

Challenging the garnet chemical-isotopic reliability in response to high-strain and temperature ductile deformation

DR. BRUNO VIEIRA RIBEIRO, PHD¹, CHRISTOPHER L. KIRKLAND², MELANIE FINCH³, CHRIS YAKYMCHUK⁴, STEVEN M. REDDY⁵ AND FREDERICO MEIRA FALEIROS⁶

¹Timescales of Mineral Systems Group, Curtin University

²Timescales of Mineral Systems Group, Curtin Frontier Institute for Geoscience Solutions, School of Earth and Planetary Sciences, Curtin University, Perth, WA 6103, Australia

³University of Melbourne

⁴University of Waterloo

⁵Curtin University

⁶Institute of Geosciences, University of Sao Paulo

Garnet is a common mineral in metamorphic rocks, prized for its chemical-isotopic systems that are sensitive to changes in pressure and temperature (P – T). This intrinsic characteristic makes garnet a valuable tool for constraining the conditions and timing of metamorphic and associated geological processes. However, the reliability of garnet's chemical-isotopic systems can be challenged by additional processes often associated with metamorphism, such as mineral intracrystalline deformation. Although garnet is typically considered a rigid and stable mineral, nanoscale studies have shown that dislocations within the crystal can cause segregation of major and trace elements like Ca, Mg, Fe, Na, and Ti into intracrystalline defects. Yet, the full extent of these processes on grain-scale garnet geochemistry remains underexplored. We investigate the impact of intracrystalline deformation on garnet chemistry (major and trace elements) and the Lu–Hf isotopic system via in situ laser ablation triple quadrupole spectrometry technique for the first time.

Our findings reveal that garnet recrystallization, leading to subgrain formation in response to grain boundary gliding, does not significantly promote grain-scale element mobility. However, elements such as Ca, Mg and trace elements (e.g., La, Ce, Lu, Hf, Sm, Ti, Zr and U) are mobilised on the grain-scale when the dislocation density exceeds the threshold needed to form a network, facilitating re-equilibration during retrograde shearing. Despite such grain-scale mobility, we show that associated P – T differences across low- and high-strain domains are negligible and unresolvable, reinforcing its geochemical robustness to estimate the prograde garnet growth conditions. Nonetheless, this dislocation network enables syn-kinematic Lu and Hf, directly affecting the garnet Lu–Hf geochronometer and thus the timing of intracrystalline deformation. Our results suggest that chemical perturbations and isotopic resetting in garnet under high-temperature deformation are more complex than previously assumed.