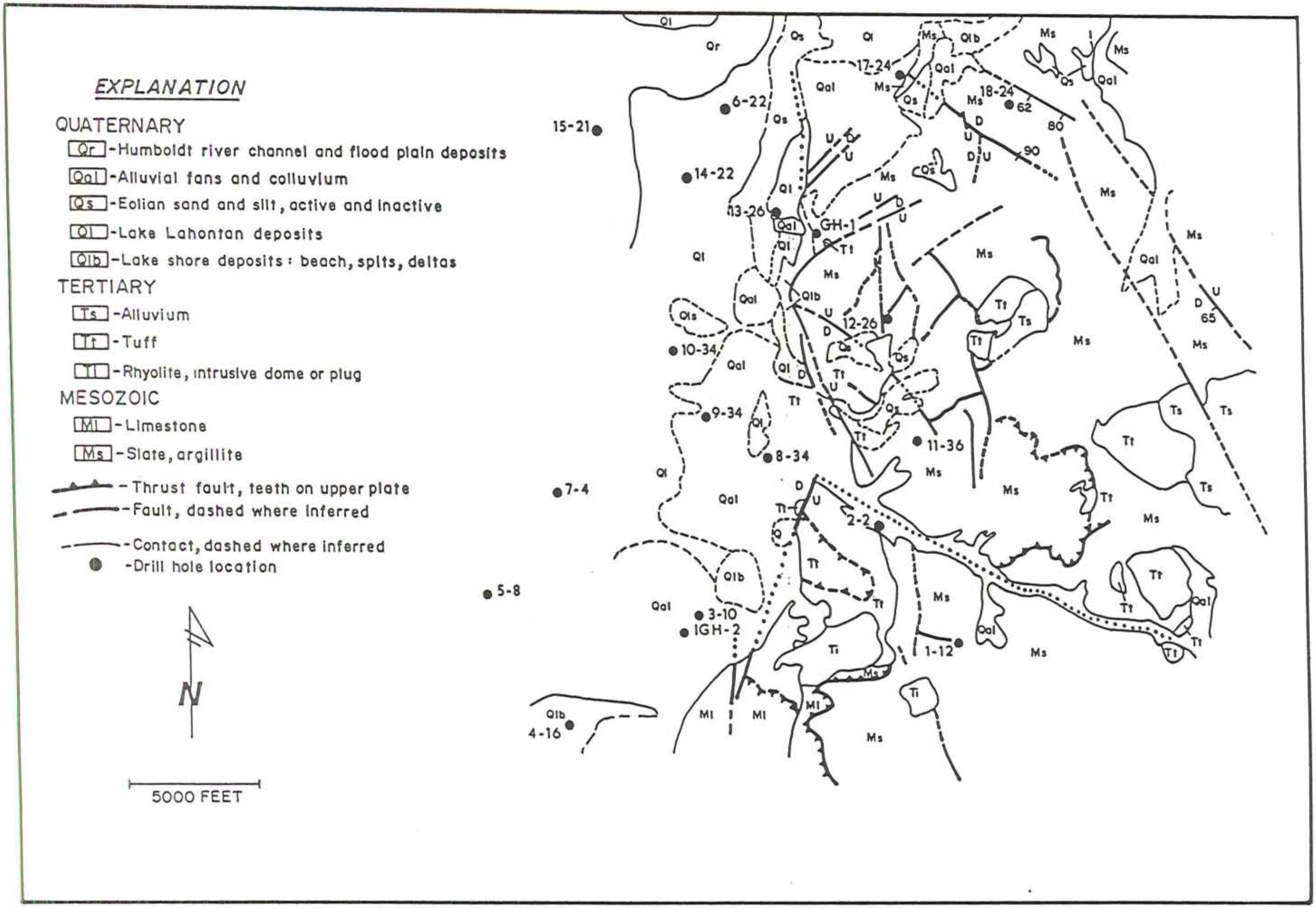
Base map from Lovelock and Oreana 15 minute topographic quadrangles

68° *Maximum temperature, degrees C*

• *Drill Hole Location*

Figure 1

NEV,CO-005a



GENERALIZED GEOLOGY OF THE COLADO AREA PERSHING COUNTY, NEVADA

NEV.CO-001

Figure 2

EXPLANATION

Qr	Humboldt River Channel and flood plain
Qls	Landslides
Qal	Alluvial fans and colluvium
Ql	Lake Lahontan deposits undifferentiated
Qlb	Lake shore deposits, beach, spits, deltas
Ts	Alluvium, tuffaceous mudstone
Tls	Limestone, lacustrine with interbedded clastic sediments
Tt_2	Non-welded tuff, crustal poor
Tal_2	Alluvium, abundant rhyolite cobbles and a few clasts of other lithologies,
Trb	Rhyolite breccia dikes
Tt	Tuff, white, crystal poor
Trd	Rhyolite sills and dikes, feeders to Tt
Tal	Coarse conglomerate, mostly limestone, quartzite and andesite clasts
qv	Quartz veins
Ta	Andesite flows
Jd	Diorite
Jl	Lovelock Formation
JTRw	Interbedded, limestone, quartzite, and mudstone
JTRl	Limestone
JTRq	Quartzite
JTRs	Slaty-shale, mudstone, and minor siltstone
TRs	Siltstone
lsb	Limestone breccia in thrust plates

Trf	Rhyolite flow
Tri	Rhyolite intrusive dome or plug, feeder for Trf
Tp	Pyroclastics, includes perlite, minor ash-flow tuffs, and tuff or ash altered to clays
cv	Calcite veins
bs	Basalt sills

scope of this study. The limestone units in the thrust sheets have been mapped as Lovelock Formation (Speed, 1974).

The Mesozoic rocks are covered in places by erosional remnants of Tertiary rhyolitic volcanic rocks that include pyroclastic deposits and perlite. Small intrusives exposed south of Coal Canyon (Figures 1 and 2) are probably the source of the pyroclastic rocks.

The Quaternary deposits consist of Lake Lahontan sediments and alluvium in the Humboldt Valley. The lake sediments include sand, silt, clay, and beach gravels. The alluvium consists of poorly sorted gravels in alluvial fans, stream beds, and colluvium on steep slopes.

The Colado area is intensely faulted, especially near the range front. The principal structures are high-angle faults which strike north-northwest, northeast, and north-south. The lack of marker beds in the Mesozoic rocks make determination of displacement difficult. Generally, however, the relative offset is only tens of feet to a few hundred feet. The faults and veins of the Willard mines, on the western flank of the West Humboldt Range east of Colado, trend northeast and dip northwest. These faults are terminated and offset by faults which predate the Tertiary volcanic rocks.

Coal Canyon marks the trend of a major east-west structural discontinuity that was active prior to emplacement of the Tertiary rocks. At its western end the zone truncates marker horizons and faults within the Mesozoic rocks. Tertiary rocks in the eastern portion of the area shown in Figure 2 extend across the canyon without apparent displacement.

Quaternary faulting is evident in two locations in the northern part of the study area. In section 12, T28N, R32E, coarse alluvium with beach lines on it has been offset 3 to 5 feet. The scarp cuts Lake Lahontan beach features which are about 18,000 years old. In section 23, southeast of Woolsey, a trough which appears to be a fault line graben separates the range front from its alluvial apron. The graben may have been modified by Lake Lahontan.

Alteration and Mineralization

Gold, antimony, and minor copper and silver were produced from the Colado area between 1905 and 1951 (Johnson, 1977). Gold production came from quartz veinlets in fracture zones and breccia along northeast-striking faults that dip northwest at the Willard mines. The ore was free-milling gold and silver from surface exposures (Johnson, 1977). Copper, lead, and zinc were associated with the gold in the quartz veins.

Antimony was produced from the Johnson-Heizer and Adriene mines which are both located on northwest-striking faults that dip southwest. A total of 527 tons of ore was mined at the Johnson-Heizer mine from 1916 to 1946 (Johnson, 1977). The Adriene mine produced 15 tons of antimony and the Rosal mine was developed for antimony but no production was reported. Recent activity in the area consisted of exploration drilling around the south Willard mine and cat work at the Johnson-Heizer mine.

North-trending quartz and carbonate veins are locally abundant on the eastern flank of the West Humboldt Range, north of Coal Canyon. While the age of these veins has not yet been established, fragments of the carbonate veins occur in the Tertiary gravels whereas the quartz veins cut the older Tertiary rocks.

Strong hematite staining occurs around the prospects and extensively along the range front north of Coal Canyon in the Tertiary and Mesozoic rocks along this zone. In the andesite lava flow (Ta) hematite is associated with sericite, calcite, chlorite, quartz, and clay.

The Tertiary rhyolites have been altered to montmorillonite at several locations in the Colado area (Papke, 1970); production has been small and the quality marginal. Most of the clay deposits were formed by hydrothermal alteration of tuff or perlite. A perlite unit within the pyroclastic (Tp) unit south of Coal Canyon has been partially altered to clay. Some production has come from this deposit.

Alteration, apparently related to the active geothermal system, occurs in the alluvium penetrated by the 500-foot gradient hole 14-22 (Figures 1 and 3). The alluvium is silicified at depths from 100 feet to total depth (30-150 m) and pyritized in the interval between 300 and 400 feet (90-120 m).

Geochemistry

Multielement geochemical analysis of the drill cuttings has been performed in order to more closely define the position and extent of the geothermal resource. Recent studies demonstrate that the trace element geochemistry of well cuttings from geothermal systems can be a useful exploration guide, particularly in the early stages of geothermal development (Bamford, 1978; Bamford and others, 1980; Bamford and Christensen, 1979; Christensen and others, 1980b). Trace element distributions developed as a

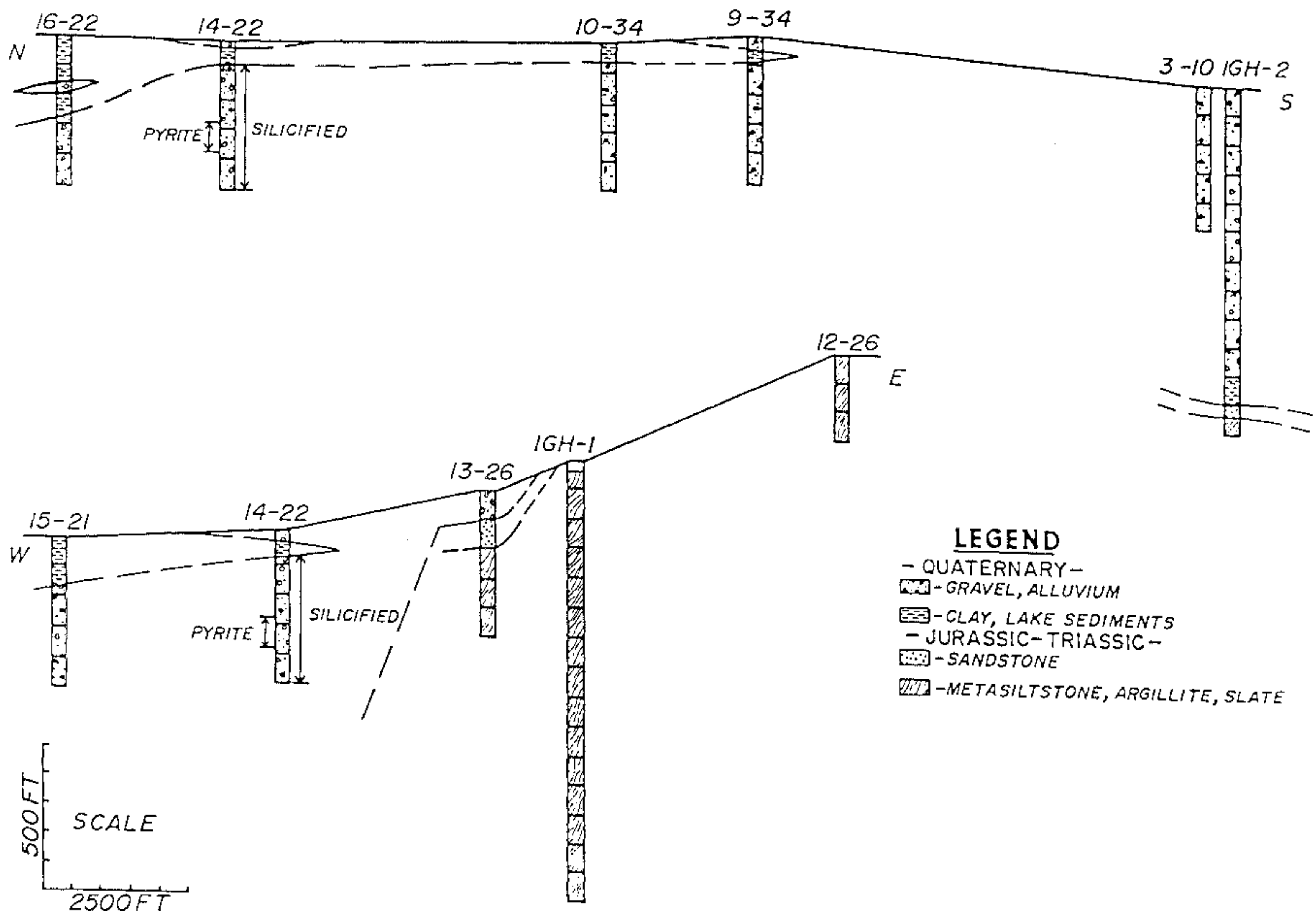


Figure 3. Distribution of rock types and alteration in the thermal gradient wells.

consequence of temperature gradients and fluid flow within a geothermal system place constraints on the possible geometry of the present system and may provide insight into its thermal and convective history.

Analytical Techniques

Samples were prepared for analysis by washing all individual 10-foot interval samples, compositing samples over 100-foot intervals, and pulverizing to less than 270 mesh in a SPEX tungsten carbide shatterbox. Pulverized samples were dissolved by a four acid digestion procedure (Christensen and others, 1980a).

Samples were analyzed for 37 elements by inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Elements determined by ICP-AES were Na, K, Ca, Mg, Fe, Al, Si, Ti, P, Sr, Ba, V, Cr, Mn, Co, Ni, Cu, Mo, Pb, Zn, Cd, Ag, Au, As, Sb, Bi, U, Te, Sn, W, Li, Be, B, Zr, La, Ce, and Th. Specifics of the analytical instrumentation and procedures, as well as an evaluation of the quality of analyses are summarized in Christensen and others (1980a). In addition, As was determined on each sample solution by a colorimetric procedure, and Hg was determined in solid samples by gold film mercury detector.

In order to distinguish chemical variations resulting from geothermal processes from the dispersion of analytical values expected in natural normal or lognormal background geochemical populations, analytical values were partitioned graphically through the use of cumulative probability plots following the procedures described by Sinclair (1974, 1976) and Lepeltier (1969). The method permits estimation of population parameters for mixed distributions of two or more populations. Bold contour values presented in Figures 4 through 7 have been determined by this method, and thus represent statistically determined thresholds separating distinct geochemical populations. Other contours have been added for clarity.

Of the elements investigated, Hg, As, Li, and Be appear to belong to more than one population and are regularly zoned about the present geothermal system. The distributions of these elements are, in general, largely independent of rock type and consequently provide the clearest expression of recent hydrothermal activity. Data for these elements are presented graphically in this report and a data summary for all elements are included in the Appendix.

Discussion

As, Hg, Li, and Be are commonly enriched in thermal fluids (Ellis and Mahon, 1977; Weissberg and others, 1979) and have been shown to form characteristic dispersion patterns about other hot-water geothermal systems (Bamford, 1978; Capuano and Moore, 1980; Bamford and others, 1980, Christensen and others, 1980b). The distributions of these elements in two representative cross sections (Figures 4-7) is compared with the measured temperatures in the same sections in Figure 8.

