Dynamics of the Iceland Plume: Recycling the Iapetus Ocean?

Dept. of Earth Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom,  
(1) Danish Lithosphere Centre, Øster 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 $\epsilon_{Nd} \approx +10$, a superchondritic 
Os isotope ratio (187Os/188Os is ~0.138) and a relatively unradiogenic Sr isotope signature 
(87Sr/86Sr 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 $\epsilon_{Nd}$ value 
(20), a sub-chondritic Os isotope ratio (187Os/188Os is ~0.126) and a relatively radiogenic Sr 
isotope signature (87Sr/86Sr 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 $\epsilon_{Nd} \approx +5$ and $\epsilon_{Nd} \approx +10$ 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 $^{143}\text{Nd}/^{144}\text{Nd}$ ratios (right) are plotted against $(\text{La/Yb})_n$ 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 $\Delta T/4$ 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 $^{143}\text{Nd}/^{144}\text{Nd}$ ratios and $^{187}\text{Os}/^{188}\text{Os}$ ratios through time for the two main mantle components that are sampled by the Iceland Plume.
References

Jakobsson, S.P., 1972, Chemistry and distribution pattern of Recent basaltic rocks in Iceland, Lithos 5(4), 365-386
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., 1997b, Pb Isotopic and elemental evidence for OIB derivation from young HIMU mantle, Chemical Geology 139, 51-74