

Evidence for melting of garnet pyroxenite in the generation of Hawaiian post-erosional lavas: effects of a marble-cake mantle during melt generation

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Isotopic variations in mantle-derived melts are a primary source of information on the age, origin and magnitude of chemical heterogeneities in the convecting mantle. Understanding the relationship between the melting process and the generation and preservation of chemical heterogeneity in basaltic magmas is therefore of the utmost importance. Preferential melting of mafic veins in predominantly peridotitic mantle is a potential source of chemical and isotopic heterogeneity in mantle-derived melts. Previous studies have proposed a role for melting of garnet pyroxenite in the origin of the garnet signature in MORB [e.g. Hirschmann and Stolper, 1996]. At high degrees of mantle melting, such as that responsible for the generation of MORB, the signature of pyroxenitic melting may be difficult to detect unambiguously. However, because pyroxenites have a lower T_{solidus} than peridotites, small degree partial melts should contain a more pronounced signature from pyroxenite melting. We have examined the Os-isotope systematics of Hawaiian post-erosional lavas from the Koloa Volcanic Suite, Kauai and the Honolulu Volcanic Series, Oahu to evaluate the role of pyroxenite melting in the generation of these highly enriched small-degree partial melts.

Post-erosional lavas

Primitive, highly alkalic, silica-undersaturated magmas have erupted from several Hawaiian volcanoes following a volcanic hiatus after cessation of shield- and post-shield stage volcanism. The alkalic late-stage or post-erosional magmas are much more incompatible-element enriched than their earlier shield counterparts, yet have more 'depleted' or MORB-like Sr- and Nd-isotope signatures. These magmas are generated through

much smaller extents of partial melting than main shield-stage magmas, although the exact mechanisms of melt generation are a matter of considerable debate. Several models have been proposed to explain the seeming inconsistency between the incompatible-element enriched nature of post-erosional magmas and their depleted isotopic signatures. These include: (1) melt generation through very small degree melting of a depleted mantle source (e.g. Frey and Roden, 1987); (2) melt generation from a recently metasomatized mantle source (e.g. Clague and Frey, 1982); and (3) incompatible-element enrichment via melt/mantle interaction during melt migration through a large volume of depleted mantle (e.g. Frey and Roden, 1987). New Os-isotope data for Hawaiian post-erosional lavas and for spinel lherzolite and garnet pyroxenite xenoliths hosted within these lavas reveal that none of the above models adequately accounts for the chemical and isotopic compositions of the post-erosional lavas. Instead, we propose a melt mixing model involving melts generated from both mafic (e.g. pyroxenitic) and ultramafic components in the mantle.

Results and discussion

Os-isotopic composition is sensitive to melting of mafic components in the mantle because such components commonly have much higher Re/Os than ultramafic components, and so over time will develop very radiogenic $^{187}\text{Os}/^{188}\text{Os}$ values. Because of the high [Os] and low Re/Os common to nearly all ultramafic rocks from both continental and oceanic settings, ultramafic components within the mantle are not expected to possess radiogenic $^{187}\text{Os}/^{188}\text{Os}$, an expectation which is confirmed by isotopic analyses of abyssal peridotites and ultramafic xenoliths world-

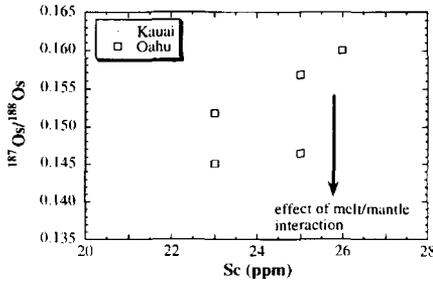


FIG. 1.

wide. Spinel lherzolite xenoliths hosted within the Oahu post-erosional lavas have Os-isotopic compositions ($^{187}\text{Os}/^{188}\text{Os} = 0.124\text{--}0.130$) typical of abyssal peridotites. Many of these lherzolites have been extensively metasomatized (e.g. Sen, *et al.*, 1993), but this metasomatism has had essentially no effect on the Os-isotope composition of the xenoliths. If Hawaiian post-erosional lavas were generated simply by melting of depleted mantle peridotite, metasomatized or otherwise, then they should possess Os-isotope signatures similar to the Hawaiian spinel lherzolites. This is not what we observe.

