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New Interpretation of Earth-Mantle Heterogeneities Favoring a Whole Convective Mantle Structure

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Mantle convection mode and geochemical characteristics of oceanic basalts

The mode of Earth's mantle convection remains a highly debated question. Geochemical composition of oceanic basalts has been widely held to support a chemically layered mantle structure. However, this classical interpretation can still be controversial. The extent of mantle heterogeneities is the foremost criterion in making assessments on the nature of mantle dynamics. The distinction between OIB's and MORB's compositions in the various oceanic domains is classically considered a major fact in justifying the division of the mantle into two distinct source reservoirs: the upper mantle as the MORB source and the OIB's originating elsewhere in the mantle. However, the large size of heterogeneities at the scale of oceanic domains have been neglected. Although trace elements can be remarkable tracers of magmatic processes, they have not been fully used to discuss the nature of mantle heterogeneities. The main reason for this resides in the fact that trace elements fractionate from the source to the derived magmas leading to difficulties in estimating the source content. Taking into account these observations, the question of mantle heterogeneities was investigated on the basis of two specific approaches: (1) by considering the mantle heterogeneities at the scale of oceanic domains, and (2) by analyzing the trace element compositions of the oceanic basalts in the (Th/La, Nb/La) diagram. This diagram provides interesting insights for distinguishing mantle magmatic processes and sources.

Oceanic domains

A comprehensive data base of oceanic basalts compositions using literature data was created. Analysis of Sr, Nd, and Pb isotopic and incompatible trace element ratios allows to identify five distinct large scale oceanic domains: Atlantic-East Pacific (AEP), Indian Ocean (IO), Kerguelen-South Atlantic (K-SA), Hawaii (H), and South Central Pacific (SCP). If the SCP domain is discarded, a coherent evolution can be seen in the geochemical compositions of the three domains AEP, IO, and KSA whose compositions cover the whole range observed in oceanic basalts. These three domains extend along elongated trends roughly parallel with respect to each other in the (Th/La, Ta/La), ($^{206}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$) and ($^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$) representations. This suggests that these domains were generated under the same types of processes.

Trace element analysis in the (Th/La, Nb/La) representation

Theoretically in the (Th/La, Nb/La) representation (Figure 1), magmatic differentiation processes in the mantle are characterized by trends with positive slopes that include the source composition. The magmas produced are depicted in figure 1 at the right and upper end of the trend along with the residues at the left and low end side of it. Such trends clearly differ from those portraying mixing with CC materials directed towards the CC composition field that stands outside the mantle domain. This diagram allows also to distinguish mantle sources with different residual degrees. In this (Th/La, Nb/La) representation, the SCP domain displays trends directed towards the CC pole supporting the presence of recycled CC material in the source of these basalts. The other domains extend on elongated trends with positive slopes consistent with those expected from intramantellic magmatic differentiation. In each domain, the OIB plot at the upper end of the trend whereas the MORB plot at the lower end. Furthermore, in good consistency with their Sr, Nd, and Pb isotopic compositions, the location of the domains in the (Th/La, Nb/La) representation indicates increasing residual states of mantle sources in the order KSA<IO<AEP. This analysis leads to the following interpretations: (1) OIB's and MORB's correspond to magmas resulting from the partial melting of the same mantle source in a two stage melting process (2) OIB's are produced first from the partial melting of the most fusible materials and (3) MORB's are subsequently produced through the partial melting of the residual part following the OIB extraction. A more thorough analysis indicates that this source is heterogeneous and mostly composed of a combination of residual peridotitic material, and differentiated and recycled oceanic lithosphere. The parallel trends displayed by the oceanic basalts from different oceanic domains in the ($^{206}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$) representation can be correctly explained within the framework of such a mantle source model. This analysis leads to distinguish large-scale oceanic domains with particular residual characteristics and reveals the existence of a genetic link between the OIB and MORB in each of these domains. These features are consistent with a whole mantle convective structure.

