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Geochemistry of Gakkel Ridge

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The Arctic Mid-Ocean Ridge Expedition (AMORE 2001) mapped and sampled the western 1000 km of Gakkel Ridge in 2001. Seafloor spreading is nearly orthogonal at 1.3 cm/yr in the west and 1.0 cm/yr in the east, with no large ridge offsets or hotspots. Multibeam bathymetry and dredge lithology show three distinct magmatic-tectonic zones. The Western Volcanic Zone [WVZ: 8° W – 3°E] has several elongate volcanic highs with no offsets. The Sparsely Magmatic Zone [SMZ: 3°E-29°E] extends from a sharp boundary at 3°E where the axis abruptly becomes 1000 m deeper and only peridotites are exposed on the axial valley floor for 120 km, and there is sparse volcanism for ≈250km. The Eastern Volcanic Zone [EVZ: 29°-85°E] has localized volcanic centers separated by lengthy sections of tectonized seafloor. Volcanism is highly focused without offsets, showing that magmatic segmentation can arise by mantle processes alone.

$Na_{8.0}$ of basalt is high, and extent of melting is low along Gakkel R.. Extent of melting varies irregularly: it is slightly higher in the WVZ, and lowest in the SMZ. $Fe_{8.0}$ is low and anticorrelated with $Na_{8.0}$, suggesting that mantle temperature is low. Amount of melting is not correlated with spreading rate along axis. Instead, we suggest melting becomes more sensitive to changes in mantle composition and temperature at ultraslow rates. Peridotite compositions generally show low extents of melting but are juxtaposed with highly depleted lherzolites and dunites that may reflect earlier melting events and/or local zones of melt extraction (Dick et al., this volume).

La/Sm in basalts, an indicator of mantle enrichment, decreases from 8°W to 3°E in the WVZ. The strong depletion and low temperatures account for the break in magmatic activity at 3°E. High La/Sm at 15°E decreases eastward to constant intermediate values. All MORB from the WVZ are enriched in H_2O and Ba relative to rare earth elements (REE), and have high H_2O/Ce and Ba/La. To a lesser degree, they are enriched in REE relative to Nb. The order of enrichment is H_2O>Ba>Rb>K>La: similar to certain subduction zone signatures. There is a sharp gradient or boundary in H_2O/Ce and Ba/La at 3°E. To the east, basalts resemble Pacific MORB. To the west, H_2O/Ce and Ba/La remain high along Knipovich Ridge, suggesting a large anomaly. Sr-Nd-Pb-He isotopic data (Soffer et al., this volume) provide additional constraints on the nature of this distinctive geochemical anomaly.

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An arctic mantle domain boundary: Evidence from the Gakkel Ridge

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Basalts from the ultra-slow spreading Gakkel Ridge (GR) between 7ºW and 86ºE allow characterization of the scale and impact of Arctic upper mantle heterogeneity. The GR has no fracture zone offsets and the spreading rate varies smoothly from ~12 to ~6 mm/yr from west to east. Michael et al. (Nature 2003) observe that this change is associated with decreased degrees of melting (F) eastward but not with increased source enrichment. They divide the GR into three zones based on inferred magma supply: the magmatically robust Western Volcanic Zone (WVZ), the deep Sparsely Magmatic Zone (SMZ), and the volcanically punctuated Eastern Volcanic Zone (EVZ). We report Sr-Nd-double spike Pb-He isotopes and ICP-MS trace elements on GR basalts, showing that the Arctic upper mantle houses a sharp geochemical discontinuity near the SMZ midpoint that resembles the Australian-Antarctic Discordance (AAD).

The WVZ (7ºW-3ºE) and EVZ (27ºE-86ºE) possess distinct geochemical signatures indicating the robust nature of the boundary. The EVZ does not display elevated abundances of the LIL elements Cs, Rb, and Ba, despite the slower spreading rate and decreased F. Moreover, EVZ basalts have the lowest Sr isotope ratios among ridges north of Iceland, indicating that the EVZ mantle shows the greatest long-term LIL element depletion among these ridges. WVZ basalts form a field at higher Sr-lower Nd isotope ratios than the EVZ, with no overlap. WVZ lavas have lower $^{3}He/^{4}He$ and high $^{208}Pb/^{206}Pb$, akin to Indian Ocean MORB, yet they lack elevated $^{207}Pb/^{204}Pb$. Instead, they cluster with EVZ basalts below the Indian MORB trend.

The Gakkel geochemistry has important implications for the dynamics of ultra-slow sea floor spreading which are not consistent with some simple models of MORB genesis. For example, the decreased west-to-east spreading rate and lower F are not accompanied by preferential sampling of enriched veins. Moreover, the SMZ is not simply a surface tectonic expression of ultra-slow spreading rates (c.f. Dick et al. Nature 2003). Models must account for the fact that the SMZ (like the AAD) contains a convective boundary that separates upper mantle domains, which exist independent of spreading rate. Common features of the SMZ and AAD (great depths, fracture dominated topography, low magma production, boundaries separating mantle domains with coherent isotopic characteristics, and histories reflecting long-term convective isolation) indicate a close relationship between sea floor structure, bathymetry and upper mantle convective processes.