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TRIP REPORT
GEOLOGICAL SOCIETY OF AMERICA
CORDILLERAN SECTION MEETING AND FIELD TRIPS
MARCH 25 - APRIL 2, 1988
LAS VEGAS, NEVADA

BY
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Pursuant to Work Directive 13 under Task Order 002, Interagency Agreement NRC-02-85-004, Russell G. Raney, Bureau of Mines, Western Field Operations Center, attended the Geological Society of America (GSA) meeting and associated field trips. These included:

1. GSA field trip, Gold Deposits of the Las Vegas Region, March 26-28;

2. GSA symposium, Oil and Gas Exploration in the Great Basin, March 31;

3. Overflight of the Nevada Test Site, March 30;

4. GSA field trip, Geology of the Nevada Test Site, April 1; and

5. Non-GSA sponsored side trip to the River Mountains and the Saddle Island detachment zone.

Also pursuant to Work Directive 13, the following meeting and field trip handout materials are enclosed:

General Items

Enclosure 1. GSA field trip guidebook (one each) entitled "This Extended Land: Journeys in the Southern Basin and Range." The guidebook was included as part of the Gold Deposits of the Las Vegas Region field trip. Additional copies are available through the Department of Geoscience, University of Nevada, Las Vegas, Las Vegas, NV 89154, (702) 739-3262. Cost is $20.00 plus $2.00 shipping and handling.

Enclosure 2. Abstracts with Programs, 1988. 84th Annual Meeting, Cordilleran Section, Geological Society of America (one each). Additional copies are available through GSA, P.O. Box 9140, Boulder, CO 80301. Cost is $8.00.

Gold deposits of the Las Vegas Region

Enclosure 3. Gold Deposits of the Nelson District by P. A. Drobeck, R. R. Kern, and S. L. Jenkins.

Enclosure 4. The Colosseum Gold Mine by D. L. McClure and H. W. Schull.

Enclosure 5. The Morning Star Gold Mine by K. Ashburn.

Enclosure 6. The Frisco Mine, Mohave County, Arizona by E. Huskinson.

D1018 / WM-11 / NH14

Enclosure 7. Geology and Structural Control of Gold Mineralization at the Van Deeman Prospect, Mohave County, Arizona by F. L. Hillemeyer, P. A. Drobeck, and W. T. Dodge.

Overflight of Yucca Mountain

Enclosure 8. Four aerial photographs showing geological, geographic, and topographic features of the Yucca Mountain area (one set of originals).

Geology of the Nevada Test Site

Enclosure 9. Characterization of Percolation in the Unsaturated Zone: Surface-Based Borehole Investigations. Anonymous, U.S. Geological Survey Water Resources Division, Nuclear Hydrology Program.

Enclosure 10. Monitoring Hydrologic Conditions in the Vadose Zone in Fractured Rocks, Yucca Mountain, Nevada by Parviz Montazer.

Enclosure 11. Nevada Nuclear Waste Storage Investigations, G-Tunnel Underground Facility.

GSA FIELD TRIP
GOLD DEPOSITS OF THE LAS VEGAS REGION
March 26-28, 1988

Gold deposits in the Las Vegas Region have been exploited sporadically for more than 150 yr. In the late nineteenth and early twentieth centuries, gold discoveries led to the establishment and subsequent development of the Nelson (El Dorado Canyon), Oatman, and Searchlight mining districts. The Nevada/California/Arizona "gold rush" of the 1980s has led to renewed activity in these districts.

The purpose of this field trip was to examine (albeit briefly) several of the mines and prospects in the Las Vegas Region in light of recently developed information as it pertains to lithology, structure, and the potential for low-grade, high tonnage gold mineralization. The trip itinerary was:

Day 1. Nelson District, including the Wall Street-Blackhawk, Rand-Quaker City, Techatticup, and Jubilee Mines. The Colosseum Mine (in production) was visited in the afternoon.

Day 2. The Morning Star (producing) and Castle Mountains deposits were examined.

Day 3. Visits to the Frisco and Van Deeman deposits.

The following descriptions and accounts of the various mining districts, mines, and prospects were abstracted from the field trip guidebook and printed material provided by the authors and supplemented by on-site lectures.

GEOLOGY OF THE NELSON DISTRICT 1/
by
R. R. Kern, P. A. Drobeck, and S. L. Jenkins

Geologic Setting

The Nelson District is about 50 kilometers (km) south of the intersection of the Las Vegas and Lake Mead shear zones within a zone of mid-Tertiary extensional faulting. Detachment faulting has been noted in the Black Mountains, Newberry Mountains, and the River Mountains, to the east, south, and north, respectively, of the district. District basement rocks include Precambrian schists, gneisses, and pegmatites directly overlain by Tertiary volcanics; Paleozoic sediments occur west of the district in the Clark Mountains.

History and Production

Major mining began in 1862 at the Techatticup Mine, which ultimately became the district's largest producer. The Duncan, Wall Street-Blackhawk, Jubilee, Magnolia, and Rand were also significant producers. Early production in the Nelson District was not recorded; however, more than 100,000 tr oz Au and 2.3 million tr oz Ag were reported between 1907 and 1954. It is thought that actual production was at least twice that amount.

Lithology

The Nelson District is characterized primarily by Tertiary igneous rocks with minor outcrops of Precambrian gneiss in the vicinity of the Carnation and Jubilee Mines.

Patsy Mine Volcanics, the lowermost and most widely distributed unit of the Tertiary volcanics, represent the development of a composite volcanic field. The unit has a maximum thickness of 3,960 meters (m) with K/Ar ages ranging between 22.8 and 15.2 my. Patsy Mine Volcanics have been divided into three informal members:

1. Upper member. Approximately 460 m of distinctive gray to dark brown basalt flows.

2. Middle member. Light colored tuffs, tuff breccias, lithic tuffs, reworked tuffs, and rhyolite flows.

3. Lower member. Principally basalt, basaltic andesite, andesite, and latite flows; agglomerates; flow breccias; and minor tuffs.

The Nelson Quartz Monzonite (Techatticup Pluton), a large multiphase although dominantly monzonitic laccolith, has intruded the volcanic rocks. In the field, the chilled margins of the pluton appear to be identical to massive portions of the Patsy Mine Volcanics; however, petrographic studies have revealed major differences in composition and fabric.

1/Refer to enclosure 3 for full text.

Alluvium, colluvium, and Quaternary tufa associated with recent hot springs are also present in the district.

Structural Geology

Known structures in the Nelson District are all Tertiary and related to pre-Basin and Range regional extension. A low-angle system of extension (detachment faulting) is responsible for faulting developed in the district and for ore zone structural preparation. Individual ore bodies, as well as the regional trend, follow the east-west detachment fault system.

The district represents a major transition in the regional style of detachment deformation. Upper plate volcanic rocks north of the district generally dip steeply eastward as they are cut and rotated by west-dipping normal faults; upper plate rocks to the south dip to the west at steep angles as the result of east-dipping normal faults.

Within the district proper, three structural-lithologic zones are recognized:

1. An upper plate comprising upper units of the Patsy Mine and overlying volcanics that has been incised by numerous north- and northwest-trending normal faults. The faults have greatly rotated the Patsy Mine rocks.

2. A detachment zone that hosts lower Patsy Mine Volcanics and Nelson Quartz Monzonite. This zone is characterized by a highly complex fault/jointing system that dips 20 to 30° N. The zone is further complicated by the synkinematic sill-like Nelson Quartz Monzonite. In the past, the zone has been called the "Nelson Fault Zone" but, due to its extreme complexity, most workers prefer the term "Nelson Chaos." The hundreds of faults, large and small, within the chaos have created an area of highly fractured and permeable rock into which mineralizing fluids were introduced. The zone hosts the major ore bodies of the district: the Wall Street, Magnolia, Rand, and Techatticup. Lines of evidence suggest the process of mineralization was post-detachment, not synkinematic.

3. A lower plate characterized by Nelson Quartz Monzonite and minor Precambrian gneiss.

Alteration and Mineralization

Three hydrothermal systems in the district have been identified, but more work is needed to fully understand their ramifications.

The oldest is a weak hydrothermal system associated with intrusion of the Nelson Quartz Monzonite and development of the detachment fault. Propylitic alteration is common above, on, and below the detachment zone. This type of alteration is common in detachments through the Southwest, and is not believed to be ore-related.

Gold, silver, and base metals occur in quartz-calcite veins and stockwork zones within the second hydrothermal system. Most of the productive ore bodies occur within the chilled margin of the intrusive within the detachment zone; some smaller bodies, such as the Carnation, occur in the lower Patsy Mine Volcanics. Argillic alteration is also widespread.

The third system is related to Quaternary hot springs that deposited kaolinite-aragonite-selenite tufas on gravel. Tufa deposits are closely associated with the advanced argillic alteration zones, suggesting the two may be related. No mineralized material occurs with tufa deposits.

Individual Mines in the Nelson District 2/

Rand and Quaker City

The combined production of the Rand and Quaker City Mines is thought to be more than 50,000 tr oz Au extracted from 1,830 m of underground workings; the Rand Shaft is 100 m deep. The mines are on a series of east-northeast-striking high- and low-angle fault zones that are a part of the detachment system. Gold, silver, and minor base metals occur in quartz-calcite veins and stockwork in highly fractured Nelson Quartz Monzonite.

Wall Street and Blackhawk

Recent drilling has delineated a modest resource of gold-bearing material that would be available for open-pit mining. When the Wall Street was in production (it was the third or fourth largest producer in the district), ore was removed primarily from underground stopes in south-dipping veins, with lesser amounts mined from north-dipping veins.

Techatticup

This mine, the largest in the district, is estimated to have produced more than 175,000 tr oz Au between 1860 and 1900; an additional 50,000 tr oz Au were produced from 1900 to 1930. The mine also operated through the Depression and into 1942, but this production went unrecorded. Techatticup Mine was developed by a 210 m shaft and 4.8 km of underground workings on two steeply-dipping quartz-calcite veins within the Nelson Quartz Monzonite. No significant tonnage of disseminated gold/silver ore or alteration halo has been recognized.

2/Abstracted from GSA field trip guidebook.

Jubilee

The Jubilee was developed in intensely fractured and faulted Patsy Mine Volcanics above a major strand of the regional detachment system. The hill upon which the mine is located hosts three south-dipping veins and one north-dipping vein. Further, rocks in the mine area are characterized by stockwork and local sheets of calcite-dominated veinlets. Alteration occurs as a weak propylitic halo.

Personal Observations and Comments

None of the mines visited in the Nelson District are in production. Homestake Mining Co. and others, however, are engaged in limited exploration programs in the district. To date, Homestake has delineated "modest low-grade reserves" in the vicinity of the Wall Street-Blackhawk workings; drilling by AMAX is in progress some 5 km to the east of the Homestake play. Unless a greater tonnage is delineated, it is unlikely that the Wall Street-Blackhawk will come on-stream in the near future.

Detachment faulting and subsequent high-angle normal faulting, block rotation, and brittle deformation have provided the structural preparation for mineralization in the Nelson District. This structural style may exist (to a greater or lesser degree) at Yucca Mountain. Numerous high-angle normal faults (with possible block rotation), a significant zone of intense brecciation in Solitario Canyon, and a postulated detachment zone or zones underlying the proposed repository area may have provided the porosity and permeability necessary for mineralization to occur, provided there was a source of mineralizing fluids. A postulated underlying metamorphic core complex and/or plutonic rocks at depth, Quaternary basaltic volcanism at Crater Flats, and the existence of nearby plutonic rocks may represent such a source.

GEOLOGY OF THE COLOSSEUM GOLD MINE 3/
by
D. McClure and H. W. Schull

History and Production

The Colosseum Mine, located in the Clark District, San Bernardino County, CA, is approximately 72 km southwest of Las Vegas. Gold was discovered at the property in 1865, 5 yr after organization of the district. Prior to the 1930s, production at the Colosseum deposit went unrecorded. Between 1930 and 1942, when the mine was shut down by War Production Board Order L-208, a production of 615 tr oz Au was recorded. Minor amounts of silver, copper, and lead were also produced. The mine began current operations in November 1986.

Since 1970, several companies have been involved in exploration at and near the site. More than 42,367 m of diamond core, percussion, and reverse circulation boreholes have been completed to date. Presently, measured resources are estimated as 7.3×10^6 metric tons (mt) at 2.3 grams (g)/mt Au. "Significant" but unspecified additional inferred resources grade between 0.6 and 1.0 g/mt Au. The estimated open-pit mine stripping ratio (waste to ore ratio) during the life of the operation is 3.8:1.

Ore is crushed to minus 80 mesh and processed in a 3,400 mt/d carbon-in-pulp (CIP) cyanide leach plant. The gold-bearing lixiviant is strained to remove the carbon which is then stripped using a hot caustic solution. A double electrowinning process followed by smelting results in a marketable gold/silver dore.

Lithology

Gold is associated with pyrite in breccia clasts, replacing dolomite, and in "crackle" breccia veinlets in two small breccia pipes. The pipes also host gold associated with quartz and as disseminations.

Structural Geology

The Sevier Thrust belt (Cretaceous) characterizes the general structure in the vicinity of the Colosseum Mine. Two major thrusts of the Clark Mountain Thrust complex have been mapped near the property; a third major thrust, the Keystone, is located approximately 900 m southwest of the west breccia pipe. Normal faulting related to Basin and Range tectonism further complicates the structural picture. Ore minerals (primarily sulfides) occur in the two breccia pipes that have intruded the underlying Precambrian gneiss into Paleozoic sediments of the upper plate of the Keystone Thrust. The overlying sediments have been removed through erosion.

3/Refer to enclosure 4 for full text.

Alteration and Mineralization

Alteration within and in proximity to the breccia pipes consists primarily of sericitization and argillation; pyrite, hosting submicroscopic gold, is the primary ore mineral.

Personal Observations and Comments

The major elements required for epigenetic ore deposition (ground preparation, a source of mineralizing fluids, etc.) are present at the Colosseum deposit. Thrusting of the Paleozoic section and concurrent brittle deformation provided the conduits for subsequent mineralization. This kind of structural preparation, whether due to detachment faulting or thrusting, is common to all but one (Castle Mountains deposits) of the mines and prospects visited on this field trip. These pre-depositional elements for epigenetic ore deposition may be present at or proximal to Yucca Mountain.

MORNING STAR GOLD MINE 4/
by
K. Ashburn

History and Production

The Morning Star deposit is located in San Bernardino County, CA, on the eastern flank of the Ivanpah Mountains about 100 km south of Las Vegas. Elevation at the property is 1,400 m.

Gold and base metals were recognized at the property as early as 1907. Sporadic exploration activity occurred between 1907 and the late 1930s when the property was acquired by Haliburton Oil Co. The company delineated nearly 1.8 x 10^6 mt of ore in extensive underground development workings before being shut down in 1942 by War Production Board Order L-208. The shutdown order came before production could begin.

In 1964, Vanderbilt Gold Corp. acquired the property and conducted an exploration program that included extensive drilling and an evaluation of the existing underground workings. From 1980 to 1982 the property was further developed underground; however, in 1983 poor economic projections forced the company to switch development to an open-pit operation. Limited production began in late 1986.

Full-scale production commenced in November 1987. Current operations include open-pit mining and heap leaching. Measured resources are estimated at 7.26 x 10^6 mt of ore at 2.6 g/mt Au; a mine life of 9 to 10 yr is projected. Production data to date are proprietary.

Geologic Setting

The Morning Star deposit, located in the southernmost portion of the Sevier Thrust belt, is hosted by Jurassic Ivanpah granite in the upper plate of a low-angle thrust. The Ivanpah granite is one of seven Jurassic and Cretaceous granitic plutons that make up the Teutonia Batholith, one of the largest intrusive complexes in the eastern Mojave Desert. Tertiary high-angle normal faulting related to Basin and Range tectonism overprints the rocks at the deposit.

Lithology

The Ivanpah granite is the principal rock type in the mine area. The granite hosts numerous dikes of pegmatitic to aplitic composition. Mafic dikes that range in composition from diabase to diorite are widespread. K/Ar dating of biotite in the granite indicate an age of 137 my.

4/Refer to enclosure 5 for full text.

Structural Geology

Ore deposition was (locally) structurally controlled by a semi-continuous low-angle thrust the upper plate of which is strongly altered and highly fractured. Post-depositional structures, high to moderate angle faults and fractures, are consistently unmineralized and contribute significantly to pit wall instability.

Alteration and Mineralization

Gold occurs as free gold, commonly coating or filling fractures in pyrite, chalcopyrite, and galena in quartz ± calcite veins, veinlets, stringers, and stockwork in the upper plate. A zone of secondary supergene mineralization occurs along the upper plate/lower plate contact. Gold may be associated with covellite within this zone. Galena and gold are typically argentiferous; no silver minerals, however, have been recognized.

Propylitic alteration is pervasive and occurs in both upper and lower plates. Conversely, alteration associated with mineralizedveins consists of silicification (confined to discrete veins, veinlets, and stringers), sericitization, and argillation.

Personal Observations and Comments

Fracturing of upper plate rocks during transport provided the ground preparation for the Morning Star ore zone. However, this may be a case of "too much of a good thing" in that this essential element of epigenetic ore deposition has caused, and will continue to cause, serious engineering problems related to pit wall stability. This, in effect, acts to increase the stripping ratio (safety and other considerations aside) and negatively affect the profitability of the operation.

GEOLOGY OF THE CASTLE MOUNTAINS GOLD DEPOSIT

by

H. Linder

Geologic Setting

Located 97 km south of Las Vegas and 24 km southwest of Searchlight, the Castle Mountains gold deposit is within the old Hart mining district at an elevation of 1,372 m. The climate and topography are typical of the eastern Mojave Desert.

The Castle Mountains, in which the deposit occurs, consist of Miocene rhyolite flows, domes, and pyroclastics that overlie Proterozoic gneissic basement rocks. The mountain range occupies a north-northeast-trending structural block characterized by shallow westerly fault dips. Younger, mafic volcanic rocks, extending from the Piute Range, cover the eastern and southeastern parts of the Castle Mountain Range.

History and Production

Jim Hart, the district's namesake, is credited with the discovery of gold on the property in 1907. Minor unrecorded production ensued in a short-lived gold boom before the coarse-gold veins played out at depth. Two large clay pits subsequently were developed on the property. In 1983, a 41% interest in the Oro Belle deposit (a part of the Castle Mountains deposit) was acquired from Vanderbilt Gold by Viceroy Resources Corp. of Canada. A major exploration program was mounted by Viceroy in 1985 under the direction of Harold Linder, resulting in the discovery of the Jumbo and Lesley Ann deposits in 1986.

Viceroy has expanded its holdings to include more than 1,700 mining claims that cover the entire range. Published reserves total more than 21.77 x 10^6 mt averaging 2.06 g/mt Au. Reserves for the individual deposits include:

1. Oro Belle -- 6.53 x 10^6 mt at 1.44 g/mt Au.
2. Lesley Ann -- 6.17 x 10^6 mt at 3.12 g/mt Au.
3. Jumbo -- 9.07 x 10^6 mt at 1.75 g/mt Au.

Viceroy Resources, through its wholly-owned operating company, B & B Mining, plan a 7,256 mt/d heap leach operation to begin operating in mid-1988.

Lithology

Rocks at the Castle Mountains deposits are predominantly west-dipping rhyolite flows, tuff breccias, flow breccias, and other pyroclastics that have been intruded by rhyolite domes, plugs, and hydrothermal breccias. A series of arcuate silicified fractures form a zone 457 m by 2,134 m that may represent a part of the rim of a small caldera some 8 km in diameter. The major portion of the mineralized material lies within the area of the postulated caldera.

Mineralization and Alteration

The Castle Mountains deposits are classified as volcanic-hosted epithermal with gold as the major metal plus minor silver; base metals are absent. Mineralized material is closely related to permeability and occurs in brittle, well-fractured or brecciated rock. Gold is associated in hematite, replacing pyrite in vuggy quartz veins and fractures and in silicified breccias. While most gold is very fine-grained, some coarse gold has been observed in underground workings at the Oro Belle and in drill core. All ore reserves occur in the oxidized zone; unaltered sulfides have been noted below the water table at a depth of 168 m.

The most common forms of alteration are silicification (pervasive) and argillation. Two high-grade clay pits have been developed west of the gold deposits; the pits are currently inactive.

Personal Observations and Comments

The Castle Mountains deposits represent a radical departure from other deposits examined during the course of this field trip in that ground preparation here was not the result of tectonism. While the detailed geology and structure of the deposit are unknown, it appears that ground preparation and subsequent mineralization were functions of intrusion and hydrothermal fracturing.

Viceroy's planned production target of mid-1988 seems overly optimistic in that no ancillary facilities are in place (or under construction). Moreover, the lack of infrastructure (power, adequate water supplies, adequate access roads, etc.) leads one to conclude that mid-1989 or early 1990 may be more reasonable target dates.

GEOLOGY OF THE FRISCO MINE 5/
by
E. Huskinson

Geologic Setting

The Frisco Mine, 40 km west of Kingman, AZ, and about 145 km south of Las Vegas, is near the north end of the Union Pass mining district on the west flank of the Black Mountains. Rocks in the vicinity of the mine consist of a series of volcanic flows and tuffs overlying granite and gneiss. The Black Mountains Detachment Fault separates the overlying volcanics from the basement rocks.

Two ore bodies, the Gold Crown and the Gold Dome, have been delineated in the upper plate of the detachment fault. A third ore body is inferred in altered crystalline rocks in the lower plate.

History and Production

Activity at the Frisco Mine has been sporadic since its discovery in 1890. Approximately 36,300 mt ore at 1.37 to 2.06 g/mt Au were produced from the underground workings between 1890 and 1930. Portions of the ore were milled on-site and the balance shipped to the Katherine mill about 11 km to the west.

From 1984 to 1986, approximately 79 kg Au were recovered at the property in a cyanide leach operation. Negative economics (drop of gold prices and increased stripping ratio) forced closure of the mine in late 1986. Currently, 69 hectares (ha) of patented claims and 260 ha of state leases are undergoing exploration by two Canadian mining companies.

Lithology

The Black Mountains Detachment Fault separates the two dominant rock units in the mine area. Rocks of the lower plate (below the detachment) consist of Precambrian gneiss, porphyritic granite, and granodiorite. Metavolcanic rocks occur locally as does mylonitized and brecciated gneiss.

Upper plate rocks consist of Tertiary rhyolite flows, vitrophyres and tuffs overlain by a sequence of andesite, latite, and basalt flows. A 21 to 49 m thick, locally flow banded rhyolite porphyry immediately overlies the basement rocks.

The primary ore horizon of the Gold Crown ore body is a 9.1 to 12.2 m zone of quartz-cemented rhyolite breccia that grades 0.31 to 12.6 g/mt Au. As the gold is silica-encapsulated, it is not amenable to leaching without milling. The ore zone is overlain by a thick kaolinite alteration cap that must be removed prior to mining.

5/Refer to enclosure 6 for full text.

The Gold Dome ore body consists of about 10 m of mineralized basalt breccia cemented by quartz and calcite. Gold values in this unit range between 0.31 and 16.3 g/mt and average 2.33 g/mt. The ore zone is overlain by a basic vitric tuff. No milling would be required.

Two additional areas on the property, the Granite and the Granite Extension, are currently being explored. Information to date indicates interstitial fillings of quartz and coarse calcite in these areas host gold-bearing hematite after pyrite. The grade of this material ranges between 0.68 and 4.97 g/mt Au.

Structural Geology

The Black Mountain detachment, traceable for more than 40 km, is the most important structural feature in the vicinity. Generally forming the boundary between upper and lower plate rocks, the fault is characterized by a zone of cataclastic breccia of variable degree and thickness. A high-angle normal fault, the King Edward, transects the Frisco property on the east. Numerous smaller, high-angle normal faults have been mapped.

Alteration and Mineralization

Kaolinite, the predominant alteration product associated with the Gold Crown ore body, occurs in masses more than 17 m thick; the kaolinite is consistently barren of metallic minerals. Silicified kaolinite and zeolites constitute the major alteration at the Gold Dome ore body. These alteration products occur in vitric tuffs that host relative low gold values.

Propylitic alteration with a weak argillic overprint, and in some places coupled with weak silification, characterize the alteration products in the Granite and Granite Extension areas.

Personal Observations and Comments

Ore associated with the Gold Crown ore body consists of silica encapsulated gold that will require milling prior to leaching. This would increase operating costs. Past operations were apparently rather inefficient in that closure of the mine was necessary when the price of gold fell below $300/tr oz.

If large tonnages were delineated in the Granite and Granite Extension areas, and milling costs for the Gold Crown ore were minimized, the deposits could probably be exploited at a profit.

GEOLOGY AND STRUCTURAL CONTROL OF GOLD MINERALIZATION AT THE VAN DEEMAN PROSPECT, MOHAVE COUNTY, ARIZONA 6/ 7/

by

F. L. Hillemeyer, P. A. Drobeck, and W. T. Dodge.

Gold mineralization at the Van Deeman Prospect occurs within a locally thick package of brecciated Precambrian through late Mesozoic crystalline rocks along an extensive low-angle normal fault. Drilling as of October 8, 1987, has identified a gold resource totaling about 34,000 tr oz (1.166 mt Au). The low-angle fault (the Van Deeman Fault) hosting the gold mineralization at the Van Deeman was previously termed a detachment fault, but it is not herein because there is some evidence that the fault may have initiated at a moderate to high angle and was subsequently tilted to the present-day low angle by younger faulting. The Van Deeman Fault separates the crystalline assemblage of rocks from an upper plate assemblage consisting of middle Tertiary volcanic and sedimentary strata. The Van Deeman Fault seems to have evolved from early episodes of ductile shearing and the development of mylonites, to later stages of folding and brittle style of brecciation and fracturing. It is this package of brecciated rocks that hosts the majority of gold mineralization and attendant quartz-sericite-hematite-pyrite-clay alteration. This alteration assemblage forms a widespread zone along the low-angle normal fault with gold-arsenic-tellurium mineralization forming much more restricted northeast-trending elongate, tabular bodies within the altered fault breccias. The rather consistent northeasterly trend of mineralization within the low-angle normal fault is controlled by high-angle faults and/or slight undulations in the low-angle normal fault.

6/Repeated from handout material provided by authors.
7/Refer to enclosure 7 for full text.

SUMMARY

"Detachment fault" and its French equivalent "decollment" imply detachment of a layer or sheet along a bounding surface (Dennis, 1972). During the past decade, numerous detachment faults were identified in the southwestern United States, many of which are associated with metallic mineralization. In recent years, a mystique has arisen with respect to detachment faulting, detachment terranes, and accommodation zones; for a period of time these terms were almost synonymous with "gold deposit." It was as if the detachment "sucked gold out of the country rock and re-deposited it in places that the explorationist could find it" (Drobeck, 1988, personal communication). The presence of a detachment fault or zone simply indicates that the rocks may (or may not) have been transported and, in doing so, may (or may not) have been sheared, fractured, or otherwise deformed during which permeability and/or porosity were relatively increased.

One of the purposes of the gold mine field trip was to show that although gold and other commodities can certainly be associated with detachments, they can also be associated with thrusts, intrusions and any number of mechanisms that provide structural preparation and a source of mineralizing fluids. A factor common to all of the mines and prospects visited on the field trip (with the possible exception of the Castle Mountains deposits) is epigenetic ore deposition. In all cases, the host rock was suitably prepared, whether such preparation was the result of detachment faulting, thrusting, intrusion, or some other mechanism. Further, the prepared ground was infiltrated by fluids emanating from one or more intrusive bodies. In addition, ore occurs in a wide variety of rock types that include basalt, basaltic andesite, andesite, rhyolite, rhyolite porphyry, rhyolite breccia, hydrothermal breccias, tuffs of varying composition, granite, quartz monzonite, felsite, and gneiss. If gold deposition were preferential with respect to host rock type, it is not apparent at these deposits.

