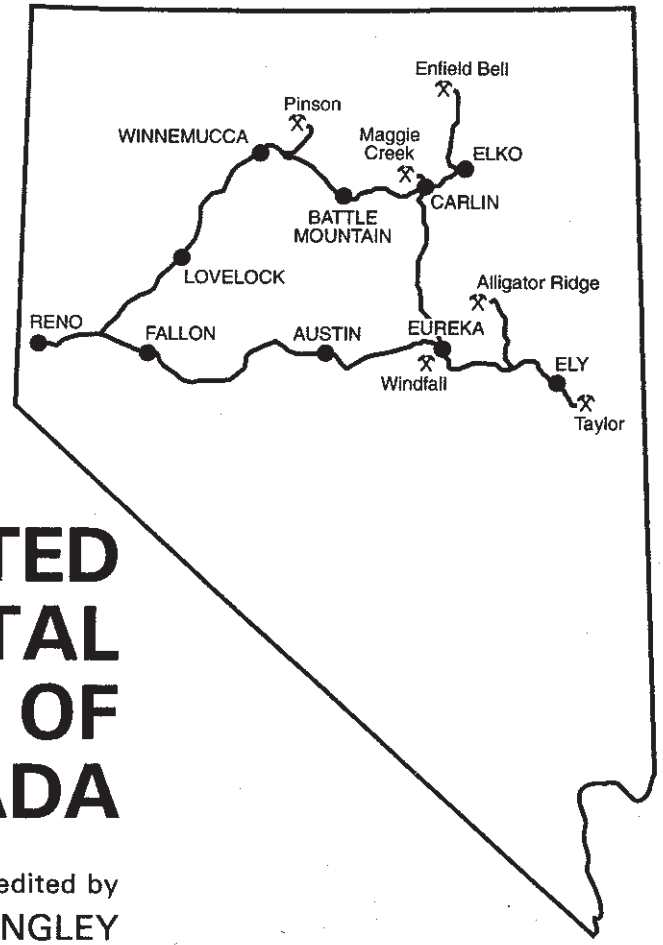
UNIVERSITY OF NEVADA-RENO
MACKAY SCHOOL OF MINES



NEVADA BUREAU OF MINES AND GEOLOGY
REPORT 40

SEDIMENT-HOSTED PRECIOUS-METAL DEPOSITS OF NORTHERN NEVADA

edited by
JOSEPH V. TINGLEY
HAROLD F. BONHAM, JR.

Guidebook prepared for October 31–November 3, 1984 field trip held in conjunction with the Society of Economic Geologists Fall 1984 meeting, Reno, Nevada

A road log and trip guide to the Pinson, Enfield Bell, Maggie Creek, Windfall, Alligator Ridge gold mines and the Taylor silver mine; articles on geology and mineralization of Pinson, Enfield Bell, Maggie Creek, Alligator Ridge, and the Carlin district; and a history of the Carlin discovery.

nbmg nevada bureau of mines & geology

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JOSEPH V. TINGLEY
HAROLD F. BONHAM, JR.

1986

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ROAD LOG AND TRIP GUIDE

SEDIMENT-HOSTED PRECIOUS-METAL DEPOSITS OF NORTHERN NEVADA:

RENO TO PINSON, ENFIELD BELL, MAGGIE CREEK, WINDFALL, ALLIGATOR RIDGE GOLD MINES, AND THE TAYLOR SILVER MINE, WITH A RETURN ROAD LOG TO RENO

Joseph V. Tingley and Harold F. Bonham, Jr., *Nevada Bureau of Mines and Geology*

with sections by Robert J. Stuart, Freeport McMoRan Gold Co., and W. Brent Wilson, Windfall Mine

Portions of this road log are modified from Benoit and Desormier, 1983, Berger and Erickson, 1983, Durgin, 1984, Garside, 1981, Garside and Bonham, 1984, Ketner and Poole, 1979, Poole, Thorman, and Howard, 1979, Roberts, 1969, Roberts and Wrucke, 1979, and Tingley, 1983.

DAY ONE: Reno, Pinson Mine, Elko (log ends at Carlin)

Cumulative Mileage

0.0 Leave Sparks. Road log begins at the junction of McCarran Boulevard with Interstate 80 on the east side of Sparks.

0.6 Helms gravel pit on left.

1.9 Vista exit, leaving Sparks. This is the low, marshy area along the Truckee River for which the Truckee Meadows is named; ahead is the Virginia Range. The Truckee River existed before warping and faulting uplifted the Virginia Range; apparently as uplift took place the river downcut at about the same rate, so no deep lake was formed in the Truckee Meadows area.

2.3 Mesozoic shale in roadcut on left.

The Truckee River, which originates at Lake Tahoe, crosses eastward through the Virginia Range along Interstate 80, a distance of about 20 miles, then turns near Wadsworth and flows another 20 miles north to end at Pyramid Lake.

2.7 Entering the Truckee Canyon and Virginia Range. The U.S. Army Corps of Engineers has deepened the channel of the Truckee River in this area in order to lessen the backing-up of flood waters and to lower the water table in the swampy Truckee Meadows. The Truckee Canyon has been used since the days of the 49'ers 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.

3.2 River gaging station on right. Triassic(?) andesitic metavolcanic rocks are exposed along the Truckee River for the next 3 miles. Farther east in the canyon, Miocene tuffaceous and diatomaceous sedimentary rocks and interbedded rhyodacitic to basaltic flows are the main rock types. Locally these rocks are covered by Pleistocene lava flows and lake beds.

4.7 Lockwood exit. Abandoned tuff-stone quarry at 1:00 on the south side of the canyon. The tuff at one time was made into blocks for use in building construction but could not compete with cinder blocks. For the next 8 miles, Miocene tuffaceous and diatomaceous sedimentary rocks of the Truckee Formation and intertonguing dacitic and rhyodacitic flows of the Kate Peak Formation are the main rock types.

6.1 Mustang exit, Mustang Bridge Ranch. In this area Pleistocene basalt flows overlie the Miocene rocks.

6.8 To the left, sanitary landfill serving the Reno-Sparks area.

8.6 To the right, gravel pit in Truckee River gravels.

10.5 Patrick exit.

11.0 Pleistocene Lake Lahontan sediments on right in roadcut. At its highest level in Pleistocene time, Lake Lahontan extended up the Truckee Canyon to approximately this point. From this point eastward, flat-lying, varved Lahontan lake sediments are exposed in road and railroad cuts and the canyon sides.

12.4 Sand pit in Lahontan sediments on left.

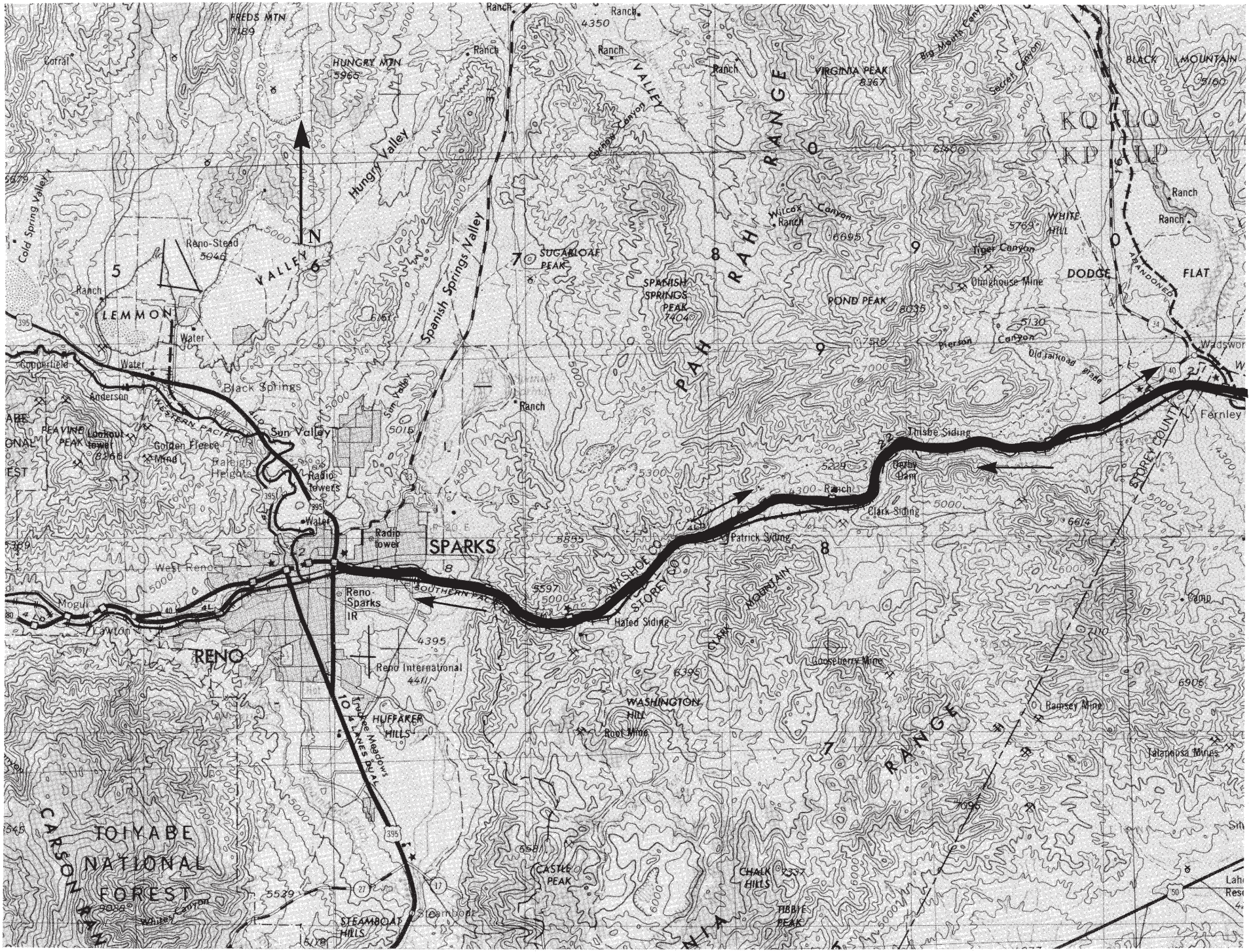
13.0 To the right, Sierra Pacific Power Co. Tracy power station, which consists of three units of 53-, 83-, and 110-megawatt capacity. The 110-megawatt unit is used for base load while the other two are used for peaking. The plant uses either natural gas or fuel oil. The natural gas is supplied by the Southwest Gas Co., whose pipeline extends northeast into Idaho. The new power line running to the northeast is a 345,000-volt intertie to the North Valmy coal-fired generating station near Battle Mountain.

13.9 Clark Station exit.

15.2 To the right, diatomite plant of Eagle-Picher Industries. The open-pit mines are about 7 miles to the east, and will be seen later. Diatomite (diatomaceous earth) is extensively used as absorbents, filter materials, 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 filler for domestic and foreign consumption.

For the next 8 miles Miocene basaltic to rhyodacitic flows and interbedded tuffaceous to diatomaceous sedimentary rocks of the Chloropagus and Kate Peak Formations are the predominant rock types.

The Gooseberry Mine of Asamera Minerals Inc. is located about 9 miles to the south of this point. Production at the mine is from an east-trending, high-angle, quartz-calcite vein that cuts late Miocene flows of intermediate composition (Kate Peak Formation). Adularia from the vein has been dated at about 10 m.y. by K-Ar methods (Morton and others, 1977). The mine is an underground operation; current production is from the 800- and 1000-foot levels. Ore minerals include native gold, acanthite, electrum, and native silver. Sparse pyrite, chalcopyrite, sphalerite, and galena are


FREDS MTN
7189
HUNGRY MTN
5965
Corral
Ranch
Hungry Valley
Cold Spring Valley
Reno-Stead
5046
VALLEY
N
LEMMON
Water
Copperfield
Anderson
Black Springs
Spanish Springs Valley
Sun Valley
Sun Valley
Golden Fleece
Mine
Raleigh Heights
Radio towers
Radio tower
SPARKS
West Reno
Mogul
Wylom
RENO
Reno-Sparks IR
Reno International
4411
HUFFAKER HILLS
Truckee Meadows
10 LANES DUAL
TOIYABE NATIONAL FOREST
CARSON
Whiney Canyon
STEAMBOAT HILLS
Steamboat
SUGARLOAF PEAK
SPANISH SPRINGS PEAK
7404
Clarks Canyon
VALLEY
PAH RAH RANGE
VIRGINIA PEAK
8367
Big Mouth Canyon
Secret Canyon
Wilcox Ranch
Wilcox Canyon
6695
POND PEAK
8035
Tiger Canyon
Ohnghouse Mine
Pierson Canyon
Old railroad grade
WHITE HILL
5789
BLACK MOUNTAIN
5160
KQ LQ
KP LP
DODGE FLAT
ABANDONED
Wadsworth
Fernley
Truckee Siding
Derby Dam
Clark Siding
Patrick Siding
Hafed Siding
WASHOE CO
STOREY CO
STOREY COUNTY
CLARK MOUNTAIN
Gooseberry Mine
WASHINGTON HILL
Root Mine
Ramsey Mine
Talapoosa Mines
CASTLE PEAK
CHALK HILLS
TIBBITS PEAK
PAH RAH RANGE
Camp
Lahontan Res

also present. The vein averages 7 feet in width. Proven plus probable reserves are 607,000 tons averaging 0.23 ounces of gold and 9.71 ounces of silver per ton (Durgin, 1984).

17.4 To the left, an artifical ox-bow lake created when the freeway was built as the Truckee River was diverted to the south side of the highway. More recently a new channel was cut, eliminating two railroad bridges which were trouble points during floods.

18.0 To the right, Derby Dam. This small concrete and earthen structure is used to divert water from the Truckee River southeastward to Lahontan Reservoir on the Carson River. Lahontan and Derby Dams, and the connecting diversion canals, are parts of the Newlands Reclamation Project begun in 1903, the first U.S. Government project authorized under the Reclamation Act of 1902. In normal years, the project can provide over 90,000 acres with year-round irrigation, mainly in the Fallon area.

18.8 Thisbe–Derby Dam exit.

20.6 High up at 2:00 are the waste dumps at the Celatom Mine which supplies the diatomite processed in the Eagle-Picher plant at Clark Station. The white band in the canyon wall is rhyolitic tuff, not the diatomite bed.

20.8 Orchard exit.

21.5 Alta Formation (pyroxene andesite) in roadcuts to left.

21.9 Painted Rock exit.

22.6 To the left, ignimbrites overlain by Lake Lahontan sediments.

22.8 Painted Rock. Oligocene ignimbrites, 28–22 m.y. old, exposed on left.

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 sedimentary rocks. Note the well-developed shorelines which represent various stages of Lake Lahontan. Hazen Hot Springs are located near the south end of this range.

32.8 The power line crossing the highway is an 800,000-volt D.C. line that runs from The Dalles hydroelectric station located near Portland, Ore., to Sylmar, Calif., near Los Angeles.

34.2 To the left of the freeway lies the Truckee Range. The visible part of this range is composed of basalt from two or three large shield volcanoes which are 5 to 7 m.y. old.

41.0 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 1 acre of vats could produce 10 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.

42.6 Churchill County line.

46.3 Hot Springs-Nightingale exit. Brady's Hot Springs, known to the 49'ers as Tenderfoot Station, was a point on the California Trail. Located near the middle of the dreaded Forty Mile Desert, the springs were always a blessing and occasionally a curse. The water was potable when cooled, but thirst-crazed oxen were commonly scalded when they rushed into the boiling water. Between 1869 and 1912, the Central Pacific Railroad had a station near here. The hot springs were the site of a resort and spa for many years. Prior to 1959 the resort consisted of a spa, restaurant, bar, gas station, and cabins. The springs dried up in 1959, apparently due to geothermal drilling. The area remained vacant until 1978 when Geothermal Food Processors, Inc. began operating the world's first geothermal food processing plant, using one of the existing geothermal wells to provide hot water as a source of process heat and wash water. Onions are the main vegetable processed here.

50.3 Note diatomite deposits on the left side of the freeway. This diatomite is part of the Truckee Formation of Pliocene age.

54.3 The large valley to the right of the freeway contains the Carson Sink, 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 on both sides of the freeway.

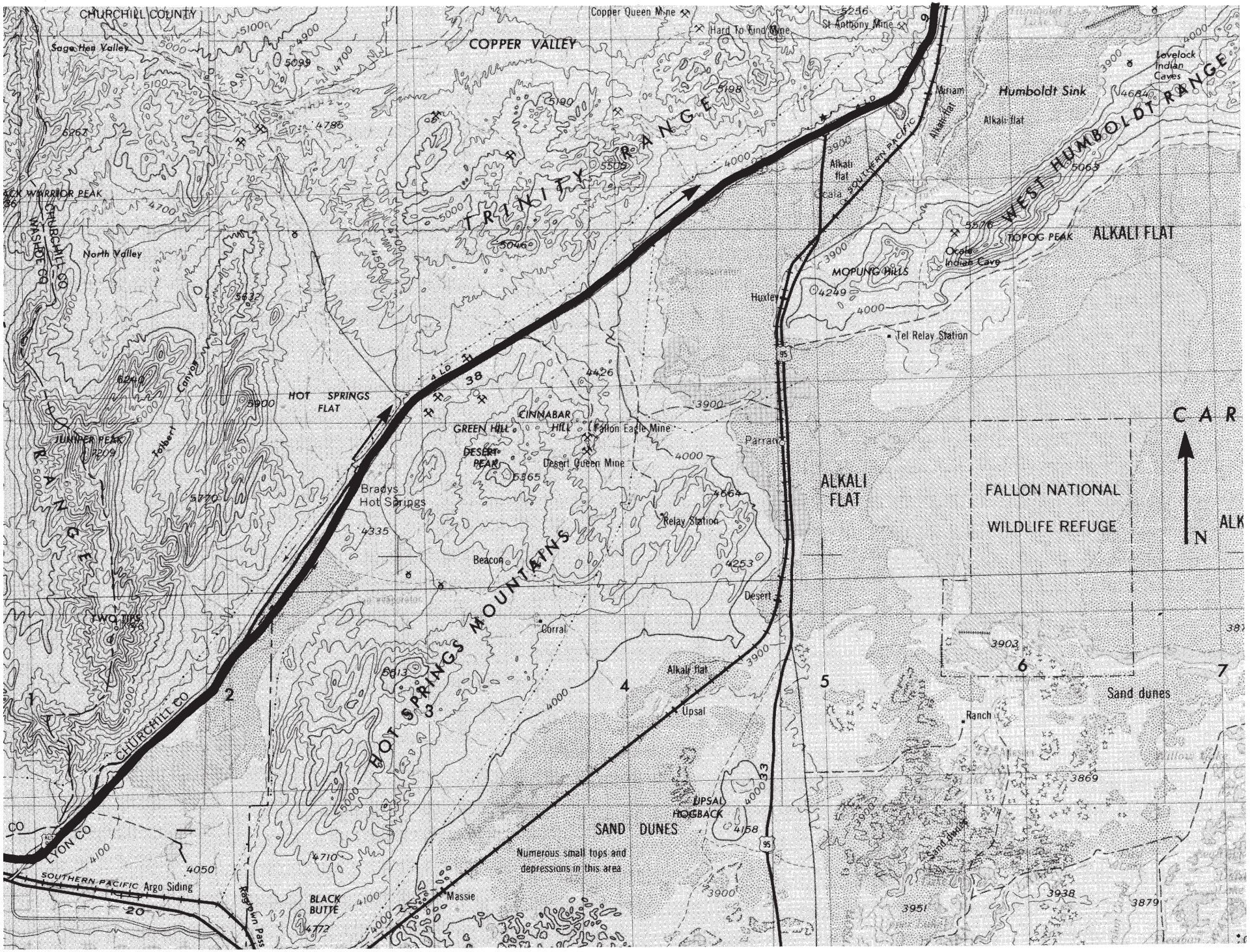
58.9 Jessup exit. Drill roads to left (north) are within the Jessup mining district.

Jessup is a precious-metal district discovered in 1908 and operated mainly until 1909. Recorded production from the district has been only about $15,000 from one claim, the Gold King. Most of the workings are located in rhyolite intrusive bodies or near the contact between the bodies and older metavolcanic rocks (Willden and Speed, 1974).

59.8 The mountains to the left of the freeway are the Trinity Range, which consist of metamorphosed volcanic and sedimentary rocks of Jurassic and Triassic age intruded by Cretaceous granitic stocks and overlain by Tertiary volcanic and sedimentary rocks.

64.0 Intersection, U.S. Highway 95, Fallon cutoff. The West Humboldt Range is located to the right, beyond the alkali flat. This range is composed predominantly of calcareous siltstone, shale, and argillite of the Auld Lang Syne Group (Late Triassic–Early Jurassic). The Mopung Hills are at the southwest end of the West Humboldt Range. Highly colored rocks visible here are rhyolitic ash-flow tuffs which have been hydrothermally altered. Lake Lahontan terraces can be seen on the flanks of the Mopung Hills.

67.8 Toy (St. Anthony) mining district is about 2 miles to the left of the highway. Tungsten was discovered here in 1908 in contact deposits related to the St. Anthony stock. This was the first scheelite-bearing contact metamorphic ("tactite") deposit to be discovered and mined in the United States. At the St. Anthony deposit scheelite occurs in metamorphosed calcareous and argillaceous rocks of the Auld Lang Syne Group near their contact with a Cretaceous granodiorite intrusive body. The deposit was worked mainly before and during World War I.


CHURCHILL COUNTY
COPPER VALLEY
Copper Queen Mine
Hard To Find Mine
St Anthony Mine
Sagehen Valley
TRINITY RANGE
Humboldt Sink
Alkali flat
Miriam
Lovelock Indian Caves
WEST HUMBOLDT RANGE
SOUTHERN PACIFIC
Alkali flat
Calla
TOPOG PEAK
ALKALI FLAT
Ocale Indian Cave
MOPUNG HILLS
Huxley
Tel Relay Station
BLACK WARRIOR PEAK
WASHOE CO
CHURCHILL CO
North Valley
HOT SPRINGS FLAT
CINNABAR HILL
GREEN HILL
Fallon Eagle Mine
DESERT PEAK
Desert Queen Mine
Parran
JUNIPER PEAK
Tolbert
Canyon
Bradys Hot Springs
Relay Station
Beacon
Desert
ALKALI FLAT
FALLON NATIONAL WILDLIFE REFUGE
N
TWO TIPS
Corral
HOT SPRINGS MOUNTAINS
Alkali flat
Upsal
Ranch
Sand dunes
UPSAL HOGBACK
SAND DUNES
Numerous small tops and depressions in this area
Massie
BLACK BUTTE
Reservation Pass
LYON CO
CHURCHILL CO
SOUTHERN PACIFIC Argo Siding

Windmill
Willow Canyon
Pole Brown Canyon
Black Rock Cap
Brown Canyon
Orenna
Ranches
Ranch
Rocky Canyon
INDIAN PEAK
Pole Canyon
Sacramento Canyon
LONE MTN
Emerick Canyon
COLD MTN
LINCOLN HILL
American Canyon
Dry Gulch
WENZEL HILL
Troy Canyon
PACKARD
FLAT
BLACK KNOB
BUFFALO MTN
Cow Canyon
Relief Cap
Woolsey
Colado Siding
Rodak Siding
Covered Reservoir
Cook Canyon
Windmill
LONE MTN
Cem
Lovelock
Nevada Mine
Pershing Mine
Cem
Tanks
SOUTHERN PACIFIC
GRANITE POINT
Granite Point
Radio station
Derby
Beacon
Toulon
TOULON PEAK
Toulon Lake
Humboldt Lake
HUMBOLDT SINK
Wildhorse Pass
Beacon
CARSON SINK
BUENA VISTA HILLS
CHOCOLATE BUTTE
ANTELOPE VALLEY
SIDEWINDER RANGE
PERSHING CO
UPPER VALLEY
LOWER VALLEY
WEST HUMBOLDT RANGE
TRINITY RANGE
VISTA VALLEY
N

69.7 Pershing County line.

71.1 Toy (Browns) mill site. The foundations to the right, near the railroad, are the remains of the Toy mill where the St. Anthony Mining Co., a subsidiary of the Atolia Mining Co., milled tungsten ore from the St. Anthony deposit.

72.6 The ragged spire on the skyline to the left of the highway is Ragged Top Mountain in the Trinity Range. The rocks are rhyolitic welded tuffs which occupy the center of the Ragged Top caldera, a Miocene eruptive center.

74.0 Toulon. The large buildings to the right are the Toulon mill, erected prior to World War I to treat tungsten ores from the Nightingale district. Tungsten ores from many nearby districts including Ragged Top, Mill City, and Oreana were hauled here for treatment. During World War I, the plant was used to produce white arsenic, and the large arsenic roasting furnaces can still be seen in the largest (south end) part of the building. In recent years, the mill has been modified to treat antimony and gold ores.

83.5 Lower Valley. This part of the lower Humboldt valley, just above the Humboldt Sink, was the jumping-off point for the emigrant trains following the Overland Trail to California. Called Great Meadows or Big Meadow, the extensive area of grasses here provided a last watering spot and rest area just before crossing the Forty Mile Desert.

85.4 Lovelock exit.

86.5 Lovelock, county seat of Pershing County. Pershing County was formed from the southern half of Humboldt County in 1918. At that time, mining formed the main economic base for the region when tungsten mines at Mill City and silver mines at Rochester and Seven Troughs were in full operation. Today, the main activity is alfalfa farming and feedlot operations, although mining is gaining importance here again.

88.0 Humboldt River.

91.9 To the right, about 1 mile up the alluvial fan is a large drill pad. This is where Getty Oil Co. drilled a noncommercial geothermal well to a total depth of 7,965 feet. The maximum reported temperature is 282°F at a depth of 7,064 feet (Jones, 1982).

92.8 Coal Canyon exit. To the left of the highway is the northern part of the Trinity Range, which consists mainly of granitic intrusive rocks, metasedimentary rocks of the Auld Lang Syne Group, and Quarternary–Tertiary volcanic rocks. On the left side of the highway is the Eagle-Picher diatomite plant. The diatomite is mined from deposits in the Trinity Range about 20 miles west of Lovelock.

The West Humboldt Range is to the right of the highway and consists mainly of Mesozoic limestone, shale, and quartzite, Quaternary–Tertiary volcanic rocks, and Cretaceous granitic intrusive bodies. The rocks in this area were subjected to large-scale folding and thrust faulting during the Jurassic. Several of the thrust faults are well exposed in this range.

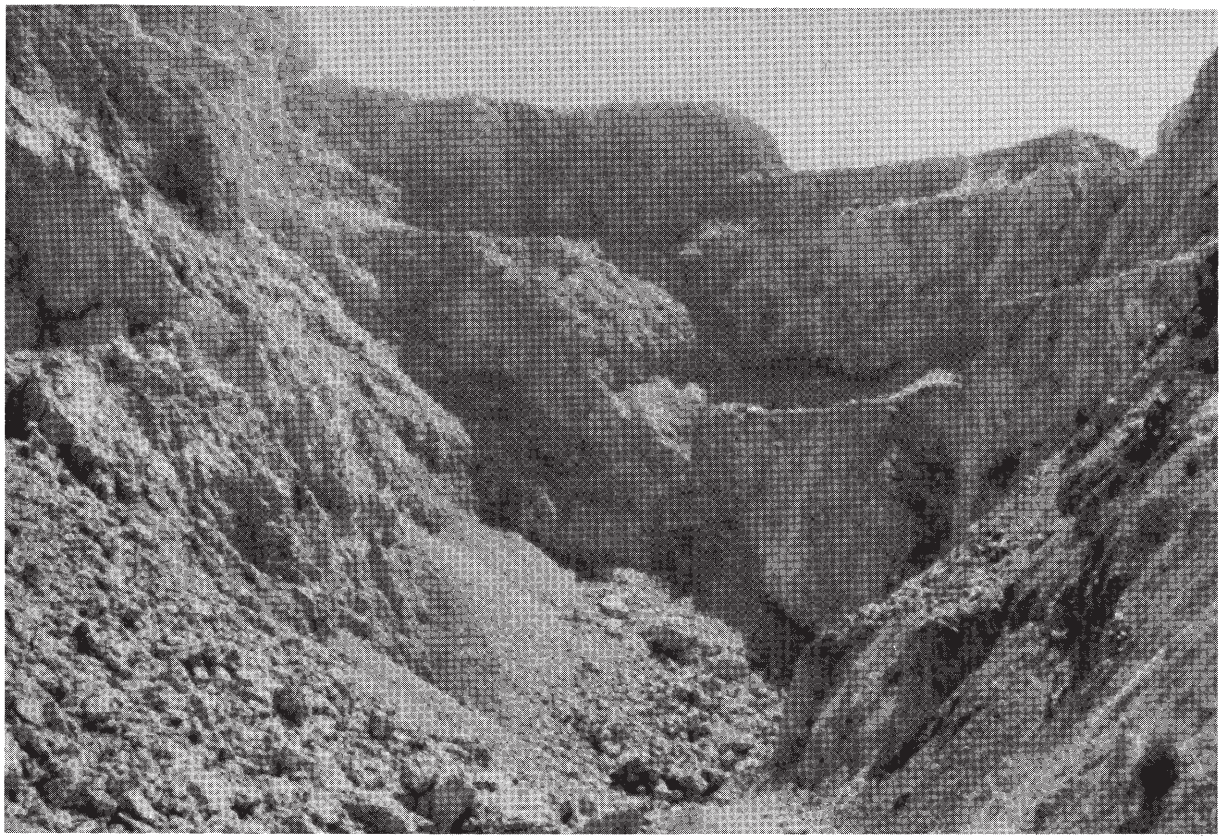
The area of drill roads on the hill ahead and to the right is in the Willard mining district, a gold district active from about 1905 into the early 1950's. Antimony has been mined from deposits to the north of Willard.

The Relief Canyon open-pit gold mine is located on the western margin of the southern end of the Humboldt Range, approximately 20 miles northeast of Lovelock. Lacana Gold Inc., owner and operator of the project, has mined and is presently heap leaching 739,300 tons of oxide ore grading 0.036 ounces of gold per ton, with very minor silver and mercury credits. The remaining mining reserve on Lacana's property is 6 million tons grading 0.032 ounces per ton, using a cutoff grade of 0.015 ounces per ton. Santa Fe Mining Co. controls additional reserves on the dip-projection of the deposit. Strata-bound and strata-conformable gold metallization of the oxide reserves occurs as micron-sized particles of native gold and electrum associated with jasperoidal silica, pseudomorphic hematite after pyrite, and fluorite. Associated elements include antimony and arsenic. The principal host rock is a thick, folded breccia comprising limestone, shale, and siltstone clasts within a clay and mudlike matrix, underlain by platform-margin carbonates of the Triassic Cane Spring Formation, and overlain by pelitic deltaic rocks of the Upper Triassic Grass Valley Formation. The breccia has been interpreted to be either a tectonically deformed submarine debris flow or a complex thrust fault breccia (M. Fiannaca, written commun., 1985).

99.0 Oreana. The small mill to the left of the highway was built in the 1960's to treat antimony ores from the mines in the Sutherland mining district (near Willard). It was later converted to a custom mill and has treated small amounts of tungsten ore from nearby areas. The Arabia silver-lead district is to the far left, in the hills west of the Humboldt River. Complex silver-lead-antimony deposits were discovered here in 1859, and the first smelter in Nevada was built on the Humboldt River in 1867 to treat Arabia ores.

The Rochester silver district is about 10 miles to the east of Oreana in the southern Humboldt Range. Silver deposits were discovered at Rochester in 1912 and have produced almost 9 million ounces of silver (mainly between 1912 and 1929). ASARCO has done exploration in the district and has defined over 100 million tons of mineralized material containing 1 to 2 ounces of silver and small amounts of gold per ton. Couer de Alene Mines now owns the Rochester deposit. The low-grade mineralization consists of quartz veins and stringers which fill thin, randomly oriented, closely spaced fractures between major veins in rhyolite of the Permian–Triassic Koipato Group (Vikre, 1981). Sulfide minerals include acanthite, sphalerite, and tetrahedrite.

For about the next 20 miles, the Humboldt Range can be seen to the right of the highway. The highest point, Star Peak, is at the north end and has an elevation of 9,834 feet. The range consists primarily of Triassic sedimentary and volcanic rocks which have been deformed by normal faulting, thrust faulting, folding, and have undergone low-grade regional metamorphism. One intrusive mass can be seen at Rocky Canyon, about 6 miles up the range on the right. In addition to Rochester, several other historic mining districts are located in the Humboldt Range. Unionville, on the east side of the range, was active in the 1860's, and Mark Twain tried his hand at mining here during his Nevada residency. The earliest



South pit, Standard Mine, Humboldt Range, Nevada.

study of the geology of the Humboldt Range was done by Clarence King and geologists of the Fortieth Parallel Survey who passed this way in the late 1860's.

104.1 Oreana pegmatite to the right. Mined for scheelite, the pegmatite also contained beryl. Ragged outcrops are the Rocky Canyon stock. The Humboldt River and Rye Patch Reservoir can be seen to the left of the highway.

109.1 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 Humboldt Sink.

111.1 To the right of the highway is the Standard gold mine. The Standard Mine is perhaps the first deposit of "micron" or "disseminated gold" exploited within Nevada. The deposit was discovered in 1932 and was mined prior to World War II. Gold is disseminated in a silicified, iron-stained breccia along a thrust contact (Johnson, 1977). Host rocks here are the Triassic Grass Valley and Natchez Pass Formations. Note drill roads from recent gold exploration.

113.0 A geothermal well can be seen to the right of the highway (Phillips Petroleum Co. Campbell E-1 drill pad and reserve pit).

114.1 To the immediate right of the highway, the road up the alluvial fan provides access to Phillips Petroleum Co. Campbell E-2. The drill pad and reserve pit are about 1½ miles up the alluvial fan and are not easily visible from the highway.

117.8 To the right of the highway in the lowermost hills is a large area of hydrothermal alteration. This altered area has been explored for disseminated gold deposits by numerous companies and was the site of a small leaching operation several years ago. Union Oil Co. Campbell No. 1 geothermal drill pad and reserve pit is just below the altered rocks.

To the left of the highway near the railroad tracks are some low mounds of tufa, sinter, and outcrops of silicified rocks associated with an old hot spring system. Sulfur was mined here in the 1860's.

The prominent cone-shaped peak on the far left horizon is Majuba Hill, a multiple rhyolitic plug which has intruded Triassic–Jurassic rocks of the southern Antelope Range. Intrusive breccias are associated with the plug, and an extensive area of hydrothermal alteration is centered on the plug. Ore deposits at Majuba Hill are principally copper and tin with byproduct gold, silver, and lead. The latest exploration activity at Majuba was for porphyry molybdenum. (Mackenzie and Bookstrom, 1976).

118.0 Humboldt House exit. To the left of the highway, old buildings and the remains of an orchard mark the site of Humboldt House, a station on the Central Pacific Railroad. Humboldt House was noted for its dining facilities, trees, and a fountain which provided overland travelers a relief from the surrounding desert landscape. Drill pads to the right mark the sites of recent geothermal test drilling.

Phillips Petroleum Co. has one production well, one dry hole, six stratigraphic tests, and many shallow temperature-gradient holes at Humboldt House. Additionally, Union Oil Co. has drilled in

PERSHING COUNTY
Keystone Mine
Woody Can
Box Canyon
Long Canyon
ALPHA MOUNTAIN
5374
HAYSTACK BUTTE
Pole Canyon
Bonita Canyon
Rosebud Pk.
6574
Rosebud Canyon
Double O Mine
Rabbithole (site)
Water pump
Cosgrave
Windmill
Windmill
ANTELOPE RANGE
MAHUBA MOUNTAIN
6844
Mahuba Canyon
Poker Brown Gap
Humboldt
Imlay
Valley Siding
Florida Canyon
Santa Clara Canyon
STAR PEAK
Bloody Canyon
Eldorado Canyon
Coyote Can
Buffalo Canyon
Echo Canyon
Spillway
4133
Ranch
Windmill
Windmill
Trough
Louse Canyon
Reddy Canyon
SOUTHERN PACIFIC
DUN GLEN
LR
MQ
N

New Springer Mine and mill of Utah International, Inc., at Tungsten, Eugene Mtns., Nevada.

the area and has one deep test. The exploration results show a thermal anomaly of significant size and geothermal fluids of good quality, suggesting that a geothermal reservoir of commercial quality exists at depth.

121.8 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. 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 ¼ 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. Exploration for disseminated gold has been conducted in this area by several companies. Presently the Pegasus Gold Corp. is exploring the property and has recently announced the definition of 11.8 million tons averaging 0.032 ounces of gold per ton with an estimated stripping ratio of 1.91 to 1 (Pegasus Gold, Inc., 1984 annual report).

125.3 Imlay exit.

129.5 Mill City interchange. The old town of Mill City was located on the south banks of the Humboldt River (just to the north of the highway). Stamp mills located there were built to treat silver ores from the Humboldt Range camps. The paved road to the left leads north to the Eugene Mountains and mining camp of Tungsten.

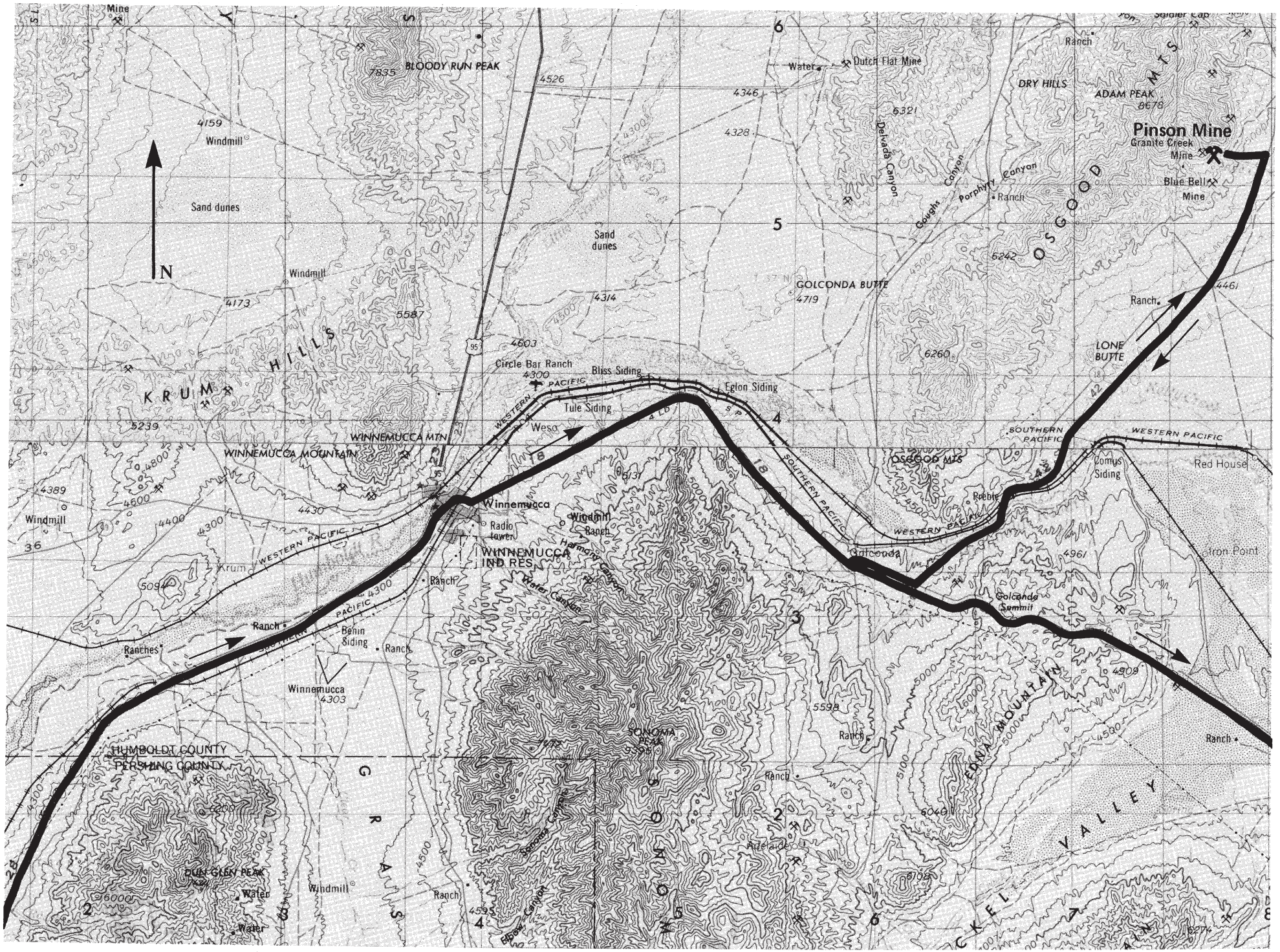
As the highway turns and heads north beyond Mill City, the mine area around the camp of Tungsten can be clearly seen. Tungsten was discovered here in 1916, and the mines were brought into production during the period of high tungsten prices created by World War I. With only a few short periods of inactivity, tungsten was produced here by the Nevada Massachusetts Co. until 1958. The camp produced over 1.8 million units of WO_3 during 1917–57, and at the time of closure was the largest tungsten mine in the U.S. General Electric Co. is the present owner, and through its subsidiary, Utah International, resumed production at the property in 1982. Due to depressed metal prices, the mine closed again after only 6 months of operation and the property is now on standby.

The scheelite deposits at Tungsten occur in tactite (skarn) bodies that formed in certain thin carbonate units of the Middle Triassic Raspberry Formation. The tactite bodies formed as replacements of carbonate rocks near their contact with small Cretaceous granodiorite stocks that intruded the Triassic rocks along the eastern front of the range.

For about the next 15 miles, the East Range will be to the right of the highway. The East Range is composed mainly of Upper Triassic rocks of the Auld Lang Syne Group that have been subjected to large-scale folding and thrust faulting. Some Cretaceous intrusive rocks are present in the north part of the range. Several small mining districts are scattered along the East Range; perhaps the most important is the Sierra or Dun Glen district which has recorded both lode and placer gold production.

137.8 Cosgrave exit.

143.4 Humboldt County line. Blue Mountain can be seen to the far left, and Winnemucca Mountain is ahead, just to the left and north of the highway. Across the Humboldt River to the north (left), the tracks of the Western Pacific (Union Pacific) Railroad can be seen heading west into the Black Rock Desert. East of here both Union Pacific and Southern Pacific tracks run parallel and fairly close together. We have been following the Southern Pacific tracks from Reno to here. From this point the Union Pacific route crosses into the Black Rock Desert and passes to the north of Reno. To


Pinson Mine
Granite Creek Mine
Blue Bell Mine
ADAM PEAK
8678
DRY HILLS
Dutch Flat Mine
Water
Ranch
Soldier Cap
OSGOOD MTS
Dakada Canyon
Cough Canyon
Porphyry Canyon
GOLCONDA BUTTE
4719
LONE BUTTE
Sand dunes
Windmill
BLOODY RUN PEAK
7835
KRUM HILLS
WINNEMUCCA MTN
WINNEMUCCA MOUNTAIN
Circle Bar Ranch
4300
Bliss Siding
Tule Siding
Wesa
Eglon Siding
WESTERN PACIFIC
SOUTHERN PACIFIC
Winnemucca
Radio tower
WINNEMUCCA IND RES
Harding Canyon
Water Canyon
Benin Siding
Ranches
Winnemucca
4303
Krum
Comus Siding
Red House
Rabbit
Golconda
Golconda Summit
Iron Point
EDNA MOUNTAIN
SONOMA PEAK
9395
Sonoma Canyon
Adelaide
HUMBOLDT COUNTY
PERSHING COUNTY
DULL GLEN PEAK
7400
Elbow Canyon
GRASS VALLEY
N

the northwest of Blue Mountain, in the far distance, the Jackson Mountains and Pine Forest Range can sometimes be seen. The Pine Forest Range, on the north margin of the Black Rock Desert, extends north to the Oregon border.

146.6 Rose Creek overpass. The Krum Hills and Winnemucca Mountain are to the north, across the Humboldt River. The town of Winnemucca is straight ahead and the Sonoma Range is to the southeast of Winnemucca. To the south, in the north end of the East Range, small dumps of the Rose Creek tungsten mine can be seen.

149.2 The Ten Mile mining district to the north, north of the Humboldt River, covers the area of low hills generally between the river and the skyline to the north. The district includes numerous small gold prospects and mines developed in quartz veins that cut phyllite. At one property, the Golden Amethyst, free gold occurs in matrix of pale amethyst and quartz.

155.6 Winnemucca, Humboldt County seat. Originally known as French Bridge or French Ford, Winnemucca was a crossing point on the Humboldt River. The town was named Winnemucca after a local Indian chief (the name supposedly means "One Moccasin"). 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 Jurassic–Triassic clastic and sedimentary rocks, Tertiary rhyolitic intrusive rocks, and Tertiary andesite and basalt flows. The Sonoma Range consists of structurally complex Paleozoic and Mesozoic marine sedimentary and volcanic rocks and Tertiary welded and nonwelded silicic ash-flow tuffs. The Winnemucca mining district is located on Winnemucca Mountain. 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.

158.8 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.

166.7 Button Point. Tertiary welded and nonwelded silicic ash-flow tuffs which locally include thin units of air-fall tuff and sedimentary rocks.

173.6 Golconda–Midas 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).

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), 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), copper (0.05 ppm), lithium (0.36 ppm), manganese (0.10 ppm), and mercury (0.0001 ppm).

176.2 Highway turns north to the Golconda tungsten-manganese mine.

177.2 Golconda tungsten-manganese mine in low hills to the east (right). The tungsten-manganese deposits occur in ferruginous and manganiferous clay beds in alluvial gravel that overlies the Cambrian Preble Formation. In part, the deposits are overlain by travertine that forms an irregular, horizontal sheet that strikes north. Kerr (1940), 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.

The tungsten-manganese deposits were discovered in 1885 with the expectation of finding gold and silver (Pardee and Jones, 1920). The deposits occur as blankets and veins adjacent to a fault trending N25°E and 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.

The mineralogy of the ores is 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 wolframite nor scheelite have been found in the ores.

Penrose (1893) recognized that the travertine and associated tungsten-manganese deposits were 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. The most likely source of the metals deposited by the hot springs system was the carbonaceous phyllite, shale, dolomitic limestone, and calc-silicate altered limestone known to underlie the Golconda deposits.

178.0 Bedded-barite occurrences in the Cambrian Preble Formation are located south of the highway at this point. Greenish-weathering phyllitic shale with some interbedded dolomitic limestone is exposed along the sides of the road.

178.3 Exposures of tightly folded Preble Formation limestone along the side of the road.

These exposures display 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, 1974a). In the immediate area, the folding forms a belt 36 miles long by 6 miles 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 the folded limestone beds, in particular, 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 east-directed Antler (Late Devonian–Early Mississippian) orogenic forces. Erickson and Marsh (1974a) recognized the remnants of an Antler-age thrust plate on top of this westward-overturned fold belt to the east at Iron Point. The autochthonous rocks are Ordovician Comus and Valmy 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. The Shwin Formation is isoclinally folded, and the geologic map by Gilluly and Gates (1965) 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 be ascribed to the Antler orogenic event. In Elko County, Nev., Willden and Kistler (1967) recognized asymmetric isoclinal folding and accompanying metamorphism that clearly predates the Silurian and Devonian Lone Mountain Dolomite and is therefore unrelated to the Antler orogenic event.

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 (Gilluly and Gates, 1965) and near the Getchell Mine in the Comus Formation (Berger, 1975) indicates that the early Paleozoic borderland consisted of local troughs and basins with rapid facies changes. The black shale 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 (Berger and Erickson, 1983).

178.5 The road at this point parallels the Humboldt River through Emigrant Canyon.

Both sides of Emigrant Canyon consist of rocks of the Middle and Upper Cambrian Preble Formation. The bulk of the exposed rock consists of phyllitic shale. The contact with the underlying Osgood Mountain Quartzite is transitional and generally marked by a dirty, green micaceous quartzite or coarse sandstone. The shale is interbedded with finely to coarsely recrystallized limestone, sandy limestone, or dolomitic limestone, but because of intense deformation, the true thickness of the Preble Formation is not certain. Erickson and Marsh (1974b) 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 overtuned to the west. The mechanism of the folding is uncertain, but predates early Pennsylvanian time (Erickson and Marsh, 1974b).

179.8 Bridge across the Humboldt River.

181.3 The dirt road on the left leads to the Preble Mine, a low-grade disseminated gold occurrence in the Preble Formation. The property was discovered by Cordilleran Explorations Co. in 1972.

182.3 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 their bases and platy near their tops. To the north, the flows lap onto the Osgood Mountain Quartzite.

189.7 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.

194.0 Turn left to the west and follow the dirt road up Granite Creek which leads to the Pinson disseminated gold deposit. This deposit was discovered by the Cordilleran Explorations Co. in 1970. The mineralization occurs in the Comus Formation along a strand of the Getchell fault. Typical of the carbonate-hosted gold occurrences, the gold is associated with anomalous concentrations of arsenic and mercury. The Granite Creek, Tip Top, and Marcus tungsten deposits are located farther up Granite Creek. Tungsten-bearing garnet skarns occur in the Preble Forma-

Pinson open pit, view looking east, Osgood Mountains, Nevada.

tion around the periphery of the Osgood Mountains granodiorite stock.

To the right, north of Pinson mill, 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 gouge in the portal of the Pacific Mine.

The Getchell fault zone contains disseminated gold mineralization intermittently from here north to the Getchell Mine. Early exploration activity by the Getchell Mine, Inc. defined a broad zone of mineralization with the highest gold values associated with altered limestone beds.

194.5 Pinson Mine, tour led by mine staff. Following mine tour, group will retrace the route back to Golconda then proceed east on Interstate 80 to Battle Mountain and Elko.

215.0 Golconda overpass, turn left, travel east on Interstate 80. The gravel road to the right (south) leads to the Adelaide mining district. The district produced silver and copper ores from replacement ore bodies in silicated and silicified rocks of the Cambrian Preble Formation. The district has been active since 1866, but the main production years were 1897–1910. From 1897 to 1898 the Golconda and Adelaide Railroad was constructed between the mines at Adelaide and a smelter at Golconda. The railroad was removed in 1914 and taken to the new camp of Rochester in Pershing County. Smelter foundations and slag can be seen north of the highway just east of the town of Golconda.

From here, Interstate 80 climbs into Edna Mountain, a low range of hills separated from the Osgood Mountains to the north by the narrow valley of the Humboldt River.

219.4 Preble Formation on both sides of the highway. When the highway again curves to the southeast, it crosses the general trace of the Iron Point thrust fault; upper-plate rocks (to the east) are Permian–Pennsylvanian Antler Peak Limestone. Beyond the curve, the trace of the Golconda thrust fault is crossed; upper-plate rocks (to the east) are chert and shale of the Permian–Pennsylvanian Pumpernickel Formation. Areas of alteration in the Pumpernickel are related to Cretaceous quartz diorite dikes that cut the older rocks. Scattered copper mineralization is found in some of these altered zones, and considerable prospecting has been done south of the highway between here and the summit.

220.7 Golconda Summit.

222.5 Eastside of Golconda Summit. Roadcut drops back into the lower plate of the Iron Point thrust (to the east, lower-plate Cambrian Preble Formation).

224.5 Iron Point mining district exit. Colorful alteration on both sides of the highway occurs in shale and chert of the Ordovician Valmy Formation. The Valmy outcrops north of the highway have been explored for vanadium. Black shale here contains barium, copper, nickel, silver, vanadium, and zinc. Highest concentrations of metal occur in a stratigraphic zone about 35 feet thick that has been traced for some 1,000 feet along strike to the north (U.S. Geological Survey and Nevada Bureau of Mines, 1964). Silver prospects occur north of this zone at the Silver Coin Mine (headframe and old buildings to north). In the mid-

1970's, deep drilling was done in this area to explore for copper-molybdenum mineralization in skarns associated with small quartz diorite intrusive bodies that underlie the district. A large area here shows anomalous values of arsenic, antimony, and mercury, and there has been exploration for sediment-hosted gold.

230.4 Pumpernickel Valley exit. Pumpernickel Valley extends to the right, south of the highway; the broad valley of the Humboldt River is to the left, north of the highway. For the next few miles into Battle Mountain, the view will consist of the Osgood Mountains, now directly north of us in the distance, the Snowstorm Mountains to the north at about 9:00, the Sheep Creek Range ahead at about 11:00 north of the highway, the town of Battle Mountain directly down the road ahead, Mount Lewis in the Shoshone Range in the distance beyond the town of Battle Mountain, and Battle Mountain just this side of the town and south of Interstate 80. The Snowstorm Mountains, on the north skyline, are just north of the Midas gold district. The mountains are composed of a thick sequence of silicic volcanic flows, ash flows, and plugs associated with a volcanic province that extends north to the Idaho border.

236.4 Stonehouse exit. Stonehouse to the right on the flanks of the narrow, north-trending hill. Rock here is quartzite of the Ordovician Valmy Formation; alteration is associated with small gold-bearing quartz vein deposits. To the north of the highway, the Valmy power plant is seen just to the north of Treaty Hill. Treaty Hill, which once marked the boundary of Piute lands (west) and Shoshone lands (east) is composed of Valmy and Battle Formations capped on the north and southeast by Tertiary basalt flows. The power plant, serving the Reno area and north to Idaho, is northern Nevada's first and only coal-fired power plant and is owned jointly by Sierra Pacific Power Co. and Idaho Power Co. The first 250-megawatt unit of the plant was completed in December 1981; a second unit, also 250-megawatt, is now under construction and is scheduled for completion in June 1985. Coal for the plant is shipped by rail from Utah. At present, coal consumption is 1.7 million tons annually.

240.9 Valmy.

246.4 Mote exit. To the north of the highway, at about 10:00, basaltic andesite of Miocene age can be seen capping the Sheep Creek Range. The volcanic rocks overlie a complexly folded and faulted section of western assemblage Paleozoic rocks which include the Ordovician Valmy Formation, Silurian Elder Sandstone, and Devonian Slaven Chert. The cuts and open pit just below the volcanic flows are part of a barite mining operation of Milchem Corp. Bedded barite occurs in the Slaven Chert.

To the right, the lower slopes of Battle Mountain extend along the south side of the highway. Small prospects and cuts in this area are in the Elder Creek district, a northern section of the main Battle Mountain mining district. Prospecting for porphyry copper and molybdenum was done here, principally in the early 1970's.

249.4 Lander County line.

253.8 Battle Mountain. Battle Mountain derives its name from an Indian battle which took place 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. When the Central Pacific Railroad came through in 1869, a settlement called Reese River Siding was established at the confluence of the Reese and Humboldt Rivers, about 2 miles north of the battle site; the siding was renamed Battle Mountain in January 1870 (Roberts and Wrucke, 1979).

