A simple explanation for the 'constant' Ce/Pb, Nb/U and other incompatible trace element ratios in oceanic basalts

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One of the most intriguing compositional features of the mantle was unraveled by the discovery of the constant Ce/Pb (25 ± 5) and Nb/U (47 ± 10) ratios in oceanic basalts[1]. Later studies showed that some other incompatible trace element ratios (e.g., Th/U, Ti/Gd) in MORB are also constant[2]. These ratios are constant because the elements are perfectly incompatible ($D_i^{sol/liq}$ <<1), they have identical $D_i^{sol/liq}$ values during magma differentiation processes and/or their sources experience an unrealistically high degree of partial melting[2,3]. However, a complementary general explanation for the origin of this mantle feature that is consistent with other data, particularly the heterogeneous Sr-Nd-Pb-Hf-Os-noble gas isotopes in oceanic basalts, is needed. A proposed explanation is that the ratios are not really constant[4]. This notion can be illustrated by binary plots of incompatible trace elements showing that the correlation between each element pair is expressed by the equation $y = mx + b$, where y and x are the elements, m is the slope of the correlation line and b is the y-intercept of the line when $x = 0$. Note that m is constant, and the equation becomes $y/x = m$ when $b = 0$. Between trace elements $b \neq 0$, but for some pairs such as Ce-Pb, Nb-U, Th-U, and Ti-Gd, their b approach 0 such that $(y - b)/x$ are within $y/x \pm error$ $(= m)$. These relationships exist because the wide range of each incompatible trace element content in oceanic basalts represents a binary mixture of enriched and depleted mantle components. That is, despite the heterogeneity of their mantle sources, the variation of each trace element in oceanic basalts is unified simply into a single depleted to enriched (i.e., overlapping D-MORB to E-MORB and FOZO to EM1-EM2-HIMU) linear array. Moreover, trace elements that maintain similar incompatibilities within the entire mantle depth/pressure range of magma generation correlate well when paired together as their y-intercepts approach 0. The same is true for paired trace elements that equally become less incompatible with increasing depth/pressure (e.g., the 'garnet effect') of melting. Pairing these different types of elements generates large y-intercepts and poor correlations.

Cited references: [1]*Hofmann et al. (1986) EPSL 79, 33-45*; [2]*Arevalo & McDonough (2012) Chem. Geo. 271, 70-85*; [3]*Simms & DePaolo (1997) GCA 61, 765-784;* [4]*Castillo (2016) Lithos 252–253, 32–40*.

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