As stated earlier, the elements necessary for epigenetic ore deposition appear to be present at or proximal to Yucca Mountain, notwithstanding the conclusions of McKee (1979) regarding the dearth of metallic mineralization in ash-flow tuffs. The issue of resource potential at the proposed high-level waste (HLW) site on Yucca Mountain cannot be resolved without a comprehensive resource assessment program that includes exploration borehole drilling.

References Cited

Dennis, J. G. Structural Geology. Ronald Press Co. (New York), 1972, pp. 271.

Drobeck, P. A. Personal communication, GSA Field Trip "Gold Mines of the Las Vegas Region." Mar. 25-26, 1988.

McKee, E. H. Ash-Flow Sheets and Calderas: Their Genetic Relationship to Ore Deposits in Nevada. GSA Spec. Pub. 180, pp. 205-211.

OVERFLIGHT OF YUCCA MOUNTAIN
0600-0830, March 30, 1988

The flight over Yucca Mountain departed Las Vegas shortly before 0600 to take advantage of the low sun angle; weather was clear with winds gusting to 45 knots. The initial line of flight was south of and essentially parallel to Highway 95.

Approaching from the south, the aircraft skirted the west margin of Crater Flat. Several passes over the Flat were made (at a rather disconcerting low altitude) in order to observe Bare Mountain (west of Crater Flat) and the basalt flows and cones southwest of Yucca Mountain. The low sun angle provided the opportunity to observe several fault scarps (Ghost Dance, Bow Ridge, Windy Wash) on and proximal to Yucca Mountain.

Following along the western margin of Crater Flat, the aircraft banked right and flew a line immediately above the site of the proposed repository on Yucca Crest southwest to Lathrop Wells Cone. Turning north, the aircraft followed the east flank of Yucca Mountain (west margin of Fortymile Wash), banked slightly left, and overflew the site of the proposed repository surface facility. Another north-south pass over Yucca Crest (at an even lower altitude) was made before returning to Las Vegas.

The attached aerial photographs [enclosure 8, courtesy of U.S. Air Force and the U.S. Geological Survey (USGS)]) show some of the geologic, geographic, and topographical features of the Yucca Mountain region.

GSA SYMPOSIUM
OIL AND GAS EXPLORATION OF THE GREAT BASIN
1330-1640, March 31, 1988

Preface

Petroleum exploration in the Great Basin has been underway in fits and starts since before the turn of the century. Production in Nevada commenced with the 1954 discovery of the Eagle Springs field in Railroad Valley, Nye County, that spawned a flurry of exploration activity which continues to date.

As the major portion of the presentations in this symposium relied heavily on graphic material (charts, graphs, slides, etc.), a significant loss of detail in the synopses is unavoidable.

A Brief History of Petroleum Exploration in the Great Basin

by
W. Smith

Oil seeps and tar sands have been known in the Great Basin for more than 100 yr, but little in the way of exploration was done until after World War II. Between 1900 and 1941, several shallow exploration wells were drilled on the Arden Dome and near Fallon, NV, and in the Virgin Field, Rozel Point, and Farmington, UT; these resulted in no production. In 1950 and 1951, several significant exploration wells were drilled in various locations that produced valuable data but no oil.

In 1953, Gulf Oil mounted an exploration program in Elko County, while Shell Oil Co. opted to confine their exploration efforts to Railroad Valley in Nye County. Gulf reported "encouraging" results in its program but did not report any discovery. Shell, on the other hand, discovered oil in the Eagle Springs field, Railroad Valley, in 1954. This discovery and the subsequent discoveries of the Grant Canyon and Blackburn fields engendered renewed interest in Nevada petroleum potential by the major oil companies; exploration activity is ongoing.

The Grant Canyon Oil Field
Nye County, Nevada

by
H. Duey

Northwest Exploration Co. completed its discovery well, No. 1 Grant Canyon Unit in the Grant Canyon field, on September 11, 1983. The well flowed 1,816 barrels of oil per day (BOPD) from the Devonian Simonson (Guilmette ?) dolomite at a depth of 1,333 to 1,356 m. Two additional wells have been completed. Cumulative production totals for the field as of December 31, 1986, are 5,260,430 barrels (bbl) of oil. The discovery well (No. 1) has been shut-in.

Production has been from a fault block in a fault zone that separates Railroad Valley from the Grant Range. The reservoir is in intensely fractured, vuggy Simonson (Guilmette ?) dolomite sealed by Tertiary valley fill. The estimated recoverable reserves of the Grant Canyon field total 13 million bbl of oil.

Blackburn Field, Nevada: A Case History
by
C. Scott

Structure

The region in which the Blackburn field is located is characterized by a complex system of normal block faulting, thrusting, tear faults, unconformities, and numerous facies changes. Hydrocarbon generation and the physical location of the field were greatly affected by late Mesozoic thrusting. The field is situated on a Tertiary anticline that is fault-bounded.

Wells

The first two wells in the field, Blackburn No. 1 and No. 2, were dry (No. 1 drilled into granite). Blackburn No. 3, the discovery well, encountered oil on three horizons: (1) Indian Wells Formation (Tertiary), (2) Chainman Formation (Mississippian), and (3) Nevada Formation (Devonian). Blackburn No. 10 produces from poorly welded, porous tuffs and tuffaceous sandstones of the Indian Wells Formation. The formation is capped by a welded tuff unit. Blackburn No. 14 and No. 16 produce from a pay zone in the Nevada Formation characterized by highly fractured calcareous dolomite capped by shales of the Chainman Formation. The shales were emplaced by an attenuation fault. Production from the Blackburn field as of June 1987 was 1,112,644 bbl of oil.

Application of Wildcat Oil and Gas Data to Hydrologic studies in East-Central Nevada
by
W. A. McKay

Nevada's Carbonate Aquifer Project (NCAP) has benefited from a review of more than 100 wildcat oil and gas records from East-Central Nevada. The review has yielded a variety of hydrologic data from drill-stem tests (DST) that are used in the determination of hydraulic head, hydraulic conductivities, and pressure-depth relationships.

Potentiometric maps were constructed, using head values computed from more than 50 DST, for the region that includes Railroad, White River, Coal, and Newark Valleys. Potentiometric surfaces and flow directions derived from DST analysis are compared with results from previous efforts at delineating flow systems in the carbonate rocks of eastern Nevada.

Petroleum Potential of Microplate Accretions of the Basin and Range Province

by

J. Lintz

Several areas within western Nevada have been identified as blocks of material associated with the accretion of microplates on the continent. These blocks appear to have had the potential for hydrocarbon resources at the time of accretion. However, post-accretionary events (faulting, folding, stripping of seals, etc.) have probably degraded the potential to varying degrees. Conditions favorable to hydrocarbon generation have been indicated by sparse conodont indices (CIC). To date, the accretionary areas have yet to be tested by drilling.

Delineation of a Late Mesozoic Thrust Belt in East-Central Nevada

by

G. Cameron

The oil fields of Pine and Railroad Valleys are thought to be intimately associated with a structural belt of northwest-trending thrust faults that extend from Clark to Elko Counties. The Cretaceous belt is characterized by low-angle thrusts that place older Paleozoic miogeosynclinal rocks over younger Paleozoic miogeosynclinal rocks. An eastward transport direction is suggested by fault and fold geometries involving rocks as young as Triassic.

Thrusting along the belt, based on field relationships, is thought to have been completed by Oligocene time. Throughout the belt, the easternmost exposed thrust has placed Devonian carbonate reservoir rocks on top of Mississippian clastic source rocks and, collectively, thrusting has telescoped the western margin of the Mississippian Antler Basin.

Fold-Thrust Belt Exploration for Hydrocarbons in the Basin and Range Province

by

D. Roeder

NOTE: Dr. Roeder's excellent presentation was accompanied by numerous maps and charts depicting the geology of the Basin and Range Province, restored terranes, cross sections, and graphic representations of the methodology for hydrocarbon exploration in the ranges. Without this material, it is very difficult to adequately and accurately synopsize his presentation. To prevent any unintentional misrepresentation of his paper, his abstract from the GSA Programs and Abstracts is repeated verbatim.

In the Basin-and-Range Province of Nevada, Paleozoic passive-margin deposits contain major oil sourced in Mississippian shales and pooled in tectonically juxtaposed Devonian carbonates. Traps are neither understood nor predictable in detail; they consist of imbricates within the external units of the Sevier fold-thrust belt, offset and tilted at Neogene growth faults.

Exploration in the province proceeds from a restoration of Neogene extension through balanced cross sections, paleogeographic and thermotectonic restoration, eventually to mapping prospective trends and to their detailing by reflection-seismic profiling.

There are major technical problems but also encouragement, in each step. Critical elements of Neogene extension include bulk strain, depth extent and interconnection of faults, tilt, and detachment. They are controlled bu COCORP and other seismic data, by the potential fields, by the thermotectonics of the core complexes, and by the stratigraphic extent exposed in the ranges. Critical elements of thrust-belt architecture include the size and taper of the Sevier belt, the restored depth to basement detachment, the state of synkinematic erosion, and the structural style as sampled by the ranges with exposed Paleozoics. Critical elements of a depositional model include thickness and paleobathmetry of the reef-prone Devonian, the wedge shape of the Antler foredeep fill, and the paleotectonics of the Permo-Pennsylvanian. A palinspastically restored network of stratigraphic section is our database.

Petroleum Exploration in Nevada, Then and Now

by

A. Chamberlain

Early petroleum exploration efforts in Nevada primarily targeted Paleozoic sediments deposited in the Cordilleran Miogeosyncline. Following the discovery of the Eagle Spring field (Railroad Valley--Nye County) in 1954, exploration emphasis shifted from a Paleozoic to a Tertiary play. As a result of the Eagle Spring discovery, most exploration boreholes drilled between 1954 and the early 1980s terminated at the Tertiary unconformity.

In the early 1980s, exploration emphasis returned to the Paleozoic play following the discovery of Mississippian oil in Devonian carbonate rocks in the Blackburn field. Several new developments that may guide the explorationist to new discoveries in Nevada include: (1) A better understanding of depositional environments of the Mississippian Antler Basin and their relationship to source rock richness and maturation, (2) depositional environments of the Devonian carbonates and their relationship to reservoir trends, and (3) the Mesozoic thrust belt trend and its relationship to oil generation, migration, and structural traps.

GSA FIELD TRIP
GEOLOGY OF THE NEVADA TEST SITE
0700-1830, April 1, 1988

The field trip departed Las Vegas at 0700 and arrived at the Mercury Badge Office shortly after 0830. After all participants were issued badges, we departed for Yucca Mountain.

Yucca Mountain

Arrived Yucca Summit at about 0930 and received a short (10 min) briefing on the geology and hydrology of the area by representatives of the USGS and a geologist from the Department of Energy (DOE). The origins, lithology, structure, Quaternary volcanism, and seismicity of the mountain were discussed. Infiltration rates, ground water regime, and local and regional ground water flow patterns were also discussed. The briefings disclosed nothing in the way of new information except that the DOE, for reasons not quite clear to the USGS, has enjoined the Survey from further ground water infiltration and flow studies in which tritium levels (byproduct tritium from weapons testing) in ground water were used as tracers.

More than an hour was spent observing Yucca Crest, Crater Flats and the contained basaltic cones, Solitario Canyon, Bare Mountain, and other geographic, geologic, and topographic features that could be seen from the summit of Yucca Mountain. Handout material pertaining to hydrologic conditions at Yucca Mountain are included as enclosures 9 and 10; no handout material pertaining to geology was distributed.

G-Tunnel

Forty-five minutes to an hour were spent at G-Tunnel in Ranier Mesa. The facility has been used in the past for weapons effects tests and is now being used to conduct geotechnical studies in support of the Nevada Nuclear Waste Storage Investigations (NNWSI). A description of the tests that have been concluded, planned tests and studies, cross section of part of Ranier Mesa, and plan views of G-Tunnel are presented in enclosure 11.

SEDAN Crater

Before departing for Las Vegas, the site of the SEDAN event was briefly visited. SEDAN was part of Operation Plowshare in which the feasibility of using nuclear explosives for mining and civil engineering projects (such as canals) was investigated. In 1962, a 100-kiloton device was detonated 194 m below ground surface in alluvium. The resulting crater is 122 m deep (maximum) and 390 m (maximum) in diameter.

Personal Observations and Comments

The field trip title "Geology of the Nevada Test Site" is misleading. The "geology" portion was limited to a very brief briefing by the Survey (no handout material pertaining to geology of the area was distributed). An inordinate amount of time (from my perspective as a resource-oriented geologist) was expended on two talks pertaining to hydrology. A better feeling for the proposed HLW repository site would have been gained were the participants allowed to hike over the area rather than being confined (I assume for security purposes) to the area of a drill pad on the crest. None of the USGS geologists, and especially the geologist from DOE, were willing to discuss resource potential and its impact on the Yucca Mountain project. When asked why the recent consultant draft of the Yucca Mountain Site Characterization Plan (CDSCP) did not include drilling into the brecciated zone in Solitario Canyon, a USGS geologist stated, "They're afraid they might find something." I assume his response was tongue-in-cheek.

While the trips to G-Tunnel and the SEDAN crater were interesting, I felt they added little to one's understanding of the geology of the Nevada Test Site.

Miscellaneous Activities

Tuesday, 29 March

Departed Las Vegas via rental car to examine exposures of a detachment fault in the River Mountains west of Lake Mead. This extemporaneous "mini field trip" was suggested by P. A. Drobeck, leader of the gold mines field trip of March 25-28. I was accompanied by Mr. Ronald Sheets, a doctoral candidate from the University of Virginia, who provided much-needed information and insight pertaining to the lithology and structure of the area. Unfortunately, we were constrained to "roadside geology" on paved roads; the car rental agreement prohibited off-road travel.

The River Mountains are characterized by a 13.5 mya andesite-dacite stratovolcano surrounded by a field of dacite domes and flows. The core of the stratovolcano is occupied by the River Mountains stock, a complex pluton of quartz monzonite. The River Mountains are bounded on the southeast by the Eldorado Valley-Hamblin Bay fault system and on the east by the Saddle Island low-angle normal (detachment) fault and the Bitter Spring Valley strike-slip fault. We were unable to gain access to Saddle Island for a closer look at an exposure of the detachment reportedly characterized by slickensides and mylonitic texture.

Wednesday, 30 March

During the course of the day, following the overflight of Yucca Mountain, I met with the following individuals on an informal basis to renew old acquaintances and to discuss the geology and resource potential of Yucca Mountain:

Dr. Warren Hamilton, USGS.
Dr. Bruce Blackerby, Geology Department, CA State Univ., Fresno.
Dr. Robert Merrill, Geology Department, CA State Univ., Fresno.
Harold Linder, Consulting Geologist.
F. L. "Bud" Hillemeyer, Fischer-Watt Gold, Inc.
Evan Sleeman, President, Nevada Star Resource Corp.

ENCLOSURE 3

GOLD DEPOSITS OF THE NELSON DISTRICT

CLARK COUNTY, NEVADA

by

P. A. Drobeck, R. R. Kern, S. L. Jenkins

ABSTRACT

The Nelson District, located approximately 40 miles southeast of Las Vegas, Nevada is one of the oldest mining districts in the state and has recorded production of over 100,000 ounces of gold and 2.3 million ounces of silver. The district occurs in Tertiary monzonitic intrusives and Miocene volcanics. The district occurs within a major east-west fault zone which is characterized by normal faulting, strike-slip faulting, detachment faulting, large volumes of fracturing, lacolithic intrusion of the Nelson Monzonite, and quartz-calcite-gold-silver veining. Large volumes of volcanic rocks above and peripheral to known ore zones have been intensely hydrothermally altered, but most ore zones themselves show little wallrock alteration other than the mineralized veins.

Recent work in the district indicates the mineralization is highly structurally controlled by low angle detachment faulting and east-west transform (or "accommodation") faulting. There is clearly much more structurally prepared rock than ore. This observation, and the lack of hydrothermal brecciation, indicate that Nelson ores formed by passive flooding of epithermal fluids in large fault zones.

INTRODUCTION

Nelson, a small community located in the El Dorado Mountains, is centrally located within the district. Access is via U.S. Highway 95 from the west. Lake Mohave is located 7 miles east of Nelson (fig. 1). Homestake Mining Company has been exploring the district since early 1987 and has outlined small reserves in the western portion of the area.

HISTORY

Gold was discovered on the Honest Miner claim near the Rand Mine in 1857 and arrastres found on the property indicate mining may have begun even earlier. Major mining began in 1862 at the Techatticup Mine which became the largest producer in the district. Other significant producers were the Rand, Wall Street-Blackhawk, Duncan and

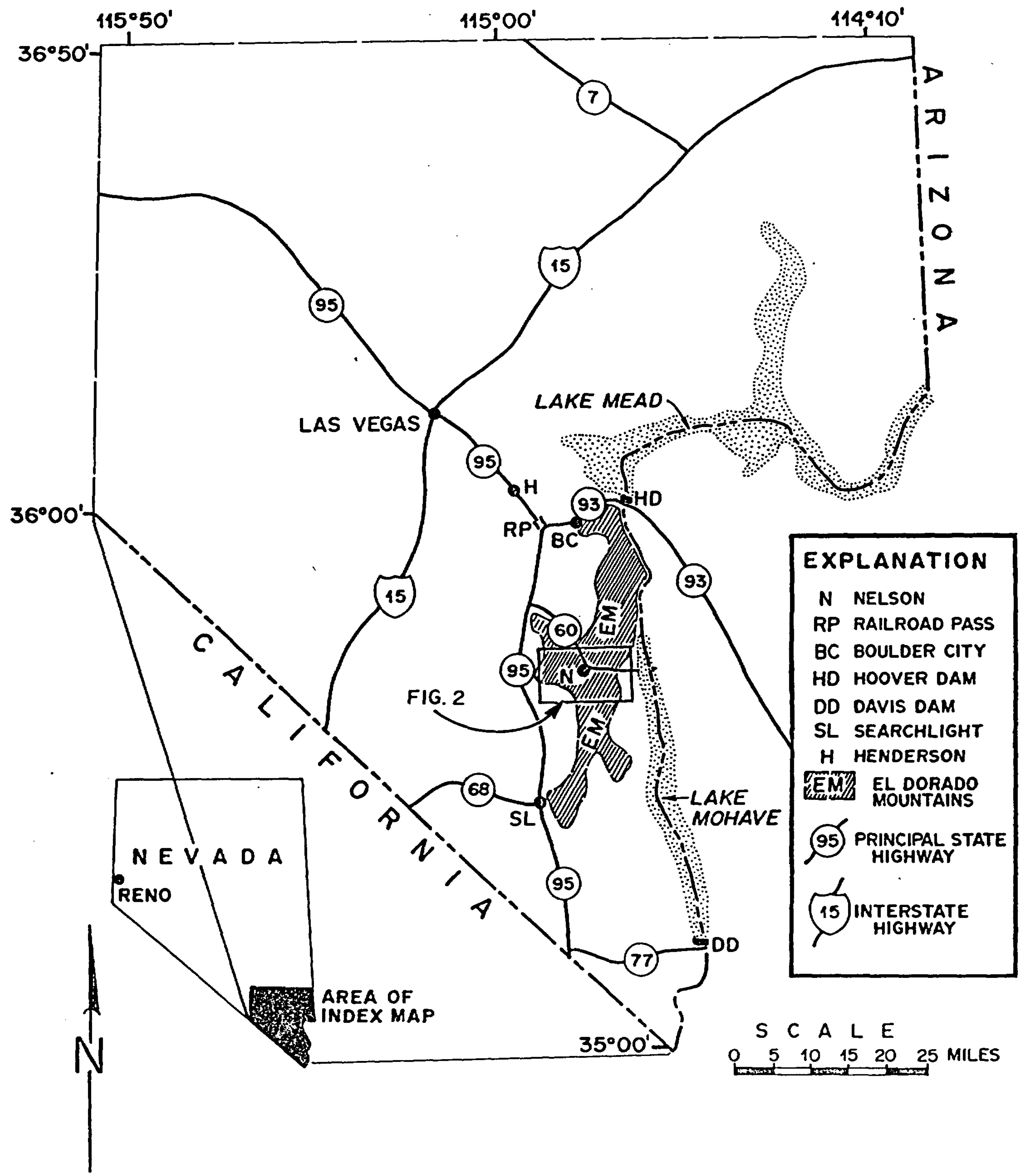


FIGURE 1. LOCATION MAP

the Jubilee. Production records are sketchy and thought to be at least twice that recorded. Recorded production from the district between 1907 and 1954 is 100,600 ounces of gold and 2,360,000 ounces silver.

Recent exploration in the district beginning in the 1970's has been conducted by Intermountain Exploration, Amselco, Exxon, Weaco and finally Homestake.

GEOLOGY

REGIONAL SETTING

The Nelson district lies within a zone of mid-Tertiary extensional faulting as defined by Frost and Martin (1982). It is located 30 miles south of the intersection of the Las Vegas and Lake Mead shear zones (Spencer, 1984). Detachment faulting has been documented at Nelson by Anderson (1971), to the north in the River Mountains by Smith (1982), to the south in the Newberry Mountains by Hillemeyer (1984) and to the east in the Black Mountains by Wilkins (1984), Hillemeyer and Durning (1987) and Faulds et al., (1987).

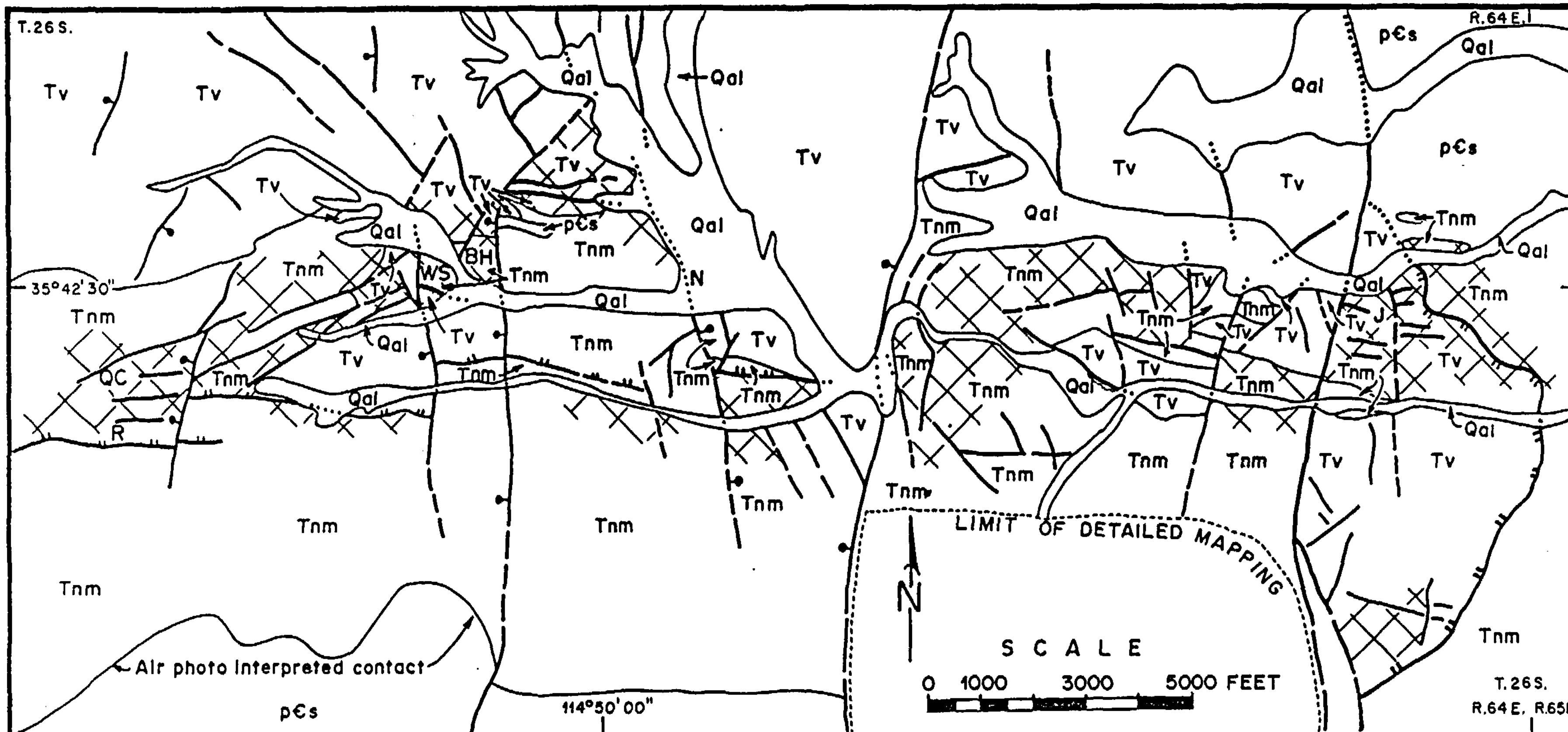
Tertiary volcanics rest directly on a heterogeneous series of gneisses, schists and pegmatites of Precambrian age. The nearest Paleozoic sediments are located in the Clark Mountains to the west.

LITHOLOGIES

Almost all the rocks in the main Nelson District are Tertiary igneous rocks. The only pre-Tertiary rocks are minor outcrops of Precambrian gneiss near the Carnation Mine and three small hills of gneiss north of the Jubilee Mine.

The Tertiary volcanic rocks have been described by Hansen (1962), Longwell (1963), Anderson (1971), and Anderson (1972). The lower most unit is known as the Patsy Mine Volcanics which represent development of a composite volcanic field. Maximum observed thickness of this unit is 13,200 feet and K-Ar ages range from 22.8 to 15.2 mya (Anderson, 1971). The Patsy Mine Volcanics are the most abundant volcanic rocks in the district. They have been divided into three informal members (Hansen, 1962). The lower member is predominantly andesite, basaltic andesite, basalt, and latite flows, flow breccias, agglomerates, and minor tuffs. The middle member is comprised of light colored tuffs, tuff breccias, lithic tuffs, reworked tuffs, and rhyolite flows. The upper member is comprised of distinct dark grey to dark brown basalt flows approximately 1500 feet thick.

The Tuff of Bridge Spring was named by Anderson (1971) and was mapped by Hansen (1962) as part of the Golden Door Volcanics. This rhyolite tuff forms a typical ash flow tuff cooling unit about 800 feet thick from which K-Ar age dates indicate an age of 15.4 mya (Anderson, 1971).



