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Zircon diversity in the Skaergaard intrusion and the late-stage evolution of mafic intrusions in sub-volcanic magma plumbing systems

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The textures and chemistry of zircon record the crystallization histories of fractionated interstitial melts in mafic rocks and they can be used to unravel a range of competing physicochemical processes in magma plumbing systems. The 56 Ma Skaergaard intrusion, related to the East Greenland flood basalts and opening of the North Atlantic Ocean, was emplaced at shallow levels (~2 km deep) as a box-shaped 280 km^3 magma reservoir that subsequently cooled and crystallized as a closed system. This study involved the detailed petrology of 100+ samples, SEM-cathodoluminescence imaging, and LA-ICP-MS trace element analysis of zircon, both from mineral separates and in thin section, from all components of the Skaergaard intrusion, including a suite of granophyres and sills (Tinden, Sydtoppen). Zircon abundances range from several crystals to 100s of crystals per thin section. There is a very large range of zircon morphologies, including euhedral crystals with stubby or prismatic terminations, coarse skeletal to hopper grains, fine sub- to anhedral zircon, and oriented clusters of acicular needles. Inclusions of co-crystallizing accessory phases (apatite, rutile, monazite, thorite, columbite, xenotime) are abundant, particularly in rocks from the Sandwich Horizon and in granophyres. Temperatures calculated by Ti-in-zircon thermometry and modelled zircon saturation temperatures are consistent with crystallization from highly fractionated near-solidus melts (600-800°C). Zircon occurs primarily within interstitial crystalline pockets with two distinct mineral assemblages reflecting crystallization from late-stage conjugate immiscible Si- and Fe-rich melts. Trace element concentrations (e.g., Li, Ti, Hf, REE) and ratios (e.g., Th/U, Nb/Yb. Lu/Hf, Th/Y, Ce/Nd) in zircon vary widely throughout the intrusion as a function of the starting parent magma composition, crystallization of cumulus minerals prior to zircon saturation and of interstitial minerals following initial zircon saturation, liquid immiscibility, disequilibrium crystallization resulting from late-stage vapor saturation, and reheating from late sill intrusion. The remarkable morphological and geochemical diversity of zircon in the Skaergaard intrusion, unprecedented in the plutonic environment, demonstrates the critical role of distinct crystallization environments between the floor, walls, roof, and center of the Skaergaard magma body during closed-system solidification of a sub-volcanic magma plumbing system.