Triple-Halogen (Cl-Br-I) Signatures of Salt Melt Inclusions in Kiruna-Type Magnetite-Apatite Ore Systems – Proof of Formation Via Evaporite Anatexis

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The origin of Kiruna-type magnetite-(apatite) (MtAp) deposits is widely debated, with proposed formation models ranging from purely orthomagmatic to entirely hydrothermal processes. The debate largely centers on the nature of the fluids forming in these deposits, especially the occurrence of iron-rich ore-stage melt inclusions that are composed of chlorides, sulfates, and carbonates. Inclusions of this type are ubiquitous in many MtAp deposits and they have been controversially interpreted to either represent partial melts of evaporite-bearing carbonate rocks in response to magma intrusions, or to be hydrosaline liquids forming halite condensates during magmatic fluid exsolution in shallow crustal settings.

We present the first-ever triple-halogen (Cl-Br-I) in situ LA-Q-ICP-MS melt inclusion results from MtAp deposits at El Laco and Laco-Salar (Chile). Additionally, we determined halogen signatures in chloride-rich Fe-K-Na salt melt inclusions from the subvolcanic Biely Vrch porphyry-Au deposit. These inclusions have previously been interpreted to have formed by magmatic exsolution of a hypersaline brine followed by halite condensation and provide a comparative basis for the magmatic-hydrothermal formation mechanisms proposed for salt inclusions in MtAp deposits.

These data show that the MtAp melt inclusions from both sites exhibit exceptionally low Br/Cl and I/Cl ratios, closely resembling those in surficial evaporitic halite and differing markedly from those found in typical magmatic-hydrothermal settings. In contrast, the fluids from Biely Vrch display significantly higher Br/Cl and I/Cl ratios, aligning with those observed in other porphyry-type and arc-related magmatic-hydrothermal systems globally. These results strongly support the anatectic model of salt melt generation and demonstrate that halogen signatures are a valuable diagnostic tool for identifying and understanding the role of evaporite anatexis in the ore genesis of MtAp deposits worldwide and for the further development of MtAp ore system models.