Dynamics of the Iceland Plume: Recycling the Iapetus Ocean?

Y.Smit*, I.J.Parkinson, D.W.Peate(1) A.S.Cohen and C.J.Hawkesworth(3)
Dept. of Earth Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom, (1)Danish Lithosphere Centre, Oester Voldgade 10, L, DK-1350 Copenhagen K, Denmark, (2) Dept. of Earth Sciences, University of Bristol, Wills Memorial Building, Queen's Road, Bristol, BS8 1RJ, UK * Currently at: Laboratoire Magmas et Volcans, Département des Sciences de la Terre, Université Blaise Pascal, 5 Rue Kessler, 63038, Clermont-Ferrand, France, y.smit@opgc.univ-bpclermont.fr

In order to better understand plume-mantle dynamics, the origin and history of mantle material entrained in plumes needs to be well understood. This can be achieved by studying the geochemical signature of products of mantle plumes, i.e. basaltic lavas, placed in a context that is supported by geophysical evidence when available. Here we present a model for recycling of oceanic crust and lithosphere after subduction and mixing with a primitive mantle component. The model is based on the Nd-Os isotopic and major and trace element characteristics of the studied lavas in combination with constraints from previously published isotopic data and can explain the geochemical composition of both the current and past Iceland Plume.

The main sample area used for this study is the Snæfellsnes Transect, which runs from the Western tip of Snæfellsnes Peninsula to the Langjökull Volcanic System in the Western Riftzone, Iceland. This transect was not only chosen because of the systematic compositional changes, already indicated during previous studies of the post-glacial basaltic lavas along this transect (Jakobsson, 1972; Sigmarsson, 1992; Hardarson, 1993) and which might be related to their relative distance from the plume axis, but also because the lavas along this transect represent a snapshot of the underlying mantle in recent times and therefore represent a radial cross-section of the Iceland Plume. Additional samples used in this study are several primitive basaltic lavas from Þeistareykir, part of the Northern Riftzone.

The lavas that have been analysed can be divided into two main groups and a transitional group based on location and chemical composition. The composition of the axial group, represented by lavas from the main rift-zone, is dominated by melts from a mantle component with a strongly depleted trace element signature, a high εNd value (~+10) , a superchondritic Os isotope ratio ($^{187}Os/^{188}Os$ is ~0.138) and a relatively unradiogenic Sr isotope signature ($^{87}Sr/^{86}Sr$ is ~0.7030). In contrast, the composition of the off-axis group, represented by most of the lavas from Snæfellsnes Peninsula, is dominated by melts from a mantle component with an enriched trace element signature relative to the axial group and a low εNd value (~+5), a sub-chondritic Os isotope ratio ($^{187}Os/^{188}Os$ is ~0.126) and a relatively radiogenic Sr isotope signature ($^{87}Sr/^{86}Sr$ is ~0.7034). The lavas from the transitional group have intermediate major and trace element signatures and isotope characteristics.

The data from this study form near perfect trends for trace element ratios and isotope ratios (see figure 1). These trends are considered to represent a mixing relationship between melts derived from the two main components with a superimposed melting effect.

All the studied lavas are thought to be derived from two main components within the Iceland Plume itself based on previously published diagrams (Thirlwall, 1995; Fitton et al., 1997; Kempton et al., 2000). Assuming that these two major plume components are co-genetic, a two stage LREE depletion has to take place to explain the observed εNd +5 and εNd +10 end member compositions. The first stage of depletion is by achieved by melting of PM, forming DMM. This is the mantle source for new oceanic crust and lithosphere. Both crust and lithosphere are then subducted and mix with a primitive mantle component resulting in the reservoir tapped by the Iceland Plume. The recycling of the oceanic crust is supported by the HIMU-like Ce/Pb ratios and K-depletion as described by Thirlwall (1997). Adding a primitive mantle component is necessary in order to explain that the most depleted Nd isotope signature corresponds with a radiogenic Os isotope signature, while the less depleted Nd isotope signature corresponds with a subchondritic Os isotope signature. This is clearly in contrast with what would be expected as a result from simple recycling.

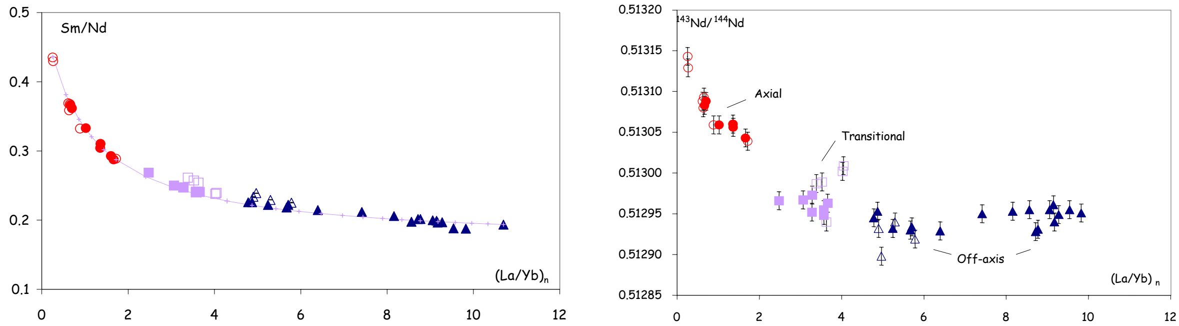

Figure 1. Two diagrams in which the near perfect trends described above are illustrated. Sm/Nd ratios (left) and $^{143}Nd/^{144}Nd$ ratios (right) are plotted against $(La/Yb)_n$ ratios. The trends are thought to represent mixing with a superimposed melting effect.

