# Observations from a Visit to Constellation Copper Corporation's San Javier Project, Sonora, Mexico

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## Introduction

Approximately 2 days (evening Oct. 16, all of Oct 17 and morning of Oct. 18) were spent on-site at the San Javier project with Mr. Gary Parkinson and David Brown. I examined reports and drill core (Cerro Verde) and also made site visits to La Trinidad, the edge of Cerro Colorado, Mesa Grande, and Cerro Verde. I was asked to examine the properties and compare them with other known IOCG deposits and to provide recommendations for further exploration.

The Cerro Verde, La Trinidad, and Mesa Grade prospects do appear to be members of the IOCG (iron oxide-copper-gold) class of deposits. Brief review of available data suggests that the Cerro Verde area may be part of a larger IOCG district that extends to the Yaqui River to the northeast and includes copper and gold deposits and prospects of the San Antonio district including Luz del Cobre, though these have traditionally been thought of as porphyry-related.

Copper-gold mineralization occurs within hematitized intermediate to felsic extrusive, probably subaerial, volcanic rocks of the early Tertiary (?) Tarahumara Volcanic unit. These volcanic rocks overlie terrestrial to lacustrine (?) sediments of the Barranca Group. The sediments appear to consist of siltstones and sandstones with coal layers that grade upwards into coarse conglomerates immediately below the Tarahumara volcanic rocks. It is unclear from drill core and map patterns whether the Tarahumara volcanic rocks rest unconformably or conformably on the Barranca sedimentary rocks. In some instances it appears the contact may be occupied by a low-angle structure (thrust or extensional normal fault).

Mineralization appears to be both structurally and lithologically controlled. The Cerro Verde deposit, as currently understood, contains a major resource of low-grade (~0.35-0.4% Cu) copper oxide mineralization. Drilling practices and quality control of samples and data at the project appears satisfactory.

## Iron Oxide-Copper-Gold (IOCG) deposits

Iron oxide-copper-gold deposits are a relatively recently recognized class of deposits (Hitzman, et al., 1992; Williams et al., 2005). They range in age from late Archean to the Pliocene and are found in a number of different tectonic settings (e.g., rift, subduction zone, basin collapse) (Hitzman, 2000). They display a variety of morphologies but generally show a spatial relationship to major, crustal-scale fault zones. The metal content of the deposits is highly variable. Iron oxides are the dominant mineral gangue. The deposits are sought for copper and gold but may contain a host of trace metals including light rare earth elements (predominantly Ce and La), silver, molybdenum, zinc, cobalt, lead, tungsten, bismuth, and uranium, as well as significant fluorine, boron, and chlorine.

IOCG deposits occur in mafic to felsic igneous rocks, metamorphic rocks, or sedimentary rocks. They are generally spatially and temporally associated with batholithic complexes of intermediate to felsic composition although there is continuing debate about whether the deposits are genetically directly related to these magmas (Pollard, 2000) or whether these intrusive bodies simply provided the thermal energy to drive large-scale hydrothermal systems which resulted in metal scavenging from surrounding host rocks (Barton and Johnson, 2000; Hitzman and Valenta, 2005).

Whatever their origin, IOCG deposits are invariably associated with very large volumes of hydrothermally altered rocks (10 to over 100 km$^3$; Hitzman, 2000).

The deposits are structurally controlled. Most occur along major (crustal-scale) shear zones and are essentially vein systems, often in ductile-brittle transition zones with apparently metamorphic mineral assemblages that may be hydrothermally, rather than metamorphically, derived (e.g. Salobo, Carajás district, Brazil – 784 Mt @ 0.96% Cu, 0.58 g/t Au). Many large deposits develop in fault jogs or at fault intersections (Fig.1). In these locations the deposits form stockwork zones (e.g. Sossego, Carajás district, Brazil – 245 Mt @ 0.97% Cu, 0.3 g/t Au) or breccia "pipes" (e.g. Olympic Dam, Australia - 761 Mt @ 0.5 g/t Au, 1.5% Cu, 0.6 kg/t $U_3O_8$ – 425 ppm U). Manto-style mineralization (Fig. 2) is also possible where IOCG fluids are structurally channeled into favorable units and/or structural traps (e.g. Candelaria, Chile – 470 Mt @ 0.95% Cu, 0.22 g/t Au, 3.1 g/t Ag). While the physical size of deposits is highly variable, the Ernest Henry deposit in Australia (167 Mt @ 1.1% Cu, 0.54 g/t Au) can be taken as a "typical" economically significant IOCG. It has a footprint that is approximately 1 km long by 300m wide and extends over 1 km downdip as a breccia zone along a major fault (Mark et al., 2000).