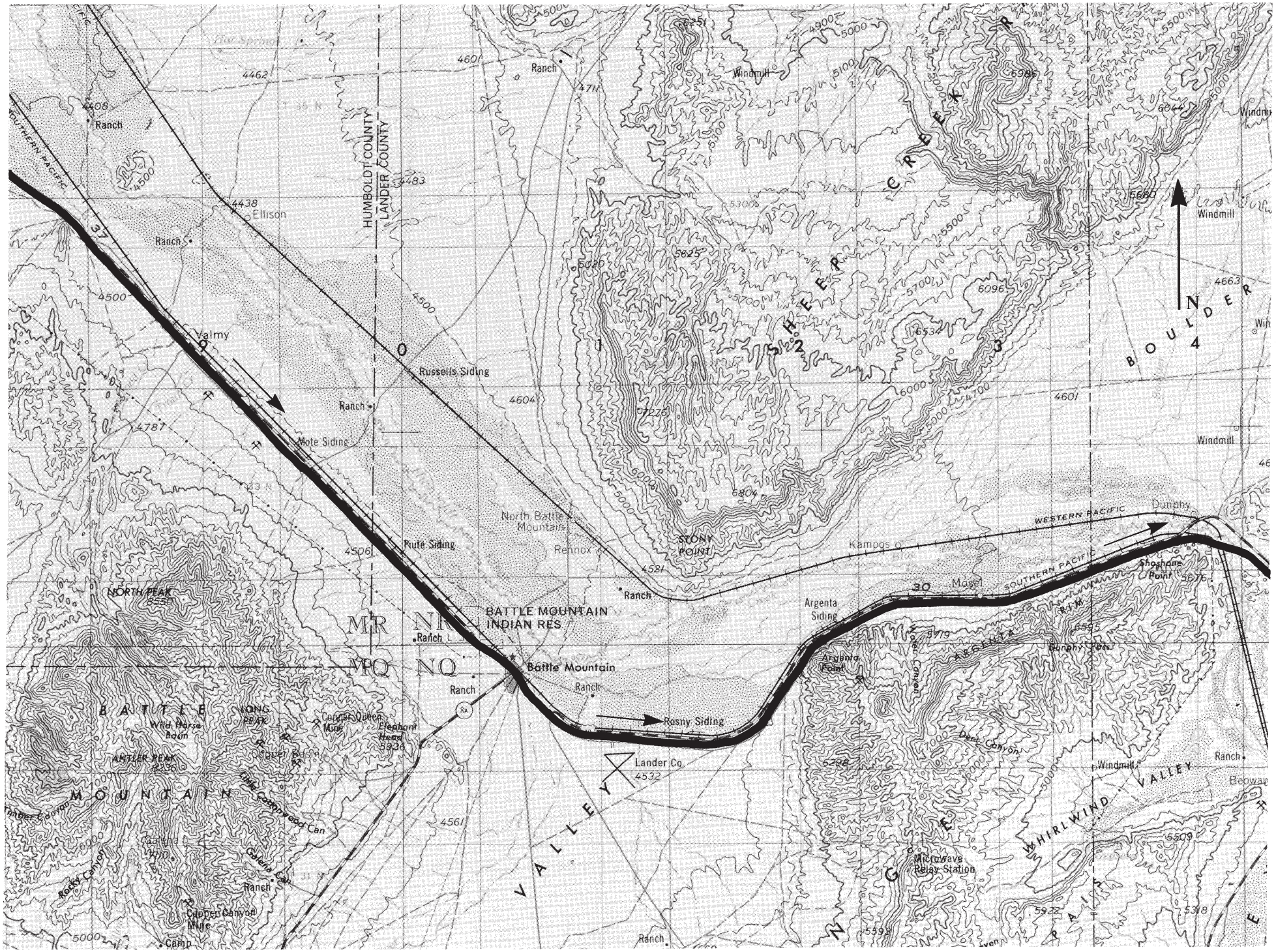
The hill with the "B.M.", Elephant Head, can be seen to the right, at about 3:00. Large waste dumps from the Duval copper operations at Copper Canyon can be seen further to the south on the skyline of the range.

Mining in the Battle Mountain mining district dates to 1863 when silver was discovered in Galena Canyon in the south-central part of the mountain. Discoveries of copper and silver in the vicinity of Copper Canyon in 1864 led to the forming of the Battle Mountain mining district in 1866. Several small mills and smelting works were soon in operation and one lot of hand-sorted ore was shipped to Swansea, Wales. These early high-grade operations had exhausted their ore bodies by 1885, and the district remained unproductive until 1909 when rich gold deposits were discovered at Bannock.

The copper deposits were actively mined during World War I and World War II. Duval Corp. acquired the copper properties in 1961 and began large-scale open-pit operations at both Copper Canyon and Copper Basin in 1967. Copper production continued until 1981 when depressed prices caused operations to be suspended. Duval, however, produces gold from a recently developed gold-bearing skarn deposit adjacent to their copper mine in Copper Canyon. The Duval copper deposits rank third in total production in Nevada and, from 1967 to 1974, produced about 108,000 tons of copper metal. An important byproduct of the copper deposits has been turquoise. Turquoise from the Blue Gem deposit (now in the Duval Copper Basin pit) is famous throughout the southwest. Nevada provides most of the gem turquoise, much of which occurs in the Battle Mountain area, used in Arizona and New Mexico Indian jewelry.

Battle Mountain is also the center of a major barite industry, mines of which are located in the Shoshone Range and Tuscarora Mountains to the south and east, respectively. Several barite processing plants are located along the railroad both in town and east of town. Nevada is the principal domestic source of barite, producing 90 percent of the total 1982 U.S. production and 50 percent of the material consumed in the U.S. (Papke, 1982, p. 12).

The following description of the geologic setting and ore deposits of the Battle Mountain mining district is modified from Stewart and others (1977). Stewart, in turn, credits Roberts and Arnold (1965).


SOUTHERN PACIFIC
HUMBOLDT COUNTY
LANDER COUNTY
Ellison
Ranch
Valmy
Russells Siding
Mote Siding
Piute Siding
North Battle Mountain
Rennox
STONY POINT
SHEEP CREEK
BOULDER
Windmill
Kampos
Mosel
Argenta Siding
Argenta Point
WESTERN PACIFIC
SOUTHERN PACIFIC
Dunphy
Shoshone Point
Dunphy Pass
ARGENTA
BATTLE MOUNTAIN INDIAN RES
Battle Mountain
Rosny Siding
Lander Co.
NORTH PEAK
LONG PEAK
ANTLER PEAK
BATTLE MOUNTAIN
Wild Horse Basin
Copper Queen Mine
Elephant Head
Dear Canyon
Microwave Relay Station
WHIRLWIND VALLEY
Beowawe
VALLEY
Rocky Canyon
Copper Canyon Mine
Camp

Battle Mountain, in general, consists of sedimentary and volcanic rocks of Cambrian, Ordovician, and Devonian ages (Harmony, Valmy, and Scott Canyon Formations) unconformably overlain by sedimentary rocks of Pennsylvanian and Permian ages (Battle, Antler Peak, and Edna Mountain Formations). Upper Paleozoic siliceous and volcanic assemblage rocks of the Pumpernickel and Havallah Formations are thrust over these lower and upper Paleozoic rocks along the Golconda thrust fault. All of these formations have been intruded by small bodies of granitic rocks of Tertiary age and are overlain locally by small patches of volcanic rocks of Tertiary and Quaternary ages. The rocks of the district are complexly folded and faulted. Most of the faults trend north or northeast and both normal and thrust faults are common.

The ore deposits of the district are closely related spatially, and probably genetically, to the intrusive rocks. Copper-gold replacement deposits in the Copper Canyon and Copper Basin areas are the most productive in the district. At Copper Canyon the ore is mainly copper sulfide ore in the lower conglomerate of the Battle Formation and, to a lesser extent, in the hornfels of the middle unit of the formation. At Copper Basin the ore consists of oxidized and secondary copper minerals in sandstone and shale of the Harmony Formation, in dikes and sills of quartz monzonite porphyry, and in conglomerate of the Battle Formation.

The Tomboy and Minnie gold deposits at Copper Canyon were mined by Duval from 1978 to 1984. These deposits contain gold and minor silver with negligible copper and occur in the lower part of the Battle Formation and in a poorly sorted sandstone of the Harmony Formation. Gold is associated with pyrite and pyrrhotite along with some galena and sphalerite (Blake, Kretschmer, and Theodore, 1978).

In December of 1984 the Battle Mountain Gold Co. was formed to assume gold mining operations of Duval Corp. Currently (1985) the company is mining gold and silver at the Fortitude Mine, located in the Copper Canyon area. Reserves as of January 1985 were 11,684,000 tons containing 0.154 ounces of gold per ton and 0.831 ounces of silver per ton (Preliminary Prospectus, Battle Mountain Gold Co., July 1985). The ores of the Fortitude Mine occur within calc-silicate and skarnlike contact-metamorphosed, calcareous rock units adjacent to a porphyritic intrusive stock. These calc-silicate and skarnlike rock units are selectively replaced by sulfide minerals which have associated gold and silver in the form of electrum and silver sulfides. Locally the ores are strata-bound massive sulfide replacement bodies or mantos (Preliminary Prospectus, Battle Mountain Gold Co., July 1985).

Gold-silver vein deposits of the district yielded only a small production. Most of the veins are narrow, ranging in width from less than 1 foot to 5 feet. The ore bodies tend to be pockets that do not persist far along the strike or dip. Production has come mainly from the oxidized zone, where the gold and silver have been enriched.

Lead-zinc-silver vein deposits have yielded a significant production. These veins are within prominent north-trending fault zones on the fringe of the copper-gold zone. Ore minerals are argentiferous galena, sphalerite, and gold. Gangue minerals are quartz, calcite, and pyrite. The veins range in thickness from a few inches to 3 feet and have been traced for thousands of feet along the strike.

Placer gold deposits have been worked in Copper Canyon, Box Canyon, Philadelphia Canyon, Iron Canyon, and Vail Canyon. Most of the placer workings are in fan material near the mouths of canyons along the range front; some deposits have been found in older terrace and stream bottom gravels. The placer gold was derived mainly from local sources and concentrated during erosion of the source veins.

Several antimony-bearing veins occur in the outer zone of ore deposits in the Galena Canyon area between Copper Canyon and Copper Basin. The veins, in general, are narrow and lenticular, and production has been small.

Arsenopyrite is widespread in the ore deposits of the Copper Canyon and Iron Canyon areas and in the southwestern part of Copper Basin.

A deep molybdenum-porphyry deposit at the Buckingham Mine, located between Copper Basin and Copper Canyon, has been extensively drilled by several major companies. Stockwork quartz veins containing molybdenite and pyrite occur in a complex of granitic igneous rocks at depths as great as 4,000 feet.

The turquoise deposits in the district occur along limonite-stained shear zones in argillized quartz monzonite and in hornfels and quartzite of the Harmony Formation. Nodules and veinlets of turquoise, as much as 4 inches wide, are localized in fractures and are mined by open pits, bulldozer trenches, and, at the Blue Gem Mine, by extensive underground workings and open stopes.

256.6 Imco barite plant. At the present time barite shipments from Battle Mountain represent the principal tonnage of freight on the Southern Pacific Railroad in Nevada. The barite is mostly used for drilling mud in oil exploration.

For the next few miles, the highway crosses the broad Reese River Valley. Just to the north of Battle Mountain, the Reese River joins the Humboldt River. The Reese, normally a muddy trickle, occasionally floods and parts of Battle Mountain have been inundated in wet years. To the southeast of the highway, the mining districts of Hilltop and Lewis are located in the Shoshone Range around the base of Mount Lewis. Mount Lewis, the highest peak, occupies the center of a collapse structure known as the Mount Lewis cauldron. It is one of the oldest Tertiary volcanic centers in Nevada. Relatively deeply eroded, the greater part of the rocks exposed lie well below the base of the original volcanic edifice. Within the subsided mass, breccia pipes, plugs, and dikes together with remnants of tuff and volcaniclastic deposits, record an episode of Oligocene volcanism. A ring fault outlines the deeply eroded cauldron. Thrust faults of Early Mississippian and early Mesozoic age that cut Paleozoic and Mesozoic strata in the cauldron have been deformed by subsidence and dip steeply inward near the ring fault. In the interior of the cauldron, the faults dip more gently

where they form a concentric pattern around a centrally located cluster of plugs and breccia pipes (Wrucke and Silberman, 1975).

The lower hills directly ahead, the Argenta Rim, are composed of thrust slices of Devonian Slaven Chert and Elder Sandstone which are exposed beneath the Ordovician Valmy Formation. There are several barite pits along the flanks of this part of the range, and the workings seen on the eastern skyline are also barite mines.

268.0 Milchem barite plant on the north side of the highway; Argenta Siding.

For the next few miles, Boulder Valley can be seen extending to the northeast, north of the highway, railroad, and Humboldt River. The Tuscarora Mountains extend across the head of Boulder Valley to the northeast, and, if weather conditions are right, dumps from the Carlin gold mine can be seen high on the west side of these mountains about 25 miles in the distance.

272.7 5-m.y.-old basalt flows to south capping Argenta Rim.

275.8 Eureka County line.

277.5 Dunphy, another barite plant on the north side of the highway here.

281.8 Humboldt River crossing.

282.9 Rest stop to the south of the highway. Whirlwind Valley extends to the gap in the low hills, then continues to the southwest into the northern Shoshone Range. The Beowawe geyser site is along the southern margin of Whirlwind Valley along a major fault zone which is at least 35, and possibly up to 70, miles in length (Garside and Schilling, 1979). The geothermal area at Beowawe has the highest reported subsurface temperatures in Eureka County and one of the highest steam-well temperatures in Nevada. It is one of the most drilled areas in the State (Garside and Schilling, 1979). The site shows as a white streak in the middle distance; in cold weather, a series of plumes can be seen along the spring terrace.

284.4 Beowawe turnoff. About 6 miles to the south, a small town can be seen on the railroad. Crescent Valley is another 15 miles south of Beowawe. Several major gold deposits lie to the southeast and southwest of Crescent Valley, including the Gold Acres Mine in the Bullion district and the Cortez and Horse Canyon Mines in the Cortez district. The Gold Acres deposit was discovered in 1935 and produced 181,200 ounces of gold from a disseminated ore body formed in carbonate rocks below a thrust zone. The Cortez deposit was discovered in 1966 and has produced almost 1 million ounces of gold. Horse Canyon, just southeast of Cortez on the east side of Mount Tenabo, has just been placed into production and has announced reserves of 187,000 ounces of gold (Bonham, 1982).

285.0 Sheared Vinini Formation in roadcuts.

289.9 Silicic pyroclastic rocks, andesite, and bedded tuffs are exposed in roadcuts to the left (north) for the next 3 miles.

292.1 Emigrant Springs, a watering and resting place used by wagon trains which took this route in the 1840's and 1850's.

293.7 Emigrant Pass (elevation 6,114 feet). Emigrant trains took this pass to avoid the narrow canyon of the Humboldt River to the south. Vinini Formation chert and shale are exposed in outcrops at the pass; west of the pass andesitic volcanic rocks and silicic pyroclastic rocks occur in the roadcut.

To the east, the highway passes through more Tertiary volcanic rocks, then crosses through a sequence of Tertiary–Quaternary sedimentary rocks which flank the east slopes of the Tuscarora Mountains and fill the Mary's Creek and Maggie Creek drainages.

296.0 Grey perlite in roadcuts.

300.0 Well-bedded, gray and buff sands.

300.7 Palisade Canyon Rhyolite to the south of the highway.

302.2 West Carlin exit.

303.6 Carlin turnoff, town is to the south of the highway.

DAY TWO: Elko, Enfield Bell Mine, Maggie Creek Mine, Elko

Cumulative Mileage

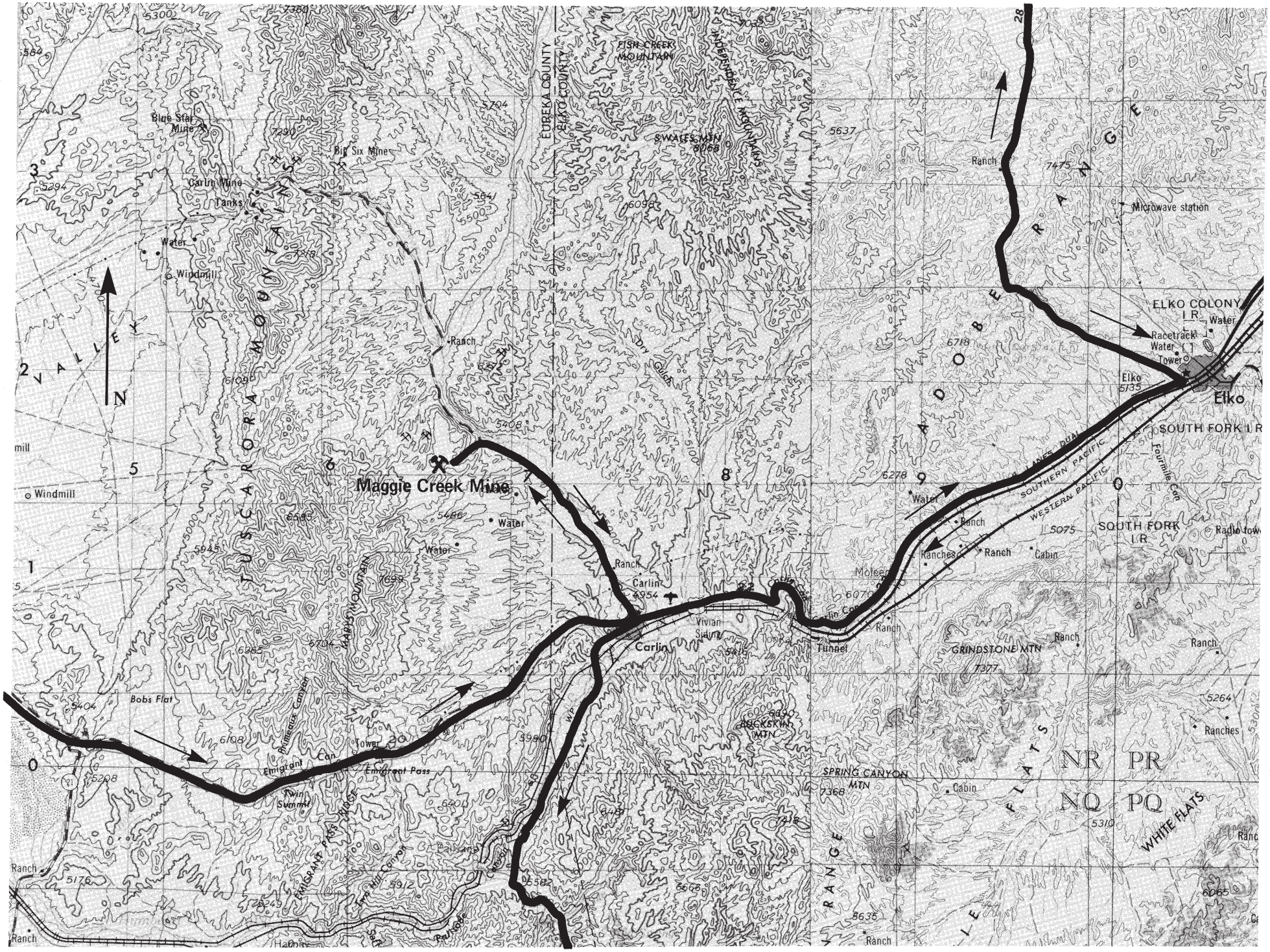
0.0 Leave Red Lion parking lot at 8 a.m., take Interstate 80 west toward Carlin. The town of Elko is to the south of the highway.

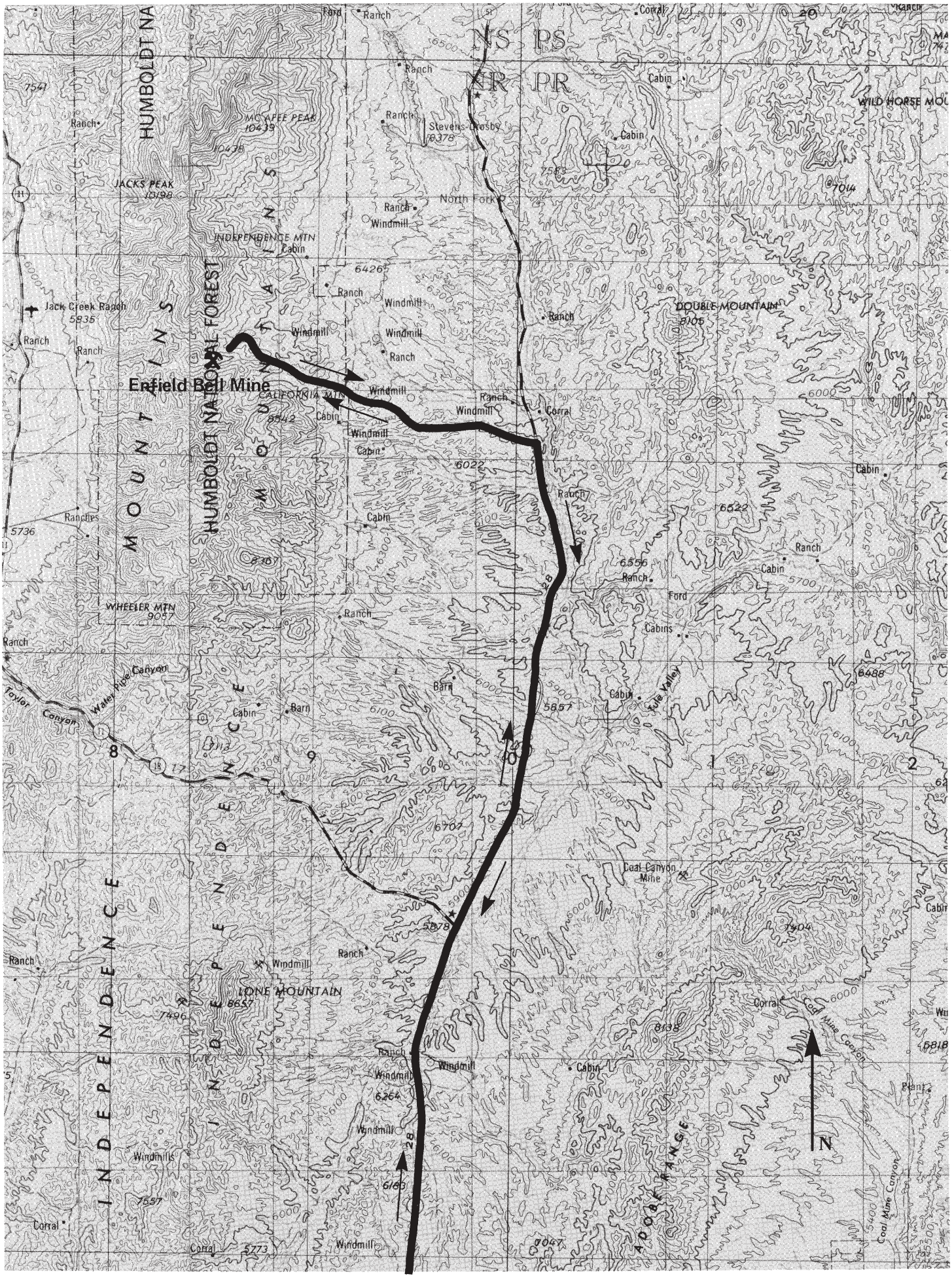
2.6 State Route 225 exit. Take route to the north (Boise); the Elko airport is to the left. South of town, oil shale beds in the Oligocene(?) and Eocene Elko Formation are exposed in the canyon across the Humboldt River. Ruins of the Catlin oil shale retort are also in this area. Oil shales have been of interest here since the 1870's when attempts were made to utilize them as coal for the railroad. In 1916, a retort was installed and a considerable amount of oil was produced. Some activity continued until 1920, but little has been done since (Granger and others, 1957).

We are now climbing into the Adobe Range, composed largely of the Mississippian and Pennsylvanian Diamond Peak Formation (conglomerate and sandstone).

10.3 Adobe Summit (elevation 6,548 feet).

24.5 Dinner Station, formerly a stop on the Elko–Silver City (Idaho) stage line; the stage arrived here from Elko in time for "dinner." The solitary mountain to the west is one of three Lone Mountains in Nevada. This one, part of the southern Independence Mountains, is composed mainly of the Nannies Peak intrusive, a 38-m.y.-old (K. B. Ketner *in* Coats and McKee, 1972) quartz monzonite porphyry that has intruded thrusted eastern and western assemblage sedimentary rocks of Ordovician and Devonian age. The intrusive body forms bold, jointed outcrops along the entire north-trending summit of Lone Mountain; sedimentary rocks form the lower flanks of the mountain. The Merrimac mining district occupies all of Lone Mountain. The principal mines encircle the crest and are confined mainly to the intrusive contact zone. Between 1866 and 1949, a little over $1 million worth of copper, gold, lead, silver, and zinc was produced from this district. Minor tungsten is present, and several small barite


Maggie Creek Mine
Carlin
Elko
ELKO COLONY I.R.
SOUTH FORK I.R.
EUREKA COUNTY
ELKO COUNTY
TUSCARORA MOUNTAINS
ADOBE RANGE
INDEPENDENCE MOUNTAINS
FISH CREEK MOUNTAIN
S. WALES MTN
HARRIS MOUNTAIN
GRINDSTONE MTN
BUCKSKIN MTN
SPRING CANYON MTN
WHITE FLATS
SOUTHERN PACIFIC
WESTERN PACIFIC
Blue Star Mine
Big Six Mine
Carlin Mine
Tanks
Windmill
Water
Ranch
Cabin
Ranches
Microwave station
Racetrack
Tower
Radio tow
Vivian Siding
Tunnel
Bobs Flat
Emigrant Pass
Twin Summit
Emigrant Can
Primeback Canyon
Fourmile Can
Dry Gulch
Tin Can
Tom Can
Tom Hill Canyon
Railroad
Lander
NR PR
NQ PQ


Enfield Bell Mine
HUMBOLDT NATIONAL FOREST
INDEPENDENCE MOUNTAINS
MCAFEE PEAK
10439
JACKS PEAK
10198
INDEPENDENCE MTN
CALIFORNIA MTN
8542
WHEELER MTN
9057
LONE MOUNTAIN
DOUBLE MOUNTAIN
8105
WILD HORSE MOUNTAIN
North Fork
Stevens-Crosby
6378
Jack Creek Ranch
5835
Coal Canyon Mine
Coal Mine Canyon
Taylor Canyon
Wales Hide Canyon
Tula Valley
ADOBE RANGE
N

occurrences are also reported (Granger and others, 1957). The Adobe Range is to the right (east). The low hills on both sides of the highway are composed mainly of Tertiary tuffaceous sedimentary rocks.

28.6 Intersection with State Route 226 which leads to the west. We continue north on State Route 225. State Route 226 cuts through the Independence Mountains then turns north. The old mining camp of Tuscarora is located about 25 miles west of here, in the Tuscarora Mountains. Placer gold was discovered in the Tuscarora district in 1867, and lode deposits of gold and silver were found in 1871. Mineralization occurs in narrow veins in andesite that are rich in silver, and in wide, poorly defined, gold-bearing fracture zones in bedded tuffaceous rocks. The age of mineralization at Tuscarora has been dated at 38 m.y., which is the oldest Tertiary epithermal vein mineral deposit in northern or central Nevada (McKee and Coats, 1975, p. 11). The district produced 162,031 ounces of gold and 7,138,684 ounces of silver until 1950 (Granger and others, 1957), although most production was prior to 1900. In the past few years many of the old dumps have been removed and treated by heap leaching.

For about the next 20 miles, between this point and the turnoff to the Enfield Bell Mine, the highway follows the eastern front of the Independence Mountains. Wheeler Mountain, on the south end of this part of the range (to the west, just north of State Route 226) has an elevation of 9,057 feet; McAfee Peak, to the north, north of the Enfield Bell Mine reaches an elevation of 10,439 feet. Freeport's mining operations are primarily along the crest of the range and extend over the western side. Elevations at the mine site are about 7,800 feet.

Freeport's land holdings here are extensive. The original claim block, at the time of the first company announcement in 1978, covered 14 full and 19 partial sections, some 42 square miles of claim area within the Humboldt National Forest.

39.1 Thick Oligocene(?) dacite flow.

40.0 North Fork, Humboldt River.

ROAD LOG

along Freeport access road from State Route 225 to Enfield Bell Mine

by Robert J. Stuart

Cumulative Mileage

44.8 Freeport road turnoff from State Route 225. Proceed west on Freeport road. Foreman Creek drainage to right. Confluence with North Fork, Humboldt River, ½ mile at 6:00. Rancho Grande at right across Foreman Creek. Bing Crosby owned this ranch at one time.

47.3 Limestone boulders to left. From mileage point 44.8 to 51.6, outcrops are mapped as Ts_3—tuff, vitric ash, tuffaceous siltstone and sandstone, conglomerate, and limestone (Hope and Coats, 1976). Outcrops of freshwater limestone cap hill to the left.

48.3 Road to gravel pit at right. California Mountain at about 12:00 with switchback drill roads. Exposures are lower-plate Devonian–Silurian Roberts Mountains Formation and Silurian–Ordovician Hanson Creek Formation.

Enfield Bell Mine behind first and second saddle to the north (about 1:00).

49.0 At 2:00, Freeport's Jerritt Canyon mill complex.

49.4 Stump Creek crossing.

50.9 Tailings pond at right. Mid-Tertiary(?) volcanic rocks at left.

The volcanic sequence consists of, from oldest to youngest:

1. Sedimentary rocks, including paper-thin shale, ostracod marl, and water-laid tuff.
2. Pink lithic tuff with volcanic fragments overlying a light-gray to buff lithic tuff with volcanic and sedimentary fragments.
3. Andesite flows and welded crystal tuffs.

51.6 Freeport security gate. Mill complex straight ahead. Reset odometer.

0 Security gate. Pass through and turn left 200 feet past gate. Warehouse and maintenance shop at left. Mill complex at right. Surge tank, with a capacity of 115,000 gallons, will supply plant for 12 hours. Thickener has a capacity of 1.5 million gallons. Active ore stockpile of -8-inch material crushed by a 4 by 6 jaw crusher.

Turn left around warehouse.

0.15 Stop sign. Turn right onto haul road. CHANGE TO LEFT-HAND DRIVE. (Drive on left side of road.)

0.45 Veer left onto main haul road. Quaternary gravels in roadcuts.

0.55 "Million dollar" culvert over California Creek to protect Lahontan trout habitat. Crossing Tertiary andesitic volcanic rocks which consist mainly of welded tuff with shard texture, collapsed pumice fragments, and plagioclase (An_{39-44}) in a glassy to vitreous groundmass. Common accessory minerals are augite, biotite, enstatite, and hornblende.

0.85 At 8:00, andesite cliff east of California Creek. California Mountain with reclaimed drill roads in distance.

1.65 Reclaimed rock quarry (Tertiary andesite) for tailings dam.

2.65 Tertiary sedimentary rocks (water-laid tuff, paper-thin shale, and claystone) on right side of road. Upper-plate Ordovician McAfee Quartzite on skyline to right.

3.15 Tertiary sedimentary rocks in valley and on ridge to right.

3.85 Skyline peaks from 1:00 to 2:00 are McAfee Quartzite overlying upper-plate Ordovician Snow Canyon Formation. Tertiary lithic tuff in roadcut to left.

4.45 Quaternary paleovalley to left. This valley marks the western extent of the Tertiary volcanic rocks. Snow Canyon Formation on hill at 10:00 and to the right. Lower-plate Hanson Creek jasperoid at 12:00.

View of Enfield Bell Mine, Jerritt Canyon, Independence Mountains, Nevada.

4.65 Upper-plate/lower-plate contact at left. Snow Canyon Formation greenstone in thrust contact with lower-plate Roberts Mountains Formation.

5.15 Hanson Creek jasperoid on skyline to left. Quaternary solifluction terraces on Snow Canyon Formation slope from 3:00 to 4:00.

5.35 Approaching northerly plunging anticline composed of Roberts Mountains Formation. Hanson Creek jasperoid exposed along axis of anticline.

5.65 Crossing south fork of Winter's Creek drainage. Area underlain by Roberts Mountains Formation.

6.05 Left turn to mine services building and upper maintenance shops. North-dipping Hanson Creek jasperoid north of buildings.

6.35 Hanson Creek jasperoid and Roberts Mountains Formation at right. Snow Canyon Formation at left in thrust contact with Roberts Mountains Formation.

6.55 Entrance to pit area.

Following tour, group will retrace route back to Elko.

105.4 Intersection, State Route 225 and Interstate 80, proceed west on Interstate 80 toward Carlin.

110.4 Peak on skyline at 10:00 is Grindstone Mountain composed of Pennsylvanian Moleen Formation. Bluffs in foreground composed of Mississippian and Pennsylvanian Diamond Peak Formation and Permian rocks.

111.4 Canyon at 9:00 is South Fork of the Humboldt River, where the Donner party emerged late in 1846 following a disasterous misguided detour around the south end of Ruby Mountains. This delay caused the party to reach the high Sierra Nevada too late in the year to avoid heavy snow. Only a few survivors reached the Sacramento Valley the following spring.

112.8 Roadcuts on right expose upper Miocene Humboldt Formation composed largely of continental volcaniclastic rocks.

113.5 Hunter exit on right.

115.7 Roadcuts on right expose Pennsylvanian and Permian rocks composed of siltstone, sandstone, limestone, and dolomite.

116.2 Hills and bluffs on right composed of Pennsylvanian and Permian rocks.

116.5 For the next few miles, between here and the town of Carlin, we will be traveling through a sequence of flysch deposits (rocks derived from the advancing front [west to east] of the Roberts Mountains thrust sheet).

116.9 Roadcut on right (north) composed of Lower and Middle Pennsylvanian Tomera and Moleen Formations (undivided). Outcrop consists of detrital limestone and fine-to coarse-siliceous sedimentary rocks derived from final uplifts of the Antler orogenic highland to west.

117.8 To the right, prominent tan cliffs (hoodoos) encrusted with swallow nests consist of Eocene(?) limestone-gravel conglomerate.

119.0 Enter Carlin Canyon where antecedent Humboldt

River crosses Piñon Range. Trappers and Indian traders entered Carlin Canyon for the first time about 1828. This route was used subsequently by most parties traveling to California both before and after gold was discovered there in 1849. Chinese track gangs built the first railroad (Central Pacific) through the Canyon in 1868, and a second (Western Pacific) was built in 1907. The first highway opened this route to automobiles in 1913.

Steeply dipping beds at 12:00 are rocks of Pennsylvanian age.

119.1 Cross Humboldt River. Cliffs on the right are same Pennsylvanian formations.

119.3 At 9:00, prominent gray limestone cliff is basal unit of Pennsylvanian Moleen Formation resting on brown slope-forming Diamond Peak Formation. Red beds at 9:00 to 11:00 are uppermost Diamond Peak Formation of Mississippian and Pennsylvanian age.

119.7 At 11:00 to 12:00 above railroad tunnels is an unconformable contact between gray Pennsylvanian and Permian Strathearn Formation on the right and red-brown Diamond Peak Formation on the left.

120.0 Tonka at 9:00.

120.4 Cross Humboldt River and enter tunnel.

120.7 Emerge from tunnel and cross Humboldt River.

At 3:00 as we emerge from the tunnel, nearly vertical, red to purple conglomeratic flysch units of the Diamond Peak Formation are seen, overlapped by steeply dipping Strathearn beds. The Diamond Peak flysch represents the acute phase of uplift in the west from Early Mississippian to Early Pennsylvanian time. At this locality the Moleen and Tomera Formations have been eroded and the Strathearn rests unconformably on the Diamond Peak. The Strathearn is roughly equivalent in age to the Antler Peak Limestone. Although these two units locally contain thin sand and pebbly sand layers, this lithology contrasts sharply with that of the preceding orogenic units and marks the end of the Antler orogeny in this region. The unconformity represents regional deformation of late Middle Pennsylvanian age. The deformation postdates the Antler orogeny and has been termed the Humboldt orogeny by Ketner (1977).

120.8 At 9:00, across the river is a fault separating Diamond Peak Formation on the east and Lower Mississippian Webb Formation on the west. The Webb forms smooth slopes and the Diamond Peak forms rugged outcrops. Composed of Antler orogenic debris, the Webb Formation is the oldest formation in this area.

120.9 At 3:00, well-exposed, reddish, lowermost Mississippian Webb Formation (west) resting on poorly exposed Ordovician Vinini Formation (east).

121.8 Building on left is an old mill once used in processing diatomite mined from lake beds in the Miocene Humboldt Formation north of highway.

123.1 At about 1:00, Mary's Mountain, composed almost entirely of upper-plate western assemblage rocks of Ordovician, Silurian, and Devonian age.

123.9 Cross Maggie Creek. Large building at 9:00 adjacent to railroad tracks is an old railroad ice house. Ice cut from nearby ponds was stored here to stock refrigerator cars.

125.2 Enter town of Carlin.

125.5 Turn right on road to Newmont mines. The Maggie Creek Mine is about 9 miles to the north, and the Carlin Mine is another 10 miles beyond the Maggie Creek area. As we head north, the Independence Mountains are on the east and the southern Tuscarora Mountains are to the west. The Maggie Creek Mine (and the adjacent Gold Quarry deposit) are located in the Carlin window in the Roberts Mountains thrust zone. The Carlin window is directly ahead on the northeast end of Mary's Mountain, a northeast-trending projection from the southern end of the Tuscarora Mountains. Maggie Creek itself cuts through the window, and the road, which follows Maggie Creek, provides a good view of a cross section through the thrust sheet. We will, however be turning west onto the Maggie Creek Mine road before the exposures in the canyon can be seen. To the east, the thrust contact between Devonian limestone and contorted and crumpled upper-plate rocks descends to the floor of the valley and then swings around to the northeast where it is concealed by the Humboldt Formation and alluvium. Further up the canyon, the Roberts Mountains Formation (indurated dolomite, limestone, and siltstone of Silurian age) is overlain by about 300 feet of Lower Devonian limestone.

131.0 Gold Quarry road.

132.5 Maggie Creek Mine access road, turn left (west) and proceed to mine. Mine tour led by Carlin Gold Mining Co. (Newmont) mine staff.

Following tour, group will retrace route back to town of Carlin.

141.5 Carlin, turn east on Interstate 80 and return to Elko.

DAY THREE: Elko, Windfall Mine, Alligator Ridge Mine, Ely

Cumulative Mileage

0.0 Leave Red Lion parking lot at 8 a.m., take Interstate 80 west toward Carlin. We will retrace our Day Two route to Carlin, then turn south on State Route 278 to Eureka.

23.0 Town of Carlin.

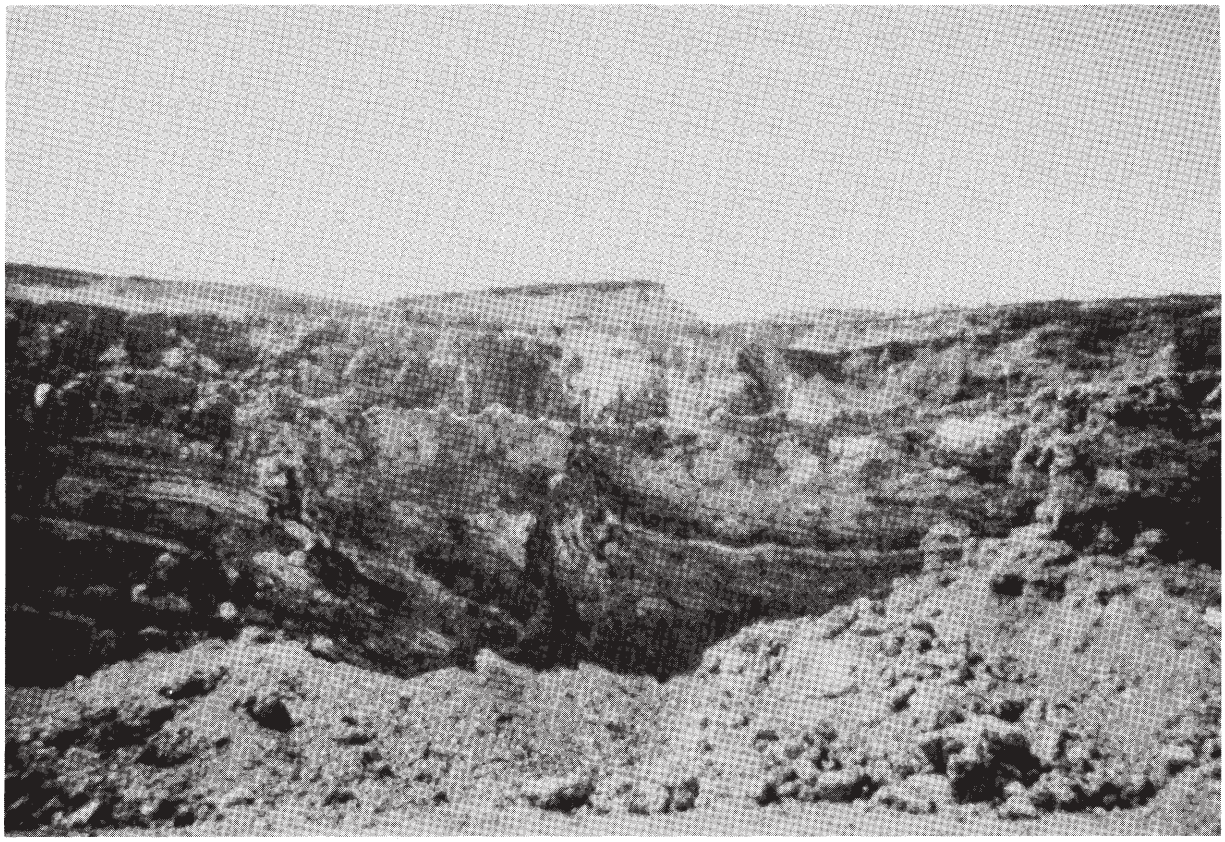
24.6 At junction State Route 278, turn left (south) to Pine Valley and Eureka.

25.6 Carlin Social Club.

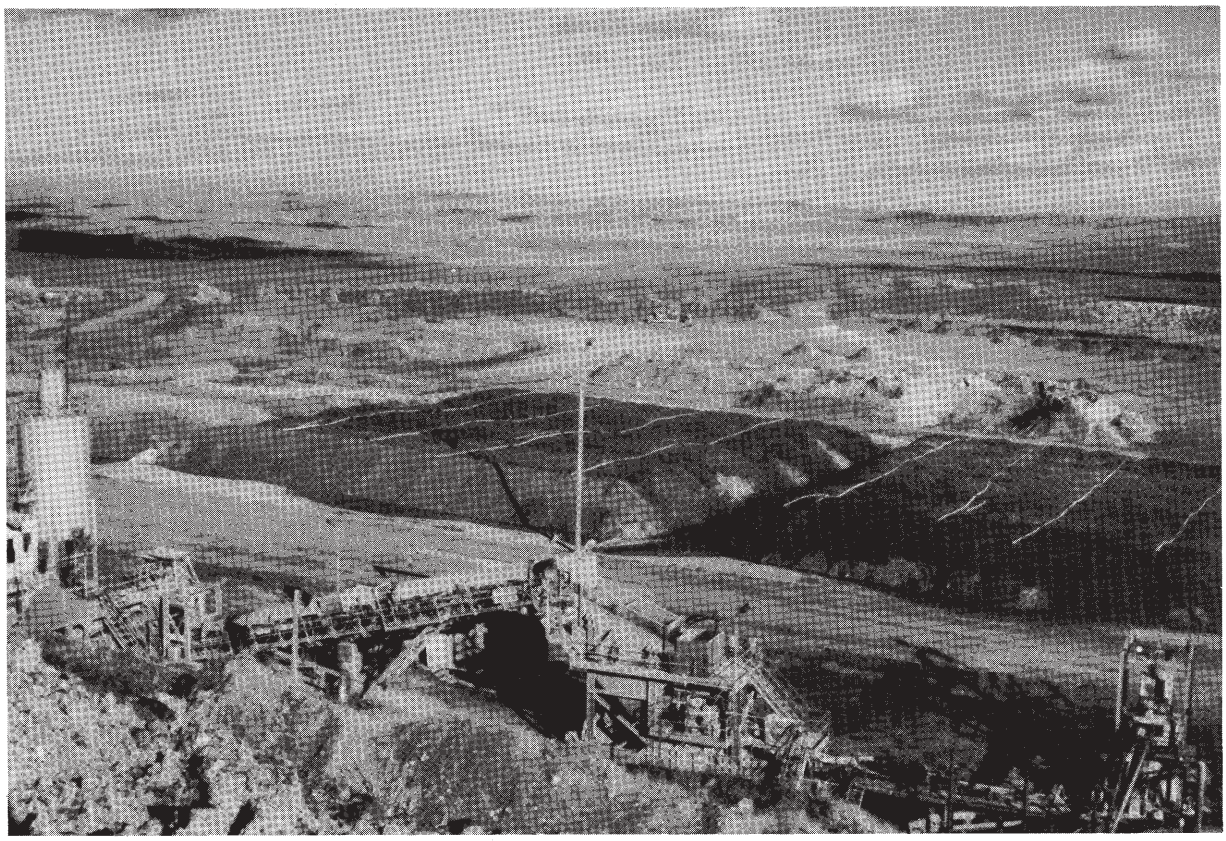
25.8 Crossing the Southern Pacific tracks, then the Humboldt River, then the Union Pacific tracks. Note hot springs.

27.8 Brown, rugged outcrops at 12:00 to 3:00 are composed of upper Miocene Palisade Canyon Rhyolite. Humboldt River cuts through rhyolite, forming a rugged canyon that forced the 49'ers to detour north of the canyon at Carlin Spring. Rhyolite also forms dip slope east of the highway.

29.0 Light-colored outcrops at 3:00 just above the valley floor consist of upper Miocene Humboldt Formation.



View of Les fault, Maggie Creek pit, Tuscarora Mountains, Nevada.



View of heap leach pads, Maggie Creek Mine, Tuscarora Mountains, Nevada.

29.4 Eureka County line.

29.9 Roadcuts along highway expose Palisade Canyon Rhyolite.

33.5 Road to right leads to townsite of Palisade. Lead and silver ores from the Eureka mining district were shipped north to Palisade on the Eureka and Palisade (narrow gauge) Railroad between 1875 and 1938. The rails of this railroad were torn up and shipped abroad just prior to World War II, but the roadbed and trestles can still be seen in Pine Valley.

34.0 Dam and reservoir in Pine Creek on right. Enter Pine Valley. Oligocene tuff and tuffaceous sedimentary rocks on right. Younger landslide mass on left is composed largely of volcanic debris.

34.4 Pine Mountain in the distance at 1:00.

35.8 At 3:00, light-colored outcrops are tuff.

36.2 Drab outcrops on both sides of highway are composed of Humboldt Formation. Remnants of the old narrow-gauge railroad bed of the Eureka and Palisade Railroad can be seen on the flood plain of Pine Creek.

37.8 Light-colored tuff and sedimentary rocks in low hills on the left comprise the Pliocene and Pleistocene Hay Ranch Formation.

38.6 Tomera Ranch on right. Grove of trees west of the ranch was the site of a railroad station on the Eureka and Palisade Railroad. The road to the left leads up Ferdelford Creek Valley. Hay Ranch Formation on both sides of valley. Pine Mountain in distance to east of highway consists of lower-plate Devonian rocks exposed in a window very close to the leading edge of the Roberts Mountains allochthon.

About 12 miles to the east up Ferdelford Creek, at the north end of the Piñon Range, Newmont Exploration has developed low-grade gold reserves at the Rain property. Announced reserves at Rain are 1,188,700 ounces of gold contained in 11.7 million tons of ore (Bonham, 1982). The host rocks for the deposit are siltstone, shale, and minor sandstone of the Lower Mississippian Webb Formation, considered to be an allochthonous unit of the Roberts Mountains thrust (Ketner and Smith, 1982). In the area drilled, the rocks are fractured, bleached, iron stained, and silicified. A conspicuous outcrop of jasperoid breccia lies along the margin of the deposit.

For the next 40 miles, we will be traveling south through Pine Valley and pass through lacustrine deposits of the Hay Ranch Formation. The formation is composed of clay, vitric tuff, limestone, and tan tuffaceous siltstone and sandstone which interfinger with conglomerate. These deposits are considered to be middle Pliocene to middle Pleistocene (Roberts, Montgomery, and Lehner, 1967).

44.1 Ranch on right.

44.9 Trout Creek.

47.5 Road to right to Amoco well site, East Bailey Ranch No. 1.

48.2 Hay Ranch, formerly a station on the Eureka and Palisade Railroad. The continuation of the Piñon Range, to the east of the highway, here is composed of complexly faulted Paleozoic carbonate rocks. To the west, on the west side of Pine Valley, the northern part of the Cortez Mountains can be seen. Rocks in this part of the Cortez Mountains consist of Jurassic metavolcanic rocks which have been intruded by granitic rocks of Early Cretaceous(?) age.

49.8 Road to the west leads to the Modarelli iron mines. The deposit lies about 1 mile east of the crest of the Cortez Mountains, 9 miles to the west of the highway. Iron ore (martite) occurs as a replacement of rhyodacite and rhyolite in Mesozoic volcanic flows. Total production through 1961 was 395,900 tons averaging about 57 percent iron (Roberts, Montgomery, and Lehner, 1967).

56.5 Union Pass road.

59.6 Blackburn oil field to the east of the highway. Amoco Production Co. completed the discovery well in this field in April 1982. A second producing well was completed in 1983. Little information has been released concerning this field, but the interval between 7,060 and 7,199 feet was reported to be a favorable zone during drillstem tests on the first producing well. The reservoir at the Blackburn field is rumored to be a 100-foot-thick sandstone in the Devonian Nevada Formation. Production through December 1983 was 81,828 barrels (Garside and Weimer-McMillion, 1982; 1983). Although by no means a large oil field, it is the only one other than Railroad Valley where oil is produced in Nevada. The Blackburn discovery has caused a rush of oil exploration in the entire northeastern part of the State.

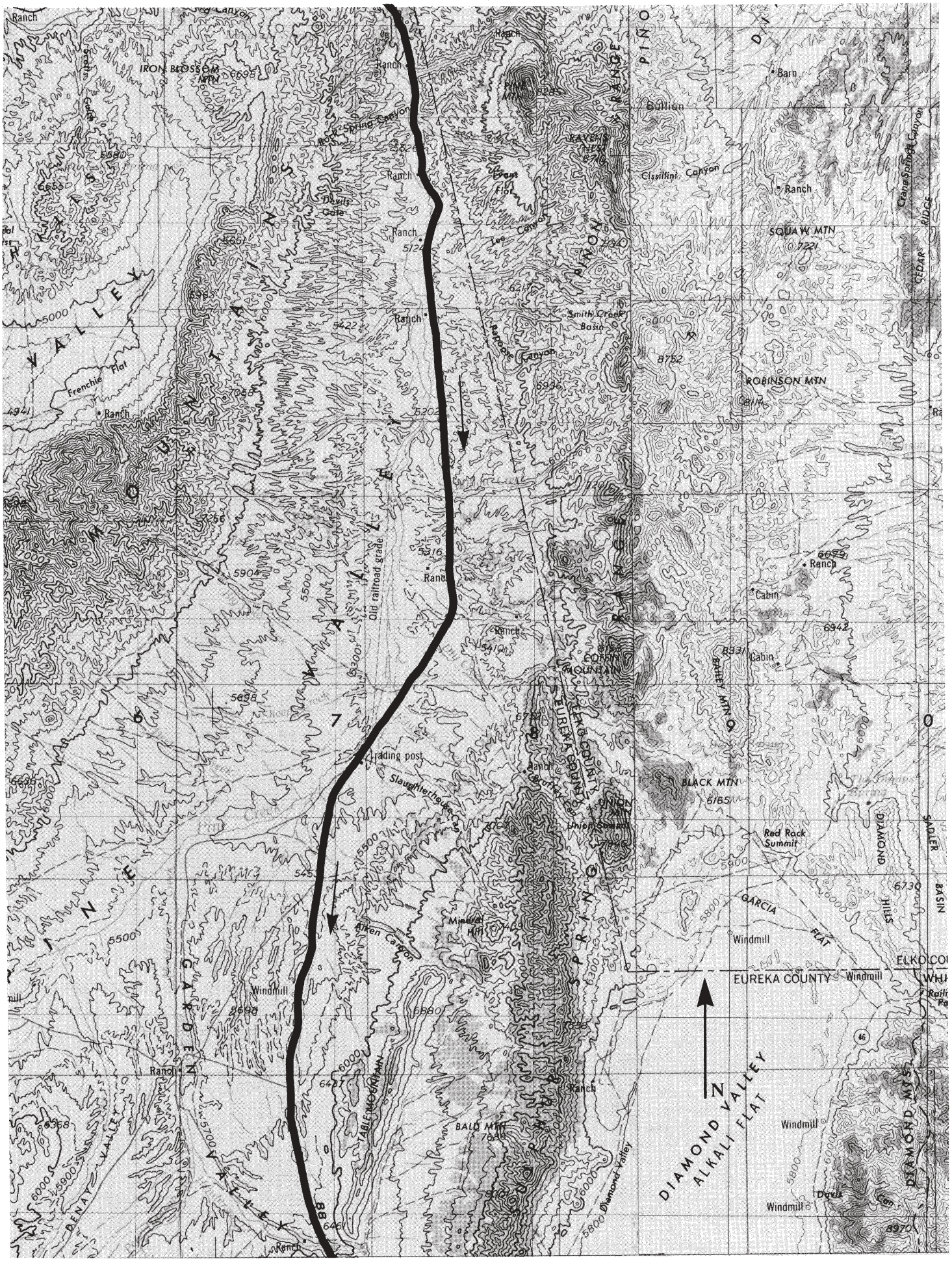
61.1 Road to oil wells.

In the foothills of the Sulphur Springs Range to the east, at the foot of Union Pass, a group of oil seeps and thermal springs occur at the Bruffey Ranch. The seeps and hot springs are associated with a major fault zone between the Pine Valley graben and the Sulphur Spring/Piñon horst to the east. Oil was noted to occur at springs here over 50 years ago by the ranch owner. He reported black, tarry masses, half the size of a goose egg, oozing out on the surface of the water (Foster and others, 1979, p. 531). The main hot springs at the Bruffey Ranch have prominent terraces of calcareous sinter. The old travertine deposits here contain barite and fluorite (Garside and Schilling, 1979).

61.2 Blackburn, formerly a station on the Eureka and Palisade Railroad.

65.1 Mineral, site of another old railroad station.

The Mineral Hill mining district is located 5 miles to the east in the low hills west of the main Sulphur Spring Range. Discoveries in the district occurred in 1870. The major production (silver, lead, zinc, copper) occurred between 1871 and 1876, although some production was recorded as late as 1938. Total recorded production is $2,500,662 (Roberts, Montgomery, and Lehner, 1967). The principal ore bodies are in crushed and fractured limestone adjacent to a thrust fault. Jasperoid is found in many places. The major minerals include tetrahedrite, galena, sphalerite, molybdenite, and pyrite. The host rock at Mineral Hill is carbonate rock of the Devonian Nevada Formation.


