Geophysical Research Abstracts, Vol. 8, 09564, 2006
SRef-ID: 1607-7962/gra/EGU06-A-09564

Combining multiple diffusion profiles to determine the integrated temperature-time histories of thermal pulses

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Crustal rocks are commonly affected by thermal pulses, in which the rocks are subjected to elevated temperatures for relatively short periods of time, e.g. dyke injection, heat advection by hot fluids, frictional heating, etc. Although an estimate of the peak temperature attained by the rocks affected by a thermal pulse can often be obtained from geothermometry, it has been much more difficult to estimate the DURATION of the thermal pulse itself, and hence, the resultant thermal (T-t) history that the rocks have experienced.

We present a new and powerful method of determining the integrated temperature and duration of such thermal pulses using microanalytical techniques coupled with solid-state diffusion theory. By using the concept of the mean diffusion distance (x-bar) [defined as the average distance that a diffusing solute species (isotope, element, molecule, etc.) migrates over a certain time t at a certain temperature T], we show there is a single T-t curve corresponding to a particular x-bar. The determination of two different mean diffusion distances in the same rock will consequently produce two different T-t curves, and the intersection of these two curves will yield a unique T-t condition that is consistent with both T-t curves and thus reflects the integrated T-t effect of the thermal pulse experienced by the rock.

This method can be used in ANY situation where at least two different diffusion profiles exist. One possibility involves measuring concentration gradients of only a single diffusing species, which has a different diffusivity in two different minerals in the same rock. Alternatively, concentration gradients of two different diffusing species can also be measured within a single mineral. The underlying concept in either approach is that the two measured diffusion profiles will, in combination, uniquely determine the integrated T-t history of the rock. If diffusion profiles representative of more than two different diffusivities can be measured, these will place additional constraints on the T-t history of the thermal pulse and may allow for the calculation of a “best-fit” T-t history and corresponding uncertainties.

We have successfully used this method to tightly constrain the flow of hot fluids in shear zones in the lower crust of Norway (Bergen Arcs) to be of very short duration (kyrs), suggesting that this method may have widespread applicability in elucidating the thermal histories of any rocks which have experienced thermal pulses.