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Igneous crystallization and localized deformation > 15 km beneath the Mid-Atlantic Ridge, 14-16 N

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ODP Leg 209 drilled 19 holes at 8 sites along the Mid-Atlantic Ridge (MAR) from 14°42' to 15°44' N. At 6 sites, 354 m of core over 1075 m of penetration recovered a mixture of peridotite and intrusive gabbroic rocks. Drilling at 4 sites yielded 25% gabbroic rocks and 75% peridotite. Core from a 5th site is mainly peridotite. Core from the 6th, Site 1275, is gabbroic, but contains 24% lherzolite interpreted as residual peridotite "impregnated" by igneous plag and pyroxene. Impregnated peridotites are also found at 3 other sites. The overall proportion of gabbroic rocks versus peridotite from all 6 sites is similar to dredging and submersible sampling in the area.

Impregnated peridotites from Site 1275 have "equilibrated" textures and contain olivine, 2 pyroxenes, plag and Cr-rich spinel. Mg#, Cr# and Ni are high, extending to residual peridotite values. Crystallization pressure can be estimated using local lava compositions. 87 MORB glasses from 14 to 16°N with Mg# from 60 to 73 [from PetDB] could be plagioclase lherzolite saturated at 5.4 kb (±1.4 kb, 2σ) and 1220°C (±16°C, 2 σ) [using Kinzler & Grove, JGR 92]. Plag ranges from An 60 to 75. Subsolidus PT for the plag spinel lherzolite assemblage are not well constrained, but are about 3 to 6 kb and 700-1200°C, consistent with igneous PT estimates. Thus, melts began to cool and crystallize at depths > 15 km.

Impregnated and residual peridotites in our core appear undeformed. Though they may have a strong olivine LPO, there are few shape fabrics. Instead skeletal, interstitial pyroxene and spinel extend for mm in 2D and 3D. Core from 5 of 6 sites (except 1275) includes high T mylonitic shear zones (mainly impregnated peridotite) and low T fault gouge. Shear zones and faults are not all parallel; numerous, cross-cutting planes of localized deformation formed at >1000°C to <100°C, from >15 km to the seafloor. These accommodated subsolidus deformation during corner flow and exhumation of peridotites and high P igneous rocks, in keeping with previous inferences that the thermal boundary layer beneath the MAR extends to about 20 km. Penetrative deformation of blocks between shear zones and faults was minor. If this is a general process at slow-spreading ridges, then one would predict that shallow mantle anisotropy in the Atlantic would be less pronounced than in the Pacific, consistent with recent seismic data.

5.6.13

Constraints from the Gakkel Ridge on the origin of MORB

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Basalts recovered from the ultra-slow spreading Gakkel Ridge (GR) allow tests of several hypotheses for the petrogenesis of MORB (1). This ridge has the slowest spreading rate of any major ridge system and must reflect the effects of thickening lithosphere as the spreading rate slows to the east. Do the geochemical effects of a thick lid mimic those of mantle temperature, or are lithospheric thickness and mantle temperature readily distinguished? (2) It has long been suggested that the mantle contains low melting components that carry a signal of trace element and isotope enrichment, and therefore that the apparent source composition becomes progressively enriched as extent of melting decreases. Recent Nd and Os isotope evidence support this view. With its thin crust and great depths, the Gakkel ridge represents the lowest mean extent of melting, therefore the average composition should be the most enriched. The apparent source enrichment should increase as spreading rate slows eastwards.

Major element composition of Gakkel basalts reflects the low extents of melting by which the thin crust is derived, with very high $Na_{8.0}$ values correlating with depth. Major pressure-sensitive elements show systematic changes eastward. Melting process modeling shows thicker lithosphere leads to lower silica content with little change in $Fe_{8.0}$, in contrast to mantle temperature variations that cause lower silica with increasing $Fe_{8.0}$. Lid thickening effects are observed in the Gakkel data, with lithosphere as thick as 40 km at slowest spreading. The major element effects are distinguishable from those of mantle temperature and show that changing thickness of the cold lid does not account for global systematics.

The Gakkel Ridge mean trace element composition is within error of MORB global average, except for high Sm/Yb and Dy/Yb in the eastern samples, reflecting the thickening lithosphere. Garnet must play a role in MORB melting even at these slow spreading rates and cool temperatures. Highly incompatible element abundances are similar to average values from other basins. While Rb, Cs, and Ba are higher than the mean EPR lava, they are lower than the mean MAR and very similar to the mean Indian Ocean MORB. There is no systematic increase in source enrichment eastward. Thus on the basis of a regional basin comparison and from the along strike gradient, there is scant evidence for a global relationship between melting extent and source enrichment.