182-W IMPLICATIONS FOR SILICATE MAGMA OCEAN PROCESSES IN TERRESTRIAL PLANETS.

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Introduction: The short-lived ^{182}Hf-^{182}W isotope system ($t_{1/2}$ = 8.9 Ma; [1]) can be used as an important tool to study processes that took place within the first 60 Ma of Solar System (SS) formation. Because of the fractionation of lithophile hafnium from siderophile tungsten during metal-silicate segregation processes, this system provides important information about early planetary differentiation. Formation and crystallization of magma oceans in differentiated planetary bodies, resulting from accretionary and radiogenic heating [2], can also lead to fractionation of Hf from W. If the fractionations occur while ^{182}Hf is alive, mantle domains with distinct tungsten isotopic compositions will form. Further, addition and subsequent mixing of late accreted material to the mantle or isolation of mantle domains from such processes can also produce isotopic heterogeneities in W.

Terrestrial rocks that sample a source reservoir which formed during the very early stages of the Earth's history, and has remained isolated from mantle convection for 4.5 Ga, should directly reflect its primitive isotopic signatures. Ocean Island basalts (OIB) have often been interpreted to derive from deep-seated mantle plumes that originate near the core-mantle boundary. Studies of noble gases have concluded that some OIB carry primordial signatures and, therefore, indicate at least one primitive mantle source component.

Samples and Results: OIB from the Hawaiian and Samoan hotspots show large variations in long-lived isotope compositions (Pb, Hf, Nd, Sr). In addition, these samples exhibit a large range in helium isotope ratios with ^{3}He/^{4}He of as low as ~8 R/RA, similar to the average helium ratios of mid ocean ridge basalts and ^{3}He/^{4}He ratios of up to 32 R/RA. Because of the presence of high ^{3}He/^{4}He melts in Samoa and Hawaii, their sources have been interpreted to represent primitive, un-degassed mantle.

We analyzed OIB samples from Samoa and Hawaii that are representative of the exent of isotopic heterogeneity in these systems with regard to long-lived radiogenic isotope (Hf, Nd, Sr, Pb) and helium isotopic compositions. Tungsten concentrations range from 90 to 970 ppb, and according to [3], reflect their derivation from a source characterized by normal W abundances. Tungsten isotopic analyses reveal deficits in ^{182}W of up to 18 parts per million in some of the basalts, compared to terrestrial standards (Fig. 1). These negative ^{182}W anomalies do not correlate with long-lived radiogenic isotope systems but exhibit good negative correlations with new and previously published helium ratios. Samples with low ^{3}He/^{4}He show no deviation in ^{182}W from terrestrial standards. By contrast, those OIB characterized by high helium ratios yield well-resolved negative tungsten anomalies (Fig. 2).

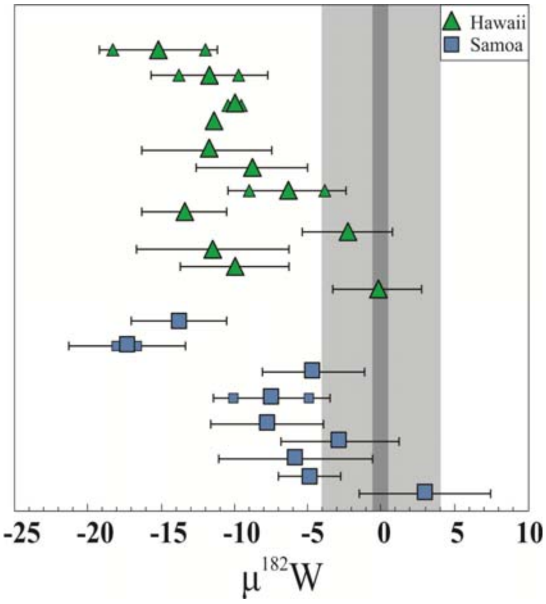

Figure 1. Well resolved deficits in ^{182}W in most Hawaiian and Samoan OIB. Light and dark grey bars represent 2SD = 4ppm and 2SE = 0.5 ppm, respectively, of Alfa Aesar W standards (n = 68).

Discussion: Deficits in 182-tungsten can be produced by various processes within the first 60 Ma of Solar System formation. The negative correlation with ^{3}He/^{4}He requires a source reservoir that is characterized by low Hf/W and high He/(U+Th) ratios. Silicate crystal-liquid fractionation in a magma ocean can create a reservoir that is characterized by low Hf/W. However, this mantle domain would at the same time be enriched in other incompatible elements, such as Th and U, leading to low He/(U+Th) and over time to low ^{3}He/^{4}He.

