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# GEOLOGY AND MINERAL DEPOSITS IN THE HILLSBORO MINING DISTRICT, SIERRA COUNTY, NEW MEXICO

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**ABSTRACT**—The Copper Flat porphyry copper deposit in the Hillsboro mining district in the Animas Mountains in central New Mexico is one of the older Laramide-age porphyry copper deposits in the Arizona-Sonora-New Mexico porphyry copper province. The Copper Flat porphyry copper deposit has measured and indicated reserves of 194 million short tons at 0.26% Cu, 0.008% Mo, 0.002 oz/short ton Au, and 0.05 oz/short ton Ag and inferred reserves of 8 million short tons of ore at a reported grade of 0.23% Cu, 0.004% Mo, and 0.01 oz/short ton Ag. The Hillsboro district consists of Cretaceous andesites surrounded by Paleozoic sedimentary rocks and Quaternary alluvial fan deposits. A quartz monzonite stock (74.93±0.66 Ma, <sup>40</sup>Ar/<sup>39</sup>Ar) hosting a mineralized breccia pipe is located in the center of the district and a series of latite dikes radiate outwards from this quartz monzonite porphyry. The quartz monzonite porphyry and the latite dikes are co-genetic. Base-metal replacement deposits occur near the porphyry deposit and are genetically related to porphyry deposit. The Copper Flat porphyry copper deposit consists of Cu, Au, Mo, and Ag hosted in disseminated sulfides and sulfide-bearing veins in the quartz monzonite and a central breccia pipe. Chemical analyses of surface samples of the porphyry copper deposit indicates that they are enriched in Cu and Mo and depleted in Ag, As, Pb, Zn, Ba, Bi, Mn, and V relative to the vein and replacement deposits. Propagating outward radially from the Copper Flat porphyry copper deposit are Laramide polymetallic veins hosted by the latite dikes. The veins vary tremendously in chemical composition, but are typically enriched in Au, Ag, Cu, As, Bi, Cd and depleted in Mo relative to the porphyry copper and carbonate-hosted replacement deposits and contain as much as 8,560 ppm As, 385 ppm Cd, 3,400 ppm Bi, and 130 ppm Te. Carbonate-hosted replacement deposits are found distal from the porphyry center of the district. Replacement deposits are enriched in Pb, Zn, Ba, V, and depleted in Au and Cu relative to the vein and porphyry-copper deposits and contain as much as 45 ppm As, 66 ppm Bi, and 93 ppm Cd in some samples. No discrete particles containing Au or Ag were identified using the electron microprobe, although electron microprobe studies show Au, Ag, and Mo are found in some minerals, but Te, Se, Cd, Bi, and As were not detected.

## INTRODUCTION

The Copper Flat porphyry copper deposit in the Hillsboro mining district in the Animas Mountains in central New Mexico is one of the older Laramide-age porphyry copper deposits in the Arizona-Sonora-New Mexico porphyry copper province (Fig. 1; McLemore, 2008). The Copper Flat Quartz Monzonite Porphyry Stock (CFQM) intruded the vent of an andesitic volcanic/intrusive complex and hosts porphyry copper mineralization. Polymetallic Laramide veins are associated with latite/quartz latite dikes and both radiate outwards from the CFQM, and are flanked by distal carbonate-hosted Pb-Zn and Ag-Mn replacement deposits to the south and north. Miocene-Holocene placer gold deposits occur in arroyos draining the CFQM and vein deposits (McLemore et al., 2000). Names of types of mineral deposits (i.e. Laramide veins and carbonate-hosted Pb-Zn replacement deposits) are from Cox and Singer (1986), North and McLemore (1986, 1988), McLemore and Lueth (1996), and McLemore (2001).

This update is a continuation of a series of reports on the Hillsboro mining district. The first paper presented new geochemical and geochronological data and, combined with earlier studies, provided a refinement of the model for the evolution of the mineralization in the Hillsboro district (McLemore et al., 1999). Subsequent publications summarized previous work, characterized the petrology and mineralogy of the various magmatic, mineralizing, and alteration systems; defined the genetic relationship among the four distinct types of mineral deposits; and refined a model for the evolution of the Copper Flat volcanic/

intrusive magmatic-hydrothermal system. Munroe (1999) and Munroe et al. (1999, 2000) described mine waste characterization of dumps in Hillsboro mining district, excluding the CFQM deposit. Raugust (2003) and Raugust and McLemore (2005) discussed the water quality in the Hillsboro district, including the CFQM deposit. The purposes of this paper are to 1) summarize previous studies, 2) examine the whole-rock trace element chemistry in the Hillsboro mining district (including new trace element

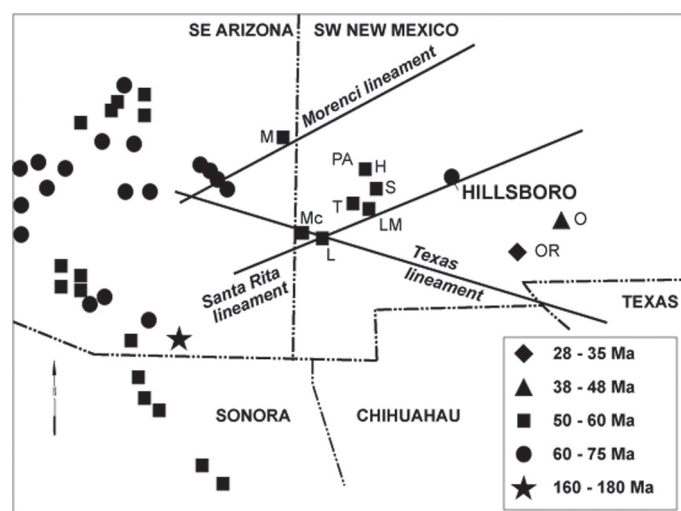


FIGURE 1. Laramide Arizona-New Mexico-Sonora porphyry copper province (from McLemore et al., 1999; McLemore, 2008). PA-Piños Altos, H-Hanover Mountain, S-Santa Rita, T-Tyrone, LM-Lone Mountain, L-Lordsburg, Mc-McGee Peak, and M-Morenci. OR (Organ) and O (Orogrande) are younger Mid-Tertiary porphyry copper deposits.