The greatest temperatures observed in the 20 gradient holes, up to 113°C, were measured in hole 14-22. In this hole, as well as in several others (5-8, 7-4, 13-26, and 16-22), the maximum temperatures are encountered at less than total depth, strongly suggesting that thermal fluids are rising into the alluvium and flowing laterally through shallow aquifers at depths of 200-400

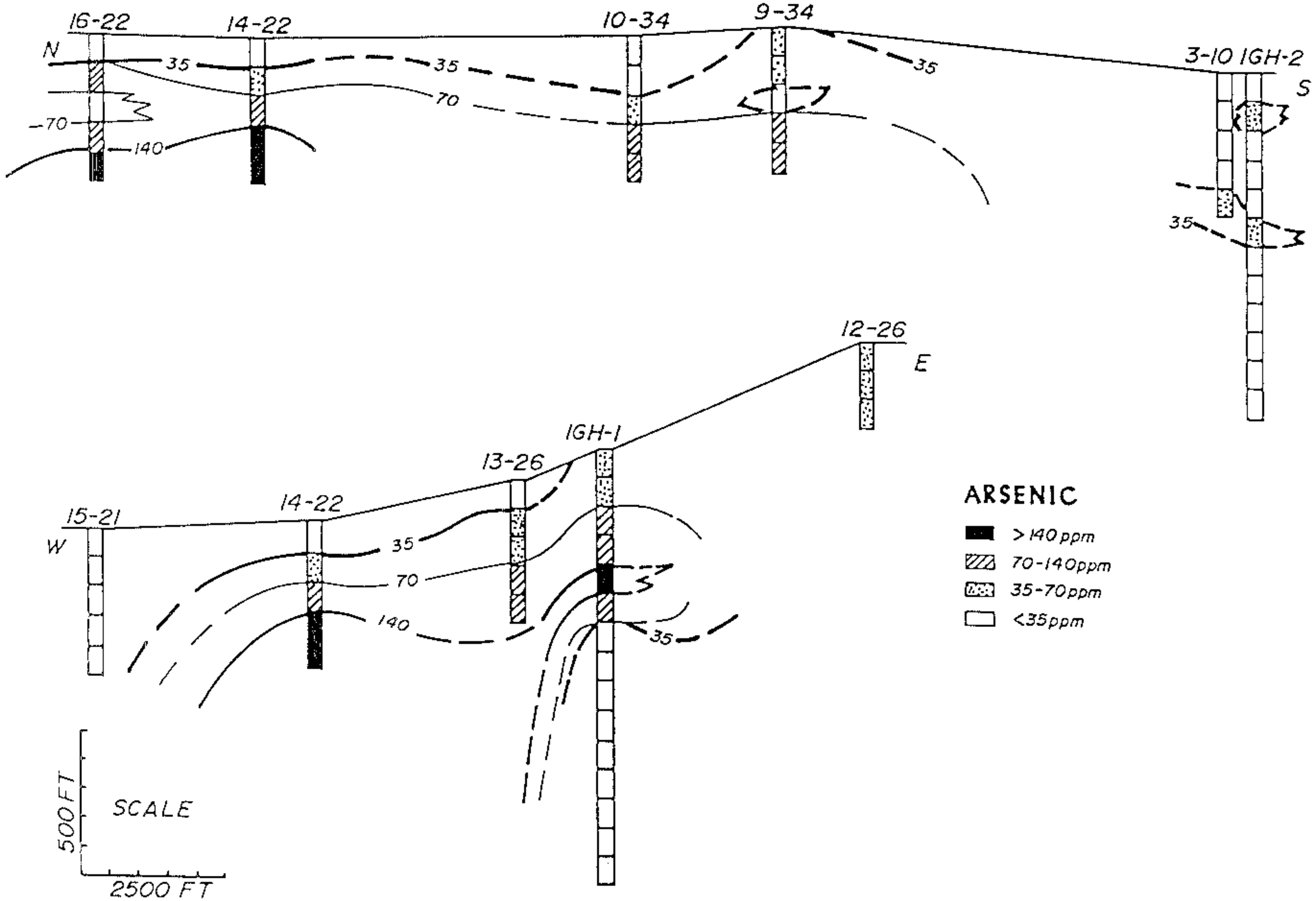


Figure 4. Arsenic distribution in drill cuttings.

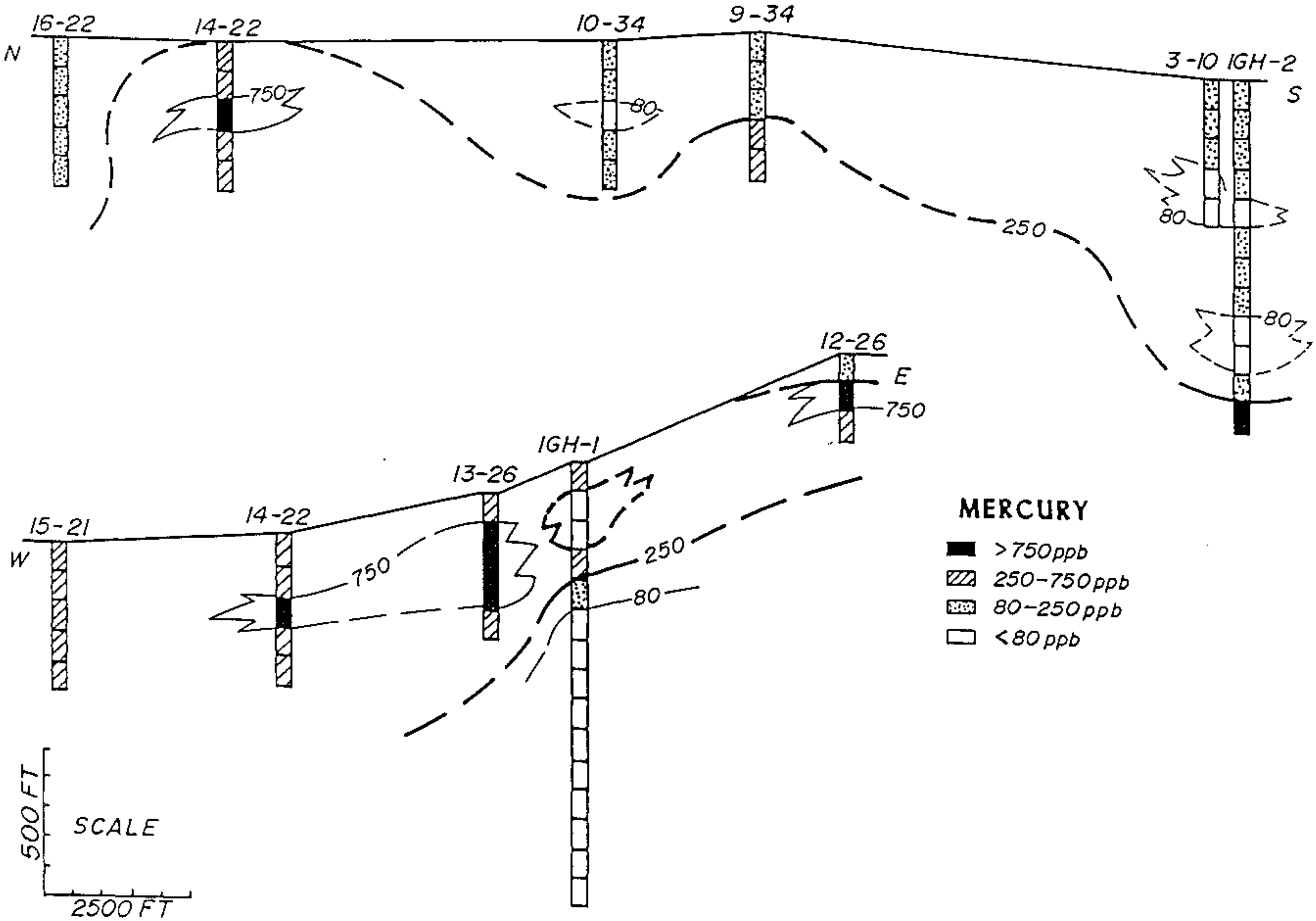


Figure 5. Mercury distribution in drill cuttings.

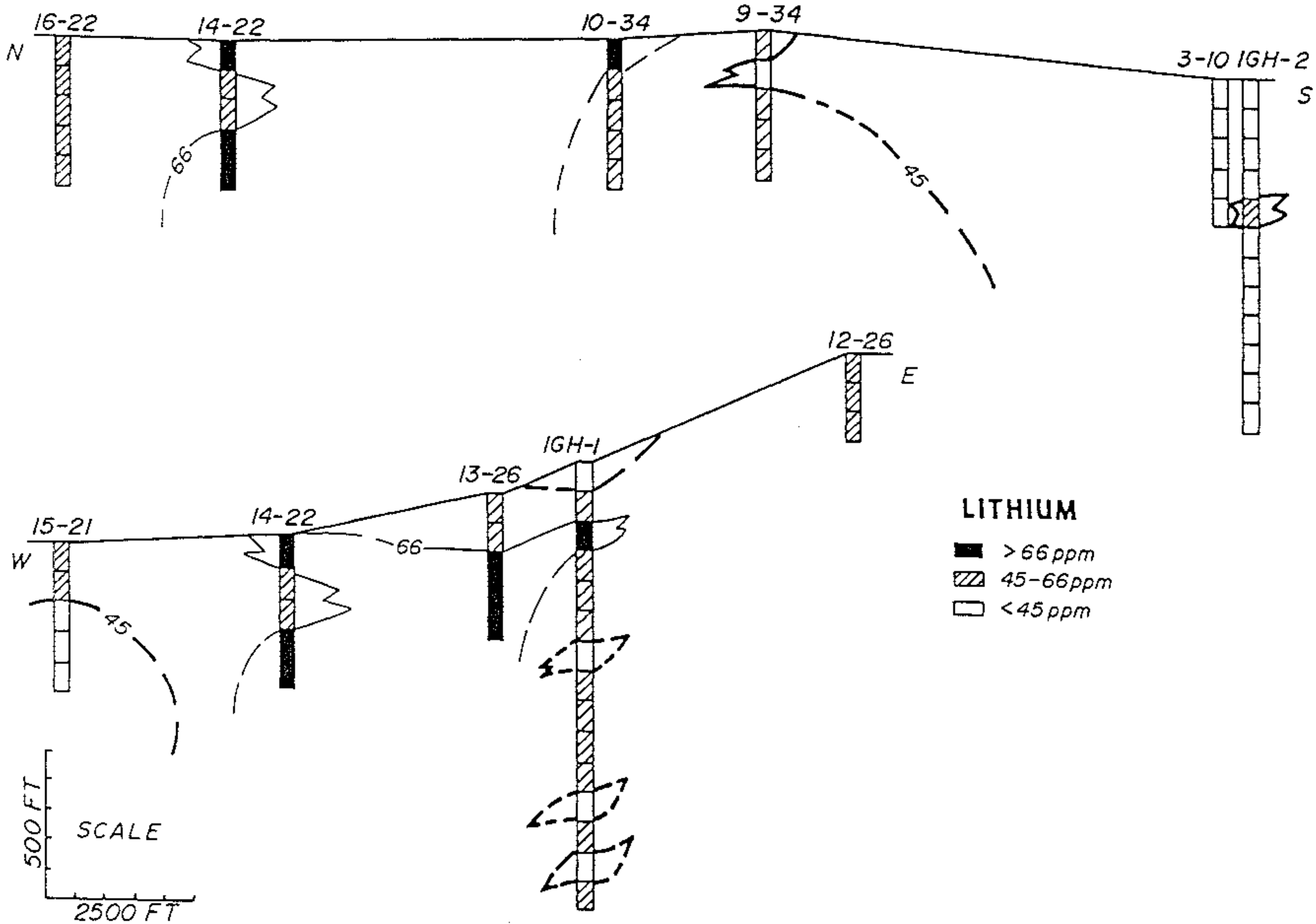


Figure 6. Lithium distribution in drill cuttings.

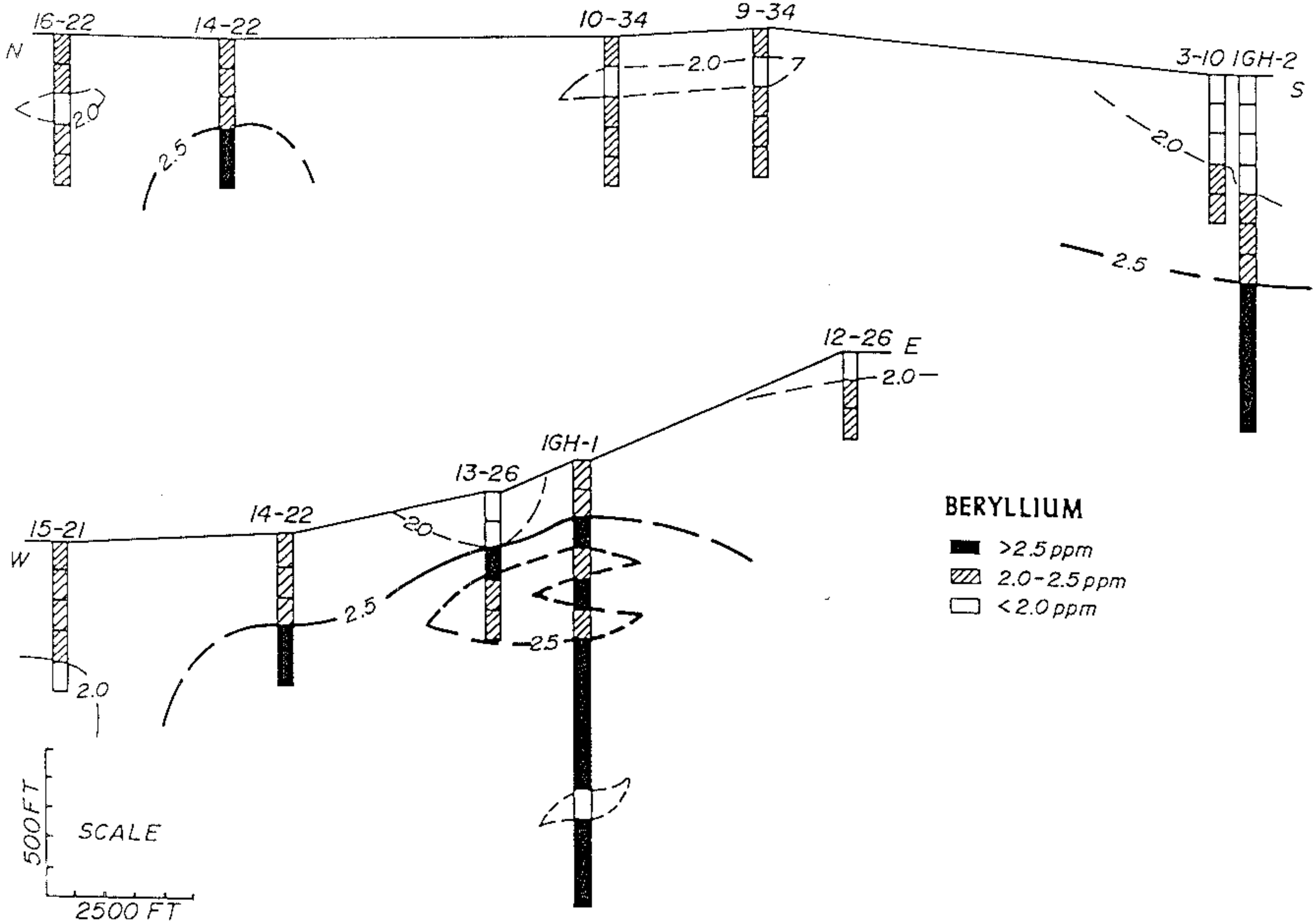


Figure 7. Beryllium distribution in drill cuttings.

