Mantle heterogeneity recorded by Sr isotopes in Mauna Loa olivine-hosted melt inclusions with unusual trace element fingerprints

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Introduction

Ocean island basalts (OIBs) form in regions of active hot mantle upwelling and display a variety of compositions that reflect a heterogeneous mantle source. Basaltic lavas host early-crystallized minerals (e.g., olivine) trap melts—called melt inclusions—that preserve pre-existing compositional heterogeneity in the magma chamber before melt aggregation processes occur. Significant heterogeneity has been found in melt inclusions from a single lava (Jackson and Hart, 2006; Harlou et al., 2009; Sobolev et al., 2011; Koornneef et al., 2015; Reinhard et al., 2016; Reinhard et al., in review). Of interest are extremely rare ultra-depleted melts (UDMs), which have been identified only in melt inclusions in some oceanic lavas. While most melt inclusions have trace element compositions similar to the host whole rock lava, UDMs are melts that are highly depleted in highly incompatible elements compared to the whole rock. Another set of melt inclusions with exotic compositions are those with large Sr anomalies (i.e., Sr excess compared to trace elements that behave similarly under mantle melting and differentiation processes, such as Nd or Sm) in their trace-element patterns. The origin of rare melt inclusions, which has been a source of debate, will be the primary goal of this study. How UDMs and inclusions with Sr anomalies form, why these melts only exist as inclusions in crystals, and why the melts are so rare? The ideal location to study these unusual melts is at Puu Wahi—a suite of scoria cones on the northeast ridge of Mauna Loa (Lockwood, 1995). Puu Wahi olivine-hosted melt inclusions are ideal because they are glassy, unusually large (<500 µm diameter), and known to contain both exotic melt inclusion types. Understanding the Sr isotopic signals of rare, exotic melt inclusions has implications for the mantle source of Hawaii or even crustal processes that operate to overprint mantle signals in melt inclusions. The $^{87}\text{Sr}/^{86}\text{Sr}$ compositions of a set of ~20 melt inclusions, paired with major and trace element data, will be used to evaluate the origin of the unusual major and trace element patterns in inclusions.

Results

Major and trace element analyses were conducted last summer, supported by an ERI fellowship. Major element, minor element, Cl, and S chemistry of melt inclusions were conducted at the UCSB electron microprobe facility. Cl and S analyses were conducted in a separate session with 4 detectors on Cl to maximize the precision of Cl. Trace elements were measured using a Thermo Scientific Element XR ICP-MS.
coupled to a Resonetics M-50E 193nm ArF excimer laser at Laboratoire Magmas et Volcans, Clermont-Ferrand, France. About 20 melt inclusions have been selected for further isotopic study. Each melt inclusion is isolated by grinding away the olivine with accessory melt inclusions. The olivine crystal has negligible Sr and Nd and does not need to be removed entirely as long as the target melt inclusion is by itself.

UDM inclusions were not found among a population of 267 melt inclusions analyzed for trace elements. However, four high Sr anomaly melt inclusions and an ultra-calcic (>13 wt.% CaO) melt inclusion, which has not been found previously at Puu Wahi, were discovered. Another set of two melt inclusions form a group of melt inclusions that show higher trace element values and negative Sr anomalies (Sr/Sr*<1) in the trace element pattern (Fig. 1) where Sr/Sr* = Sn/SN(NbN, SIm), where N denotes normalization to primitive mantle values from McDonough and Sun (1995). The melt inclusions within this study called 'high Sr anomaly melt inclusions' are defined as those with Sr/Sr*>1.6, and 4 of the 266 melt inclusions examined in this study have Sr/Sr* value above this threshold. (By comparison, 9 of the 148 inclusions examined by Sobolev et al. have Sr/Sr* > 1.6). Two of the high Sr/Sr* inclusions in this study are hosted in olivines with Fo values of 84.5, 85.3, 87.1, and 87.6. However, the MgO content of all of the high Sr/Sr* inclusions are 7.1 - 7.7 wt.% MgO irrespective of the Fo content of the host olivine. The high Sr/Sr* melt inclusions are relatively low in Cl (53 – 58 ppm Cl) compared to the Puu Wahi melt inclusion population: the average Cl concentration of all the melt inclusions examined here is 80 ppm ± 51 ppm (2 SD), and the highest Cl and lowest Cl concentrations are 198 ppm and 36 ppm, respectively.

