Heavy rare earth elements and the origin of primitive volcanic rocks

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Why?

Heavy rare earth elements (HREEs), especially lanthanides from Sm to Lu, are widely used to constrain the origin of basaltic and more primitive volcanic rocks. The reasoning for this lies in the strong compatibility of HREEs in garnet, which increases from Sm to Lu. Partial melts from sources with residual garnet thus acquire high ratios of less compatible HREEs to more compatible HREEs (e.g., high Sm/Lu or Dy/Yb).

Evidence of residual garnet in the HREE composition of volcanic rocks is often thought to reflect melting at pressures above the spinel-garnet transition in the mantle. But what is the influence of mantle temperature and mantle rock type (i.e., peridotite vs. pyroxenite) on melt HREE composition, since they both dictate not only the pressure but also the degree of meting and the amount of garnet in the source? This is what we wanted to find out.

How?

We utilized REEBOX PRO (Brown et al. 2016), a simulator of adiabatic decompression melting of the mantle, to study the behavior of HREEs (namely Dy and Yb) in partial melts of the mantle. We simulated partial melting of depleted peridotite, pyrolitic peridotite, pyroxenite, and peridotite-pyroxenite mixtures at mantle potential temperatures of 1350–1650°C and lithospheric thicknesses of 50–150 km. These parameters are fitting for continental environments (e.g., continental flood basalts), but may be relevant for oceanic island environments as well.

What?

Our results show that low Dy/Yb ratios (i.e., flat REE pattern typical of mid-ocean ridge basalts) do not necessarily indicate shallow melting within the spinel stability field. Such REE patterns can also be generated beneath thick lithosphere (~100 km), given that mantle potential temperatures are high (>1500 °C) and garnet is completely consumed from a peridotitic source by melting. On the other hand, high Dy/Yb ratios typical of oceanic island basalts can be generated beneath thinner lithosphere (~50 km), if the source is pyroxenitic and thus rich in garnet.

Based on our findings, the pressure of melting cannot be judged based on HREE without taking account of the thermal regime and mantle source composition. For further information and application to continental flood basalts of the Karoo large igneous province, see Heinonen et al. (2022).

References

Brown, E. L. & Lesher, C. E., 2016: REEBOX PRO: a forward model simulating melting of thermally and lithologically variable upwelling mantle. *Geochemistry, Geophysics, Geosystems 17*, 3929–3968.

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