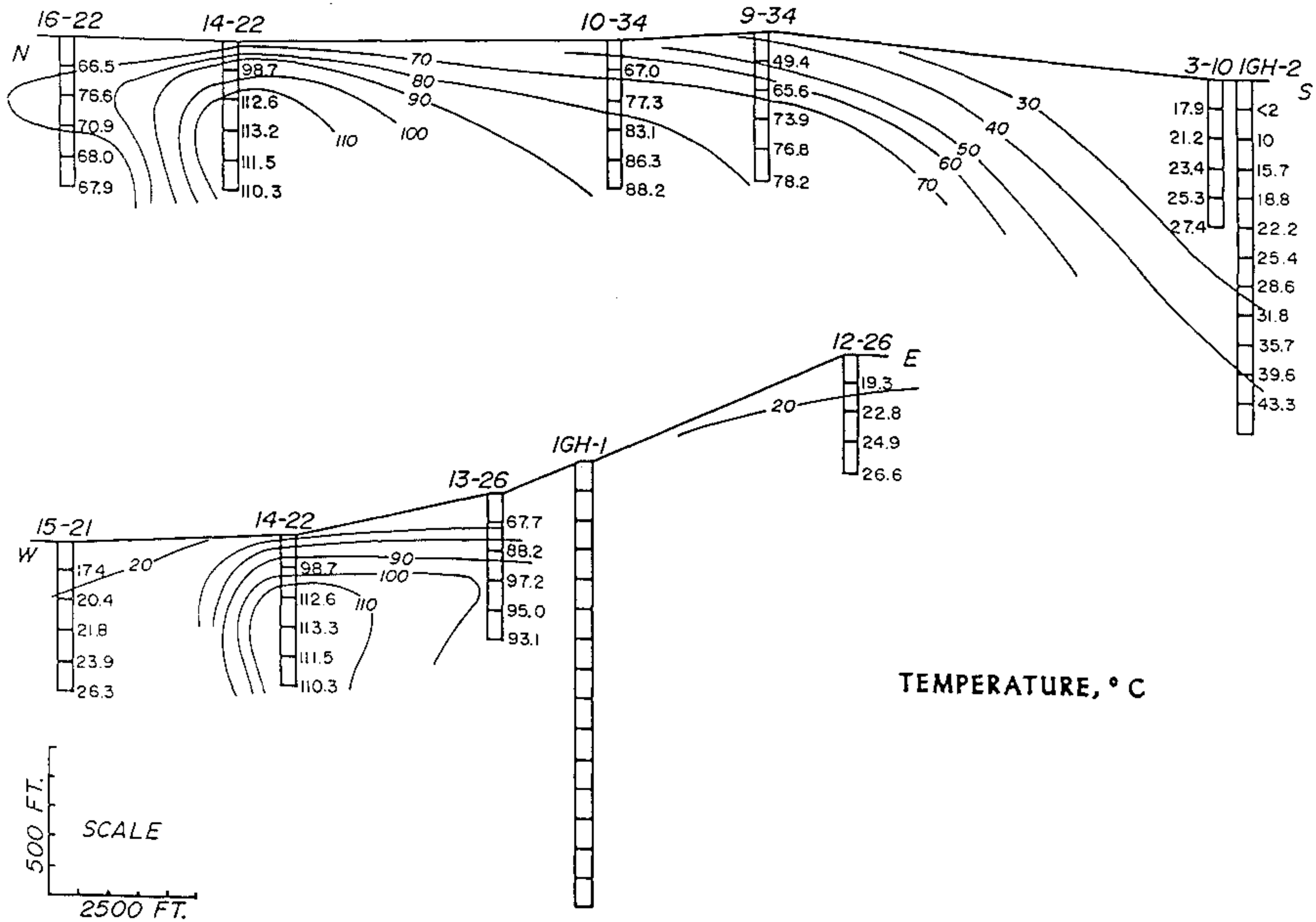


Figure 8. Temperature distribution in thermal gradient wells.

feet (60-120 m). The spatial distributions of several elements bear close correspondence with the temperature profile.

The numerical and spatial distributions of As and Hg are the most instructive. The numerical distribution of As concentrations strongly suggests the presence of three distinct geochemical populations with threshold concentrations between them of 35 and 140 ppm. The greatest concentrations occur in the deepest samples from holes 14-22, 16-22, and 18-24. Hg concentrations throughout the entire prospect area are significantly greater than those observed about nongeothermal areas or widely peripheral to these areas (Capuano and Moore, 1980). Statistical evaluation shows that Hg data similarly belong to two overlapping lognormal populations with different dispersions. A threshold value of 250 ppb effectively separates values of a higher, more widely dispersed, population from values representing a mixture of the two populations below. Spatially, these anomalous Hg values occur above and around the highest As values and the highest measured temperatures.

A similar distribution pattern of As and Hg is observed at Roosevelt Hot Springs, Utah. The observed distributions and heating experiments indicate that Hg remobilization occurs at temperatures as low as 200°-$250^{\circ}C$ and that the distribution of Hg peripheral to the thermal center is largely produced by the present thermal configuration (Christensen and others, 1980b). The restricted peripheral concentration of Hg observed at Colado is also probably temperature controlled and suggests that temperatures present at the base of the Hg anomaly at the time of its development may have approached $200^{\circ}C$.

Li data show less conclusive evidence of distinct statistical populations, and a less definitive spatial distribution. Higher concentrations are in general located within the alluvium, and may, especially in the 200-300 foot (60-90 m) depth interval, reflect the lateral flow of thermal fluid toward the southwest within a shallow groundwater aquifer. The high Li concentrations observed in the alluvium could also in part reflect the contribution of detrital siliceous volcanic materal. The consistently greater concentrations about the higher temperature locations though strongly support the relationship between thermal fluid flow and Li enrichment.

Be concentration values similarly appear to belong to two overlapping but distinct lognormal populations. The greatest concentrations occur in holes 13-26 and 14-22, and in the two intermediate-depth gradient holes, coincident with the thermal anomaly at shallow levels.

The distributions of these four elements appear to be remarkably coincident. All are enriched within the area near drill hole 14-22 and exhibit systematic reduction away from this area. These elemental distributions are consistent with the measured temperature distributions at Colado and reflect the configuration of active, near-surface fluid pathways in a hot-water geothermal system. The data suggest that thermal fluids rise through the alluvium in the vicinity of gradient hole 14-22 to depths of 200-400 feet (60-120 m), then flow laterally to the southwest within alluvial aquifers down the hydrologic gradient, probably mixing with cooler groundwaters in the process. As the fluids cool, Li, Be, As, and Hg are deposited in response to the changing physical and chemical conditions. As and Be appear to be deposited in higher temperature zones; Li begins to deposit early but forms a rather dispersed geochemical anomaly about the system; Hg is anomalously high throughout the entire geothermal area but is concentrated in a shallow halo above the As and Be anomalies. This configuration is similar to that observed about the Roosevelt Hot Springs thermal area, Utah (Christensen and others, 1980b).

The observed distributions of temperature, As, Hg, Li and Be reflect the form of fluid flow paths, and appear to be largely independent of lithochemical effects. The prominent Hg concentration (750 ppb) occurring in the lowermost interval in IGH-2 may reflect Hg deposition from thermal waters flowing along a permeable zone at the base of the alluvial section.

Structurally, the area between drill holes 13-26 and 14-22 appears to be a critical area. The mapped geology (Sibbett and Bullett, 1980) and available gravity data (Mackelprang, personal communication) suggest that one of the Basin and Range faults bounding the western margin of the West Humboldt Range passes between the two holes and abruptly changes trend in this area. The apparent structural intersection may form a favorable conduit for the conduction of thermal fluids into the shallow permeable alluvium. Prominent As and Be concentrations mark the position of shallow thermal fluid flow in the vicinity of drill hole 14-22. The extension of the anomalous Hg concentrations eastward from the most prominent As anomaly suggests that the thermal anomaly may extend this direction as well.

Other Element Distributions

There are a number of elements in addition to As, Hg, Li, and Be which are known to be mobile in geothermal fluids (Ellis and Mahon, 1977; Ellis, 1979; Weisberg and others, 1979) and can be redistributed within a geothermal system through water-rock interaction. It is entirely possible and expected that one or more other elements could prove useful in other geothermal areas. In the Colado area, however, other possible elemental distributions related to geothermal processes either are obscured by geochemical distributions formed during other geologic events, or are developed at concentration levels below the detection limits of the analytical methods employed.

Although several of the major elements, particularly the alkali and alkaline earth metals, are commonly present in significant concentrations in thermal fluids, their redistribution within the rocks resulting from interaction with these fluids is masked by the greater variability due to lithologic differences between samples. Elements for which this is true in the Colado area include Na, K, Ca, Mg, Fe, Al, Si, Ti, P, Sr, Ba, and Mn.

Another group of elements are of limited value in this area due to their low concentrations and uncertainties associated with the preparation and analysis of samples. Elements present largely or entirely at concentrations lower than the limits of determination (Christensen and others, 1980a) include: V, Mo, Pb, Th, Ag, Au, Bi, U, and Te. Three other elements of limited value because of loss or contamination during preparation and analysis include Si (lost during HF sample digestion), W (contamination introduced from WC mill used for sample comminution), and B (contamination introduced from borosilicate glass.

Evaluation of geochemical data by cumulative probability plots permits rapid discrimination between elemental distributions belonging to a simple statistical population and mixed distributions of two or more populations.

The numerical variability of a number of elements in this study, when evaluated in this manner, is found to be consistent with the variability expected within a single lognormal population. The apparently random spatial distribution of extreme high and low values for these elements further supports this suggestion. Elements in the Colado area which belong to a single background geochemical population and are evidently not significantly redistributed by geothermal processes include Ba, Cu, Mn, Sr, Fe, Cr, Ni, Pb, Sn, La, and Ce.

The numerical distributions of a number of other elements are polymodal. Their distributions, however, are clearly related to the lithologic variability of samples and the influence of other geologic processes. Zn, Cu, and Cd in particular are present in greater concentrations in the dark-colored Mesozoic argillites and slates, whereas Zr is relatively less abundant in these rocks than in the overlying alluvial material. Apparent spatial zoning of these elements is due simply to the distribution of lithologies intersected in the drill holes. Sb and Au are largely present in concentrations well below the limits of the analytical procedure but occur in anomalous concentrations in a few isolated alluvial sample intervals. This is attributable to the likely presence of detrital material within alluvium from the Sb and Au deposits in the West Humboldt Range to the east. Similarly, Co is irregularly enriched in samples from the vicinity of the mineral deposits as well as in alluvium. The polymodal distributions of these elements are related to the combined effects of multiple geochemical and geologic events and not apparently to redistribution by the present geothermal system.

Conclusions

Analysis of cuttings from 18 shallow temperature gradient drill holes and from two intermediate depth gradient holes within the Colado geothermal area outlines an area of anomalous geochemistry spatially coincident with an area of anomalously high measured temperatures. Both are apparently related to the shallow flow of geothermal fluids. As these thermal fluids interact with rock material, Li, As, Be, and Hg deposit in a characteristically zoned sequence.

In the Colado area, fluids appear to rise to shallow levels near drill hole 14-22, perhaps along permeable zones resulting from the intersection of deep structures. As the fluids enter the alluvium, they flow southwestward within shallow aquifers down the local hydrologic slope. Increased temperatures and enhanced concentrations of As, Li, Be, and Hg mark the course of fluid flow. Anomalously high concentrations of Hg at the base of the alluvium suggest that significant flow occurs along this interface.

The distributions observed suggest that the discharge of thermal fluids from depth into the alluvium is spatially restricted to a small area in the vicinity of gradient hole 14-22 (S22, T28N, R32E). The larger area of the observed thermal anomaly and of known thermal wells is due to pluming of warm fluid within shallow aquifers.

Acknowledgements

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Mackelprang clarified interpretation of the geology and geophysics of the Colado area. Critical manuscript reviews by Joe Moore, Howard Ross, Ted Glenn, and Jim Stringfellow are appreciated.

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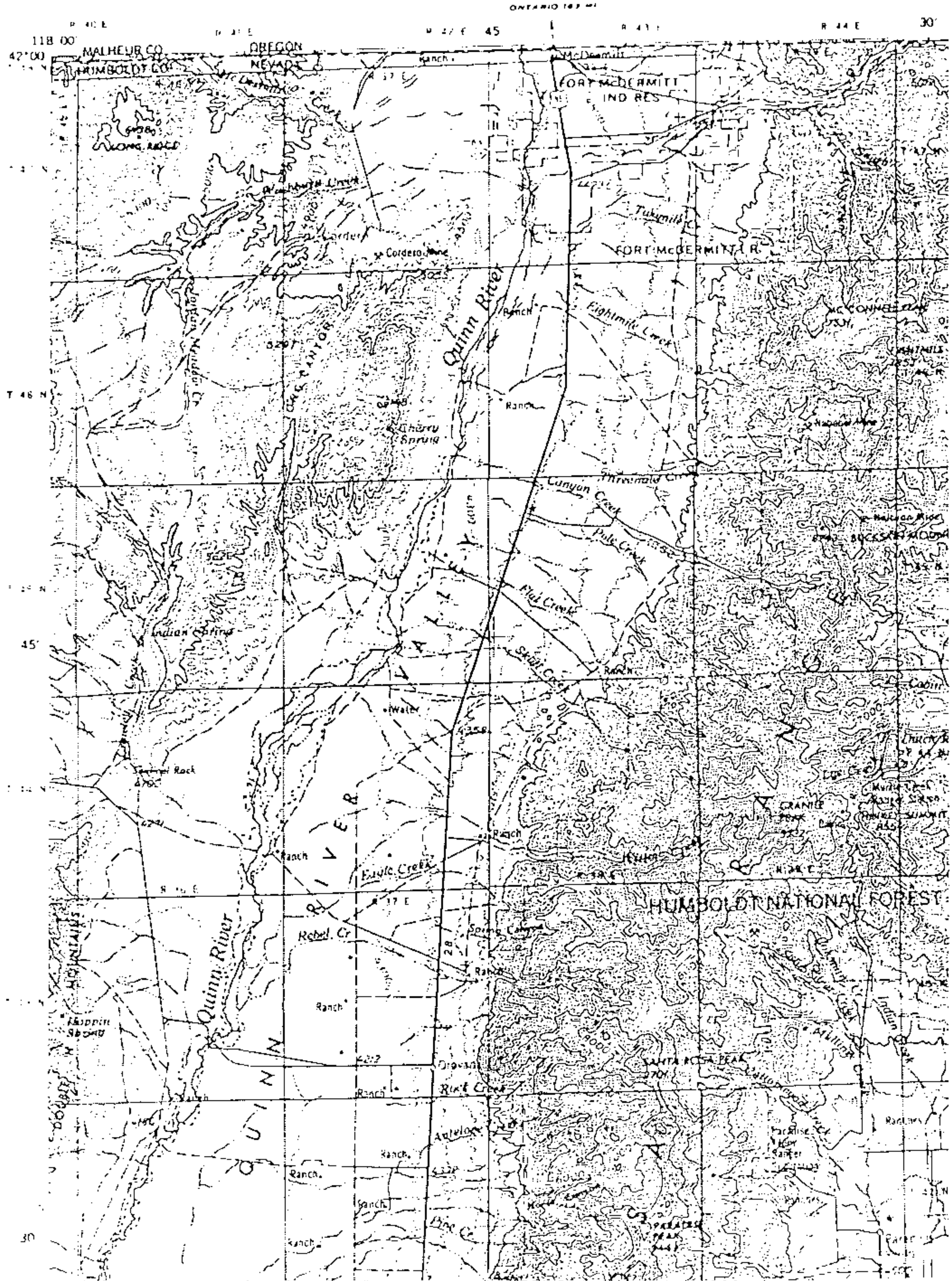

McDERMITT CALDERA AREA ROUTES

Roadlog and Trip Guide--Winnemucca to Golconda

by Byron R. Berger and Ralph L. Erickson

Distance	Cumulative mileage	
0.0	0.0	Junction of 3rd St. and Bridge St. Proceed northeasterly on 3rd St. (U.S. Highway 40) to beginning of divided highway. The Winnemucca townsite is situated in the Humboldt River valley between Winnemucca Mountain and the Krum Hills, to the northwest, and the Sonoma Range to the south. The Krum Hills consist of Juro-Triassic clastic rocks with some interbedded carbonate and sparse volcanic rocks, Tertiary rhyolitic intrusive rocks, and Tertiary andesite and basalt flows. The Sonoma Range consists of structurally complex Paleozoic and Mesozoic clastic, carbonate, and volcanic rocks and Tertiary welded and non-welded silicic ash-flow tuffs. The Winnemucca mining district is located on Winnemucca Mountain, where gold and silver were discovered in 1863. The early productive lodes occurred in quartz veins with small amounts of copper and lead. Gold also occurs in carbonaceous beds associated with seams of quartz and calcite.
3.2	3.2	Interstate 80. Continue travelling northeast on divided highway. Paradise Valley extends to the north to the Santa Rosa Range. The Hot Springs Range bounds Paradise Valley on the east. The southern part of the Hot Springs Range consists of Cambrian and Ordovician clastic rocks, predominantly feldspathic sandstone, some chert, shale, and greenstone and minor amounts of limestone. The Dutch Flat mining district is located on the west side of the range where placer gold was discovered in 1893, and small mercury deposits occur around the south end of the range.
5.2	8.4	Button Point. Tertiary welded and nonwelded silicic ash-flow tuffs, locally with included thin units of air-fall tuff and sedimentary rocks, occur in the outcrops adjacent to the highway.

GOLCONDA AREA ROUTES

Distance	Cumulative mileage	
6.7	15.1	Golconda offramp (Exit 194). Exit freeway to the right and turn left back across the freeway at the stop sign. At the next stop sign turn right and proceed to the east towards Midas. The prominent hill immediately to the south of the overpass across the freeway is Kramer Hill which consists of the Cambrian Osgood Mountain Quartzite, a light-brown weathering, white to light-gray, thin-to massive bedded, relatively pure quartzite. The quartzite is intruded by Upper Cretaceous granodiorite dikes which are commonly altered, with biotite replaced by chlorite + magnetite + calcite, and plagioclase replaced by sericite. Gold was discovered on Kramer Hill in 1866, and minor amounts of bullion were produced through the first part of the 1900's. All values were recovered from oxidized ore in quartz veins (Vanderburg, 1938, U.S.B.M.I.C. 6995). Steam from active hot springs can be seen on the north and northeast sides of the town of Golconda. According to Garside and Schilling (1979, NBMG Bulletin 91), the springs range from 109° to 165°F, are anomalously radioactive, and are actively depositing travertine. Metals in the spring waters include arsenic (0.02 ppm), manganese (0.10 ppm), copper (0.05 ppm), mercury (0.0001 ppm), and lithium (0.36 ppm).
2.6	17.7	Highway bends to the north ~~of~~ to Golconda tungsten-manganese mine.
2.7	20.4	Turn right on dirt road, proceed 0.4 miles and then turn right on dirt road 0.1 mile to open pit of the Golconda Mine. Stop 1. These tungsten-manganese deposits occur in ferruginous and manganiferous clay beds in alluvial gravels that rest on the Cambrian Pebble Formation. In part the deposits are overlain by travertine, which forms an irregular, horizontal sheet that strikes north-south. Kerr (1940, Bull. Geol. Soc. America) delineated two stages of tufa development. An older tufa caps higher elevations and is underlain by the tungsten-manganese blankets, whereas the younger tufa fills in depressions between the higher elevations, and forms a bench with intermittently active springs.