IRON BLOSSOM MTN
Spring Canyon
Devils Gate
Frenchie Flat
Old railroad grade
Trading post
Slaughterhouse
Aiken Canyon
TABLE MOUNTAIN
BALD MTN
Diamond Valley
DENAY VALLEY
Windmill
Ranch
Barn
Bullion
Elssillini Canyon
SQUAW MTN
ROBINSON MTN
Smith Creek Basin
Papoose Canyon
Cabin
COFFIN MOUNTAIN
EUREKA COUNTY
BLACK MTN
Union Summit
Red Rock Summit
DIAMOND HILLS
GARCIA FLAT
SADLER BASIN
DIAMOND VALLEY
ALKALI FLAT
DIAMOND MTS
88
46
N

71.7 Road to the west (right) leads to the Buckhorn mining district, Cortez Canyon, and continues north to Crescent Valley and south to Austin. The Buckhorn mining district is about 18 miles to the west and is in the low area on the eastern flank of the Cortez Mountains (on western horizon). The Buckhorn Mine, the only major mine in the Buckhorn mining district, was discovered in the winter of 1908-09. George Wingfield, a prominent early Nevada mining financier who controlled the mines at Goldfield, acquired the ground and put Buckhorn into operation in 1914. Production at Buckhorn, through 1950, totaled $1,109,838 (39,024 ounces of gold and 311,278 ounces of silver) (Roberts, Montgomery, and Lehner, 1967). Mineralization at Buckhorn occurs in highly altered Miocene basalt and is concentrated in a chaotic breccia zone along a steeply dipping fault (S. Monroe, oral commun., 1982). Free gold at Buckhorn occurs with limonite along fine fractures and veinlets within the breccia zone. At depth, this zone contains abundant pyrite and marcasite. Hydrothermal explosion breccias, sinter deposits, and silicified conglomerate crop out in the district. Cominco now controls this deposit. Following several years of exploration, in 1982 Cominco announced estimated reserves of 2.5 million tons of ore containing 0.12 ounces of gold and 1.05 ounces of silver per ton (Bonham, 1982).

The prominent area of roads and workings on the crest of the Cortez Mountains just north of Mount Tenabo (highest peak, elevation 9,162 feet) is the haul road and dumps of the Horse Canyon area. Cortez Gold Mines announced reserves at this deposit in 1982 were 3.4 million tons containing 0.05 ounces of gold per ton (Bonham, 1982). The Horse Canyon deposit is hosted by the Wenban Limestone and upper-plate Vinini Formation, which are mineralized adjacent to the Roberts Mountains thrust or possibly along a high-angle structure east of the thrust contact. A prominent rib of jasperoid breccia lies along the trace of the thrust here.

75.8 Tonkin Summit road.

To the southwest, on the right of the highway, are high peaks of the Roberts Mountains. Western Peak, highest peak at the range front, is 9,061 feet; Roberts Creek Mountain in the background is 10,193 feet. To the west, the range is connected with the adjacent Simpson Park Mountains at Tonkin Summit.

The Roberts Mountains are essentially an eastward-tilted block composed of western assemblage rocks with a belt of windows of eastern assemblage rocks throughout the central part which are overlapped on the east by Tertiary volcanic rocks. Geology in the Simpson Park Mountains is generally similar to that of the Roberts Mountains. These ranges have been intensely explored for gold by many companies over the years since the discovery of the Carlin gold deposits in 1962. The area lies centered along the "Eureka-Battle Mountain Mineral Belt" described by R. J. Roberts (1964). The Cortez district lies just to the northwest of the Roberts Mountains, and a new discovery, the Tonkin Springs deposit of Shield Resources, Inc., lies just west of Tonkin Summit. Other valuable resources also compete for consideration in this area, however, and a large part of the high peaks of the Roberts Mountains are scheduled for wilderness designation.

The Roberts Mountains are the type locality of the Roberts Mountains thrust fault. Work here by Merriam and Anderson (1942) identified the thrust fault that juxtaposed the shale-chert facies (western assemblage) with the carbonate-quartzite facies (eastern assemblage).

76.7 Alpha, an old station on the Eureka and Palisade Railroad. This was an important station during the railroad construction in 1874. Work stopped here for the winter and a town quickly sprang up. The local stage-line owner, sensing business, tried to stall railroad construction so he could monopolize the heavy traffic into Eureka. He failed, the railroad was completed to Eureka in 1875, and Alpha soon died (Paher, 1970).

The highway now climbs toward Garden Pass; Mount Hope is directly ahead.

86.7 Henderson Summit road.

88.7 Garden Pass.

91.7 Road to right leads to the mining area on the southeast side of Mount Hope. Mount Hope is composed of a composite plug of rhyolite porphyry that has intruded chert and shale of the Ordovician Vinini Formation, conglomerate and limestone of the Permian Garden Valley Formation, and cogenetic ignimbrite. The Mount Hope mining district is located on the southeast side of the mountain. Activity in the district dates to 1870 when lead-zinc mineralization was discovered in skarns formed along the southern contact zone of the intrusive plug. Total production, most of which was between 1941 and 1947, from replacement bodies in the skarn is reported at $1,335,393 (Roberts, Montgomery, and Lehner, 1967).

In 1978, Exxon Minerals Co. acquired claims in the area and began an exploration program for molybdenum. In 1981, Exxon announced the discovery of over 450 million tons of ore with grades ranging from 0.13 to 0.32 percent MoS_2. Exxon still holds the property, but at present there is no activity here.

92.8 Tyrone Gap in the Sulphur Spring Range was eroded from conglomerate and sandstone of the Permian Garden Valley Formation. Diamond Valley is directly ahead. The Diamond Valley farm area extends from here down the valley. Agricultural development began in 1962, utilizing well water for irrigation. The Diamond Mountains form the skyline on the east side of the valley.

93.8 Ridge to the right (southwest) is steeply dipping Permian Garden Valley Formation.

94.7 Whistler Mountain, in the background to the right, is composed of Jurassic granite.

99.7 Sadler Brown turnoff. Low hills on the right side of highway are composed of Ordovician Eureka Quartzite.

104.7 End, State Route 278, turn left (east) on U.S. Highway 50 toward Eureka. Ahead to the south, on the north slopes of the Fish Creek Mountains, are the large headframe and buildings of Ruby Hill, the center of the Eureka mining district. The buildings are at the Fad shaft, sunk during

DIAMOND VALLEY
ALKALI FLAT
ALKALI FLAT
DIAMOND VALLEY
GARDEN VALLEY
SUTRO RANGE
SOURKRAUT RANGE
WESTERN PEAK
SOURKRAUT CREEK MTN
Garden Pass
Henderson Summit
MT HOPE
Mount Hope Mine
Bailey Pass
McCluskey Pass
Tonkin Summit
Meadow Canyon
Ranch
Corral
T 24 N
T 23 N
T 21½ N
R 53 E
5767
5833
5882
5888
5890
5988
9294
6000
6500
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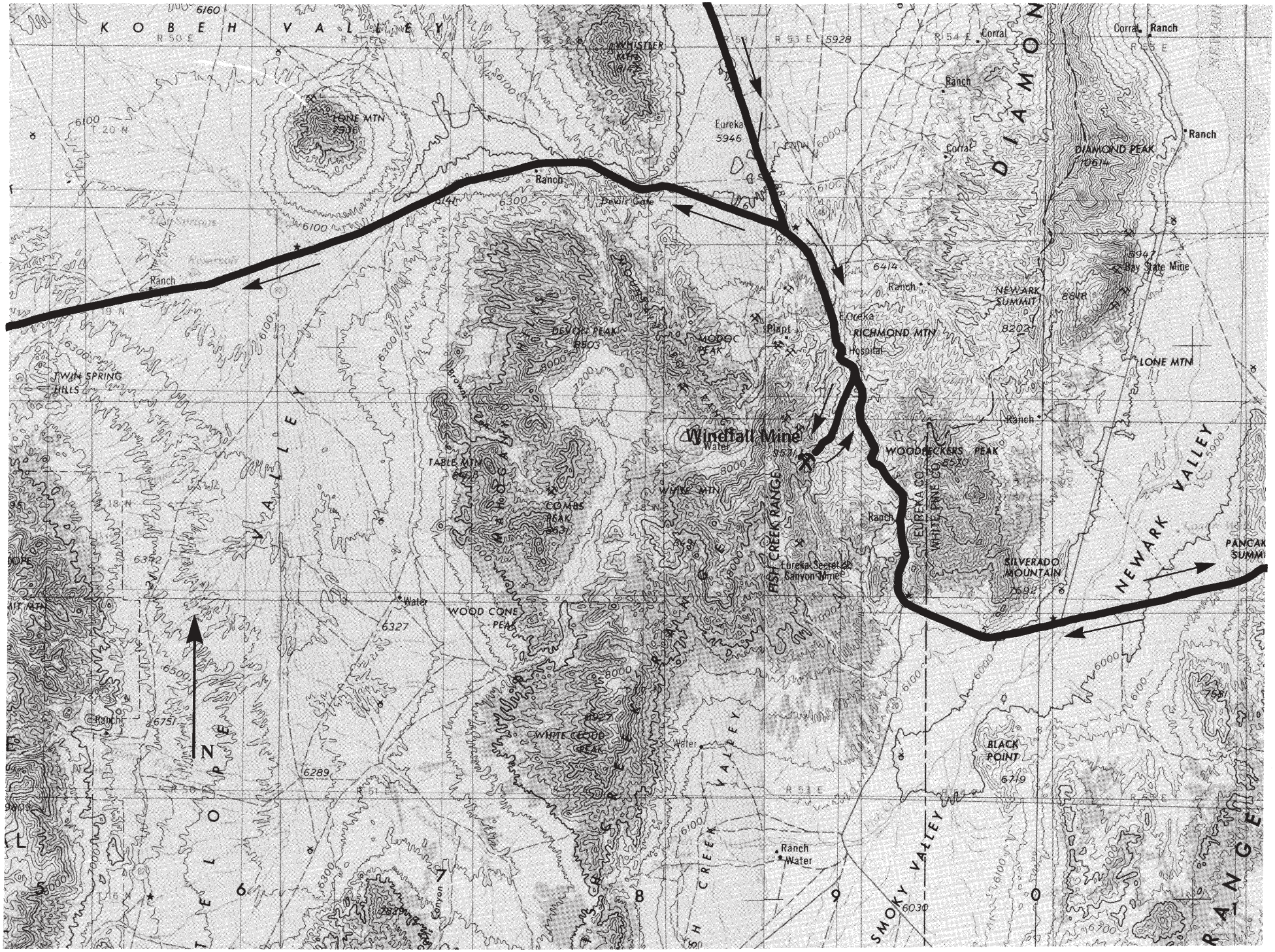

KOBEH VALLEY
LONE MTN
WHISTLER KEYS
Eureka
5946
Ranch
Corral
Devils Gate
DIAMOND PEAK
10614
Bay State Mine
NEWARK SUMMIT
8202
RICHMOND MTN
Eureka
Hospital
Plant
MODOC PEAK
DEVORL PEAK
8503
TWIN SPRING HILLS
Windfall Mine
Water
TABLE MTN
COMBS PEAK
WHITE MTN
POST CREEK RANGE
Eureka Secret Canyon Mine
WOODPECKERS PEAK
EUREKA CO
WHITE PINE CO
SILVERADO MOUNTAIN
NEWARK VALLEY
PANCAKE SUMMIT
WOOD CONE PEAK
WHITE CONE PEAK
BLACK POINT
6719
SMOKY VALLEY
N

Fad shaft, Ruby Hill, Eureka district, Nevada.

1945–49 to 2,500 feet. The town of Eureka is ahead to the left, in the canyon to the east of the mines.

Mining activity at Eureka dates to September 1864 when oxidized gold-silver-lead ores were discovered. It was not until 1869, however, that a successful smelting method was developed to treat the iron-rich ores. Following development of the first successful blast furnace, 16 small smelters were installed, and the resultant smoke and fumes earned Eureka the title of "Pittsburgh of the West" (Love, 1966). Most of the production of the district was between 1871 and 1888, and during this period it is said that the Eureka district controlled the lead markets of the world. Total production from the mines on Ruby Hill to 1966 has been approximately 2,722,000 tons of ore with an estimated value of $122 million (Love, 1966).

Beginning in about 1919 and continuing until the late 1960's, several attempts have been made to develop and exploit a large body of sulfide ore contained in a downdropped block of ground to the north of the large oxide ore bodies mined during 1871–88. Excessive flows of water have stopped work on this project every time it has been attempted. On completion of a drill program in 1960, announced ore reserves in the faulted ore block were 2.5 million tons assaying 0.216 ounces of gold and 8.85 ounces of silver per ton, 6.45 percent lead, and 11.45 percent zinc (Love, 1966). The ore bodies at Eureka are replacement deposits in limestone and dolomite of Cambrian age. In the Ruby Hill area, almost all of the ore bodies occur in brecciated Eldorado Dolomite. In the Adams Hill area, ores occur in rocks of the Hamburg Dolomite, Windfall Formation, and Pogonip Group.

Of historical interest, the West's first apex case was fought in Eureka during 1877–81 over rights to a bonanza ore body known as Potts Chamber. This case, forerunner of many similar suits in other western mining districts, was carried all the way to the U.S. Supreme Court (Paher, 1970).

107.7 Entering town of Eureka, county seat of Eureka County. The slag on the left of the highway on the lower end of town is speiss (arsenical slag) from the 1870 vintage smelting operations. Eureka was the southern terminus of the Eureka and Palisade Railroad and the center of wagon and stage transportation for most mining camps in eastern Nevada. In 1878, the town boasted 9,000 residents and was Nevada's second largest city (Paher, 1970).

ROAD LOG

along U.S. Highway 50 and Windfall Canyon road to Windfall Mine

by W. Brent Wilson

Cumulative Mileage

108.7 Eureka County Courthouse. Proceed east on U.S. Highway 50 (towards Ely).

109.0 Slag dumps from early smelters.

109.4 Craggy outcrops of Hanson Creek Formation (Ordovician) on right side, behind the ball diamond. The Eureka Quartzite (also Ordovician) caps the ridge above the Hanson Creek Formation.

Windfall pit, Eureka district, Nevada.

The Newark Canyon Formation (Early Cretaceous), comprised of limestone, conglomerate, and sandstone, crops out on the left side of the highway.

109.5 Road on right side leads to New York Canyon and the Diamond Mine. Approximately ½ mile south along this road lies the Seventy-Six Mine, site of the original discovery in the Eureka mining district. This mine was not a great producer but stimulated interest in the district that facilitated the discovery of the large ore bodies. The production at the Seventy-Six Mine came from deposits in fractured dolomite of the Hanson Creek Formation.

109.7 Old county hospital on left side. Rocks are the Permian Carbon Ridge Formation, predominantly carbonaceous sandstone and shale.

110.7 Road junction, U.S. Highway 50 and Windfall Canyon road. Carbon Ridge and Newark Canyon Formations crop out on the right; Mississippian Diamond Peak Formation on the left. The exposed ledge by the highway is a conglomerate unit of the Diamond Peak Formation.

Turn right and follow Windfall Canyon road to the south.

0.7 Craggy outcrops of Diamond Peak Formation cap ridge on the left side. Newark Canyon Formation on the right.

1.2 Conical Hill to the left is comprised of Upper Mississippian Chainman Shale on the north slope and Carbon Ridge Formation on the top of the hill.

1.7 The Ratto Spring Rhyodacite (Oligocene) occurs on both sides of the road, although the exposures are poor in this area. This unit occurs extrusively and intrusively; rocks in this vicinity are extrusive. In the Windfall Mine area, the Ratto Spring Rhyodacite has intruded as dikes. Straight ahead on the skyline Eureka Quartzite caps Hoosac Mountain. To the right of the quartzite are mine dumps of the Rustler pit, one of the currently active pits at Windfall.

2.3 Windfall Mine mill area. Bold outcrops of Eureka Quartzite(?) exposed on right side of road, and up the slope of Hoosac Mountain to the left.

Following tour, group will retrace route back to U.S. Highway 50.

NOTE: The road log between this point and the Alligator Ridge road, and from that point to Ely will be very brief. For a more detailed log, refer to Day Four, Ely to Eureka.

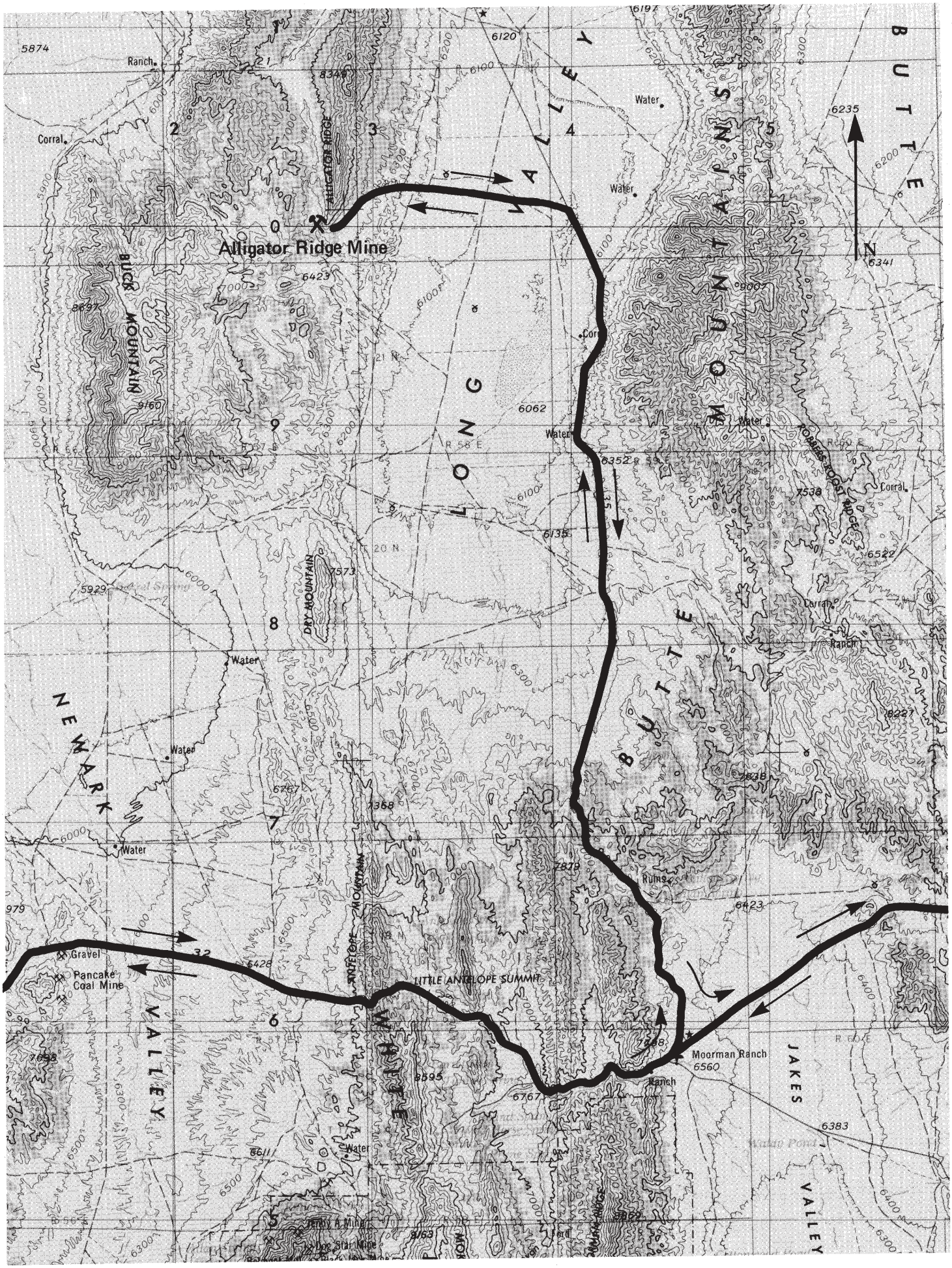
113.1 Pinto Summit (elevation 7,376 feet).

118.3 Road to Fish Creek and Currant, White Pine County.

118.6 Paved road to the left leads up Newark Valley. The large, dark dump at the foot of the hills on the west side of the Newark Valley road is in the Pinto mining district.

The Pancake Range can be seen south of the main highway, ahead to the right.

130.5 Pancake Summit (elevation 6,517 feet). About 1 mile south of Pancake Summit, a small coal deposit was discovered sometime prior to 1875. Some coal was mined and shipped to Eureka for use in the lead smelters. The coal is probably of


Alligator Ridge Mine
ALLIGATOR RIDGE
BUCK MOUNTAIN
DRY MOUNTAIN
LONG VALLEY
BUTTE MOUNTAINS
BUTTE
NEWARK VALLEY
JAKES VALLEY
LITTLE ANTELOPE SUMMIT
Moorman Ranch
Pancake Coal Mine
Ranch
Corral
Water
Ruins
Gravel
N

View of heap leach operation, Windfall Mine, Eureka district, Nevada.

Mississippian age. No recent attempts have been made to mine the deposit.

132.5 Newark Valley. To the southeast, on the right side of the highway, the highest portion of the White Pine Range can be seen. Mount Hamilton (elevation 10,742 feet) stands to the west of the north-trending spine of the range; Treasure Hill (elevation 9,378 feet) is to the east on the ridge. The White Pine mining district takes in all of this area around both peaks; the mining town of Hamilton was located at the foot of Treasure Hill.

143.3 Antelope Summit (elevation 7,433 feet), crossing the White Pine Range.

148.5 Dirt road leading to ghost town of Hamilton to the right.

154.1 Road to Alligator Ridge Mine (and Ruby Marshes) leads to north from U.S. Highway 50. Turn left onto road to mine.

160.7 Summit; road crosses the southern part of the Butte Mountains.

164.6 Entering Long Valley. Buck Mountain is to the northwest across the valley; Alligator Ridge is the narrow, north-trending ridge on the northeast side of Buck Mountain.

183.5 Turn left to Alligator Ridge Mine road. Road continues north to the Ruby Marshes, a fishing area on the southeast side of the Ruby Mountains.

The Alligator Ridge Mine is located on the southern end of Alligator Ridge. The Alligator Ridge Mine is usually included within the old Bald Mountain mining district, which lies about 12 miles to the northwest. No historic mining activity is recorded for the area of the new mine, however, and it rates as a new discovery in a new area. The Vantage disseminated gold deposits (Alligator Ridge Mine) were discovered on June 23, 1976, by a professional prospector working on a grubstake agreement with Amselco. Outcrops of jasperoid were recognized and sampled, and most of the original samples assayed 0.1 to 1 ppm gold.

192.4 Alligator Ridge Mine, tour of deposit by mine staff. Following the mine tour, we will retrace our route to U.S. Highway 50, then travel to Ely for the night.

232.1 Junction, U.S. Highway 50, turn left and proceed to Ely.

DAY FOUR: Ely, Taylor Mine, return to Reno via Ely, Eureka, Austin, and Fallon

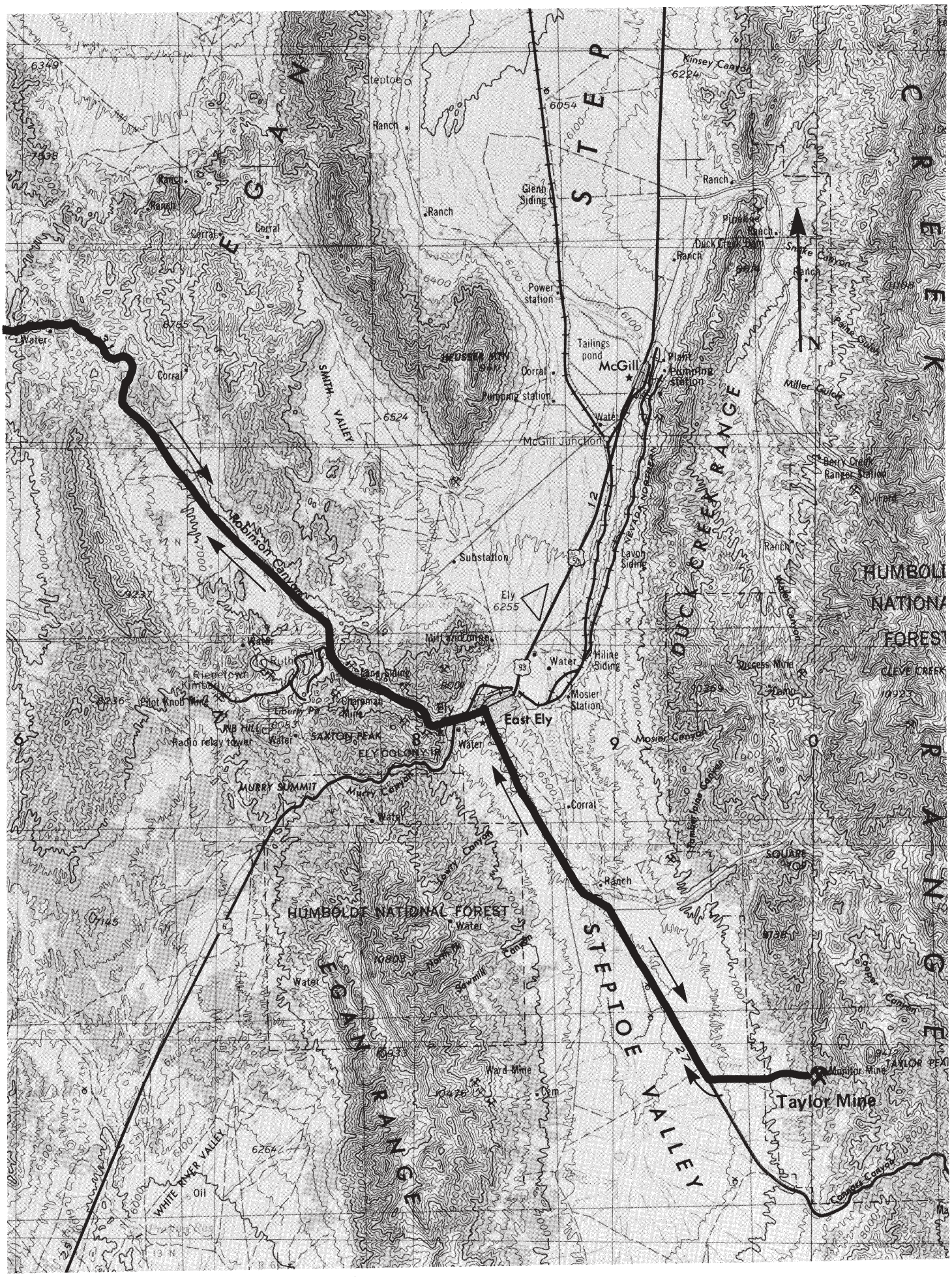
Ely–Taylor Mine–Ely trip segment

Cumulative Mileage

0.0 Leave downtown Ely, travel east on Aultman Avenue, U.S. Highway 50.

1.0 Intersection of U.S. Highway 50 with U.S. Highway 93, turn right (south) onto combined U.S. Highway 50-93 toward Pioche. We will be traveling south down Steptoe Valley. The Egan Range is directly south of Ely to the right; the Schell Creek Range is to the east on the east side of Steptoe Valley.

1.8 U.S. Highway 6 to Tonopah, Egan Range on right, Schell Creek Range on left.


Steptoe
Ranch
Corral
Water
Glenn Siding
Power station
Tailings pond
McGill
Plant
Pumping station
McGill Junction
Substation
Ely
East Ely
Mill and Cone
Hiline Siding
Mosier Station
Lavoy Siding
Success Mine
Berry Creek Ranger Station
Kinsey Canyon
Duck Creek Ranch
Smoke Canyon
Miller Gulch
Robinson Canyon
Friepetown
Kimberly
Pilot Knob Mine
Liberty Pit
Greenman Mine
WB HILL
SAXTON PEAK
Radio relay tower
ELY COLONY PK
MURRY SUMMIT
Murry Canyon
Lavoy Canyon
HUMBOLDT NATIONAL FOREST
Sawmill Canyon
Ward Mine
Cem
Mosier Canyon
Square Top
Monitor Mine
TAYLOR PEAK
Taylor Mine
Copper Canyon
Cherry Creek
WHITE RIVER VALLEY
Oil
STEPTOE VALLEY
DUCK CREEK RANGE
EGAN RANGE
SMITH VALLEY
NEVADA NORTHERN
HUMBOLDT NATIONAL FOREST
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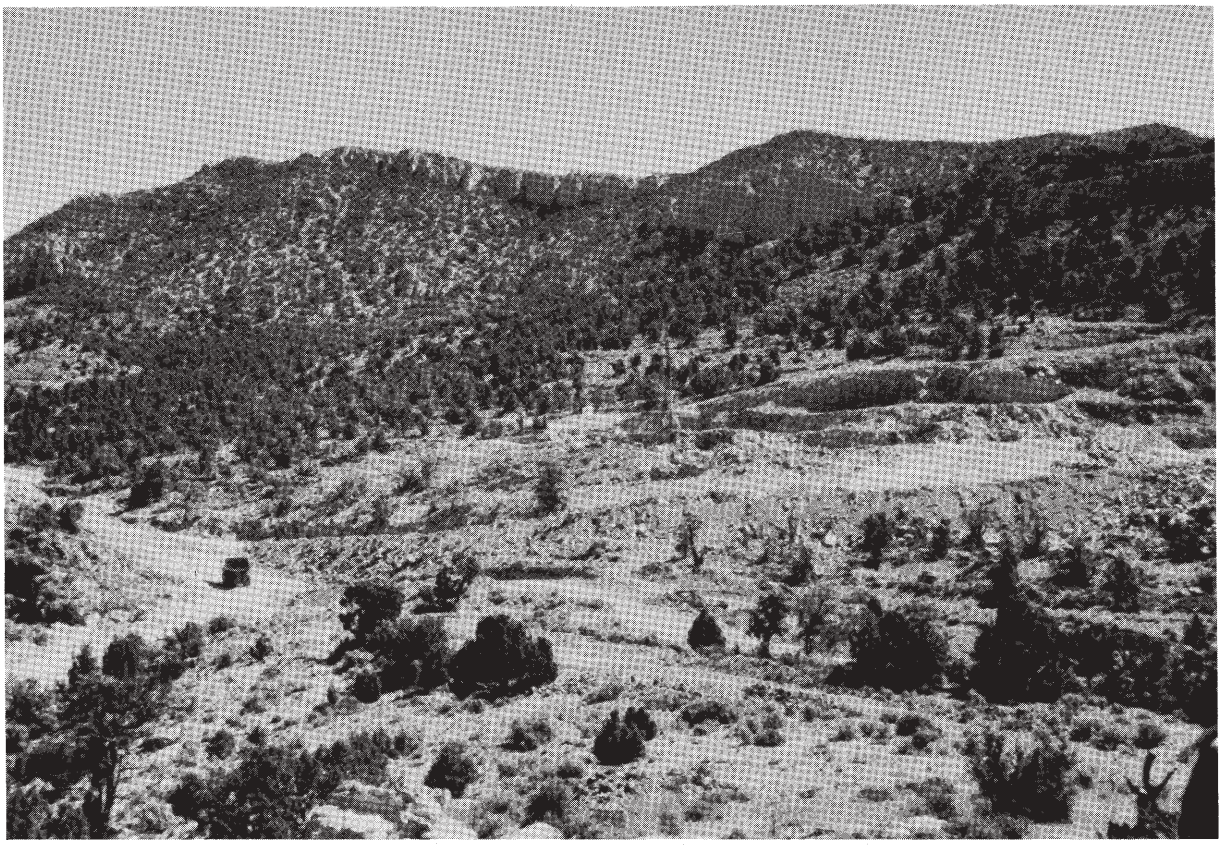


View of Argus pit, Taylor Mine, Schell Creek Range, Nevada.

6.5 Right, road to Ward Charcoal Ovens State Monument. The monument protects six beehive charcoal ovens built in 1876 to furnish fuel for furnaces at the mines. Road is also access to Ward Mountain.

7.7 Comins Lake. The old Argus and Monitor stamp mill sites are on the east shore of this lake, just southwest of the highway. These mills were built in the early 1880's to treat silver ores from both the Taylor and Ward districts.

8.6 To the left, road to Success Summit.

To the northeast is the southern end of the Duck Creek Range (western part of the Schell Creek Range), a complexly faulted area of Cambrian to Mississippian rock units.

Due east in the foreground are light-colored limestone units of the Devonian Guilmette Formation. The thin, resistant unit between tree lines and capping the ridge is Mississippian Joana Limestone.

14.0 Road to Ward Mountain and charcoal ovens. Drill roads at the Ward mining district can be seen in Egan Range to the west. The Ward district occupies the entire width of the range here, but most of the development is on the northern slope of Ward Gulch. The district was organized in 1872 with the discovery of rich lead-silver veins and replacement pods along fissures and intrusive dikes that cut east-dipping Paleozoic rocks. Deep drilling has revealed that the Paleozoic section here is intruded at depth (approximately 2,000 feet below the surface) by a 35-m.y.-old quartz monzonite stock. The stock intrudes up to the Guilmette Formation, but vertical feeder dikes extend up through the Ely Limestone and are exposed at the surface of the main workings. Massive sphalerite and chalcopyrite ores occur in tactite and marble horizons of the Guilmette and Joana directly above the main igneous body. Less intense mineralization occurs in the dikes which are often propylitically altered and contain galena in addition to copper and zinc sulfides. The main porphyry body is relatively unmineralized.

15.2 At 3:00, across the valley at the base of Egan Range, craggy, domelike features are Tertiary volcanic rocks; small beehives at the base of hill are coke ovens. The soft, treeless slopes of the Egan Range are composed of Pennsylvanian–Permian carbonate rocks. The treed benches at the base of the range are underlain by Tertiary volcanic rocks.

At 9:00, looking into the Schell Creek Range. The cream-colored resistant unit is the Ordovician Eureka Quartzite overlying the Ordovician Pogonip Limestone.

15.5 Taylor Mine road, turn left (east) onto gravel access road. Basal half of the Schell Creek Range consists of Devonian carbonate rocks; the break in slope is underlain by Mississippian sand and shale (Chainman Shale); top part is composed of Pennsylvanian Ely Limestone.

The diagonal valley coming in from the north conceals a fault. The Mississippian Joana Limestone, which dips southeast, is the highest unit of the northwestern block.

The Taylor mining district is directly ahead, on the western slopes of the Schell Creek Range. The district was discovered in 1873, and some

Taylor mill, Schell Creek Range, Nevada.

60,000 tons of ore averaging 20 ounces of silver per ton was produced from the Argus and Monitor Mines during the following 20 years. Silver King Mines, the present operator, began work in the district in 1962 with the intent of developing deep ore beneath the old mine workings. Although no deep high-grade ore was developed, a significant amount of low-grade, near-surface material was found. When silver prices began to rise, this material became of interest and further work was done on the deposit. In 1980, Silver King announced a reserve of 10 million tons of 3-ounces-per-ton silver ore, and mining began in 1981.

18.5 Taylor Mine, tour of mine led by mine staff.

Following the mine tour, group will retrace route to Ely, then travel west on U.S. Highway 50 to Reno.

22.0 Intersection, U.S. Highway 50, turn right and return to Ely.

37.0 Ely, to the north about 12 miles. The stack of Kennecott's McGill smelter can be seen on the east side of Steptoe Valley. Copper ores were shipped by rail from the mines west of Ely to McGill for concentration and smelting. The copper mines have been idle for several years, although the smelter has operated intermittently on concentrates from other properties.

Turn left on U.S. Highway 50, pass through downtown Ely, and proceed to Eureka, retracing the Day Three route.

Ely–Reno trip segment

0.0 Downtown Ely.

0.3 Entering Robinson Canyon. The Robinson mining district lies west of Ely.

The Robinson district was organized on March 16, 1868. Early mining centered on small deposits of precious metals in the district. Most of the early prospecting was done in the metamorphosed sedimentary rocks on the periphery of the altered porphyry bodies. However, less than $1 million in metals was produced from the peripheral deposits prior to large-scale copper mining in the mineralized porphyry. The district first attracted attention as a possible large copper-producer in 1902 following the discovery of a large tonnage of 2- to 4-percent copper ore on the Ruth group of claims. Nevada Consolidated Copper Co. was incorporated in 1904, and the first production from the open-pit porphyry copper deposit at Ruth was recorded in 1908 (Hose, Blake, and Smith, 1976).

Production from 1908 through 1963 was 255 million tons of ore averaging a little more than 1 percent copper, with a total metal value of nearly $1 billion.

The ore has been produced mainly from six major disseminated-type deposits; the Liberty Pit deposit accounts for 70 percent of the total district production. Less than 1 million tons of base metal and gold ores have been produced from replacement-type deposits in the district. Sulfide ore has accounted for virtually the entire district production. Secondary chalcocite enrichment made up the higher grade ores mined during the district's early history, but primary chalcopyrite with subordinate bornite were the principal ore

minerals for many years. Oxidized copper ores were mined as direct smelting ore and as flux for use in the smelter. About 20 percent of the district production has come from underground mining operations and the remainder from large open pits.

The copper deposits in the Robinson mining district occur in a marked, east-trending zone defined by outcrops of bleached limestone, jasperoid, leached porphyry, and limonitic staining. Most of the copper ore occurs in the altered porphyry, although about 20 percent of the total production has been derived from the metamorphosed sedimentary rocks adjacent to the porphyry bodies.

There are three types of copper ore: enriched disseminated ore, primary disseminated ore, and replacement ore. Supergene-enriched ore has been important in all the disseminated-type ore bodies, where it often attains a thickness of 300 feet. Overall grade of enriched ore bodies ranges from 1 to 2½ percent copper. High-grade ore containing 4 to 5 percent copper is common in parts of some of the enriched ore bodies. Primary disseminated chalcopyrite ore occurs in altered porphyry and in adjacent silicated sediments. The primary ore in the porphyry ranges from a cutoff grade of 0.4 percent copper to 2 percent copper, and large parts of porphyry ore bodies average more than 1 percent copper. Several small replacement-type ore deposits occur in the outer parts of the zone of alteration. They have yielded a few thousand tons each of copper, gold, lead, silver, and zinc, and minor amounts of manganese. There are many small replacement-type occurrences of these metals distributed erratically around the entire district, forming a rough pattern around the zone of disseminated copper deposits.

0.6 Middle and Upper Devonian Guilmette Formation in canyon walls. Upper Devonian Pilot Shale and Lower Mississippian Joana Limestone on left overlying Guilmette. On right, numerous faults east of railroad tunnel displace Guilmette and possibly some older Paleozoic carbonate rocks.

0.9 Crossing bridge over railroad; Guilmette Formation on both sides of highway.

1.3 Entering structurally complex area involving faulted and altered Guilmette Formation, Pilot Shale, Joana Limestone, and Upper Mississippian Chainman Shale. Tailings of Ruth pit at 11:00.

2.2 Chainman and Joana Mines on left in altered Chainman Shale and Joana Limestone produced modest amounts of gold and silver from siliceous gossans and veins in limestone near shale contacts. The Chainman and Joana formations were named after these mines.

Lane Valley is located near the eastern end of the east-west axis of mineralization that defines the Robinson mining district (Wilson, 1978). At 9:00, unaltered Pennsylvanian Ely Limestone forms cliffs on skyline.

2.8 Ghost town of Lane City (Mineral City) on right in Lane Valley was a major gold and silver camp in the late 1800's.

3.0 To the left, area where copper ore from the Ruth pit was blended and loaded into rail cars to be hauled 25 miles to McGill for milling and smelting. To the right, Ely Limestone faulted against Chainman Shale.

3.8 Entering canyon with Ely Limestone on both sides of road.

5.2 Keystone Junction. State Route 44 leads to Kennecott copper mines near Ruth. Prominent hill east of junction composed of Tertiary rhyolitic intrusive body which contains vesicles lined with quartz and semi-gem-quality garnets.

Red headframe to south marks the Deep Ruth shaft which was sunk to develop and mine the Deep Ruth ore body. The underground project was abandoned and much of the ore was later mined from the Ruth pit.

5.7 On both sides of highway, brown, altered Permian Arcturus Formation.

6.9 Roadcut in Chainman Shale. Low ridge at 9:00 composed of Joana Limestone.

7.1 Radar Ridge from about 9:00 to 12:00 consists of marine Pennsylvanian and Permian strata in the west limb of a westward-overturned anticline that trends north–northwest.

8.0 Low ridge at 9:00 to 10:00 composed of Joana Limestone.

9.4 Entering Copper Flat.

10.4 Hills at 2:00 to 4:00 composed of Pennsylvanian Ely Limestone and Permian Riepe Spring Limestone, Rib Hill Sandstone, and Arcturus Formation.

12.3 BLM Copper Flat-Gleason Creek seeding area. Crested wheat grass experimental seeding along highway on left side extending up to Radar Ridge.

13.3 High hills at 1:00 to 2:00 are Oligocene felsic volcanic rocks.

14.9 At 1:00 near highway, outcrops are yellowish-gray Arcturus Formation.

15.2 Begin ascent to Robinson Summit on crest of Egan Range. The late Mesozoic–early Cenozoic Ely-Black Rock lineament (left-slip fault zone with about 10 miles of displacement) trends northwest across east-central Nevada, passing just north of Ely and through Robinson Summit (Howard, 1976; Thorman and Ketner, 1979).

15.9 Dark-colored Tertiary volcanic rocks at 12:00 in high hills; yellowish-gray Arcturus Formation in roadcuts.

17.9 Area of Oligocene felsic volcanic rocks.

18.0 Robinson Summit (elevation 7,607 feet). Roadcut in Oligocene felsic lavas, flow breccias, and volcaniclastic rocks.

19.8 Oligocene volcanic rocks on both sides of highway.

20.6 Thirty Mile road. Oligocene volcanic rocks on both sides of highway.

23.7 Hill directly ahead at 12:00 composed of Oligocene volcanic rocks unconformably overlying Permian Park City Formation.

24.7 Grayish-yellow outcrops at 1:00 at base of hill are altered carbonate rocks of the Park City Formation. Hill at 10:00 composed of Oligocene volcanic rocks overlying Eocene Sheep Pass-like lacustrine deposits.

Ghost town of Treasure Hill, White Pine district, Nevada.

25.0 Entering Jakes Valley. White Pine Range visible from 10:00 to 2:00 is mostly Paleozoic carbonate rocks.

27.1 Wooded, low hills at 3:00 are composed of Oligocene volcanic rocks unconformably overlying Pennsylvanian carbonate rocks with karst surface.

28.1 Low hills at 12:00 to 2:30 consist of limestone of the Permian Pequop Formation.

32.5 Road on right to Alligator Ridge Mine and Ruby Marshes.

32.8 East-dipping Pequop Formation exposed along range front north and south of highway is on east limb of Illipah anticline that trends north.

34.0 Moorman Ranch on left. Upper Paleozoic strata become progressively older through canyon.

34.9 Pequop Formation on both sides of highway.

36.5 Abandoned homestead on right. Exposures of Arcturus Formation on both sides of highway.

37.0 Lower Permian Riepe Spring Limestone along highway.

37.1 On right side of highway is Riepe Spring-Ely Limestone contact. The Ely Limestone is composed of medium- to thick-bedded limestone with lenticular and nodular chert layers.

38.1 Dirt road to left (west) leads to Hamilton located at the foot of Treasure Hill, White Pine mining district. Historical marker on right is near fault contact between Ely Limestone and Chainman Shale.

Rich silver ore at Treasure Hill was discovered in 1868. The discovery resulted in an influx of more than 10,000 people into this area in 1868. Hamilton was the county seat of White Pine County until a disastrous fire in 1885. Within 10 years, the silver ore was nearly mined out, and the population steadily decreased. The Hamilton (White Pine) district produced $30 million in silver, lead, and minor zinc, copper and gold. Most of the silver was mined from spectacular bonanza bodies of cerargyrite near the top of Treasure Hill in the Middle and Upper Devonian Guilmette Formation just below the Upper Devonian Pilot Shale. Most of the lead came from irregular replacement bodies in Paleozoic dolomitized limestone adjacent to faults concentrated in a belt west of Treasure Hill. Small copper deposits occur near Cretaceous stocks west of the lead belt. (Humphrey, 1960).

Recent work in the White Pine district has been confined to small-scale open-pit operations (mainly of old dump material) on Treasure Hill. Some activity has also taken place in the western part of the district, around the Seligman and Monte Cristo stocks, where several companies have conducted exploration for copper, molybdenum, and tungsten deposits in deep skarn zones.

At the major property, Phillips Petroleum has reportedly drilled out an estimated 5.5 million tons of material averaging 0.3 percent WO_3 and 0.2 percent MoS_2 (Forest, 1982).

38.6 Tertiary limestone forms low rounded hill at 3:00 and extends along right side of highway for 0.5 miles. Ely Limestone at 3:00 on skyline.

39.6 Illipah Sandstone Member of Chainman Shale forms ridge on right side of highway. Bed dips northeast on east limb of Illipah anticline.

40.3 Reddish-brown exposures at 11:30 to 12:30 are jasperized upper part of the Joana Limestone.

Gray Joana Limestone caps ridge on skyline at 12:00.

40.9 Steeply dipping silicified Joana Limestone ridge on right.

41.5 West-dipping Chainman Shale on right in west limb of Illipah anticline.

42.9 Barren spot at 3:30 at base of ridge is the well site for the Tenneco Oil Co. No. 1 Illipah drilled in 1967. The well spudded in the basal part of the Chainman Shale and bottomed in the Eureka Quartzite at 7,620 feet. A normal stratigraphic section was penetrated below the Pilot Shale. Poor petroleum shows were reported in cores of Guilmette Formation, in an interval of lost circulation.

43.4 Antelope Summit (elevation 7,433 feet).

43.9 Ely Limestone in roadcuts dips west in west limb of Illipah anticline.

44.9 Roadcuts in Ely Limestone. Beds dip east in one of several north-trending anticlines and synclines involving Ely Limestone and Chainman Shale on west side of the White Pine Range.

46.3 Crossing east-dipping Ely Limestone and Chainman Shale on east limb of anticline. East-dipping Chainman-Ely contact in roadcut on right.

47.7 Entering Newark Valley. Crossing north-trending Emigrant anticline. One mile north of highway is the site of the Suntide-Sinclair No. 1 Nevada-Federal "A" well drilled in 1964. Total depth was reached at 7,980 feet in the Eureka Quartzite. Shows of oil were encountered in the Joana Limestone, Guilmette Formation, Devonian Simonson Dolomite, and Silurian Laketown Dolomite; a good gas show was recorded in the Guilmette.

The Belmont mill processed lead ores from the mineralized belt west of Treasure Hill.

48.5 Varicolored Tertiary sedimentary rocks in roadcut on right. Note discordant contact between Tertiary units.

49.6 Prominent range on skyline at 12:00 to 1:30 is the Diamond Mountains. Buck Mountain at 1:30 to 2:30 is underlain by Mississippian, Pennsylvanian, and Permian rocks that are folded into a north-plunging syncline.

50.9 The Pancake Range at 10:00 to 1:00 is composed of Mississippian, Pennsylvanian, and Permian rocks.

54.6 Road on right to Buck Mountain. Yellowish-gray ridges from 11:00 to 2:00 composed of Ely Limestone and equivalent strata. Low butte at 10:30 composed of undivided Chainman Shale and Diamond Peak Formation. Skyline ridge at 9:00 to 11:00 composed of Pennsylvanian and Permian rocks. Buck Mountain at 3:00.

55.7 Crossing Chainman Shale and Diamond Peak Formation on east side of Pancake Range.

56.6 Chainman Shale in roadcut on left. Tertiary silicic volcanic rocks cap Diamond Peak and Chainman strata at 3:00 to 3:30.

57.4 Pancake Summit (elevation 6,517 feet).

62.6 Newark Mountain at 3:00 composed of Devonian Nevada Formation carbonate rocks. Alhambra Hills in foreground at 1:30 to 2:30 composed of Devonian carbonate rocks.

64.6 Low hills at 9:00 composed of Chainman Shale, Diamond Peak Formation, and associated rocks.

65.0 Paved road on right up Newark Valley to Strawberry. Black Point at 9:30 to 10:00 composed of Oligocene Richmond Mountain Andesite. The Pinto (Silverado) mining district in saddle at 2:30 has produced a small amount of silver. Farther north on the east side of the Diamond Mountains, the Newark (Strawberry) mining district has produced more than $1 million in tungsten, silver, and minor lead, copper, zinc, and gold from veins and stockworks in the Newark Formation.

66.5 Nevada Formation on right at southern end of Diamond Mountains.

67.7 Devonian Devils Gate Limestone thrust over Devonian Nevada Formation at 3:00.

69.6 Enter Eureka County.

69.8 Road to Duckwater on left.

70.5 Pinto Canyon. Roadcut on right exposes high-angle fault juxtaposing Silurian dolomite and Oligocene tuff.

71.5 Oligocene volcanic rocks on left and Silurian dolomite on right.

71.7 Roadcut on right exposes Oligocene bedded tuffs.

74.9 Pinto Summit (elevation 7,376 feet). Roadcuts expose Oligocene bedded tuffs and upper Tertiary–lower Quaternary piedmont-gravel deposits.

76.7 Richmond Mountain at 12:00 is capped by the Oligocene Richmond Mountain Andesite. Roadcut on left exposes nonmarine Newark Canyon Formation of Cretaceous age.

77.6 Windfall Mine road.

78.5 Windfall Canyon at 8:00. Skyline ridge at 8:30 to 9:30 is Fish Creek Range composed of Cambrian and Ordovician rocks. Brown outcrop at 3:00 is conglomerate of Diamond Peak Formation.

78.8 Entering town of Eureka. The Eureka mining district lies south and west of town.

See log description of Eureka, Day Three.

79.9 Leaving town of Eureka. Paved road on right leads to Diamond Valley and Newark Canyon.

80.8 View northward into Diamond Valley. Diamond Peak at 3:00 in Diamond Mountains; Whistler Mountain at 11:00; Roberts Mountains at 11:30 in far distance.

83.0 Intersection, State Route 378 to Carlin, proceed to west on U.S. Highway 50.

83.8 Devils Gate Pass at 12:00. Ridge at 8:30 composed mainly of Cambrian rocks; Ruby Hill, located near northern end of ridge, is site of bonanza ores of the Eureka district.

84.8 Whistler Mountain at 1:30 and Mahogany Hill at 9:00 to 11:00. Lone Mountain at 11:30 on distant skyline.

85.9 Entering Devils Gate Canyon. At 9:00, dark-colored Ordovician Vinini Formation detached from Roberts Mountains allochthon overlying Mississippian Chainman Shale. Devils Gate Limestone (type locality), Pilot Shale, and Chain-

man Shale exposed on north side of canyon; two cliff-forming alaskite sills of Jurassic age occur in the Chainman Shale.

86.1 Vinini Formation overlying Mississippian Antler flysch at 9:00. Vertically jointed cliff at 3:00 is Jurassic alaskite sill in Chainman Shale. Roberts, Montgomery, and Lehner (1967) suggested that the toe of the upper plate of the Roberts Mountains thrust moved into the depositional base and overrode the orogenic clastic rocks.

86.2 Devils Gate Pass. Upper Devonian and Lower Mississippian rocks exposed on north side of canyon. Devils Gate Pass contains westernmost outcrops of Pilot Shale and Chainman Shale in this area. The Devonian and Mississippian rocks exposed here are just east of the leading edge of the Roberts Mountains allochthon.

94.5 Roberts Creek road to right (north) leads to the southern Roberts Mountains, the Roberts Creek area.

Lone Mountain is ahead, just to the north of the highway. Lone Mountain (elevation 7,932 feet) is underlain by Ordovician Pogonip Group, Eureka Quartzite (the type locality), and Hanson Creek Formation; Silurian Roberts Mountains Formation and Lone Mountain Dolomite; and Devonian Nevada Formation and Devils Gate Limestone. The small Lone Mountain mining district on the north side of the mountain produced a minor amount of high-grade zinc-lead-silver (zinc carbonate) ore in the 1950's.

Antelope Valley extends to the south. Ahead, but south of the highway, is the Monitor Range. Antelope Peak (elevation 10,220 feet) and Summit Mountain (elevation 10,476 feet) are at the north end of the range. The range here is made up of middle Tertiary welded and nonwelded silicic ash-flow tuffs locally lying on low-angle faults. Tuffs may define a caldera.

99.0 Antelope road on left (south).

104.0 Three Bar road on left (north).

112.3 Road on left leads to old Belmont silver camp located 66 miles to the south. Lincoln crested wheat grass seeding along highway.

111.3 Rest area, Lincoln crested wheat seeding.

116.2 Entering Lander County. About 35 miles south on the east side of Toquima Range is the East Northumberland Canyon bedded-barite district, a major barite source; just northwest of the barite district is the Northumberland gold mine.

122.8 Ackerman road to right (north). Also to the right, Simpson Park Mountains, which trend northeast and consist of siliceous (western) assemblage Ordovician rocks and Tertiary volcanic rocks.

124.1 Hickison petroglyph site, camp.

124.6 Hickison Summit. Tertiary air-fall tuff overlain by Tertiary welded ash-flow tuff; both units are faulted.

126.6 Tertiary volcanic rocks along highway.

131.7 Road to Linka Mine on left. Linka (Spencer Hot Springs) mining district in the low hills to south has produced more than $1 million in tungsten from a skarn deposit. Skarns developed in Ordovician Hanson Creek carbonate rocks near their contact with Cretaceous granodiorite.

134.7 Crossing north end of Big Smoky Valley. Mount Jefferson (elevation 11,949 feet), to the south in the Toquima Range sequence of middle Tertiary welded ash-flow tuffs, is a resurgently domed caldera. The Toiyabe Range is just ahead.

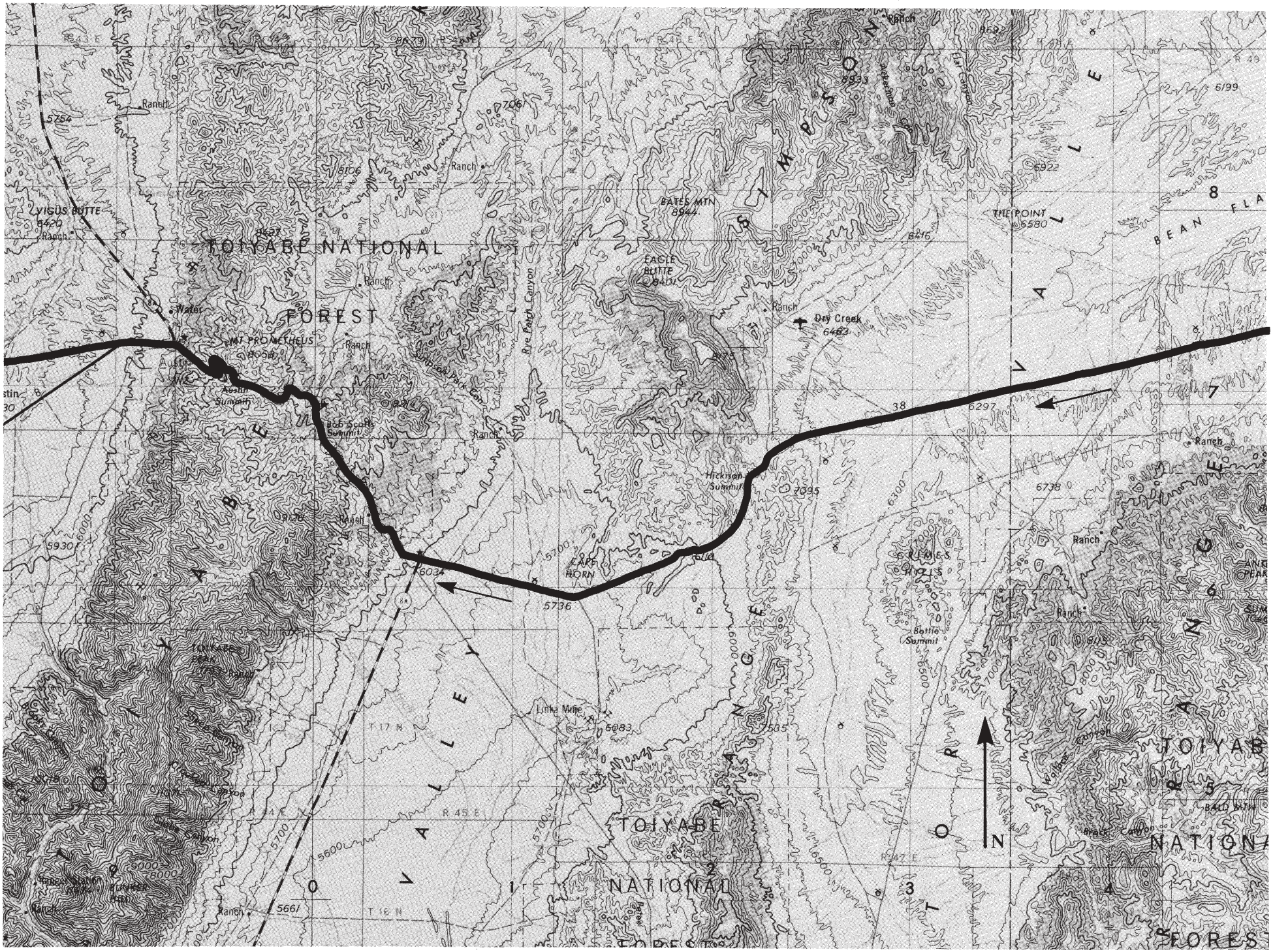
The portion of the Toiyabe Range immediately north and south of the highway is composed of a Jurassic granodiorite mass. To the south for several miles, the more rugged portion of the range is composed of a series of thrust sheets involving lower Paleozoic rocks. The Roberts Mountains thrust is exposed in Kingston Canyon, about 12 miles to the south.

