Letter Report
Geology and Ore Deposits of the Great Basin Symposium

April 1-5, Sparks, Nevada

by

Russell G. Raney

The following presentations/poster sessions were attended:

1. **EPITHERMAL, VOLCANIC-HOSTED, GOLD-SILVER DEPOSIT EXPLORATION TECHNIQUES USEFUL IN NEVADA AND OTHER AREAS** by H. F. Bonham, Jr., Thomas P. Lugaski, William Aymard, Nevada Bureau of Mines and Geology.

2. **MAGMATIC AND HYDROTHERMAL ACTIVITY, CALDERA GEOLOGY, AND REGIONAL EXTENSION IN THE WESTERN PART OF THE SOUTHWESTERN NEVADA VOLCANIC FIELD** by Donald C. Noble and Steven I. Weiss, University of Nevada, Reno; Edwin H. McKee, U.S. Geological Survey.

3. **GOLD MINERALIZATION AT FLUORSPAR CANYON, NEAR BEATTY, NYE COUNTY, NEVADA** by James D. Greybeck and Andy B. Wallace, Cordex Exploration Company.

4. **GEOLOGY AND GEOCHEMISTRY OF THE SLEEPER GOLD DEPOSITS, HUMBOLDT COUNTY, NEVADA--AN INTERIM REPORT** by J. T. Nash, U.S. Geological Survey; W. C. Utterback, AMAX Gold, Inc.; and J. A. Saunders, University of Mississippi.

5. **DEFINING GOLD ORE ZONES USING ILLITE POLYTYPES** by Phoebe L. Hauff and Fred A. Kruse, University of Colorado; Raul J. Madrid, Conquistador Gold, Ltd.

6. **EXAMINATION OF SELECTED SATELLITE AND AIRBORNE REMOTE SENSING SYSTEMS FOR GEOLOGIC MAPPING AND MINERAL EXPLORATION IN SEMIARID TERRAINS** by G. B. Bailey, U.S. Geological Survey; J. L. Dwyer, TGS Technology, Inc.

7. **HYDROTHERMAL ALTERATION AT THE CALICO HILLS, NYE COUNTY, NEVADA** by F. W. Simonds and R. B. Scott, U.S. Geological Survey.

8. **FAULT-RELATED GOLD MINERALIZATION: ORE PETROLOGY AND GEOCHEMISTRY OF THE MORNING STAR DEPOSIT, CALIFORNIA** by Ronald Wynn Sheets, Virginia Polytechnic Institute and State University; Kent Ausburn, Vanderbilt Gold Corporation; Robert J. Bodnar and James R. Craig, Virginia Polytechnic Institute and State University.

9. **CONCEALED MINERAL DEPOSITS IN NEVADA: INSIGHTS FROM THREE-DIMENSIONAL ANALYSIS OF GRAVITY AND MAGNETIC ANOMALIES** by Richard J. Blakely and Robert C. Jachens, U.S. Geological Survey.

10. **GEOLOGY AND MINERALIZATION OF THE GOLD ACRES DEPOSIT, LANDER COUNTY, NEVADA** by Stanley T. Foo and Robert C. Hays, Jr., Cortez Gold Mines.

11. **PRECIOUS METAL DEPOSITS, STRUCTURAL BLOCKS, AND VOLCANISM IN THE SOUTH-CENTRAL NEVADA STRUCTURAL ZONE** by John C. Kepper, Consultant; Thomas P. Lugaski and William Aymard, University of Nevada, Reno.

Initial and/or renewed contact and conversations with the following persons provided additional information and sources of information pertaining to mineralized areas within the Yucca Mountain vicinity:

1. Stephen Green, Noranda Exploration (formerly chief exploration geologist for GEXA Gold's Mother Lode mine);

2. Ronald Sheets, Department of Geological Sciences, Virginia Polytechnic Institute and State University 1/;

3. Walter S. Lombardo, Chief, Las Vegas Branch, Nevada State Department of Minerals;

4. Thomas P. Lugaski, Assistant to the Dean for Research and Development, MacKay School of Mines, University of Nevada-Reno 1/;

5. Steven Castor, Nevada Bureau of Mines and Geology 1/;

6. Ron Hess, Geologic Information Specialist, Nevada Bureau of Mines and Geology;

7. W. F. Simonds, U.S. Geological Survey 1/;

8. R. D. Catchings, Research Geophysicist, Office of Earthquakes, Volcanoes, and Engineering, U.S. Geological Survey 1/;

9. Harold Linder, Consulting Geologist, Harold Linder and Associates, Tempe, Arizona;

10. Paul Garrison, GEOMAN Geological Services, Billings, Montana;

11. James Ruiz, Consulting Geologist, Breckenridge, Colorado;

12. Allene Kramer, Sales Manager (maps and publications), Nevada Bureau of Mines and Geology;

13. Becky Weimer-Purkey, Geologic Information Specialist, Nevada Bureau of Mines and Geology.

1/Speaker/Author, Great Basin Symposium.

Footnotes following the individual author's abstract are those of the reviewer.

