Trip 8:

Copper Creek, Tiger, San Manuel Open Pit, Kalamazoo

October, 1994

Bootprints Along the Cordillera

Porphyry Copper Deposits from Alaska to Chile

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Dear Field Trip Participants:

On behalf of the **Arizona Geological Society, Society for Mining, Metallurgy and Exploration Inc., and the U. S. Geological Survey**, we bid you welcome to the Bootprints Along the Cordillera field trip program. We have assembled a collection of field trips that portray the geologic and mineralogic diversity that exists along the cordillera of North and South America.

We wish to thank all of the field trip leaders who volunteered their time, effort, and expertise to organize their individual trips. We also want to thank collectively, all of the mining companies and staff who graciously allowed us to visit their properties. Without their cooperation, this program would not have occurred. A special thanks goes to Kathie Harrigan of Asarco for her help in the compilation of the field trip guides. We also want to thank Tucson Blueprint who underwrote the complete reproduction cost of the guides.

Mark Miller and Jim Briscoe
Field Trip Co-Chairmen
October 2, 1994

Dear Field Trip Participants:

The emphases of this field trip will be on what the mid-to upper-levels of a porphyry copper system look like.

Our first stop will be at Magma Copper's San Manuel mine. A brief overview of the geology and underground and open pit operations will be given by Leu Sandback and crew. Part of this stop will include an overlook stop to view the copper oxide open pit and some of the exposed geology.

After leaving the mine area, we will travel across the San Pedro Valley and into the western flanks of the Galiuro Mountains to Copper Creek. At Copper Creek, several stops have been planned to observe breccia-masses, alteration features and porphyry intrusives. Discussions will be on the relevance of our observations and their relationships to the deep porphyry copper deposit. The last stop will be over the deep copper deposit in the American Eagle Basin.

The trip will provide both geological and scenic opportunities worthy of vigorous discussions and Kodak moments.

James Guthrie

COPPER CREEK:
An Example of the Upper Portions of a Porphyry Copper System

By James O. Guthrie

Introduction. What does the partially eroded, upper levels of a Laramide porphyry copper system look like? Copper Creek may be an example. In the American Eagle Basin area, the upper portions of a porphyry copper deposit has been intersected at a depth of 2000 plus feet. The deposit lies within an area of several square miles that contains breccia pipes, tourmaline alteration, clusters of porphyry plugs, quartz-sericite alteration, strong veining, and scattered copper occurrences.

Copper Creek, part of the Bunker Hill mining district, is located 45 miles north northeast of Tucson, along the western flank of the north-central Galiuro Mountains (Figure 1).

Between 1863 and 1980 intermittent surface mining was carried out in the district (Simons, 1961; Kuhn, 1951; Arizona Department of Mines and Mineral Resources) (Table 1, Summary of Production). Deep exploration, initiated by Bear Creek in the late 1950's, was continued by Magma, Newmont and Exxon into the mid-1980's. Magma presently holds the property. In the American Eagle Basin area, deep-drilling has delineated a deep copper resource of 80 million tons containing 0.78% Cu (Guthrie and Moore, 1978). Phelps-Dodge has drilled north and south of the American Eagle area, but their results are unknown.

This article and the following field trip guide are to serve as a platform for discussion and speculation about the upper levels of a porphyry copper system. Contributing to this discussion are geologic data on the Ann Mason deposit (Dilles and Einaudi; 1992) and the San Manuel deposit (Hausen et al, 1988). The possible importance of boron in a porphyry system will also be discussed.

Geology. Copper Creek lies within the remnants of andesitic, volcanic pile erupted onto the eroded surface developed on Precambrian, Paleozoic, and Mesozoic rocks. Intruding these units are granodiorite stocks and numerous dacite porphyry bodies. Alteration and copper mineralization are spatially and temporally associated with the porphyries. Overlying these rocks are the Miocene Galiuro Volcanics. The older rocks are exposed along the western edge of the shallow (10^{o}), eastward tilted Galiuro Mountains.

Precambrian rocks, exposed primarily north and south of Copper Creek, consist of Pinal Schist, Oracle Granite, and the Dripping Springs Quartzite (Krieger, 1968; Creasey et al., 1964). Paleozoic sediments and Mesozoic clastics occur as partially exposed outcrops, north and east of Copper Creek (Simons, 1964 ; Krieger, 1968; Guthrie and Moore, 1978) (Figure 2).

The Laramide Glory Hole Volcanics were erupted onto an erosional surface developed on the older basement rocks. Ash flow tuffs, tuff breccias, lavas, and flow breccias form a heterogeneous pile of andesitic to latitic

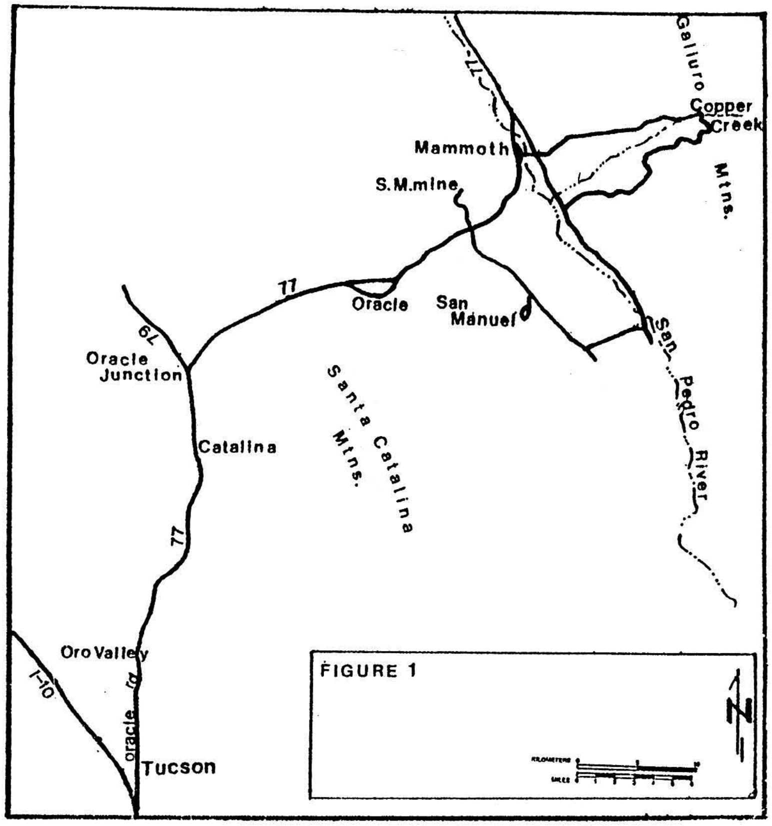


Figure 1: Location map showing Copper Creek and field trip route.

