

IRON ISOTOPE FRACTIONATION DURING PLANETARY DIFFERENTIATION. F. Z. Teng^{1,†}, N. Dauphas¹, and R. T. Helz², ¹Origins Laboratory, Department of the Geophysical Sciences and Enrico Fermi Institute, University of Chicago, 5734 South Ellis Ave. Chicago, IL 60637, U.S.A. (teng@uchicago.edu; dau-phas@uchicago.edu), ²U. S. Geological Survey, Reston, Virginia 20192, U.S.A. (rhelz@usgs.gov), [†]Present address: Isotope Laboratory, Department of Geosciences and Arkansas Center for Space and Planetary Sciences, University of Arkansas, 113 Ozark Hall, Fayetteville, AR 72701, U.S.A.

Introduction: Studies of isotopic variations in terrestrial and extraterrestrial rocks can potentially be used to identify the processes that governed planetary differentiation. For example, Fe isotopic compositions of lunar and terrestrial basalts are slightly heavier than those of chondrites, Mars and Vesta, which has been ascribed to evaporation-induced kinetic Fe isotopic fractionation during the giant impact that formed the Moon [1]. This interpretation assumes that Fe isotopic compositions of basalts can represent those of their sources (*i.e.* mantle), which is supported by studies of other metal/metalloid isotopes. For instance, Li and Mg show no isotopic fractionation during basaltic differentiation at temperatures greater than 1050°C [2,3]. However, Fe chemistry is unique in that two oxidation states are present in magmas. During partial melting and fractional crystallization, they partition differently between melts and solids, which can potentially produce measurable isotopic fractionation. Studies of mantle peridotites have shown measurable Fe isotopic fractionation during mantle melting [4,5] while the effect of fractional crystallization on Fe isotopes, which is more directly related to Fe isotopic systematics of basalts, has not been systematically evaluated yet. In order to address this question, we have measured the Fe isotopic compositions on a set of well-characterized samples from Kilauea Iki lava lake, Hawaii.

Samples and geological background: The Kilauea Iki lava lake formed during the 1959 summit eruption of Kilauea volcano by filling a pre-existing crater. The lava lake cooled and crystallized as a small, self-roofed, closed magma chamber, with a melt-rich interior, surrounded on all sides by partially molten regions, extending outward to fully solidified rock [6]. The lava lake therefore provides an ideal field laboratory for studying the effect of basaltic differentiation on isotopic fractionation.

A variety of samples from the lava lake, ranging from olivine-rich cumulates to andesitic segregation veins and covering the whole spectra of chemical compositions, mineralogy, petrology and crystallization temperatures have been analyzed. The whole-rock powders are the same as those used in previous studies [2,3,6]. For two samples, almost pure (>98 %) olivine separates were handpicked under a binocular micro-

scope, cleaned with Milli-Q water for 3×10 minutes in an ultrasonic bath, and dried down under a heat lamp before dissolution.

