FIELD TRIP DAY FOUR
Buena Vista Hills, Humboldt Mafic Complex, Western Nevada

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Introduction

The purpose of this portion of the field trip is to examine the spatial and temporal distribution of sodium-rich hydrothermal alteration and iron oxide mineralization generated by a saline hydrothermal system driven by the Middle Jurassic Humboldt mafic complex. The Humboldt system is of particular interest because it represents a basaltic magmatic end member of intrusion-driven hydrothermal systems and, in this case, one where the fluids are largely, perhaps entirely, externally derived brines. Outcrops of Jurassic rocks within the complex record multiple, mutually crosscutting magmatic and hydrothermal events at different structural levels as exposed by mid-Tertiary extension. Mapping of selected areas across this large igneous complex allows definition of the relationships among the magmatic, structural, and hydrothermal features. In turn, these enable an interpretation of the overall temporal and spatial evolution of a large intrusion-driven hydrothermal system (Johnson and Barton, 2000). From geology and geochemistry, one can estimate that upwards of 15 billion tonnes of iron and 35 million tonnes each of copper and zinc were moved by the hydrothermal system (Johnson, 2000). What happened to these metals and what are the implications for other systems? These are among the issues to consider.

Key goals for the visit to the Humboldt complex are as follows:

1. To gain an appreciation for the scale, rock types, and hydrothermal features associated with one of many Fe oxide-rich, sodic-alteration-dominated hydrothermal systems in the Jurassic of the western United States;
2. To examine some of the key structural, igneous, and hydrothermal features, especially their crosscutting relationships and their implications for the overall time-space development of the complex;
3. To consider the geological and geochemical constraints on mass transfer in this system, and the implications for mineralization; and
4. To compare the Humboldt hydrothermal system with the Yerington district and other areas with iron oxide-rich styles of mineralization and associated sodic-calcic alteration.

There are three stops, all in the central part of the Humboldt mafic complex. The first provides an overview from the northwest end of the complex. The second focuses on albitized Jurassic sediments in the northern Buena Vista Hills. The third, composing most of the day, is a traverse through a partial cross section of intensely altered and mineralized rocks in the Buena Vista mine area in the southern Buena Vista Hills.

The best exposures of syngenetic iron oxide, copper-rich, and five-element mineralization are impractical to visit in a one-day trip. Their locations and some of their features will be briefly described as appropriate during the day.

BEGIN TRIP: Lovelock To STOP 1

From Lovelock, drive north on I-80. The drill roads and cuts on the high peak to the east (Gypsum Mountain) are development work on gypsum prospects in the Middle Jurassic Lovelock and Mittlebury Formations. These restricted-basin marine units are coeval with the quartz-sand dominated Boyer Ranch Formation, which is exposed farther to the east. All are roughly coeval with the Humboldt mafic complex.

Approximately 6 mi north of Lovelock, exit I-80 and turn right (east) onto Coal Canyon road and continue east (Fig. 1). The white dumps on the left side of the road are diatromaceous earth for the Eagle-Picher Colado Plant. The mine workings in the hills on the north side of the road are gold and antimony occurrences in the Willard District. Bentonite clay was produced from the workings on the south side of the road. At approximately 15.4 mi (9.4 mi from Coal Canyon exit) a road to the north leads to Pegasus’ Relief Canyon mine, a Carlin-type gold deposit. Gold is recovered from the leach pads in the valley, north of the road. Dumps on the skyline above the leach pads are from the Rochester open pit silver mine.

At approximately 17.8 mi (11.8 mi from Coal Canyon Exit) pull over and park on the side of the road.

STOP 1—North End of Complex, an Overview

This stop provides a south-facing overview of the western half of the Humboldt Complex. From this point, looking to the southeast we see the low Buena Vista Hills in the foreground, the Carson sink to the south, and the Stillwater Range in the distance (Fig. 1). The road crossed the north end of the West Humboldt Range in Coal Canyon and the continuation of this range is seen to the southwest. Mafic rocks of the Humboldt mafic complex are exposed in the West Humboldt Range to the southwest, the Buena Vista Hills to the south, and in the Stillwater Range to the southeast (see regional geologic map in Johnson and Barton, 2000).

The open pits and mine dumps to the south are part of the Mineral Basin district, which extends from the eastern flank of the West Humboldt Range to the western flank of the Stillwater Range. The district has produced more than 4 million tons of iron ore at an average grade greater than 50 wt percent iron (Moore, 1971). All iron produced from this district, which is the largest of several located in the Humboldt complex, has come from an area centered on the Buena Vista Hills.

The dark rocks exposed on the eastern flank of the West Humboldt Range are Tertiary-Quaternary basalts overlying
Tertiary volcanic rocks. The older rocks dip up to 60° and give evidence of the major mid-Tertiary extension seen within the complex. The light-colored rocks to the northeast are altered Tertiary felsic volcanic rocks, which host silver-antimony-mercury mineralization in the Antelope Springs district. Spectacular isoclinal folding in Lovelock assemblage rocks in the lower plate of the Fencemaker Thrust is exposed in the skyline. Movement on the thrust postdates emplacement of the Humboldt complex.

STOP 2—Northern Buena Vista Hills; Chocolate Butte; Jurassic Sedimentary Rocks, Their Alteration and Tertiary Tilting

Drive south on Coal Canyon road. Pass the road on the left (east) leading to the north end of Buena Vista Valley (18.8 mi). At approximately 21 mi take the left-hand fork (Anderson Ranch Road) and continue driving south-southeast.

The low hills to the west are composed of scapolitized and albitioned Jurassic gabbros and volcanic rocks. These hills host magnetite-dominated mineralization at the Thomas, Hematite, and SE Section 29 mines. Magnetite-rich dump material is periodically shipped from the Thomas mine to the west coast for use as concrete aggregate. The hills to the south, at one o'clock, are the northern Buena Vista Hills. Continue driving for approximately 6 mi more and turn east (left) onto the small dirt road leading to the small open pit of the American Ore mine and park (24.8 mi). The open pit and mine dumps to the west are the Segerstrom-Heizer mine which exploited magnetite replacement bodies and veins in scapolitized gabbroic and volcanic rocks. Production totaled at least 1.2 Mt tons of iron ore. Estimated reserves are greater than 35.5 Mt of ore with an average grade of 30 wt percent iron (Moore, 1971). Walk up to the lower ridges of Chocolate Butte.

