New insights into the ore genesis of the Exotica deposit at Chuquicamata (Northern Chile) through the neoformation of Cu-oxide minerals from gel-like precursors

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Cu-rich solutions seep out presently at several parts of Mina Sur, the exotic mineralization south of the giant porphyry Cu-deposit of Chuquicamata (Atacama Desert, northern Chile). At the places where these solutions outflow, they give rise to the formation of blue and green Cu-bearing precipitates, a gel-like material. Within these jelly materials, typical exotic Cu-minerals such as atacamite, brochantite and other less common Cu-sulfates such as devilline, spangolite, schulenbergite are found, in part just as traces. Malachite crusts underneath gels were recognized. Chrysocolla, the main copper mineral of the exotic mineralization, was never identified in the copper gels.

Mineralogy, chemistry, and pH of the water-gel solutions are intimately related. The Cl/SO_4 ratio of water-gel solutions dominated by Cu-sulfates is < 0.25 and 2.38 in water-gel solutions dominated by Cu-chloride. The Cu-hydroxide-chloride atacamite is associated with solutions with a pH slightly below 6. Most Cu-sulfates (e.g. brochantite, spangolite) are associated with slightly acidic water (pH 6.0 to 6.5) whereas the Cu-sulfate devilline is stable in gels associated with near neutral to slightly alkaline water (pH 7.2 to 7.8). Gels kept in sealed bottles develop within months textures similar to those seen in exotic veins. Similarities in terms of mineralogy, chemistry and/or texture suggest that these gel-like materials are a normal and major step in the formation of exotic Cu-mineralization. Although it was generally assumed that mineraloid such as chrysocolla were formed by the solidification of a hydrogel of Cu-silica, the other copper minerals such as atacamite were also shown to develop within gel-like materials. Gels and associated neoformation of Cu-minerals found today in Mina Sur are assumed to mirror past ore formation processes of porphyry Cu-deposits in northern Chile.

A total of 27 water samples were analyzed for their chemistry (major and trace elements) and stable isotope composition of water ($\delta^{18}O$ and $\delta^{2}H$) and sulfate ($\delta^{34}S$ and $\delta^{18}O$). Water isotope composition of the different waters plots on an evaporative trend. Intersection between evaporation line and LMWL suggests that Estación San Pedro is the main source of industrial water in Chuquicamata. On the northeast side of the Mina Sur pit, gels are assumed to be derived from industrial water that have leached Cu-oxide zones located north of Mina Sur. On the southern part of the pit, high Cl and NO_3 rich waters seeping out suggest that the lower, saline aquifer of the Loa basin is involved and crops out. For these waters no isotopic data were obtained except for one sample which sulfate isotope composition suggests its derivation from local evaporite formation. Some of these saline outflows give rise to Cu-rich gels containing atacamite. The most plausible source of Cu contained in these outflows of saline waters is a residual or unknown supergene zone buried on the southern part of the pit that was leached by this saline groundwater. Their continuous formation (since 2005) and their abundance suggest that the Cu-source may be important. Among wells, SR3 and SR4 have different origin than the other wells, possibly being groundwater derived west of the mining complex, possibly from the Cordillera de Domeyko. Well SR4 is clearly contaminated by surrounding waste dumps or possibly by residual sulfide oxidation that may be active in this area. All other wells have high Cl, NO_3 and sulfate isotope composition suggesting that they may be derived from the lower saline aquifer.

The studied Cu-gels may be a normal precursor of atacamite, brochantite and other Cu sulfates found in supergene oxidation zones. Although the main Cu phase in the Exotic Mina Sur, chrysocolla, was not evidenced in the gel-like material, it is not excluded that a longer maturation of some gels may develop this Cu-silicate mineraloid. The question whether the Cu of some of these gels is derived from Cu-waste dump or from an unknown supergene zone is still open. In particular, the presence of a possible unknown supergene zone on the southern part of Mina Sur cannot be ruled out and should be further investigated.