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The Relationship Between Stable Isotope Diffusion, Zonation and Thermometry: a Case Study From The Adirondack Mountains, NY

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Retrograde diffusion is recognized as an important factor in the stable isotope geochemistry of slowly cooled rocks. However, it has never been demonstrated by micro-analysis that natural minerals are zoned with respect to stable isotopes in a way consistent with closed system interdiffusion during cooling.

We have combined ion-microprobe analysis of oxygen isotopes in magnetite with bulk mineral oxygen isotope thermometry and numerical modeling of interdiffusion in two lithologically similar samples of magnetite bearing quartzo-feldspathic gneiss from the northeast Adirondack Highlands. Bulk mineral oxygen isotope analysis shows that both samples have undergone significant retrogression ($T_{mt-(qtz,fsp)}$ = 511-570 C) from peak metamorphism at 725 C. The two samples differ, however, in their patterns of isotopic discordance, with $T_{qtz-fsp} >> T_{mt-(qtz,fsp)}$ in one sample and $T_{qtz-fsp} < T_{mt-(qtz,fsp)}$ in the other. Fast Grain Boundary diffusion modeling indicates that the former pattern is consistent with closed system retrogression, while the latter is not (Eiler et al., 1992 CMP; 1993 GCA). Diffusion modeling also predicts that interdiffusion during cooling will produce 1‰ isotopic zonation in magnetite grains, and 1‰ differences between small (0.1 mm) and large (0.5 mm) grains. The pattern of isotopic resetting in the other sample allows for no such predictions, but suggests open system alteration that might be expected to produce more irregular zonation.

Ion microprobe analysis (e.g. Valley and Graham, 1991 CMP) shows that the zoning patterns of magnetite grains from the two samples are dramatically different, the first showing clear core to rim zonation in multiple grains ($\Delta_{core-rim}$ = 1.13± 0.40 ‰ ; $1\sigma\bar{x}$; see figure) and predicted grain-size vs. core composition variations. The second sample, on the other hand, shows extremely irregular zonation both within and between grains over an 8‰ range.

The correlation of thermometric and modeling results with zonation shows that bulk mineral data, when interpreted with detailed modeling, can accurately determine the processes active during retrogression. These results provide a quantitative basis for using bulk-mineral stable isotope fractionations in thermometry, speedometry and studies of fluid-rock interaction.