Geochronology and metamorphism

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Precise age information is an essential prerequisite for the determinations of events and the quantification of rates of metamorphic and tectonic processes within an orogenic cycle. Of particular interest are the time of mineral growth, partial melting and major tectonic activity as well as rates for mineral growth, heating, burial, deformation, cooling and uplift. Well determined values for these parameters combined with thermobarometry are essential components for the construction of P-T-t paths in metamorphic terranes. These paths in turn provide basic information on possible tectonic settings for metamorphism and yield constraints on orogenic processes.

For medium to high grade terranes high precision ages (i.e. errors less than *c.* 5 m.y.) can only be obtained on a routine basis by use of the U-Pb and K-Ar decay systems. In these systems the difference in geochemical character between parent and daughter isotope is large enough to obtain reliable age information from the analyses of a single mineral.

In order to take advantage of the high analytical precision of mineral ages a full understanding of the behaviour of the parent-daughter system in the minerals used for dating is required. Resetting or disturbance of an isotopic system in a mineral can be caused by two important processes: diffusion and/or recrystallisation. Thus for a reliable interpretation of high quality mineral ages information on the diffusion parameters of the parent-daughter system in a given mineral as well as the behaviour of the crystal lattice in response to its thermal history is essential. Experimental data for diffusion of relevant parent and daughter elements is limited to a few minerals including hornblende (Harrison, 1981; Baldwin *et al.*, 1990), sphene (Cherniak, 1993) and apatite (Cherniak *et al.*, 1991). This data provides the cornerstone for the interpretation of other systems where no experimental and only field calibrations are available (e.g., zircon, allanite, garnet, monazite). From empirical studies it is obvious that zircon, garnet and monazite have high closure temperatures. For monazite the closure temperature is probably around 700°C (Copeland *et al.*, 1988), for garnet above 800°C (Mezger *et al.*, 1989) and even higher for zircon. Therefore these three minerals are of paramount importance for the reconstruction of the histories of high grade terranes.

Zircon and monazite can incorporate high concentrations (up to several thousand ppm) of U and/or Th. Both elements decay to Pb through decay schemes that produce several alpha-particles. These particles destroy the lattice of the host mineral and lead to metamictisation. For these phases information for diffusion in the metamict state may be important. From the metamict parts radiogenic Pb can be readily removed which leads to a disturbance in the U-Pb decay system. This metamictisation is a particularly serious problem in zircons due to the high activation energy of recrystallisation which prevents lattice healing and promotes slow continuous Pb-loss. In monazite this metamict state is apparently much easier to repair, even at relatively low temperatures, which is demonstrated by the crystalline state even of monazites with high Th-contents. Recrystallisation leads to expulsion of the Pb and thus the radiometric clock is reset. This resetting is a basically different process from cessation of diffusion due to cooling. Thus for a valid interpretation of monazite ages it is essential to know more about their behaviour during cooling in terms of Pb-diffusion but also recrystallisation. In some cases monazites seem to recrystallise only partially which complicates the interpretation of these mineral ages unless well characterised fragments of single grains can be analysed (DeWolf, 1994). Only after a more complete understanding of diffusion and recrystallisation processes is available will it be possible to take advantage of the high precision ages that can be obtained from these minerals in high grade terranes.

So far a major use of mineral ages using different phases and decay systems has been the establishment of cooling paths. Such paths can be very precise because, due to the lower temperatures, the chances of diffusional loss and recrystallisation are more and more diminished as cooling proceeds. Mineral ages from metamorphic rocks that crystallised below the closure temperature for the decay system of interest are easier to interpret and provide essential information that allows for a combination of thermobarometric information with the time of mineral growth. Particularly good success with the quantification of metamorphic processes has been achieved in recent years with the determination of multiple metamorphic episodes within a single terrane, deformation rates and growth rates of garnets (Christensen *et al.*, 1989) and cooling and uplift histories. It is still a particular challenge to obtain precise information on the prograde history for most metamorphic terranes.

References

Baldwin, S.L., Harrison, T.M. and Fitz Gerald J.D. (1990) *Contrib. Mineral. Petrol.*, **105**, 691–703.

Cherniak, D.J. (1993) *Chem Geol.*, **25**, 177–94.

Cherniak, D.J., Lanford, W.A. and Ryerson, F.J. (1991) *Geochim. Cosmochim. Acta*, **55**, 1663–73.

Christensen, J.N., Rosenfeld, J.L. and DePaolo, D.J. (1989) *Science*, **244**, 1465–9.

Copeland, P., Parrish, R.R. and Harrison, T.M. (1988) *Nature*, **333**, 700–3.

DeWolf, C.P. (1994) PhD Thesis, University of Michigan, Ann Arbor, USA.

Harrison, T.M. (1981) *Contrib. Mineral. Petrol.*, **78**, 324–31.

Mezger, K., Hanson, G.N. and Bohlen, S.R. (1989) *Contrib. Mineral. Petrol.*, **101**, 136–48.