

Hydrothermal Minerals and Precious Metals in the Broadlands-Ohaaki Geothermal System: Implications for Understanding Low-Sulfidation Epithermal Environments

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Abstract

The Broadlands-Ohaaki geothermal system is a boiling hydrothermal system hosted by a sequence of Quaternary felsic volcanic rocks and Mesozoic metasediments. More than 50 wells have been drilled (400 to >2,600 m deep) to assess the geothermal potential for the production of electricity. Fluids and precipitates sampled from wells, along with descriptions of the alteration minerals in more than 500 drill cores, provide a three-dimensional picture of the distribution of fluid types and secondary minerals. Interpretation of these features and the distribution of gold and silver highlight the relationship between alteration and mineralization in an active, low-sulfidation epithermal environment.

Quartz, illite, K feldspar (adularia), albite, chlorite, calcite, and pyrite are the main hydrothermal minerals that occur in the deep central upflow zone at $\approx 250^\circ\text{C}$ and >600 m depth. These minerals form through recrystallization of the volcanic host rocks and incorporation of H_2O , CO_2 , and H_2S in the presence of a deeply derived chloride water containing $\sim 1,000$ mg/kg Cl and $\sim 26,400$ mg/kg CO_2 . At the same time, and on the periphery of the upflow zone, illite, smectite, calcite, and siderite form through hydrolytic alteration in the presence of CO_2 -rich steam-heated waters that contain <30 mg/kg Cl and $\sim 13,000$ mg/kg CO_2 . Upward and outward from the deep central upflow zone, mineral patterns reflect the shift from rock-dominated to fluid-dominated alteration and the prevailing influence of boiling, mixing, and cooling on fluid-mineral equilibria. Accordingly, the abundance of quartz and K feldspar increase toward the upflow zone, whereas clay abundance increases toward the margin of the upflow zone (with smectite dominating at $<150^\circ\text{C}$ and illite dominating at $>200^\circ\text{C}$); the abundance of chlorite, pyrite, and calcite varies here, but albite is absent.

Geothermal production wells with high fluid fluxes are the main sites of precious metal mineralization. The deep chloride water (with or without minor amounts of vapor) enters the well at depths >500 m and undergoes a pressure drop that causes boiling. As a result, precious metals precipitate and accumulate as scales on back-pressure plates or as detritus in surface weir boxes; these deposits contain <10 to $>1,000$ mg/kg Au, <100 to $>10,000$ mg/kg Ag and ~ 10 to $\sim 1,000$ mg/kg As and Sb, each. Within production wells, platy calcite deposits as a scale at the site of first boiling near the fluid feed point, while crustiform-colloform-banded amorphous silica deposits in surface pipe work. By contrast, the hydrothermally altered host rocks contain low concentrations of gold, ranging from <0.01 to 1.0 mg/kg Au (68 analyses), and these correlate positively with arsenic (<100 to $\sim 5,000$ mg/kg) and antimony (<10 to ~ 500 mg/kg).

Reaction path modeling using SOLVEQ and CHILLER shows that calcite, K feldspar, gold, and amorphous silica deposit in sequence from a chloride water that cools along an adiabatic boiling path (300° to 100°C), analogous to fluid flow in a production well. By contrast, calcite, quartz, K mica, and pyrite deposit from a chloride water that cools due to mixing with CO_2 -rich steam-heated waters; dilution prevents precipitation of precious metals. Thus field observations and reaction path modeling demonstrate that boiling is the main process influencing the deposition of precious metals.

The results of this study show how peripheral hydrolytic alteration by CO_2 -rich steamheated waters relate to propylitic and potassic alteration by chloride waters in the epithermal environment of a hydrothermal system. Both the distribution of alteration mineral assemblages associated with the different water types and the broad-scale distribution of temperature-sensitive smectite and illite reflect the location of the upflow zone. On a local scale, the occurrence of platy calcite, crustiform-colloform silica, and K feldspar in veins indicates the existence of boiling conditions conducive to precious metal deposition.