Distance	Cumulative mileage

The Cambrian rocks beneath the alluvial deposits consist primarily of phyllitic shale with lesser amounts of interbedded, thin carbonaceous limestone.

The tungsten-manganese deposits were discovered in 1885 in the expectation of finding gold and silver (Pardee and Jones, 1920, USGS Bull. 710-F). They occur as blankets and veins adjacent to a fault trending N.25°E., and the blankets dip gently to the northwest. The deposits vary from a few inches to a few feet in thickness, and in places are intermixed with the top of the tufa cap. The veins consist of linear masses of anastamosing groups of veinlets along the northeast trend beneath the tufa caps. Both ferruginous and manganiferous vein fillings contain tungsten with accompanying quartz, barite, and jarosite. Kerr (1940) reports that the ferruginous zones in part replace the manganiferous phases, and there is a higher concentration of tungsten in the ferruginous zones. The paragenesis of vein types is best observed in the Cambrian sediments away from the high concentrations of manganese and iron. Quartz veins with sericite selvagos are the earliest and these veins contain minor amounts of manganese. This episode was followed by manganese-calcite veins which retrograded the sericite to illite, and finally the ferruginous veins were emplaced. The veins acted as feeders to the blanket deposits. In general, the manganiferous and ferruginous materials are separated into different layers, although both occur as streaks in the layers of the other material. The manganiferous and ferruginous layers are underlain by a massive illite layer with some fine quartz-rich zones. Tungsten occurs in all of these layers.

The mineralogy of the ores in very complex. Iron occurs primarily as goethite, lepidocrocite, and amorphous limonite minerals. Manganese occurs as psilomelane, hollandite (?), and pyrolusite. Tungsten occurs in limonite as an unidentified complex. Ferritungstite and tungstite may occur, but have not been identified. Tungsten also occurs as a heterogeneous mixture in psilomelane. Neither wolfranite nor scheelite have been found in the ores.

The major element chemistry of the ores is given in Table 1.

Table 1.

Analyses of Tungsten-Manganese Ores from the Golconda, Nevada Occurrences

(all values given as weight percent of the oxide)

Analysis	1	2	3	4	5	6	7
SiO_2	1.70	4.70	38.54	0.21	1.70	----	----
Al_2O_3	0.34	----	12.96	1.32	0.34	----	----
Fe_2O_3	3.32	12.00	24.71	0.47	3.32	12.00	0.49
MgO	1.26	----	3.05	0.45	1.26	----	----
CaO	3.44	1.99	1.44	0.22	3.44	1.99	----
Na_2O	n.d.	----	0.78	0.53	n.d.	----	----
K_2O	0.35	----	2.12	3.42	0.35	----	3.53
TiO_2	----	----	0.51	----	----	----	----
P_2O_5	n.d.	----	0.83	----	----	----	----
MnO	65.66	48.96	0.09	68.33	65.66	48.96	70.52
WO_3	2.78	1.54	2.64	2.24	2.78	1.54	2.31
H_2O	4.16	----	12.19	4.04	4.16	----	4.17
BaO	5.65	4.73	----	4.16	5.65	4.73	4.29

n.d. none detected in analysis
---- no analysis made

Samples:

1. Penrose (1893), manganese ore
2. Pardee and Jones (1920), manganese ore
3. Kerr (1940), ferruginous ore
4. Kerr (1940), psilomelane
5. Kerr (1940), psilomelane
6. Kerr (1940), psilomelane
7. Kerr (1940), hollandite

Marsh and Erickson (1974) found a distinct geochemical partitioning between the manganiferous and ferruginous layers. The black manganiferous layers contain higher concentrations of barium, cobalt, copper, niobium, nickel, strontium, and thallium than the orange-brown ferruginous layers which contain higher concentrations of arsenic, boron, beryllium, germanium, and vanadium.

To the east of the tungsten-manganese deposits, altered limestone occurs along a northeastern trend. The limestone is locally silicified, and Kerr (1940) found a jarosite vein with quartz, barite, calcite, psilomelane, and limonite derived from the alteration of an earlier mineralized rock that probably contained pyrite and scheelite. This interpretation is consistent with the reference of Berger, Silberman, and Koski (1975, Econ. Geol.) to skarn-type mineralization at depth beneath the tungsten-manganese deposits.

Penrose (1893, Jour. Geol.) recognized that the travertine and associated tungsten-manganese deposits are related to Pleistocene hot springs activity. Water apparently emerged along the northeast-trending faults in the Preble Formation phyllite with a parallel line of springs in limestone upslope from the exploited tungsten-manganese deposits. It is evident that the early waters were silica-rich and were followed by tungsten-bearing carbonate-rich waters. White (1955, Econ. Geol.) believes that the travertine and tungsten-manganese deposits were deposited contemporaneously. A drill hole near the Golconda mine encountered considerable marcasite and a temperature of 143°F at 220 feet. A short distance northeast of this hole is a well that flows 1.5 gallons/minute of water at 69.5°F (Garside and Schilling, 1979). The most likely source of the metals deposited by the hot springs system was the carbonaceous phyllite shales, dolomitic limestones, and calc-silicate altered limestones known to underlie the Golconda deposits.

Distance	mileage	
1.0	21.4	Return to paved road and proceed to the northeast.
0.8	22.2	Turn right on dirt road (opposite gravel pit) and proceed to the east. This road

Distance	Cumulative mileage	
		permits access to bedded barite occurrences in the Cambrian Preble Formation. Exposed along the sides of the road are greenish-weathering phyllitic shales with some interbedded dolomitic limestone.
0.8	23.0	Stop 2. Exposures of tightly-folded Preble Formation limestone along the side of the road.

The purpose of this stop is to examine important structural relations in the Preble Formation that cannot be reconciled with traditional concepts of the regional structural history. The Preble Formation and underlying Osgood Mountain Quartzite are regionally metamorphosed and folded into south-plunging asymmetric folds overturned to the west (Erickson and Marsh, 1974). In the immediate area, the folding forms a belt 60 km long and 10 km wide, extending from the southern part of the Sonoma Range on the south to the northern end of the Osgood Mountains to the north. The axes of the folds and, in particular, the folded limestone beds are of considerable importance in the localization of mineralization throughout the fold belt.

The westward-overturned folds must have been produced by a west-directed compressive force, and they are not compatible with simple upwarping or with the eastward-directed Antler (Late Devonian) orogenic forces. Erickson and Marsh (1974) recognized the remnants of an Antler-age thrust plate on top of this westward-overturned fold belt to the east of this stop on Iron Point. The autochthonous rocks are the Ordovician Comus and Vinini formations. In contrast, to the north Berger (1975) recognized the Comus Formation to be isoclinally folded in the same manner as the Preble Formation, and could find no evidence of Antler-age faulting separating the Cambrian rocks from the Ordovician rocks. Hotz and Willden (1964) found east-dipping isoclinal folds in the Upper Cambrian Harmony Formation in the Hot Springs Range immediately west of the Osgood Mountains. Gilluly and Gates (1965) interpreted the Middle Cambrian Shwin Formation in the Shoshone Range to be autochthonous or parautochthonous.

Distance	Cumulative mileage	

The Shwin Formation is isoclinally folded, and the geologic map by Gilluly and Gates suggests eastward dips for the stratigraphic units within the Shwin. The Shwin Formation is metamorphosed in a manner similar to the Preble Formation, and, as in the case in the Golconda area, the metamorphism cannot to ascribed to the Antler orogenic event. In Elko County, Nevada, Willden and Kistler (1967) recognized asymmetric isoclinal folding and accompanying metamorphism that clearly predates the Silurian and Devonian Lone Mountain Dolomite, and is unrelated to the Antler orogenic event. Therefore, the style and orientation of folding observed at this stop is of regional importance.

There are also important ramifications of this deformation to metallization in the region, as follows. 1. The tectonic thickening of carbonate rocks on the axes of the folds has influenced the grade and extent of mineralization at the Getchell gold mine in the Osgood Mountains and in the skarn deposits of the Adelaide Mine in the Sonoma Range. 2. Remobilization of barite into economic occurrences has taken place throughout the fold belt. 3. The tight folding has resulted in highly fractured axial planes of folds, and silver-bearing galena-quartz veins are common particularly in the dilated zones on the plunging noses of the folds. 4. The presence of metavolcanic rocks in the Shwin Formation in the Shoshone Range (Gullily and Gates, 1965) and near the Getchell Mine in the Comus Formation (Berger, 1975) indicate that the early Paleozoic borderland consisted of local troughs and basins with rapid facies changes. The black shales and volcanic rocks that accumulated on this borderland are metalliferous and enriched in such elements as arsenic, barium, copper, silver, vanadium, and zinc. Many of these elements can be readily moved during metamorphism or plutonism and deposited along unconformities and faults as well as in the axial parts of folds.

Distance	Cumulative mileage	
0.8	23.8	Return to paved road. Optional trip to Getchell Mine.

Distance	Cumulative mileage	
0.0	23.8	Continue to the northeast on the paved road towards Midas. The road parallels the Humboldt River through Emigrant Canyon. Both sides of Emigrant Canyon are made up of Middle and Upper Cambrian Preble Formation. The bulk of the exposed rock consists of phyllitic shale. The contact with the underlying Osgood Mountains Quartzite is transitional and is generally marked by a dirty, green micaceous quartzite or coarse sandstone. The shale is interbedded with fine to coarsely recrystallized limestone, sandy limestone, or dolomitic limestone. Because of intense deformation, the true thickness of the Preble Formation is not certain. Erickson and Marsh (1974) report fossil evidence that the upper part of the Preble Formation may be Ordovician. The folding in the Preble Formation consists of a regionally extensive series of asymmetric isoclinal folds overturned to the west. The mechanism of the folding is uncertain, but predates early Pennsylvanian time (Erickson and Marsh, 1976) and is clearly not related to the Antler orogeny.
1.5	25.3	Bridge across the Humboldt River.
1.4	26.7	The dirt road to the left leads to a low-grade disseminated gold occurrence in the Preble Formation. The property was discovered by Cordilleran Explorations Co. in 1972.
1.0	27.7	The southern part of the Osgood Mountains consists of Tertiary biotite-hornblende andesite tuff and Miocene andesite and andesitic basalt flows. The flows are highly vesiculated at the bases and platy near their tops. To the north the flows lap onto the Osgood Mountains Quartzite.
7.2	34.9	End of pavement. Proceed to left towards north. The road to the northeast leads to the epithermal gold camp of Midas. The road to the west leads to a bedded barite occurrence in the Preble Formation. The low hills immediately to the north consist of dolomitic limestone and shale of the Ordovician Comus Formation. The beds are isoclinally folded with east-dipping limbs. The Getchell fault is on the west side of these low hills.

Distance	Cumulative mileage	
4.3	39.2	The dirt road to the west follows Granite Creek and leads to the Pinson and Ogee-Pinson disseminated gold occurrences discovered by the Cordilleran Explorations Company in 1970. The mineralization occurs in the Comus Formation along a strand of the Getchell fault. Typical of the Carlin-type gold occurrences, the gold is associated with anomalous concentrations of arsenic and mercury. Farther up Granite Creek are located the Granite Creek, Tip Top, and Marcus tungsten deposits. Tungsten-bearing garnet skarns occur in the Preble Formation around the periphery of the Osgood Mountains granodiorite.
0.3	39.5	The mine dumps along the eastern edge of the range are from the Pacific and Valley View tungsten deposits. The Getchell fault trends along the edge of the range and realgar was reported in the fault gauge in the portal of the Pacific mine. The Getchell fault zone contains disseminated gold mineralization continuously from here north to the Getchell mine. Early exploration activity by the Getchell Mine, Incorporated defined a broad zone of mineralization with the best gold values associated with altered limestone beds.
3.4	42.9	The dumps on the left are from the Riley and Riley Extension tungsten deposits. The Getchell fault is exposed in the portal of the Riley mine and is mineralized. Most of the carbonate beds in the Preble Formation are in the footwall of the fault zone and are calc-silicated. The main section of limestone beds in the Preble trends away from the granodiorite contact north of the Riley Extension mine and into the Getchell fault zone where it is mineralized.
0.5	43.4	The small open pit to the west is the Section 4 pit of the Getchell mine and was used primarily as a source of oxidized ore during the 1960's. The Getchell fault is well exposed in the pit, and the best gold values occur in relatively thin limestone beds. At this locality the thickest part of the carbonate section is east of the pit and is exposed in underground workings, the dumps from which can be seen lower on the hill.

Distance	Cumulative mileage	
0.9	44.3	The tailings along the west side of the road are from tungsten-mining activity. The low hill on the east consists of Ordovician mafic metavolcanic rocks with large included blocks of the Comus Formation. Pillow-like structures can be found in some exposures of the volcanic rocks.
0.7	45.0	The Getchell mill and village. The majority of the gold ore here was produced from three large open pits along the Getchell fault.

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Roadlog--Battle Mountain to the Tomboy and Minnie gold deposits of Duval Corporation at Copper Canyon

(modified from R. J. Roberts and C. T. Wrucke, 1979, Antler Orogeny Penrose Conference, and Shawe, D. R., Poole, F. G., and Heyl, A. V., 1978, Nev. Bureau Mines and Geology Report 32.)

Distance	Cumulative mileage	
0.0	0.0	Battle Mountain, Nevada. Turn right from U.S. Highway 80 onto Nevada Highway 8A at one block west of stop light, and proceed southward. Battle Mountain derives its name from an Indian battle which took place in its northeastern foothills in 1861. The battle began near present-day Beowawe when Shoshone Indians attacked a California-bound wagon train at Gravelly Ford. Following the initial attack, the emigrants regrouped and chased the Indians westward. The Indians finally took a stand in the rocks near the site of the letters B. M. and were soundly defeated. A settlement called Reese River Siding was established about 2 miles north of the battle site at the confluence of the Reese River with the Humboldt when the Central Pacific Railroad came through this region in 1869; this siding was rechristened Battle Mountain in January 1870. Battle Mountain is the center of majòr barite and metal mining industry. The barite mines are distributed throughout the region. Copper and gold are the principal metals produced in the area; the copper production is centered at Copper Basin in the northeast part of Battle Mountain and the gold production at Copper Canyon in the southern part.
0.8	0.8	Overpass over U.S. Highway 80. At 12:00 BM initials on northeastern foothills of Battle Mountain. Antler Peak shows on the skyline at 1:00 over the Duval pit, Copper Basin. At 1:15 Long Peak, underlain by brown-weathering Harmony Formation; at 2:00, North Peak, Valmy Formation (note dark talus). The Osgood Mountains 35 miles to the west at 3:00, represent the westernmost exposures of autochthonous rocks of the tránsitional facies.
3.1	3.9	The foothills here are underlain by "Elephant Head" quartz latite ash flow tuff similar to Caetano tuff of Cortez area (approx. 34 m.y.). Believe it or not, this is the type locality of

GEOLOGICAL AND GEOCHEMICAL RELATIONSHIPS AT THE GETCHELL MINE AND VICINITY, HUMBOLDT COUNTY, NEVADA

Byron R. Berger

Introduction

The Getchell gold mine, located in eastern Humboldt County, Nevada (Figure 1), was a producer of gold bullion intermittently between 1938 and 1967. This occurrence is one of several disseminated-type gold deposits in the western United States, including Carlin, Cortez, Gold Acres, Jerrett Canyon, Mercury, and numerous smaller deposits (Roberts and others, 1971). The geological and geochemical characteristics of these deposits are similar; high gold to silver ratio, associated arsenic and mercury, carbonaceous limy host rocks, associated intrusive igneous rocks, and extensive silica replacement.

The purposes of this report are to describe the geologic relationships at the Getchell mine and their effects on the localization of gold mineralization, and to present data concerning the geochemical characteristics of the ore bodies and the consequent ramifications for exploration.

