

ABSTRACT

The Mercedes District, located in north-central Sonora, Mexico, represents one of the northernmost expressions of the extensive Oligocene endowment of epithermal Au-Ag deposits along the western margin of the Sierra Madre Ignimbrite Province. The district contains two major, normal-fault-hosted, low- to intermediate-sulfidation, base-metal-poor, quartz+Mn-oxide+calcite+Au+Ag veins, the Mercedes and Klondike veins, as well as a number of other mineralized structures all together holding a resource of 50.2 t (1.62 M oz.) Au and 517 t (16.61 M oz.) Ag. The most remarkable of these lesser zones is the Lupita-Diluvio complex, consisting of a mineralized listric fault and overlying fractured slide block containing a stockwork of quartz+calcite+Au+Ag of much lower grade than the Mercedes and Klondike veins.

While sharing a close spatial association and structural setting, these three zones vary distinctively in grade, texture, mineralogy, geochemical zonation and structural orientation. The NW-striking Mercedes vein contains the highest grades, most intense textural disruption, highest supergene mineral content and poorest expression of classical epithermal metal zonation. The WSW-striking Lupita-Diluvio complex contains the lowest grades, least disrupted, and least supergene-altered veins and retains a classical epithermal zonation pattern. The Klondike vein is intermediate in all aspects between the two end members. These observations suggest that textural modification through tectonic and hydrothermal brecciation permitted a number of supergene processes; namely carbonate dissolution, formation of Ag halides, and minor supergene reorganization of Au and Ag; that directly impacted the metal tenor, zonation and economics of each ore body. These effects are a consequence of the broader structural setting of the Mercedes district within a step-over between two grabens that are themselves part of the Basin and Range continental-scale extensional province.

This district provides an excellent example of how large-scale structure can have direct control on district, vein, and hand-sample scale features of epithermal systems, which can guide the exploration for, and evaluation of, these globally significant systems.

Key Words: Mercedes, Sonora, Epithermal, Grade Control, Zonation
INTRODUCTION

The western slopes of Mexico’s Sierra Madre Occidental are home to one of the world’s premiere epithermal Au-Ag provinces. Several score districts are known (cf. Clark, 1990; Clark, 1998; Camprubi and Albinson, 2007; Gastelum-Morales, 2014) ranging from artisanal to world-class production while vigorous exploration activity continues to produce new prospects.

The Mercedes District (Figure 1), located 215 km south-southeast of Tucson, Arizona, in northern Sonora, Mexico, produced an estimated 2.8 t Au through 1939. Mining since 2010 has yielded 10.2 t Au and 44.48 t Ag through September 2014, with a remaining year-end 2013 global reserve and resource estimate of 50.2 t Au and 516.7 t Ag (Table 1).

Gold and silver mineralization is hosted within three producing veins (Mercedes, Klondike and Barrancas), three veins in pre-development (Diluvio, Lupita and Rey de Oro) and several currently sub-economic veins scattered over an area approximately 10 × 5 km. While the veins in the district appear to share the same broad mineralogical and paragenetic signature, there are significant differences in the structural settings, textures, geochemical fingerprints, and Au-Ag grades of each vein system.

This study considers the productive Mercedes and Klondike veins, as well as the Diluvio/Lupita prospect, as representative members of a tectonic, textural and economic continuum of epithermal veins within the Mercedes District. Epithermal systems are commonly considered in terms of their metallogenetic environment (e.g., Sillitoe, 1993; Camprubi et al., 2003; Sillitoe and Hedenquist, 2003), structural setting (e.g., Spörli and Cargill, 2011; Echavarria, et al., 2006), mineralogical characteristics (e.g., Hudson, 2003; Moncada, et al., 2012) or a district-scale synthesis of a few of these factors (e.g., Castor et al., 2003), but it is comparatively rare for a vein system to be examined from a perspective that connects how processes at widely disparate scales integrate to create the individualities of each deposit. This paper interprets the Mercedes district using a “crustal to crystal” model to explain why compositionally similar and genetically related veins have such economically different characters.

METHODS

A total of 52 diamond drill holes from 13 cross sections were examined from three study zones. The accessible core (at the time of this study in May-August, 2012) was largely restricted to vein intercepts. From these, a total of 108, 30 μm-thick, polished thin sections were prepared to study vein miner-
**Epithermal grade controls—Mercedes, Sonora, Mexico**

Table 1. **YEAR-END 2013 MERCEDES DISTRICT REMAINING RESERVES AND RESOURCES.**

<table>
<thead>
<tr>
<th></th>
<th>Au (t)</th>
<th>Ag (t)</th>
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<tbody>
<tr>
<td>Proven + Probable Reserve</td>
<td>26.3</td>
<td>261.9</td>
</tr>
<tr>
<td>Measured + Indicated Resource</td>
<td>11.1</td>
<td>135.3</td>
</tr>
<tr>
<td>Inferred Resource</td>
<td>12.8</td>
<td>119.5</td>
</tr>
<tr>
<td>Total all categories</td>
<td>50.2</td>
<td>516.7</td>
</tr>
</tbody>
</table>

Further, it is presumed that this paragenetic association holds true for the other Mercedes area vein systems that display a very similar mineralogical and paragenetic disposition. Assuming these conditions, assay pulps were grouped into populations centered every 50 m of elevation, and the plots were interpreted according to the graphical method outlined by Loucks and Petersen.

Fieldwork was conducted between May and August 2012. Working faces in the Mercedes and Klondike mines were mapped for gross textural information and sampled for fill-in geochemistry. Underground exposures from the 1080 to 960 meter levels were examined in the Mercedes Mine and from the 1160 to 1060 meter levels in the Klondike Mine. The existing Yamana geodatabase, compiled by the skilled work of the geologists acknowledged at the end of this paper, was used for the surface geological maps, and these data were verified and supplemented with surface reconnaissance over the course of the summer.

The data for the structural analysis of the Mercedes and Klondike veins was gathered along accessible underground exposures of the vein-hosting faults, using a Brunton International Pocket Transit with a magnetic declination correction of 10° East. Lower-hemisphere stereonet plots used to determine the fault orientations were generated using GEOrient software created by Rod Holcombe, under the free academic use agreement.

**REGIONAL GEOLOGY**

The Mercedes district lies atop a basement composed of Proterozoic crystalline rocks and Paleozoic sediments of the Mazatlan province (Molina-Garza and Iriondo, 2007). Starting in the Jurassic, the region was heavily influenced by synoptic-scale sinistral tectonics, particularly involving the controversial Mojave-Sonora Megashear, bringing the Papago, Cortes and Caborca terranes from their depositional locations near present-day Nevada and docking them against the North American craton to the southwest of the Mercedes district’s present location (Centeno-Garcia et al., 2008 Anderson and Silver, 2005). The resultant NNW-SSE convergence and accretion, defined by Mesozoic structures throughout central and southern Sonora (Henry, 1986), are also recorded in a number of NE-SW-oriented basement structures inferred to have directed the extensive copper porphyry mineralization in northern Sonora (Turner et al., 1982).

Magmatic activity in the region began in the late Cretaceous in association with the subduction of the Farallon plate to the west of the District (McDowell and Clabaugh, 1981). Products of this magmatism, regionally known as the Lower Volcanic Complex (McDowell and Keizer, 1977), are a suite of intermediate to felsic batholiths and related volcanic rocks exposed and correlative throughout the length of the Sierra Madre Products of this magmatism began in the late Cretaceous in association with the subduction of the Farallon plate to the west of the District (McDowell and Clabaugh, 1981). Products of this magmatism, regionally known as the Lower Volcanic Complex (McDowell and Keizer, 1977), are a suite of intermediate to felsic batholiths and related volcanic rocks exposed and correlative throughout the length of the Sierra Madre (Ferrari et al., 2007; Gonzales-Leon et al., 2000; McDowell and Clabaugh, 1981). The intrusions are thought to be genetically related to a significant endowment of Cu-porphyry and related mineralization represented by the giant Cananea and La Cari-
dad Cu deposits and the Alacran-Nacozari porphyries, skarns and carbonate replacement Cu-Pb-Zn deposits, all within 100 km of the Mercedes camp (Damon et al., 1983; Anderson and Silver, 1977).