EPITHERMAL, VOLCANIC-HOSTED, GOLD-SILVER DEPOSIT EXPLORATION TECHNIQUES USEFUL IN NEVADA AND OTHER AREAS

by

H. F. Bonham, Jr., Thomas P. Lugaski, and William Aymard,
Nevada Bureau of Mines and Geology

Models for the three main types of volcanic-hosted, gold-silver deposits (adularia-sericite, acid-sulfate, and alkalic, and the relationship of these deposit types to volcanic landforms have been described. With the recent discoveries of major volcanic-hosted gold-silver deposits in the circum-Pacific region (e.g., El Indio in Chile, Pajingo in Australia, Ladolam, Lihir Island, Papua New Guinea, Hishikari in Kyushu, Japan, and Sleeper and Paradise Peak in Nevada, U.S.A.), renewed interest in these types of deposits has been generated. Exploration techniques for volcanic-hosted gold-silver deposits must be designed to match specific deposit types (emphasis added) 1/.

The exploration techniques needed include: 1) first-order studies, and 2) an exploration program designed to fit the climatic, topographic, and vegetation parameters of the exploration area.

First-order exploration techniques for volcanic-hosted, gold-silver deposits include: (1) delineation of areas of intermediate to silicic volcanism, predominately subaerial; (2) utilization of satellite (Landsat MSS, TM; SPOT) or airborne (SAR; commercial multispectral scanners) imagery to detect regional lineaments, areas and types of hydrothermal alteration, vegetation and topographic anomalies, and volcanic centers; and (3) definition of trace-element associations from existing literature, i.e., areas containing prospects, mines or occurrences of Au, Sb, As, and Hg.

After target areas have been defined utilizing the above criteria, exploration programs must be designed to fit the climatic, topographic, and vegetation parameters of the selected areas. In areas of dense vegetation and rugged topography, such as the island arcs of the southwest Pacific, stream sediment geochemistry utilizing 1 ppb detection levels for Au is an effective reconnaissance tool. Satellite or airborne radar (SAR) has been shown to be effective in mapping the geology in areas of dense vegetation, and its use in mineral exploration needs to be explored. Once anomalous areas have been identified, volcanic setting and deposit model type are important parameters for additional exploration.

In areas of excellent exposure and moderate to intense exploration activity such as the southwestern U.S.A. and the Andes of Peru and Chile, many of the deposits that will be found in the future will either be concealed beneath shallow, post-ore cover, or the ore-grade mineralization will not crop out at the present erosional surface (emphasis added). Exploration for these types of deposits should involve correct identification of deposit type (i.e., adularia-sericite, acid-sulfate, or alkalic), trace-element geochemistry utilizing both stream sediment, rock-chip, and geobotanical techniques and geophysical methods including VLF, resistivity, IP, magnetics, and gravity measurements.

Remote sensing techniques using commercially available Landsat TM, SPOT, or airborne data in combination with regional geochemical and geophysical studies will play an important role in detection of concealed ore deposits in the near future. With modern computer techniques, existing geological, map, lineament, geochemical, and geophysical data can be coregistered with and overlain directly on the remotely sensed image, allowing direct correlation of one data set with another, thus enhancing the explorationist's ability to discover volcanic-hosted precious-metal deposits.

1/This is important for DOE to realize in resource assessment studies during site characterization.

MAGMATIC AND HYDROTHERMAL ACTIVITY, CALDERA GEOLOGY, AND REGIONAL EXTENSION IN THE WESTERN PART OF THE SOUTHWESTERN NEVADA VOLCANIC FIELD

by

Donald C. Noble and Steven I. Weiss,
University of Nevada, Reno,
Edwin H. McKee, U.S. Geological Survey

Igneous activity of the southwestern Nevada volcanic field can be divided into three magmatic stages. The main magmatic stage, which began about 15.2 Ma and ended with eruption of the Tiva Canyon Member of the paintbrush Tuff about 12.8 Ma, was characterized by the caldera-forming eruption of a number of voluminous silicic ash-flow sheets, mostly of subalkaline character, and small volumes of silicic and intermediate lavas. A thick, west-dipping section of intracaldera(?) ash-flow tuff exposed on Sleeping Butte appears to mark a newly recognized collapse caldera that predates the Belted Range Tuff. The onset of the Timber Mountain magmatic stage followed a lull in volcanic activity of about 1 to 1.5 million years. The lithologically distinctive rocks of the Timer Mountain stage include: (1) precursor rhyolite lavas and surge deposits; (2) two major compositionally zoned ash-flow sheets, the Rainier Mesa and overlying Ammonia Tanks Members of the 11.4-Ma Timber Mountain Tuff, and several overlying small-volume ash-flow units; and (3) an assemblage of late rhyolitic tuffs and lavas and associated mafic and intermediate lavas that were erupted prior to about 10 Ma. A late magmatic stage is represented by alkaline, peralkaline, and subalkaline rocks of the Black Mountain and Stonewall Mountain volcanic centers and rocks of other centers to the northwest that were erupted between about 7 and 9 Ma.

