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Some Current Research in Eastern Nevada and Western Utah

by the U.S. Geological Survey

The following papers were presented as posters or oral presentations at a meeting in Elko, Nevada, on September 19 and 20, 1991, sponsored by the Elko Chapter of the Geological Society of Nevada. The purpose of the meeting was to present some of the current research and activities of the U.S. Geological Survey in eastern Nevada and western Utah.

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PROGRESS ON STUDIES OF THE GEOLOGIC SETTING OF MIOCENE VOLCANIC ROCKS AT THE SLEEPER GOLD-SILVER MINE, HUMBOLDT COUNTY, NEVADA

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The Sleeper gold-silver deposit occurs in a local Miocene volcanic field 40 km south of the McDermitt caldera complex of northwest Nevada. New exposures in the mine and drill cores have provided information on the covered Miocene section that is 0 to >500 m thick at the mine site and unconformably overlies Mesozoic basement. This Tertiary section consists of about 180-400 m of volcaniclastic sedimentary rocks and interbedded intermediate-composition flows, overlain by 0 to 310 m of rhyolite porphyry flows, which in turn are disconformably overlain by 0 to 80 m of Quaternary fluvial and lacustrine deposits. The sedimentary rocks are chiefly massive to weakly bedded, clay-rich deposits of probable lacustrine airfall tuffs; they are interbedded with fluvial conglomerate in the lower part of the section, and with increasing amounts of andesitic flows and flow-breccias in the upper half. Basaltic flows and lapilli tuff are locally present at the top. The rhyolite porphyry generally has consistent composition with local zones of vesicular texture, flow breccia, and variable phenocryst proportions. Geochemistry of Cr, Nb, Ni, Sc, Th, Ti, Y, and Zr can be used to distinguish these units in all but extremely altered rocks; megascopic identification of volcaniclastic rocks in cuttings is very difficult.

The rhyolite flow, originally >300 m thick and glassy, was favored for bonanza veins, stockwork fractures, and hydrothermal breccias that collectively contain >90 percent of ore. The rhyolite is devitrified and silicified over broad areas peripheral to the deposit; glassy groundmass persists in local zones 10-30 m thick more than 250 m west of the orebody. Dikes and sills of rhyolite porphyry are recognized in cores, but details of flow directions for the flows have not been determined. Where visible, flow banding has a low angle; we have no evidence for a domal structure. Rhyolite flows are found up to 2.4 km east and southeast of the mine, but not to the northeast, and the western extent is not defined by drilling in Desert Valley. The flows, and underlying units, may be restricted to a small area, perhaps by a graben reflecting earliest Basin and Range extension.

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The volcaniclastic sedimentary rocks and andesite-basalt flows are pervasively altered in the mine area (within 1 km of ore). Pyrite-marcasite is notably present in most of this alteration, and is abundant (>5 percent) in vesicular flows. Calcite-chlorite alteration is present >300 m from ore. The age(s) of FeS_2 and alteration in rocks below and distant from ore has not been determined, but could represent earlier stages of an evolving hydrothermal system and might have implications for sources of metals and ore fluids.

Ages of rhyolite porphyry and ore formation are roughly 16 Ma according to available information. The rhyolite porphyry is judged to be older than the 15.6 Ma peralkaline ashflow tuff of Long Ridge, which is more than 80 m thick 3 km northeast of the mine but is apparently eroded at the mine. Geochronology of volcanic rocks and ore stages are under study by E.H. McKee, USGS.

COMPARISON OF BASIN GEOMETRY AND FAULTING STYLES ALONG A REGIONAL SEISMIC-REFLECTION PROFILE FROM RAILROAD VALLEY TO LAKE VALLEY, NEVADA

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Two seismic reflection lines which together compose a 90-km-long east-west profile at ~38°25'N latitude in east-central Nevada help to define the structure beneath Railroad Valley, White River Valley, and several other valleys and ranges to the east. The Cenozoic evolution of this region was dominated by west-dipping normal faults. Preliminary seismic interpretations

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are being integrated with ongoing geologic mapping, gravity and magnetic studies, and with drill hole data along this transect.

The seismic lines used in this study were recently purchased, with limited publication rights (1:100,000 scale without shot points), by the U.S. Geological Survey from Professional Geophysics Inc. (PGI). The seismic lines were recorded in 1984 using a 1024-channel sign-bit system (10-ft groups with zero offset)--this provides excellent resolution, especially in the shallow part of the section. Locations of PGI seismic lines ECN#1 and ECN#2 are shown on the 1:250,000-scale centerfold Geologic Map. Preliminary interpretations discussed below are based on processing by the contractor; the U.S. Geological Survey is, however, currently reprocessing these lines and is integrating them with synthetic seismograms and other well data.

In the Grant Canyon oil field on the east side of Railroad Valley, a gently west-dipping (~25°) normal fault appears to have controlled Neogene basin development. The fault is clearly defined by fault-plane reflections and by terminations of east-dipping reflections from Tertiary and Paleozoic strata that have been rotated toward the fault; the fault projects eastward to nearby outcrops of a major low-angle extensional fault mapped in the Grant Range (Lund and others, this volume). Complex reflection patterns in the hanging-wall probably correspond to chaotically faulted Paleozoic rocks similar to those exposed nearby in the Grant Range. A steep gravity gradient and a line of springs along the east side of the valley suggest the presence of listric normal faults that merge into the low-angle fault at depth. There is no evidence for significant offset of the low-angle fault by younger steep faults. Prominent subhorizontal reflections from volcanic horizons underlie the central and western part of the valley and continue without major interruption into the Bacon Flat area. Because these strata are not significantly rotated, it is reasonable to infer the presence of an antithetic (east-dipping) normal fault in the vicinity of the Grant Canyon field; such a fault would define the western boundary of the "hanging-wall chaos."

White River Valley at this latitude consists of three east-dipping half-grabens and two intervening basement highs. Two half-grabens in the western part of the valley are bounded by west-dipping faults with intermediate to steep dips. The largest half-graben occupies the east side of the valley and is bounded on the east by a steeply west-dipping normal fault that is expressed on the surface by a line of springs. A prominent, gently west-dipping reflection beneath the easternmost part of the valley underlies east-dipping basin fill and resembles a low-angle normal fault. Such a fault has been mapped farther north in the adjacent Egan Range, where the range-front extends farther west.

East-dipping reflections in the southern Egan Range correspond to a homoclinal Paleozoic sequence overlain by a veneer of Late Cretaceous and early Tertiary rocks. These reflections continue to the east beneath Cave Valley, which is bounded on the east by a moderately west-dipping normal fault that may become listric at depth. The deepest basin-fill strata dip eastward (toward the fault), but most of the basin-fill produces subhorizontal reflections; deposition of these flat strata apparently post-dated Neogene faulting. These patterns are similar to those in the center of Railroad Valley and suggest that rapid, short-lived Neogene extension produced this basin.

