

Hydrothermal Mobilization of High Field Strength Elements in Alkaline Igneous Systems: Evidence from the Tamazeght Complex (Morocco)

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Abstract

The Tamazeght alkaline complex (High Atlas Mountains of Morocco) is a middle Eocene volcanic to plutonic mass, ranging from silica-saturated to silica-undersaturated rocks and carbonatites. Some of the most evolved units are nepheline syenites and pegmatites, which show evidence of hydrothermal alteration. These rocks also contain the highest concentrations of Zr in the complex, although these concentrations are not sufficient to form exploitable reserves. High field strength element (HFSE) minerals (predominantly the zirconosilicates) commonly occur as secondary phases that are richer in Ca and F (cancrinite ($\text{Na}_6\text{Ca}(\text{CO}_3)$) (AlSiO_4)₆·2H₂O), calcic catapleiite ((Ca,Na)ZrSi₃O₉·2H₂O), rinkite ((Ca,Ce)₄Na(Na,Ca)₂Ti(Si₂O₇)₂F₂(0,F)₂). Furthermore, they partly or completely replace primary HFSE phases (e.g., zircon, eudialyte ($\text{Na}_4(\text{Ca,Ce})_2(\text{Fe}^{2+},\text{Mn},\text{Y})\text{ZrSi}_8\text{O}_{22}(\text{OH},\text{Cl})_2$)). Altered nepheline crystals adjacent to these replaced minerals host fluid inclusions that, based on textural evidence, are interpreted to have formed during alteration. The inclusions have high salinity (25 wt % NaCl equiv), are Ca rich, and were trapped at ~300°C. They contain several solids in addition to a liquid phase and a vapor bubble. One of the most common daughter minerals is a Ca-La-Ce phase (parisite?). Other daughter or trapped minerals include zircon, a Ti (±Nb) silicate or oxide (rutile?), an Mn hydroxide(?), and less commonly, sphalerite and galena. The occurrence of zircon, parisite, and rutile are evidence for mobilization of Zr and other HFSE during hydrothermal alteration.

Based on data available for the solubility of ZrO₂ in H₂O-HF solutions and estimates for the concentration of Zr in the fluids at the Tamazeght complex (possibly as high as ~0.05 m), we suggest that HFSE transport occurred by mixed metal OH-F complexing. This transport requires a fluid with an elevated F concentration and a temperature of ±300°C. In addition, it can only take place in the near absence of Ca. We propose that a residual F-rich brine evolving from crystallization of pegmatites at <500°C leached and transported HFSE. Upon interaction with surrounding limestone, the fluid cooled rapidly and gained Ca. This caused deposition of fluorite (fluorite is very sparingly soluble), which buffered a_F to low levels in the fluid causing precipitation of the HFSE in the form of secondary minerals. Because the hydrothermal event was short-lived and relatively restricted in space, HFSE were not concentrated to ore grades.