

## Petrogenesis of Apatite-Rich Rocks (Nelsonites and Oxide-Apatite Gabbronorites) Associated with Massif Anorthosites

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### Abstract

We report field, petrographic, mineralogical, and geochemical data for two P-rich rock types of the anorthosite suite—Fe-Ti oxide-apatite rock (or nelsonite) and Fe-Ti oxide-apatite gabbronorite (or oxide-apatite gabbronorite). These rocks are taken from the Château-Richer, Labrieville, and St. Urbain massifs in Quebec; from the Roseland massif in Virginia; and from the Carthage massif in New York. Our data set includes X-ray fluorescence (XRF) and instrumental neutron activation (INA) analyses of whole-rock samples, as well as electron-microprobe (EMP) and INA analyses of separated apatites.

At St. Urbain and Labrieville, nelsonite forms a small capping on massive hemoilmenite deposits fully contained within anorthosite, whereas at Roseland, nelsonite occurs as dikelike bodies within country rock. All three nelsonite occurrences consist almost entirely of ilmenite + apatite (but do not have a 2:1 oxide/apatite ratio), with only trace amounts of other minerals. All oxide-apatite gabbronorites form sill-like layers within or near the margins of anorthosite massifs and contain ilmenite ± magnetite, apatite, orthopyroxene + clinopyroxene, and plagioclase.

All apatites are F rich and Cl poor, consistent with high-temperature magmatic crystallization. Concentrations of apatite rare earth elements (REE) are highly variable (e.g.,  $La_N \approx 700\text{--}2,000\times$  chondrites), but patterns show a consistent fractionation (e.g.,  $La_N/Lu_N \approx 10\text{--}20$ ) with small to moderate negative Eu anomalies. Interestingly, the Labrieville nelsonite and its apatite lack an Eu anomaly, consistent with crystallization in a highly oxidizing environment.

Apatites in both rock types are enriched in REE relative to whole-rock samples (by factors of 3 to 10), but REE patterns of apatites and whole rocks are parallel in each case. Mass-balance calculations indicate that for nelsonite, 100 percent of the REE is contained in apatite; for oxide-apatite gabbronorites, ~100 percent of the light REE, ~90 percent of the middle to heavy REE, and ~75 percent of Eu are in apatite. These results can be explained satisfactorily by assuming that the rocks are cumulate in origin. If, on the other hand, nelsonites and oxide-apatite gabbronorites represent liquids, apatite  $D_{REE}$  values must vary by more than a factor of 3.

Our field, mineralogical, and geochemical observations indicate that most nelsonites and oxide-apatite gabbronorites are not related directly. Indeed, apatites from oxide-apatite gabbronorites contain lower Sr and MgO but higher REE than those in nelsonites, indicating that nelsonites are the more primitive rock type. Nelsonites probably formed as cumulates primarily within larger deposits of Fe-Ti oxide (locally mobilized as dikelike bodies). oxide-apatite gabbronorites also represent cumulates, but these are related spatially and genetically to associated jotunitites and mangerites and appear to form at several stages in the evolution of a particular anorthosite complex.