The Chocolate Butte-American Ore area is one of the more accessible and interesting outcrops of the Jurassic sedimentary rocks. To the east of the American Ore mine are exposures of pervasively albitioned Boyer Ranch Formation at the base of Chocolate Butte (Fig. 2). Speed (1976) interprets the Boyer Ranch Formation as the lateral equivalent of the carbonate-evaporite rocks of the Lovelock and Muttlebury Formations exposed to the west in the West Humboldt Range (see regional geologic map in Johnson and Barton, 2000) based upon stratigraphic location and similar lithologies in the lower part of the formation. This is consistent with more recent work, including our own, which indicates a transition from a restricted saline basin into volcanic-rich basins with a fluvial or reworked eolian sand component.

Here, the Boyer Ranch Formation dips 60° E and is composed of granular to interlocking albite and rounded to sub-rounded quartz grains. Variable amounts of carbonate and limonite-hematite after black sands and pyrite define original bedding. Distinctive patches of chlorite ± tourmaline(schorl)
occur within the pervasively albited outcrops. The volcanic pile is interpreted to interfinger with the Boyer Ranch Formation here and elsewhere (Speed and Jones, 1969). Albite-albized mafic dikes intrude the arenite in the southern portion of the outcrop area. In addition to the correlation with the evaporite-bearing Lovelock and Muttlebury Formations, evaporites are reported within the Boyer Ranch Formation in the Clan Alpine and Stillwater Ranges (Speed and Jones, 1969). Tourmalines from this locality have exceptionally high δ¹¹B, > 8 per mil, consistent with a marine/evaporitic signature. These values are heavier than anything reported in the literature for a hydrothermal mineral deposit (Slack, 1996).

This area has not been mapped by the authors in detail, and thus the relationship between the albited quartzites and volcanic rocks and the iron oxide mineralization is uncertain. However, based on comparison with other areas such as in the southern Buena Vista Hills (Stop 3), the albited outcrops most likely overlie both the iron oxide mineralization and scapolite alteration.

STOP 3—Buena Vista Mine Traverse

Backtrack to the Coal Canyon road and turn south (left). The mine dumps of the Thomas mine are on the left. The dumps head on the right side of the road and are from the Ford mine. This property, originally called the Iron Horse, was discovered in 1952 and leased to the Ford Motor Company during which time a few thousand tons of iron ore were shipped to Dearborn, Michigan (Reeves and Kral, 1955). The high hills to the southeast are the Northern Buena Vista Hills. A mafic dike swarm, similar to the one at the Buena Vista mine, is exposed on the northwest side of these hills (see Johnson and Barton, 2000). Drive south past the northern Buena Vista Hills toward the Buena Vista mine area. Most of this section is paved; the last few miles are a broad but rough dirt road. At approximately 9.2 mi from the fork with the Anderson Ranch road there will be a turn to the right. Drive straight on the smaller dirt road.

Continue driving south approximately 1.6 mi to the Buena Vista Mine. As you approach the Buena Vista Mine area from the north (large dumps can be seen ahead), the first outcrops near the road are composed of pervasively scapolitized porphyritic gabbro. Outcrops higher on the hills to the east are part of the scapolitized mafic dike swarm that forms a large part of the Buena Vista Hills. The highest peak to the east is composed of northwest-trending sheeted dikes that make up greater than 75 percent of the outcrop area (Fig. 3). Pass the large dump near the road and turn east. Park on the east side of the large dump just north of the foundations of the old concentrator. The Buena Vista mine traverse begins here.

STOP 3.1—Parking area; overview of Buena Vista mine area

The Buena Vista mine area contains some of the best examples of high-temperature, pervasively scapolitized igneous rocks, lower-temperature albic and carbonate-chlorite alteration, and iron oxide mineralization. Tilting by mid-Tertiary extension exposes a contiguous section of at least 1.5 km in height through intermediate to shallow levels of the Jurassic system (Fig. 4). This area is part of a dismembered dike swarm at least 6 km in length that extends from the Anderson Ranch area 6 km to the east to sporadic exposures in the Pleistocene beach terraces west of the mine.

Magnetite-rich mineralization is present with intense sodic alteration all along this swarm. The Buena Vista mine produced more than 600,000 tons of iron ore with an average grade above 55 wt percent Fe (Moore, 1971). A resource of more than 100 Mt with >30 wt percent Fe is present (United States Steel, unpublished reports). Radtke (1962, 1964) described coulsonite, a new vanadium-iron spinel, and the geology of the iron oxide bodies in the Buena Vista mine area. Later, Nickle (1968) and Koncuk (1980) investigated aspects of the hydrothermal alteration and iron mineralization in the Buena Vista mine area.
A northwest-southeast-oriented Jurassic mafic dike swarm composed of multiple generations of dikes makes up most of the exposures around the mine and in the nearby hills. Shallow gabbroic rocks are exposed in the western portion of the area and are cut by the dike swarm. Mafic dikes both cut and feed volcanic and volcaniclastic rocks exposed upsection to the east. These relationships are shown qualitatively in Figure 4a.

The open pit and various cuts are developed within a large brecciated area that roughly parallels the dike swarm (Fig. 5a). Multiple mutually crosscutting relationships among dikes, breccias, and hydrothermal features are well exposed here. They provide some of the key evidence for understanding the time-space evolution of the complex. In general, alteration is zoned from high-temperature scapolitic assemblages in the west, which are overlain and overprinted by lower temperature albitic and carbonate-assemblages to the east. The geology and alteration of the immediate mine area is summarized in Figures 5a and 5b. Mapping used to compile these sheets was completed at scales ranging from 1:850 to 1:2,000 with rib mapping completed in critical areas at a scale of 1:120.

The traverse follows the geologic map and begins in the deepest exposures (to the west) and weaves in and out of the central breccia/mineralized zone into the upper part of the area that is heavily mineralized with magnetite. Lower temperature albite and carbonate-chlorite alteration assemblages are exposed farther to the east in predominantly volcanic and volcaniclastic rocks. The traverse goes up section to the lower limit of widespread albitization, but the best examples of these assemblages are exposed further upsection (east) and in the Stillwater Range.

From this point, walk to the north end of the large dump to the west to the first outcrop on the traverse.