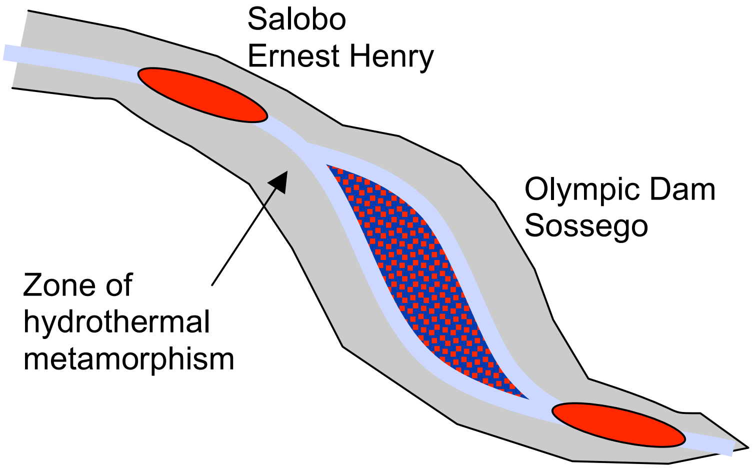

**Figure 1.** Cartoon of structural setting of IOCG deposits. The deposits may occur on major faults or shear zones (e.g. Salobo, Ernest Henry) or within dilational jogs along fault zones (e.g. Olympic Dam, Sossego).

IOCG deposits share a characteristic suite of alteration types (Hitzman et al., 1992; Haynes, 2000) (Fig. 3). Magnetite-bearing sodic and/or sodic-calcic alteration, characterized by the development of replacive albite (±scapolite) in more felsic host rocks and albite-actinolite-diopside (±scapolite) in more mafic rocks, is the dominant alteration type in most IOCG systems. Potassic alteration generally post-dates sodic and sodic-calcic alteration. This style of alteration is also commonly replacive, unlike the vein-controlled potassic alteration in porphyry systems, and is characterized by the formation of orthoclase-magnetite in more felsic rocks and biotite-magnetite in more mafic rocks. Hematite may replace, or form instead of, magnetite in structurally high-level systems. A number of IOCG deposits contain late and structurally high-level zones of hydrolytic alteration characterized by the replacement of earlier alteration assemblages by martite (hematite after magnetite), sericite, carbonate minerals, and quartz.

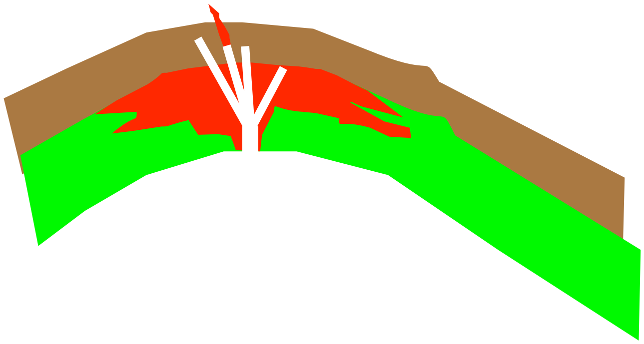

**Figure 2.** Cartoon of a manto-style IOCG deposit formed where hydrothermal fluids guided by a major high-angle structure are trapped by an impermeable unit leading to the development of a tabular zone of alteration and mineralization. This model is based on the Candelaria deposit in Chile but has smaller scale analogues throughout the coastal range of Chile and Peru; similar patterns of mineralization are observed in Baja California.

