Experimental Insights on Reactive Melt Migration in the Upper Mantle

MATEJ PEC[1] BEN HOLTZMAN[2] MARK ZIMMERMAN[3]
DAVID KOHLSTEDT[3]

[1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology (mpec@mit.edu)
[2]Lamont-Doherty Earth Observatory, Columbia University
[3]Department of Earth Sciences, University of Minnesota

The formation of oceanic plates requires extraction of large volumes of melt from the mantle and emplacement along a narrow spreading centre. 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.

Here 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). The partially molten rock is formed from 50:50 mixtures of San Carlos olivine (Ol, ~Fo_{90}) and either clinopyroxene (Cpx) or orthopyroxene (Opx) plus 4, 10 or 20 vol% of alkali basalt. The source is a disk of alkali basalt.

During the experiments, melt, undersaturated in silica, from the source dissolved pyroxene in the partially molten rock and precipitated an iron-rich Ol (~Fo_{82}), thereby forming a pyroxene-free reaction layer at the interface between the source and the partially molten rock. In experiments 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. Three-dimensional reconstructions using micro-CT images revealed that the morphology and spacing of the channels depends on the initial melt fraction of the partially molten rock. With 20 vol% melt, multiple and voluminous channels developed. At lower melt contents, fewer and thinner channels developed. The exact mineralogy (Ol:Cpx or Ol:Opx) did not seem to influence the channel morphology. This process of channel development was accompanied by an abrupt increase in effective permeability of the partially molten rock as recorded by the pore-pressure volumometer.

Our experiments demonstrate that melt-rock reactions can lead to channelization in mantle lithologies. Channelization significantly increases the bulk permeability and allows for rapid melt extraction. The observed lithological transformations broadly agree with those observed in nature.