During the Timber Mountain magmatic stage, volcanic activity evolved from caldera-forming eruptions of major ash-flow sheets to eruption of local units of tuff and lava from vents located mainly in the western part of the southwestern Nevada volcanic field. Field relations and geochronologic constraints show that the Rainier Mesa Member of the Timber Mountain Tuff was erupted from vents within the Timber Mountain caldera as enlarged to encompass the formerly recognized Oasis Valley and Sleeping Butte caldera segments. Eruption of the Ammonia Tanks Member resulted in the formation of a smaller caldera nested within the Timber Mountain caldera. Sphene-bearing ash-flow cooling units of the tuff of Fleur-de-Lis ranch exposed locally inside the western margin of the Timber Mountain caldera, on which dates of 11.3±0.3 and 11.4±0.1 Ma have been obtained, are of the same age as the Ammonia Tanks Member. These tuffs may reflect pulses of late pyroclastic activity related to the Ammonia Tanks Member, as do the tuffs of Buttonhook Wash and Crooked Canyon exposed on and around Timber Mountain. Post-Ammonia Tanks high-silica rhyolite tuffs lacking sphene exposed in the Bullfrog Hills west of the Timber Mountain caldera represent a renewal of Rainier Mesa-type magmatism. These tuffs and associated silicic and intermediate lavas may in part have been erupted from fissure vents formed during crustal extension.

Hydrothermal activity and mineralization took place during both the main and Timber Mountain magmatic stages. Epithermal gold and fluorite mineralization at the Sterling, Mother Lode, Daisy, and other properties along the northern and eastern margins of Bare Mountain, and probably also at the Wahmonie district, is related to subjacent porphyry-type magmatic systems about 13 to 13.5 million years old (emphasis added). The most intense and widespread hydrothermal activity and epithermal Au-Ag mineralization related to the Timber Mountain magmatic stage is found in the Bullfrog Hills in the western part of the volcanic field. Mineralization at the Bond Gold Bullfrog and Gold Bar mines, as well as at a number of previously producing properties and prospects, is structurally controlled by normal faults and appears to be related to magmatic activity of the later part of the Timber Mountain stage.

Crustal extension in the western part of the southwestern Nevada volcanic field involved movement along both a regional low-angle detachment fault (the "Original Bullfrog-Fluorspar Canyon Fault") and higher-angle normal faults that in part postdate and cut the low-angle structure. Rotation of fault blocks in the Bullfrog Hills took place mostly after eruption of the Timber Mountain tuff and was complete by the time the subhorizontal, 7.6 Ma Spearhead Member of the Stonewall Flat Tuff was deposited. A younger episode of normal faulting that postdates the Stonewall Flat Tuff produced most of the present topography in areas to the northwest.

GOLD MINERALIZATION AT FLUORSPAR CANYON, NEAR BEATTY, NYE COUNTY, NEVADA

by

James D. Greybeck and Andy B. Wallace,
Cordex Exploration Company

Fluorspar Canyon lies on the northern flank of Bare Mountain, 185 km (115 miles) northwest of Las Vegas, Nevada. Disseminated gold occurs in several geological settings at Fluorspar Canyon, and the overall system provides an example of the transition between several "classes" of epithermal gold deposits. Each of the zones has a distinctive geochemical and alteration association, which is, at least in part, a function of host rock lithology. Low-angle faults (detachment-style) are an important control on gold mineralization.

Two mineralized zones occur in Cambrian sedimentary rocks and are typical "Carlin-type" deposits. The West Zone is hosted by limestone in the Halfpint Member of the Nopah Formation. Highest gold values are associated with intense silicification and fluorite mineralization. Anomalous concentrations of arsenic, antimony, mercury, and <u>thallium</u> (emphasis added) 1/ are present with gold in the Halfpint Member. The South Zone is hosted by silty limestones and calcareous siltstones of the Carrara Formation. Subtle alteration is present as decalcification. Anomalously high arsenic occurs in the zone, and silver, copper, molybdenum, and thallium tend to correlate with gold. Massive fluorite veins, mined since 1916, occur in the dolomite of the Bonanza King Formation above the gold mineralization.

Disseminated gold mineralization occurs within Miocene volcanic rocks 2/ at Fluorspar Canyon at the Secret Pass Zone. Gold mineralization occurs in strongly propylitized, argillized, and silicified ash-flow tuffs; <u>arsenic, antimony, mercury, and thallium are anomalous</u> (emphasis added). Silver also correlates well with gold but occurs in low concentrations (typical Au:Ag ratios are 4:1).

Normal faulting is the principal structural control of the three zones of known gold mineralization. Both low-angle and high-angle faults occur, and better grade zones are associated with intersections of these faults. At the West Zone, a low-angle fault forms the footwall of the favorable host rocks. At the South Zone, disseminated gold mineralization occurs in the footwall of a low-angle fault where more favorable host rocks occur. At the Secret Pass Zone, a low-angle fault juxtaposes the mineralized volcanic rocks in the hanging wall and unmineralized Paleozoic carbonate and clastic rocks in the footwall. This structure at the Secret Pass Zone is interpreted to be a segment of a large-scale detachment fault that soles a broad sheet of allochthonous terrane (Carr and Monsen, 1988). This segment is called Fluorspar Canyon detachment.

1/Anomalous thallium values are also reported at the Yucca Mountain Addition by Castor, Feldman, and Tingley, <u>Mineral Evaluation of the Yucca Mountain Addition, Nye County, Nevada</u>.
2/The Miocene volcanics are exposed north of the Fluorspar Canyon Fault.

