

Distribution and evolution of F and Cl in plutonic systems traced by volatile-bearing minerals (amphibole, biotite and apatite)

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Fluorine and chlorine are ubiquitous volatile components in mantle- and crust-derived magmas, and they play an important role in magmatic differentiation, hydrothermal alteration and related mineralization processes. However, tracing their distribution and evolution in magmatic and especially plutonic systems is not an easy task because of the transport of Cl- and F-species in fluids during late magmatic activities. The Cl and F in melts can be determined from halogen concentrations in minerals, provided that partitioning between minerals and melts are constrained, which is not the case for all F- and Cl-bearing minerals such as amphibole and biotite. Based on available partitioning models between mineral/melt, mineral/fluid, melt/fluid, a set of equations has been derived to determine Cl and F concentrations in melts from the Cl and F concentrations in amphibole, biotite and apatite. As far as possible, the effect of mineral composition (mainly Mg# of biotite and amphibole) on halogen partitioning has been taken into account and these equations can be applied for a wide variety of magma compositions.

The new calculation procedure has been applied to a plutonic system, the Liujiawa pluton, eastern Dabie orogen (China). Cl and F concentrations in amphiboles, biotites and apatites from different rock types (gabbronorite, two-pyroxene diorite, clinopyroxene diorite and hornblende gabbro) have been determined by electron microprobe. The gabbronorites, two-pyroxene diorites and hornblende gabbro represent magmas which evolved from the same primary magma by differentiation with little crustal contamination, while the clinopyroxene diorites show clear evidence of mixing between low-F mafic and high-F felsic magmas. The abundant high-Al amphiboles in the hornblende gabbros indicate water-rich high-temperature (~ 860 °C) mafic magmas. Most amphiboles show a negative correlation between $\log(\text{Cl}/\text{OH})$ and Mg-number and a positive correlation between $\log(\text{F}/\text{OH})$ and A-site occupation. Biotites from the gabbronorite and two-pyroxene diorite show a slight positive correlation between $\log(\text{Cl}/\text{OH})$ and Mg, which is however not valid for those from the clinopyroxene diorite. Apatites from all the samples are rich in F and show negative correlations between Cl and F concentrations.

In our case study, we demonstrate that the Cl concentration in melt remains approximately constant at 1000-2000 ppm over the major course of crystallization, but decreases dramatically at low temperatures as a result of fluid exsolution. The F concentration in melt remains at 2000-3000 ppm and is not largely affected by fluid exsolution because of its strongly preferred incorporation into melt. Interestingly, the Cl and F evolution is similar to that of halogen behavior determined in volcanic systems [1-2]. This indicates that the evolution of Cl and F in melts during crystallization and late magmatic stages at depth (plutonic systems) is similar to that observed in volcanic systems during decompression and degassing.

References:

- [1] Villemant B, Boudon G (1999) H_2O and halogen (F, Cl, Br) behaviour during shallow magma degassing processes. *Earth Planet Sci Lett* 168:271-286.
- [2] Shinohara H (2009) A missing link between volcanic degassing and experimental studies on chloride partitioning. *Chem Geol* 263:51-59.