

Spatial Statistics of Isotopic Variations Along Mid-Ocean Ridges

David W. Graham (dgraham@oce.orst.edu)¹ & Frank J. Spera (spera@magma.geol.ucsb.edu)²

¹ College of Oceanic & Atmospheric Sciences, Oregon State University, Corvallis, OR, 97331-5503, USA

² Dept. of Geological Sciences, University of California, Santa Barbara, CA 93106, USA

How isotopic variations in basalts erupted at the Earth's surface are linked to convective mixing in the underlying mantle is a central problem in geodynamics. The range of variations in basalts from mid-ocean ridges (MORB) and ocean islands (OIB) are known to depend on mixing rates in the underlying mantle (Allègre and Lewin, 1995). However, the size, shape and distribution of chemical and isotopic heterogeneities (clumps) within the Earth's mantle, and their evolution through geological time, still remain poorly quantified. Large amplitude heterogeneities occur at both short and long distances, ranging from the width of pyroxenite veins (<1 m) in orogenic peridotites (Polvé and Allègre, 1980) to global scales (>10⁴ km) such as the Dupal anomaly (Hart, 1984). There is also evidence that scales of isotopic heterogeneity vary regionally (e.g. Allègre et al., 1984)

The objective of this study is to quantify the length scale(s) of upper mantle heterogeneity through spatial statistical analyses of MORB. We have begun by defining the "scale of segregation" (L) determined from the spatial self-correlation for ³He/⁴He, ⁸⁷Sr/⁸⁶Sr, ¹⁴³Nd/¹⁴⁴Nd and ^{206,207,208}Pb/²⁰⁴Pb in "zero age" lavas sampled along the globe-encircling mid-ocean ridge system. Our working hypothesis is that small scale convective patterns in the upper mantle play a significant role in dispersion of the isotopic tracers and other trace elements. Differences in L between the respective ocean basins may then be quantitatively related to unsteadiness of small-scale mantle convection, due to thickening of the oceanic lithosphere, plume impingement, and lateral temperature differences between continental and oceanic lithosphere.

The correlation coefficient R is calculated between every pair of points at separation distance r. For each point pair, R(r) is given by the ensemble average of the product of the deviations in isotope composition from the population mean, normalized to the population variance (Danckwerts, 1952). The total number of point pairs (N) for n samples is given by N=n(n-1)/2. As an example, for the global data set of Sr and He isotopes (n=1238 and 576, respectively) the number of point pairs is well in excess of 10⁵ (765703 and 165600, respectively). A value of R(r) close to 1 indicates that, at a given location, an isotope ratio above (or below) the population average is likely to be associated with an above (or below) average value at a distance r away. A value of R(r) close to zero implies a random relationship, and a value

close to -1 implies an anti-relationship. R(r) approaches unity at small r because points close together are from the same 'clump' of mantle. The value of r at which R first goes to zero is denoted as r*. On a diagram of R(r) vs. r (the correlogram), the integral of R(r) from r=0 to r=r* is the scale of segregation L, and is related to the size of a 'clump'. Within the Earth's interior, such clumps may vary in size and shape and their boundaries may be diffuse. Lithosphere recycling at subduction zones and plume input from the lower mantle or transition zone are two ways by which such clumps are introduced to the upper mantle. We use the L concept because it is a quantitative estimate of size which is precisely definable from spatially referenced geochemical data.

Only a narrow range of L values is found within each ocean basin. In general, the isotope tracers give L values between 350-750km for the North Atlantic, South Atlantic and Indian Oceans. For the Pacific Ocean, L appears to be significantly less, between 140-180km, indicating that mantle 'clumps' in this region are smaller, in agreement with the (non-spatial) statistical approach of Allègre et al (1984). Our results provide good evidence that the dispersion of isotopic anomalies in the upper mantle is primarily controlled by small-scale convection. On a geological time scale, mantle flow is undoubtedly unsteady. Small-scale convective cells, having their long axes aligned sub-parallel to the plate scale flow, are one simple manifestation of this unsteadiness. The amplitude and frequency of cellular wobble controls the extent of lateral mass transport (dispersion) between these convective cells (Camassa and Wiggins, 1991). Based on the spatial correlation analysis of isotopic tracers, this dispersion appears to be more efficient in the Pacific upper mantle than elsewhere.

Allègre CJ, Hamelin B & Dupré B, *Earth Planet. Sci. Lett.*, **71**, 71-84, (1984).

Allègre CJ & Lewin E, *Earth Planet. Sci. Lett.*, **136**, 629-646, (1995).

Camassa R & Wiggins S, *Physica D*, **51**, 472-481, (1991).

Danckwerts PV, *Appl. Sci. Res.*, **3**, 279-296, (1952).

Hart SR, *Nature*, **309**, 753-757, (1984).

Polvé M & Allègre CJ, *Earth Planet. Sci. Lett.*, **51**, 71-93, (1980).