This first phase of magmatism ceased in the early- to mid-Paleocene, and a lull in plutonic activity in the Sierra Madre persisted until the Eocene (Ferrari et al., 2007). The resumption of magmatism at 46 Ma is the earliest expression of the “ignimbrite flare-up” that defines the geology of the Sierra Madre Occidental. Silicic eruptive activity peaked from 27 to 33 Ma, resulting in the formation of an ignimbrite province 1200 km long, 250 km wide and locally exceeding 1000 m thickness composed of dominantly rhyolite ignimbrites, tuffs and flows. This eruptive cycle deposited over 300,000 km$^3$ of material cumulatively termed the Upper Volcanic Supergroup (Ferrari et al., 2007; McDowell and Keizer, 1977).

Starting about 30 Ma, much of western Mexico was affected by the southernmost expressions of Basin and Range extension (Henry and Aranda-Gomez, 1992). In the region hosting the Mercedes district, this manifests as a province of roughly north-south to northwest-southeast-trending grabens (Figure 2) filled with colluvium sourced from their bounding ranges. The Mercedes district is located in the highlands between the western Los Pinos and eastern Bacanuchi and Aconchi grabens. The Mercedes highlands appear to be a set of anticlines related to a structural relay zone where the southern Aconchi graben terminates and extension is taken up after a ~20 km jog to the north-northeast by the Bacanuchi graben (Figure 2).

The Oligocene extensional event is a significant structural control on the epithermal geology of northwestern Mexico. Many of the world-class vein systems in the region, including the Fresnillo, Guanajuato, San Dimas, Ocampo and Santa Eulalia districts, exhibit the same northwest orientation (Henry and Aranda-Gomez, 1992; Burtner, 2013). The shared alignment between these systems, dated between 26–31 Ma, and the mineralization in the Mercedes district suggest the vein systems are likely part of the same magmato-metallogenic arc.

**DISTRICT GEOLOGY**

The geology of the Mercedes district (Figure 3) exposes roughly 2500 m of stratigraphic thickness (Figure 4), with units ranging from Cretaceous to late Miocene. The following is a review of the most significant units on the Mercedes property. Some mapped units seen in figures 3 and 4 are not described for the sake of brevity.

**Basement Sediments**

A suite of interbedded silty limestones, mudstones, and locally, graded diamictites form the oldest rocks exposed on the property. The package is exposed only within the northwest-striking anticlines that separate the Mercedes, Klondike and Lupita/Diluvio basins (Figures 3 and 4). Work by Gonzales-Leon et al. (2000) in the Arizpe and Bacanuchi quadrangles.

![Figure 2. Regional setting of the Mercedes district. Approximate traces of several local grabens are outlined in green and the approximate extent of the district geologic map in Figure 3 is represented by the white box at left-center.](image-url)
immediately east and northeast of the Mercedes district suggests that these units are correlative to the Early and Middle Cretaceous Bisbee Group sediments and the Late Cretaceous Picacho conglomerate.

**Lithic Tuff/Volcaniclastic Package**

Unconformably overlying the Mesozoic sediments is a sequence of pinkish, densely welded lithic tuffs. These are characterized by an abundance (20–40% by volume) of lithic fragments and local fiamme. The clasts are typically angular and range in size from 1–2 mm up to several centimeters and are composed of rhyolite and, possibly, andesite porphyry. Lower members contain up to 10% quartz phenocryst fragments and sparsely distributed sanidine crystals. There appears to be a somewhat gradational transition between the lower crystal-lithic tuffs and the upper lithic tuffs. These units are predominantly found within the limbs of the two northwest-trending anticlines that extend across the property.

The lithic-tuff package represents the lowest unit in the local stratigraphy known to contain epithermal mineralization at Mercedes. Notably, a fractured block of the lithic tuff forms a normally displaced host to the Diluvio stockwork system. Deeper drill holes within the Mercedes zone suggest that Au-Ag mineralization may be present in tuff-hosted continuations of these tuffs and other similar units within the region are poorly understood, the stratigraphic relationships on the property suggest that the tuffs are a member of the Arroyo Alcaparras igneous sequence, with ages between 72 and 69 Ma (Gonzales-Leon et al., 2000).

**Andesite**

The most economically significant stratigraphic unit on the property is a series of andesitic volcanics that host the epithermal quartz-carbonate Mercedes, Barrancas, Klondike, Rey de Oro and Lupita veins. These andesites also cover the Diluvio stockwork system. The andesites are a sequence of flows, flow-breccias, and minor laharp deposits exceeding 500 m in thick-
Figure 4. Schematic district stratigraphic column illustrating the relationships described in the text. Ages given for units are from putative correlations from this study to units mapped by Gonzales-Leon et al. (2000).
ness and are spatially restricted to two chevron-shaped zones along the limbs of the major northwest-striking anticlines on the property. The connection between the andesites and the anticlines is somewhat unclear. No clear field relationships were observed between the andesite flows and underlying lithic tuffs during the course of this study. The macroscopic textures of the andesites commonly change dramatically over short distances, ranging from flow-oriented porphyries to coarsely fragmental flow breccias and lahar deposits.

Despite the textural variation, all the andesites across the property are plagioclase-hornblende porphyries, locally enriched in magnetite as an accessory. Euhydrul to subhedral hornblends are the predominant phenocrysts, forming 10–50% of the rock by volume, and ranging in size from 1–5 mm. Lathy plagioclase phenocrysts of largely andesine composition (An_{29}–An_{46} via Michel-Levy method on 37 phenocrysts from 4 samples; Michel-Levy, 1894 and Glazner, 1980) compose another 5–20% of the rock volume. The phenocrysts are held in a pilotaxitic matrix dominated by feldspar microlites that commonly maintain the flow textures visible in outcrop-scale exposures.

All accessible exposures of the andesites display varying degrees of alteration, with the intensity of alteration increasing towards the vein systems. Samples from approximately 1.5 km southwest (perpendicular to strike) of the Mercedes vein contain partially chloritized amphiboles and biotites while samples from the margins of the vein have undergone complete replacement of the ferromagnesian minerals to chlorite and hematite as well as total argillization of the feldspars. In samples proximal to the vein, minor amounts of epidote are present both as replacement products within the plagioclase phenocrysts and as small disseminations within the altered groundmass commonly present near chloritized biotites and hornblendes. It is unclear whether the distal alteration signature corresponds to hydrothermal alteration related to the mineralization event or if it represents authigenic deuteric alteration related to the emplacement of the andesites themselves.

Given that even the most distally accessible andesites show clear evidence of alteration in the hornblendes, biotites and feldspars, it is unlikely that the unit within the property can be accurately dated to give an absolute lower boundary on the time of mineralization. Textural and stratigraphic relationships suggest that the andesite package likely correlates with the Cerro Las Jarillas sequence studied several kilometers to the northeast by Gonzales-Leon et al. (2001). That study reported a 40Ar/39Ar age of 58.67±0.17 Ma from a biotite phenocryst. However, 1:50,000 scale mapping published by the Servicio Geologico Mexicano (SGM, 1999) interpreted these volcanics as Late Cretaceous, instead correlatable with the Arroyo Alcarros volcanics, also of Gonzales-Leon et al. (2001), deposited between 69 and 72 Ma. The uncertainty of the correlation between the units described by Gonzales-Leon et al. and those on the Mercedes property is reflected on the age given as > 58.6 Ma in figure 4.

**Latite dike-dome-flow complex**

An entirely unaltered biotite-alkali feldspar latite porphyry dome-flow complex, present mainly in the Mercedes zone, overlies and intrudes the andesites along the same structural weakness that controlled the emplacement of the Mercedes vein. It is characterized by strongly flow-banded latite porphyry with large, 5–10 mm phenocrysts of concentrically zoned alkali feldspars and smaller 1–2 mm phenocrysts of euhydrul biotite and hornblende within a fine-grained matrix of plagioclase and alkali feldspar.