EXPLANATION

QUATERNARY — Qal — Alluvium

TERTIARY — Tnm — Nelson "monzonite" intrusives

TERTIARY — Tv — Patsy Mine and Golden Door volcanics

PRECAMBRIAN — pЄs — Gneiss and schist

"Nelson Chaos"

Geologic contact

High angle fault, ball on downthrown side

Detachment fault

N: Nelson — QC: Quaker City Mine

R: Rand Mine — WS: Wall Street Mine

BH: Blackhawk Mine — J: Jubilee Mine

FIGURE 2. NELSON DISTRICT GEOLOGY

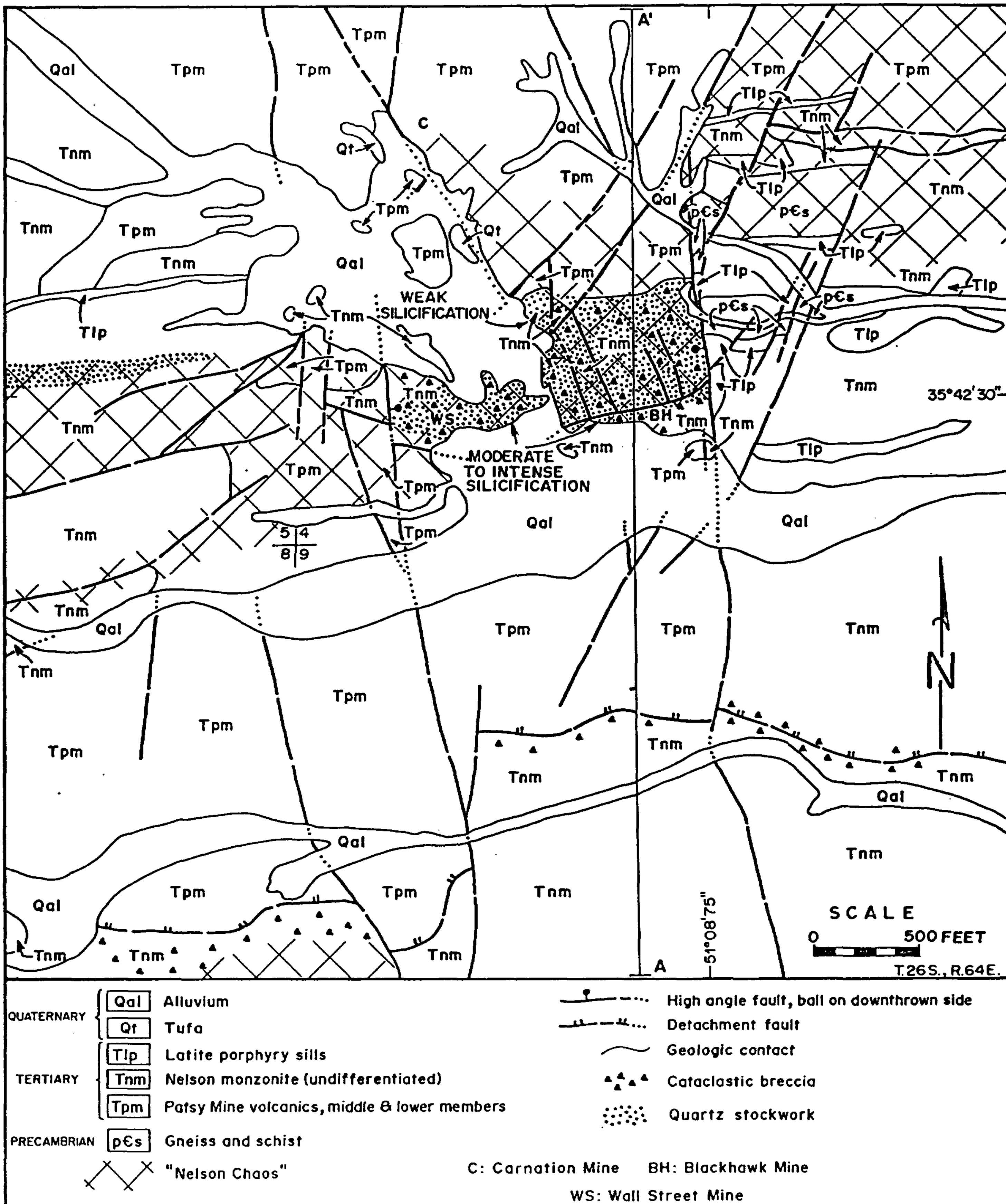


FIGURE 3. WALL STREET-BLACKHAWK GEOLOGY AND ALTERATION.

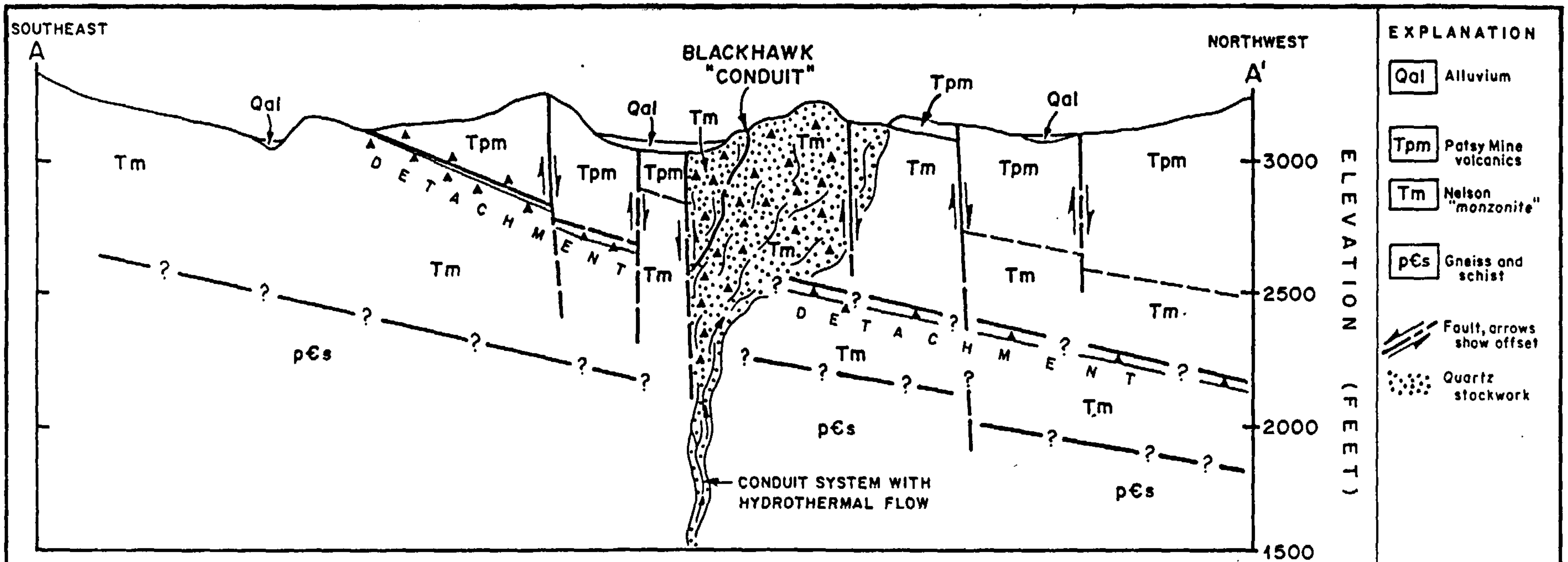


FIGURE 4. CROSS SECTION A–A'.

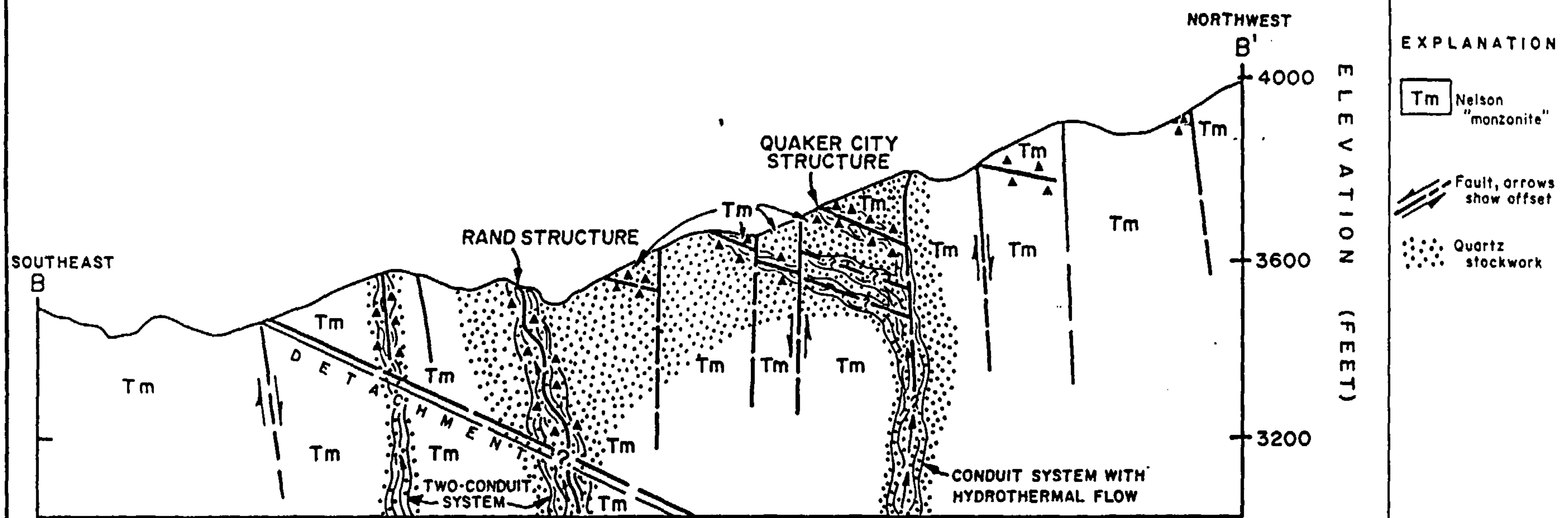


FIGURE 6. CROSS SECTION B–B'.

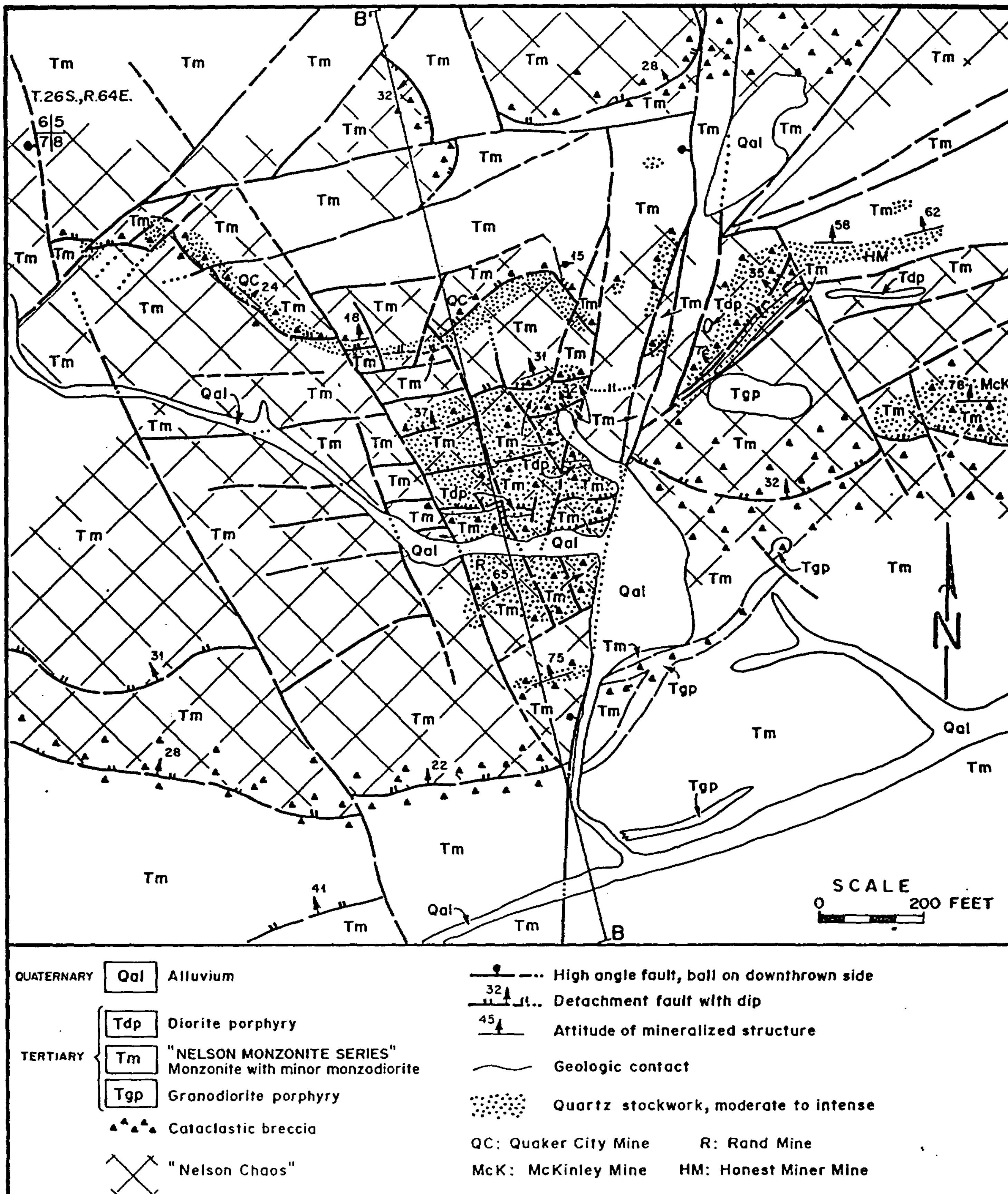


FIGURE 5. RAND-QUAKER CITY GEOLOGY AND ALTERATION.

The Mount Davis Volcanics are a very complex series of rhyolite to basalt flows, tuffs, and volcaniclastics. They are not exposed within the main district but do outcrop 2 to 5 miles further north and to the east of the district (Longwell, 1963; Anderson, 1971). They have been dated at 10.6 to 14.6 mya (Anderson, 1971).

The volcanic rocks have been intruded by a large laccolithic body named the Nelson Quartz Monzonite by Hansen (1962), and called the Techatticup Pluton by Anderson (1971). The intrusive is multiphase, although dominantly monzonitic in composition. The chilled margins of the pluton appear nearly identical to massive portions of lower Patsy Mine Volcanics in the field. This laccolithic body is elongated east-west and appears to dip 20 to 30 degrees north.

Quaternary calcareous tufa is found in several areas of the district associated with recent hot springs. Thick alluvium and colluvium is present in the larger drainages.

STRUCTURE

The observed structures in the Nelson District are all Tertiary in age and are related to pre-Basin and Range regional extension. Detachment faulting has been documented in Nelson and the surrounding areas (Anderson, 1971; Smith, 1982; Hillemeyer, 1984; Hillemeyer and Durning, 1987). This low-angle system of extension is directly responsible for the faulting developed at Nelson and for the structural preparation of ore zones. The east-west trend of the district and of the individual orebodies follows the regionally developed east-west striking detachment fault system (fig. 2).

The Nelson District lies astride a major break in the style of detachment deformation. North of the district, upper plate volcanic rocks generally dip steeply eastward because they are cut and rotated by numerous west-dipping normal faults. South of the Nelson District, the upper plate volcanic rocks dip steeply westward because they are cut by east-dipping normal faults.

The central district area can be divided into three structural-lithologic volumes: an upper plate of Patsy Mine Volcanics and all overlying volcanics; a detachment zone comprised of lower Patsy Mine Volcanics and Nelson Quartz Monzonite; and a lower plate of Nelson Quartz Monzonite with minor Precambrian gneiss.

The upper plate is cut by a series of north-trending and north-northwest-trending normal faults. These faults have severely rotated the Patsy Mine Volcanics. The flattest dips observed were on the order of 30 , but 70-85 dips are most common.

The detachment zone occurs as a complex anastomosing system of faulting, not as a single detachment fault. The zone dips northward 20° to 30°. The zone's structural complexity is augmented by the synkinematic, sill-like Nelson Quartz Monzonite. The monzonite's variably chilled margin encouraged complex fault patterns to develop. The detachment zone is characterized by hundreds of minor faults, intense jointing, and intense fracturing. Volborth (1973) recognized the zone and named it the "Nelson Fault Zone." We informally refer to this zone as the "Nelson Chaos." The prominent trend of faults within the zone is east to east-northeast with all ranges of dips. This pattern suggests there may be a strike-slip component of movement along these faults.

In places there are one or two distinct fault surfaces which can be termed a detachment fault (i.e., approximately one-half mile south of the Wall Street Mine). In other places, no one fault surface can be mapped as "the detachment"; instead, the detachment faulting was accommodated by movement along the hundreds of faults within the chaos. A good example of this feature is the zone between the Blackhawk Mine and the town of Nelson.

This complex detachment zone formed a large area of well fractured and permeable rock. Observed thicknesses of the zone range from 200 feet to 500 feet. This zone hosts the major orebodies of the district: the Wall Street, Rand, Magnolia, Jubilee, and the Techatticup.

The detachment system has been cut by younger north-trending normal faults and rarely by northeast-trending normal faults. This relationship suggests there may be a deeper and younger master detachment fault below present exposures. Progressive uplift of the region in association with extension would produce this phenomenon. Because mineralization has been observed cutting one of the north-trending faults (near the town of Nelson) and along a northeast-trending fault (Rand Mine), it is believed that the mineralization is post-detachment in age, not synkinematic.

ALTERATION AND MINERALIZATION

The three hydrothermal systems evident in the Nelson District have developed a complex alteration assemblage pattern. Our mapping completed to date has initiated an understanding of these alteration suites, but a more detailed mapping-petrograpy-geochem study would be necessary to fully assess the complex subtleties.

Detachment-Related Hydrothermal Alteration

The oldest hydrothermal system was a weak one associated with intrusion of the synkinematic Nelson Quartz Monzonite and development of the detachment fault. This system developed widespread propyllitic alteration within the detachment zone, below the detachment locally, and possibly above the detachment zone. This alteration developed round clots of chlorite up to one inch in diameter, some replacement of mafics by chlorite, and minor epidote. This type of alteration is found associated with most detachment faults in the Southwest USA and is not believed to be related to ore.

Mineralization-Related Hydrothermal Alteration

The second hydrothermal system formed the known mineralization and has a complex alteration assemblage. The mineralization occurs as quartz-calcite veins and stockwork zones with two to six stages of veining. Most of the productive deposits occur in the chilled margin of the Nelson Monzonite in the detachment zone, but smaller deposits such as the Carnation Mine occur in lower Patsy Mine Volcanics.

Several types of alteration have been mapped in direct association with the mineralization. Mapping at the Blackhawk Mine has shown a weak eastward halo of propyllitic alteration. Hence, some of the district's propyllitic alteration is related to the mineralizing hydrothermal alteration.

The west and north flank of the Wall Street Mine has an obvious halo of argillic alteration in lower Patsy Mine Volcanics. A 20 foot to 100 foot-wide linear zone of advanced argillic alteration extends westward from the Wall Street for approximately 1,000 feet. This alteration is characterized by most of the mineral constituents being converted to white clays and portions of the zone having obliterated rock textures. Weak argillic alteration is more widespread, especially northeast of the mine, and occurs as partial clay replacement of phenocrysts and minor clay developed on fractures. These alteration types occur elsewhere in the district. The argillic alteration has not affected the Nelson Monzonite.

Small zones of quartz-alunite alteration were also mapped. This alteration includes argillic alteration, but has minor alunite replacing lapilli and phenocrysts, and locally minor silicification. The most impressive zone of this alteration is on the hill south of the town of Nelson. This alteration is also lithologically restricted to middle Patsy Mine Volcanics.

The productive mines and established reserves in the district are all quite similar in character. The veins are comprised of quartz and calcite in varying proportions. At the Rand Mine, in the west portion of the district, detailed sampling showed that increased calcite in the veins was directly proportional to increased gold grades, suggesting that the calcite veining was the main ore stage.

All of the productive mines occur in ENE to E-W trending faults, parallel to sub-parallel to the trend of the detachment zone and of the Nelson Chaos. The mines all lie within an east-west belt of mineralization which is 5 miles long and 1/2 mile wide. Ore has been mined from both north-dipping (i.e. Quaker City, Rand, Techatticup, Duncan mines) and south dipping veins (Wall Street, Blackhawk, Jubilee mines). At some mines, both north and south-dipping veins occur, resulting in stockworks and some bulk-mineable reserves. The Wall Street, Blackhawk, and Jubilee mines are examples of this type of occurrence.

The Techatticup Mine, in the east central portion of the district, was the largest producer in Nelson. Most of its production went unrecorded because it was mined from 1857 to 1907 before the tax man got after them. Total production from 1857 through 1942 is thought to be over $4.7 million (approximately 230,000 oz. Au equivalents). The mine was reportedly very high grade, but unfortunately no specific figures are published. The shaft is 600 feet deep and the vein was stoped from the 500 level to the surface. The vein strikes east-west and dips 60° - 85° northward. Unfortunately no significant stockwork mineralization occurs around the vein. It is interesting to note that a flat fault was found just above the 400 level which had offset the vein 100' to the north.

Quaternary Alteration

The younger hydrothermal alteration is related to a system of Quaternary hot springs. These springs deposited kaolinite-aragonite-selenite tufas on Quaternary gravels. Numerous small tufa deposits occur closely associated with the advanced argillic alteration zones, leading to speculation that the two may be related.

Geochemistry

Mineralization in the Nelson District occurs in quartz-calcite veins and stockworks. Besides gold and silver, very anomalous copper, lead and zinc occur sporadically. However, correlation between base and precious metal values is very poor. Therefore, base metals do not provide an exploration guide for gold and silver.

CONCLUSIONS

Mineralization in the Nelson District is related to a major east-west trending zone of detachment faulting. Mineralization of tectonic breccias occurred in the late Tertiary after intrusion of the synkinematic laccolithic Nelson Quartz Monzonite. Gold, silver and base metals in varying proportions occur in quartz-calcite veins and stockworks hosted by the breccias.

REFERENCES

Anderson, R.E., 1971; Thin Skin Distension in Tertiary Rocks of Southeastern Nevada, GSA Bulletin, Volume 82, pp. 43-58.

Anderson, R.E., et al, 1972; Significance of K-Ar Ages of Tertiary Rocks from the Lake Mead Region, Nevada-Arizona, GSA Bulletin, Volume 83, pp. 273-288.

Bingler, E.C., and Bonham, H., 1973; Reconnaissance Geologic Map of the McCullough Range and Adjacent Areas, Clark County, Nevada, Nevada Bureau of Mines Map 45.

Faulds, J. E., et al, 1987; Possible Modes of Deformation Along Accommodation Zones in Rifted Continental Crust, GSA Abstract, in press.

Frost, E. G., and Martin, D. L., 1982, Comparison of Mesozoic compressional tectonics with mid-Tertiary detachment faulting in the Colorado River area, California, Arizona, and Nevada in Geologic excursions in the California Desert: Geol. Soc. of America Cordilleran Section field trip volume and guidebook, p. 111-159.

Hansen, S. M., 1962; The Geology of the El Dorado Mining District, Clark County, Nevada; PhD Thesis, Missouri University, 328 pp.

Hillemeyer, F. L., 1984, Geometric and kinematic analysis of high and low-angle normal faults within the Mojave-Sonoran detachment terrane, M.S. Thesis, San Diego State University, 209 pp.

Hillemeyer, F. L., and Durning, W. P., 1987; Extensional tectonics and its relationship to gold mineralization in the Black Mountains, Mohave County, Arizona; A.I.M.E. Annual Meeting Abstract, p. 81.

Longwell, C. R., 1973; Reconnaissance Geology Between Lake Mead and Davis Dam, USGS Professional Paper 374-E.

Smith, E. I., 1982; Geology and Geochemistry of the volcanic rocks in the River Mountains, Clark County, Nevada and comparisons with volcanic rocks in nearby areas; in Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona and Nevada, Cordilleran Publishers, pp. 41-54.

Spencer, J., 1984; Map in 1984 AGS Field Guide.

Volborth, A., 1973; Geology of the Granite Complex of the El Dorado, Newberry and Northern Dead Mountains, Clark County, Nevada, Nevada Bureau of Mines and Geology Bulletin 80, 40 pp.

Wilkins, J. Jr., 1984, Stratigraphic and tectonic setting of the north-central Black Mountains and Detrital Valley, Mohave County, Arizona; Arizona Geol. Soc. 1984 Fall Field Trip Guide, 4 pp.

COLOSSEUM GOLD MINE

Clark Mountain Range

San Berrardino County
California

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ENCLOSURE 4

Abstract. Gold mineralization at the Colosseum Mine is submicroscopic and associated with pyrite. Pyrite occurs in breccia clasts, replacing dolomite, in crackle breccia veinlets with traces of quartz, and as disseminations in two small, interconnected intrusive pipe complexes of rhyolitic felsite and breccias of felsite and wall/country rock. Breccia types grade from felsite plus wall rock of Precambrian gneiss to cross-cutting breccias of felsite, gneiss, and Paleozoic sedimentary rocks that are in contact with the Precambrian gneiss terrane one-quarter mile (400m) southwest of the Colosseum pipes. Mineable reserves are estimated to be 8 million short tons (7.3 million metric tons) at 0.074 troy ounces of gold per short ton (2.3 g/metric ton) at a cutoff of 0.03 troy ounces of gold per short ton (1.0 g/metric ton).

Introduction

The Colosseum Mine is within the old Clark Mountain mining district located approximately 45 miles (72 km) southwest of Las Vegas, Nevada in San Bernardino County, California (see Figure 1). The Clark Mountain mining district was organized in the 1860's. During the late 1800's, significant amounts of silver and minor amounts of gold, copper, lead, tungsten, and fluorite were produced from several mines in the district. During the early to middle 1900's there was intermittent production of the various ores.

Gold mineralization at the Colosseum Mine was discovered in 1865 but no recorded production occurred until the 1930's. During that decade approximately 615 troy ounces (19 kg) of gold, with minor silver, copper, and lead, was produced (Hewett, 1956). The mine was closed in 1942 as a non-essential industry during World War II. Subsequent to the War years the property saw sporadic, minor exploration by several individuals and companies.

The recent exploration history of Colosseum began in 1970 and has continued intermittently until the present. Three companies, Draco Mines, Placer Amex, and Amselco Exploration, have sponsored the bulk of this exploration work, including over 139,000 feet of diamond, percussion, and reverse circulation drilling (Lacy, 1986).

The property was acquired by Dallhold Resources, an Australian based company, in 1986. Colosseum Gold, Inc. is a Dallhold subsidiary created to operate the Colosseum Mine. Construction of a 3,400 short ton per day (3,084 metric ton/day) carbon-in-pulp cyanide mill started in November, 1986 and is scheduled for completion in September, 1987. Pre-production mining operations commenced in May, 1987.

Mineable ore reserves are estimated to be 8 million short tons (7.3 million metric tons), in two ore bodies, with an average grade of 0.074 troy ounces per short ton (2.3 g/metric ton) at a cutoff grade of 0.03 troy ounces per short ton (1.0 g/metric ton). There are significant additional geologic reserves in the range of 0.02 to 0.03 troy ounces per short ton (0.6 to 1.0 g/metric ton). Stripping ratio, waste: ore, for life of mine is estimated to be 3.8:1.

Regional Geology

Structural Geology

The Clark Mountain mining district is located at the southern end of the Great Basin physiographic province near the southern limit of the Sevier thrust belt which trends southwest from Wyoming across Utah and southern Nevada into southeastern California. The Clark Mountain thrust complex described by Burchfiel and Davis (1971) is part of the Sevier thrust belt and consists of three major thrust faults and one major normal fault. Two of these three thrust faults, the Mesquite Pass thrust (Hewett, 1956) and the Keystone thrust (Burchfiel and Davis, 1971 and Sharp, 1984), are mapped near the Colosseum Mine (see Figure 2). The latest movement of the Mesquite Pass thrust, which moved the upper plate from west to east predates 190 to 200 m.y. ago (Burchfiel and Davis, 1973). The Keystone thrust fault is a decollement thrust that overthrust middle to lower Paleozoic marine sedimentary rocks eastward onto lower Paleozoic marine sedimentary rocks and Precambrian crystalline rocks. The age of thrusting of various segments of this fault occurred from 138 m.y. ago (Sutter, 1968) to 85 m.y. ago (Sharp, 1984). Sharp (1984) interprets the last movement on the Keystone thrust as gravitational gliding of the upper plate east to west.

The structural picture has been complicated by subsequent normal faulting associated with Basin and Range tectonism. In the Clark Mountain area Hewett (1956) mapped the Clark Mountain fault and the Ivanpah fault, two northwest trending Basin and Range normal faults which border a wedge-shaped horst of Precambrian crystalline basement rocks upraised between blocks of Paleozoic marine sedimentary rocks (see Figure 2). Dobbs (1961) describes Hewett's (1956) Clark Mountain normal fault as a thrust fault within the Paleozoic section which would correspond with Burchfiel and Davis's (1971) Keystone thrust. Sharp (1984) notes both the Keystone thrust and the Clark Mountain normal fault within the Paleozoic section. Field evidence clearly indicates that, at least in the area of the Colosseum Mine, the Precambrian-Cambrian contact is a depositional unconformity and not a fault contact as Hewett (1956) describes. In addition, again within the limited area of the Colosseum Mine, field mapping to date has clearly indicated the Keystone thrust fault but the Clark Mountain normal fault has been harder to document. If both faults exist in this area they lie within approximately 500 feet (150 meters) of each other within the Paleozoic section as Sharp (1984) proposes (see Figure 2).