GENERAL GEOLOGIC SETTING

The Getchell mine is located in the Potosi mining district on the eastern flank of the Osgood Mountains, about 70 km northeast of Winnemucca, Nevada (Figure 1). Initial geologic mapping in a portion of the Osgood Mountains was done by Hobbs (1948), followed by a study of the entire Osgood Mountains 15-minute quadrangle by Hotz and Willden (1964).

Studies of the mineral deposits of the Potosi mining district include Hobbs and Clabaugh (1946), Joralemon (1949, 1951, 1975), Cavender (1963), Hsu and Galli (1973), Silberman and others (1974), Taylor (1974), Berger (1975), Berger and others (1975), Berger (1976), and Taylor and O'Neil (1977).

In the vicinity of the Getchell mine (Figure 2 and 3), lower Paleozoic sedimentary rocks are intruded by a granodiorite stock of Cretaceous age (Silberman and McKee, 1971). The oldest rocks are Middle and Upper Cambrian carbonaceous shale and thin-bedded limestone, in part intercalated, called the Preble Formation (Hotz and Willden, 1964). The shale beds are commonly phyllitic, and appear light-greenish in the near surface weathered zone. The Preble Formation is unconformably overlain by a sequence of intercalated dolomitic limestone and chert, shale, siltstone, and mafic volcanic rocks belonging to the Comus Formation of Early and Middle Ordovician age. The mafic volcanic rocks are in part intrusive into the intercalated dolomitic limestone and chert, although vesicular textures, pillow-like structures, and interbedded shale indicate that they are mainly submarine flows. All of these lower Paleozoic rocks are isoclinally folded, with the fold axes overturned to the west (Erickson and Marsh, 1974). This style of folding is not seen in younger rocks. North of the mine area, Etchart Limestone and chert, shale and quartzite of the Farrel Canyon Formation are imbricately thrust over the older Paleozoic rocks. The Etchart Limestone is similar to the Highway and Antler

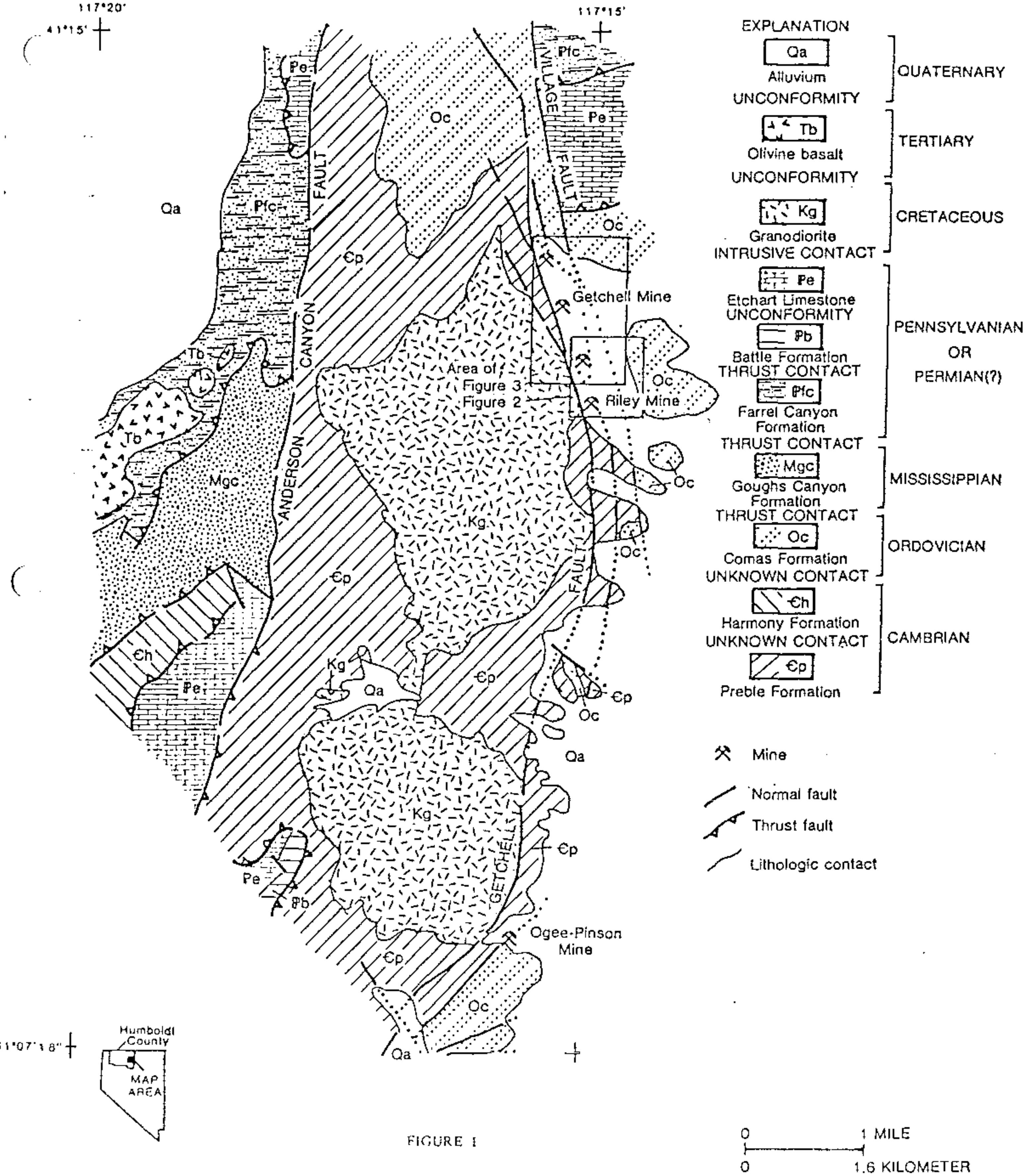
117°20'
41°15'
117°15'
Qa
Pe
Pfc
Oc
Tb
Mgc
Ch
Pe
Kg
Cp
Pb
ANDERSON CANYON FAULT
VILLAGE FAULT
GETCHELL FAULT
Getchell Mine
Riley Mine
Ogee-Pinson Mine
Area of Figure 3
Figure 2
41°07'18"
Humboldt County
MAP AREA
EXPLANATION
Qa
Alluvium
QUATERNARY
UNCONFORMITY
Tb
Olivine basalt
TERTIARY
UNCONFORMITY
Kg
Granodiorite
CRETACEOUS
INTRUSIVE CONTACT
Pe
Etchart Limestone
UNCONFORMITY
Pb
Battle Formation
THRUST CONTACT
Pfc
Farrel Canyon Formation
PENNSYLVANIAN OR PERMIAN(?)
THRUST CONTACT
Mgc
Goughs Canyon Formation
MISSISSIPPIAN
THRUST CONTACT
Oc
Comas Formation
ORDOVICIAN
UNKNOWN CONTACT
Ch
Harmony Formation
UNKNOWN CONTACT
Cp
Preble Formation
CAMBRIAN
Mine
Normal fault
Thrust fault
Lithologic contact
0 1 MILE
0 1.6 KILOMETER

FIGURE 1

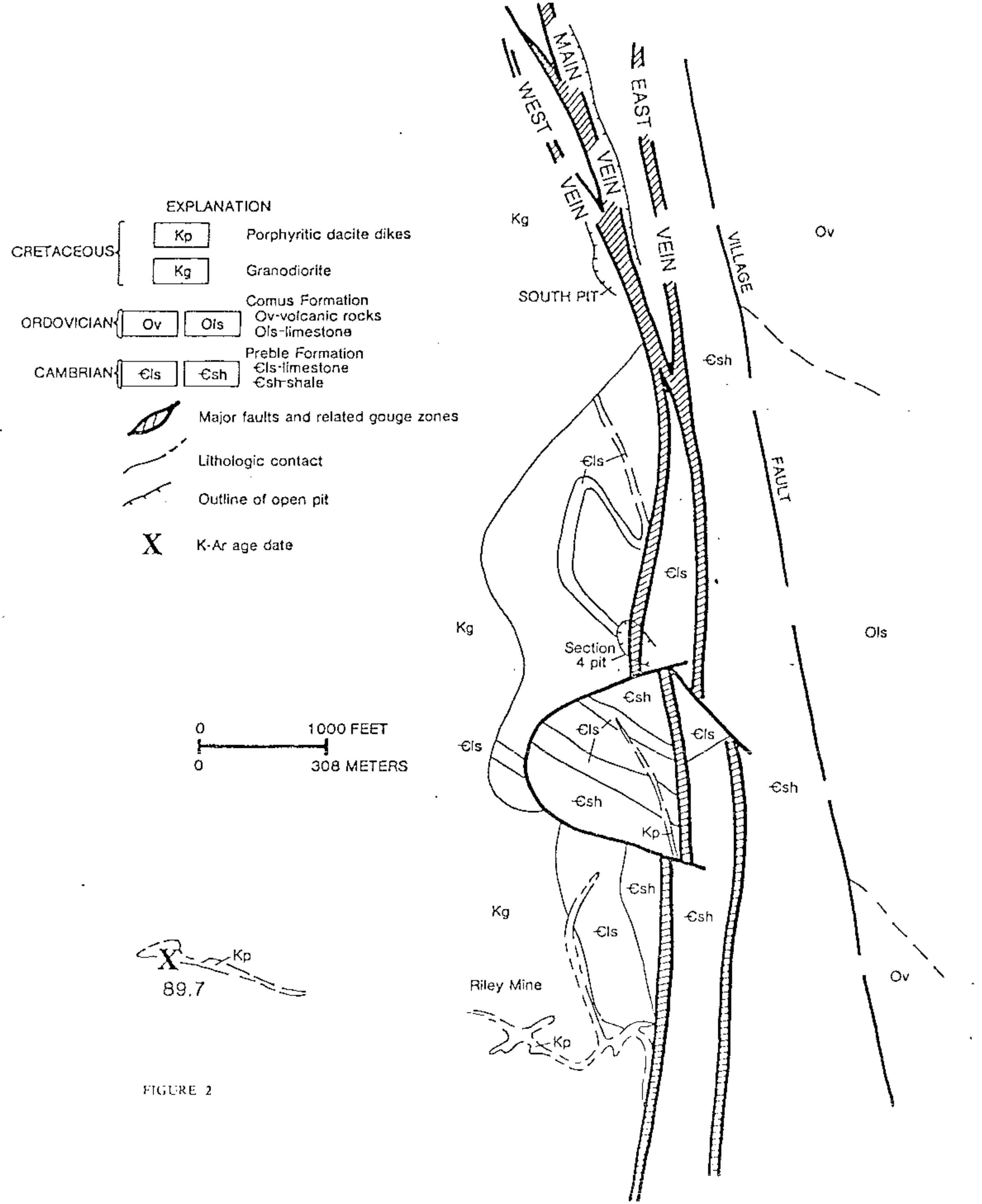
EXPLANATION
CRETACEOUS
Kp
Porphyritic dacite dikes
Kg
Granodiorite
ORDOVICIAN
Ov
Ols
Comus Formation
Ov-volcanic rocks
Ols-limestone
CAMBRIAN
Єls
Єsh
Preble Formation
Єls-limestone
Єsh-shale
Major faults and related gouge zones
Lithologic contact
Outline of open pit
X
K-Ar age date
0
1000 FEET
0
308 METERS
X
Kp
89.7
MAIN VEIN
WEST VEIN
EAST VEIN
VILLAGE FAULT
SOUTH PIT
Section 4 pit
Riley Mine
Kg
Ov
Ols
Єsh
Єls
Kp

FIGURE 2

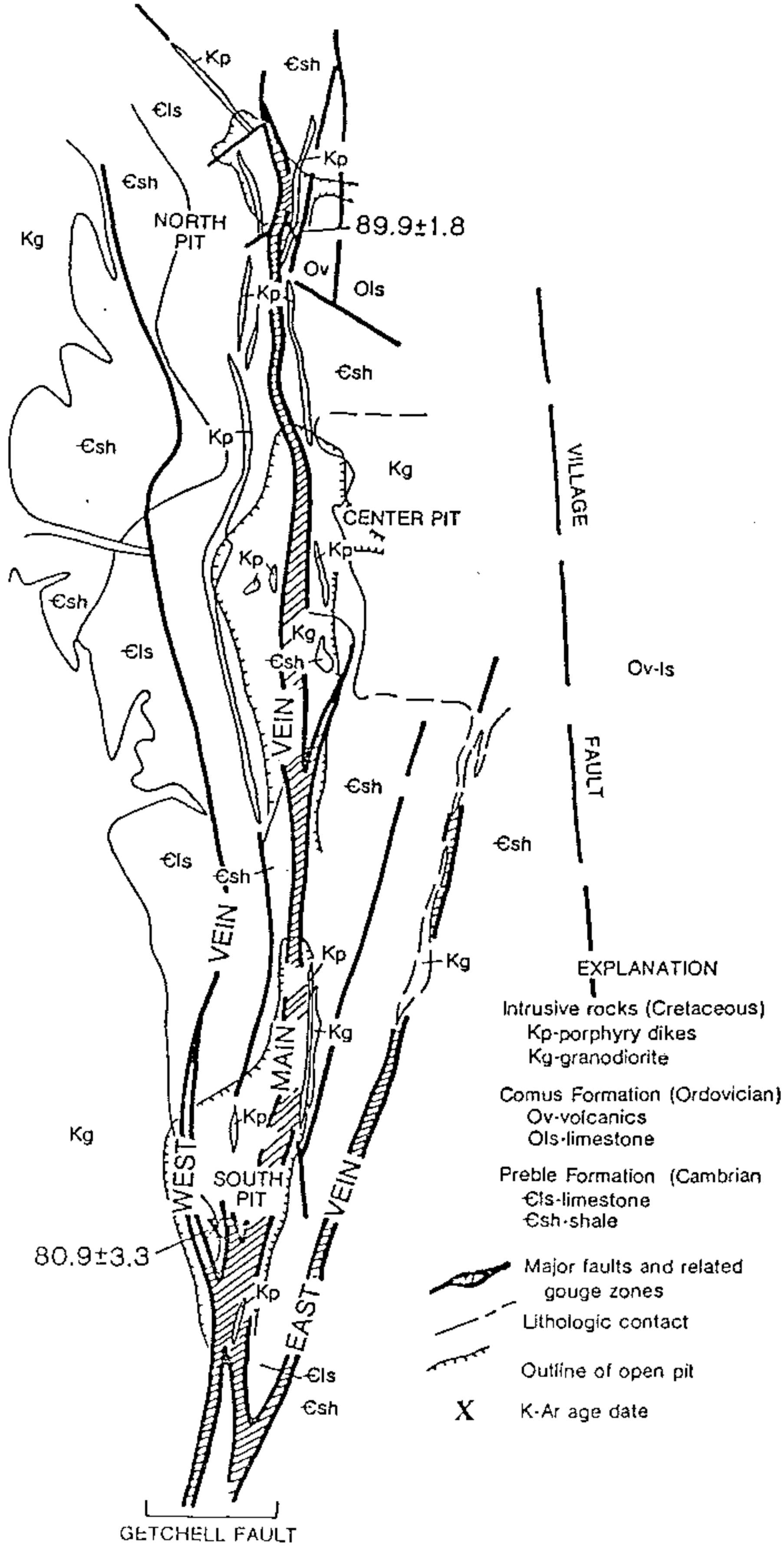

FIGURE 3. Geologic map of Getchell mine area. *Revised from Silberman, Berger, and Koski (1974, after Joralemon, 1951).*

Peak Formations found elsewhere in the region, and contains rocks of Middle to Late Pennsylvanian or Early Permian age (Hotz and Willden, 1964). The Farrel Canyon Formation of Pennsylyanian (?) to Permian age resembles the Havallah and Pumpernickel Formations found to the south and southeast of the Osgood Mountains.

The Cretaceous Osgood Mountains biotite granodiorite and related dike rocks intrude all of the Paleozoic rocks. The stock is an homogenous, coarse body of variable grain size. The dikes consist of both granodiorite and dacite porphyry. The stock is symmetrical, and appears to dip outward 45°-60° on both east and west flanks (Continental Oil Co., unpublished aeromagnetic data, 1973). There is a metamorphic aureole around with the intrusion with a mineral assemblage in shaly rocks consisting of cordierite-, biotite-, and andalusite-hornfels. Locally limy beds are recrystallized and calc-silicate minerals are developed.

