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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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The structure of the oceanic crust beneath slow-spreading ridges is heterogeneous and comprises gabbroic bodies and intervals of mantle rocks. Such heterogeneity characterizes the portion of the oceanic crust drilled at Atlantis Massif (IODP Site U1309, MAR 30°N). Intervals of primitive olivine-rich troctolites were recovered at different depths within the gabbroic sequence from IODP Hole U1309D. Their poikilitic-disequilibrium textures and heterogeneous modal-geochemical compositions were interpreted as marking local and partial assimilation of mantle intervals into the gabbroic sequence, during a period of enhanced magmatism. Olivines in olivine-rich troctolites represent relicts of pre-existing mantle olivine, while clinopyroxenes and plagioclases are crystallized during reactive percolation. The melt-rock interactions were triggered by percolation of primitive MORBs, but their timescales have never been modeled and remain uncertain. Our aim is to constrain timescales of (i) mantle-melt interactions and (ii) cooling of the gabbroic sequence forming the oceanic crust at Atlantis Massif. We intend to understand the dynamics of mantle assimilation into, and the formation of, slow-spreading oceanic crust. Chemical compositions of olivines are in equilibrium with those of poikilitic and interstitial clinopyroxenes. Geochemical traverses along olivine show no core-to-rim chemical variations for major (Mg# = 84-85 mol%) and trace elements (e.g., Co = 150-190 ppm; Zn = 71-86 ppm) generally concentrated in olivine. Flat profiles suggest complete chemical re-equilibration of olivine crystals with the locally modified percolating melt. Three-dimensional (3D) diffusion models reveal that complete chemical re-equilibration of 3mm-size mantle-derived olivine with percolating MORB can be attained within only ∼30 yr (e.g., for Zn) and ∼370 yr (e.g., for Fe-Mg and Ca), during a diffusive re-equilibration process at magmatic conditions (T = 1200 °C and P = 2 kbar). Because chemical zoning was not measured, and thus we have no constraints on the time lapsed after re-equilibration (past the kinetic window), the determined timescales of high temperature chemical re-equilibration (HTCR) are first order minimum durations. These timescales, together with the downhole chemical heterogeneity inherited from the precursor mantle, suggest that the oceanic crust at Atlantis Massif was formed by episodic small-scale (less than 10 m-thick) magmatic intrusions and partial assimilation of the upwelling mantle. Elements preferentially hosted in clinopyroxene (KdOL < KdCPX) display lower concentration at olivine rims compared to the relative crystal cores (e.g., CaO_rim = 0.04-0.06 wt% and CaO_core = 0.08-0.1 wt%). The core-to-rim decrease of Ca concentrations in olivine points to cooling induced subsolidus re-distribution of Ca from olivine into adjacent clinopyroxene. Ca-cooling geospeedometry provides cooling rates of 0.01-0.001 °C/yr down to a minimum temperature of ∼1000°C, which are similar to cooling rates determined throughout Hole U1309D using thermochronometry and magnetic data. Overall, constant downhole cooling rates suggest emplacement of multiple sills into approximately constant temperature lithosphere and depths. 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.