Fig. 4. a. Generalized geologic map of the southern Buena Vista Hills. b. Generalized alteration map of the southern Buena Vista Hills. Modified from Nickle (1968).
STOP 3.2—Scapolitized sheeted dikes and breccias; deepest exposures and metal loss

At this stop intensely scapolitized, variably brecciated dikes and early volcanic (?) rocks show multiple igneous and hydrothermal events typical of the deeper exposures (Fig. 6a-d). These rocks comprise the deepest exposures seen on this traverse and lie near the base of the intensely brecciated zone that carries the majority of the iron mineralization to the east at shallower paleodepths.

Prominent scapolite (white) matrix breccias in this outcrop are cut by several generations of scapolitized dikes (Figs. 6b-d). Scapolite veins and individual crystals are truncated by dikes. Clasts of early light-colored scapolitized material occur as inclusions within the dikes. Scapolitized gabbroic rocks are exposed to the south and west of these outcrops. Relatively young mafic dikes cut all of the above rocks. Excellent examples of mutually crossing cutting relationships can be seen in several of the outcrops (cf. Fig. 6c), particularly where mafic dikes cut scapolitic veins and are in turn pervasively scapolitized. Single crystals of scapolite up to 0.3 m replace groundmass minerals and can be seen growing inward from dike margins. Locally, these dikes both cut earlier scapolite-bearing veins and are incorporated into breccias along their margins. At this stop, it is not clear if the brecciated rocks here are true breccias with or without clast rotation or if they are pseudobreccias formed by the pervasive replacement along veins forming clast-like ghost fragments. Both fabrics are common in the mine area and typically can only be identified where igneous textures are preserved or veins within clasts are cut off, indicating displacement.

The alteration assemblages are dominated by scapolite with minor hornblende, titanite, apatite, calcite, and rare allanite (SP-2a assemblages, see Johnson and Barton, 2000). These outcrops are characteristic of the most intense scapolitic alteration where mafic minerals are largely removed from the rock. Most of these outcrops contain > 65 vol percent scapolite, and commonly >90 vol percent over significant volumes. In addition to the removal of mafic silicates, magnetite is scarce or absent in many of these outcrops reflecting the transition from deep, magnetite-absent assemblages to the west (down section) to magnetite enriched assemblages to the east (up section, Fig. 5b).

These rocks record the passage of a large amount of fluid and have had their compositions profoundly modified. Most components other than Na and Cl are strongly leached from these rocks. Analyzed samples demonstrate that these rocks have lost all of the copper, and greater than 4.5 wt percent FeO as compared with fresh gabbroic rocks, reflecting the loss of and/or the replacement of primary mafic minerals by Mg-rich amphibole or pyroxene (see Johnson and Barton, 2000; Johnson 2000).

Walk southeastward across flats to the small hill just west-northwest of the small cement structure to see intensely altered host rocks outside of the main zone of brecciation and magnetite mineralization. STOP 3.3—Dikes and sediments; the nature of the host rock

This stop has two main outcrops: the first one is partially covered by dump material and the second outcrop forms a small hill just south of the dump (Fig. 7a). These outcrops demonstrate supracrustal rocks at this level; this interpretation contrasts with that of earlier workers who have interpreted the deep, coarse-grained scapolitic rocks as altered gabbros.

The fine-grained rocks at the first, more-northerly outcrop, are similar to those at the previous stop and are composed of strongly scapolitized and veined volcanic (?) rocks with <10 vol percent feldspar phenocrysts. They are moderately brecciated and cut by mafic dikes. One dike can be followed downhill to the west where it thins, becomes brecciated, and ends (Fig. 7b). Clasts of similar composition are found on the west side of the outcrop in a scapolitized breccia (Fig. 7a). Timing relations are not clear here, but plausible explanations are that the dike either intruded into wet unconsolidated breccia and exploded or was truncated by a younger brecciation event and incorporated into the host rocks.

The outcrop to the south contains scapolitized sediments on the north side of the highest point (Fig. 7c). Bedding orientations are variable, but in general have a northeast strike and dip steeply to the west indicating that these sediments are overturned (Fig. 7a). This is consistent with difficult-to-see graded bedding that is locally present. This is one of the few readily accessible areas where sedimentary rocks have been identified this deep (down section). To the south, the sedimentary rocks are in contact with intensely altered dark, fine-grained rocks. The contact between the two units is roughly parallel to the orientation of bedding in the sedimentary units. Due to the fine-grained nature of these rocks and the conformable contact, these rocks are interpreted that these rocks are part of the volcanic package (Fig. 5a).

From the sedimentary outcrops walk to the southeast, cross the road, and walk to the edge of the open pit. STOP 3.4—Overview of Buena Vista mine open pit

This is the largest open cut in the Buena Vista mine area. The cut extends to the east where the depth of mining was limited to 1 or 2 benches centered on magnetite-rich portions of the breccia complex. Continuous sections are rare in the pit given the abundance of small faults, some of which can be seen in the bench faces. Nonetheless, a consistent picture emerges from integration of maps of all exposures (Fig. 8). Given limited time the pit is not worth entering; however, several important features can be seen from here.

The form of the magnetite-rich mineralization can be seen along the high wall and along the edge of the pit lake (Fig. 9a). As shown by these exposures, the form and orientation of the cuts and the map of the pit area, magnetite bodies are strung out in a zone roughly parallel to the dike orientations. These massive, apatite-rich bodies commonly have crustiform banding consisting of coarse magnetite crystals (0.5 to 3 cm across), which are locally dendritic, intergrown with 1 to 20 vol percent apatite (Figs. 9b and 9c). The apatite ranges from fine-grained anhedral crystals to elongate hopper-shaped crystals up to 5 cm long. The latter, like the dendritic magnetite, grow toward vein centers and constitute some of the best evidence for open-space filling in the deep mineralization. Fluid inclusions within the hydrothermal apatites are hypersaline and commonly contain multiple phases including aqueous liquid, vapor, halite, and rare hematite (Fig. 9d;
Buena Vista Mine Area
Distribution of rock types and breccias

Quaternary
- Mine dumps and concentrator tailings
- Dunes, beach & stream deposits

Jurassic
- Mafic dikes
  - Youngest, altered but rarely mineralized
  - Intermediate, commonly mineralized
  - Oldest, commonly mineralized
- Breccias, many types (crackle, pseudo-replacement, matrix & clast-supported)
- Breccias, heterolithic (clasts of different rock types & alteration styles)
- Gabbroic intrusive rocks (medium-grained equigranular & fine-grained weakly porphyrylic)
- Mafic volcanic rocks (lava flows and pyroclastics)
- Clastic sedimentary rocks (volcaniclastic sands & debris, flows; graded beds are present)

