Zircon chronochemistry of the Mesa Falls Tuff (Yellowstone, USA): Progressive remelting of a felsic source by underplated mafic magma

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Zircon ($ZrSiO_4$) contains a wealth of petrogenetic information for intermediate to felsic igneous rocks. Excimer (193 nm) laser ablation (ELA) provides access to these data via highly reproducible *in situ* (≥15 micrometer spot) sampling for analysis by ICP-MS. Rapid scanning over a wide mass range by quadrupole ICP-MS allows concurrent measurement of major and trace elements with U-Th-Pb isotopes. Integration of spatially resolved age and compositional data forms the basis of zircon chronochemistry.

In order to understand better the temporal and chemical evolution of felsic magma bodies in the upper crust, the zircon chronochemistry of large-volume ignimbrites of the Yellowstone volcanic field is being examined. Three populations of zircons can be distinguished in the 280 km^3 Mesa Falls Tuff (MFT) based on combined age and trace element criteria. Population 1 is oldest (1350 ± 30 ka) and has extremely high U with very negative Eu anomalies. Population 2 has intermediate age (1300 ± 30 ka) and trace element characteristics. Population 3 is youngest (1190 ± 70 ka) and has the lowest U with the smallest negative Eu anomalies. Smooth trace element variations within and between the 3 populations provide evidence for zircon growth from progressively higher degree partial melts of a felsic source (feldspar + zircon residue) culminated by mixing with primitive melt. These and published data are consistent with remelting of plutonic residues and altered (^{18}O-depleted) caldera-fill of the Huckleberry Ridge Tuff (2000 ka, 2500 km^3) by underplated mafic magma 160 ± 100 kyr prior to eruption of the MFT.

Zircon and Zr/Hf ratios: Assessing magmatic fractionation in the crust

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In the Earth's mantle and most of the crust Zr/Hf ratios cluster very closely at near-chondritic values of ~35-38, reflecting the extreme geochemical similarity of the two elements. Some minerals, including amphibole, clinopyroxene, garnet, and sphene, partition Zr and Hf unequally (David et al., 2000; Bea, in press), but because of their relatively low abundances and/or K_Ds they are generally inefficient at fractionating the ratio. In contrast, extraction of zircon, the dominant reservoir for both elements, can effectively reduce Zr/Hf (Linnen & Keppler, 2002; Bea, in press). We suggest that strong deviations from chondritic Zr/Hf in the crust reflect separation of zircon from melt.

Zr/Hf ratios of </=20-30 are common in highly felsic rocks including aplites, roof facies of plutons, and high-silica rhyolites (e.g. Hildreth, 1981; Wark & Miller, 1993), and apparently comagmatic series show a pattern of near-constant chondritic Zr/Hf with increasing SiO_2 followed by abrupt decline beginning at ~72-75 wt% (e.g. Bea, in press; Harper et al., in press). Although less well-documented, granitic cumulates appear to show complementary high ratios >40-45.

Zr/Hf ratios can be used to identify the products of fundamental, uniquely intracrustal fractionation processes. Almost all crustal magmas achieve zircon saturation, but only at relatively low temperatures (generally ~850 C or less). Effective segregation of the zircon, and presumably of the entire coexisting crystallizing assemblage, is required to achieve whole-rock variability in Zr/Hf. This suggests, for example, that high-silica rhyolite magmas form by effective, relatively low-T melt segregation and that melt-depleted granitic crystal mushes (cumulates) are marked by elevated Zr/Hf. Near-chondritic ratios denote absence of effective melt-mush segregation under zircon-saturated conditions.