A global analysis of the oxygen isotope composition of basalts: evidence for low and high ^{18}O reservoirs in the mantle

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Introduction

It is now well established that the mantle is compositionally heterogeneous on a variety of scales. The ultimate cause for these heterogeneities is the recycling of continental and oceanic crust via subduction into the mantle. Stable isotope studies have the potential to make important contributions to studies of mantle heterogeneity , but their application has lagged behind radiogenic isotopes. In this contribution we examine oxygen isotope variations in basalts and discuss their causes.

Oxygen isotopes are strongly fractionated during low-temperature processes such as weathering and hydrothermal alteration. Therefore, subduction related processes should provide an effective mechanism of introducing oxygen of variable composition into the mantle.

Methods

From 130 literature sources, plus a large amount of our own unpublished data and that provided by colleagues, we have assembled a database consisting of 2855 O-isotope analyses, which is accompanied by major element chemistry and/or radiogenic isotope data for approximately 40% of the entries. This database, which contains a bibliography is available from the authors upon request.

As is well known, the O-isotope composition of volcanic rocks, particularly glassy and microphyric lavas, can be modified through secondary processes such as weathering and hydration. Therefore, our primary database has been screened 'to look through' these effects. Based upon the $\delta^{18}O$–H_2O relationships observed for the total sample population, we have limited our 'working' database to include only (i) historic lavas younger than 1500 years, (ii) pristine submarine glasses and (iii) samples with measured water contents of less than 0.75 %. Modification of these criteria, for example reducing the water content limit to 0.5% or increasing it to 1.0% do not significantly alter the basic conclusions.

Results

The total variation in O-isotope composition for Neogene volcanic rocks is almost 18 ‰ extending

TABLE 1: O-isotope characteristics of basalts erupted in different tectonic settings

tectonic setting	number	^{18}O range	mean ^{18}O-value 1 $\pm$ σ
Oceanic bas.(all)	440	2.9 to 7.5	5.4 0$\pm$ 0.75
MORB	127	5.2 to 6.4	5.73 $\pm$ 0.21
OIB	148	4.6 to 7.5	5.48 $\pm$ 0.51
Iceland	104	2.9 to 6.2	4.5 0 $\pm$ 0.81
Ocean arc bas.	33	5.3 to 7.5	6.10 $\pm$ 1.10
Back-arc bas.	28	5.5 to 6.6	5.93 $\pm$ 0.26
Continental bas.(all)	303	4.3 to 11.4	6.36 $\pm$ 1.o6
CIB	171	4.5 to 8.1	6.08 $\pm$ 0.66
CAB	82	4.8 to 7.7	6.24 $\pm$ 0.65
CFB	17	4.3 to 6.5	5.59 $\pm$ 0.64
Italy	33	6.3 to 11.4	8.47 $\pm$ 1.44

from δ^{18}O-values −0.2 to 17.4 ‰ with an average value of 6.8 ‰. The screened database has a reduced variation with an average value of 6.2 ‰, which clearly reflects the removal of lavas whose O-isotope composition has been affected by secondary subsolidus alteration . The overall variation for basalts with a δ^{18}O-range from 2.9 to 11.4 ‰ is a clear indication that both low-^{18}O and high-^{18}O reservoirs have contributed to basalt petrogenesis. This substantial ^{18}O variation must reflect either significant O-isotope heterogeneity in the mantle source regions or substantial interaction of basaltic magma-crust prior to eruption, or variable combinations of these two effects. The screened database has been considered in terms of seven tectonic settings (Table 1): 1) MORB, 2) OIB, 3) fore-arc troughs and back-arc basins, 4) oceanic arcs, 5) continen-tal arcs, 6) continental rift-zones and 7) continental flood basalts. Additionally, Iceland and the intraplate potassic magmatism of Italy have been treated separately because of their special O-isotope character.

MORB has the most uniform O-isotope composition of all basalt types and can be used as a reference against which basalts erupted in other tectonic settings can be compared. Continental basalts are enriched in ^{18}O by comparison to oceanic basalts and exhibit considerably more variability in O-isotope composition, a feature attributed to interaction with ^{18}O-enriched continental crust during magma ascent. Intraplate oceanic and continental basalts have highly variable ^{18}O/^{16}O ratios, with individual localities exhibiting ^{18}O-values which are both significantly lower and higher than MORB and displaying ^{18}O-ranges in excess of 2 ‰. Basalts associated with subduction at convergent plate margins are slightly enriched in ^{18}O as an intrinsic feature of the subduction process. Low ^{18}O-values observed in both oceanic and continental settings generally have been interpreted to reflect the interaction of parental basaltic magmas with crust altered through high-temperature water-rock exchange. While this explanation is reasonable at certain locations where evolved lavas are particularly depleted in ^{18}O relative to their mafic parental compositions, such as the Yellowstone Plateau and Iceland, it cannot be applied to all locations where low ^{18}O-values are observed.

For Hawaii, the Cameroon Line and Iceland, there is substantial reason to consider that the ^{18}O-depletion observed in basalts is a primary feature of the mantle source. This unusual signature may be caused by the extraction of the continental crust from the upper mantle early in earth history. Systematic co-variations are observed between O-isotope ratios and Sr-, Nd-, and Pb-isotope ratios, indicative of the same intramantle, end-member components (DMM,EM-I,EM-II,HIMU) deduced from radiogenic isotope studies and suggesting a common process for their origin.