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data), 3) describe the mineralogy and alteration (including new petrographic examinations), and 4) to refine the paragenesis of the CFQM deposit.

### METHODOLOGY

This report summarizes published and unpublished geologic, petrographic, mineralogical, and chemical data. A geologic map was compiled in ARCMAP@ using U.S. Geological Survey topographic maps as the map base and by modifying Hedlund (1977a, b, 1985). Mineral occurrences, deposits, mines, prospects, and mills were identified, plotted in ARCMAP@, and compiled in the New Mexico Mines Database (Appendix 1; McLemore et al., 2005a, b). Another set of geochemical data for this area consists of rock and mineralized samples that were collected and analyzed for various elements by Korzeb and Kness (1994), Korzeb et al. (1995) and McLemore et al. (1999) (Appendix 2). Geochemical anomaly maps were constructed using ARCMAP@ (Appendix 2).

Selected Hillsboro samples (Table 1) were examined using an SX-100 electron microprobe located at New Mexico Institute of Mining and Technology in order to determine the location and concentration of elements of economic interest, including the analysis of samples using backscattered electron imaging (BSE) in order to identify and examine elemental zonation. Chemical mapping for Mo and Au were carried out on broad areas (1.6x1.6 cm) of selected samples in order to attempt to locate grains containing anomalous abundance of those two elements. Analytical conditions for chemical maps were a 15 kV accelerating voltage and a 200 nA probe current. Images were collected at 1024 x 1024 resolution with a dwell time of 8 ms per point. Quantitative analyses were carried out for a range of elements, including S, Fe, Cu, As, Mo, Ag, Cd, Au, Bi, Te and Pb within pyrite, chalcopyrite and molybdenite from samples of the porphyry copper deposit, and within galena, chalcopyrite, and pyrite from the carbonate-hosted replacement (Appendix 3). For these analyses, an accelerating voltage of 15 kV was used, with a high probe current of 200 nA. Because of the low abundances of some of the trace elements, long count times were used in order to obtain detection limits in the range of 50 to 400 ppm, depending on the element. The count times were as follows: As 120 sec., Ag 120 sec., Cd

120 sec., Au 300 sec., Bi 120 sec., and Te 120 sec. Background count times were one-half of peak count times. Calibration standards include a range of natural and synthetic phases, including, pyrite, galena, Mo, Cu, GaAs, an Au-Ag alloy, ZnTe, Bi, and Cd.

### MINING HISTORY

Mining in the Hillsboro district dates to 1877 along the Laramide veins that radiate outwards from the CFQM deposit. In that same year, placer gold from Snake and Wick Gulches was produced. Fissure veins yielded approximately 51,000 oz of gold (Harley, 1934; Hedlund, 1977a, b) and the placer deposits approximately 110,000 oz (Segerstrom and Antweiler, 1975; Hedlund, 1977a, b) of total gold production until 1931. After the increase of price of gold from \$20.67 to \$35.00 in 1933, there was renewed interest in mining and the period 1932-1943 yielded 15,200 oz of gold. In the mid-1970s various attempts were made to exploit the placers and dump material from various older workings (Hedlund, 1977a, b). Because of low grade and beneficiation problems there was little metals recovery.

At Copper Flat, the Sternberg mine produced approximately 200 short tons of copper ore between 1911 and 1934 (Harley, 1934; Hedlund, 1977a, b) from oxidized outcrops of the CFQM stock. Newmont Mining Company was among the first to explore for disseminated copper ore. Six inclined holes totaling 1,026 m were drilled in 1952 (Kueller, 1955; Hedlund, 1977a, b). Bear Creek Mining Company drilled 20 holes for a total of 2,848 m in 1958 and 1959, and discovered a mineralized breccia pipe within the stock (Hedlund, 1977a, b). Inspiration Consolidated Copper began drilling at Copper Flat in 1967, and by 1973 had drilled an additional 28 holes for a total of 7,024 m (Hedlund, 1977a, b).

Quintana Minerals Corporation leased the property from Inspiration Consolidated Copper in 1974 and between 1974 and 1976, 127 holes were drilled for a total length of 28,680 m (Hedlund, 1977a, b). In 1980, Quintana Minerals Corporation began construction at the site and produced copper from March 1982 to June 1982. During this period 1.5 million short tons ore containing 7.4 million pounds Cu (grade 0.44% Cu), 2,301 troy ounces Au, and 55,966 troy ounces Ag were produced; Mo grade was 0.0088% (M3 Engineering and Technology Corporation, 2012).

TABLE 1. Location and field descriptions of samples collected for electron microprobe study (NAD 27, UTM coordinates, zone 13). Chemical data are in Appendix 3.

SAMPLE NO.	UTM EASTING	UTM NORTHING	FIELD DESCRIPTION	LOCATION NAME
Hill-11-1	263319	3650720	Coarse monzonite with feldspar grains 1 inch long	Northwest corner of pit
Hill-11-2	263236	3650723	Coarse monzonite with thin veinlets of quartz, malachite, chrysocolla, chalcopyrite, pyrite, molybdenite.	West well
Hill-11-3	263130	3650701	Quartz veins up to 2 inches thick in monzonite	East pit
Hill-11-4	263369	3650114	Pyrite and quartz veins in altered monzonite	Edge of deposit
Hill-11-5	-	-	Rhyolite dike with pyrite and quartz veins	Dump
Hill-11-7	264735	3651798	Pyrite veins in rock.	Little Jewess

Mining was discontinued by Quintana Minerals in 1982 because of low copper prices. The mine was closed and the mill sold. Since the 1980s, Hydro Resources, Rio Gold, and Gold Express conducted exploration programs and Alta Gold attempted to obtain mining permits in the mid-1990s but went into bankruptcy.

