Fluids in high-grade rocks: stable isotope constraints on source and transport mechanisms

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Advances in theoretical modelling of fluid transport under high-grade metamorphic conditions have, in recent years, developed more rapidly than observations on real rocks. Analysis of geological examples are important as they allow the applicability of the assumptions used in theoretical modelling to be rigorously tested. We have investigated the positions and topology of reaction and isotope fronts across closely sampled (centimetre scale), drilled traverses of fluid infiltration-driven amphibolite to granulite (S. India) and granulite to eclogite (W. Norway) transitions.

On Holsnoy, Norway, eclogite formation involves plagioclase breakdown to jadeite, zoisite, kyanite and quartz and is caused by hydrous fluid ($X_{H2O} > 0.75$) infiltration. In the undeformed granulite-facies anorthosite precursor, water is observed to have flowed along grain boundaries and cracks. The topology of argon and carbon isotope profiles (measured from fluids trapped in garnet grains) can be modelled assuming a linear kinetic exchange between fluid and rock with different Damkohler numbers for each isotope.

Granulite formation in South India involves orthopyroxene growth at the expense of garnet and biotite and is promoted by influx of a CO_2-rich fluid ($X_{CO2} > 0.8$) which moves by micro-hydraulic fracture. Fluid-rock disequilibrium results in patchy 'incipient' granulite formation, possibly controlled by nucleation kinetics. Isotope - fronts are not sharp, but do verify the prediction that the rate of isotope front transport is controlled by the elemental abundance in the rock; carbon isotope fronts are displaced further from the reaction front in graphite-poor than graphite-rich localities. Based on models which take into account disequilibrium, the mechanisms and rates of fluid infiltration and time-integrated fluid fluxes can be estimated from the geometry and topology of the fronts analysed in the drilled traverses.

Patchy incipient charnockites (orthopyroxene granulites) occurring within biotite- or amphibole-bearing gneiss have been described from numerous classic localities in S. India and Sri Lanka, but their origin remains a matter of debate. The transition from amphibolite facies to granulite facies can be accomplished by increasing temperature and/or a decrease in the activity of H_2O; and the generation of anhydrous assemblages that characterise granulites may be a result of several processes. (1) Granulite facies metamorphism may have acted on rocks already 'dried' by earlier metamorphic events ('vapour-absent' metamorphism, Lamb and Valley 1984). (2) Partial melting can preferentially partition H_2O from the restite into the silicate melt, leaving fluid-enriched in CO_2 or exhausting the free fluid phase (Burton and O'Nions 1990). (3) Infiltration of deep-source CO_2 may decrease H_2O activity, driving dehydration reactions to completion (Janardhan *et al.* 1979). Although these processes are not mutually exclusive, there is abundant field evidence in both southern India and Sri Lanka that dehydration reactions are closely associated with shear zones and brittle fractures which provide conduits for fluid transport. Studies of the abundance and $\delta^{13}C$ of CO_2 in fluid inclusions from gneiss-incipient charnockite pairs show that CO_2 in incipient charnockite is more abundant and isotopically heavier that the CO_2 in associated gneiss. An external source of CO_2 is required to account for the shift to heavier carbon isotope values. Carbon isotope data across gneiss-charnockite reaction boundaries show that the carbon isotope front has been decoupled from the dehydration reaction front by CO_2 advection. Granulite formation occurred during more than one period in the evolution of the southern Indian crust, but stable isotope data require an external source of CO_2 during the stablisation of the younger incipient charnockite assemblages.

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