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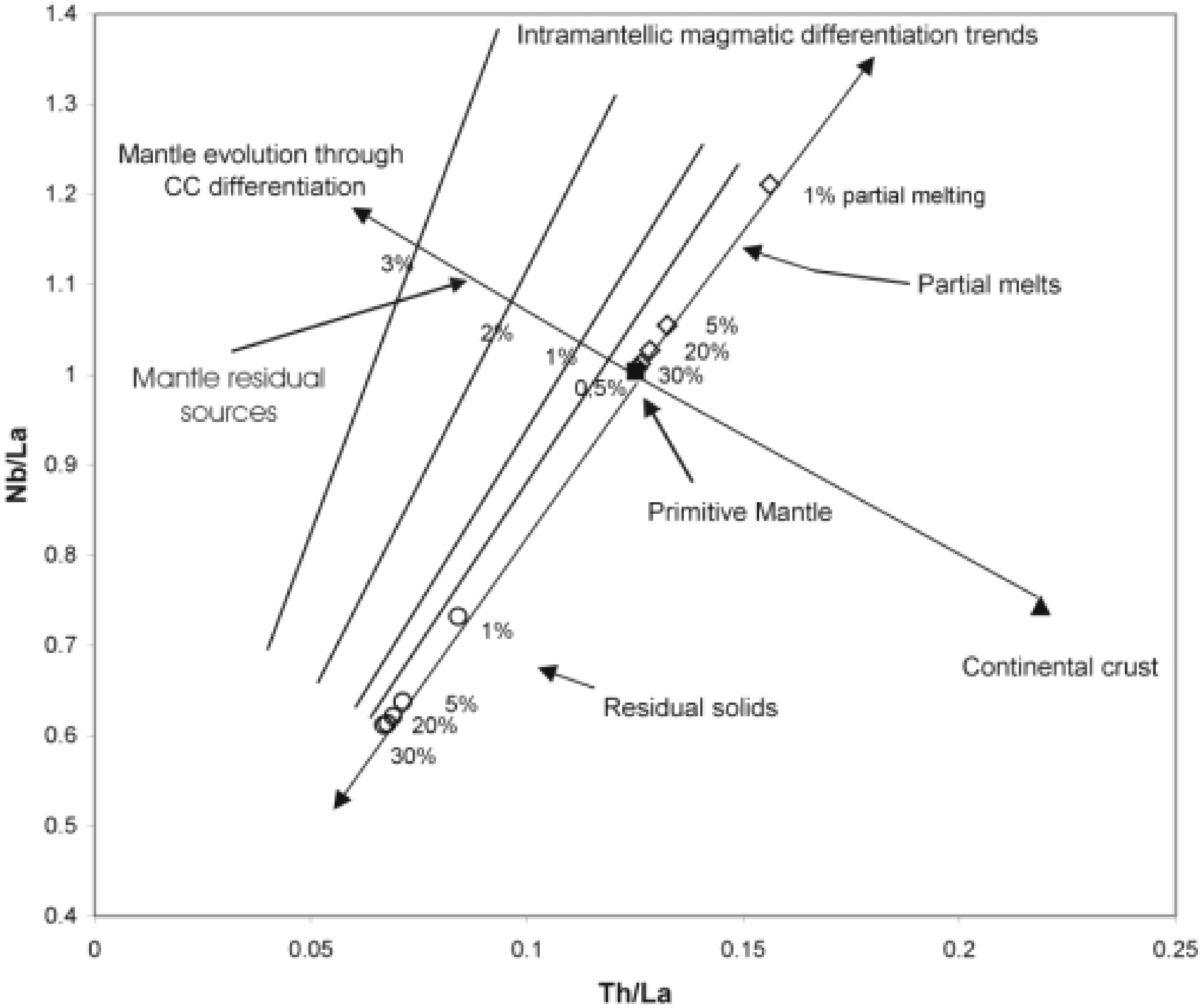

Figure 1. Theoretical differentiation processes in the (Th/La, Nb/La) representation. Open diamonds and circles: Melt and residual solids, respectively, resulting from partial melting of a primitive peridotitic mantle source