Submarine Alkalic Lavas Around the Hawaiian Hotspot;
Plume and Non-Plume Signatures Determined by Noble Gases.

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Abstract

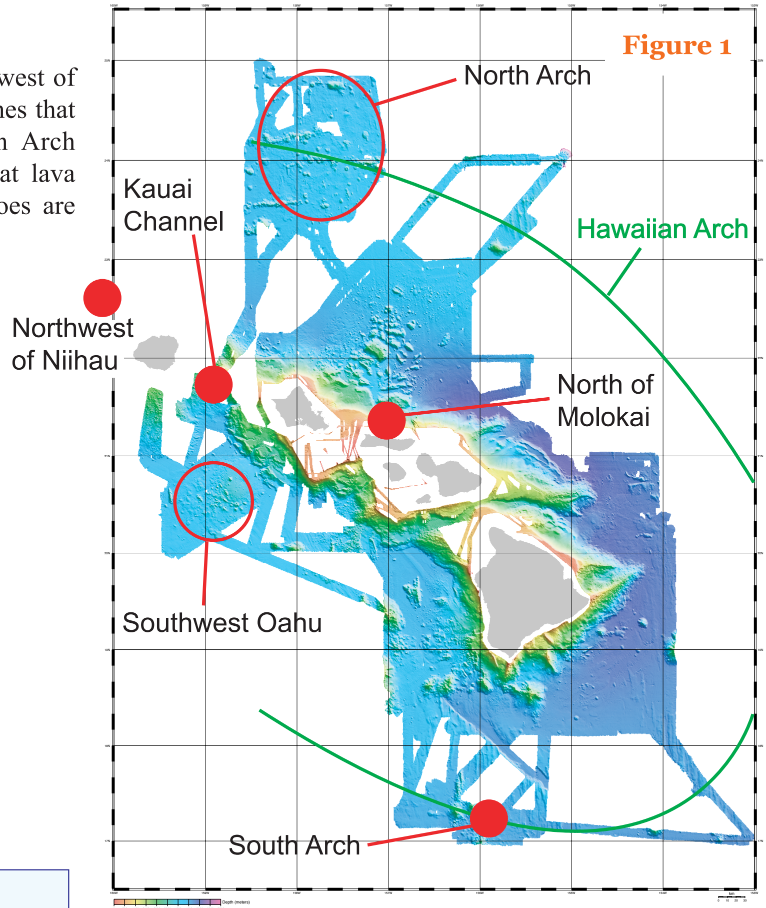
Noble gas isotopic ratios were determined for submarine alkalic volcanic rocks distributed around the Hawaiian islands to constrain the origin of such alkalic volcanism. Samples were collected by dredging or using submersibles from the Kauai Channel between Oahu and Kauai, north of Molokai, northwest of Niihau, Southwest Oahu, South Arch and North Arch volcanic fields. Sites located downstream from the center of the hotspot have $^3He/^4He$ ratios close to MORB at about 8 Ra, demonstrating that the magmas erupted at these sites had minimum contribution of volatiles from a mantle plume. In contrast, the South Arch, located upstream of the hotspot on the Hawaiian Arch, has $^3He/^4He$ ratios between 17 and 21 Ra, indicating a strong plume influence.

Differences in noble gas isotopic characteristics between alkalic volcanism downstream and upstream of the hotspot imply that upstream volcanism contains incipient melts from an upwelling mantle plume, having primitive $^3He/^4He$. In combination with lithophile element isotopic data, we conclude that the most likely source of the upstream magmatism is depleted asthenospheric mantle that has been metasomatised by incipient melt from a mantle plume. After major melt extraction from the mantle plume during production of magmas for the shield stage, the plume material is highly depleted in noble gases and moderately depleted in lithophile elements. Partial melting of the depleted mantle impregnated by melts derived from this volatile depleted plume source may explain the isotopic characteristics of the downstream alkalic magmatism.

Downstream Alkalic Volcanism

Samples from the Kauai Channel, north of Molokai and northwest of Niihau are from thin lava flows and small flat-topped volcanic cones that are located closed to the shield volcanoes. In contrast, North Arch volcanic field, covering a large area (25000 km^2), comprises flat lava flows 250 km north of the island of Oahu. All of these volcanoes are situated downstream from the center of the hospot (Fig. 1).