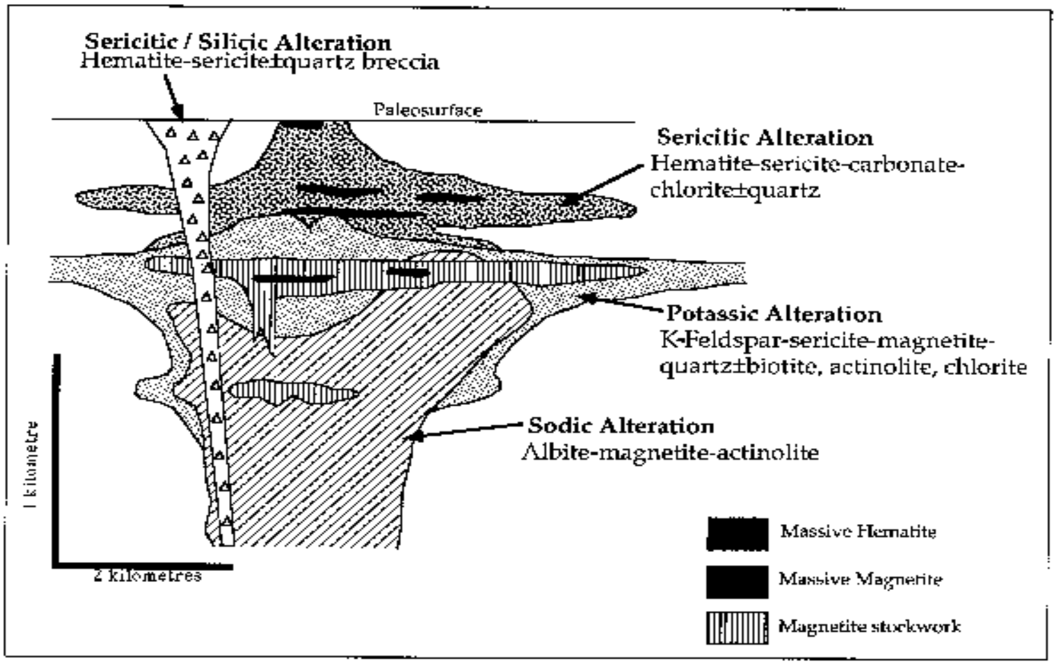

**Figure 3.** Cartoon illustrating the general alteration patterns in IOCG deposits (from Hitzman et al., 1992). Sodic (and sodic-calcic) alteration is generally deep and associated with magnetite – it represents the largest alteration zone in IOCG systems. The sodic and sodic-calcic alteration is cut by potassic alteration (generally at higher structural levels). Most Cu-Au deposits are spatially associated with potassic zones. Some systems contain high-level sericitic alteration (also termed "hydrolytic" or "HSCC" – hematite-sericite-carbonate-chlorite); the giant Olympic Dam deposit occurs within hydrolytic alteration.

Copper-gold and other metals may be precipitated during any of the alteration stages, but significant mineralization is most common during potassic alteration although the giant Olympic Dam deposit is associated with hydrolytic alteration (Reeve et al., 1990). Gold is generally spatially and temporally related to sulfides in these deposits.

## San Javier Systems

The prospects observed at San Javier (Cerro Verde, La Trinidad, and Mesa Grande) all appear to have similar characteristics. All display moderate to intense hydrolytic alteration (carbonate-sericite) with associated hematite mineralization. There is little evidence of earlier sodic or potassic alteration, though P. Henley notes the presence of "adularia" in a number of samples and whole rock analyses show enhanced $K_2O$ values suggesting that a precursor potassic alteration event may be present. Little to no evidence was seen of magnetite mineralization.

The alteration suite and the lack of magnetite suggest that these prospects represent very high levels of an IOCG system. The absence of discrete magnetic anomalies in the area of Constellation's properties suggests that these prospects may be structurally detached from the lower portions of the hydrothermal systems that would be expected to have large areas of sodic alteration.

