Changes in oxygen isotope ratios of metasediments during regional-metamorphic crustal-scale fluid flow, Mount Lofty Ranges, South Australia

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Introduction

Fluid infiltration during metamorphism may control the stability of mineral assemblages, transport heat and mass, and influence deformation; hence constraining crustal fluid flow is important in understanding tectono-metamorphic processes. Unmetamorphosed sediments generally have characteristic $\delta^{18}O$ values: limestones have $\delta^{18}O$ values of 20–30‰ (V-SMOW); shales 14–20‰, and quartzites 10–15‰. Metasediments in some metamorphic terrains have closely similar $\delta^{18}O$ values; however, the $\delta^{18}O$ values of sedimentary rocks are sometimes lowered by several permil during regional metamorphism (e.g. Valley 1986, Wickham, 1990). Additionally, many S-type granites that, from $^{87}Sr/^{86}Sr$ ratios or trace element abundances, were probably derived from pelitic rocks have $\delta^{18}O$ values of around 9–12‰. Wickham (1990) concludes that the source rocks of these granites are metasediments with lower $\delta^{18}O$ values than their unmetamor-

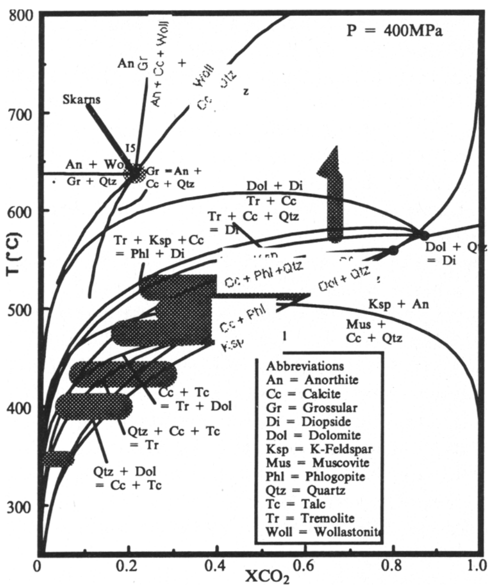

Fig. 1. T-X_{CO_2} section in the system K_2O-CaO-MgO-Al_2O_3-SiO_2-H_2O-CO_2 at 400MPa. Aside from a few skarns close to a granite, the marbles define a general increase in XCO_2, suggesting that prograde metamorphism of the marbles was dominated by internal buffering.

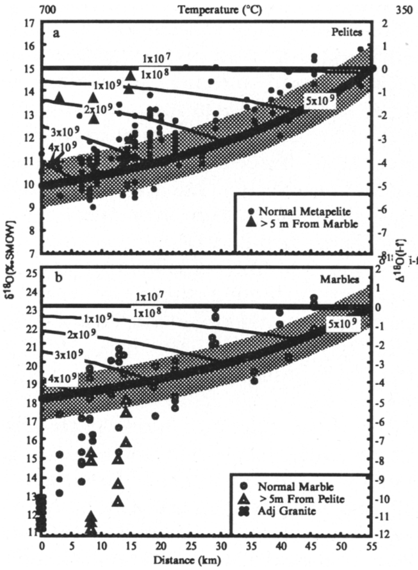

Fig. 2. Variation in $\delta^{18}O$ values of pelites (2*a*) and marbles (2*b*) with distance and temperature within the Mount Lofty Ranges. The observed oxygen isotope resetting may be accounted for by fluids flowing up-temperature with time-integrated fluid fluxes (solid lines) of up to 5x10^9 moles/m^2. Many pelites have $\delta^{18}O$ values that are within 1‰ of the minimum predicted $\delta^{18}O$ values (shaded region). Fluids in the pelites may have been derived from these rocks at lower grades; however, the fluids in the marbles were probably, at least in part, derived from the surrounding siliceous rocks.

phosed protoliths. Predicted shifts in $\delta^{18}O$ values due to metamorphic devolatilisation are generally $< 1-2‰$, implying that the wholesale lowering of $\delta^{18}O$ values reflects fluid infiltration.

Here, we document changes in stable isotope ratios of marbles and metapelites in the Mount Lofty Ranges, South Australia, during regional metamorphism. The Mount Lofty Ranges is ideal for this study because: 1) a coherent stratigraphy exists from low to high grades; 2) the area has a simple tectono-metamorphic history with little polymetamorphism; and 3) there are few veins or mineralised faults, suggesting that local fluid flow was not superimposed on any regional fluid flow systems.

