The ascent of a magmatic-hydrothermal fluid recorded in zoned alteration mineral assemblages in Butte, Montana, USA

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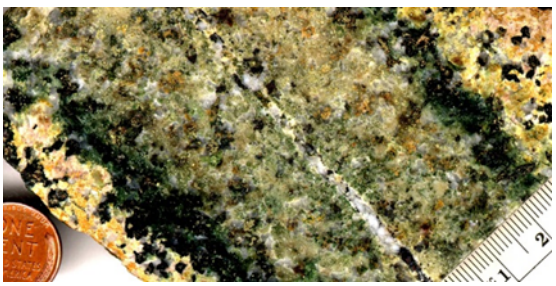
Hydrothermal alteration deep in the Butte porphyry copper deposit includes biotite, andalusite, muscovite, K-feldspar and plagioclase (An30) that formed at ~650ºC [1]. Shallow alteration contains muscovite, chlorite and pyrite in some settings, and epidote, chloirte, carbonates, albite and K-feldspar in others [2]. Geochemical modeling of reaction of a magmatic fluid with the Butte granite in the range of 600°C to 200°C at 100 MPa shows that one single fluid composition produces veins and alteration of every variety observed. Temperature decrease, itself, causes change in mineral assemblages, but its effects are coupled with pH decrease from neutral to acidic as temperature decreases, and with acid neutralization by rock reaction along a fluid flow pathway.

The computations illuminate why the particular assemblages in zoned vein envelopes (Figure below) form, and how one alteration assemblage evolves upward to another with decreasing temperature over a scale of many hundreds of meters. If one fluid type yields all vein stages and alteration types, then the cause of the variations in veins and alteration lies not in magmatic processes, but entirely in the hydrothermal regime and the staging of delivery of fluids into the fracture system. The occurrence of a single fluid composition is supported by measurements of fluid inclusions in the Butte system [3], which show that the salinity and CO_2 concentration of primary fluids is similar in all Butte Pre-Main Stage vein types, suggesting a common origin.



Zoned envelope: inner musc-chl to outer K-feld-musc-bi.

[1] Mercer, C., and Reed, M., 2013, *Economic Geology* **108**, 1347-1377. [2] Reed *et al* 2013, *Economic Geology*, **108**, 1379–1396. [3] Rusk, B., *et al* 2008, *Economic Geology*, **103**, 307-334.