Though the San Javier systems display abundant veining and faulting, it is unclear from the available data what the fundamental structural controls are for hypogene mineralization. The available geological mapping does not suggest the presence of a major (crustal-scale) fault zone in the area, though such zones are associated with the majority of IOCG deposits. A fresh look at the regional geology may help understand the setting of the system.

The overall grade of Cerro Verde is low relative to other mined IOCG deposits worldwide. The general lack of pyrite, combined with the relative abundance of carbonate in high-level systems, means that supergene blankets are generally not developed. Thus a supergene deposit must rely on the existing in-situ copper grade. The average grade at Cerro Verde (approximately 0.35% Cu) is about what would be expected in many IOCG systems. This grade can only be raised through definition of higher-grade structural zones.

## Key Observations

Alteration:

The alteration suite defined in the field and by petrography by P. Hensley (report to Constellation) is an assemblage of sericite-carbonate-hematite with subsidiary barite, fluorite, apatite, and light rare earth element (LREE) minerals such as bastnaesite and florencite. This assemblage is very similar to structurally high-level hydrolytic (or HSCC – hematite-sericite-carbonate-chlorite alteration) found at Olympic Dam, Australia. Quartz appears to be relatively rare in the assemblage at Cerro Verde and when present is paragenetically late. The paucity of quartz is typical of many IOCG systems (including Olympic Dam), though some do contain high level zones of massive silicification.

The petrography, combined with the available regional radiometrics (regional potassium high around Cerro Verde), suggests that the area may have been subjected to a pre-mineralization potassic alteration event (potassium feldspar flooding). No evidence was observed during the limited field visit of regional sodic (albite) or sodic-calcic (albite-actinolite-epidote-scapolite) alteration typical of many IOCG systems.

Rocks observed in drill core are typically tan to brownish in color (Fig. 4 a-d) indicating ferroan carbonate and sericite alteration of much of the groundmass of the volcanic rocks. Mafic phenocrysts, probably originally relatively uncommon given the original igneous composition, are difficult to distinguish in hand specimen and have probably been largely replaced by iron oxide. Plagioclase and orthoclase phenocrysts are chalky white to greenish and have been replaced by sericite and carbonate. Though several intervals contain relatively abundant chlorite (Fig. 5), these appear to be rare. Chlorite is a typical constituent in some high level, hydrolytic IOCG systems, but is generally best developed in mafic protoliths.