Field trip stop 3.1
Road
Building

Fig. 5. a. Simplified lithologic map of the immediate mine area. b. Simplified alteration map of the immediate Buena Vista mine.
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Pit lake

< 5% exposure

Field trip stop

Buena Vista Mine Area
Distribution of hydrothermal features

Hydrothermal Alteration
- Chlorite-carbonate alteration
- Albitic alteration
- Scapolitic alteration
- Magnetite-out
- Chlorite-carbonate alteration (Fe-carbonate-chlorite; albite; rutile; sulfide)
- Magnetite breccias (as clasts, matrix & replacement)
- Massive magnetite-apatite (replacement & open-space fill; contains >50% magnetite)
- Magnetite-out (igneous & hydrothermal absent)

> 5 volume % magnetite
- (as open-space fill & replacement)

> 15 volume % magnetite
- (as open-space fill & replacement)

> 5 volume % magnetite
- (as open-space fill & replacement)

Magnetic alteration
- albite-chlorite-magnetite-hematite (S-1, S-2)
- Magnetite breccias
- Magnetite-out (igneous & hydrothermal absent)

Distribution of hydrothermal features

FIG. 5. (Cont.)
Johnson, 2000). Sulfides are rare here, but pyrite and chalcopyrite are locally intergrown with magnetite in intermediate stage assemblages.

The massive magnetite-rich zones grade outward first into magnetite-replaced and magnetite-cemented breccias and then into disseminated magnetite-bearing breccias and stockworks (Fig. 8). These typically lack the voluminous apatite found in the more massive bodies. We will look at a variety of mineralized breccia types on the next stop.

Several generations of dikes can be seen within the pit exposures. The earliest identified dikes are strongly scapolitized ("snowflake" dikes that will be seen at Stop 3.7). These early dikes are both cut and replaced by magnetite-rich assemblages. Prominent, later dikes similar to Stop 3.2 are scapolitized but lack iron oxide mineralization. These dikes cut albite-bearing massive magnetite-chlorite bodies on the east and west sides of the pit. The youngest dikes are chloritized and cut all other hydrothermal assemblages except carbonate-chlorite. We will see an example of these dikes at Stop 3.10.

From the edge of the pit, walk east to the large west-facing wall. The traverse follows the edge of the workings eastward into a cut called "shoebox trench."

STOP 3.5—West-facing benches and shoebox trench; breccias and other features of the ore zone

Exposed along the bench faces here are multiple kinds of magnetite-rich breccias and small replacement bodies as well as multiple generations of altered mafic dikes. These breccias are characteristic of the strongly mineralized zones in the Buena Vista Hills. The traverse follows the outer edge of strong magnetite mineralization within the larger zone of brecciation in the Buena Vista mine area (8 and 10a). Many breccia types are exposed along this traverse; they range from crackle breccias to heterolithic, matrix-supported breccias.
Heterolithic breccias can be difficult to distinguish from the others. They can contain different original lithologies but more commonly have clasts with different alteration histories (Fig. 10c).

At the south end of the bench face are magnetite-rich replacements and breccias which grade into massive replacement bodies just below the current level of exposure (Fig. 8). Most of these breccias are clast-supported, crackle, and replacement breccias that are composed of strongly scapolitized volcanic rocks (Fig. 10a). Magnetite mineralization accompanied early scapolitic alteration and continued until the earliest stages of albite alteration. Overprinting albite alteration commonly redistributes magnetite on a local scale, generally coarsening the grain size, without significant loss or introduction of iron. Small-scale examples of this feature are seen in the selvages of albite-chlorite veins cutting some of the massive replacement and disseminated ores. The earliest stages of albite alteration accompany actinolite hornblende-apatite-calcite veins and vug filling and are followed by albite-chlorite assemblages. The latest stage of albite alteration is commonly associated with hematite rather than magnetite and is relatively scarce at this level of the hydrothermal system, but becomes widespread up section in the Buena Vista Hills and elsewhere in the complex (Johnson and Barton, 2000).

Continue around the small bend in the face. Here, intensity of brecciation and degree of magnetite replacement drop, transitioning into scapolite-rich crackle breccias. Early scapolitized magnetite-bearing breccias are overprinted by albite ± chlorite ± hematite assemblages in a number of prominent zones (Figs. 8, 10b). These are readily identified by the

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**Fig. 7.** a. Outcrop map of scapolitized sedimentary and volcanic rocks. b. 4–16 photograph of disrupted mafic dike. c. 4–17 photograph of scapolitized sediments.
Field Stop 3.4 & 3.5

Key: mt-rich breccias and massive replacement

Largely unbrecciated and unmineralized rocks
- Late mafic dikes
- Early mafic dikes
- F. g. volcanic rocks, minor phenocrysts, replaced by scap-mt
- Porphyritic gabbro (15% phenocrysts)

Alteration
- Albite-chlorite±hematite±rutile

Mineralized rocks
- Massive mt replacement, >30% mt
- Mineralized breccia, commonly heterolithic, >25% mt
- Crackle breccia, minor transport, largely volcanic
- Matrix-supported, heterolithic breccia
- Heterolithic breccia, volcanic flows, gabbro, mineralized rock; matrix- & clast-supported

FIG. 8. Interpreted outcrop map of the Buena Vista open pit.
white-pink color of albite in the breccia matrix and along clast rims. Scapolite commonly persists in the cores of the clasts.

Climb to the next bench up through the small notch in the bench face to the opening of the “shoebox” trench. The notch contains a scapolitized dike cutting a magnetite-rich breccia and replacement body. Most of the cut is composed of a scapolitized dike cutting a magnetite-rich breccia and replacement body. The breccia exposed in the cut and the lower wall comprises scapolitized volcanic and intrusive clasts. Rare clasts of albitized material are present in the form of complete and partial or broken rims on a number of clasts. On the next bench above, this unit contains clasts of magnetite in addition to the scapolitized clasts (Fig. 10c). These heterolithic breccias cut other breccia units but commonly have gradational margins. Continue walking to the back of cut.