The latite is localized near a vertically foliated dome or vent structure that deforms the extreme northwestern part of the Mercedes vein. The latite flows and other dike/dome feeders have been traced in outcrop and drill holes in a NW-trending belt up to 10.0 km long and 2.5 km wide, extending well to the southeast of the Mercedes vein zone. The chilled margins of the latite are composed of glassy porphyry that is in contact with the Mercedes vein and contains minor but measurable Au grades. Notably, hydrothermal veining has not been observed in any latite on the property, while veining commonly extends several dozen meters away from the major veins within the andesites. The extensive retention of glassy latite in contact with the vein and the presence of measurable grades within the unit suggest that the latite is post-mineral and has entrained trace amounts of mineralized rock. The latite could provide an upper boundary for the age of mineralization at the property.

Fresh samples of the glassy latite were collected from a road cut approximately 25 m SW of the historically mined stope of the Mercedes vein. These samples were dated using the 40Ar/39Ar method on two hornblende and two biotite crystals. The hornblendes produced an arithmetic mean age of 26.27±0.14 Ma while the biotites produced an arithmetic mean age of 26.14±0.07 Ma for an overall mean age of 26.15±0.16 Ma (see Appendix I.). Closure temperatures for these two systems range between ~500–575°C for hornblende and ~250–300°C for biotite (Chiaradia et al., 2013). The statistically identical ages of the hornblende and biotite hint that the biotites have not been heated past their closure temperature, which is easily within the range of epithermal systems since initial crystallization. This fact, along with the widespread retention of vitreous groundmass in the glassy chilled margins and wholly fresh appearance of the feldspar, biotite, and hornblende phenocrysts throughout (especially when compared to the extensive regional alteration of the andesites), suggests that the latite has been unaffected by hydrothermal alteration, and these dates provide an absolute bound on the youngest age of mineralization. Mineralization near this time would coincide with the earliest expressions of basin and range extension in northern Sonora (Henry and Aranda-Gomez, 1992) and make mineralization roughly contemporaneous with the normal faulting associated with the opening of the nearby Aconchi and Los Piños grabens; both are assumed to be related to the regional basin and range extension, and filled with syntectonic Baucarit Formation rocks.
with ages measured between 33 and 5 Ma elsewhere in Sonora province (Bartolini et al., 1994).

**Baucarit Formation**

The entire area to the NW of the andesite basins is overlain by a thick sequence (30 to >250 m) of the Miocene Baucarit Formation, which dips regionally 3–5 degrees to the WSW and WNW. The formation is predominately bedded conglomerate in the map area, with variably argillized welded ignimbrite to non-welded ash-tuff horizons. The post-mineral unit covers the west/northwest strike extension of all known vein trends, as demonstrated by the discovery of the covered Barrancas Vein zone in 2009.

**MERCEDES/BARRANCAS VEIN ZONE**

The Mercedes vein is the most laterally extensive and highest-grade vein found on the property. Mineralization has been defined along 1400 meters of strike (trending 130–135°) and over 500 meters down dip. Northwest of Mercedes, vein mineralization continues on a parallel fault strand named Barrancas, with economic Au-Ag values identified in three ore shoots along an additional 1200 meters of strike length. The Barrancas zone is economically and geologically significant in that it was discovered by drilling beneath 50–200 meters of post-mineral Baucarit Formation.

The Mercedes vein ranges between 1 and 25 m wide (Figure 6) and is strongly brecciated with few if any primary textures intact. It dips steeply, typically between 75–90° southwest-southwest, though it has been deformed and tilted as shallow as 55° to the northeast in the area of the Centinela and Tierra de Nadie ore shoots and where it contacts the latite intrusion at the northern extent of its surface expression. It is localized by a dextral oblique normal fault and bounded by a strongly milled zone of clay gouge along the hanging wall margin. The vein is composed of unique light-to-dark-olive-green, Fe-bearing quartz (Burtner, 2013) and andesite clasts in a matrix of dark Mn-oxide-bearing calcite and local rhodochrosite cement.

Grades locally exceed 640 ppm Au and 3700 ppm Ag in the high-grade ore shoots, but average 8.7 ppm Au and 95 ppm Ag. The vein contains a resource of 18.66 t Au and 208.4 t Ag at a cutoff grade of 2.0 ppm Au-equivalent (Au+Ag/150; Hawksworth et al., 2009). Au occurs as native Au and possibly as high-fineness electrum, whereas the Ag occurs as cerargyrite and a number of other Ag-bearing phases (most likely argentojarosite, native Ag, electrum, and secondary Ag sulfides). The exact ore mineralogy, both hypogene and the subsequent supergene products, are uncertain due to the lack of high-grade samples available for examination and equipment limitations.

The highest grades are constrained in a series of bonanza ore shoots named (from southeast to northwest) Casa Blanca, Centinela, Tierra de Nadie, Corona de Oro and Breccia Hill. Of these, the Corona de Oro ore shoot contains the highest grades and grade thicknesses of the drilled sections of the Mercedes vein. For the purposes of this study, four representative cross sections (8860, 9100, 9550 and 9880; nomenclature reflects position within the local exploration grid) were selected in an attempt to achieve adequate lateral and vertical spacing to delineate the variations in mineralogy, geochemistry, and structure along the vein, with consideration given to the availability of core and access to underground workings in proximity to the chosen sections.

Minera Oro Chico began mining the vein in 1937 by underground methods that stopped to the surface. The mine was closed in 1940, with decreasing grades at depth cited as the reason for abandonment. However, exploratory drilling in the late 1990s and early 2000s by Meridian Gold Company/Yamana Gold intersected the bonanza-grade Corona de Oro ore shoot (hole M07-176D with 7.10 meters @ 76.17 g/t Au and 373.0 g/t Ag) less than 15 m below the deepest historic workings. Underground mining began in 2010, with the first production of doré in December 2011.

**Structural Setting**

The Mercedes vein is localized within a fault running parallel to the district-wide, northwest-southeast trending structural fabric defined by the axes of the anticlines, andesite basins, and faults that transect the property. The Mercedes fault is accessible at a number of underground exposures and is characterized by a zone of < 1–4 m thick foliated clay gouge with entrained clasts of vein and andesite. Platy “foliations” in the clay gouge reveal several generations of fault movement, with sickenlines revealing a dextral-normal sense of faulting. Some foliation generations display an entirely normal sense of slip, while others record slightly oblique dextral-normal slip. No observations of purely strike-slip motion were observed. Measurements of the strike and dip were taken at 16 underground exposures of the Mercedes fault to record a mean strike of 144°, dipping 83° (SW according to right-hand rule convention, which will be used throughout this paper). The four highest-grade ore-shoots (Breccia Hill, Corona de Oro, Centinela and Casa Blanca, Figure 6) along the vein are localized where a deviation in fault strike and/or dip created favorable geometries for dilation and subsequent pressure drops during fault activity (Burtner, 2013).

**Vein Mineralogy and Textures**

**Paragenesis**

Mineralogical sequence of the Mercedes vein (Figure 7, top) consists of three major hydrothermal phases followed by a final phase of weathering. At least one significant brecciation event separated Phases I and II, with additional brecciation likely occurring during Phase II.

Phase I of the Mercedes vein is dominated by a light-to-dark-olive-green quartz. It is commonly saccharoidal, but clasts of both coarsely crystalline quartz and banded chalcedonic tex-
Figure 5. Representative vein samples. A. Typical Mercedes vein high grade. 32 ppm Au and 232 ppm Ag. B. Mercedes vein high grade with visible Au. 652 ppm Au and 463 ppm Ag. C. Crustiform-banded green quartz-Mn-oxide bearing calcite from 1060 level, Klondike vein. D. Boxworks after sulfides, euhedral cavities arrowed. Klondike Vein. E. Boxworks after sulfides and subtle platy replacement boiling textures (arrowed). Lupita vein outcrop. F. Phase III crustiform quartz veinlets cutting Mn-oxide sponge after Mn-oxide bearing calcite, Diluvio stockwork.
tures occur. True platy calcite pseudomorph boiling textures are uncommon, but the quartz in places shows an unusual “frothy” texture with many small apparent gas voids in high-grade zones. The green quartz in high-grade zones is commonly associated with Fe-oxide-coated boxworks (hematite>goethite>>jarosite), as well hematite pseudomorphs after pyrite. The original Phase I sulfides have been completely oxidized during subsequent weathering. Though pyrite appears to have been the principal sulfide, some boxworks appear to retain non-pyritic habits. Significantly, remnant, weakly polyhedral open spaces are present suggesting that some of the silver mineralization may have been due to silver sulfides or sulfosalts. The close spatial association between the green quartz, boxworks of hematite-limonite after sulfides, and high Au grades suggests the precious metal mineralization was introduced during Phase I.