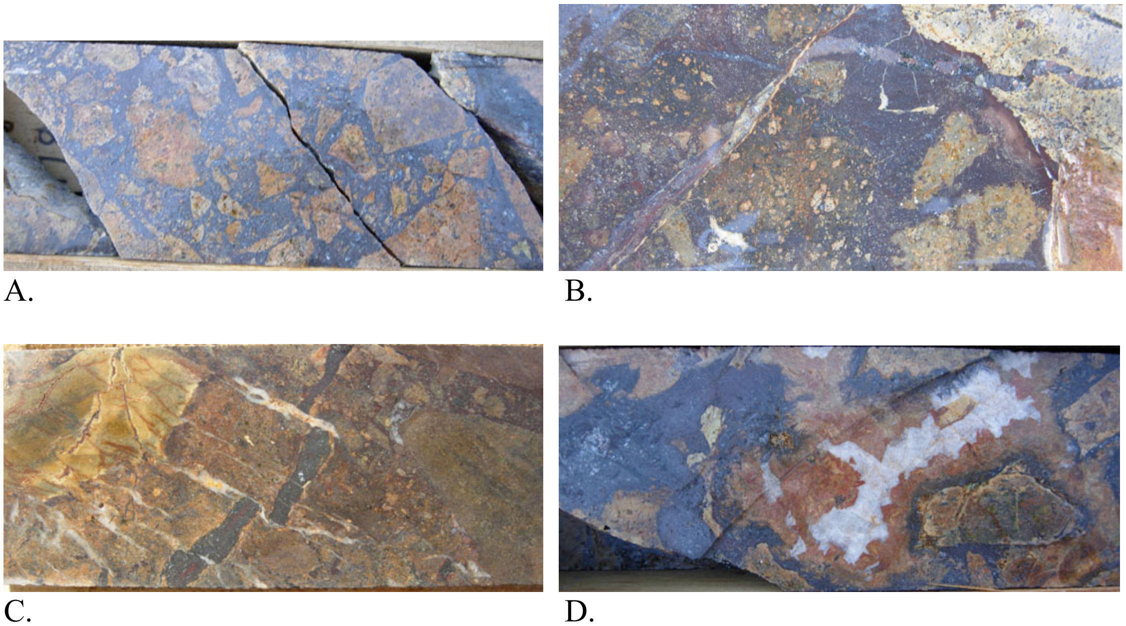

**Figure 4.** Typical carbonate-sericite altered Tarahumara volcanic rocks from Cerro Verde. A. Specular hematite breccia with clasts of tan colored dacite. Clasts are uniformly altered and display sharp to irregular edges resulting from in-situ replacement by hematite, typical of IOCG systems. SJ-06-7, 184m. B. Specular hematite breccia with the hematite dull red in color probably due to recrystallization during supergene weathering. The breccia contains tan to brown altered volcanic clasts in a hematite matrix. The darker tan clasts show ragged edges. Apparent remnants of igneous phenocysts occur in the hematite suggesting near total replacement of volcanic rocks by hematite locally. Note the wavy hematite vein that cuts both clasts and matrix and is truncated and offset by a later, brittle vein of hematite-quartz (formed during low angle faulting event?) SJ-06-7, 176m. C. Typical brown colored (carbonate-sericite altered) andesite (?) cut by a supergene weathered (dull) specular hematite vein that is cut and offset by later, discontinuous quartz veins. SJ-06-7, 199m. D. Small carbonate-sericite altered volcanic rock clast in a specular hematite-carbonate breccia. Specular hematite precipitated first, followed by red-brown weathered carbonate (ferroan dolomite?) and then white (non-ferroan) calcite+ dolomite. Sulfides are most common on the edges of the white carbonate. SJ-06-7, 185m.

Some zones in the drill core display less obvious carbonate-sericite alteration (Fig. 6). Plagioclase in these zones is still sericitically altered, but the groundmass has a grey to purplish color indicative of slight hematization but lacking intense replacement by carbonate and sericite. Distinguishing these less altered zones on geological sections will be important for better understanding the distribution of hydrothermal alteration. Interestingly, several of these less altered zones are still cut by abundant hematite veining (with chalcopyrite) suggesting that the major hematite veining and brecciation event post-dates the period of intense hydrothermal alteration.

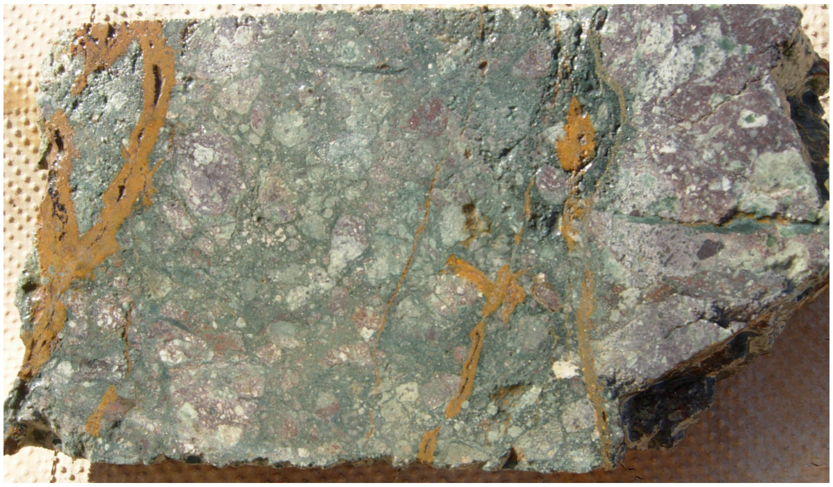

**Figure 5.** Rare chloritic breccia. Volcanic clasts are purplish to slightly tan colored suggesting relatively weak carbonate-sericite alteration. Chlorite is most abundant in the matrix of the breccia though it has also replaced some small clasts. Is this alteration style part of the hydrolytic event or is it related to later, structural deformation? SJ-06-25, 63m.