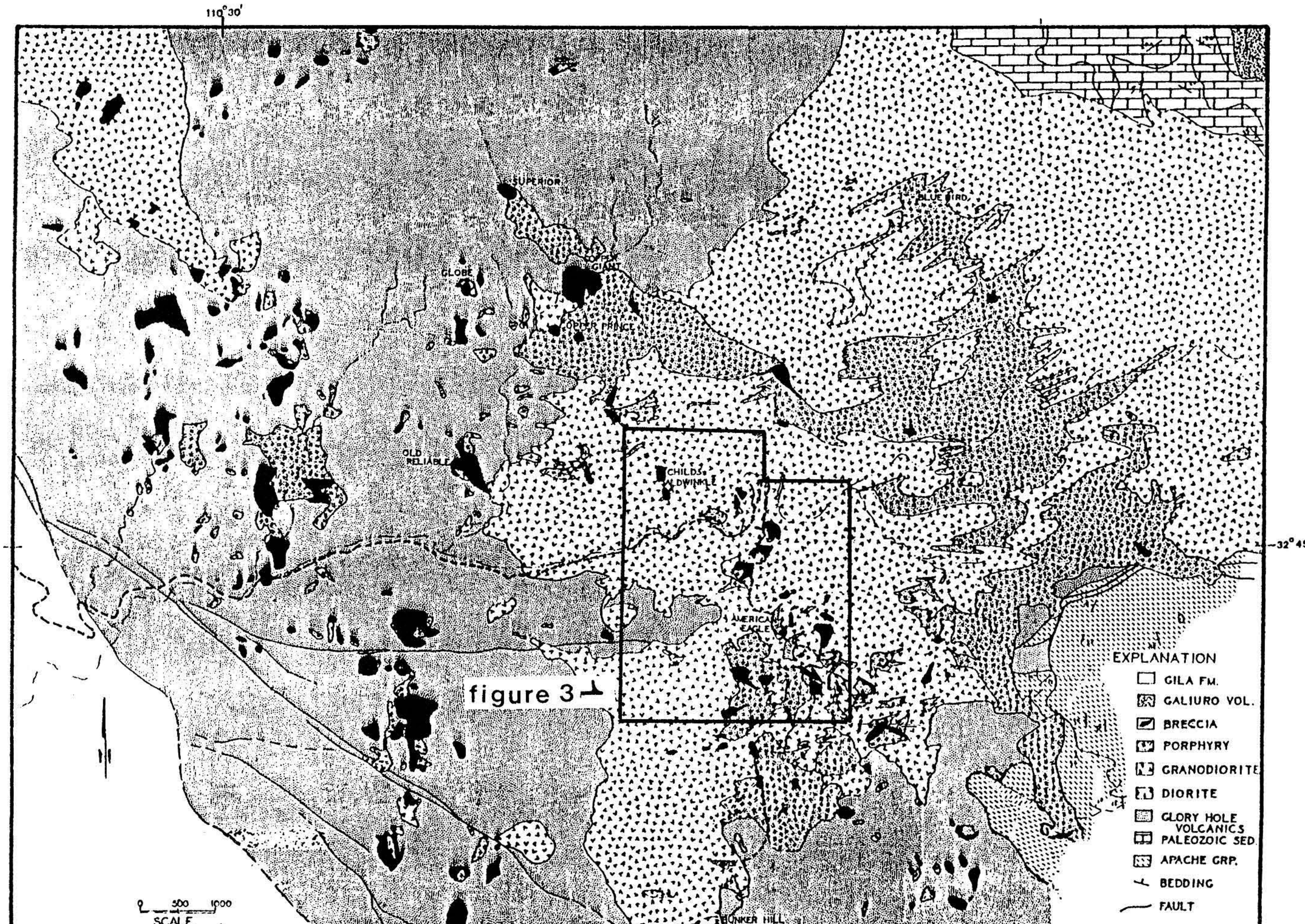


Figure 2: Generalized geologic map, Copper Creek area.

volcanics. The volcanics, adjacent to the granodiorite stocks, are thermal metamorphosed to a, dark gray, dense, very fine-grained biotite-quartz-feldspar hornfels. Three north-northwest aligned stocks of biotite-hornblende granodiorite intrude the above rocks. North to south, the stocks are, Boulder Mountain, Copper Creek, and Sombrero Butte. The granodiorite exhibits a hypidiomorphic-granular to slightly porphyritic texture. Locally, darker, dioritic phases are present.

Porphyry intrusives occur as small plugs and dike-like bodies that are clustered mainly along three north-northwest trending zones (Figure 2) The eastern and central zones are contained mainly within the central Copper Creek stock. Although the northern end of the central zone is in Glory Hole Volcanics, it appears to bridge the gap between the Copper Creek and Boulder Mountain stocks. It also extends south into the Sombrero Butte stock. The western zone is almost entirely in the Glory Hole Volcanics. The majority of breccia-masses are located in the central and western zones (Figure 2).

The shape of the porphyry bodies varies from equant to irregular to dike-like. Drilling suggests that these plugs are steep, irregular, columnar-shaped bodies that extend to at least 3500 feet (1070 m) (the depth of drilling), without much change in texture or mineralogy (Figure 4).

There are two compositional types of porphyry. The first type is the pink porphyry. It has a distinct aplitic-textured groundmass with medium-grained phenocrysts of plagioclase and minor biotite. Compositionally, they are quartz monzonite alaskites. This porphyry comprises much of the eastern porphyry zone and some of the southern central zone. (Figure 2). Breccia masses and sulfides are uncommon. Associated alteration consists of K-feldspar flooding of the adjacent host rock.

The second compositional type is the dark porphyry. It forms a distinct dark-colored, porphyritic intrusive and occurs primarily in the central and western porphyry zones (Figure 2). Breccia masses and strong alteration are commonly associated. Chalcopyrite and pyrite are associated with the central zone; pyrite is the primary sulfide in the western zone. Compositionally, the dark porphyry is a dacite or micro-granodiorite porphyry.

The dark porphyry textures range from a crowded, phenocryst-supported texture to a phenocryst-poor, matrix-supported texture. Phenocrysts consist of medium-grained plagioclase, hornblende, biotite, and occasional quartz. The groundmass of the crowded porphyry consists of an aplitic-textured, intergrowth of quartz and K-feldspar. In the uncrowded porphyry the groundmass contains fine-grained plagioclase-laths, biotite and hornblende along with the K-feldspar and quartz. The plagioclase laths can become abundant enough in the open-textured porphyries to give the groundmass a trachytic texture.

Breccia masses (breccia pipes) are a common feature at Copper Creek. Because many of the hydrothermally affected breccias have no depth information, the term "breccia mass" is preferred to "breccia pipe". The breccia masses vary from several 10's to many 100's of feet in surface dimension, and range from equant to elongate to irregular in shape (Figures 2 and 3). Breccia masses are spatially and temporally associated with the dark porphyry intrusive bodies as the porphyries are adjacent to, occur as fragments in, and intrude the breccia masses. Breccia fragments range from coarse-sand to large boulder in size and are always composed of the host rock surrounding the breccia. The breccia contacts with the host rock are sharp. The fragments are angular in shape, although locally rounded fragments may occur. Texturally the breccias vary from shattered-breccias, with little interstitial open-space, to fragment supported-breccias, with some open-space;

TABLE 1: Summary of Copper Creek metal Production: 1863-1980.
from Simons, 1964 and records at the Arizona Department of Mines and Mineral Resources.

Mine	Period	Copper (lbs)	Molybdenium (lbs)	Lead (lbs)	Silver (oz)	Gold (oz)
Childs-Aldwinkle	1932-38	5,859,033	6,946,782		26,938	723
	1957-65	1,450,000	~440,000		~1760	~50
Old Reliable	1905-16	700,000			55,000	
	1972-80	11,000,000				
Copper Prince	1937	1,227,667				
Clark/Scanlon	1905-30	200,000			15,000	
Blue Bird	1863-1920	~$150,000				
	1926-39	200,000		4,000,000	119,000	
	1948	2,100		31,200	1,685	3

TABLE 2: Compilation of Copper Creek Age Dates

ROCK UNIT	AGE	METHOD	SAMPLE	REFERENCE
Glory Hole Volcanics	62.8+/-1.3	K-Ar	whole rock	Shafiqullah et al., 1980
Mule Shoe Volcanics	73.7+/-1.8	K-Ar	hornblende	Shafiqullah et al., 1980
Williamson Canyon volcanics	75.8+/-1.4	K-Ar	biotite	Keith, 1977
Copper Creek granodiorite	69.7+/-0.0	K-Ar	biotite	Creasey and Kistler, 1962
Copper Creek Granodiorite	66.0+/-2	K-Ar	biotite	Guthrie and Moore, 1968
Andesite Porphyry	65.8+/-1.6	K-Ar	biotite	Shafiqullah et al., 1980
Pink Porphyry	60.5+/-1.5	K-Ar	biotite	Guthrie and Moore, 1968
Dark Porphyry	52.5+/-0.5	K-Ar	biotite	Guthrie and Moore, 1968

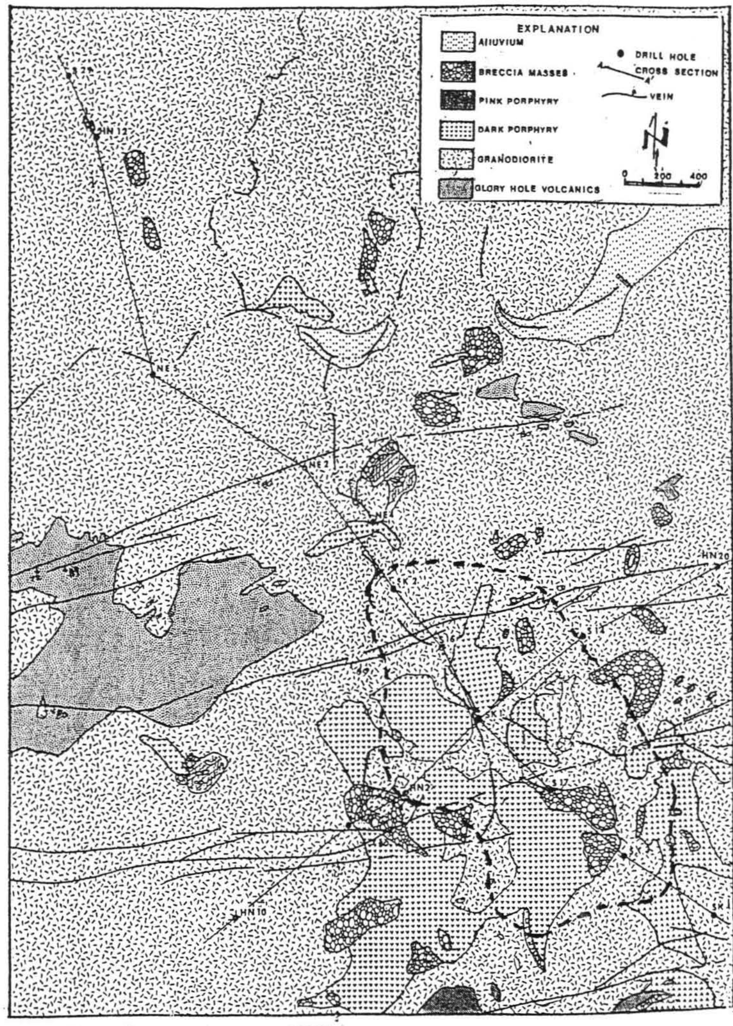


Figure 3: Generalized geologic map, American Eagle Basin and adjacent area. Cross-section lines and drill holes used to construct sections are located on the map. Outline of deep copper deposit shown by dashed line.

to matrix supported-breccias with little open-space. Alteration consists primarily of silica and sericite, with variable tourmaline, pyrite, specular hematite, and chalcopyrite. Interstitial areas are partially to completely filled with the same alteration products.

