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Diffusional modification of prograde chemical zoning in garnet and its bearing on the estimates of prograde metamorphic conditions in medium to high grade rocks

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Preserved prograde chemical zoning in metamorphic garnet is often used for quantification of pressure and temperature conditions during its growth. However, from the time that zoning is established during growth, intra-crystalline diffusion continually acts to modify it. This operates at various rates throughout the entire metamorphic cycle and causes progressive deviation of garnet compositional profiles from those established during growth, potentially leading to large errors if these compositions are used to estimate pressure-temperature (P–T) conditions. To illustrate, we quantify the extent of compositional changes due to intra-crystalline diffusion occurring during 20 Ma of burial along 16–19°C/km geotherms followed by 1, 15 and 30 Ma of exhumation, for a pelitic sample. Typically, garnet growth in our modelling starts at c. 420°C and 5.5–7 kbar and is terminated at Tmax (600–750°C at c. 10–10.5 kbar). Calculations involve development of growth zoning (inferred from equilibrium thermodynamic modelling) and its simultaneous modification due to intra-crystalline multi-component diffusion along these prescribed paths. This allows us to quantify the extent to which zoning modification depends on crystal growth rate and size, maximum temperature achieved, and garnet composition.
The use of diffusionally modified garnet compositions for thermobarometry leads to shortening of the inferred prograde pressure-temperature paths (relative to the actual path experienced) and can introduce significant errors in estimates of P–T conditions at different stages of a rock's evolution. In our model example, the conditions of earliest garnet growth would be overestimated by c. 1.5–2 kbar and c. 40–70°C for garnet crystal diameters of c. 3–5 mm in samples eventually reaching mid-amphibolite facies temperatures (or by 2–4 kbar and c. 130–180°C for crystal diameters of c. 0.2–0.5 mm). The conditions of earliest garnet growth in crystals reaching 1 mm in diameter can be overestimated by up to c. 300°C for rocks achieving lower granulite facies conditions. Modification of the garnet composition during decompression also leads to underestimation of the peak pressure reached, by c. 1.5–2.5 kbar and c. 100–150°C for garnet diameters of c. 3–5 mm (if Tmax = 600–650°C) and by c. 2–3 kbar and 170–200°C for garnet diameters of c. 5–10 mm (if Tmax = 700–750°C). These results suggest that garnet compositional zoning must be considered with extreme caution when natural samples are used to obtain the prograde evolution of rock samples that reached peak metamorphic conditions exceeding c. 600°C, unless metamorphic timescale was very brief.