Farther to the south, the highest portion of the range is composed of thick ash-flow tuffs which fill a caldera. The eastward bulge of the range is near the northern margin of the caldera. The area around the high peaks, including 11,775-foot Arc Dome, is being considered as a wilderness area.

136.6 State Route 376 (8A) to Round Mountain and Tonopah on left. Several mining districts lie to the south here in the Toiyabe and Toquima Ranges.

In the Toiyabe Range to the west, the Big Creek mining district has produced more than $1 million of antimony from stibnite-bearing quartz veins in deformed and silicified Paleozoic sedimentary rocks; the Twin River (Millett) mining district produced more than $1 million in gold, silver, tungsten, and minor lead and zinc. At Kingston Canyon, U.S. Energy Corp. and Crested Butte Silver Mining Co. are developing a mine at the old Victorine property. Announced (estimated) reserves are 1.5 million tons of ore containing 0.236 ounces of gold and 0.696 ounces of silver per ton. The mineralized zone at Victorine is associated with flat-lying fault zones which cut carbonaceous limestone of Early Cambrian age. Most of the Toiyabe Range is now being extensively explored for precious metals. The area of the caldera in the southern part of the range is receiving special attention.

In the Toquima Range to the east, mining districts include the Northumberland district, which produced $1 million in gold and minor silver from silicified carbonaceous shaly dolomite and limestone of Silurian and Devonian age, near a Jurassic granite stock (Kleinhampl, 1984, p. 157). Western States Minerals Corp. is presently operating an open-pit gold mine in the Northumberland district. The ore is hauled to heap-leach pads in nearby Big Smoky Valley. Fine-grained, disseminated gold ore is present in the vicinity of a thrust fault where it separates Silurian–Devonian Roberts Mountains and Ordovician Vinini Formations. High-grade gold ore is reportedly associated with jasperoid. The Northumberland and nearby East Northumberland Canyon barite districts have produced about 1.75 million tons of bedded barite, which is interlayered with chert and argillite of the Devonian Slaven Chert (K. Papke, oral commun., 1984). The Round Mountain district has produced $13 million in gold, in addition to minor mercury, silver, and tungsten (Kleinhampl, 1984, p. 174). Gold and silver occur in quartz- and iron-mineralized sheeted zones in Tertiary rhyolitic ash-flow tuffs and associated placers. The deposit in the rhyolitic tuffs has


TOIYABE NATIONAL
FOREST
TOIYABE
NATIONAL
FOREST
VIGUS BUTTE
MT PROMETHEUS
Austin
Austin Summit
Sunbeam Park
Rye Patch Canyon
BATES MTN
8944
EAGLE BUTTE
Dry Creek
6483
THE POINT
5580
BEAN FLA
Hickison Summit
CAPE HORN
GRIMES HILLS
Battle Summit
Linka Mine
TOIYABE PEAK
Ranch
Water
Pinyon Station
Ranch
5754
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5736
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N

Town of Austin, large dumps from mine workings in distance, Reese River district, Toiyabe Range, Nevada.

recently been reactivated. The Manhattan district has produced more than $10 million in gold and silver from sheeted zones in Lower Cambrian quartzite, along with minor antimony, arsenic, and mercury from veins and replacement deposits in Cambrian limestone (Kleinhampl, 1984, p. 141). Production from the Belmont district totaled $4 million in silver and minor gold from quartz veins in Ordovician limestone and shale near a Cretaceous granite stock (Kleinhampl, 1984, p. 56).

137.1 Frontier Station.

137.5 Argillite of Ordovician Valmy Formation in roadcuts, siliceous (western) assemblage rocks.

137.8 Jurassic stock exposed in roadcuts for next several miles.

141.5 Bob Scotts Campground.

141.6 Bob Scotts Summit (elevation 7,267 feet).

142.9 Grass Valley–Cortez road. The McGinness Hot Springs area is about 10 miles to the north. This fossil spring system has been recently explored as a bulk-minable gold prospect.

144.3 Tertiary welded ash-flow tuff overlying quartz monzonite.

145.3 Austin Summit (elevation 7,484 feet). Jurassic quartz monzonite along highway.

145.6 Note increase in alteration in stock.

146.0 Main part of Austin mining area. Note large dumps.

146.1 Austin, center of the Reese River mining district. Silver was discovered in 1862 at Austin, which quickly became a boomtown with a population of nearly 10,000. Rich ores were shortly mined out, however, and since 1886 only sporadic operations have taken place. Total production of silver and minor gold prior to 1886 has been reported variously at $20–65 million. Base metals were not recovered. Since 1886 about $1 million in silver and minor gold, copper, lead, and zinc has been produced. Somewhat less than $1 million of uranium has been produced from the southern part of the district (Apex or Rundberg Mines) in recent years (Stewart, McKee, and Stager, 1977).

Until recently, Austin was the county seat of Lander County. Battle Mountain, about 90 miles to the north in the northern part of the county, was successful (by election) in capturing the county seat away from Austin. One of Austin's remaining reasons for existence has now been removed, and the population has dwindled to a few hundred. Many historic buildings can be seen on both sides of main street, including the Gridley Store, old county courthouse, and the International Hotel. On the eastern edge of town, the blue buildings house Lombardi Turquoise Co., miner and producer of turquoise from mines to the north and to the west.

Jurassic quartz monzonite in the district has intruded Cambrian and Ordovician rocks, mostly impure quartzite, chert, and shale, and is locally overlain by Tertiary volcanic and sedimentary rocks.

The productive silver-bearing veins in the district fill distinct fractures, mostly in quartz monzonite, that strike north-northwest and dip moderately to the northeast. The veins contain, in addition to

quartz, rhodochrosite, and other carbonate minerals, argentite, arsenopyrite, chalcopyrite, enargite, galena, molybdenite, polybasite, proustite, pyrargyrite, pyrite, sericite, sphalerite, stephanite, stibnite, tetrahedrite, and xanthoconite. All of these minerals have been considered to be hypogene; acanthite, chalcocite, and covellite are reported as supergene minerals. Alteration of wall rocks adjacent to the veins resulted in the formation of calcite, chlorite, dolomite, pyrite and other sulfides, quartz, sericite, tourmaline, and rutile.

147.6 Quartz veins form a stockwork in quartz monzonite.

148.2 Intersection with State Route 305, continue on U.S. Highway 50 west. Stokes Castle to south, south of the mouth of Pony Canyon, was built in 1897 by a railroad executive for his family. Austin monument by highway on right commemorates the district's discovery site below the road. Aplite-veined Jurassic granite in roadcuts.

149.1 Road to Big Creek to left (south), access road to FMC's Quito or Dry Canyon gold property. FMC has reportedly drilled out a small area of gold mineralization (some 600,000 tons) near the old Dry Canyon (Antimony King) antimony property.

150.3 Junction with State Route 2 (the east end of the Carroll Summit road). Now entering Reese River Valley.

154.9 Crossing Reese River.

155.7 Pony Express Trail.

159.8 Tree-covered, rounded mountains at 10:00 are rhyolite domes on the northern margin of a major cauldron in the Shoshone Mountains.

161.4 Miocene ash-flow tuffs of the Edwards Creek Tuff and New Pass Tuff are exposed along the highway for several miles. Other extensive rhyolite and ash flows occur to the south.

164.7 Mount Airy Summit (elevation 6,679 feet), northern Shoshone Mountains. A stop on the Pony Express and Overland Mail routes, a station was maintained here from 1861 through 1869.

166.1 Smith Creek Valley.

170.4 New Pass road.

170.5 New Pass (elevation 6,483 feet), which separates the Desatoya Mountains and New Pass Range. The New Pass mining district is located to the northeast. Gold deposits consist of free gold, with minor amounts of silver occurring with lead and copper sulfides, carbonates, and oxides, in quartz veins along steeply dipping faults that cut a greenstone unit of the Havallah sequence. Most of the ore is oxidized, but some sulfide minerals are reported from the deeper workings. The Lombardi Turquoise Co., Austin, Nev., also operates a turquoise mine in this district.

170.9 Churchill County line.

172.2 Tertiary volcanic rocks, mainly rhyolitic air-fall tuffs, are exposed north and south of highway.

172.8 Ruins of Overland Mail Station on right. One of the stations known as New Pass Station, this one was used during the 1870's and later years (Paher, 1970).

172.9 New Pass Tuff exposed in roadcuts on both sides of highway.

174.6 Edwards Creek Valley ahead, Clan Alpine Mountains across the valley to the west. The Clan Alpine Mountains to the northeast and southwest are composed mainly of Tertiary volcanic rocks, but an exposure of Triassic sedimentary rocks intruded by Cretaceous granodiorite is present at Tungsten Mountain, directly ahead across the valley. Skarn occurrences near this contact zone have been mined for tungsten.

176.9 Outflow facies ash-flow tuffs can be seen in northern Desatoya Mountains at 8:00 to 11:00. To the west, at the mouth of Cherry Creek in the Clan Alpine Mountains, are the remains of the camp of Clan Alpine. Gold was discovered near here in 1869 and a small stamp mill was built. Cerargyrite, argentite, and gold occur in quartz veins and silicified zones in rhyodacite and quartz latite (Willden and Speed, 1974). Production was small. In later years, the Alpine mining district was expanded to include gold and tungsten occurrences to the northeast (Tungsten Mountain).

182.2 Caldera margin at 9:00. Note massive nature of intracaldera tuffs to south.

192.2 Alpine road to right.

195.6 Cold Springs gas station and highway maintenance station. The Desatoya Mountains are to the east and the Clan Alpine Mountains to the west. Both ranges consist of Tertiary volcanic rocks which overlie Mesozoic clastic sedimentary rocks and lesser amounts of upper Paleozoic siliceous and volcanic rocks. The Tertiary rocks are primarily silicic ash-flow tuffs.

Just east of the Cold Springs buildings, a small hill marked by numerous old prospects and cuts can be seen. Some silver was mined here.

197.1 Ruins of Cold Springs stage station, a stage stop on the old Overland Trail, and a nearby telegraph station.

203.9 Zeolitized lacustrine tuffs, both sides of highway.

206.2 Junction with State Route 2, which continues east through Eastgate and over Carroll Summit in the Desatoya Mountains (the old U.S. Highway 50 route). Continue northeast on U.S. Highway 50. To the left (southeast) are the buildings at Eastgate Station.

Along the left (south) side of the highway can be seen cuts and trenches in the Eastgate zeolite deposit. Zeolite-rich beds crop out in the area generally between the two highways. The zeolites, clinoptilolite and mordenite, with some erionite and phillipsite, occur in lacustrine sediments of Miocene age (Papke, 1972).

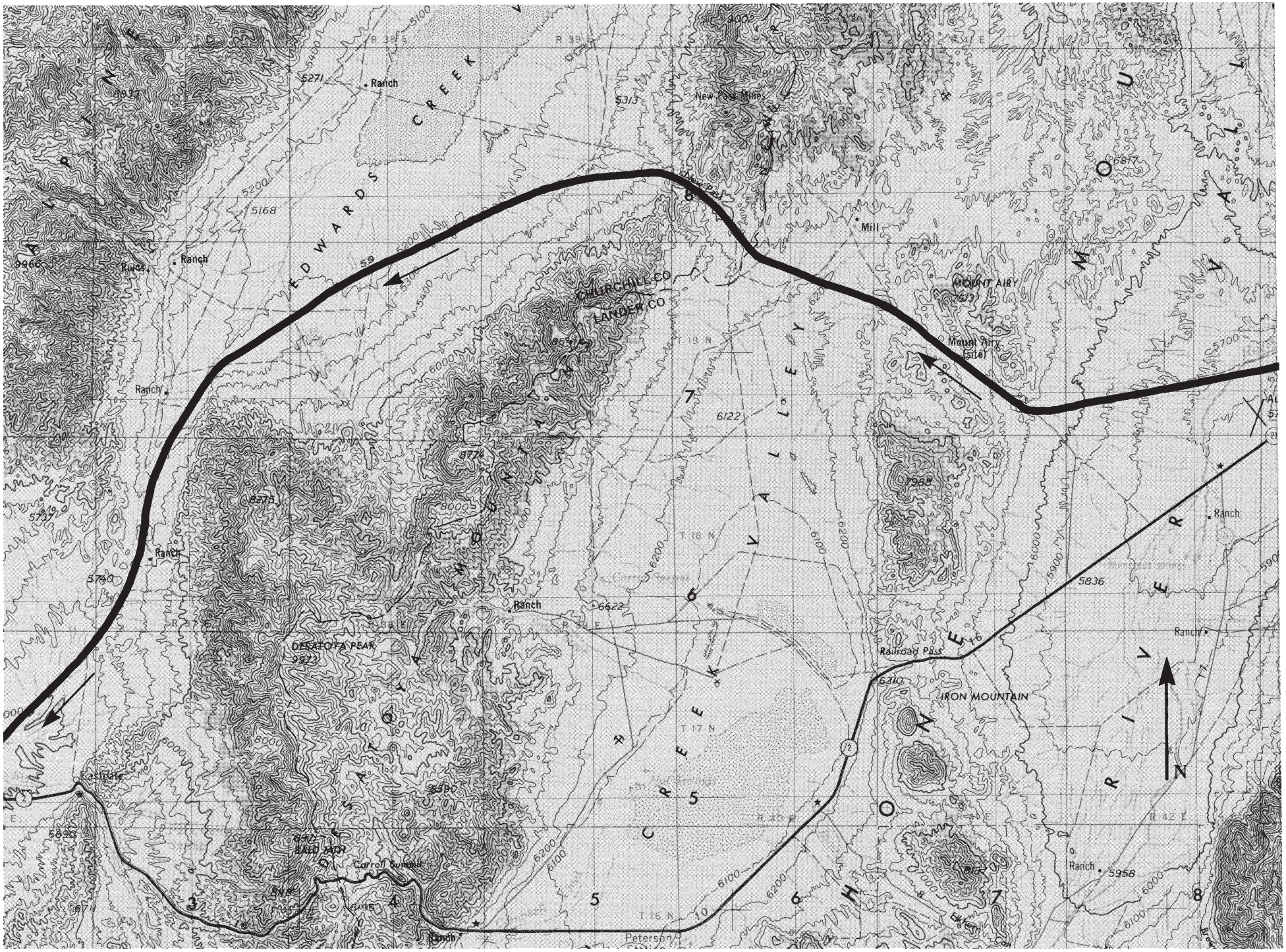
207.2 Middle Gate.

209.3 Middle Gate cafe and station; junction with State Route 361 to Gabbs. Continue east on U.S. Highway 50.

211.1 The Westgate mining district, at the southern end of the Clan Alpine Mountains, has produced some silver, lead, and gold from quartz veins that cut Mesozoic argillite and marble. A custom mill was completed at Westgate in 1939 and operated for a time on ores obtained from properties in the Wonder, Fairview, and Eastgate mining districts.

212.0 Fairview Peak at 11:00.

213.7 The Bell Mountain Mine is located about 4 miles to


EDWARDS CREEK
ALPINE
MOUNTAIN
New Pass Mine
Mill
MOUNT AIRY
Mount Airy (site)
CHURCHILL CO
LANDER CO
Ranch
Ranchy
DESATOYA PEAK
9973
BALD MTN
Carroll Summit
Eastgate
Peterson
Railroad Pass
IRON MOUNTAIN
HOLLOW
CREEK
VALLEY
RIVER
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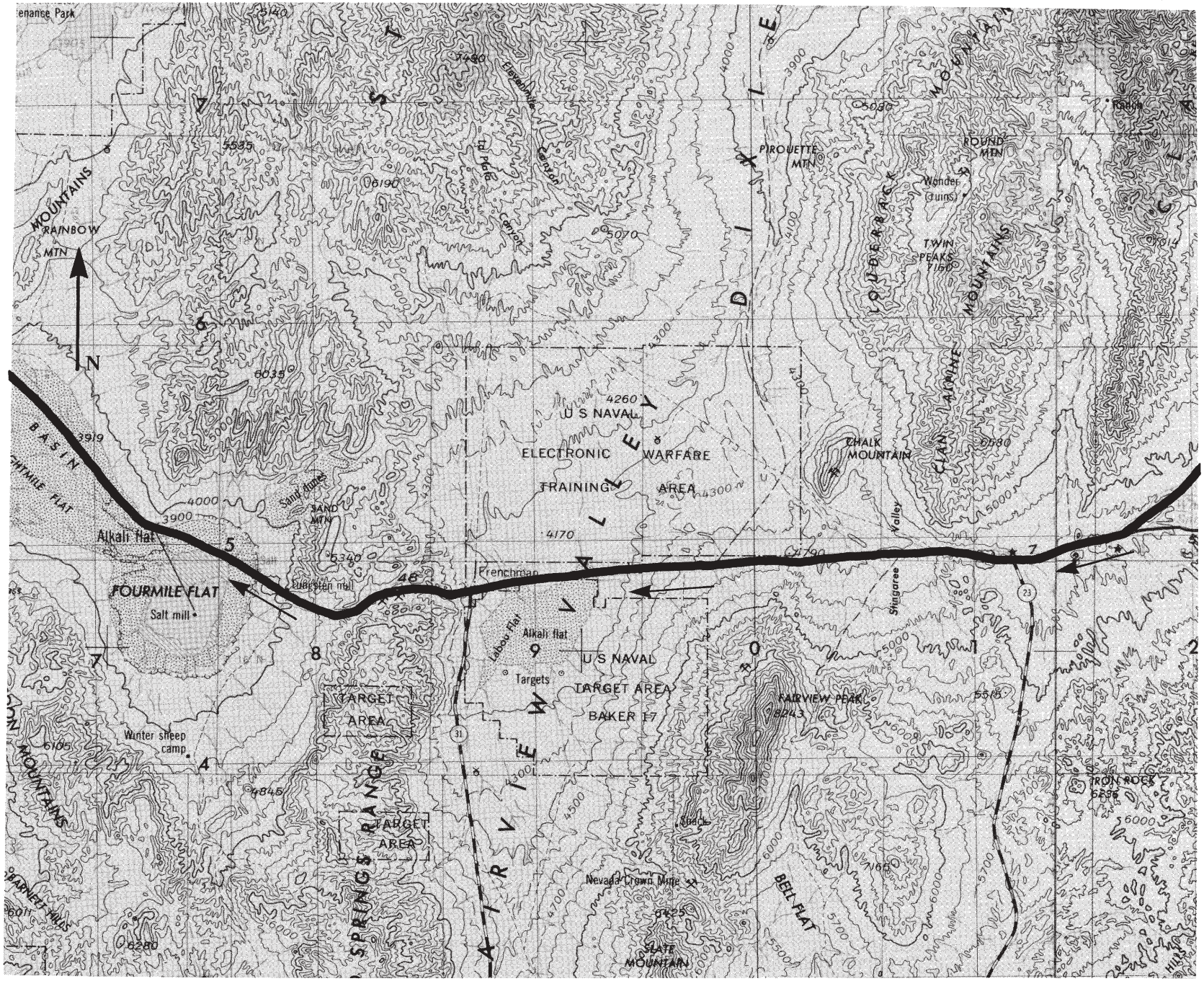
RAINBOW MTN
MOUNTAINS
N
BASIN
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Alkali flat
Salt mill
Winter sheep camp
Sand dunes
SAND MTN
Tungsten mill
Frenchman
Alkali flat
Labou flat
Targets
U S NAVAL
ELECTRONIC WARFARE
TRAINING AREA
U S NAVAL
TARGET AREA
BAKER 17
TARGET AREA
TARGET AREA
SPRINGS RANGE
AIRVILLE
VALLEY
DIXIE
PIROUETTE MTN
ROUND MTN
Wonder (ruins)
TWIN PEAKS
LOUDERBACK MOUNTAINS
CHALK MOUNTAIN
FAIRVIEW PEAK
Nevada Crown Mine
SLATE MOUNTAIN
BELL FLAT
IRON ROCK
Shingaree Valley
Rabbit
Elephantville
El Picho Canyon
Landon
MARNEY HILLS
MOUNTAINS

the south of the highway. At Bell Mountain, silver and gold ore occurs in an east-trending calcite and quartz vein which averages 36 feet in width. Slightly over 500,000 tons of ore containing 2 ounces of silver and 0.06 ounces of gold per ton are blocked out. Another 500,000 plus tons containing 1 ounce of silver and 0.03 ounces of gold per ton are considered proven. Originally scheduled to go into production in the fall of 1981, low silver prices have placed this project on the inactive list.

214.7 Chalk Mountain is to the right, at 3:00, north of the highway. Mesozoic dolomite (light color) has been intruded by quartz monzonite (the dark area on the west flank). Minor tungsten, iron, and copper mineralization occurs in the dolomite around the intrusive body. Lead and zinc have been mined from replacement deposits in the dolomite on the east flank of the mountain, and some prospecting for molybdenum has been done here.

Both the east and west sides of Chalk Mountain are bounded by basin-and-range-type faults. There was approximately 3 feet of displacement along the eastern fault during the December 1954 earthquakes. This fault extends northward into the Wonder mining district, 10 miles to the north, and has been displaced twice in historic time, in 1903 and 1954. Precious-metal mineralization in quartz veins at Wonder occurs in Tertiary volcanic rocks. The district has produced over $6 million in gold and silver (Willden and Speed, 1974).

216.4 South of the highway at this point, the principal mines of the Fairview mining district can be seen on the northwest flank of Fairview Peak. The majority of the deposits at Fairview are in quartz veins that cut a Tertiary dacite intrusive body. The principal ore minerals are: argentite, bromyrite, cerargyrite, chalcopyrite, electrum, embolite, galena, gold, polybasite, pyrargyrite, pyrite, silver, sphalerite, stephanite, and tetrahedrite.

The Fairview deposit was discovered in 1905 and was the scene of a frantic boom during 1906–07. The largest production occurred between 1911 and 1917 when about $1 million in gold and $2.8 million in silver were produced (Willden and Speed, 1974).

Highway descends into Fairview Valley. Most of area ahead to the north and south of the highway is a U.S. Navy training area (bombing range). It is common to see planes making bombing runs from the north, across the highway. Targeting areas south of Frenchman and on the flanks of the range west of Fairview Peak.

220.8 Small fault formed by Dixie Valley-Fairview Peak earthquakes crosses the road here. About 8 inches of displacement with upthrow to east and a slight right-lateral component. The total length of the fault was about ½ mile.

222.1 Frenchmans Station.

224.2 Intersection; road extends south along the eastern front of the Sand Springs Range. The Sand Springs granitic pluton comprises most of the range in view to the south. A few miles to the south and up into the range near its crest, a nuclear device was detonated at the bottom of a shaft in the granite. Known as Project Shoal, the test was part of a program to study characteristics of man-made nuclear events.

About 20 miles to the south, associated with the contact zone of another granitic pluton, the Nevada Scheelite Mine has produced over $12 million in tungsten from skarn deposits. Highway climbs pass dividing Sand Springs Range (south) from Stillwater Range (north).

226.3 At 3:00, vertical, west-striking, Mesozoic phyllite is overlain by flat-lying Tertiary volcanic rocks. The phyllite extends to the base of the hill at 9:00 where it is in contact with the granite stock that forms the steep hillside. A light-colored rhyolite dike intrudes the phyllite; this dike extends across the road and into the hill south of the road.

227.2 To the left, south of the highway, are the remains of Summit King Mine and mill. From its discovery in 1905 until 1951, about $2 million worth of silver as well as some gold was mined here from a system of vertical, west-trending fissure veins in both Mesozoic metamorphic rocks and in Tertiary dikes and volcanic rocks. The veins were as much as 10 feet in width and consisted mainly of vuggy quartz and wall rock fragments, some calcite, and minor pyrite. The silver values probably occurred as argentite and cerargyrite. Adularia from the nearby Dan Tucker Mine has been dated by K-Ar at 19.5 m.y. (Garside and others, 1981).

A thrust fault is exposed in the prominent hill at 12:00. Mesozoic(?) limestone, dipping steeply south, forms the upper plate of the thrust; phyllite forms the lower plate.

Ahead, to the right on the point of the range can be seen the ruins of a small tungsten mill.

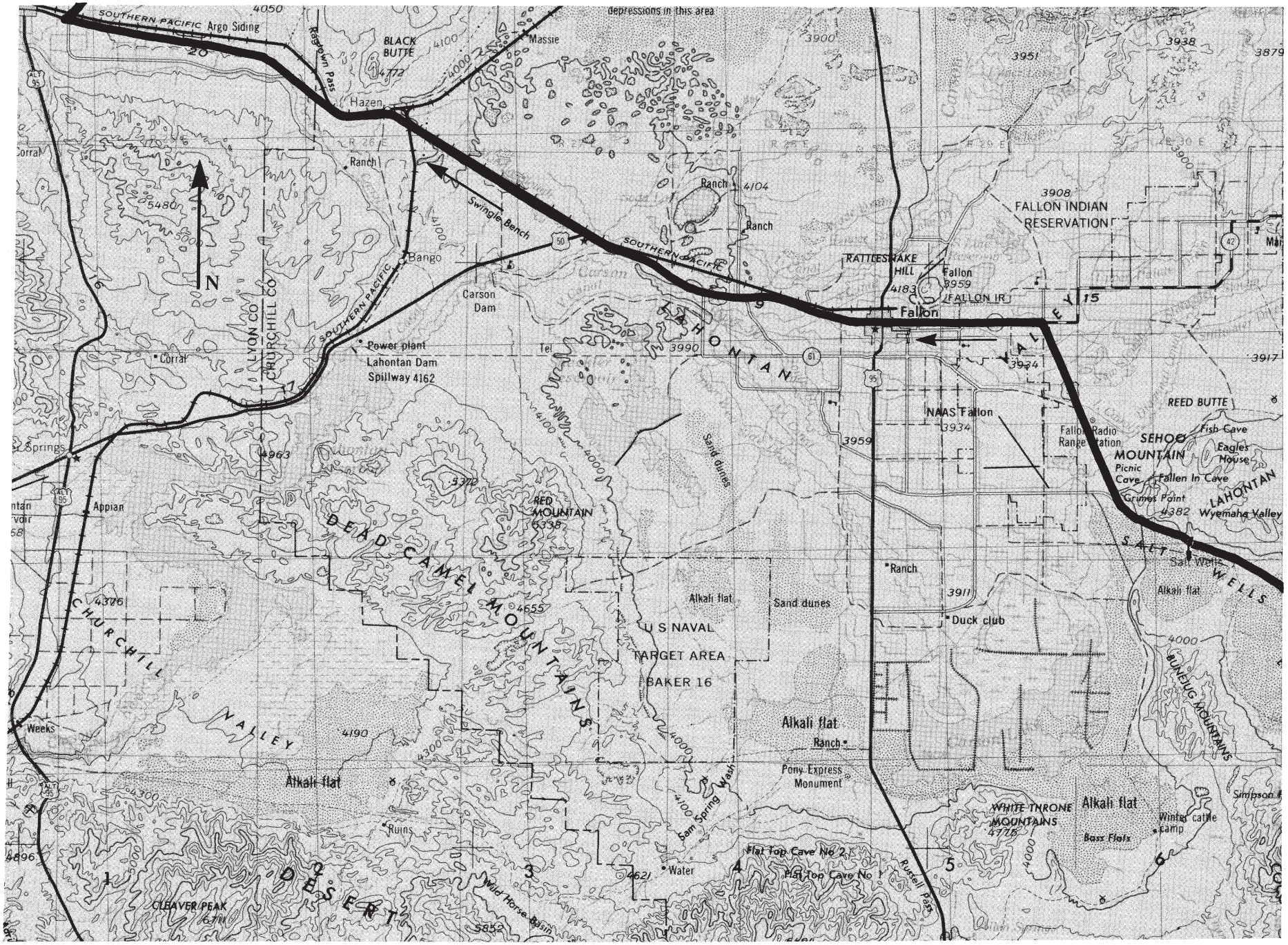
229.0 At 1:00 to 5:00, 6–7-m.y.-old basalt flows overlie silicic air-fall tuff and sedimentary rocks.

230.0 Just north of the road is the site of the Sand Springs Pony Express and stage station. Road extends north from this point to Sand Mountain.

Sand Springs was the scene of the old-timer's tall tale related in Slemmons (1966) that tells of the Chicken Craw gold-rush of 1907. The story is that Larry Hunt, a desert dweller, was operating a wayside inn at the time. Dressing some chickens for a Sunday dinner, Larry discovered fair-sized gold nuggets in the craws of two, and thereupon slew his entire flock. He found more nuggets. Convinced that chickens were not eating gold in the neighborhood, he set out with two companions to learn from where the chickens had come, and discovered they had been purchased from a farmer near Wadsworth, 70 miles away. Confusion was added to distance when he learned that the chickens had been owned by no fewer than four farmers before they were sold to him. The area in which the chickens ate the gold nuggets for gravel remains undiscovered.

232.2 Highway crosses Fourmile Flat. About halfway across, on the north side of the highway, are graves of early pioneers (highway here parallels a portion of the Overland Trail of the 1850's). To the south (left) in the center of the playa are buildings of a salt works. Between 1863 and 1871, salt from here was shipped to Virginia City for use in silver milling. Salt is still produced here for less exotic uses such as road deicing and livestock feed.

233.9 Road to the left leads to salt works. Basin to the west is known as Eightmile Flat, part of the larger


SOUTHERN PACIFIC
Argo Siding
depressions in this area
BLACK BUTTE
4172
Massie
Ragtown Pass
Hazen
Ranch
Swingle Bench
Bango
Carson Dam
Power plant
Lahontan Dam
Spillway 4162
Corral
LYON CO
CHURCHILL CO
N
Springs
Appian
Weeks
CHURCHILL VALLEY
Alkali flat
Ruins
CLEAVER PEAK
DESERT
Wild Horse Basin
Water
Sam Spring Wash
Pony Express Monument
Flat Top Cave No 2
Flat Top Cave No 1
Russell Pass
U S NAVAL TARGET AREA BAKER 16
DEAD CAMEL MOUNTAINS
RED MOUNTAIN
5338
Sand dunes
LAHONTAN
Tel
RATTLESNAKE HILL
4183
Fallon
3959
FALLON IR
FALLON INDIAN RESERVATION
3908
NAAS Fallon
3934
Fallon Radio Range Station
Duck club
SALT WELLS VALLEY
Salt Wells
REED BUTTE
SEHOO MOUNTAIN
Fish Cave
Eagles House
Picnic Cave
Fallen In Cave
Grimes Point
4382
LAHONTAN
Wyemaha Valley
BUNEJUG MOUNTAINS
WHITE THRONE MOUNTAINS
4775
Bass Flats
Winter cattle Camp
Simpson
1
3
4
5
6

Salt Wells Basin that includes both Eightmile and Fourmile Flats.

235.2 Numerous thin basalt flows in range to the north (at 3:00). Cocoon Mountains are south of the highway and the Bunejug Mountains are northwest of them, on the far side of Eightmile Flat. Bunejug Mountains are so named because on a topographic map the mountain resembles a june bug. The name "Bunejug" was inadvertently given to this mountain by a small child who, unable to pronounce the word "Junebug," called it "Bunejug." The moundlike form of the Cocoon Mountains, just behind the june-bug form, suggested the name Cocoon Mountains.

240.5 Salt Wells borax area, to the left, along the south side of the road. The area is thought to be the site of the first clay borate discovery in Nevada. Ulexite was discovered here in 1870 and a plant was built by American Borax Co. the same year (Papke, 1976). This was the pioneer borax project in the Great Basin, a precursor of an important industry in Death Valley in later years (Paher, 1970).

241.5 Salt Wells, a freight and stage station dating from 1905. The colorful paint scheme and lights provide subtle clues as to its present use.

245.5 Grime Point. Indian caves in basalt cliffs northeast of the highway. Lahontan Valley ahead, Fallon Naval Air Station to the west. Aircraft-carrier pilots fly planes to this field from the West Coast and use the field as a base during bombing, gunnery, and rocket practice on nearby bombing ranges.

247.5 Lazy B Guest Ranch.

250.8 Junction of State Route 116 to Stillwater; continue along U.S. Highway 50.

Stillwater Wildlife Refuge is to the north. Runoff irrigation water from Fallon area creates marshes which are renowned for their diverse waterfowl population.

Most of the surface outcrops during the next 9 miles consist of a thin veneer of Quaternary Fallon Formation shallow lake sediments. The sediments include clay, sand, and gravel. Small outcrops of sandstone and claystone of the underlying Sehoo Formation are distributed along the first 3 miles.

253.9 Rattlesnake Hill to the right, north of the highway, is composed of black to dark-gray Quaternary basalt flows around a shallow summit crater. The basalt flows are largely covered with Lake Lahontan sediments and young eolian sand. The basalt flows were extruded by quiet eruptions from the Rattlesnake Hill vent; the central vent is filled with agglomerates.

255.5 Fallon (elevation 3,960 feet), the market center for the surrounding stock-raising and irrigated-farming area. Continue to stoplight at Williams and Maine (not Main!), county courthouse at right. Continue straight ahead on U.S. Highway 50.

259.8 Junction of road to Soda Lake. A cluster of maars or explosion pits with gently sloping dark cones form the low, domelike ridge to the northwest. The centers of the two largest cones are occupied by Soda Lake and Little Soda Lake. Lake levels are both 3,989 feet; Soda Lake has a maximum depth of about 230 feet below the general surface of the desert outside the cone. The ash cone that encloses Soda Lake on three sides rises to an elevation of 4,104 feet and contains basaltic debris interbedded with lake sediments. The youngest eruptions from these cones were probably less than 7,000 years ago. In about 1855, the lake waters were discovered to be rich in sodium carbonate, and production of this material from the brines began in 1868 and continued to around 1900 (Papke, 1976). After an unlined canal from the Newlands project was routed around the northern end of the cone, the water table rose, diluting the brines and covering the old evaporation ponds and buildings.

263.4 Ragtown was a welcome oasis on the Carson River for the exhausted and thirsty emigrants who stopped here to recuperate after the terrible 40-mile trip across the barren, dusty, sandy Carson Sink from the last water on the Humboldt River. Sometimes as many as five or six wagon trains were camped at one time, recovering strength for the crossing of the Sierra Nevada, the last barrier before reaching California. After a time, Indians came here to sell their services as guides in exchange for commodities. Here, too, for many years an enterprising blacksmith had a shop to repair the wagons shrunken and broken by the trip down the Humboldt and across the desert. Asa L. Kenyon was the only white resident in 1854, although a great many other traders camped nearby in the summer. There are various stories about the origin of the old town's name, one being because the cloth shelters had fluttering ends, another because of the ragged clothing travelers washed in the river and spread on the sagebrush to dry. But early diaries indicate that the spot was so named because the area was covered with rags of mattresses and other household goods discarded as travelers lightened their loads before the long pull over the Sierra Nevada. The place might as well have been called Irontown for the hundreds of wagons and farming implements abandoned. A burying ground contains more than 200 graves of early travelers who died here of famine and exhaustion (Angel, 1881, p. 365).

264.6 Junction U.S. Highway 50 and Alternate U.S. 50. Continue west on Alternate U.S. 50.

265.1 Older telegraph poles in salt flats and ponds between the highway and the railroad at 3:30 have bases that are swollen into "bell-bottoms" by the crystallization of salt between wood fibers.

The next several miles includes deep lake sands and clays of the Quaternary Sehoo Formation. The sediments were deposited 7,000 to 27,000 m.y. ago. Locally, sand dunes and a shallow water table forms hummocky terrain with many marshes and ponds. The prevailing northeasterly direction of winds in this area has locally eroded elongated troughs (yardangs) and longitudinal dunes.

271.2 Enter and leave Hazen. Here, the main line of the Southern Pacific Railroad turns northeast on its way to the east; Southern Pacific branch lines extend south from this point to Mina (via Hawthorne) and east to Fallon.

Established in 1902 when Southern Pacific re-

aligned its route, Hazen became important as the junction point for freight and passengers traveling south to Tonopah and Goldfield.

273.2 In railroad cut north of highway at 3:00, are late Quaternary pyroclastic deposits of basalt.

274.2 Badlands topography, which resulted from erosion of Lake Lahontan sediments, on both sides of highway.

282.7 Intersection, turn right (north) on Alternate U.S. 95 for about 2 miles, pass under Interstate 80 overpass, turn left onto freeway on ramp and proceed west on Interstate 80 to Reno.

317.7 Reno, trip ends at MGM Grand Hotel.

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GEOLOGY OF THE PINSON MINE, HUMBOLDT COUNTY, NEVADA

by E. L. Kretschmer
Pinson Mining Co., Winnemucca, NV

ABSTRACT

The Pinson Mine is one of three Carlin-type gold deposits which occur along the east flank of the Osgood Mountains, Humboldt County, Nevada. The Pinson and the nearby Preble and Getchell deposits exhibit similar features in that gold ore occurs along wide shear zones in silicified carbonate and/or carbonaceous host rocks.

At the Pinson Mine, sedimentary rocks of the Preble (Middle to Late Cambrian) and Comus (Ordovician) Formations are intruded by a Cretaceous granodiorite stock. Gold mineralization, controlled by a northeast-trending fault system, occurs as fine disseminations in jasperoid and silicated limestone and siltstone of the Comus Formation in a contact metamorphic aureole surrounding the stock. Altered dikes and sills of intermediate composition are associated with the gold mineralization.

Two types of ore bodies are present in the Pinson ore zone; both are related to silicification produced in a shallow, hydrothermal system and occur in a broad area of brecciation along a shear zone. The "A" ore body is characterized by intense silicification, while the "B" ore body is less silicified. The gold is generally submicroscopic, has a gold-silver ratio that often approaches 100:1, and occurs with silica and pyrite or iron oxides. Late-stage calcite veins, often with silica, are present in the ore bodies and in the hanging wall. The mineral assemblages resemble low-temperature vein deposits; antimony, arsenic, and mercury, often with barium and fluorine, are important trace elements.

INTRODUCTION

The Pinson Mine, located 38 miles northeast of Winnemucca in north-central Nevada, is situated, along with two other gold deposits, on the east flank of the Osgood Mountains in the Potosi mining district, Humboldt County, Nevada. The importance of the district was established with the discovery of gold at the Getchell deposit in 1934. A mill was erected, gold production began in 1938, and the facility operated periodically until 1967. The Potosi district also produced tungsten from numerous small tactite deposits during World War II and the Korean War.

HISTORY

Paul A. Pinson was 8 years old when he arrived in San Francisco from France in 1853. As a young man he worked as a scout for early exploration expeditions in California and Nevada, including Clarence King's first ascent of Mount Whitney. Pinson also did some prospecting in the early mining camps of Nevada. He moved into the Golconda area around 1885 and established what is now known as the Pinson Ranch. One of his eight children, Clovis, managed ranches in the vicinity but also had a love of prospecting.

Clovis Pinson and partner, Charles Ogee, found small siliceous outcrops that resembled early Getchell ore and staked the area in 1945. Getchell Mines Inc. leased the claims and mined approximately 50,000 tons in 1949 and 1950. That activity appeared to exhaust the ore body, and the claims lay dormant until the late 1960's when some exploration work was conducted on them.

In 1970, the Cordex I Syndicate leased the property. The area was recognized as being on the Getchell structural zone, and it appeared that there were good possibilities of finding other ore bodies along the trend. After geologic mapping and geochemical sampling, a program of rotary drilling was started in 1971. The first 17 holes were drilled mainly around the old Pinson pit and encountered low-grade values. But on the 18th hole drilled to test a possible northeast extension, 90 feet of good mineralization was encountered. This is referred to as the Pinson "A" zone ore body, which is 1,000 feet long, averages 60 feet in thickness, and contains 1.5 million tons averaging 0.18 ounces of gold per ton. It is obscured by 10 to 50 feet of alluvium and thus was not recognized during the previous mining. Further drilling indicated 1.7 million tons averaging 0.15 ounces of gold per ton plus an additional tonnage of low-grade ore in the "B" zone ore body, which occurs in the vicinity of the old pit.

In 1972, further prospecting and geochemical sampling 15 miles south of Pinson led to a virgin discovery known as the Preble deposit in which 1.5 million tons averaging 0.07 ounces of gold per ton were indicated. However, this deposit was not economically viable at the then-existing gold price of $65 per ounce.

Various evaluations were made of the Pinson deposit over a period of several years, and in 1975 a 330-foot adit was driven to obtain a bulk sample of the gold ore for mill testing. In early 1979, when the price of gold had reached $250 per ounce and over $1 million had been expended on the properties, a new feasibility study was undertaken. This indicated that the project would be profitable. The Cordex I Syndicate was reorganized into a partnership called Pinson Mining Co. and plans were made to put the property into production. Ten years after the discovery of the new ore body, the first gold bullion was produced.

DEPOSIT GEOLOGY

Rocks in the vicinity of the Pinson Mine consist of Paleozoic sedimentary rocks intruded by a Cretaceous granodiorite stock. The oldest rocks are Middle to Late Cambrian Preble Formation, which can be separated into three distinct members. The lower member consists of sandy shale, quartzitic sandstone, and phyllitic shale. A sequence of limestone, carbonaceous shale, calcareous shale, and subordinate phyllitic shale and quartzitic sandstone make up the middle member. The upper member comprises phyllitic shale, sandy shale, and a few carbonaceous beds.

The Comus Formation, a thin-bedded carbonate and shale unit of Ordovician age, overlies the Preble Formation and is the host rock for the Pinson ore. Rhythmic interbedding of the carbonates and shaly beds are often seen and sometimes occur as fine laminations (J. Graney, oral commun. and unpublished company reports, 1983). The sedimentary rocks have been intruded by a medium- to coarse-grained, granular granodiorite stock which has been dated (Silberman, Berger, and Koski, 1974) at 85–90 m.y. (Cretaceous). Aplite, pegmatite, and porphyritic dikes and

sills of intermediate composition are associated with the stock, which crops out approximately 1,200 feet north of the mine. The mine lies within a conspicuous contact metamorphic aureole that extends irregularly up to 10,000 feet from the margins of the stock. Within the contact aureole shale is metamorphosed to chiastolite/andalusite-biotite or cordierite-muscovite hornfelses, and carbonate rocks are metamorphosed to marble, light-colored calc-silicate rocks, and dark garnet tactite. The tactite deposits contain scheelite and many of them were mined for tungsten during the period 1942–57 (Hotz and Willden, 1964).

The major structure of the area is a prominent northeast-trending normal fault which has controlled the gold mineralization. This structure has been traced by drilling for 8,000 feet northeast along strike and shows a uniform dip of 40°–50° SE. For half the mapped distance, the fault forms the contact between the Preble and Comus Formations; for the remainder of the distance it cuts the Comus and offsets limestone and intercalated units (fig. 1). Where the structure occupies the contact zone, it is 50–70 feet wide, sheared, and brecciated.

Two main types of ore are present and related to silicification produced in a shallow, hydrothermal system.

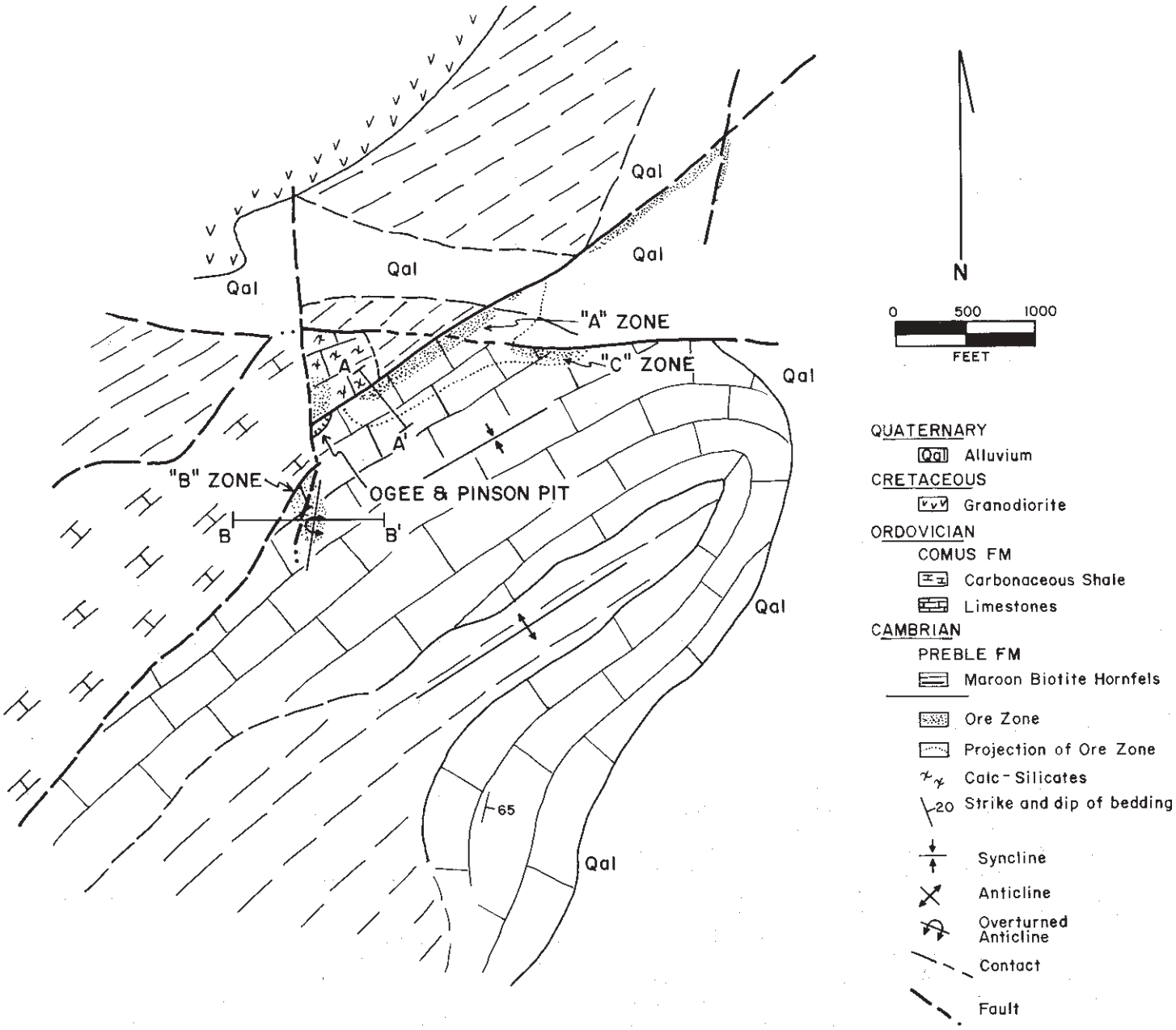

FIGURE 1. Geology of the Pinson Mine area.

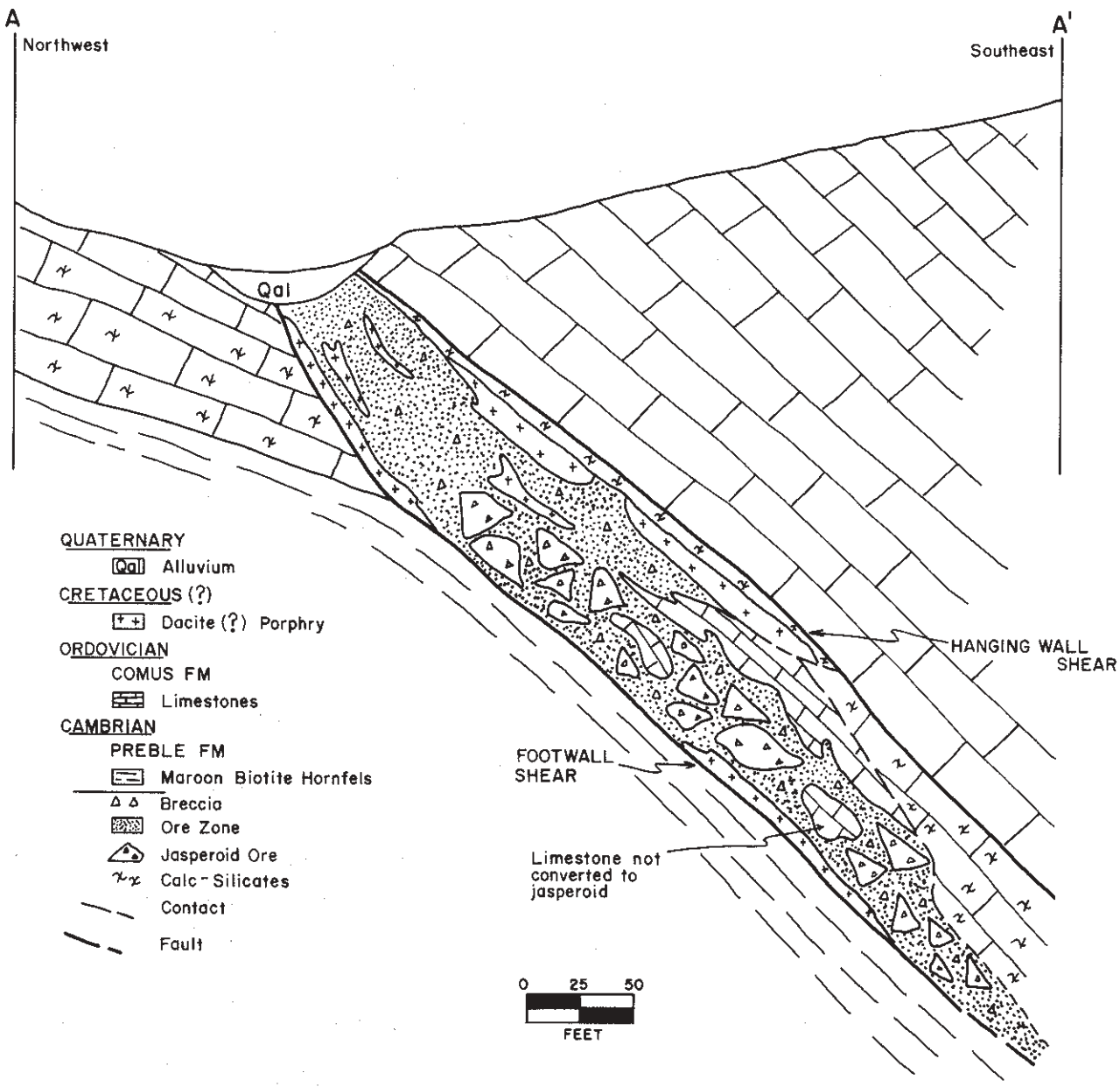

FIGURE 2. Cross section of Pinson ore zone, "A" ore body.

The "A" ore body is localized along the 70-foot-wide northeast-trending shear zone bounded by a definite hanging wall and footwall strand (fig. 2). The "A" ore body is characterized by intense silicification, in which intercalated limestone and siltstone beds of the Comus Formation are completely replaced by a dense jasperoid that locally carries gold values from 0.20 ounces up to several ounces per ton. The jasperoid is confined to a 60- to 70-foot-wide zone along the northeast-trending fault. Polished sections of the jasperoid reveal a relatively simple mineralogy: silica, goethite, lepidocrocite, and hematite, with sparse remnants of pyrite, marcasite, and gold (Powers, 1978). Gold size is less than 30 microns and most commonly less than 5 microns (W. R. Kemp, unpublished company report, 1973). Gold occurs as a free phase and has been seen as micron-size inclusions in arsenic-bearing pyrite (Wallace and Wittkopp, 1983). The gold-silver ratio often approaches 100:1. Highly altered andesite or dacite porphyry sills and dikes lace the "A" ore body in irregular fashion (Hill, 1971). The dikes are argillized, sericitized, and contain low gold values near the ore zone (W. R. Kemp, unpublished company report, 1972).

The "B" ore body begins in the vicinity of the old Ogee and Pinson Mine workings and trends southward for approximately 1,000 feet. The host rocks are a less-silicified shale and a punky, leached silty carbonate horizon of the Comus Formaiton. The "B" ore body occurs in a fold axis that has been sheared and brecciated along a north-trending shear zone (fig. 3), with influence from a northeast-trending fracture system that is sympathetic with the "A" ore body structure. Here, in the Comus Formation drilling indicates the carbonaceous shale above, below, and bounding the carbonate rocks on the west. The gold mineralization occurs with limonite and kaolinite along numerous fractures in a zone of subtle, pervasive silicification. This fracture system allows good dissemination and uniform grade. Though of lower grade than the "A" ore body, the "B" ore body is more extensive. In addition, frac-

FIGURE 3. Cross section of Pinson ore zone, "B" ore body.

turing and oxidation exposes the gold and allows the ore to be treated readily by cyanidation.

Modest tonnage has been developed from the "C" ore body, which occurs along a crosscutting normal fault that trends N50°E at the north end of the 'A" ore body (fig. 1). The grade and mineralization is similar to that of the "A" ore body.

GEOCHEMISTRY

Surface geochemical sampling and analysis of drill cuttings indicated an association of antimony, arsenic, and mercury with the mineralized zone, as is typical of most Carlin-type deposits (Hill, 1971; Crone, 1982). Analyses were also performed for copper, lead, silver, and zinc, but these elements showed no association with the gold mineralization (Hill, 1971). Barium and fluorine have recently been found associated with the gold mineralization (R. Connors, written commun., 1982).

Surface grid sampling of rock chips indicated that the mineralized zone could readily be found where it outcropped by its association with mercury, and to a lesser extent, with antimony and arsenic. However, where the zone extends to the northeast from the "A" ore body and is covered by transported material of decomposed granodiorite and some clay, use of these elements was ineffective.

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THE GEOLOGY OF THE ENFIELD BELL MINE AND THE JERRITT CANYON DISTRICT, ELKO COUNTY, NEVADA

by D. J. Birak
Freeport McMoRan Gold Mining Co., Elko, Nevada
and R. B. Hawkins
Freeport McMoRan Gold Mining Co., Reno, Nevada

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INTRODUCTION

The discovery of disseminated gold deposits in the Jerritt Canyon district and the development of the Enfield Bell Mine have contributed greatly to a resurgence in exploration for disseminated gold deposits in Nevada and the western United States. The Jerritt Canyon project and the Enfield Bell Mine is a 70:30 joint venture between the Freeport Gold Co. and FMC Gold Inc., which are wholly owned subsidiaries of their parent companies, Freeport-McMoRan Inc. and FMC Inc. respectively.

