Heterogeneities in the mantle plume: Spatial scales and ages

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Recycling of oceanic crust through subduction, mantle upwelling, and remelting in mantle plumes is a widely accepted mechanism to explain ocean island volcanism. However, neither time scales of this process nor spatial scales of the resulting mantle heterogeneities are well understood.

We report data on trace elements, $^{87}Sr/^{86}Sr$, $^{207}Pb/^{206}Pb$, and $^{208}Pb/^{206}Pb$ ratios for 138 melt inclusions in olivine phenocrysts from single lava of Mauna Loa shield volcano, Hawaii, indicating enormous mantle source heterogeneity. The variations in isotopic compositions and trace element ratios far exceed all known ranges for Hawaiian shield stage volcanoes. The variation range is highest for melt inclusions trapped in the most magnesian olivines. This is consistent with the interpretation that melt inclusions in early olivine phenocrysts yield information on the compositions of unmixed parental melts, while lavas and inclusions in more evolved olivine are mixtures of these melts.

We show that highly radiogenic strontium ($^{87}Sr/^{86}Sr=0.7081\pm 0.0006$, 2σ) in severely Rb-depleted melt inclusions matches the isotopic composition of 200-650 Ma old seawater. We infer that such seawater must have contaminated the Mauna Loa source rock, prior to subduction, imparting a unique ‘time stamp’ on this source. Small amounts of seawater-derived strontium in plume sources may be common but can be identified clearly only in ultra-depleted melts originating from generally highly (incompatible-element) depleted source components.

We also show that the Sr-rich component of Mauna Loa lavas is particularly unradiogenic ($^{87}Sr/^{86}Sr < 0.7030$), supporting the suggestion that it corresponds to plagioclase cumulate gabbros from recycled oceanic crust (Sobolev et al, Nature, 2000).

Enormous isotope heterogeneity of melts mixed in a single plumbing system favours small-scale mantle source heterogeneity preserved in the mantle plume. The presence of 200-650 Ma old oceanic crust in the source of Hawaiian lavas implies a time-scale of general mantle circulation with an average rate of about 2 (± 1) cm/a, a much faster rate than previously thought.

Modeling relationships between a mantle plume, a large igneous province and a mass extinction

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Large Igneous Provinces (LIPs) are known for their rapid production of enormous volumes of magma, for dramatic thinning of the lithosphere and for their links to global environmental catastrophes. Controversy surrounds even the basic idea that LIPs form through melting in the heads of thermal mantle plumes. The Permo-Triassic Siberian Traps – the type example and the largest continental LIP, is located on thick cratonic lithosphere and was synchronous with the largest known mass-extinction event. However, there is no evidence of pre-magmatic uplift nor of a large lithospheric stretching of the basaltic sequence, predicted above a plume head. Moreover, estimates of magmatic CO_2 degassing from the Siberian Traps are considered insufficient to trigger climatic crises leading to the hypothesis that the release of thermogenic gases from the sediment pile caused the mass extinction.

Here we present petrological evidence for a large amount (15 wt%) of dense recycled oceanic crust in the head of the plume and developed a thermomechanical model that predicts no pre-magmatic uplift and requires no lithospheric extension. The model employs source-composition and temperature [1, 2] petrological constraints, non-linear elasto-visco-plastic rheology [3] and pressure- and temperature-dependent melting of a heterogeneous mantle. The model implies extensive plume melting and heterogeneous delamination of the thick cratonic lithosphere during a few hundred thousand years. The model also suggests that massive CO_2 and HCl degassing from the plume could *alone* trigger the Permian-Triassic mass extinction and predicts it happening *before* the main volcanic phase.

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