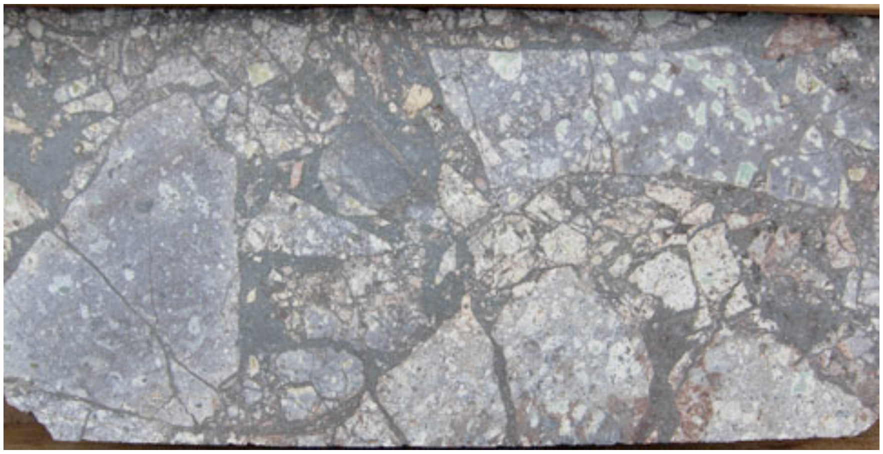

**Figure 6.** Less altered (grey to purple colored) igneous clasts in a specular hematite matrix. The clasts show sericitic alteration of feldspar phenocyrsts (pale green color), but less obvious alteration of the volcanic groundmass, though the purplish color suggests weak hematization. Contrast the color of the clasts here with those in Figure 4. The clasts in this sample display apparently differing phenocryst abundance suggesting some movement during brecciation. There is a slight suggestion of bleaching on some clast rims. SJ-06-4, 131m.

## Iron Oxides and Sulfides:

The prospects are dominated by hematite-rich veins and breccias containing minor sulfides (pyrite, chalcopyrite). Unlike most IOCG deposits and prospects that are characterized by a position within or adjacent to significant magnetic anomalies, the available regional magnetic data does not show even a weak magnetic anomaly in the Cerro Verde area. This is highly unusual for this deposit type. One possibility is that Cerro Verde represents a high level portion of an IOCG system that has been structurally displaced (along low-angle structures?) from its deeper, more magnetite-rich core. The absence of any magnetic anomalies for several kilometers around the prospects would suggest that if they are structurally displaced, the displacement might be substantial.

Little magnetite was observed in drill core or in rocks in the field, though soils were locally enriched in fine-grained magnetite suggesting it is present in the area. Hematite is abundant. Hypogene hematite is generally medium- to coarse-grained specularite. A variety of other hematite types are present – dominantly earthy and botyroidal. It is suspected that these are supergene and formed by oxidation of specularite and subsequent re-precipitation of less crystalline hematite. There is little evidence of significant supergene transport of hematite.

Sulfides observed in core are chalcopyrite and pyrite. Both are associated with hematite veins, commonly present in vein centers and often intergrown with late dolomite and/or calcite. Petrographic work suggests the sulfides are paragenetically late relative to hematite, typical of IOCG systems.

Chalcopyrite is the dominant sulfide and occurs most commonly within or immediately adjacent to hematite-carbonate veins (Fig. 7). Grain size is generally fine to medium. While most chalcopyrite occurs within or immediately adjacent to veins, local zones of wallrock replacement by chalcopyrite were also noted (Fig. 8). Pyrite occurs with chalcopyrite and separately. Pyrite is commonly somewhat coarser grained than chalcopyrite. Local pods of semi-massive pyrite up to several centimeters across were observed in drill core.


