Melt transport in the mantle beneath oceanic spreading ridges

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Tabular dunites within the mantle section of the Oman ophiolite fulfill chemical and structural criteria for porous conduits that preserve disequilibrium between the mantle and migrating melts at depths from ~ 45 km to the base of the crust (Kelemen et al., Nature 95, JGR 95, Phil Trans Roy Soc London 1997, G-cubed 00).

Porous flow in dunites can account for the flux of pyroxene-undersaturated melt from > 1 GPa to the base of the crust (Braun & Kelemen, G-cubed 02). 226Ra excess is negatively correlated with 230Th excess in young MORB from the East Pacific Rise (Sims et al., GCA 02) as predicted (97). 226Ra excess likely has a shallow origin, perhaps by reaction of Th-bearing melt and depleted, uppermost mantle (Jull et al., GCA 02, submitted).

Transport of ~ 90-95% of melt in high porosity (~3%) dunite conduits, with the rest migrating by diffuse porous flow through residual peridotites, accounts well for available data. Obviously, melt transport in dikes is important in the cold "lithosphere". Hydrofracture may generally arise within one compaction length of the base of the thermal boundary layer, where melt moving via porous flow begins to crystallize in pore space (Kelemen et al., JGR 95; Korenaga & Kelemen, JGR 97; Kelemen & Aharonov, AGU Monograph 98), and at shallower depths.

New studies (Braun & Kelemen, 02 in prep.; Hassler et al., 02 in prep.) confirm that Oman mantle dunites equilibrated with MORB-like melts (Kelemen et al., Nature 95). Trace cpx in Oman mantle dunites is in REE exchange equilibrium with MORB and with lavas that formed the crust at an oceanic spreading ridge. Spinels in Oman dunites have ~ 0.2 to 1 wt% TiO_2, similar to high Cr# spinels in MORB and dredged dunites from ocean ridges, but different from low-Ti spinels in residual peridotite worldwide, and in mantle dunites from some ophiolites (e.g., Bay of Islands, Suhr et al., G-cubed 02). Gradients in composition at Oman mantle dunite contacts are sharp, with width/element independent of diffusivity. Dunite contacts formed via reaction with melt during porous flow, rather than in a static, diffusive boundary layer.

As may be common (e.g., Becker et al., EPSL 01), Oman dunites show higher whole-rock $^{187}Os/^{188}Os$, and lower Os and Ir concentrations, than residual harzburgites (Hassler et al., 02 in prep.). Re-decay at measured concentrations cannot account for the isotope variation. If the differences are not due to alteration, then melts in dunites must have had higher Os isotope ratios than the surrounding peridotites, and must have been capable of dissolving Os- and Ir-rich phases during transport.

Thermal convection of the mantle wedge

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Thermal models suggest that partial melting of subducted material older than 20 Ma is unlikely beneath arcs. In contrast, geochemical and petrological inferences – e.g., explanations for high Th/La in basalts, as well as for data on "adakites"– suggest that partial melting of subducted basalt and sediment is common.

PT estimates for equilibration of primitive arc lavas with the mantle, and for metamorphic conditions in the Kohistan and Talkeetna arc sections, including our new results, require Moho temperatures of ~ 900-1000°C at ~ 1 GPa, ~200 to 400°C hotter than in thermal models. Crystallizing melts do not have to lie on a steady-state geotherm, so petrological estimates need not coincide with the thermal structure in models. However, other constraints suggest that high Moho temperatures are present over large regions for long periods of time.

Thermal models do not account well for the shape of low velocity anomalies in the mantle wedge beneath arcs. Observations of a 6% slow P-wave velocity anomaly at the base of arc crust for long distances along the strike of the NE Japan and Tonga arcs (Zhao et al., 92 to 00) suggest that there is melt in the mantle just below the arc Moho. In addition, arc topography and gravity data are better fit with a weak coupling between the subducting plate and the overlying mantle (Billen & Gurnis, EPSL 01).

If the mantle wedge viscosity is lower than has been considered in previous modeling, due to the effects of H_2O and/or melt, then cooling at the base of the arc and along the subduction interface could lead to thermal convection that is faster than the subduction velocity, thinning thermal boundary layers at the base of the arc and above the subducting plate. This will occur if mantle wedge viscosities are less than ~ 10^{19} Pa s. Thermal convection in a weak wedge could raise temperatures at the top of the subducting plate by at least 100°C, suggesting that melting of subducted material in normal, steady-state subduction is inevitable, rather than impossible.

Other alternatives to explain high Moho temperatures are non-steady "delamination" of lower arc crust or advective transport of heat by rising diapirs and/or magma. However, these scenarios are unlikely to produce a weak, low Vp mantle wedge at steady-state, or to raise the temperature of subducting basalt and sediment.