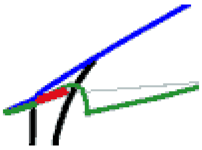

No Plumes Along Mid-Ocean Ridges

Dean C. Presnall

Department of Geosciences, University of Texas at Dallas, Texas, USA

Bayerisches Geoinstitut, Universität Bayreuth, Germany

Geophysical Laboratory, Washington, D. C., USA

dpresnall@ciw.edu

Hot plumes were considered by *Morgan* (1971, 1972) to be basic components of a whole-mantle thermal convection regime that guides and helps maintain volcanism along spreading ridges. These plumes have been considered to be the main or even total (*Yamamoto et al*., 2007) source of thermal energy that drives plates. They would also provide the energy for enhanced lava production and locally higher temperatures along spreading ridge. A recent paper (*Presnall & Gudfinnsson*, 2007) presents a new model for the generation of mid-ocean ridge basalts (MORBs) and oceanic lithosphere formation. This model addresses the temperatures of melt extraction along mid-ocean ridges, an approach toward mapping of mantle heterogeneity beneath ridges, and the existence of hot plumes at volcanic centers (*e.g.,* Jan Mayen, Iceland, Azores, St. Helena, Tristan, Bouvet, Afar, Easter) on or close to ridges.

An earlier model (*Klein & Langmuir*, 1987; 1989; *Langmuir et al*., 1992; hereafter LKP), involves a range of short (cool) to long (hot) melting columns, with aggregate melts produced at the surface that combine melt increments from the entire depth range of a column. They introduced the parameters Na8 and Fe8 (Na_2O and FeO normalized to MgO = 8%), in order to remove the variations of Na_2O and FeO caused by low-pressure fractional crystallization and to reveal the chemical systematics produced by melting. To explain variations of Na8 and Fe8 *vs.* axial ridge depth, LKP claimed that long melting columns that start at high T and P produce melts that are high in Fe8, low in Na8, and characteristic of shallow ridges with a thick crust. In contrast, they proposed that short melting columns that start at low T and P produce melts that are low in Fe8, high in Na8, and characteristic of deep ridges with a thin crust. These were called the global trends and were considered to be characteristic of ridge lengths of hundreds to thousands of km.

In a global reevaluation of the LKP modeling, *Presnall & Gudfinnsson* (2007) confirmed that when Na8 and Fe8 are plotted against each other, rough positive and inverse trends occur, as reported by LKP. However, no ridge segments with "global" lengths were found that support an increase of Na8 and decrease of Fe8 with increasing axial ridge depth. This absence of this key correlation requires a different kind of modeling. In the system CaO-MgO-Al_2O_3-SiO_2-Na_2O-FeO (CMASNF), solidus melt compositions in the plagioclase/spinel lherzolite transition (~0.9-1.5 GPa) show an inverse correlation of Na_2O *vs.* FeO at constant MgO (*Presnall et al*., 2002; *Presnall & Gudfinnsson*, 2007). This matches the global Na8-Fe8 correlation of LKP but occurs for solidus melts over a very narrow P-T range of ~1.2-1.5 GPa and ~1250-1280°C.

Also, if MgO is relatively uniform but allowed to vary slightly, Na_2O varies positively with FeO during progressive fractional melting of ascending mantle source material (*Presnall & Gudfinnsson*, 2007). In this modeling, the inverse variation of Na8 *vs.* Fe8 is caused by mantle heterogeneity rather than temperature variations. The positive correlation is produced by fractional melting over a narrow pressure range. For example, Figure 1a shows, for the Carlsberg Ridge, a ridge of "global" length

© MantlePlumes.org

sampled over a distance of ~5,300 km, that neither Na8 nor Fe8 correlate with ridge depth. Thus, the LKP modeling fails. However, the combined Red Sea and Carlsberg data show an inverse correlation in which the Red Sea data are consistently displaced to higher Fe8 and lower Na8 values than the Carlsberg Ridge values (Figure 1b). This is consistent with mantle heterogeneity in which the Red Sea mantle is enriched in FeO/MgO and depleted in Na_2O relative to the mantle beneath the Carlsberg Ridge. Melt extraction over a large and varying P-T range from a chemically homogeneous mantle is replaced by melt extraction at relatively constant P-T conditions from a heterogeneous mantle.

