

## SUPPLEMENTARY MATERIALS

### Diffusion calculations

In order to assess how subsolidus cooling history might affect the measured D/H of olivine and apatite in Apollo 12 olivine basalts, we performed simple calculations using available diffusivity data. We compared Fe-Mg interdiffusion rates in olivine with those of H in olivine and results of those calculations are shown in Table S1 for the time needed to diffuse 500  $\mu\text{m}$  at temperatures of 600°C, 800°C, 1000°C and 1200°C. Olivine grains are typically mm-sized in basalt 12035 (e.g., Fig. 1a). We calculated the length of time needed to diffuse 500  $\mu\text{m}$  using the diffusion length equation:  $x = 2\sqrt{Dt}$ .

The equation we used for Fe-Mg interdiffusion in olivine at oxygen fugacities less than  $10^{-10}$  Pa is from Dohmen and Chakraborty (2007):

$$\log[D_{\text{FeMg}}(\text{m}^2/\text{s})] = -8.91 - \frac{220000 + (P - 10^5) * 7 * 10^{-6}}{2.303RT} + 3X_{\text{Fe}}.$$

The diffusion of H in olivine was calculated using an equation for diffusion parallel to [100] from Demouchy and Mackwell (2003):

$$DV_{\text{Me}[100]} = 10^{-4.3} \exp\left(-\frac{225}{RT}\right).$$

The results of the diffusion calculations at the select temperatures for Fe-Mg interdiffusion and H in olivine are shown in Table S1 and the diffusion coefficients are plotted in Supplementary Fig. S1. The calculations demonstrate that hydrogen diffusion in olivine is extraordinarily fast. This suggests that at the conditions that dictated cooling of the Apollo 12 olivine basalt suite, hydrogen would have diffused out of any olivine-hosted melt inclusions if the interstitial liquid was dry. If the interstitial liquid still had “water”, then the hydrogen in olivine-hosted melt inclusions would have had ample time to diffusively equilibrate with this hydrogen in the melt, as demonstrated experimentally for olivine-hosted melt inclusions in terrestrial magmas (Gaetani *et al.*, 2012).

Apollo 12 sample 12035 presumably cooled 11 m from the low-pressure lunar surface (Walker *et al.*, 1976a). Hydrogen trapped in melt inclusions equilibrates rapidly with melt surrounding the host-olivine grains (Gaetani *et al.*, 2012) and therefore any hydrogen contained in melt inclusions would have either equilibrated with interstitial liquids, or for the most slowly cooled lavas, hydrogen would have escaped. Our diffusion calculations fur-

ther indicate that hydrogen reservoirs in melt inclusions would have fully equilibrated with the water-depleted lava surrounding host crystals during formation of the Apollo 12 basaltic cumulates, and support the model for D/H exchange followed by dehydration of the Apollo 12 olivine basalt magmas (Fig. 4).

We also used the recent determination of diffusion of H in apatite by Higashi *et al.* (2017) to calculate diffusion of H at the same temperatures as we did for olivine in Table S1 (600–1200°C) using the equation:

$$D = 6.71 \times 10^{-13} \exp\left(-\frac{80.5}{RT}\right).$$

Results of the diffusion calculations for 600–1200°C are shown in Fig. S1. Not surprisingly, Fe-Mg interdiffusion in olivine is slower than H diffusion in apatite by several orders of magnitude at all temperatures. As basalts 12035 and 12040 have partially re-equilibrated olivine compositions, it would be expected that hydrogen in olivine-hosted melt inclusions in these two samples would have equilibrated with external hydrogen in the melt.

Basalt 12018 has olivine-hosted melt inclusions that have high OH and low  $\delta\text{D}$ , consistent with rapid D/H equilibration with a magma that had not dehydrated and still had significant hydrogen. An apatite grain analyzed for D/H in basalt 12018 has  $\delta\text{D} = +1439 \pm 103$  ( $2\sigma$ ), suggesting that apatite had not exchanged its D/H significantly since crystallization, as diffusion of H is slower in apatite than olivine at high temperature (Fig. S1). Olivine zoned in iron and magnesium in basalt 12018 shows that this sample has not undergone complete Fe-Mg re-equilibration of olivine. Interestingly, the diffusion of H in apatite and olivine is expected to be similar at low temperatures, suggesting a potential method to distinguish between high temperature magmatic D/H exchange and lower temperature subsolidus D/H exchange in igneous samples. For example, if olivine-hosted melt inclusions and apatite have similar D/H in a sample, this could be consistent with subsolidus equilibration of D/H (Treiman *et al.*, 2016). Apatite and olivine-hosted melt inclusions in basalt 12040 are similar in D/H, and would be consistent with this model of Treiman *et al.* (2016). If olivine-hosted melt inclusions and apatite have different D/H in a sample, this could be consistent with a high-temperature exchange, that affected the D/H of olivine-hosted melt inclusions but did not significantly alter the D/H of apatite. Apatite and in basalt 12018 are very different in D/H, and would be consistent with high-temperature hydrogen exchange model shown in Fig. 4; the olivine-hosted melt inclusions would have exchanged D/H in Stage I, after apatite crystallization.