The Jerritt Canyon district lies within the Independence Mountains in north-central Elko County, Nev., approximately 80 km north of Elko (fig. 1). The Enfield Bell Mine is located in the center of the Independence Mountains in the Jerritt Canyon window of the Roberts Mountains thrust. Ore is mined from carbonaceous and oxidized parts of the Roberts Mountains and Hanson Creek Formations, and is treated in a standard cyanidation mill, located approximately 12.8 km east of the mine.

We gratefully acknowledge the management of the Freeport Gold Co. and the Freeport Exploration Co. for permission to publish this report. We thank Freeport geologists, especially those of the Jerritt Canyon District Office, for their critical reviews of the manuscript and stimulating discussions of the complex geology of the deposit; these reviews and discussions have contributed greatly to our current level of understanding of the history of the Jerritt Canyon district and the Enfield Bell Mine.

HISTORY AND PRODUCTION

The discovery of gold mineralization in the Jerritt Canyon district was preceded by an antimony-exploration program initiated by FMC Inc. in 1971, on the basis of the antimony occurrences in the area reported by Lawrence (1963). Exploration emphasis shifted to gold when geologists recognized similarities between this area and the Carlin ore bodies. Mapping, sampling, and geochemical analyses led to the discovery of a gold anomaly along the north fork of Jerritt Creek. Drilling of this anomaly in 1973 revealed significant grades and thicknesses of gold mineralization in the lower part of the Roberts Mountains Formation. On the basis of this discovery, additional drilling was performed that delineated several small pods of low-grade gold mineralization; the mineralization was significant but not in sufficient amounts to constitute a minable discovery.

In 1976, the Freeport Exploration Co. assumed management of the project through a joint-venture agreement with FMC Inc. and began an expanded program of geologic mapping and geochemical sampling that led to a new understanding of the geology of the district. Several new geochemical anomalies and drilling targets were defined, including the Marlboro Canyon ore body, which is now part of the Enfield Bell Mine. Although a classic 'bull's-eye'' geochemical target was the clue that led to the initial

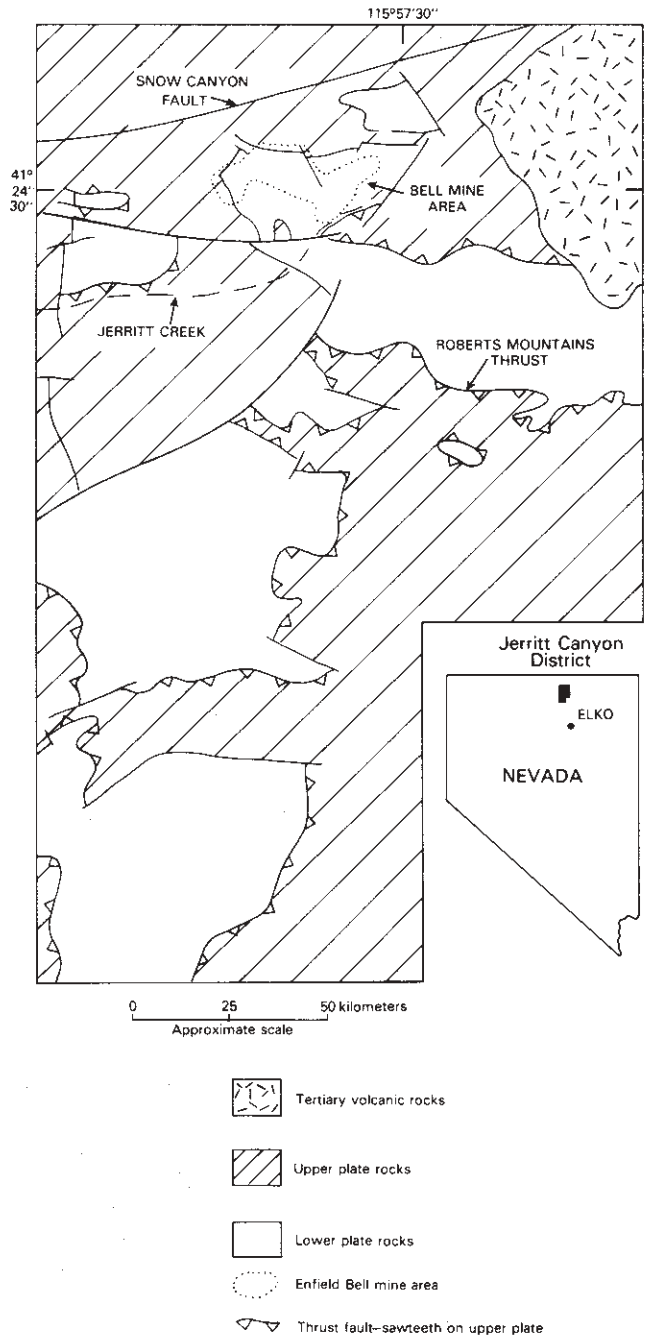

FIGURE 1. Location and general geology of the Jerritt Canyon district and the Enfield Bell Mine area. Diagonal lines, exposures of upper-plate rocks; unpatterned, exposures of lower-plate rocks.

discovery in the north fork of Jerritt Creek, the bulk of current reserves were found beneath a cover of colluvium and soil that was geochemically barren.

A decision to proceed with the construction of a mine and mill was made in 1979, and full-scale mill production began in July 1981. Current reserves are in four ore bodies, designated the Marlboro Canyon, North Generator Hill, West Generator Hill, and Alchem deposits. Mining has proceeded for the past 3 years within the Marlboro Canyon deposit and in part of the North Generator Hill deposit, referred to as Lower North Generator Hill. Milling proceeds at a design rate of 3,200 tons per day (2,900 t/d) of oxidized and carbonaceous ore.

REGIONAL GEOLOGY

The geology of the Jerritt Canyon district (Hawkins, 1973) is similar to that of the Lynn window (Radtke and others, 1980), insofar as much of the district is composed of Paleozoic sedimentary and volcanic rocks of the upper and lower plates of the Roberts Mountains thrust (fig. 1). The upper plate consists of an Ordovician eugeosynclinal sedimentary and volcanic assemblage composed of shale, argillite, chert, quartzite, intermediate to mafic flows, and lesser amounts of limestone and bedded barite. Basinal miogeosynclinal rocks compose the lower plate and consist of Ordovician and Silurian siltstone, limestone, chert, and quartzite. Deformation during the Late Devonian Antler orogeny moved the eugeosynclinal rocks (allochthon) eastward over the miogeosynclinal assemblage (autochthon), along the Roberts Mountains thrust (Merriam and Anderson, 1942). Good exposures of the thrust are uncommon in the Jerritt Canyon district. Where it is exposed, the thrust contact may be highly undulatory. Folding of the lower- and upper-plate rocks is recognized locally as a manifestation of this thrusting. A major southwest-plunging asymmetric anticline, referred to as the Map anticline, may have formed at that time.

Contemporaneous with the Robert Mountains thrust, several imbricate low-angle normal and reverse faults within the upper and lower plates were formed. These faults are important insofar as they caused locally significant truncations of stratigraphy that provided excellent pathways for hydrothermal fluids. Several of these structures have been recognized with the lower-plate rocks in the Enfield Bell Mine area.

Tertiary igneous activity in the district produced several extrusive and intrusive rock types, none of which are found in the immediate mine area. A granodioritic to tonalitic pluton, measuring approximately 4,000 m^2 in outcrop area, was emplaced in the southwestern part of the district. although no age determinations have yet been made on this pluton, it maybe as old as 120 m.y., equivalent in age to the Gold Strike stock north of the Carlin Mine (Housen and Kerr, 1968), or an young as 38 m.y., equivalent in age to the Mount Neva stock near the town of Tuscarora, Nevada. (Coats and McKee, 1972). Possibly contemporaneous with granitic plutonism was the formation of several intermediate to mafic dikes and sills. These intrusive bodies are widely scattered across the district and are relatively small; their outcrops generally measure less that 10 m wide by 30 m long.

Deposition of andesitic and rhyolitic flows and ash flows occurred about 43 to 34 m.y. ago (Stewart, 1980). Deposition of the andestic volcanic rocks is interpreted, from mapping evidence, to be the earlier of these two events. Subsequent faulting and erosion have limited exposures of the volcanic rocks to the extreme northeast corner of the district. Regional magnetic data suggest that these volcanic rocks continue beneath valley-fill gravel to the east.

Basin-and-range-associated tectonism during the Miocene (Stewart, 1980) created a steep block-faulted terrain. Three conspicuous basin-and-range fault sets trend east-west, northwest, and northeast within the district. Hawkins (1982) postulated that the east-west-trending fault set may have been active during the Mesozoic, and was followed by the development of northeast- and northwest-trending faults during the basin-and range event. The Snow Canyon fault, one of the major east-west-trending faults, occurs just north of the Jerritt Canyon window (fig. 1). Similar but smaller scale east-west-trending faults in the Enfield Bell Mine are the Marlboro Canyon, Bell, and Ridge faults (fig. 2), which may have also formed first during the Mesozoic.

Erosion of uplifted blocks along these faults has locally removed the upper-plate rocks and exposed the lower plate as windows in the Roberts Mountains thrust (fig. 2). In most areas, the contact between upper- and lower-plate rocks in the Jerritt Canyon district is thought to be a high-angle fault. Exposure of the Roberts Mountains thrust is limited. Continued erosion has resulted in a steep terrain and the locally thick alluvial and colluvial cover in the district.

REGIONAL STRATIGRAPHY

Most of the rocks in the Jerritt Canyon district are Paleozoic sedimentary and volcanic rocks that have been assigned to the upper and lower plates of the Roberts Mountains thrust (Hawkins, 1973).

LOWER-PLATE ROCKS

Lower-plate stratigraphy with the Independence Mountains was described by Kerr (1962) and Hawkins (1973). Although a continuous, undisturbed stratigraphic section has not yet been recognized, sufficient exposures are present to enable the reconstruction of a complete section form the base of the Eureka Quartzite through the Roberts Mountains Formation (fig. 3).

The Eureka Quartzite of Middle Ordovician age is recognized throughout most of central Nevada as a prominent cliff-forming member of the autochthonous assemblage. Exposures of the formation in the district are limited to the southern parts of the Jerritt Canyon window, where it is composed of thick-bedded orthoquartzite. Fresh rock is generally light gray, with scattered grains of oxidized pyrite; weathered surfaces may be slightly yellow brown. Quartz grains are cemented by silica except near the contact with the over-lying Hanson Creek Formation, where carbonate cement may also occur. Although bedding is indistinct, beds are generally massive and more than 3 m thick. Fossils are rare, but local exposures yield graptolite molds. Measured thicknesses of the Eureka Quartzite range from 150 to 190 m. Although the base of the formation has not been well studied, the upper contact is interpreted to be gradational with the Hanson Creek Formation.

The Hanson Creek Formation, considered to be of Late Ordovician and Early Silurian age by Matti and others (1975), is the major host rock at the Enfield Bell Mine and is exposed in many parts of the Jerritt Canyon window. On the basis of surface and subsurface data, the Hanson Creek Formation is here subdivided into five lithologic units–unit 1 (youngest) through unit 5 (oldest) (fig. 4). Because the upper parts of the Hanson Creek Formation are much better known and occur more commonly in outcrop than the lower units, the units are numbered consecutively from the top down.

The lower three units of the Hanson Creek Formation, units 3 through 5, are carbonaceous banded limestones.

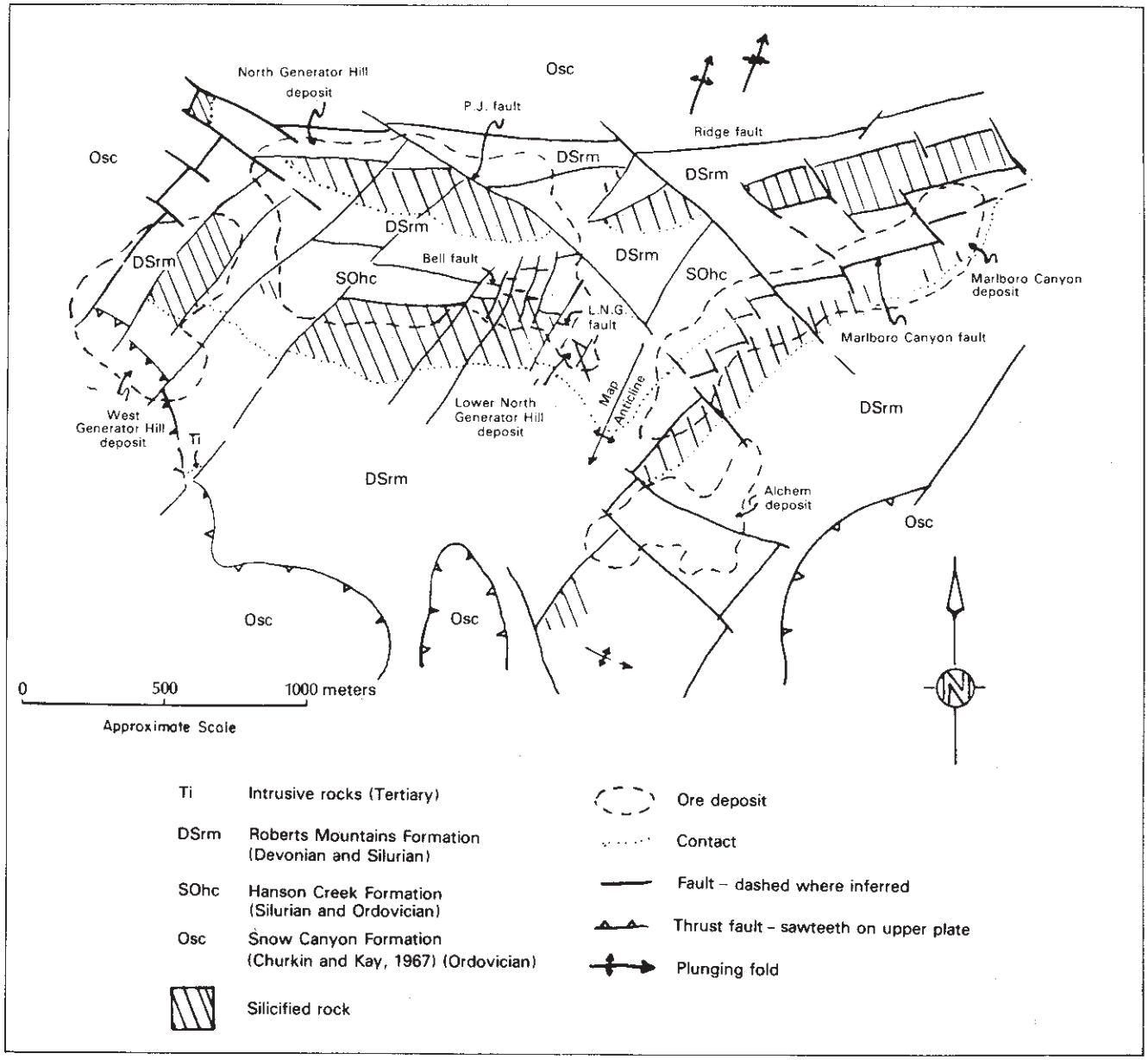

FIGURE 2. Preliminary geologic map of the Enfield Bell Mine, Jerritt Canyon district, Elko County, Nevada.

The banding, best developed in unit 3, results from alternating beds of micritic limestone and laminated dolomitic limestone, in which the laminated beds are the most carbonaceous. Pyrite occurs in both types of beds, although it is more abundant in the laminated beds.

The basal unit, unit 5, as measured, consists of 5 to 30 m of dolomitic limestone and thin-bedded micritic limestone, with some laminated calcareous siltstone near the basal contact. Fossils recognized throughout are crinoidal, brachiopod, bryozoan, and radiolarian fragments. Near the top of unit 5, an intraclastic layer has been recognized in which the intraclasts contain fossil debris mixed with carbon stringers and pods and sparry calcite cement. Locally, lenses and pods of black, carbonaceous chert have been recognized.

The overlying unit 4 is a 30- to 40-m-thick sequence of carbonaceous banded limestone containing abundant black chert nodules and lenses, 5 to 25 cm long, oriented parallel to bedding. Micrite beds may be faintly laminated, whereas laminated dolomitic limestone beds are locally absent. Fossil fragments are similar to those found in the basal unit.

The middle unit of the Hanson Creek Formation, unit 3, is a sequence of alternating carbonaceous micritic limestone beds. This unit, which is the main host for gold mineralization in the Enfield Bell Mine (fig. 4), has been measured at more than 90 m thick in exposures in the southern part of the district. Chert beds, generally less than 0.1 m long and 2 cm thick, occur sporadically in the lower part of the unit. Fossils recognized in this unit are similar to those in the lower two units, with the addition of trilobite fragments. Studies have shown that gold mineralization favors the more permeable laminated beds, which occur locally in tenfold greater abundance than in the micrite beds.

Overlying unit 3 is a varyingly textured, 30-m-thick unit of limestone - unit 2. Four different rock types have been recognized in this unit: (1) thick-bedded limestone, (2) wavy thin-bedded to nodular limestone, (3) oolitic limestone, and (4) wavy-laminated limestone. The rock is weak to noncarbonaceous, weakly pyritic, and locally is entirely composed of dolomite. Fossils are fairly evenly distributed and resemble those recognized in the lower three units; however, trilobite fragments have not been recognized in this unit.

The uppermost unit of the Hanson Creek Formation, unit 1, is composed of 3 to 40 m of interbedded black chert and carbonaceous limestone. Chert beds are more consistent than in units 3, 4 or 5, and may exceed 1 m in length and 5 cm in thickness. Pinching and swelling of the chert as a result of soft-sediment deformation is common. Sponge spicules, radiolarians, and the absence of diagenetic-replacement textures suggest a sedimentary, nondiagenetic origin for the chert. The limestone beds, which are thicker than the chert beds, compose as much as 75 percent of the measured thickness near the base of the unit. Both laminated and nonlaminated limestone beds have been recognized.

The contact between the Roberts Mountains and Hanson Creek Formations appears to be disconformable, a contention that was also supported by the work of Matti and others (1975). Whereas previously published reports (Mullens and Poole, 1972; Merriam and McKee, 1976) placed the uppermost unit of the Hanson Creek Formation as part of the overlying Roberts Mountains Formation, Freeport Gold Co. geologists cite the sharpness of the contact between this uppermost unit and siltstone of the Roberts Mountains Formation, as well as the similar textures and mineralogy within the five units of the Hanson Creek Formation, as evidence that the uppermost unit, 1, more properly belongs within the Hanson Creek Formation.

The Roberts Mountains Formation of Middle Silurian to Early Devonian age (Matti and McKee, 1977) is exposed throughout the Jerritt Canyon district. The basal 30 m of this formation is host to gold mineralization in the Enfield Bell Mine (fig. 4). The estimated thickness of the Roberts Mountains Formation is 300 m; however, the uppermost part has been truncated by the Roberts Mountains thrust, which forms the upper contact of the formation. The major rock type of the Roberts Mountains Formation is laminated, fissile, varyingly calcareous to dolomitic siltstone. The rock is composed of well-rounded, well-sorted quartz silt grains, with carbonate as cement. Accessory minerals include illite-sericite, chlorite, anastamosing carbon filaments, disseminated pyrite, and a distinctive heavy-mineral suite. Black lenses composed of carbon, pyrite euthedra, and fibrous chalcedony, 0.5 cm thick and 2 to 5 cm long, oriented parallel to bedding, are common in the basal part of the formation. Fossils are rare and are limited to graptolite molds on parting surfaces.

A 10- to 15-m-thick bed of laminated to thin-bedded silty limestone occurs near the base of the formation. The more fissile siltstone beds commonly weather into small platy fragments and form gradual slopes, whereas the silty limestone unit is more resistant and can be traced in outcrop for hundreds of meters along strike.

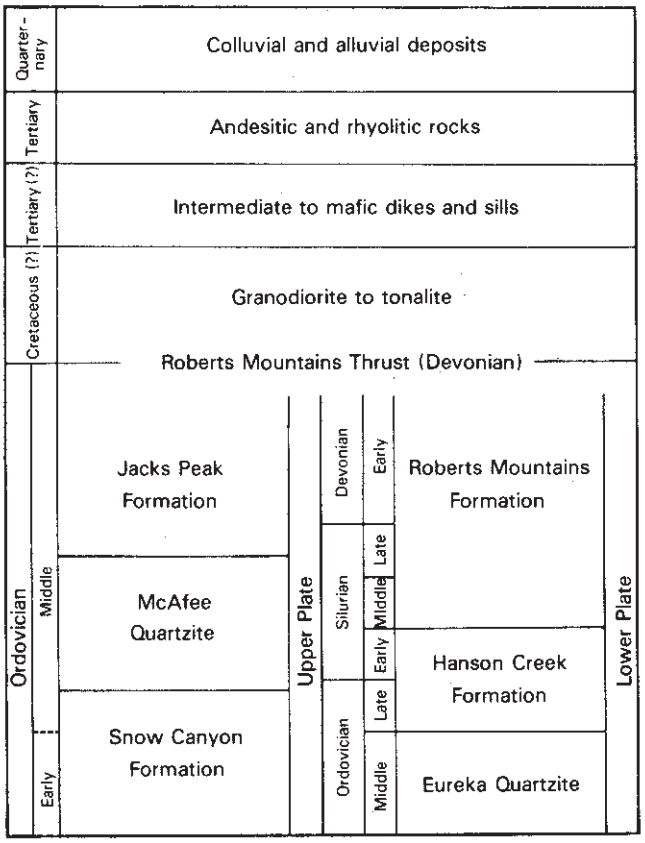

FIGURE 3. Stratigraphic section of the Jerritt Canyon district. Stratigraphy for upper-plate rocks for Churkin and Kay (1967), and for lower-plate rocks from Mullens and Poole (1972), Matti and others (1975), and Merriam and McKee (1976).

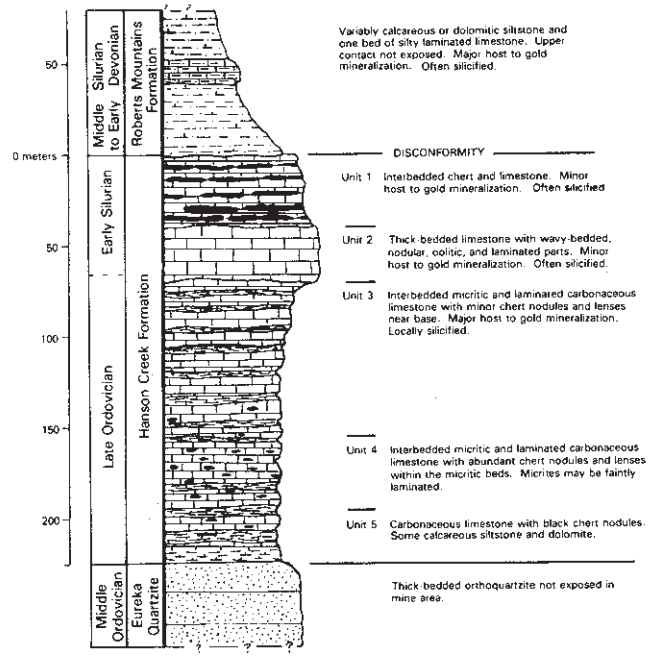

FIGURE 4. Generalized stratigraphic section of lower-plate rocks in the Enfield Bell Mine area.

UPPER-PLATE ROCKS

The upper-plate rocks (western facies) in the Independence Mountains have been correlated with eugeosynclinal rocks of the Ordovician Valmy Group (Churkin and Kay, 1967). Three formations of Ordovician age are recognized locally, in ascending order: the Snow Canyon Formation (Early and Middle Ordovician), the McAfee Quartzite (Middle Ordovician), and the Jacks Peak Formation (Middle Ordovician).

Whereas exposures of the McAfee Quartzite and Jacks Peak Formation are limited to the northern-most part of the Jerritt Canyon district, the Snow Canyon Formation commonly flanks lower-plate rocks throughout the district. Only the Snow Canyon Formation is described here.

The rocks that compose the Snow Canyon Formation in the Jerritt Canyon district are predominantly siliceous sedimentary rocks, estimated at 350 m thick (Churkin and Kay, 1967). Except for the more resistant members, the Snow Canyon does not crop out well and forms smooth, talus-covered slopes.

Shale, fissile siltstone, and argillite form the bulk of the Snow Canyon section. These rocks are carbonaceous and much less calcareous or dolomitic than those of the Robert Mountains Formation. Weathered exposures show a characteristic orange-brown staining. Bedding generally is very wavy and contorted, and soft-sediment-compaction features are common. Graptolite molds are locally abundant.

Interspersed with the clastic rocks are multicolored, wavy chert beds that exhibit a knobby texture on their bedding planes, referred to locally as cobblestone texture. Bedding is generally less than 10 cm thick. Bedded gray barite locally occurs with the chert.

Discontinuous layers of gray to brown quartzite, generally less than 3 m thick, occur within the finer grained clastic sequence. A thicker quartzite unit, with scattered shale horizons, apparently caps the Snow Canyon Formation. Both types of quartzite are composed of quartz sand grains and scattered pyrite, cemented with silica or carbonate. Carbon and random quartz veinlets are recognized locally. Crossbedding, though sparse, has been observed in the thinner quartzite and siltstone beds.

Mafic pillow lavas occur with the Snow Canyon Formation, sandwiched between argillaceous-rock sequences, Chert and limestone can be found sporadically with the lavas. The limestone beds occur between successive pillow structures. Alteration of these lavas has changed the primary minerals to chlorite, sericite, and carbonate. Phenocrysts of plagioclase and pyroxene commonly are totally altered to calcite.

Limestone is the least continuous rock type in the Snow Canyon Formation. Besides occurring within altered mafic lavas, limestone has been recognized interspersed with laminated chert, shale, and siltstone. A section of shaly carbonaceous limestone capped by a cliff-forming intraformational limestone breccia apparently occurs near the base of the formation on the west margin of the Enfield Bell Mine area.

GEOLOGY OF THE ENFIELD BELL MINE

The Enfield Bell Mine is located in the northern part of the Jerritt Canyon window, in an area approximately 3,300 m long east-west by 1,200 m wide north-south (fig. 2). The mine comprises four known ore deposits, in order of decreasing size: the Marlboro Canyon, North Generator Hill, West Generator Hill, and Alchem deposits. Current reserves are 13.7 million tons (12.5 million t) at an average grade of 0.199 troy oz Au per ton (7.03 g Au/t), occurring in both oxidized and carbonaceous sedimentary rocks. Mineralization is structurally and lithologically controlled with the upper banded limestone of the Hanson Creek Formation, unit 3, and the lower siltstone of the Roberts Mountains Formation (fig. 4). Lesser amounts of ore occur in silicified sections of both formations. Small slices of geochemically barren upper-plate rock have been recognized in the Marlboro Canyon pit. Gold currently is being mined from Marlboro Canyon and a part of North Generator Hill known as Lower North Generator Hill (fig. 2).

STRUCTURE

Faulting is common in the Enfield Bell Mine area and is the most important structural feature related to mineralization; folding may have been contemporaneous with a premineral set of faults. The four sets of faults in the Enfield Bell Mine area range in age from Devonian to Tertiary. The oldest faults are the Roberts Mountains thrust and sympathetic subparallel low-angle normal and reverse faults with the upper- and lower-plate assemblages. The presence of imbricate low-angle faults became evident when detailed mapping revealed reversals and truncations of stratigraphy along brecciated low-angle shears.

East-west-trending faults are the next-younger set of major faults in the mine area. These faults are cut by younger northwest- and northeast-trending faults. The ages of these three fault sets are somewhat equivocal; however, the east-west-trending system is postulated to have formed first during the Mesozoic, with an overprint of Tertiary motion. One such fault is the Snow Canyon fault (Hawkins, 1982), which occurs immediately north of the mine area (fig. 1). Smaller scale east-west-trending faults within the mine area are the Marlboro Canyon Fault in the Marlboro Canyon ore body, the Bell and L.N.G. faults in the Lower North Generator Hill ore body, and the Ridge fault, which forms the north boundary of the Jerritt Canyon window (fig. 2).

Figures 5A and 5B show typical cross sections through the Lower North Generator Hill and Marlboro Canyon deposits that illustrate the characteristics of the Bell and Marlboro Canyon faults, which were the main conduits for mineralization in their respective ore bodies. In each deposit, rocks of the Roberts Mountains and Hanson Creek Formation form the footwall block (north) against rocks of the Hanson Creek Formation in the hanging wall (south). Estimated relative vertical displacement on these faults is 100 m. Both faults dip steeply south but change dip and strike directions over short vertical and horizontal distances. The Marlboro Canyon fault changes strike in the western part of the Marlboro Canyon ore body to more northeasterly, whereas the Bell fault changes strike to northeasterly in the east end of the Lower North Generator Hill ore body (fig. 2). Both faults became shallower in dip on progressively deeper mine levels.

The L.N.G. fault is also an east-west-trending fault that may have formed as a result of uplift along the Bell fault; it appears, for the most part, to be a bedding-plane fault. This fault, which dips gently south, is believed to have formed as a result of slippage along the boundary between silicified and unsilicified part of the Hanson Creek Formation. The amount of displacement on the L.N.G. fault changes to a northwesterly strike on the east side of the Lower North Generator Hill ore body (fig. 2).

After formation of the Marlboro Canyon and Bell faults, the high-angle northwest-and northeast-trending faults were formed during Basin and Range tectonism. Mapping evidence of active mine faces suggests that the northeast-trending faults postdate the northwest-trending faults. However, the fact that the northwest-trending P.J. fault in the North Generator Hill deposit cuts both east-west- and northeast-trending faults indicates that some of the northwest-trending faults postdate the northeast-trending faults. Although the genetic relations of faulting in the mine area are still equivocal, all the faults are interpreted to predate gold mineralization. Ore coincides with faults and blossoms at fault intersections. Figure 6, a geologic map of a typical ore bench in the Lower North Generator Hill pit, shows the relation of these structures.

The Map anticline, a southwest-plunging asymmetric fold that occurs between the North Generator and Marlboro Canyon ore bodies (fig. 2), is believed to have formed as a result of thrusting. The western limb of this fold strikes west-northwest and dips south-southwest, whereas the eastern limb strikes north-northeast and dips east-southeast. Dips on each limb range from 25° to 65°; the eastern limb is the steepest. The fold limbs are delineated by dipping beds of jasperoid, which can be readily seen in aerial photographs.

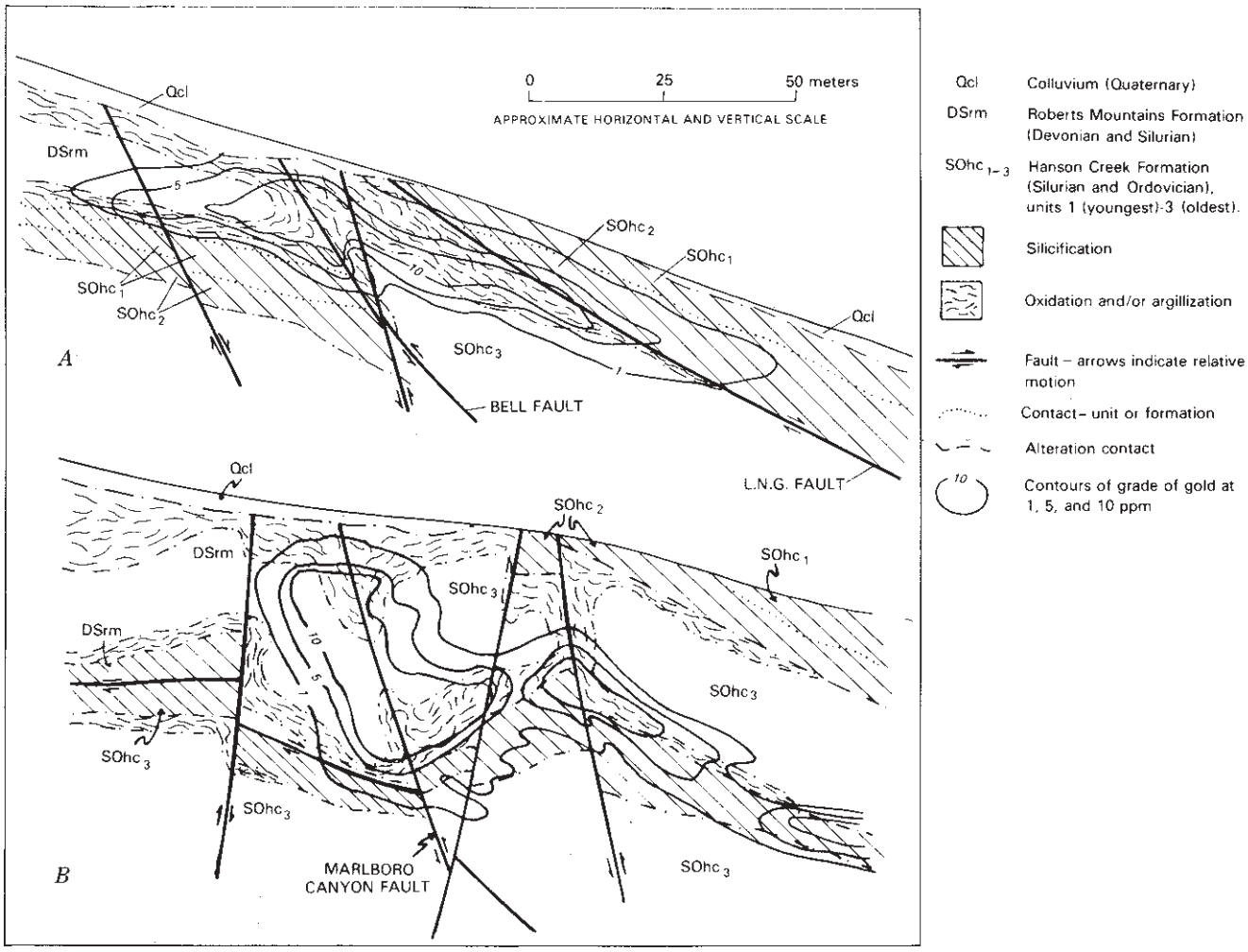

FIGURE 5. A, north-south cross section through the central part of the Lower North Generator Hill deposit. Contours of gold grade are 1, 5, and 10 ppm. B, north-south cross section, looking eastward, through the central part of the Marlboro Canyon ore body. Gold mineralization is strongly structurally controlled, with greater vertical than horizontal continuity. Contours of gold grade are 1, 5, and 10 ppm.

ORE BODY MORPHOLOGY

The ore in the Endfield Bell Mine occurs in two distinct modes. The largest ore zone, containing the most continuous and highest grades of gold, are elongate, steeply to moderately dipping tabular zones (Marlboro-type ore zones), which are typical sites for ore deposition in North Generator Hill and in most of Marlboro Canyon. The second type of ore zone (Alchem-type ore zone) is also tabular but is associated with low-angle faults, commonly containing stratiform jasperoid bodies. The bulk of the ore tonnage in the western Marlboro Canyon, Alchem, and West Generator Hill deposits are from Alchem-type ore zones.

Figure 5B shows a cross section of a typical Marlboro-type ore zone. A mushroom-like appearance is created by gold values increasing in large increments from the surface downward, tapering off more gradually below the main ore intervals. Figure 7 shows a typical cross-sectional view of an Alchem-type ore zone. The ore occurs in both unsilicified and silicified parts of the Roberts Mountains Formation and in silicified sections of the underlying Hanson Creek Formation. The contact between these two formations is interpreted to be, at least in part, a low-angle fault. The best ore grades occur in rocks of the Roberts Mountains Formation, and the ore zone may be highly undulatory.

Gold in both types of ore zones is disseminated in the rock - quite typical of ore zones observed in other deposits, such as Carlin. Gold grains observed in thin section may exceed 5 μm in diameter but are generally smaller than 2 μm. Where large enough to be observed petrographically, gold grains commonly are spatially associated with geothite, which may be pseudomorphic after pyrite.

ALTERATION

Three major hydrothermal events have altered the rocks of the Enfield Bell Mine: (1) silicification, (2) oxidation and argillization, and (3) carbonization. Silicification, the predominant event, resulted in alteration of the limestone to hard, dense, varicolored jasperoid. The jasperoid bodies in the mine area stand out in strong relief from the surrounding terrain and are approximately tabular in shape. Although about 35 to 40 percent of the rocks in the mine area are jasperoid, jasperoid constitutes less than 10 percent of the ore. The degree of silicification recognized in the mine area ranges from scattered quartz veining to complete replacement of the carbonate fraction. Silicification has affected rocks of both the Roberts Mountains and Hanson Creek Formation but is more intense in limestone of the Hanson Creek Formation. Mine mapping suggests that all but, possibly, the latest phase of silicification occurred before Tertiary block faulting. Jasperoid can be seen in razor-sharp contact against unsilicified rocks, horizontally juxtaposed along high-angle faults. The nearly stratiform

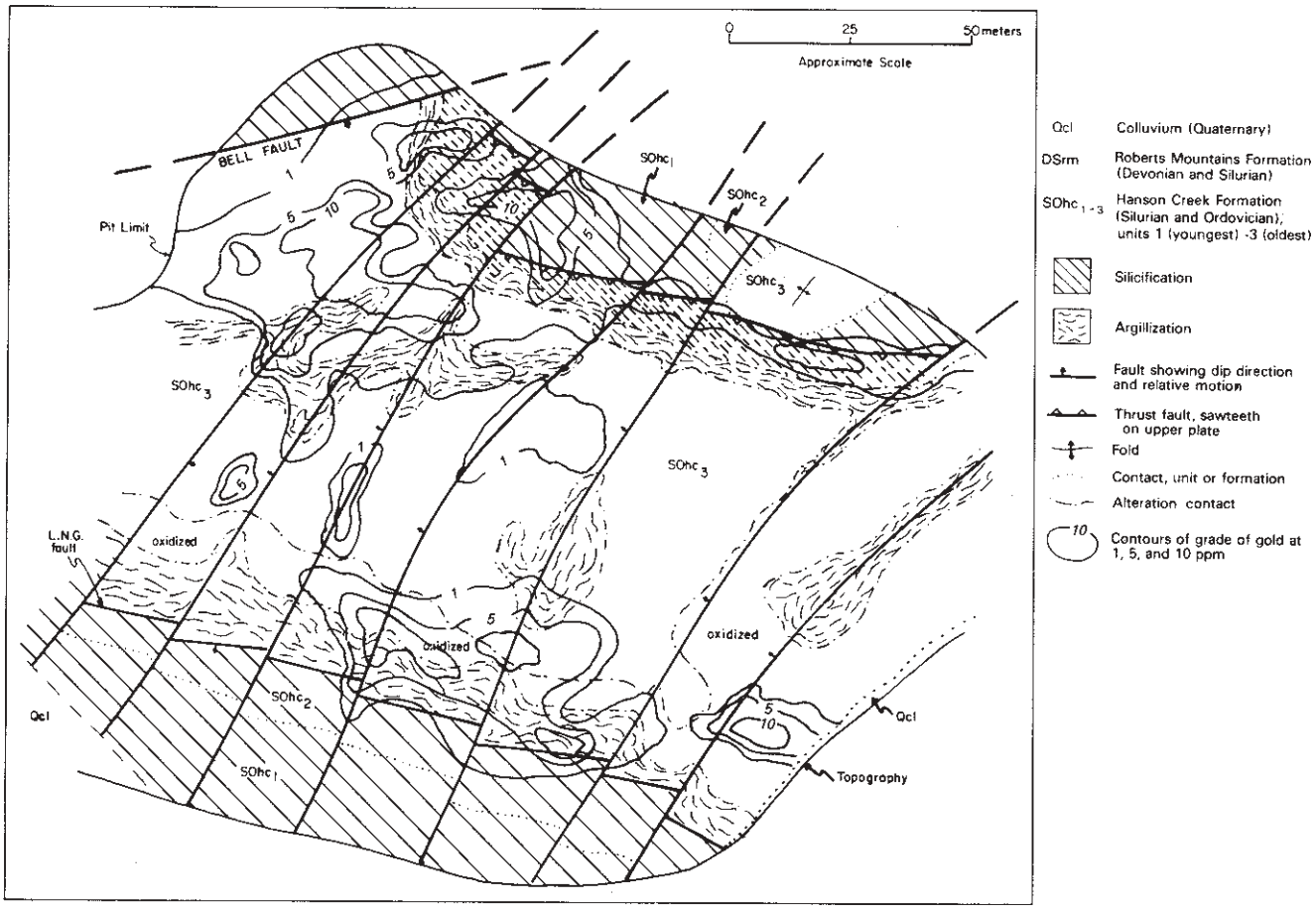

FIGURE 6. Geologic map of a typical mine level in the Lower Generator Hill ore body.

appearance of the jasperoid bodies is interpreted to be the result of silicification along low-angle faults as well as replacement of chemically favorable rock types. The major stage of silicification that formed the jasperoid bodies is also believed to predate gold mineralization. Gold values occur in silicified and unsilicified rocks on either side of high-angle faults. Gold mineralization does not normally occur in ore-grade concentrations in jasperoid and generally is homogeneously distributed and of lower grade relative to the range of values found in the main ore zones. Locally, the jasperoid bodies may host gold mineralization higher than 30 ppm, but generally it ranges from less that 0.05 to 1.5 ppm.

Oxidation and argillization may be the most economically important alteration events to have taken place in the Enfield Bell Mine area; the oxidized and argillized rocks contain the highest gold values and are relatively easy to treat with conventional cyanidation techniques of gold recovery. These two types of alteration coincide spatially and are believed to have similar, but not necessarily contemporaneous genesis. Oxidation of the Roberts Mountains Formation produced a tan to light-orange-brown semifriable siltstone. Pyrite grains are well oxidized to limonite and geothite, and carbon is generally absent. The rock may also be noncalcareous, owing to associated but limited decalcification. Oxidation with the Hanson Creek Formation is similar to that recognized in the Roberts Mountains Formation, except for (1) local oxidation of black, carbonaceous chert lenses and beds to light-brown chert or black chert with brown rims, and (2) preferential oxidation of the more permeable laminated beds of unit 3 of the Hanson Creek Formation. Again, as in the Roberts Mountains Formation, oxidation of the Hanson Creek Formation may have been accompanied by decalcification.

Argillization of the Enfield Bell Mine rocks took place along structurally controlled zones and is considered an advanced, more localized stage of the oxidation process. This alteration produced clay-rich zones within the Hanson Creek and Roberts Mountains Formations that are highly tabular, with greater vertical than horizontal continuity. Their shape is due to formation along high-angle structures, such as the Marlboro Canyon and Bell faults, where argillized Hanson Creek limestone occurs against argillized Roberts Mountains siltstone (fig. 5A, 5B). Argillization is also recognized in rocks directly above and below jasperoid bodies. One such occurrence is along the L.N.G. fault, where argillized and oxidized Hanson Creek limestone forms the footwall of the fault against unargillized jasperoid in the hanging wall (fig. 5A). Whereas primary rock textures are commonly preserved in the argillically alteration minerals are kaolinite, sericite, illite, smectite, alunite, jarosite, quartz, and iron oxide; carbonate, pyrite and carbon are rare. Gold values in the argillized and oxidized rocks range from less than 0.05 to more than 150 ppm; the highest gold value measured to date was within argillized Roberts Mountains siltstone, assaying 685 ppm.

Most of the observed effects of oxidation and argillization are believed to have formed nearly contemporaneously after silicification. Argillized rock grades into oxidized rock, whereas razor-sharp contacts between argillized and silicified or carbonaceous rock have been observed. Some oxidation may have occurred before argillization and silicification, as evidenced by oxidized, decalcified, unsilicified beds of limestone interbedded with silicified limestone.

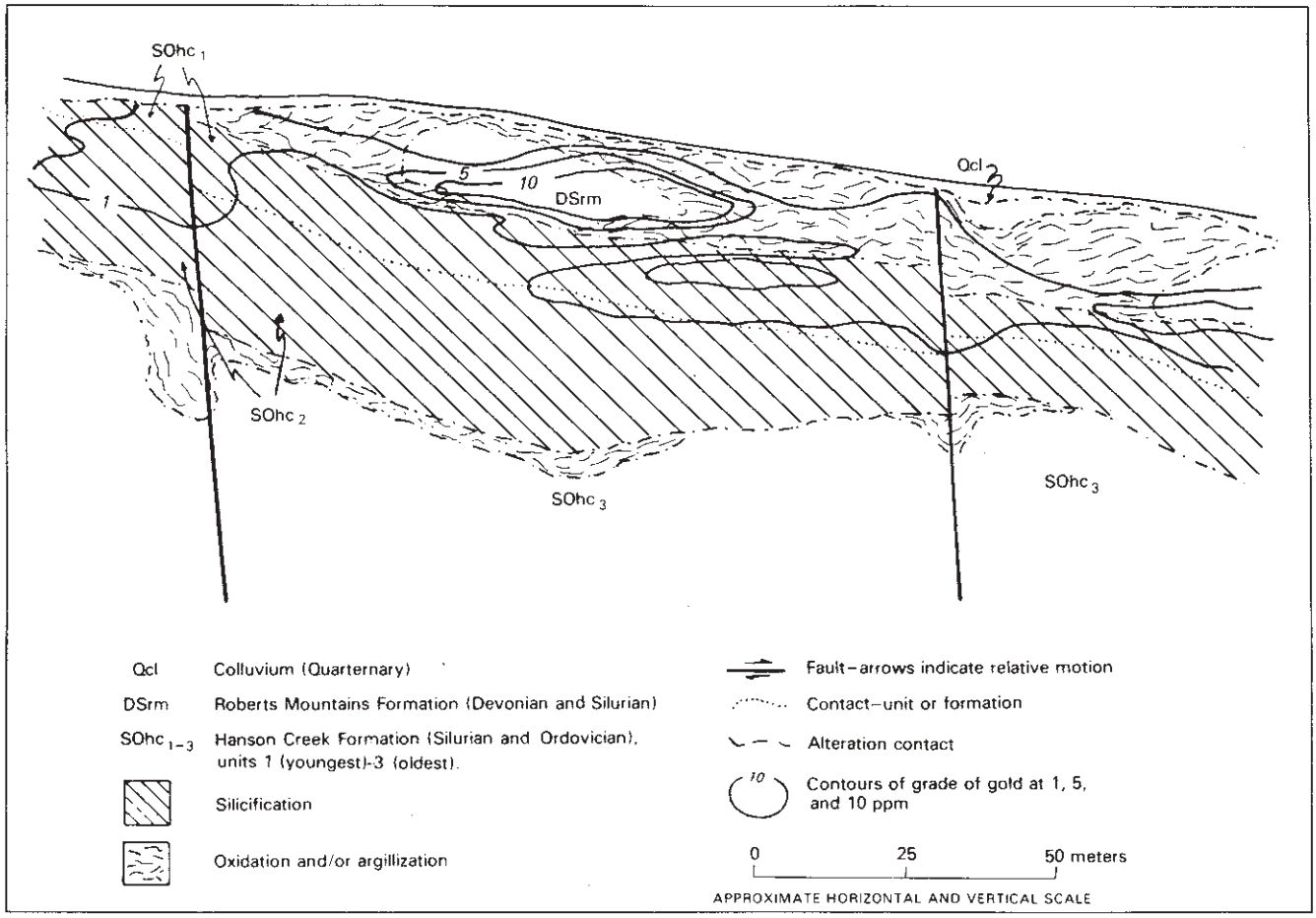

FIGURE 7. North-south cross section through the western part of the Marlboro Canyon ore body, showing the stratiformity of gold mineralization in an Alchem-type or zone. Contours of gold grade are 1, 5, and 10 ppm.

Replacement of carbonate by silica normally results in a highly impermeable rock that would resist the effects of oxidation and argillization.

Carbonization of the rocks in the Enfield Bell Mine area is strongly controlled by structure. Carbonization produced black, sooty carbonaceous zones within much less carbonaceous or oxidized rock. High-and low-angle fault zones may have localized the carbon. Commonly the carbonized rock is sheared and may be host to realgar and orpiment. It is believed that primary sedimentary hydrocarbons migrated or were concentrated in the highly permeable fault zones, possibly through the action of large-scale pressure solution. Gold values within the remobilized carbon zones may be high along main ore trends, generally ranging form less that 0.05 to 35 ppm. Locally, values of more than 150 ppm have been detected.

ACCESSORY MINERALOGY

Several gangue minerals occur in the rocks of the Enfield Bell Mine, some of which locally are excellent indicators of gold mineralization, whereas others are simply indicate hypogene activity on a district-wide scale. The most reliable mineralogic indicators of gold mineralization are realgar and orpiment. Realgar is by far the most abundant arsenic mineral, whereas orpiment occurs as an oxidation of realgar. Minor arsenopyrite has been detected through x-ray diffraction. Realgar and orpiment are found in carbonaceous rock in veins, intermixed with white sparry calcite, as veins in carbonaceous rocks, and as small scattered grains with remobilized carbon along fractures and shears. Although arsenic minerals have not been recognized in completely oxidized or argillized rock, significant arsenic values have been detected. District-wide geochemical arsenic values range from traces to more than 1,000 ppm; higher concentrations are generally associated with higher gold grades.

Cinnabar is also a good indicator of gold mineralization, although it is far less abundant than the arsenic minerals. Dull blood-red grains of cinnabar have been found disseminated in high-grade ore zones. District-wide geochemical analyses have yielded mercury values from traces to more than 50,000 ppb. The highest mercury values are invariably associated with high arsenic values in remobilized carbon zones, where cinnabar may be found finely disseminated with realgar and orpiment.

Barite and stibnite constitute the rest of the volumetrically important accessory minerals. Although they are not reliable indicators of gold mineralization, these two minerals are abundant in the mine area, where they are almost entirely restricted to jasperoid bodies. Barite occurs as euhedral encrustations on fractures or in vugs, as thin white veinlets, or as massive mosaic-textured pods and veins in jasperoid bodies and, less commonly, in oxidized siltstone. Euhedral dipyramidal barite crystals, as much as 10 cm long, have been found in clay-filled vuggy zones in jasperoid. Although barite may be locally abundant, the geochemical data for barium distribution are inconclusive.

Stibnite forms euhedral acicular crystals in radiating clusters or vein fillings of anhedral to subhedral grains. Veins of stibnite range from less than 1 to more than 15 cm in width. Stibnite and barite are commonly found inter-

mixed, and mantling of stibnite with barite in some occurrences indicates a slightly earlier deposition for stibnite. Alteration of stibnite through hypogene and supergene process formed three common antimony oxides as rims or complete replacements of stibnite crystals: stibiconite ($H_2Sb_2O_5$), valentinite (Sb_2O_3), and kermesite (Sb_2S_2O). Both stibnite and antimony oxides have been observed as coatings and encrustations on euhedral quartz crystals. Geochemical antimony values from traces to as much as 500 ppm have been detected district-wide. Some native sulfur crystals occur with stibnite, presumably as a more advanced oxidation product of the stibnite.

Other accessory minerals that have been recognized either megascopically, microscopically, or with x-ray diffraction are calcite, jarosite, alunite, variscite, dolomite, lepidocrocite, collophane, possible scorodite ($FeAsO_4 \cdot 2H_2O$), and dusserite $BaFe_3(AsO_4)_2 \cdot 2(OH)_5$. Except for calcite and jarosite these minerals are only sparse, and it is equivocal whether they formed through hypogene processes. Calcite is more commonly found as white blocky veins in Hanson Creek limestone and in lesser amounts in Roberts Mountains siltstone or in jasperoid bodies. Botryoidal encrustations of calcite (travertine?) occur in vugs in oxidized limestone or jasperoid bodies and can contain as much as 1.5 ppm of gold. Jarosite, which is a fairly common constituent of argillized rock, also occurs as small cinnamon-brown crystals on fracture surfaces in silicified and unsilicified rock.

Base-metal sulfides have not been observed in the Enfield Bell Mine area, although they have been reported in other disseminated gold deposits (Harris and Radtke, 1976). Anomalous geochemical values of copper, lead, and zinc have been obtained from surface samples in the Enfield Bell Mine area.

Silver values in the Enfield Bell Mine are typical of those in other disseminated systems and range from less than 0.05 to 1.5 ppm. Typically the Au/Ag ratio exceeds 20:1. Data on other common trace elements, such as Mn, Tl, or W, are inconclusive.

SUMMARY AND CONCLUSIONS

Gold mineralization in the Jerritt Canyon district and the Enfield Bell Mine is hosted within carbonaceous and oxidized parts of autochthonous lower-plate rocks of the Roberts Mountains thrust. Thrusting and associated imbricate low-angle faults provided excellent pathways for the movement of hydrothermal fluids, especially where intersected by high-angle faults. These conduits allowed the gold-bearing fluids to migrate upward into structurally and chemically favorable horizons. Alteration events, such as silicification, oxidation, argillization, and carbonization, occurred during the hypogene history of the deposit, though not necessarily contemporaneously with gold mineralization. A preliminary genetic sequence for the Enfield Bell Mine ore bodies is as follows: (1) deposition of Paleozoic miogeosynclinal and eugeosynclinal rocks in separate basins; (2) thrusting and folding of eugeosynclinal rocks over the miogeocline during Antler tectonism; (3) high-angle faulting during the Mesozoic; (4) small-scale oxidation of parts of the lower-plate rocks; (5) silicification of the lower-plate rocks to form jasperoid bodies; (6) high-angle block faulting during the Tertiary, possibly contemporaneously with intrusive activity; (7) formation of zones of remobilized carbon; (8) deposition of gold; (9) oxidation and argillization of carbonaceous rocks; and (10) deposition of stibnite, barite, realgar, and orpiment.

Although many questions on the hydrothermal history of the Jerritt Canyon district remain to be answered, continued production and exposure of the ore body are still adding to the knowledge gained thus far.

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GENERAL GEOLOGY OF THE MAGGIE CREEK GOLD DEPOSIT, EUREKA COUNTY, NEVADA

by Charles E. Ekburg
Carlin Gold Mining Co., Carlin, NV

INTRODUCTION

The Maggie Creek Mine is located on the southeast flank of the Carlin window in the Maggie Creek mining district, 9 miles north of the town of Carlin, Nevada (fig. 1). Exploratory drilling was initiated by the Carlin Gold Mining Co. late in 1977. Development drilling began in the spring of 1978 and continued until the fall of 1979. Mining of the Maggie Creek deposit began in July 1980.

