Goldschmidt 2023 Abstract
https://doi.org/10.7185/gold2023.17797

Diffusion-induced stress as a mechanism for mineral replacement with implications for the duration of metamorphic events

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Diffusion chronometry in compositionally zoned minerals offers insights into the duration of orogenic events and sometimes suggests surprisingly short timescales of regional metamorphism. Garnet chemical profiles from Holsnøy, Norway, for example, have been interpreted to represent 10^2–10^4 year timescales because of sharp changes in grossular mole fraction (X_{Grs}) [1]. Here, we investigate how sharp chemical profiles may be consistent with longer durations of metamorphism.

Subducted meta-anorthosite granulites from Holsnøy were partially metamorphosed under eclogite facies conditions [2] of ~680 °C and ~2.1 GPa [1,3], producing garnets with two distinct compositional zones [1-3]. The eclogite facies rims are more calcic ($X_{Grs} \approx 0.24$–0.26) than the relic granulite cores ($X_{Grs} \approx 0.16$–0.18). Rim–core profiles are asymmetric with relatively flat X_{Grs} rims followed by abrupt X_{Grs} drops (~0.05–0.06) over 1–2 micrometers at core-rim interfaces which then decay smoothly into the core composition. Abundant micrometer to sub-micrometer fracture networks propagated from the eclogite–granulite garnet interfaces into the granulite garnets.

We propose that diffusion-induced stresses between garnet zones create microfractures which allow for fluid infiltration and interface-coupled dissolution-reprecipitation (ICDR). Based on compositional stress theory [4-5], we show that diffusion between mineral zones with ~0.08 X_{Grs} difference can generate 400–500 MPa of differential stress. This stress keeps the composition change across the interface sharper than expected relative to standard constant pressure models. Further, the stress may create fractures in the garnet, facilitating fluid infiltration, ICDR, and the resultant asymmetrical chemical profiles. As diffusion-induced stresses limit the relaxation of compositional zones and allow for progressive ICDR, standard diffusion chronometry may substantially underestimate timescales of metamorphism. We suggest that the duration of eclogite facies metamorphism on Holsnøy may have reached or even exceeded 10^6 years.

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Financial support from the US National Science Foundation Directorate of Geosciences (EAR-2208229) is gratefully acknowledged.