Table S1. Calculated time needed to equilibrate an average olivine grain at a respective temperature in Fe-Mg and H in basalt 12035. Fe-Mg diffusion data in olivine from Dohmen and Chakraborty (2007) and H in olivine from Demouchy and Mackwell (2003). See Supplementary Material for details.

T (°C)	Olivine composition	Minimum Fe-Mg diffusion time	Minimum H diffusion time
1200	Fo <sub>56</sub>	~10 y	~1 d
1000	Fo <sub>56</sub>	~150 y	~25 d
800	Fo <sub>56</sub>	~7800 y	~3.5 y
600	Fo <sub>56</sub>	~2.2 × 10 <sup>6</sup> y	~1150 y

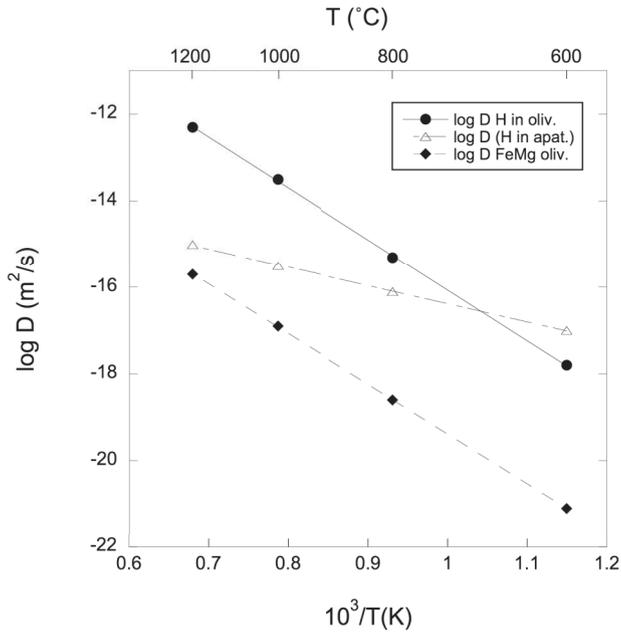


Fig. S1. Calculated diffusion coefficients for hydrogen and Fe-Mg interdiffusion in olivine, and hydrogen in apatite. See text for details.

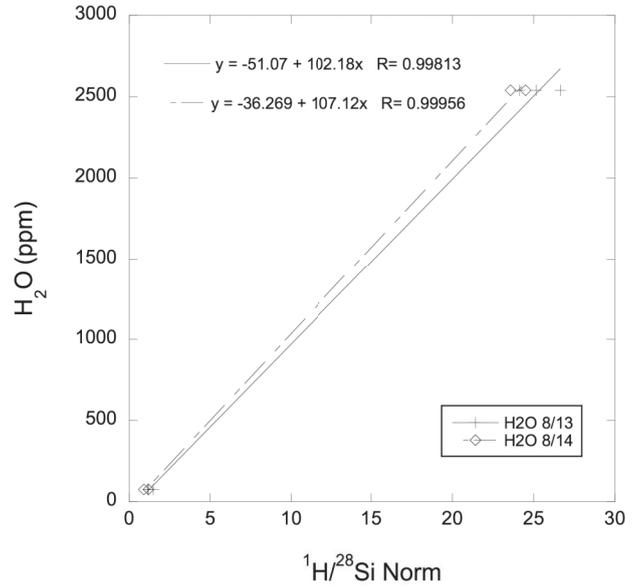


Fig. S2. H<sub>2</sub>O (ppm) vs. <sup>1</sup>H/<sup>28</sup>Si normalized to SiO<sub>2</sub> content (e.g., Hauri et al., 2002). The two linear fits are for the two days of analyses in 2014.