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Fluid flow pathways through the oceanic crust: reaction permeability and isotopic tracing

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It is generally assumed that the dominant means of creating permeability in ocean floor hydrothermal systems is fracturing, induced either by cooling or by tectonic stress. Here we show textural evidence that metamorphic reactions can create a hierarchy of permeable pathways through gabbroic rocks similar to a fracture hierarchy. Isotopic microsampling shows that just as with fractures, most flow occurs through the larger channelways, and that even at the microscale, flow can be extremely heterogeneous with alteration affecting only certain minerals in the framework, leaving others untouched. Reaction permeability is created in three ways; dissolution creating open porosity, microcracking due to volume increase reactions involving olivine, and expansion of water due to rapid heating in dyke margins, particularly when intruded into brecciated rocks.

Our data comes from IODP Hole U1309D, which was drilled to 1400 mbsf in the footwall of the Atlantis Massif detachment fault at the Mid-Atlantic Ridge 30°N. The core is composed of gabbroic rocks interlayered with olivine rich troctolites, with several basalt/diabase sills in the top 130 m. The dominant alteration occurred in the greenschist facies, at depths at least 1 km below seafloor, and decreases in intensity downhole. Whole rock oxygen isotope values range from +5.5 permil to +1.5 permil, indicating variable degrees of interaction with seawater at temperatures generally > 250 °C. Gabbroic rocks and diabases exhibit a range of Sr isotope ratios from MORB values (0.70261) to intermediate ratios (0.70429). Microsampling shows that amphiboles are often more radiogenic than coexisting plagioclase and can sometimes be isotopically altered in the same rock as completely unaltered primary minerals. Large (10 cm) amphibole-filled vugs show values ranging up to 0.708, close to seawater. In some cases however the secondary minerals are virtually unaltered indicating low fluid fluxes in pervasive alteration.

SEM textures in broken surfaces reveal extensive evidence for dissolution reactions creating porosity, particularly in diabase where pyroxene is selectively dissolved and the porosity partially filled by actinolite needles. If far-from-equilibrium fluid (such as black smoker fluid) interacts with pyroxene at 300-400 °C, dissolution rates of several microns/day are possible. Fluid volume increase in dyke margins due to heating provides space nearby for dissolved components to precipitate without immediately closing the dissolution porosity, which may be an important part of the process. Amphibole-filled vugs in gabbro are interpreted as the final result of the positive feedback between dissolution and permeability – creating fluid flow tubes analogous to karst in limestone. But in contrast, permeability created by volume increase cracking is self-limiting once the primary phase responsible (olivine) is gone, and hence leads to pervasive olivine replacement but little fluid flux.