GEOLOGY AND GEOCHEMISTRY OF THE SLEEPER GOLD DEPOSITS, HUMBOLDT COUNTY, NEVADA--AN INTERIM REPORT

by

J. T. Nash, U.S. Geological Survey,
W. C. Utterback, AMAX Gold, Inc.,
and J. A. Saunders, University of Mississippi

Epithermal gold-silver deposits of the quartz-adularia type at the Sleeper mine were emplaced in a local Miocene rhyolite flow-dome complex south of the McDermitt volcanic field. The rich deposit is a combination of superimposed very high-grade bonanza veins, medium-grade breccias, and lower grade stockworks. High-grade banded veins comprise more than 60 percent of reserves, but zones with less than 0.1 oz Au/t also are significant. Altered volcanic rocks are exposed on a pediment east of the pits, but <u>the Sleeper orebody is covered by 20-50 m of alluvium</u> (emphasis added).

Structural controls of many types and scales are important at Sleeper. The local volcanic complex and veins reflect late Miocene extension. Multiple stages of silification and gold-silver mineralization suggest repeated opening of a controlling north-striking fracture zone. Step-like Basin and Range faults downdropped the Sleeper deposit about 300-600 m and preserved it from erosion. The veins, other ore structures, and Basin and Range faults are cut by north-, northeast-, and northwest-striking high-angle faults having offsets of less than 15 m. Some post-ore structures were the sites of acid leaching and opal-kaolinite-alunite deposition dated at 6 Ma.

Multiple high-grade, banded quartz-adularia-gold veins are semicontinuous for more than 1,200 m along strike and more than 500 m downdip and are comparable to classic epithermal veins rather than hot springs deposits. The veins range up to 3 m wide and generally dip 60-70°W; commonly, there are many parallel and splaying veins spanning a zone more than 30 m wide. The veins contain more gold than silver. Locally, gold content averages more than 20 oz/t (!), and ranges to more than 170 oz/t (!!) (emphasis added!). Deposition of spectacular banded electrum and microcrystalline quartz-adularia was followed by brecciation and then by later stages of opal and micro-quartz rich in naumannite or stibnite.

Broad zones of hydrothermal breccias and stockwork veinlets are richer in pyrite-marcasite and in silver (Ag>Au) than the veins; most of these structures formed after the bonanza veins. Widespread early flooding by silica and pyrite created brittle rocks that were favored for later ore stages. The breccias are clast supported, derived from adjacent wallrocks, and cemented by silica and 5-10 percent pyrite and marcasite. Stockwork veinlet zones grade into the breccias and have similar mineralogy but reflect less dilation.

Alteration of host rocks is broadly controlled by structure but has diffuse boundaries. Multiple stages of opal, cristobalite, and microcrystalline quartz with fine-grained pyrite, marcasite, and adularia or sericite characterize the ore zone. Igneous textures generally survive except in zones of late acid leaching. Plagioclase phenocrysts have been variably replaced by opal or quartz, sericite, or alunite-kaolinite, but sanidine is little altered. Glassy groundmass persists locally in rocks more than 300 m from ore, but generally has been transformed to aphanitic mixtures dominated by opal. Least altered rocks contain smectite 1/, are sparsely fractured, and contain no ore. Sericite-pyrite alteration is most abundant in lower-grade zones adjacent to veins. All rocks in the pits are enriched in K and S, and depleted in Ca and Na; Al commonly is mobile. The ore zones are generally enriched in As and Se and are sporadically enriched in Sb, Hg, Tl 2/, and Mo; concentrations of Ba, Bi, Cu, Pb, Te, and Zn are generally low.

Several features suggest that the Sleeper deposit did not form by conventional hydrothermal mechanisms. The abundance of opaline silica, repeated mono- or bimineralic layers, and the mass of gold in ore shoots cannot easily be explained by equilibrium thermodynamic models. We suspect that silica and gold were transported and deposited as colloids. Alteration of volcanic glass, supplemented by boiling, may have created very high Si-Au concentrations in ore fluids. Fine banding in veins suggests quiescent, gently effervescent conditions in contrast to adjacent pre- and post-vein hydrothermal breccias. The changes from high sulfide content in breccias to no sulfide in veins may be a reflection of boiling, loss of H_2S, and oxidation.

Reviewer's note: The Sleeper discussion was included here because in its SCP comments, USGS stated that a Sleeper-type deposit may exist in the alluvium of Crater Flat proximal to the Yucca Mountain site.

1/Smectite is reported in drill holes on Yucca Mountain.
2/Thallium is reported in anomalous amounts at the Yucca Mountain Addition (Castor, Feldman, and Tingley).

DEFINING GOLD ORE ZONES USING ILLITE POLYTYPES

by

Phoebe L. Hauff and Fred A. Kruse, University of Colorado,
Raul J. Madrid, Conquistador Gold, Ltd.

Many of the sediment- and volcanic-hosted disseminated gold deposits that constitute the basis for the modern "gold rush" occurring now in Nevada eluded discovery for nearly a century partially because the gold was too small (microns in size) and too sparse (0.1-0.025 oz/t) to detect by conventional methods. The associated mineralogy, particularly clays, was largely undetermined. **Recent research has shown that the clay mineral illite 1/ is associated with gold mineralization in many disseminated gold deposits** (emphasis added). Where present, it can reflect lateral and vertical zonation around gold ore bodies. Illites change crystal structure with temperature and may act as geothermometers, indicating temperatures of ore deposition and proximity to hypogene and supergene fluids. The more ordered, higher temperature 2M phase is generally associated with high gold values. Less ordered, low-temperature disordered illites, found peripheral to the main gold-bearing zones, contain more interlayer water and often mixed-layer smectites. The method proposed in this paper utilizes the structural ordering of the illite crystal lattice to predict certain zonal relationships within the ore body and combines X-ray diffraction and reflectance spectroscopy for field identification of potential economic ore zones.