Stratigraphy

The Precambrian crystalline rocks within the area of the Clark Mountain mining district are biotite gneiss and granite gneiss (see Figure 2) formed from sedimentary rocks as a result of high grade regional metamorphism (Dobbs, 1961). The general fabric of the gneissic layers is northwesterly. The gneisses have been intruded by alaskite and pegmatite dikes generally concordant with the regional fabric. Local andesite dikes of unknown age cross cut the regional Precambrian fabric.

Paleozoic marine sedimentary rocks that outcrop in the vicinity of the Colosseum Mine (see Figure 2) range in age from Cambrian to Pennsylvanian (Dobbs, 1961 and Sharp, 1984). In that area the Cambrian Tapeats quartzite lies unconformably on the Precambrian basement. The Cambrian Bright Angel shale overlies the Tapeats quartzite. This contact is shown by Sharp (1984) as the Clark Mountain fault. Overlying the Bright Angel shale in thrust fault contact (Keystone thrust) is the upper Cambrian to Devonian Goodsprings Dolomite. Conformably overlying the Goodsprings are the Devonian Sultan Limestone and the Mississippian Monte Cristo Limestone. Unconformably overlying these two limestone formations is the Pennsylvanian Bird Spring Formation.

Mine Site Geology

The host and probable source for gold mineralization at the Colosseum mine are two, small felsite breccia pipes that intruded Precambrian crystalline basement rocks and then overlying Paleozoic marine sedimentary rocks approximately 100 m.y. ago. The felsite pipes and some narrow felsite dikes were intruded orthogonally (northeast) to the regional northwest trending fabric of the Precambrian rocks (see Figure 2). The two pipe bodies are steeply dipping to the southeast. The present day surface expression of the pipes is two tear-drop shaped bodies approximately 500 feet (150 m) by 700 feet (210 m) connected by a 100 - 150 foot (30 - 45 m) arcuate dike of brecciated felsite. The northeasterly pipe is called the East Pipe and the southwesterly pipe is called the West Pipe.

The Precambrian rocks near the intrusive pipes are equigranular, quartz-feldspar rocks with minor sericite and little or no gneissic texture and for the purposes of mine mapping are called granite. Within 50 to 100 feet (15 - 30 m) of the intrusive body the granite is altered. Alteration is as sericite and pyrite in place of biotite and magnetite, respectively (Schüll, 1987). The Precambrian granites near the intrusive breccia pipe complex locally exhibit a crackle to mosaic style of brecciation, i.e. the rocks fragmented and the pieces were rotated but not transported. The result is an abundance of open spaces often filled with pyrite or the oxidized remnant of pyrite.

The felsite is mostly aphanitic groundmass with less than 5% phenocrysts. Phenocrysts are quartz, biotite, altered and/or bleached, and feldspar, generally altered to a white porcellaneous chalky material (Schull, 1987). The felsite is often banded or flow foliated. Petrographic work has established that the felsite is rhyolitic. Age determinations on phenocrysts of mica from felsite samples from the East and West pipes gave dates of 99.8 ± 3.6 m.y. and 102 ± 4 m.y., respectively (Sharp, 1984). The felsite represents the initial intrusive phase of the pipe complex.

Subsequent to this initial phase, a period of brecciation occurred that fragmented the pre-existing rocks including the felsite, the Precambrian granite wall rocks, and the then overlying Cambrian quartzites and shales. These fragmented lithologies were incorporated as breccia fragments in a matrix of felsite from another magmatic pulse. This breccia type represents the igneous breccia described by Sharp (1984). Pit mapping terminologies currently in use are descriptive rather than genetic, thus this breccia type is now termed felsite clast breccia, felsite-granite clast breccia, and granite-felsite clast breccia depending on the volume percentage of clasts of the various lithologies (Schull, 1987). The sediment clast content of these breccia types is generally quite small, usually less than 5%. The contacts between these breccias are vague or gradational in the field. These breccias locally exhibit abundant open spaces due to subsequent local crackle to mosaic brecciation much like the brecciation of the granite wall rock described earlier. Like the granite, these open spaces are often filled with pyrite or the oxidized remnant of pyrite.

These breccias are speculated to represent at least one and probably several cyclic magmatic surges and recessions. The magmatic injection cycle over-pressuring and fragmenting the overlying rocks and the recessive cycle allowing the fragmented roof/wall rocks to be displaced downwards and become breccia fragments in a matrix composed of the next fluid magmatic surge. This style of brecciation is evident in both the East and West pipes and to some degree in the arcuate interconnecting dike.

The West pipe was subjected to an additional phase of brecciation as evidenced by rock fragments of the Goodsprings dolomite included variably with fragments of the previously mentioned shale, quartzite, granite, and felsite in a finely comminuted rock flour matrix. Sharp (1984) termed this breccia style as rubble breccia. Current pit mapping terminology for this breccia style is granite sediment clast breccia and sediment clast breccia, again depending on the volume percentage of the various clast lithologies (Schull, 1987). This breccia style generally contains a significant percentage of sediment clasts, locally to the point of being exclusively sediment clasts. Clasts of dolomite or sulfide replacement of dolomite are singularly characteristic of these breccias. They are generally matrix supported but locally are clast supported. Clast sizes vary from granules to boulders. Megascopically the matrix looks much like felsite but petrography work has established it as a finely comminuted rock flour (Sharp, 1984). Contact relationships of these breccias with all other rock types are generally sharp where visible, but the contacts have been quite difficult to recognize in pit mapping to date because of near surface oxidation. These sediment clast breccias form irregular pipe-like masses as well as very narrow arcuate breccia dikes.

Sharp (1984) calls on late stage magma movement accompanied by fluidization, through the release of carbon dioxide gas, as the mechanism for emplacement of the sediment clast breccias. The recession of the final magmatic phase probably caused fragmentation and brecciation which stoped its way into the then overlying Goodsprings dolomite. The fragments of dolomite and other lithologies were then transported, according to Sharp (1984), down the pipe in a fluid medium as much as 3,200 feet (975 m). This distance estimate by Sharp (1984) is based on the presence of dolomite fragments within the West Pipe at a hole depth of 1,900 feet (580 m). This distance plus Sharp's (1984) estimate of the pre-erosion restored Precambrian and Paleozoic sections over the pipe complex indicates the 3,200 feet (975 m) of fragment mixing.

Alteration and Mineralization

The main products of hydrothermal alteration of the Colosseum pipes are adularia and sericite (Jackson, 1985). Adularia occurs throughout the pipe complex and is most strongly concentrated in the margins of the East and West pipes and in the sediment clast breccias of the West pipe, thought to be zones of greatest permeability and thus highest fluid flow. Moderate sericite distribution is the approximate inverse of the adularia within the pipes. Sericite is also visually significant within the Precambrian granite near the pipe boundaries (Schull, 1987). Moderate to strong argillic alteration is apparent within the granite around the pipes and locally along fractures and shears within the pipe rocks. The visual alteration associated with the hydrothermal activity related to emplacement of the pipes does not extend a significant distance away from the pipes but apparently does extend vertically, with little change, from the surface to 2,300 feet (700 m), the deepest drill intercept of pipe lithologies (Schull, 1987).

Gold mineralization at Colosseum is associated with sulfide mineralization, chiefly pyrite. Gold occurs as free gold with minor alloyed silver. Particle size ranges from 1 micron up to 1 mm but most particles fall in the range of 5 to 20 microns (Corbett, 1980 and Strong, 1984). Electron microprobe work indicates another unknown minor component (Strong, 1984) within free gold particles. Anomalous tellurium in the Colosseum pipes suggests the presence of gold tellurides and may be the unknown component identified by Strong (1984).

The silver to gold ratio for the Colosseum pipes generally appears to be 1:1. However, electron microprobe analysis indicates only 10 to 15% free silver alloyed with the gold particles. This discrepancy indicates the presence of other silver minerals. Although some silver will be recovered during the proposed milling process it is not a significant economic consideration.

Petrographic and mineralogic work by Odekirk (1974), Corbett (1980), Matter (1983), Strong (1984), and Jackson (1985) indicates that the gold occurs primarily in contact with pyrite, in fractures (within the pyrite) or along pyrite grain edges, secondarily as particles encased inside euhedral pyrite, and rarely as isolated particles in quartz and other gangue minerals but spatially always close to pyrite. Minor amounts of sphalerite, chalcopyrite, and galena are associated with the pyrite occurring as inclusions and co-precipitates and, similarly to gold, as particles in contact with pyrite in fractures and along grain boundaries. Jackson (1985) indicates a strong geochemical correlation between adularia and gold in the West pipe.

The gold mineralization at Colosseum is thought, by Corbett (1980) and Sharp (1984), to have been emplaced in two separate mineralizing events interspersed with or accompanying several pyrite events, based on the residence sites for the gold. Strong (1984) argues that all the residence sites for the gold could be explained by one gold mineralizing event. Further study during mine life is appropriate before defining the sequence of gold deposition event(s) at Colosseum.

Gold mineralization in the West pipe extends from the surface to at least 900 feet (275 m) of depth, the current extent of drilling. The East pipe gold mineralization also extends to the depth of drilling: 800 feet (240 m). The West pipe contains more tons of gold ore at a higher grade than the East pipe.

Gangue mineralization, other than sulfides or their oxidized remnant, indicated by petrography includes quartz, siderite, sericite, and dolomite. Megascopically, quartz is the most evident gangue mineral. It occurs as veins and veinlets with pyrite, as small drusy crystals in open spaces, and as a general rock flooding which is the most dominant style of silicification.

Pyrite mineralization megascopically ranges from absent to 30% of rock volume. Other sulfides are comparatively very minor. The pyrite is generally euhedral, very fine to very coarse grained, and occurs as separate crystal grains, in clusters, and in massive intergrowths. Corbett (1980), Sharp (1984), and Strong (1984) speculate varyingly on several generations of pyrite mineralization, but the exact number of mineralizing events that deposited pyrite and other associated minerals may be difficult to determine.

The pyrite mineralization at Colosseum occurs in three distinct styles (Schull, 1987): a disseminated style, an open space or vein/fracture filling style, and a replacement style. The disseminated style exhibits very fine to very coarse grained euhedral pyrite disseminated through the rock in amounts up to 10% by volume. This mineralization style can be seen variably in all the pipe lithologies and in the wall rock granite. The open space or vein/fracture filling style is indicative of pyrite deposition in open spaces caused by brecciation and/or fracturing. The pyrite varies from discrete euhedral pyrite crystals completely covering a fracture surface to narrow veins and veinlets of massive pyrite, often with quartz, to massive intergrowths of pyrite filling open spaces between clast supported breccia fragments. This style of mineralization is also seen in all the pipe lithologies but is often characteristic of the brecciated granite wall rock. The replacement style of pyrite mineralization is exhibited mostly by the sediment clast breccias. Here dolomite breccia fragments have been preferentially replaced by pyrite. The degree of replacement varies from minor to total with the intensity of pyrite replacement zoned concentrically to the clast rim. Sediment clast breccias are locally mineralized by all three pyrite styles and thus are seen to contain up to 30% pyrite by volume.

Oxidation of the pyrite mineralization is intense and pervasive in the upper 100 to 300 feet (30 to 90 m) of the deposit and locally restricted by fractures below those depths. The oxidized remnant of pyrite is generally earthy to jasperoid goethite with pyrite casts as evidence of even greater oxidation and leaching.

Gold mineralization in and around the Colosseum pipes is microscopically and geochemically associated with pyrite. However, pyrite does not necessarily contain gold. Locally samples containing greater than 10% pyrite can contain less than 100 ppb gold, while most areas containing greater than 10% pyrite contain ore grade gold values. This indicates that gold mineralizing processes did not occur in all portions of the pipe rocks that were previously mineralized by sulfides. The causes of gold occurrence and nonoccurrence within lithologically similar, spatially close rocks is the focus of current study and is germane to establishing the genesis of the gold within the pipes, as well as to the economics of selective mining at Colosseum.

References

Burchfiel, B.C. and Davis, G.A., 1973, Possible Igneous Analogy of Salt Dome Tectonics, Clark Mountains, Southern California, American Association of Petroleum Geologists Bulletin, Vol 57, No. 5, pp. 933 - 939.

Burchfiel, B.C. and Davis, G.A., 1971, Clark Mountain Thrust Complex in the Cordillera of Southeastern California, Geologic Summary of Field Trip Guide, University of California, Riverside, Campus Misc. Contr., No. 1, pp. 1-28.

Corbett, R.K., 1980, Mineralogical Work on Selected Gold Ore Samples from Cal-Pipe Project, California, Colorado School of Mines Research Institute Report N90525.

Dobbs, P.H., 1961, Geology of the Central Part of the Clark Mountain Range, San Bernardino County, California, Unpublished M.S. Thesis, University of Southern California, 115 pp.

Hewett, D.F., 1956, Geology and Mineral Resources of the Ivanpah Quadrangle, California and Nevada, USGS Prof. Paper 275, 172 pp.

Jackson, S.E., 1985, Geochemical Characteristics of the Colosseum Breccia Pipe Complex, Unpublished Consultant's Report.

Lacy, W.C., 1986, An Evaluation of the Colosseum Mine Project, San Bernardino County, California, Unpublished Consultant's Report.

Matter, P., 1983, Petrographic Analysis of Polished Thin Sections, Colosseum Project, San Bernardino County, California, Unpublished Consultant's Report.

Odekirk, J.R., 1974, Rock Samples from the Cal-Pipe Deposit, California, Unpublished Memorandum, Newmont Mining Co.

Schull, H.W., 1987, A Report on the Pre-Mining Development Geology of the Colosseum Gold Deposits, San Bernardino County, California, Unpublished Consultant's Report.

Sharp, J.E., 1984, A Gold Mineralized Breccia Pipe Complex in the Clark Mountains, San Bernardino County, California, Arizona Geological Society Digest, Vol. 15., pp. 119 - 139.

Strong, D.F., 1984, Mineralographic and Chemical Study of Polished Sections From the Amselco Inc. Colosseum Property, Unpublished Consultant's Report.

Sutter, J.F., 1968, Geochronology of Major Thrusts, Southern Great Basin, California, Unpublished M.S. Thesis, Rice University, 32 pp.

TOUR STOPS

Stop 1
View the Keystone thrust fault and/or Clark Mountain normal fault. View Tapeats quartzite, Bright Angel shale, and the Goodsprings dolomite(?).

Stop 2
View Precambrian biotite-sericite gneiss, showing northwest trending fabric typical of the Precambrian rocks locally, cross-cut by northeast trending andesite dike of unknown age.

Stop 3
Near East pipe ore body. View Precambrian granite gneiss showing typical sericitic and argillic alteration near the breccia pipe contact.

Stop 4
East pipe ore body. View typical lithologies and sulfide mineralization styles of the East pipe.

Stop 5
West pipe ore body. View typical lithologies and sulfide mineralization styles of West pipe.

THE MORNING STAR GOLD MINE

Kent Ausburn, Vanderbilt Gold Corp.

ABSTRACT

The Morning Star Mine is located in the eastern Mojave desert, San Bernadino Co., California.

Gold mineralization is hosted by late Jurassic to early Cretaceous Ivanpah granite and is associated with locally persistent thrust faulting related to Sevier orogeny compressional tectonics. High to moderate angle faulting and fracturing of upper plate rocks was integral in localizing ore grade mineralization in the thrust fault upper plate at Morning Star.

Mineralization occurs in quartz ± calcite veins. Ore minerals include pyrite + chalcopyrite + galena ± sphalerite ± covellite + Au-Ag. Ag/Au is approximately 2:1. Mineralization post-dates Sevier deformation, and pre-dates Tertiary Basin and Range structures. Matrix correlation of 16 elements plus Au and Ag indicates that Cu, Pb, Mo, Bi, and Sn show the most significant posative correlation with Au-Ag occurance. Proven reserves are 8 million tons of .06 oz/ton Au ore. Mine life is projected at 9 to 10 years with a 40 to 55 thousand ounces of Au per year production schedule.

INTRODUCTION

The 1000 acre Morning Star property is located on the eastern flank of the Ivanpah Mountains, approximately 65 miles south of Las Vegas, Nevada in San Bernadino county, California. Mine elevation is roughly 4600 feet. Climate and vegetation are typical of the high eastern Mojave desert.

At present, proven reserves are approximately 8 million tons of .06 ounces Au per ton. Ore is being crushed to 3/8 inch and cyanide heap leached. Planned production for 1988 is 40,000 ounces of Au. Projected mine life is nine to ten years.

HISTORY

Gold mineralization was discovered at the site of the Morning Star Mine in 1907. The property was prospected intermittently until the late 1930's when it was acquired by Haliburton Oil Company. Haliburton performed extensive underground development work, resulting in the blocking out nearly 2,000,000 tons of gold ore. In 1942 the operation was shut down by war production Order L 208 before production could begin.

Vanderbilt Gold Corporation acquired the Morning Star in 1964. Sampling of existing workings and underground drilling continued intermittantly until 1979. From 1980 to 1982 the mine was developed as an underground operation utilizing trackless mining techniques. In 1983 the dicision was made to convert the Morning Star to an open pit, cyanide, heap leach mining operation. Limited open pit, heap leach production of mine run ore began in November, 1986. Full scale production of crushed ore began November, 1987.

GEOLOGY

The Morning Star Mine is situated at the southern extreme of the Jurassic-Cretaceous Sevier thrust belt. Stacked thrust sheets of Grand Canyon series Paleozoic sedimentary and Precambrian basement rocks define the Clark Mountains immediately north of the Ivanpah Mountains. Morning Star mineralization is hosted by late Jurassic Ivanpah granite in the upper plate of a low angle thrust fault. The Ivanpah granite is one of seven Jurassic and Cretaceous age granitic plutons that comprise the Teutonia Batholith, one of the largest intrusive complexes in the eastern Mojave Desert. The Morning Star thrust fault is the only incidence of Sevier orogeny related faulting of Teutonia batholith crystaline rocks.

The Morning Star is 15 to 20 miles west of the mapped western limits of the Colorado River trough extensional (detachment) terrane. High angle Tertiary Basin and Range related normal faulting overprint Morning Star and rocks. Minor normal slip along the plane of the Morning Star thrust fault may have occurred during Tertiary extensional tectonics.

LITHOLOGIES

Rocks in the Morning Star Mine vicinity are dominated by the medium to coarse grained, inequigranular, holocrystaline late Jurassic to early Cretaceous Ivanpah granite. Ivanpah granite is approximately 60% K-feldspar (perthitic orthoclase), 20% quartz, 15% plagioclase (oligoclase), and 5% biotite. A detailed description of Ivanpah granite mineralogy is available in Beckerman, etal.(1982). Coarser grained pegmatitic and finer grained aplitic late stage differentiates are common. Mafic dikes of diabase to diorite and lamprophyre composition, ranging from very fine to medium grain textures, are scattered throughout the intrusion. Sutter (1968) produced a biotite K/Ar age date of 137 my for the Ivanpah granite. The mafic dikes are considered late stage in the Ivanpah granite intrusive episode.

STRUCTURE

Localization of Morning Star precious metal mineralization is controlled by a locally continuous low angle fault oriented roughly N20° W, 32° W. Mylonitic foliation, oriented coplanar to the fault plane, occurs in upper plate rock, becoming increasingly well developed toward the fault plane. The plane of slip within the fault zone is characterized by sheared granite that is strongly clay altered. Throughout the mine area a fine to medium grain diorite or lamprophyre dike occurs intermittantly along the fault zone - lower plate contact. The dike is clearly pre-faulting, the slip-plane of the fault having roughly followed the upperdike-granite intrusive contact as an inherent zone of weakness. Mylonitic foliation is absent in the lower plate, shearing was not penatrative below the fault plane. Slip and faulting induced deformation is confined to the upper plate. With the exception of a weak propyllitic overprint, lower plate rock is fresh and unfoliated away from the fault zone-lower plate contact. In contrast, upper plate rock is commonly strongly altered and foliated well away from the fault zone.

Thrust faulting typically brings deeper seated rocks into juxtaposition on shallower level rocks. This is often manifested as older rocks emplaced on top of younger rocks. It can also involve emplacement of upper plate rocks which have undergone deep level, high temperature-pressure ductile deformation on top of higher level, lower temperature-pressure brittle to non deformed lower plate rocks. Mylonite zones associated with low angle normal faults ("detachment" faults) consistently occur in the lower plate as a result of deeper level, ductily deformed lower plate rocks having been brought into juxtaposition with higher level brittly or undeformed rocks. Thus mylonitic ductile deformation of upper plate rocks is compelling evidence in favor of a thrust fault mechanism for the Morning Star low angle fault. Macro-and microscopic foliation shear direction indicators are ambiguous. Both S - and Z - drag folds are present, probably indicating post thrusting normal fault slip due to realization of compressional strain.

High to moderate angle faults and fractures cut upper plate, and to a lesser extent, lower plate rocks. These faults and fractures occur in a variety of orientations. Only minor to no displacement is indicated. Much of the faulting and fracturing of the upper plate occurred during and immediately subsequent to thrust transport. The ore controlling structures apparently belong to this set of structures. Structures that cut both upper and lower plate rocks are consistently unmineralized. They typically display clay-chlorite fault gouge and fault polish, and post-date mineralized structures. These post-mineralization structures are responsible for most of the pit wall instability at the Morning Star Mine.

VEINING, MINERALIZATION, AND ALTERATION

Mineralized veining is primarily associated with the N20°W, 32°W Morning Star thrust fault structure and a set of variably NE to E-W striking, N to S steep to moderately dipping structures. Veining varies from thin veinlets and stringers to inch wide veins. A mineralized, quartz ± calcite stockwork - breccia zone of a few inches to a foot in thickness is associated with the immediate upper plate - thrust fault contact. All other structures are interpreted as post-ore. Ore mineralization consists of pyrite + cholcopyrite + galena ± covellite ± sphalerite + Au-Ag in quartz ± calcite veins. Calcite veins commonly contain galena as the only sulfide. Secondary supergene Cu-mineralization, represented as covellite, is concentrated along the upper plate thrust fault contact. Some secondary gold enrichment may be associated with this supergene zone. Gold occurs free, commonly coating or filling fractures on pyrite, chalcopyrite, and galena. Gold and galena are typically argentiferous. No silver minerals have been recognized. Ore grade mineralization defines a tabular ore body roughly coplaner with the Morning Star thrust fault. This ore zone typically extends 60 to 100 feet into the upper plate from the thrust fault - upper plate contact. Ore grade generally increases toward the thrust fault, but high grade ore associated with high-angle structures can extend well over 100 feet into the hanging wall.

Weak to moderate argillic ± sericitic alteration is closely associated with mineralized veins. Propylitic alteration characterized by pyrite + calcite + chlorite + epidote is pervasive, occurring in both the upper and lower plate. Silicification is confined to discrete veins, veinlets, and stringers.

GEOCHEMISTRY

Besides the obvious gold-silver anomalies associated with Morning Star mineralization, the following elemental concentrations have been noted: (1) Cu: <100 to 3000 ppm

(2) As: <1.0 to 9.0 ppm (3) Hg: <.1 to.125 ppm (4) Mo: 0.5 to 10.1 ppm (5) Pb: 8.6 to 2500 ppm (6) Sb: < .30 ppm (7) Tl: < .50 ppm (8) Zn: 11.5 to 350 ppm (9) Bi: < .3 to 57 ppm (10) Cd: < .3 to 6.1 ppm (11) Ga: < .45 to 8.6 ppm (12) Pd: < .09 ppm (13) Pt: < .3 ppm (14) Se: < 1.7 ppm (15) Sn: < .45 to 1.1 ppm (16) Te: < .5 ppm

Matrix correlation of the above elements indicate that Cu, Mo, Pb, Bi, and Sn show the most significant positive correlation with Au and Ag occurance.

CONCLUSIONS

(1) Morning Star mineralization is hosted entirely within the 137 my (Jurassic-Cretaceous) Ivanpah granite.

(2) The structural ore controls at the Morning Star are the N20° W, 32° W Morning Star thrust fault and a set of NE to E-W high to moderate angle faults-fractures.

(3) Formation of mineralized high and moderate angle structures in the upper plate apparently occurred during and just subsequent to thrust transport of the upper plate. Unmineralized high angle structures probably formed during Tertiary Basin and Range extensional deformation. Mineralizing hydrothermal activity apparently occurred sometime between these two deformational events.

(4) Hydrothermal fluids apparently moved up the primary, deep rooted N20° W, 32° W Morning Star thrust fault system conduit and were channeled into the upper plate along the NE E-W high and moderate angle structures. Channeling

of fluids into the lower plate was apparently inhibited by the relatively impermeable thrust fault shear zone, and lack of fracture conduits.

(5) Ore mineralization defines a tabular orebody within the upper plate that is coplanar to the Morning Star thrust fault. Gold values generally increase toward the thrust fault.

(6) Gold occurs free, coating associated sulfides. Gold and gal ena are argentiferous. No individual silver minerals have been identified.

(7) Potential for additional Au-mineralization along the strike of the Morning Star thrust fault can only exist where adequate brittle fault-fracture deformation of the upper plate occurred during and immediately after thrust fault transport, producing an adequate hydrothermal conduit system for upper plate mineralization. The Morning Star thrust was probably not adequate by itself.

References

Beckerman, G.M., Robinson, J.P., Anderson, J.L., 1982; The Teutonia Batholith: A large intrusive complex of Jurassic and Cretaceous age in the eastern Mojave Desert, Calif. in Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada: Cordilleran Publishers pgs. 205-211.

Sutter, J.F., 1968, Chronology of major thrusts, southern Great Basin, California: M.S. Thesis, Rice Univ., 32 p.

ENCLOSURE 6

THE FRISCO MINE

MOHAVE COUNTY, ARIZONA

Ed Huskinson, Jr.

ABSTRACT

The Frisco Mine is a gold property in western Mohave County, Arizona. Discovered in 1890, the mine has produced between 18,000 and 25,000 ounces of gold, with the last production of 2,300 ounces realized between 1984 and 1986. The potential exists to discover 75,000 to 125,000 ounces or more on the property.

