Rapid olivine growth in deep magmas: The symptoms

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Standard petrological and geochemical models assume that igneous minerals crystallize in conditions near equilibrium over large time scales (years to thousand years) due to slow rates of cooling in magma reservoirs in planetary interiors. Our investigation of several olivine-rich rocks (oceanites from Piton de la Fournaise and Hualalai, gabbros from the mid-Atlantic ridge and Rum Island, lunar basalt) reveals however that olivine usually crystallizes in conditions far from equilibrium over short time scales (minutes to weeks). The early rapid growth of olivine is evidenced by the occurrence of dendritic P-rich zoning, crystallographically aligned subcrystals, and inclusions of melt and Cr-spinel that presumably represent partial engulfment of a vestigial compositional boundary layer. We infer that olivine subsequently matures from dendritic into euhedral morphologies as the conditions approach equilibrium and growth mechanism switches from diffusion-controlled to interface-controlled. Our findings suggest that (1) igneous olivine does not crystallize in a concentric pattern from core to rim, but in a branching pattern from center to apices, followed by progressive backfilling; (2) the growth rates are not constant throughout crystal growth but vary from fast to slow (10^{-6} to 10^{-9} m/s); (3) magmas achieve high degrees of supersaturation with olivine, despite magmatic environments of slow cooling.