Fluid Inclusion Analysis of Quartz and Alunite in Acid-Sulfate Alteration near Porphyry Peak, Bonanza Caldera, Colorado

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INTRODUCTION

This study assesses the hydrothermal alteration system responsible for the advanced acid-sulfate alteration near Porphyry peak, south-central Colorado. A Unocal report by Varga and Smith (1982) mapped the alteration of an exogenous rhyolitic dome on the northern rim of the collapsed Bonanza caldera. The report noted the potential for precious metal deposit and recommended further exploration of the area. My work in conjunction with my student co-workers on the Colorado 1999 Keck project is aimed at developing a more complete understanding of the hydrothermal processes involved. This knowledge can then be applied to make a more robust assessment for the prospect of precious metal deposits in this system.

The mineral assemblage quartz + alunite, located on the rhyolitic dome, is indicative of acid-sulfate alteration (Heald, *et al.*, 1987). This type of alteration is commonly associated with mobilization and concentration of precious metals, primarily Au, to economically significant levels.. An analysis of several effects of hydrothermal activity on the host rock can help to understand specific aspects of the hydrothermal system and put further constraints on the potential for precious metal ore.

This paper's contribution to the understanding of local hydrothermal system is to reconstruct the hydrothermal evolution of the area using fluid inclusion data from in and around the zone of quartz-alunite alteration. Fluid inclusions are microscopic samples of thermal fluids, trapped and preserved during crystal growth. Methods of fluid inclusion analysis can provide accurate values for the temperature, pressure and composition of the fluids at the time of entrapment (Bodnar, *et al.*, 1986). Also, inclusions can indicate whether boiling was involved in the system. Boiling is especially capable of concentrating metals and therefore is often associated with metal deposits of economic significance. This study's focus is to construct a model for the hydrothermal processes in terms of fluid temperature, presence of boiling, depth, and origin of heat and hydrothermal fluids.

GEOLOGIC BACKGROUND AND SETTING

A series of silicic intusives, dated at 33 my, are interpreted as late events in the Bonanza caldera's magmatic history (Varga and Smith, 1984). The Porphyry Peak and Sheep Mountain rhyolites are two of the larger such intrusions and both have been highly altered by hydrothermal activity. Altered Porphyry Peak rhylolite is the dominant unit present in the field area, ranging from relatively unaltered rhyolite with a biotite-sanidine phenocryst assemblage to highly silicified rock with granular quartz that retains few primary minerals.. The alteration is centered on a dome-shaped hill directly south of Porphyry Peak, interpreted as a post-caldera exogenous dome (Varga and Smith, 1982). This feature is referred to as the Southwest dome in this report.

The zone of quartz + alunite alteration is confined to elevations above 11,200 on the Southwest dome. A region of intense silicification with intact beta-quartz phenocrysts with an alunite fringe occurs in the saddle between the Southwest dome and the Porphyry Peaks. Varga and Smith originally interpreted this area as a silicic intrusion, adjacent, but separate from the alunitized dome. Although the expression of the alteration in the saddle is slightly different, the spatial relationship to the primary alunite suggests it is genetically related.

DESCRIPTION AND PETROGRAPHY OF FLUID INCLUSIONS

Analytic data were gathered exclusively from inclusions determined to be either primary or pseudosecondary origin. The criteria I used to determine the inclusion origin were: their position along distinct crystal growth planes in quartz and alunite, large relative size, regular shape with sharp edges, no apparent geometric relation to other inclusions (e.g. fracture plane) or the termination of fracture plane at crystal boundary. Measured inclusions ranged from 2-90 µm in the largest dimension, but were most commonly 5-10 µm across. The preponderance of inclusions are vapor rich, with the vapor bubble typically exceeding 90% of the total inclusion volume.. Vapor rich inclusions are problematic in that the fluid component will form a thin film on the walls of the inclusion as it homogenizes during heating runs rendering T_h impossible (Roedder, 1984). The scarcity of primary inclusions, the predominance of vapor-rich inclusions, and the small size of inclusions in general, limited the number of homogenization temperatures I was able to obtain.

