

## Cu mineralization processes in hydrothermal deposits

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Concentration and deposition of Cu in hydrothermal deposits, which are the major source of Cu, have been discussed for a long time. Recent attempts to analyze metal concentrations in hydrothermal fluids in fluid inclusions by LA-ICPMS and to quantify the redox state of magmas by rare-earth compositions in zircon have revealed Cu concentration and precipitation mechanisms in magmatic hydrothermal systems.

To concentrate copper in the fluids that exsolved from a magma requires an oxidized condition for the parental magma that prevents sulfide precipitation from the magma directly. This oxidized magma may form along the magmatic zones where a sulfate-bearing oceanic plate subducts. Unless the magma assimilates reduced materials such as crustal sedimentary rocks, the magma fractionates and finally exsolves  $\text{SO}_2$ - and Cu-enriched fluids.

To precipitate Cu sulfides from a hydrothermal fluid, either of the following processes is required: 1) decrease of temperature, 2) decrease of salinity, 3) increase of pH, or 4) increase of  $\text{H}_2\text{S}$  concentration. In porphyry Cu systems, it has been argued that either of the temperature decrease, pH increase by the reaction that formed muscovite alteration, or increase of  $\text{H}_2\text{S}$  by disproportionation of magmatic  $\text{SO}_2$  at  $<400^\circ\text{C}$ , is the major process for Cu mineralization. This study, however, found processes different from the previous ideas in the Grasberg (Indonesia) and El Salvador (Chile) porphyry Cu deposits and compared them with the process in the Arakawa hydrothermal vein deposit in Akita.

In the Grasberg deposit, the intrusive rocks responsible for Cu mineralization contain igneous anhydrite, which suggests that the original magma was highly oxidized ( $F_{\text{O}_2} > \text{FMQ} + 2$ ). In the deposit, high-temperature hydrothermal fluids reacted with the host rocks, resulting in magnetite and subsequent anhydrite and sulfides precipitation. This occurrence indicates that the oxidation of ferrous iron in igneous minerals promoted the reduction of  $\text{SO}_4^{2-}$  to  $\text{H}_2\text{S}$  and Cu mineralization. At El Salvador, the reaction between Ca-bearing minerals (plagioclase, hornblende, titanite) in the host intrusive rocks and fluids promoted anhydrite and sulfide precipitation, which indicates disproportionation of gaseous  $\text{SO}_2$  in the fluids. These reactions at Grasberg and El Salvador occurred at  $400\text{--}650^\circ\text{C}$ , following to the potassic alteration which includes abundant hydrothermal K-feldspar, biotite and magnetite. On the other hand, the fluid inclusion study of the Arakawa deposit indicates that the Cu mineralization was triggered by mixing of a relatively high-temperature ( $>300^\circ\text{C}$ ) and high-salinity fluid and a low-temperature and low-salinity fluid.

The different Cu mineralization processes in hydrothermal systems are ascribed to a fluid pressure condition (lithostatic or hydrostatic) between the porphyry and epithermal systems, which may or may not form high temperature potassic alteration.

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