Currently, THEMAC Resources Group, Ltd. is applying for mining permits to resume operations at the mine, with updated measured and indicated reserves of 194 million short tons at 0.26% Cu, 0.008% Mo, 0.002 oz/short ton Au, and 0.05 oz/short ton Ag and inferred resources of 8 million short tons of ore with a reported grade of 0.23% Cu, 0.004% Mo, and 0.01 oz/short ton Ag. (M3 Engineering and Technology Corporation, 2012). Total known production for the Hillsboro district is in Table 2.

### GEOLOGIC SETTING

Numerous studies have described the Hillsboro mining district. The Laramide vein deposits are described by Lindgren et al. (1910), Harley (1934), and Reeves (1963). The CFQM porphyry copper deposit was first described by Kuellmer (1955), and later by Dunn (1982, 1984). Fowler (1982) described the breccia pipe within the CFQM deposit. Segestrom and Antweiler (1975) described the placer gold deposits. Lovering and Heyl (1989) briefly described jasperoid replacement of Paleozoic limestones south of Copper Flat. Detailed geologic mapping has been performed by Hedlund (1977a, b) and Seager et al. (1982). The geochemistry and evolution of deposits in the Hillsboro district is described in detail by McLemore et al. (1999, 2000). The environmental issues in the Hillsboro district are described by Munroe (1999), Munroe et al. (1999, 2000), Raugust (2003), and Raugust and McLemore (2005).

The CFQM deposit and associated rocks and mineral deposits at Hillsboro are about 75 Ma (McLemore et al., 2000), and are a product of magmas generated during the subduction of the Farallon plate beneath the North American plate between 75 and 50 Ma that resulted in the Southwestern North American porphyry copper province (Fig. 1; Titley, 1995; Keith and Swan, 1996; McLemore et al., 2000). Cretaceous andesite flows, volcanic breccias, and volcanoclastic rocks were erupted from the Copper Flat volcano (McLemore et al., 1999, 2000). Andesite flows occur as an approximately circular outcrop of 6 km diameter and is at least 830 m thick, as measured from drill-hole data (Fig. 2). The andesite is in fault contact and surrounded by Paleozoic sedimentary rocks to the north, south, and southwest, and is unconformably overlain by Quaternary-age alluvial fan deposits (Fig. 2).

The CFQM intruded the vent of the volcano, whereas the unmineralized Warm Springs quartz monzonite intruded the andesite south of CFQM (Hedlund, 1977a, b, 1985; McLemore et al., 2000). Unmineralized quartz monzonite also occurs in the northern part of the district. These two unmineralized intrusions are likely small, satellite stocks that intruded along fracture zones on the flanks of the volcano. At least 34 latite, quartz latite, and monzonite radial dikes intruded the andesite and CFQM, but do not intrude the Warm Springs quartz monzonite. The Kneeling Nun Tuff and Sugarlump Tuff unconformably overlie the andes-

ite flows locally (Hedlund, 1977a, b, 1985; McLemore et al., 2000). The sequence of geologic events is summarized in Table 3 and a summary of alteration assemblages is in Table 4.

### GEOCHEMISTRY OF IGNEOUS ROCKS

One of the problems in determining the magmatic differentiation history of a porphyry copper system is that most of the rocks exposed exhibit varying degrees of alteration that affect the major and trace element composition. Many methods of differentiating altered versus unaltered rocks have been proposed using geochemical variation diagrams (Leitch and Lentz, 1994; Stanley and Madeisky, 1994; Wilt, 1995; Keith and Swan, 1996). Like many porphyry copper systems, the samples from Hillsboro exhibit varying degrees of alteration (Table 4; McLemore et al., 1999, 2000). McLemore et al. (1999) used the alteration filter diagrams proposed by Wilt (1995) and Keith and Swan (1996) to identify altered versus relatively fresh samples from the Hillsboro district. Unaltered samples also tend to have LOI (loss on ignition) concentrations of less than 3%.

Unaltered andesites in the Hillsboro district are metaluminous and alkaline; the unaltered quartz monzonites and latites are metaluminous to peraluminous and alkaline to subalkaline. The linear variation in  $\text{Na}_2\text{O}+\text{K}_2\text{O}/\text{SiO}_2$ ,  $\text{V}/\text{TiO}_2$ ,  $\text{SiO}_2$  vs.  $\text{TiO}_2$ , and  $\text{SiO}_2$  vs.  $\text{Zr}/\text{TiO}_2$ , and various major elements suggests that these igneous rocks are comagmatic (McLemore et al., 1999, 2000). Pearce element plots (Pearce et al., 1984) of  $\text{Na}/\text{Zr}$  vs.  $\text{Al}/\text{Zr}$  and  $(\text{K} + \text{Na})/\text{Mg}$  vs.  $\text{Al}/\text{Mg}$  indicate that magmatic differentiation was controlled in part by feldspar fractionation (McLemore et al., 1999, 2000). These plots along with geologic mapping (by Hedlund, 1977a, b, 1985; McLemore et al., 1999, 2000; V.T. McLemore, unpublished mapping) also indicate that the quartz latite dikes are closely related to the intrusion of the three quartz monzonite porphyry intrusions. The igneous rocks are classified as syn-collision to volcanic arc granites (Pearce et al., 1984).

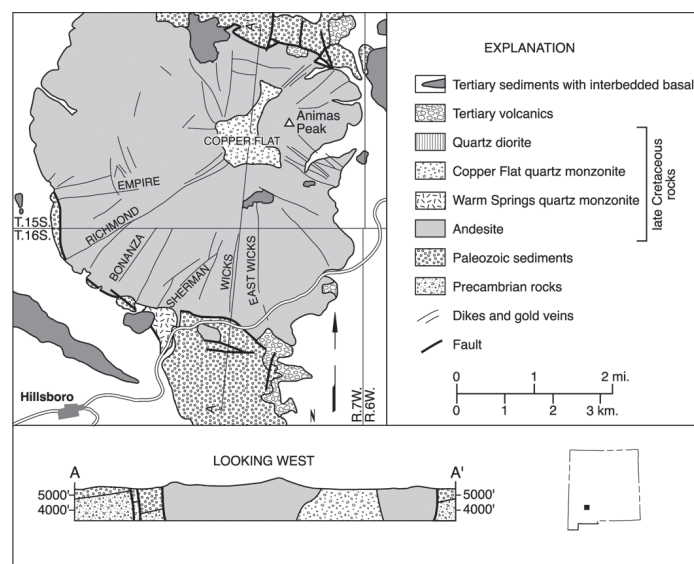


FIGURE 2. Geology of Hillsboro mining district (from McLemore et al., 1999)



TABLE 2. Metals production from the Hillsboro district, Sierra County (U.S. Geological Survey, 1902-1927; U.S. Bureau of Mines, 1927-1990; Harley, 1934; M3 Engineering and Technology Corporation, 2012; NMBGMR, unpublished data). \*Includes production from Tierra Blanca district in 1939 and from the Caballo district in 1957. Production from 1902-1932 is estimated from unpublished records.