In the samples analyzed, fluid inclusions are abundant in quartz veins, coarse quartz crystals, quartz phenocrysts and coarse, euhedral alunite

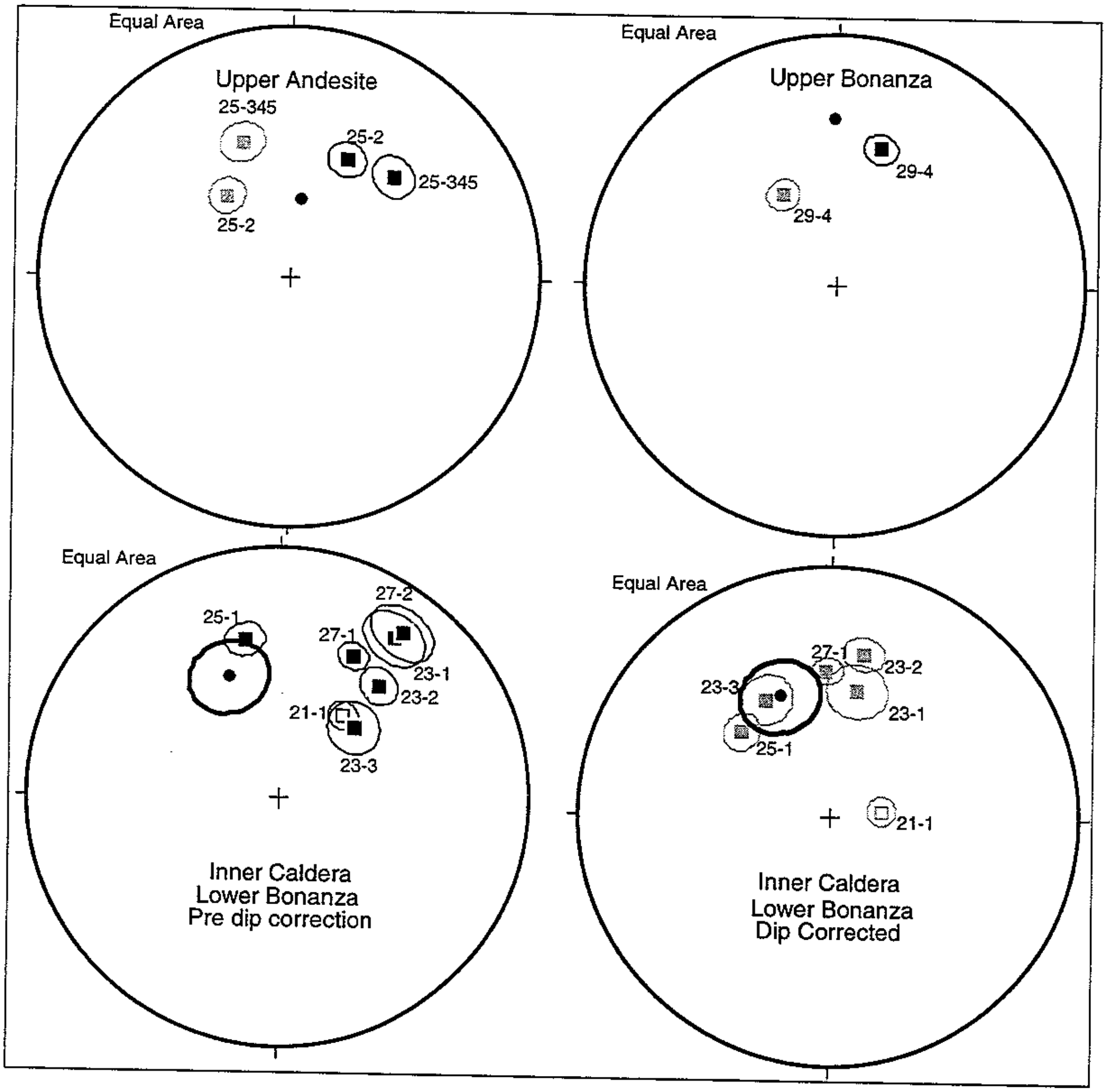

Figure 4. Stereonets show pre-dip corrected TRM directions in black and dip corrected TRM directions in grey. Control TRM directions are shown as black dots. The black dot in the center of the 95% confidence circle is the thermally demagnetized lower Bonanza control from Findlay Ridge. Other dots are controls from altenating field technique. Site Ids are shortened for space. For example, site 72599-1 is shown as 25-1.