Visible/near infrared spectral measurements using both laboratory and field-portable reflectance spectrometers were used to verify the in-situ distribution of illite polytypes at several Nevada deposits. Changes in the visible/near-infrared reflectance spectra were observed as illites progressed from the lower temperature, less ordered variety to the higher temperature 2M type. Distinctive absorption features appearing in the reflectance spectra at 1.90 m, 2.20 m, and between 2.3-2.5 m allowed detection of the interlayer water, structural water (OH^-), and some octahedral layer characteristics.

At the Preble deposit, located along the Getchell trend in north-central Nevada, gold mineralization is hosted by the Middle Cambrian Preble Formation. Silicification has occurred in the thin-bedded, carbonaceous, calcareous, silty, phyllitic shales that host the mineralization (Kretschmer, 1988; Percival et al, 1988), which is post-metamorphic and occurs both in silica replacement bodies and along silica-coated fractures within a major high-angle normal fault zone (Madrid et al, 1988). Illites are found throughout this deposit and appear to vary in crystallinity or polytype with the alteration and hydrothermal temperatures. Outside of the ore zone, they can exhibit poor crystallinity, whereas within the ore zone ordered, 2M illites with well defined spectral features consistently appear. Alteration across the deposit can also be tracked using the change in polytypes.

The combined x-ray diffraction and reflectance spectroscopy study of illite polytypes from several mines has, therefore, established that sufficient spectral differences exist to allow identification using near-infrared reflectance spectroscopy. Field and laboratory spectrometers have successfully identified polytypes. Illite polytypes can be related to field-derived, hydrothermal alteration zones. Field reflectance spectroscopy can assist exploration efforts by providing detailed mineralogical information in real-time at the field location. The potential also exists, given sufficient spectral and spatial resolution and favorable instrument sign-to-noise, to identify these polytypes from the air using high spectral resolution remote sensing (imagining spectrometry).

1/Illite is reported in drill holes at Yucca Mountain.

EXAMINATION OF SELECTED SATELLITE AND AIRBORNE REMOTE SENSING SYSTEMS FOR GEOLOGIC MAPPING AND MINERAL EXPLORATION IN SEMIARID TERRAINS

by

G. B. Bailey, U.S. Geological Survey,
and J. L. Dwyer, TGS Technology Inc.

Remotely sensed data acquired from satellite and airborne platforms are valuable and often under-utilized tools for geologic mapping and mineral exploration, especially in semiarid terrains where rocks are well exposed. Data from six different satellite and airborne remote sensing systems that record reflected and emitted electromagnetic radiation in visible through thermal infrared portions of the spectrum were acquired over the same geologic test site in Utah. Attempts were made to evaluate and to document the geologic information content of these various data and to develop data products that best display the information.

The Central Drum Mountains, west-central Utah, were selected as a field site because a variety of rock types are well exposed in a physiographic setting typical of the semiarid western United States. Rocks exposed include a sequence of limestones, dolomites, and shales that overlies quartzite and argillite. Felsic, intermediate, and mafic volcanic rocks occur in contact with sedimentary units. The volcanic rocks have been hydrothermally altered in places, and some adjacent carbonate rocks have been bleached and recrystallized. A contact metamorphic aureole in the central part of the area is characterized by carbonate bleaching and development of calc-silicate minerals in limestone and shale units. The aureole is associated with the intrusion of two small stocks; a fresh diorite and mineralized and intensely altered monzonite porphyry. Faults controlled numerous gold-bearing jasperoid bodies.

Initial remote-sensing studies of this area focused on comparing capabilities of Landsat multispectral scanner (MSS) and thematic mapper (TM) data to detect hydrothermally altered rocks and to discriminate different lithologic units present in the field area. Simultaneously acquired MSS and TM data were digitally enhanced using band ratioing, principal components analysis, and other techniques. The TM data provide greater geologic information compared to MSS data. A map of hydrothermally altered rocks interpreted from TM data accurately portrays the occurrence of all known exposures of such rocks in the area but does contain certain errors of commission. Unaltered rocks containing significant concentrations of Fe-oxide minerals and hydroxyl-bearing or recrystallized carbonate minerals appear similar to altered rocks on the TM images.

Images produced from multispectral Satellite Pour l'observation de la Terre (SPOT) data proved less useful than TM data because of their more limited spectral coverage. However, panchromatic SPOT data improve the detail of TM-based interpretations. By digitally merging SPOT panchromatic data with various enhanced TM images, new images were created that capture most of the information in TM data, but at 10-m spatial resolution. Furthermore, when the enhanced TM images are merged with the second image of the SPOT panchromatic stereo pair, rather spectacular, high-spatial resolution, false-color stereo images are produced. These proved very useful for interpreting all aspects of the geology.

