CLOSURE OF ISOTOPIC SYSTEMS: OLD PARADOXES, NEW PARADIGMS

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Exactly 30 years ago, Jäger (1967) proposed that isotope transport in mineral geochronometers could be described only as a function of temperature. Her model was based on a field study of the central Alps, and was later expanded to a complex edifice considered to have a universal validity. This edifice was characterized by a series of logical implications which only permitted one internally consistent solution.

Jäger's (1967) first assumption was that fluids and recrystallization play a minor role in resetting mineral ages, which is achieved essentially by temperature. The second assumption was that for a given mineral there existed a metamorphic isograd in the Central Alps that was the locus of peak metamorphic ages for that mineral (up-temperature of this isograd, it would give younger cooling ages; down-temperature of this isograd, older, mixed ages). It is clear that different age estimates for the metamorphic peak automatically imply anticorrelated up/down shifts of the “closure” isograd. From the choice of 38 Ma for the age of the peak metamorphism it follows, with logically inescapable necessity, that the “closure temperature” for U/Pb in monazite is 420 °C.

This paradox was initially not recognized as such, as only recently the diffusion behaviour of Pb has been both successfully measured and theoretically modelled in a sufficient number of minerals.

Based on literature of the last 3 years and on a reanalysis of Jäger's (1967) data base, a new paradigm imposes itself.

Thermally activated diffusion of isotopes is an extremely slow process, and “closure temperatures” are consequently higher by approx.150–200 °C than in Jäger's model. This means that most of her minerals were plagued by substantial isotopic inheritance from their polymetamorphic history, and that the age of 38 Ma for metamorphism in the Central Alps is itself a mixing age and therefore incorrect.

A younger age, coupled to higher closure temperatures, explains most paradoxes, but a model assuming that temperature alone resets ages is unable to account for the patchy age distribution in most recent field studies in the Alps and elsewhere. The role of fluids and deformation in promoting recrystallization of minerals, and thus isotope transport, have been widely recognized only in the last 5 years. It is a much faster process than thermally activated diffusion, and will overrun it in most rocks. This means that minerals can undergo a rejuvenation even at very low T — but not because their thermal retentivity is low, but because of local fluid circulation and shearing.

What do we look for to date metamorphism? Dating without understanding the processes that formed the rock as we see it is insufficient. We need first to map microstructures, assess relict vs. newly formed minerals, and estimate regional and outcrop-scale water activity before we attempt translating an analytical number into a geological age.