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Fe-Ti Oxide Petrochemistry of the Skaergaard Intrusion Records Closed-System Fractional Crystallization and Late-Stage Silicate Liquid Immiscibility

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The Fe-Ti oxide minerals, magnetite (Fe_3O_4) and ilmenite ($FeTiO_3$), are effective recorders of differentiation and subsolidus modification in magmatic systems. In this study, the microanalysis of Fe-Ti oxides in the Eocene Skaergaard intrusion was used to investigate the range of physicochemical processes that occur during cooling and crystallization of a single batch of Fe-rich tholeiitic magma. The sample set includes rocks from every subzone of the Layered Series (n = 14) and the majority of subzones in the Marginal Border Series (n = 4). In Skaergaard, Fe-Ti oxides occur throughout the magmatic stratigraphy (5–10 vol%), with polyphase primocryst aggregates of subequal magnetite and ilmenite appearing after ~60% crystallization (base of Lower Zone c). Oxidation-induced ilmenite exsolution (e.g., trellis-type, sandwich-type) produced during subsolidus cooling (<700°C), is common within magnetite, and a technique was established using EPMA quantitative mapping for reintegrating the exsolution products to estimate magmatic compositions. A comparison of results from different analytical methods (EPMA spots, EPMA maps, LA-ICP-MS spots) underscores the effect that intragrain heterogeneity has on determining magnetite compositions. Systematic trends in compatible (Cr, Ni) and incompatible (HFSE) elements in magnetite and ilmenite record progressive fractional crystallization in a closed system magma reservoir with Cr/Zr being a particularly effective proxy for intrusion-scale differentiation. Textural evidence such as replacive symplectites along oxide rims and the presence of skeletal ilmenite supports an important role for silicate liquid immiscibility during late-stage differentiation of the Skaergaard intrusion. These immiscibility-related textures, coupled with V systematics, indicate that most of the oxides in the Lower and Middle zones are products of a reactive Fe-rich liquid in a consolidating cumulate pile following segregation of the conjugate Si-rich liquid. These findings demonstrate how oxide petrochemistry of the Skaergaard intrusion can reliably record the competing effects of different magmatic processes (e.g., fractionation, immiscibility) and the importance of considering subsolidus re-equilibration when interpreting primary signatures. These results also highlight the value of oxide petrochemistry for assessing the magmatic and subsolidus history of a closed-system layered intrusion, and the utility of Fe-Ti oxide geochemistry as a petrogenetic indicator of magmatic processes in mafic intrusions within Earth's crust.