

Experimental fractionation of H₂O-CO₂-S-Cl-bearing arc basalts, and its significance for porphyry copper formation

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Porphyry copper deposits are genetically related to differentiated arc magmas that are characterized by high Sr/Y ratios, which feature is thought to result from magma fractionation at high pressure. However, significant debate persists regarding the question which specific property of these magmas rendered them so fertile. Potential candidates are: (1) higher Cu content, (2) higher S content, (3) higher Cl content, (4) higher H₂O content.

To better understand how pressure affects these magma properties, we conducted experimental crystallization series at 0.4, 0.7 and 1.0 GPa and 1200 °C to 750 °C using piston cylinder presses. We used zircon liners to prevent loss of Fe, S, and chalcophile elements to the noble metal capsules. Furthermore, to produce larger crystals and melt pools that can be easily analyzed by FTIR and LA-ICP-MS, we employed cooling rates that gradually decreased from 12.5 °C/hour at 1100 °C to 0.15 °C/hour at 750 °C. The starting material was a natural basaltic trachyandesite that was doped with volatiles and trace elements at geologically realistic concentrations: 50.0 wt.% SiO₂, 18.8 wt.% Al₂O₃, 1.7 wt.% FeO_{tot}, 9.4 wt.% CaO, 6.4 wt.% MgO, 3.1 wt.% Na₂O, 1.2 wt.% K₂O, 3.5 wt.% H₂O, 4800 ppm CO₂, 2200 ppm S, 1000 ppm Cl, and 200 ppm Cu. Sulfur was added in the form of anhydrite, which imposed an oxygen fugacity of log₁₀fO₂ = FMQ+2.0 (±0.5).

A SEM-EDS phase map of an experiment that was cooled at 1.0 GPa from 1100 °C to 850 °C within 10 days is shown below. Clinopyroxene and spinel are the first two minerals to crystallize. At about 1000 °C, amphibole and anhydrite start to crystallize, followed by magnetite, sulfide and apatite. Plagioclase starts to crystallize at ~975 °C at 1.0 GPa, at ~1025 °C at 0.7 GPa, and at ~1050 °C at 0.4 GPa.

All minerals and quench glasses are currently being characterized by EPMA (major elements, S, Cl), FTIR (H₂O, CO₂; glasses only) and LA-ICP-MS analysis (trace elements) to (i) fully reconstruct the chemical evolution of the silicate melt, (ii) determine mineral–melt partition coefficients, and (iii) integrate the results into a quantitative fractionation model.

