Silicon isotope geochemistry of Ocean Island Basalts: Search for deep mantle heterogeneities and evidence for recycled oceanic crust

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Introduction

Analyses of Ocean Island Basalts (OIB) have shown that the Earth's mantle contains isotopically distinct components, but current debate about the degree and scale of compositional variability persists. Isotopic heterogeneities in OIBs for both radiogenic and stable isotope systems have been attributed to the presence of recycled materials in different mantle reservoirs. Our new high-precision MC-ICP-MS Si isotope data for a diverse suite of OIBs representing the EM-1, EM-2, and HIMU mantle components are in general agreement with previous estimates for the δ^{30}Si value of Bulk Silicate Earth. However, small systematic variations are present; HIMU (Mangaia, Cape Verde) and Iceland OIBs are enriched in the lighter isotopes of Si (δ^{30}Si intermediary between Mid Ocean Ridge Basalts and chondritic values), which most likely reflects the incorporation of ~25% recycled altered oceanic crust in the plume source.

Silicon isotopes to trace mantle heterogeneities

The existence of mantle endmembers was originally proposed to explain the variable radiogenic isotope ratios observed in OIBs such that OIBs sample chemically distinct mantle sources, and isotopic compositions represent mixtures of various mantle components in OIB sources [1]. These geochemical source characteristics are thought to be the result of specific mantle processes: EM-1 may incorporate recycled lower continental crust material or delaminated subcontinental lithosphere, EM-2 may arise from the recycling of continental-derived sediments, and HIMU may involve recycled oceanic crust [2-4].

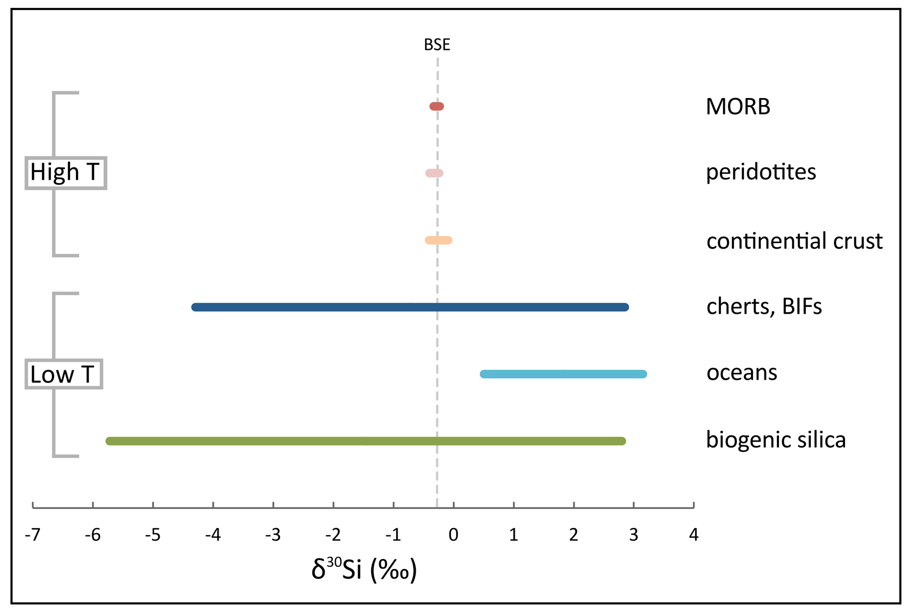
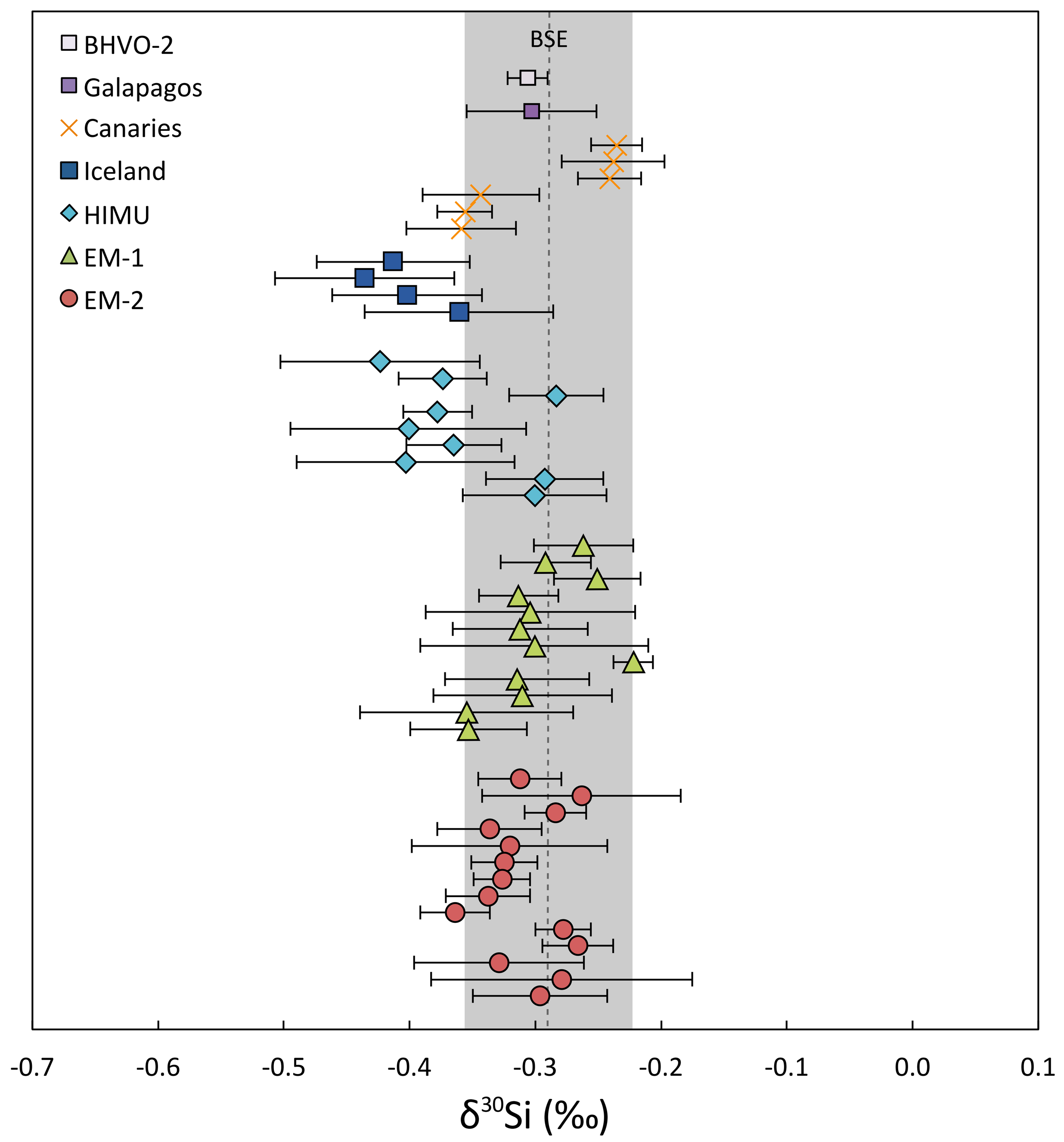