The addition of a core component to the mantle plume would also lead to a negative ^{182}W signature in OIB. However, highly siderophile element (HSE) concentrations in our studied OIB are consistent with sources with normal HSE compositions [e.g., 4]. The lithophile and siderophile behavior of Hf and W, respectively, make metal a good candidate for reservoirs characterized by very low Hf/W ratios. Metallic iron droplets could have been formed by disproportionation reactions ($FeO = Fe_2O_3 + Fe$; [5]) during the crystallization of an early terrestrial magma ocean. It has been suggested that such Fe liquids could potentially also store significant amounts of helium [6]. Since lithophile elements, such as Th and U are not incorporated in metal phases, primordial ^{3}He/^{4}He would be retained.

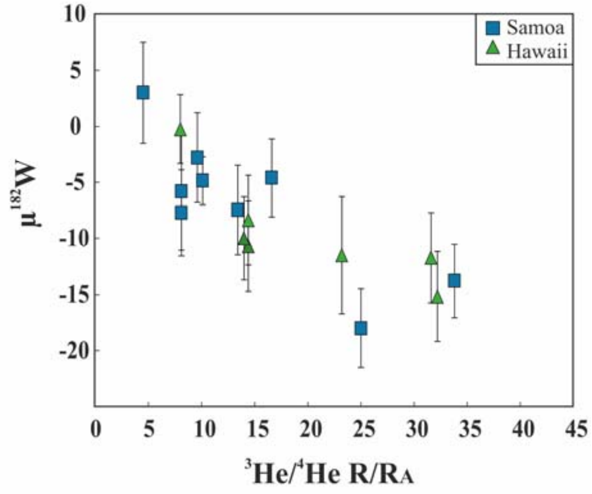

Figure 2. Negative correlation of μ^{182}W versus ^{3}He/^{4}He ratios in Hawaiian and Samoan OIB.

In addition to these geochemical observations, seismic anomalies also suggest Fe-rich silicates or metal-rich domains close to the core-mantle boundary. So-called ultra-low velocity zones (ULVZ) are characterized by greater densities than the ambient mantle and can be found beneath both Hawaii and Samoa. Mantle plumes tapping ULVZ that incorporate ambient mantle and potentially recycled material could result in the observed negative W-He correlation in our studied OIB (Fig. 3).

Conclusions: Deficits in ^{182}W together with high ^{3}He/^{4}He in OIB from Hawaii and Samoa require a source component characterized by low Hf/W and high He/(Th+U) that formed within the first 60 Ma of solar system formation. Geochemical and geophysical constraints point towards stranded metal in the lowermost mantle as a potential source candidate leading to the observed W and He signatures. This lower mantle reservoir must have remained isolated from mantle mixing throughout the Earth's history.

Our study shows that isotopic signatures formed by early magma ocean processes within differentiated terrestrial planets can be retained throughout a planet's history, and on Earth, can be sampled 4.5 billion years later by deep-rooted mantle plumes.

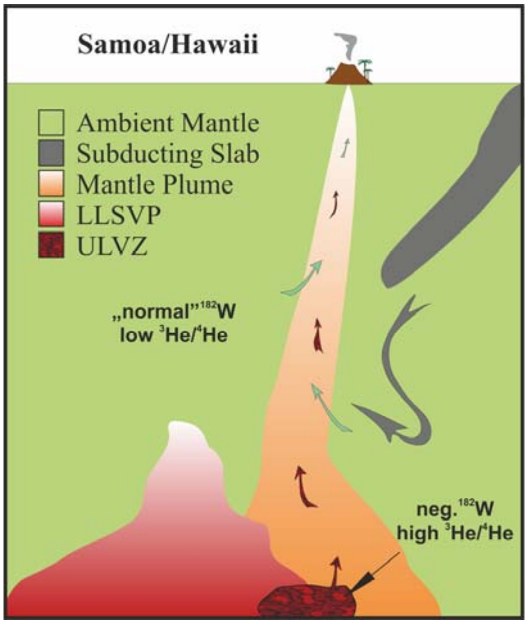

Figure 3. Incorporation of various mantle sources into the mantle plumes beneath Samoa and Hawaii can lead to the observed negative W-He correlation.

References:

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