A. B.

**Figure 7.** Typical copper mineralization at Cerro Verde. A. Weakly altered andesite-dacite cut by specular hematite vein with clot of chalcopyrite in vein center. SJ-06-7, 169m. B. Supergene oxidized version of A with green copper oxides in the center of a supergene weathered hematite vein. The location of the copper oxides suggests very little mobilization and migration of copper during the supergene event. SJ-06-4, 136m.

Throughout much of the Cerro Verde area, the hematite and sulfides have been oxidized producing a hematite-goethite-copper “wad”-tenorite-copper carbonate assemblage. There is little evidence of significant copper migration and no evidence for the formation of a supergene blanket (see Fig. 7). The relative paucity of sulfides (especially pyrite), combined with the relative abundance of carbonate (dolomite>calcite), suggests limited potential for copper migration during supegene weathering.

**Figure 8.** Chalcopyrite occurring as vein filling and replacement of wall rock in carbonate-sericite altered dacites at the base of the Tarahumara sequence. This style of copper mineralization (veining and wall rock replacement) appears to be relatively common in both the basal Tarahumara and uppermost Barranca Group conglomerates in recent holes from the northern portion of the Cerro Verde prospect. SJ-06-24, 201m.

## Structural Geology:

While the outcrops and core demonstrate a wide variety of structures in the area (low- and high-angle structures, joints, fractures), the available data make it difficult to determine their relative importance. David Brown's current geologic map of Cerro Verde indicates that generally N-S (and to a lesser extend NW-SE) oriented faults and fractures control a large amount of alteration and iron oxides-sulfides. Our observations at La Trinidad suggest the prospect represents a generally N-S trending mineralization zone as does the high-grade zone on the eastern side of the Mesa Grande prospect. Field observations at Cerro Verde suggest that much of the intense hematite veining and associated sulfide mineralization occurs along high-angle structures (Fig. 9a), though not enough were measured to determine whether N-S or NW-SE-oriented structures were more important.

David Brown pointed out the importance of low-angle structures that were evident at both the La Trinidad and Cerro Verde prospects (Fig. 9). While supergene hematitzation and copper mineralization are prominent on many of these structures, there appeared to be little evidence of significant sulfides along them. This suggests that the low-angle structures may form significant barriers to supergene fluid migration, hence accumulating copper oxides, but that they may not have been important during hypogene mineralization. It is possible that these structures post-date significant hypogene mineralization. This possibility is also suggested by the lack of magnetic anomalies in the Cerro Verde area.


A. B.

**Figure 9.** Low angle structures. A. Silicified low-angle structure with copper oxides. The carbonate-sericite altered volcanic rocks above the structure is cut by high-angle hematite veins with minor copper oxides; one of the larger veins appears to truncate along the low-angle structure. Note the absence of significant hematite in the low-angle structure suggesting it may have formed after hematite veining. This outcrop is located near the Penoles DDH14 drill pad. B. Well exposed low-angle structure located along the drill access road near SJ-06-27. The fault is silicified, lacks abundant hematite, and has a weak concentration of copper oxides. Well-developed hematite veining in the overlying carbonate-sericite altered volcanic rocks appears to be cut by the flat fault.

## Recommendations

The exploration group on-site is doing a good job of collecting geological information in a tough environment (very steep terrain). Currently a large amount of geological information exists but is yet to be utilized. These recommendations are focused on helping to upgrade the prospect through definition of higher grade areas that can help increase the overall grade (and hence economics) of the prospect.

Near-term work with existing drill and assay data:

1. Use drill logs to better define the oxide zone, mixed oxide-sulfide, and sulfide zones on the sections. Model these surfaces to determine if they are controlled by existing surface topography (unlikely from what we saw in the field – thick oxide in some places, sulfides at the surface in others) or by high- (and low-?) angle structures.
2. Utilize assay and geological information to create a series of cross sections that are contoured with respect to both copper and gold grades. Can higher-grade (>0.6% Cu, >0.5 g/t Au) zones be defined? These may help to establish whether high- and/or low-angle structures controlled hypogene mineralization. The existing data suggests that structural controls may be subtle. However, the presence of known N-S trending higher grade zones at both La Trinidad and Mesa Grande would seem to suggest that similar structural controls should be present a Cerro Verde. Definition of these zones followed by targeted drilling to ensure

that they are intersected have the best potential for improving the grade of the prospect.