Fig 1. Silicon isotopes in the silicate Earth. Large variations in Si isotope composition occur in low-T surface environments. In contrast, igneous materials display a narrow range of Si isotope compositions, so Si isotopes may be useful as tracers for the presence of crustal material (derived from low-T surface processes) in OIB source regions [5-13].

The study of Si isotopes in OIBs has the potential to investigate possible heterogeneities in the mantle. Relatively large (~several per mil per atomic mass unit) Si isotopic fractionation occurs in low-temperature environments during biochemical and geochemical precipitation from dissolved Si, where the precipitate is preferentially enriched in the lighter isotopes [14]. In contrast, only a limited range (~tenths of a per mil) of Si isotope fractionation has been observed in high-temperature igneous processes [11,15]. Therefore, Si isotopes may be useful as tracers for the presence of crustal material (derived from low-temperature surface processes) in OIB source regions.

Results: Silicon isotope variations in OIBs



Average δ^{30}Si values for OIBs representing the EM-1, EM-2, and HIMU mantle components are all in general agreement with previous estimates for the δ^{30}Si value of Bulk Silicate Earth (BSE; δ^{30}Si = −0.29 ± 0.07‰, 2 sd) [16]. However, some locations exhibit systematic light Si isotope enrichment; on average OIBs from Iceland (δ^{30}Si = −0.40 ± 0.06‰, 2 sd) and the HIMU localities Mangaia (δ^{30}Si = −0.35 ± 0.05‰, 2 sd), Canary Islands La Palma (δ^{30}Si = −0.36 ± 0.00‰, 2 sd and Cape Verde (δ^{30}Si = −0.39 ± 0.04‰, 2 sd) are lighter than the rest of the OIBs measured in this study.

Fig. 2. Silicon isotope data for OIBs representing the HIMU, EM-1, and EM-2 mantle endmembers (±2 se). $\delta^{30}Si = ((^{30}Si/^{28}Si)_{sample}/(^{30}Si/^{28}Si)_{NBS28} - 1) \times 1000$. The light grey box represents the Si isotopic composition of BSE (±2 sd) as estimated by [16]. Most OIBs have compositions within the range expected for BSE, but Iceland and HIMU-type OIBs are relatively enriched in light Si isotopes.

