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The magmatic-hydrothermal continuum of hydrous peralkaline liquids: integrating experiments with natural observations

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The largest deposits of rare earth elements (REE) in the world are attributed to carbonatite/alkalic igneous origins. However, in detail, the economic REE ore often reflects deposition in metasomatically altered, sometimes brecciated country rock. Understanding the nature of the magmatic-hydrothermal transition in these deposits then is key to providing a framework of how the deposits form. Here we integrate knowledge from experimental petrology of hydrous peralkaline compositions with observations from one of the most promising HREE prospects in USA, Hicks Dome (IL).

By making a haplogranite system peralkaline through adding small amounts of Na_2O, a liquid composed of ~40% H_2O:60% $Na_2Si_2O_5$ coexists in equilibrium with quartz and feldspar at 330°C and 1 kb[1]. Likewise, a small addition of Na_2O to silica undersaturated syenites results in a similar water-rich peralkaline liquid coexisting with nepheline + feldspar at the same P-T but only if 2% carbonate is added[2]. Both of these peralkaline liquids are shown to readily form in imposed thermal gradients—since any magma emplaced in the upper crust will produce a thermal aureole, one can infer that hydrous peralkaline liquids form and dominate down temperature evolution of many magmatic systems. The ubiquitous occurrence of ring complexes around alkalic intrusions globally evidences such processes.

Hicks Dome is a Permian cryptoexplosive center in the southern Illinois Basin, where alkaline ultramafic magmatism and brecciation intersect Paleozoic carbonate host rocks and regional fluorite mineralization. Drill core from the dome's interior contains breccias with fluorite extensively replacing dolomite clasts and localized HREE-bearing phases. In thin section (FSB-38-2515), a calcite vein cuts through breccia with xenotime depositing along the edges of the vein. Whole section CL demonstrates pervasive fluorine migration. Microdrilling of both calcite and breccia clasts followed by radiogenic isotope analysis indicate the calcite likely forms from peralkaline fluid rather than carbonatite: $^{87}Sr/^{86}Sr$ of all locations in the FSB section record 0.7080-0.7085, much closer to dolomite country rock ratios than the "igneous" ratio (~0.7040) of primary magmas. We will present new results for Nd and Pb ratios to improve source knowledge.

[1] Lundstrom (2020) JGR, doi.org/10.1029/2019JB017654

[2] Lundstrom et al. (2022) Front. Earth Sci, doi.org/10.3389/feart.2022.970264