The Maggie Creek deposit is divided into the main pit and the west pit (fig. 2). Gold mineralization in the main pit is continuous for 2,400 feet and is from 200 to 600 feet

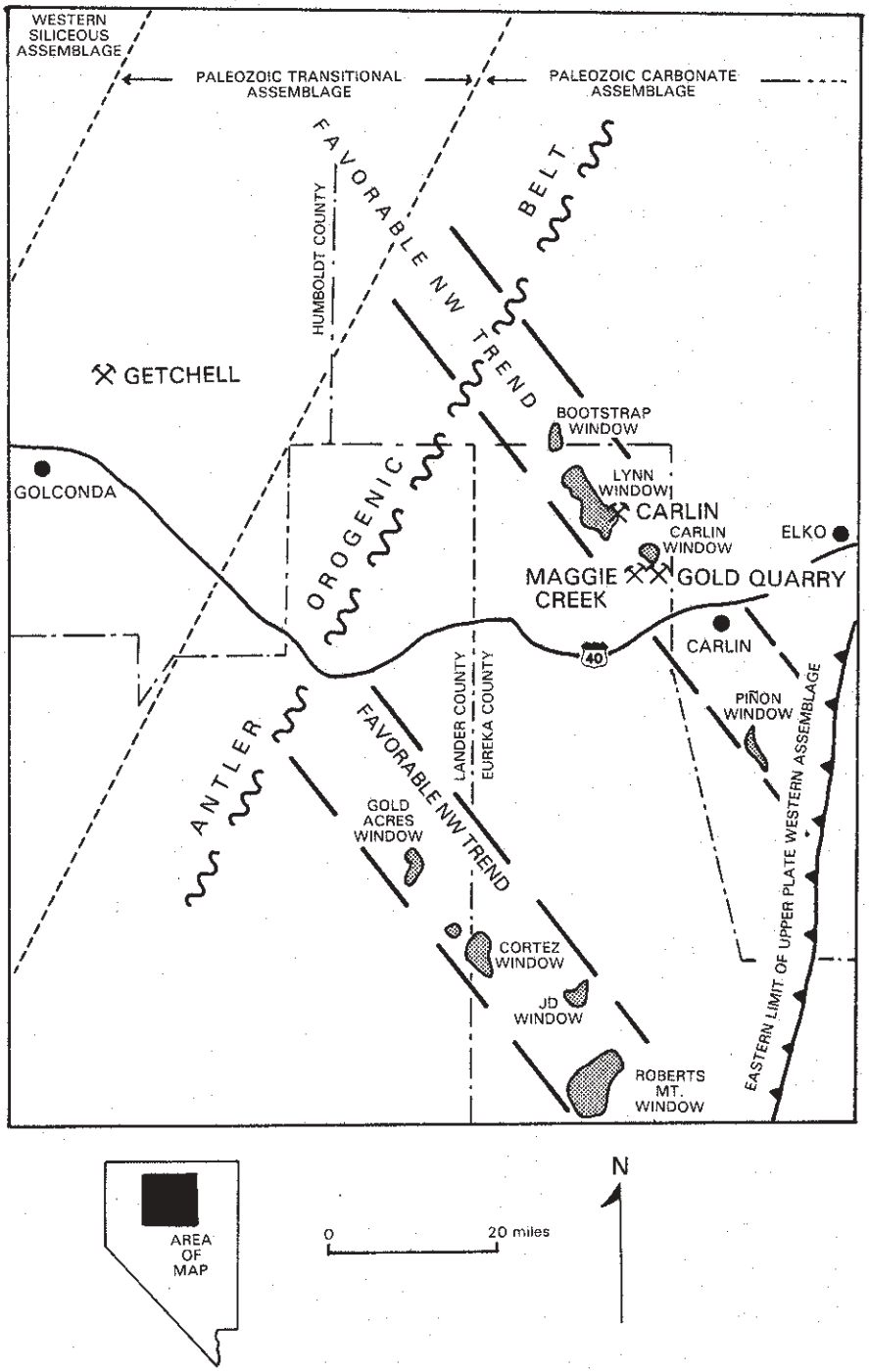


FIGURE 1. Map showing location of favorable northwest trends of gold mineralization, Maggie Creek Mine, and windows in the Roberts Mountains thrust sheet.

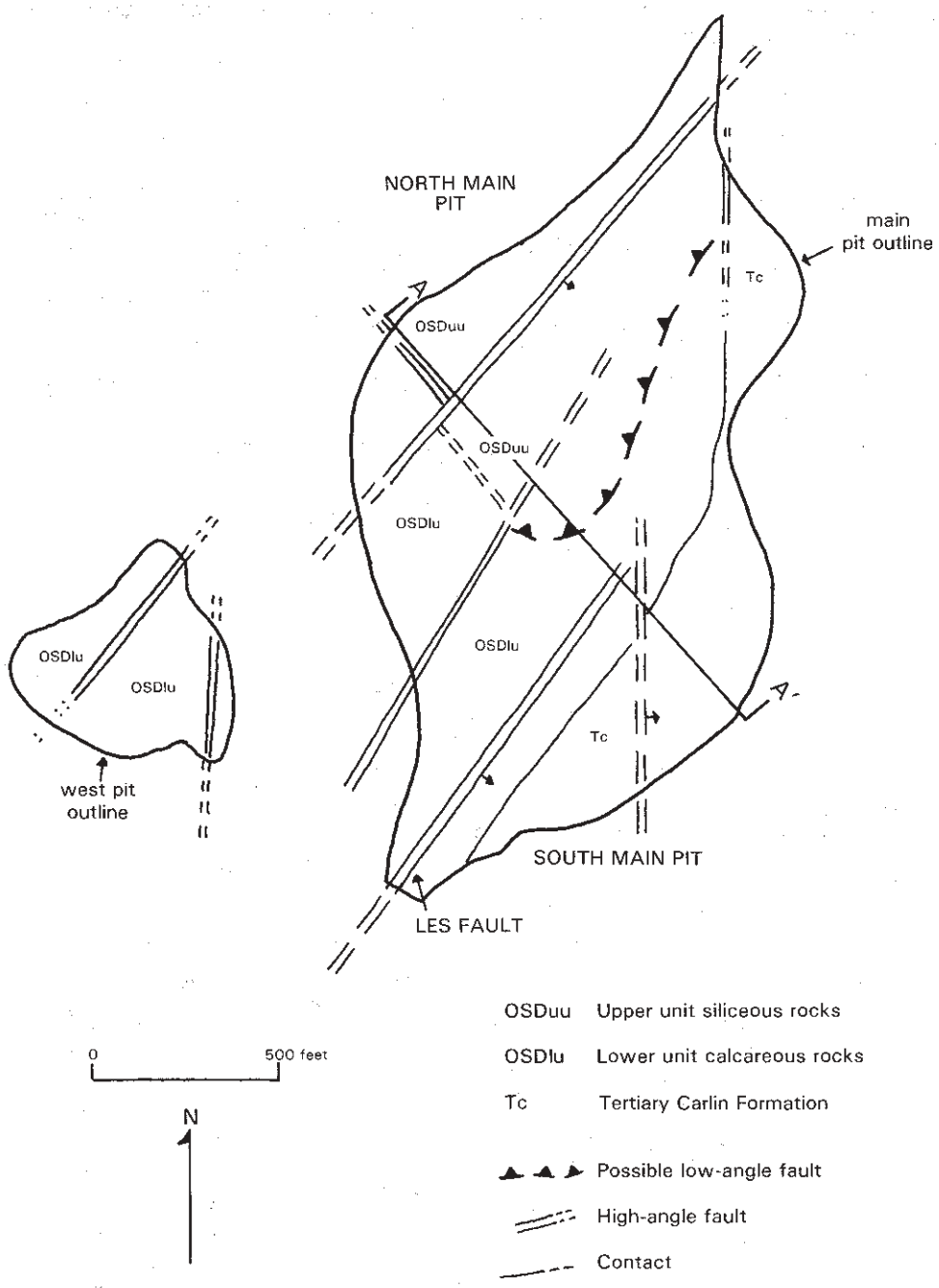


FIGURE 2. Simplified geologic map of the Maggie Creek deposit.

wide. The main pit is divided into two areas: 1) the south main zone, in which gold mineralization occurs in silty argillaceous limestone and sandstone of a lower calcareous unit, and 2) the north main zone, in which gold mineralization occurs in siltstone, chert, and shale of an upper siliceous unit (fig. 2). The west pit is isolated from the main pit. It is equidimensional in plan and is about 400 feet across.

STRATIGRAPHY

Rocks in the Maggie Creek area consist of Ordovician to Devonian sedimentary rocks capped by Tertiary volcaniclastic rocks and lacustrine and gravel deposits (fig. 2).

The Paleozoic rocks, which are part of the upper plate of the Roberts Mountains thrust sheet, are divided into a calcareous lower unit and a siliceous upper unit. The lower unit includes argillaceous, silty, variably dolomitic limestone, siltstone, and some interbedded sandstone. The upper unit consists of thin-bedded chert, shale, and siltstone similar to the Vinini Formation near the Carlin Mine. A low-angle contact between the upper and lower unit appears, in places, to be conformable and, in other places, to be unconformable.

The early Pliocene Carlin Formation overlies the Paleozoic rocks. Regnier (1960) described the Carlin as predominantly soft, tan to reddish, muddy, tuffaceous sandstone and siltstone interbedded with conglomerate, with sub-

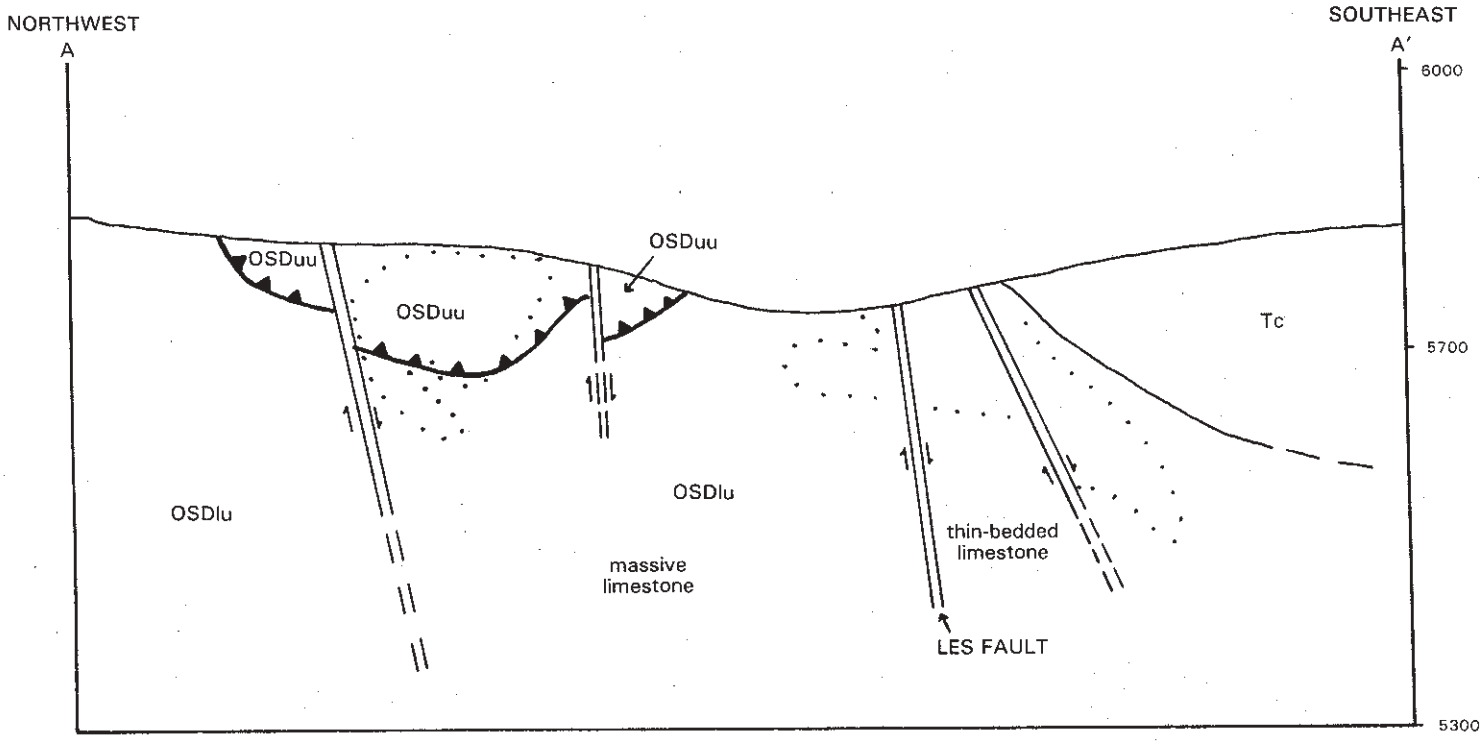
ordinate vitric tuff and ash, diatomite, limestone, and calcareous shale. The clay (montmorillonite) content of these lake-deposited sediments is considerably higher near the Maggie Creek area. Most of the clays appear to have been derived from water-laid tuffs and could represent younger members of the Carlin Formation. Adjacent to the ore zones, some of the clays have been derived from the erosion of the hydrothermally altered Paleozoic units. The erosion of these mineralized clays gives the appearance of mineralization in the clayey units; however, the clayey units postdate the gold mineralization.

STRUCTURE

High-angle faulting played a key role in the formation of the Maggie Creek deposit. The predominant ore control is the Gold Quarry fault system, which is defined as the northeast-trending major fault forming the southeastern boundary of the Carlin window, and a group of minor sympathetic faults and fractures, most of which trend northeasterly. Alteration and mineralization in the Maggie Creek deposit are controlled by these steeply dipping fault structures and by more gently dipping, permeable horizons. Mineralization in the south main zone is controlled by a normal fault that strikes approximately N30°E and dips steeply southeastward. This fault, called the Les fault, appears as wide breccia zone separating thin-bedded argillaceous limestone in the hanging wall from massive limestone in the footwall (fig. 3). Solution activity is strongly evident along its strike. Beds that dip gently to the southeast also control ore occurrence, but to a lesser degree. Mineralization in the north main zone is controlled by a N55°E fault that also dips steeply to the southeast (fig. 3). Stratigraphic ore control is much more evident in the north main zone than the south main zone.

ALTERATION

Both the upper and lower sedimentary units have undergone considerable lithologic changes in areas of mineralization and hydrothermal alteration. Impure limestone of the lower unit has been decarbonatized to siltstone and shale. More advanced stages of decarbonatization are accompanied by silicification to form silicified siltstone and chert. Alteration of siltstone, shale, and chert in the upper unit is typified by silicification in the form of replacements, space fillings, and quartz veinlets. Argillization is present in both the upper and lower units. Illite is the major alteration clay mineral, with lesser amounts of kaolinite and montmorillonite.



0 200 feet

OSDuu Upper unit siliceous rocks

OSDlu Lower unit calcareous rocks

Tc Tertiary Carlin Formation

Possible low-angle fault

High-angle fault

Contact

Outline of ore-grade mineralization

FIGURE 3. Simplified geologic cross section (A–A') of the Maggie Creek deposit.

MINERALIZATION

Gold mineralization in the Maggie Creek deposit occurs as fine, native gold particles disseminated within hydrothermally altered sedimentary rocks. There is an association of gold and pyrite in the unoxidized ore. The pyrite ranges in size from 10 to 50 microns and comprises up to about 5 percent of the rock. Carbonaceous ore is mostly found in the west pit, where the depth of supergene oxidation has reached only 60 feet below the surface due to restriction of weathering by a Tertiary capping of clay and gravel. Refractory ore exists in carbon zones as well as in sulfide zones with little or no carbon content. The refractory nature of both zones apparently stems from auriferous pyrite that is not amenable to rapid oxidation.

In oxide ore, visible gold shows a strong affinity for iron oxides. Gold is also known to occur with clays and quartz. No visible gold has yet been found in unoxidized ore, and very little has been detected in Carlin carbonaceous ore. This suggests that in disseminated gold ores, visible particulate gold is the product of supergene movement and agglomeration of submicron-size gold liberated from auriferous pyrite during oxidation.

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GENERAL GEOLOGY OF THE CARLIN GOLD BELT

by H. F. Bonham, Jr.
Nevada Bureau of Mines and Geology, Reno, Nevada

INTRODUCTION

Since 1962, over 14.7 million ounces of gold have been discovered in the Carlin gold belt, which is herein defined as the group of gold deposits that extends from the Dee Mine on the northwest to the Rain deposit on the southeast in Elko and Eureka Counties, Nevada (fig. 1). Included in this group of deposits are the Bootstrap, Gold Strike, Blue Star, Carlin, Maggie Creek, and Gold Quarry Mines.

The deposits in the belt are aligned along a northwest-southeast trend which is also the location of the Bootstrap, Lynn, and Carlin windows in the Roberts Mountains thrust and of the intrusion of numerous dikes, plugs, and stocks of intermediate composition. The intrusive rocks range in age from Jurassic to Miocene (Smith and Ketner, 1976; Morton and others, 1977; Radtke, 1981).

The gold deposits occur predominantly in thin-bedded, argillaceous, carbonate rocks and in calcareous shales of Ordovician to Mississippian age, although significant amounts of gold also occur in argillite, chert, and granitic rocks.

REGIONAL GEOLOGY

Cambrian to Devonian rocks in northeastern Nevada have been divided into two main assemblages, an allochthonous western or siliceous assemblage, and a parautochthonous, carbonate or eastern assemblage. The western assemblage rocks are predominantly chert, pelite, sandstone, greenstone, and minor carbonate. The eastern assemblage rocks consist mainly of carbonate, quartzite, and shale. Economic gold mineralization occurs in rocks of both assemblages.

The western and eastern assemblages are separated by a major regional structure, the Roberts Mountains thrust. The Roberts Mountains thrust is thought to have been emplaced during the Late Devonian and Early Mississippian Antler orogeny (Evans and Mullens, 1976; Stewart, 1980). Ketner and Smith (1982) postulated that the movement on the thrust also occurred during the Mesozoic in northeastern Nevada.

The Cambrian to Devonian rocks of the western and eastern assemblages in the Carlin area are overlain by Mississippian rocks of the overlap assemblage, a sequence of predominantly clastic rocks of flysch provenance derived by erosion of the Antler orogenic belt. The Mississippian rocks in the Carlin area are locally overlain with angular discordance by carbonate and clastic rocks of Pennsylvanian and Permian age.

The Paleozoic rocks are intruded by granodioritic stocks and dikes of Jurassic and Cretaceous age. The intrusive rocks occur in a linear belt which is also the location of the gold mineralization.

Tertiary rocks in the Carlin area include shale, siltstone, intermediate to silicic tuffs and lavas of Eocene and Oligocene age, silicic dikes, plugs, and stocks of Eocene and Oligocene age, mafic and silicic volcanic rocks and tuffaceous sedimentary rocks of Miocene age, and tuffaceous sedimentary rocks of Pliocene and Quaternary age.

GOLD DEPOSITS

Gold deposits in the Carlin gold belt occur in both upper-(western or siliceous assemblage) and lower-plate (eastern or carbonate assemblage) rocks and in granitic rocks. The host rocks at the Dee and Bootstrap Mines are upper-plate argillite and granitic dike rocks. Host rocks at the Gold Strike and Blue Star Mines include upper-plate argillite, chert, carbonate, and granodiorite. The main host rock at the Carlin Mine is thin-bedded carbonate of the Roberts Mountains Formation. The host rocks at Maggie Creek and Gold Quarry Mines are principally upper-plate argillite and carbonate. The Rain deposit at the southeastern end of the belt occurs in argillaceous rocks of the Mississippian Webb Formation.

The ore control in the gold deposits of the Carlin gold belt includes high-angle faults with dominant north, northeast, and northwest trends. The intersection of these high-angle faults with favorable lithologies (thin-bedded, carbonaceous, argillaceous, carbonate rocks) has produced local strata-bound ore bodies.

The ore bodies contain native gold, typically in submicron-size particles, arsenic sulfides, pyrite, stibnite, minor amounts of lead, copper, and zinc sulfides, cinnabar, and locally, a variety of rare thallium minerals (Noble and Radtke, 1978).

Gangue and alteration minerals include locally abundant jasperoid, barite, hydrocarbons, kaolinite, sericite, quartz veins and veinlets, and organic carbon. Minor amounts of anhydrite occur in some ore bodies. Minerals in oxidized ore include dussertite, antimony oxides, gold, barite, and at the Blue Star Mine, turquoise.

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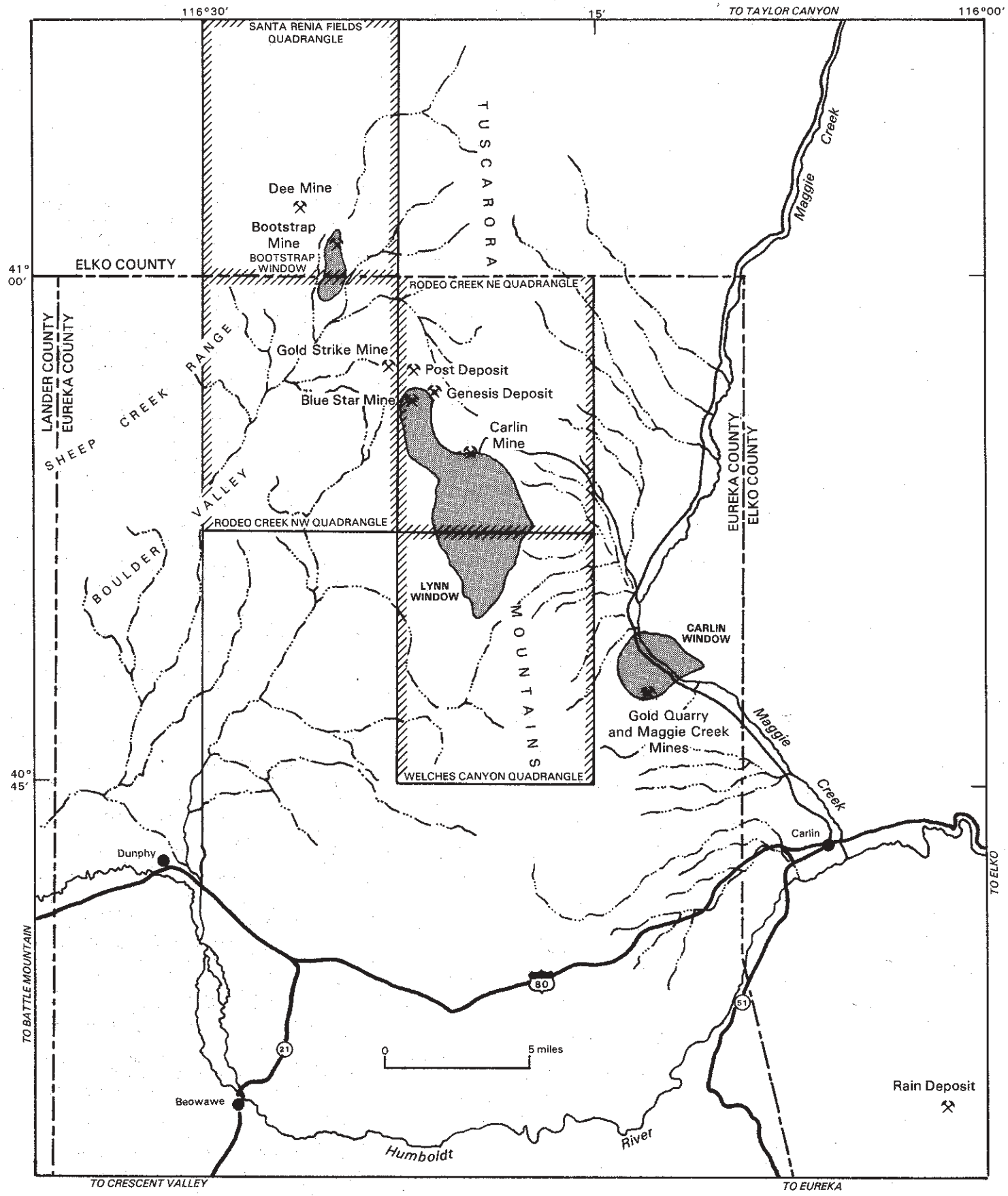

FIGURE 1. Map showing location of gold deposits in the Carlin gold belt in north-central Nevada. (Modified from Evans and Mullens 1976).

THE CARLIN STORY

by Ralph J. Roberts
Winnemucca, NV

In this guidebook dealing with sediment-hosted gold deposits in northern Nevada, it is fitting to include the story of the discovery of the Carlin Mine, first major gold mine of this type (fig. 1). The story involves not only the work of venturesome Newmont Mining Corp. geologists, but includes painstaking studies by many geologists who went before and assembled the geologic framework of northern Nevada.

REGIONAL GEOLOGIC FRAMEWORK

The sediment-hosted gold-bearing deposits in northern Nevada and other parts of Nevada that are known as Carlin-type deposits were localized by complex stratigraphic and structural controls. These controls include Precambrian fracturing, sedimentation in Paleozoic time, orogeny in late middle Paleozoic, latest Paleozoic and early Mesozoic time, and plutonism, volcanism, and faulting in Mesozoic and Tertiary time. There is no single critical control of metallization—all of these events played significant roles.

Among the early workers who participated in unraveling this complex story, Hague (1892) first correctly interpreted the coarse clastic Carboniferous rocks in the Diamond Mountains as evidence of orogeny somewhere to the west. Ferguson (1924) later recognized pre-Permian orogeny near Manhattan in central Nevada. Nolan (1928) played down this orogeny and instead emphasized contrasts in sedimentation between eastern California and eastern Nevada, defining a north-northeast-trending late Paleozoic "high" extending through central Nevada. Eardley (1947) later called this high the "Manhattan geanticline." Within this geanticline in the Roberts Mountains, Kirk (1933) recognized two distinct facies, a deep-water chert–black-shale facies and a shelf-carbonate facies, both of Ordovician age. Later, Merriam and Anderson (1942) found a thrust fault between the two facies that they named the Roberts Mountains thrust. They suggested that the thrust might be of Laramide age. The pioneering work by Ferguson, Kirk, and Merriam and Anderson laid the foundation for all subsequent work on the Paleozoic stratigraphy and structure in Nevada.

Regional synthesis of the geologic framework in north-central Nevada began with studies by Ferguson, Muller, and Roberts in 1939 in the Sonoma Range quadrangle (1:250,000). Previously, Muller had directed mapping by the Stanford University Field Camp during 1934-38 and was well aware of the complex juxtaposition of Paleozoic and Mesozoic rocks by thrust faults in the Sonoma and adjacent ranges. None of this work was published, but it formed a nucleus for further mapping by Ferguson, Muller, and Roberts in 1939 and succeeding years. Subsequently, four 30′ quadrangles, Winnemucca, Mount Moses, Mount Tobin, and Golconda (Ferguson and others, 1951a; Ferguson and others, 1951b; Muller and others, 1951; Ferguson and others, 1952) were published. As part of this project, Roberts (1951) mapped the 15′ Antler Peak quadrangle, which is in the southeastern part of the Golconda quadrangle and includes the principal ore deposits known in the area. An unexpected dividend of this work was that the Early Pennsylvanian Battle Formation, consisting of coarse boulder beds, was found overlapping complexly folded and faulted pre-Pennsylvanian rocks like those riding on the upper plate of the Roberts Mountains thrust in the Roberts Mountains. This orogenic event was named the Antler orogeny after Antler Peak where the overlap of the Battle Formation is well exposed (Roberts, 1949; 1964).

Regional correlations later permitted us to extend the the Roberts Mountains thrust and thus the area of orogeny from Eureka on the east, to Manhattan on the south, and to Mountain City on the north (Roberts and Lehner, 1955; Roberts, 1964). In 1958, a regional summary was published (Roberts, Hotz, Gilluly, and Ferguson, 1958) which brought together available stratigraphic and structural information and synthesized the sedimentary and orogenic history of north-central Nevada.

GEOLOGIC HISTORY OF NORTH-CENTRAL NEVADA

In Paleozoic time, the area that is now Nevada was the site of the Cordilleran geosyncline, on the western continental margin. Sedimentary and volcanic rocks were deposited in the geosyncline in three principal settings: in western, offshore deep water, a siliceous facies accumulated, consisting of chert, shale, quartzite, and mafic volcanic rocks together with thin calcareous units; eastward, on the continental slope, a transitional facies of shale, chert, and limestone was deposited; farther eastward, on the shallow-water continental shelf, there was a carbonate facies consisting of limestone, dolomite, and minor amounts of shale and sandstone. During Late Devonian and Early Mississippian time, the Antler orogeny in western Nevada caused uplift and movement of the siliceous and transitional facies eastward about 100 miles on the Roberts Mountains thrust onto the carbonate shelf.

Ketner and Smith (1982) have suggested that the Antler orogeny and the Roberts Mountains thrust are not necessarily related, and that the thrust may be of Mesozoic age in northeastern Nevada. In north-central Nevada, however, the Roberts Mountains thrust plate reached the vicinity of Eureka by Early Mississippian time and was the proximate source of the coarse clastic Diamond Peak Formation (Roberts and others, 1967; Brew and Gordon, 1971; Johnson and Pendergast, 1981; Speed and Sleep, 1982), and reached a point near Elko at about the same time (Dott, 1955). In regional geologic mapping in the Piñon Range, Smith and Ketner show clearly that the Webb and Chainman Formations (Early Mississippian) overlap the Vinini Formation of the Roberts Mountains allochthon (Smith and Ketner, 1978, section A-A′) and that the Webb and Chainman also overlap the Devonian Devils Gate Limestone of the carbonate autochthon (Smith and Ketner, 1978, section B-B′). In 1982, however, they queried their 1978 work and indicated that the Roberts Mountains thrust may be Mesozoic, based on structural relationships in northeastern Nevada.

Coats and Riva (1983) recently evaluated thrusting in northern and northeastern Nevada, recognizing that the Roberts Mountains thrust plate was in place there in Late Devonian or Early Mississippian time, but was moved again on younger thrust faults in Mesozoic time. Earlier, Ferguson, Muller, and Roberts (1951a; 1951b; 1952) were well aware of Mesozoic thrusting in the Sonoma Range area, having mapped many such faults involving Triassic and Paleozoic rocks in the Winnemucca, Golconda,

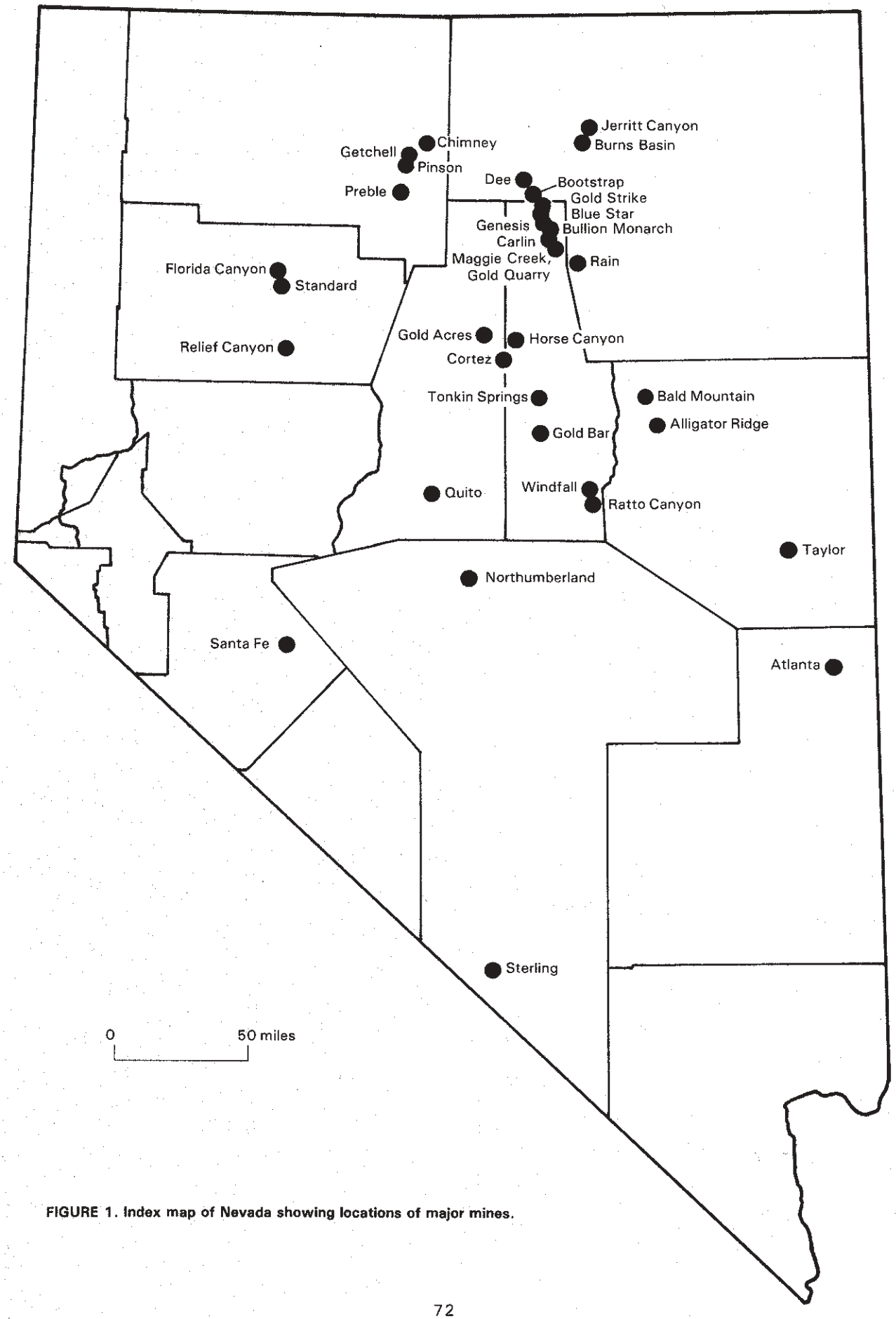

FIGURE 1. Index map of Nevada showing locations of major mines.

Mount Moses, and Mount Tobin quadrangles. At Antler Peak, fortunately, these Mesozoic thrusts did not involve the late Paleozoic rocks, for the Battle Formation of Early Pennsylvanian age rests with clear-cut sedimentary contact on the rocks and complex structural features of the Roberts Mountains plate (Roberts, 1964, p. A28, fig. 12), firmly dating the orogeny and thrust as pre-Early Pennsylvania.

Other workers, including Johnson and Pendergast (1981), Speed and Sleep (1982), and Murphy and others (1984), have evaluated the age of the Antler orogeny and the relationship of the Roberts Mountains thrust plate to the orogeny. They all agree that the thrust plate moved during Late Devonian and Early Mississippian time into its present position and is an integral part of the orogeny. Speed and Sleep (1982, fig. 1) divided the thrust plate into two parts, a central enclave that underwent little Mesozoic deformation, and marginal parts northeast of Carlin and southwest of Tonopah that underwent significant Mesozoic deformation. These later movements are not related to the Antler orogeny and do not affect the dates of the orogeny or of movement of the Roberts Mountains plate.

Initially, the Antler orogenic belt was a zone of low relief, and only fine clastic sediments (Webb and Chainman Formations, Early Mississippian) were shed eastward. Later the belt was more sharply uplifted, causing coarse clastic debris (Diamond Peak Formation, late Early through Late Mississippian) to flood into central and eastern Nevada. In places, this debris attained thicknesses of 3,000 meters (Brew and Gordon, 1971; Stewart, 1980) along a front extending from Elko through Eureka. By Early Pennsylvanian time, the front had been eroded to the vicinity of Antler Peak, where the Battle Formation, a coarse conglomerate, overlapped the Roberts Mountains thrust plate; by Middle Pennsylvanian time the Antler Peak Limestone was forming there, followed by the Edna Mountain Formation of Permian age composed of limestone, sandstone, and fine conglomerate. These formations are called the Antler sequence (Roberts and others, 1958).

During latest Paleozoic and earliest Mesozoic time, the Antler belt and overlapping Antler sequence were overridden from the west during the Sonoma orogeny by the Golconda thrust plate which is composed of the Havallah sequence (Silberling and Roberts, 1962). The Havallah sequence consists of the Pumpernickel Formation (chert, shale, and greenstone) and the Havallah Formation (shale, chert, limestone, and sandstone). These units are equivalent in age to the rocks of the Antler sequence, but they are oceanic facies that evidently were laid down in a deep-water marine trough in western Nevada.

In Mesozoic time, marine sedimentary rocks onlapped the Antler and Sonoma orogenic belts from the west; the most easterly trace of these rocks is near the 117° meridian. In Eureka County, freshwater sedimentary rocks in the Cortez Mountains are associated with subaerial volcanic rocks (Stewart, 1980).

Tertiary rocks in north-central Nevada consist of sedimentary rocks ranging from fine-grained claystone and siltstone to coarse-grained clastic rocks, and of volcanic rocks ranging from pyroclastics to flows of varied composition. Quaternary alluvium fills the valleys and laps onto the flanks of the ranges.

Plutonic rocks in north-central Nevada are from Permian to late Tertiary in age, but are mostly middle Mesozoic through early Tertiary (120–30 m.y.) (Silberman and McKee, 1971; Stewart, 1980). Some of these intrusive rocks are closely associated with precious-metal deposits. For example, orthoclase is an early vein mineral at Copper Canyon and may have been derived from the adjacent (38-m.y.-old) Copper Canyon stock (Roberts and Arnold, 1965). Also, the Cortez gold deposit is associated with 32-m.y.-old intrusive rocks (Erickson and others, 1966).

THE CARLIN MINE DISCOVERY

Although gold placers and gold prospects have been known in the Lynn mining district since 1907 (Vanderburg, 1936; 1938), production was small until the opening of the Carlin Mine (Hardie, 1966; Roberts, 1966; Roberts and others, 1967). As part of the cooperative program of county mapping carried on by the U.S. Geological Survey and the Nevada Bureau of Mines, A. E. Granger, assisted by G. C. Simmons, M. M. Bell, and P. D. Proctor, began mapping Eureka County in 1952; when Granger left the Geological Survey in early 1954, Roberts, Lehner, and Bell carried on the project. Later, K. M. Montgomery joined the project and assisted in compilation of maps and in preparation of the final manuscript.

With the background of the regional geologic framework as known in the middle 1950's, we continued mapping the geology of Eureka County. Wherever possible, existing geologic maps were used. (We later used Roen's (1961) more detailed map of the Lynn district.) Gaps between these maps were filled in by reconnaissance, using available base maps. The final product was compiled on a scale of 1:200,000, released as an open-file map (Lehner and others, 1961), and published at 1:250,000 in 1967 (Roberts and others, 1967).

Early during the course of field work, we met a prospector from Winnemucca named Frank Maloney. Maloney had prospected for gold and copper in northern Eureka and southwestern Elko Counties for several years and was enthusiastic about the potential of the region. He first took us to see the Copper King Mine in the Carlin window, about 7 miles north of the town of Carlin. The copper mineralization was not impressive, but the controlling structure, a low-angle thrust fault in siliceous shale and chert, was spectacular. Maloney also reported that he had obtained low-grade gold assays at the Copper King Mine. Later, in 1955, we visited the Bootstrap Mine, about 20 miles northwest of Copper King in company with Marion Fisher of Battle Mountain, one of the owners. Gold ore was being mined at the Bootstrap Mine in carbonate rocks below a low-angle thrust fault that carried chert and shale in its upper plate. This relationship was identical to that described by Merriam and Anderson (1942) in the Roberts Mountains, and we later established that the thrust was the Roberts Mountains thrust.

Lehner and I mapped the Carlin, Lynn, and Bootstrap windows in 1954, and in 1955 we presented a paper at the meeting of the Cordilleran Section of the Geological Society of America. We discussed the regional extent of the Antler orogeny and noted that carbonate windows exposed by erosion through the Roberts Mountains thrust plate were alined northwesterly. We also noted that the windows formed two belts, one extending from Eureka northwestward to Battle Mountain, and the other in the Carlin area from the Copper King Mine northwestward to the Bootstrap Mine (fig. 2). These alinements are now known, respectively, as the Eureka and Carlin mineral belts.

During the late 1950's I accompanied many groups of geologists from the U.S. Geological Survey and the Nevada Bureau of Mines, as well as geologists and mining engineers from industry, on both formal and informal trips into north-central Nevada to show them the stratigraphic and structural framework and the position of mineral deposits in this framework. In 1960, I published a paper (Roberts,

FIGURE 2. Map showing alinement of windows in upper plate of the Roberts Mountains thrust (from slide copy used by Roberts and Lehner, Cordilleran Section, Geological Society of America, 1955).

1960) on the "Alinements of mining districts in north-central Nevada," which defined some mineral belts and pointed out that many mineral deposits are localized on the margins of windows in the Roberts Mountains thrust plate (figs. 2, 3). Therefore, exploration was suggested along the mineral belts at window margins.

In the summer of 1961, I presented two informal talks, one at the Geological Society of Nevada in Reno, and the other before the Eastern Nevada Geological Society in Ely, Nevada. I covered essentially the same material as in the paper—the Cordilleran geosyncline, Antler orogeny, Mesozoic and Tertiary volcanic and plutonic history, struc-

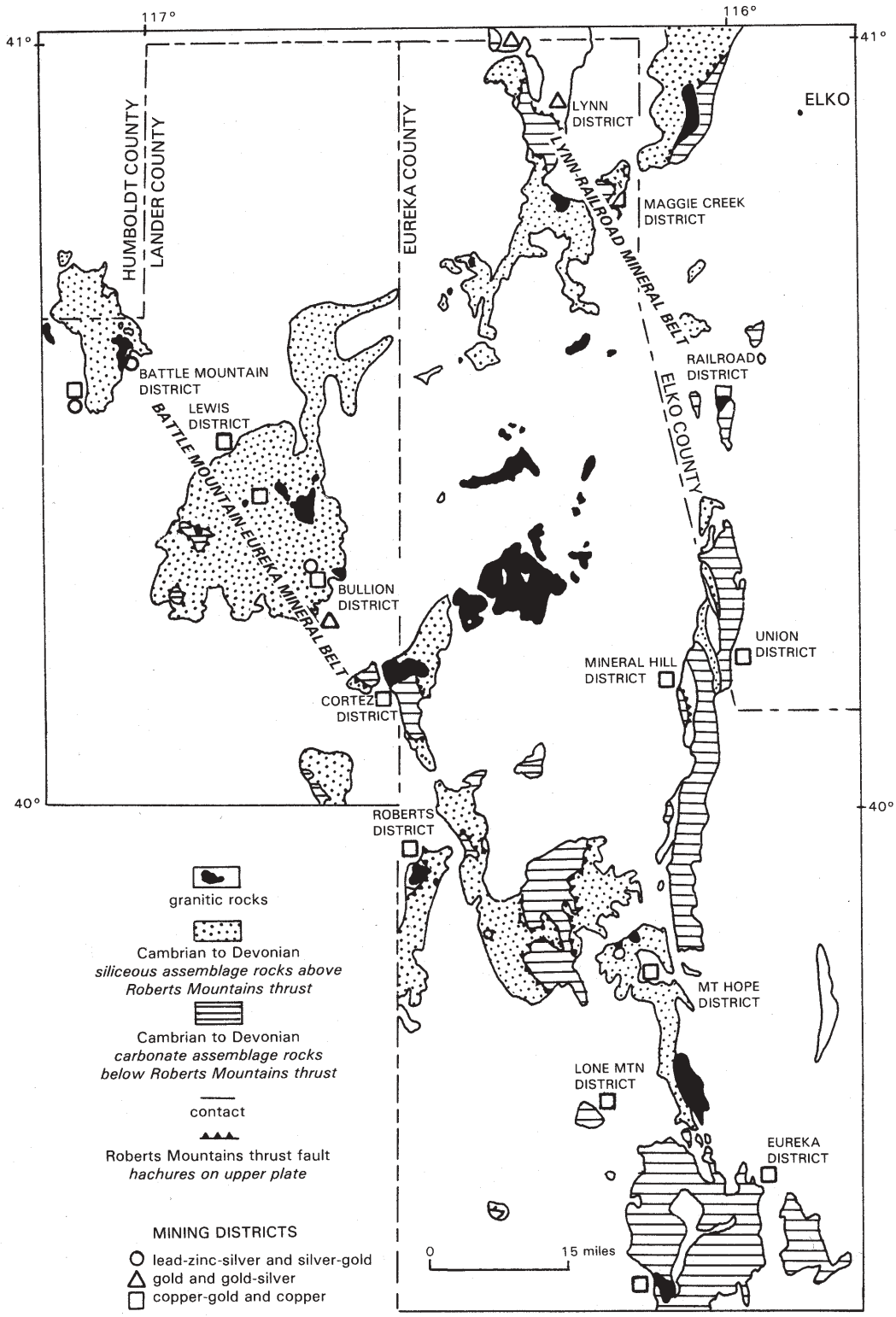

FIGURE 3. Alinement of mining districts in the Battle Mountain–Eureka and Lynn-Railroad mineral belts (Roberts, 1960).

tural development, and touched briefly on controls of metallization in the region. After the meeting in Ely, John Livermore asked to discuss some aspects of his regional exploration program with me.

It turned out that John (J. Livermore, oral commun., 1984) came to Nevada in 1949 to work at the Standard Mine, a low-grade disseminated gold deposit in the West Humboldt Range near Lovelock. In 1952, he joined the staff of Newmont Mining Corp. In 1961 he was assigned to search for disseminated gold deposits in Nevada. In the course of this work he visited Getchell and Gold Acres; while at Gold Acres, Harry Bishop, mine manager, advised him to look at the Blue Star Mine in the Lynn district. John examined the Blue Star and several other prospects in the spring of 1961. When I gave the talk on the geology of north-central Nevada in July 1961, John and his associate, Alan Coope, were easily able to translate our regional picture into a specific prospecting program. They carried out preliminary sampling along the margin of the Lynn window in early September 1961. I visited John in the field in late September to help identify rock units, especially to differentiate jasperoid in autochthonous carbonate rocks from silicified shale in allochthonous units.

Preliminary sampling disclosed low-grade gold metallization. Claims, which covered the site of the present Carlin Mine, were then staked and samples were cut in bulldozer trenches. The samples from one trench yielded an average of 0.22 ounces of gold over a width of 80 feet adjacent to a porphyry dike. And so, the Carlin Mine was discovered, thanks to two Newmont geologists who knew what they were looking for and were willing to bet on regional geologic concepts!

CHARACTERISTICS OF CARLIN-TYPE DEPOSITS

The development of the environment in which the Carlin-type deposits are localized is not only a matter of stratigraphic and structural controls related to the Roberts Mountains thrust, but involves subsequent folding, doming, and faulting which modify the initial setting (fig. 4). Carlin-type deposits differ in detail from one another, but exhibit certain host-rock, structural, mineralogic, and geochemical similarities that set them apart from all other classes of deposits in the western cordillera.

HOST-ROCK CHARACTERISTICS

All Carlin-type deposits are localized in carbonate-bearing units. Commonly these units contain silty beds that are relatively permeable after carbonate cement is leached early in the ore-forming process. At the Carlin and Bootstrap Mines the unit is the Roberts Mountains Formation, a

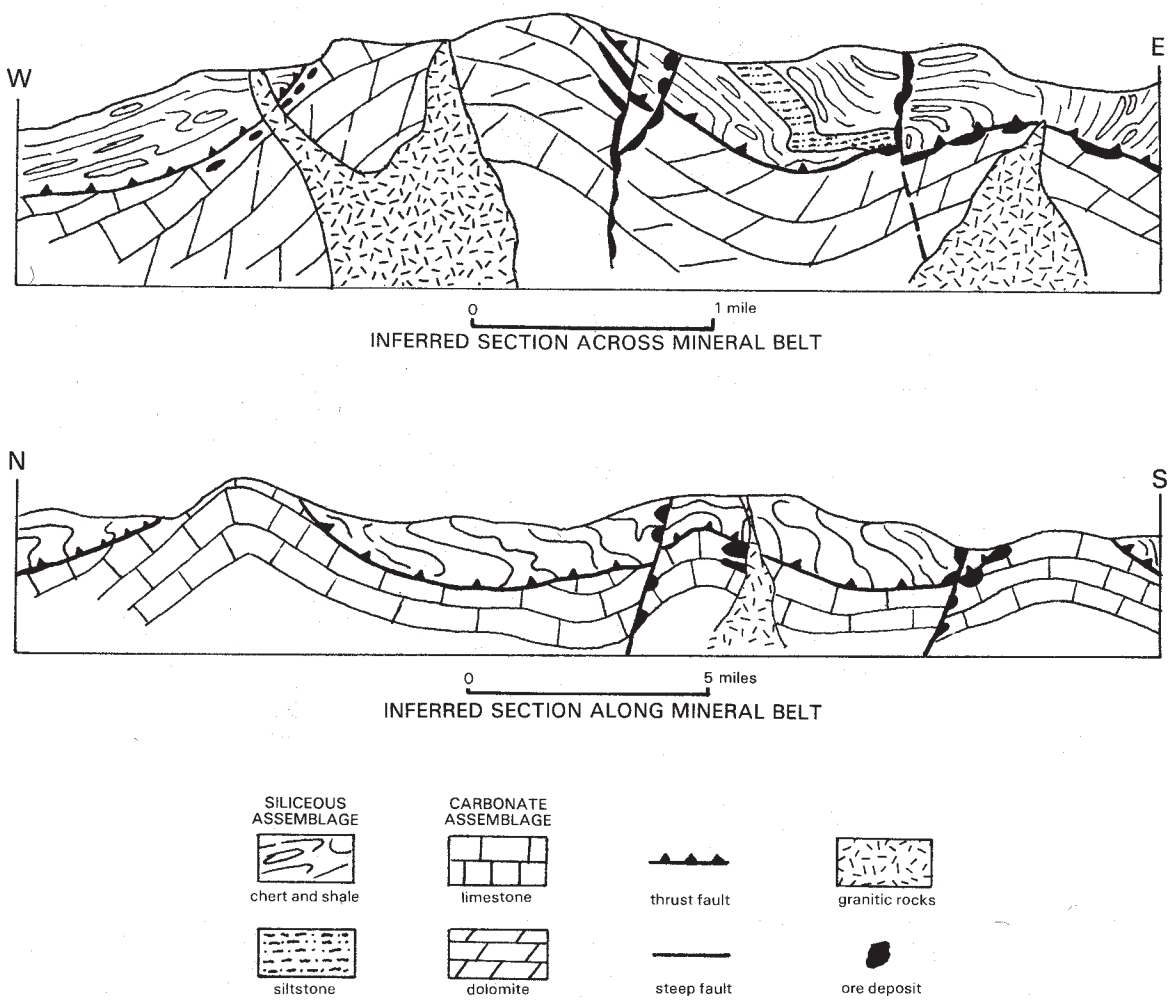

FIGURE 4. Inferred sections across and along a mineral belt in north-central Nevada showing possible sites for ore deposition. (Modified from Roberts, 1966).

calcareous dolomitic siltstone (Hardie, 1966; Evans and Mullens, 1976; Mullens, 1980; Radtke, 1981; Bonham, 1986); locally porphyry dikes are also metallized. At the Maggie Creek and Dee Mines the unit is the Valmy Formation, which consists of calcareous shale and limestone in the upper plate of the Roberts Mountains thrust (C. Ekburg, oral commun., 1982; Wallace and Bergwall, 1984). At Gold Acres the units are sheared calcareous beds above the thrust and propylitically altered igneous sills that were emplaced into the upper part of the thrust zone (Ketner, *in* Gilluly and Gates, 1965). At the Pinson Mine (Hotz and Willden, 1964; Kretschmer, 1984) the unit is calcareous shale in the Comus Formation. At Jerritt Canyon the unit includes the upper part of the Hanson Creek and lower part of the Roberts Mountains Formations (Birak and Hawkins, 1984).

Little work has been done thus far in studying the comparative chemistry of these units, but it seems likely that certain elements such as calcium, magnesium, carbon, and iron will be found in all of them.

STRUCTURAL CHARACTERISTICS

Certain structural characteristics are present in all Carlin-type deposits. The deposits are in the frontal part of the Roberts Mountains thrust plate (Roberts and Lehner, 1955; Hardie, 1966; Roberts, 1966), but concomitant folding and shearing of both the upper and lower plates increased structural complexity (Evans and Theodore, 1978). Later, during Mesozoic time, doming, clearly related to emplacement of granitic bodies caused uplift of both carbonate rocks and overlying thrust plate (fig. 4). Examples are the Adam Peak stock in the Osgood Mountains and associated Getchell and Pinson deposits (Hotz and Willden, 1964) and the unnamed intrusive body between the Maggie Creek and Carlin deposits (Evans, 1980). These intrusive bodies trend northerly and evidently follow major fracture zones that may have had their inception in the Precambrian (Roberts, 1966; Shawe and Stewart, 1976). On aeromagnetic maps major intrusive bodies commonly appear as positive anomalies (Zietz and others, 1977) (fig. 5).

Raul Madrid (oral commun., 1985) considers the folding in the Carlin belt to be related to compression in Mesozoic time, but I feel that the folding is largely due to uplift over intrusive bodies, similar to drape folding in the northern Rocky Mountains.

Other major fracture zones, which also may have had their inceptions in Precambrian time, in the region trend northwesterly and northeasterly. The northwesterly trends are of fundamental importance for they control the major mineral belts in this part of Nevada. (See Roberts, 1966). The mineral belts are related to emplacement of intrusive bodies which locally domed both carbonate autochthon and Roberts Mountains thrust plate. As uplift proceeded, fracturing intensified and an environment favorable for the formation of ore bodies ensued. Subsequent erosion resulted in exposure of the windows. However, it is emphasized that the ore zone was overlain by 1,000 to 3,000 feet of cover during ore formation (Hardie, 1966; Roberts and others, 1971; Vikre, 1984) and that the principal cover was the Roberts Mountains thrust plate.

Basin-and-range faulting, which began in mid-Tertiary time, also followed northerly, northeasterly, and northwesterly trends. These faults may be in part reactivation of older faults but are mostly post-metallogenesis.

MINERALOGIC CHARACTERISTICS

Carlin-type deposits are characterized by an epithermal mineral assemblage including orpiment and realgar, stibnite, cinnabar, pyrite, and native gold in a gangue of carbonate, quartz, clay minerals, and minor barite. Locally, at the Carlin Mine, sphalerite and galena are found in the ore bodies, but these minerals, and possibly also the barite, may be part of an earlier metallization (C. Ekburg, oral commun., 1982). Radtke (1981) states that the temperature of ore formation ranged from about 250°C to 150°C. However, Kuehn and Bodnar (1984) suggest, on the basis of fluid inclusion studies, that temperatures may have reached 300°C, and pressure during ore formation may have been as high as 1500 bars. This high temperature and high pressure prevailed presumably during the early stages of metallization.

GEOCHEMICAL CHARACTERISTICS

The geochemical suite in the Carlin-type deposits includes antimony, arsenic, gold, mercury, silver, and thallium. Minor amounts of lead, copper, zinc, molybdenum, and tungsten in these deposits (Radtke, 1981; Bagby, 1984; Wallace and Bergwall, 1984) may belong to an earlier metallogenic event, possibly related to Mesozoic intrusive activity (Adkins and Rota, 1984).

Dickson and others (1979) have shown that most of these metals are contained in the Roberts Mountains Formation and could have been leached from that unit by regionally pervasive hydrothermal solutions; gold, however, is present in very low concentrations in the Roberts Mountains Formation. I suspect that the gold may have been derived from magmatic sources. Organic carbon compounds are commonly present in the ore bodies. These compounds could have been derived from the Roberts Mountains Formation or from carbonaceous shale of the upper-plate Valmy Formation.

SUMMARY AND CONCLUSIONS

The Carlin-type gold deposits are an unusual, major class of disseminated gold deposits that formed in the frontal zone of the Roberts Mountains thrust plate, mostly in autochthonous carbonate rocks of the lower plate, but also in allochthonous rocks of the upper plate and in igneous rocks that cut both plates. Most of the deposits are on the flanks of domal uplifts which are exposed as erosional windows in the thrust. The domes are structurally controlled along major fracture zones and are developed over intrusive bodies. One important element in ore formation is that the thrust plate covered the windows at the time of ore formation; the thrust plate was relatively impermeable, thus impeding flow of ore-forming solutions and confining them mostly to the lower plate. Locally, permeable carbonate units are present in the upper plate and are metallized in places. In addition, associated intrusive rocks contain significant metallization.

Although more than 10 Carlin-type deposits are now known, with total reserves exceeding 14.7 million ounces of gold (Bonham, 1982), there are many areas of excellent potential in the Carlin belt in areas covered by thrust plates, younger volcanic rocks, and alluvium. Prospecting can be carried on by combining a detailed geologic mapping program with carefully planned and executed geochemical and geophysical studies. Attention should be given especially to the flanks and noses of intrusive bodies, which are usually highs on aeromagnetic maps such as the one compiled by Zietz and others (1977).