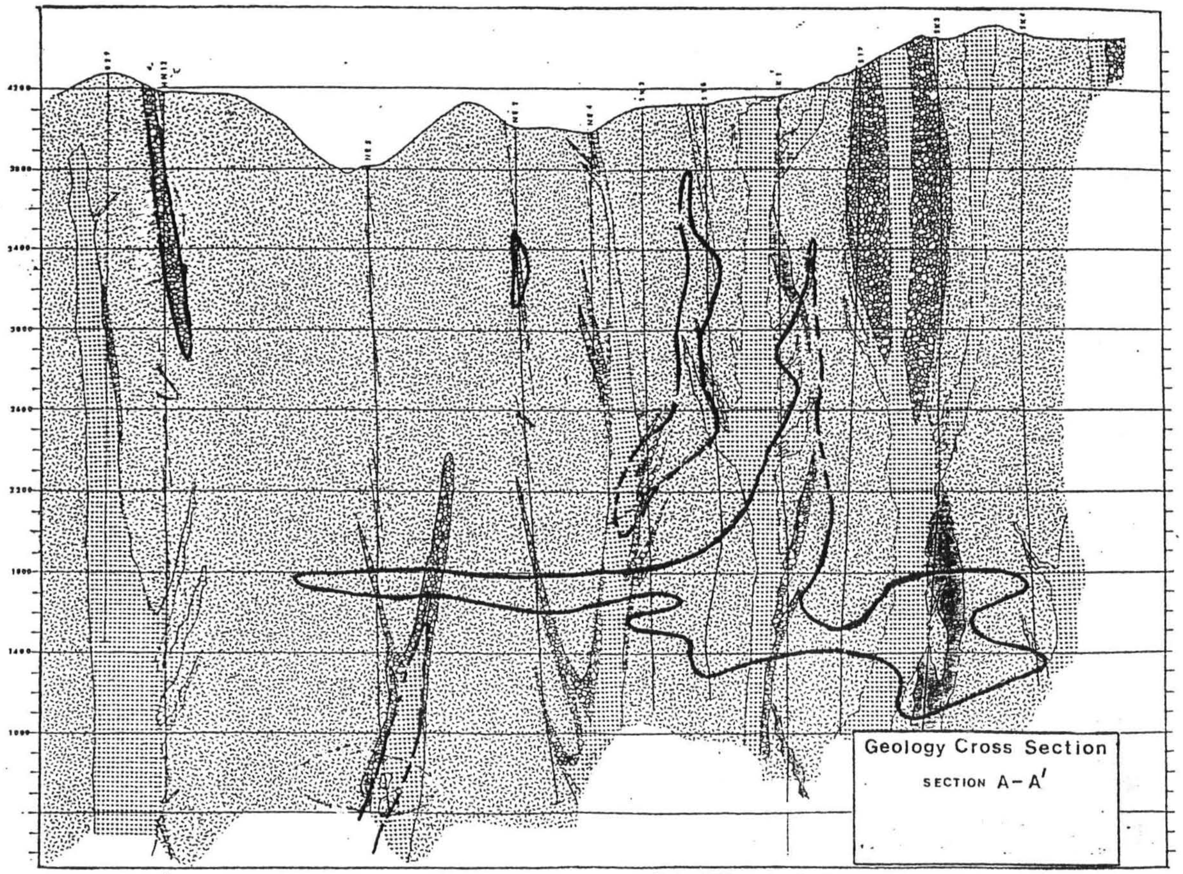
Field observations suggest that many of the breccias formed when porphyry bodies forcefully broke and shattered the host rock. Evidence of this is seen in the presence of intrusion breccias adjacent to and above porphyry plugs. Stress-zones above porphyry intrusions also form where intersecting fracture sets occur. Hydrothermal fluids accentuate these zones by further hydrofracturing the rock and by hydrothermally leaching the fine-grained material between fragments. Breccia masses also formed along faults where undulations occurred forming lenticular bodies.

Underground workings and drill results indicate that breccia masses have variable shapes and dimensions. Several drill holes have intersected breccias whose upper portions could not be located at the surface. In other areas drilling beneath a breccia did not intersect it, suggesting a flat, sheet-like shape. The American Eagle and Copper Prince breccias pinch-out into vein-like structures 200-300 feet (60-90 meters) below the surface (Simons, 1964). Underground mapping at the Old Reliable indicates a carrot shape, with the breccia narrowing downward with depth (Guthrie and Moore, 1978). Drilling and underground workings indicate that the Childs-Aldwinkle breccia is truly pipe-shaped. It extends over 700 feet (215 meters) in depth, and, in the upper 300-400 feet (90-120 meters) it branches upward into three separate breccia bodies (Simons, 1964; Kuhn, 1941; Guthrie and Moore, 1978). The Childs-Aldwinkle breccia pipe is also unique because it is an isolated body, contains molybdenite, chalcopyrite and bornite, and has inter-fragmental pegmatitic material. No other breccia mass at Copper Creek is presently known to have all these characteristics.

Pre- and post-Copper Creek granodiorite structural features can be observed or inferred at Copper Creek. Pre-Glory Hole Volcanic faults are suggested by north-south to northwest faults that drop Paleozoic units against Precambrian rocks (Krieger, 1968). This same direction is seen in the trends of intrusive bodies and some breccia masses (Figure 2). Post-volcanic and pre-granodiorite structures are shown by northwest to east-west faults that displace the volcanics internally and against the older basement units (Figure 2). Several of these faults, now expressed by quartz-pyrite vein systems, are cross-cut and intruded by the granodiorite (Kreiger, 1968; Guthrie and Moore, 1978). Post granodiorite-porphyry intrusive structures are expressed by east-west veins and fracture sets. Basin and Range faulting has rejuvenated several of the older structures, causing some confusion as to age relationships.

Age Dates. The K-Ar age dates for Copper Creek igneous rocks are tabulated in Table 2. The ages range from 69.7 to 52.5 Ma. A comparison of the single age date for the Glory Hole Volcanics with the Copper Creek granodiorite ages indicates a thermally reset age for the volcanics. Their age is probably similar to the volcanics north (Williamson Canyon) and south (Muleshoe) of Copper Creek; i. e., between 76-74 Ma. The dark porphyry age appears to be too young when compared to the ages of the granodiorite, .

Alteration. Phyllic alteration is common district-wide. It is expressed by quartz and sericite, with or without pyrite, tourmaline, and specular hematite. The alteration is controlled by fractures, veins, breccia masses, and porphyry intrusions. Potassic alteration is very minor and occurs mainly in the



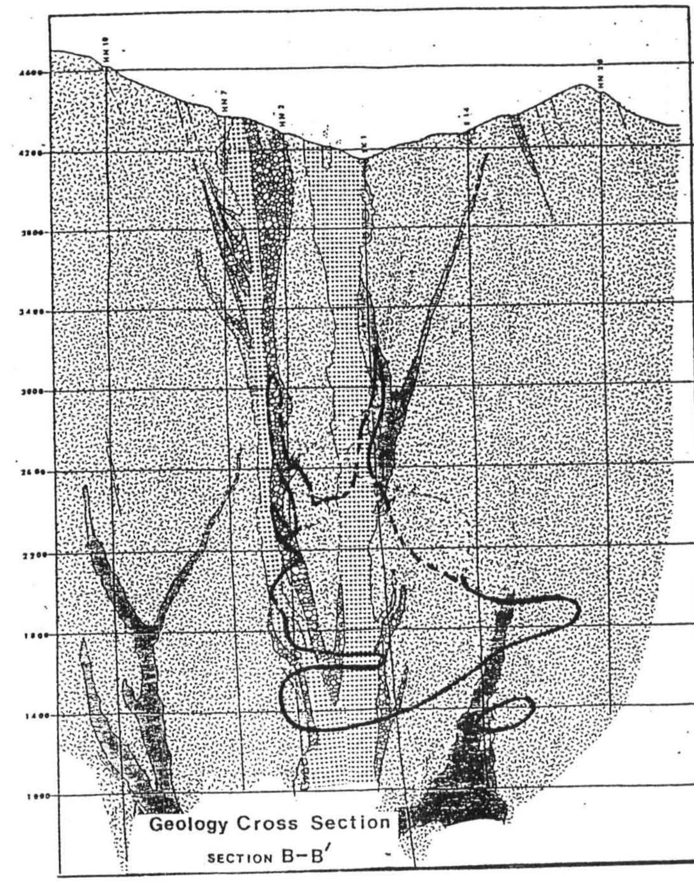


Figure 4: Geologic cross-sections, A-A' and B-B', showing trace of drill holes and the 0.4% copper outline of the copper deposit. Scale and rock symbols are the same as in Figure 3. Section A-A' looking northeast; section B-B', looking north-northwest.

