The origin of magma lenses and the deep crustal structure of fast spreading ridges

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A key unsolved problem is the role of axial magma chambers in the growth of ocean crust. Gabbroic rocks from Hess Deep, drilled during ODP Leg 147, record processes of melt migration and channelized magma flow and provide direct evidence that the entire thickness of the gabbroic layer forms simultaneously, not from the top down as previously believed. In the "top down" model, the gabbroic layer is formed by the downward accumulations of crystals settling out of the magma lens. In this model, the cumulate crystals build downward with high melt porosity and compact slowly to produce the gabbro layer. However, the mineral chemistry of the gabbros shows that they were crystallized from very hot melts, chemically unlike those found at site 894 (oxide-rich ferrogabbros and tonalite dikelets) interpreted to be the frozen residues of a magma lens.

Further, textural evidence suggests that pressure solution, resulting in extensive mutual interpenetration of grain boundaries, was an important process in reducing melt porosity in the gabbros ([*Natland and Dick,* 1996] and this volume). This is consistent with geochemical evidence suggesting that the gabbros froze with less than 4% of melt trapped between crystals and with the prediction that rocks beneath the melt lens must have less than 5% melt, based on low attenuation of seismic shear waves [*Burnett et al.,* 1989]. Such a low residual melt porosity requires an extremely efficient process of expulsion of melt from between crystals, inconsistent with simple compaction. At the same time, examination of the cores shows that most crystal growth and melt expulsion occurred in generally vertical fracture networks or narrow dike-like bodies averaging about 3 m, but ranging down to as little as 1 cm, in thickness. What emerges is a picture of very rapid melt expulsion from a mostly-solid layer of gabbro directly beneath the melt lens. Melt expulsion was not only thorough, but occurred almost immediately, providing a nearly impermeable base into which dense, iron-rich magmas in the thin melt lens could not sink.

Cores from Leg 147 show that the melt lens is a pool of the coolest, most highly fractionated, iron-rich and siliceous melt at the top of the crystallizing melt column. Calculated melt and solid densities indicate that all melts, no matter how iron-rich, are buoyant throughout the lower crust, so the melt lens does not represent a level of neutral buoyancy. Instead, the lens collects against an upper cap rock of hot but impermeable sheeted dikes. The lens is available to mix with more primitive magmas during major inflation-eruption cycles, which have to rupture this cap rock before magma can escape to the sea floor.

References:
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