Six-band, 20-m spatial resolution Thermal Infrared Multispectral Scanner (TIMS) data acquired over the Drum Mountains were evaluated to determine their capabilities to differentiate rock types, particularly various silicate rocks which typically have similar reflectance characteristics in the wave length regions covered by TM but which vary in their thermal emittance spectra. Due to influences of surface temperature, TIMS data are often highly correlated among bands. Drum Mountains TIMS data were digitally enhanced using a decorrelation stretch technique. The resultant images provided excellent separation of the three major rock sequences in the field area: meta-clastic, carbonate, and volcanic rocks. However, differentiation of rock types within these groups was not better than the discrimination provided by TM data.

The Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) is an experimental airborne sensor developed by NASA, a prototype to the High resolution Imaging Spectrometer (HIRIS) that is planned for deployment on the Space Station's first polar orbiting platform in the mid-1990s. AVIRIS records reflected solar radiation in 220 contiguous spectral bands between 0.4 and 2.45 fm at 20-m spatial resolution, thus providing a detailed spectrum for each 20-m X 20-m ground pixel imaged. AVIRIS data acquired over the Drum Mountains, unfortunately, were characterized by a low sign-to-noise ratio in the 1.85 to 2.45 fm region, thereby inhibiting evaluation of the utility of AVIRIS data for geologic studies in semiarid terrains. Some success in analysis of AVIRIS data was achieved by digitally matching AVIRIS image spectra with laboratory spectra of known minerals and with spectra measured in the field using a portable field spectrometer.

Capabilities to interpret geologic information from remotely sensed data have improved significantly since the launch of Landsat 1 as a result of advancements in sensor technology. Sensor spectral characteristics and spatial resolution are the variables that most dictate the types and amounts of geologic information available from the data. More comprehensive interpretations typically result from the application of multiple sensors. Sensor evaluation studies in the semiarid and geologically diverse Drum Mountains are continuing with evaluation of a second AVIRIS data set and with evaluation of data recently acquired by 24-channel and 63-channel airborne multi-spectral scanners.

<u>Reviewer's note</u>: The DOE should be encouraged to consider the techniques presented above as part of resource assessment studies at Yucca Mountain and analogue areas.

HYDROTHERMAL ALTERATION AT THE CALICO HILLS, NYE COUNTY, NEVADA

by

F. W. Simonds and R. B. Scott, U.S. Geological Survey

Presence of a high-level epithermal system is suggested by a study of hydrothermal alteration and hot-spring deposits in Miocene volcanic rocks at the Calico Hills in south-central Nevada. The Miocene rocks consist of a sequence of silicic ash-flow tuffs and rhyolitic lavas that were erupted from the nearby Timber Mountain-Oasis Valley caldera complex. The Miocene section is gently domed, exposing a central core of middle Paleozoic shales and carbonate rocks. Doming and hydrothermal activity are attributed to a pre-9 Ma intrusion postulated on the basis of geophysical data and the distribution of hydro-thermal effects. The entire stratigraphic section is broken by high-angle and low-angle normal faults that were active between 13 and 9 Ma. The low-angle normal faults, probably related to regional extension, occur in both the Paleozoic and Miocene sections and locally between the two sections.

Pervasive silicification of the Miocene volcanic rocks is the dominant type of alteration in the Calico Hills. Comparison of altered rocks with unaltered counterparts indicates that hydrothermal fluids leached calcium, sodium, iron, and manganese from the volcanic rocks and redistributed potassium and aluminum. A potassium-silicate alteration assemblage is represented by disseminated pyrite and adularia that occur with silicification in stratigraphically and structurally controlled zones. Locally, silicification is overprinted by intense alunite metasomatism beneath paleo hot-spring sinter deposits. The hot-spring deposits occur as small vents along fault scarps and as a thick apron around one large area of hydrothermal explosion breccia. The presence of hydrothermal breccias indicates periods of self-sealing and rupture, conditions sometimes favorable for precious-metal mineralization. Minor element analyses of samples from hot-spring sinter and adjacent silicification do not show a geochemical signature indicative of mineralization. However, limited analyses from the Paleozoic shales show enrichment in arsenic, antimony, copper, lead, and zinc, along with traces of silver and gold. The pattern of alteration indicates an early stage of potassium-silicate alteration followed by an acid-sulfate stage associated with hot-spring formation. The apparent lack of precious metals in both stages of alteration suggests that the system was barren. However, the possibility that mineralization could be contained in the shales at depth needs further examination 1/.

1/This may also be the case for underlying Paleozoic rocks at Yucca Mountain.

FAULT-RELATED GOLD MINERALIZATION: ORE PETROLOGY AND GEOCHEMISTRY OF THE MORNING STAR DEPOSIT, CALIFORNIA

by

Ronald Wynn Sheets, Virginia Polytechnic Institute and State University,
Kent Ausburn, Vanderbilt Gold Corporation,
and Robert J. Bodnar and James R. Craig,
Virginia Polytechnic Institute and State University

The Morning Star gold deposit is hosted by the Ivanpah granite in the hanging wall of the Morning Star Fault, eastern Mojave Desert, California. Disseminated base- and precious-metal mineralization is confined to quartz ± carbonate veins and stockwork breccias that occur as (1) a tabular body of high-grade ore subparallel and adjacent to the Morning Star thrust fault and (2) small pockets at high structural levels of the hanging wall. Mineralized veins and breccias cut mylonites associated with the thrust fault, but no mineralization has been found within the mylonites or clay fault gouge that decorates the present fault zone. Early quartz ± carbonates ± galena veins show evidence of crystal plastic deformation, whereas the remaining mineralization is post-tectonic and was deposited in open fractures.