American Eagle Basin as thin, K-feldspar-rich veinlet selvages or as irregular patches.

Phyllic alteration occurs about quartz-sulfide veins as selvages with an outer chlorite-rutile-calcite-clay-limonite zone and an inner quartz-sericite-pyrite zone, with or without specular hematite and tourmaline. In the Glory Hole Volcanics Vein selvages form bleached zones up to several 10's of feet in width.

Breccia masses exhibit variable phyllic alteration. It can range from thin quartz-sericite-chlorite rinds on the breccia fragments to the total replacement of the fragments by quartz-sericite, and the partial to total filling of the interstitial area with quartz, tourmaline, pyrite, chalcopyrite, and/or specular hematite. The alteration is usually tightly limited to the breccia, with adjacent host rocks affected a foot or so beyond the contact. It is only where porphyries and breccia masses are closely clustered, as in the American Eagle Basin, that the host rocks are strongly altered outside the breccia (Figure 3). The Childs-Aldwinkle locally contains a pegmatitic quartz-orthoclase-biotite-sulfide interstitial filling that pre-dates the quartz-sericite-sulfide alteration.

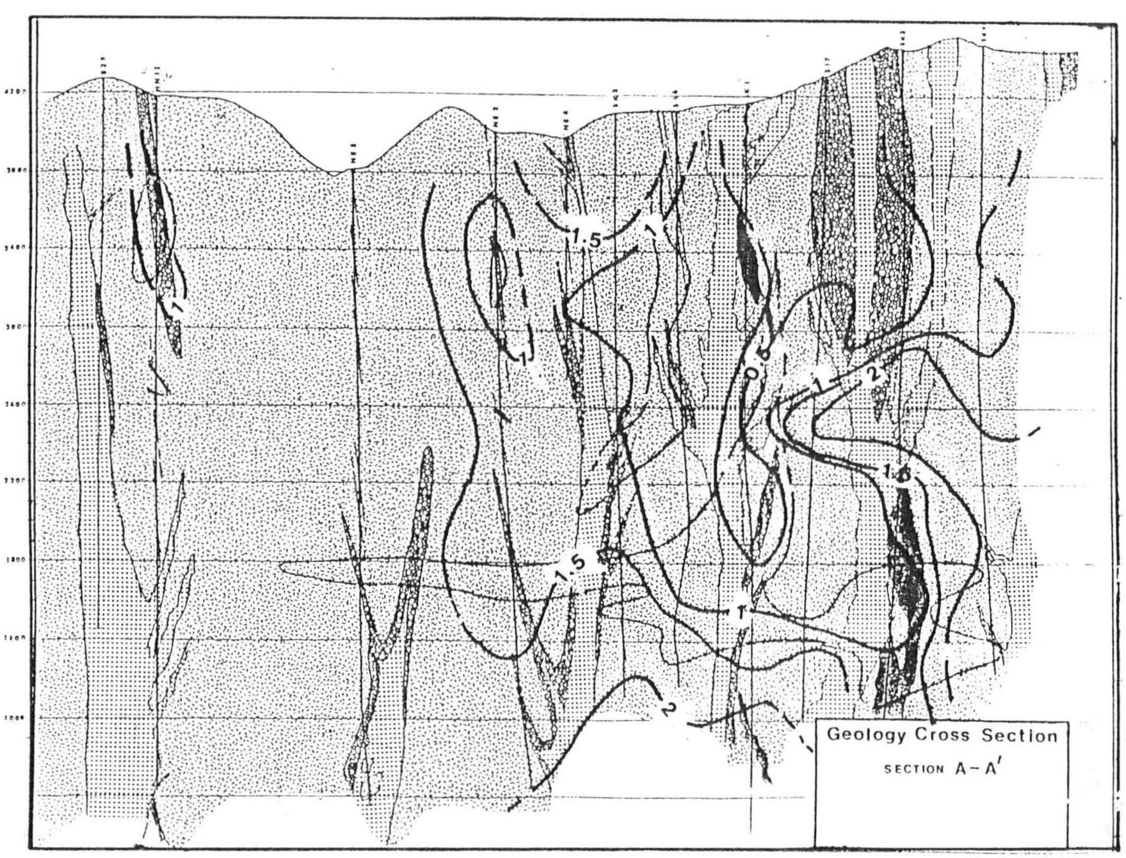
Porphyry intrusive bodies show minor to intense phyllic alteration. Where intensely altered, the groundmass consists of quartz-sericite and may exhibit a vuggy, leached texture. The plagioclase and ferromag phenocrysts are totally replaced by sericite. Often tourmaline, specularite, pyrite, chalcopyrite and quartz are disseminated in the groundmass or form crystals in the vugs.

Drilling in the American Eagle Basin has provided a three dimensional view of the alteration associated with the zone of deep copper deposition. At the surface the principal alteration is phyllic, with minor, patchy potassic alteration. Silicification appears to be mainly near surface and closely associated with breccia masses. Tourmaline does not appear to extend deeper than 500 feet (150 meters) It occurs as fine-acicular, radial growth to massive clots of intergrown tourmaline-quartz in breccia masses, in veins and their selvages, and as rare sunbursts in porphyries.

The general three dimensional pattern of alteration associated with the copper deposition has been determined from pulps of drill core and cuttings by XRD and XRF analyses (Hausen et al, 1988; Hausen, 1980). These methods can semi-quantify the amounts of quartz, feldspar, micas, chlorite, etc., present in the pulverized rock. Using the ratio of total feldspar over quartz plus muscovite, a zone of feldspar destruction, and phyllic alteration, was mapped (Figure 5). The phyllic alteration, expressed by the low ratios, forms a crude, steep cylindrical shape that extends down from the surface to the zone of copper deposition (Figure 5). The alteration overprints and bottoms out on a relatively flat floor of potassic alteration (Figure 5).

The potassic floor, reflecting the increase in feldspar content appears below the copper zone (Figure 5). Drill core shows that orthoclase is the main alteration mineral and occurs as vein selvages and as pervasive replacement of the granodiorite and porphyries. Purple anhydrite is a common mineral in the potassic-altered zone and occurs with quartz-sulfide veins. The presence of anhydrite with phyllic alteration suggest alteration overprinting.

Mineralization. Copper Creek sulfides at are pyrite and chalcopyrite. They average about 1-3 volume percent, and rarely exceed 5 volume percent. The sulfides are controlled by veins, breccias, intensely altered zones, and stockwork fractures. They also occur as rare disseminations in porphyry intrusions. Oxidation is rare, except in breccias where may extend 50 to 150 feet (15-45 meters) in depth.



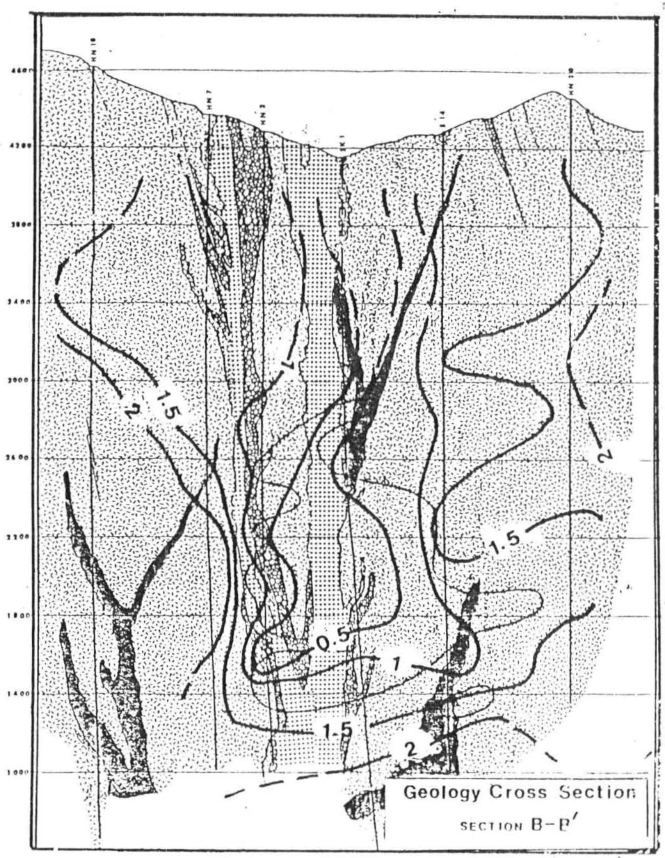


Figure 5: Alteration overlain on geological sections on A-A' and B-B'. Contour line represents the ratio of XRD values for total feldspar/sericite+quartz. The lower numbers, .5 and 1, represent phyllic alteration. Note the crude columnar shape of the pattern. Potassic alteration at and below 2.