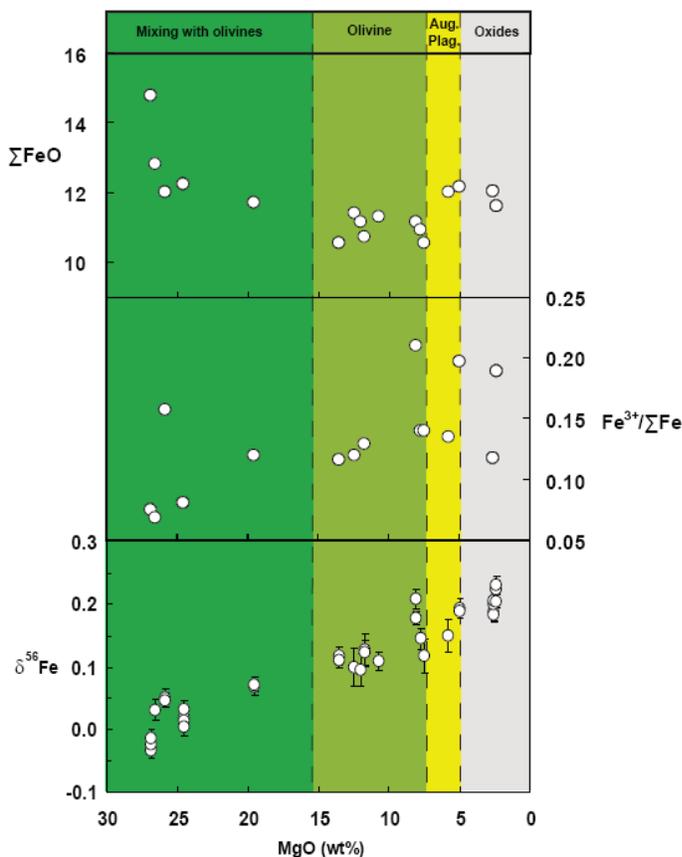


Fig. 1. Variations of total FeO contents (ΣFeO), $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratios and $\delta^{56}\text{Fe}$ values as a function of MgO contents in the Kilauea Iki lava. The MgO content of the primitive Kilauea Iki lava is 15.4 wt% [7]. Samples with $\text{MgO} > 15.4$ wt% were produced by mixing of melts with olivine crystals while those with $\text{MgO} < 15.4$ wt% reflect sequential fractional crystallization of olivine, augite (Aug.), plagioclase (Plag.) and Fe-Ti and Fe oxides [6].

Analytical Methods: Both whole-rock powders and olivine separates were dissolved in $\text{HF-HClO}_4\text{-HNO}_3$. Iron was purified on an ion exchange resin [8] and its isotopic composition was analyzed by either

sample-standard bracketing or Cu-doping method on a Neptune MC-ICPMS at the University of Chicago, with an external precision $\leq 0.034\%$ (2σ) [9].

Results: The $\delta^{56}\text{Fe}$ values correlate negatively with MgO and total FeO contents (ΣFeO), and correlate positively with $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratios (Fig. 1). Olivine cumulates have higher MgO contents (up to 26.87 wt%) and lower $\delta^{56}\text{Fe}$ values (down to -0.03%) while late-stage veins have lower MgO contents (down to 2.37 wt%) and higher $\delta^{56}\text{Fe}$ values (up to $+0.22\%$). 42 olivines from two hand samples have the largest range in $\delta^{56}\text{Fe}$ values reported for igneous minerals, from -1.10 to $+0.09\%$ (Fig. 2). The average $\delta^{56}\text{Fe}$ of these olivines is $-0.22 \pm 0.25\%$ (1σ), which is significantly lower than that of whole rocks (*i.e.*, $+0.11$ and $+0.12$).

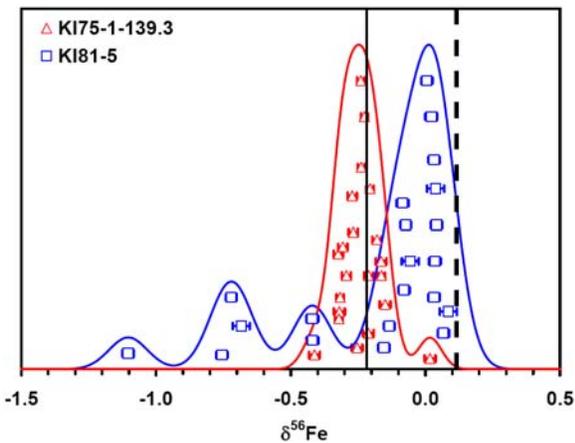


Fig. 2 Iron isotopic compositions of olivines from the Kilauea Iki lava lake. The curves are kernel density estimates with automatic bandwidth selection. The 2 curves have the same surface area. The vertical solid line is the average $\delta^{56}\text{Fe}$ (-0.22) of all olivine samples while the dashed lines are the average $\delta^{56}\text{Fe}$ ($+0.11$ and $+0.12$) of those two whole rocks.