To the east, the north end of Muleshoe Valley is characterized by a narrow "sag basin" pattern between the southern Schell Creek Range and Dutch John Mountain--Muleshoe Valley has no well-defined bounding faults. Lake Valley on the east end of the profile, is a broad, complex basin containing normal faults with opposing dips. The progressive steepening of westerly dips in basin-fill beneath the west side of the Lake Valley basin suggests the presence of a major east-dipping listric fault.

GEOLOGY AND ORE DEPOSITS OF THE VALMY AND NORTH PEAK QUADRANGLES, BATTLE MOUNTAIN MINING DISTRICT, NEVADA

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As many as 12 sedimentary rock-hosted and other types of Au-Ag deposits have recently been discovered in the northwestern part of the Battle Mountain mining district in the general area of the historic workings at the Marigold mine. These deposits (including Lone Tree, Stonehouse, 8-South, Top Zone, and Red Rock) are mainly in a 5-km-wide zone astride the projection to the south of north-south aligned ore zones at the Chimney Creek and Rabbit Creek deposits, about 75 km to the north. The 8-South deposit, the largest deposit present near the old Marigold mine, formed, presumably during the Tertiary, mainly as replacement of Pennsylvanian and Permian Antler sequence rocks that are tectonically below the Mississippian, Pennsylvanian, and Permian Havallah sequence in the upper plate of the Golconda thrust. Emplacement of the Golconda allochthon occurred subsequent to the early Late Permian and prior to deposition of the Permo-Triassic Koipato sequence in the Tobin Range. As previously

determined elsewhere in the mining district, the rocks of the Havallah sequence here also apparently acted as impermeable barriers to precious metal-bearing, epigenetic hydrothermal fluids. A relatively minor amount of ore is present in some of these deposits in mineralized faults that cut rocks of the Ordovician Valmy Formation.

Geologic studies of the Havallah sequence in the Valmy and North Peak 7-1/2 quadrangles, completed in 1990 and supported partly by the Nevada Bureau of Mines and Geology, have shown that the Golconda allochthon is made up of at least six tectonostratigraphic packets of rock whose most widespread sequences include distinctive Mississippian ribbon chert, basalt, and (or) volcaniclastic sand sequences near the local tectonic bases. In individual tectonic packets, these rocks are commonly overlain by a clastic-dominant assemblage of rocks, including calcite-cemented quartz sandstone, siltite, sandy bioclastic limestone, and calcareous pebbly conglomerate, together with variable amounts of black sponge-spicule-bearing chert and micrite. The bulk of the rocks in the Golconda allochthon seemingly are correlative with lithotectonic unit 2 as described by Murchey (1989, Ph. D. thesis, U.C. Santa Cruz) in the Willow Creek area of the mining district. In addition, hemipelagic argillite and siliceous argillite containing minor chert that crop out just to the south of the Stonehouse deposit in the northern Havallah Hills provisionally have been correlated with Pennsylvanian and Permian lithotectonic unit 1 of Murchey. The hemipelagic argillite and argillite unit is in thrust contact with overlying rocks of lithotectonic unit 2. Hemipelagic argillite and siliceous argillite also crop out near the trace and inferred trace of the Golconda thrust in the general area of the historic Marigold mine, and these rocks can be used as tectonostratigraphic markers indicative of the nearby presence of the sole of the Golconda allochthon. The hemipelagic argillite and siliceous argillite unit crops out discontinuously for approximately 8 km south from the Marigold mine, generally within 0.8 km of the trace of the Golconda thrust. Approximately 1.6 km northwest of the abandoned Oyarbide ranch, the hemipelagic argillite and argillite unit is folded into a broad open anticline whose hinge line has a northwesterly trend. The trace of this hinge line should be one of the most likely sites to penetrate the sole of the Golconda thrust at relatively shallow depth and thereby test rocks below the thrust for mineralization. In fact, broad open folds are fairly common throughout the Golconda allochthon in the quadrangles and the folds generally have north-south trending hinge lines. These folds probably formed at the same time as the east-directed tectonic emplacement of the allochthon. In places, the location of some north-south-striking faults, weakly mineralized during the Tertiary, may have been

controlled initially by the presence of shattered hinge lines of the open folds developed during regional thrusting.

Relatively recent dip-slip displacements of some magnitude also occurred in the area along range front-forming, northeast-striking faults that post-date mineralization and that parallel other post-mineral faults along the regionally extensive Midas trend. Offset Tertiary gravels along the Oyarbide fault, down dropped block on the northwest, suggest a dip-slip component of displacement of approximately 700 m; such offsets may have occurred during the last 3-4 m.y.

STRATIGRAPHY AND STRUCTURE OF THE NORTHERN PANCAKE RANGE, NYE COUNTY, NEVADA: A PROGRESS REPORT

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In order to test the hypothesis that a Cretaceous thrust belt extends northward through Railroad Valley, Nevada, I have examined the northwestern Grant Range, mapped by Karen Lund and others, on the east side and the northern Pancake Range on the west side of Railroad Valley. I saw no unequivocal evidence of regional thrusting or compressional tectonics in the northwestern Grant Range.

On the west side of Railroad Valley, I observed large-scale compressional features in the Pennsylvanian and Permian(?) rocks of the northern Pancake Range. There, 10 km west of Duckwater, the primary N-S ridge of the northern Pancake Range represents the overturned west limb of an east-vergent south-plunging syncline. Beds on the west limb dip 82°E to 45°WSW and are chiefly overturned. Three sequences of synorogenic deposits are present on the west limb: (1) Upper Mississippian Diamond Peak silica-cemented, chert-clast conglomerate; (2) chiefly Pennsylvanian Ely Limestone, the upper part of which contains several matrix-supported chert- and limestone-pebble conglomerate beds, as much as 4 m thick; (3) a Permian(?) limestone- and chert-clast conglomerate, with interstratified red, gritty, calcareous sandstone and siltstone, which appears to lie conformably on Lower Permian platy, aphanitic limestone. This latter conglomeratic unit had previously been mapped as Cretaceous Newark Canyon Formation. As it is folded conformably with the underlying Permian and Pennsylvanian

sequence and appears to be the youngest unit involved in folding, the age of this unit is critical in establishing the maximum age of compressional tectonism in and around Railroad Valley.