The imbricate thrust faults juxtaposing the early and late Paleozoic formations have been interpreted by Erickson and Marsh (1974) in the Edna Mountain area south of the Osgood Mountains as representing two distinct episodes of deformation--Late Pennsylvanian to Early Permian and Late Permian to Early Triassic (Sonoma orogeny). The Getchell fault zone, an anastomosing system of high-angle, dip-slip faults, cuts the thrust faults along the eastern margin of the Osgood Mountains and the zone is a clearly younger feature. Hobbs (1948) and Joralemon (1951) felt that the Getchell fault system postdated the granodiorite stock, and that the earliest sense of movement on the fault was lateral based on presumed mullion structures and horizontal slickensides. Berger and Taylor (1974) re-evaluated the field evidence and concluded that the displacement has been predominantly vertical, and that the fault system controlled the emplacement of the granodiorite stock and related dikes. The fault system has been active to the present as evidenced by the displacement of Quaternary(?) alluvium in the mine area.

MINERALIZATION IN THE OSGOOD MOUNTAINS

Mining activity in the Osgood Mountains has been described by Hotz and Willden (1964). For completeness, a brief summary of the types of deposits other than disseminated gold and the geochemical characteristics of some is presented here.

Barite is a widespread gangue mineral in many of the hydrothermal mineral deposits in the Osgood Mountains. In addition, barite commonly occurs as rosettes in carbonate beds of the Ordovician Comus and Cambrian Preble Formations, and massive, bedded barite deposits are known in sec. 12, T. 37 N., R. 41 E., sec. 32, T. 38 N., R. 42 E., and sec. 30, T. 39 N., R. 42 E. Silver-bearing quartz veins cross-cut the bedded barite, but otherwise there is no hydrothermal sulfide mineralization accompanying the barite.

Metasomatic skarn deposits occur in carbonate host rocks around the periphery of the Osgood Mountains granodiorite. A number of the skarns have been mined for tungsten, with the most active periods being 1942-1945 and 1951-1957. Copper is a minor accessory element in most of the deposits, and molybdenum is a significant co-product of the Moly tungsten mine (figure 2). Tin is present in garnet-pyroxene skarn as an accessory trace element.

Disseminated sulfides occur in the granodiorite stock in two places, one within each of the exposed lobes. Hotz and Willden (1964) referred to the zone in the central part of the northern lobe west of the Riky mine as the Section 5 pit (sec. 5, T. 38 N., R. 42 E.), and at this locality tungsten occurs with quartz in a matrix of quartz sericite and pyrite. The second zone is located at the north end of the southern lobe (secs. 19, 20, T. 38 N., R. 42 E.) and was described by Neuerburg (1966) as consisting of "thin seams of iron sulfides along subparallel irregular fractures." Molybdenum and tin occur in trace amounts in these altered zones.

Small silver-bearing quartz veins occur at numerous localities throughout the range. The veins are fault controlled, and are also common in the broken noses of plunging antiformal structures. Lead and zinc are associated with the silver, and secondary oxides of these elements are common in outcrop. Gold is present in amounts subordinate to the silver.

Minor manganese sulfide and oxide prospects occur at several localities in the range. Most are in chert of the Farrel Canyon Formation as coatings along fractures and as a matrix cementing breccia fragments.

GEOLOGY AT THE GETCHELL MINE

The geology of the Getchell mine area is shown on Figure 3. The alluvium and dump materials have been omitted to better illustrate the geologic relationships.

The Getchell fault system generally consists of two persistent gouge zones referred to locally as the "footwall strand" (Joralemon, 1951) and the "hangingwall strand" (Berger and Taylor, 1974). However, a single fault is not consistently present in either position for the entire length of the range (Figure 1). In the mine area, the Getchell fault exclusive of the Village fault has been simplified into three main strands that are of importance in the localization of the mineralization. These are the West, Main, and East veins (Figure 2 and 3). Ancillary faults do contain gold mineralization, although this mineralization is of limited economic importance.

At the mine, the Getchell fault system consists of a series of anastomosing, east-dipping, normal faults. The dip of the faults varies from about 30° to 60°, with the eastern strand generally dipping more steeply than the western strands. In spite of a thick gouge zone along the Main vein of the Getchell fault (Figure 3), the greatest vertical displacement appears to have taken place to the east along the Village fault, although the absolute displacement is unknown. This interpretation is based on the stratigraphic continuity of the Preble Formation limestone across the Main vein of the fault system in the Getchell mine workings and on drill data south of the workings and along the Village fault (unpublished data, Continental Oil Co.).

Limestone of the Preble Formation is the most important host rock for gold mineralization in the mine area. Arenaceous limestone beds (1-2" thick) are intercalated with equally thick carbonaceous shale beds. The shales are in part limy, particularly in the North Pit area. Thick shale units lie both stratigraphically above and below the predominantly limestone portion of the formation. Against the intrusion the shales are metamorphosed to cordierite-andalusite hornfels. Biotite hornfels appears along some faults and biotite schist appears along others. Berger and Taylor (1974) interpreted these biotite-rich areas as faults ancestral to the present day Getchell system. The shale and limestone beds strike northerly and dip 30°-50° to the east. Outside the zone of contact metamorphism Pre-Cretaceous regional metamorphism has converted the Preble shales into phyllitic rocks.

The main mass of the granodiorite stock is located along the west side of the mine area (Figure 3). It forms the footwall of the West vein of the Getchell fault system in the South pit. Another large mass is located in the hangingwall of the Main vein to the east of the Center pit. Hotz and Willden (1964) suggested that the latter mass was offset approximately 0.7 miles laterally from the main stock. However, an intricate set of offshoot granodiorite dikes along the East vein and to the north of the body along the Main vein imply that the body was emplaced along the faults and is not an offset portion of the main stock. Three- to ten-foot wide granodiorite and dacite porphyry dikes also were emplaced along the Main vein. All of the intrusive dikes are of Cretaceous age (Silberman and McKee, 1971; Silberman and others, 1974).

Several sequences of Tertiary and Quaternary alluvial deposits cover most of the eastern portion of the mine area. These deposits have been unaffected by hydrothermal activity. A rhyolitic ash is incorporated in the oldest alluvium exposed in the North, Center, and South pit areas. The ash units are found in the alluvium in the east wall of all of the open pits and about two miles north of the mine along the Village fault. The largest exposure of ash is adjacent to the North pit entrance ramp. Joralemon (1951, 1975) felt the ash adjacent to the North pit was genetically related to the gold mineralization. However, eroded fragments of mineralized rock occur in alluvium beneath the ash beds, and portions of the ore zones are truncated by alluvium-filled channels which contain the ash beds.

GEOLOGIC RELATIONS OF THE GOLD MINERALIZATION

Gold was discovered at Getchell in 1934. Opencut and undergound production of primarily oxide ore commenced in 1938 and continued to 1950. The gold was extracted using the cyanide process. Sulfide ores, mined from three open pits, were primarily treated during a later stage of mining (1962-1967) using a fluid-bed roast to oxidize the ores prior to cyanidation. The bullion production record for both periods of mining is given in Table 1.

The gold ore deposits are low temperature (Nash, 1972) replacements of limestone along the Getchell fault zone with the faults serving as conduits for the ore solutions. Typical of many epithermal deposits, the ore bodies form irregular pods of erratic grade (Figure 4). Mining widths averaged 12 meters (Joralemon, 1951), although zones as much as 61 meters wide were mined. Deep explorations shows that the mineralization persists at least 1 kilometer down-dip on the Getchell fault system and also occurs along the parallel Village fault (Berger, 1976). Although the major strands of the Getchell fault appear to converge down-dip, the complex pattern of mineralization remains consistent to considerable depths, and there is still more than one persistent mineralized structure at the deepest levels investigated.

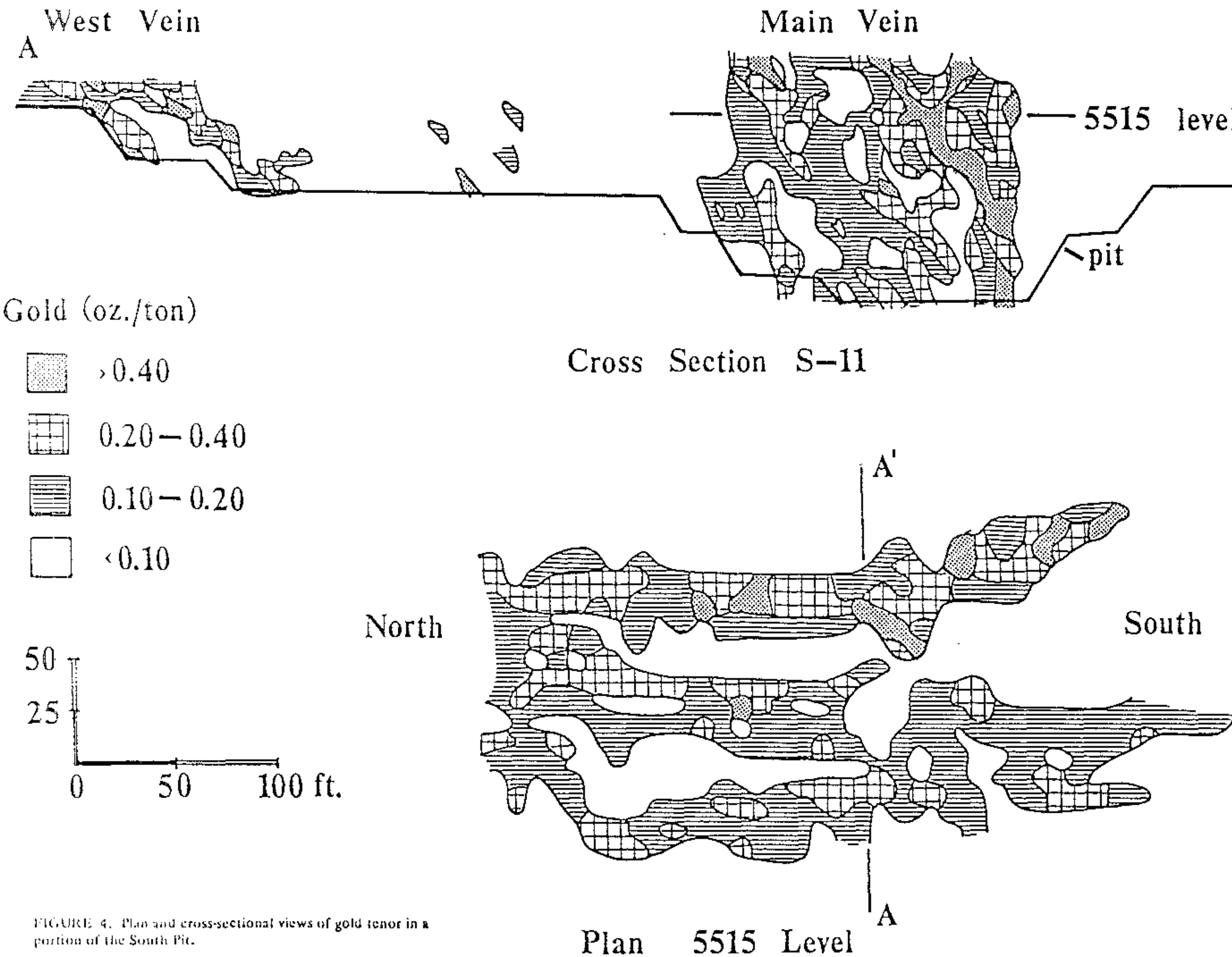

FIGURE 4. Plan and cross-sectional views of gold tenor in a portion of the South Pit.

TABLE 1. Gold production at the Getchell mine*

1938-1950

Year		Ounces	Value
1938		24,818	$ 868,632
1939		49,135	1,719,740
1940		63,385	2,218,467
1941		59,515	2,083,033
1942		49,168	1,720,868
1943		34,949	1,223,232
1944		35,536	1,243,760
1945		9,925	347,375
1946-47		No Production	
1948		10,754	376,390
1949		18,758	656,530
1950		32,090	1,123,150
	TOTAL	388,033	$13,581,177

1962-1967

	Tons	Ounces/Ton
North Pit	804,130	0.33
Center Pit	396,100	0.25
South Pit	879,400	0.23
Section 4	33,400	0.23
	2,113,030	0.271

*Data compiled as shown from annual reports of Getchell Mine, Incorporated.

Alteration and Ore Mineralogy

Hydrothermal alteration consists chiefly of decarbonatization accompanied by silicification of the limestone beds. Some portions of the limestone have been completely altered to fine, granular quartz. Secondary quartz is also present in all other rock types in the mineralized zone. Where relict bedding is preserved, the quartz is very fine grained, and the grains are elongated parallel to the bedding. Where silicification is more intense, the quartz is fine to medium grained, and grew obliquely to the bedding. All of the secondary quartz grains display an irregular outline in contrast to the equant, mosaic texture found in the unmineralized metamorphosed rocks. Polished section examination has shown some native gold to be jacketed by and along the margins of quartz grains (Joralemon, 1949). Amorphous and/or cryptocrystalline masses of silica referred to as "jasperoid" have only been found in oxidized portions of the mineralized zones and are probably supergene in origin.

Some of the silicified zones are surrounded by pods of carbonaceous material. The carbon has probably been in part remobilized from limestone and shale by the hydrothermal solutions, and is a mixture of amorphous carbon, organic carbon complexes (B. R. Berger, unpublished data), and graphite (Botinelly and others, 1973). The most carbonaceous zones occur where shale made up a significant proportion of the host rock. Where the bedding has been preserved, the carbonaceous material forms thin laminae paralleling quartz layers. The carbon often surrounds the quartz, but is not, in general, adjacent to subhedral pyrite grains which form elongate clots parallel to the bedding. The pyrite is intergrown with larger quartz grains and commonly contains blebs or rims of arsenopyrite. Joralemon (1949, 1951) found some visible gold in association with pyrite, arsenopyrite, and carbonaceous material. Where silicification is more intense, the carbonaceous material forms irregular, intergranular mattes surrounding quartz grains. However, the sulfides again tend to be enclosed by elongate quartz grains and not carbonaceous material, implying that there is a closer relationship of gold to quartz and sulfide than to carbonaceous material (Wells and others, 1969). Depending on the original host rock mineralogy, other alteration products include sericite, clay, and chlorite. Cordierite, andalusite, and biotite are altered to sericite and/or chlorite. Feldspar is argillized and/or sericitized. X-ray data from an altered granodiorite mass in the South pit indicate that the clay is primarily kaolinite.

Realgar and orpiment are late-stage products of the hydrothermal activity. They are generally interstitial to other ore and gangue minerals along veins, fractures, or bedding planes. In rocks with considerable carbonaceous material, realgar and orpiment are surrounded by dense mattes of late-stage remobilized carbon.

The igneous dikes and portions of the main stock are altered. Plagioclase is altered to sericite and kaolinite; biotite is altered to sericite, chlorite, and pyrite. Stockwork quartz veins cut the igneous bodies, and these veins are cut by calcite-dolomite veins in the South pit. Realgar occurs along the stockwork veins and around the boundaries of altered feldspar grains. Much of the groundmass of the porphyritic intrusions is altered to quartz and clay. Joralemon (1949) suggested that the alteration of the igneous dikes may be deuteric. The only deuteric alteration noted during the present study consisted of partial sericitization of biotite in dikes crosscutting tactite in the Riley mine to the south of the Getchell mine (Figure 2). Intense argillic alteration and pervasive quartz and sericite along dike boundaries are found only in dikes located in areas having gold mineralization. Away from the ore bodies or within the granodiorite, dikes are fresh; even a short distance from the Getchell fault they do not show alteration of any sort.

Minor ore minerals include cinnabar, stibnite, and occasional chalcopyrite and sphalerite. In addition to quartz and calcite, gangue minerals include marcasite, magnetite, barite, fluorite, and chabazite. Stibnite is most common in the South pit ore body and along the East vein. Fluorite occurs in the North pit ore body as do the rare minerals getchellite ($Sb_3As_2S_3$) and galkhaite ($(Hg,Cu,Tl,Zn)(As,Sb)S_2$) (Botinelly and others, 1973).

Stratigraphic and Structural Ore Controls

The Getchell and Village faults are the primary loci of mineralization. Alteration and metallizations string out along minor structures into the hangingwall or footwall only a few meters. The hydrothermal solutions mineralized all rock types in the mine area, although economic mineralization for the most part appears to be restricted to the limestone and limy portions of the shale of the Preble Formation.

The strike and dip of the bedding in the Preble Formation are subparallel to the Getchell fault; as a result the replacement ore bodies in plan view are thin and sheet-like zones along the fault. Isoclinal folding of the sedimentary rocks also controls the mineralization: (1) the folds have duplicated the relatively thin limestone member of the Preble Formation resulting in a thicker mineralized zone transected by the fault zone; and (2) increased permeability in the crushed noses of the folds allowed the mineralization to follow the plunge, increasing ore length. However, the folds do not carry the mineralization away from the main fault zone more than a few meters. Depending on the position of the limy rocks relative to the fault the mineralization can occur either against the footwall or adjacent to the hanging wall.