YEAR	ORE (TONS)	COPPER (lbs)	LODE GOLD (oz)	PLACER GOLD (oz)	SILVER (oz)	LEAD (lbs)	VALUE (\$)
1877-1904	—	—	134,000	104,000	—	—	6,750,000
1891	—	—	—	—	—	—	253,000
1892	—	—	—	—	—	—	354,424
1893	—	—	—	—	—	—	458,388
1894	26,225	310,000	16,785	—	112,500	—	432,680
1902	1428	3400	988	—	1,508	80,000	20,500
1903	8	—	6	—	—	—	1
1904	1,000	16,000	2,400	—	8,001	—	52,000
1905	3,464	35,984	552	—	3,644	—	12,800
1906	3,200	5,000	684	—	3,733	—	15,500
1907	602	4,255	236	—	1,311	—	5,000
1908	827	7,124	551	—	12,157	73	17,000
1909	194	15,523	401	—	1,755	860	8,900
1910	5,530	1,747	94	—	1,585	296	1,880
1911	2,570	4,555	92	—	1,005	422	1,840
1912	90	2,918	90	—	510	94	1,800
1913	4	352	13	—	34	—	280
1914	6	939	11	—	43	—	220
1915	10	1,442	32	—	197	129	640
1916	56	5,621	71	—	889	246	1,400
1917	38	5,377	63	—	3,835	4,616	4,300
1918	14	3,693	—	—	4	—	700
1919	58	3,044	160	—	524	5,945	3,700
1920	688	17,278	428	—	2,500	—	11,000
1921	9	73	30	—	1	—	600
1922	38	4,939	111	—	688	—	2,300
1923	53	2,845	210	—	415	725	4,200
1925	61	5,210	79	—	830	—	1,600
1926	52	5,878	143	—	1,354	2500	3,000
1927	656	13,658	436	—	1,306	4333	8,800
1928	34	2,000	123	—	306	—	2,500
1929	41	3,222	79	—	50	—	1,600
1930	109	7,302	159	—	563	—	3,300
1931	469	4,100	4,278	—	525	7700	85,600
1932	497	9,000	342	—	1,204	16000	7,100
1933	272	3,000	239	221	1,277	600	10,177
1934	761	14,100	462	1,139	4,647	700	60,109
1935	666	22,000	1,098	1,761	2,561	18,400	104,481
1936	983	34,980	1,638	1,620	4,571	—	120,788
1937	469	17,400	357	1,234	2,587	—	70,309
1938	268	13,900	425	2,073	2,104	—	90,138
1939*	1,160	29,900	868	2,271	3,427	100	115,306
1940	1,084	25,000	684	1,688	2,219	3,300	87,588
1941	4,581	20,000	432	989	1,562	1,100	53,269
1942	11	—	16	582	79	—	20,811
1943	—	—	—	4	—	—	70
1944	—	—	—	8	—	—	175
1946	12	400	7	—	83	—	377
1947	4	—	1	—	3	—	20
1948	6	—	4	—	65	—	199
1949	11	1,000	35	—	338	—	1,728
1950	111	3,600	121	—	491	—	5,428
1951	1,214	—	289	—	52	—	0,162
1952	563	—	125	—	30	—	4,402
1953	1,230	—	265	—	51	—	9,426
1955	10	400	2	3	11	—	2,259
1957*	304	3,300	4	58	4	—	1,138
1961	16	118	12	—	17	63	350
1982	1,200,000	7,400,000	2,289	—	55,996	—	5,000,000
Total 1877-1982	1,261,767	8,091,577	173,032	117,651	245,152	148,202	14,287,101
Estimated total 1877-1982		8,100,000	160,000	120,000	134,000	154,000	14,500,000

TABLE 3. Sequence of major geologic events in the Hillsboro mining district. Deposition of the Copper Flat porphyry copper and vein deposits and formation of jasperoids most likely overlapped in time. From McLemore et al. (2000).

GEOLOGIC EVENT	AGE	MINERALIZATION AND ALTERATION
Eruption of alkali basalt	4 Ma	None
Uplift of the Copper Flat volcanic/intrusive complex followed by erosion	21-22 Ma to present	Minor supergene enrichment of porphyry copper deposit, Placer gold deposits
Eruption of Sugarlump and Kneeling Nun Tuffs (Emory caldera)	35-34 Ma	None in the Hillsboro district
Burial? or possibly minor erosion?	75 Ma to 35 Ma	Minor supergene enrichment of porphyry copper deposit?
Formation of jasperoids	75-35 Ma	Followed by deposition of carbonate-hosted replacement Ag-Mn and Pb-Zn deposits
Latite and quartz latite dikes	75-70 Ma	Vein (Au, Ag, Cu) deposits, type 4, 5, and 6 alteration (Table 4)
Intrusion of quartz monzonite porphyry and formation of breccia pipe deposit	75 Ma	Porphyry copper deposits (Cu, Au, Ag, Mo), type 1, 2 and 3 alteration (Table 4), formation of skarn and marble in limestone
Eruption of andesite volcano	75 Ma	None, possible early deuteric alteration

These data are consistent with highly evolved arc magmatism related to subduction of the Farrallon plate (Keith and Swan, 1996). The preserved portion of the CFQM is low in sulfur with total sulfur contents less than 7% (McLemore et al., 1999, 2000) and pyrite contents of typically less than 2%, although higher concentrations of pyrite occur locally. Collectively, these data suggest that the igneous rocks in the Hillsboro district are part of a differentiated comagmatic suite. The geochemical composition of the altered rocks is consistent with the alteration mineral assemblages and reflects the dominance of potassic alteration.

