Formation of magmatic Fe-Ti-V-P deposits within the Lac St. Jean anorthosite suite, Saguenay, Québec, Canada: Insights from trace element composition of Fe-Ti oxides and apatite

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The Lac St. Jean anorthosite suite (1170-1140 Ma) located near Saguenay, Québec is a voluminous massif-type anorthosite complex associated with anorogenic anorthosite-mangerite-charnockite-granite (AMCG) magmatism of the Grenvillian orogeny. This anorthosite complex hosts many Fe-Ti-V-P ore bodies along its margins composed of nelsonite (~2/3 Fe-Ti oxides, ~1/3 apatite) or Fe-Ti oxides (magnetite and/or ilmenite). The origin of these deposit types is still highly debated, as i) liquid immiscibility of Fe-Ti-P-rich melts or ii) fractional crystallization have been proposed as formation models for these deposits. Mineralization displays a wide variety of forms in the Lac St. Jean anorthosite suite: i) massive to semi-massive tabular pods of Fe-Ti oxides ± apatite that are either concordant or discordant to host anorthosite (e.g., Buttercup, Lac Perron), ii) massive to disseminated Fe-Ti oxides ± apatite that are layered/foliated with gabbronoritic host rocks (e.g., Lac à Paul, Lac Margane), or iii) massive Fe-Ti oxide ± apatite bodies containing anorthosite and dunite xenoliths (e.g., St. Charles de Bourget). EPMA analysis of plagioclase from both disseminated ores and barren anorthosite hosting the deposits reveals that Fe-Ti oxide deposits containing apatite (i.e. nelsonites) have plagioclase with andesine composition, while those deposits which do not contain apatite contain plagioclase with labradorite composition. Applications of laser ablation (LA)-ICP-MS analysis of both Fe-Ti oxides and apatite with this project have proven to be vast, as information about magma evolution, crystallization sequences, and crustal contamination were obtained. Nickel, Cr, and V contents of magnetite show elevated concentrations within magnetite that crystallized without apatite compared to magnetite that crystallized with apatite in nelsonitic ores. This information combined with plagioclase compositions indicate that the nelsonitic ore bodies crystallized from a more evolved magma. Elevated Ti contents within magnetite are indicative of prominent crystallization of magnetite before ilmenite, whereas magnetite that crystallized with abundant ilmenite is considerably Ti-poor. Shallow positive slopes on an Eu/Eu* vs. Sr plot, rather than high positive slopes, indicate crystallization of apatite before significant plagioclase fractionation. Crustal contamination appears to be negligible in the formation of these ore bodies as ilmenites have low Nb and Ta contents with respect to ilmenites from the world class Tellnes deposit in Norway, which according to the literature has undergone significant crustal contamination based on Sm-Nd results. Our results clearly show that trace element compositions of both Fe-Ti oxides and apatite are very useful in constraining the formation of these enigmatic deposits.