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Publication Date:
2007-07

Permanent Link:
https://doi.org/10.3929/ethz-b-000005284

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The role of fluid immiscibility in the formation of magmatic-hydrothermal ore deposits

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Experimental studies suggest that large immiscibility gaps exist in H₂O-salt (±CO₂, CH₄) fluids at the P/T-conditions prevailing in subvolcanic to plutonic environments. Not surprisingly, therefore, samples recording the former coexistence of two types of fluids are rather common in the magmatic-hydrothermal systems. One major consequence of fluid immiscibility is chemical fractionation. PIXE, SXRF and LA-ICP-MS analyses of individual fluid inclusions have shown that Cu, Au, B, As, Sb and Li are often systematically enriched in vapor inclusions relative to coexisting brine inclusions (e.g., Williams-Jones and Heinrich, 2005). In the case of Cu and Au it is believed that this behavior is caused by the formation of stable sulfur complexes in the vapor phase, although definitive experimental proof is lacking so far. Another major consequence of fluid immiscibility is that differences in density and/or wetting properties lead to physical separation of the two fluid phases. This, together with chemical fractionation, can result in chemical zonations at various scales, e.g., the formation of epithermal gold deposits above porphyry-Cu deposits.

Fluid inclusion studies and experimental data suggest that intermediate to felsic magmas crystallizing at depths relevant for magmatic-hydrothermal ore deposits first exsolve a single-phase fluid of intermediate density and low salinity (2-10 wt% NaCl equiv.) upon cooling (e.g., Audétat and Pettke, 2003). Fluid immiscibility commonly does not occur until the magma has approached its solidus, where pressure starts to change from lithostatic to hydrostatic. Due to the pressure decrease and the low salinity of the bulk fluid, the mass of vapor generated may often exceed that of the coexisting brine, such that the bulk fluid can be thought of a vapor plume at that stage. However, in view of the high metal content and relatively low mobility of brines it is nevertheless feasible that some deposits formed predominantly from brines rather than from vapors, and that the condensation of brine out of a low-density bulk fluid helped to concentrate the metals in a small rock volume. Element partitioning between coexisting fluid phases combined with quantitative fluid flow models will advance our understanding on how elements are separated, distributed and concentrated up to ore grade in magmatic-hydrothermal environments.

References