Apatite as a fluid recorder during the genesis and evolution of IOA deposits

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Fluids not only play a critical role in the formation of ore deposits but also can also modify the primary composition of their minerals during later fluid-rock interaction. The texture and geochemistry of a mineral reflects the chemistry of the fluid and/or melt with which it equilibrates. Both can be used to decipher the origin of the ore deposit and probable later metasomatic overprints. Iron oxide-apatite (IOA) deposits are an important type of high-grade hypogene ore deposit. Two models have been proposed to explain their origin: (1) crystallization from highly evolved iron-phosphate melts and (2) fluid-induced formation (Knipping et al., 2015, Geology 43, 591-594). Fluid inclusion studies of some of these IOA deposits indicate that extremely hot (~800 °C) hypersaline fluids (up to 90 wt.% NaCl eq.) were present during their formation (Li et al., 2015, Ore Geol Rev 67, 264-278). However, the role of these fluids during the formation of IOA ores is not clear. Furthermore, as such high-temperature fluids cool down, they may modify the IOA ores and related ore-forming minerals via auto-metasomatism and/or fluid exchange with surrounding country rock fluids.

After magnetite, apatite is the second most common mineral in IOA deposits. Apatite can host a variety of trace elements and thus provide a detailed geochemical record of the ore-forming process and the evolution of fluids associated with these deposits (Pan and Fleet, 2002, RIMG 48, 13-49; Harlov, 2015, Elements 11, 171-176). Apatite from IOA deposits usually contains high concentrations of Si, Na, Sr, Ba, LREE, halogens (F, Cl), and other anions such as OH^-, CO_3^{2-}, and SO_4^{2-}, which are sensitive to a number of parameters (fluid chemistry, temperature, pH, and fO_2) present during the formation and subsequent variable evolution of the IOA deposit (Harlov, 2015; Mao et al., 2016, Econ Geol 111, 1187-1222). Therefore, the IOA geochemical signature should reflect an equilibrium with the chemical composition of the fluid. This signature varies broadly from IOA deposit to IOA deposit, especially with respect to the REE and Cl content (cf. Harlov et al., 2002, Chem Geol 191, 47-72; Taghipour et al., 2015, Can Mineral 53, 479-496; Harlov et al., 2016, Econ Geol 111, 1963-1984; Jonsson et al., 2016, Am Mineral 101, 1769-1782), indicating that some IOA deposits could be mined for REE (cf. Harlov et al., 2016). It also suggests/implies that the apatite (+ magnetite) crystallize from highly evolved, brine-rich fluids originating as segregations derived from subvolcanic igneous intrusions.