

## Formation of Anhydrous and Hydrous Skarn in Cu-Au Ore Deposits by Magmatic Fluids

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### Abstract

Most skarn ore deposits are characterized by two distinctly different alteration styles. An early prograde stage with anhydrous minerals, such as garnet and pyroxene, forms from relatively high-temperature, hypersaline liquid. A later retrograde stage with hydrous minerals, such as epidote, amphibole, and chlorite plus sulfide ore minerals, forms from lower temperature, lower salinity fluids. These two alteration stages commonly have been thought to reflect a dominance of magmatic and meteoric water, respectively, with relevance to the source of ore metals. We report data from two different skarn systems, one being part of the world's largest Cu-Au resource. Stable isotope compositions of anhydrous and hydrous alteration minerals from both deposits indicate a magmatic source for both the prograde and retrograde stages:  $\delta^{18}\text{O}$  averages 5.0 per mil for garnet (range, 3.4–7.2‰), 6.5 per mil for pyroxene (4.3–8.2‰), and 7.1 per mil for amphibole (4.3–8.7‰). The  $\delta\text{D}$  values of late amphibole are more complex, with magmatic values (–77 to –78‰) for one deposit and both magmatic and lighter values for another deposit that could be explained either by magmatic degassing or by limited mixing with meteoric water. We conclude that the differences in fluid composition—prograde versus retrograde stages—resulted from a magmatic fluid that intersected its solvus during the early stage, creating vapor and hypersaline liquid, whereas in the later stage this magmatic fluid did not intersect its solvus because it followed a different cooling path. This late, low-salinity liquid only boiled once its vapor-pressure curve was reached, causing sulfide ore to precipitate during the retrograde stage.

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