Metal zoning is common at Copper Creek. Districtwise, the central porphyry zone contains the majority of surface copper, mainly in breccia masses. The American Eagle basin deep copper deposit lies in this central zone. The eastern porphyry zone lacks sulfides. Pyrite is the principal sulfide associated with the western porphyry zone. At depth, quartz-anhydrite veinlets with some chalcopyrite and bornite occur, but the copper content rarely exceeds 0.1%. North and south of the American Eagle Basin are the Blue Bird and Bunker Hill lead-silver mines.

Vertical zoning is very pronounced in the American Eagle Basin. The upper portions are pyrite rich; with depth the pyrite diminishes and chalcopyrite increases. In the main copper zone, vein controlled chalcopyrite is the only sulfide. Below the main zone, bornite, molybdenite, anhydrite and minor digenite appear. This transition corresponds to a drop in fracture/vein density, a decrease in sulfide content, and an increase in potassic alteration (Figure 4). Chalcopyrite, +/- bornite, occurs at higher levels in the pyrite zone and is associated with certain breccia masses. Molybdenite occurs at these upper levels only in the Childs-Aldwinkle breccia.

Contoured 0.4% Cu values in the American Eagle Basin outlines the general morphology of the copper deposition (Figure 4). The main zone consists of a generally flat, blanket-shaped zone. It corresponds with the overlap of phyllic and potassic alteration between the 1800 and 1400 foot (450-425 meters) elevation. (Figure 4). The upper portion consists of several steep, columnar-shaped extensions controlled by steep veins and porphyry/breccia contacts (Figure 4). Some of these steep features extend to the surface. Geometrically, the American Eagle Basin copper deposit consists of two forms: a lower, flat, blanket-shaped body, lying 2000 to 2400 feet (600-730 meters) below the surface, and an upward extending zone consisting of steep, columnar-shaped bodies. The deep copper deposit' shape generally corresponds with a surface area of clustered porphyry plugs, breccia masses, and strong phyllic alteration (Figure 3). Where isolated, as in the Childs-Aldwinkle breccia, the deep, vein controlled copper deposition does not appear to be present.

Boron. The association of tourmaline with breccia masses is not unique to Copper Creek, but is reported from porphyry copper occurrences in Mexico, Chile and Peru (Sillitoe, 1976; Sillitoe and Sawkins, 1971; Kents, 1964). Although tourmaline is not volumetrically abundant, it often occurs in the upper portions of a porphyry system. The presence of tourmaline implies that boron was an integral part of the porphyry magma and the later hydrothermal phases.

What effect could boron have on the porphyry magma and the development of a copper deposit? In the following discussion, data derived from experimental work and field observations are presented. The data and conclusions given are not to prove a case, but to generate more interest in boron and its possible role in porphyry copper systems.

Experiments: Boron added to a water-saturated haplogranitic melt affects it in a number of ways:

1) It lowers the melts solidus temperature. For a water saturated silicate melt at 1 Kbar, the solidus temperature is 715°C. The temperature can be lowered by 30°C with the addition of 2 wt. % B_2O_3. The addition of 17 wt % B_2O_3 lowers the solidus temperature by 115 to 145°C (Pichavant, 1981, 1983; Benard et al., 1985).

2) Boron in a silicate melt can increase the solubility of H_2O into the melt (Pichavant, 1981, 1983). At 100 MPa_{H_2O} the solubility of H_2O will increase by 1 mole H_2O/mole B_2O_3.

3) The viscosity of the silicate melt decreases since the boron assists in the depolymerization of the melts aluminosilicate network structure (London 1987; Pichavant 1987, 1991; Dingwell et al., 1992). The addition of 1 wt % B_2O_3 at 600°C can decrease a haplogranitic melts viscosity by 2 orders of magnitude (Pichavant, 1991; Dingwell et al., 1992).

The disruption of the silicate melt's aluminosilicate network has other significant geochemical consequences. Besides facilitating the incorporation of H_2O, it increases the solubility of high charge density cations (Group IV and V elements) and may involve the expulsion of Al, (Pichavant, 1983, 1987; Manning and Pichavant, 1988). The persistence of the aqueous volatiles in the silicate magma into the late stages of magmatic differentiation provides the means for concentrating the incompatible elements (metals) into the late or residual magma (Manning and Pichavant, 1988). Boron's partition coefficient favors the aqueous vapor-phase. The resultant aqueous phase exhibits an increase in silica activity and Na/K ratios. Pollard, et al., (1987) observed that boron-bearing fluids, in equilibrium with previous chloride-bearing solutions, lead to potassic alteration. If the boron-bearing fluids are diluted, then the rocks will be albitized.

Field investigations: Granites can contain 1-12 ppm boron without tourmaline being present. The boron is generally associated with micas (Saucer and Troll, 1990; Malenko et al., 1979). In granitoid intrusive complexes, boron often with anomalous levels of F, Sn, Mo, Li, Rb, Ag, and Cu, occur in large halos in their upper levels (Gundobin, 1988).

In tin regions investigators have noted that Sn occurs in either F-rich or B-rich systems (Pollard et al., 1987). Often the B-Sn systems exhibit brittle failure features such as breccia pipes and stockwork fracturing. The conclusion is that the greater H_2O solubility of boron-bearing melts can contribute a greater fluid over pressure, which can exert a high mechanical energy on the enclosing rocks.

Discussion. The geologic setting at Copper Creek suggests that the upper levels of porphyry copper systems typically include the presence of plug-like intrusions of porphyry and associated breccia masses, (either singularly or in clusters), sets of steep sulfide veins, and areas of strong phyllic alteration. Only those areas of clustered porphyry and breccia bodies that exhibit associated strong phyllic alteration and local copper mineralization would potentially host a deep porphyry copper deposit. Scattered breccia-masses, like the Old Reliable and Childs-Aldwinkle, appear to be isolated systems that may contain small tonnages of higher grade copper well up in the pyrite zone, but have a low potential for the presence of a deeper, low-grade, high tonnage deposit. To form a large porphyry copper deposit, a cluster of porphyry intrusions that overlap in time are required. They are able to furnish a sufficient volume of hydrothermal fluids to promote the hydrofracturing of host rocks and to carry the metals and deposit them in the structurally prepared zones.

A comparison of Copper Creek to two well-defined porphyry deposits allows for addition speculation. Because both the San Manuel-Kalamazoo and Ann Mason deposits are structurally rotated, a good cross-sectional view of their geology, alteration and mineralization distribution has been mapped

(Hausen et al., 1988; Lowell, 1968; Dilles and Einaudi, 1992). Both deposits exhibit clustering of rod-like porphyry intrusive bodies into a granitic host with the development of parallel shells of alteration and copper deposition. The copper deposition occurs at the interface of the older, inner zone of potassic alteration, and the younger, overlapping outer zone of phyllic alteration to form an inverted, cup- or bullet-shaped ore shell.

The upper portions of the Ann Mason deposit are better preserved than that of San Manuel. It shows that the phyllic alteration extends upward, as a widening column above the copper zone. Tourmaline breccias form pipe-like bodies about 4000 feet (1220 meters) above the copper zone. It is suggested that the top of the porphyry copper mineralization formed at 5000 feet (2.5 Km) and extends to a depth of 13000 feet (4 Km) (Dilles and Einaudi, 1992). The breccias bottom-out at about 5000 feet (1.5 km) depths. Using these parameters, Copper Creek has had 3500 to 5000 feet (1100-1500 meters) of cover removed.

The presence of boron may provide an explanation for the geologic, alteration and metallization characteristics of porphyry copper systems. Lowered viscosity and solidus temperature allow the porphyry melts to be intruded over long distances as a small, pipe-like body. The low viscosity explains how the magma is able to form intrusion breccia zones. The increased H_2O solubility provides the necessary fluid over-pressures to form the breccias at shallow depths and the deep, fracture stockworks. The abundant hydrous fluid explains how such small bodies can form strong areas of hydrothermal alteration. The affect of boron on the hydrous fluid's chemistry explains the core of potassic alteration.

Summary. The presence of tourmaline-bearing breccias, porphyry intrusions, phyllic alteration, and scattered copper mineralization are all considered to be features of a high level porphyry copper system. The potential for a possible deep porphyry copper deposit is increased where a clustering of these features occur. The possible depth to such deposits, however, may be over 2000 feet (610 meters).