Inclusions in Quartz- Most quartz veins and coarse, euhedral crystals display a high density of primary and secondary inclusions. Some vug-filling crystals on the periphery of alteration are barren with the exception of secondary inclusions along healed microfractures. Inclusions are less abundant in the anhedral quartz, characteristic of the core of alteration and, where present, are mostly too small to be measured. Inclusions display a variety of geometries, but are most commonly spherical or eliptical. Large quartz phenocrysts in the vuggy silica from the saddle area contain large (15-25 μm) fluid-rich inclusions with symetrical negative crystal shape. Because these phenocrysts also occur in the unaltered rhyolite, it is assumed that these inclusions are of igneous origin and do not represent the acid-sulfate fluids.

Inclusions in Alunite- Euhedral blades of alunite contain inclusions parallel to very obvious growth planes, clustered in the apex of the crystal. Most alunite inclusions are eliptical with well-defined edges, and lower in density and more consistent in size than inclusions in quartz (4-7 μm). Secondary inclusions are absent in alunite crystals. Inclusions in less well developed alunite, like granular silica, are sparse and difficult to see.

I have concluded that inclusions are strictly $NaCl-H_20$ in composition since no daughter minerals or inclusions with multiple vapor bubbles indicating presence of other volatiles, such as CO_2 were observed to suggest otherwise.

TEMPERATURES OF HOMOGENIZATION

I obtained temperatures of homogenization using a Fluid Inc. heating/cooling analytical stage at the College of Wooster, Wooster, Ohio. Homogenization temperatures of primary and psuedosecondary inclusions range from 185 -320 ° C, with 60% falling between 220° C and 270° C (Fig. 1). Despite the small data set, consisting of 68 inclusions, some distinct trends exist. 1) All inclusions measured in alunite homogenize above 265° C. 2) The mean temperature for inclusions in quartz associtated with alunite is almost 30° C higher than in quartz outside alunitized area. 3) Adjacent inclusions with similar L/V ratios have T_h values that differ by up to 80° C. 4) Regularly shaped inclusions with negative crystal geometry in quartz phenocrysts homogenize above 400° C, the analytical limit of the apparatus, indicating igneous origin.

PALEODEPTH

. The P/T conditions of boiling fluid provide an estimate for the paleodepth of boiling in hydrothermal fluids. The salinity of the fluids adjusts the boiling curve to determine actual temperature of entrapment and reconstruct the paleodepth of entrapment (Haas 1971). Unfortunatley unexpected difficulties in equipment did not allow for this measurement. Assuming a salinity of 2% weight equivalent NaCl, the paleodepth for boiling in the quartz veins 230-250° C is roughly 300 meters. For alunite, with boiling measured at 270-280° C, the depth is 600 m (Fig. 2). The 2% weight equivalent NaCl is consistent with most published values for acid-sulfate alteration. The absence of daughter halite crystals also supports this assumption.

BOILING

Boiling of hydrothermal fluids has been cited by many authors as a primary mechanism for mobilization and concentration of metals in the formation of ore deposits (Drummond and Ohmoto, 1985). The coexistance of liquid-rich and vapor-rich inclusions is the most common evidence cited for the presence of boiling in a system. In my samples, fluid-rich inclusions definitely coexist within a majority of vapor-rich inclusions. However, the scarcity of liquid-rich inclusions is problematic in that there is no method for control against the processes of annealing and necking-down which can create false evidence for boiling. Some assemblages containing multiple liquid-rich inclusions, occurring primarily in quartz veins, show inconsistent temperature readings among adjacent inclusions. This variability can be a result of either physical changes to the inclusion or heterogeneous entrapment of a multi-phase system, and thus muddles the argument for boiling. No all-liquid inclusions were observed in association with the assemblages (Bodnar, et al., 1986), which weakens the argument for necking down, but does not provide conclusive evidence either way.