Structural investigations in the northern Pancake Range are underway. My recent mapping shows that the east limb of the syncline north of McClure Spring exposes the Pennsylvanian-Permian contact, which appears to be disconformable, with local relief of generally less than one meter. There, the conglomeratic upper Ely Limestone is well exposed; the upper contact lies about 10 m above a conspicuous red calcareous mudstone and just above the coarsest conglomerate in the area (maximum chert-clast size of 0.25 m). The larger chert clasts are well rounded. Limestone clasts are also present and include fragments of large rugose corals. The east limb dips 23° to 80° SW, exposing about 260 m of upper Ely. This dipping panel of synorogenic conglomerates and interstratified marine limestones also forms the west limb of a nearly isoclinal anticline. The east limb of the anticline is onlapped by Oligocene ash-flow tuffs which locally dip 12-14° NE. If the bounding unconformity is rotated to horizontal, the anticline-syncline pair becomes more upright but is still east vergent. If the Permian(?) synorogenic deposits, formerly considered Cretaceous, prove to be Permian, then the foldbelt in the northern Pancake Range may be Permian, Triassic, or Jurassic in age and unrelated to the Cretaceous Sevier thrust belt of Utah.

LATE PLIOCENE AGE OF BASIN FILL ABOVE THE RABBIT CREEK GOLD DEPOSIT, HUMBOLDT COUNTY, NEVADA

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Basin-fill alluvium mapped as Quaternary gravel conceals gold deposits east of the Osgood Mountains, Humboldt County, Nevada. Open-pit mining of the concealed deposits presents an opportunity to study the basin fill. The alluvium is a very poorly sorted, variably indurated conglomerate with a mean grain size ranging from medium-grained sand to pebble. Study of a 140-m section of core above the Rabbit Creek gold deposit showed a significant change in the proportions of clast types at a depth of about 90 m. Limestone makes up 35% of the clasts in the upper 90 m, but only 5% of the clasts in the lower 50 m; siltstone and metasedimentary rocks make up 26% of the clasts in the upper part versus 54% in the lower part; mafic volcanic clasts are 7% (upper part) versus 4% (lower part); silicified rocks are 10% (upper) versus 4% (lower). The change in proportions of clast types reflects a change in the source area (the northern Osgood Mountains and Dry Hills area).

Several samples of volcanic ash were collected from local lenses of channel fill cutting the alluvium about 30 m below the surface. The ash consists of about 70-90% coarse-sand-size glass shards with bubble-wall and bubble junctions (refractive index of about 1.500). Heavy-minerals, many with glass adhering to crystals, include zircon, magnetite, ilmenite, and two pyroxenes. Apatite is lacking in all samples. Six zircons per sample were visually selected to represent the youngest population and were dated by fission-track methods. Visual inspection and excessive scatter in the single-grain ages from all three samples indicate the presence of both primary volcanogenic and detrital zircons. Deleting the statistically older grains from the data set resulted in ages of 2.8±0.8 Ma (4 grains) and 2.7±1.0 Ma (5 grains) for two of the

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samples. We suggest that the two Late Pliocene ages represent the age of the volcanic ash and of the enclosing alluvium at 30 m. Thus, all deeper alluvium is Pliocene or older and the change in source area occurred before 3 Ma. All grains in the third sample yielded older ages and are probably detrital. The youngest grain counted in this sample was 7.9±2.3 Ma, possibly placing a minimum age on rocks exposed in the source area.

THE BASAL TERTIARY UNCONFORMITY IN CENTRAL ELKO COUNTY, NEVADA

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Basal Tertiary rocks in central Elko County are 39 to 41 Ma (upper Eocene) rhyolite ash-flow tuffs and andesitic flow breccias. Late Eocene volcanism began with the eruption of several rhyolite ash-flow tuffs that filled topographic lows and probably covered most if not all of the region. Andesitic flow breccias were erupted following the initial ash-flow events, with subordinate ash-flow events occurring during and after the andesitic eruptions. Sources of the ash-flows and flow breccias have not been identified. However, features in the flow breccias suggest many local vents. These rocks overlie folded and faulted Devonian to Triassic strata. Based on the limited number of localities where these Eocene rocks are in depositional contact with the pre-Tertiary rocks and on the areal distribution of pre-Tertiary rocks, the early Tertiary topography was of low to moderate relief cut primarily on Permian and Triassic rocks. Pre-Tertiary west-northwesterly-trending high-angle faults and low-angle "thrust" faults are locally overlain by the ash-flow tuffs.

On the east side of the southern Snake Mountains, seven miles north of Wells, ash-flow tuffs (circa 40 Ma) unconformably overlie early Mississippian sandstone that is juxtaposed against Permian limestone and chert and Triassic shale and limestone along a west-northwest-trending high-angle fault. This fault is interpreted to be part of the west-northwest-trending Wells fault system, a Mesozoic structure with right slip of approximately 40 miles. An ostracod-rich limestone (Eocene?) underlies the basal ash-flow tuff at two localities along the unconformity, and rests on Mississippian sandstone and Triassic shale. At the southern tip of the southern Snake Mountains, three miles north of Wells, ash-flow tuffs rest

on the early Mississippian sandstone. Andesitic flow breccias are sandwiched between late Eocene rhyolite ash-flows tuffs at the southern locality. Miocene(?) lacustrine ash beds overlie the flow breccias at the northern locality and are themselves overlain by 14 Ma rhyolite flow rocks. The Tertiary and pre-Tertiary units at the northern locality dip easterly about 40°.

In the northern Pequop Mountains, on the east side of Pequop Pass (Nanny Creek area), late Eocene Tertiary volcanic rocks are preserved in a paleodepression. The basal two ash-flow tuffs (circa 40 Ma) rest on Devonian Guilmette and Mississippian Chainman and Diamond Peak formations in the center of the paleodepression. Overlying two-pyroxene andesitic flow breccias lap onto the Mississippian Diamond Peak Formation, Pennsylvanian Ely Limestone, and Permian Pequop Formation to the north. High-silica (77-80 percent) rhyolite ash-flows occur as isolated knobs in the breccia flows and are interpreted to be remnants of more extensive ash flows that are preserved in paleodrainages. Hornblende-bearing dacitic(?) flows (age unknown) overlie the two-pyroxene andesite flows. Relief in the paleodepression is at least 1,500 feet. The Guilmette and Chainman formations are juxtaposed along an east-west trending high-angle fault below the unconformity. This fault is interpreted to be related to the Wells fault system. Units above and below the unconformity dip easterly about 40°.

At the south end of the East Humboldt Range, north and south of Nevada State Highway 229, two-pyroxene andesitic flow breccias and intercalated hornblende dacitic(?) flows overlie folded and faulted Permian and Triassic strata. A K-Ar whole rock age of 32.5 ± 1.0 Ma was determined for one of the flow breccias (Snoke and Lush, 1984). However, we suspect these rocks are older, probably about 40 Ma, like those in the southern Snake Mountains; we have sampled a hornblende-rich flow breccia for $^{40}Ar/^{39}Ar$ dating. The unconformity appears to be broadly folded, but sufficient data are not yet available to support this interpretation. A basal Tertiary conglomerate occurs locally along the unconformity. At one locality, the basal conglomerate contains clasts of a rhyolite ash-flow tuff that is lithologically similar to the basal ash-flow tuffs noted in the Pequop and Snake Mountains, and clasts of ostracod-rich limestone that contain biotite flakes.