Separating Phase I from Phase II is a major brecciation event. This event appears to have been both hydrothermal, with vertical transport of host andesite and Phase I clasts up to 400 m vertically, and tectonic, resulting in the emplacement of Phase I clasts within the clay gouge in the vein-hosting fault. Very little to none of the Phase I material appears to have escaped this brecciation event intact.

Phase II mineralization consists of an early gray- and green-quartz stage and a later carbonate stage consisting of a dark, Mn-oxide-bearing calcite with rare rhodochrosite forming cement that is the matrix surrounding the fragmented Phase I mineralization. Where not obviously associated with features of Phase I mineralization, Phase II mineralization contains low- to sub-economic grades of Au and Ag, typically < 5 ppm Au and < 18 ppm Ag, likely due to unrecognized inclusions of Phase I minerals.

The final phase of epithermal mineralization consists of quartz-carbonate veinlets and drusy-quartz vug-fill that cross-cut the much more voluminous Phases I and II. There is no evidence of sulfide or precious metal mineralization associated with these veinlets, nor is there any evidence of boiling textures. Few veinlets show any evidence of brecciation or tectonic displacement and they commonly crosscut the vein system and extend into the wall rocks as a low-density stockwork. Locally, Phase III veinlets can be found in outcrop, up to 50 m away from the vein trace. The stockwork nature of these veinlets and crosscutting relationships suggest that they may be part of a later hydrothermal event of uncertain relationship to the ore-forming hydrothermal system.

Phase IV consists of the pervasive, supergene oxidation event that postdates hydrothermal mineralization. In addition to the extensive oxidation of the wall rocks, the Mercedes vein is oxidized at all depths studied. The inferred Phase I sulfides have been oxidized to Fe oxides, oxyhydroxides and sulfates, generally goethite with local zones of jarosite. Visible gold specks are commonly present in earthy hematite pseudomorphs after pyrite. In many of the highest-grade core samples, spongy brown cerargyrite is present in the porous quartz-hematite boxworks defining the high-grade zones. Cerargyrite represents the only silver mineral positively identified in this study. Detailed studies on metallic concentrates during pre-feasibility mine studies also had difficulty in determining silver mineralogy.
Macro Textures: Outcrop to Hand Sample-Scale

The Mercedes vein is, in essence, a vein breccia. In all of the core and working faces examined in this study, crustiform mineralization was highly localized and present only as fragmental clasts of the Phase I mineralization up to 10 cm across. Over 90% of the breccia clasts are Phase I quartz, with the remainder mostly completely oxidized wall rock andesite. The percentage of clasts and matrix vary, but the vein is typically 20–50% clasts and 50–80% matrix composed mainly of Phase II carbonate.

All quartz clasts show evidence of milling, with most ranging from sub-angular to fully rounded; the andesite clasts tend to be more angular. Deep drill holes, notably M08-286D, which intercepted the vein at 653 m elevation, intersect unoxidized...
andesites with pervasive and intense chlorite-pyrite alteration and texture that is not seen in higher-level andesites. Oxidized pieces of this material, with the pyrite altered to hematite, are found as clasts within the vein breccia as high as 1020 m elevation. This evidence, paired with the rounding of the clasts, implies significant amounts of vertical transport within the vein system, as much as 400 m in some locations.

High-grade zones, locally over 300 ppm Au and containing visible native gold, are strongly correlated with a particular set of textural characteristics. These intervals are distinguished by a porous, clast-supported breccia containing dark-olive-green, saccharoidal, Phase I quartz-vein fragments in a matrix of minor Phase II carbonates and abundant hematite that locally contains boxwork-style textures formed from the oxidation of hypogene sulfides. These intervals also possess highly variable Au:Ag ratios, but tend to contain higher average ratios than the lower-grade zones. The bulk of the Au is submicroscopic, and intercepts greater than 500 ppm Au routinely lacked macroscopic Au. Uncommon visible Au was uniformly associated with the highly porous, hematitic, green-quartz breccia. The individual grains were commonly 1–3 mm in size, with one specimen containing a flake 8 mm across within a hematitic box work. They are irregularly shaped, spongy and deeply golden in color, suggesting a high fineness. Conversely, lower-grade ore (5–15 ppm Au) is typically less porous, much less hematitic, and has a high proportion of Phase II carbonates cementing lesser amounts of light-green, Phase I quartz clasts.

Micro Textures: Loupe to Microscopic-Scale

Samples of Phase I quartz examined from all levels of the vein record evidence of vigorous boiling. In particular, feathery vapor-phase inclusions imply rapid depressurization and “flashing” (Moncada et al., 2012) of the hydrothermal fluids. This mechanism has been invoked to explain bonanza-grade Au and Ag deposits in other deposits (Brown, 1986; Dong et al., 1995; Sillitoe, 1993; Cooke and Simmons, 2000; Moncada et al., 2012) and appears to be responsible for the high-grade ore shoots in Mercedes as well.

Ordinarily, the distribution of boiling textures may provide a guide to the extent of Au and Ag mineralization, as precious metal deposition tends to occur within and slightly above the boiling zone (Buchanan, 1981; White and Hedenquist, 1990; Simmons, et al., 2005; Camprubi and Albinson, 2007). However, brecciation and vertical transport within the Mercedes vein subsequent to Phase I mineralization makes any interpretation of the vertical extent of boiling impractical. Samples from the lower levels of the Mercedes workings, at 960 m elevation, possess equally abundant boiling textures as those higher in the system. Textural evidence supports up to 400 m of vertical transport for wall-rock clasts entrained within the vein breccia during the Phase I/Phase II brecciation event, and it is possible that the deepest samples from the mine workings may have been transported similar distances.

In sharp contrast to the ubiquity of boiling textures in the Phase I minerals, evidence of boiling is absent within the Phase II minerals. None of the diagnostic skeletal textures of calcite under boiling conditions (Simmons and Christenson, 1994; Moncada et al., 2012; Dong et al., 1995) were found in Phase II mineralization from any level of the Mercedes vein. The lack of boiling textures, and low grades of Au-Ag mineralization within intervals dominated by Phase II, suggest that the Au-Ag mineralization was restricted to Phase I.

Geochemical Zonation

Element Correlations

Graphical analysis of bivariate plots comparing Au concentration (in ppm) on the vertical axis to a variety of major and trace elements common in epithermal systems (also ppm) along the abscissa (Figures 8A to H) reveals several interesting relationships. Low-grade Au (< 1 ppm) possesses a fairly strong positive correlation with low grade Ag (< 10 ppm, Figure 8A) but a poorly defined correlation at higher grades. Au and As concentrations (Figure 8B) appear to be uncorrelated. Au and Mn (Figure 8E) also appear to be uncorrelated, reflecting a lack of appreciable Au mineralization within Phase II Mn-oxide-bearing carbonates. There is a moderately strong positive correlation between Au and Cu (Figure 8C), Hg (Figure 8D), Pb (Figure 8F), Sb (Figure 8G) and Zn (Figure 8H).

Vertical Zonation

The Mercedes vein is mineralized along greater than 450 m of dip, a distance comparable to many other low-sulfidation epithermal vein systems (i.e., Simmons et al., 2005). Figures 9A and 9B are graphs of selected trace and major element concentrations vs. absolute elevation in the vein system. While regression analysis produces weak trends in the variation of these elements with elevation, the calculated R² values for the trend lines and visual interpretation of these data do not support the existence of significant vertical zonation for any of the elements considered within the Mercedes vein, consistent with the observations of vertical transport of vein material seen throughout the Mercedes vein.

Loucks-Petersen Zonation

Figure 10 is a plot of Pb/Zn vs. Ag/Zn ratios with sample symbology defining a series of 50-m-elevation groups containing the available samples from the Mercedes vein. There does not appear to be any sort of coherent pattern to these data using the graphical interpretation method of Loucks and Petersen (1988), further supporting a lack of vertical elemental zonation within the Mercedes vein.

