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Chemical mantle heterogeneity as a cause of its isotopic heterogeneity – a statistical model for Sr, Nd, Hf and Pb

Yu.A.Kostitsyn
GEOKHI RAS, Moscow, Russia

Generally accepted geochemical model of the earth mantle evolution (Zindler and Hart 1986; Hofmann 1997) suggests that the main cause of the Earth mantle heterogeneity (EM-I, EM-II, HIMU, LOMU, DUPAL, FOZO, etc.) is a recycling of a crustal material come back to mantle at subduction zones. A portion of recycled continental crust, as it is assessed from a mass balance consideration, should be at least a few times more than the mass of present continental crust. However, Rb-Sr, Sm-Nd, U-Th-Pb, Lu-Hf isotopic systems – both isotopes and related trace elements – are well suitable for analysis of mixing processes in heterogeneous systems. A review of Sm-Nd and Lu-Hf isotopic data for mantle rocks particularly shows that there are some irresistible problems in attempts to explain all mantle isotopic variations by admixing of crustal material (Kostitsyn 2004). There should be additional processes responsible for some types of the mantle isotopic anomalies.

Worldwide MORB tholeiites show well evident, regular multidimensional correlations of trace elements Rb, Sr, Sm, Nd, U, Th, Pb, Lu, Hf and their ratios Rb/Sr, Sm/Nd, U/Pb and Lu/Hf in log-log scale, extending up to two orders in concentrations of some of them. This suggests that the chemical variations in the high-degree melting derivatives could be inherited from their source rocks, at least in part. It is possible that the mantle dispersed chemical heterogeneity was produced by previous magmatic or metasomatic processes. Incomplete removing of melting products from a source area, melts moving and partial crystallization, i.e. mantle intrusive activity, could be a possible mechanism responsible for a mantle chemical heterogeneity. Adequate mechanism of efficient homogenization of a mantle material in a scale larger than dimensions of an individual magmatic body is unknown and probably does not exist.

If there exist a long living chemical heterogeneity in the mantle source, one obviously

must take into account its possible influence on isotopic composition of Sr, Nd, Pb and Hf there.

Above considerations lie in a base of a Monte-Carlo model of the related chemical and isotopic heterogeneity evolution of the mantle material. This model:

1. Splits a mantle source on a number of domains, homogeneous in trace element and isotopic composition. The number of domains was used from 1000 to 100000 in various attempts with the same principal result.

2. Splits the 4.5 Gy time span on a number of steps (from 20 to 450).

3. On every step in every domain contents of Rb, Sr, Sm, Nd, U, Th, Pb, Lu, Hf is changed by a random number generator to get at the finish a statistical distribution of every element and every ratio of the elements like in MORB. This is rather a sophisticated part of the model.

4. On every step all isotopic ratios are changed in according with a decay law.

5. On every step a 3% material exchange between random pairs of domains is modeled. The degree of exchange was found by trial and error way. Too high degree makes the source fully homogeneous; too low degree, close to 0%, led to 4.5 Gy "mantle isochrons" arising in common isochron plots (such as $^{143}Nd/^{144}Nd$ vs. Sm/Nd or $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$).

The calculated model shows that the known mantle isotopic heterogeneity in Sr-Nd-Pb-Hf isotopic multispace is in a good statistical agreement with a global chemical heterogeneity of MORB. It explains a negative correlation of Nd and Sr isotopic ratios (mantle array), $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ isotopes correlation, corresponding to an age 1.7-1.8 Gy (Hart 1988), and some other details. Particularly it explains a HIMU-shift in lead isotopic composition of some of simulated rocks despite such a special anomalous source was not involved in the model.

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