In the Windermere Hills, 20 miles northeast of Wells, ash-flow tuffs and andesitic flow breccias equivalent to the upper Eocene rocks in the southern Snake and Pequop Mountains rest unconformably on Triassic strata. A succession of fluvial and lacustrine strata, probably of Miocene age, overlie the volcanic rocks (Karl Mueller, University of Wyoming, oral commun., 1991).

A few miles southwest of Wells, near Clover Hill, rhyolitic ash-flow tuff and andesitic breccia occur in a faulted sequence of Paleozoic and Tertiary rocks. Snoke and Lush (1984) report a K-Ar age of 26.8 ± 5.0 Ma on plagioclase from rock in this sequence. These volcanic rocks, like those in the Windermere Hills, are considered to be equivalent to the upper Eocene in the Snake and Pequop Mountains; we believe the K-Ar age is too young and are presently working on dating biotite from a flow rock by the $^{40}Ar/^{39}Ar$ method.

The oldest units depositionally overlain by the Tertiary rocks are Mississippian sandstone in the southern Snake Mountains and the Upper Devonian Guilmette Formation in the northern Pequop Mountains. At both localities the units below the unconformity are cut by west-northwesterly-trending high-angle faults which do not offset the overlying Tertiary rocks. These localities may have been areas of ramping along strike-slip faults in the Wells fault system, bringing older rocks to higher structural levels, or conversely, these may have been areas of deeper erosion. The number of localities where Eocene rocks are in depositional contact with older rocks is small (probably 6-8) and thus the importance of these relationships is difficult to determine. However, in this same area, Permian or Triassic rocks are the youngest pre-Eocene strata preserved in every range. Therefore, the occurrence of late Eocene rocks resting depositionally on Devonian and Mississippian strata is significant, but we just don't know how to interpret it at this time.

Snoke, A.W., and Lush, A.P., 1984, Polyphase Mesozoic-Cenozoic deformational history of the northern Ruby-East Humboldt Range, Nevada; in Lintz, Joseph, Jr., ed., Western Geological Excursions, Geological Society of America 1984 Annual meeting, Reno, Nevada, n. 4, p. 232-260.

NEW DATA FOR JURASSIC EVOLUTION OF THE PILOT RANGE AND NEARBY MOUNTAINS, NORTHEASTERN GREAT BASIN

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Much of the data upon which tectonic models for Mesozoic evolution of the eastern Great Basin are based has historically been more intuitive than factual because pre-Cenozoic events are extremely difficult to date unambiguously. Over the last decade, substantial progress

has been made in carefully separating those data which unambiguously record Mesozoic tectonics from those that may record Cenozoic tectonics or a combination of the two. Much new data for Mesozoic tectonism in the northern Nevada-Utah border region has stemmed from combined geochronology and structural studies and, more recently, petrologic studies. Although the data are still scanty and do not uniquely confirm specific tectonic models, they nonetheless provide firm constraints for models and point to fruitful directions for future studies.

Mesozoic tectonism probably began after the last regional sedimentary rocks were deposited, but Late Jurassic plutons provide the best markers for assessing ages of structures. Mountain-building is inferred to be mid-Jurassic and younger from (1) lack of post-Lower Jurassic strata with regional affinities in the Great Basin and (2) orogenic deposits shed into basins in central Utah beginning in the Middle Jurassic.

Middle and Late Jurassic tectonism, dated by relations with widespread ~160-165 Ma plutons and dikes, varies considerably from place to place. In the Newfoundland Mountains and Silver Island Mountains of Utah, plutons were emplaced into shallow crust (<7 km) that was undergoing or had recently undergone approximately west-directed extension. In the Silver Island Mountains, that extension is probably associated with strike-slip faults that indicate NNE-directed shortening and WNW extension. In both mountain ranges, thrust faults predate the normal faults and plutons; the thrusts ramp up to the east and southeast through Ordovician strata, and probably have a few km of offset. In marked contrast, Jurassic plutons in the Pilot and Toano Ranges are deeper (~12 km) and were emplaced into ductilely deforming crust. Metamorphism in the Pilot Range produced mineral assemblages that indicate 150 °C temperature changes over just 3 km in like strata. I interpret the sharp gradients in temperature and the high T (550-600 °C) low P (3-4 kbar) assemblages nearest a Jurassic pluton to indicate metamorphism induced by magma emplacement. The pluton in the Toano Range intruded greenschist- to lower-amphibolite-facies rocks at about 3.5 kbar. Accompanying metamorphism in the Pilot Range was shortening manifested by SE-vergent huge folds and minor thrust faults.

Jurassic tectonism in the northeastern Great Basin close in time to plutonism appears to range from brittle extension and strike-slip tectonics at shallow levels in the east, to ductile shortening at deeper levels in the west. Thrust faults older than plutonism probably only slightly modified the crust, since the faults seem to be of small offset and because emplacement depths for plutons are appropriate for stratigraphic thicknesses. The data support a model for regional shortening but for which local conditions were chiefly controlled by plutonism. Oceanic plates

were subducting roughly eastward under the North American plate, probably inducing shortening within the continental plate. Three tectonic provinces in the early Late Jurassic were: (1) A province of voluminous plutons, in NW Utah, that was accompanied by widespread extension above and near the plutons. (2) A province west of the zone of plutons, in NE Nevada, in which strata were metamorphosed by sparse plutons but were not tectonically extended; these rocks continued to shorten during plutonism. (3) A province farther west (Ruby Mountains area) in which crustal shortening was of larger magnitude along the edge of the Precambrian continental crust, as suggested by Jurassic(?) high-P metamorphism. I submit that large-magnitude crustal shortening in province 3 was caused by focusing of thrust faults at a sharp bend in the ancient Precambrian crustal edge, causing overthrusting of much greater magnitude than elsewhere. If this model is correct, Jurassic tectonism in the eastern Great Basin is the result of back-arc magmatism imprinting a pronounced extensional fabric on the brittle crust inboard of weaker crust undergoing ductile shortening.

INTERRELATIONSHIP OF MINERALIZATION, VOLCANISM, AND TECTONISM, NORTHERN TUSCARORA MTS., ELKO COUNTY, NEVADA

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Introduction

The occurrence of Late Eocene-Early Oligocene volcanic-rock-hosted epithermal mineralization in the western Great Basin is uncommon despite voluminous volcanic activity in the region during this period. Thus, the latest Eocene mineralization in the Tuscarora mining district and vicinity is somewhat unique. We hypothesize that this uniqueness stems from the relative timing of volcanism and extensional tectonics in the area. Furthermore, the apparent relationship of known mineralization to specific volcanic edifices and the occurrence of volcanic

rocks for which eruptive centers only have been inferred as yet suggests that there is additional potential for late Paleogene epithermal mineralization in the region.