### DESCRIPTION OF ORE DEPOSITS AND GEOCHEMICAL ZONING

Porphyry copper, Laramide vein, carbonate-hosted Ag-Mn and Pb-Zn, and placer gold deposits are found in the Hillsboro district

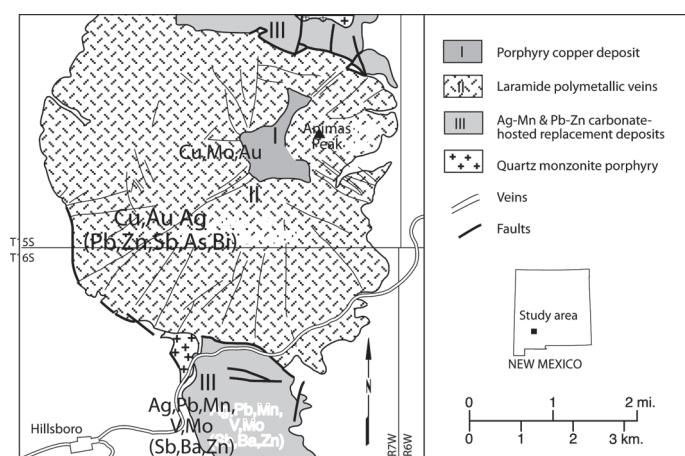


FIGURE 3. District zoning of Hillsboro mining district (from McLemore et al., 1999).

(Fig. 3; Appendix 1). Collectively, the evidence suggests that the deposits found in the Hillsboro district were formed by multiple convective hydrothermal systems related to the Copper Flat volcanic/intrusive complex (Hedlund, 1977a, b, 1985; McLemore et al., 1999, 2000).

### Porphyry copper deposit

The porphyry copper deposit is located in the center of the Hillsboro district (Fig. 3), and hosted by the CFQM in the form of disseminated sulfides and sulfide-bearing veins. The known breccia pipe is 396 m long, 183 m wide, and has a vertical extent of almost 518 m (Dunn, 1982, 1984) and has a preferred NNE-SSW orientation. Thin veinlets containing quartz, chalcopyrite, pyrite, molybdenite, bornite, biotite, and epidote cut the CFQM. Late magmatic and hydrothermal minerals include biotite, K-feldspar, sericite, quartz, carbonate, chlorite, kaolinite, sphene, magnetite, and apatite. The alteration is moderate to well developed (Table 4), and generally consists of replacement of feldspars by white phyllosilicate minerals, and biotite replacement by sericite or chlorite (Fig. 4). Supergene oxidation is restricted to the upper 6-9 m of the sulfide zone (Castellano et al., 1977), and no significant supergene geochemical stratigraphy is developed over the Copper Flat porphyry-breccia system. Quaternary-age overburden ranges from 0 to 6 m. Whole-rock chemical analyses of surface samples of the porphyry copper deposit indicates that they are enriched in Cu and Mo and depleted in Ag, As, Pb, Zn, Ba, Bi, Mn, and V relative to the vein and replacement deposits (Table 5; Appendix 2). Quintana Minerals Corp. analyzed 4,246 samples of drill core and cuttings from 149 drill holes for Cu and Mo from the porphyry-copper deposit. The mean of these samples is 0.29% Cu and 0.01% Mo; the maximum concentration in samples is 4.04% Cu and 0.49% Mo (McLemore et al., 2000).

TABLE 4. Summary of hydrothermal alteration assemblages associated with mineralization in the Hillsboro district (Fowler, 1982; Hedlund, 1985; McLemore et al., 1999).

HOST ROCK/TYPE OF MINERAL DEPOSIT	ALTERATION MINERAL ASSEMBLAGE	ALTERATION TYPE
Quartz monzonite/porphyry copper deposit	Biotite, K-feldspar, quartz, pyrite	1-biotite-potassic
	K-feldspar, chlorite, quartz, pyrite	2-potassic
	Sericite, quartz, pyrite	3-sericitic
Andesites adjacent to the latite dikes and polymetallic veins	Epidote, chlorite, sericite, pyrite, magnetite	4-propylitic
	Sericite, calcite, chlorite, quartz, pyrite	5-argillic
	Chlorite, kaolinite, sericite, calcite, quartz, pyrite	6-propylitic
Latite/quartz latite dikes associated with the polymetallic veins	Quartz, K-feldspar, pyrite, epidote, chlorite	4-propylitic
	Quartz, sericite, chlorite, pyrite	5-sericitic
Limestones, dolostones	Garnet, epidote, magnetite, quartz	6-skarn
	Marble, recrystallized limestone	7-marble
	Quartz, iron and manganese oxides	8-jasperoid

### Laramide vein deposits

The Laramide veins occur along the contact of quartz latite veins radiating from the CFQM within the andesites surrounding the CFQM. The veins vary tremendously in chemical composition, but are typically enriched in Au, Ag, Cu, As, Bi, Cd, and depleted in Mo relative to the porphyry copper and carbonate-hosted replacement deposits and contain as much as 8,560 ppm As, 385 ppm Cd, 3,400 ppm Bi, and 130 ppm Te (Table 5; Appendix 2).

### Carbonate-hosted Pb-Zn deposits

The carbonate-hosted Ag-Mn and Pb-Zn deposits occur on the flanks of andesite to the north and south of district. The deposit consists of pods of Ag-Mn and Pb-Zn replacements and Pb-Zn skarns and veins in Paleozoic-age limestone and dolomite. The replacement deposits are enriched in Pb, Zn, Ba, V, and depleted in Au and Cu relative to the vein and porphyry copper deposits and contain as much as 45 ppm As, 66 ppm Bi, and 93 ppm Cd in some samples (Table 5; Appendix 2).

