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Title: COMPOSITIONS OF HYDROTHERMAL FLUIDS THAT FORMED MAIN STAGE VEINS IN BUTTE, MONTANA: EVIDENCE FROM FLUID INCLUSIONS

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Abstract: The Main Stage (MS) vein system at Butte, which is superimposed on earlier porphyry copper mineralization, is one of the world's largest Cordilleran-style base metal lode deposits. Butte Main Stage veins are meter-scale polymetallic veins surrounded by sericitic alteration. The vein system is zoned from a central Cu-rich zone containing covellite, chalcocite, digenite, and enargite to an intermediate zone containing both Cu and Zn sulfides, to a peripheral zone dominated by sphalerite, galena, and rhodochrosite, commonly in breccias. Pyrite occurs in all zones and quartz becomes more abundant outward from the central zone of the deposit.

Most inclusions analyzed are primary inclusions located along growth zones in euhedral vein quartz. Sphalerite and rhodochrosite contain inclusions with similar phase ratios to inclusions in quartz. Fluid inclusions in Main Stage veins are similar in appearance throughout the central, intermediate, and peripheral zones such that only one type of fluid inclusion dominates all samples observed. At room temperature the fluid inclusions are liquid rich containing a bubble that occupies about 20 volume percent of the inclusion (B20 inclusions). We found neither halite-saturated nor vapor-rich inclusions in any Main Stage vein, and daughter minerals are extremely rare. All Main Stage inclusions analyzed contain less than 5 wt% NaCl equiv, and many contain 1 mol% or less of CO_2. Most inclusions homogenize to liquid between 230° and 300°C. No systematic variation in salinity or homogenization temperature was observed from the Cu-rich central zone outward to the Pb-, Zn-, Mn-dominated peripheral zone.
Lack of vapor-rich inclusions indicates that the inclusions were trapped in the liquid field at pressures above the boiling curve. Main Stage veins extend from the present surface to depths greater than 2 kilometers. Maximum estimated depths of formation are 4 to 6

kilometers based on pressure estimates from pyrite-quartz veins with sericitic alteration in pre-Main Stage (pre-MS) mineralization. At such pressures, an isochoric temperature adjustment of up to about 50°C is required, indicating that MS vein formation occurred at temperatures between about 230° and 350°C.

Preliminary LA-ICP-MS analyses of MS fluid inclusions indicates that central zone fluids are highly enriched in As and Sb relative to deep pre-MS fluid inclusions, but contain little Cu, Pb, Zn, or Mn. O isotopes in quartz and sericite suggest that MS hydrothermal fluids had a mixed magmatic-meteoric source. Upon fluid unmixing into brine and vapor, As and Sb are typically sequestered into the vapor phase. Therefore the enrichment of As and Sb in MS fluid inclusions suggests that magmatic vapors, derived from fluid unmixing at depth, supplied metals and volatiles that condensed into circulating meteoric waters to form Main Stage veins.