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## Occurrence and recovery of Rare Earth Elements from kimberlite tailings in diamond mines

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### Introduction

Rare earth elements (REEs) are crucial for the global transition to a green economy. However, economic occurrences are rare, and production is concentrated geographically, making the supply chain vulnerable to disruption. Consequently, they are classified as critical minerals in many jurisdictions including Canada and the US, and alternative sources are required to prevent potential disruption in the supply chain. Potential secondary sources such as mine tailings (coal, bauxite ore, iron ore, and processed kimberlite), by-products, and other industrial wastes would reduce reliance on primary deposits. Kimberlites are mantle-derived igneous rocks that are available globally and are important primary sources of diamond. Some kimberlites contain significant concentration of REEs (up to 1600 ppm; e.g. Nowicki et al. 2008) and other critical minerals (e.g., Ni, Co, and Nb) at levels comparable to some primary REE deposits such as South China Clay (Hellman & Duncan 2014). Tailings of kimberlites, accumulated at diamond mines, are potential secondary sources of REEs. Extraction of REEs from such tailings would facilitate the transition of the diamond industry into a circular economy with added economic and environmental benefits. However, the deportment of REEs in kimberlites and their behavior during hydrothermal and supergene alteration are poorly understood.

In this study, we are using kimberlite tailings from the Snap Lake (Canada) and Voorspoed (South Africa) diamond mines and core samples from both localities to study the presence, distribution, deportment, and behavior of REE in kimberlites. The Snap Lake (SL) mine is situated in a subarctic region and has a decade-long mining history, while Voorspoed (VS), located in a hot semi-arid environment, has been in operation intermittently for over 100 years. The 523±6.9 Ma Snap Lake kimberlite is a subhorizontal hypabyssal dyke with at least six facies (Fulop et al. 2018). The 138.1±1.7 Ma Voorspoed carbonate-rich olivine lamproite (previously Group -II kimberlite) pipe has a complex geology characterized by varied volcanoclastic facies (VK; Howarth & Skinner 2012).

### Materials and Methods

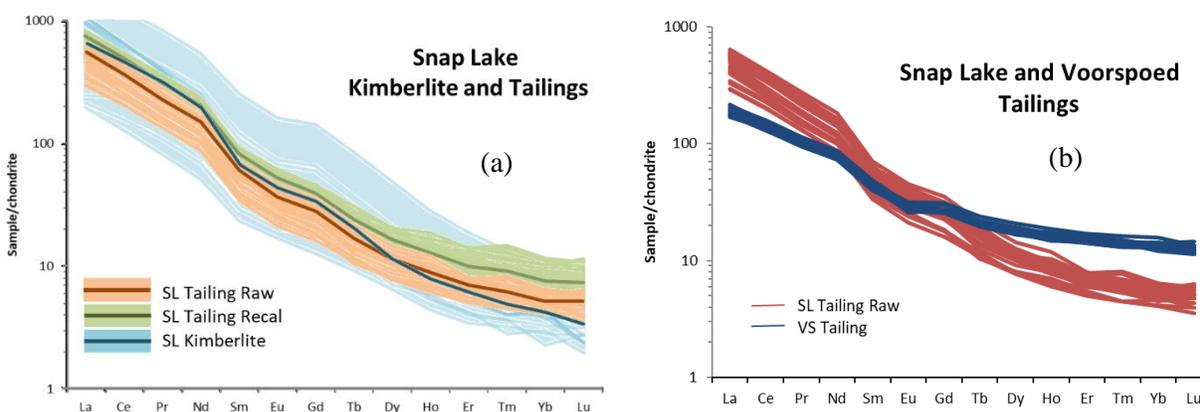
A total of 46 thin-sections from kimberlites and 40 epoxy mounts from kimberlite tailings have been used in this study. These comprise 19 thin-sections from 5 facies of Snap Lake hypabyssal kimberlite and 30 epoxy mounts of coarse and fine processed kimberlite (tailings) from Cell 3 of Snap Lake East cell, North pile tailing facility. The coarse processed kimberlite (coarse) samples were collected from the surface of the tailing pond at 8 locations and the fine processed kimberlite (fine) samples were collected from the surface and at about 130 cm depths at 10 sites. Further, Voorspoed samples comprise of 27 thin-sections from three

lithological units of volcanoclastic kimberlite and 10 epoxy mounts of coarse, intermediate and fine processed kimberlite tailings. The Voorspoed tailing samples were collected from three tailing dumps (Dump A and B of Phase 1 and Dump A of Phase 2).

The whole-rock major and trace element composition of kimberlite and tailings were analyzed by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) and Inductively Coupled Plasma - Mass Spectroscopy (ICP-MS), respectively at ALS Geochemistry, Moncton. Mineralogical characterization and identification of REE-host minerals were done using petrographic microscope at Dalhousie University, Canada, followed by Scanning Electron Microscope (SEM) equipped with BSE imaging and EDS analyses, and by Raman spectroscopy at St. Mary's University, Canada. The chemical composition of selected minerals in the kimberlite and tailing samples was determined using electron probe microanalyzer (EPMA) at University of Toronto, Canada.

### Preliminary Results and Discussion

The highest concentration of REEs in Snap Lake kimberlite core samples (1575 ppm) occurs in samples containing monazite veins/veinlets (Monazite-III). The REE content in both coarse and fine tailings is below that in SL kimberlite core. However, higher SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> and lower CaO and MgO content of tailings suggest dilution of tailings with granitoid wall-rock material ~30% for fine tailings and up to 50% for coarse tailings. After adjustment for this dilution, total REE is similar in SL kimberlite and in SL tailings. However, the tailings show an enrichment in HREE relative to the kimberlite samples (Figure 2a).