Post-erosional lavas from Oahu and Kauai show large Os-isotopic variations, and extend to values more radiogenic than the most radiogenic shield stage lavas and far more radiogenic than any peridotites studied to date. $^{187}\text{Os}/^{188}\text{Os}$ ranges from 0.142–0.160 in post-erosional lavas from Oahu, and from 0.137–0.159 in post-erosional lavas from Kauai. Although some Hawaiian shield-stage lavas do possess fairly radiogenic Os (but not as radiogenic as the post-erosional lavas), radiogenic Os in shield-stage lavas are accompanied by very radiogenic Sr and unradiogenic Nd. Mixing of depleted mantle with high- $^{187}\text{Os}/^{188}\text{Os}$ plume-derived magmas is therefore not possible, because such mixing would preserve the non-MORB-like Sr- and Nd-isotope signatures of the plume melts but quickly buffer the Os to the composition of the depleted mantle peridotite. The only components in the mantle beneath Hawaii known to possess both depleted Sr- and Nd-isotope signatures and radiogenic Os are garnet pyroxenites sampled as xenoliths from Salt Lake Crater, Oahu. These xenoliths equilibrated between 50 and 75 km depth (Sen, 1988). In contrast to the spinel lherzolites hosted within the same lavas, these garnet pyroxenites possess much more variable and more radiogenic Os-isotopic compositions. $^{187}\text{Os}/^{188}\text{Os}$ in the pyroxenites ranges from 0.134–0.175. Melting of these pyroxenites and mixing with melts generated

by smaller degrees of melting from mantle peridotite can produce the radiogenic Os and MORB-like Sr- and Nd-isotopic signature of the Hawaiian post-erosional lavas.

Correlations between Os-isotopes and major and trace elements sensitive to melting of garnet pyroxenite support our model. Melts derived from garnet pyroxenite should have high abundances of elements such as aluminium or scandium. Small-F melts of sub-lithospheric garnet lherzolite will have lower concentrations of Sc and Al_2O_3 . Therefore, we should expect a positive correlation between Sc or Al_2O_3 and $^{187}\text{Os}/^{188}\text{Os}$ in the post-erosional lavas. Indeed, such correlations are observed in both the Kauai and Oahu post-erosional lavas (e.g. Fig. 1), although there is considerable scatter. We also observe statistically significant correlations between Os- and Nd- and Pb-isotopic compositions, with more radiogenic Os associated with higher or more MORB-like $^{143}\text{Nd}/^{144}\text{Nd}$ and lower $^{206}\text{Pb}/^{204}\text{Pb}$.

Processes such as melt/mantle or melt/crust interaction during melt migration will quickly destroy any correlation between Os-isotopic composition and either incompatible element tracers such as Nd and Pb or tracers of the melting process such as Al and Sc. Melt/crust interaction also cannot account for the radiogenic Os of the garnet pyroxenites. The decoupling of Os and other elements during melt/mantle interaction results from the much higher concentration of Os in mantle peridotite relative to the melt. Given that we do observe correlations between Os-isotopic composition and other elements in the erupted lavas, the extent of melt/mantle interaction subsequent to melt mixing was very limited.

Conclusions

The highly radiogenic Os of Hawaiian post-erosional lavas requires incorporation of a pyroxenitic melt component in these lavas. The correlations between Os-isotopic composition and major elements such as Al further reveals that incorporation of these melts also had a noticeable effect on the major element compositions of the melts. Melt compositions are often utilized by petrologists and geochemists to infer conditions of melt generation and the nature of the mantle source. However, such inversions often assume a single lithologically homogeneous source component. Our results indicate that such assumptions may lead to inaccurate conclusions regarding the melting process, and that the effects of melting a lithologically heterogeneous 'marble-cake' mantle must be considered.