The eastern (back) portion of shoebox trench is composed of scapolite- and magnetite-rich breccias (Fig. 8). On the north face a well-developed crackle breccia grades into a magnetite-rich replacement breccia and both magnetite- and scapolite ± magnetite-cemented breccias. The breccia bodies are commonly clast-supported with angular to subangular clasts. Rounded to subrounded clasts are common in the pseudobreccias (replacements) formed by coalescing vein envelopes. In bodies composed of volcanic flows, continuity in trachytic textures can be traced from one “clast” to the next demonstrating the lack of transport and rotation. Rounded clasts are common in true breccias but are found only in the heterolithic breccias. Two generations of dikes are found near the back of the cut. Crosscutting relationships are not seen here, but the northern dike is pervasively scapolitized whereas the southern dike is weakly scapolitized and contains minor pyrite. This dike is cut by a late barite-carbonate-pyrite vein that is characteristic of the late-stage, generally shallow carbonate-chlorite alteration higher in the section to the east.

From the end of shoebox trench, backtrack to the edge of the north face and climb the hill to the north. The large waste dump to the north is the next stop.

**STOP 3.6—Waste dump – multiple hydrothermal assemblages and textures**

The dump is an excellent place to have lunch because it is approximately halfway through the traverse, it contains some
of the best examples of various ore and breccia types, and it offers good mineral collecting. Titanite crystals up to 4 cm across andapatite crystals up to 25 cm long have been found in calcite-apatite-amphibole vugs.

Many of the early, high-temperature to intermediate paragenetic relationships can be found in this dump material. Early scapolite-hornblende-titanite ± magnetite veins and breccia fill are found in nonmineralized to weakly mineralized samples similar to veins seen in the earlier portions of the Buena Vista mine traverse. Magnetite-rich veins and breccias containing hornblende-apatite ± scapolite cut these assemblages. The large, euhedral titanite and apatite crystals are part of a transitional assemblage between scapolite- and albite-dominated alteration composed of veins or vug filling of hornblende-titanite-apatite-calcite-scapolite/albite (SP-4 assemblage, Johnson and Barton, 2000). As demonstrated on the breccia bodies at the previous stop, albite-bearing alteration largely overprints scapolite alteration at this level. In the massive magnetite-rich ore material on the dump, these assemblages consist of chlorite-rich material and albite/oligoclase-rich material.

An issue to consider at this stop is the geochemical ramifications of the large replacement bodies. Although open space features are common throughout the complex both in veins and breccia bodies, most of the large magnetite-rich bodies replace rock and thus require removal of many elements, notably a large amount of aluminum, a relatively immobile element. This issue is common to iron oxide ± copper ± gold occurrences globally (see descriptions in Hitzman et al., 1992). In contrast, in the silicate-dominated hydrothermal assemblages, aluminum is approximately conserved during alteration (Johnson, 2000; see guidebook paper Johnson and Barton, 2000).

Next, walk eastward from the eastern end of the dump, up the small ravine to the north-south road. Walk northward along the road to the northern dump and stop at the small road cut on the southeastern end (snowflake dikes).

**STOP 3.7—Snowflake dikes; the fringe of the main breccia zone**

This stop exposes typical intense scapolitic alteration at the margin of the main breccia body. Although minor crackle breccias are present here, the majority of this exposure is not brecciated. It illustrates the difficulty in identifying various lithologies in the brecciated zone. Exposed in the road cut are spectacularly developed scapolitization of mafic dikes and volcanic rocks. Younger scapolitized mafic dikes cut both of the above units (Fig. 11a). Scapolitized dikes with multiple and one-sided chilled margins are well exposed in this and other road cuts leading to the highest benches of the mine.

The coarse-grained scapolite rock is termed “snowflake” rock due to the distinctive radiating texture of the scapolite blades extending from veins into their envelopes (Fig. 11b). The rock consists of mainly scapolite with interstitial mafic-sessio-hornblende and titanite. These have replaced igneous groundmass and feldspar phenocrysts. Magnetite is rare in these rocks and alteration type (<0.5 vol percent).

The other rocks are interpreted as mainly volcanic in origin with subordinate dike material, although the rocks resemble a weakly porphyritic gabbro exposed at Stops 3.10. Volcanic features such as flow tops or trachytic fabrics have not been identified and the phenocryst size and abundances are similar to the fine-grained, weakly porphyritic gabbro exposed in other portions of the mine area. Nonetheless, a volcanic origin is supported by the fine-grained nature of the preserved feldspar phenocryst sites, the lack of coarse-grained clinopyroxene phenocrysts typical of intrusive rocks elsewhere, and the lack of discernable intrusive textures in the intervening
and additional exposures of mineralized breccias and massive
and a view up section

STOP 3.8—Top benches; variants on the ore zone
west of and above the main workings open cuts.

These are south-
or apatite only. A large apatite vein is exposed cutting one of

Later veins consist principally of hornblende-calcite-apatite
blende ± titanite ± apatite assemblages with minor magnetite.

eralized zone. The earliest veins consist of scapolite ± horn-
blende ± titanite ± apatite assemblages with minor magnetite.

The highest benches provide an overview of the mine area

and the area to the southwest (Reeves and Král, 1955). This zone is a portion of the resource outlined by United States Steel (unpublished reports).

A younger weakly scapolitized and chloritized dike that cuts
an older pervasively scapolitized dike truncates the eastern edge of the strongly mineralized zone (Fig. 12). Further east along the bench face are more scapolitized breccias with variable magnetite contents similar to the breccias at the west end of the face. In some weakly mineralized rocks magnetite clearly replaces primary mafic minerals. Pinkish-white albite ± chlorite replaces scapolite breccia in a number of easily distinguished zones. The eastern end of the face exposes weak to intense albite alteration overprinting scapolitized breccias. Similar material occurs in small outcrops in the floor of the cut. These breccias here are dominantly scapolitic whereas similar breccias exposed in “albite creek” at the next stop are strongly overprinted by albite alteration, which is becoming more prevalent as one goes to the east.

From the east side of this bench, walk down hill to the east-southeast into the small ravine. Follow the small ravine down hill to the large gully, “albite creek,” at the bottom.

STOP 3.9—Albite creek; shallower styles of alteration
A walk along this gully passes a variety of features illustrating the spatial and temporal development of alteration at intermediate portions in the hydrothermal system. Albite creek is near the deeper limit of well-developed albite alteration within the Buena Vista Hills and is one of the better-exposed, readily accessible areas of this style of alteration (Fig. 4b).