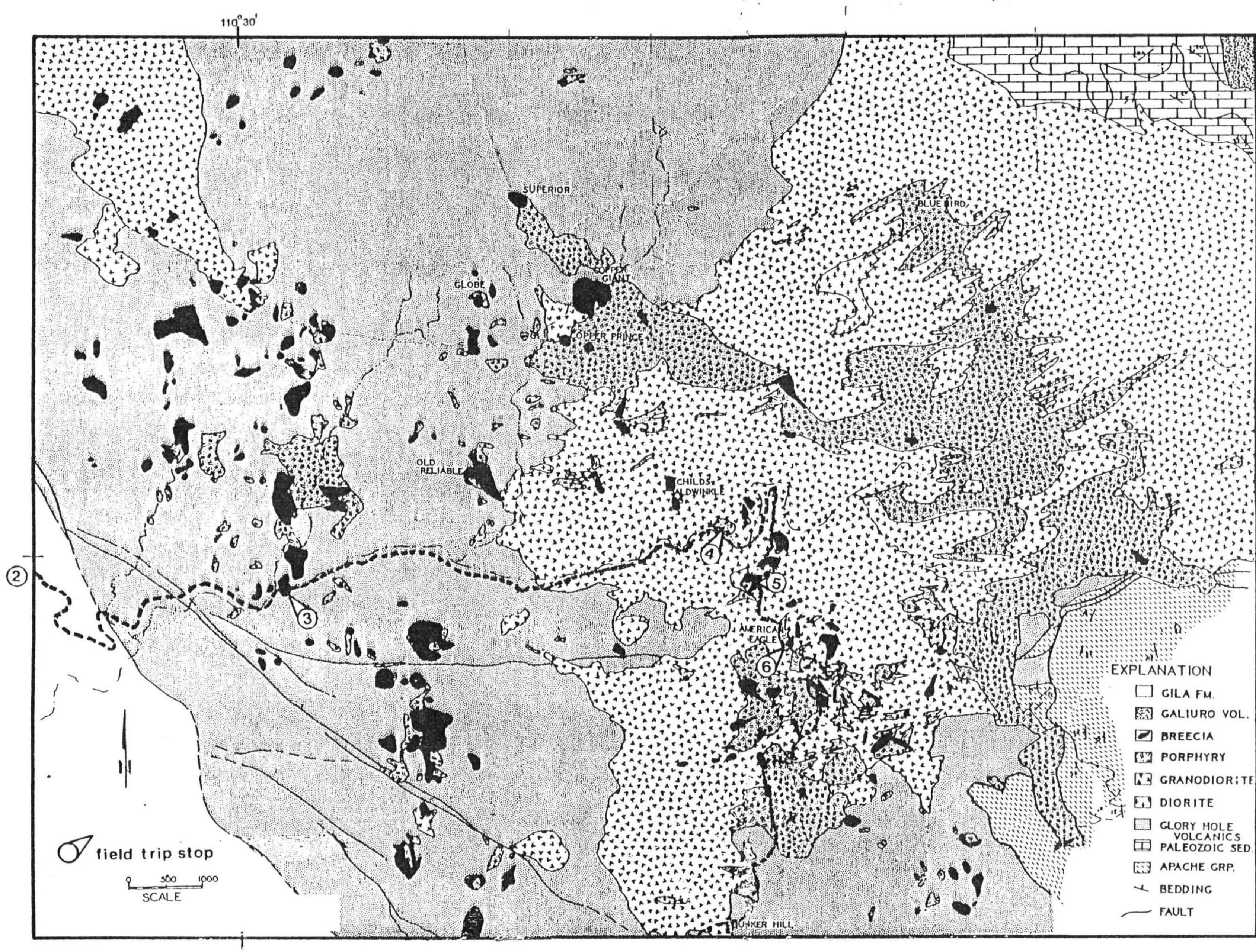


Figure 6: Generalized geologic map, Copper Creek, showing route and stops. Some of the important mines are named.

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FIELD TRIP GUIDE: COPPER CREEK.

The Upper Portion of a Porphyry Copper System

By James O. Guthrie

Coming from Tucson, take Oracle Road (State Highway 77) north, past Oro Valley and Catalina. The mileage for the field trip begins at the San Manuel turn off on State Highway 77 (Figure 1). The mountains on your right are the Santa Catalina Mountains, a mid-Tertiary up-lifted, igneous-metamorphic core complex. For some of the recent geologic work on the core complex, refer to Narvk and Bykerk-Kauffman, 1990. The hills to the left are the Tortolita Mountains which are geologically similar to the Catalina Mountains. At Oracle Junction (State Highway 79 intersection) continue north on Highway 77.

Near the town of Oracle 1.44 Ga Oracle granite is exposed in the road cuts. When the view to the north (left) is unrestricted, you may see the trace of the San Manuel fault. The distant dark colored rocks are the upper plate. The lower plate is the closer lighter colored units . Signal Peak, the conical hill, is in the lower plate unit. The San Manuel mine is about 4 miles east.

Past the 2nd Oracle turnoff, the highway descends into the San Pedro trough. The Galiuro Mountains are the range across the valley. The thick bedded, flat-lying units are the mid-Tertiary Galiuro volcanics.

At the San Manuel turnoff, leave Highway 77. At the stop sign, turn left and proceed west under the Highway. We will stop at the San Manuel guard shack, about 2 miles ahead. Magma personnel will meet us there.

STOP 1: San Manuel mine. Magma personnel will give a slide presentation on the geology and mining techniques at the San Manuel underground, block-cave mine. After the presentation the group will be transported to an overlook where the open-pit, copper-oxide operation can be viewed.

The San Manuel underground operation mine has produced over 600,000,000 tons with an average grade of 0.65%. The San Manuel ore body has about 4 years of life remaining. The mining and development of the Kalamazoo ore body are in progress. Of the 60,000 tons mined daily, approximately 1/3 is contributed by the Kalamazoo ore body.

For those interested in some of the recent geologic thought on the San Manuel mine area, refer to the article by Force and Dickinson, 1994.

After the overview, travel back to the San Manuel turnoff. Go under the bridge and make a left turn onto Highway 77.

ROAD LOG

0.0 San Manuel turnoff. Most of the road cuts are in the Gila Conglomerate. At 1.5 miles the San Manuel fault can be seen crossing the highway in the road cut to the left. The bed rock is Oracle granite. A ridge of crystalline rock trends south several miles.

..**4.5 Mammoth turn-off.** Turn right and descend into Mammoth. Watch your speed!

5.2 Blue Bird Road. Turn right. On the right is a sand and gravel plant, and on the left, a baseball field. The road crosses the San Pedro river bed and into a mesquite forest. (*If the river crossing is impossible, return to the main street of Mammoth, just west of the baseball field, turn right and return to Highway 77. Cross the bridge and pick up River Road, on the right at about 0.4 miles. Go south (right) about 2 miles to the Copper Creek Road*).

6.0 Intersection with River Road. Proceed across the paved road onto the beginning of the Copper Creek dirt road. The dirt road follows the wash for less-than a mile before climbing up onto the old fan surface.

The walls of the wash consist of 5-6 Ma lake beds of the Quiburis Formation (Shenk, 1990). Note the fine-grained, bedded nature of this unit. Many of the beds contain gypsum. To the north is a gypsum mine; to the south is the White Hills diatomite deposit (Shenk, 1990). These units probably represent near-shore, shallow lake deposits. Fossils are absent except for rare plant remains. Ash beds occur in the lake beds; one can be seen in the road at 6.9 miles, just as the road begins to climb onto the fan surface.

The road crosses pediment gravels which are composed mainly of Galiuro volcanics. Drive carefully. Any recent rains can produce rough areas.

8.9 Cattle pen. It is here that Ranchers Exploration and Development Company obtained their water supply for leaching the Old Reliable mine (1972-1982). They pumped the water to the mine site in a five-inch line laid along the road. (More will be said about their operation later in the guide.)

11.2 Curve with water tank.

13.1 STOP 2. Overlook. At this stop a general discussion of Copper Creek geology will be given. Refer to the enclosed geologic map; the stop is off the map, on the center left (Figure 6).

Look up Copper Creek Canyon. The Galiuro volcanics form the skyline and once covered the older Laramide units. Sombrero Butte and Little Sombrero Butte are the large, blocky hills to the south (right). Two prominent, rounded hills can be seen to the right of the canyon in the mid-distance. The furthermost hill consists of Dripping Springs Quartzite; the nearer, Copper Creek granodiorite. The American Eagle basin is located just northeast of the Copper Creek granodiorite hill.

In the middle foreground, in the canyon bottom, is the Magma water treatment ponds for the Old Reliable leach field drainage. Let your eyes travel left from the ponds and up the ridge; the edges of the terraced blast area of the Old Reliable should be visible.

During March, 1972, Ranchers, in partnership with DuPont Chemicals, detonated 2,000 tons of explosives to rubblize the Old Reliable breccia pipe. Reserves announced were 4,000,000 tons of 0.74% copper (~60,000,000 pounds of contained copper). Ranchers produced 11,000,000 pounds of cement copper between 1972-75 and 1979-81.

Most of the rocks in the area between the treatment plant and the near foreground are Glory Hole volcanics. These rocks consist of andesitic, ash breccias, ash flows and flow breccias that have been thermally metamorphosed to hornfels by the intrusion of the Copper Creek granodiorite stock.

Visible on the southern canyon wall are several rugged-appearing, resistant outcrops. Breccia masses often are visible as resistant knobs. The linear, wall-like exposures are silicified and pyritized faults. The approximately 1200 foot displacement of a quartzite unit within the volcanics indicates that the movement on the east-southeast fault was down on its northside. Further east the east-west fault zone is intruded and cut by the granodiorite (Figure 6). Faulting and subsidence took place prior to the intrusion of the granodiorite. It is unknown whether this faulting is due to Caldera subsidence or to other structural processes.

Peeking over the hills to the far left is the light-colored, bouldery outcrop of the Boulder Mountain granodiorite stock. The range front fault, sub-parallel to the older east-southeast faulting, drops the conglomerates of the Quiburis Formation (the rocks beneath our feet) against the older crystalline rocks (Figure 6).

