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How do magmatic and hydrothermal processes interact in the Saint-Honoré alkaline complex (Québec, Canada) to form Nb and REE deposits?

L.PAUL BEDARD[1], NILS VAN WEELDEREN[1], ANNE-AURÉLIE SAPPIN[2], MICHEL GRÉGOIRE[3] AND HÉLÈNE LEGROS[4]

[1]Universite du Quebec a Chicoutimi (UQAC)
[2]Natural Resources Canada
[3]Géosciences Environnement Toulouse (GET)
[4]Ministère des Ressources naturelles et des Forêts (MRNF)

The Saint-Honoré alkaline complex, a cylindrical intrusion located in the Grenville Province (Canada), is a major source of critical minerals with mineral resources of 1060 Mt at 1.75% total rare earth elements (REE) and 416 Mt at 0.41% Nb_2O_5. The complex exhibits a concentric zonation, with carbonatites surrounded by syenites. The carbonatites display a zonal pattern, ranging from Ca-carbonatite in the outer zones to Mg-carbonatite and Fe-carbonatite in the centre. Nd and Sr isotopes suggest that the complex is related to the Central Iapetus Magmatic Province. U-Pb dating on apatite and zircon from the carbonatite and syenite yields an age range of 580-576 Ma, interpreted as the emplacement age of the complex, whereas the 564 Ma U-Pb age [1] on hydrothermal apatite suggests a long-lived hydrothermal system. The REE deposit is hosted by the Fe-carbonatite at the complex's core. In the >500 m zone, magmatic activity predominates as indicated by the occurrence of primary bastnäsite-(Ce) inclusions within idiomorphic barite, high BaO concentrations (up to 15%), and lower chlorine contents (1000-2000 ppm). The shallower zones exhibit increased hydrothermal influence, marked by bastnäsite-(Ce) clusters, brecciation, BaO leaching, and elevated chlorine concentrations (1000-2000 ppm). This suggests an initial magmatic co-crystallization of barite and bastnäsite-(Ce), followed by hydrothermal leaching and dissemination of REE in the upper zones. The Nb deposit occurs in the Mg-carbonatite, which is spatially associated with syenite enclaves and abundant apatite. The interaction between carbonatite magma and syenite enclaves likely triggered fluorapatite crystallization, depleting the magma in F (which is critical for Nb solubility), and leading to extensive pyrochlore crystallization. Subsequent hydrothermal activity at 564 Ma contributed to the alteration of pyrochlore into columbite-Fe. Thus, while magmatic processes were crucial for the initial concentration of REE and Nb in the Saint-Honoré complex, hydrothermal activity appears to play a significant role in modifying mineralization. Preliminary results suggest that, in the carbonatite mineral system, the high Ba concentrations of carbonatite could be a suitable indicator for targeting REE mineralization and that evidence of contamination by alkaline rocks could be a key parameter for identifying Nb occurrences.

[1] Legros et al. 2025. Lithos 498-499:107980.