KLONDIKE VEIN

The Klondike vein is located in the northeastern end of a mapped wedge of andesite flows and flow-breccias, similar
to the lithologic setting of the Mercedes vein. Mineralization extends more than 800 m along strike and about 400 m vertically. On average the vein strikes 110° and dips sub-vertically 70–90°.

Compared to the Mercedes vein, the Klondike vein is much less brecciated. Extensive portions of the vein system are intact with meter- to centimeter-scale crustiform banding. The mineralogy of the vein is similar to that of Mercedes and the other veins in the district, composed mainly of banded chalcedony, green crystalline quartz, Mn-oxide-bearing calcite, and clear calcite.

The Klondike vein zone (Figure 11) is between 1 and 50 m wide. The fault zone anastomoses to the southeast and joins the Rey de Oro stockwork zone, which strikes 140° and dips 45° for nearly 400 meters along strike. Au occurs as native Au and possibly high-fineness electrum. Ag chiefly occurs within cerargyrite and several other unidentified phases; likely argentotjarosite, native Ag, secondary Ag sulfides, and possibly electrum. However, a poor Au-Ag correlation suggests that electrum is only a minor component. Grades are generally lower than those of the Mercedes vein, only locally exceeding 60 ppm Au and 200 ppm Ag. The Klondike vein saw minor historic production, with modern production on the vein beginning in 2010. Current resource estimates include 4.08 t Au and 25.1 t Ag at average grades of 6.3 ppm Au and 39 ppm Ag (Hawksworth et al., 2009).

Diamond drilling has defined two ore shoots of lower grades than Mercedes. These are also localized in dilation zones produced by changes in dip and strike of the fault-hosting vein. For the purposes of this study, two study cross sections (11080 and 11260) were chosen based on the access to core and underground exposures (Figures 12 and 13).

**Structural Setting**

The Klondike vein is hosted in a west-northwest trending fault zone that lies sub-parallel to the northwest-southeast structural fabric in the region. The Klondike fault is accessible within the current underground workings and is characterized by a 1–2 m zone of foliated clay gouge with minor entrainment of host andesite. These foliations record several generations of fault motion, with slickenlines indicating dextral-oblique kinematics. Measurements were taken at 10 underground exposures and revealed a mean strike of 280°, dipping 77°.

![Figure 8](image-url) Selected Au-element log-log correlation plots for the Mercedes and Klondike veins. Mercedes: A. Ag, B. As, C. Cu, D. Hg, E. Mn, F. Pb, G. Sb, and H. Zn. Klondike: I. Ag, J. As, K. Cu, L. Hg, M. Mn, N. Pb, O. Sb, P. Zn. All units in ppm.
Figure 9. Mercedes vein vertical geochemical zonation. A. Ag, Au, Cu, Pb and Zn vs. elevation. B. As, Hg and Sb vs. elevation.
Vein Mineralogy and Textures

Mineralogy and Paragenesis

The paragenetic sequence of the Klondike vein (Figure 7, middle) is very similar to that of the Mercedes vein, consisting of three major hydrothermal phases followed by a final phase of weathering and supergene effects upon the mineralogy of the ore body. At least one significant brecciation event separated Phases I and II, with local brecciation ongoing during Phase II.

Phase I mineralization within the Klondike vein appears nearly identical to Mercedes Phase I. It is dominated by a variably light- to olive-green, commonly saccharoidal quartz, with trace amounts of unoxidized disseminated pyrite, chalcopyrite, and galena most common in texturally intact crustiform vein intervals.

Phase II mineralization in Klondike closely resembles Phase II mineralization in the Mercedes vein. It is dominated by a dark, Mn-oxide bearing calcite with minor milky to clear quartz. However, the lower degree of brecciation within the Klondike system results in large sections of intact, banded vein material as well as Phase II cement surrounding Phase I vein clasts. In the banded section, a discrete boundary exists between the Phase I minerals and the Phase II carbonates, commonly with Phase I clasts peppering the boundary zone. In some samples, hematite is found as massive, reddish streaks contained within the dark carbonates. These appear to represent oxidized relict sulfide bands.

The final, Phase III, hydrothermal mineralization in Klondike is again similar to Mercedes, predominantly composed of white to clear crystalline quartz and calcite as both stockwork veinlets that cut through the vein into the country rock and drusy vug fill. However, in contrast to Mercedes, small amounts of amethystine quartz are present as druse within open spaces in the vein.

Phase IV represents products of incomplete supergene oxidation of sulfide minerals to hematite and goethite and rare Cu oxides. Isolated examples of Phase I galena and pyrite have remained unoxidized due to encapsulation by quartz and the
relatively incomplete brecciation as compared to the Mercedes vein. No cerargyrite was observed, nor has it been reported from the Klondike vein, but high silver grades and mineralogy similar to the Mercedes vein suggest that it may nonetheless be present.

Macro Textures: Outcrop to Hand Sample-Scale
The most significant dissimilarity between the Mercedes and Klondike veins is the amount of unbrecciated crustiform vein material. Intact sections of vein on the scale of a 10 m working face were observed in several levels of the Klondike mine (notably the 1140 and 1060 levels) as well as in core and material from the mine dump. In the more massive banded sections, the vein was typically constructed of two or more thick (> 10 cm) bands of either Phase I or Phase II material along with smaller, rhythmically banded sections of all three main hydrothermal phases. While these banded sections remain largely intact, local zones of centimeter-scale fragmentation are abundant, but transport of the fragments is minimal and generally restricted to in-situ rotation and juxtaposition.

Although the presence of intact vein material is common within the Klondike vein, zones of brecciation are also common. Qualitatively, the banded and brecciated vein material occurs in a roughly 1:1 ratio, as observed in the accessible underground workings and drill core. Breccia clasts are composed of both Phase I minerals and oxidized host andesites up to 10 cm across, and tend to be more angular than breccia clasts within the Mercedes vein.

The highest grade ore in the Klondike vein has the same general textural characteristics as that from Mercedes; a porous agglomeration of darker-olive-green clasts in a matrix of largely hematitic boxworks after sulfides, with only minor amounts of Phase II carbonates.

Micro Textures: Loupe to Microscopic-Scale
Vigorous boiling textures, like those observed in the Mercedes vein, are ubiquitous in Klondike vein Phase I quartz. The close association of Au-Ag mineralization with these same minerals implies that boiling was the mechanism behind deposition of precious metals in Klondike as well. Despite the lesser amounts of apparent hydrothermal transportation within the Klondike vein, these textures are apparent in clasts and banded veins at all levels.

The dominant Phase II mineralogy is, like in the Mercedes vein, an intergrowth of Mn-oxides and calcite with up to 70% of the volume composed of the splotchy Mn minerals. As in Mercedes, the lack of boiling textures and the weak spatial associations between Phase II mineralization and Au-Ag suggest that this phase was not responsible for the precious metal endowment in the Klondike vein.

Geochemical Zonation
Element Correlations
Bivariate plots of Au and selected major and trace elements (Figure 8I-P) display a somewhat different correlative signature.
Figure 12. Klondike vein vertical geochemical zonation. A. Ag, Au, Cu, Pb, and Zn vs. elevation. B. As, Hg, and Sb vs. elevation.
than the same plots for the Mercedes vein. Au appears to be uncorrelated with Ag (Figure 8-I), As (Figure 8-J), Hg (Figure 8-L), Mn (Fig 8-M), and Sb (Figure 8-O). Au concentrations have a positive correlation with Cu (Figure 8-K), Pb (Figure 8-N) and a less well-defined positive correlation with Zn (Figure 8-P).

Vertical Zonation

The Klondike vein has been sampled along nearly 350 m of dip. Figures 12A and 12B show plots of common epithermal trace element concentrations vs. absolute elevation in the Klondike vein. Like the Mercedes vein, Au, Ag, As, Cu, Pb, and Zn do not display statistically significant vertical zonation trends, despite calculated trendlines showing weak increases or decreases with elevation. However Hg displays some zonation with elevation. The plot of Hg vs. elevation shows a dramatic and statistically robust (R² = 0.5511) increase in Hg concentration with depth. This increase is contrary to the classical epithermal elemental zonation defined by Buchanan (1981) and others.