Ore petrography and electron microprobe analyses have identified two stages of hypogene mineralization, designated primary and secondary, that were deposited under different physical and chemical conditions. Primary mineralization consists of early quartz, pyrite, sericite, hematite, and ilmenite, followed by carbonates, galena, and electrum, and finally by chalcopyrite, sphalerite, and silver-bearing tetrahedrite. Electrum was deposited during the primary stage of mineralization as free grains in quartz and with galena as inclusions and fracture fillings in pyrite. Based on fluid inclusions and mineral equilibria, primary stage mineralization formed between 280 and 450°C at a high sulfur activity relative to secondary mineralization.

Secondary mineralization consists of minor pyrite and hematite, occurring as overgrowths on original grains, and carbonates. Covellite, digenite, acanthite, uytenbogaardtite (Ag_3AuS_2), and electrum also occur during the early part of the secondary stage. The remaining minerals in the secondary episode -- malachite, azurite, tenorite, goethite and native Bi -- are clearly supergene and may constitute a tertiary episode of mineralization. During the secondary stage of mineralization, electrum occurs (1) intergrown with acanthite and/or uytenbogaardtite containing inclusions of covellite and (2) as rims around primary electrum grains. The difference in electrum fineness between the two stages of mineralization is distinct; the fineness of primary-stage electrum is restricted to between 630 and 690, whereas secondary-stage electrum is greater than 820. Secondary mineralization was deposited below 135°C, but no minimum temperature has been established. The secondary stage is believed to be a low-temperature hydrothermal episode of mineralization that has enhanced the ore grade.

Geochemical analyses of samples from the main tabular ore body adjacent to the fault indicate a strong positive correlation between Au and Ag and Cu, Mo, Pb, Bi, and Sn. The Pb and Cu are associated with electrum of the primary stage of mineralization as galena and chalcopyrite, respectively, and Cu and Bi occur associated with electrum in secondary mineralization as covellite and native Bi. The origin of the Mo and Sn anomalies is as yet unknown, because no Mo- or Sn-bearing minerals have been identified.

CONCEALED MINERAL DEPOSITS IN NEVADA: INSIGHTS FROM THREE-DIMENSIONAL ANALYSIS OF GRAVITY AND MAGNETIC ANOMALIES

by

Richard J. Blakely and Robert C. Jachens, U.S. Geological Survey

Pre-Tertiary basement is exposed over only about 20 percent of Nevada, yet this 20 percent is host to an estimated two-thirds of the base- and precious-metal deposits and prospects in the State. Basement rocks buried beneath Cenozoic volcanic and sedimentary deposits presumably are similarly endowed and could be targets for mineral exploration in areas where the Cenozoic cover is thin. Interpretation of gravity data provide information on the depth to basement beneath Cenozoic cover and thereby help identify accessible target areas. Magnetic interpretations complement gravity interpretations by providing the location of shallow igneous rocks, and important constraint for regional mineral appraisals insofar as igneous rocks are associated with mineral commodities.

Analysis of regional gravity data from Nevada was undertaken with two main objectives: to define the location and shape of the surface of pre-Tertiary basement and to produce a gravity map that reflects variations of density within the pre-Tertiary basement. Both objectives contribute directly to the analysis of mineral resources of Nevada, the first by specifying the three-dimensional distribution of potential host rocks, and the second by placing constraints on the permissible lithology of concealed basement. We have developed an iterative method which, for the most part, succeeds at this task.

The dominant, first-order feature of the basement gravity of Nevada is an enormous area of low gravity that spans the entire state between lat 37° and 40.5° N. The regional gravity low reflects sources within the pre-Tertiary basement, but its strongest geologic correlation is with the distribution of middle Tertiary silicic ash-flow tuffs. The broad gravity low may reflect silicic intrusions within the middle and upper crust that are the counterparts of the volcanic rocks at the surface.

The map showing the thickness of Cenozoic cover suggests that a vast area of Nevada is underlain by basement at relatively shallow depth. Although about 80 percent of the State is covered by Cenozoic deposits, these deposits are thicker than 1 km only over about 20 percent of the State. Consequently, 60 percent of the State is covered by Cenozoic deposits sufficiently thin that pre-Tertiary basement rocks are within reach of current exploration techniques. A large area in the extreme northwestern corner of Nevada is blanketed by an extraordinarily thick volcanic sequence, and the crust in this part of Nevada must be dramatically different from anywhere else in the State.

A regional aeromagnetic survey, acquired as part of the National Uranium Resource Evaluation (NURE) program, also was used in our interpretations. NURE profiles were measured approximately 120 m above terrain, and this low altitude provides a significant advantage in the detection of shallow magnetic sources. Areas of Nevada with magnetic sources interpreted to be within 1 km of the surface were determined by both qualitative and quantitative techniques. This analysis shows that 46 percent of the State of Nevada is underlain by magnetic sources within 1 km of the surface, a testimony to the widespread magmatic events that accompanied the Mesozoic and Cenozoic tectonic development of this region.