ACKNOWLEDGEMENTS

I am greatly indebted to John Livermore of Cordex Exploration Co., Reno, Nevada, who furnished many details of events leading up the discovery of the Carlin

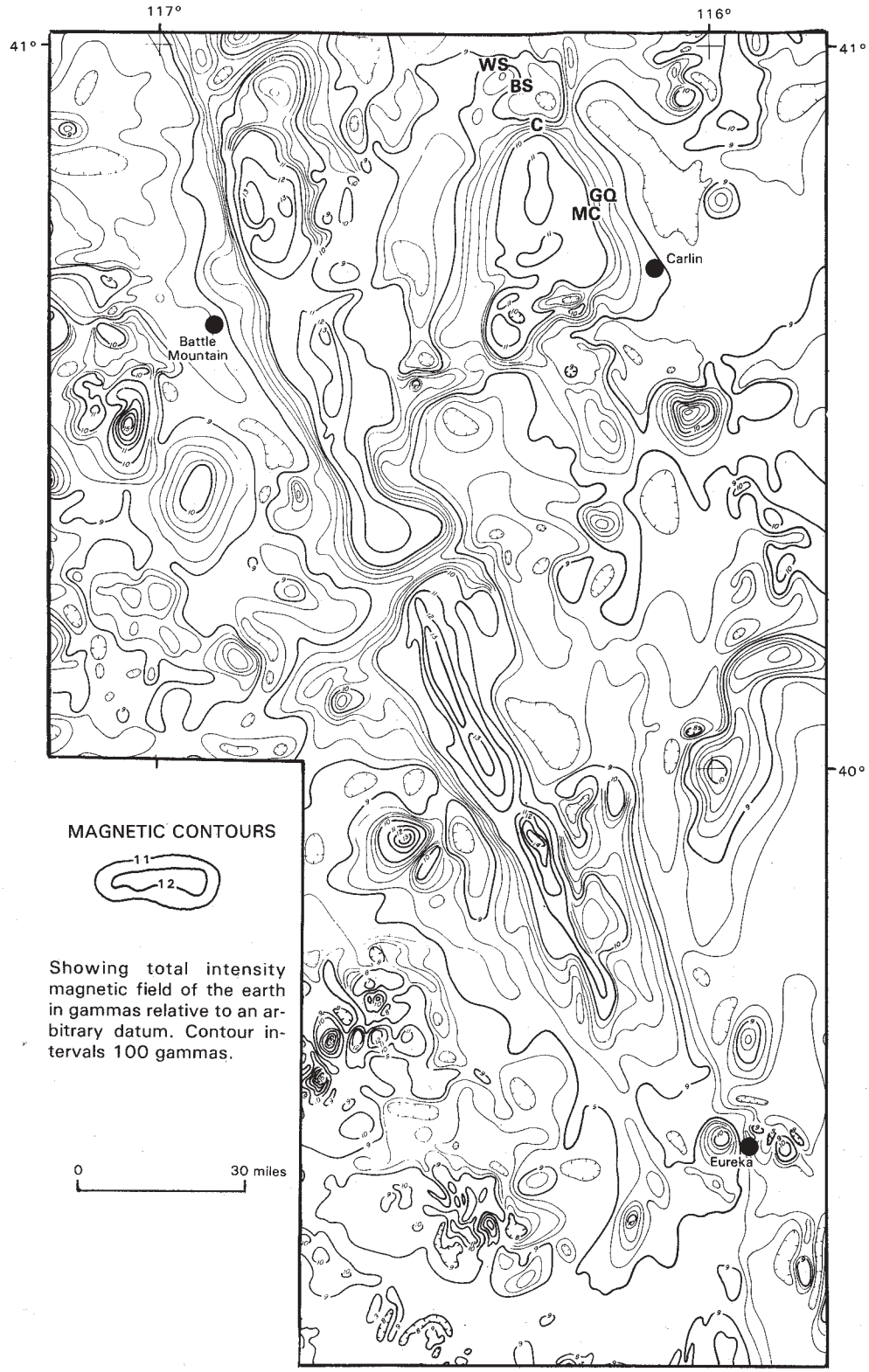

FIGURE 5. Aeromagnetic map of north-central Nevada showing major mines. BS—Blue Star; C—Carlin; GQ—Gold Quarry; MC—Maggie Creek; WS—Western States. (Modified from Zietz and others, 1977).

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GEOLOGY OF THE EUREKA-WINDFALL AND RUSTLER GOLD DEPOSITS, EUREKA COUNTY, NEVADA

ABSTRACT

The Windfall gold mine, discovered in 1908, was exploited on an intermittent basis for some 30 years thereafter as an underground mine with attendant cyanide vat-leaching facility. Approximately 65,000 tons of ore assaying 0.365 ounces of gold per ton was mined and milled on the site during this period. Idaho Mining Corp. acquired the property around 1968 and proved reserves in excess of 3 million tons assaying 0.03 ounces of gold per ton. Mining of this ore body began in 1975 and continued through 1978. Subsequently, the Rustler deposit, an extension of the Windfall ore body approximately ½ mile south, was placed into production and has operated continuously since. The Rustler deposit is currently being mined by open-pit methods with attendant heap-leach, carbon adsorption recovery system. The mine employs approximately 40 persons. Production is approximately 1,500 tons per day.

GEOLOGY OF THE EUREKA-WINDFALL GOLD DEPOSIT

by W. L. Wilson
Windfall Venture, Grand Junction, CO

INTRODUCTION

The Eureka-Windfall gold deposits are located in Eureka County, Nevada, in the southern part of the Eureka mining district, at the northern end of the Fish Creek Range. In this area the range is comprised of Paleozoic sedimentary rocks that have been intruded by igneous rocks of various ages. According to Nolan (1962), the Roberts Mountains thrust, a major structural feature of the region exposed just west of the district, exerted a major influence on the structural features in the Eureka mining district. This took the form of near-surface disturbances in front of the advancing thrust. Most of the deformation in the Eureka mining district is late Mesozoic, as contrasted with the Roberts Mountains thrust, which is considered Late Devonian to Mississipian in age.

The stratigraphic section is well documented in this area and has been described by Nolan and others (1956). For purposes of this discussion, stratigraphic descriptions include only those sedimentary rock units of economic interest and the Oligocene rhyodacite dikes which have intruded the area.

SEDIMENTARY ROCKS

SECRET CANYON SHALE

The Secret Canyon Shale is of Middle Cambrian age and is divided into two members. The lower member is a 200-to 225-foot-thick unit of greenish siltstone that weathers to tiny, brownish to greenish shards. The upper Clarks Spring Member is 425 to 450 feet thick and consists of thin-bedded silty limestone with yellow or reddish argillaceous partings. Both members are incompetent and are highly faulted and folded.

HAMBURG DOLOMITE

The Hamburg Dolomite is the principal host rock for ore bodies in the Windfall Mine. On the basis of fossil evidence, the Hamburg Dolomite has been dated as Middle and Late Cambrian (A. R. Palmer, *in* Nolan and others, 1956, p. 18). The Hamburg Dolomite forms a prominent ridge comprised predominantly of massive dolomite except for a lowermost, thinly banded, massive blue-gray limestone which immediately overlies the Secret Canyon Shale. All of the economic ore found to date in the Windfall deposits occurs in the uppermost portion of the Hamburg Dolomite. The dolomite has been subjected to intense alteration in the mine area, resulting in a rock that has been called "sanded dolomite" (Lovering and Tweto, *in* Nolan, 1962, p. 8, 44). Sanded dolomite retains the texture and color of normal dolomite or takes on additional coloration due to the thorough oxidation of the pyrite contained in the dolomite. In the mineralized area of the Windfall deposit, much of the Hamburg Dolomite has been subjected to an intergranular corrosion by mineralizing solutions, which results in easy disintegration during the mining process. Most of the gold ore at the Windfall Mine occurs in sanded dolomite.

DUNDERBERG SHALE

The Dunderberg Shale of Late Cambrian age overlies the Hamburg Dolomite. The contact is sharp and comprises a zone of slipping and faulting. The Dunderberg Shale is composed of brown fissile shale and thin-bedded, nodular blue-gray limestone. The shale, as a rule, is poorly exposed, but the associated limestone member makes it possible to identify the formation with relative ease (Nolan, 1962, p. 8). In places, particularly south of the mine area, the shale has been completely eliminated by shearing, faulting, or stoping by the intrusive rhyodacite body.

INTRUSIVE ROCKS

The dike rock in the Windfall Mine area was originally called hornblende andesite by Hague (1892), who distinguished it as the oldest of the volcanic rocks in the area. It was identified as having both intrusive and extrusive phases. It is intrusive in the vicinity of the ore deposits; the extrusive phase is exposed approximately ½ mile northeast of the Windfall Mine. The intrusive portions of the dike rock were poorly exposed in the mine area, but as mining in the Windfall deposit progressed, better exposures became available for examination. In the mine area, this rock unit

has been subjected to intense hydrothermal alteration, and the feldspars have been almost completely replaced by kaolinite. Nolan studied the andesite in some detail and reported that it varied in composition and in texture as well as mode of emplacement. Where fresh, it is characterized by large, well-zoned phenocrysts of andesine-labradorite and by thoroughly altered hornblende. Biotite is commonly present in grains larger in size, but in amounts considerably less than hornblende. The groundmass ranges from holocrystalline to hypocrystalline, and dusty quartz and feldspar laths are common constituents. Nolan believed that the intrusive andesite bodies apparently reached the surface along channelways which were successively reopened and invaded by several varieties of rock. Conclusive evidence was lacking, but the occurrence of several different lithologic types of intrusive rocks as well as breccias with rock fragments several inches in diameter suggested this mode of emplacement. No ore deposits are known in the andesite; however, the Windfall ore deposits are adjacent to the andesite, and these ores appear to have different characteristics from ores in other parts of the district. It appears that hot solutions followed channels along the margins of the andesite and directed mineralizing solutions to the favorable dolomite host rock.

More recent studies of the Pinto Summit 15′ quadrangle by Nolan, Merriam, and Blake (1974, p. 6) indicate a new classification for the hornblende andesite as the Ratto Spring Rhyodacite. They described the rhyodacite as ". . . porphyritic, and containing about 30 to 40 percent phenocrysts of hornblende, plagioclase, biotite, and scarce quartz, in a fine-grained flow-banded groundmass that is gray to light brown in the freshest specimens but often reddish brown as a result of later alteration of the iron-bearing minerals." The rhyodacite has been dated at approximately 36 m.y. (Oligocene) (McKee and others, 1971, p. 36–37).

GEOLOGIC AND STRUCTURAL SETTING

Sedimentary rocks in the Windfall Mine area strike nearly north; dips range from near vertical to approximately 60°E. The area has been shaped into antiforms and synforms, and there may be a relationship of ore deposits to the antiforms (Nolan, Merriam, and Blake, 1974). The Windfall Mine, as well as the remainder of the ore deposits in the Eureka district, is located within an antiform. Thrust faults of lesser magnitude than the Roberts Mountains thrust occur in the general area of the mine. These thrust faults involve rocks of Carboniferous age and postdate the Roberts Mountains thrust. The minor thrust plates are folded and cut by one major transverse fault and at least three major normal faults as well as by numerous smaller faults of several types. In the mine area, the dike rocks seem to have been emplaced principally along the contact between the Hamburg Dolomite and the Dunderberg Shale. Faulting probably occurred in Pleistocene or more recent time; however, none of these later faults have been observed in the Windfall Mine area.

ORE DEPOSITS

The Windfall gold deposits differ substantially from the other ore occurrences in the district in that they are low-grade, tabular, and have indistinct assay walls. The deposits occur predominantly adjacent to the Hamburg-Dunderberg contact and/or the Hamburg-rhyodacite contact. Gold is disseminated into the wall rock, particularly in areas where sanding of the dolomite has occurred, and concentrations of gold are found to disseminate farther into the wall rock along a northeast-trending set of fractures. The mineralization has a vertical extent of at least 300 feet and apparently is confined to the Hamburg Dolomite; however, a minor occurrence of ore was encountered in the Dunderberg Shale, also near the contact. Further data will be needed to assess the significance of this occurrence.

There is a strong geochemical association of arsenic and mercury with gold. The arsenic and mercury form halos around the gold ore bodies; the highest concentrations of arsenic and mercury are in close proximity to the Hamburg-Dunderberg contact and the Hamburg-rhyodacite contact. Arsenic and mercury mineralization is disseminated into the shale for a limited distance and is quite useful in drilling as a guide to proximity to the contact. High concentrations of arsenic and mercury indicate close proximity to the contact, while away from the contact the shale has very little arsenic and mercury, nor does the rhyodacite. The ore appears to have been formed by the result of hydrothermal solutions circulated through the dolomite at relatively shallow depths of burial by epithermal fluids of low pH.

Although the genesis of the ore deposit is not fully understood, it has characteristics of a disseminated deposit in that it is tabular in form, with indistinct assay walls, and it also has characteristics of a replacement deposit in that the solutions containing gold apparently replaced certain minerals in favorable beds adjacent to the solution passageways. Perhaps the classification disseminated-replacement would be most suitable.

METALLURGY

The Windfall ores are treated by heap leaching of mine-run ore, without crushing. At the time it was placed in production, the Windfall facility was the only "stand-alone" heap-leach operation with no attendant milling facility. Recoveries are greater than 80 percent. The sanded ore leaches rapidly and extremely well. The siliceous ore leaches well, although the leach cycle needed for this type of ore is somewhat longer; however, recovery of gold is still approximately 80 percent.

The recovery process consists of placing mine-run ore on asphalt pads in heaps approximately 30 feet high and applying a dilute cyanide solution. One of the unique aspects of the Windfall facility is the almost exclusive use of ponding, although sprinkling is sometimes used. Applying solutions through ponds allows operation in colder climates (the Windfall facility operates year-round at an elevation of approximately 7,600 feet in an area where moderately severe winters can be expected); as ice builds up on the pond surfaces, it acts as an insulant as subsequent solutions are injected into the heap under the layer of ice. The pregnant solution is collected and the precious metals are precipitated on activated carbon in a 5-column precipitator. The metals are desorbed from the carbon and recovered by electrowinning and melting to produce dore bullion. The carbon is reactivated each cycle.

GEOLOGY OF THE RUSTLER GOLD DEPOSIT

by W. Brent Wilson
Windfall Mine, Eureka, NV

The ore in the Rustler deposit occurs principally in the Hamburg Dolomite, proximate to the contact with the Dunderberg Shale or a rhyodacite intrusive body. Much of the Rustler ore occurs in zones that have been thoroughly (greater than 98 percent) silicified, and some of these have been brecciated. The gold is micron size and is accompanied by anomalous amounts of antimony, arsenic, barium, mercury, and silver. Base metals are notably absent in the ore, distinguishing the Windfall-Rustler deposits from other deposits in the heart of the Eureka mining district, 2½ miles to the north. Drilling has shown that ore-grade material continues from the south end of the Windfall pit to the north end of the Rustler pit. Likewise, a mineralized zone continues to the south from the Rustler pit for at least ½ mile, but further drilling is needed to establish grade and tonnage figures.

An irregularly shaped rhyodacite dike in the Rustler area generally trends north and dips about 70°W. It diverges from the Hamburg and Dunderberg contact at the north end of the pit into the Hamburg Formation along a suspected fault zone. At the south end of the Rustler pit, the dike is about 400 feet from the contact, where it essentially dies out but emerges again a few hundred feet to the south. The Hamburg-rhyodacite contact evidently exerted some control on the mineralizing fluids, as it generally marks the western limit of known mineralization.

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Old Windfall pit, looking east.

GEOLOGY AND GENESIS OF THE ALLIGATOR RIDGE MINE, WHITE PINE COUNTY, NEVADA

by Charles J. Tapper
Santa Fe Mining Co., Reno, NV

INTRODUCTION

The purpose of this report is to describe the general geologic setting and some of the unique alteration and mineralization features of the Alligator Ridge disseminated gold mine. Although the Alligator Ridge deposits are similar to the other sedimentary rock-hosted or "Carlin-type" deposits in many ways, some of the unique features, such as the hydrothermal explosion breccias, suggest significant differences in genesis. A generalized genetic model will be presented to illustrate some of these differences and to describe how these deposits may have formed.

The Alligator Ridge gold mine is located approximately 40 miles northwest of Ely, Nevada, in the northwest corner of White Pine County. The mine can be reached from Ely by approximately 70 miles of paved highway. The mine is located in the Vantage Basin which lies between the southern Ruby Mountains to the West and Alligator Ridge, part of the Maverick Springs Range, to the East.

The disseminated gold ore deposits are hosted primarily in the Pilot Shale, part of the lower Paleozoic carbonate-and-transitional assemblage (fig. 1) of East-central Nevada. These rocks are continental-shelf carbonate deposits and clastic rocks shed eastward off of the Antler orogenic highland during the Devonian and Mississippian.

Previous, published work on the Alligator Ridge Mine includes deposit overviews by P. J. Klessig (1984a and 1984b), a published abstract by J. C. Ainsworth (1983) covering some of the findings of his geochemical study of the Alligator Ridge deposits. An unpublished MS thesis by R. P. Ilchik (1984) documented some of the effects of hydrothermal maturation of organic material in the Pilot Shale at the Alligator Ridge Mine.

The writer would like to acknowledge Ed Flood and Jeff Pontius of NERCO minerals and Ron Parratt, Wayne Bruce, and Wade Hodges of Santa Fe Mining for their encouragement in the preparation of this report. Acknowledgement is also extended to Ed Bartels and Clynt Naumann of NERCO Minerals and Alan Glaser of Amselco Exploration.

GEOLOGY

STRATIGRAPHY OF THE VANTAGE BASIN

The stratigraphy of the Vantage Basin (fig. 2) played an important role in localizing alteration and gold mineralization in the Alligator Ridge deposits. The lowermost exposed units are the Devonian Nevada Formation and Devils Gate Limestone. The Nevada Formation is exposed in Alligator Ridge, on the east side of Vantage Basin, but most exposures in the Vantage Basin are of the uppermost Devils Gate Limestone. The Devils Gate Limestone is overlain by the Mississippian-Devonian Pilot Shale, which is typically 480 feet thick in the Vantage Basin (Ilchik, 1984) and, where unaltered, consists of a lower calcareous, carbonaceous, pyritic siltstone unit that is approximately 300 feet thick. This is overlain by an upper calcareous, carbonaceous, pyritic claystone that is roughly 160 feet thick. The contact between the two units may be marked by a discontinuous interbedded chert and claystone unit (Klessig, 1984a). Limestone lenses are common in the lower Pilot Shale. The Pilot Shale is overlain by the Joana Limestone which is approximately 120 feet thick (Ilchik, 1984) in the Vantage Basin. The Joana Limestone is a sparry, crinoidal limestone typically containing abundant chert nodules. The Joana Limestone is overlain by the Chainman Shale, which is dominantly claystone and siltstone where exposed in the Vantage Basin.

Unconformably overlying an erosional surface that consists of at least the Pilot Shale, Joana Limestone, and Chainman Shale are Tertiary tuffaceous volcaniclastic sedimentary rocks that are at least 500 feet thick (Klessig, 1984a). The tuffaceous rocks likely are part of the Miocene-Oligocene tuffaceous sedimentary rocks that occur in the area (Hose and Blake, 1976), although Eocene-Paleocene ash-flow tuffs occur in areas north of and south of the Vantage Basin. These rocks are unconformably overlain by basaltic andesite flow rocks (Ilchik, 1984). The present surficial geology (fig. 3) resulted from erosion of the Tertiary and older rocks and deposition of alluvial gravels and valley fill of Quaternary age.

STRUCTURE OF THE VANTAGE BASIN

The Vantage Basin forms a gentle, south plunging anticline that is breached in the center to expose a core of Devils Gate Limestone. The Pilot Shale dips westward under the Joana Limestone and Chainman Shale on the west side of the basin. On the east side of the Vantage Basin, a large northeast trending graben, the "Vantage graben", juxtaposes Chainman Shale, on the downdropped side, and Pilot Shale. The boundary fault system, the "Vantage fault system", includes numerous strands and parallel faults, among which is the "PC fault". The PC fault cuts through the Vantage-1 and Vantage-2 workings downdropping the upper Pilot Shale against the lower Pilot Shale in the former and moving the Chainman Shale and Joana Limestone against Pilot Shale in the latter (fig. 4). The Vantage Basin is truncated on the east side by a large horst-block of Devonian Nevada Formation and Devils Gate Limestone. The faults were likely formed after the initiation of basin-and-range style faulting, which began approximately 17 m.y. ago (Stewart, 1980).

The ore deposits are localized along northeast-trending structures that are parallel to the Vantage fault system, including the PC fault, and at intersections between northeast-trending and west-northwest trending cross faults. A small-scale anticline parallels the strike of the Vantage fault system, and probably was formed as a result of drag along those faults. The axis of the anticline crosses the Vantage-1, -2, and -3 ore bodies and may have been a control on gold mineralization. A picture of the Vantage-1 and -2 openpits and the eastern side of the Vantage Basin is shown in figure 5.

ALTERATION

Alteration in the Alligator Ridge deposits is strongly zoned within the Pilot Shale and uppermost Devils Gate Limestone. The alteration zones form flat-lying horizons that are stacked vertically and grade laterally outward and upward from strongly altered rock into unaltered rock. Within the Vantage Basin, there is some overlap between

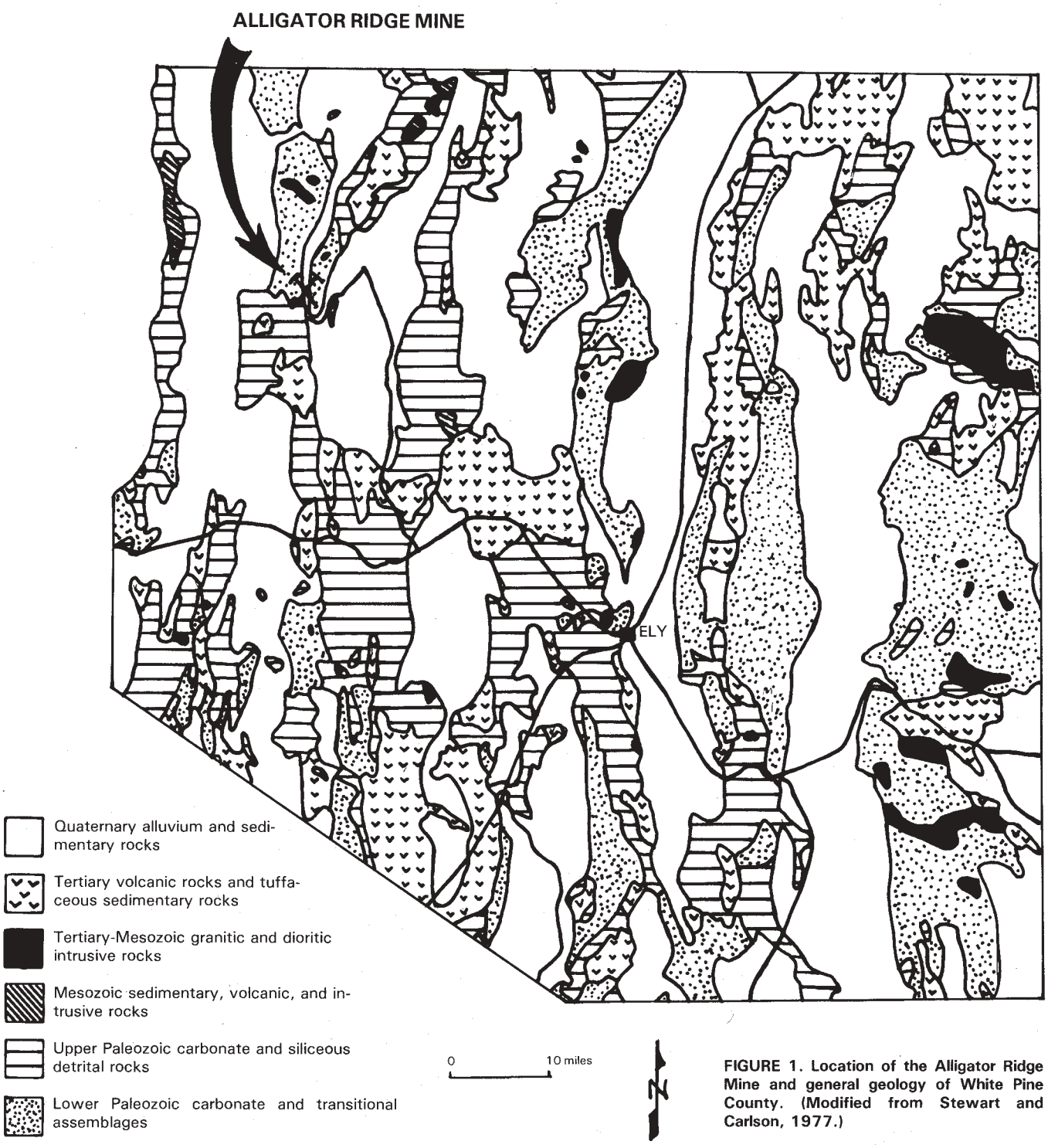
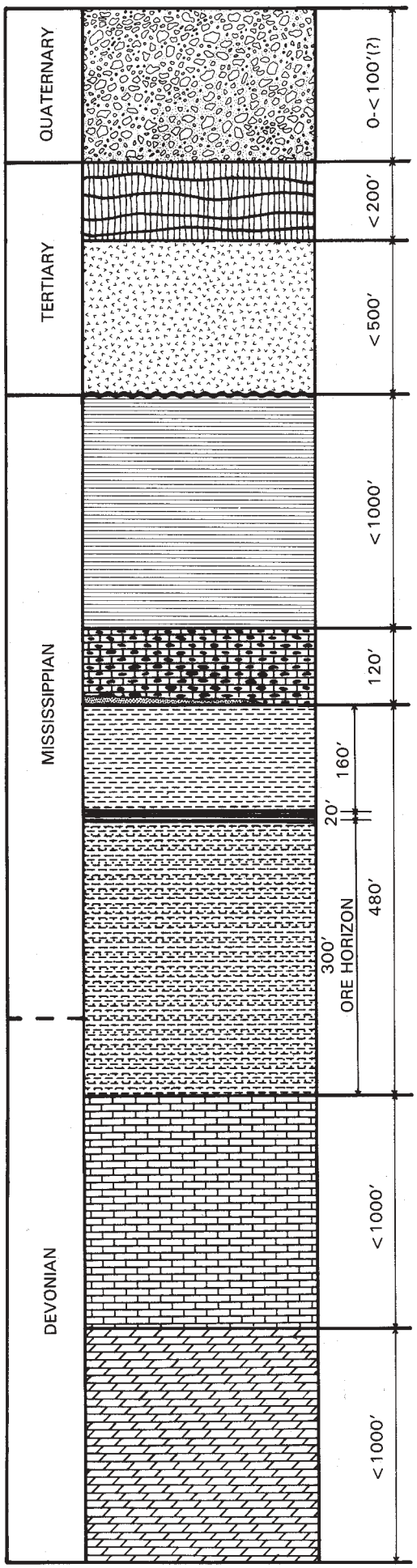


FIGURE 1. Location of the Alligator Ridge Mine and general geology of White Pine County. (Modified from Stewart and Carlson, 1977.)

alteration around the Vantage-0, -1, -2, -3 deposits, the A.R.M. deposit, and smaller hydrothermal centers on the west side of the basin. Also, the amount of alteration decreases as the Pilot Shale section dips southward.

The lowermost alteration zone is a jasperoid breccia developed at the Devils Gate–Pilot Shale contact and derived mainly from the Devils Gate Limestone. It is variable in thickness and distribution. Typically the jasperoid breccia is brownish black to reddish brown in color and a matrix-supported breccia. These rocks are well silicified and have a sucrosic texture. Stibnite, typically partially oxidized to stibiconite occurs in earlier-formed veins. The jasperoid breccia contains closely spaced fractures and abundant later-formed veins and open-space coatings of kaolinite, barite, jarosite, quartz, and calcite. Alunite may be present as veins, but is less common.

In the areas of strongest alteration, the jasperoid breccia is capped by a zone of strong hypogene oxidation and strong acid leaching ("strong hypogene oxide zone"). In this zone, the Pilot Shale is decalcified and argillized, punky, weakly to strongly silicified, and is bleached to a light gray color. Alteration minerals include jarosite, kaolinite, barite, hematite, and less commonly, alunite. Hydraulic fracture textures and hydrothermal brecciation is typical of rocks in the strong hypogene oxide zone. Hydrothermal explosion breccias extend upward from the



Alluvium and valley-fill gravels

Basaltic andesite flow rock: Dark green to black, hornblende-plagioclase-biorite-bearing basaltic andesite

Tuffaceous sedimentary rocks: White to yellow to pinkish water-lain volcanic sandstones and claystones

Chainman Shale: Non-calcareous, greenish-black, greasy claystone and interbedded siltstone. Lower part of unit may be calcareous shale or thin-bedded, platy, light-gray, micritic limestone

Joana Limestone: The lower contact may be marked by a calcareous quartzite, typically with well-rounded grains. The limestone is thin- to thick-bedded, medium-gray, crinoidal, cherty, sparry, and bio-clastic

Pilot Shale: Lower 300′ is dominantly a calcareous, carbonaceous, pyritic siltstone with some limestone lenses. Discontinuous interbedded chert and claystone may separate the lower siltstones from the upper 160′, which consists of calcareous, carbonaceous, pyritic claystone

Devils Gate Limestone: Light- to medium-gray, thin- to medium-bedded micritic limestone

Nevada Formation: Gray to tan to light-brown, saccharoidal, thin-bedded dolomite

FIGURE 2. Stratigraphic column for the Vantage Basin. (Modified from Klessig, 1984a, and Ilchik, 1984.)

strong oxide zone and crosscut the overlying, less altered rocks. The hydrothermal explosion breccias occur as dike-like bodies of clast-supported and/or matrix-supported heterolithologic breccias, typically consisting of clasts of Pilot Shale and the basal jasperoid breccia.

The strong hypogene oxide zone grades vertically and laterally into a transitional zone of weaker hypogene oxidation (''weak hypogene oxide zone''). Rocks of the weak hypogene oxide zone are characterized by pervasive hematite and/or jarosite stain, often in the form of liesegang banding. Rocks of the weak hypogene oxide zone are typically decalcified, although the decalcification and oxidation ''fronts'' rarely exactly coincide.

In the Vantage-2 and -3 deposits, where a more complete section of Pilot Shale is preserved and not completely oxidized, the weak hypogene oxide zone grades into carbonaceous Pilot Shale (the ''carbon zone''). Some of the carbonaceous Pilot Shale is hydrothermaly altered (Ilchik, 1984) and apparently contains activated carbon. The hydrothermally altered Pilot Shale is typically also decalcified. Alteration minerals typical of the carbon zone are relatively rare occurrences of realgar-orpiment (typically in association with stibnite in calcite veins) and stibnite in calcite veins. Minor kaolinite may be present in hydrothermally altered carbonaceous rocks.

Along the southward, downdip extension of the Pilot Shale–Devils Gate Limestone contact, there is a decrease in the amount of jasperoid formed in the uppermost Devils Gate Limestone. The amount of hypogene oxidation decreases, but even deep drilling (400 feet or more) south of the Vantage-2 pit encountered a small weak hypogene oxidation zone developed in the lowermost Pilot Shale at the contact with the Devils Gate Limestone.

Hydrothermally altered carbonaceous material is also present in the Devils Gate Limestone. A hole drilled east of the Vantage-1 pit encountered 50 feet of ''normal'' Devils Gate Limestone and then entered carbon-enriched limestone that contained a large amount of ''sooty'', black carbonaceous material. This material resembled the hydrothermally altered carbon found in the Pilot Shale. Deep drilling in the area south of the Vantage-2 pit in 1984 intersected a breccia zone, apparently a hydrothermal breccia body, in the upper Devils Gate Limestone that contained clasts of limestone in a carbonaceous matrix that exhibited streaming textures. The carbonaceous material was apparently hydrothermally altered. The occurrance of this breccia is unique because breccia-body formation below the contact between the Devils Gate Limestone and the Pilot Shale is not observed in the Vantage-1 or Vantage-2 pits, or on Jasperoid Hill.

Surficial weathering of unaltered carbonaceous, calcareous, pyritic Pilot Shale resulted in the formation of a 20-to 40-foot zone of very weak oxidation. The shale becomes brownish black to orangish brown in color and was not decalcified. It is evident that surficial weathering did not cause the brightly colored (and commonly decalcified) rocks found in the mine workings.

An alteration map based on the fall 1983 pit configuration of the Vantage-1 and Vantage-2 pits is shown in figure 6. The alteration map shows the vertical zonation of the alteration (e.g. the small pit in the center of the Vantage-2 pit penetrated the carbon zone to expose the ore-bearing rocks of the strong oxide zone), the breccia bodies crosscutting the carbon zone, the decalcification ''front'', and the lateral zonation of the weak oxide zone around the breccia bodies and the PC fault zone in the southeast corner of the pit. The altered Chainman siltstone unit illustrates the higher permeability of siltstone relative to claystone. The alteration/geology cross sections (figs. 7 and 8) illustrate the vertical zonation of the alteration in the Vantage-2 deposit.

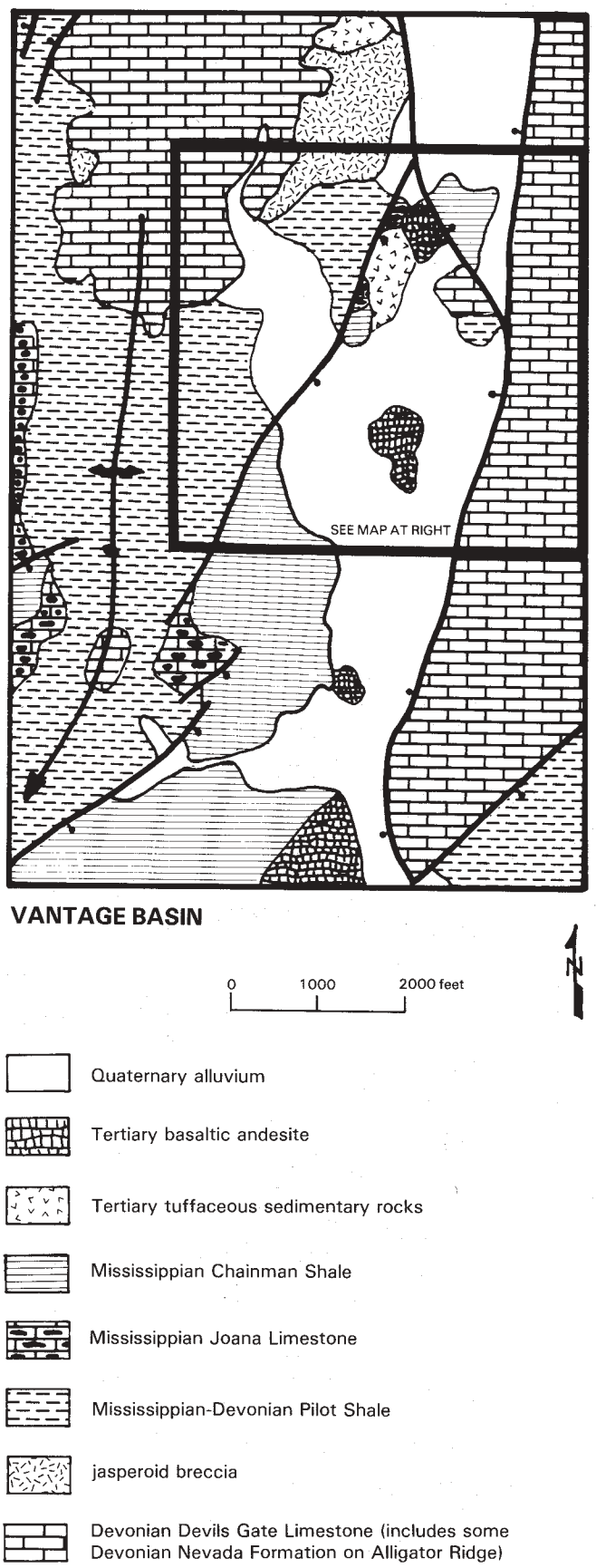
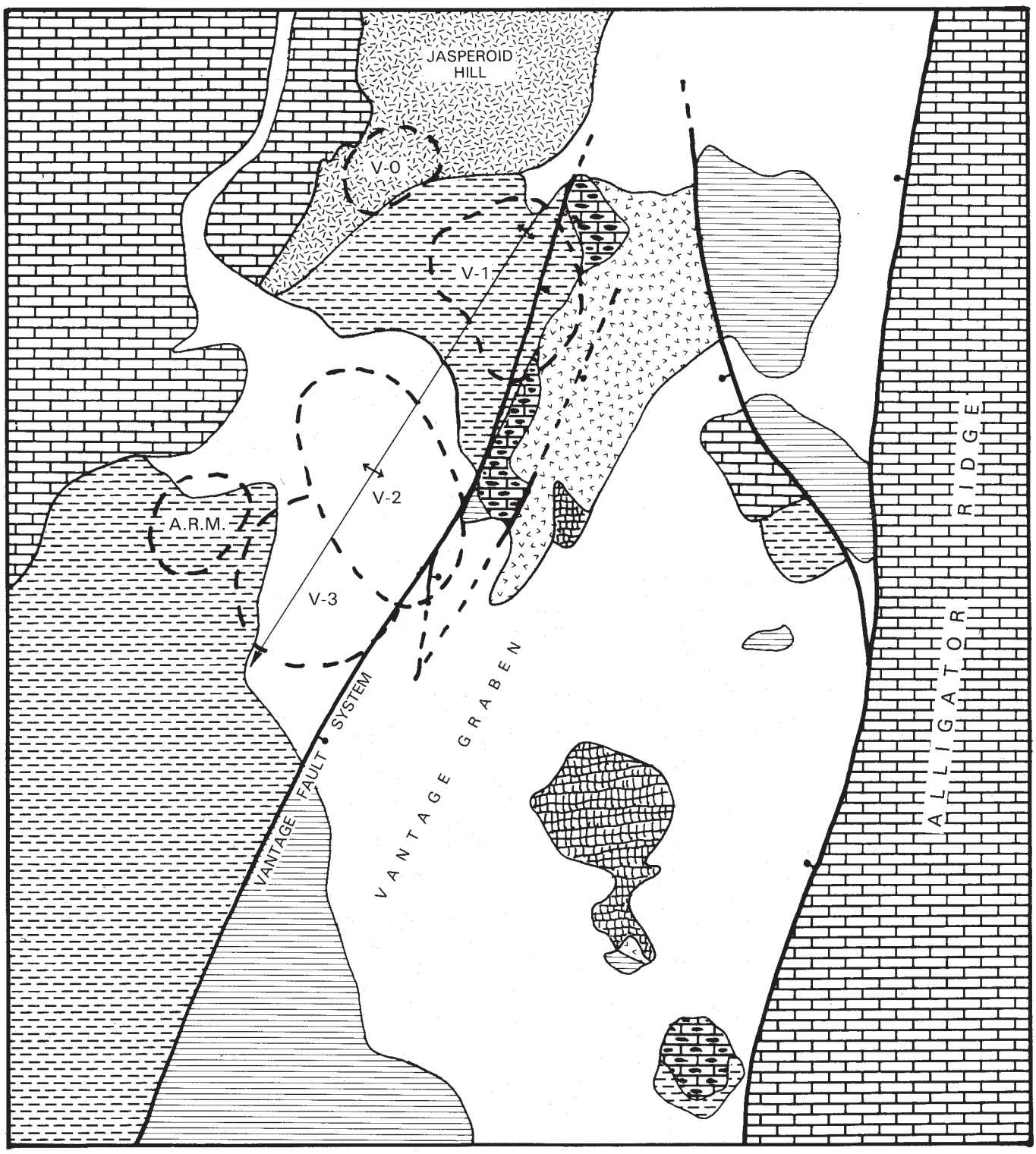


FIGURE 3. Geology of the Vantage Basin and the eastern Vantage Basin (inset) showing the location of ore deposits. (Modified from Ilchik, 1984, and Tapper, 1984a.)



EASTERN VANTAGE BASIN

0 500′ 1000′

N

fault, dashed where inferred, ball on downthrown side

anticlinal axis

pit outline

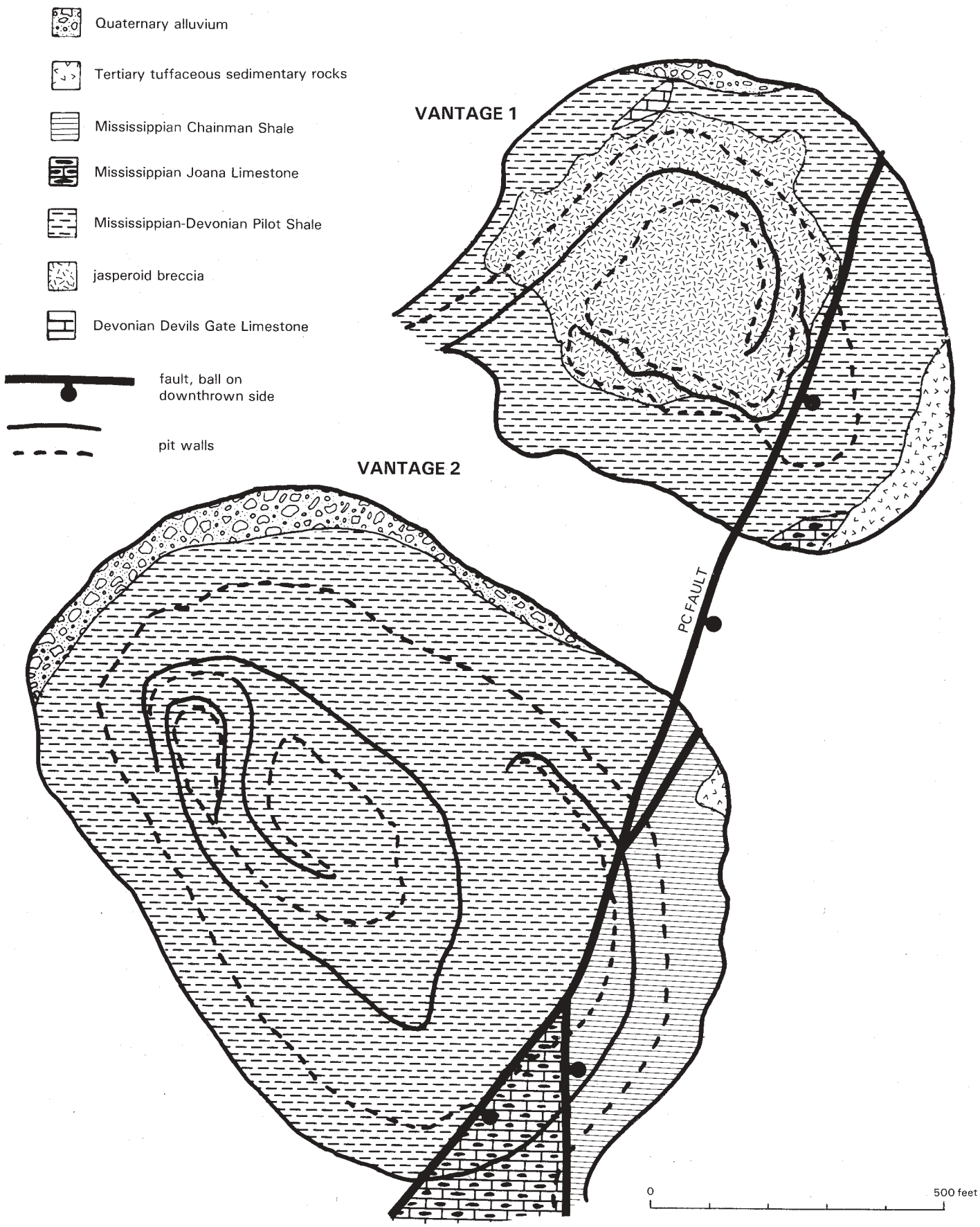


FIGURE 4. Geology of the Vantage-1 and Vantage-2 pits, based on fall 1983 pit configuration. (Modified from Tapper, 1984b, and Glaser, 1984.)

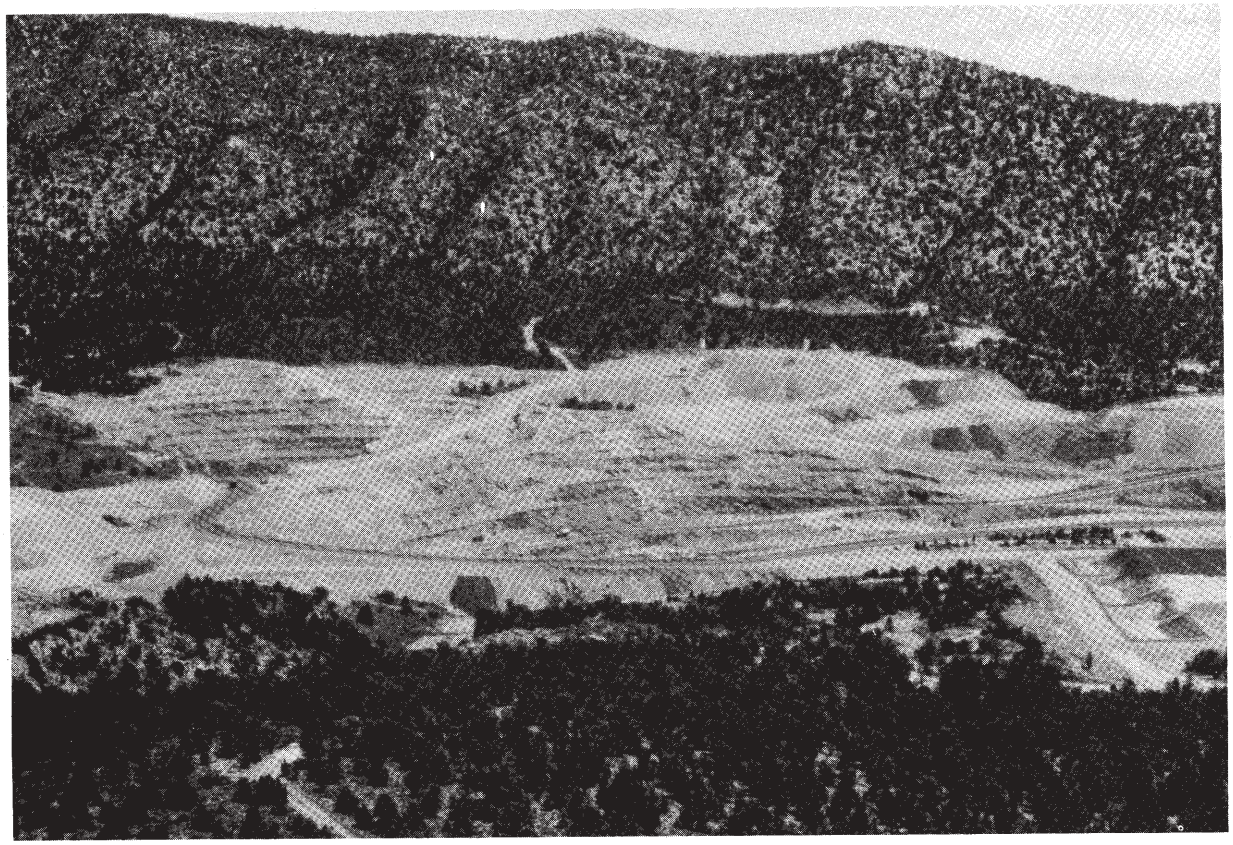


FIGURE 5. Photograph, looking east, of the Vantage-1 and -2 pits, June 1983.

HYDROTHERMAL BRECCIAS

The presence of abundant examples of hydrothermal brecciation at the Alligator Ridge deposits distinguishes these deposits from those at, for example, Carlin or Jerritt Canyon. Hydrothermal brecciation and hydrofracture textures are ubiquitous in the rocks of the strong hypogene oxide zone. Relatively large breccia bodies are found in the Vantage-1 and -2 pits to be localized along relatively minor fault zones. The breccia bodies tend to be localized more along the anticlinal axis crossing the Vantage-1 and -2 ore bodies. Very little tectonic brecciation is found at the Alligator Ridge deposits. That which is present is small scale and is found along the PC fault that cuts the Vantage-1 and -2 deposits. The small amount of tectonic brecciation that does occur along that fault consists of locally-derived clasts in a sheared matrix and are unlike the hydrothermal breccias.

The hydrothermal explosion breccias at the Alligator Ridge Mine are dike-like bodies of heterolithologic breccia that open downward into less disrupted rocks in the relatively flat-lying strong hypogene oxide zone (fig. 7). The examples described below are from the Vantage-1 and Vantage-2 pits. Figure 9 shows one of the breccia bodies in the north wall of the Vantage-2 pit. Typically, the breccia bodies are strongly hypogene oxidized and acid-leached and the alteration forms a continuum with the relatively stratabound part of the strong hypogene oxide zone.

Three main breccia types have been observed: 1) clast-supported, 2) matrix-supported, and 3) jigsaw-puzzle and crackle breccias. Clast-supported breccias (figs. 10 and 11) typically consist of strongly oxidized and acid-leached clasts of Pilot Shale and rounded clasts of the basal jasperoid breccia. The area between clasts typically is blown clean of rock flour and is partly filled by crystalline barite with or without drusy quartz, crystalline to earthy jarosite, alunite, kaolinite, and specular hematite. Matrix-supported breccias (figs. 12, 13, 14, and 15) typically consist of oxidized, acid-leached, silicified, angular to rounded Pilot Shale clasts and rounded clasts of the basal jasperoid breccia suspended in a matrix of silica and rock flour. Streaming textures are common in the silica and rock flour matrix. Alteration minerals, which may take the place of silica in the matrix, include barite, jarosite, and alunite. Some hematite or jarosite stain is common. Another type of matrix-supported breccia observed in the Vantage-1 pit and termed a "rubble breccia" (fig. 16) consists of a crumbly zone of uncemented rock flour and clasts of Pilot Shale and jasperoid breccia. Most clasts, including some up to boulder sized, exhibit some rounding. The clast-supported and matrix-supported breccias grade in to less mobilized breccia types, the jigsaw-puzzle and crackle breccias, and out to undisrupted rock.

The distribution of breccia types within the bodies appears to be related to the intensity of vapor streaming. In the breccia bodies in the north wall of the Vantage-2 pit, clast-supported breccias form in the narrow, upper part of the bodies where vapor streaming was most strongly focussed. The vapor stream transported jasperoid-breccia clasts as much as 200 feet vertically, typically rounding them, and removed the comminuted material from the interstices between clasts. The clast-supported zone grades downward into a broader zone dominated by matrix-supported breccias. Jigsaw-puzzle breccias and crackle breccias (fig. 17) are found at the margins of the breccia bodies where the well-mobilized breccias grade into undisrupted rock.

The rubble-breccia zone observed in the Vantage-1 pit was apparently formed by vigorous vapor streaming through a narrow structure near the contact between the

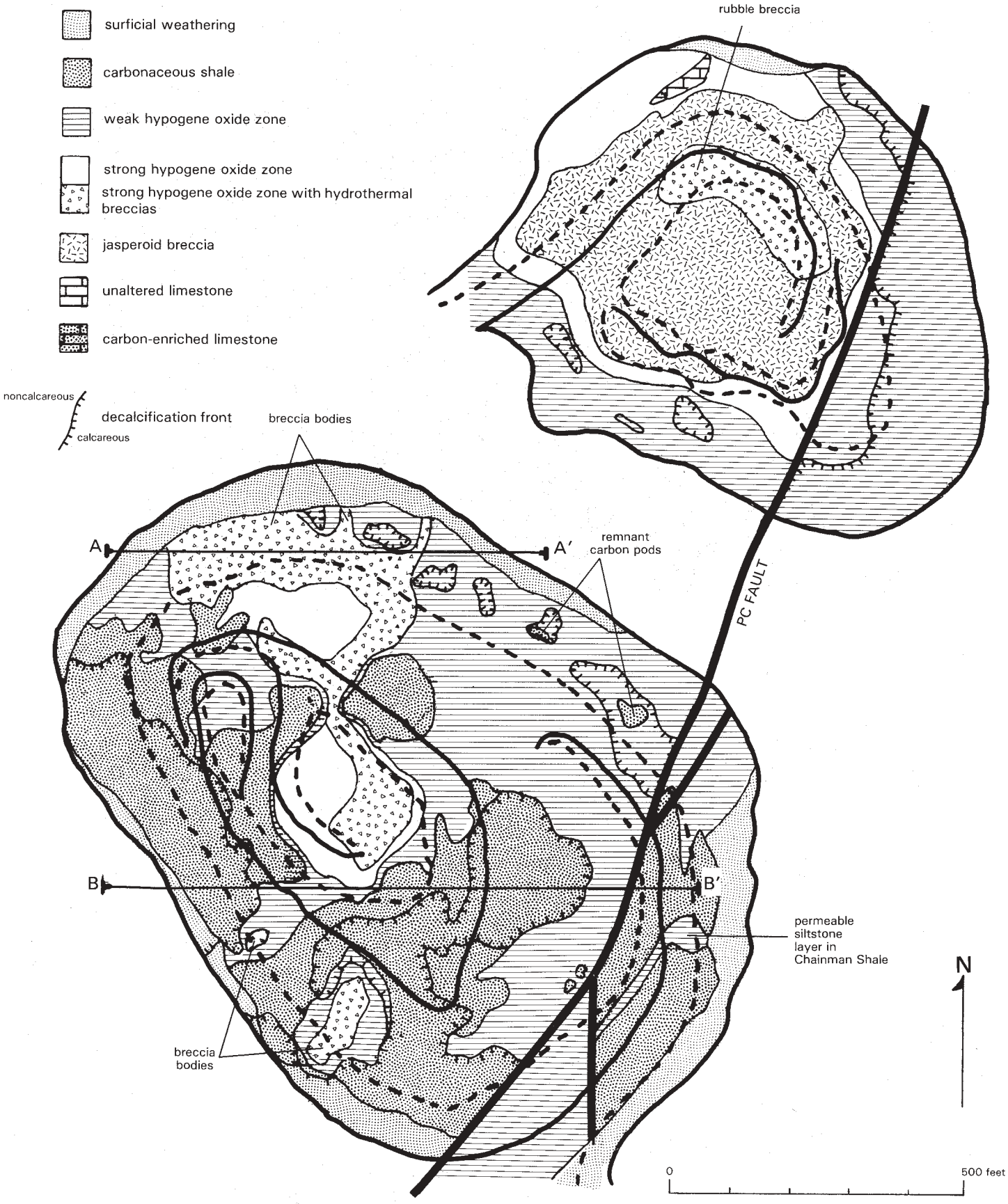


FIGURE 6. Alteration and geology map of the Vantage-1 and -2 pits, based on fall 1983 pit configuration. (Modified from Tapper, 1984b, and Glaser, 1984.)