From this stop the road descends steeply into the canyon proper. Caution is stressed due to the roughness of the road, the loose cobbles, and possible rain damage. As you descend, notice the heterogeneous nature of the Conglomerates in the road cuts and hill slopes.

As you come around the hairpin curve, the road parallels the range front fault which crosses the road just before the small side canyon.

14.4 Side canyon. The rocks observed here and along the road to the next stop consist of hornfelsed Glory Hole volcanics. Their breccia textures can be seen on weathered surfaces. In the side canyon, boulders and cobbles of altered, tourmalinized, iron-stained breccias and altered dark porphyries can be seen. The dark color of the volcanics is due to the formation of fine-grained biotite-feldspar-quartz during thermal metamorphism.

As the road continues up the canyon, note the very strong, steep fracturing. These near east-west trends are very prevalent throughout the Copper Creek area. Many of the veins of the district trend in the same direction.

The dump above the road on the left is from an adit into a silicified-pyritized fault zone. The resistant ridge of this fault can be seen on the southern canyon wall to your right.

14.7 Quartzite outcrop. On the left are two breccia masses above the cliff-forming outcrop of quartzite. The quartzite dips gently upstream, indicating the volcanics are near flat-lying. As we travel across the creek, other outcrops of quartzite can be seen above and along the right side of the road. Along the same horizon, but farther northwest, there is a small lens of limestone.

14.9 STOP 3 Breccia. In the road cut and stream bed are examples of breccia development in volcanics.

If you climb down into the creek bottom,
be very careful of the steep, rubbly slope.

Look closely at the breccia fragments--their size, shape. composition, alteration, and what fills the inter-fragmental areas. Although most of the fragments are pebble to small-cobble in size, there is wide range of sizes. Fragments are primarily angular in shape. Those fragments which appear rounded probably owe their shape to alteration and not to abrasion.

Phyllic alteration has pervasively affected the small fragments, but only partially affect the large fragments. Where visible the rock textures indicate that the fragments are the Glory Hole Volcanic. The inter-fragmental areas, varying from mildly to strongly open-spaced, contain quartz, tourmaline, pyrite, and sericite.

Are the alteration and pyrite deposition evenly distributed or in local zones? If channeling of hydrothermal fluids occurred, it may suggest a fairly rapid fluid flow. Good occurrences of pyrite-quartz-tourmaline can be viewed in the stream bed.

Well displayed in the road cut is the contact between the breccia and the host rock. This contact, although intruded by dark porphyry, is sharp and abrupt. The limited strong alteration of the adjacent host rock may imply a short-lived hydrothermal episode or a limited fluid flow. How can a mass of rock shatter so intensely and still maintain the sharp contacts with the non-broken host rock?

On the slopes of the canyon, several breccia masses can be seen as rough, knobby outcrops.

<u>When finished return to the vehicles and continue up the road.</u>

15.4 Treatment plant. Magma maintains this facility to capture the acidic waters that drain from the Old Reliable leach area. The bottom level of the Old Reliable, just above the side canyon (Saloon Gulch) floor, forms the floor for the leach pile. Water is caught and piped to the evaporation ponds.

Up Saloon Gulch, so named in memory of past establishments upstream, drains the area north and northeast of Copper Creek. The Copper Prince, Globe (Glory Hole), and Copper Giant mines, and other copper stained breccias occur in the northern area (Figure 6).

Ahead and in a small side drainage is the tailings from milling of the Childs-Aldwinkle ore.

<u>Continue past the fenced ponds and up the road. At about 15.6 miles is a wide area in the ascending road.</u> In the canyon bottom, to your left, you can find ore specimens from the Childs-Aldwinkle mine. They occur with the gravels along the canyon edges and in the stream bottom.

15.7 Below tailings. It is here that the contact between the Glory Hole volcanics and Copper Creek granodiorite cross the road (Figure 6). From here on much of the bed rock consists of granodiorite. Observe the unaltered granodiorite with veins and fracturing along the road cut. When you see the old mill foundations, look left and into the creek bottom. One can see the origin of the name Copper Creek.

16.0 Old Mill foundation, ore bin, and bridge. The Childs-Aldwinkle haulage adit is straight ahead. When you see other foundations, note the side canyon. The canyon passes below the glory holes of the Old Reliable mine; they are not visible until farther along the road. The roadbed you see along the opposite canyon wall is the remains of a narrow gauge railroad. It hauled ore from the Old Reliable and Childs-Aldwinkle mines to a mill just up the canyon. The story is that the mill ran three months, then was closed down due to declining copper prices.

LUNCH BREAK. <u>In a wide spot up the road less than 0.1 mile.</u>

16.1 Stop 4; Dark porphyry plug. A plug of dark porphyry intruded into granodiorite is exposed in the creek bottom (Figures 3 and 6). Two features will be viewed: the contact relation between igneous rock types, and the occurrence of alteration and mineralization.

The porphyry-granodiorite contact is a zone of intrusion breccia. Xenoliths of granodiorite and occasional Glory Hole Volcanics are common in the porphyry. The granodiorite was brittle enough to break, but warm enough that very little chilling occurred at the porphyry margins. The dark porphyry magma must of been very fluid to be able to squeeze along the thin fractures and hydraulic-out fragments. What could make the magma's viscosity low enough to be intrude upward several 1000's of feet and still able to form intrusion breccias?

Patches of spotted, altered rock occur locally in the breccia margins and adjacent granodiorite. The light green spots consist of very fine sericite. Look carefully to see if other recognizable minerals are present.

In the dark porphyry is an east-west fracture-vein. Note the increase in alteration and sulfide deposition toward the east. At the vein intersection with the porphyry-granodiorite contact occurs a zone of intense phyllic alteration. Hydrothermal fluids appear to seek and travel along intrusive contacts. When looking at the vein, note that the oxidation of sulfides is very shallow.

Return to the vehicles and continue up the road. The dump you see just to the right of the old mill foundations, in the small side drainage, is material from the Childs-Aldwinkle mine. Molybdenite chalcopyrite, bornite and some copper oxides can be found here. The road climbs and curves around Post Office point. The cleared off area across the canyon is where three aligned breccias occur. They have been named the Railroad Breccias. Besides containing some copper oxide, some of the breccia fragments consist of dark porphyry. The rock terraces along the canyon floor represent the outskirts of the town of Copper Creek.

16.5 Post Office. The foundation before you, with the name of Copper Creek, is the remains of the old post office. During the heydays of mining, two towns existed, Copper Creek and Sombrero Butte. Virgil Mercer, whose family homesteaded east of Sombrero Butte, said the town with the larger population had the school; therefore, the school's location sometimes changed yearly.

The narrow gauge railroad came through the cut behind the water tank. In the railroad cut, left of the path from the post office, a breccia that contains mainly specularite is exposed.

Continue straight ahead and toward the American Eagle basin. (The road that branches to the left takes you back into the canyon. It also connects with other roads that allow access to the Blue Bird Mine and the area above the Childs-Aldwinkle glory holes.) Observe the strongly fractured and iron oxide stained granodiorite in the road cut. Veins are common.

16.6 Red breccia. The road has cut through and exposed both contacts of this breccia (Figure 3). Note the sharp, abrupt contacts between the breccia and granodiorite. Very much like STOP 3. The red hematite indicates strong oxidation in the upper portions of the breccia. At the second contact, up the road, the intrusion of a dark porphyry can be seen. It intrudes along the contact and sends fingers out into the breccia. The presence of porphyry as fragments (railroad breccia) and the intruding of the red breccia implies a close association between breccia formation and dark porphyry intrusion.

Below is the haulage level for the American Eagle mine. At the top of the slope before you are two breccia masses. They occur at the outer, northern edge of the American Eagle basin.

16.7 STOP 5: Intrusion breccia. Exposed in this road cut is a complex zone of small dark porphyry bodies and brecciated, fractured granodiorite (Figure 3).

At the first dark porphyry outcrop, it appears that a darker variety is intruded by a lighter, pinkish variety. Do they represent two separate intrusions? Note the number of granodiorite xenoliths and the wispy trails of pinkish K-spar. Is the K-spar being mobilized from the xenoliths?

Look closely at the thin injections of porphyry along the fractures. Can you see where plagioclase phenocrysts were unable to fit into the fracture and remained behind? The melt had to be fairly fluid.

In and adjacent to the dark porphyry are patches and zones of sericite, tourmaline, and sulfides. Where these alteration patches occur within the intrusion breccia, the vuggy areas appear to correspond to inter-fragmental regions. Up the road and around the curve, you will observe areas in the granodiorite that exhibit a slightly vuggy, breccia-like texture. Sometimes these open-spaces will contain crystals of quartz, tourmaline, chalcopyrite, or feldspar. One can imagine these interstitial areas filled with very-fine grained porphyry that was subsequently been leached out by hydrothermal solutions, forming the open-space texture. Here the alteration-leaching process has not progressed very far.

