

Supplemental Text

1. Lithologic Distribution

All samples were classified into seven lithologic groups for statistical comparison, with the exception of samples from the earlier Polarstern Cruise 4, which can be found in *le Roex et al.* [1992]. In all 4045 kg of rock was recovered from the orthogonal super segment, with an equal number of dredge stations located on the rift valley walls and floor. The breakdown of recovered rocks includes, 86% basalt, 5% diabase, 4% peridotite and dunite, 3% gabbro, and 2% hydrothermal and volcanoclastic deposits (plus erratics). On the oblique super segment, 3512 kg of rock from the three amagmatic segments was principally collected from the rift valley walls, which excluding erratics consisted of 44% peridotite and dunite, 39% basalt, 2% diabase, 2% gabbro, and 8% volcanoclastics, hydrothermal deposits, and massive sulfides. Joseph Mayes Seamount yielded 318 kg of rock, with 97% being basalt and pillow basalt, 2% diabase and 1% erratics. The volcanically active yet deeply rifted Narrowgate segment yielded 1119 kg of rock, of which 67% was basalt/pillow basalt, 21% diabase, and 11% hydrothermal and volcanoclastic material. The majority of the Narrowgate segment dredge hauls were located on the rift valley walls. As mentioned in the main text, we interpret our inability to recover basalts from both rift valley floor and wall locations to indicate a localized absence of basaltic crust, as ocean basalts are highly fractured relative to peridotite and gabbro and thus are more readily sampled by dredging.

2. Analytical Methods

Electron Microprobe Analytical Details

Major element basalt glass analyses were made on a five-wavelength-spectrometer JEOL JXA-8900R electron microprobe at the Smithsonian Institution using JEOL software with ZAF corrections. Each glass was analyzed for 10 elements with a 24 by 17 um rastering beam at 15 kV and 20 nA. Count times for major elements were 10 seconds on peak and 5 seconds off peak for background correction, except for K₂O, MnO and P₂O₅, which had slightly longer count times. The internal basalt glass standard VG-2 [Melson et al., 2001] was used with three mineral standards: apatite, microcline, and

magnetite. To monitor for instrumental variation VG-2 was run at the beginning of each 45-sample mount and after every 10 samples. A minimum of five spots comprised each glass data analysis. Analyses having sums less than 98.5% and greater than 100.5% were deleted and rerun. If 1σ for the unknown sample is not less than the 2σ for all VG-2 analyses, the sample was rerun. Analytical details are further discussed in Melson et al., [2001].

Fourier Transform Infrared Spectroscopy (FTIR)

Basalt glass volatile concentrations were measured at the University of Tulsa using micro-FTIR methods. Visibly unaltered glass shards were chosen from a representative sample suite. In all 40 glasses were measured for CO_3^{2-} , molecular CO_2 , molecular H_2O (H_2O_m), and OH. Glass shards were mounted in Buehler Transoptic® and polished on both sides to a wafer thickness of 40–300 μm . Thickness measurements were made with a digital micrometer (± 1 μm precision) and mapped on photographs for later reference. Samples were analyzed using established methods [e.g., Dixon et al., 1995a; Michael, 1995], with absorbance measured for dissolved water (3535 cm^{-1}), molecular water (1630 cm^{-1}), and carbonate bands (1515 and 1430 cm^{-1}) at two points on each wafer, and on two different wafers for each sample. Dissolved water concentrations for most samples represent the average of four spot measurements, with an average reproducibility for all samples equal to 4% and for most samples less than 3%. Carbonate bands (1435 and 1515 cm^{-1}) and molecular water (1630 cm^{-1}) absorbance spectra were corrected for background spectrum by subtracting a devolatilized basalt glass [Dixon et al., 1995a]. The carbonate doublet and molecular water peaks were fit to this background level and subjectively adjusted using existing methods [e.g., Dixon and Stolper, 1995b]. CO_2 reproducibility was generally 15-20% due to the uncertainty in the compositional dependence of the molar absorptivity for dissolved carbon in silicate glass and the uncertainty in the background correction methods. Degassing corrections are discussed in the results section.