Discussion: The large chemical variations in Kilauea Iki lavas mainly result from post-eruptive redistribution of olivine phenocrysts and crystallization of pyroxenes, plagioclases and oxide phases during cooling of the lava lake [6] (Fig. 1). The samples with $\text{MgO} < 15.4$ wt% can be modeled by fractional crystallization with a difference in $\delta^{56}\text{Fe}$ between minerals and melts ($\Delta^{56}\text{Fe}$) of ~ -0.1 to -0.3% (Fig. 3). Consequently, the average $\delta^{56}\text{Fe}$ of the crystals are estimated to be ~ 0 to -0.2% assuming that the $\delta^{56}\text{Fe}$ of the primitive melts is $\sim +0.1\%$. These values are used to model the compositions of samples with $\text{MgO} > 15.4$ wt% by mixing the primitive melts ($\delta^{56}\text{Fe} = +0.1\%$) with olivine crystals ($\delta^{56}\text{Fe} = 0$ to -0.2%) (Fig. 3). The above model can explain all whole-rock lava data,

suggesting that fractional crystallization was the main process that affected Fe isotopic systematics in the lava lake. However, olivine separates are highly heterogeneous and have $\delta^{56}\text{Fe}$ values well beyond the range defined by the above theoretical modeling, which indicates that other processes other than fractional crystallization have also affected the Fe isotopic systematics in the lava lake. This includes chromatographic processes during relative motion of melts and crystals.

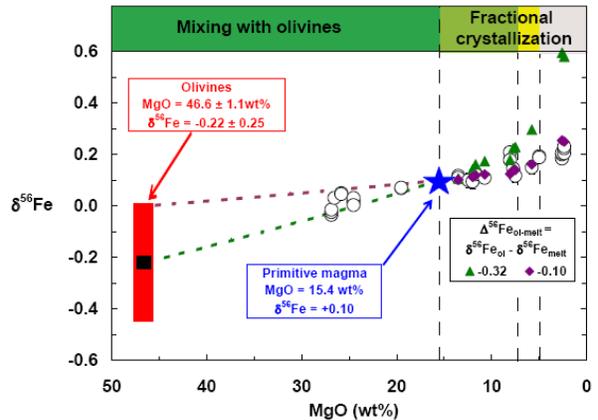


Fig. 3. Variations of Fe isotopic compositions as a function of MgO content in the Kilauea Iki lava. Filled symbols represent calculated Fe isotopic compositions during fractional crystallization by assuming a Rayleigh distillation process with different average crystal-melt fractionation factors. Dashed lines represent calculated mixing lines between the primitive Kilauea Iki lava and olivines. Sample crystallization sequences are same as those in Fig. 1.

Our study indicates that unlike Li and Mg isotopes, Fe isotopes fractionate during basaltic differentiation at both whole-rock and mineral scales, due to the change of Fe oxidation states. This suggests that the Fe isotopic composition of basalts may not represent that of their sources. Thus caution should be exerted when using whole-rock basalt Fe isotopic data to estimate and compare those of different planetary bodies and constrain the processes of planetary differentiation.

Acknowledgement: Helpful discussion with Shichun Huang is highly appreciated.

References: [1] Poitrasson F. et al. (2004) *EPSL*, 223, 253–266. [2] Tomascak P. B. et al. (1999) *GCA* 63, 907–910. [3] Teng F. Z. et al. (2007) *EPSL* 261, 84–92. [4] Weyer S. et al. (2005) *EPSL* 240, 251–264. [5] Weyer S. and Ionov D. A. (2007) *EPSL* 259, 119–133. [6] Helz R. T. (1987) *Geochem. Soc. Spec. Publ. 1*, 241–258. [7] Wright T. L. (1973) *GSA Bulletin* 84, 849–858. [8] Dauphas N. et al. (2004) *Anal. Chem.* 76, 5855–5863. [9] Dauphas N. et al. *in prep.*