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Detrital apatite trace-element compositions: A robust new tool for mineral exploration

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Apatites from the major types of mainly magmatic-hydrothermal mineral deposits (30 localities, mostly in British Columbia, Canada) together with apatites from carbonatites (29 intrusive complexes) and unmineralized rocks (11 localities) have been analyzed by electron microprobe and laser ablation-inductively coupled plasma mass spectrometry (922 analyses in total). A series of optimized discrimination diagrams using Mg, V, Mn, Sr, Y, La, Ce, Eu, Dy, Yb, Pb, Th, and U were constructed to discriminate apatites from carbonatites, unmineralized rocks and different deposit-types. The first step of the discriminant analysis distinguishes apatites from mineral deposits from those in carbonatites and unmineralized rocks. The second discrimination step separates apatites into the different deposit-types, including orogenic Au, orogenic Ni-Cu (PGE), porphyry Cu-Mo-Au and epithermal Au-Ag, W skarn, polymetallic skarn, and undivided Kiruna-type IOA and IOCG deposits. Apatites determined to have iron oxide affinity in the second step are further subdivided into Kiruna-type IOA and IOCG breccia-type deposits. Apatites classified as having porphyry and skarn affinities are subsequently discriminated in a third step into alkalic porphyry Cu-Au, porphyry Cu-Mo-Au, porphyry Mo, porphyry-related Cu-Au breccia, W skarn, and polymetallic skarn. In terms of element abundances, apatites from mineral deposits are characterized by higher Ca and correspondingly lower total contents of trace-elements that partition onto the Ca sites (rare earth elements, Y, Mn, Sr, Pb, Th, and U) than apatites from unmineralized rocks and carbonatites. Apatites from worldwide carbonatites have the most fractionated rare earth element distributions with light rare earth element enrichment (Ce/Yb_{CN} = 35-872), high V (1.6-1, 466 ppm), Sr (1, 840-22, 498 ppm), Ba (1.8-275 ppm), and Nb (0.4-19 ppm) contents, the lowest W contents (0.05-0.55 ppm), and no significant Eu anomalies (Eu/Eu* = 0.9-1.2). Apatites from alkalic porphyry Cu-Au deposits in North American Cordillera possess high V contents (2.5-337 ppm), whereas apatites from calc-alkaline porphyry Cu-Au and Cu-Mo deposits have high Mn contents (334-10, 934 ppm) and typically large negative Eu anomalies (Eu/Eu* = 0.2-1.1). Apatites from iron oxide Cu-Au (IOCG) and related Kiruna-type iron oxide-apatite (IOA) deposits in Canada, China, and Mexico, typically have large negative Eu anomalies (Eu/Eu* = 0.2-1.5) and low Mn contents (40-5, 753 ppm). Apatites from orogenic Ni-Cu, porphyry-related Cu-Au breccia, Au-Co skarn, Pb-Zn skarn, and Cu skarn deposits have relatively low abundances of impurity cations. Rukhlov et al. (2016) tested our apatite discrimination approach on four porphyry Cu-Mo-Au deposits in south-central British Columbia and found that detrital apatite grains in down-ice basal till were correctly classified as originating from porphyry deposits. This approach has been further extended to 10 separate areas in the glaciated and underexplored Nechako Plateau of central British Columbia. Preliminary results reveal that known mineral occurrences in the Nechako Plateau were correctly classified by detrital apatite grains recovered from down-ice till. These studies collectively demonstrate the usefulness of apatite as a detrital indicator mineral in grassroots exploration.