An important major element ratio, K2O/TiO2, is a rough proxy for 87Sr/86Sr. The higher the K2O/TiO2 ratio, the higher the 87Sr/86Sr. Only the high Sr anomaly melt inclusion has almost twice as high K2O/TiO2 than the other melt inclusions (K2O/TiO2 = 0.19 compared to 0.36 for the highest Sr anomaly melt inclusion), which suggests this melt inclusion should have higher 87Sr/86Sr than the other melt inclusions. A high 87Sr/86Sr than the majority of Mauna Loa lavas would require interaction with recycled seawater-derived materials, which retain seawater's high 87Sr/86Sr, but lose Cl upon subduction of oceanic crust. Since the ultra-calcic melt inclusion has a similar K2O/TiO2 value to Mauna Loa lavas, then its 87Sr/86Sr is likely to be Hawaiian-like and not have Sr isotopes similar to mid-ocean ridge (MOR) lavas.

**Future work and hypotheses**

Future work will require analyzing 87Sr/86Sr in individual melt inclusions in a set of 20 melt inclusions that capture the variability of chemical compositions from the Puu Wahi eruption from Mauna Loa. Sr isotopes have not been measured before in ultra-calcic melt inclusions, thus there are a lot of possibilities for their Sr isotopic composition. Ultra-calcic melt inclusions have been found in different tectonic settings, including volcanic arcs and mid-ocean ridges. The prevalence of these melt inclusions implies these melts have a similar process in different locations. However, at Mauna Loa only 1 in 280 melt inclusions measured for major elements have this ultra-calcic signature. **We will test three hypotheses for the origin of the ultra-calcic signature in melt inclusions from Mauna Loa:** (1) partial melting of a clinopyroxene-rich source, (2) partial melting of a depleted peridotite source, and (3) partial melting clinopyroxene-rich veins. The Sr isotopes between these different sources, however, will vary depending on whether the melted ultramafic rock is of Hawaiian origin or from the underlying oceanic crust. Ultramafic xenoliths from Hawaii typically have Hawaiian-like Sr isotopes, which are higher values than typical Pacific oceanic crust. However, this may be biased as Hawaiian ultramafic rocks are nearer the surface and more likely to get picked up by ascending melt. The ultra-calcic melt inclusion will likely have a Hawaiian-like 87Sr/86Sr since its K2O/TiO2 is similar to the other Mauna Loa melt inclusions.

A remaining question is how melts with large positive Sr anomalies form. A common geologic material with large Sr anomalies is gabbro, which is abundant in the deep oceanic crust, and we infer that gabbro is responsible for the large positive Sr anomalies in some Puu Wahi inclusions. However, the manner in which the gabbro signature was inherited by the melt inclusions is unknown. **We will test three hypotheses for the origin of Sr anomalies in melt inclusions:** (i) interaction with Hawaiian gabbros in the deep roots of Hawaiian volcanoes, (ii) interaction with MOR-like gabbros from the oceanic crust beneath Hawaii, or (iii) melt formation by melting recycled ancient oceanic gabbros, which are gabbros that were injected into the mantle at subduction zones. If the melt inclusions interacted with Hawaiian gabbroid crust, the melt inclusions with Sr anomalies would have 87Sr/86Sr values identical to Hawaiian lavas. If the melt inclusions interaction with MORB gabbros underlying Hawaii, they will have 87Sr/86Sr ratios shifted away.
from Hawaiian lavas toward lower values found in MORB. If Puu Wahi melt inclusions have a recycled ancient lower oceanic crust source, the $^{87}\text{Sr}/^{86}\text{Sr}$ of Puu Wahi melt inclusions would be lower than EPR-MORB. This is because gabbro formed at ancient ridges have even lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than modern MORB (owing to lower Rb/Sr in gabbro than depleted mantle), and the magnitude difference between the melt inclusions and EPR-MORB would be directly proportional to the age of the gabbro protolith. If the $^{87}\text{Sr}/^{86}\text{Sr}$ of high Sr anomaly melt inclusions is higher than Hawaiian rocks (as implied by $\text{K}_2\text{O}/\text{TiO}_2$), then another hypothesis would have to be formed.

References
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