Geologic Setting

Volcanology

The first major pulse of volcanic activity in the vicinity of the Tuscarora mining district consists of andesitic to dacitic lavas, intrusions, and volcaniclastic deposits related to a composite central-vent stratovolcano that we informally call the McCann Creek Mountain volcano[1] (Fig. 1). The main eruptive sites of this composite mass consist of a granodiorite intrusion and swarms of closely spaced dikes. The volcaniclastic rocks form aprons around the main mass, and extensive lakes formed in a depression around the foot of the volcano. A date of 38.4 ± 1.5 (McKee and Coats, 1975) on alteration of these rocks in the Tuscarora mining district suggests a Late Eocene age for the McCann Creek Mountain volcanism.

Continuing volcanism in the region shifted to caldera-centered eruptions and more silicic compositions and lesser volumes of andesite. On the northern side of the McCann Creek Mountain volcano, a rhyolitic ash-flow, termed the "ignimbrite of Tuscarora" by Coats (1987), was erupted from what we informally call the Big Cottonwood Canyon caldera (Fig. 1). This thick, lithic-rich single cooling unit was a ring-fracture eruption that apparently filled its own depression. The tuff is very pumiceous, white and phenocrysts include quartz, both clear and smoky, sanidine, and minor biotite. Minor tuffisite dikes of a more latitic composition were intrusive into the lithic-rich tuff within the ring-fracture zone. The southern margin of the Big Cottonwood Canyon caldera truncates the northern margin of the McCann Creek Mountain stratovolcano. Andesitic dikes intrude the ring zone of the caldera, locally forming flows on the intracaldera ash-flow.

Onlapping the Big Cottonwood Canyon caldera on its northern margin are rhyodacite ash-flows erupted from a caldera we tentatively relate to ash-flows and domes in the Rock Creek mining district to the southwest and extending west of the district along Willow Creek Ridge where there is a poorly constrained, large gravity low (Erwin and others, 1985). We informally refer to this inferred volcanic center as the Toe Jam Creek caldera (Fig. 1). The tuff

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[1]Cruson and Limbach (1985) refer to this volcanic center as the Mount Blitzen caldera. We were unable to find any field evidence of caldera-like structures or deposits in the McCann Creek Mountain-Mt. Blitzen area, and therefore have not adopted their terminology. Unlike Cruson and Limbach (1985), we mapped a caldera margin immediately north of McCann Creek Mountain for a volcanic center discussed below.

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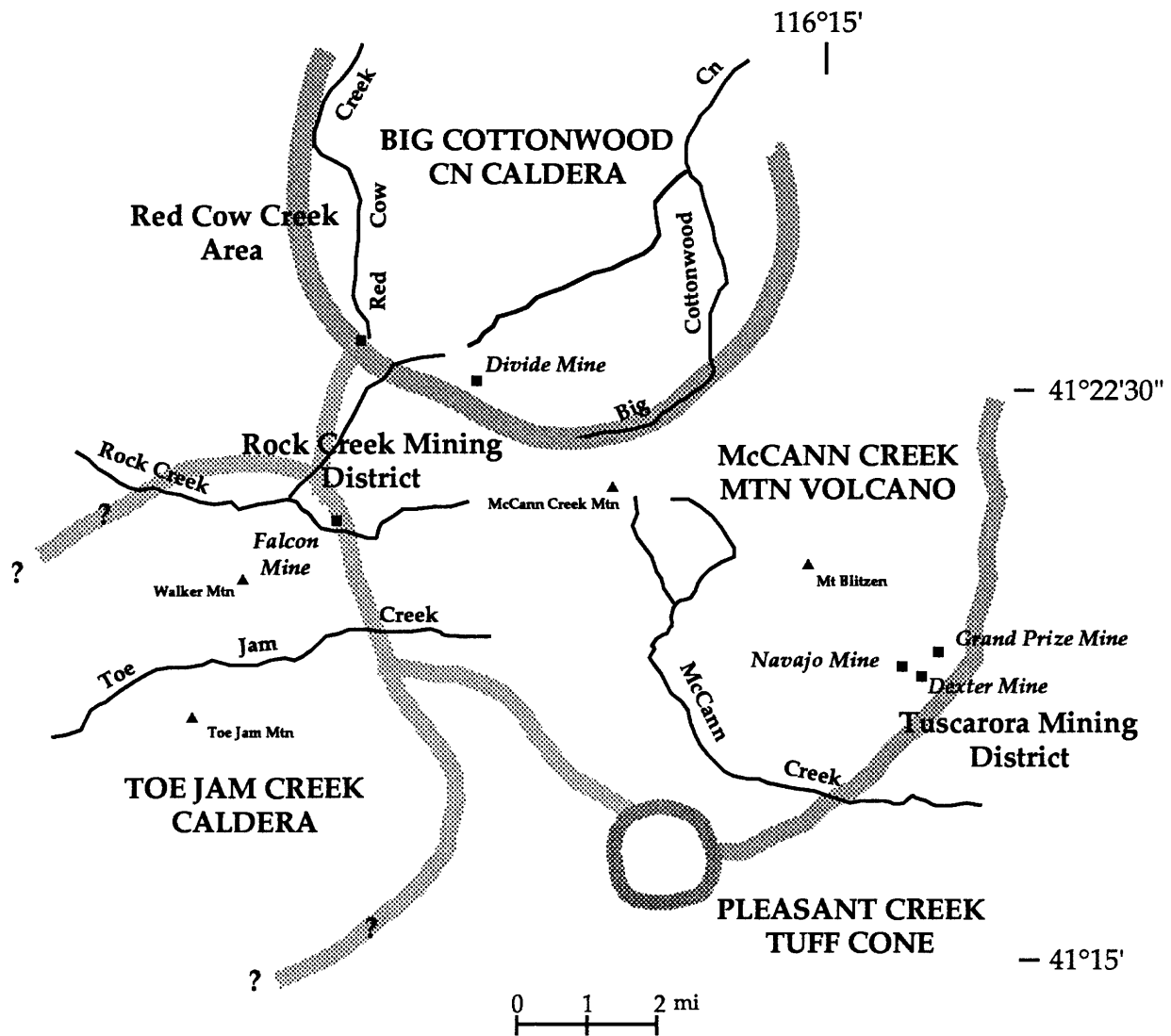Figure 1. Sketch map of the northern Tuscarora Mountains volcanic centers. The outlines of the Big Cottonwood Canyon caldera and Pleasant Creek tuff cone are based upon field mapping. The Toe Jam Creek caldera is inferred from some field observations and interpretation of geophysical data. The outline of the McCann Creek Mountain volcano is generalized from field observations and reconnaissance mapping.

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is reddish and contains phenocrysts of sanidine, biotite, wormy quartz, and minor hornblende. A dome on Walker Mountain that intrudes these rhyodacites may be a ring intrusion and has been dated at 35.4±1.1 Ma (McKee and others, 1976). This brackets the Big Cottonwood Canyon and Toe Jam Creek calderas at between ≈38 and ≈36 Ma. Andesitic intrusions and flows occur around the margin of this caldera, apparently into the ring-fracture zone.