Evidence in support of boiling in this system includes the dominant presence of vapor-rich inclusions, both as primary and filling obvious secondary fracture planes. This indicates that a vapor phase was present at some point during mineralization. The predominance of vapor-rich inclusions has been cited as evidence for boiling in several localities, including Julcani, Peru (Deen, 1995) and Goldfield, Nevada (White, 1971). Vapor dominated inclusions in an ore-bearing hydrothermal system near Lepanto Philippines has been interpreted as a zone directly overlying the level of boiling where the vapor has completely separated from the two phase fluid. (Hedenquist, *et al.*, 1994) Although boiling can not be proven unequivocally, the evidence suggests a proximity to boiling at some time in the hydrothermal evolution of the system (Ray Coveney, pers. comm, 2000).

DISCUSSION

The temperatures of homogenization, the minimum temperatures of boiling and the paleodepth are all consistent with a magmatic hydrothermal system as defined by Rye, *et al.*, (1992) at a depth of 300-600 m. This depth is consistent with other acid-sulfate regions. Magmatic alteration systems derive acidity from the disproportionation of magma-derived SO_2 to produce H_2SO_4 and H_2S. Acidic alteration of wall-rock is generally acknowledged to begin as the vapor plume containing SO_2 begins to condense. Boiling of fluids at higher levels leads to a further decrease in pH (Drummond and Ohmoto, 1985). The increase in acidity enhances the fluid's potential for precious metal transport as the vectors for precious metals, often sulfates or chlorides, are more soluble in acid solutions. In some localities, such as Nansatsu, Japan and Summitville, Colorado, the condensate is interpreted as mixing with meteoric waters to produce the observed alteration. Mixing with meteoric water subsequently increases pH and may contribute to metal deposition (Drummond and Ohmoto, 1985).

Structural evidence for shallow depth

The presence of dome-related structures, studied by field partner Angie Dudek, suggests that the rock was very near the surface at the time it was deformed. Also, the well-preserved morphological features of the caldera imply minimal effects of erosion. Varga and Smith (1982) estimated 100-200 feet of erosion from the original surface of the dome. This evidence conflicts with the paleodepth calculated from the recorded temperature of boiling and detracts from the argument for a hypogene origin for the alunite.. To reconcile this disparity requires some influence of burial and subsequent erosion. Varga and Smith (1982) mapped a unit of ashfall pumice overlying the altered Porphyry Peak rhyolite in the low area between the two Porphyry Peaks. The presence of an easily erodable unit overlying the dome, and emplaced a relatively short while after the dome, provides a mechanism for some of the required pressure.

To more completely explain the disparity in paleodepth values, I propose a system analogous to the vapor-dominated zone overlying the primary zone of boiling at Lepanto, Phillipines (Hedenquist, *et al.,* 1994) with fluid convection outward from the core of alteration. The vapor-dominated zone represents a departure from the fluid boiling curve, "cooling" isothermally rather than isoenthalpically, and thus is shallower than T_h values indicate. The slight increase in liquid-rich inclusions in samples outside the quartz + alunite zone suggests a reattachment to the boiling curve as acidic fluids are neutralized as they convect outward. Thus, the low-end of T_h values from peripheral quartz are more representative of the true paleodepth. A temperature range of 190-210° C yields a paleodepth of 100-200 meters. This figure is much more compatible with structural evidence. The primary boiling zone coincides with the high-end temperature in the quartz + alunite core. Temperatures of 270-280° C indicate a paleodepth of 600-700 meters, consistent with a magmatic hydrothermal system. This idealized model is depicted in Figure 3.

Ore Potential

The system at Porphyry Peak compares favorably to many acid-sulfate systems with established ore components. However, these systems are highly variable in terms of tonnage, type of ore and metal ratios. Factors which can effect the concentration and ratio of metal deposition include, the original chemistry of the magma chamber and host rock, level of interaction with meteoric waters, intensity of boiling and mechanisms of secondary enrichment. The geochemical data needed make a secure statement of the type or concentration of precious metal deposit goes beyond the information provided by this study. Cu-Au depostion in acid-sulfate systems is commonly associated with an enargite-luzonite mineral horizon (Hayba, *et al.,* 1986). This type of mineralization has not been located in the surficial samples collected. If such a horizon were located through drill cores, it could be assumed that precious metal deposition had occurred.