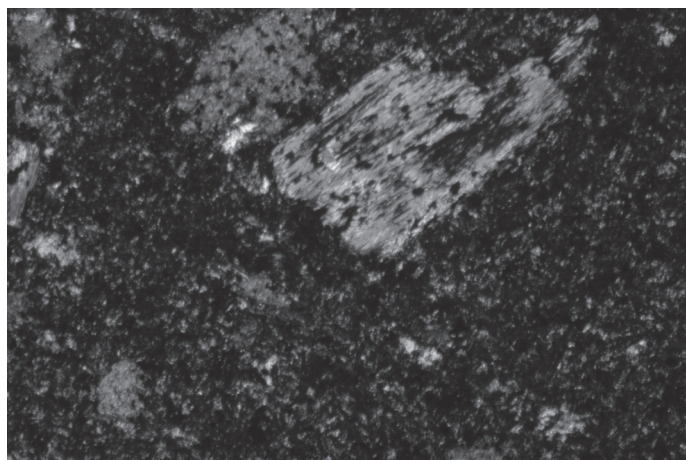


FIGURE 4. Biotite grain is replaced by sericite (sample Hill-11-5).

### Placer Gold Deposits

The placer gold deposits in the Hillsboro district represent the second most productive placer gold districts in New Mexico (McLemore, 1994, 2001). The most productive deposits in the district were found in drainages and gulches radiating from the Copper Flat area. Total production from placer deposits is estimated as 120,000 oz Au and accounts for most of the gold production from the district (McLemore, 1994). Placer gold occurs in four gravel units ranging in age from latest Miocene to Holocene (Segerstrom and Antweiler, 1975). The gold is apparently derived from the mechanical weathering of the porphyry copper and Laramide vein deposits. Segerstrom and Antweiler (1975) estimated that approximately 8.4 million yards of material containing 34,500 ounces Au remain in placer deposits (grade of 0.006 oz/cu yd); at least one company has examined the placer potential (Christensen, 2007).

### District Zoning

Many workers in the district have recognized district-scale elemental zoning (Fig. 3; Harley, 1934; Fowler, 1982; Hedlund, 1985; McLemore et al., 1999, 2000). The low sulfur (<7%) CFQM porphyry copper deposit forms the center of the district and is characterized by Cu, Mo, and minor Au (McLemore et al., 1999, 2000). Trending radially from the CFQM are Laramide veins, with carbonate-hosted replacement deposits (Ag, Pb, Mn, V, Mo, Zn) located in the distal southern and northern parts of the district. Placer gold deposits were formed by erosion of the porphyry copper and Laramide vein deposits and occur in the drainages and alluvial fans emanating from the CFQM and Laramide vein deposits.

Element distribution plots (representing geochemical anomaly maps) derived from the available whole-rock data (Appendix 2) show that the distribution of most elements either reflect the district zoning or indicate that some of the Laramide veins are locally enriched in certain metals. Rubidium and, to a lesser extent, potassium, plots show a definite halo surrounding the



TABLE 5. Summary of chemical analysis of samples from Hillsboro mining district (modified from McLemore et al., 2000). All the data is in ppm (parts per million) except for Au, which is in ppb (parts per billion). N is number of samples analyzed, na- not available. Raw data are in Appendix 2.

	Au	Ag	Cu	Pb	Zn	Mo	As	Sb	Ba	Bi	Mn	V	Cd
CFQM Porphyry copper deposits													
Maximum	8810	2.6	>9999	250	1032	475	9	30	1000	23	2415	173	8
Minimum	<2	<2	4	<5	14	<2	<0.6	<0.6	140	<10	19	<2	<0.6
Average	620	0.8	1806	34	170	35	2	2	613	14	320	46	-
N=24													
Laramide vein deposits													
Maximum	64600	590	57337	9175	17026	68	8560	43	3000	4958	59796	626	385
Minimum	<2	<2	<2	<5	11	<2	<0.6	<0.6	<100	<10	5	2	<0.6
Average	3921	28	3428	770	863	12	120	3	671	231	2954	13	-
N=194													
Carbonate-replacement deposits													
Maximum	99	64	196	10000	>20000	160	388	26	20000	104	49430	>2000	93
Minimum	<2	<2	7	<5	227	<2	1.6	<0.6	<100	11	149	25	<0.6
Average	48	32	110	5151	12665	39	93	14	5238	52	15254	352	-
N=8													
Jasperoids													
Maximum	19	<2	49	49	268	2	21	na	301	na	176	131	na
Minimum	<5		2	8	10	<2	0.8		21		52	2	
Average	13		11	28	68	2	7		123		110	26	
N= 8													

CFQM deposit and may be an indication of geochemical alteration surrounding porphyry copper deposit (McLemore et al., 1999). Tellurium values up to 130 ppm are found in veins in the northern part of the district and as much as 3,400 ppm Bi, 385 ppm Cd, and 8,600 ppm As are detected in some samples of Laramide veins (Appendix 2).

## RESULTS AND DISCUSSION

Chalcopyrite, pyrite and molybdenite are the most important ore minerals found in the CFQM and breccia deposits (Fig. 5). The carbonate-replacement deposits contained pyrite, galena, and chalcopyrite and also show anomalous Au (as much as 430 ppm) and Ag (as much as 560 ppm) as presented in Appendix 3.

Although, as noted from previous studies (McLemore et al., 1999, 2000), this investigation did not show there to be geochemically significant trace elements in the Copper Flat ores; the lack of detectable trace elements in specific minerals examined by electron microprobe analyses may be explained as follows.

There are only very low concentrations of these elements in the Hillsboro district deposits.

Trace elements occur in specific zones (for example, see Chaffee, 1982; Jones, 1992; Nurmi, 1985). Because only a few samples were collected for this project, we may not have sampled the specific zones where these trace elements are found in anomalous concentrations.

The electron microprobe analysis has a detection limit of between 50-400 ppm, depending on the element, and trace elements analyzed could have been present in concentrations less than the detection limit.