Here, rocks are strongly altered to both scapolitic and albite assemblages. Exposures consist mainly of altered volcanic rocks and hydrothermal breccias that are cut by mafic dikes (Figs. 5a and 13a). Albite alteration is well developed and is typical of some of these styles as they are exposed higher in the section. Albite ± hematite overprints scapolite-hornblende-magnetite assemblages. Magnetite is partially replaced by hematite, scapolite by albite and hornblende by various combinations of actinolite, albite, oxides, chlorite and

groundmass, although the latter may not be preserved in intensely altered rocks.

The contact between the snowflake dikes and the fine-grained rock veins within the snowflake rock appear to be cut off by the fine-grained rocks, indicating that at least some of these rocks may be intrusive rather than volcanic in origin. In other areas of the mine area, the snowflake rock is dike-like and clearly cuts fine-grained rocks and hydrothermal veins contained in it.

Alteration mineralogy in the fine-grained rocks is the same as in the snowflake dikes: scapolite replacing most of the rock with interspersed clots of magnesio-hornblende-titanite. This outcrop is cut by a variety of high-temperature hydrothermal veins typical of exposures below and to the north of the mineralized zone. The earliest veins consist of scapolite ± hornblende ± titanite ± apatite assemblages with minor magnetite. Later veins consist principally of hornblende-calcite-apatite or apatite only. A large apatite vein is exposed cutting one of the younger scapolitized dikes in the center of the exposure.

Follow the road to the south and contour around the small hill to the highest benches in the mine area. These are southwest of and above the main workings open cuts.

STOP 3.8—Top benches; variants on the ore zone and a view up section

The highest benches provide an overview of the mine area and additional exposures of mineralized breccias and massive

magnetite replacements cut by several generations of scapolitized dikes (Fig. 12). This area is the up-section continuation of the main ore zone and illustrates some of the transitions to shallower styles of alteration. With good light from this vantage point, one can see orange to tan limonitic zones in the hills to the south. These are the expression of more intense albite-chlorite-carbonate (-sulfide-hematite) alteration assemblages higher in the volcanic section (Fig. 4b). The next stop illustrates some of these features.

In this exposure, breccias range from strongly mineralized to weakly mineralized crackle breccias to clast- and matrix-supported breccias with truncated veins within clasts and rotation of preserved trachytic fabrics demonstrating transport. The northern exposures on the lower of these two benches contain scapolitized fine-grained rocks cut by massive magnetite and by magnetite-cemented and magnetite-replaced scapolite breccia. Scapolitized clasts within these breccias are partially replaced by magnetite and chlorite. The floor of this cut contains massive to disseminated magnetite-chlorite ± apatite mineralization, characteristic of the higher-grade ores produced (Fig. 12). Magnetic surveys over this area show the presence of a large magnetite-rich zone beneath these benches and the area to the southwest (Reeves and Král, 1955). This zone is a portion of the resource outlined by United States Steel (unpublished reports).

A younger weakly scapolitized and chloritized dike that cuts an older pervasively scapolitized dike truncates the eastern edge of the strongly mineralized zone (Fig. 12). Further east along the bench face are more scapolitized breccias with variable magnetite contents similar to the breccias at the west end of the face. In some weakly mineralized rocks magnetite clearly replaces primary mafic minerals. Pinkish-white albite ± chlorite replaces scapolite breccia in a number of easily distinguished zones. The eastern end of the face exposes weak to intense albite alteration overprinting scapolitized breccias. Similar material occurs in small outcrops in the floor of the cut. These breccias here are dominantly scapolitic whereas similar breccias exposed in “albite creek” at the next stop are strongly overprinted by albite alteration, which is becoming more prevalent as one goes to the east.

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Diagram:

**Key:**
- **snowflake dikes**
- **Cg. scap-hblbd, >70% scapolite**
- **Cg scap-hblbd breccia, >70% scapolite**
- **Mg. scap-hblbd rocks, typically volcanic**
- **Scapolitized fg. volcanic rocks, minor phenocrysts**
- **Brecciated fg. porphyritic gabbro**
- **Porphyritic gabbro (30% phenocrysts)**

**FIG. 11.** a. Sketch map of snowflake outcrop and dikes. b. Road cut exposing snowflake scapolite cutting volcanic rocks.
ferroan dolomite. Titanite, where originally present, is typically converted to fine-grained aggregates of red-brown anatase or rutile. In a number of places magnetite is not oxidized to hematite but rather is recrystallized and coarsened during albitization. Iron does not appear to be added or lost from these rocks during magnetite-stable albitic alteration (Johnson, 2000).

In addition to albitic assemblages, exposures of carbonate-chlorite and associated veins types are exposed in many outcrops along the creek. These veins are mainly composed of ferroan dolomite ± chlorite ± hematite and may have appreciable concentrations of barite, sulfides (pyrite-chalcopyrite), and late quartz (see fig. HM-Modal, Johnson and Barton, 2000). In outcrop, this association is colored orange due to limonite formed by the weathering of ferroan dolomite and minor sulfides. Albite creek is also significant because it is within the upward continuation of the mineralized portion of the main breccia zone.

After descending from Stop 3.8 to the base of the small ravine, examine a mafic dike that is intruded between weakly scapolitized porphyritic volcanic rock and scapolitized, magnetite-cemented and magnetite-replaced pseudobreccia and clast-supported breccia (Fig. 13b). Weakly developed albite-chlorite zones overprint scapolite along small northwest striking structures. Many of the magnetite-rich replacement bodies contain igneous-like textures composed of scapolite and magnetite intergrowths. Scapolite is replaced by albite in a number of places and preserves the earlier hydrothermal textures.

Continuing down creek, a series of mafic dikes cut the breccia bodies and contain various scapolitic or albitic alteration assemblages and textures. These dikes can be used as time lines to document the relative timing of different alteration events. This is because they have consistent features throughout the map area.

Some dikes contain pyrite, particularly the younger ones with only albitite-chlorite alteration or older ones where scapolitic alteration is overprinted. The pyrite here, like other sulfides in the complex, is enriched in $\delta^{34}$S. Sulfides typically have $\delta^{34}$S greater than 8 per mil, indicating origin from a sulfate-bearing fluid, most likely from an evaporitic source (M.D. Barton and D.A. Johnson, unpub. data). Weathered surfaces

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**Fig. 12. Outcrop geologic map of top benches, Buena Vista mine.**
of strongly scapolitized dikes highlight large knots of scapolite where scapolite growth radiates outward from an unseen nucleation site. Weak albite alteration commonly attacks areas between the knots.

