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Controls of sub-solidus hydrology on the formation of high-grade tin deposits in granites

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Tin has been an important metal since the beginning of the Bronze Age, and remains so today. Most mined tin is from mineralization that primarily formed in the roofs of granitic intrusions and the overlying host rocks. There, it commonly occurs with other strategic and critical metals such as W, Li, In, and REE. The tin is mobilized from granitic, metal-enriched magmas by an aqueous phase exsolved from the hydrous melt during crystallization. At least three main tin precipitation mechanisms have been identified in prototypic deposits: (1) mixing of metal-bearing, magmatic aqueous fluids with meteoric water resulting in fluid cooling, pH increase, and oxidation, (2) gradual cooling of magmatic fluids without mixing with meteoric water, and (3) phase separation of the fluids (boiling). All these ore deposition mechanisms, however, do not explain how the fluids are collected from larger intrusion volumes and focused to form localized high-grade ore bodies.

Here, we present numerical fluid flow simulations suggesting that tin-bearing magmatic fluids can remain trapped post-crystallization in intergranular pore space in a cooling intrusion. The released heat from the intrusion induces convection of meteoric water, which in turn cools the apical parts of the intrusion and enables brittle rock deformation and a permeability increase. This self-organized interplay mobilizes and efficiently focuses the temporarily stored, tin-bearing magmatic fluids into spatially confined ore deposition sites as a naturally occurring sub-solidus process. Conditions for tin ore deposit formation are met within these fluid-focusing sites. Temperatures, pressures, fluid compositions, and time scales of the simulated fluid evolution closely resemble observations from natural ore samples.

Our results suggest that the variety of proposed tin deposition mechanisms may all be linked to a single overarching hydrological control. Intrusion depth and/or the permeability structure at a specific deposit may determine the relative expression of the abovementioned tin precipitation mechanisms depending on the local geological conditions. We hypothesize that magmatic fluids can remain stored post-crystallization until near the ductile-to-brittle transition, which provides an alternative explanation of magmatic-hydrothermal ore formation, e.g., hydrothermal REE deposits, and a natural interpretation for sub-solidus granite alteration.