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Low-δ^{18}O Rhyolites from Yellowstone: Magmatic Evolution Based on Analyses of Zircons and Individual Phenocrysts

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The Yellowstone Plateau volcanic field is one of the largest centers of rhyolitic magmatism on Earth. Major caldera-forming eruptions are followed by unusual low-δ^{18}O rhyolites. New oxygen isotope, petrologic and geochemical data from rhyolites belonging to the 2·0 my eruptive history of Yellowstone are presented, with emphasis on the genesis of low-δ^{18}O magmas erupted after the Huckleberry Ridge Tuff (2·0 Ma, 2500 km^3) and Lava Creek Tuff (0·6 Ma, 1000 km^3). Analyses of individual quartz and sanidine phenocrysts, obsidian samples and bulk zircons from low-δ^{18}O lavas reveal: (1) oxygen isotope variation of 1–2‰ between individual quartz phenocrysts; (2) correlation of zircon crystal size and δ^{18}O; (3) extreme (up to 5‰) zoning within single zircons; zircon cores have higher δ^{18}O; (4) Δ^{18}O disequilibria between quartz, zircon and homogeneous unaltered host glass where zircon cores and some quartz phenocrysts have higher δ^{18}O values. These features are present only in low-δ^{18}O intra-caldera lavas that erupted shortly after caldera-forming eruptions. We propose that older, hydrothermally altered, ^{18}O-depleted (δ^{18}O $\sim$ 0‰), but otherwise chemically similar, rhyolites in the down-dropped block were brought nearer the hot interior of the magma chamber. These rhyolites were remelted, promoting formation of almost totally molten pockets of low-δ^{18}O melt that erupted in different parts of the caldera as separate low-δ^{18}O lava flows. Alteration-resistant quartz and zircon in the roof rock survived early hydrothermal alteration and later melting to become normal δ^{18}O xenocrysts (retaining their pre-caldera δ^{18}O values) in the low-δ^{18}O magma that formed by melting of hydrothermally ^{18}O-depleted volcanic groundmass and feldspars. Zircon and quartz xenocrysts exchanged oxygen with newly formed melt through diffusion and overgrowth mechanisms leading to partial or complete isotopic re-equilibration. Modeling of the diffusive exchange of zircon and quartz during residence in low-δ^{18}O magma explains δ^{18}O and Δ(Qz–Zrc) disequilibria. The exchange time to form zoned zircons is between a few hundred and a few thousand years, which reflects the residence time of low-δ^{18}O magmas after formation and before eruption.

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