Tectonic Setting

The Eocene volcanism in the northern Tuscarora Mountains sits astride a zone of northeast-striking Late Eocene faults. Small exposures of Paleozoic rocks within and immediately around the McCann Creek Mountain volcanic complex and megabreccia blocks within the Big Cottonwood Canyon caldera suggest that there were local "islands" of these rocks within the fault zone, with more substantial uplifted Paleozoic rocks to the south of the zone. A depression coincident with the northeast-trending fault zone is indicated by (1) small exposures of pre-volcanic conglomerates south of the Tuscarora townsite and to the northeast in the Mt. Velma 15' quadrangle (Coash, 1967); (2) lacustrine sediments interbedded with these Eocene volcanic rocks; and (3) apparent higher elevations in the southern Tuscarora Mountains and to the north in the Bull Run Mountains (cf. Hope and Coats, 1976; Coats, 1987).

Mineralization

Epithermal mineralization is associated with each of the McCann Creek Mountain, Big Cottonwood Canyon, and Toe Jam Creek volcanic centers. The Tuscarora district is associated with the McCann Creek Mountain center, the Rock Creek district includes mineralization associated with both the Big Cottonwood Canyon and Toe Jam Creek centers, and the Red Cow Creek area is associated with the Big Cottonwood Canyon caldera.

The Tuscarora mining district is located along the southern margin of the McCann Creek Mountain volcanic center, and contains the earliest dated Tertiary epithermal-style mineralization in Nevada at 38.4±1.5 Ma (McKee and Coats, 1975). Quartz-adularia±calcite veins occur both in andesitic, volcaniclastic, and lacustrine rocks. Sulfide minerals include pyrite, argentite, stephanite, pyrargyrite, proustite, sphalerite, galena, chalcopyrite, enargite, bornite, and arsenopyrite (Nolan, 1936). There are two main structural trends displayed by the veins in the district. North of the Dexter mine and west of the May-Be-So claim (Nolan, 1936), the veins predominantly strike north-northwest (western district) and are continuous with hydrothermal alteration to the north. The eastern district mines and the Dexter veins strike

predominantly northeast. The greatest silver production came from the NNE-trending eastern district veins and NNW-trending veins along the western-eastern district boundary. The Dexter mine has been largely a gold producer.

The Rock Creek mining district is situated west of Tuscarora and includes the Falcon mine near the eastern margin of the Toe Jam Creek caldera and the Divide mine on the southern margin of the Big Cottonwood Canyon caldera. At the Divide mine, fine-grained quartz-barite veins and cemented breccias occur in northeast-striking fractures, in part within the ring-fracture zone of the Big Cottonwood Creek caldera. Electrum occurs in dark, chalcedonic silica, and pyrite is abundant. Mineralization within this caldera continues to the northwest from the Divide mine into the Red Cow Creek area which adjoins the Rock Creek district. The veins in the Red Cow Creek area are similar to the Divide mine vein in that there are quartz-barite veins and cemented breccias as well as banded quartz veins.

The Falcon mine is in the main part of the Rock Creek district, where the ores appear to be controlled by faults along the eastern boundary of the inferred Toe Jam Creek caldera. The veins are north-striking and characterized by chalcedonic, banded silica and silica-cemented breccias with abundant pyrite, specular hematite, and minor cinnabar. Just west of the Falcon mine is a mercury prospect along a N5°W fault. North of the Falcon mine, silicified faults strike N5°E and also contain mercury mineralization.

Discussion

The volcanic activity at the three centers described above appears to us to be possibly part of a single evolving magmatic system or closely related magmatic systems. The clustering of the volcanic centers, the narrow temporal range of volcanic activity, the sequence of ash-flow volcanism from more rhyolitic earlier to subsequent rhyodacitic compositions, the intrusion of occasional andesites into the calderas, and the proximity of geothermal activity in the calderas to the margin of the composite stratovolcano is consistent with a zoned or closely interrelated magma system(s). Active tectonism within the northeast-trending fracture zone may have been the predominant control on the localization of the volcanic centers.

What makes the northern Tuscarora Mountains region different from other Late Eocene to Oligocene volcanic centers in the western Great Basin is that extension and basin formation were consanguineous with volcanism. Regional fault patterns and the alinement of mineralized areas suggest that extension was taking place along a northeast-trending zone of structures. Deep-crustal fracturing provided pathways for meteoric fluids, in part ponded in large lakes

surrounding the volcanic edifices, to penetrate sufficiently deep to set up convecting hydrothermal systems near the waning stage of each volcanic cycle.

The Tuscarora mineralization is interpreted to be due to the lateral flow of fluids above and away from a heat source beneath the main volcanic edifice. The main feeder zones were north-northwest trending faults, with discharge being controlled by the intersection of these fractures with basin-related northeast-striking faults. Dissimilarities between the dated Tuscarora mineralization and the ores and structural geology of the Dexter mine and the presence of 'high-level' mercury mineralization in Berry Basin may be indicative of a later mineralizing event--possibly even Miocene.

The widespread alteration and veining on the southern and western edges of the Big Cottonwood Canyon caldera coupled with the lack of mineralization along the eastern edge are suggestive that the McCann Creek Mountain stratovolcano strongly influenced the hydrology during this mineralizing period. Likewise, the main Rock Creek district mineralization (Falcon mine) may have been hydrologically influenced by the older stratovolcano. However, altered flows are crosscut by 35.4±1.1 Ma rhyodacite domes making up Walker Mountain (Coats, 1987) on the southwest side of the district suggesting that the heat source for the geothermal activity is related to the Toe Jam Creek volcanic cycle and probably not the older McCann Creek Mountain volcanism.

In the Rock Creek district and Red Cow Creek area, we interpret the chalcedonic character of the ores, the presence of cinnabar and stibnite at some localities, and locally extensive silicification of the host rocks to indicate that the exposed veins are quite shallow in their respective hydrothermal systems. This implies that the vein structures may be more prospective at deeper levels.

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GEOLOGY OF THE SOUTHERN PART OF THE
GOSHUTE INDIAN RESERVATION, NEVADA AND UTAH

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The Goshute Indian Reservation, Nevada and Utah, includes parts of the Deep Creek
Range, Deep Creek Valley, and Antelope Valley. These areas are underlain by Proterozoic
metasedimentary rocks, Cambrian to Permian siliciclastic and carbonate rocks, and Tertiary
plutonic, volcanic, and sedimentary rocks. In the southern part of the Reservation (southern
Deep Creek Range), Cambrian to Permian carbonate and siliciclastic rocks and Eocene to
Oligocene volcanic rocks are well exposed. The Paleozoic rocks are attenuated by low-angle-to-
bedding, younger-over-older faults that occur throughout the sequence but are most prominent
at the Guilmette Formation-Pilot Shale contact, in Silurian-Ordovician dolomites (Laketown and
Fish Haven Dolomites), and at the top of the Eureka Quartzite. After low-angle faulting, the
rocks were deformed into broad gentle folds which were later cut by down-to-the-west normal
faults. Mapping to date suggests that only the down-to-the-west normal faults postdate late
Eocene to early Oligocene volcanic rocks.

