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Retrieving timescales of crustal evolution beneath a slow-spreading mid-ocean ridge: the case of Atlantis Massif (IODP Site U1309D, MAR 30°N)

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Our understanding of high temperature processes in the oceanic lithosphere requires a deep comprehension of solid-solid or solid-melt chemical exchanges in response to constantly varying conditions (e.g., temperature and melt chemistry). The diffusion kinetics controlling crystal chemical re-equilibration allow to reconstruct timescales of magmatic processes to ultimately reconstruct the dynamic evolution of the oceanic lithosphere. Beneath slow-spreading mid-ocean ridges and in ophiolitic analogues, local and partial assimilation of mantle intervals into gabbroic sequences is a process widely invoked to explain the disequilibrium textures and heterogeneous modal-geochemical compositions of gabbroic rocks. Likewise, intervals of primitive olivine-rich troctolites in the oceanic crust drilled at the Atlantis Massif (IODP Site U1309D, 30°N Mid-Atlantic Ridge) were interpreted as former mantle slivers. Olivine cores represent relicts of pre-existing mantle olivine, while clinopyroxenes and plagioclases are crystallized during reactive percolation of a primitive MORB. Here, we aim at constraining timescales of mantle-melt interactions and cooling of the Atlantis Massif gabbroic sequence to understand the dynamics of mantle assimilation into, and the formation of, slow-spreading oceanic crust. Geochemical traverses along olivine, which is in chemical equilibrium with adjacent clinopyroxene, show no core-to-rim chemical variations for major and trace elements compatible in olivine. Three-dimensional diffusion models reveal that complete chemical re-equilibration of 3 mm-size mantle-derived olivine with percolating MORB was attained within only ~30 yr (e.g., for Zn) and ~370 yr (e.g., for Fe-Mg and Ca) at magmatic conditions (T = 1200 °C and P = 2 kbar) (HTCR process). Temperature-dependent distributed elements, such as Ca ($K_d^{OL} < K_d^{CPX}$), display lower concentrations at olivine rims compared to the relative crystal cores, pointing to cooling induced subsolidus Ca re-distribution. Ca-cooling geospeedometry provides cooling rates of 0.01-0.001 °C/yr down to minimum temperatures of ~1000°C, which are similar to cooling rates determined throughout Hole U1309D using thermochronometry and magnetic data. According to geochemical profiles and diffusion modeling, the HTCR process is faster than the emplacement of single melt injections, suggesting that at each melt injection mantle is partially incorporated in the oceanic crust. The continuous uplift controlled by the long-lived detachment fault contributes to the rapid cooling of the magma bodies.