Alkali basalts from North Arch, Kauai Channel, North of Molokai, Northwest of Niihau have $^3He/^4He$ that are similar to MORB value and on-land post-shield and rejuvenated lavas, demonstrating that these abyssal alkalic lavas have common origin as post-shield and rejuvenated stage lava and their source should be depleted MORB mantle (Fig. 2). This idea is further supported by Ne isotope data and Sr-Nd isotopes (e.g., Dixon and Clague, 2001) of North Arch lavas that are more depleted than shield stage rocks.



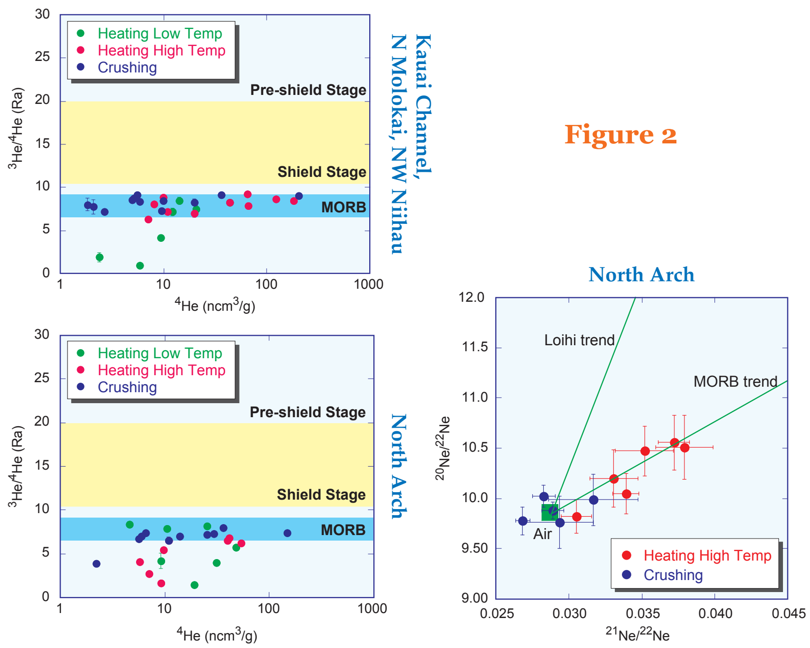
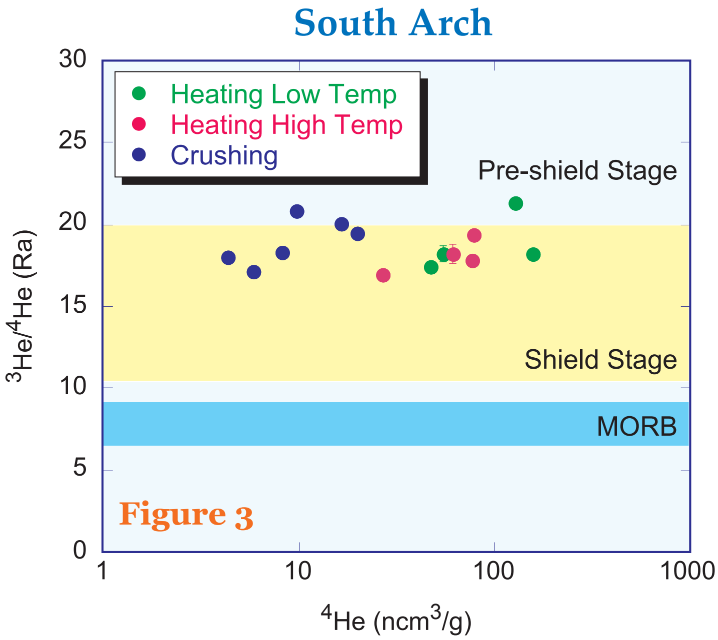