Geological Setting

The Mount Lofty Ranges comprise an interlayered sequence of marbles, psammitic, and pelitic metasediments that underwent medium-pressure (400–500MPa) regional metamorphism during the Delamarian Orogeny at 470–415Ma. Peak metamorphic grade increase from the lowermost biotite zone (T $\approx$ 350°C) to the migmatite zone (T $\approx$ 700°C) along a 50–55km section parallel to lithological strike, and synmetamorphic granite plutons occur in the highest grade areas of the terrain. Fig. 1 is a $T-X_{CO_2}$ section in the K_2O-CaO-MgO-Al_2O_3-SiO_2-H_2O-CO_2 system at 400MPa constructed using the data of Berman (1988). The marbles define a general increase in X_{CO_2} with temperature and, aside from a few skarned samples close to a granite, they do not contain low-X_{CO_2} assemblages. These data suggest that prograde metamorphism of the marbles was dominated by internal buffering.

Stable Isotope Data

Oxygen isotope ratios of 71 marbles and 156 metapelites from the Mount Lofty Ranges are shown in Fig. 2 (data from Cartwright *et al.*, 1994). The rocks are divided into: 1) 'normal' samples; 2) rocks from within 5m of the marble-metapelite contacts that are used to constrain across-strike fluid flow; 3) orthoamphibole-bearing metapelites; and 4) skarned garnet + wollastonite marbles at the contact with the Milendella granite. Both the metapelites and marbles show systematic changes in $\delta^{18}O$ values with regional metamorphic grade. From the lowermost biotite to the migmatite zone $\delta^{18}O$ values of normal metapelites decrease from 14–16‰ to as low as 9.0‰, and calcite (Cc) $\delta^{18}O$ values of normal marbles decrease from 22–24‰ to as low as 13‰. Both metapelites and marbles show additional isotopic resetting close to their mutual boundaries; however this is restricted to a 1–5m wide zone. In addition the marbles close to the Milendella granite have relatively low $\delta^{18}O$(Cc) values (12–13‰).

Discussion

The isotopic changes in Fig. 2 are greater than expected during internally-buffered devolatilisation, implying widespread fluid-rock interaction. Contact metamorphism prior to the regional event appears not to have affected these rocks, and there are very few indications of localised fluid flow (e.g. mesoscopic veins or mineralised faults). Except for the skarned marbles, down-temperature fluid flow from the granites ($\delta^{18}O \approx 8.4‰$) is unlikely to explain the resetting of oxygen isotopes in the metasediments due to: a) the paucity of skarns at granite-metasediment contacts; b) the absence of low-X_{CO_2} mineral assemblages in most marbles (Fig. 1); c) insufficient granite to provide the water required for isotopic resetting over 50–55km; and d) the fact that the $\delta^{18}O$ values of the marbles and metapelites retain a several permil difference even at high metamorphic grades. The observed oxygen isotope resetting may be accounted for by fluids flowing up-temperature along strike during the regional metamorphism with time-integrated fluid fluxes of up to $5x10^9$ moles/m^2 (Fig. 2). Fluids in the metapelites may have been derived from these rocks at lower grades; however, the degree of isotopic resetting in the marbles suggests that the fluids in this unit were, at least in part, derived from the surrounding siliceous rocks. Up-temperature fluid flow need not have overcome the buffering capacity of the marbles, explaining the trend in T-X_{CO_2} in Fig. 1. Variations in $\delta^{18}O$ at individual outcrops suggest that time-integrated fluid fluxes and intrinsic permeabilities may locally have varied by an order of magnitude. There has been no wholesale homogenisation of oxygen isotopes perpendicular to strike, and the marble-metapelite boundary represents a discontinuity in both $\delta^{18}O$ and X_{H_2O} values, suggesting that across-strike fluid flow was limited. For fluid flow lasting 0.1 to 10Ma actual fluid fluxes are 10^{-7} to 10^{-10}m/s and intrinsic permeabilities are 10^{-16} to $10^{-20}m^2$.

References

Cartwright, I., Vry, J.K., and Sandiford M.J. (1994) Changes in stable isotope ratios of metapelites and marbles during regional metamorphism, Mount Lofty Ranges, South Australia: mplications for crustal scale fluid flow. *Contrib. Mineral. Petrol.* In submission.