The Childs-Aldwinkle glory holes can be seen to the northwest, . To the north northeast the dumps of the Blue Bird mine are visible.

Return to the vehicles and drive into the American Eagle Basin. Stay to the left.

17.0 STOP 6: American Eagle breccia. (Figure 3) The main feature of this stop is the very intense alteration, both in and outside the breccia. This is the principal difference between isolated breccia/porphyry bodies, like the Old Reliable, and the breccia/porphyry clustering as seen in the American Eagle basin. Looking about the small basin area, one can see the various breccia masses. The deep zone of copper deposition, about 2400 feet (730 meters) below the surface, crudely conforms to the shape of the drainage basin. Tourmaline is a very common mineral in and about these breccia/porphyry bodies.

The adit is driven into the American Eagle breccia. Just inside it branches into two, short tunnels.

BE CAREFUL!!! INSIDE THE LEFT TUNNEL IS A 30 FOOT WINZE (SHAFT)!!!!!

(WHO KNOWS WHAT EVIL LURKS IN THE HEART OF A WINZE?)

The breccia contact is well exposed at the mouth of the adit. Follow the contact up one side, across the roof, and down the other side. Is the contact planar or irregular? The rock on the right of the adit entrance is granodiorite; the left side is dark porphyry. The American Eagle breccia is a lens-shaped body that occurs at the contact between granodiorite and porphyry. Mining shows that the breccia narrows downward into a N60E 'vein' at 300 feet (Weed, 1913).

If you walk down the road toward the covered shaft, the dark porphyry occurs exposed along the road cut. The porphyry is intensely altered to quartz-sericite. Locally, there are vugs containing specular hematite, quartz, tourmaline, and/or chalcopyrite. Up the road is a strongly fractured and altered granodiorite. A short climb above the drill pad is the American Eagle breccia where the contact is well exposed. The contact consists of an abrupt change from angular breccia to closely spaced, fractured granodiorite. The fractures parallel the breccia contact and exhibit very strong phyllic and tourmaline alteration. Follow the contact up to the top. Along the outcrop you can observe flat slabs in the breccia that appear to have spalled-off the fractured granodiorite. Within the top of the breccia, some crude layering can be seen.

When finished, drive on up the road, staying right of the fork and around the curve, where the road begins to climb out of the basin. Strong breccia development can be seen along the road. The breccia that forms much of the hill contains areas of very strong quartz-tourmaline-breccia. At mileage 17.3 some of this material can be found along the road.

17.5 Top of saddle. Little Sombrero and Sombrero Buttes are straight ahead. The Bunker Hill mine dumps are below. Like the Blue Bird mine to the north, it is a lead-silver vein deposit.

This concludes the field trip. We will return back to River Road and Mammoth by the Mercer Ranch road.

17.8 Road fork. Take right fork.

18.2 Bunker Hill mine.

18.9 Road fork. Turn right onto Mercer Ranch road.

24.2 Road fork. Take right fork.

28.0 Intersection with River road. Turn right. The large wash you cross is the mouth of Copper Creek.

31.5 Intersection with Blue Bird road. Turn left, through the mesquites and across the San Pedro river bed. *(If the river crossing is flooded, return to River Road, turn left. Where it connects with Highway 77, about 2 miles, turn left and head for Tucson.)*.

32.2 Intersection with Mammoth main street. Turn left and proceed to Highway 77 and back to Tucson.

References.

Bernard, F., Moutou, P. and Pichavant, M., 1985, Phase relations of tourmaline leucogranites and the significance of tourmaline in silicic magma: Jour. Geol., 93, 271-291.

Creasy, S.C., and Kistler, R.W., 1962, Age dates of some copper-bearing porphyries and other igneous rocks in southeastern Arizona - in Geological Survey Research 1972: U.S. Geol. Surv. Prof. Paper 450-D, 1-5.

Dilles, J.H., and Einaudi M.T., 1992, Wall-rock alteration and hydrothermal flow paths about the Ann-Mason porphyry copper deposit, Nevada - A 6-Km vertical reconstruction: Econ. Geol., 87, 1963-2001.

Dingwell, D.B., Knoche, G.R., Webb, S.L., and Pichavant, M., 1992, The effect of B_2O_3 on viscosity of haplogranitic liquids: Amer. Mineral., 77, 457-461.

Force, E.R., and Dickinson, W.R., 1994, Tucson Wash - An introduction to new work in the San Manuel and Mammoth districts, Pinal County, Arizona; Guidebook for Field Trips, 9th V.G. McKelvey Forum, U.S. Geol. Surv. Circ. 1103-B.

Gundobin, G.M., 1988, Mineralization and the behavior of fluorine, boron, and rare elements in latite-andesite granitoids: Internat. Geol. Review, 30, 62-70.

Guthrie, J.O. and Moore, D.G., 1978, The geology of the Copper Creek area, Bunker Hill Mining District, Galiuro Mountains, Arizona; Ariz. Geol. Soc. Digest XI, p.25-31.

Hausen, D.M., 1980, Quantitative measurements of wall rock alteration in the exploration of buried mineral deposits: SME AIME transactions, 266, 1853-1860.

__________, Guthrie, J.O., and Thomas, L.A., 1988, Alteration study of the American Eagle Breccia-pipe and associated copper porphyry occurrence, Copper Creek, Arizona: Minerals, Metals and Materials Society Process Mineralogy VIII, 109-128.

Keith, S.B., 1977, Compilation of radiometric age dates for Arizona: Ariz. Bur. Geol. Mineral Tech. Open-file Report 77-1a, 187p.

Kents, P. 1964, Special breccias associated with hydrothermal developments in the Andes: Econ. Geol. 59, 1551-1563.

Krieger, M.H., 1968, Geologic map of the Holy Joe Peak quadrangle, Pinal County, Arizona; U.S. Geol. Surv. Geol. Quad Map GQ 669.

Kuhn, T.H., 1941, Pipe deposits of the Copper Creek area, Arizona: Econ. Geol. 36, p.512-538.

London, D., 1987, Internal differentiation of rare-element pegmatites; effect of boron, phosphorus, and fluorine: Geochim. Cosmochim. Acta, 51, 403-420.

Malinko, S.V., Berman, I.B., Listayn, A.Ye., and Stolyarava, A.N., 1979, Boron in rock-forming minerals based on data from a local radiographic analysis: Internat. Geol. Review, 21, 1274-1284.

Manning, D.A.C., and Pichavant, M., 1988, Volatiles and their bearing on the behavior of metals in granitic systems, in Taylor and Strong, Eds., Recent advances in the geology of granite related mineral deposits: Canadian Inst. Mining and Metallurgy Spec. Vol. 39, 13-24.

Naruk, S.J., and Bykerk-Kauffman, A., 1990, Late Cretaceous and Tertiary deformation of the Santa Catalina metamorphic core complex, in Gehrels, G.E., and Spencer, J.G., eds., Geologic Excursions through the Sonoran Desert Region, Arizona and Sonora: Az. Geol. Surv. Spec. Paper 7 - Field Trip Guide Book, 86th Annual Meeting, Cordilleran Section, Geologic Society of America.

Pichavant, M., 1981, An experimental study of the effects of boron in a water saturated haplogranite at 1Kbar vapor pressure: Contrib. Mineral. Petrol., 76, 430-439.

___________, 1983, Melt-fluid interaction deducted from studies of silicate-B_2O_3-H_2O system at 1Kbar: Bull. Mineral., 106, 201-211.

___________, 1987 Effects of boron and H_2O on liquidus phase relations in the haplogranite system at 1 Kbar: Amer. Mineral., 72, 1056-1070.

___________, 1991, The effect of B_2O_3 on the viscosity of haplogranitic melts: Geol. Soc. Amer. Abstr. with Program, 72, 533.

Sacerer, A., and Troll, G., 1990, Abundance and distribution of boron in the Hauzenberg (Bavaria) granite complex: Geochim. Cosmochim. Acta, 54, 49-55.

Shafiqullah, M., Damon, P.E., Lynch, D.J., Reynolds, S.J., Rehrig, W.A., And Raymond, R.H., 1980, K-Ar geochronology and geologic history of southwestern Arizona and adjacent areas, in Jenny, J.P., and Stone, C., eds., Studies in western Arizona: Ariz. Geol. Soc. Digest 12, 201-260.

Shenk, J.D., 1990, Economic geology of the White Cliffs diatomite deposits, Mammoth, Arizona; M.S. Thesis, Univ. Ariz., 157p.

Sillitoe, R.H., 1976, A reconnaissance of the Mexican porphyry copper belt; AIME Transactions, 85, B-170-B-189.

Sillitoe, R.H., and Sawkins, F.J., 1971, Geologic, mineralogic and fluid inclusion studies relating to the origin of copper-bearing tourmaline breccia pipes, Chile: Econ. Geol., 66, 1028-1041.

Simons, F.S., 1964, Geology of the Klondyke quadrangle, Graham and Pinal Counties, Arizona: U.S. Geol. Surv. Prof. Paper 461.

Weed, W.H., 1913, "Chimney" or "pipe" deposits in the porphyries: Mining and Eng. World, 38, 375-378.