Loucks-Petersen Zonation

Figure 13, like figure 10 for Mercedes, shows a plot of Pb/Zn vs. Ag/Zn with samples symbologically classified into 50 m elevation groups. Using the Loucks and Petersen (1988) graphical analysis method, there does not appear to be any significant vertical elemental zonation within the Klondike vein.

LUPITA/DILUVIO VEIN SYSTEM

The Lupita vein is located outside of the two major andesite basins, forming the southern footwall contact on a third poorly defined andesite-filled basin. It is located approximately 2 km north of the Klondike vein and 5 km northeast of the Mercedes vein. It is unique among the veins on the Mercedes property in that it crops out as a curvilinear, silicified hogback 1–3 m in width, cropping out along nearly 1500 m of strike (average 272°) dipping 20–50° at the surface. Drilling suggests the dip shallows to near horizontal at depth.

The vein is compositionally similar to both Mercedes and Klondike, composed of banded green quartz and Mn-oxide-
bearing calcite but is only locally brecciated. Grades along the vein locally exceed 50 ppm Au and 65 ppm Ag with grades of 1–3 ppm Au and 10–30 ppm Ag common (Hawksworth et al., 2009).

At the surface, similar to Mercedes and Klondike, andes- ites (green, PEA) form the hanging wall of the Lupita vein while the lithic tuff sequence (pink, KTQ) forms the footwall. This arrangement changes at depth, where 300–400 m down dip, at roughly 1150 m elevation, the hanging wall abruptly changes to a highly fractured block of the lithic tuff/volcaniclastic se- quence (Figure 14).

The fractured and mineralized block overlying the Lupita structure is the Diluvio stockwork zone and consists of a network of centimeter to > 40 m quartz-calcite(±Mn oxide) veins and veinlets containing localized high-grade ore shoots within a broad envelope of low grade Au+Ag mineralization. The block is interpreted as a cohesive unit of the lithic tuff/volcaniclastic sequence that slid along a listric or half-graben-style structure and was subsequently buried by later andesitic flows. Grades in the Diluvio stockwork are generally lower than that of Lupita vein, with Au in the 0.5–3 ppm and Ag in the 5–20 ppm ranges occurring locally in thicknesses exceeding 150 meters. Three cross sections along the Lupita vein (4970, 5000 and 5240) and one through the Diluvio stockwork (9940) were evaluated.

**Structural Setting**

The Lupita fault, hosting the Lupita vein and forming the footwall of the Diluvio stockwork zone, is unusual in the context of the structural fabric of the property. The outcrop of the fault and vein has a curvilinear strike shifting from 215° on the west to 270° on the east. The Diluvio block is highly fractured and veinlet/fracture orientations within the Diluvio stockwork show all orientations except dips to the SE, with the dom- inant trend of 285°, dipping 35°. This orientation is somewhat oblique to the surface trace of the Lupita vein (Burtner, 2013; M. Hawksworth and F. Cazares, pers. comm., 2012). No kine- matic indicators were found within the available core, but the
geology of the fault and the stratigraphically-displaced block of lithic tuffs suggest the Diluvio stockwork is hosted within a normally-faulted block down-dropped along the listric Lupita structure and covered by post-faulting andesites and Baucarit Formation rocks.

The unique northeast-trending orientation of the Lupita structure, as well as its stratigraphic location within the Mesozoic lithic-tuff sequence suggests that it may be a reactivated structure created during the northwest-southeast directed compression affecting the region during the late Mesozoic (Henry, 1986; Turner et al., 1982).

**Vein Mineralogy and Textures**

**Mineralogy and Paragenesis**

The paragenetic sequence of the Lupita and Diluvio vein systems (Figure 7, bottom) consists of three major hydrothermal phases followed by a final phase of weathering and supergene effects on the mineralogy of the ore body. Much of the vein system appears to have formed as passive multi-stage filling of existing fractures within the large fault block. At least one minor brecciation event separated Phases I and II, with additional brecciation ongoing during Phase II. Detailed treatments of the mineralogy of each Phase follows.

As in both Mercedes and Klondike, Phase I mineralization is dominated by greenish quartz along with lesser milky to clear quartz. However, compared to the two southern zones the quartz has a generally lighter, milky-green hue. Both color types are most commonly found as banded, chalcedonic intervals and less common crystalline and crustiform textures. Uncommon blebs of unoxidized pyrite and chalcopyrite are present within the Phase I quartz. Precious metal mineralization appears to be associated with the Phase I mineralization as the highest grades are linked with the green-quartz-bearing zones. Neither quartz-carbonate nor precious metal mineralization appears to extend into the andesites covering the Diluvio block.

Carbonate phases, both dark Mn oxide-bearing calcites and clear calcites compose the Phase II mineralization. The Mn-calcite is again abundant, but the less manganiferous calcites form a greater proportion of the Phase II carbonates in Lupita/Diluvio than in either Klondike or Mercedes. As in Klondike, deposition of Au and Ag may have continued during Phase II, but again, this typically low-grade mineralization may be due to small amounts of Phase I material contained within the dominantly carbonate intervals.

Phase III mineralization is somewhat more complex in Lupita/Diluvio than in the other zones in this study. In addition to the late crosscutting quartz and calcite veinlets that define Phase III elsewhere in the district, Lupita/Diluvio contains appreciable amounts of amethystine quartz as late, comb-textured veinlets. Pseudomorphs of gypsum after anhydrite are present in Lupita/Diluvio; they are especially common at higher elevations.

As in Mercedes and Klondike, Phase IV at Lupita/Diluvio is a supergene oxidation assemblage. Due to the burial of the Diluvio zone and the indurated nature of the Lupita vein, oxidation is less widespread and is most abundant at higher elevation. Hematite and goethite are the most common products and have extensively permeated the wall rocks as well. Jarosite appears to be absent in any quantity. Mn-oxides, likely pyrolusite, are widespread as fracture coatings, dendrites and spongy vug fill. This latter texture is related to the destruction of Phase II Mn-calcite by meteoric waters, leaving only the finely intergrown Mn-oxides. Gypsum is present as pseudomorphs after hydrothermal anhydrite.

**Macro Textures: Outcrop to Hand Sample-scale**

The Lupita/Diluvio system is dominated by intact-banded veins and only minor vein breccias. Transport of the clasts appears to be minimal and is restricted to rotation and minor displacement. Brecciation is minimal to absent in much of the Diluvio stockwork, and most of the veins show either massive crystalline or crustiform textures. While the Phase I minerals dominate the bulk of the Lupita structure, Diluvio veinlets contain mostly Phase II carbonates or Phase III amethystine quartz with only minor amounts of the Phase I quartz present.

At higher levels within the Lupita vein, weathering has leached much of the carbonate from the matrix surrounding the Phase I quartz, leaving behind a spongy residue of the Mn-oxides formerly contained within the Phase II carbonates. Local boxworks after sulfides within these intervals suggest that near-surface oxidative weathering of the sulfides generated an acidic fluid partially responsible for the destruction of the carbonates, leaving behind the crustiform quartz and Mn-oxide residue. Drilling within the Diluvio area has encountered common voids, ranging from 0.3 to > 3 m in width, which are interpreted to be zones where carbonate minerals have been leached out.

Limited amounts of high-grade material exist from the Lupita/Diluvio. These tend to be somewhat lower grade (maximum 150 ppm Au, typically 25 ppm Au, 88 ppm Ag) than the high-grade samples examined from both Mercedes and Klondike. The samples are vein breccias containing considerable amounts of saccharoidal Phase I quartz with lesser amounts of carbonate, and little of the hematitic boxworks that are diagnostic of the Mercedes and Klondike high-grade is present.

