

**THE SIGNIFICANCE OF OH CONTENTS IN LUNAR APATITES.** J. F. Pernet-Fisher<sup>1</sup>, Y. Liu<sup>2</sup>, Y. Guan<sup>2</sup>, Y. Chen<sup>2</sup>, G. H. Howarth<sup>1</sup> and L. A. Taylor<sup>1</sup>; <sup>1</sup> Planetary Geosciences Institute, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA; (Email: jpf@utk.edu), <sup>2</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, USA.

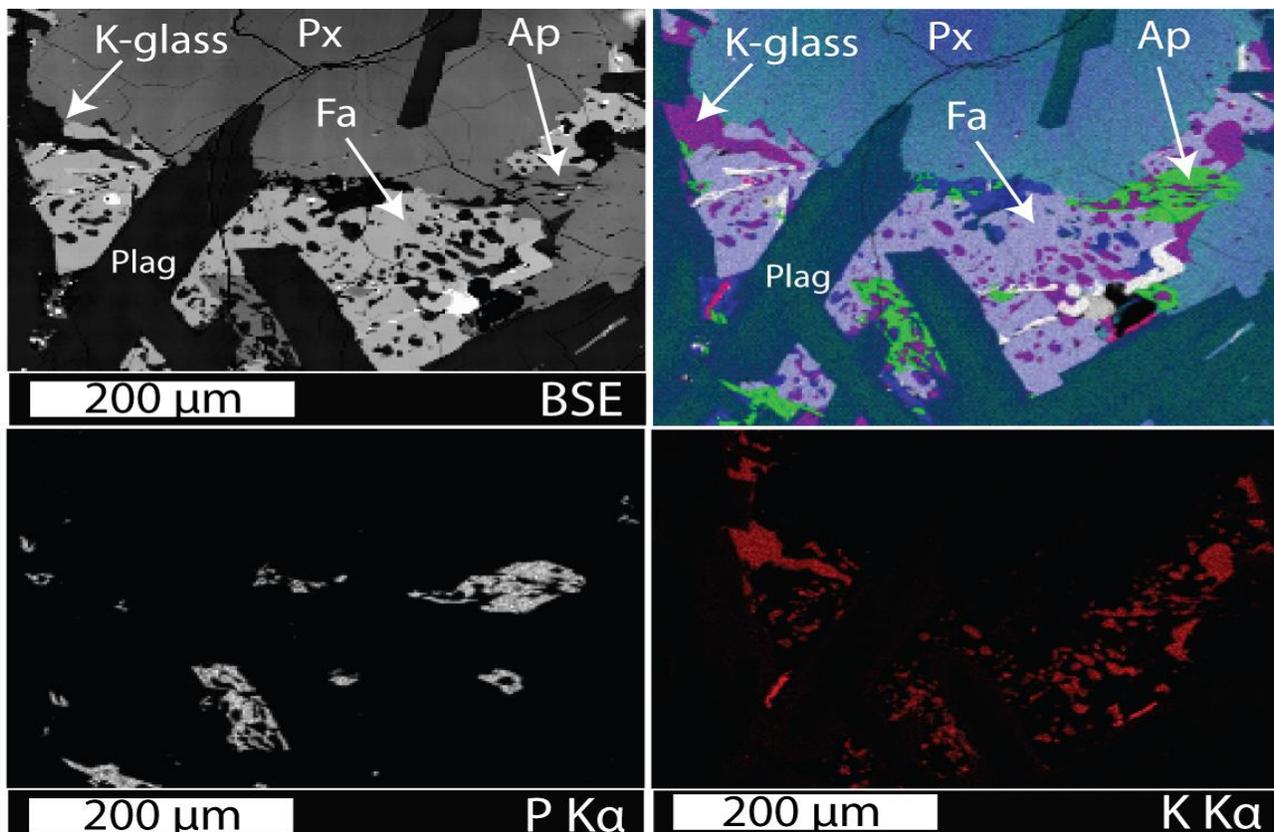
**Introduction:** Water contents (both OH and H<sub>2</sub>O) of lunar apatites are commonly used to estimate the lunar-mantle water budget; however, we question the significance of these reported estimates. We demonstrate that mesostasis pockets within lunar basalts represent isolated heterogeneous systems that have evolved independently from each other, each displaying distinct ranges in OH concentrations. In addition, we note that apatites crystallize from K-rich and REE-P rich portions of late-stage silicate-liquid immiscibility (SLI) [1, 2] which requires an additional set of OH partitioning coefficients when back-calculating magmatic water content. This has largely been overlooked within the literature, and as such, casts serious doubt on previous calculated OH contents of parental magmas and, subsequently water estimates of the lunar mantle, etc.