Assessing the possible causes of Si isotope variability in OIBs

Silicon isotope fractionation during magmatic differentiation?

In general, small Si isotope fractionations are observed during magmatic differentiation [15]. However, Si isotope compositions of OIBs exceed the expected variability, and occur over a much smaller range of SiO_2 content.

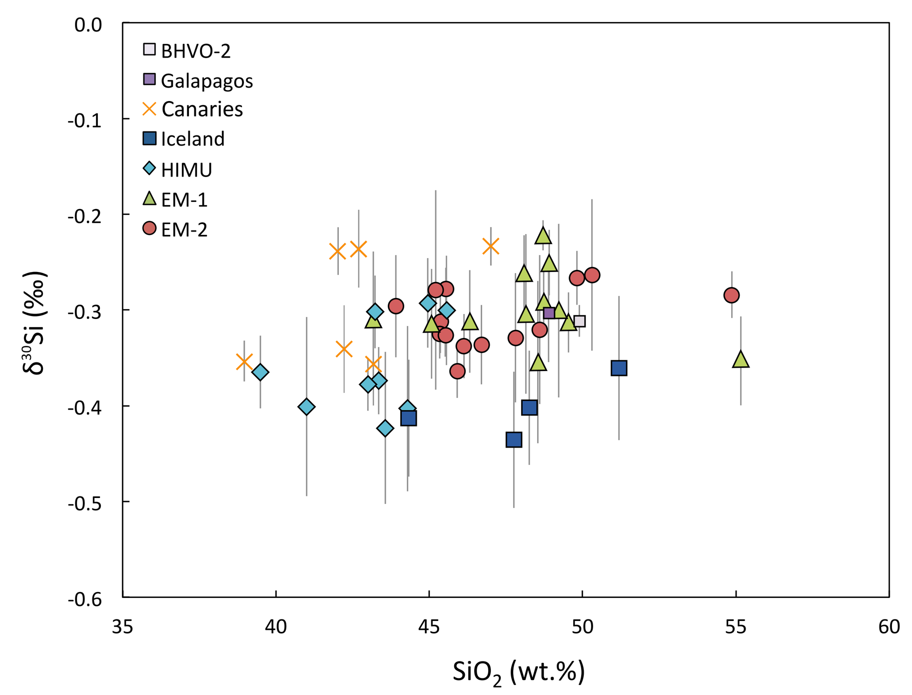


Fig. 3. Plot of δ^{30}Si as a function of SiO_2 content for the OIBs in this study. No correlation between δ^{30}Si and silica content is observed.

Preservation of primitive Si isotope heterogeneity in OIB source regions?

Calculations predict Si isotope variations among silicates with four-fold Si coordination (*e.g.* olivine) and six-fold Si coordination (Mg-perovskite), so the Mg-perovskite-rich lower mantle may be ~0.1‰ lighter on the $^{30}Si/^{28}Si$ ratio than the upper mantle [17]. The light Si isotope enriched OIBs in this study may therefore reflect the isotopic composition of the lower mantle.

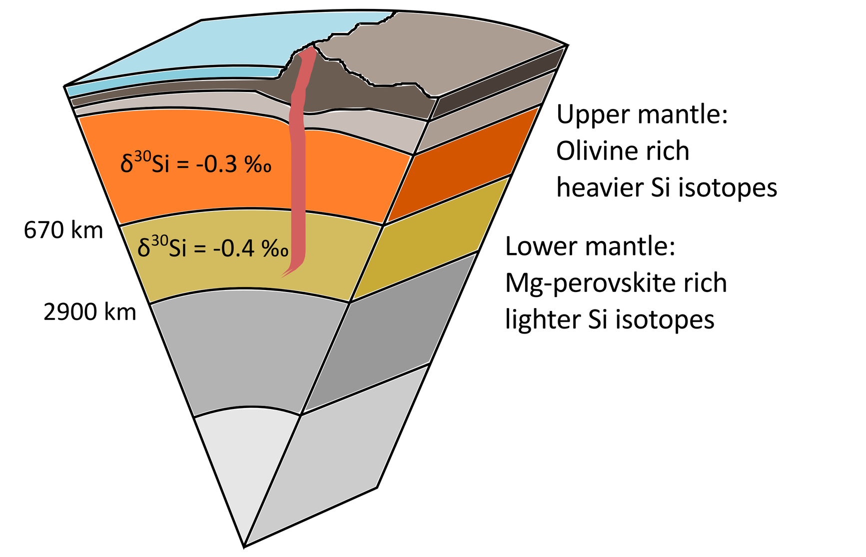


Fig. 4. Schematic representation of Si isotope heterogeneity resulting from Si isotope fractionation between mantle minerals at high pressure.