3. Utilize sections to map the Tarahumara-Barranca contact in three dimensions and plot this surface utilizing three-dimensional mapping software. Does this contact provide clues to the presence of structures? Current drilling suggests potentially significant mineralization is present in the uppermost Barranca Group conglomerates. Is this mineralization stratigraphically controlled with the potential for manto-style orebodies or is this mineralization indicating proximity to high-angle feeder structures?
4. Though it is difficult to distinguish different lithologies in drill core within the Tarahumara volcanic rocks, this should be attempted. My cursory examination of the drill core suggested that a first pass differentiation between volcanic breccias and volcanic flows (and/or intrusions) should be possible. Existing logs, supplemented by examination of core photographs, should be sufficient for a first attempt. This is important in that there may be a lithological control to higher-grade mineralization. Understanding the geology within the Tarahumara package may aid significantly in discerning these controls.
5. The degree of hematization and hematite veining and brecciation should also be plotted on sections. Judging from assays, the patterns derived from this exercise should mimic patterns derived from isopaching assay values. There is not always a one-to-one correlation between intensity of wallrock alteration and the degree of hematite veining. Thus, significant differences in the degree of alteration, hematite veining and brecciation, and/or grade could help identify structures and/or hydrothermal fluid pathways.

Most IOCG deposits are fundamentally structurally controlled. Relatively narrow zones of higher-grade mineralization commonly account for a disproportionate amount of the economic ore. Hence, discovery of these structural trends is critical, even at an early stage during exploration. Despite the excellent exposure and large number of drill holes at a wide variety of angles, there is not yet a clear understanding of structural controls at Cerro Verde. It is possible (but considered unlikely) that the prospect does not have a well-defined structural control. There may be more than one important structural trend or structural intersections may be critical for forming narrow rod-shaped high-grade zones.

The work on the existing data recommended above should produce the information required to evaluate the importance of structural controls for hypogene mineralization (and later supergene copper movement). However, another means of better understanding the prospect is to utilize the large number of new exposures generated by construction of the drill roads, together with the existing outcrop. These should be mapped in detail by a structural geologist to gather information on fault and vein orientation and any kinematic indicators (slickenlines, etc.) not easily available from drill core. Structural information should be integrated with observations of alteration assemblages and intensity related to different structures or structural trends. Constellation geologists or a specialized consultant could do this work. A better understanding of structural controls on alteration and mineralization in the short term should save money for Constellation in better drill planning.

Another relatively limited project that would be worthwhile is collection of a suite of altered volcanic rock samples from throughout the prospect area – central, north, south, east and west portions of the surface and from a variety of elevations (from the top of the mountain to the creek on the east side of Cerro Verde and in deep drill holes). The samples should be as widely spaced as possible. The samples should be sent for whole rock analysis as well as for petrographic analysis. This suite may help to determine if significant variations in alteration mineralogy and chemistry (especially $K_2O$) exist within the area.

## Regional Exploration

Though Constellation's focus is on definition of an open-pit, bulk mineable resource at Cerro Verde, the company should be aware of developments in the district. IOCG deposits rarely occur in isolation. Even the meager regional geophysical data available suggests reasonable quality targets within the district (such as the Luz del Cobre area to the NE which has known mineralization associated with well-defined magnetic and radiometric (K and U) anomalies. There appears to be a very real possibility that Cerro Verde is allocthonous. A deeper core zone with potential mineralization (magnetite-bearing?) should be present somewhere in the area and based on available magnetics this zone could be to the SW, NE or N. The project geologist should make a point to visit other areas of the district and try and become more familiar with the regional geology and economic geology. As noted during my visit, IOCG deposits form from highly oxidized fluids. Given the abundant coals found in the upper Barranca Group, it appears to me that there is potential for a very high-grade, probably structurally controlled deposit somewhere in the district.

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