A large albitized breccia body composed of clasts of porphyritic volcanic rock occurs at the lower end of the creek just before it opens onto the road (Fig. 13a). Here, clasts are pinkish-white, reflecting replacement by albite, although they retain a fine-grained fabric indicating earlier scapolitization. Early scapolitic alteration is preserved in a number of places, especially near the mouth of the creek. A few clasts contain vesicles partially filled with scapolite and/or albite (Fig. 13c). Magnetite is widespread in this albitized breccia and is replaced in part by hematite. Minor ferroan dolomite is also present as indicated by limonitic boxwork irregularly developed in the breccia.

These breccias are similar to albitic breccias found at higher structural levels in the Buena Vista mine area and elsewhere in the Humboldt complex. Specular hematite and pyrite increase in abundance upward. Chalcopyrite is locally

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**Key**

- Outcrops are mainly composed of volcanic rocks, strongly brecciated and mineralized, overprinted by albite-chlorite-hematite.
- Late mafic dikes
- Early mafic dikes
- Massive mt replacement, >30% mt
- Mineralized breccia, commonly heterolithic, >25% mt
- Crackly breccia, minor transport, largely volcanic
- Matrix-supported, heterolithic breccia
- Heterolithic breccia, volcanic flows and gabbro. Matrix- & clast-supported
- Mg. scap-hbl rocks, typically volcanic
- Mg. brecciated scap-hbl rocks, typically volcanic
- Scapolitized fg. volcanic rocks, minor phenocrysts
- Porphyritic gabbro

**Alteration**

- Knotty scapolite in dikes
- Pyrite-bearing dikes
- Ferroan dolomite±chlorite±hematite
- Albite-chlorite±hematite±rutile

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**Field Stop 3.9**
a common constituent in these structural sections, for example in upper White Rock Canyon in the Stillwater Range (Johnson and Barton, unpublished mapping). Geochemically, the albitic assemblages have varied signatures most commonly showing a strong depletion in most elements (calcium, magnesium, iron, and basemetal) with localized enrichment, particularly of iron, copper, and barium in mineralized sections (Johnson, 2000).

At the mouth of the albite creek, climb out of wash on the north bank and head northwest across the small ridge towards the horseshoe-shaped cut (camp trench).

**STOP 3.10—Camp trench; a geologic synopsis**

This cut contains nearly the full hydrothermal paragenesis of the Buena Vista Mine area. Exposed are good exposures of intact and brecciated, weakly porphyritic gabbro, magnetite-replaced breccia, and massive magnetite-apatite ore. Several generations of mafic dikes cut these rocks and various alteration assemblages (Fig. 14a). This trench overlies the southern portion of the large magnetite-rich zone, extending northward to the benches at Stop 3.8 indicated by magnetic surveys (Reeves and Kral, 1955).

The south end of the cut is composed of scapolitized gabbro. Unlike many of the outcrops exposed in the mine area, igneous textures are preserved in these rocks. The gabbro is weakly porphyritic and consists of approximately 30 vol percent feldspar phenocrysts in a fine-grained groundmass. Mafic minerals are composed of clinopyroxene phenocrysts and xenocrysts partially replaced by hydrothermal (sodium-rich) pyroxene (Johnson, 2000). The fine-grained groundmass is pervasively replaced by coarse-grained scapolite. Although some of these textures are typical of scapolitized volcanic rocks, this unit is interpreted as intrusive based upon the lack of volcanic features such as vesiculated flow tops and on textural characteristics such prominent pyroxene crystals that link these exposures to other outcrops which, in aggregate, define a large discordant body. The outcrop pattern of this unit appears to cut stratigraphy identified in unambiguously volcanic and volcaniclastic rocks (Fig. 5a).

Many vein types cut this porphyritic unit. Early, discontinuous scapolite-only veins are exposed in a number of places (Fig. 14a). These are cut by relatively abundant scapolite-hornblende ± magnetite veins. Calcite + apatite + titanite is present as vug-fills and as small veins that cut the scapolitic assemblages. The latter typically have albite envelopes, which can be identified by their white color and more massive texture (Fig. 14a). Small magnetite-bearing brecciated zones cut the gabbro and have magnetite contents up to 40 vol percent. In the middle of the gabbro outcrop, an early, thin scapolitized dike crosses first-generation scapolite-hornblende veins.

A younger weakly scapolitized (?) and chloritized dike is exposed at the contact between the gabbro and the magnetite-replaced scapolitic breccia. The chlorite-rich, scapolite-poor alteration and the lack of significant hydrothermal magnetite here and to the south indicate that the dike postdates most of the magnetite introduction. The disparity between the rocks on either side of the dike suggests that it intruded a Jurassic fault that was contemporaneous with the hydrothermal systems (Fig. 14a-c). Evidence for symmaggmatic, synhydrothermal faulting is present elsewhere in southern Buena Vista hills and in other parts of the complex (Johnson and Barton, 2000).

The magnetite-replaced scapolitic breccia is typical of much of the mineralized rocks exposed within the main Buena Vista pit. Primary textures are largely destroyed within these rocks. Where preserved within clasts, these rocks are composed of approximately 30 vol percent feldspar phenocryst sites that resemble the gabbro or fine-grained phe-nocryst-poor rocks. Numerous scapolite-magnetite veins cut the outcrop. To the west these rocks grade into massive magnetite-apatite rock.

Massive magnetite-apatite rocks are largely composed of medium- to fine-grained magnetite with variable apatite contents. Coarse-grained magnetite (>0.5 cm) commonly cuts finer-grained varieties (Fig. 14a). Apatite occurs in crustiform bands and as disseminated grains within the face. Apatite contents range from 0 to 35 vol percent. Remnant scapolitized fragments are found in a few places. Magnetite-titanite-hornblende veins, calcite, calcite-titanite vug filling occur in massive magnetite. At the west end of the horseshoe-shaped part of the pit a young chloritized mafic dike cuts the massive ore. This dike is typical of the youngest generation of dikes in the mine area. Late ferroan-dolomite veins of the carbonate-chlorite association cut this dike. Similar ferroan-dolomite veins in the floor of the cut contain late quartz. Sulfides are rare here, but pyrite and chalcopyrite have been found in these late carbonate veins.

