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Diffusion-induced stresses preserve sharp chemical contacts: implications for subduction timescales with natural examples from Holsnøy, Norway.

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Intracrystalline diffusion is used to estimate timescales of igneous and metamorphic processes. When diffusion occurs between different-sized species, the associated volume change should generate internal stress. Standard diffusion models, however, assume a constant pressure, and the effects of diffusion-induced stress remain uncertain. Here, we present model results that reveal how stress impacts diffusion and provide natural examples using eclogite facies garnet.

We use the framework of Larché and Cahn to quantify diffusion-induced stresses [1]. They show that compositional stresses caused by composition change are analogous to thermal stresses caused by temperature change. Thus, modified thermoelastic equations provide a means to quantify compositional stress. Combining their approach with the multicomponent diffusion treatment of Hess and Ague [2] , we model the impact of compositional stress on the chemical evolution of garnet. Diffusion occurs until the decrease in chemical energy is balanced by the increase in strain energy from compositional stress. We find that compositional stress causes initially sharp chemical contacts to remain sharp while developing smooth, diffuse limbs.

We test our model using garnet from subducted metaigneous rocks, Holsnøy, Norway. The grossular garnet endmember has a 9–10% larger molar volume than the pyrope and almandine endmembers. Thus, Ca-Mg-Fe interdiffusion should generate stress. Garnets from Holsnøy have core-rim contacts with large (0.08–0.10) and small (0.01–0.02) X_{Grs} changes. The contacts with large X_{Grs} changes are extremely sharp; X_{Grs} drops by 0.04–0.05 over 1–2 µm. In contrast, contacts with small X_{Grs} changes have diffuse core-rim contacts. Using standard diffusion methods, the diffuse contacts yield a peak metamorphic timescale over an order of magnitude longer than the sharp contacts. When compositional stress is incorporated, both types of contacts yield the same, longer timescale of 200–300 kyr. Neglect of compositional stress in diffusion chronometry may therefore lead to underestimation of true timescales. The large core-rim X_{Grs} changes are predicted to generate hundreds of MPa of stress. Consistent with this prediction, garnet chemical maps reveal microfractures radiating from the core-rim boundaries.

[1] Cahn, J. & Larché, F. (1982). *Acta Metallurgica*, 30, 1835-1845.

[2] Hess, B., & Ague, J. (2023). *Geochimica et Cosmochimica Acta*, 354, 27-37.