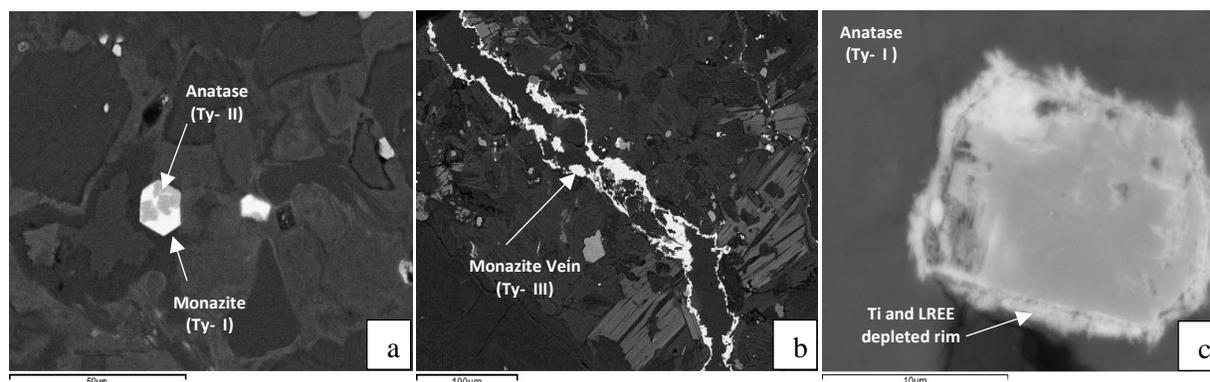


**Figure 1:** REE plot for (a) Snap Lake kimberlite core and tailings samples showing higher HREE in tailings than kimberlite (fields represents all data, thick line is median) (b) tailings from Snap Lake and Voorspoed showing higher HREE in VS than in SL.

Comparison of REE concentration in SL and VS tailings shows that the average REE concentration in SL kimberlite tailings (mean= 690 ppm; n=32) is higher than that of VS (mean=204 ppm; n=10). Voorspoed tailings shows lower LREE but notable enrichment in HREE relative to SL tailings (Figure 2b).

In the Snap Lake kimberlite, the host minerals for REEs are monazite, anatase, and apatite. Monazite has the highest concentration with up to 50 wt% REEs, followed by apatite with up to 1.5 wt%, and anatase with up to 7000 ppm. Preliminary mineralogical results of Snap Lake tailings confirmed the presence of the three minerals in both coarse and fine fractions. Based on the texture and composition, three types of monazites, four types of anatase, and two types of apatite were identified (Figure 1). Monazite-I is intergrown with Anatase-II, which we interpret as pseudomorphs after perovskite, the primary host of REE, not preserved in SL (Figure 1a). Monazite-II occur as discrete grains within the groundmass and within altered olivine macrocrysts. Monazite-III fills veins/veinlets in some facies increasing REE content in these

samples (Figure 1b). Anatase-I contains REE, and commonly zoned showing leaching of Ti from the rim, which is accompanied by depletion in La and enrichment in Nd (Figure 1c).



**Figure 2:** (a) Anatase-monzite aggregate formed as a break-down product of primary perovskite (b) Vein of monazite associated with the highest bulk rock REE content in PA110311A sample (1575 ppm) (c) Alteration rim of Anatase - I showing La depletion.

The two types of apatite in the SL kimberlite are Apatite-I, which occurs as elongated prismatic/acinular crystals and Apatite-II, which occurs as isolated euhedral crystals. Apatite-II has higher REE concentration (7400 - 15,500 ppm) than Apatite-I (540- 4800 ppm; Milligan et al. 2017) .

## Conclusion

Our results suggest that in Snap Lake kimberlite replacement of perovskite with anatase during hydrothermal alteration by deuteric CO<sub>2</sub>-rich fluids resulted in formation of monazite intergrowths with anatase and concentration of REE in monazite (Figure 1a). Monazite is now the main host of REE both in kimberlite samples and in the tailings in SL. During subsequent low-temperature alteration LREE were leached out of anatase rims, residually enriching the rims with HREE. Preliminary geochemical data show that both SL and VS tailings are enriched in HREE relative to LREE as compared to the initial kimberlite rock. The high concentration of REE in monazite has significant economic implications because of the amenability of monazite to beneficiation and metallurgy.

## References

- Fulop, A., Kopylova, M., Kurszlauskis, S., Hilchie, L., Ellemers, P., & Squibb, C. (2018). Petrography of snap lake kimberlite dyke (Northwest Territories, Canada) and its interaction with country rock granitoids. *Journal of Petrology*, 59(12), 2493–2518.
- Hellman, P. L., & Duncan, R. K. (2014). Evaluation of rare earth element deposits. *Transactions of the Institutions of Mining and Metallurgy, Section B: Applied Earth Science*, 123(2), 107–117.
- Howarth, G. H., & Skinner, E. M. W. (2012). The geology and emplacement of the volcanoclastic infill at the Voorspoed Group II kimberlite (orangeite) pipe, Kroonstad Cluster, South Africa. *Journal of Volcanology and Geothermal Research*, 231–232, 24–38.
- Milligan, R., Fedortchouk, Y., Normandeau, P. X., Fulop, A., & Robertson, M. (2017). Features of apatite in kimberlites from Ekati Diamond Mine and Snap Lake, Northwest Territories, Canada: modelling of kimberlite composition. 11th International Kimberlite Conference Extended Abstract No. 11IKC-4519
- Nowicki, T., Porritt, L., Crawford, B., & Kjarsgaard, B. (2008). Geochemical trends in kimberlites of the Ekati property, Northwest Territories, Canada: Insights on volcanic and resedimentation processes. *Journal of Volcanology and Geothermal Research*, 174(1–3), 117–127.