Very fast silicic magma genesis in caldera and rift environments based on isotope zoning in zircons, experiments, and thermal modeling

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Large-volume sub-liquidus silicic rocks are erupted in caldera environments with short repose time. Modern in situ isotopic methods have recently permitted analysis of isotopic and trace elemental abundances on micron to smaller scale and demonstrate strong crystalline heterogeneity. We review recent discoveries of isotopically (O, U-Pb) zircons in large volume ignimbrites (Snake River Plain, Kamchatka, and Iceland).

We report results from a long-duration isotope exchange experiment with natural zircon and rutile that was held for 4 months at 850°C and 0.3 kbars in a silica-rich solution doped with ^{18}O, ^{2}H, ^{7}Li and ^{10}B. The length-scales of in-diffusion were examined by depth profiling using time-of-flight (TOF) and Cameca 1270 high-sensitivity dynamic SIMS. Rutile and zircon developed ~2 μm and ≤0.13μm Fickian profiles, respectively, suggesting that rutile diffusion coefficients were at ~400 times greater than zircon's, and both are consistent with the wet diffusion coefficients for zircons and rutiles reported by Watson and Cherniak (1997) and Moore et al (1998). These results are relevant for interpreting timescales of magma evolution, in particular those related to controversial sharp intra-crystal zircon oxygen isotopic gradients. We instead consider sharp boundaries to be related to rapid episodes of solution-reprecipitation that outpace diffusive exchange, and generate concave-up zircon crystal size distributions (CSDs). Isotopic profiles in natural zircons will translate into 100-1000 yrs residence and characterize 100-1000 km^3 volumes of near-liquidus magmas.

Given diffusive-equilibration and recrystallization timescales, these new results call for very fast magma segregation from diverse in $\delta^{18}O$ hydrothermally-altered protoliths, occuring rapidly at shallow depths. As oxygen is a major component of silicates and oxides, isotopic variation of several permil reflect tens of percent of mass addition. Isotopic diversity in zircons spanning 2-7‰ $\delta^{18}O$ characterize near-liquidus magmas of 100-1000km^3 volume. Coexisting high, normal and low-$\delta^{18}O$ zircons indicate contributions from diverse protoliths, and convective mixing on 10^2-10^3 yr. timescales comparable to mineral-diffusive, solution-reprecipitation, and crystal size distribution timescales. Modeled convective rates of silicic magmas are fast enough to homogenize ~1000 km^3 magma over 10^4 yr. timescales.

Numerical experiments demonstrate the feasibility of rapid (10m/yr) convective melting rate which may translate into >10km^3/yr magma production rates over spatial dimensions of typical calderas. We suggest that neither conductive cooling nor hydrothermal refrigeration are capable of dissipating heat sufficiently fast to prevent catastrophic melting.

Evidence for a mid-crustal channel flow during the Sveconorwegian orogeny of Baltica ?

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New structural, petrological and SIMS U-Pb zircon data from SE Norway suggest that a mid-crustal channel flow may have developed during the main Sveconorwegian orogenic phase at the margin of Baltica. The 500 km wide Sveconorwegian orogen is interpreted as the product of a hot and long-lived, polyphase, bivergent orogeny, resulting from the collision of Baltica with another major plate (Amazonia, Laurentia) at the end of the Mesoproterozoic. The Sveconorwegian orogen is built on Mesoproterozoic crust that youngs toward the west. The orogeny followed a voluminous 1200-1130 Ma bimodal, within-plate magmatism in the west, more extensive than previously assumed. High-pressure (HP) metamorphic rocks are only recorded in the east of the orogen. These three observations suggest a warm lithosphere at the onset of orogeny, increasingly warmer toward the west. At around 1080 Ma, Bamble and Kongsberg were thrusted westwards on top of Telemark marking the onset of collisional tectonics. The main orogenic phase started at c. 1050 Ma. In the Idefjorden terrane, HP granulite-facies mafic boudins and kyanite gneisses locally record conditions of c. 930 °C - 1.3 GPa at c. 1050 Ma. This was followed by widespread LP amphibolite-facies partial melting. Leucosomes associated with top-to-the-west regional kinematics and resulting from muscovite-, biotite- and amphibole-dehydration melting of orthogneiss and paragneiss, range in age from 1039 ± 17 to 997 ± 16 Ma, as provided by low-U zircon rims. This partial melting episode was coeval with metamorphism along the Vardefjell shear zone bounding the Idefjorden terrane in the west, and coeval with widespread syn-collisional granitic plutonism and LP amphibolite- to granulite-facies metamorphism in the west of the orogen in Rogaland-Vest Agder. The reported long-lived high-grade conditions suggest development of a mid-crustal west-directed (?) channel flow activated after c. 1040 Ma, probably associated with a slowly eroding orogenic plateau. Lack of foreland basins to the east of the orogen is consistent with west directed flow. In this model, the low-grade Telemark supracrustals may belong to a shallow orogenic lid, covering a large area in the centre the orogen and characterized by deposition of immature sediments in grabens (Eidsborg Fm <1118 Ma, Kalhovde Fm <1065 Ma). At c. 980 Ma, the Sveconorwegian orogeny propagated eastwards in the footwall of the arcuate, southeast-verging, "Mylonite Zone" back-thrust, leading to eclogite-facies metamorphism in the Eastern Segment. Convergence was followed by gravitational collapse after c. 970 Ma. High-grade LP conditions were maintained in Rogaland-Vest Agder until c. 930 Ma and were associated with voluminous post-collisional plutonism, including anorthosites.