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Advances in the spatial resolution and precision of oxygen isotope measurements by SIMS have greatly improved the analytical leverage of this stable isotope system for high-temperature processes. Subtle intragrain diffusive oxygen isotope zoning can now be utilized to determine temperatures, rates, and durations of linked physical and chemical transformations in deep, hot, deforming rocks. Diffusion at metamorphic conditions produces characteristic oxygen isotope zoning within minerals that can be 1) modeled to extract time-temperature histories, and 2) used as internal markers to relate changes in grain size and shape to the time-temperature history of a rock.

Quantitative modeling of oxygen isotope diffusion zoning differs from modeling of well-known thermochronometry systems that involve Ar, He, or Pb loss and requires additional considerations, like the maintenance of mass flux balance. We have expanded the Fast Grain Boundary (FGB) program (Eiler et al., 1994) and rewritten it in Python to improve its usefulness and accessibility for quantitative thermal history modeling. The FGB program can (i) fit a thermal history to measured oxygen isotope data through forward modeling, (ii) perform statistically rigorous inversion of measured oxygen isotope data to back out a range of possible thermal histories, or (iii) predict the diffusion zoning that should develop in all minerals of a rock for a given thermal history.

In many cases, oxygen diffusion is one of multiple processes – e.g., grain growth, fluid-mediated recrystallization, dynamic recrystallization, dissolution, etc. – that can act to create intragrain oxygen isotope zoning. Characteristic modifications of diffusion zoning can be used to recognize these processes and their timing relative to the temperature conditions at which diffusion occurred. Moreover, modifications of the diffusion profile that can be tied microstructurally to porphyroclast or porphyroblast development provide a time-temperature framework in which to locate high-temperature metamorphic and deformational fabric formation. We illustrate the utility of oxygen isotope zoning in titanite porphyroclasts for determining the relative timing, temperatures, and fluid compositions in amphibolite- to granulite-facies shear zones of the Adirondack Mountains.