

Iron Oxide-Phosphate liquid immiscibility in a calc-alkaline tonalite (Adamello Batholith, Italy)

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Liquid immiscibility is often invoked as an important process in both magmatic differentiation and the formation of critical mineral deposits. However, the existence and importance of this process in typical magmatic systems remains heavily debated. Here we present evidence for silicate liquid immiscibility in the calc-alkaline Western Adamello Tonalite (Italy). Evidence of immiscibility is preserved as mm-sized aggregates of magnetite and apatite, with trace zircon and minor quantities of the main silicate rock-forming phases. The magnetite and apatite have compositions identical to those found in the tonalite matrix, as expected for equilibrium crystallization of immiscible liquids. However, the presence of additional magmatic phases not observed in the matrix, most notably interstitial titanite and pyrophanite-rich ilmenite, shows that equilibrium between the two liquids was not maintained to the solidus. Multiple mineral thermometers (Mg-in-magnetite, Zr-in-titanite, Ti-in-zircon) record temperatures between ~900°C and 675°C, showing that this assemblage crystallized at supra-solidus to near-solidus conditions and demonstrating that immiscibility occurred during crystallization of the tonalite. Reconstructed bulk compositions based on image analysis of WDS maps show that the magnetite-apatite clusters contain ~70% FeO^T, ~10% CaO, ~7% P₂O₅, and lesser amounts of SiO₂, Al₂O₃, TiO₂ and ZrO₂, comparable to immiscible Fe-Ca-P liquids produced experimentally, and also to Kiruna-type iron oxide-apatite deposits. While the observed clusters may potentially represent quenched immiscible liquids, we argue it is most likely that they represent cumulates crystallized from an Fe-rich silicate liquid due to the high solidus observed in simplified Fe-P-O systems. The Western Adamello Tonalite is a prototypical K-poor calc-alkaline system: oxybarometers suggest fluid-saturated crystallization at ≤3 kbar at *f*O₂ near NNO+1, while radiogenic isotopes indicate only limited crustal assimilation. Therefore, these observations demonstrate that liquid immiscibility can occur even in a ‘typical’ arc magmatic system. We argue that many other evolved arc magmas likely approach this immiscibility field, which may be reflected in the common spatial association of magnetite with apatite in many granitoids. Finally, given this example of immiscibility in a ‘typical’ arc magma, we suggest that immiscibility on the scale required to produce Kiruna-type deposits may require only limited assimilation of phosphates or similar material.