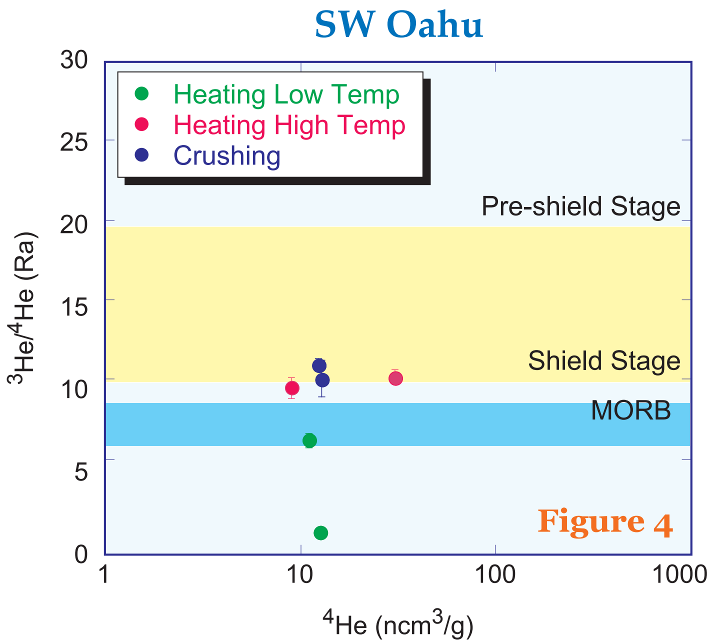
Figure 2

Upstream Alkalic Volcanism

South Arch is located on the southeastern part of the Hawaiian Arch (Fig. 1). It consists of a few lava flows, several meters thick, covering an area of 10x30 km. Since its location is unique as is in the upstream of the dragged mantle plume by a plate, it will provide a key how far the mantle plume spreads and materially interacts with surrounding mantle beneath lithosphere.

$^3He/^4He$ ratios range from 17 and 21, which are at the higher end of the range of the shield stage rocks. This clearly demonstrates that the source of South Arch is related to a mantle plume.



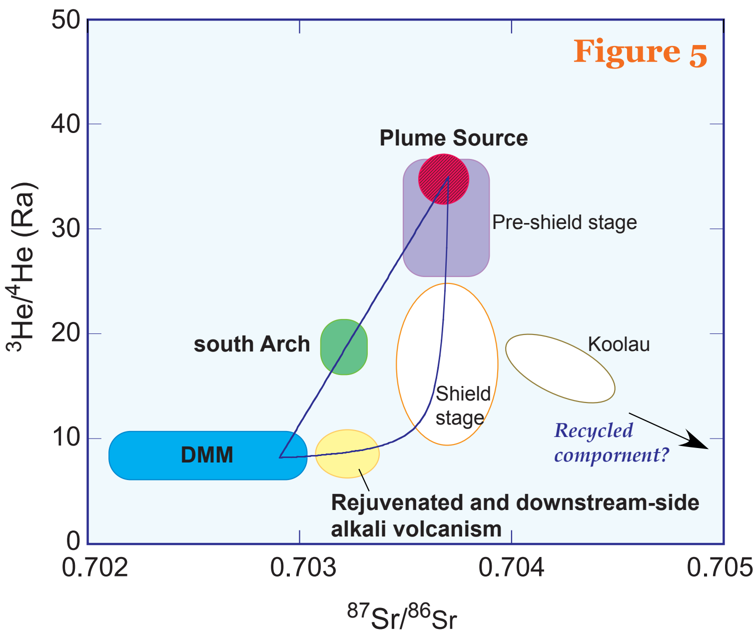


Southwest Oahu

Southwest Oahu volcano is a newly recognized volcano by the 2001 Kairei/Kaiko cruise. K-Ar dating demonstarates that Southwest Oahu and Waianae and Koolau on Oahu Island are similar in age of about 3 Ma (Noguchi and Nakagawa, 2003). He isotope ratios of the two samples recovered from flat flow surface show higher $^3He/^4He$ than MORBs, indicating these rocks are different from post-shield and rejuvenated stages rocks. Relatively low $^3He/^4He$ among the isotopic range of the shield stage suggests that the flux from a mantle plume was presumably smaller than that for the shield volcanoes on Oahu Island.

Discussion and Model

Noble gases, which represent tracers of volatiles, demonstrate that the submarine alkalic volcanism that appears at the downstream of a mantle plume is produced from depleted sources that are unrelated to a mantle plume. In contrast, our data requires extensive influence from a mantle plume in the upstream (South Arch) in excess of 200 km from the plume center. Sr, Nd and Pb isotope ratios of the downstream alkalic basalts do not overlap either with those of MORBs or shield stage magmas, but have isotopic compositions intermediate between them (Fig. 5). Sr, Nd and Pb isotope ratios of South Arch also plot away from the isotope ranges defined by shield stages and MORBs. These observation requires that upstream and downstream alkalic volcanism had different sources and also suggests decoupling of volatiles and lithophile elements for the formation of their sources.