Previous lunar mantle-water estimates have been generally calculated from apatite OH contents without information of this petrologic context. This has resulted in a wide range of reported water contents for the lunar mantle ranging from 64 ppb to 750 ppm [e.g. 3-6]. This led to the suggestion that the lunar mantle may

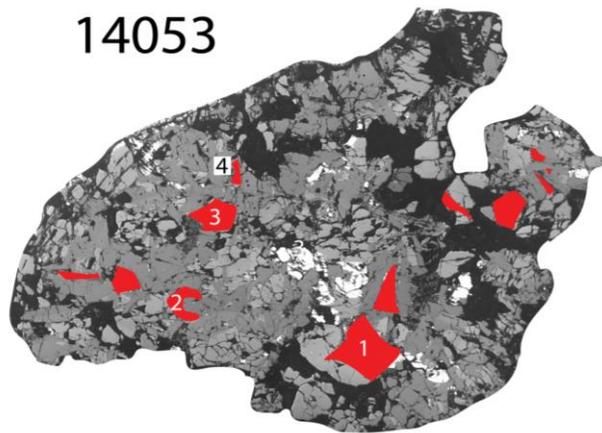
contain similar water abundance as the Earth's upper mantle. However, the wide range of estimated mantle-water contents raises the question of the validity of deriving bulk-water contents from *in-situ* apatite OH analyses.

In order to address this, we report new *in-situ* apatite OH concentrations from a number of mesostasis pockets from a single lunar basalt, taking into account their petrologic context. We demonstrate that relating the OH content of apatites to individual mesostasis pockets, in particular taking in to consideration the secondary OH partitioning due to the SLI, is critical to any robust estimate of magma water contents.

**Methods and Results:** Apollo 14 basalt 14053 was selected for detailed mesostasis investigation because of the large modal proportions of mesostasis, and sufficiently large apatites for analysis. One chip was polished and mounted in Indium, minimizing plucking and cracks. Detailed X-ray maps were obtained using a Cameca SX100 EMP. Maps for Ti, Ca, Fe, K, F, P, and Ba were obtained in order to fully characterize individual mesostasis pockets and to target apatites for SIMS OH and  $\delta$ D analysis (Fig. 1). SIMS analyses



**Figure 1.** Backscatter, P, K and combined X-ray maps of a representative mesostasis pocket. Ap (Apatite); Fa (Fayalite); Plag (Plagioclase); Px (Pyroxene); K-glass (K-rich glass).



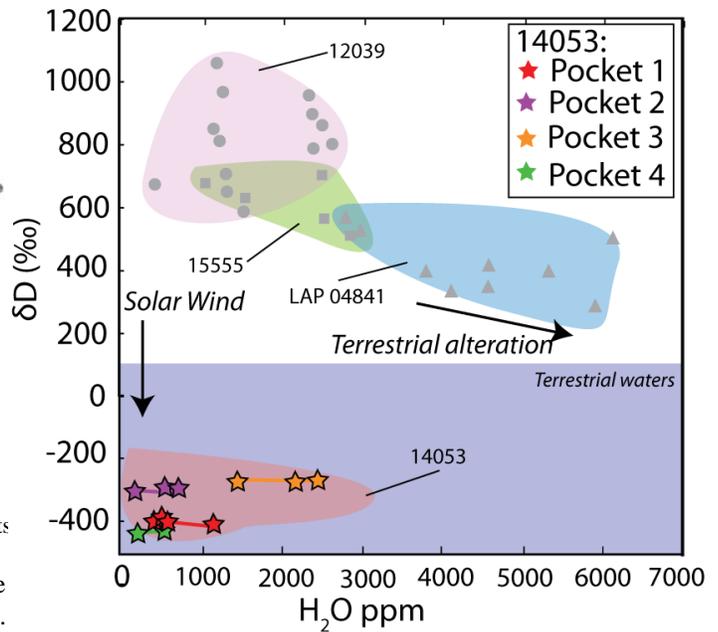
**Figure 2.** Reflected light image of 14053. Red areas highlight major mesostasis pockets. Numbers denote the pockets