The geometry of the ore bodies is shown in Figure 4. Both cross sectional and plan views are shown from the South pit (Berger, 1975). The higher grade bodies form scattered pods and narrow, continuous shoots down the dip of the vein. Although in the interior of the veins ore grade generally decreases gradually away from high-grade bodies, locally it decreases abruptly. The high-grade bodies commonly persist to the margin of the vein, where grade drops off abruptly.

Joralemon (1975) reported that for ore grades exceeding 0.10 ounces per ton the ore bodies apex within 9 to 15 meters of the present-day land surface, reflecting current topographic highs and lows and implying a very young age for the deposit. Berger and others (1975) found that for the minimum grade of 0.10 ounces per ton gold, the relation between the top of the north ore body and the surface prior to mining is as shown in Figure 5. Small pods of ore and altered rocks cropped out or were exposed in shallow trenches along ancillary faults in the footwall of the North pit ore body (Witt, 1936b). Where the Center Pit is now located, silicified gold-bearing ledges up to 45 m high and 24 m thick were traceable for over 900 m to the south (Witt, 1936a) to the South Pit (Figure 3). Mine reports indicate that an ore width of over 31 m was covered directly by 1 to 6 m of unaltered, unmineralized alluvium in the South Pit area (unpublished data, Getchell Mine, Inc., 1934). Five hundred meters south of the South pit over 15 m width of ore cropped out, and gold ore crops out at the Riley tungsten mine, 2 km south of Getchell. The mineralization is pervasive along parts of the Getchell fault, and what constitutes ore is wholly dependent upon the economics of mining and recovery. As a result, the geometry of ore pods can vary depending on the chosen cutoff grade, and no age can be inferred from the ore geometries.

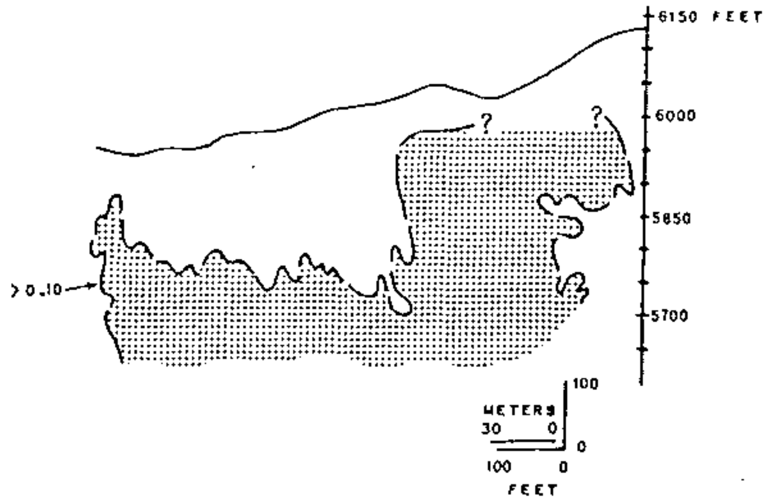

FIGURE 5. Longitudinal, vertical projection of ore apex (greater than 0.10 oz/ton) North Pit orebody, Getchell mine. *Taken from Getchell mine cross sections N19–N36.*

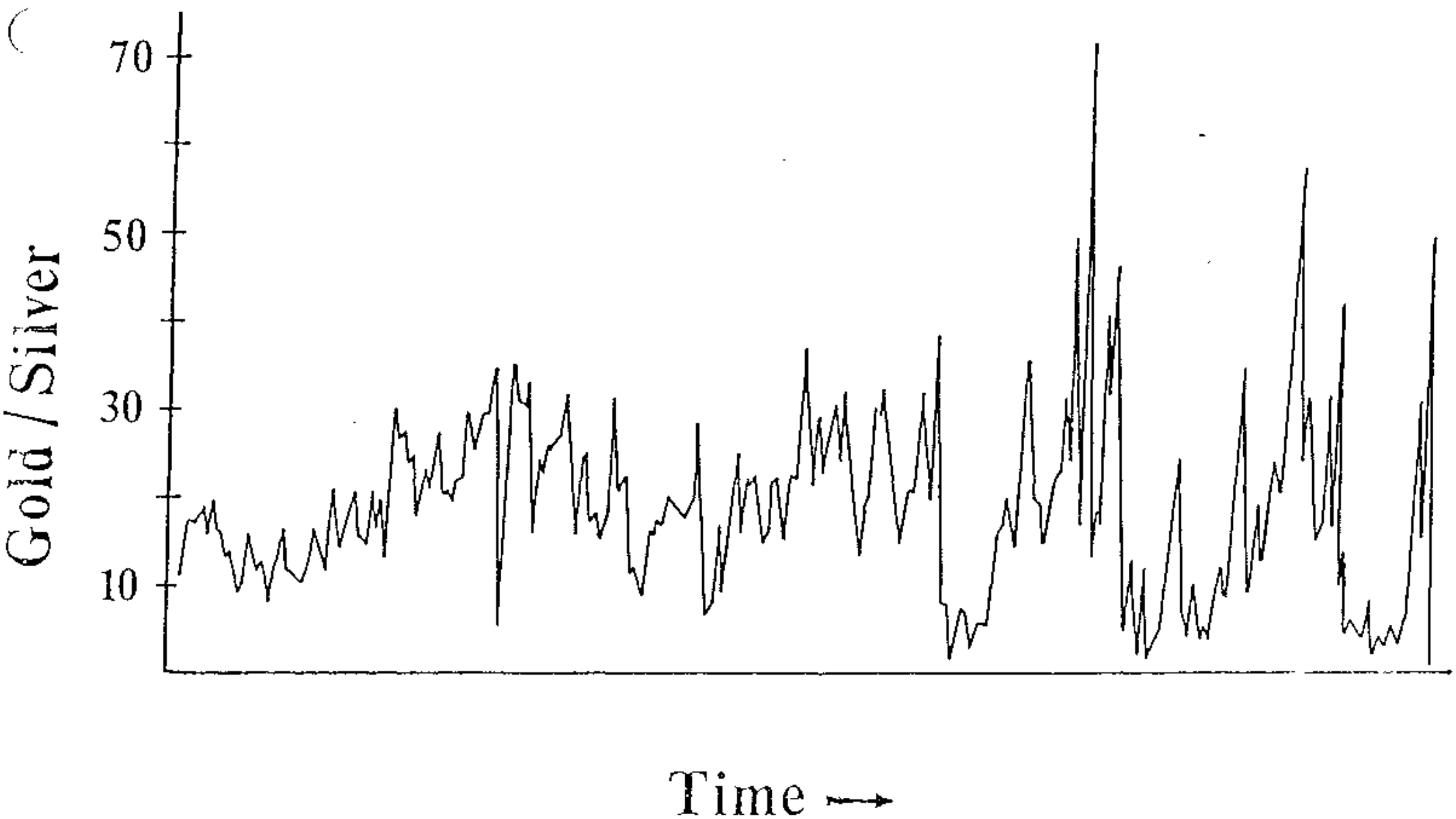

FIGURE 6. Gold to silver rations for bullion produced at Getchell for the period 1938-1945. *Unpublished data, Getchell Mine, Inc.*

GEOCHEMICAL NATURE OF THE MINERALIZATION

Gold occurs in the native state as micrometer- to submicrometer sized particles. Unpublished electron microprobe data (A. Radtke, personal commun.) show the gold to occur in association with carbonaceous material, within sulfide minerals, and as particles within and between quartz and clay grains. The average grade of the exploited Getchell ore bodies was about 9 to 10 ppm (Table 1). The subeconomic mineralization ranges from 0.02 ppm to 3 ppm gold. Silver is generally less than 1 ppm in the ore zones, but ranges from 0.2 ppm to 16 ppm in samples taken for this study. The gold to silver ratio in bullion for the period 1938 to 1945 is shown in Figure 6. Presuming that the mining progressed to greater depths with time, there is no discernible systematic trend to increased gold/silver ratios with depth in the oxidized parts of the ore bodies which made up the bulk of the ores mined. Cycles of progressively higher ratios followed by progressively lower ratios possibly reflect the somewhat irregular grade distributions shown in Figure 4, and the poor gold-silver correlations shown in Table 4 also corroborates this interpretation.

Erickson and others (1964) suggest that the trace element suite found at the Getchell deposit is similar to that found at the Carlin gold mine (Hausen, 1967; Radtke and others, 1972) and other disseminated gold deposits (Ferguson, 1924; Gilluly, 1932; Wells and others, 1969). Arsenic, mercury, and antimony are most closely associated with gold mineralization. Erickson and others (1964) also suggested that tungsten may be anomalous in the Getchell ore, though any genetic relationship is obscured by the proximity of tungsten-bearing tactites to the main productive gold zones.

The average trace element content of the Getchell gold deposit based on 50 samples collected for this study is shown in Table 2. The most notably enriched elements are arsenic, antimony, and mercury. The low concentration of copper, zinc, and lead is conspicuous and characteristic of the disseminated gold deposits along the Getchell fault. There appear to be trace element variations between the north, center, and south ore zones (Table 3) although the population of 50 samples evenly divided for each pit is not large enough to statistically validate the differences shown. Nevertheless the geological relationships in the pits provide corroborative evidence to the geochemical variations shown. Silver, molybdenum, and tungsten are highest in the South pit (Figure 3) where the most pre-gold calc-silicate is in evidence. Disseminated molybdenite can be found in the granodiorite stock adjacent to tungsten-bearing skarn along the West Vein, and granodiorite dikes in the east wall of the pit are spatially associated with the alteration of some of the Preble Formation limestone to a garnet-pyroxene skarn. The average mercury abundance increases from about 15 ppm in the North pit to over 80 ppm in the South pit. The highest mercury values occur as cinnabar in association with antimony. The footwall of the Center pit is siliceous hornfels, which may explain the generally lower concentrations of copper, lead, and zinc in the central ore zone. However, the concentrations of these base metals are uniformly low and the differences between the pits minor.

TABLE 2a. Average trace element content of the Getchell gold deposit.

Element	Average abundance(%)	Element	Average abundance(%)
Arsenic	0.285	Nickel	≤0.0018
Boron	0.0052	Lead	0.0018
Barium	0.019	Antimony	≤0.0935
Cobalt	≤0.0009	Strontium	≤0.0186
Chromium	0.0031	Titanium	0.103
Copper	0.0047	Vanadium	0.034
Gallium	≤0.0016	Tungsten	0.0016
Lanthanum	0.0028	Yttrium	≤0.0015
Manganese	0.0113	Zinc	0.0050
Molybdenum	0.001		

TABLE 2b. Abundance of arsenic, mercury, and antimony in ore and unmineralized host rock.

[Numbers in parantheses show the sample population size]

Element	Ore	Background
Arsenic	0.285% (181)	0.0003% (74)
Mercury	0.0022% (181)	0.000007% (50)
Antimony	0.0325% (36)	0.0007%(40)

TABLE 3. Trace element variations in parts per million between mining areas at the Getchell mine.

[All samples other than Oxide Zone represent primary sulfide ore]

Location	Ag	Cu	Pb	Zn	Mo	As	W	Hg
North Pit	2.3	84	27	99	22	2,800	26	15
Center Pit	1.9	69	14	69	13	2,800	19	30
South Pit	7.4	44	42	98	208	2,800	33	88
Oxidized Ores	---	169	59	---	18	900	--	14

The results of a correlation analysis of selected elements in ores are shown in Table 4. The ore samples were collected from all of the mining areas including the Section 4 pit south of the South pit and north of the Riley mine (T. 38 N., R. 42 E.). The relatively higher correlations between gold and molybdenum and gold and tungsten are interesting in light of the trace-element chemistry of disseminated molybdenite and scheelite-bearing skarn mineralization in the area. These correlations suggest that the gold, molybdenum and tungsten were deposited in response to different geochemical parameters than the arsenic, mercury, antimony, and thallium. Arsenic, mercury, antimony, and thallium are closely related, with thallium also showing a dependent relationship with molybdenum. The fluorine content is linearly independent of all of the elements except arsenic. The lack of correlations between gold, arsenic, mercury, and antimony with copper, lead, and zinc underscore the deficiency of base metals as a characteristic of the disseminated gold ore bodies.

TABLE 4. Table of correlation coefficients for selected elements in ores from the Getchell mine.

	Number of Qualified Pairs											
CORRELATION COEFFICIENT	Au	Ag	As	Hg	Sb	W	Tl	F	Mo	Cu	Pb	Zn
Au		78	67	77	44	81	42	37	57	56	48	49
Ag	.11		66	77	44	78	43	34	59	60	51	52
As	.13	.20		72	37	69	40	30	46	46	44	46
Hg	.20	.29	.73		36	82	40	30	57	57	56	58
Sb	.004	.60	.91	.69		37	37	38	15	16	9	8
W	.24	.09	.33	.27	.37		47	37	59	58	50	52
Tl	.14	.33	.71	.73	.72	.38		37	17	17	8	10
F	-.10	-.05	.50	.13	-.04	-.07	-.04		7	7	0	0
Mo	.50	.32	.08	.03	-.20	.38	.75	-.26		66	58	59
Cu	-.10	.19	-.03	-.05	-.13	-.008	-35	-.15	.05		58	59
Pb	-.02	.48	-.01	-.08	.14	-.08	-.21		.05	.13		58
Zn	-.10	.09	-.03	-.11	-.26	.13	.41		.21	.38	.55	

There is no strong evidence, however, for mechanical or chemical supergene leaching and enrichment of gold at the base of the oxidized zone. Some depletion of arsenic and mercury has taken place in the oxidized, mineralized zones (Table 3) but no enriched areas are recognizable. The abundances for arsenic and mercury from selected samples are given in Table 5. Therefore, observed arsenic and mercury dispersion halos are primarily hypogene features, a fact which is useful in applying these data to exploration.

TABLE 5. Representative arsenic and mercury data from oxidized ores.

[Data from Erickson and others (1964)]

Sample No.	Arsenic	Mercury	Sample No.	Arsenic	Mercury
252	700	3	216-G	500	9
250	30	<2	216-H	300	6
212	3,000	3	216-J	1,000	5
214-C	1,000	10	216-K	700	9
245	2,000	2	216-R	40	8
246	1,000	8	216-S	1,000	30
251	500	<2	216-T	500	14

Major element redistribution accompanying hydrothermal alteration is illustrated in Table 6. In the limestone calcium, carbon dioxide, and magnesium were removed and silica, aluminum and iron were added. There was a loss in the granodiorite of silica, ferrous iron, and sodium. Since there was a decrease of bulk density during alteration, there was probably a significant loss of aluminum. Titanium, phosphorus, and manganese were essentially unchanged. There was an increase in ferric iron, magnesium, calcium, potassium, water, and carbon dioxide.

Trace element halos around the ore bodies are not extensive except where the rock is strongly fractured. Erickson and others (1964) demonstrated that calcite and quartz veinlets and limonite-coated fractures away from the pervasive hydrothermal alteration represent leakage halos and may contain pathfinder elements leading to buried mineralization. The present study has found that arsenic and mercury have moved along fractures for several hundreds of meters laterally and vertically from the ore zones. Within the pervasively altered zones and in fractured rock away from the main faulting, arsenic and mercury anomalies are scarcely broader than the areas with detectable concentrations of gold (more than 0.02 ppm).

TABLE 6. Whole rock analyses of altered and unaltered rock types in the Getchell mine area.

	1	2	3	4	5	6	7	8	9	10
SiO_2	67.6	68.4	65.9	44.0	5.8	2.4	53.1	83.4	76.4	59.0
Al_2O_3	16.8	16.8	16.8	16.8	.80	.34	26.4	4.2	5.1	10.4
Fe_2O_3	1.3	1.6	1.5	2.3	.43	.10	3.0	1.70	.11	1.30
FeO	1.6	1.4	2.0	.96	.01	.02	5.3	2.60	1.20	1.90
MgO	1.0	1.2	1.4	2.4	.26	.42	1.7	.13	.21	.83
CaO	4.0	4.0	4.3	10.4	52.7	54.9	.19	.92	1.10	1.60
Na_2O	3.5	3.5	3.6	.06	.07	.06	1.0	.01	.01	.05
K_2O	2.8	2.8	2.8	7.8	.12	.02	3.9	1.10	1.30	2.60
TiO_2	.42	.40	.53	.62	.04	.02	.87	.23	.35	.38
P_2O_5	.22	.22	.19	.27	.09	.10	.14	.25	.70	.09
MnO	.10	.09	.07	.10	--	.01	.11	.30	.077	.097
CO_2	.05	.05	--	10.1	40.1	42.6	.05	--	--	--
H_2O^+	--	--		3.3	.01	.02	5.1	.80	1.50	1.20
H_2O^-	--	--						2.30	9.80	19.0
F(%)								.12	.15	.13
Au (ppm)	--	--		7.8				9.3	.08	6.2
As (%)	--	--		.50				.39	3.6	14.5
Hg (ppm)	--	--		19.5				101.8	110.6	112.5
Sb (%)	--	--		.001				.005	.068	.17
Tl (ppm)	--	--		--				80	50	69

1, 2 Granodiorite--unaltered, Hotz and Willden (1964)
3 Granodiorite--unaltered, Silberman and others (1974)
4 Granodiorite--altered, Silberman and others (1974)
5, 6 Preble Formation--limestone, Hotz and Willden (1964)
7 Preble Formation--phyllite, Hotz and Willden (1964)
8, 9, 10 Preble Formation--altered limestone, this study

The variation of total sulfur and total carbon (carbonate and organic) with gold, arsenic, and mercury contents in ores is shown in Table 7. There is no apparent correlation between the gold tenor and the sulfur or carbon contents, suggesting that gold was introduced at a different stage in the alteration-metallization paragenesis. An increase occurred in sulfur introduced as pyrite in the sedimentary rocks during hydrothermal activity. The hydrothermal solutions apparently removed virtually all the carbonate from intensely altered limestone (see CO_2 analyses for altered and unaltered limestone, Table 4). Assuming that these solutions were just as effective in removing carbonate from other rock types as well, the carbon analyses shown for altered rock in Table 7, which are total carbon determinations, represent mainly carbonaceous material rather than carbonate.

