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Atomic Level Characterization of Magmatic Zircon Oscillatory Zones via Atom Probe Tomography

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Cathodoluminescence (CL) imaging of magmatic zircon often reveals characteristic oscillatory zonation textures, which appear as a series of parallel three-dimensional growth shells of differing width. This resulting oscillatory zonation pattern is understood to reflect the heterogeneous distribution of trace element concentrations. However, characterizing these individual, commonly micrometer-scale growth zones in order to evaluate processes (e.g., mechanisms of crystal growth) occurring at the nanometer scale has been challenging.

Here we use Atom Probe Tomography (APT) to provide 3-dimensional atomic reconstructions of the interface between finely spaced (~1 µm) oscillatory bands in a well-characterized magmatic zircon from the Jurassic Chon Aike silicic large igneous province in Patagonia, Argentina. Two APT reconstructions that sample an interface between oscillation bands of brighter and darker CL intensities show that trace element concentrations change sharply (<10 nm) across these interfaces. The growth domains are most clearly observed in the reconstructions by their contrasting Yttrium concentrations, though calculated bulk volume concentrations of the two sub-volumes indicate changes in other detectable trace elements as well (e.g., P, Be, U, Yb).

The incorporation of trace elements into the zircon structure is controlled by dynamics occurring at the zircon-melt interface. Major changes in CL intensity are thought to reflect external forcing due to changing magmatic conditions (e.g., temperature, pressure, and composition) such as during a magma mixing event. While small-scale oscillatory growth bands are likely a result of internal forcing due to feedbacks in local supersaturation and disequilibrium growth [1], such as enriched boundary layers caused by the interplay between crystal growth and diffusion in the melt. However, the observed Yttrium profiles of less than 10 nm in length are difficult to reconcile with mathematical models of zonation caused by enriched boundary layers [2]. Therefore, we explore alternative mechanisms capable of producing near atomically sharp boundaries of changing trace element concentrations.

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