**Micro Textures: Loupe to Microscopic-Scale**

While retaining the same overall mineralogy as Phase I in Mercedes and Klondike, the textural characteristics of the Lupita/Diluvio Phase I are markedly different. Crustiform and coliform textures are plentiful throughout both intact vein segments and breccia clasts in the Lupita vein as well as in the stockwork veinlets of the Diluvio system. The coliform zones display variable amounts of recrystallization textures under the microscope, chiefly mosaic, feathery, flamboyant or plumeous (Dong et al., 1995; Moncada et al., 2012) textures. Silica replacement of calcite is only locally developed as pseudo-acicular or ghost-bladed textures (Dong et al., 1995, Moncada et al.,...
2012) and many intercepts, especially within the Diluvio stockwork, retain feathery, bladed calcite. Saccharoidal textures are rare within the Lupita/Diluvio system, but are consistently associated with the highest-grade material. The remaining pyrite and chalcopyrite within the veins are of similar character to that of Klondike, forming small blebs disseminated within the Phase I quartz, commonly in proximity to clasts of the host andesite and lithic tuffs entrained within the vein.

Vapor-rich fluid inclusions are present throughout the feathery quartz, but two-phase liquid-vapor inclusions are also present suggesting that episodic overpressurization, fracturing and boiling within the Lupita/Diluvio system was not as intense or widespread as in Mercedes or Klondike. This is supported by the lack of significant hydrothermal brecciation and vertical transport of vein material in Lupita/Diluvio. Furthermore, boiling textures are found at all depths within the system. These two observations suggest mineralization may extend deeper within the Lupita vein and the overall lower grades in the Lupita/Diluvio system are the result of a lack of conditions resulting from sudden depressurization and a subsequent lack of flash boiling that formed the localized bonanza-style deposition seen in the ore shoots of Mercedes and Klondike.

There is no evidence of boiling in any of the Phase II samples studied, and the absence of elevated Au-Ag grades in the dominantly Phase II zones demonstrates that this phase of mineralization was not responsible for the precious metal endowment of the Lupita/Diluvio system.

Geochemical Zonation

Element Correlations

Bivariate plots of Au concentration and selected trace and major elements for the Lupita vein (Figure 15A-H) and the Diluvio stockwork (Figure 15I-P) share similar patterns, but together vary dramatically from the plots of the Mercedes and Klondike veins (Figure 8). Most notably, Au appears to lack correlative relationships with all elements considered (As, Cu, Hg, Mn, Pb, Sb and Zn) with the exception of a weak positive correlation with Ag (Figure 15A) in the Lupita vein. This relationship is not seen in the Diluvio stockwork, where Ag appears uncorrelated with Au (Figure 15I).

Vertical Zonation

Unlike the Mercedes and Klondike veins, plots of metals
Figure 16. Lupita vein vertical geochemical zonation. A. Ag, Au, Cu, Pb, and Zn vs. elevation. B. As, Hg, and Sb vs. elevation.
Figure 17. Diluvio stockwork vertical geochemical zonation. A. Ag, Au, Cu, Pb, and Zn vs. elevation. B. As, Hg, and Sb vs. elevation.
and trace elements vs. absolute elevation for the Lupita vein (Figure 16A-B) and Diluvio stockwork (Figure 17A-B) show clear evidence of vertical zonation in some or all of the elements considered. Within the Lupita vein As and Sb show a well-defined trend of decreasing concentrations with depth. Conversely, Pb and Cu both seem to increase in concentration with depth. Ag, Au, Hg, and Zn do not display any statistically robust tendencies. The trends for As, Pb, Sb, and Cu agree well with the expected zonation trends for an epithermal vein exposed at the level of boiling and precious metal deposition (Buchanan, 1981; Berger and Silberman, 1985).

In contrast to the other vein systems in this study, the Diluvio stockwork zone shows statistically robust and visually obvious vertical zonation trends for all elements considered. As, Ag, Au, and Hg show distinctly decreasing concentrations with depth while the base metals Cu, Pb, and Zn exhibit clearly increasing concentrations within the stockwork. This pattern fits well within the expected model of elemental zonation for an intact epithermal vein.

**Loucks-Petersen Zonation**

Plots of Ag/Zn vs. Pb/Zn for the Lupita vein (Figure 18) and Diluvio stockwork (Figure 19), like the direct concentration vs. elevation plots, begin to show coherent patterns. The data for the Lupita vein appear to be visually organized, but does not conform to any patterns with respect to vertical zonation. There does appear to be a weak positive correlation between Ag/Zn and Pb/Zn, signifying elevational uniformity in codeposition of Ag, Pb, and Zn, but this pattern is unconfirmed with mineralogical evidence. There does not appear to be any significant zonation between Ag and base metals.

In sharp contrast to the other vein systems considered in this study, the Diluvio stockwork displays a coherent Loucks-Petersen zonation pattern. There is a clear “Ω”-shaped pattern formed by a relative increase in Ag/Zn vs. Pb/Zn at higher elevations and a decreasing Ag/Zn vs. Pb/Zn at lower elevations in the stockwork. Figure 20 shows the interpreted pattern (Figure 20A) and the resolved notional trends of Ag/Zn (Figure 20B) and Pb/Zn (Figure 20C) with elevation that combine to create

![Lupita Vein: Covariation of Ag/Zn and Pb/Zn by Elevation](image-url)

*Figure 18. Loucks-Petersen Ag/Zn vs. Pb/Zn zonation plot for the Lupita vein. Hotter colors represent higher elevations. Samples are grouped in 50 m intervals.*
Epithermal grade controls—Mercedes, Sonora, Mexico

The Mercedes, Klondike and Lupita/Diluvio veins are classic examples of fault-hosted epithermal vein systems. The post-mineral latite porphyry that deformed the Mercedes vein establishes an upper age of mineralization at 26.15 Ma. A lower bound is less certain, given the lack of datable minerals within the hydrothermal assemblage and the uncertainty in age of the host andesites. The district structural setting and vein orientations within roughly northwest-southeast trending oblique normal faults strongly implies that vein deposition within the Mercedes and Klondike faults followed the onset of regional Basin and Range extension that began ca. 30 Ma (Henry and Arandagomez, 1992). The timing of the Lupita/Diluvio vein system is less certain given the lack of field relationships between datable units and the differing orientation of the vein-hosting structure. However, the strong mineralogical and paragenetic similarities to the Mercedes and Klondike veins and possibility that the Lupita structure is an extensionally reactivated expression of the known Mesozoic ENE-WSW compressional structural fabric allows for the interpretation that the Lupita/Diluvio system is roughly contemporaneous with mineralization in the Mercedes and Klondike veins.

Both field and experimental studies (Varga, et al., 2004; Trudgill and Cartwright, 1994; Fossen, et al., 2010) document that deformation within stepover zones between grabens can produce both local antiformal structures and a network of normal faults with orientations sweeping from sub-parallel to perpendicular to the grabens within the relay zone. The clear similarities between observed vein orientations in the Mercedes district with those structural analogs supports our proposal that an analogous structural scenario, albeit at a larger scale, controlled vein deposition in the Mercedes district. Within the district itself, the orientation of the veins within the overarching northeast-southwest principal minimum strain axis during the observed Ω-shaped curve. The pattern of higher elevation, relative Ag enrichment, and lower elevation Pb enrichment is consistent with the expected metal zonation within an intact epithermal vein system (Buchanan, 1981).

DISCUSSION

The Mercedes, Klondike and Lupita/Diluvio veins are classic examples of fault-hosted epithermal vein systems. The post-mineral latite porphyry that deformed the Mercedes vein establishes an upper age of mineralization at 26.15 Ma. A lower bound is less certain, given the lack of datable minerals within the hydrothermal assemblage and the uncertainty in age of the host andesites. The district structural setting and vein orientations within roughly northwest-southeast trending oblique normal faults strongly implies that vein deposition within the Mercedes and Klondike faults followed the onset of regional Basin and Range extension that began ca. 30 Ma (Henry and Arandagomez, 1992). The timing of the Lupita/Diluvio vein system is less certain given the lack of field relationships between datable units and the differing orientation of the vein-hosting structure. However, the strong mineralogical and paragenetic similarities to the Mercedes and Klondike veins and possibility that the Lupita structure is an extensionally reactivated expression of the known Mesozoic ENE-WSW compressional structural fabric allows for the interpretation that the Lupita/Diluvio system is roughly contemporaneous with mineralization in the Mercedes and Klondike veins.

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Figure 19. Loucks-Petersen Ag/Zn vs. Pb/Zn zonation plot for the Diluvio stockwork. Hotter colors represent higher elevations. Samples are group in 50 m intervals.
extension appears to have been controlled by the stepover between the Aconchi and Bacanuchi grabens.