TABLE 7. Sulfur and carbon data for selected ore and host-rock samples showing correlation between sulfur, carbon, gold, arsenic, and mercury.

		Gold oz/ton	Arsenic ppm	Mercury ppm	% Sulfur	% Carbon
SOUTH PIT	Carbonaceous (oxidized)	0.023	700	100.9	0.10	0.90
	Carbonaceous	0.006	640	72.6	0.74	1.17
	Carbonaceous	0.05	0.16%	45.8	0.89	1.42
	Carbonaceous	0.029	0.84%	641.8	1.28	0.97
	Carbonaceous	0.006	2.1%	67.9	2.46	1.10
	Siliceous	0.006	380	69.0	1.27	0.46
	Siliceous, arsenical	0.131	12.8%	248.9	6.7	0.23
	Siliceous, arsenical	0.015	5.7%	400.1	6.9	0.34
CENTER PIT	Argillic, arsenical	0.175	6.4%	93.9	4.5	0.20
	Argillic, arsenical	0.090	7.8%	89.3	7.7	0.51
NORTH PIT	Carbonaceous	0.114	0.28%	57.6	1.12	2.29
	Carbonaceous, arsenical	0.073	4.8%	467.8	2.88	1.72
	Carbonaceous limestone (unmineralized)	----	0.012%	0.505	0.44	10.9
	Limestone (unmineralized)	----	0.007	0.82	0.18	7.13
	Carbonaceous shale (unmineralized)	----	0.0480	0.86	0.16	3.55

AGE AND ORIGIN OF THE MINERALIZATION

Age Relationships

Controversy has surrounded discussions concerning the ages of the various disseminated gold deposits. Associations of mineralization with Basin-Range faults and Tertiary volcanic rocks have led several workers to assume a late Tertiary to Quaternary age for all of the disseminated gold occurrences (Joralemon, 1951; Hotz and Willden, 1964; Hardie, 1966). At most of the occurrences, geologic relationships are obscure, allowing only maximum age estimates.

Silberman and others (1974) and Berger and others (1975) interpreted the age of the Getchell deposit to be Cretaceous based on both field and laboratory evidence. Alteration assemblages associated with gold mineralization yielded K-Ar ages of 80 to 96 m.y., and the mineralization is consistently associated with intrusive dikes of the same age. Granodiorite and/or porphyry dikes of similar or equivalent composition occur in all of the mineralized areas along the Getchell fault trend including the Hansen Creek (3 km south of Getchell), Summer Camp Creek (5 km south), Ogee-Pinson mine (10 km south), and Preble prospect (32 km south). A discordant Cretaceous age obtained using K-Ar was found for sericite from a granodiorite dike in the Preble deposit (M. L. Silberman, personal commun.). Oxidation of the dike rocks inhibits using radiometric age dating techniques on most samples. Further investigations of the age relationships are currently being done by B. R. Berger and R. P. Ashley of the U.S. Geological Survey. Fission track studies on apatite from the granodiorite stock in the South Pit indicate a major thermal event during the Miocene. The significance and precision of this event need to be assessed before a better understanding of the relationship of the age to the gold mineralization can be reached.

Character of the Hydrothermal Solutions

Discussion of the geochemistry of the ore-forming solutions is tenuous due to the lack of detailed laboratory studies relevant to the Getchell deposit. The ore mineral suite (Au-As-Hg-Sb) and alteration assemblage (quartz-clay-K-mica) suggest one possible interpretation that the mineralization took place from near-neutral to slightly alkaline, low salinity solutions (Tunell, 1964; Barnes and Czamanske, 1967; Seward, 1973; Learned and others, 1974). Fluid inclusion studies by Nash (1972) suggest that the temperature of formation may have been as high as 200°C, and the salinity of the fluid about 6% (NaCl equivalent by weight). The character of the products of alteration and metallization, taken together with properties of the fluid, suggest that the ore constituents may have been transported as sulfide complexes in solutions of low ionic strength (F. W. Dickson, personal commun.). Fluids having these properties are found in presently active hot springs systems. Joralemon (1951) noted the similarities between present-day hot springs systems and the alteration and mineralization at Getchell. Hausen and Kerr (1967) suggested a similar origin for the Carlin deposit and the stable isotope data of Rye and others (1974) are consistent with a thermal spring origin for the Cortez deposit.

EXPLORATION GUIDES

The Getchell gold deposits contain many of the characteristics that typify the Carlin-type disseminated gold occurrences. They are as follows:

(1) Moderate to low temperature hydrothermal replacement-type deposits;
(2) They are best developed in thin-bedded, carbonaceous, sandy carbonate rocks;
(3) Intrusive igenous rocks of intermediate granitic composition are present as dikes or sills;
(4) Gold predominates over silver in abundance, and the gold is associated with arsenic, mercury, and antimony and to a lesser extent with thallium, fluorine, tungsten, and molybdenum; and
(5) High-angle faults serve as conduits for the ore-forming solutions.

These characteristics are the best exploration guidelines. The geochemical studies at Getchell suggest several other relationships that may be useful in regional exploration programs.

There is a consistent trace-element suite through all of the skarn, stockwork sulfide, and disseminated gold deposits in and around the Osgood Mountains stock. This is the suite Mo-W±Sn. This fact of occurrence suggests that irrespective of the relative ages of the various types of deposits, the same trace-element suite is being produced by hydrothermal activity, implying that the crustal source of magmas is the same through time or the crust is uniform in composition, giving rise to a consistent trace-element suite through time. This is particularly exemplified if one considers the disseminated gold mineralization to be much younger (e.g., Miocene) than the skarn formation which has been interpreted to be Cretaceous by Silberman and others (1974). An analogous magma to-hydrothermal situation has been inferred by the present author from studies by Shawe (1977) in the Round Mountain, Nevada, 7 1/2-minute quadrangle, where the trace-element suite of Mo-Sn-W is associated with four separate episodes of igenous activity spanning the time interval from approximately 90 m.y. to at least 26 m.y. B.P. Additionally, Joralemon (1978) documents a Carlin-type gold deposit in the area; the fact of this occurrence again underlines the possible importance of the Mo-Sn-W trace-element suite as an exploration guide.

The whole-rock chemistry of the Osgood Mountains stock may provide some clues as to the types of igneous rocks that may be related to the disseminated gold deposits. Neuerburg (1966) found the stock to be higher than normal granitic rocks in its gold content, and showed that the gold content was highest near the eastern contacts with the sedimentary rocks. Berger (1979) reported that the trace-element suite Mo-Sn-W is found associated with leucocratic batholithic rocks in southwestern Montana that have low K_2O/Na_2O ratios and low calcium contents. The data in Table 6 show the Osgood Mountains stock to also be somewhat sodium-rich relative to potassium, further suggesting that the whole-rock chemistry may provide clues to the species of metals associated with specific igneous complexes.

Berger (1976) and Brooks and Berger (1978) investigated two approaches to exploration in the Getchell area. The presence of potassium-rich alteration phases and thallium in the ores suggested that radiometric surveys may be of some value in exploration. Figure 7 shows the results of an aeroradiometric survey over the Getchell mine area. A trend clearly outlines the fault zone,

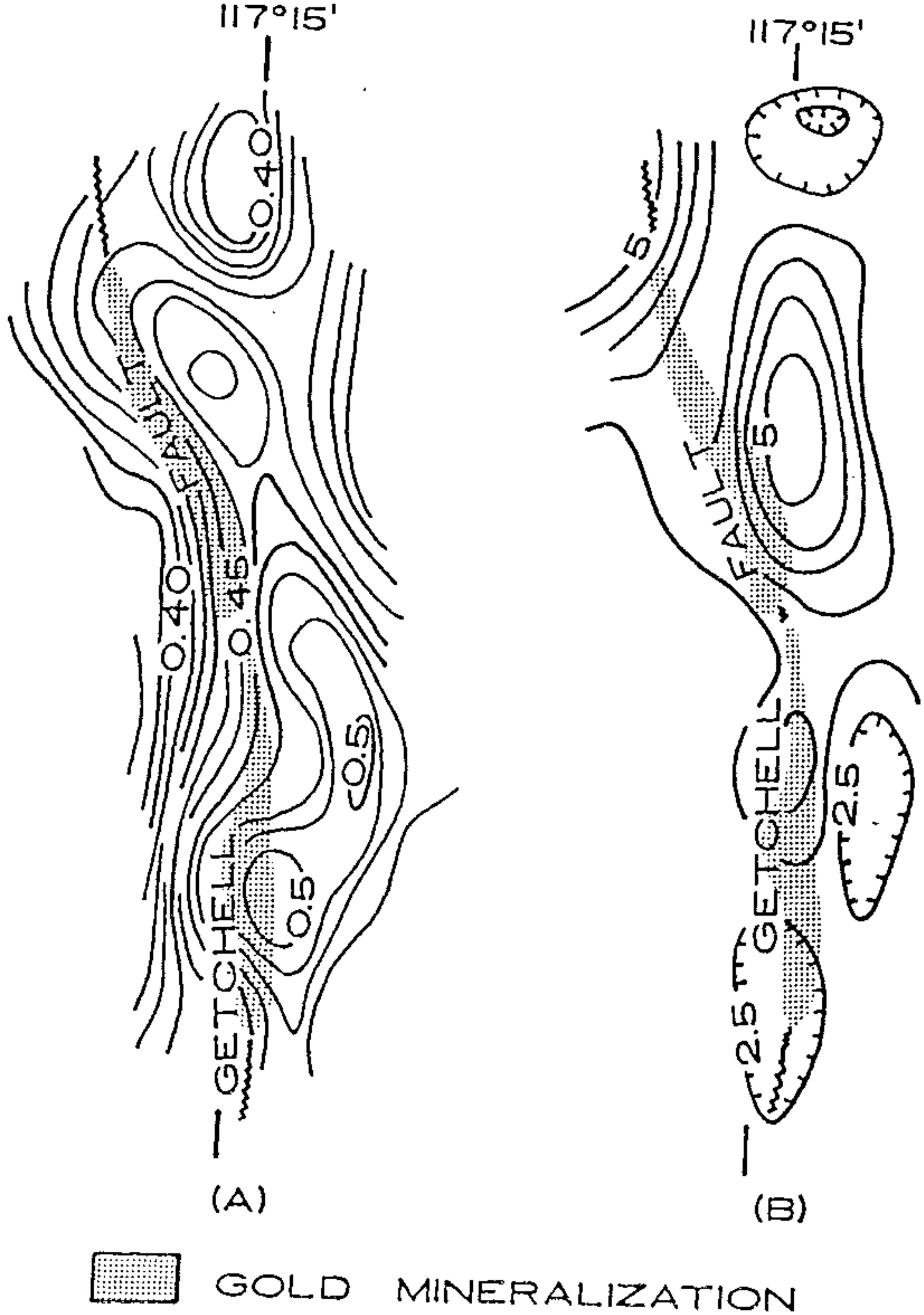

FIGURE 7. Bi^{214}/K^{40} ratios (A) and Tl^{208} radiation (B) over gold mineralization at the Getchell mine. *Data from Berger (1976).*

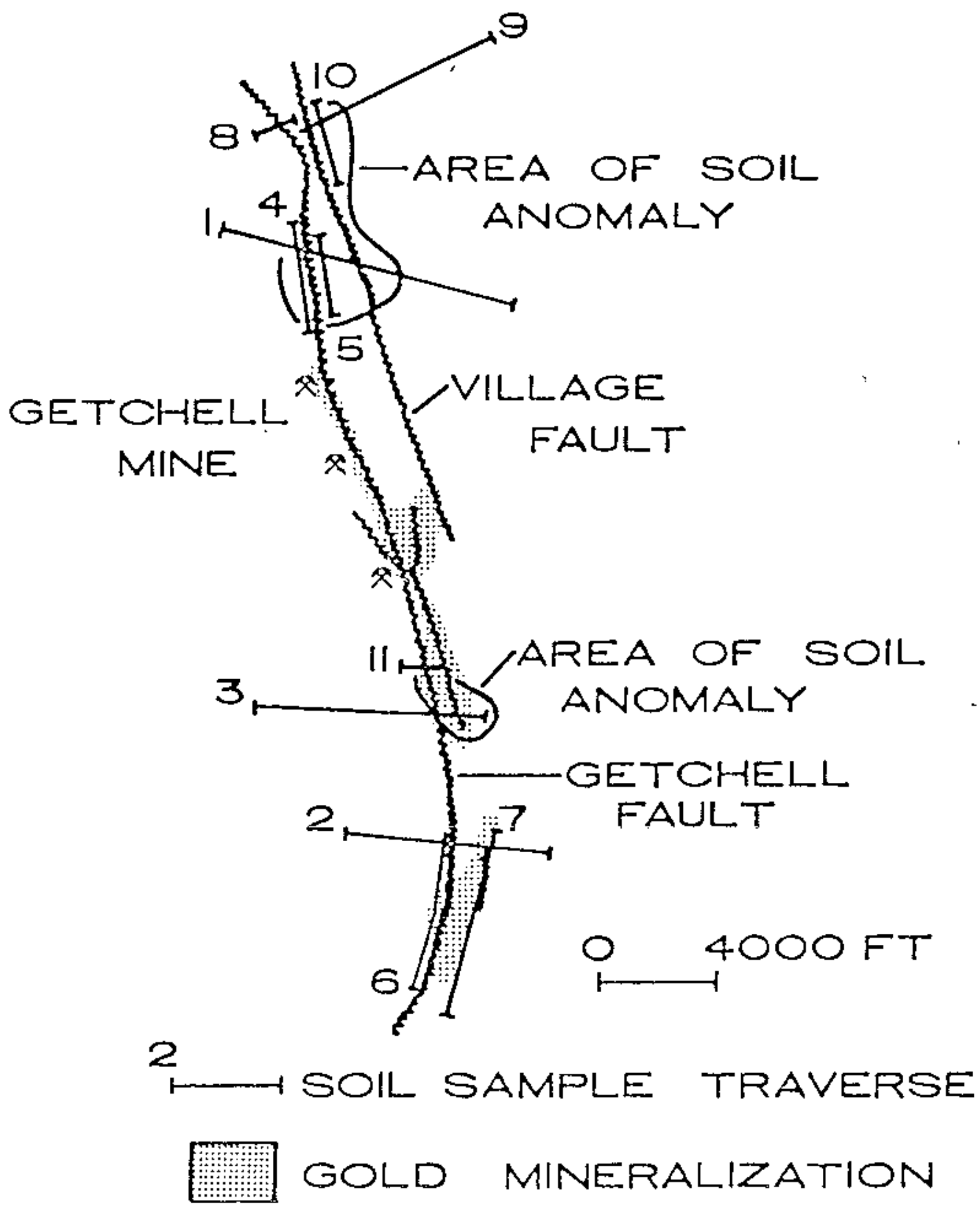

FIGURE 8. Relationship of anomalous concentrations of arsenic in soil to gold mineralization at the Getchell mine. *Data from Brooks and Berger (1978).*

but the locations of ore grade mineralization are not detected. Figure 8 shows a summary of the findings of Brooks and Berger (1978) wherein they found that arsenic and mercury in soils may be anomalous in the vicinity of gold mineralization, but the soil type plays a stronger role in arsenic and mercury entrapment than the presence or absence of arsenic and mercury in mineralized rock beneath the soil. Thus high-organic soils can lead to partial or displaced anomalies.

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