Grain-scale equilibrium reactions guide fluid-driven eclogitization of dry crustal rocks

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When a fluid infiltrates dry rocks it facilitates re-equilibration of the mineral assemblage to the prevailing P-T-X conditions. This can promote weakening of the rock and subsequent ductile deformation. We present a detailed micro-structural and mineral chemical study of eclogitization of initially dry rocks of the continental crust that were not affected by ductile deformation. The studied sample features an incomplete, fluid-induced transition from lower crustal granulite to eclogite, and the transition is fully preserved. None of the mineral phases show any signs of ductile deformation, indicating that the transformation was entirely static. Material transport during the reaction was limited to the availability of an aqueous fluid. Our microstructural and mineral chemical observations along the transect reveal that the reaction occurs in three distinct steps: The plagioclase-plagioclase grain boundaries were the first to re-equilibrate followed by clinopyroxene-plagioclase and garnet-plagioclase phase boundaries. Lastly, the grain/phase boundaries that included only garnet and/or clinopyroxene are involved in the transformation. Thermodynamic modelling of local equilibria at dry (no H_2O) and wet (H_2O in excess) conditions reveals that this stepwise transformation is caused by the varying reactivity of the local assemblages at the prevailing P-T conditions. Those reactions that result in the largest decrease of the Gibbs free energy from the dry case to the wet case occur first. Once the reaction is facilitated, this effect is amplified by the volume decrease. This decrease is largest at those grain and phase boundaries that have reacted first, and leads to the formation of new fluid pathways. Our calculations reproduce the observed local mineral assemblages, indicating that element transport is limited, which is also supported by the observation that the fabric of the granulite is preserved in the eclogite. The process described here is self-amplifying and as a result reactive fluid flow is guided by the local energy budget along grain and phase boundaries. Element transport during static re-equilibration is limited to the extent where it is thermodynamically advantageous.