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Chlorine incorporation into amphibole and biotite in high-grade iron-formations: Interplay between crystallography and metamorphic fluids

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Abstract

Minor amounts of markedly Cl-rich amphibole and biotite are found in the Archean (2.8–2.9 Ga) iron-formation lithologies from the eastern Beartooth Mountains, Montana, U.S.A. These rocks are typified by mineral assemblages of quartz + magnetite + orthopyroxene + garnet ± clinopyroxene ± plagioclase having equilibrated during granulite facies conditions of ~775–800 °C and 6–8 kbar. The metamorphic Cl-rich amphibole and biotite are prograde and occur as inclusions in orthopyroxene and garnet as well as in the matrix. The high-grade Fe-rich amphiboles (mostly Cl-rich potassic-hastingsite and magnesio-ferri-hornblende) and biotites contain concentrations of Cl reaching up to 2.9 and 3.4 wt%, respectively. Biotites contain up to 10.5 wt% BaO and 6.9 wt% TiO_2. Substitution of Cl into amphibole and biotite is more likely where Cl-bearing anion sites are enlarged. In amphibole threshold values of the $X_{Fe^{2+}}$, ^{A}K, and ^{T}Al appear to be a precondition before significant amounts of Cl are incorporated into the structure. In biotite, in addition to $X_{Fe^{2+}}$, substitution of ^{T}Al also is positively correlated with Cl. The high Cl content in the minerals is suggestive of a coexisting high salinity aqueous fluid. Based on calculations using mineral chemistry, estimations of the aqueous fluid composition indicate a Cl-rich aqueous fluid (~25 wt% NaCl) with f_{H_2O}/f_{HCl} ratios of ~0.68–0.82. There is evidence for brine-CO_2 immiscibility during peak metamorphism. In amphibole once the threshold values for significant Cl incorporation are attained, the Fe^{2+}-Mg partitioning of the amphibole and the coexisting mafic silicates changes such that the amphibole more favorably partitions Fe^{2+}. A feedback mechanism can be generated such that the more Cl available from a fluid the more Fe^{2+}-rich the amphibole can become, and this produces a crystal structure that can accommodate more Cl, which makes this amphibole more favorable for Fe^{2+} incorporation, and the cycle continues until Cl saturation in the crystal structures is reached or aqueous Cl^- is fully equilibrated with the amphibole.

Keywords: Chlorine, iron-formation, amphibole, biotite, Archean