Contribution of recycled material to the Si isotope signature of OIBs

Subduction likely introduces a wide variety of materials into the mantle, including oceanic and continental crust and sediments and oceanic lithosphere, which may have undergone variable degrees of seafloor alteration and subduction zone modification [3,18]. The presence of unaltered oceanic crust (with MORB-like Si isotope composition) would not create Si isotope variations in OIBs. However, isotopic variations in Iceland and HIMU-like OIBs have most often previously been explained by the incorporation of recycled oceanic crust into the plume source [2,18-22]. This suggests that if recycling of oceanic crust is the source of the light Si isotope enrichment observed in HIMU and Iceland OIBs, the material must be modified either prior to or during subduction. The potential contribution of subducted material on the Si isotope signature of OIBs can be calculated from a simple mass balance.

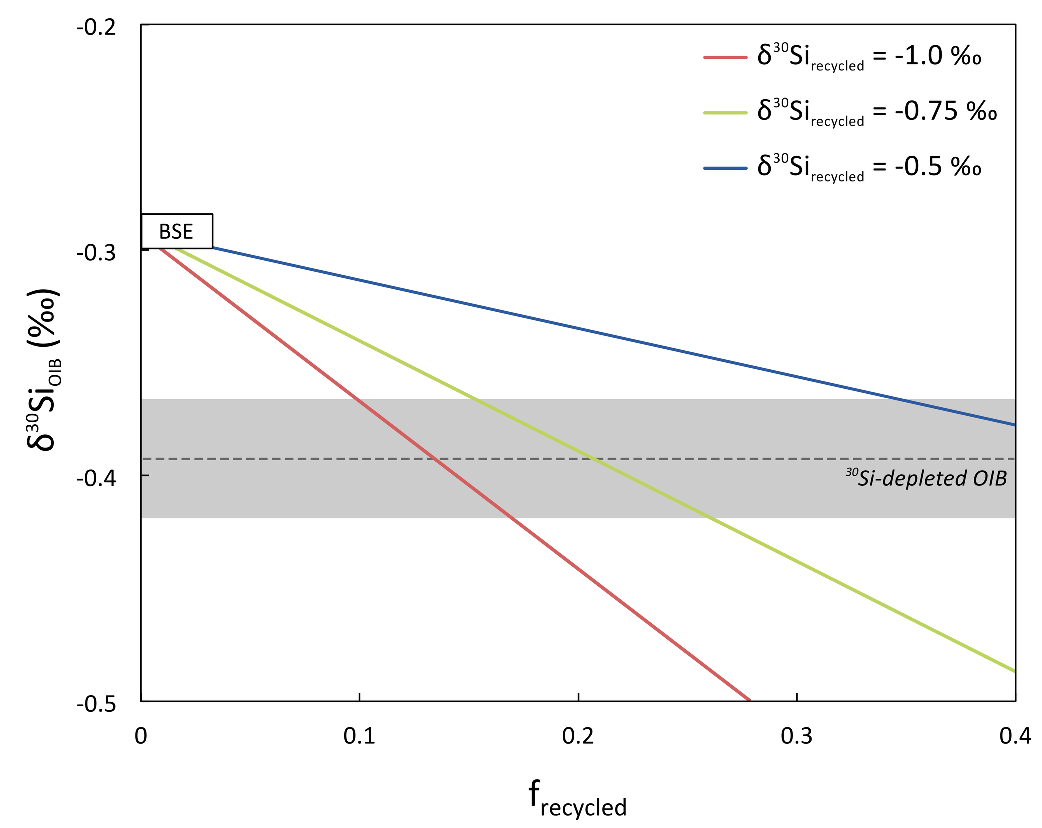


Fig. 5. Plot of δ^{30}Si as a function of the fraction of recycled component present in OIB source region. The shaded box represents the average Si isotopic composition (± 2 sd) of the light-isotope enriched OIBs measured in this study (Iceland, Mangaia, La Palma, Cape Verde). Here we consider a subducted package with a bulk δ^{30}Si of −1.0‰, −0.75‰, and −0.5‰ (consistent with plausible compositions of altered oceanic crust with or without a small portion of sediment).

Conclusions

- **At first order, OIBs exhibit homogeneous Si isotopic compositions generally in agreement with estimates for the δ^{30}Si value of BSE**
- **Some systematic variations are present; Iceland and HIMU type basalts exhibit light Si isotope enrichments relative to other OIBs, MORB, and the estimate for BSE**
- **The most likely cause of the Si isotopic variability in HIMU and Iceland is the presence of ~25% recycled altered oceanic crust in the plume source**
- **However, the sampling of a primitive, light Si isotope enriched reservoir cannot be ruled out as a potential source of Si isotope variations in OIBs**

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