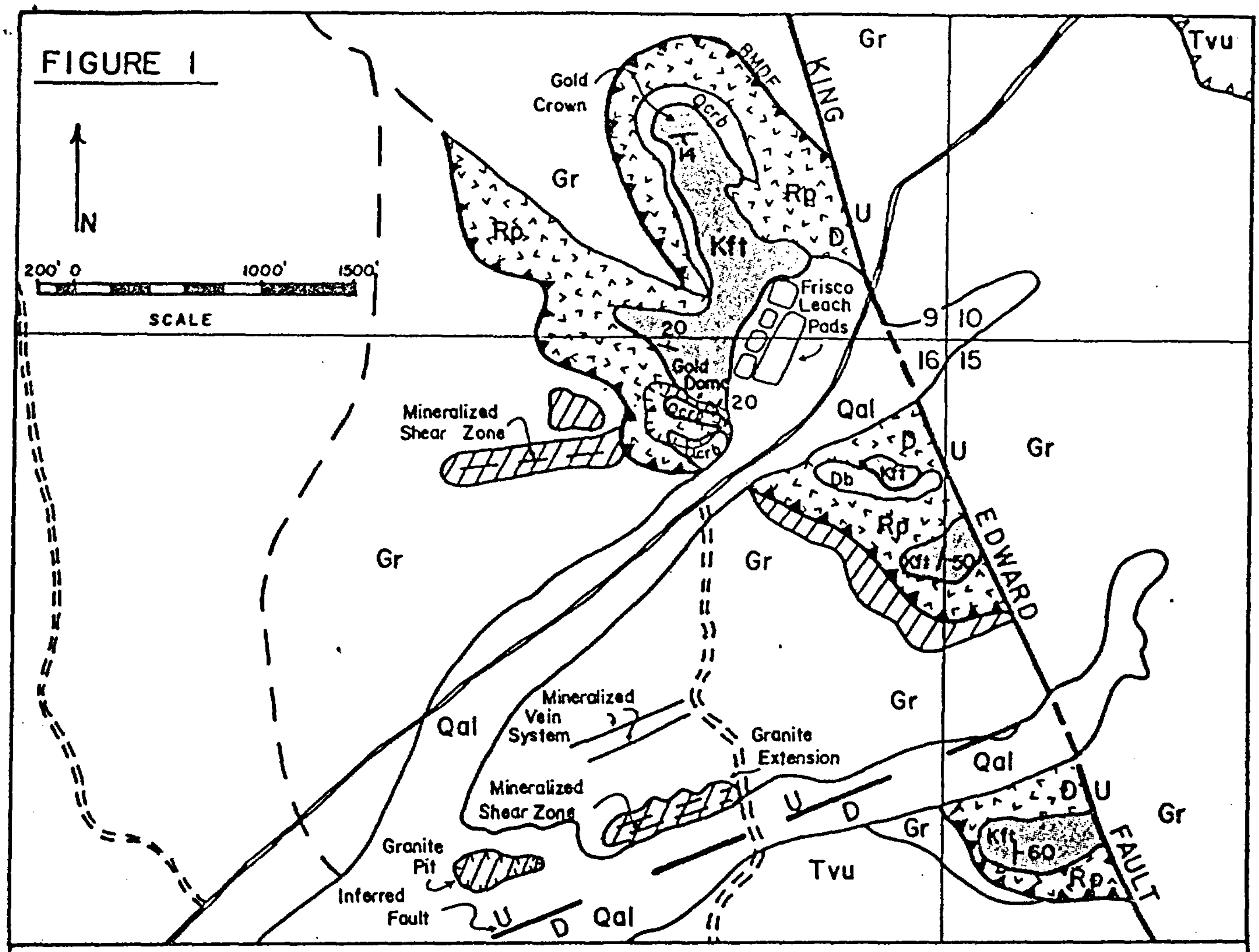
There are two known ore bodies: the Gold Crown and the Gold Dome, both hosted in volcanic rocks in the upper plate of the Black Mountains detachment fault. In addition, there appears to be a third ore deposit in altered crystalline rocks in the lower plate below the fault. The average grade of the ore bodies is 0.068 opt Au, and much of the ore appears to be amenable to heap leach extraction. The gold to silver ratio is 1:1.

Mine infrastructure is well established, and an active exploration program at the property is ongoing (November, 1987).

INTRODUCTION

The Frisco Mine is a gold property 25 miles west of Kingman, Arizona, nine miles east of Bullhead City, Arizona, and 90 miles south of Las Vegas, Nevada. An abandoned loop of Hwy 68 transects the property, and numerous dirt roads provide good access throughout (Fig. 1).

Gold was discovered on the Frisco property in 1890,



GENERALIZED GEOLOGIC MAP
FRISCO MINE AREA
- Ed Huskinson, Jr. -

Qal	QUARTERNARY ALLUVIUM
Tvu	TERTIARY VOLCANIC ROCKS, UNDIFFERENTIATED : ANDESITE AND RHYOLITE FLOWS, TUFFS AND FLOW BRECCIAS.
	FRISCO MINE UNITS
Kft	KAOLINIZED FRAGMENTED TUFF
Qcrb	QUARTZ CEMENTED RHYOLITE BRECCIA (ORE ZONE)
Rp	RHYOLITE PORPHYRY
Db	DIABASE (LOCALLY PORPHYRITIC) DIKES, ETC.
BMDF	BLACK MOUNTAINS DETACHMENT FAULT (LOW ANGLE NORMAL FAULT) TEETH ON UPPER PLATE
	AREAS OF QUARTZ / CARBONATE AND/OR FeOx STAIN ALTERATION; USUALLY MINERALIZED.
Gr	PRECAMBRIAN GRANITE / QUARTZ MONZONITE : LOCALLY PORPHYRITIC AND/OR GARNETIFEROUS ; OFTEN GNEISSIC.

and there has been sporadic production since then. Between 1890 and 1930, approximately 40,000 tons of ore grading 0.40 to 0.60 opt Au were produced from stopes in the main mine workings. Their production costs were 0.20 opt Au. Part of this was processed on the property and part was milled at the Katherine Mill on the Colorado River, about 7 miles west of the mine.

During the last period of production from 1984 to 1986, approximately 2300 ounces of gold were leached from ore on the property. Production ceased when the price of gold fell below $300.00 per ounce and the stripping ratio reached 2:1.

Consisting of 168 acres of patented claims and 640 acres of state lease, the property is being explored by two Canadian mining companies: Gerle Gold (US) Inc., in joint venture with Mahogany Minerals (USA) Inc.

There are two ore bodies, both hosted in volcanic rocks: the Gold Crown and the Gold Dome. In addition, exploration is on-going at the Granite and Granite Extension areas to the southwest where gold mineralization occurs in Precambrian rocks. The gold to silver ratio is 1:1.

GEOLOGY

Regional Setting

The Frisco mine is on the west flank of the Black Mountains, near the north end of the Union Pass Mining District. The rocks comprise a closely related series of volcanic flows, with associated tuffs, which rest on Pre-cambrian crystalline rocks, chiefly granite and gneiss.

The contact between these units appears to be a low-angle (less than 45 degree dip) normal fault, the Black Mountains Detachment Fault (BMDF, Fig. 1).

Lithology

A) Lower Plate

The lower-plate rocks below the detachment consist of Precambrian gneiss, porphyritic granite and granodiorite, with local zones of metavolcanics. At the Granite and Granite Extension areas, the gneiss is partly mylonitized and has also been brecciated.

B) Contact Zone

No evidence of a detachment rubble zone or micro-breccia has been found at the Frisco. The contact zone is a mylonite consisting of crushed and sheared gneiss of which only isolated vestiges of primary feldspars and biotite survive. Much of the biotite and plagioclase has been replaced by a fine scaly paste of sericite that is clouded with supergene hematite. Sericite inherited from former feldspars also dusts quartz grain boundaries throughout the fabric, and sericite has been dragged as foliae onto slip planes. Silicification is variable: in places it is weak, in others, the rocks are almost jasperoidal. The contact zone varies in thickness from less than 1 foot to over forty feet (Fig. 2).

C) Upper Plate

The upper-plate rocks are all Tertiary volcanics, consisting of rhyolite flows, vitrophyres and tuffs, overlain by a sequence of andesite, latite and basalt flows (Fig. 2)

Rhyolite porphyry

A rhyolite porphyry overlies the granitic basement rocks. Varying from 70 feet to 160 feet thick, the unit is characterized by numerous quartz eyes, and textures suggest emplacement as a thick flow or sill. The rhyolite unit is locally flow banded.

Quartz-Cemented Rhyolite Breccia

This is the primary ore horizon at the Gold Crown, where the bulk of the production was obtained, largely by stoping. It is a 30- to 40-foot zone consisting of banded vein matter that has formed by replacement of a rhyolite vitrophyre. Rhyolite relics are typically slab-like domains replaced extensively by dense cherty quartz in which small adularia euhedra are dispersed. Coarse cockaded epithermal quartz of prismatic habit is anchored on the rhyolite relics. This material grades from 0.009 opt Au to as much as 0.372 opt Au. All of the ore is silica-encapsulated, and must be milled.

Kaolinized Fragmental Tuff

This distinct white unit overlies the ore zone, and is thought to represent an alteration cap over the ore body. It is composed of kaolinite (hydrous alumino-silicate clay) with 5 to 10% lithic fragments. Excess silica is in the form of alpha quartz and alpha cristobalite. Because this material will have to be stripped off to open pit the underlying ore, the company is researching uses for it, such as furnace lining, smelter flux, or roofing material.

Basalt Fragment Breccia

At the Gold Dome pit, the ore is easily leached. The last production from the mine (about 2300 ounces of gold) was realized from a 30 foot breccia of basalt fragments of uncertain origin that is cemented by quartz and carbonate. Grades in this unit range from 0.009 to 0.475 opt Au, and average 0.068 opt Au. This zone is overlain by a basic vitric tuff that was probably deposited directly in a subaqueous environment. The abstruse relationship between this section and the section at the Gold Crown is under investigation.

Structure

The most prominent structural feature in the area is the Black Mountains detachment fault, a low angle (less than 45 degrees) normal fault developed in response to extensional stresses in mid-Tertiary time. The BMDF appears to extend for about 25 miles, first cropping out about three miles south of the Frisco property, and can be traced on through the Van Deemen Mine (about 20 miles north). The fault is characterized by a cataclastic breccia of variable degree and thickness, and it generally forms the boundary between lower-plate crystalline rocks and upper-plate Tertiary Volcanic rocks. There are a number of mines and small prospects associated with the fault.

Besides the Black Mountains detachment fault, the most prominent structure in the mine area is the King Edward fault. This NNW-trending high-angle normal fault has dropped the volcanic rocks of the Frisco area down, pre-

66

serving the ore zone(s) and overlying altered tuffs (Fig.1).

The lower-plate rocks display a N 15-20 W fabric, as evidenced by numerous dikes and lineations of that orientation.

There are several NE-trending high-angle structures in the area. The Arabian zone, one mile SW, strikes right toward the Frisco; however, there are no outcrops which can be traced directly onto the property from the Arabian. A set of late Tertiary NE faults cut the stratigraphy, and these account for the differences in dip between the Gold Crown, Little Frisco, and South Frisco rocks (Fig. 1).

Alteration and Mineralization

The Kaolinization displayed in the fragmental tuff unit is the most obvious alteration, and it directly overlies the Gold Crown ore body. It is thickest (>50') and most intense over the richest ore zones, and is always barren.

At the Gold Dome, the rocks overlying the ore are zeolitized and kaolinized vitric tuffs in which the glass did not devitrify, but altered directly to a comples mixture of kaolinite and zeolites (erionite and mordenite). These rocks are also silicified, forming what has been termed a silicified "hogsback" of hydrothermal breccia. This zone has weakly anomalous Au (0.009 to 0.01 opt), and is being explored at this time.

In the Granite and Granite Extension areas, the rocks have been propyllitically altered in the epizone, and there is a mineralization overprint of weak argillization, oxidation and hematite stain. This alteration is sometimes coupled with weak to moderate silicification.

Quartz and coarse carbonate fill interstices between relic fragments while pyrite cubes, now oxidized to goethite, are disseminated on matrix quartz grain boundaries. This material grades from 0.02 opt to 0.145 opt Au.

The gold associated with the quartz-cemented rhyolite breccia is silica-encapsulated, and must be milled for extraction. The gold at the Gold Dome and granite areas can be leached easily. Extraction rates are fairly rapid - 75 to 85% in 48 hours, with low cyanide consumption. Lime consumption is a little high at 11 to 13 lbs per ton of ore.

Previous perators report extraction rates of 70% at 1/2" crush during a 30-day leach cycle on material from the Gold Dome pit.

CONCLUSIONS

The Frisco Mine has drill proven and probable reserves of 260,000 tons grading 0.046 opt Au, and the potential to host from three to five times that amount.

Mineralization in the upper plate volcanic rocks is contained in rhyolite vitrophyres and breccias, and probably reflects ground preparation resulting from the reaction of these brittle units to extensional stresses generated in Mid-Tertiary time. The source of the mineralizing solutions is uncertain, but is thought to lie to the southwest. The ore fluids probably traveled along the Arabian structure which trends onto the property from that direction.

Mineralization in the lower plate granites appears to be restricted to a wide, high-angle shear zone, probably a splay off the Arabian. This zone may prove to hold the bulk of the mineralization for the property.

ACKNOWLDGEMENTS

The petrographic analyses of Mr. Sid Williams of Douglas, Arizona have been of inestimable assistance to the project. Messr's Carl Lalonde and Doug Irving aided in the field mapping, the personnel at Fischer Watt Gold and Peter Drobeck made many helpful suggestions.

Ray Hrkac, President of Gerle Gold (U. S.) Inc. generously permitted the data to be published.

REFERENCES

Bonelli, D., 1986, Introductory report on the Frisco Mine, Mohave County, Arizonaf: Priv. rpt., 18 pp.

Durning, P., and Hillemeyer, F., 1986, Precious metal deposits of southern California and western Arizona: field trip guidebook #2 Colosseum-Morning Star-Roadside-Copperstone. in: Frontiers in geology and ore deposits of Arizona and the southwest: Ariz. Geol. Soc. and the Univ. of Ariz. 1986 symposium, p. 255 - 259.

Ransome, F. L., 1923, Geology of the Oatman gold district: U. S. Geol. Survey Bull. 743, 58 pp.

Schrader, F. C., 1909, Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Arizona: U. S. Geol. Survey Bull. 397, 226 pp.

GEOLOGY AND STRUCTURAL CONTROL OF GOLD MINERALIZATION AT THE VAN DEEMEN PROSPECT, MOHAVE COUNTY, ARIZONA

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ABSTRACT

Gold mineralization at the Van Deemen prospect occurs within a locally thick package of brecciated Precambrian through Late Mesozoic crystalline rocks along an extensive low-angle normal fault. Drilling to date (October 8, 1987) has identified a gold resource totalling about 34,000 ounces. The low-angle fault (the Van Deemen Fault) hosting the gold mineralization at Van Deemen was previously termed a detachment fault, but is not herein because there is some evidence that the fault may have initiated at a moderate to high angle and was then subsequently tilted to the present-day low angle by younger faulting. The Van Deemen Fault separates the crystalline assemblage of rocks from an upper-plate assemblage consisting of middle Tertiary volcanic and sedimentary strata. The Van Deemen Fault appears to have evolved from early episodes of ductile shearing and the development of mylonites to later stages of folding and brittle style of brecciation and fracturing. It is this package of brecciated rocks that hosts the majority of gold mineralization and attendant quartz-sericite-hematite-pyrite-clay alteration. This alteration assemblage forms a widespread zone of alteration along the low-angle normal fault with gold-arsenic-tellurium mineralization forming much more restricted northeast-trending, elongate, tabular bodies within the altered fault breccias. The rather consistent northeasterly trend of mineralization within the low-angle normal fault is controlled by high-angle faults and/or slight undulations in the low-angle normal fault.

INTRODUCTION

The primary focus of this portion of the field trip will be to take a first hand look at some of the important structural controls of mineralization in an extensional environment. In addition to the structural controls, the mineralization, alteration, and geochemistry of the Van Deemen prospect will be discussed and highlighted. Structural geology studies recently conducted at the Van Deemen as part of an overall exploration effort have raised some interesting questions about the dynamics of crustal extension requiring further, more detailed geologic studies.

The Van Deemen prospect is currently an exploration joint venture between Fischer-Watt Gold Co., Inc. and Arizona Star Resource Corp. The project area is located in the northern Black Mountains, Mohave County arizona, which historically is one of the most prolific gold-producing mountain ranges in Arizona, yielding some 2.44 million ounces of gold (Figure 1). Drilling to date at the Van Deemen (October 8, 1987) has identified a gold resource from three small open pits with a total drill proven and drill possible geologic reserve of 988,000 tons grading 0.034 ounces of gold per ton.

HISTORY

The Van Deemen is located within the El Dorado Pass Mining District, a district of only minor past gold production, probably on the order of of 7,000 ounces or less. Early exploration in the area consisted of a relatively small number of shallow shafts, adits, and prospect pits, dating from the 1930's to 1940's. More recently, the Van Deemen area has been actively explored for both copper and gold. Copper exploration was conducted mostly in the 1970's and was directed toward deciphering a highly faulted and sliced Laramide (?) quartz monzonite porphyry copper system (Wilkins, 1984). The area receiving the greatest attention from the copper explorationists is east of the old Pope Mine, about 2.5 miles to the north of Van Deemen. The Van Deemen area again received attention in 1979/1980, but this time as a gold play rather than copper, and has essentially been explored for gold since then. Amselco Exploration Inc. drilled the first serious exploration drill holes for gold on the Van Deemen prospect from 1983 to 1985. Thirteen drill holes were completed by Amselco in 1983 with dissappointing results, but a second phase of nine drill holes in 1985 identified a significant gold zone with one hole showing 115 feet grading 0.047 oz./ton. The property was then explored briefly in 1985 by Red Dog Mining who completed a phase of shallow air-track drilling in the gold zone identified by Amselco. Finally, the property was acquired by Fischer-Watt Gold in late 1985 and joint-vetured with Arizona Star Resource Corp. in 1986. As eluded to earlier, the Van Deemen is an active exploration project for the joint venture.

GEOLOGY OF THE VAN DEEMEN PROSPECT

Regional Geologic Setting

The Black Mountains are an elongate, north-northwest-trending range along the east flank of the northern Colorado River trough. The range is part of a highly extended region which is flanked on the east by the Colorado Plateau and on the west by the relatively unextended McCullough and Piute Mountains. The central and northern Black Mountains are highly extended along a system of closely-spaced, north-to-norhtwest-striking normal faults that displace younger over older rocks in a dominoe-like fashion. As in the extended terranes to the north, west, and south, this extensional tectonism was accompanied by syntectonic sedimentation and voluminous volcanism of Miocene age (eg. Anderson and others, 1972). The mid-Tertiary rocks are always tilted to some degree (locally up to 90), are divided by numerous unconformities, and in general exhibit a growth faulting character. In other words, the older volcanic and sedimentary sequences are usually more steeply tilted than the younger. In many cases the tilted Tertiary rocks and the families of northwest-trending normal faults are underlain by zones of low-angle normal faulting. However, there is some debate as to whether or not these low-angle normal faults should be termed detachment faults since there is some evidence that many of the low-angle faults may have initiated at moderate to high angles and then subsequently tilted to the present-day low angle by younger faulting (Faulds and Geissman, 1986), similar to that proposed for the Yerington District by Profett (1977). It is still unclear if the low-angle faults seen in the Black Mountains should be put in the same class as the detachment faults mapped in the Newberry Mountains to the southwest (Mathis, 1982) and the Whipple Mountains to the south (Davis and others, 1980). For the purpose of this paper and the field trip, the faults in the area of the Van Deemen will be referred to as low-angle normal faults in an effort to conform to the definition of a detachment fault as proposed by Reynolds and Spencer (1985). Detachment faults are described by Reynolds and Spencer (1985) as a regionally extensive, gently-dipping normal fault that formed at a low angle and accommodated significant displacement. Utillizing the strict definition of detachment fault proposed by Reynolds and Spencer (1985), it is suggested that the "true" basal detachment is at some unknown depth below the complexly tilted and faulted blocks of the central and northern Black Mountains.

While the northernmost Black Mountains and the region around Lake Mead in southeastern Nevada have received considerable attention (Anderson, 1971, 1977, 1978; Anderson and others, 1972), studies of the central and north-central Black Mountains have been more or less of a reconnaissance nature (eg., Longwell, 1963). However, this north central portion of the Black Mountains is presently being mapped by Mr. James Faulds as part of a doctoral thesis at the University of New Mexico, Albuquerque.

Lithologies

Low-angle and high-angle normal faults in the Van Deemen area juxtapose a wide variety of rock types. In general, the rocks can be divided into lower-plate and upper-plate assemblages. The lower-plate assemblage, which is host to all the known gold mineralization at the Van Deemen, consists of Precambrian gneisses intruded by a variety of Mesozoic through Tertiary intrusive rocks, including Laramide (?) and mid-Tertiary (?) plutons and mid-Tertiary dike swarms. The upper-plate assemblage consists a variety of sedimentary rocks (generally fanglomerate) and volcanic strata consisting chiefly of intermediate flows and flow breccias, rhyolite tuff, and basalt generally correlatable with the stratigraphy described and dated by Anderson and others (1972). The steeply tilted basaltic andesite flows viewed by the field trip participants are probably correlative with the lower member of the Patsy Mine volcanics of Anderson (1978).

Structure

The simplified geologic map of Figure 1 covers the primary area of gold mineralization in the vicinity of the old Van Deemen Mine. One striking feature that can be readily seen on the map is the sinuous outcrop pattern of the contact between the crystalline

GENERALIZED GEOLOGIC MAP VAN DEEMEN PROSPECT

MOHAVE COUNTY, ARIZONA

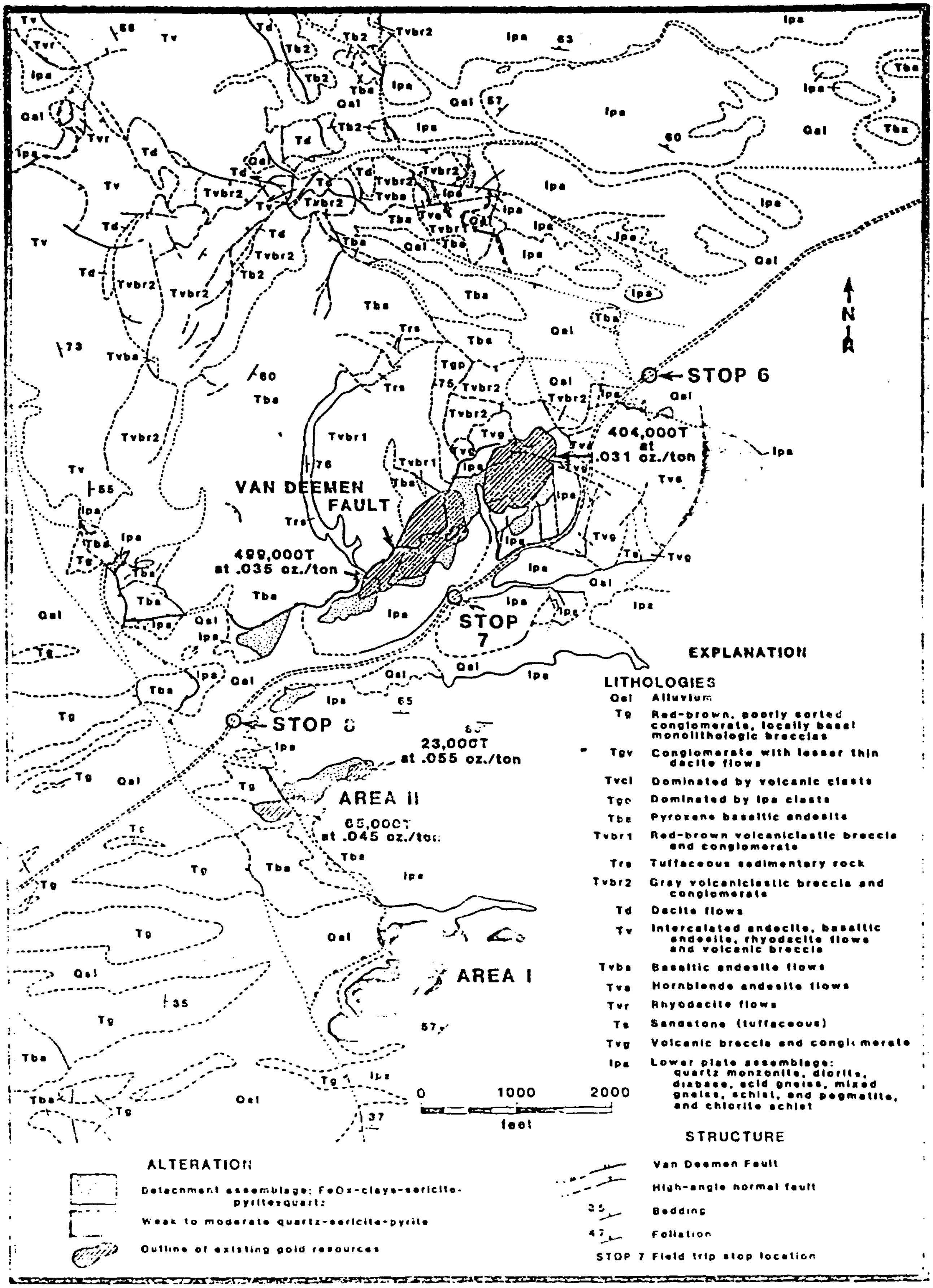


Figure 1

(lower plate) and noncrystalline (upper plate) assemblages. The sinuous outcrop pattern is a reflection of the low-angle nature of this fault contact, herein referred to as the Van Deemen fault. Another striking feature evident on the geologic map is the severe eastward rotation of the lower Patsy Mine volcanic rocks in the hanging wall. Again, as seen in many areas of the central and northern Balck Mountains, the Tertiary rocks are truncated downdip by the underlying low-angle normal fault. The low-angle fault breccias are the primary host of alteration and mineralization in the vicinity of the Van Deemen Mine.

Field evidence and thin section work indicates that the the Van Deemen Fault evolved from early episodes of ductile shearing to later stages of folding and a much more open style of brecciation. Zones of mylonitic deformation parallel the fault and locally form a package of ductilly deformed rocks up to 200 feet thick. Locally, the mylonitic rocks exhibit a well developed lineation trending northeasterly. In all instances the ductilly deformed rocks are at least partially overprinted by very brittle fracturing and brecciation, which also mimics the low-angle contact zone. Along many segments of the fault the brittly deformed zone forms a "structural sandwhich" where there is a strong slip surface at the base of the tilted and truncated volcanic or sedimentary rocks, a middle zone of complex faulting, folding, and brecciation, and then usually, but not always present, another strong dislocation surface below which the rocks are only mildly brecciated and folded. It is this package of rocks affected by an open style of brecciation and folding that provides a favorable host for the gold-bearing hydrothermal fluids at Van Deemen.

The geologic map of Figure 1 shows four of the gold zones at the Van Deemen prospect; Area I, II, II, and IV. Each gold zone occurs within the brecciated crystalline assemblage along a the Van Deemen Fault as described above. However, it is also evident that all the gold zones have a pronounced northeasterly trend. In Areas I, III, and IV the northeasterly trend of the gold zones appears to be related to a northeasterly-trending high-angle deformation zone, especially in Areas III and IV. Here the northeasterly-trending zone of deformation separates an elevated crystalline block on the southeast from a lower-lying crystalline block to the northwest. Also, this northeasterly-trending zone appears to be the separation line between highly tilted rocks on the northwest (50-80) and moderately tilted rocks on the south and southeast (20-50). To the southeast of Areas III and IV, this zone appears to have been intruded by a swarm of mid-Tertiary (?) diorite dikes (Faulds, pers. commun., 1987). It has been suggested by Faulds and others (1988 in press) that the northeast-trending zone of deformation may represent a scissors-like fault separating a more severely east-tilted block on the northwest from a less east-tilted block on the southeast. Faulds also indicates (pers. commun., 1987) that the Area III/Area IV gold zones may occur near the pivot point of the major scissors fault, with increasing oblique-slip offset occuring both to the northeast and to the southwest along this "accommodation zone". The lack of alteration or mineralization in the upper-plate volcanic and sedimentary rocks along this accommodation zone would suggest that it is occuppying a structural break that did not affect the upper-plate rocks. This zone may have been an earlier tear feature in the lower plate of the low-angle normal fault. Other gold zones, such as Area II, also have a pronounced northeasterly trend, but no high-angle zone has been observed to account for this linear trend within the low-angle normal fault. It is possible that the northeast trend is simply due to a slight undulation or "megagroove" within the Van Deemen fault and is not the result of an intersection with a high-angle fault zone. In any event, gold mineralization at the Van Deemen prospect occurs as long, tabular-like bodies, trending northeast within the extensive low-angle normal fault, but the nature of the exact structural control governing this rather consistent trend is at this time not well understood.

