**2001 Goldschmidt Conference**

# TEMPORAL EVOLUTION OF THE INTRUSIVE-HYDROTHERMAL SYSTEM AT THE BINGHAM PORPHYRY Cu-Au-Mo DEPOSIT, UTAH.

P.B. Redmond and M.T. Einaudi, Department of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305 (redmond@pangea.stanford.edu; marco@pangea.stanford.edu)

**Introduction:** The Bingham porphyry deposit represents one of the largest copper-gold-molybdenum resources in the world. Open pit exposures combined with a large number of deep drillholes provide a 2 km vertical section through the deposit. Detailed mapping, core logging and petrographic-analytical studies over the past three years have provided new insights into the temporal evolution of the magmatic-hydrothermal system.

**Porphyry Intrusions:** Five separate porphyry intrusions, including two previously undescribed, have been mapped on the basis of crosscutting relations between dikes and veins. Four of the five porphyries are latitic whereas the third in the sequence of intrusion is more mafic in composition. The occurrence of this mineralized mafic dike supports the hypothesis that mafic (minette) magma mixed with latitic magma in the parent magma chamber below the deposit and contributed metals, sulfur and volatiles to hydrothermal fluids [1].

**Wallrock Alteration Styles:** Copper-gold ore is associated with zones of abundant quartz veins and potassic alteration that varies from biotitization of hornblende to complete replacement of porphyry by quartz, K-feldspar, and minor biotite. Zones of intense K-feldspar-quartz replacement are best developed within the earliest porphyry and have the highest grades of copper and gold. Sericitic alteration is rare in the potassic core of the deposit, but is common and locally pervasive within structurally controlled zones at the NE and SW peripheries. The youngest alteration style, consisting of illite-smectite alteration of plagioclase sites (with K-feldspar and biotite stable), occurs throughout the deposit but does not affect metal distribution.

**Copper-Gold and Molybdenum Mineralization:** The high-grade (>1% Cu, > 2ppm Au) copper-gold zone at Bingham consists of the assemblage digenite$_1$-bornite$_3$-chalcopyrite$_1$ (vol. proportions) with no pyrite. Composite grains containing all three sulfide phases are common. Digenite and chalcopyrite rarely occur in contact, digenite most commonly occurs as exsolution laths within bornite, and bornite and chalcopyrite display mutual boundaries. Cathodoluminescence petrography demonstrates that these Cu-Fe-sulfides were deposited with a distinct generation of quartz and minor K-feldspar along fractures cutting both early-formed barren quartz veins and adjacent wall rock.

Electron microprobe and secondary-ion mass spectrometry (SIMS) have shown that the bulk of the gold occurs as 5-20 micron grains enclosed within, or attached to, sulfide grains (mainly bornite) and as grains enclosed in quartz or K-feldspar. Minor gold also occurs as colloidal or chemically bound gold and/or as inclusions of gold-silver tellurides and bismuthides within sulfide grains. Copper and gold were introduced contemporaneously during potassic alteration at high temperatures. Gold was preferentially deposited within bornite solid solution that later exsolved on cooling to digenite-bornite intergrowths plus native gold.

Mapping indicates that none of the numerous molybdenite-quartz veins are cut by porphyry intrusions. Thus, molybdenite was deposited after termination of dike emplacement. This is consistent with the relatively young Re-Os date of molybdenite [2]. Molybdenite-quartz veins in turn are invariably cut by quartz-sericite-pyrite veins.

**Fluid Inclusions:** Early quartz-sulfide veins with K-feldspar-biotite selvages from within the orebody contain vapor-rich ($CO_2$-rich) and hypersaline liquid inclusions with homogenization temperatures of 400 to >575ºC and 40-50 wt. % $NaCl_{equiv.}$ [3]. This study shows that barren quartz veins with K-feldspar-biotite selvages, but no sulfides, from 1000-1500m below the base of the orebody are dominated by petrographically distinct fluid inclusions that display pseudo-critical behavior during heating and were trapped in the one-phase field at estimated temperatures of 500 to >600ºC. These inclusions have salinities of 10-12 wt. % $NaCl_{equiv.}$ and contain visible $CO_2$. These data indicate that ascending $CO_2$-rich magmatic fluids underwent phase separation within the porphyry conduit at estimated paleodepths of 2-3 km.

**Timing of Mineralization:** Each porphyry intrusion produced multiple generations of quartz veins, copper-gold ore and potassically altered wall rock. Fractures filled with late quartz, K-feldspar, and Cu-Fe-sulfides may have formed during a transition from lithostatic to hydrostatic pressure conditions during each porphyry intrusive event. The mass of introduced copper and gold and the degree of alteration decreased significantly with each successive intrusion. This observation, similar to ore-dike relations at El Salvador [4], Yerington [5], and Batu Hijau [6], places constraints on the water content and depth of crystallization of the source magma chamber. Decline in copper output from a crystallizing magma chamber through time will occur if the magma contains a low initial water content and is located at depths >7 km [7, 8]. Although previous studies [2] have suggested that molybdenum may not be directly related to the same magmatic-hydrothermal system that produced the copper-gold ores, an alternative is that molybdenum partitioned into the hydrothermal fluids later than copper, as suggested for other deposits [9].

**References:** [1] Keith J.D. et al. (1997) *Jour. of Petrology*, 38, 1679-1690. [2] Chesley J.T. and Ruiz J. (1998) *SEG Guidebook,* 29, 165-169. [3] Roedder E. (1971) *Econ. Geol.,* 69, 98-118. [4] Gustafson L.B. and Hunt J.P. (1975) *Econ. Geol.*, 70, 395-428. [5] Dilles J.H. et al. (2000) *SEG Guidebook,* 32, 55-66. [6] Clode C. et al. (1999) *AusIMM PACRIM'99*, 4/99, 485-498. [7] Cline J.S. and Bodnar R.J. (1991) *JGR*, 96, 8113-8126. [8] Shinohara H. et al. (1989) *GCA*, 53, 2617-2630. [9] Dilles J.H. and Proffett J.M. (1995) *Ariz. Geol. Soc. Digest*, 20, 306-315.