Resolving rates of landscape evolution with $^{4}He/^{3}He$ thermochronometry: examples from Grand Canyon and Yosemite Valley

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Despite decades of research, the relative importance of climate versus tectonics in shaping Earth’s surface remains debated. In particular, it is unclear whether recent glacial erosion has led to a significant increase in erosion rates over the last 2Ma. One way to investigate this in more detail is to collect data that are sensitive to very low-temperatures and can provide exhumation rate constraints in slowly exhuming locations. The (U-Th)/He system is sensitive to low temperatures (<100oC), however overdispersion of (U-Th)/He ages represents an obstacle to extracting accurate and precise thermal paths. An alternative to collecting multiple (U-Th)/He ages from the same locality is to collect a large amount of information from individual crystals using 4He/3He thermochronometry. In regions of slow cooling rates, the 4He/3He spectrum can be strongly influenced by intra-crystal variations in radiation damage. This can make detecting a recent cooling signal challenging. But, if such complexity is adequately understood, each crystal has potential to tightly constrain its continuous thermal path. Here, we present examples from Grand Canyon where these methods have been developed, and Yosemite Valley where we can test the role of glaciers in forming this dramatic landscape. In Grand Canyon, differences in zonation between crystals from the same sample have helped constrain the history of fluvial incision. In this case, ICP-MS data from polished sections through crystals were inverted to account for spatial smearing associated with large spot sizes. This allowed the U and Th zonation to be implemented in a 3D diffusion model and resolve recent cooling. In Yosemite Valley, we combine 3D diffusion models of 4He/3He data with thermo-kinematic models to test the magnitude of glacial erosion. In this case, the ability to measure incision is improved using three approaches: intra-crystal variations in zonation provide precise cooling histories; age variability across crystals from the same sample due to radiation damage provide overlapping temperature sensitivity; data from different locations across the landscape are linked with a thermal model. Our results suggest that a large amount of the current topography developed more recently than 20 million years during a time of tectonic uplift of the Sierra Nevada. Importantly, as Matthes believed, Yosemite Valley is largely not a Pleistocene feature and the role of glacial erosion in shaping this landscape is therefore likely to be relatively minor.

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