Previously published aeromagnetic compilations show a narrow anomaly with north-northwest trend extending 280 km through north-central Nevada, and the feature has been interpreted as a rift zone active during the middle Miocene. Two hot-spring gold deposits are associated with basaltic rocks of the northern Nevada rift. Our interpretation of NURE profiles suggests that the northern Nevada rift extends considerably farther to the south-southeast, to at least lat 38° N. Magnetic sources in this southern part of the rift are obscured by nonmagnetic cover less than 1 km thick in most locations. By analogy with the northern part of the rift, they may be targets for hot-spring gold and mercury deposits.

Magnetic anomalies in the Walker Lane belt of southwestern Nevada have arcuate, northwesterly trends generally parallel to the Walker Lane. This pattern extends considerably northeast of the Walker Lane and may indicate an underlying tectonic fabric older than modern topography and exposed geology. All of the volcanic-hosted epithermal deposits in southwestern Nevada are located within this magnetic zone. Cox and others (this volume) proposed that late Tertiary faulting influenced the present-day magnetic anomaly patterns and was partially responsible for this regional distribution of volcanic-hosted deposits.

Reviewer's note: The above techniques may be of value to DOE in resource assessment.

GEOLOGY AND MINERALIZATION OF THE GOLD ACRES DEPOSIT, LANDER COUNTY, NEVADA

by

Stanley T. Foo and Robert C. Hays, Jr., Cortez Gold Mines

The Gold Acres disseminated gold deposit is situated on the eastern flank of the northern Shoshone Range, in Lander County, Nevada, approximately 47 km southeast of Battle Mountain. Elevated base metal values occur within adjacent skarn. Although gold distribution fits into a distinct zonation pattern with base metals, it is thought to be related to a younger mineralizing system.

Historically, both underground and open-pit mining of the area have occurred intermittently since 1935. Currently, open-pit methods are being used to exploit the remaining refractory reserves in and around the existing pits. Minable reserves are estimated at 2.2 Mt that average 0.118 troy ounces per short ton. Additional geologic reserves have been identified, totaling approximately 1.3 MT grading 0.089 troy ounces per short ton.

The stratigraphy of the region consists primarily of Paleozoic units of the upper and lower plates of the Roberts Mountains thrust, as well as younger sedimentary rocks. Igneous rocks in the area include a granitic stock of Cretaceous age beneath the deposit and Tertiary stocks, dikes, and volcanic units. Gold ore is hosted primarily in the Silurian Roberts Mountains Formation.

Important structural features within the deposit include the northwest-trending Roberts Mountains thrust and a lower imbricate thrust zone contained in the Silurian Roberts Mountains Formation. Northeast-trending high-angle structures are also important.

Alteration in the deposit includes silicification, carbonization, argillization, and oxidation. Carbonization is the most prominent alteration associated with the gold ore zone. Skarn formed in the lower plate carbonate units is also prominent within the deposit but is generally associated with waste zones.

Gold mineralization is thought to be associated with an epithermal system that postdates base-metal deposition. Reserves remaining at Gold Acres are typified by their carbonaceous and sulfidic character. Pyrite is the primary sulfide viewed in ore specimens. As and Tl 1/ display the best correlations with gold.

1/Anomalous thallium is reported at Bare Mountain and Yucca Mountain.

PRECIOUS METAL DEPOSITS, STRUCTURAL BLOCKS, AND VOLCANISM IN THE SOUTH-CENTRAL NEVADA STRUCTURAL ZONE

by

John C. Kepper, Consultant,
Thomas P. Lugaski and William Aymard,
University of Nevada, Reno

Several regional fault-bounded structural blocks make up the south-central Nevada structural zone. These blocks are associated with extensive Tertiary volcanism and precious-metal mineralization. Three of the blocks are part of a regional east-west structural grain that includes the Coaldale-Excelsior-Warm Springs (CEW), Pritchard Station, and Pancake blocks. The Goldfield and Cactus Flat blocks are fault-bounded, polygonal structures. Although gold and silver deposits occur in all of the blocks, the most productive may be the CEW block that is characterized by a swarm of en echelon fault segments similar to productive regions along the Walker Lane. En echelon, overstepping strike-slip faults and fault-bounded polygons have the potential for pull-apart and rotation-about-a-vertical-axis kinds of movements. These would result in opening of permeable zones along the bounding faults, and the creation of extensive "plumbing systems" to feed volcanic and hydrothermal deposits. However, the fault systems that define these structural blocks must be delineated first. To this end, Landsat Thematic Mapper data were used in combination with regional geophysical and geologic data to determine the distribution and orientation of the faults bordering these blocks.

The correspondence of the south-central Nevada structural zone with the area of overlap between the lower Tertiary and upper Tertiary volcanic units and the presence of detachment structures suggest that in mid-Tertiary time the region was characterized by a thin brittle zone underlain by a shallow zone of ductile extension and by high heat flow. Detachment of structural blocks, perhaps involving pull-apart and/or rotation, may have formed extensive "plumbing systems" that account for the association of precious-metal deposits and volcanism in south-central Nevada 1/.

1/Detachment, pull-apart, and rotation has been reported at Bare Mountain.