ECONOMIC SIGNIFICANCE OF RECENT GRAVITY AND AEROMAGNETIC COMPILATIONS OF THE WINNEMUCCA 1°X2° QUADRANGLE, NEVADA

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Since Erwin's (1974) Bouguer gravity compilation of the Winnemucca 1° by 2° quadrangle, Wagini (1986) added 117 new gravity stations, Sikora (1991) added 133 stations, and S.L. Robbins (written commun., 1991) obtained 228 stations in 1991, bringing the number of total stations now available within the Winnemucca quadrangle to 2,296. The Robbins data set is located in and around Pine Valley which is one of the two oil producing areas in Nevada. About 25% of the Robbins stations are along profiles which were established to show the style of gravity signature associated with two oil fields that were discovered by drilling over gravity highs within the basin. The remaining stations were established so that the regional gravity field is better defined and so that better structural interpretations can be made of the area.

Sikora's (1991) isostatic gravity map shows that a residual gravity low of about 32 mGal is associated with Pine Valley and that this low is the largest anomaly associated with valleys within the Winnemucca quadrangle. However, there are also significant gravity lows in the range of 27 to 31 mGal over Buena Vista, Pleasant, Reese River, and Grass Valleys which merit more detailed study. The estimated maximum thickness of Cenozoic fill in all these valleys is about 5 km based on the gravity lows and a generalized density-depth model controlled by drilling and density logs (Jachens and Moring, 1990, fig. 4). By contrast, several large valleys such as Humboldt River, Pumpernickel, northern Crescent, and Boulder Flat have associated gravity lows smaller than 10 mGal, suggesting that their maximum fill thicknesses are generally less than 1 km. Therefore these shallow valleys contain sufficiently thin Cenozoic deposits that the underlying pre-Cenozoic basement rocks are potentially within reach of current mineral-exploration techniques.

Aeromagnetic compilations of the Winnemucca 1° by 2° quadrangle are available as a mozaic of individual surveys most of which were flown at 2,700 m above sea level (Kirchoff-Stein, 1988) and as a merged map whereby the individual surveys were adjusted for different

datums, digitized, gridded, and downward continued to 300 m above terrain (Kirchoff-Stein and Hildenbrand, 1986).

A comparison of the aeromagnetic maps of Winnemucca with the 1:250,000-scale geologic compilation of Stewart and Carlson (1976) indicates that most of the magnetic highs are associated with igneous rocks, both intrusive and extrusive. For example, a nearly continuous north-northwest trending magnetic high of about 400 nT at 300 m above terrain cuts across the quadrangle about 10 km east of Battle Mountain and is associated at some locations with Miocene basaltic and andesitic extrusive and intrusive rocks (Zoback and Thompson, 1978; Hildenbrand and Kucks, 1988). The feature has been interpreted as a rift zone and shown to extend 280 km through north-central Nevada (Blakely and Jachens, 1991). Three Miocene epithermal gold deposits within the Winnemucca quadrangle are associated with the magnetic high at Mule Canyon, Fire Creek, and Buckhorn (M.G. Sherlock, D.P. Cox, J.V. Tingley, and D.F. Huber, written commun., 1991; Seedorff, 1991, fig. 11), suggesting that further exploration along the high may be appropriate.

A smaller but broader magnetic high of about 200 nT at 300 m above terrain is located over the Carara Mountains about 15 km northwest of Carlin. Three local peaks within the anomaly are associated with small outcrops of rock shown as Cretaceous-Jurassic granite on Stewart and Carlson's (1976) regional map, suggesting that the granites are continuous at depth. The maximum horizontal gradient of the pseudogravity transformation of the magnetic anomaly marks the approximate edge of the interpreted buried granitic pluton, and the northwest limb of this gradient is marked by a series of ten productive gold mines known as the Carlin trend. All the mines within the trend are classed as sedimentary rock-hosted deposits, and the gold in this area is considered by many to have been (1) concentrated by heat and fluids generated by intrusion of the nearby granites, or (2) subsequently channeled in along the contacts of the plutons (Cox and others, 1991; Bakken, 1991). Similar magnetic anomalies are present over other parts of the Winnemucca quad, and the edges of those anomalies provide targets for future exploration.

A striking aeromagnetic low of 800 nT at 300 m above terrain is present over recent alluvium in the central Reese River Valley near the southeast corner of Battle Mountain. Proximity to Tertiary volcanics within Battle Mountain suggests that the volcanics extend for about 5 km under the valley and are reversely polarized.

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GEOPHYSICAL PROPERTIES OF THE IBAPAH PLUTON, DEEP CREEK RANGE, NEVADA AND UTAH

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Density and magnetic physical property measurements and gravity data were collected in the Deep Creek Range as part of a study to geophysically characterize the Ibapah pluton. Density measurements for 59 samples show that the Ibapah pluton has an average grain density of 2.62 g/cm^3 and an average dry bulk density of 2.59 g/cm^3. These values are significantly lower than the 2.66 g/cm^3 average dry bulk density of 334 granite samples reported by Carmichael (1984, CRC Handbook of Physical Properties of Rocks, v. 3). Sedimentary and metamorphic rocks from the Deep Creek Range have an average grain density of 2.69 g/cm^3 and a range in grain density of 2.60 to 2.85 g/cm^3.

Magnetic susceptibility measurements of 59 samples of the Ibapah pluton indicate that these granitic rocks are moderately magnetic with an average susceptibility of 0.4×10^{-3} cgs with a range of 0.0×10^{-3} to 0.9×10^{-3} cgs. Magnetic property measurements for 17 granitic core samples from the Ibapah pluton yield a low characteristic or representative remanent magnetization of 0.03×10^{-3} emu/cm^3 and a Q, the ratio between remanent and induced magnetization, of 0.1. During thermal demagnetization these samples become nonmagnetic between 530° and 587° C, suggesting that magnetite is the dominant magnetic mineral.

Preliminary geophysical and physical-property data reveal that the Ibapah pluton has a density contrast of about -0.07 g/cm^3 with surrounding pre-Tertiary rocks, an associated isostatic

gravity low of 8-10 mGal, a moderate susceptibility of 0.4×10^{-3} cgs, a negligible remanent magnetization, and an associated magnetic anomaly of about 350 nT. Interpretation of these data suggests that the low-density and moderately magnetized Ibapah pluton extends to an intermediate depth of 5 to 10 km. These physical property measurements are fundamental to understanding the relationship between gravity and magnetic anomalies and the geometry of the Ibapah pluton.