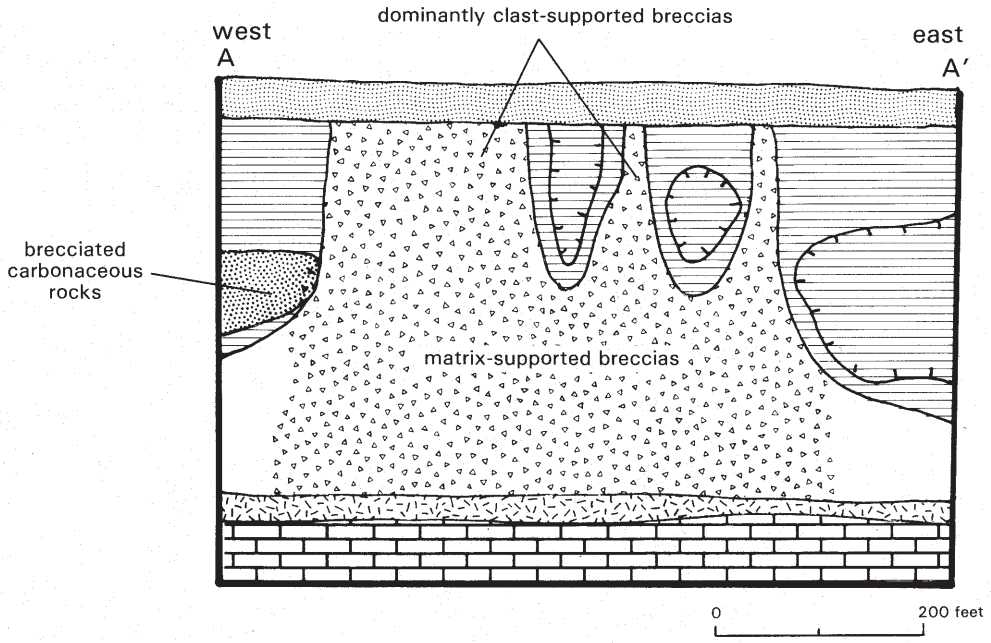


FIGURE 7. Cross section B-B′ through the northern part of the Vantage-2 deposit showing alteration zonation and hydrothermal breccias.

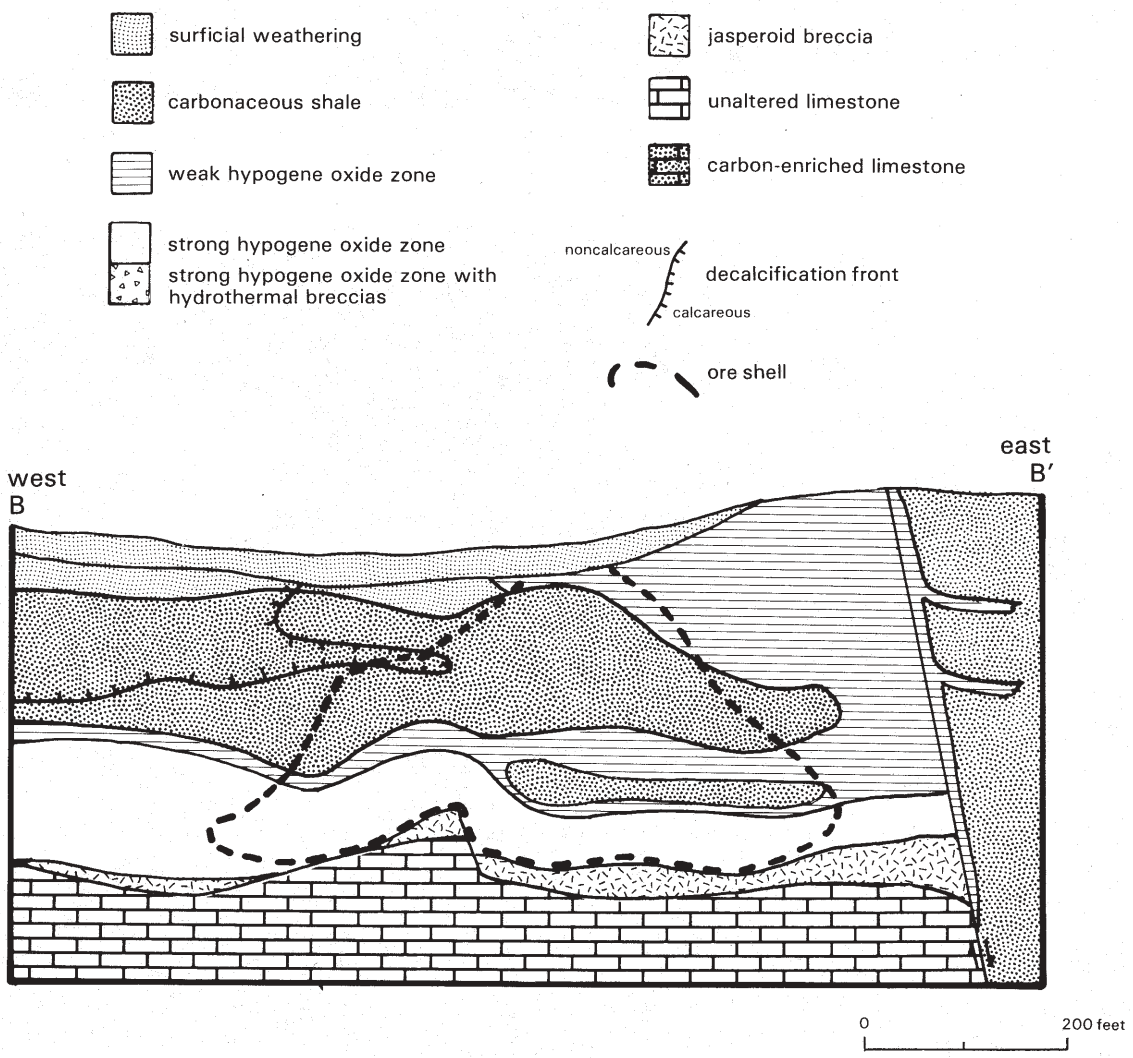


FIGURE 8. Cross section B-B′ through the central part of the Vantage-2 deposit showing alteration zonation. Note that the ore shell crosscuts the oxidation front. (Modified from Ilchik, 1984.)

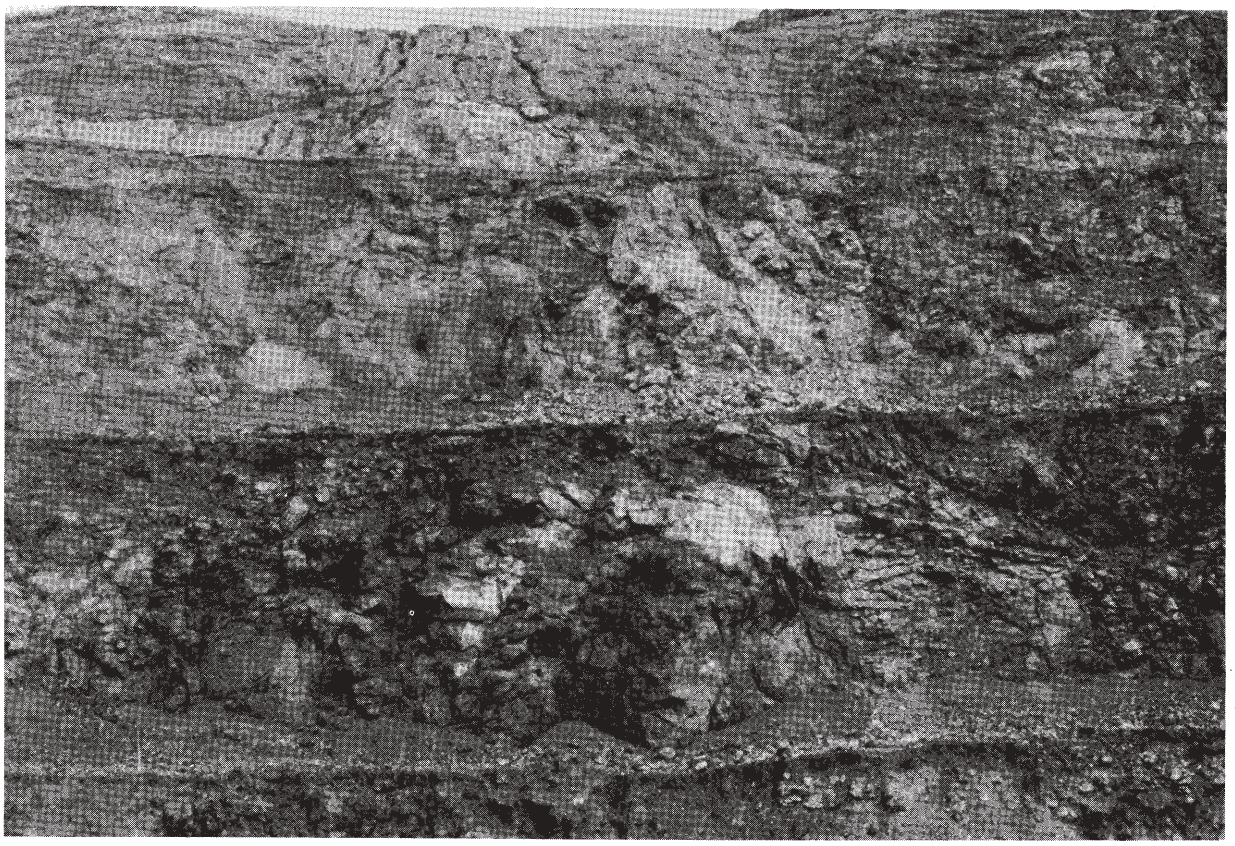


FIGURE 9. Photograph of a hydrothermal explosion breccia body in the north wall of the Vantage-2 pit. The strongly oxidized and acid-leached rocks within the breccia body are surrounded by rocks of the weak hypogene oxide zone. The breccia body is widening at the bottom of the picture as it merges with the more flat-lying strong hypogene oxide zone.

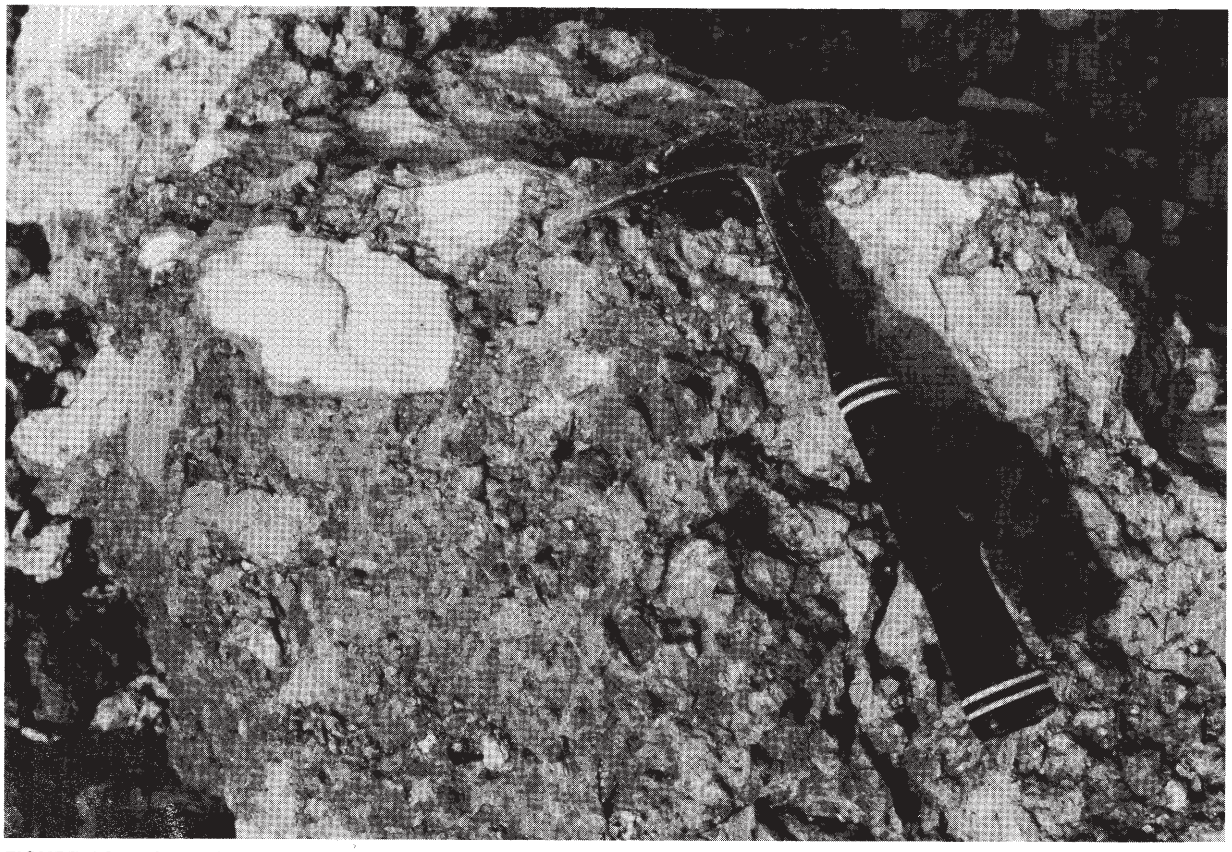


FIGURE 10. A heterolithologic clast-supported hydrothermal explosion breccia, Vantage-2 pit. The light colored clasts are strongly hypogene oxidized and argillized Pilot Shale and the dark gray clasts are jasperoid breccia. The jasperoid breccia has been transported approximately 180 feet vertically from its stratigraphic occurrence.

FIGURE 11. A heterolithologic clast-supported breccia, Vantage-2 pit, consisting predominantly of Pilot Shale clasts (light colored). Small clasts of jasperoid breccia (dark gray) are also present (several are located above the hammer in the upper left corner of the picture. Vertical transport of the jasperoid breccia clasts was approximately 180 feet.

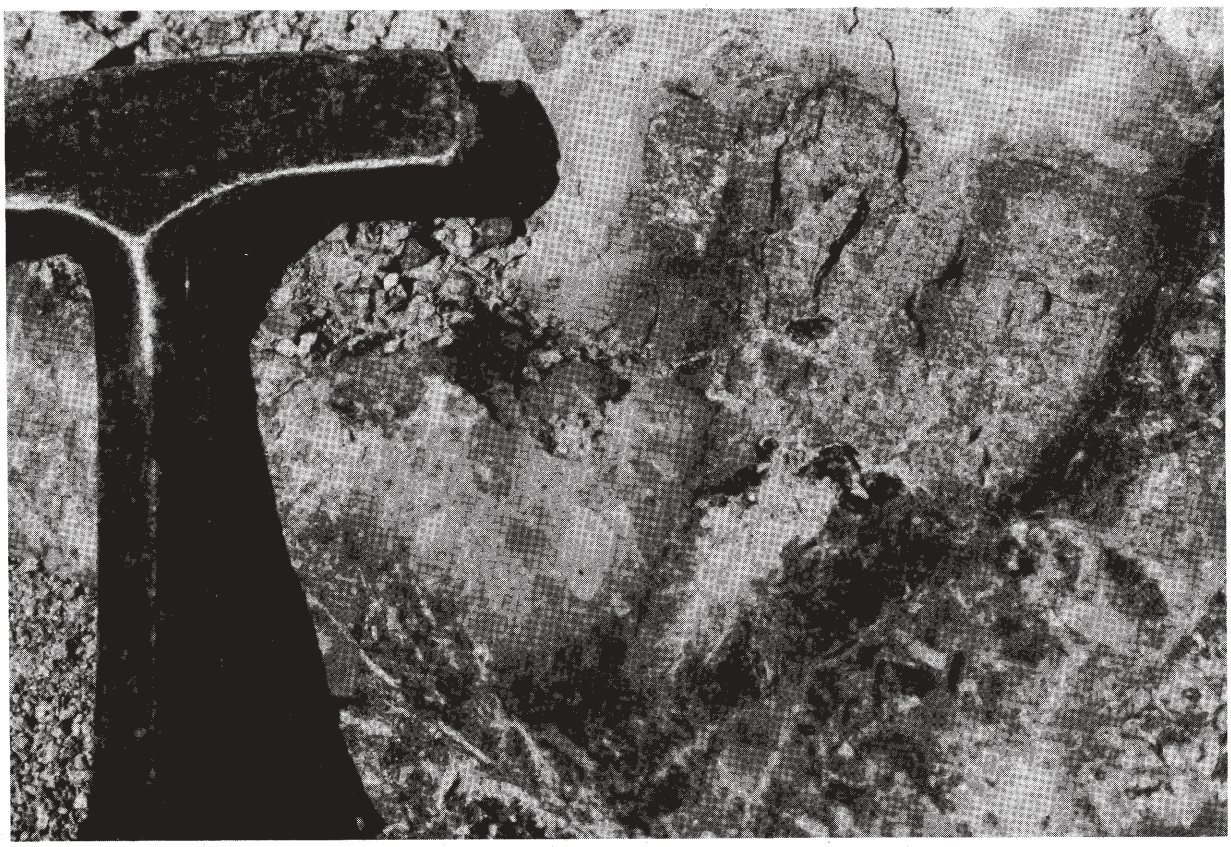


FIGURE 12. Transport-rounded jasperoid-breccia clasts (dark gray) in heterolithologic matrix-supported breccia, Vantage-2 pit. Note the Pilot Shale clasts (light gray), some of which have also been rounded. The matrix is silica and rock flour. The jasperoid breccias have been transported approximately 180 feet.

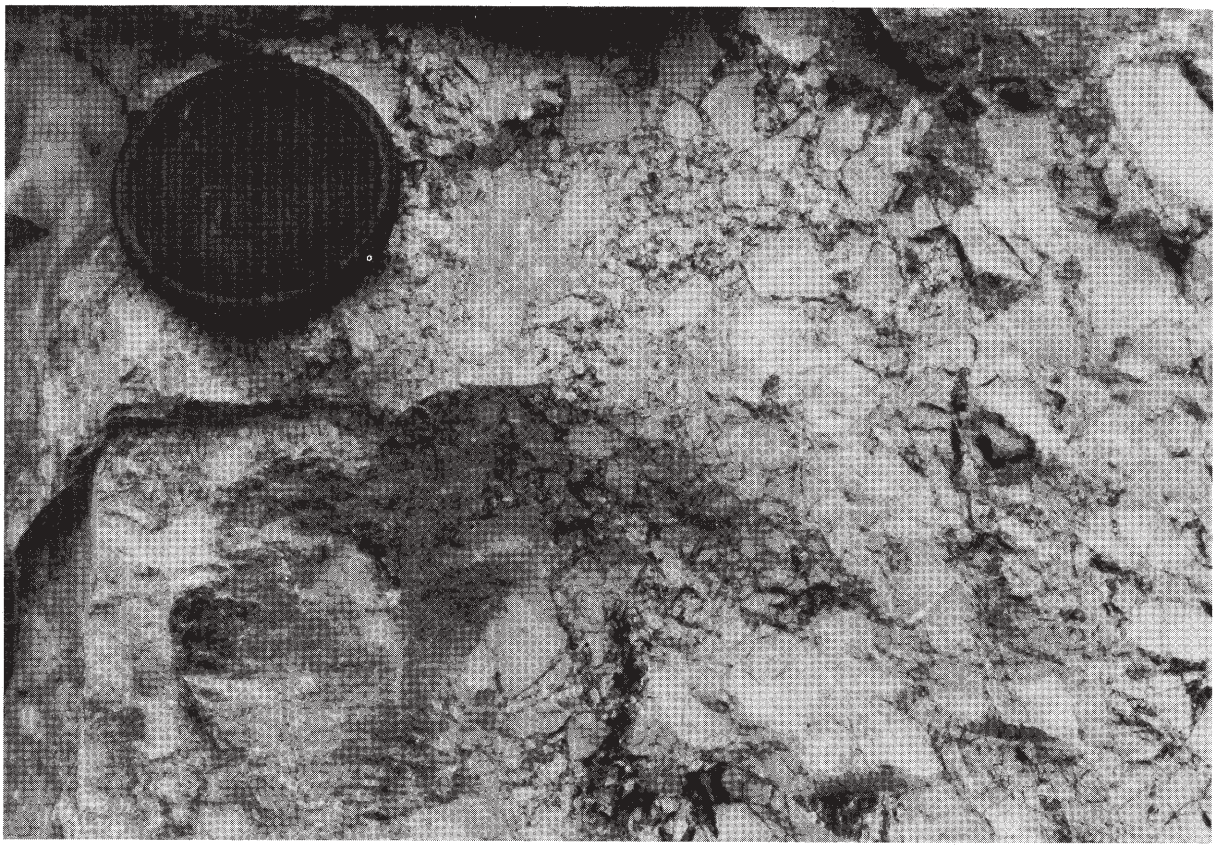


FIGURE 13. Matrix-supported breccia consisting entirely of Pilot Shale clasts that have been strongly hypogene oxidized and acid leached, Vantage-2 pits. Note that the rock grades from a crackle breccia at right into a matrix-supported breccia at left. Also note the cross-cutting vein of matrix-supported breccia (with a light gray matrix) that cuts across the picture left of center and right of the lense cap.

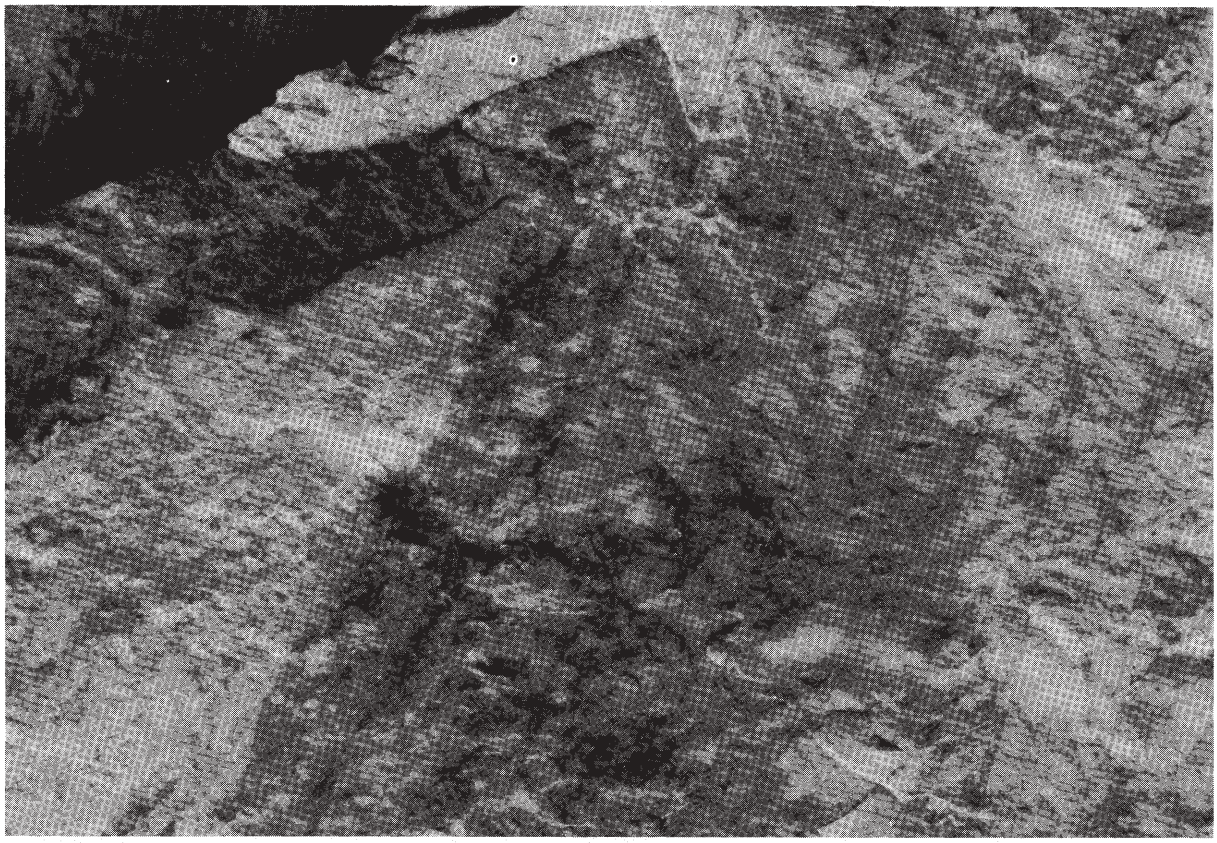


FIGURE 14. Vein with rounded Pilot Shale clasts in a silica and rock-flour matrix cross cutting crackle breccia, Vantage-2 pit. Crackle breccia has jarosite and barite on fracture surfaces.

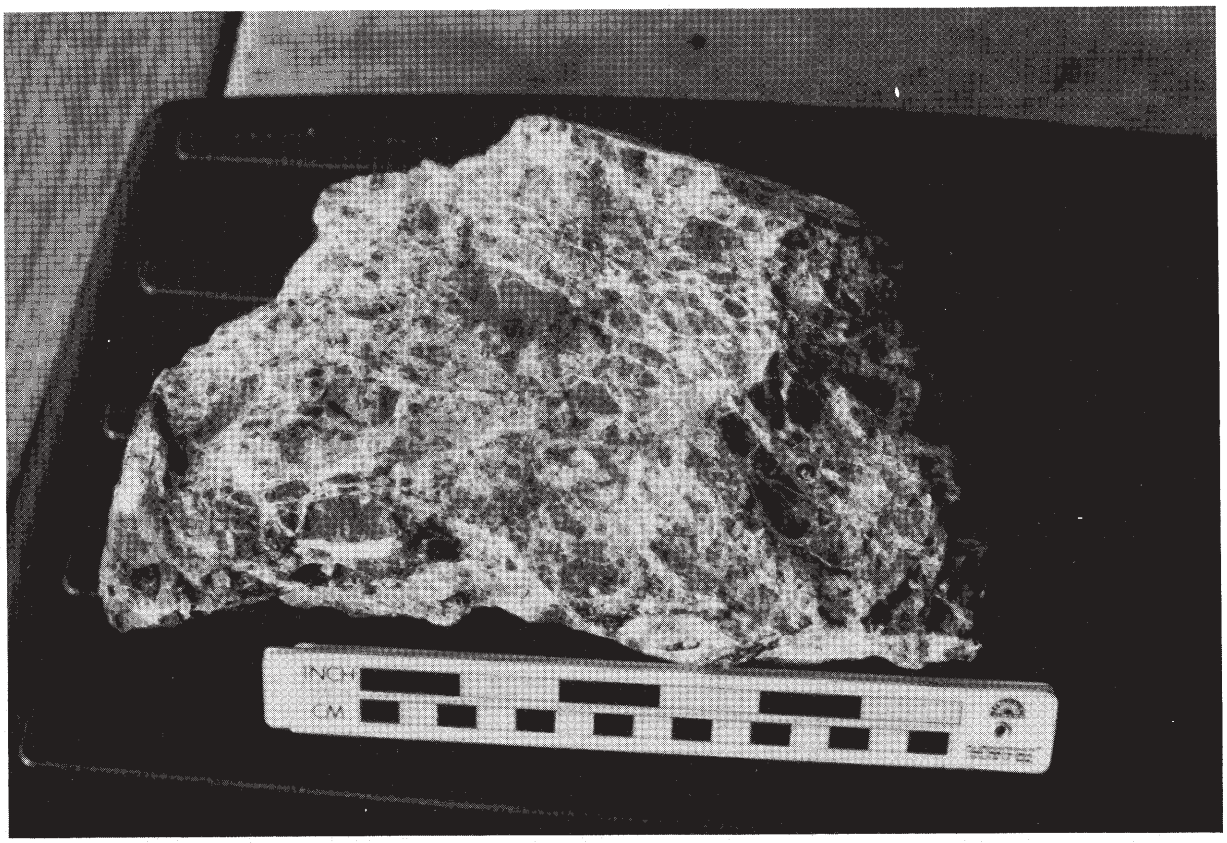


FIGURE 15. Matrix-supported breccia consisting of jasperoid breccia and Pilot Shale clasts in an alunite matrix (white), Vantage-1 pit.

FIGURE 16. Rubble breccia in Vantage-1 pit. Note the rounded boulder of jasperoid breccia. Breccia consists of rubbly zone of cobble- to boulder-sized jasperoid breccia and Pilot Shale clasts in a soft rock-flour matrix.

FIGURE 17. Crackle breccia in the north wall of the Vantage-2 pit, adjacent to a breccia body and grading into a clast-supported breccia. The fracture surfaces are coated with crystalline to earthy jarosite and hematite. The Pilot Shale fragments have been strongly hypogene oxidized and acid leached.

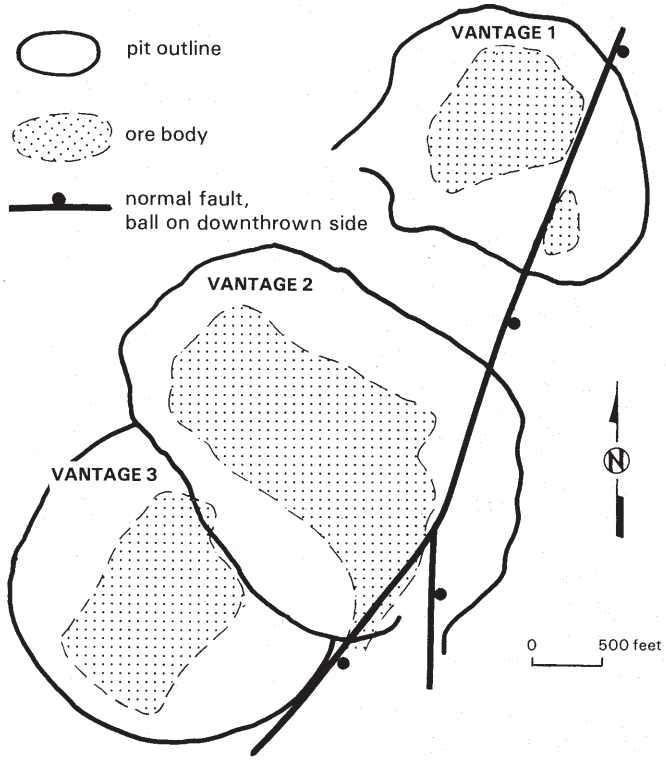


FIGURE 18. Map showing the outline of the Vantage-1, -2, and -3 pits and ore bodies. (Modified from Ilchik 1984, and Tapper, 1984a.)

jasperoid breccia–strong hypogene oxide zone to form a chaotic, rubbly zone of rounded jasperoid breccia and Pilot Shale clasts suspended in rock flour. The rubble breccia locally grades into clast-supported breccias where the rock flour has been removed by the vapor stream.

As mentioned earlier, some apparent hydrothermal breccias were discovered in the Devils Gate Limestone. These breccias were discovered during deep drilling of a deep, carbonaceous, subeconomic gold deposit located south of the Vantage-2 pit. These breccias are of a type not observed in workings from Vantage-2 northward or in exposures of the Devils Gate Limestone elsewhere in the Vantage Basin. The breccias contain limestone clasts in a carbonaceous silica and rock flour matrix. Unfortunately, little is known of this breccia type.

MINERALIZATION

Economic gold mineralization at the Alligator Ridge Mine is localized within the oxidized rocks in the lower part of the Pilot Shale and in the basal jasperoid breccia. The ore deposits are strata-bound and localized by northeast- and west-northwest-trending normal faults. The northeast-trending faults are parallel to those in the Vantage fault system. With the exception of some hanging-wall ore in the southeast corner of the Vantage-1 pit, and deep, subeconomic gold mineralization south of the Vantage-2 pit, mineralization is not localized directly along the Vantage fault system. The Vantage-1, -2, and -3 ore bodies also fall on the trend of the axis of the south- plunging anticline described earlier. The anticline may have played an important role in channeling fluids flowing within the Pilot Shale and thus acting as a control on mineralization.

The Vantage -1, -2, and -3 ore bodies and pit outlines are shown in figure 18. A cross section through the ore body in

in the Vantage-2 deposit is shown in figure 8. The Vantage-0 ore body (see fig. 3) is in low-grade mineralization within structurally prepared zones in the basal jasperoid breccia that is exposed on Jasperoid Hill. The A.R.M. pit will reach a small satellite ore body formed in the lower Pilot Shale.

Gold mineralization in the oxidized rocks is dominantly microscopic and disseminated, but some coarse gold does occur. Coarse gold occurs as dipyramids or needles that may be visible using low-power optical microscopes (Klessig, 1984a), and rare occurrences of gold visible in hand-specimen have been reported. Gold-mineralized carbonaceous rocks occur in the Vantage-2 and -3 pits. In these carbonaceous rocks, gold is submicron and its mode of occurrence is unknown. The presence of activated carbon, which can scavenge cyanide-complexed gold from the leach solutions in the recovery circuit, and abundant diagenitic pyrite cause the gold-bearing carbonaceous material to be uneconomic at the present time.

Klessig (1984b) reports an overall 9:1 gold-to-silver ratio for the Vantage deposits. Ilchik (1984) notes that the gold-to-silver ratio in the carbonaceous rocks is 1:1 and in the oxidized ore is 5:1, showing that the oxidized ores contain less silver. This suggests that the gold was originally deposited as submicron gold in unoxidized, carbonaceous Pilot Shale and oxidized at a later time. The silver could have been leached out of the gold by the oxidizing solutions and the gold could have been coarsened at the same time.

GENETIC MODEL

The genetic-model was developed to explain the alteration zonation and distribution of gold mineralization using well understood physical and geochemical processes. Unfortunately, since 1) the original surficial rocks at the Alligator Ridge deposits have been largely removed by post-mineral erosion and 2) insufficient geochemical data are available (particularly in geothermometry and fluid composition) to constrain the model of the system, some important assumptions had to be made to allow construction of the interpretive diagrams in figures 19 to 22.

The first assumption is that the mineralization at Alligator Ridge occurred after basin-and-range faulting. This assumption is supported by strong evidence that mineralization used the normal faults as conduits, including the PC and other northeast-trending faults in and parallel to the Vantage fault system. These faults cut tuffaceous sedimentary rocks that are likely of Miocene to Oligocene in age, although definitive age dates are not available. The Tertiary tuffaceous rocks are shown as the premineral surficial rocks, and although the actual surficial rocks have been removed, it is likely that the geologic section could have been close to the one represented in the diagrams.

The second assumption is that the Tertiary tuffaceous rocks in the area of Vantage basin were originally approximately 500 feet thick, although the exact thickness of these rocks cannot be determined. This implies a shallow depth of formation in the roots of a "hot-springs"-type system. A "hot-springs" type origin for this deposit is also suggested by the alteration mineral assemblages, the presence of hydrothermal breccias, and the presence of abundant acid-leached rock.

The third assumption is that the mineralizing solutions which formed the Alligator Ridge ore deposits were alkaline to slightly acidic, were at a temperature of 150 to 200 degrees Celsius, and were of low salinity. This approximates data reported by Rye (1985) for the ore-stage fluids at the Carlin disseminated gold mine. The acid leaching therefore could only be from formation of acidic solutions by condensation of vapor from boiling and effervescing solutions. It is thought that at these low temperatures gold is transported as a thiosulfate complex.

Based on the previous assumptions, a best-fit genetic model for the formation of a Vantage-2-type ore body at the Alligator Ridge Mine consists of three stages: 1) a premineral jasperoid-formation stage, 2) a main ore stage, and 3) an acid-leaching and hypogene oxidation stage. Idealized cross sections through a Vantage-2-type ore body are shown in figures 19, 20, and 21.

Stage 1, premineral jasperoid formation: jasperoid forms preferentially at the Devils Gate Limestone–Pilot Shale contact, dominantly replacing the limestone below the contact but also apparently replacing some of the lowermost Pilot Shale (fig. 19). Weak silicification of the lower Pilot Shale also occurred in this early stage. No silica veining is present in the Devils Gate Limestone below the jasperoid suggesting that physical and/or geochemical changes at the contact forced silica precipitation and enhanced carbonate soluability. A possible process for this is pressure loss and cooling of solutions due to expansion of ascending solutions that were confined to narrow conduits in the Devils Gate Limestone outward into the more permeable Pilot Shale. This process, called "throttling", would have caused the precipitation of silica to occur at or above the contact, as observed.

Stage 2, main ore stage: The main gold mineralization event seems to have occurred prior to extensive hypogene oxidation and acid leaching of the Pilot Shale, but after formation of the jasperoid breccia (fig. 20). This is suggested by the occurrance of ore-grade mineralization that cross cuts the oxidized zones and extends into the carbon zone in Vantage-2 (fig. 8), and Vantage-3. Mineralization in the jasperoid breccia is low in grade and tends to be restricted to fault zones, suggesting that the jasperoid breccia was pre-ore and that it was impermeable except where structurally prepared. Extensive hydrothermal alteration of the organic material in the Pilot Shale likely occurred at this time, forming activated carbon in the lower Pilot Shale.

Gold deposition may have occurred due to 1) reduction of the ascending solutions, 2) by scavenging of the complexed gold from solution by activated carbon, and 3) by boiling. Gold could be precipitated from a gold-thiosulfate complex by reduction of the solution by the carbonaceous material in the Pilot Shale. The scavenging of gold from solution as a gold concentrating mechanism is suggested by the abilility of the activated carbon in the carbonaceous ore to remove cyanide-complexed gold from solution. Perhaps the thiosulfate-complexed gold was removed from solution by the same process. Boiling, perhaps in response to the pressure change at the Devils Gate Limestone–Pilot Shale contact, could have caused precipitation of gold from solution. The oxidizing effect of the boiling would have been offset by the reducing environment created by the large amount of carbonaceous material in the Pilot Shale. Also, if boiling occurred beneath the water table, low pH and strongly oxidizing conditions would be less likely to occur. No data are available at this time to indicate which process or processes directly caused gold mineralization.

Stage 3. Acid leaching and hypogene oxidation: gentle boiling of solutions streaming into the lower Pilot Shale from conduits in the Devils Gate Limestone due to throttling (pressure loss) formed the bulk of the hypogene oxidation (fig. 21). Condensation of the vapor phase and effervesced gases resulted in precipitation of acid-leaching solutions. The strong oxidizing and acid-leaching environment likely occurred as a later stage simply due to the large amount of carbonaceous material present in the Pilot Shale that had to be destroyed by oxidation and the ability of the calcareous Pilot Shale to buffer low-pH solutions. Once the carbon was destroyed and the Pilot Shale decalcified,

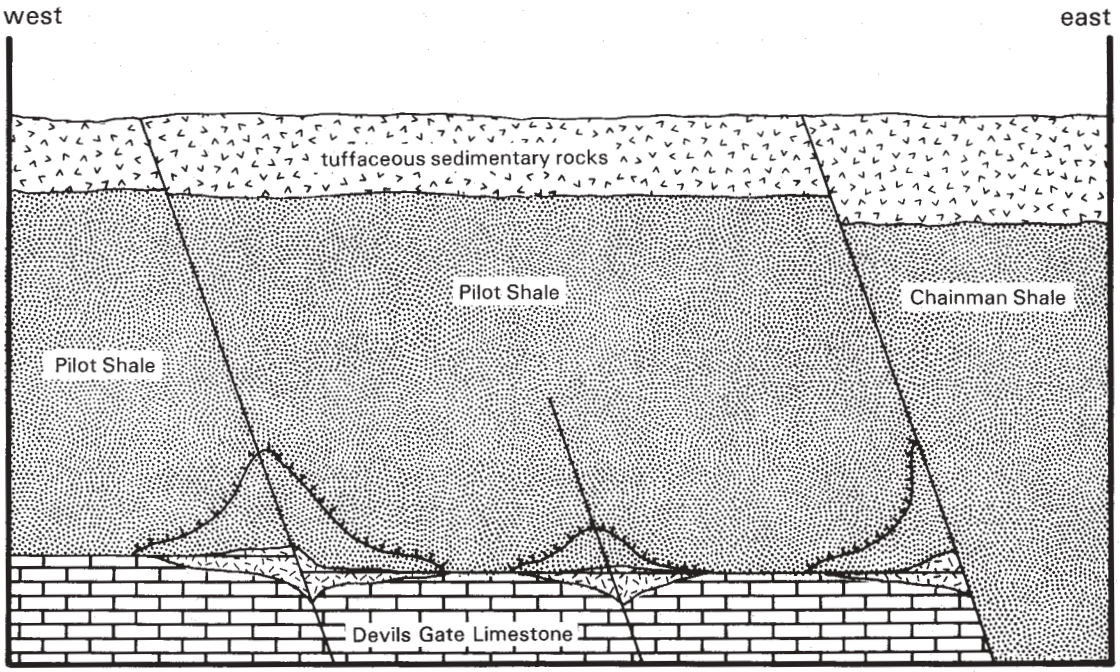
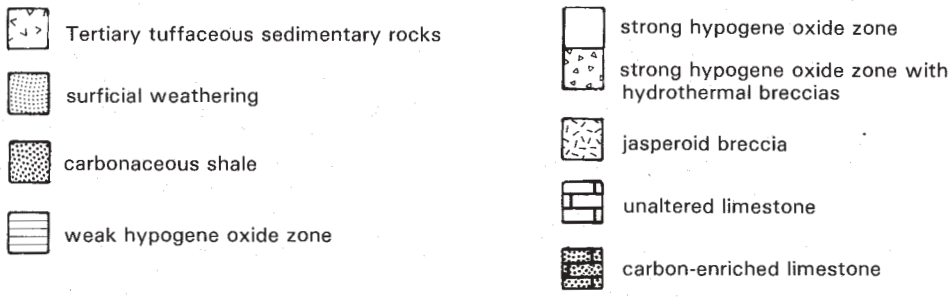


FIGURE 19. Hypothetical cross section through a Vantage-2-type ore body showing early stage jasperoid formation and decalcification.



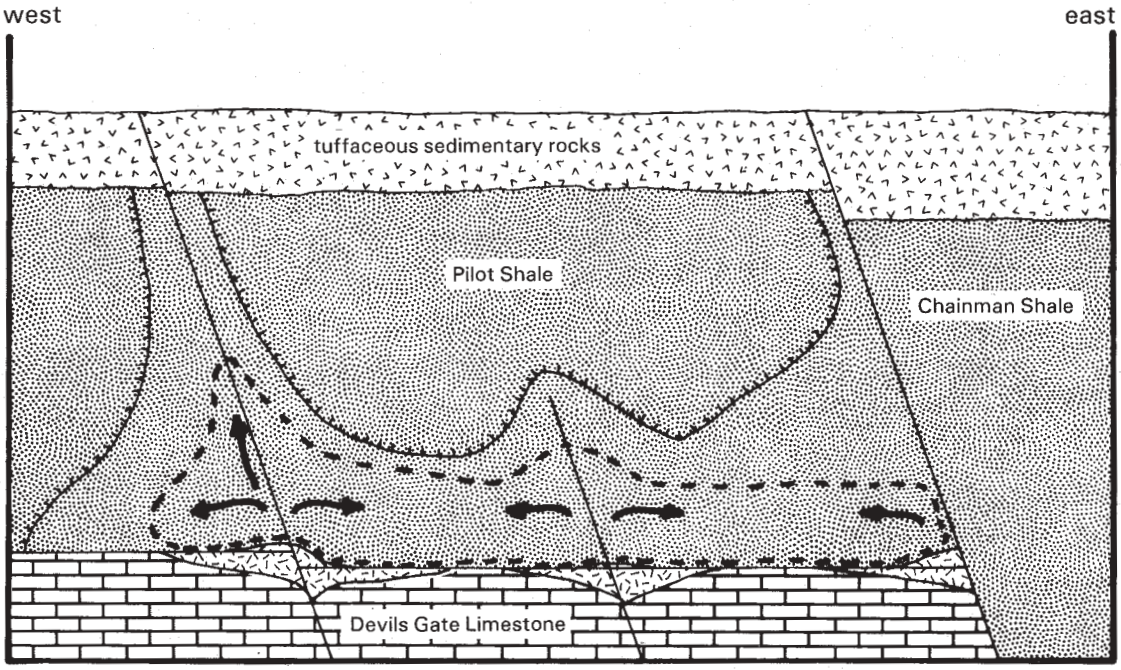


FIGURE 20. Hypothetical cross section through a Vantage-2-type ore body showing the main ore-forming stage.

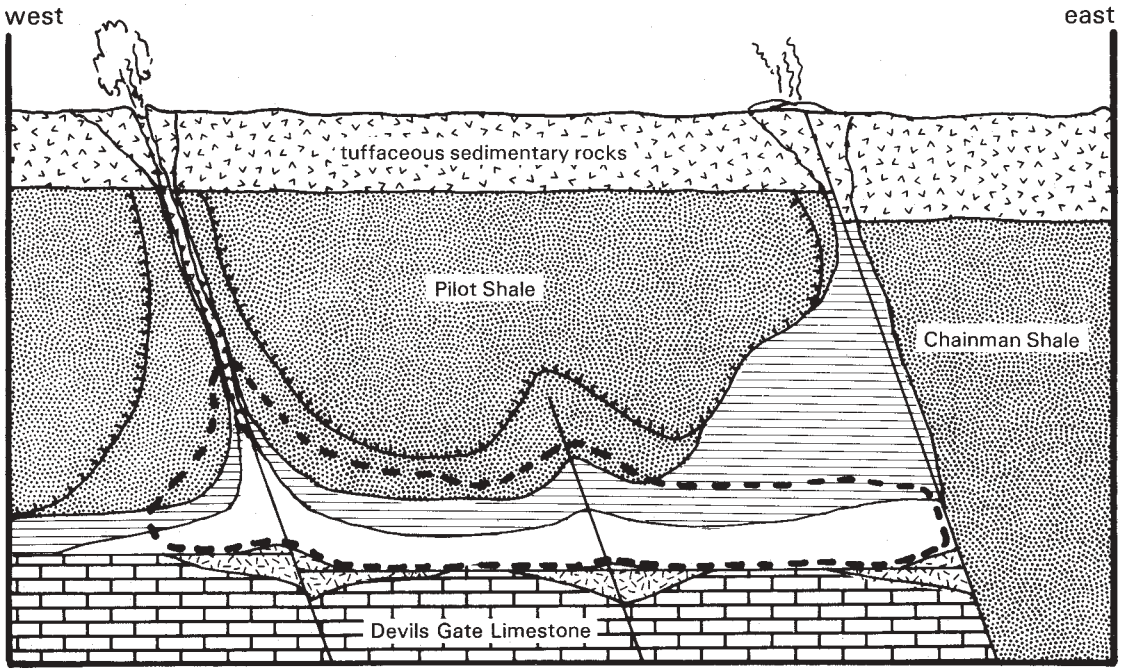


FIGURE 21. Hypothetical cross section through a Vantage-2-type ore body showing strong oxidation and acid leaching as the result of boiling. Explosive brecciation has formed a hydrothermal breccia body.

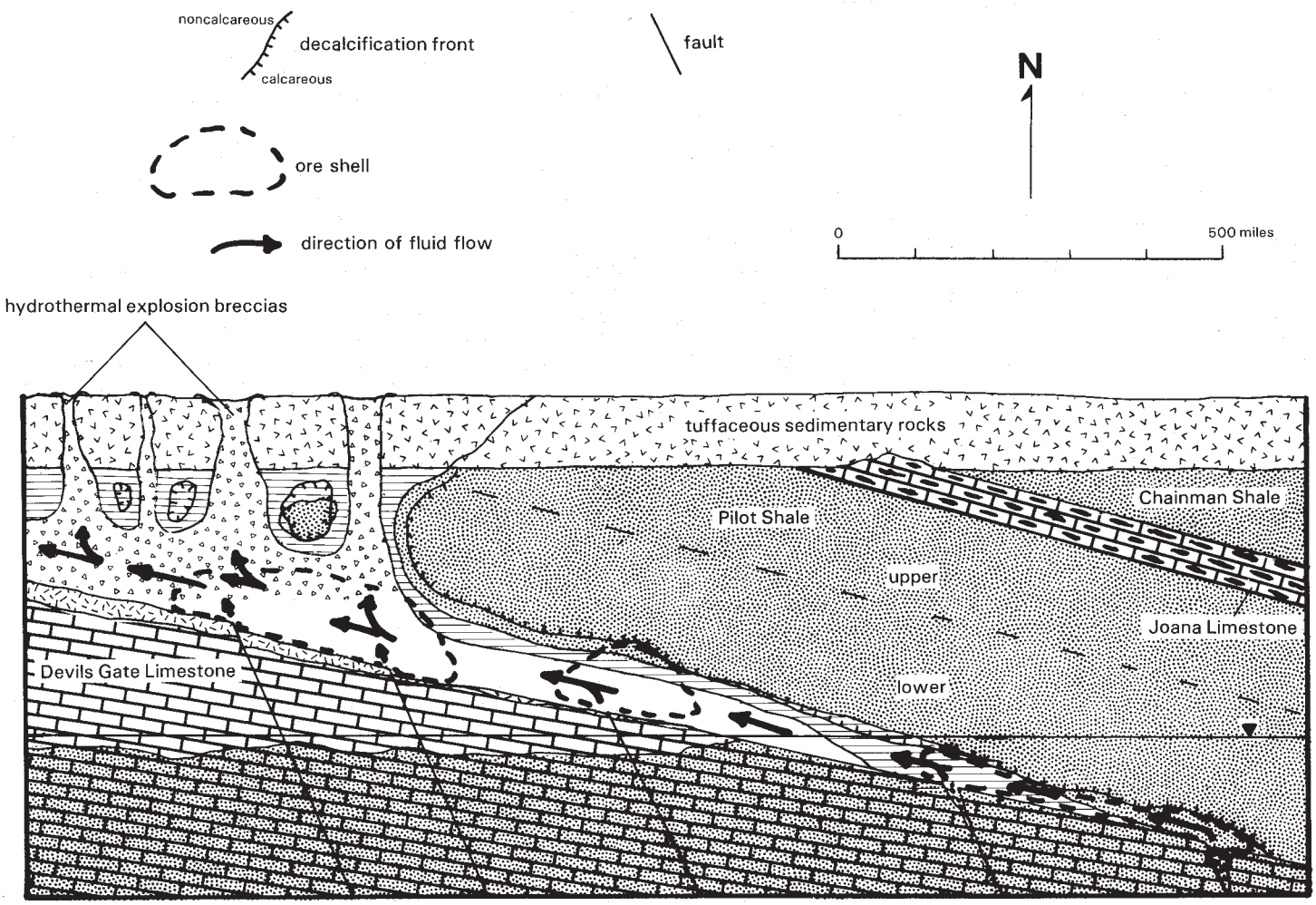


FIGURE 22. A hypothetical cross section through an Alligator Ridge–type hydrothermal system showing how the late stage alteration is controlled by updip migration of hydrothermal fluids.

oxidation and acid leaching could be carried to extremes. Another possible cause of later stage hypogene oxidation and acid leaching could be a drop in the paleo-water table. Boiling occurring above the water table would enhance the ability of the solutions to become strongly oxidizing and would promote the formation of extremely low pH solutions.

A more violent phase of boiling resulted in extensive hydraulic fracturing of the lower Pilot Shale and the formation of hydrothermal explosion breccias. This explosive activity may have been the result of self-sealing of the system by the precipitation of silica in the upper parts of the fault conduits (Berger and Eimon, 1982). Self-sealing of the conduits would have allowed the lower, permeable Pilot Shale to be flooded by solutions under lithostatic load. The relatively impermeable upper Pilot Shale claystones, presumably already folded into an anticline, could have aided in the ponding of solutions in the lower Pilot Shale. Pressure release caused by rupturing of the seal by renewed fault movement or by pressure buildup exceeding the lithostatic load plus the rock tensile strength, would result in decompression of the fluid-saturated lower Pilot Shale and flashing of the confined solutions to steam. Decompression would also promote rapid effervescing of dissolved gases such as CO_2. The pore fluid in the lower Pilot Shale, flashed to steam, hydraulically fractured the rock as it expanded. Where a pathway existed to the surface, vapor and gas streaming could have occurred, brecciating the rock and transporting rock fragments upward to form hydrothermal breccia bodies. At the Alligator Ridge deposits, the vapor streaming carried fragments of the early-formed basal jasperoid breccia at least 200 feet upward from the base of the Pilot Shale and rounded them during transport.

Another possible mechanism for breccia-body formation would be formation of a "gas cap" (Hedenquist and Henley, 1985). Since the concept of self-sealing is not universally accepted, Hedenquist and Henley (1985) proposed that once self-sealing closed off a conduit and the hydrothermal system diverted to another, vapor, steam, and CO_2 from boiling and effervescing could collect under the seal creating local overpressurized zones. Rupturing of the seal by the processes described above would initiate a hydrothermal explosion followed by gentle boiling. Either mechanism would result in the observed features.

Some gold may have been deposited due to destabilization of thiosulfate complexes during boiling. Pre-existing gold was coarsened and leached of silver in the oxidizing environment created by boiling, resulting in the change in the gold-to-silver ratio mentioned earlier.

Updip fluid flow in the lower Pilot Shale may be responsible for some of the larger scale alteration zonation and features observed in the Alligator Ridge deposits (fig. 22). It seems likely, based on alteration zonation, that the Pilot Shale was dipping to the south during alteration and gold mineralization. Some of the features that this process explains are: 1) the increase in thickness and continuity of the basal jasperoid-breccia sheet, 2) The overall zonation of hypogene alteration in the deposits, and 3) the localization of the explosive activity in the Vantage-1 and -2 hydrothermal explosion breccias above the basal jasperoid breccia sheet.

Precipitation of silica from solutions flowing upward along the Devils Gate Limestone–Pilot Shale contact would have been promoted by simple cooling and by pressure release as fluids approached the surface. Boiling, hypogene oxidation and acid leaching, may have been caused by updip flow of the solutions and the resulting change in pressure. It is also likely that below the ancient water table reducing conditions were more likely to occur. A hypothetical water table is shown in the idealized cross section in figure 16. The explosive hydrothermal activity was localized in the lower Pilot Shale because the updip-flowing solutions passed through the lower Pilot Shale and above the earlier formed jasperoid-breccia zone. Self-sealing or gas-cap formation, discussed above, would have released pressure on solutions mainly contained in the Pilot Shale and uppermost part of the jasperoid-breccia zone, hence the apparent lack of Devils Gate Limestone clasts and apparent "rootless" nature of the hydrothermal breccias. The carbonaceous hydrothermal breccias in the Devils Gate Limestone are the result of boiling of solutions and of solutions at and not above the Pilot Shale-Devils Gate Limestone contact. Because the boiling occurred below the water table, and because of the abundance of carbonaceous material and carbonate, the solutions were unable to become strongly oxidizing (low pH), except locally. The presence of hydrothermally altered carbonaceous material in the Devils Gate Limestone and the breccia bodies suggests that organic complexes could have been important transport mechanisms for gold.

SUMMARY AND CONCLUSIONS

Apparently, the Alligator Ridge disseminated gold deposits are apparently relatively young and represent the root zones of a hot-springs-type system. This is suggested by the alteration zonation, the types of alteration present (especially hypogene oxidation and argillization), the alteration mineral suite present (especially jarosite, alunite, and kaolinite), and the presence of hydrothermal explosion breccias.

Ore-body genesis can be divided into three phases: 1) an initial barren phase of jasperoid-breccia formation, 2) a phase of gold deposition within the carbonaceous Pilot Shale, and 3) a final phase of boiling, acid leaching, strong hypogene oxidation, and explosive hydrothermal brecciation. During the final stage some gold deposition may have occurred, but it is evident that much of the coarse gold in the oxidized ore is reworked, submicron gold originally deposited in carbonaceous rock.

The genetic model developed for the Alligator Ridge deposits, although not definitive, uses updip flow of the hydrothermal solutions through the Pilot Shale to explain the large-scale overall alteration zonation. On a smaller scale, physical processes such as throttling and self-sealing (or formation of a gas cap) controlled boiling and explosive brecciation.

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Northwall, Vantage-2 pit, Alligator Ridge gold mine.

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