The samples collected may not be representative of the entire deposit.

## Paragenesis

The paragenetic sequence of mineralization was originally defined by Fowler (1982) and Dunn (1982) and is slightly modified here. Hypogene mineralization occurred in three primary stages (Fig. 6), with each stage associated with different magmatic events (Table 3) and different sulfide and alteration mineral assemblages (Table 4).

Stage 1 is represented by the deposition of pyrite with minor chalcopyrite during initial emplacement of the CFQM stock and is characterized by sericite and chlorite alteration. This event comprises disseminated and vein-controlled sulfides with little ore-grade material. Cross-cutting vein relationships show an earlier vein stage (stage 1) cut by later stage 2 veins (Fig. 7). The mineralogy of the veins suggests that this early event has abundant pyrite and magnetite, minor chalcopyrite; alteration consists of chlorite, abundant sericite, carbonate, quartz, and titanite.

The formation of the Copper Flat breccia pipe occurred during stage 2. Pyrite and chalcopyrite were developed, along with minor molybdenite. Dunn (1984) noted presence of sphalerite and galena in this stage. The Laramide veins (Au-Ag-Cu) and associated distal propylitic and sericitic alteration assemblages surrounding the CFQM stock likely formed during this second stage of mineralization (Table 3). Stage 2 veins contain coarser pyrite, plus chalcopyrite and molybdenite, with abundant quartz, sericite, K-feldspar, apatite, carbonate, fluorite, and minor magnetite.

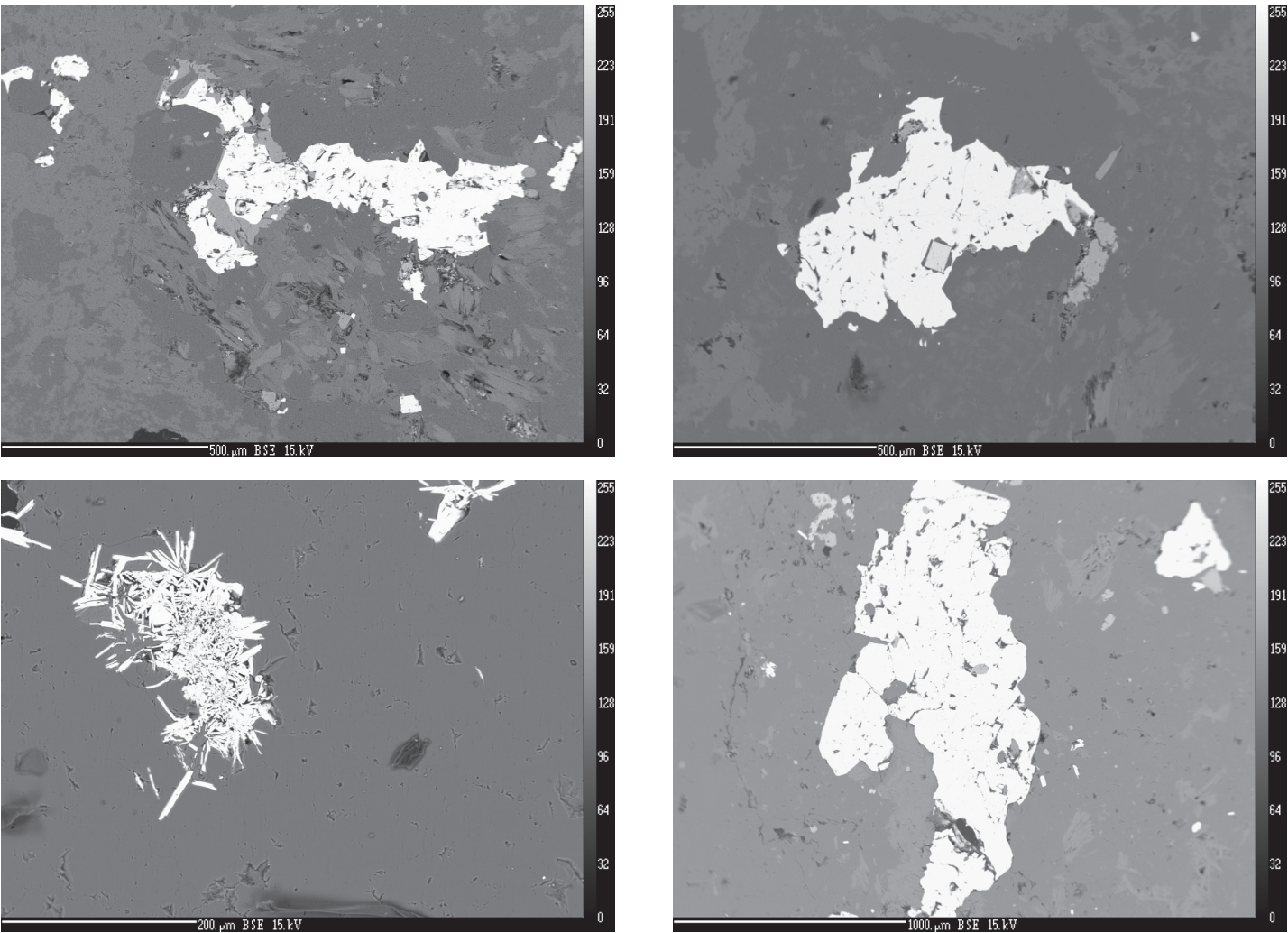


FIGURE 5. **A.** Back scattered image of chalcopyrite and magnetite (sample Hill-112a). **B.** Back scattered image of chalcopyrite with euhedral pyrite (sample Hill 11-2a). **C.** Back scattered image of molybdenite (sample Hill 11-2a). **D.** Back scattered image of pyrite (sample Hill-11-3).

The last hypogene ore comprises stage 3, and is characterized by minor sulfide minerals in the CFQM porphyry deposit. Molybdenite hosted by quartz veins, and sphalerite and galena in carbonate veins were formed during this stage of mineralization (Table 4).