In addition to the important low-angle normal faults at the Van Deemen, the area is affected by a myriad of north-to-northwest-trending normal faults which exhibit a wide range of easterly and westerly dips from 30 to 90 (Figure 1). In many instances these moderate-to-high-angle normal faults cut and offset the mineralized Van Deemen Fault. However, in just as many, or perhaps more instances, these faults merge with, but do not offset the underlying Van Deemen Fault. This observation would suggest that these faults formed syncronously with or prior to movement on the Van Deemen fault. These families of faults had a minor role as structural hosts for mineralization at the Van Deemen when proximal to the Van Deemen Fault and add to the geologic compexity of the area. These structures are interpreted to have formed perpendicular to the direction of movement along the fault and are in some instances the site for higher-grade (0.10-0.50 o/t) gold mineralization which usually occur as quartz-hematite breccia veins. These breccia veins are often keel-like in form and pinch dramatically below the Van Deemen Fault. In some instances, these mineralized structures bottom into a low-angle fault zone. Unfortunately, these structures are very eratically distributed and have very limited tonnage potential.

ALTERATION AND MINERALIZATION

Gold mineralization at the Van Deemen prospect occurs primarily in gently-dipping zones of quartz-sericite-hematite-pyrite-clay alteration of brecciated Precambrian gneiss. Alunite is locally present in minor amounts. The ateration zones are spatially associated with rocks generally exhibiting an open style of brecciation. Stacked sheets of quartz breccia are often present in the gold zones, sometimes forming at the fault contact with the upper plate, and other times forming irregular lenses in the faulted gneiss. These quartz breccias often contain mixed fragment types including brecciated chunks of vein quartz. The matrix supporting the breccia fragments appears to be made up of finely pulverized rock flour subsequently replaced by fine-grained quartz. In these quartz-breccia zones, sulphides (pyrite and arsenopyrite) occur in and near late-stage fractures. Surrounding the quartz breccia bodies are locally brecciated gneisses often severely sheared prior to alteration. The shearing has drawn the feldspars into lenses and

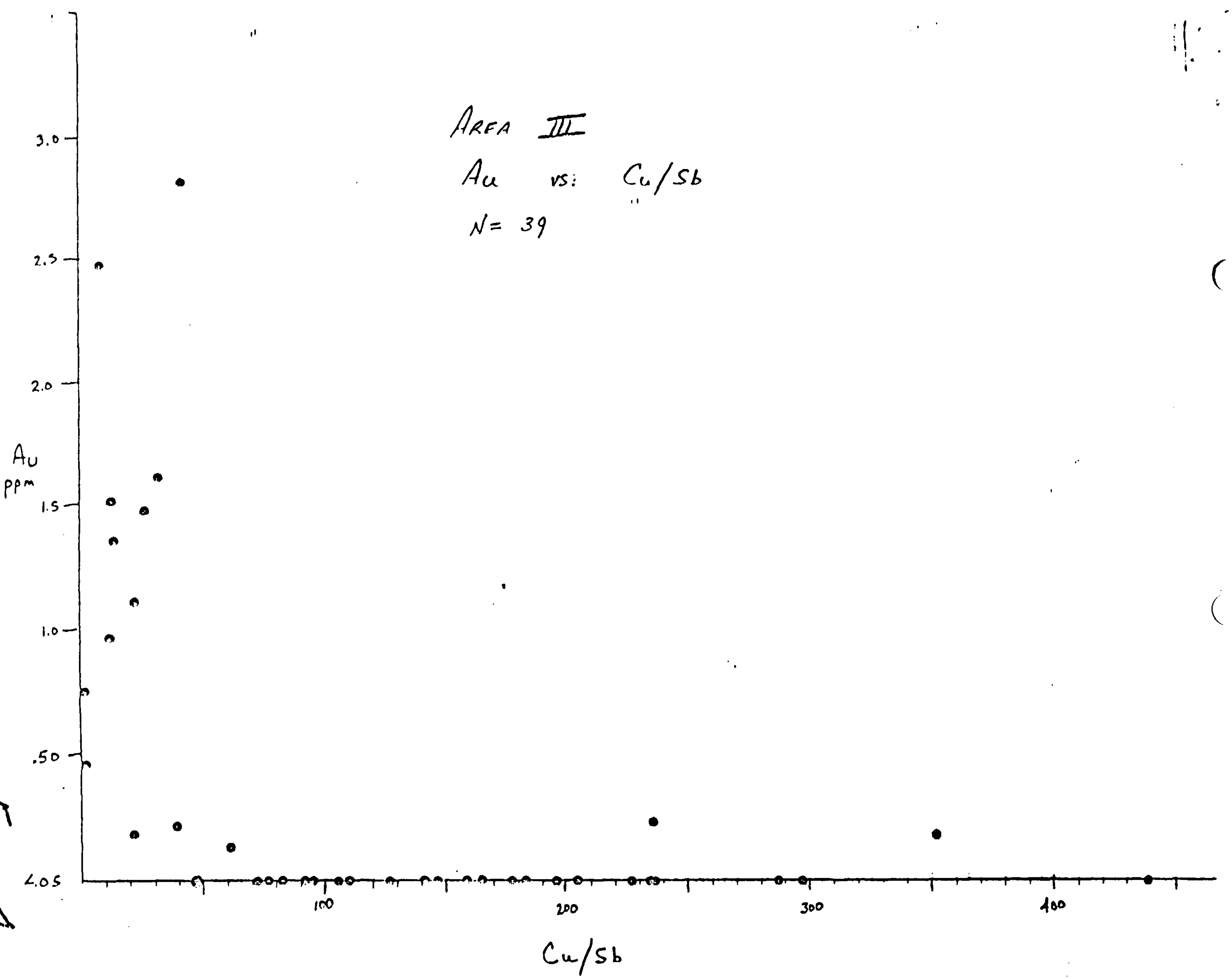

AREA III
Au vs: Cu/Sb
N= 39
Au
ppm
3.0
2.5
2.0
1.5
1.0
.50
<.05
100
200
300
400
Cu/Sb

Figure 4

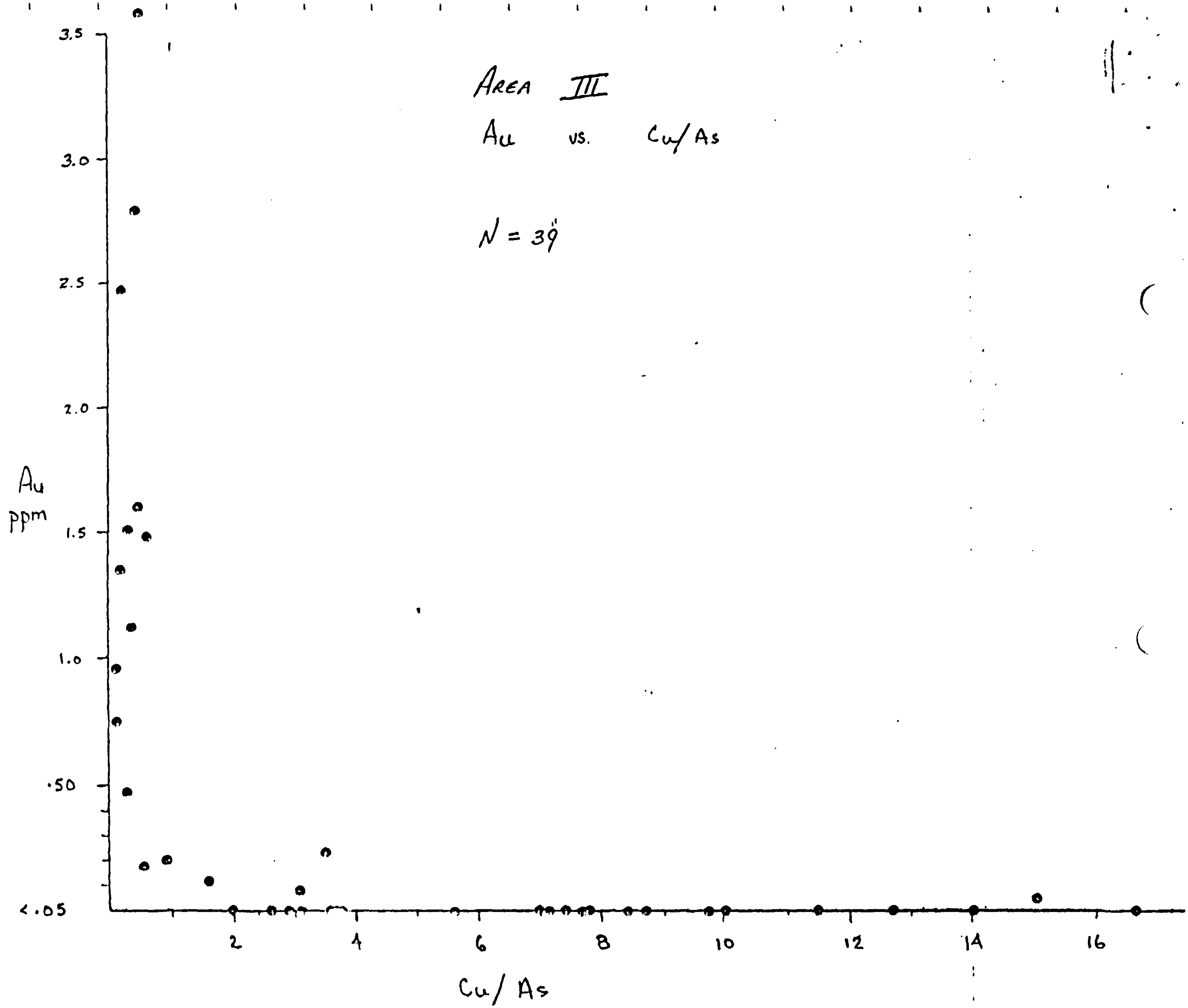

AREA III
Au vs. Cu/As
N = 39
Au ppm
3.5
3.0
2.5
2.0
1.5
1.0
.50
<.05
2
4
6
8
10
12
14
16
Cu/As

Figure 3

Antimony concentrations also appear to be distinctly different in the two zones. Most of the samples from the porphyry copper zone had no detectable antimony (-0.2 ppm) and the average concentration is .98 ppm. Most of the samples from Area III had detectable antimony and the average concentration is 3.8 ppm.

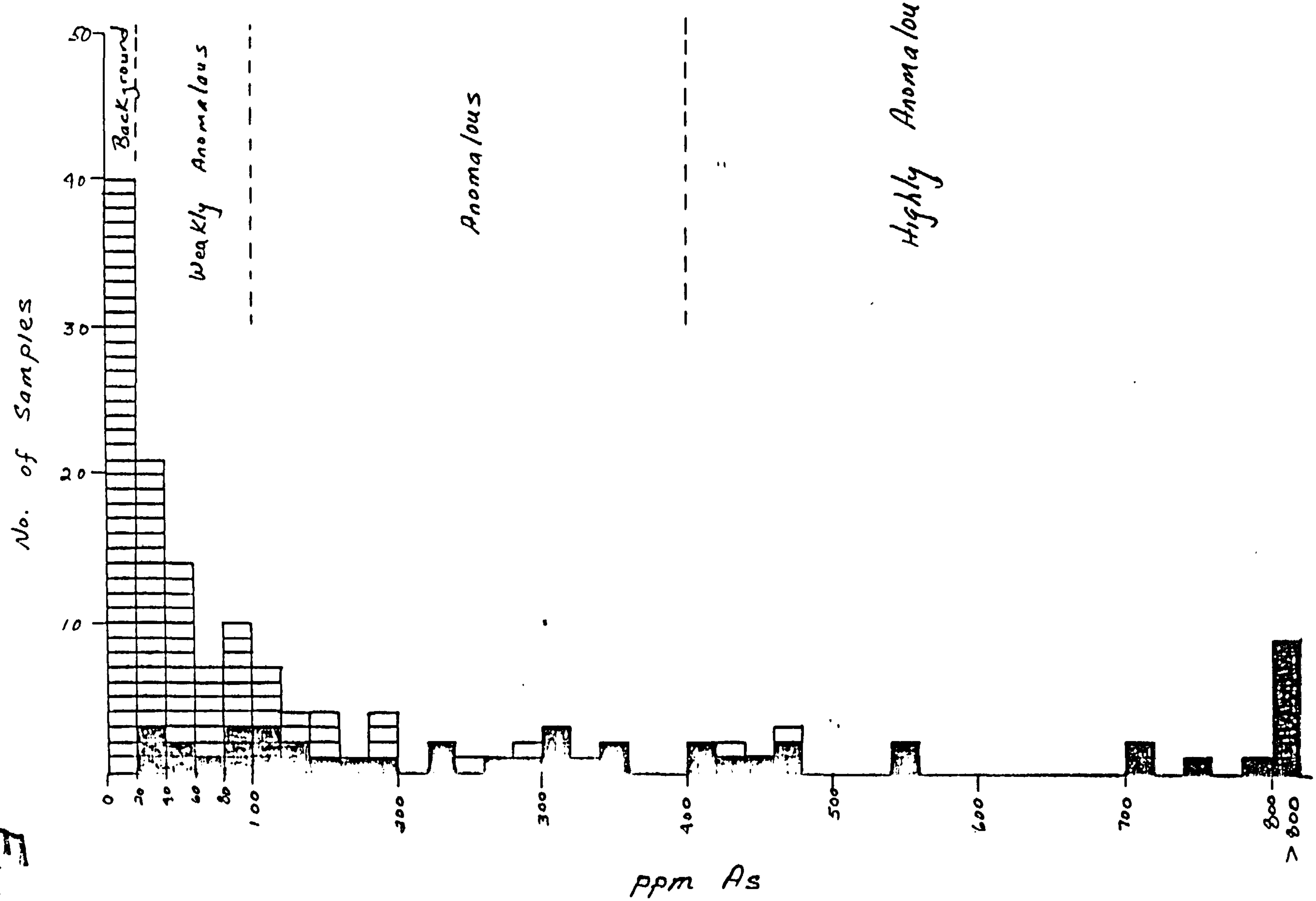
Molybdenum concentrations are also distinctly different in the two zones. The average Mo concentration in Area III is 5.6 ppm and in the porphyry copper zone is 36.7 ppm. Apparently the Mo was not leached as much as the Cu was from the leached capping.

An interesting feature of the Area III geochem is shown of figures 3 and 4, which plot the Cu/As and Cu/Sb ratios of individual samples as a funtion of gold concentration. Note the sample population is quite bimodal. With only two exceptions, samples with Cu/As ratios greater than 4 are totally devoid of gold. Likewise, with only 2 exceptions, samples with Cu/Sb greter than 75 are devoid of gold. This observation suggests that the Cu which occurs in Area III is in different samples than the Au, As, and Sb. Hence it appears that two stages of mineralization have affected differing volumes of rock within the zone. We suggest that the most likely candidate for the Cu mineralization is the Laramide porphyry copper system and that this event was overprinted by midTertiary Au-As-Sb mineralization Although Mo values in Area III are distinclty lower than in the porphyry Cu zone, it should be noted the better Mo values in Area III are mostly associated with the higher Cu values.

A control biogeochem survey has also been completed at Van Deemen in an effort to develop a tool for following the northeast-trending gold zones beneath gravel and volcanic cover. In the control study thirty-eight creosote samples were collected over known areas of gold mineralization, barren lower-plate gneisses, barren upper-plate basaltic andesites, and over pediment gravel cover. The samples were analyzed for seventeen elements. Of these elements, only arsenic and gold appear to be useful for exploration in the Van Deemen area. Anomalous concentrations of gold and arsenic resulted in a strong correlation over ore at Area II. In future biogechem exploration, +1.00 ppb gold values are considered weakly anomalous, and those with +1.50 ppb gold are anomalous. Also, samples with +0.6 ppm arsenic are considered weakly anomalous and those +1.0 ppm anomalous.

CONCLUSIONS

Gold mineralization at the Van Deemen occurs as elongate, notheast-trending tabular bodies within an extensive low-angle normal fault breccia zone. The gold-bearing zones are enveloped by an extensive body of alteration along Van Deemen Fault, which is often completely barren of gold. It would appear that when exploring this type of environment a "trendology" approach with careful attention to footwall feeders and conduits is an extremely important tool. Grid drilling the large sheet-like body of alteration at the Van Deemen on a wide spacing is not advisable due to the relatively small dimension of the gold zones perpendicular to their elongate axes. More



* Filled in box indicates sample also contained + 0.10 ppm Au

N = 147

F.L.H. - 1986

Figure 2

moderate supergene enrichment at the surface, another indication that much of the gold is probably native.

GEOCHEMISTRY

A suite of surface rock chip samples have been analyzed for eighteen elements. Of these elements, gold, arsenic, and tellurium seem to be the most significant as pathfinders. As illustrated in Figure 2, there is a strong correlation between gold and arsenic. Arsenic is sometimes present into the thousands of ppm, but is generally in the 100 ppm to 1,000 ppm range in the gold zones. The histogram shows that 71% of the rock chip samples carrying greater than 100 ppm arsenic were also highly anomalous in gold (+0.010 o/t). The correlation becomes even stronger at the +300 ppm level where 93% of the samples also contain highly anomalous to ore-grade gold. There is a similar correlation between tellurium and gold. Tellurium is locally as high as 166 ppm, but is generally in the 1 ppm to 10 ppm range and is often anomaolous in the gold zones.

Rock chip geochemistry was determined to be a useful tool in distinguishing the two episodes of hydrothermal alteration in the Van Deemen area. The Laramide porphyry-copper related alteration and mineralization is geochemically distinct from the mid-Tertiary extension related gold mineralization. Forty-two rock chip samples form the Area III gold resource were compared to 45 samples from the large zone of typical porphyry copper phyllic alteration leached capping one mile to the north. In compiling these data, samples which grossly skewed the average were deleted from the average values. The average Cu/As ratio for Area III is 6.3 whereas this ratio is 125 for the porphyry copper alteration. This ratio was calculated for each sample and then averaged. This ratio appears to be a very useful tool to differentiate the two systems. Most of this striking difference is due to much higher As concentrations in Area III (average of 190 ppm) than in the porphyry copper zone (average of 7.5 ppm). Copper concentrations themselves do not appear to be useful discriminators between the two systems. The average copper values are actually less in the porphyry copper zone than in Area III. This character is due to the porphyry zone being a leached capping and provides encouragement for finding a buried chalcocite blanket.

Another diagnostic feature is the percentage of samples with anomalous (+0.050 ppm) gold. At the Area III zone where there is an established resource, 43% of these initial samples had anomalous gold. The anomalous samples (18 of 42) themselves average 1.07 ppm gold (0.031 opt) which is surprisingly close to the grade of the contained resource. At the porphyry copper zone only 2 of the 45 samples (4.4%) had detectable gold. In fact, these two samples were from Tertiary gravel deposits with clasts eroded from the porphyry copper alteration. These two samples averaged .320 ppm gold (0.009 opt). None of the samples from the actual in-place leached capping had anomalous gold.

augen into bands that alternate with others composed of strained quartz grains, all greatly elongated in parallel. The feldspars are usually pulverized during this shearing process and subsequently replaced by dense sericite. The altered rock surrounding the tabular quartz-breccia bodies is often cut by comby quartz veins carrying considerable pyrite and arsenopyrite (?) that is usually fully oxidized. In general, where there is an increase in the amount of open, brittle brecciation and hematite and limonite there is also an increase in the old content.

The quartz-sericite-hematite-pyrite alteration is widespread along the Van Deemen Fault. The area of alteration is more extensive than the gold zones (+0.010 o/t gold). Drill holes north of Areas III and IV have shown a relatively thick package of altered rocks paralleling the low-angle normal fault, but the altered rocks carry only weak, spotty gold mineralization. Drill data available to date suggest that the northeast-trending gold zones are surrounded by a relatively large area of alteration that is mostly barren of gold. In other words, the gold zones seem to occur as elongate, tabular bodies trending northeast within a much more extensive body of alteration.

It is possible that hydrothermal fluids were being introduced into the low-angle fault zone by a wide variety of footwall conduits producing a broad, sheet-like zone of alteration. It is also possible that only the northeast-trending fault zones (accommodation zones ?) tapped a gold-bearing hydrothermal fluid source and acted as conduits carrying the precious metal into the favorable fault breccia host. Future exploration for gold mineralization at the Van Deemen will be concentrated on following out known gold zones to the northeast and southwest and identifying new gold trends.

The gold-related alteration and mineralization at the Van Deemen locally overprints zones of porphyry copper alteration as described by Wilkins (1984). In some instances it is difficult to discern one from the other or to which event a particular zone of alteration is related. In general, the porphyry alteration exhibits a phyllic alteration assemblage (quartz-sericite-pyrite), but usually lacks the hypogene earthy hematite, minor clays, and brecciation that is present in the mid-Tertiary (?) alteration. It has been suggested Van Deemen Fault zone might have simply overprinted a portion of a failed, gold-bearing porphyry copper system. However, the close spatial association of gold mineralization with the mid-Tertiary low-angle normal fault, combined with thin section work showing much of the mineralization introduced after brittle, open-style brecciation, suggests that the gold was introduced during the mid-Tertiary event, and not with the Laramide porphyry event.

No ore microscopy work has been completed to date on the gold-bearing rocks at Van Deemen, so it remains an unknown as to how and where the gold occurs. Preliminary cyanide leach tests do indicate, however, that a good percentage of the gold is free and probably quite fine. In addition, the combination of detailed surface sampling and close-spaced drilling has indicated a weak to

VAN DEEMEN PROJECT

DRILL-INDICATED GOLD RESERVES

AREA	PROVEN			PROBABLE			POSSIBLE			WASTE
	TONS	GRADE	OZ.	TONS	GRADE	OZ.	TONS	GRADE	OZ.	
II-A	65,218	.045	2946							171,370
II-B				*23,300	.055	1281				2,000
III	131,429	.033	4378	241,666	.036	8783	126,332	.035	4441	1,697,763
IV	73,507	.031	2242	200,721	.030	6041	129,569	.031	3999	1,007,502
TOTAL	270,154	.035	9566	465,687	.035	16,105	252,901	.033	8440	2,878,635
			28%			47%			25%	

Total tons all categories: 988,742

Average Grade: .034 O/T'Au
Total oz Au: 34,111
Total Waste: 2,878,635
Strip Ratio: 2.9:1

* (Estimate by Hillemeyer and Stevenson, 1986)

Of the total reserve 83,173 tons are sulfide ore.

Figure 5

closely-spaced drill holes along widely-spaced fences across favorable trends appears to be the most logical approach.

ACKNOWLEDGEMENTS

This portion of the field trip would not be possible without the gracious consent of Fischer-Watt Gold Co., Inc. and Arizona Star Resource Corp. to visit the property and review the data generated. The authors wish to thank these two companies for their willingness to open and reveal their findings to the exploration community. The authors also acknowledge the tremendous work currently under way in the area around Van Deemen by Mr. Jim Faulds, a doctoral candidate at the University of New Mexico in Albuquerque. Jim has offered great insight into the geology of the area and we are confident that by the time his dissertation is complete, many questions will be answered. The thin section analyses of Mr. Sidney William of Globo de Plomo Eterprises is also gratefully acknowledged.

REFERENCES CITED

Anderson, R. E., 1971, Thin skin distension in Tertiary rocks of southeastern Nevada: Geological Society of America Bulletin, v. 82, p. 273-288.

Anderson, R. E., 1977, Geologic map of the Boulder City 15-minute quadrangle, Clark County, Nevada: U.S. Geological Survey Geologic Quadrangle Map, GQ-1395.

Anderson, R. E., 1978, Geologic map of the Black Canyon City 15-minute quadrangle, Mohave County, Arizona, and Clark County, Nevada: U.S. Geological Survey Geologic Quadrangle Map, GQ-1394.

Anderson, R. E., Longwell, C. R., Armstrong, R. L., and Marvin, R. F., 1972, Significance of K-Ar ages of Tertiary rocks from the Lake Mead region, Nevada-Arizona: Geological Society of America Bulletin, v. 83, p. 273-288.

Davis, G. A., Anderson, J. L., Frost, E. G., and Shackelford, T. J., 1980, Mylonitization and detachment faulting in the Whipple-Buckskin-Rawhide Mountains terrane, southeastern California and western Arizona, in Crittenden, M. D., Jr., Coney, P. J., and Davis, G. H., eds., Cordilleran Metamorphic Core Complexes: Geological Society of America Memoir 153, p. 79-129.

Faulds, J. E. and Geissman, J. W., 1986, Paleomagnetic evidence of tilted basement, central parto of the Black Mountains, northwest Arizona, EOS, Fall, 1986.

Faulds, J. E., Mawer, C. K, and Geissman, J. W., 1988, Geometry and kinematics of a major accommodation zone in the highly extended upper-plate rocks of the northern Colorado River Trough, Arizona and Nevada: Geological Society of America Abstracts with Programs, v. 20, in press.

Longwell, C. R., 1963, Reconnaissance geology between Lake Mead and Davis Dam, Arizona-Nevada: U.S. Geological Survey Professional Paper 374-E, 51 p.

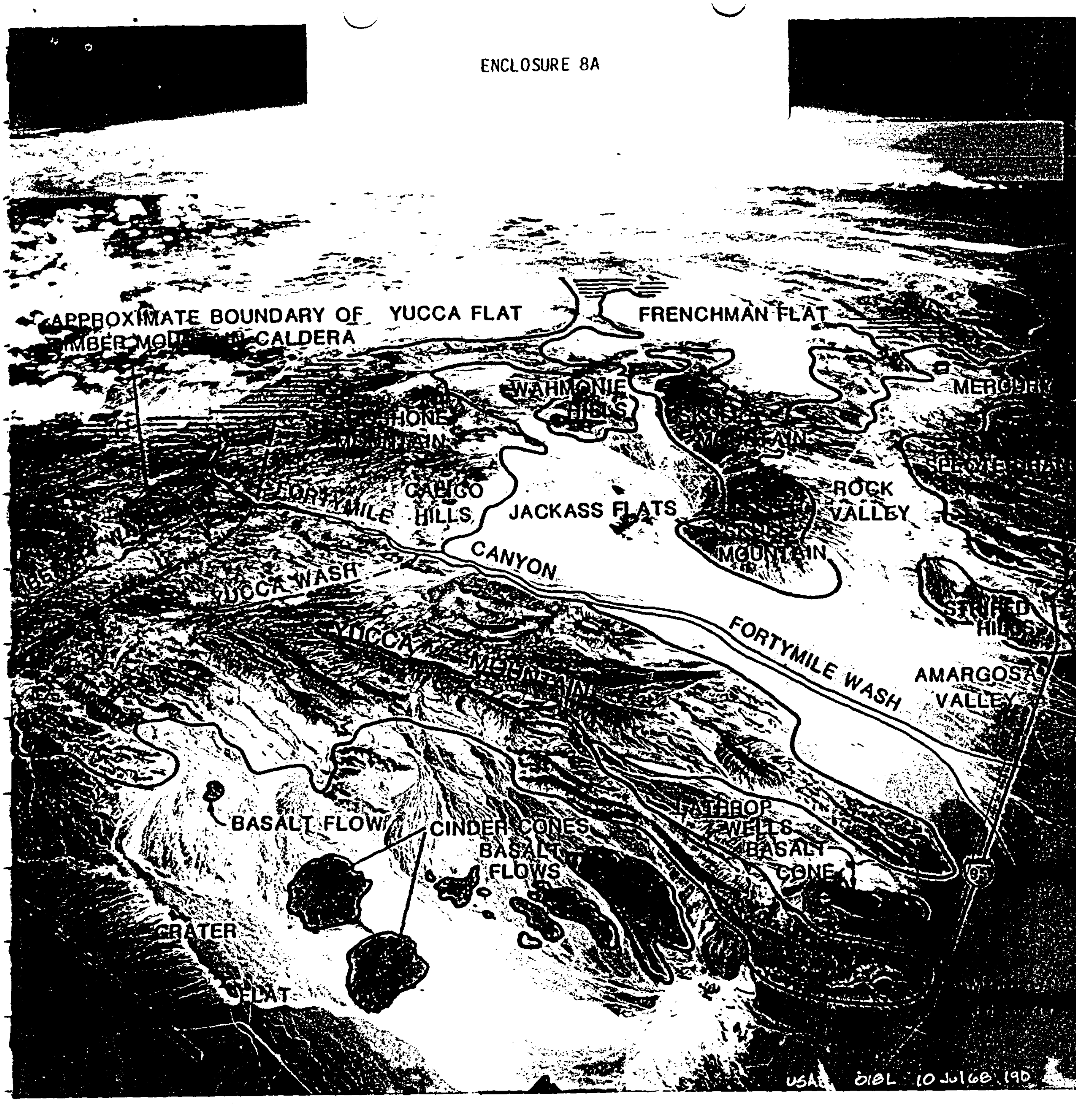
Mathis, R. S., 1982, Mid-Tertiary detachment faulting in the southeastern Newberry Mountains, Clark County, Nevada, in Frost, E. G. and Martin, D. L., eds., Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada: San Diego, California, Cordilleran Publishers, p. 326-340.