were performed with a Cameca ims-7f GEO ion probe at Caltech, following the method outlined by Liu et al. [7,8]. Multiple apatites from 4 mesostasis pockets were analyzed from 14053 (Fig. 2), displaying a similar total range in  $H_2O$ , as previously reported by [4, 8, 9]. ImageJ modal analysis of the chip gave ~5 vol% mesostasis (Fig. 2). Also, within individual mesostasis pockets, the modal proportion of apatite varies from 0.5 to 2 vol%. Apatite from different pockets range in  $H_2O$  from 218 ppm. One mesostasis pocket displays distinctly higher  $H_2O$ , ranging from 1447 to 2244 ppm (Fig. 3). The  $\delta D$  from these samples are all very low and display little variation (Fig. 3), consistent with [4], possibly due to the influence of solar-wind reactions within this sample [8].

**Discussion:** Lunar basalts follow Fenner-Trend iron-enrichment during fractional crystallization, due to low oxygen fugacity (~IW-1) prevalent in lunar magmatic systems. Combined with unusually high FeO contents (12-25 wt%) of the basaltic magmas, late-stage ferro-pyroxenes are formed associated with pockets of the late-stage mesostasis. These pockets have evolved independently from each other forming isolated, heterogeneous systems.

During this late-stage crystallization, SLI occurs, forming a K-fraction melt (felsic) and a REEP-fraction melt (ferro-basalt), analogous to the KREEP portions of the lunar magma ocean [1, 21]. Apatite crystallizes in both SLI fractions, thus requiring different sets of partition coefficients to be taken into consideration for back-calculating OH contents of the parental magmas. Such factors have been overlooked in the literature.

Indications of large disparities in apatite analyses have been previously reported from apatites in a number of basalts, where OH contents varied by a factor of 8 and  $\delta D$  values varied by a factor of 4 [11, 12]. Here,



**Figure 3.**  $\delta D$  (‰) vs.  $H_2O$  ppm of lunar apatite measured. Grey symbols represent values from the literature [10, 11]. Stars represent values from this study.

we demonstrate that whereas similar ranges in OH are observed, individual mesostasis pockets from 14053 display distinct ranges in OH concentrations (e.g. pocket 1 – 407 to 1026 ppm vs. pocket 3 – 1447 to 2244 ppm), clearly highlighting the heterogeneous nature of mesostasis pockets. If mantle water estimates for a particular sample were only based on several apatites, then this could lead to over/under estimates of magma water content. Furthermore, it is only by considering apatites *in-situ*, that the role of liquid immiscibility in fractionating OH can be taken into account, thus enabling more accurate magma water-content estimates.

**References:** [1] Taylor, L.A. et al. (2010) Brown-Vernadsky Workshop, Abstract; [2] Neal C.R. and Taylor L.A. (1989) *GCA* 53, 529; [3] Saal, A.E, et al. (2008) *Nature* 454, 192; [4] Boyce J.W. et al. (2010) *Nature* 466, 466; [5] Greenwood, J.P., et al. (2011) *Nature Geosci.* 4, 79; [6] Hauri E.H. et al. (2011) *Science* 333, 213; [7] Liu, Y. et al. (2012) *43<sup>rd</sup> LPSC*, #1864; [8] Liu, Y. et al. (2010) *41<sup>st</sup> LPSC*, #2647; [9] McCubbin, F.M. et al. (2010) *PNAS* 107, 11223; [10] Taylor, L. A et al. (2004) *Amer. Min.* 89, 1617; [11] Greenwood, J.P. et al. (2010) *41<sup>st</sup> LPSC*, #2439; [12] Tartese et al. (2013) *GCA*. 122, 58-74.