ENVIRONMENTAL IMPLICATIONS

This study shows that certain trace elements are generally low in the CFQM and associated deposits, which has positive environmental implications for the Copper Flat mine. The majority of pyrite in the Copper Flat deposit has a cubic, euhedral shape (Fig. 11), and most pyrites are relatively chemically pure with only minor trace elements (Appendix 3). Although locally, pyrites may contain minor amounts of Cu and As. Studies have shown that the more heterogeneous the pyrite, the faster the pyrite will oxidize, especially with high concentrations of As (Kwong, 1993). These studies nevertheless indicate that Co and Ni concentrations tend to inhibit pyrite from weathering, whereas As and, to a lesser degree, Cu enhance oxidation. Thus, the cubic texture of the

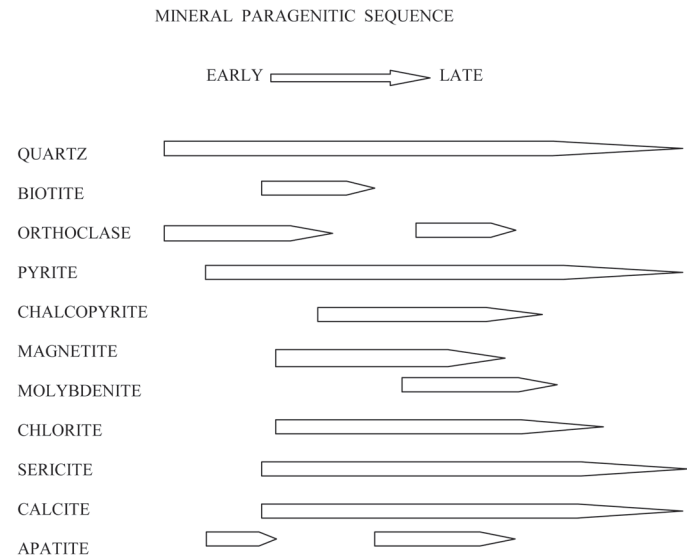


FIGURE 6. Paragenetic sequence of mineralization from interpretation of thin section samples (after Dunn, 1984 and Fowler, 1982).



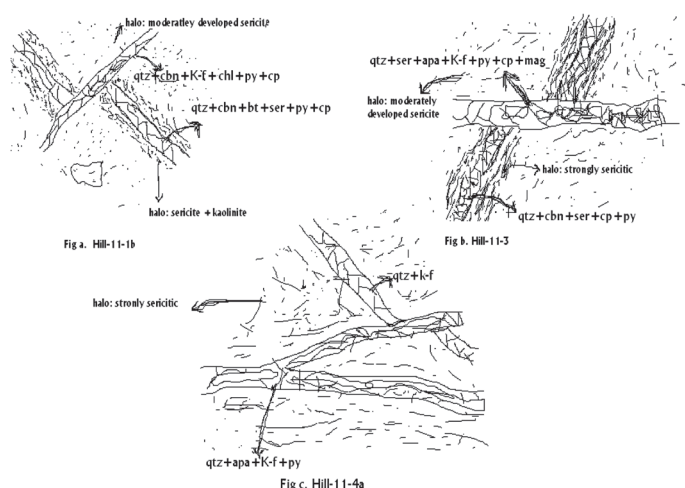


FIGURE 7. Sketches from petrographic examination of samples showing cross-cutting veins relationships noted in this study (see text for discussion). Qtz-quartz, ser-sericite, apa-apatite, K-f - K-feldspar, py-pyrite, cp-chalcopryite, cbn-carbonate, chl-chlorite, bt-biotite.

pyrites and lack of significant trace elements may likely reduce the oxidation rate of pyrite and perhaps temporarily inhibit the mobility of these elements and formation of less acid drainage, which is consistent with previous studies (Raugust, 2003; Raugust and McLemore, 2005).

### SUMMARY

The CFQM deposit in the Hillsboro mining district in the Animas Mountains in central New Mexico is one of the older Laramide-age porphyry copper deposits in the Arizona-Sonora-New Mexico porphyry copper province and consists of Cu, Au, Mo, and Ag hosted in disseminated sulfides and sulfide-bearing veins in the quartz monzonite and a central breccia pipe. The low sulfur (<7%) CFQM deposit forms the center of the district and is characterized by Cu, Mo, and minor Au (McLemore et al., 1999, 2000). Radial Laramide veins and carbonate-hosted replacement deposits (Ag, Pb, Mn, V, Mo, Zn) are distal from the porphyry center of the district. Placer gold deposits were formed by erosion of the porphyry copper and Laramide veins and occur in the drainages and alluvial fans emanating from the porphyry copper and Laramide vein deposits. This study shows no discrete mineral grains containing Au or Ag were identified in petrographic or electron microprobe analyses. However, electron microprobe study does show that Au, Ag, and Mo are found in some minerals and that Mo occurs as discrete grains as molybdenite; but Te, Se, Cd, Bi, and As are not detected.

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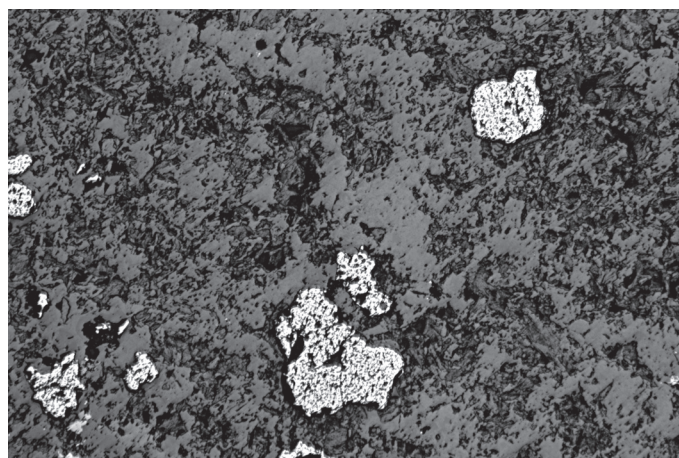


FIGURE 11. Euhedral and anhedral pyrite (sample Hill-11-3).

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