Proffett, J. M., Jr., 1977, Cenozoic geology of the Yerington district, Nevada, and implications for the nature and origin of Basin and Range faulting: Geological Society of America Bulletin, v. 88, p. 247-266.

Reynolds, S. R., and Spencer, J. E., 1985, Evidence for large-scale transport on the Bullard detachment fault, west-central Arizona: Geology, v. 13, p. 353-356.

Wilkins, J., Jr., 1984, Stratigraphic and tectonic setting of the north-central Black Mountains and Detrital Valley, Mohave County, Arizona, in Arizona Geological Society 1984 Fall Field Trip Guide - Structure and Mineralization, Kingman Area, Arizona, Wolfhard, M. R., ed., p. 67-75.

ENCLOSURE 8A



YUCCA MOUNTAIN REGION
GEOGRAPHIC FEATURES

ENCLOSURE 8B

U.S. AIR FORCE/USGS OBLIQUE
HIGH ALTITUDE AERIAL PHOTOGRAPH
10 JULY 1968

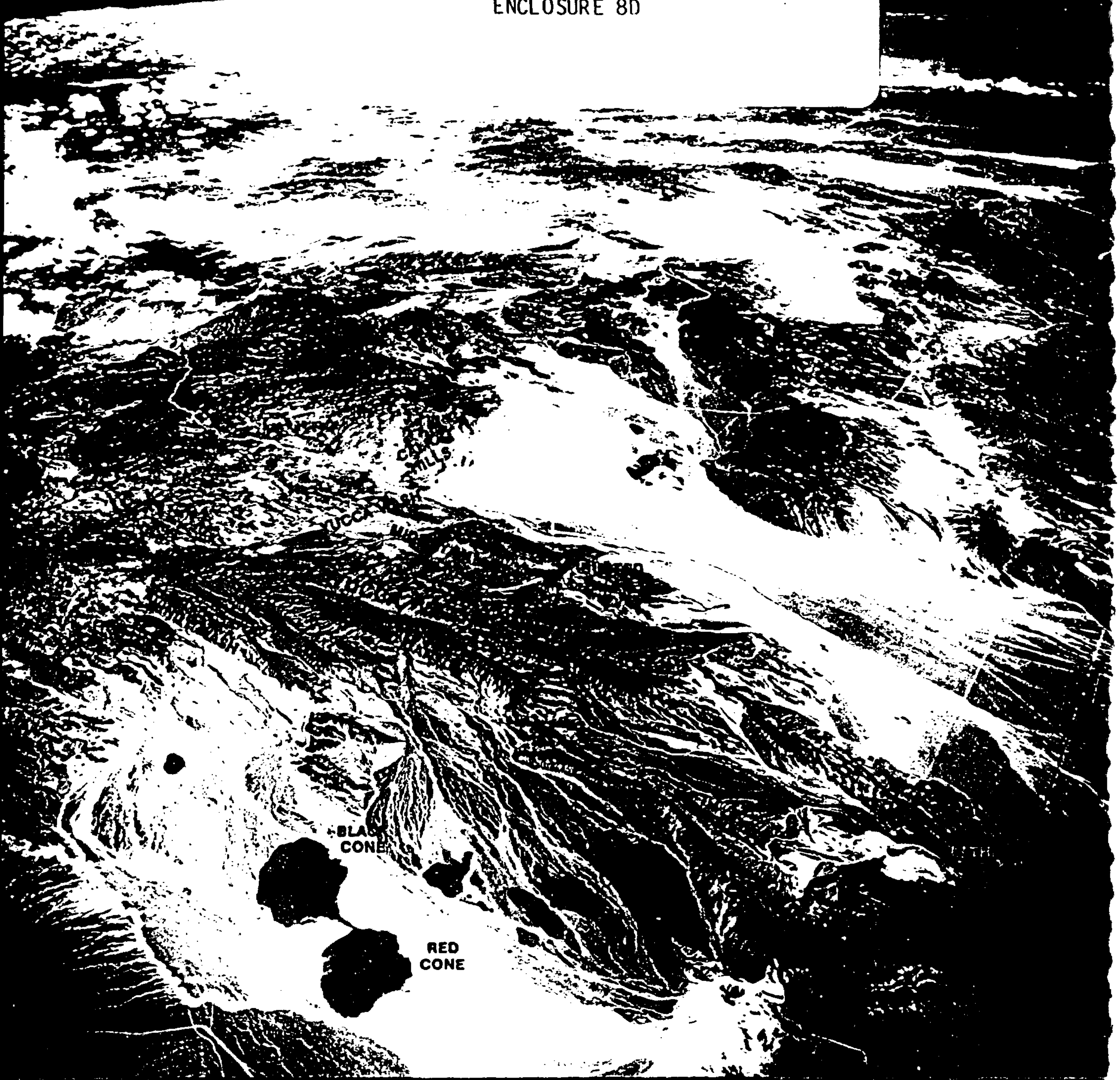
YUCCA MOUNTAIN REGION
GEOLOGIC FEATURES

ENCLOSURE 8C

U.S. AIR FORCE/USGS OBLIQUE
HIGH ALTITUDE AERIAL PHOTOGRAPH
10 JULY 1968

YUCCA MOUNTAIN REGION
TOPOGRAPHIC FEATURES

ENCLOSURE 8D



U.S. AIR FORCE/USGS OBLIQUE
HIGH ALTITUDE AERIAL PHOTOGRAPH
10 JULY 1968

CORDILLERAN SECTION GSA FIELD TRIP NEVADA TEST SITE YUCCA MOUNTAIN
APRIL 1, 1988

U.S. GEOLOGICAL SURVEY WATER RESOURCES DIVISION
NUCLEAR HYDROLOGY PROGRAM

CHARACTERIZATION OF PERCOLATION IN THE UNSATURATED ZONE SURFACE-BASED BOREHOLE INVESTIGATIONS

PURPOSE AND SCOPE

The unsaturated zone at Yucca Mountain, Nevada consists of a gently-dipping sequence of fine-grained ash-flow tuffs, mostly welded and fractured, with some ash-flow and ash-fall, nonwelded, sparsely fractured tuffs that are vitric in some parts and zeolitized in others. The unique attribute of the Yucca Mountain site is that the welded and nonwelded tuffs comprising and immediately surrounding the proposed high level radioactive waste repository are unsaturated. The water table lies some 500 to 750 meters (1,640 to 2,460 feet) below the ground surface and some 230 meters (750 feet) below the level of the proposed repository. The concept of waste disposal in a well drained, unsaturated environment has great appeal where water will not have ready access to the waste package after repository closure.

The purpose of this investigation is to support, though active in-situ testing and passive in-situ monitoring, determination of present day flux (percolation) in the unsaturated zone at Yucca Mountain. Two objectives are the primary focus of this investigation: (1) definition of the potential field within the unsaturated zone, and (2) determination of the in-situ bulk permeability and bulk hydrologic properties of the unsaturated media.

The definition and spatial distribution of the physical and hydrogeologic properties of the different flow media along with their associated potential fields is the subject of much of the testing in this investigation. Unsaturated zone system analysis and integration studies needed to develop a final model of the unsaturated zone will depend upon these data as well as data collected under other activities to characterize percolation.

This investigation is confined to that area of Yucca Mountain immediately overlying and adjacent to the boundaries of the proposed repository block. Vertically the study area extends from the near surface of Yucca Mountain to the underlying water table. This study involves dry drilling and coring of 17 vertical boreholes ranging in depth from 60 to 760 meters (200 to 2,500 feet) for a total of 5,650 meters (18,500 feet). An eighteenth borehole drilled with air may be required to support the vertical seismic profiling investigation. One horizontal borehole, drilled dry and cored, is also planned in Solitario Canyon. This borehole is estimated to be about 300 meter (1,000 feet) in length. Some of the vertical boreholes have already been drilled.

In-situ pneumatic testing of fifteen boreholes is planned. Gas diffusion studies are to be done at two borehole cluster sites. A vertical seismic profiling investigation is planned for the middle section of Yucca Mountain. Downhole instrumentation and monitoring of ambient potential within all boreholes is scheduled for a period of three to five years. Following this monitoring, downhole hydraulic (water injection) testing is planned within sixteen boreholes.

RATIONAL FOR THE STUDY

In an infinite, homogeneous isotropic system under steady state conditions, flux can be determined from a single realization of the potential gradient and the conductive properties of the media. Under these ideal conditions, flux can be estimated with almost absolute precision from a single application of a one-dimensional formulation of the D'Arcy flow equation. Since these ideal conditions are not present at the scale of the Yucca Mountain site investigation, no single realization will suffice to adequately characterize flux in the unsaturated zone. Flux must be evaluated within a time dependent, three dimensional anisotropic and heterogeneous setting.

It is proposed in this scientific investigation to evaluate the in-situ distribution of potential energy and the pneumatic and hydraulic properties of the conducting media. These parameters are needed for the evaluation of flux and flux distribution. These parameters will be determined from in-situ borehole testing and monitoring.

STEMMING AND IN-SITU INSTRUMENTATION

Instruments designed to measure and monitor the various components of the total fluid (liquid, gas, vapor) potential field in the unsaturated zone will be installed in each of the boreholes. The objective of in-situ instrumentation is to define the present-day potential energy field that controls the rate and direction of the multiphase fluid flow in the unsaturated rocks at Yucca Mountain. Definition of the potential field will not be accomplished exclusively from in-situ instrumentation, but this will also be done in other investigations such as matrix hydrologic properties testing, geophysical logging, and physical-rock properties testing.

The types of instruments that will be installed in each borehole include but are not limited to the following: (1) thermocouple psychrometers to measure water potential (combined matric and osmotic potentials); (2) heat dissipation probes to measure matric potential; (3) pressure transducers to measure pneumatic potential; and (4) thermal sensors to measure downhole temperatures. In addition, selected instrument stations in each borehole will be provided with access tubing to permit vacuum recovery of in-situ pore gases and water vapor for chemical and hydrological analyses.

Individual instrument stations will need to be isolated from each other. Based on the results of prototype tests, either bentonite, cement grout, silica flour, epoxy or some other type of filler and sealing materials that are compatible with both the hydrogeologic and hydrochemical applications of in-situ monitoring, included the possible use of inflatable packers, will be used to isolate downhole instrument stations. Isolation of the instrument stations is required in order to obtain potential measurements averaged over discrete intervals that are defined in space.

The spacing, number, and locations of individual instrument stations and the types of instruments to be employed at each station within a borehole will be determined from results of geophysical and geologic logging, fracture mapping, air permeability testing, matrix hydrologic properties testing, physical rock-properties testing, and measurements of naturally occuring gaseous-phase flow induced by borehole construction. Siting criteria are dictated by the need to provide sufficient detail to measure average values and yet characterize the effects of abrupt lithologic discontinuities and fracturing on ambient potentials.

ENCLOSURE 10

MONITORING HYDROLOGIC CONDITIONS IN THE VADOSE ZONE IN FRACTURED ROCKS, YUCCA MOUNTAIN, NEVADA

Parviz Montazer

U. S. Geological Survey, Denver, Colorado

Abstract. A 44.5-centimeter-diameter experimental borehole was drilled by a reverse-air vacuum-drilling technique to a depth of 387 meters to monitor hydrologic conditions in the vadose zone at Yucca Mountain, Nevada. This borehole was instrumented at 33 depth levels. At 15 of the levels, three well screens were embedded in coarse-sand columns. The sand columns were isolated from each other by thin layers of bentonite, columns of silica flour, and isolation plugs, consisting of expansive cement. Thermocouple psychrometers and pressure transducers were installed within the screens. Two of the screens at each level were equipped with access tubes to allow collection of pore-gas samples. At the remaining 18 depth levels heat-dissipation probes were installed within the columns of silica flour. Thermocouple psychrometers were installed together with the heat-dissipation probes at selected depth levels. After more than 2 years of monitoring, the majority of the instruments were still functioning and appeared to be producing reasonable data. A slow recovery from the disturbed state toward natural conditions was detected during the first 90 days of monitoring probably because of the large diameter of the borehole. The effect of the materials in the borehole was simulated to understand the physical phenomena that control the response of the instruments. Flow of water in an axisymetric section of the welded tuff, 100 meters in radius and 20 meters thick, was modeled with the borehole at the center. Results indicated that, after 25 days, the moisture conditions in the fracture are disturbed most severely (compared to the welded tuff matrix) by the porous material in the borehole; this disturbance may extend as far as several tens of meters away from the borehole. From this simulation and from monitoring the instruments in the borehole, the conclusion was made that the placement of material in boreholes drilled in fractured rocks could disturb the natural system severely. These results also indicate that in-situ matric potential may be monitored most effectively by psychrometric methods in empty cavities isolated in boreholes without emplacement of porous materials.

Introduction

Mechanisms of fluid flow through thick unsaturated zones consisting of heterogeneous fractured rocks are not well understood in part due to the difficulty in studying this complicated system at depth. New techniques are required in addition those established to monitor shallow unsaturated soils. Comprehensive understanding of the flow through such rocks in natural state requires: (1) Laboratory investigations, consisting of both fracture and matrix flow tests; (2) ground-surface infiltration experiments and natural infiltration monitoring; (3) borehole hydraulic and pneumatic testing; (4) in-situ intrumentation and long term monitoring of deep boreholes; (5) large-scale, in-situ hydraulic and pneumatic testing; and (6) hydrochemical characterization. All such investigations are hampered by the problems that result from the lack of established instrumentation techniques for these rocks. The purpose of this paper is to highlight some of the problems that exist with instrumentation and monitoring of the fractured rocks, and to describe a field example of borehole instrumentation and a numerical simulation.

Hydrologic instrumentation and monitoring of unsaturated fractured tuff in deep boreholes have not been attempted previously and testing of unsaturated fractured tuff have been hampered by the difficulties inherent in installation of equipment and interpretation of the results. Evans [1983] reviewed state-of-the-art instrumentation technology applicable to monitoring these types of rocks. Montazer [1982] discussed the problems associated with testing unsaturated fractured metamorphic rocks. Although, many investigators have begun research on characterization of unsaturated fractured tuff in the past few years, the author is unaware of other attempts to install instruments in unsaturated fractured rocks in deep boreholes.

This investigation is one of many being conducted be the U.S. Geological Survey, at Yucca

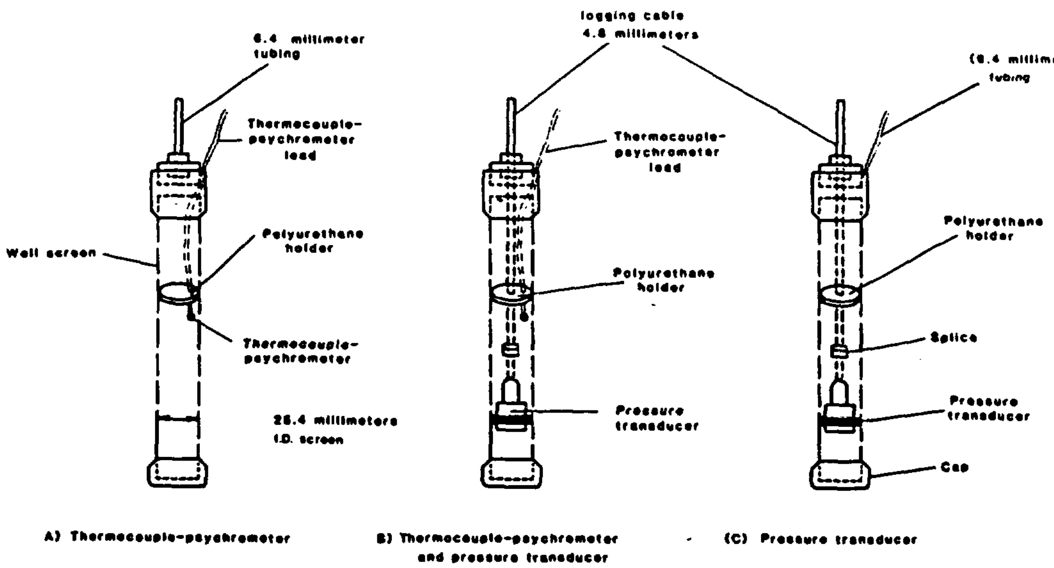


Fig. 1. Schematic diagrams of the well screens and the types of instruments installed in screens A, B, and C, test borehole USW UZ-1.

designated A, B, and C from top to bottom (with a few exceptions). The top well screen (A) contained a TP and was connected to the land surface by an access tube for gas sampling. The middle well screen (B) housed a TP and a pressure transducer. The bottom well screen (C) contained a pressure transducer and was connected to an access tube for gas sampling, and for checking calibration and proper functioning of the pressure transducer.

In addition to these IS, 18 different depths were selected for installation of HDP; TP also were installed at 5 of these depths. These HDP were designated as HDP-A or HDP-B depending on whether they were located above (HDP-A) or below (HDP-B) the nearby IS. The TP associated with these HDP were designated as HDP-TP.

Assembly and Installation of the Instruments

Prior to installation, the sensors were calibrated with cable lengths cut for the predesignated depths of installation in the borehole. After calibration, all cables with attached sensors were laid out, and instruments were inserted into the well screens and secured. The HDP ceramic tips were protected with fabric bags filled with saturated silica flour, but the bags were not placed in the well screens. The well screens and the HDP were adjusted, so that they would be located in predesignated-depth intervals. The entire assembly was transported to the test-borehole site as a bundle.

To emplace the filler material in the borehole, two tremie pipes were lowered into the borehole prior to installation of the bundle. After tremie-pipe installation, a television camera was lowered into the borehole to inspect it for obstructions. The bundle then was lowered into the borehole, attached to a 6.0-cm outside-diameter fiberglass access tube for geophysical logging. The wires and tubing of this assembly were encased in polyurethane-foam isolation plugs to prevent gas flow between instrument stations along the wires. The isolation plugs were situated so that they would be surrounded by grout during stemming. Standoffs also were installed on the fiberglass tube near each IS to prevent damage to the instruments by collision with the borehole wall during installation. The use of the polyurethane foam contaminated the borehole air with fluorocarbons and, therefore, eliminated the possibility of sampling for formation fluorocarbons.

Stemming Procedures

After the assembly was lowered into the borehole, dry materials (silica flour, sand, and bentonite) were poured through one tremie pipe, and wet materials (cement and water) were poured through the other tremie pipe to stem the hole. Final configuration of the stemmed borehole and the location of the IS and HDP are shown in figure 2. Actual location of the sensors and the contacts between different materials were determined by geophysical logs obtained inside the fiberglass tube.

Silica flour was selected as the filler material, instead of the crushed tuff that was produced during drilling, because of its uniformity, and therefore, predictability. The HDP were embedded in the silica flour. The silica flour used to stem the HDP at IS located in nonwelded and bedded tuff units was wetted, prior to installation, to a

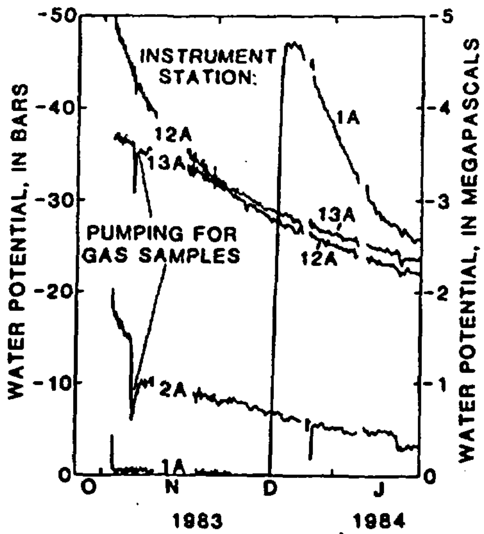


Fig. 4. Variations of water potential with time in test borehole USW UZ-1 as measured with thermocouple psychrometers installed in instrument stations.

around these probes than elsewhere in the silica-flour column either because of the added water and (or) the wet silica flour in the protecting porous fabric bag. The matric-potential measurements rapidly decreased as this water dissipated into the silica flour and possibly into the formation. Data for HDP-3A had a different trend. However, the calibration curve for the indicated range for the HDP was based on linear extrapolation from the -5-bar range, and the absolute values may not be reliable for matric potentials less than -5 bars. Examples of variation of the water potential with time measured by the TP are shown in figure 4. In this case, the water potentials initially were small; they rapidly increased during the first 90 d; then they increased more slowly. The TP were stemmed within initially dry screened sand. The unsaturated hydraulic conductivity of this sand was negligible at the presumed ambient-moisture tension in the surrounding medium. Consequently, vapor diffusion into the sand and subsequent sorption on the sand grains probably was the dominant transport process by which the moisture content of the sand backfill equilibrated with that in the formation. The rate at which this process progressed decreased exponentially with time. Three downward spikes in water potential measured by TP in IS 2A, 12A, and 13A occurred on November 8, 1983 (fig. 4). These increases in the water potentials occurred during pumping for gas samples; they probably resulted from the flow of nearly vapor-saturated air through the sand column. This vapor-saturated air increased the humidity around the TP. However, soon after pumping stopped, the normal trend resumed, as vapor condensed on the drier sand without materially changing its matric potential or diffused into the surrounding dryer sand. *This phenomenon probably indicated that, under transient conditions, advection of nearly-saturated air could occur through a relatively dry medium without equilibrating with that medium.* Another explanation for these spikes could be the flow of water droplets onto the material surrounding the TP. These droplets could have formed during pumping a warmer downhole air through a nylon tubing that was in equilibrium with geothermal gradient before pumping started. As the vapor-saturated air moved along the tube, a supersaturation temperature was attained in the tube and condensation occured. The condensate flowed along the tube wall until it fell on the material surrounding the TP. This latter explanation is unlikely because: (1) The responses to the pumping were almost immediate (within an hour); 2) both the wetting and drying cycles were indicated by relatively smooth curves that would not be expected in case of sudden and irregular fall of droplets; and 3) recent simultaneous pumping of IS-3A and IS-3C caused similar downward spike in water-potential trend of the TP in the IS-3B to which no tube is connected.

IS-1A initially measured large water potentials from October to December 1983 (fig. 4). In December 1983, this TP began measuring much smaller water potentials. This sudden reversal probably is the result of a single-point measurement technique, as discussed by Thamir and McBride [1985].

Temperature

Temperature records at various IS from November 1983 to April 1984 indicated that temperatures of the IS had nearly equilibrated with temperatures in the adjacent formation by mid-November. However, the temperatures at IS-1, IS-2, IS-3, and IS-4 indicated some variations with time. No seasonal changes would be anticipated at the depths of IS-3 and IS-4; the cause of variation was unknown. In addition, the temperature data for IS-1, IS-4, IS-7, and IS-8 indicate departures from the normal trend; the cause of these variations is not known at this time.

Pneumatic Potential

Data from the downhole-pressure transducers are shown in figure 5 for February 25-27, 1984. Diurnal-pressure changes occurred at most of the IS shown in this figure in response to more pronounced barometric changes at land surface. At greater depths, pressure responses to diurnal barometric fluctuations were damped out; however, long-term fluctuations (not shown) occurred.

These long-term fluctuations are characterized by broad lows and highs and do not seem to be directly correlated with the seasonal temperature changes. Rather, they reflect long term weather patterns with one to two month durations. The zero offset was shifted from that obtained during calibration, so that the positions of various

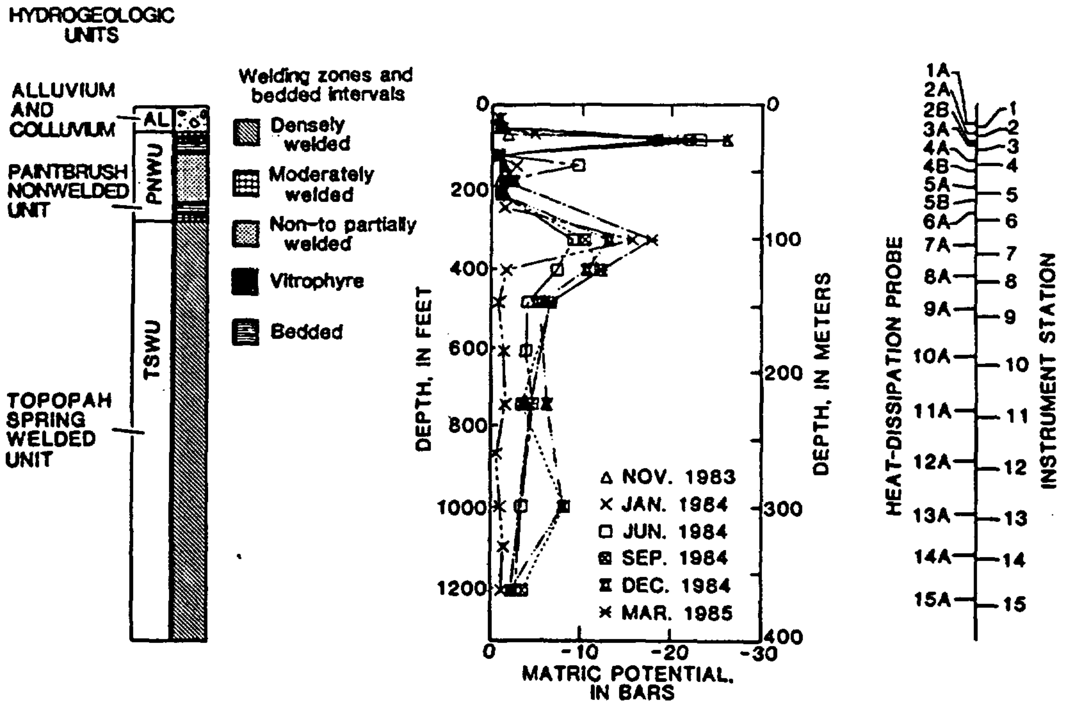


Fig. 7. Matric potential in test borehole USW UZ-1 based on data from heat-dissipation probes.

results of the HDP adjacent to alluvium and non-welded tuff probably represent the formation conditions. Deeper HDP probably are still in a non-equilibrium condition. It should be noted that these data are very noisy and these conclusions are reached on the basis of averaged and filtered data.

Variation of water potentials with depth, measured using TP in the A-screens, are shown for various times in figure 8. Initially, all TP except three showed expected trends of dry-to-wet conditions. These three TP (IS-3A, IS-6A, and IS-15A) fluctuated without any trend. IS-15A was located near the bottom of the borehole; the other two (IS-3A and IS-6A) were in bedded tuff in the upper part of the borehole. The TP in the two intervening stations (IS-4A and IS-5A) indicated trends similar to those of the majority of the TP. Individual measurements for the HDP -3A, -13A, and -15A and the three anomalous instrument stations and for IS-5 are compared in figures 9 and 10. For IS-3A and IS-6A, early measurements may have represented very dry, rather than very wet, conditions. This situation was possible because measurements by the TP could represent either very dry or very wet conditions equally well, as a result of measurement and calibration methods [Thamir and McBride, 1985]. If early data for IS-3A and IS-6a are interpreted as wetting trend (flipping the first one-third of the curves in figure 9 about -40 and -20 bars for IS-3A and IS-6A respectively), the trends would be similar to that of the IS-5A, from dry to wet.

Inspection of the long-term trends (not shown) indicated that a majority of the TP have stabilized and attained some mean value. Slight deviation from this mean valu+e occurred for some TP. Some deviations of the TP measurements (IS-1A, IS-2A, IS-14A, and IS-15A) consistently indicated gradual drying conditions; at other stations (IS-6A, IS-7A, IS-10A, and IS-13A), deviations of the TP measurements consistently indicated wetting conditions.