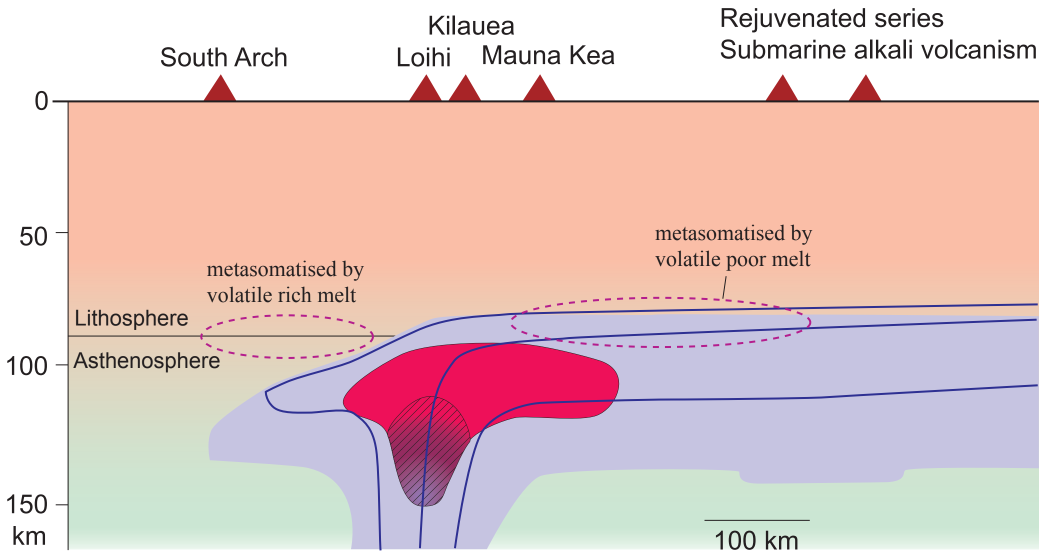


Figure 6

We propose a model that the source of the upstream and downstream volcanism are metasomatised mantle by a plume melt with various volatile and lithophile element compositions (Fig. 6). We have assumed heterogeneous mantle plume that includes portions with high and low $^{3}He/^{4}He$ ratios. A portion having high $^{3}He/^{4}He$ ratios starts to melt first at greater depth, subsequently low $^{3}He/^{4}He$ material melts to a larger melting degree at shallower depth. Incipient hydrous melts produced at the greatest depth with high $^{3}He/^{4}He$ and noble gas concentrations (and high concentrations of lithophile elements) are segregated and transported upstream of the plume, causing regional metasomatism in the lithosphere/asthenosphere upstream of the plume.

The source of downstream alkali volcanism as well as post-shield and rejuvenated series may have been a mantle metasomatised by melt from later activity of the Hawaiian mantle plume, and this metasomatising melt is depleted in volatiles because the melt was formed by late stage fractional melting in the mantle plume. This melt would retain a lithophile element signal from the plume despite having only a weak plume-derived noble gas signal. This is confirmed in the He-Sr isotopic diagram that the submarine alkalic lavas as well as the samples from postshield and rejuvenated stages plot on the concave mixing line defined by mixing of DMM and degassed plume melt (Fig. 5).

Conclusions

Submarine alkalic volcanism has different noble gas isotopic characteristics depending on its relative location compared to the plume center. Upstream volcanism has high $^{3}He/^{4}He$ ratios, despite less enriched lithophile isotope ratios. Its source is best explained as DMM mantle metasomatised by incipient volatile-rich melt from the upwelling mantle plume. In contrast, downstream volcanism has $^{3}He/^{4}He$ ratios identical to MORB, suggesting minimum volatile flux from the mantle plume to their source region. The slightly enriched lithophile isotope ratios again suggest that their source was metasomatised mantle. Variation of $^{3}He/^{4}He$ ratios between upstream and downstream volcanism are attributed to volatile-rich and volatile-poor metasomatising melts that were produced before and after the major melting of the mantle plume.