3. Pressure of Partial Crystallization - Caveats

The possibility exists that significant low-pressure Ol + Plag fractionation may occur after high-pressure Ol + Plag + Cpx fractionation, thereby overprinting the initial

crystallization history and resulting in calculated pressures skewed too low. This may influence the Narrowgate segment and especially Joseph Mayes Seamount basalts, which have low Mg#s, generally phyric basalts (mostly Ol + Plag), and the shallowest ridge depths. On the other hand, low pressure petrogenetic signatures observed in basalts formed by low mass fractions of melting may also be skewed as a result of elevated alkalis, which tend to expand the olivine liquidus field [e.g., *Biggar and Humphris*, 1981; *Langmuir et al.*, 1992; *Roeder*, 1974] and mask prior high-pressure signals. While it is not clear whether these low partial crystallization pressures at Joseph Mayes Seamount and Narrowgate segment reflect shallow initiation of Ol + Plag + Cpx crystallization or overprinting of higher pressure fractionation, they are in line with calculated basalt pressures from the slow-spreading Reykjanes Ridge (20 mm/yr) [*Dmitriev*, 1998; *Grove et al.*, 1992; *Herzberg*, 2004; *Michael and Cornell*, 1998], where crustal magma chambers have been seismically imaged. Although *Michael & Cornell* [1998] explain the low crystallization pressures along the Reykjanes Ridge by increased thermal or melt flux from the nearby Iceland plume, our study area is far from active plume upwelling and thus any added thermal/melt flux would more likely result from melt focusing toward magmatically robust segments and away from amagmatic accretionary segments. Another possible origin of an increased thermal flux could be localized 3-D upwelling beneath the ridge. Furthermore, we note that Narrowgate segment represents a very robust volcanic segment, while Joseph Mayes Smt. appears to be the largest non-hotspot ridge volcano in the world.

Another potential concern associated with estimating the equilibrium pressure for liquid + Ol + Plag + Cpx is the complex process of melt-rock reaction and/or magma mixing. This has occurred in gabbroic segregations in melt-transport channels drilled at ODP Site 895 in EPR mantle sections at Hess Deep [*Dick and Natland*, 1996]. MgO and Mg/(Mg+Fe) in such melts will be buffered by mantle olivine, even as the normal crystallization sequence for that pressure occurs. Thus, melts that have undergone partial crystallization of Ol-Pl-Cpx with partial or even complete re-equilibration in mantle conduits will give partial crystallization pressures that are too high, as Cpx appears on the liquidus at higher MgO than it would otherwise (shifting Cpx saturation to the right in Figure 9). Similarly, if melts dissolve olivine and precipitate Cpx during percolation

through gabbroic cumulates in the crust, as commonly seen in ODP Hole 735B gabbros [Dick and Natland, 1996], this will also increase MgO and Mg/(Mg+Fe) for a given CaO or incompatible element concentration [Kvassnes and Dick, 2000]. With variable extents of melt-rock interaction, one would anticipate calculation of highly variable partial crystallization pressures, particularly in regions with thicker lithosphere, such as near transforms, at ultraslow-spreading ridges, and where late melt percolation through crustal cumulates is likely significant [Dick *et al.*, 2003].

4. Correction for Hydrous Fractionation to 8 wt.% MgO

To examine the basalt chemical variability more closely, we correct glass compositions to a constant MgO value of 8 wt.%. This serves to remove the effect of low-pressure fractionation [Klein and Langmuir, 1987], however, corrected values do not represent primitive melts in equilibrium with Fo₉₀ mantle olivine. They instead serve as parental compositions, which are easily compared to other MORB suites corrected to MgO 8.0 wt.%. In order to accurately compare our data with primitive melt compositions (experimental), the latter must be fractionated to 8 wt.% MgO using the same model for fractionation. Hence, we use ‘hBasalt’ for backward and forward modeling, which takes into account the suppression of plagioclase saturation with respect to olivine and clinopyroxene [e.g., Michael and Chase, 1987]. If the effects of water are not taken into account, Fe₈ and Ti₈ values are much lower [Asimow and Langmuir, 2003] and are thus misleading for assessment of melting conditions and melt transport processes.

Corrected basalt values are calculated by regressing best-fit model LLDs for each basalt group. For each corrected lava composition, the MgO content at which plagioclase saturates the crystallizing assemblage was then calculated and averaged for each group. When correcting SiO₂, TiO₂, FeO*, Na₂O, K₂O, and H₂O, the MgO content of the individual lava and the MgO content at which plagioclase becomes saturated (MgO_{plag_in}) determines the exact regression slope(s) used. In some cases the regression slope for a given basalt group was not statistically significant, thus groups were combined and a single regression slope applied. All element-specific regression slopes are reported in Table 5, as is a detailed description of the fractionation-correction methodology for each basalt group.