**STOP 3.11—Ridge above pit; an overview of western half of the Humboldt complex (Optional)**

Walk out of the cut at Stop 3.10 and westward to the top of the ridge. From here, one gains a view across the western and southern parts of the Humboldt complex. It is an opportunity to sum up the features and scale of this enormous intrusion-related hydrothermal system and to consider it in comparison with the other systems from this field trip and elsewhere.

To the west and southwest across the northern end of the Carson Sink, the West Humboldt Range dies out southward into the low-lying Mopung Hills. Eastward tilting in the West Humboldt Range is substantial, the last component of which is recorded by prominent Miocene basalts dipping to the east (see Johnson and Barton, 2000). Within the range, deep exposures of the western part of the intrusive complex abut the early Mesozoic sedimentary section. Sodic and propylitic alteration in the igneous and sedimentary rocks is extensive, but generally not as intense as in the Mineral Basin district or other areas in the central part of the complex. In the southern part of the range, Jurassic volcanic rocks in the upper part of the complex are locally exposed through windows in Cenozoic cover and in drill core beneath the west edge of the Carson Sink (Moore, 1971). Larger, buried sections host extensive magnetite mineralization at the Pinto deposit (near the prominent light colored hill due west of the Buena Vista mine). Farther to the west and northwest, in the West Humboldt Range and to the south in the Mopung Hills, evaporite-bearing beds in the Muttlebury and Lovelock Formations fringe the Jurassic igneous rocks. Gypsum was mined at Gypsum Mountain and at the southern end of the hills. Extensive solution collapse features within the Muttlebury Formation (Speed and Clayton, 1974; Speed, 1975) demonstrate removal
a) Outcrop and Rib Map of Camp Trench

b) Lithology

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Day Four: Buena Vista Hills, W. Nevada
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Jurassic Fault
not outcrop
50-60%
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Explanation

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Jurassic Fault
no outcrop
50-60%
```

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Lithology
Alteration
Structure
```

```
60° 20' above
66 45
80 61
25 85
35
```

```
60° 25°
90
```

```
35
80
90
```

```
5\%
25\%
5\%
55\%
75\%
```

```
Rock < 1%, Veins + rock < 5%
```

```
35% 5% 25% 80%
90 80 72 68
53 60 28 48
70 43
80 40%
```

```
Albitic envelopes around amphib-apatite veins and vug fill
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Scapolite-hornblende-magnetite
Albite-chlorite
Carbonate-chlorite
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Outcrop and Rib Map of Camp Trench
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Feldspar site replaced by scapolite
Mafic site replaced by hornblende
Breccia clast replaced by scap then albite
Breccia clast replaced by scap and disseminated magnetite
Open space fill with alteration envelope (calc-hbl-ap/albite)
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Examples of symbols
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Fieldsparsite replaced by scapolite
Mafic site replaced by hornblende
Breccia clast replaced by scap then albite
Breccia clast replaced by scap and disseminated magnetite
Open space fill with alteration envelope (calc-hbl-ap/albite)
```

```
Scapolite-hornblende-magnetite
Albite-chlorite
Carbonate-chlorite
```

```
Scapolite-hornblende-magnetite
Albite-chlorite
Carbonate-chlorite
```

```
Vein with orientation (scap-hbl-mt/hbl)
Fault
Rib outline
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Contact: exposed/inferred
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Fig. 14. a. Rib map of west side of trench, following the Anaconda method. b. Outcrop lithologic map of camp trench showing. c. Outcrop alteration map of camp trench.
of substantial quantities of evaporite minerals. Along with surface-derived brines, these evaporites are the plausible sources for the huge quantities of saline fluids required to achieve the >900 km³ of high-, moderate-, and low-temperature sodic alteration within the igneous complex (see Johnson and Barton, 2000; Johnson, 2000).

To the south, in the foreground, are albite-carbonate-chlorite altered portions of the upper parts of the section in Buena Vista Hills. These exposures are typical of the >450 km³ of this alteration style within the complex which hosts most of the sulfide-bearing and hematite-rich mineralization. Examples of this suite are exposed in the Copper Kettle district, the western tip of which can be seen farther to the south comprising the low hills below the Stillwater Range. There, sodically altered volcanic rocks with hypabyssal intrusions contain minor chalcopyrite-magnetite/hematite mineralization.

To the north, along the trend of the Buena Vista Hills, deeper exposures of the igneous complex contain many of the magnetite-rich deposits of the region. These are largely within the upper part of the intensely scapolitized volume of the complex. A mix of volcanic, sedimentary, and intrusive rocks composes this zone, although alteration is typically so intense as to obliterate textural evidence of the original lithology. These intensely scapolitized rocks and many of the albited rocks have been leached of most their metals (Johnson, 2000; Johnson and Barton, 2000) with copper and zinc contents typically less than 10 ppm and iron contents commonly reduced from 4 to 5 wt percent to 0.5 to 2 wt percent. Only a fraction of the iron can be recognized in known deposits and associated magnetite-rich. Liberal estimates of what is covered or eroded (parallel to estimates of the total volume of the complex) bring this figure close to 3 billion tonnes or more. For the base metals, they may have been lost without an appropriate sulfur-bearing environment to trap them. Copper occurrences are widespread and their aggregate volume must exceed several km³ (see Johnson and Barton, 2000); however, the amount of contained copper can not be readily estimated given the lack of control.

Is there potential for economically significant mineralization? Perhaps. If there were traps such as mixing zones, preserving sulfide-rich rocks or sulfur-rich bottom waters in lakes where the metals would precipitate from the hydrothermal fluids. If not, metals would likely have been lost given the sulfur-poor, chloride-rich nature of the hydrothermal system (cf. Barton and Johnson, 1996).

These views give a sense of the scale of the Humboldt complex and associated hydrothermal alteration. They stimulate many questions. Humboldt contrasts markedly with the other intrusion-related hydrothermal systems seen on this trip; it is fundamentally mafic and the fluids are largely or entirely of external. Volumes exceed those of the Yerington district by at least a factor of 10 and those of the Birch Creek area by a factor of 30 or more. These sizes and the major, systematic variations in hydrothermal alteration and mineralization testify to the diversity of intrusion-related hydrothermal systems.

From here go down the ridge, around the south side of the pit and back to the parking area.

REFERENCES


