

## **Formation of the Kiruna-type Vergenoeg iron-fluorine deposit (South Africa) by silicate liquid immiscibility: An experimental study**

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Kiruna-type iron oxide deposits occur in a number of locations across the world. Controversy persists regarding their genesis and the formation of their assemblage dominated by sulfide-poor minerals (magnetite/hematite,  $\pm$ apatite,  $\pm$ fayalite,  $\pm$ fluorite). One hypothesis involves the separation of a volatile-bearing Fe-rich immiscible melt followed by fractional crystallization, and formation of magnetite-rich cumulate rocks. The exact role of hydrothermal vs. magmatic enrichment processes is also debated. In this study we experimentally assessed whether the bulk composition of the Kiruna-type iron-fluorine Vergenoeg deposit, South Africa (17 wt.% SiO<sub>2</sub> and 55 wt.% FeO<sub>t</sub>) may correspond to an immiscible Fe-rich melt paired with its host rhyolite. We mixed synthetic rhyolite powder with mafic end-members representing ore compositions and performed experiments at 1-2 kbar and 1010°C. We also varied the F and H<sub>2</sub>O contents of our starting compositions. Silicate liquid immiscibility occurs in experiments saturated in fluorite and performed under dry conditions at oxygen fugacity ranging from QFM-1.4 to QFM+1.8, with QFM being the quartz-fayalite-magnetite solid buffer. It however does not occur in experiments performed under more oxidizing conditions (> QFM+1.8) or at high H<sub>2</sub>O activity (> 0.2) due iron depletion in the silicate melt caused by crystallization of abundant magnetite. Where conjugate immiscible melts are observed, the Si-rich melts are andesitic to rhyolitic (61-73 wt.% SiO<sub>2</sub>), enriched in alkalis (4-7 wt.% Na<sub>2</sub>O + K<sub>2</sub>O) and contain 9-13 wt.% FeO<sub>t</sub> and 2.4-4.2 wt.% F. The Fe-rich melts are ferrobasaltic (41-50 wt.% SiO<sub>2</sub>; 21-36 wt.% FeO<sub>t</sub>) and are enriched in F (4.5-6.0 wt.%). All experiments, including those where immiscibility did not develop, contain solid phases dominated by magnetite,  $\pm$  fayalite, fluorite and tridymite.

Our results suggest that the Vergenoeg deposit may indeed have formed as a result of silicate liquid immiscibility between a ferrobasalt and a rhyolite. However, the low SiO<sub>2</sub> content of the ore compared to the Fe-rich immiscible melts indicates that the Vergenoeg pipe probably corresponds to cumulate rocks formed by crystallization of such a melt. We hypothesize that Vergenoeg represents a pipe which formed by remobilization of a mafic crystal mush and that evolved residual liquids together with the conjugate Si-rich melts were segregated during emplacement, forming the host rhyolite. Finally, we note that the F content of Vergenoeg ore (12 wt.% F) is much higher than the F solubility in the Fe-rich immiscible melt. Although this could be explained by remobilization of fluorite-rich cumulates, we cannot exclude late stage enrichment in F by hydrothermal fluids having percolated into the fluorite-bearing rhyolite around Vergenoeg.