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Henderson Porphyry Molybdenum System, Colorado: II. Decoupling of Introduction and Deposition of Metals during Geochemical Evolution of Hydrothermal Fluids

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Abstract

Fluorine-rich hydrothermal mineral assemblages developed at Henderson, Colorado, as 12 rhyolitic stocks of Oligocene age were emplaced, crystallized, and cooled inside a much larger and slightly older, rhyolitic intrusion, forming a Climax-type molybdenum deposit. The stocks are grouped into three intrusive centers, and the mineral assemblages, including ore minerals, are grouped according to their temperatures of formation as either high-, moderately high, moderate-, or low-temperature assemblages. The latter three groups are termed lower temperature assemblages, which are subdivided into two suites on the basis of position: above intrusive centers and on the flanks of the Seriate center. Integration of the mineralogy, sequence, and spatial positions of mineral assemblages defines the geochemical evolution of hydrothermal fluids, places qualitative constraints on mass transfer, and provides insight into the development of the geochemical halos that are used in exploration for porphyry orebodies.

A reconnaissance fluid inclusion study targeted the lower temperature assemblages, and a geologic assessment of results indicates that we were unable to identify fluid inclusions from several assemblages. After pooling meaningful results, the ranges of temperatures of formation for each group of lower temperature assemblages are moderately high, 600° to 460°C; moderate, 530° to 310°C; and low, 390° to 200°C, with significant differences in salinity between the two suites of assemblages. The suite formed above intrusive centers was deposited by more saline fluids (salinity commonly 28–65 wt % NaCl ± KCl equiv) than the suite formed on the flanks of the Seriate center (mostly <29 wt % NaCl + KCl equiv). The lower temperature assemblages described here do not overlap in space with higher level propylitic alteration, but fluid inclusions in one sample of propylitized rock indicate temperatures of 320° to 210°C and salinity <29 wt percent NaCl + KCl equiv.

Phase equilibria suggest that, at comparable temperatures, the suite of assemblages that formed above intrusive centers formed at higher f_{S_2}, f_{O_2}, and a_{K^+}/a_{Na^+} and slightly lower a_{K^+}/a_{H^+} than the suite of assemblages that formed on the flanks of the Seriate center. From inception of potassic alteration (~600°C) to termination of sericitic alteration (~300°C), values of log a_{K^+}/a_{H^+} of fluids remained essentially constant (~3), but the $a_{F^-} \cdot a_{H^+}$ of fluids increased. Fluids were undersaturated with respect to topaz during high-temperature silicic and intense potassic alteration, but topaz precipitated in both suites of assemblages after further fluid evolution. Topaz formed in certain less intense potassic, transitional potassic-sodic, and sericitic assemblages as the $a_{F^-} \cdot a_{H^+}$ of fluids increased with decline in temperature and probably pressure, before the fluid again became undersaturated with respect to topaz. Because fluids associated with sericite-pyrite alteration at Henderson were unusually saline (mostly 29–36 wt % NaCl equiv), cooling of evolved, magmatic fluids (rather than dilution by meteoric water) likely drove sericitic alteration by cooling through the K-feldspar-sericite buffer at nearly constant a_{K^+}/a_{H^+}. Indeed, halite-bearing fluid inclusions persist into intermediate argillic assemblages that precipitated sphalerite and F-bearing, Mn-rich garnet.

Fluorine was continuously added to wall rocks by hydrothermal fluids along the entire evolutionary paths of both suites of assemblages. The alkalis underwent a complex history of mass transfer, with the behavior of potassium fluctuating between periods of strong leaching and strong addition to the rock. Iron was leached at high to moderately high temperatures and then fixed in the rock at lower temperatures, first mainly as magnetite and then as pyrite and minor pyrrhotite and specular hematite. Molybdenum and tungsten show no evidence of any period of significant leaching or recycling.

Each mineralizing intrusion introduced juvenile magmatic hydrothermal fluids containing metals and other components, but the deposition of metals and other components was staggered over time and a wide temperature range. The order of deposition was Mo to W to Pb-Zn to Mn. The spatial zoning of metals from proximal to distal around any intrusive center generally—but not always—corresponds to the temporal sequence early to late. Moreover, the metals that were deposited relatively late tended to be deposited at about the same time throughout the system, so that Pb-Zn and Mn introduced with the earliest intrusions were not deposited until much later, after other intrusions and hydrothermal fluids were introduced. Hence, there was progressively greater decoupling between the times of introduction and deposition of metals in the order Mo to W to Pb-Zn to Mn, and this time delay lengthened for any given component introduced by an earlier intrusion compared to the same component introduced by a later intrusion. The degree of decoupling of introduction and

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deposition of components may reconcile discrepancies between differing interpretations of when the majority of Cu is deposited in porphyry copper deposits.

Hydrothermal mineral assemblages that formed above intrusive centers at Henderson resemble assemblages in other Climax-type porphyry molybdenum deposits associated with high-silica rhyolites. In contrast, the suite of assemblages that formed on the flanks of the Seriate center is similar to alteration-mineralization products formed in porphyry molybdenum deposits related to alkali syenites and in porphyry tungsten-molybdenum deposits associated with rhyolites and granites. Hydrothermal assemblages in granite-related molybdenum deposits of the differentiated monzogranite suite and granite-related molybdenum-copper deposits have little in common with either suite of assemblages at Henderson.