Reactive Melt Channelization in the Earth's Mantle

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The formation of oceanic plates requires extraction of large volumes of melt from the mantle. Several lines of evidence suggest that melt extraction is rapid and, therefore, necessitates high-permeability pathways. Such pathways may form as a result of melt-rock reactions.

We report the results of a series of Darcy-type experiments designed to study the development of channels due to melt-solid reactions in mantle lithologies. We sandwiched a partially molten rock between a melt source and a porous sink and annealed it at high pressure (P = 300 MPa) and high temperatures (T = 1200˚ or 1250˚C) with a controlled pressure gradient ($\partial P/\partial z$ = 0-100 MPa/mm). To study the influence of lithology on the channel formation, we synthesized partially molten rocks of harzburgitic (40:40:20 Ol –Opx –basalt), wherlitic (40:40:20 Ol –Cpx –basalt) and lherzolitic (65:25:10 Ol –Opx –Cpx) composition. The melt source was a disk of alkali basalt.

In all experiments, irrespective of the exact mineralogy, melt - undersaturated in silica - from the source dissolved pyroxene in the partially molten rock and precipitated olivine (~Fo_{82}), thereby forming a dunite reaction layer at the interface between the source and the partially molten rock. In samples annealed under a small pressure gradient, the reaction layer was roughly planar. However, if the velocity of melt due to porous flow exceeded ~0.1 μm/s, the reaction layer locally protruded into the partially molten rock forming finger-like, melt-rich channels in rocks of wherlitic and harzburgitic composition. The lherzolitic rocks were generally impermeable to the melt except at highest pressure gradients where a narrow fracture developed, forming a dyke which drained the melt reservoir. Three-dimensional reconstructions using micro-CT images revealed clear differences between the dyke (narrow, through-going planar feature) and the channels formed by reactive infiltration (multiple sinuous finger-like features). Apparently, the fraction of soluble minerals together with the melt fraction in the partially molten rock control whether dykes or reactive channels develop. Our experiments demonstrate that melt-rock reactions can lead to channelization in mantle lithologies, and the observed lithological transformations broadly agree with those observed in nature.

Keywords: melt - rock reaction, mantle, melt migration