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The Importance of Pressure and Fractionation in Forming Compositionally-Diverse, Rare-Earth Rich Igneous Complexes: A Case Study of the Nechalacho Layered Suite, Canada

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Alkaline igneous complexes can host important ore deposits (e.g., rare earth elements, REE) and contain a huge diversity of rock types, including silica-undersaturated (e.g., nepheline-syenite) and silica-oversaturated (e.g. quartz-syenite) compositions. Isotopic evidence frequently suggests that these rocks are derived from the same parental melt. Using recently developed thermodynamic phase equilibrium models we investigate the petrogenetic processes that generate these compositionally diverse complexes. Integration of trace-element partitioning models reveal and quantify mechanisms for REE enrichment during parental melt crystallisation.

We explore the petrogenesis of the Blatchford Lake Igneous Complex (BLIC), Northwest Territories, Canada, as a case study. The BLIC is a ~2.2 Ga intrusive complex that hosts the Nechalacho Layered Suite (NLS)—a world-class, syenite-hosted REE, Nb and Zr deposit—as well as cogenetic gabbro, granite, quartz- and nepheline-syenite. Using the most primitive BLIC gabbro as a model starting composition, we show that the observed diversity of rock types can be generated by fractional crystallisation occurring mostly at 4 to 5 kbar. This narrow pressure range represents a key 'tipping point' in the evolution of silicate melts, with shallower fractionation forming silica-oversaturated compositions, and deeper crystallisation driving residual melt to silica undersaturation. Importantly, this crystallisation pressure range coincides with a previous estimate of 4 kbar for the BLIC. Our modelling removes the need to invoke additional processes such as crustal assimilation or magma recharge, for which there is conflicting isotopic evidence. Finally, modelling of residual REE enrichment in the fractionating melts shows that pressure is also a key control in forming the heavy REE enrichment seen in the NLS. Variations in residual REE enrichment with pressure and extent of crystallisation are mostly driven by changes in abundance and composition of clinopyroxene, which has strongly composition-dependent REE partitioning. The results of this case study have global implications for the prospectivity of similar systems.