Stable isotope and textural evidence on the mechanisms of metamorphic fluid infiltration within a zone of structurally-focused high fluid flux

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Introduction

Dalradian rocks of the SW Scottish Highlands, dominantly comprising interlayered calc-phyllites, psammites and metabasite sills, have been infiltrated by H_2O-CO_2 fluids during regional greenschist facies metamorphism. Three-dimensional, syn-metamorphic fluid fluxes have been mapped on a regional scale using reaction front advection in metabasite sills (Skelton *et al.*, 1994). Fluid flow has been constrained by lithology, and by regional and local structure. Flow was channelled within the 6km thick Ardrishaig phyllites, which embodies the regional upward-facing Ardrishaig Anticline and within which fluxes increase exponentially towards the axial surface, where maximum fluxes in excess of 10^3 m^3m^{-2} were measured. Fluxes of this magnitude should have caused oxygen isotopic homogenisation of the phyllites. The mechanism by which fluid is preferentially channelled through the axial regions of anticlinal folds remains to be determined. We have undertaken stable isotopic and textural studies of the phyllites and interlayered psammites across the Ardrishaig Anticline structure to seek evidence of isotopic homogenisation and of the mechanisms of fluid flow.

Ardrishaig phyllites

Phyllites are variably calcareous, typically containing the assemblage: quartz + phengite + chlorite + calcite ± albite ± biotite ± rutile. This constrains the fluid composition to $X(CO_2) = 0.01$ to 0.02 under the P-T conditions of metamorphism (P = 8–10 kbars, T = 470°C). Psammitic mineral assemblages are generally compatible with those of the phyllites and range in thickness from 10cm to 5m, with the thicker units occurring on the eastern limb of the Ardrishaig Anticline. The Ardrishaig Phyllites have a typically striped texture comprising micaceous bands (chlorite + phengite) and bands of granular calcite + quartz interlayered on a mm-scale. Psammitic units have been found to contain quartz-rich bands of similar size and texture to those in the phyllites, the quartz being coarser and texturally distinct from the metasedimentary quartz component in the matrix.

Metabasites

Large sills situated on the limbs of the Ardrishaig Anticline show compositional zonation from undeformed, calcite-free interiors containing: amphibole + epidote + albite + chlorite + sphene ± biotite ± quartz, to sheared carbonated, amphibole-free margins containing: chlorite + calcite + quartz + albite ± epidote ± biotite ± sphene ± rutile and a buffer assemblage (Graham *et al.*, 1983). This zonation reflects the infiltration of CO_2-bearing hydrous fluid into the sills during metamorphism, with inwards advection of the metabasite carbonation reactions, and provides the basis for quantification of fluid fluxes (Skelton *et al.*, 1994). Infiltration and reaction are accompanied by penetrative deformation and development of a schistose fabric. In proximity to the hinge region, metabasites are extensively sheared, showing mineralogical and textural convergence with the host phyllites.

Textural and microstructural evidence for mechanisms of infiltration

Mappable metabasite sills are entirely absent from the hinge region of the Ardrishaig Anticline. However, phyllite-like lithologies have been found to comprise mm-scale fabric-parallel bands of (1) chlorite-albite ± epidote, of demonstrably mafic origin, and (2) granular quartz + calcite. The interbanding of mafic and quartz-calcite components in these striped chlorite-rich schists is strong evidence for a microvein origin for the quartz-calcite bands in mafic schists, and by inference, in the Ardrishaig Phyllites. Textural evidence thus indicates that the mechanism by which fluid flow is channelled into the axial regions of the Ardrishaig Anticline is one of microveining parallel to the axial plane. This

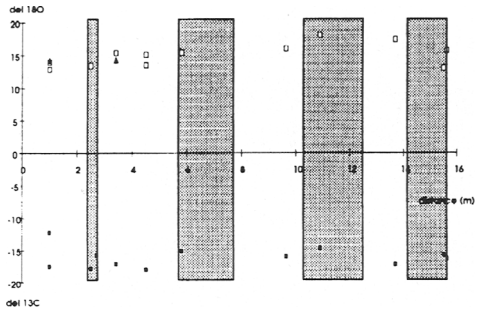

FIG. 1. Isotopic composition for a traverse through the Ardrishaig phyllites and interbedded psammites (shaded) on the east limb of the Ardrishaig anticline (squares - calcite, triangles - quartz).

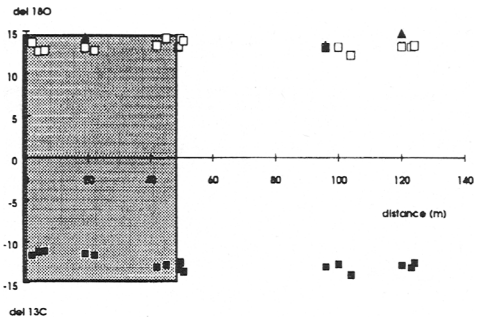

FIG. 2. Isotopic composition for a traverse through the Ardrishaig phyllites and a sheared metabasite (shaded) in the Ardrishaig anticline, in proximity to the anticlinal axis (squares - calcite, triangles - quartz).

conclusion implies that calcite is of secondary, metamorphic origin in the phyllites and carbonated metabasites, requiring that both lithologies have undergone bulk compositional change during metamorphism and accompanying infiltration. This conclusion is currently being investigated by means of microsampling of calcite-quartz bands and further geochemical studies.

Stable isotopic compositions of the ardrishaig phyllites

We have undertaken an oxygen and carbon isotopic study of silicates and carbonates in metasedimentary and metabasic rocks across the Ardrishaig Anticline. Isotopic compositions of $\delta^{13}C$ and $\delta^{18}O$ in calcites and $\delta^{18}O$ in quartz show a generally uniform range of values in all rock types (Figs.1 and 2). In the case of the metabasites, this process has involved a large increase in $\delta^{18}O$ relative to pre-metamorphic compositions. The data clearly demonstrate the attainment of oxygen isotopic homogeneity throughout all lithologies, which is consistent with the large fluxes and textural evidence for the pervasive formation of quartz-calcite microveins.

Discussion

Textural information suggests that the banding of sheared metabasites and the adjacent phyllites have provided fluid pathways via mm-scale microveins. There is no small scale deformational evidence to imply migration and recrystallisation of minerals into the quartz-rich and mica-rich domains during metamorphism. The axial region of the Ardrishaig Anticline is thus considered to represent a complex region of fabric-parallel microveins. One aspect of the infiltration event that may be elucidated with certainty is that syn-metamorphic fluid was channelled through the Ardrishaig Phyllites such that isotopic homogenisation was achieved throughout the regional outcrop of the unit. It is apparent that both large scale and small scale deformational effects contribute to the effective permeability of regionally metamorphosed rocks, in addition to lithological constraints of the rock. The mechanisms of fluid transport associated with large syn-metamorphic fluid fluxes within the Ardrishaig Phyllites may have wider relevance to fluid flow in a regional metamorphic setting, although textural evidence of these mechanisms may be obscured by subsequent reaction and recrystallisation at higher metamorphic grades.

References

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