



## Lead in Oceanic Basalts and the mantle – 20 years later

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The geochemistry of lead has been known to be anomalous since 1969, when Allègre drew attention to the “lead paradox,” which concerns the unexpectedly radiogenic nature of lead in mid-ocean ridge basalts thought to be derived from a depleted mantle reservoir. Hofmann et al. (1986) examined the chemical relationships of lead relative to other trace elements in a suite of 30 MORB and 11 OIB samples and concluded that, during mantle melting, the bulk partition coefficient of Pb is similar to that of Ce. This differs sharply from the behavior of lead in subduction-related magmas, and in the formation of continental crust, where lead is highly incompatible with a partition coefficient close to that of U and Th. Subsequently, Sims and DePaolo (1997) questioned the methodology and validity of this assessment, but no systematic reevaluation of Pb partitioning has been undertaken since that time.

Here I assess Pb partitioning in over 1000 OIB and MORB samples (mostly from <http://www.earthchem.org>) using logarithmic abundance plots of a series of other elements (U, Th, and REE) versus Pb. The slopes of these correlations vary systematically from values significantly greater than unity for Th and U to progressively lower values for La, Ce, Pr, Nd, Sm. Log-log element abundance variations for partial melts and their residues yield a correlation with slope 1.0 if the element pair has equal partition coefficients. Element pairs with slopes different from unity have different partition coefficients and the correlations will not be strictly linear, but the deviations from linearity are small and of little significance. The new results, based on vastly larger and more representative set of data, are remarkably similar to those of the original paper by Hofmann et al. (1986). The bulk partitioning of lead is closest to that of cerium in most OIB, with  $Ce/Pb = 29 \pm 9$ . Only end-member HIMU are systematically higher, and end-member EM-2 basalts are lower, than most ordinary OIB, reflecting lead loss and addition, respectively, in their sources (Willbold and Stracke, 2006, G-Cubed in

press). MORB evaluations for 11 separate ridge/seamount regions from the 3 major ocean basins show that lead partitioning relative to the REE varies only slightly, and lies on average between partitioning of Ce and Pr. Ce/Pb ratios also vary only slightly ( $27 \pm 5$  for the 11 regions,  $26 \pm 7$  for all 500 samples unweighted). This means that Pb partitioning during mantle melting is controlled most likely not by silicate minerals (which have very low partition coefficients for Pb) but by essentially ubiquitous residual sulfides. The high Ce/Pb ratios (25 to 30) contrast sharply with continental compositions, which average Ce/Pb = 4 (Rudnick and Gao, 2003) and similarly low island arc values. The lead deficit of the mantle is not completely balanced by the lead excess of the continental crust. A global Pb deficit of the accessible mantle and crustal reservoirs is closely related to the “lead paradox” of Allègre (1969) and the need for two (or more) stages in terrestrial Pb isotope evolution formalized by Stacey and Kramers (1975).

Where did the “missing” lead go? Perhaps, it went to the core, as recently (re-)advocated by Wood & Halliday (2005). Recent results on partitioning of Th, U, LREE and divalent alkaline earths (with ionic properties similar to Pb) by Corgne and Wood (2005 and Corgne et al. (2005) suggest an alternative mechanism: Crystallization of Ca-perovskite in the lowermost mantle will preferentially incorporate Th, U, and LREE in the Ca-perovskite and create a residual melt with low (Th,U)/Pb and LREE/Pb ratios. If this residual melt is denser than the solid, it will migrate downward, creating a permanent high-density D” layer early in Earth history. This layer will be relatively enriched in Pb and depleted in U, Th, LREE. The less dense solid silicate reservoir will then have increased (U,Th)/Pb and Ce/Pb ratios, as required from global Pb isotope and Ce/Pb systematics. This scenario is in good agreement with recent models derived from  $^{142}\text{Nd}$  data (Boyet and Carlson, 2005), and from the requirements from Xe and other noble gas isotopes (Tolstikhin and Hofmann (2005).