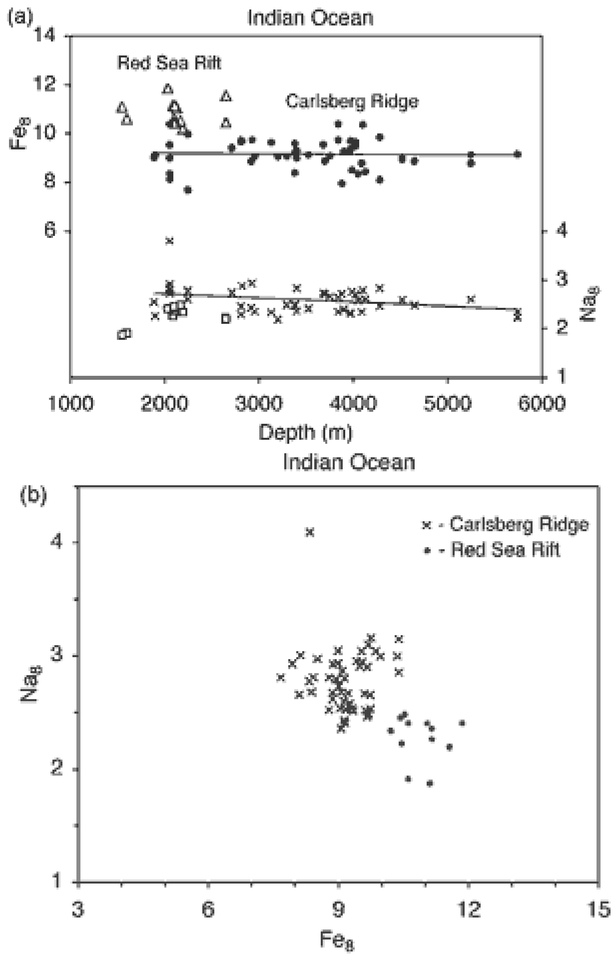

Figure 1. Na8-Fe8-depth data for Red Sea Rift and Carlsberg Ridge (from Presnall & Gudfinnsson, 2007).

Presnall & Gudfinnsson (2007) proposed that the very narrow range of P-T conditions for MORB extraction is imposed by the maximum temperature for explosive escape of CO_2 from the mantle. This maximum temperature is caused by the abrupt temperature drop of the solidus curve for carbonated lherzolite (*Wyllie & Huang*, 1975; *Eggler*, 1976; *Falloon & Green*, 1989; *Presnall & Gudfinnsson*, 2005) at about 1.8-1.9 GPa (Figure 2). These P-T conditions are the same as the narrow P-T range for MORB extraction indicated by the CMASNF solidus phase relations at the plagioclase/spinel lherzolite transition (*Presnall et al*., 2002; *Presnall & Gudfinnsson*, 2007).

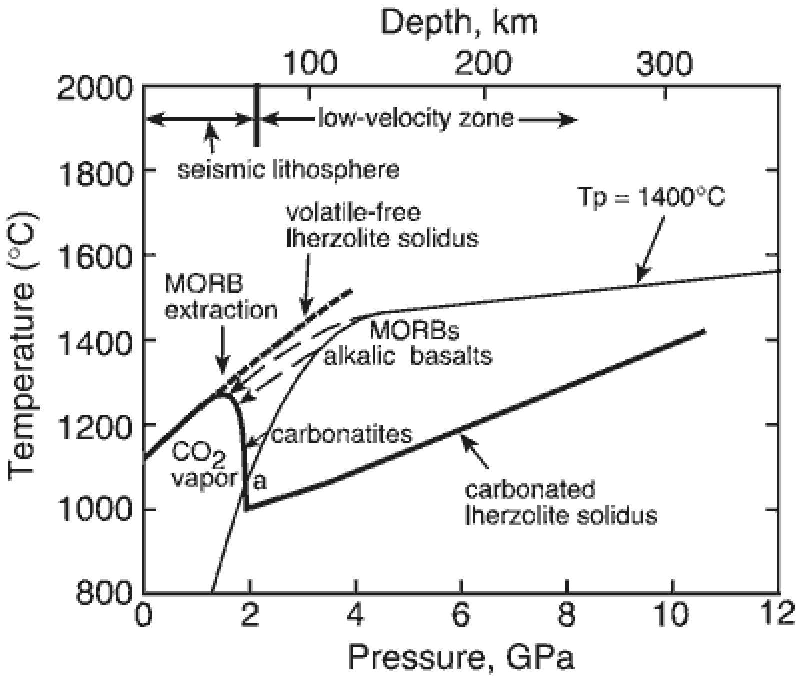

Figure 2. Pressure-temperature diagram showing solidus curves for carbonated lherzolite and volatile-free lherzolite, after Figure 1 of Presnall & Gudfinnsson (2005); based on the data of Hirschmann (2000), Dalton & Presnall (1998), Gudfinnsson & Presnall (2005) and Falloon & Green (1989). (From Presnall & Gudfinnsson, 2007).

Clague (2007) found that effusive and strombolian (explosive) eruptive features at oceanic ridges always occur together. In the model of *Presnall & Gudfinnsson* (2007), oceanic ridges are born when stresses cause fracturing through the entire thickness of the oceanic lithosphere and momentarily expose the partly melted seismic low-velocity zone to zero pressure. This causes explosive escape of CO_2, which carries melt with it to the surface, and a mature spreading ridge gradually develops. The energy for melting is decompression of rising mantle from the low-velocity zone. The flashing of CO_2 to vapor merely controls the P-T conditions for escape of the magma. Ridges die when stresses shift, close the fracture, and open a new fracture at a different locality where a new ridge develops. No interaction with the deep mantle is involved. This model accounts for the absence of thermal disturbances at the 410- km discontinuity beneath the entire length of the East Pacific Rise (*Melbourne & Helmberger*, 2002) beneath which the presumed Easter plume is supposd to lie.

