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On replacement reactions and grain size reduction

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Much remains to be learned about the links between metamorphism and deformation. Our work investigates how fluid-mediated mineral replacement reactions can load product grains with a high density of growth defects, thereby changing the physical and chemical properties of those grains, and their response to subsequent deformation. We focus on albite from a metagabbro that has experienced a replacement reaction and subsequent grain size reduction at greenschist facies conditions. Electron backscatter diffraction (EBSD) maps show that prior to grain size reduction, product grains are highly distorted, yet they formed, and subsequently deformed, at temperatures at which extensive dislocation creep is unlikely.

We use TEM to show that the observed distortion is attributable to the presence of growth dislocations. From crystal lattice curvature measured by high-angular resolution EBSD (HR-EBSD), we derive a geometrically necessary dislocation (GND) density, and show this is on the same order of magnitude as GND densities generated by crystal plasticity. We employ the Weighted Burgers Vector (WBV) algorithm to quantitatively describe the types of Burgers vectors present in GND populations. The WBV reveals the prominence of, among others, dislocations with apparent [010] Burgers vectors, which supports the idea that crystal plasticity is not responsible for the observed lattice distortion, as there are no known slip systems in plagioclase with a [010] Burgers vector.

We suggest the observed dislocations are derived from a lattice mismatch and volume change between parent and product, i.e. they are ‘misfit’ growth dislocations. HR-EBSD results demonstrate that the relatively high dislocation densities are associated with stored elastic strains on the order of 10-3. The stored strain energy provides a driving force for recovery and recrystallization. This occurs at lower than expected temperatures due to the presence of water, which increases grain boundary mobility. Grain size is reduced by one to two orders of magnitude, which relates to a reduction in viscosity of three to six orders of magnitude during subsequent creep deformation. As feldspar dictates the strength of the middle and lower crust, this aspect of fluid-rock interaction may exert fundamental controls on crustal deformation behaviour, and as such warrants further investigation in nature, theory and experiment.