5. References

- Asimow, P. D., and C. Langmuir (2003), The importance of water to oceanic mantle melting regimes, *Nature*, *421*, 815-820.
- Biggar, G. M., and D. J. Humphris (1981), The plagioclase, forsterite, diopside, liquid equilibrium in the system CaO-Na₂O-MgO-Al₂O₃-SiO₂, *Mineral. Mag.*, *44*, 309-314.
- Dick, H., J. Lin, and H. Schouten (2003), An ultraslow-spreading class of ocean ridge, *Nature*, *426*, 405-412.
- Dick, H. J. B., and J. H. Natland (1996), Late stage melt evolution and transport in the shallow mantle beneath the East Pacific Rise, in *Scientific Results*, edited by K. Gillis, C. Mevel, J. Allan and e. al., pp. 103-134, Ocean Drilling Program, Texas A&M University, College Station, TX.
- Dixon, J. E., E. Stolper, and J. R. Holloway (1995a), An experimental study of water and carbon dioxide solubilities in mid-ocean ridge basaltic liquids, Part I, Calibrations and solubility models, *J. Petrol.*, *36*, 1607-1631.
- Dixon, J. E., and E. Stolper (1995b), An experimental study of water and carbon dioxide solubilities in mid-ocean ridge basaltic liquids, Part II, Applications to degassing, *J. Petrol.*, *36*, 1633-1646.
- Dmitriev, L. (1998), Chemical variability of mid-ocean ridge basalts as a function of the geodynamic setting of their formation, *Petrology*, *6*, 314-334.
- Grove, T. L., R. J. Kinzler, and W. B. Bryan (Eds.) (1992), *Fractionation of Mid-Ocean Ridge Basalt (MORB)*, 281-310 pp., American Geophysical Union.
- Herzberg, C. T. (2004), Partial crystallization of mid-ocean ridge basalts in the crust and mantle, *J. Petrol.*, *45*, 17.
- Klein, E. M., and C. H. Langmuir (1987), Global correlations of ocean ridge basalt chemistry with axial depth and crustal thickness, *J. Geophys. Res.*, *92*, 8089-8115.
- Kvassnes, A., and H. J. Dick (2000), Deviations From dry Fractionation Trends in Gabbros From Atlantis Bank, South West Indian Ocean, *EOS, Transactions of the American Geophysical Union*, *82*(20).
- Langmuir, C. H., E. M. Klein, and T. Plank (1992), Petrological systematics of mid-ocean ridge basalts: constraints on melt generation beneath ocean ridges, in *Mantle Flow and Melt Generation at Mid-Ocean Ridges*, edited by J. Phipps Morgan, D. K. Blackman and J. M. Sinton, pp. 183-280, American Geophysical Union, Washington, D.C.
- le Roex, A. P., H. J. B. Dick, and R. T. Watkins (1992), Petrogenesis of anomalous K-enriched MORB from the Southwest Indian Ridge: 11°53'E to 14°38'E, *Contrib. Mineral. Petrol.*, *110*, 253-268.
- Melson, W. G., T. O'hearn, and E. Jarosewich (2001), A data brief on the Smithsonian abyssal volcanic glass data file, *Geochem. Geophys. Geosys.*, *3*(2001GC000249).
- Michael, P. J., and R. Chase (1987), The influence of primary magma composition, H₂O and pressure on mid-ocean ridge basalt differentiation., *Contrib. Mineral. Petrol.*, *96*(2), 245-263.
- Michael, P. J. (1995), Regionally distinctive sources of depleted MORB: Evidence from trace elements and H₂O, *Earth Planet. Sci. Lett.*, *131*, 301-320.
- Michael, P. J., and W. C. Cornell (1998), Influence of spreading rate and magma supply on crystallization and assimilation beneath mid-ocean ridges: evidence from chlorine and major element chemistry of mid-ocean ridge basalts, *J. Geophys. Res.*, *103*(B8), 18325-18356.
- Roeder, P. L. (1974), Activity of iron and olivine solubility in basaltic liquids, *Earth Planet. Sci. Lett.*, *23*, 397-410.