



The origin and significance of hypersaline magmatic volatiles in giant layered intrusions

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Fluid and melt inclusions are preserved within pegmatite bodies and cumulus minerals within mafic-ultramafic layered intrusions that host economic concentrations of the platinum-group elements (e.g., Bushveld Complex, South Africa; Stillwater Complex, Montana). The inclusions indicate that the earliest volatile phase to have exsolved from the crystallizing intrusions was a relatively anhydrous carbonic fluid (CO_2 -dominated). As crystallization proceeded, volatiles appear to have become increasingly water-rich and saline, consistent with the relative saturation limits of carbonic and aqueous fluids in mafic silicate liquids.

However, the latest stage volatiles in the layered intrusions were unusual halide melts (only slightly hydrous molten salts) of relatively simply composition ($\text{NaCl} \pm \text{KCl}$, CaCl_2) with salinities in excess of 90 wt% eq. NaCl or CaCl_2 . These volatiles were trapped at minimum temperatures of ~ 750 - 800°C , near the eutectic temperature for water-saturated felsic (very late, intercumulate) liquid. Heterogeneous entrapment of late-stage silicate melt and halide melt provides unambiguous evidence for the coexistence of both phases. However, experimental constraints on the nature of exsolved volatiles from mafic silicate liquids suggest that the halide melt phases cannot represent an exsolved phase from that coexisting silicate liquid, since this would require unrealistically high (initial) $\text{Cl:H}_2\text{O}$ ratios for the parental silicate liquid (> 9). Analysis of rhyodacitic silicate melt inclusions that coexist with the halide melt inclusions show that the coevally-trapped silicate melt had a $\text{Cl:H}_2\text{O}$ ratios of only ~ 0.1 to 0.2 . Similarly, the salt melt phases could not have evolved via the crystallization of hydrous magmatic minerals (e.g., biotite, apatite) since their abundance in the intrusion are very low.

The most plausible explanation for the halide melt phases involves the “dehydration” of an initially lower salinity aqueous fluid. This may have occurred by the reaction of the aqueous fluid with nominally-anhydrous minerals such as pyroxene, or by the late-stage alteration of cumulus minerals to hydrous mineral assemblages. Through the use of conventional hydrothermal experimental techniques, it can be shown that the reaction of a volumetrically-minor CaCl_2 -rich aqueous fluid (20 wt% eq. CaCl_2) with the assemblage diopside-enstatite-quartz at near-solidus conditions (700°C , 0.4 kbar) results in the formation of tremolite by the reaction of H_2O with the initially anhydrous mafic mineral assemblage. The resulting salinity of the saline phase, trapped as synthetic inclusions in quartz, was > 96 wt% eq. CaCl_2 , consistent with the water-poor nature of the salt melt inclusions observed in most layered intrusions globally.