GS SERIES MICROCOMPUTER PROGRAMS FOR PCs

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GSMAP and GSPOST, microcomputer programs demonstrated here in their latest versions, are two of a family designed for the Earth sciences. Both support geodetic or Cartesian coordinate systems. All require an IBM compatible personal computer with at least 512 Kbyte RAM, math co-processor chip, serial port, parallel port, graphics card, plotter that supports HPGL (Hewlett Packard Graphics Language), and digitizer interfacing with the computer through an RS232C serial port. The GSMAP system version 7.53 is a full-featured graphics program working designed for digital compilation and editing of maps and illustrations, with output to the screen, to a plotter, or to a digital file. With supporting utility programs, the system supports certain analytical tasks - computation of lengths, areas, and construction of rose diagrams. GSPOST Version 3.0 takes data from an ASCII file with row column format to make maps that display information associated with geographic points by symbol and posting of numerical values. Values can be classified into ranges (class intervals) with different symbols, different symbols sizes, and optional posting of values for each class. GSPOST's on-screen editing capability reduces or eliminates the problem of over-posting of values and can be used as an analytical tool, with direct applications to exploration geochemistry.

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DRILL HOLE HYDROGEOCHEMISTRY--A POTENTIAL EXPLORATION TOOL FOR CONCEALED DISSEMINATED GOLD DEPOSITS IN NEVADA

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Samples of water were collected from drill holes near the Pinson, Getchell, Rabbit Creek, and Chimney Creek gold deposits in northern Nevada to study the distribution of gold in the ground-water systems around concealed disseminated gold mineralization. Ground-water samples were collected during active drilling and from exploration drill holes that were several years old. The water samples from the old drill holes were collected at and below the water table using a custom-built double-check-valve bailer.

The samples were analyzed for gold at the one part per trillion (ppt) determination level by anion-exchange graphite furnace atomic-absorption spectrometry. Background for gold in the ground-water distant from these deposits was <1 ppt; in the vicinity of the deposits the gold values ranged from 2 to 310 ppt in the ground-water; and the ground-water in contact with mineralized rock contained as much as 2,800 ppt gold.

These results demonstrate that anomalous amounts of gold exist in the ground-water systems above and "downstream" from these deposits. Drill-hole hydrogeochemical techniques

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may be useful in identifying similar concealed, disseminated gold deposits in Nevada and elsewhere.

ARSENIC, ANTIMONY, AND TUNGSTEN DISTRIBUTION IN SURFACE WATER AND GROUNDWATER NEAR AND AWAY FROM CONCEALED GOLD DEPOSITS IN THE KELLY CREEK VALLEY, NEVADA

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Arsenic, antimony, and tungsten concentrations were determined in springs, surface water, and groundwater samples collected in the Kelly Creek Valley, Nevada, in order to assess the relationships of these dissolved elements with the occurrence of concealed disseminated gold deposits. Natural concentrations of arsenic range from less than 1 ug/L to as much as 1100 ug/L in the groundwater and from less than 1 ug/L to about 700 ug/L in spring and surface water samples. Antimony concentrations range from less than 1 ug/L to as much as 150 ug/L and tungsten ranges from less than 1 to 100 ug/L.

Most of the water samples were preserved with dilute hydrochloric acid to maintain the ratio of arsenite (As(III)) and arsenate (As(V)) at the concentrations that naturally occurred in the water samples. The concentration of these two forms of arsenic were then determined in the samples. The distribution of arsenic among As(III) and As(V) provides a good estimate of the oxidation-reduction conditions. When most of the arsenic occurs as As(III) the redox potential is reducing, whereas when most of the arsenic occurs as As(V) the redox potential is oxidizing. Anomalous concentrations of antimony (about 150 ug/L), tungsten (about 100 ug/L), and arsenic (about 700 ug/L with As(III) comprising greater than two-thirds of the total arsenic) were found in samples collected near the Rabbit Creek disseminated gold deposit and from a sample collected from a spring near Lone Butte.

BASAL TERTIARY VOLCANIC ROCKS AT NANNY CREEK,
NORTHERN PEQUOP MOUNTAINS, NE NEVADA

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A sequence of late Eocene andesitic to rhyolitic rocks, approximately 4,000 ft thick, is exposed near Nanny Creek in the northern Pequop Mountains, approximately 20 miles east of Wells, Nevada. This calc-alkaline sequence comprises: (1) a basal crystal-rich, biotite-hornblende ash-flow tuff (about 75 ft thick), with 68-71 weight percent SiO_2, and a $^{40}Ar/^{39}Ar$ biotite age of 41.09+/-0.16 Ma; (2) a quartz-biotite ash-flow tuff (about 175 ft thick), with 75-78 weight percent SiO_2, and a $^{40}Ar/^{39}Ar$ biotite age of 39.89+/-0.12 Ma; (3) a series (about 4,000 ft thick) of two-pyroxene andesite breccia flows and high-silica (77-80 weight percent SiO_2), crystal-poor ash-flow tuffs; and (4) a hornblende-biotite rhyolite flow (thickness unknown) with 71 weight percent SiO_2.

These volcanic rocks dip easterly about 40° and occur in what appears to be a paleodepression; the lower two ash-flow units are preserved in the axis of this depression. The basal Tertiary unconformity cuts across Paleozoic rocks from Devonian Guilmette Formation on the south to Permian Pequop Formation on the north; in addition, E-W faults cutting the Paleozoic strata terminate at the unconformity. This volcanic sequence is important in establishing the extent of Eocene volcanism in northeast Nevada. The source of these rocks has not been identified. Volcanic rocks with similar stratigraphy, rock chemistries, and ages have been found approximately 20 miles to the west in the southern Snake Mountains and with similar stratigraphy and rock chemistries 25-30 miles to the west at the northern (Clover Hill) and southern ends of the East Humboldt Mountains and in the Deadman Creek area, approximately 15 miles northwest of Nanny Creek.

MT. ICHABOD AND MAJOR GULCH, EAST OF WILD HORSE RESERVOIR

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A one-day field trip to Mt. Ichabod to see the Roberts Mountains and Golconda allochthons overlying Triassic rocks on low-angle faults; and to Major Gulch to see good exposures of well-dated strata and structures in the Golconda allochthon. Triassic rocks are deep-water turbidites of silty, argillaceous limestone and limy siltstone and sandstone. The Roberts Mountains allochthon is composed mainly of Ordovician quartzite and Silurian chert and arkosic sandstone. The Golconda allochthon is composed of Mississippian to Permian siltstone, bedded chert, argillite, conglomerate, and sporadic limestone debris flow deposits. The Golconda allochthon contains mega-inclusions of Upper Pennsylvanian to Permian strata of the overlap facies. The route follows Nevada 225 north almost to Wild Horse reservoir, east along the Charleston road to Mt. Ichabod, then east and north past Charleston to Major Gulch.