Trends for IS-14A and IS-15A (fig. 8) reflected the effects of a 15-m column of cement that was poured to plug the bottom part of the test borehole [Whitfield, 1985]. The recent tendency toward drying conditions probably indicated that, the formation was drier than the fill material at this depth. IS-1A and IS-2A also were affected by the water that was used to drill the first 17.7 m of the borehole [Whitfield, 1985]. The tendency toward drier conditions probably was indicative of the fact that conditions were dryer in the formation relative to the fill material. IS-3A, at a depth of 25.3 m, probably was not yet affected by this drilling water (figs. 8 and 10).

TP measurements probably are more reliable below depths of about 61 m because of the drier state of the formations below this depth. In addition, the TP in the A screen pumped several times for gas samples; therefore, they were more

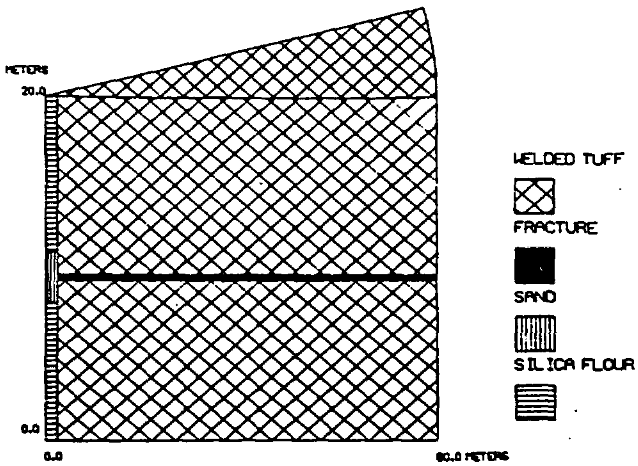


Fig. 11. A slice of the region simulated, 20 meters thick and 100 meters in radius; horizontal fracture is 0.3 meter thick.

problem (fig. 11). Flow through a 20-m thick section of the welded tuff with a 0.3-m thick horizontal fracture zone in the middle and a borehole along the center of a 100-m radius cylinder was simulated using the UNSAT2 code [Neuman, 1973]. The borehole is filled with silica flour except for the middle 3-m, which is filled with medium to coarse washed sand. The characteristic unsaturated properties of these materials are shown in figure 12. Properties of the welded tuff were from laboratory measurements. The material properties of the sand were from Davis and Newman [1983] and properties of the silica flour properties were provided by D.P. Hammermeister (U. S. Geological Survey, written commun. 1984): The fracture properties were estimated using the method described by Montazer and Harrold [1985].

A 0.5 mm/yr flux was applied to the upper surface of the model to simulate the perceived in-situ conditions and to prevent gravity from draining the model. Initially, the welded tuff was set at -20 m of pressure head, and the borehole materials were set at -100 m of pressure head.

Results of this simulation are summarized in figures 13 and 14. The pressure history at various locations within the model is shown in figure 13. The center of the sand column becomes wetter after about 1 d; however, after about 10 d, the sand begins to dry again. A point in the fracture, 3m away from the borehole wall begins to dry rapidly and approaches the same matric potential as that of the sand column. The fracture at a point 50 m away from the borehole wall also has been affected in the same manner, but with a smaller magnitude. The silica flour, in the center of the borehole, remains almost unaffected, with a slight wetting trend.

This phenomenon can be explained by the fact that the fracture has substantial saturated permeability, and drains rapidly because of the steep potential gradient towards the borehole. However, the storage in the fracture is so small compared to that in the sand column that the effect in the fracture is sensed 50 m away, but the sand column is disturbed only slightly. The later drying trend in the sand column is the result of the gradient toward the silica-flour column. The conditions simulated here are not as severe as those that existed onsite in the actual field conditions because the dry silica flour and sand could have had pressure heads much lower than 1000 m when they were placed in the borehole. One way to minimize this disturbance would be by wetting the stemming material so that the matric potentials in the stemming material and the formation are almost identical. However, precisely predicting the matric potential of the formation usually is difficult. Nevertheless, slightly wetter conditions of the stemming material could change the matric potential in the fracture substantially for long distances away from the borehole for relatively long times. These problems possibly could be avoided by not using stemming

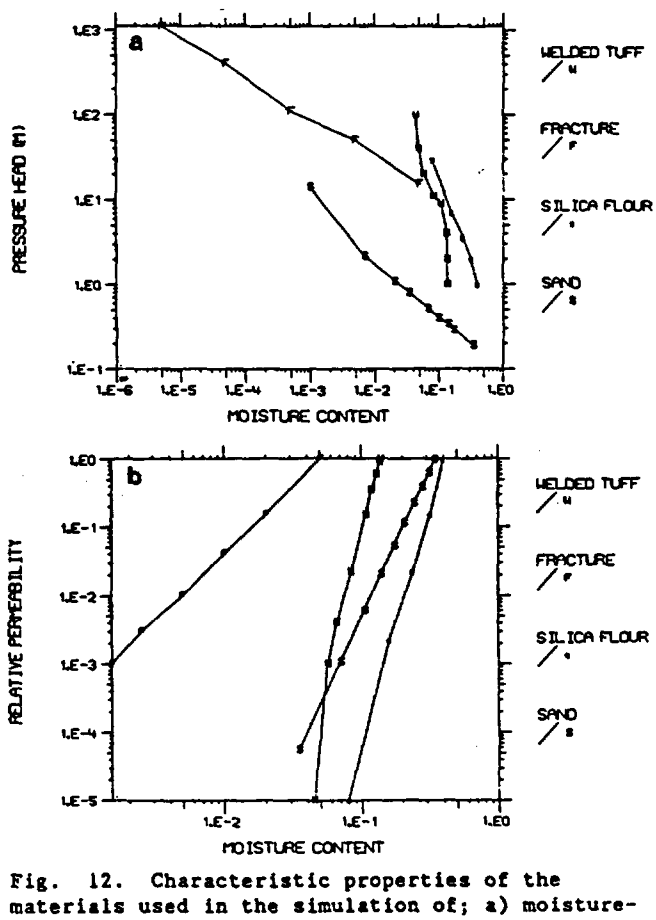


Fig. 12. Characteristic properties of the materials used in the simulation of; a) moisture-characteristic curves; and b) relative permeability versus moisture content. Values of saturated hydraulic conductivity, in meters per day, were: welded tuff, 0.3×10^{-3}; fracture, 1.0; silica flour, 1.0×10^{-2}; and sand, 5.5.

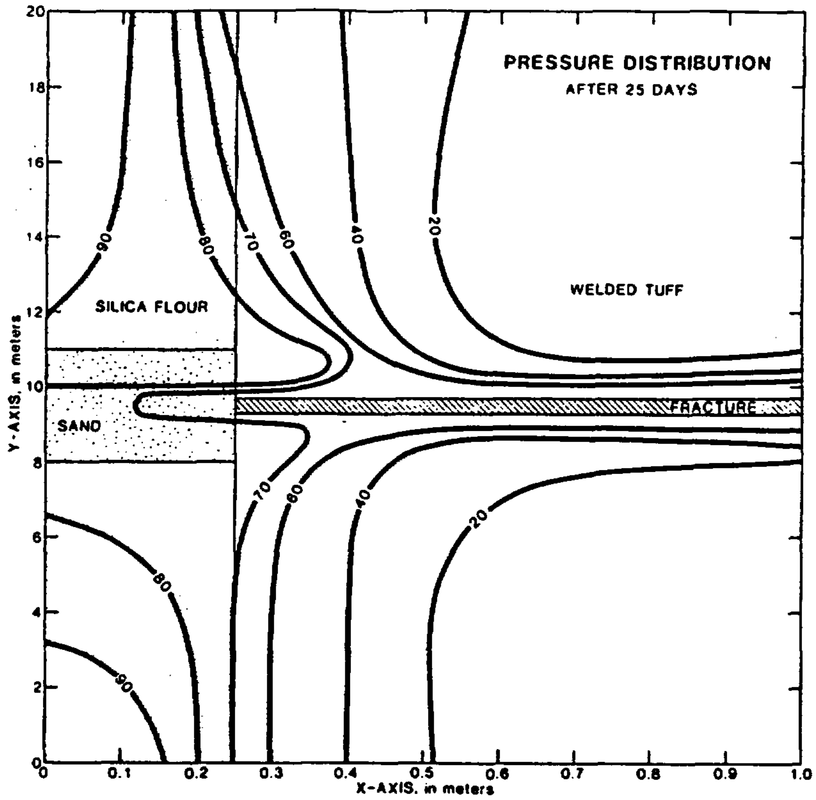


Fig. 14. Contour diagram of the pressure head distribution in the vicinity of the borehole after 25 days; slight wetting of the sand column and severe drying of the fracture are evident.

References

Davis, L.A., and S.P. Neuman, Documentation and User's Guide: UNSAT2--Variably saturated flow model, U.S. Nuclear Regulatory Commission, NUREG/CR-3390,--pp., 1983.

Evans, D.D, Unsaturated flow and transport through fractured rock related to high-level waste repositories, Nuclear Regulatory Commission, NUREG/CR-3206, 231 pp, 1983.

Montazer, Parviz, Permeability of unsaturated fractured metamorphic rocks near an underground opening, unpublished Ph.D. Thesis, 617 pp., Colorado School of Mines, Golden, Colorado, 1982.

Montazer, Parviz, and P.E. Harrold, Theoretical calculation of hydraulic properties of unsaturated fractures from roughness profiles, Proceedings, Am. Geoph. Union, December 1985, San Francisco, 1985

Montazer, Parviz and W.E. Wilson, Conceptual hydrologic model of flow in the unsaturated zone, Yucca Mountain, Nevada. U.S. Geological Survey Water-Resources Investigations Report 84-4345, 55 pp, 1984.

Morrison, R.D, Ground-water monitoring technology--procedures, equipment and applications, Prairie DuSac, Wis. Timco Manufacturing, Inc. 111 pp, 1983.

Neuman, S.P., Saturated-unsaturated see page by finite elements; Proc. ASCE, J. Hydrol. Div, 99, (HX12), pp. 2233-2250, 1973.

Palaz, Ibrahim, Application of geophysical logs to estimate moisture-content profiles in unsaturated tuff, Yucca Mountain, Nevada, in Proceedings, National Water Well Association Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone, Denver, Colorado, November 19-21, 1985.

Peters, R.R., E.A. Klavetter, J.J. Hall, S.C. Blair, P.R. Heller and G.W. Gee, Fracture and matrix hydrologic characteristics of tuffaceous materials from Yucca Mountain, Sandia Report SAND 84-1471, 63 pp, Nye County, Nevada, 1984.

Remson, Irwin and J.R. Randolph, Review of some elements of soil-moisture theory-Fluid movement in earth material. U.S. Geological Survey Professional Paper 411-D, 38 pp, 1962

Stallman, R.W. Multiphase fluids in porous

ENCLOSURE 11

G-TUNNEL COMPLEX SAFETY PROVISIONS FOR VISITORS

SAFETY GLASSES, HARD HATS, AND SAFETY SHOES ARE REQUIRED - ITEMS ARE PROVIDED AT THE PORTAL IF NEEDED

ALL TOURS WILL HAVE G-TUNNEL APPROVED ESCORTS, WHO ARE RESPONSIBLE FOR:

- BRIEFING PERSONNEL ON SAFETY RULES
- ENSURING THAT REQUIRED SAFETY EQUIPMENT IS USED
- LOGGING ALL PERSONNEL IN AND OUT
- CONTACTING REECo MINING SUPERVISION ON PA SYSTEM IN CASE OF AN EMERGENCY
- NOT ENTERING ANY UNDERGROUND AREA WITHOUT REECo APPROVAL
- FOLLOWING INSTRUCTION FOR ANY TUNNEL EXCAVATION

SPECIAL TRAIN REGULATIONS FOR ALL PERSONNEL

- PERSONNEL WILL ONLY RIDE IN CARS BEHIND THE MOTOR
- PERSONNEL WILL REMAIN SEATED WHEN TRAIN IS IN MOTION

NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS

G-TUNNEL UNDERGROUND FACILITY

BACKGROUND

The G-Tunnel Underground Facility (GTUF), part of the G-Tunnel Complex, was developed under the Nevada Nuclear Waste Storage Investigations (NNWSI) Project. The G-Tunnel Complex was established for nuclear weapons testing events, which occurred between 1962 and 1971. Since 1971, it has been used an an underground research facility by Sandia National Laboratories (SNL). Programs have included (1) containment and gate development studies for weapons work, (2) hydraulic and explosive fracturing studies for enhanced gas and oil recovery, and (3) recent testing in support of NNWSI.

NNWSI has been involved in evaluating the potential for nuclear waste repository developments at Yucca Mountain. SNL, a participant in NNWSI, initiated the development of the GTUF in 1979 primarily for underground geomechanics studies. Important phenomena being studied were

- Thermal (heat flow characteristics)
- Mechanical (stress-strain responses, excavation effects, strength relationships)
- Thermomechanical (volumetric expansion)
- Hydrothermal (heat induced water migration)

The facility now includes drifts and alcoves in welded and nonwelded tuffs on three major floor levels. Major SNL experimental efforts have been

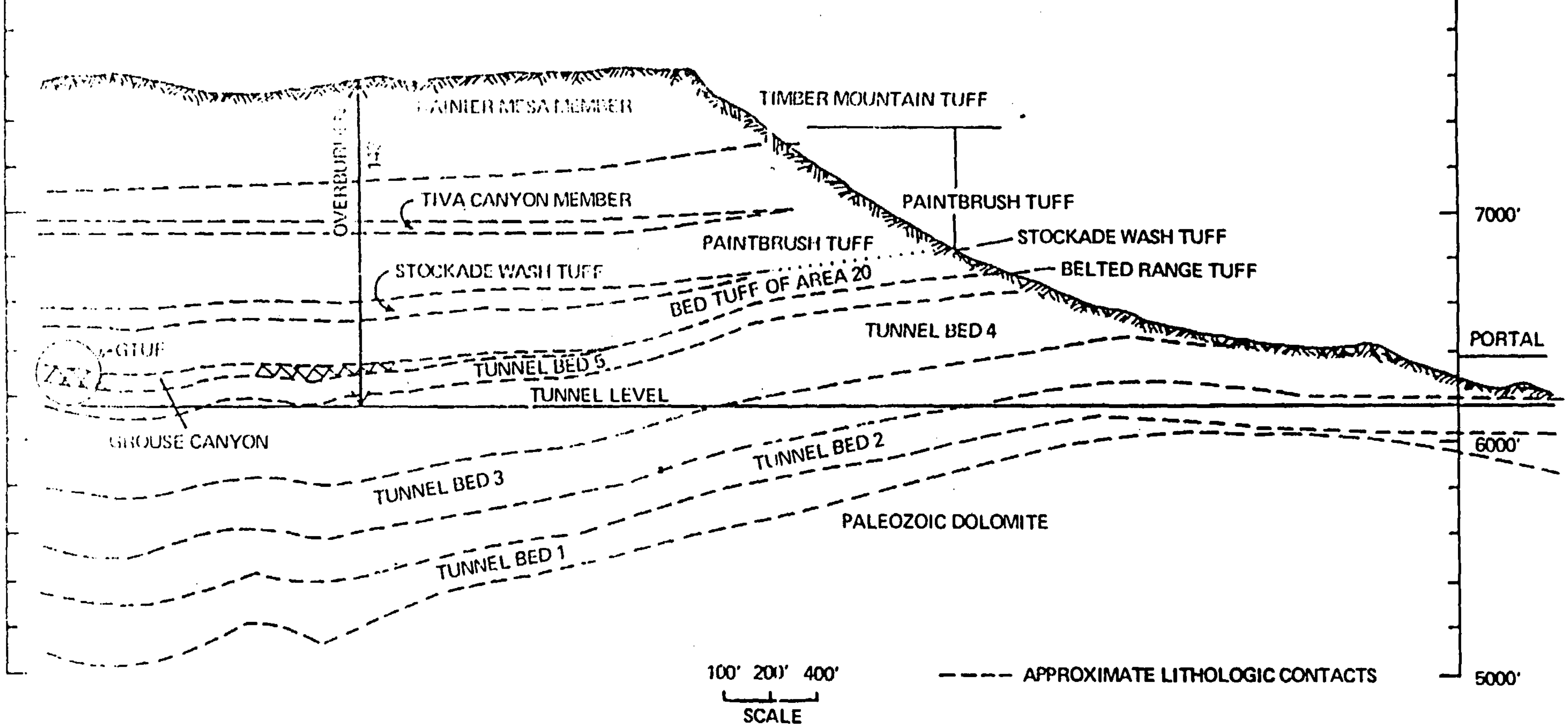
- In Situ Stress Measurements (in welded tuff)
- Small Diameter Heater Experiments (in welded and nonwelded tuffs)
- Heated Block Experiment (featuring thermal and mechanical loadings)
- Welded Tuff Mining Evaluations (excavation of demonstration drifts)
- Pressurized Slot Testing (featuring chain saw developments)

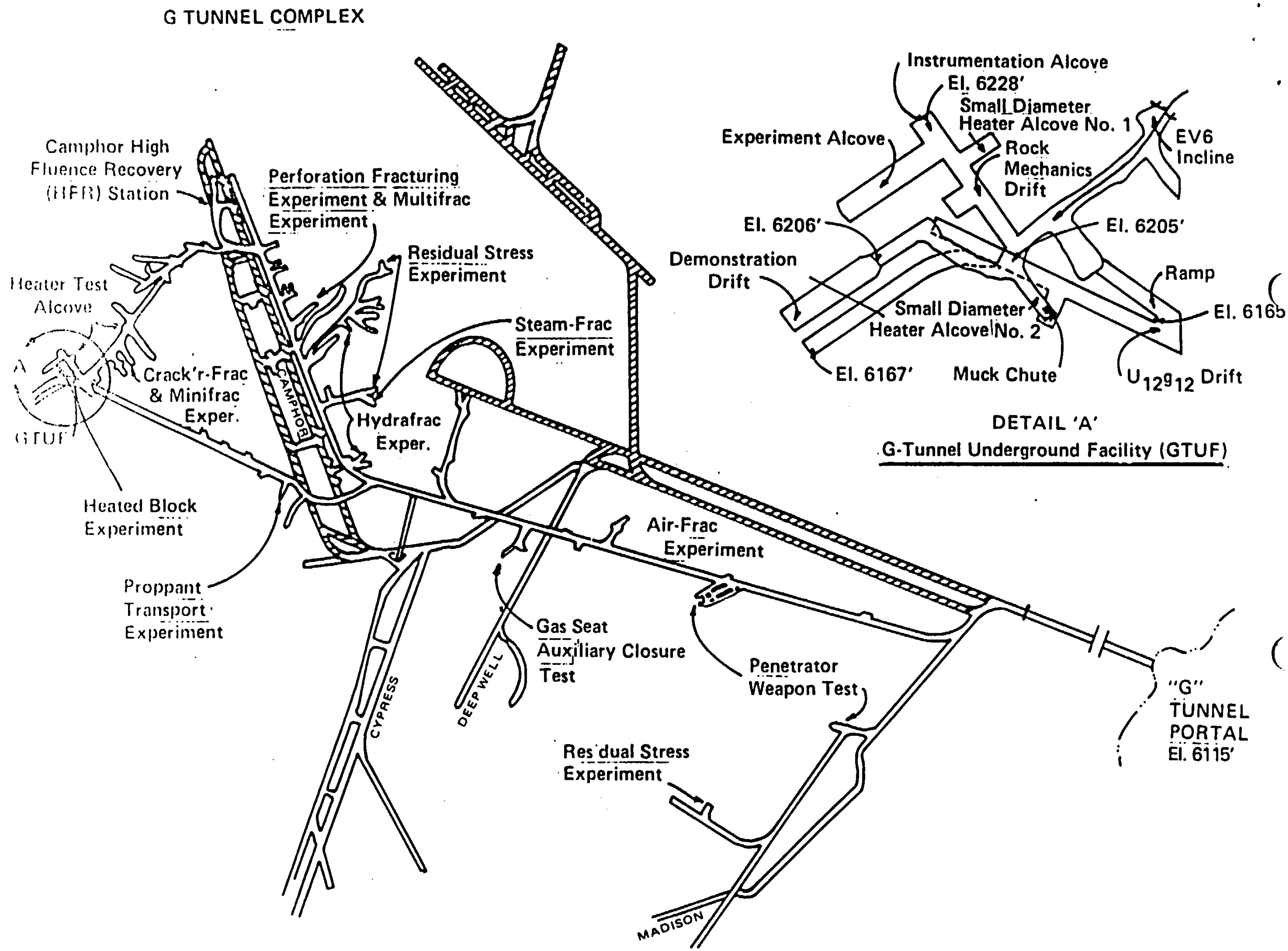
PROTOTYPE TESTING

In 1987, the GTUF became a focus for NNWSI Prototype Testing efforts in preparation for Exploratory Shaft Testing at Yucca Mountain. NNWSI researchers can perform in situ measurements in a welded tuff having thermal and mechanical properties and stress states that are similar to the welded tuff at Yucca Mountain. Similarities in welded and nonwelded tuff stratigraphies also exist. Planned activities include

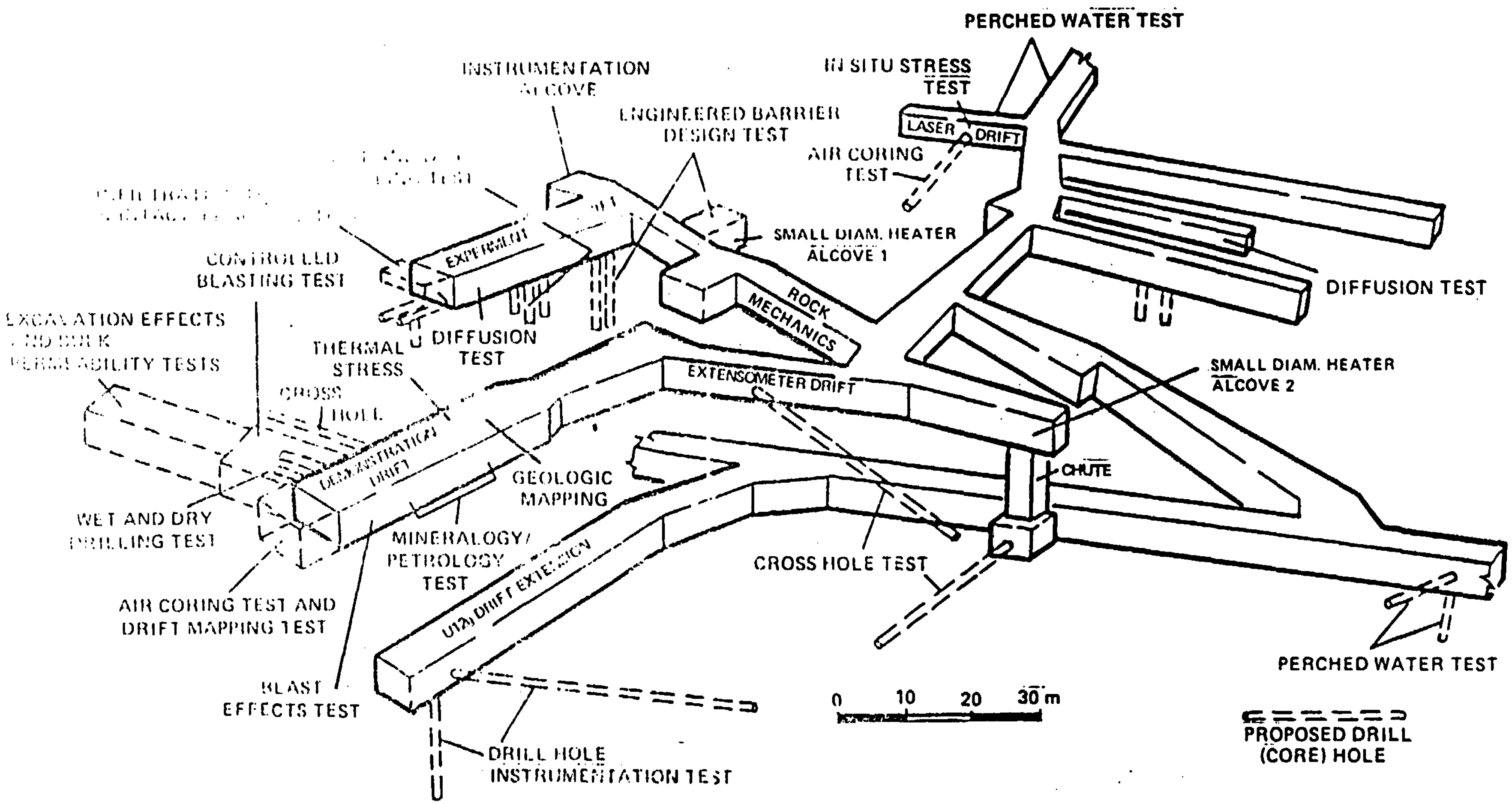
- Geological Mapping Investigations (USGS)
- Development of Drilling Methods (LANL)
- Hydrologic Investigations and Flow Evaluations (USGS, LANL)
- Engineering Barrier Simulations (LLNL)
- Thermal Stress Measurements (SNL)
- Instrumentation Evaluations (USGS, LLNL, SNL)

PARTIAL CROSS SECTION OF RAINIER MESA AT G TUNNEL LOCATION




G TUNNEL COMPLEX
Camphor High Fluence Recovery (HFR) Station
Perforation Fracturing Experiment & Multifrac Experiment
Residual Stress Experiment
Heater Test Alcove
A
GTUF
Crack'r-Frac & Minifrac Exper.
CAMPHOR
Hydrafrac Exper.
Steam-Frac Experiment
Heated Block Experiment
Proppant Transport Experiment
Air-Frac Experiment
Gas Seat Auxiliary Closure Test
DEEP WELL
CYPRESS
Penetrator Weapon Test
Residual Stress Experiment
MADISON
"G" TUNNEL PORTAL El. 6115'
Instrumentation Alcove
El. 6228'
Small Diameter Heater Alcove No. 1
Experiment Alcove
Rock Mechanics Drift
EV6 Incline
El. 6206'
El. 6205'
Demonstration Drift
Ramp
Small Diameter Heater Alcove No. 2
El. 6165
El. 6167'
Muck Chute
$U_{12}g_{12}$ Drift
DETAIL 'A'
G-Tunnel Underground Facility (GTUF)

PLAN VIEW OF GTUF NORTHWEST SECTION OF G-TUNNEL



NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS
G-TUNNEL UNDERGROUND FACILITY (GTUF)

Prior Work	Objectives	Org.	Status
Geotechnical Field Measurement	In-situ stress, mechanical, hydrologic phenomena	SNL	Report published
Small Diameter Heater	Thermal, hydrothermal phenomena	SNL	Report published
Heated Block	Thermomechanical properties/ phenomena	SNL	Report published
Pressurized Slot	Mechanical properties/phenomena	SNL	Completed, report in preparation
Mining Evaluation	Mechanical properties/phenomena	SNL	Completed; report in preparation
PLANNED WORK (Prototype Testing)			
Drift Wall Mapping/ Photogrammetry	Methodology development, concept validation	USGS	Started
Drill Hole Instru-mentation	Design/function validation	USGS	Planning
Cross Hole Testing	Hydrologic properties, transport mechanisms	USGS	Planning
Intact Fracture Test	Fracture flow mechanisms	USGS	Planning
Infiltrometer Test	Fluid flow properties, design validation	USGS	Planning
Thermal Stress Test	Thermomechanical properties/ phenomena	USGS	Approved plans
Waste Package Environment Test	Hydrothermal properties/phenomena	LLNL	Started
Air Coring Tech-nology/Dust Control	Technology validation/safety assessment	LANL	Approved plans
Diffusion Test	Geochemical processes/phenomena	LANL	Planning