CONCLUSIONS

The results of this study describe a system of hydrothermal alteration that is consistent with existing models of magmatic acid-sulfate systems. The presence of the quartz + alunite + kaolinite indicates the proper chemical environment for high sulfide concentrations, often associated with precious metals. Boiling in the system at temperatures of 250-270°C suggests a relatively shallow (300-600 m) zone of boiling, suggestive of ore-depositing conditions at depth. The ingredients requisite for ore-grade precious metal deposition are present. If this pursuit is deemed worthwhile, additional field exploration and drill cores which would provide information on the stratigraphy and the accessory mineralogy of the system should be considered.

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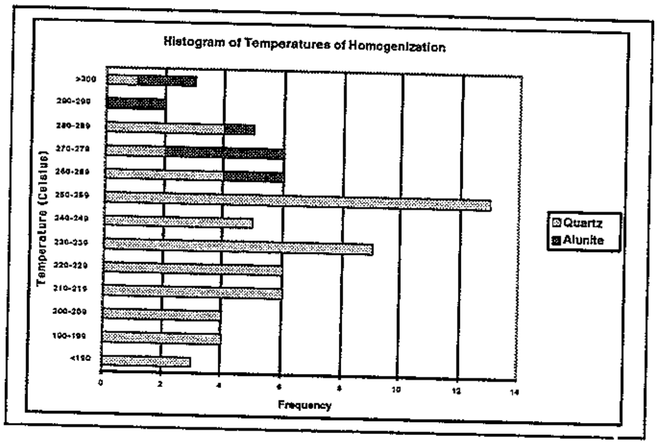

Fig. 1

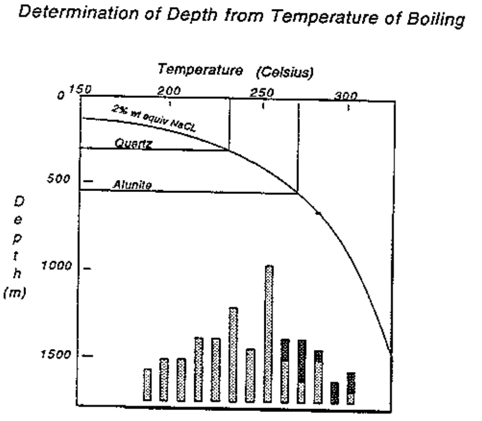

Fig. 2- Plot of depth of boiling versus temperature of homogenization for 2% weight equivalent NaCl(modified from Bodnar, et al., 1985). Plotted depths for quartz and alunite are mean values for the minerals. The histogram of homogenization values (from Fig. 1) is provided to demonstrate full range of depth constrained by the data.

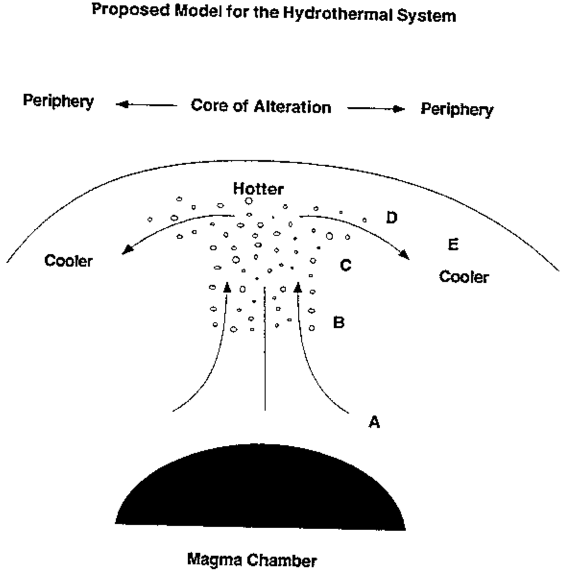

Fig. 3- Idealized model for the Soutwest dome hydrothermal system. Acidic, magma-derived fluids (A) ascend and cool until they reach the level of primary boiling (B). Vapor phase separation leaves only vapor in the ascending fluids (C). Convection of the hydrothermal system carries fluids outward at (D). Fluids decrease in acidity, temperature, and return to boiling curve, causing an increase in liquid-rich inclusions as they approach (E) at the periphery of alteration.

Isotopic Studies in the Bighorn Mountains, Wyoming: The U-Th/He Geochronology, Oxygen Isotope and Structural Perspectives

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