Moving to a local scale, the variations in textures and primary metal endowments of each vein can be explained within the regional and district-scale structural framework. The schematic in Figure 21A shows the Mercedes, Klondike and Lupita-Diluvio systems in the context of the putative regional minimum stress axis during extension. The combined effects of the fracture geometry within the graben stepover, reactivation of weaknesses inherited from Mesozoic compressional tectonics (i.e., the Lupita fault and Diluvio block), and the regional stress axis, facilitated differing degrees of dilation and subsequent hydrothermal and tectonic textural disruption of each fault-hosted vein. The Mercedes fault, oriented roughly perpendicular to the regional $\sigma_3$ during the Oligocene, experienced a relatively larger fault-perpendicular $\sigma_3$ component and accommodated a relatively greater degree of extensional deformation. The Mercedes structure thus experienced more prolonged and greater magnitude dilation than the Klondike or Lupita structures (Figure 21B). The larger potential for distention provided for drastic hydrostatic pressure changes during rupture events and created an environment conducive to the development of bonanza grades (Sibson, 1987; Sillitoe, 1993), generating the strong textural disruption and pervasive macro and microscopic boil-

Figure 20. Interpretation of the Diluvio stockwork Loucks-Petersen zonation pattern. A. Interpreted trend from Figure 19. B. Regressed trend of elevation vs. Ag/Zn. C. Regressed trend of elevation vs. Pb/Zn.
ing textures that are the hallmark of the Mercedes ore shoots. At the other end of the spectrum, the Lupita vein and Diluvio stockwork experienced much less intense tectonic disruption due to the Lupita fault’s orientation sub-parallel to the regional σ3. This alignment allowed for less dynamic boiling triggers and only minimal amounts of bonanza-grade mineralization in a larger volume of generally lower grade, texturally intact vein. The Klondike vein, with an orientation intermediate between the Mercedes and Lupita extremes, is an intermediate texture and grade disposition between the two end members.

The textural consequences of the tectonic environment directly impacted the final mineralogical, geochemical and economic signatures of each vein system. The intense brecciation, vertical transport and mixing of vein material, along with possible overprinting of multiple hydrothermal pulses at variable boiling elevations, obliterated primary geochemical zonation in the Mercedes vein. Breccia-enhanced permeability facilitated deep oxidation by meteoric fluids, allowing for significant supergene modification of the primary mineralogy and geochemistry. The post-mineral oxidation of primary sulfides, generation of secondary Ag minerals and extensive dissolution of gangue carbonates destroyed any trace of initial geochemical zonation and correlations between Au and Ag. The supergene reorganization of precious metals is especially apparent in the Au-Ag correlations within the Mercedes vein. Low-grade Au and Ag retain a strong positive correlation, but this relationship decays in higher grade material characterized by the presence of cerargyrite and abundant secondary hematite with boxwork dissolution textures. Additionally, the oxidation of sulfides and subsequent generation of carbonate-destructive acidic fluids lowered the bulk mass of barren Phase II mineralization—effectively increasing the already higher grade Mercedes vein to the rich resource that exists today. The more intact (and less permeable) Lupita vein and Diluvio stockwork were more refractory to oxidation and supergene reworking. As a result, primary sulfides remain and trace element distributions retain a classical epithermal zonation, while the lesser amount of carbonate dissolution maintained a higher gangue/ore ratio and appears to have kept the initially lower grade Lupita/Diluvio mineralization below currently economic grades. The Klondike vein, with a blend of Mercedes and Lupita/Diluvio textural characteristics, represents a transitional degree of supergene modification.

**Implications for Other Epithermal Deposits**

This study demonstrates that processes occurring at the synoptic scale can affect the characteristics of epithermal vein systems at the district, vein, hand-sample, and even fluid-inclusion scale. Many exploration projects may not acknowledge the sensitivity of epithermal vein economics to processes with such incongruent scopes. As was mentioned previously the first modern operations at the Mercedes property ceased operations due to “decreasing grades at depth” . . . only a few meters above the Corona de Oro bonanza. While all geologists can appreciate the value of stepping back and viewing a problem from a new perspective, this study illustrates several concrete consequences that understanding a vein system at multiple scales can have on the exploration and exploitation process:

1.) The Buchanan model for vertical elemental zonation may be deceiving or have little practical value in brecciated and/or supergene-reeled vein systems and can be applied reliably only to intact, banded veins with little post-mineral chemical and textural disruption. This is demonstrated by comparing the Loucks-Petersen zonation plots of the strongly
Figure 21. The Mercedes, Klondike and Lupita structures in a regional context, compare to Figure 2. A. Vein trends (blue) have been extended for clarity and a hypothetical regional $\sigma_3$ (blue arrow) is suggested based on the orientation of the extensional grabens (green). B. Hypothetical $\sigma_3$ vectors (blue arrows) with respect to average structure orientations. The vein-perpendicular component (red lines) of the $\sigma_3$ vector is shown and the relative magnitudes of each perpendicular component are compared at the bottom-right.
disrupted Mercedes vein and mostly intact Diluvio stock-
work.

2.) Supergene oxidation and weathering can have significant economic repercussions through modification of the gangue mineralogy and bulk density of the ore body. Limited physical transport and reorganization of primary Ag mineralogy may occur; possibly affecting leach chemistry, recoveries and Au/Ag ratios. Depending on the efficiency of transport, Au fineness may be increased through preferential transport of Ag out of electrum. Oxidation of sulfides and carbonate dissolution will also increase the efficiency of Au extraction in a cyanide leach.

3.) Veins within a given regional structural regime may exhibit drastically different characteristics depending on the orientation of those veins within that regime. Stepover zones or regions associated with both anomalous structural fabric and syn-deformational volcanic units may be especially prospective due to the possibility of a variety of vein orientations and the presence of a magmatic driver for epithermal mineralization.

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David Saezeda, Resource Modeling
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Mike Zbrozek, Geologist

REFERENCES


Ferrari, L., Valencia-Moreno, M., and Bryan, S., 2007, Magmatism and tectonics of the Sierra Madre Occidental and its relation with evolution of


**APPENDIX I**

$^{40}$Ar/$^{39}$Ar Age of Glassy Latite

All data and figures were provided by Willis Hames of Auburn University.

**Table I-1. ANALYTICAL DATA**

<table>
<thead>
<tr>
<th>Sample Name:</th>
<th>C-Vf-1</th>
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<tbody>
<tr>
<td>Number of Crystals:</td>
<td>4 (2 hornblende, 2 biotite)</td>
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<tr>
<td>Date Run:</td>
<td>10/12/2013</td>
</tr>
<tr>
<td>Irradiation Package:</td>
<td>AU-24</td>
</tr>
<tr>
<td>Date of Irradiation:</td>
<td>8/14/2013</td>
</tr>
<tr>
<td>Elapsed Days:</td>
<td>58</td>
</tr>
<tr>
<td>Monitor Age (FC Sanidine):</td>
<td>2.802 x 10$^{7}$</td>
</tr>
<tr>
<td>Air $^{40}$Ar/$^{39}$Ar:</td>
<td>290.0 ±1.5</td>
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<tr>
<td>$^{36}$Ca/$^{37}$Ca:</td>
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</tr>
<tr>
<td>$^{39}$Ca/$^{37}$Ca:</td>
<td>0.0006800 ±0.0000110</td>
</tr>
<tr>
<td>$^{40}$K/$^{39}$K:</td>
<td>0 ±4 x 10$^{-4}$</td>
</tr>
<tr>
<td>$^{38}$Cl/$^{39}$Cl:</td>
<td>0.01 ±0.01</td>
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<tr>
<td>% of Sample in Split</td>
<td>0.58</td>
</tr>
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</table>
Epithermal grade controls—Mercedes, Sonora, Mexico

Cumulative $^{39}$Ar Fraction

Plateau steps are magenta, rejected steps are cyan
box heights are 1σ

C-VIT-1 Hornblende SCIH (au24.2h.hbl.91)
Plateau age = 26.321±0.095 Ma (1σ)
MSWD = 1.18, probability=0.27
Includes 99.97% of the $^{39}$Ar

Age (Ma)

Cumulative $^{39}$Ar Fraction