The time constraints for this model are bracketed by a maximum model age of 1500 Ma, based on the negative Δ7/4 values found in Icelandic lavas (Thirlwall, 1997), and a minimum model age based on the calculated Re-depletion age of ~380 Ma. In order to explain current day REE and Nd and Os isotope characteristics of the Iceland Plume as well as the range found in older volcanic material attributed to the Iceland Plume (e.g. West Greenland) the actual time constraints for the model prove to be the most important factor. Modelling of the REE elements in combination with Nd and Os isotopes on the basis of these constraints suggests that formation of the recycled oceanic crust and lithosphere took place ~600 Ma ago, while subsequent subduction and mixing with a primitive mantle component (15% of the total volume) took place ~520 Ma ago (figure 2). This coincides particularly well with the formation and subduction of the Iapetus ocean.

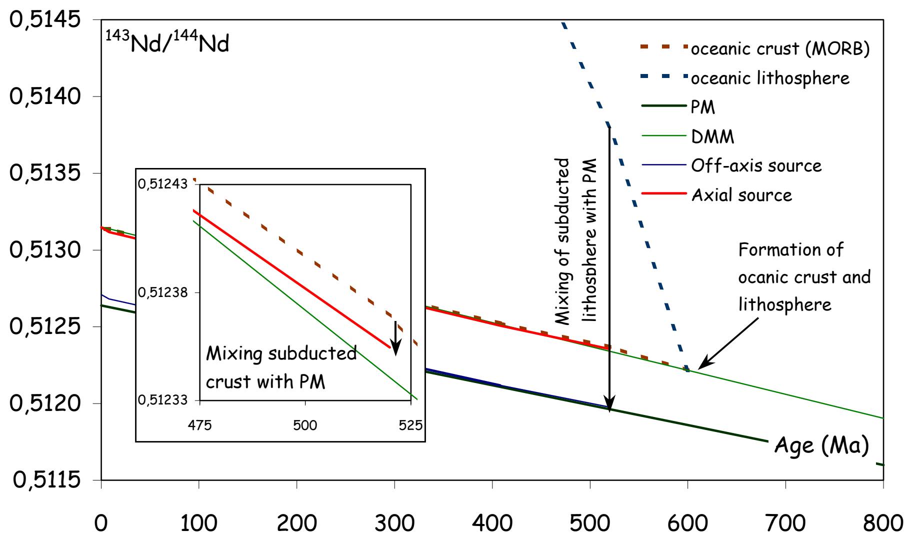

Figure 2. Evolution diagram illustrating the effect of mixing the subducted slab with a primitive mantle component on the $^{143}Nd/^{144}Nd$ ratios and $^{187}Os/^{188}Os$ ratios through time for the two main mantle components that are sampled by the Iceland Plume.

References

Fitton, J.G., Saunders, A.D., Norry, M.J., Hardarson, B.S., Taylor, R.N., 1997, Thermal and chemical structure of the Iceland plume, Earth and Planetary Science Letters 153(3-4), 197-208

Hardarson, B.S., 1993, Alkalic rocks in Iceland with special reference to the Snaefellsjokull volcanic system, PhD dissertation, University of Edinburg, 447p.

Jakobsson, S.P., 1972, Chemistry and distribution pattern of Recent basaltic rocks in Iceland, Lithos 5(4), 365-386

Kempton, P.D., Fitton, J.G., Saunders, A.D., Nowell, G.M., Taylor, R.N., Hardarson, B.S., Pearson, G., 2000, The Iceland plume in space and time: a Sr-Nd-Pb-Hf study of the North Atlantic rifted margin, Earth and Planetary Science Letters, 177(3-4), 255-271

Sigmarsson, O., Condomines, M., Fourcade, S., 1992, Mantle and crustal contribution in the genesis of Recent basalts from off-rift zones in Iceland; constraints from Th, Sr and O isotopes, Earth and Planetary Science Letters 110(1-4), 149-162

Thirlwall, M.F., 1995, Generation of the Pb isotopic characteristics of the Iceland plume, The Iceland plume and its influence on the evolution of the NE Atlantic, Journal of the Geological Society of London 152, 991-996

Thirlwall, M.F., 1997b, Pb Isotopic and elemental evidence for OIB derivation from young HIMU mantle, Chemical Geology 139, 51-74