References

- Clague, D. A., 2007, Simultaneous effusive and strombolian eruptions along mid-ocean ridges, *Geophys. Res. Abstracts*, **9**, abstract 02096.
- Dalton, J. A. & Presnall, D. C., 1998, Carbonatitic melts along the solidus of model lherzolite in the system CaO-MgO-Al_2O_3-SiO_2-CO_2 from 3 to 7 GPa. *Contrib. Min. Petrol*., **131**, 123-135, doi: 10.1007/S004100050383.
- Eggler, D. H., 1976, Does CO2 cause partial melting in the low-velocity layer in the mantle?, *Geology*, **4**, 67-72.
- Falloon, T. & Green, D. H., 1989, The solidus of carbonated, fertile peridottite, *Earth Planet. Sci. Lett*., **94**, 364-370, doi:10.1016/0012-821 x (89)90153-2.
- Gudfinnsson, G. H. & Presnall, D. C., 2005, Continuous gradations among primary carbonatitic, kimberlitic, melilititic, bsaltic, picritic, and komatiitic melts in equilibrium with garnet lherzolite at 3-8 GPa, *J. Petrol.*, doi:10.1039/petrology/egi029.
- Hirschmann, M. M., 2000, Mantle solidus: Experimental constraints and the effects of peridotite compositions, *Geochem., Geophys., Geosys.*, **1**, doi:10.1029/2000GC000070.
- Klein, E. M., & Langmuir, C. H., 1987, Global correlations of ocean ridge basalt chemistry with axial depth and crustal thickness, *J. Geophys. Res*., **92**, 8089-8115.
- Klein, E. M., & Langmuir, C.H., 1989, Local versus global variations in ocean ridge basalt compositions: A reply, *J. Geophys. Res*., **94**, 4241-4252.

- Langmuir, C. H., Klein, E. M. & Plank, T., 1992, Petrological systematics of mid-ocean ridge basalts: Constraints on melt generation beneath ocean ridges. In: Phipps Morgan, J., Blackman, D. K. & Sinton, J. M. (eds.) Mantle Flow and Melt Generation at Mid-Ocean Ridges, Geophys. Mon. **71**, *Am. Geophys. Union*., 183-280.
- Melbourne, T. I. & Helmberger, D. V., 2002, Whole mantle shear structure beneath the East Pacific Rise, *J. Geophys. Res*., **107**, 2204, doi: 10.1029/2001JB000332.
- Morgan, W. J., 1971, Convection plumes in the lower mantle, *Nature*, **230**, 42.
- Morgan, W. J., 1972, Plate motions and deep mantle convection, *in* Shagam, R., *et al*., eds., *Studies in Earth and Space Sciences* (The Harry H. Hess volume): *Geol. Soc. Am. Mem.* **132**, 7-22.
- Presnall, D. C., Gudfinnsson, G. H. & Walter, M. J., 2002, Generation of mid-ocean ridge basalts at pressures from 1 to 7 GPa, *Geochim. Cosmochim. Acta*, **66**, 2073-2090.
- Presnall, D. C. & Gudfinnsson, G. H., 2005, Carbonate-Rich Melts in the Oceanic Low-Velocity Zone and Deep Mantle, in Foulger, G. H., Natland, J. H., Presnall, D. C., and Anderson, D. L. (eds.), Plates, Plumes and Paradigms, *Geol. Soc. Am. Spec. Paper* **388**, 207-216.
- Presnall, D. C. and Gudfinnsson, G. H., 2005, Carbonate-rich melts in the oceanic low-velocity zone and deep mantle, In: Foulger, G. L., Natland, J.H., Presnall, D. C. & Anderson, D. L. (eds.), *Plates, Plumes, and Paradigms*, Geol. Soc. Am., Spec. Paper 388, 207-216.
- Presnall, D. C. & Gudfinnsson, G. H., 2007, Origin of the oceanic lithosphere, *J. Petrol*., 1-18, Advanced Access.
- Wyllie, P. J. & Huang, W. L., 1975, Influence of mantle CO2 in the generation of carbonatites and kimberlites, *Nature*, **257**, 297-299.
- Yamamoto, M., Phipps Morgan, J. & Morgan, W. J.,2007, Global plume-fed asthenosphere flow – I: Motivation and model development, *in* Foulger, G. R., and Jurdy, D. M., eds., Plates, plumes, and planetary processes, *Geol. Soc. Am. Spec. Paper* **430**, 165-188, doi: 10.1130/2007.2430(09).

© MantlePlumes.org