Hydroxyl in Lunar Regolith: Dependence on Soil Composition and Maturity. Y. Liu[1,4], Y. Guan[2], Y. Chen[3], Y. Zhang[3], J. M. Eiler[2], G. R. Rossman[2], and L. A. Taylor[4], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109. [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125. [3]Department of Earth and Environmental Sciences, University of Michigan, Ann Arbor, MI 48109. [4]Planetary Geosciences Institute, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996. (Email: yang.liu@jpl.nasa.gov)

Introduction: The Moon is a natural laboratory for understanding the formation and evolution of planetary bodies. Recent discoveries have demonstrated that water is present in different forms (OH, H_2O, and H_2O ice) on the surface of the Moon [1-4], either bounded in impact melt of soils [5], or locked in igneous samples (volcanic glass and minerals) that are indicative of the interior of the Moon [6-12].

These findings are particularly exciting for their implications in the formation of Earth-Moon system, as well as their potential as *in-situ* resources for human exploration. Moreover, *the study of the lunar regolith has provided our current knowledge about the interaction between airless bodies and the interplanetary medium*. The interaction between the surface of airless bodies and the interplanetary medium is not limited to the change in the surface optical properties by radiation and micrometeorite impacts (commonly referred to as space weathering effects), but also include *alterations* (melting and mixing) by meteorite impacts. The discoveries of water (H) in the north pole of Mercury [13-14] and on the surface of 4 Vesta [15] substantiate the requirement of a better understanding of meteorite inputs as well as solar-wind radiation effects. Here, we examine the data in Liu et al. [5] and discuss the related on-going research.

Methods: Soil grains were picked from the 125-500 μm fraction of lunar soils (highland vs. mare, immature vs. mature). These grains were embedded in Crystalbond™ adhesive and polished. These samples were then cleaned with acetone, ethanol, and then repeatedly with dichloromethane, in order to remove the contamination from the Crystalbond™ adhesive. Some samples were polished to achieve two parallel sides for analyses with a PerkinElmer spectrum GX Fourier Transform InfraRed (FTIR) spectrometer. Both doubly and singly-polished grains were measured using a Cameca IMS 7f-GeO Secondary Ion Mass Spectrometer (SIMS) for OH contents and D/H values.

The study of Liu et al. [5] used the MPI-DING reference glasses (GOR128-G, GOR132-G, KL2-G, ML3B-G) and their reported OH contents in Jochum et al. [16]. We now directly measured OH contents of these MPI-DING reference glasses using the PerkinElmer FTIR. Chips of reference glasses were kindly provided by Drs. Jochum and Stoll at Max Plank Institute, Germany. A MORB glass was also included as a standard.

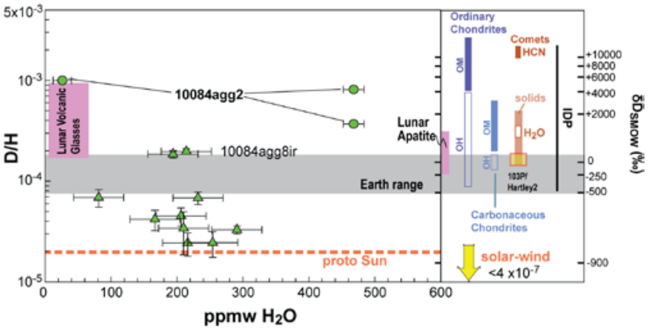

Fig. 1. *D/H values versus OH contents (in ppmw H_2O) of lunar agglutinitic glasses (from [5]).*

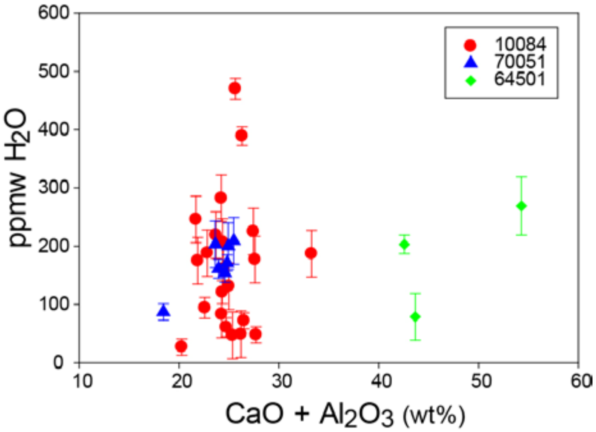

Fig. 2. *The OH contents (in ppmw H_2O) versus CaO + Al_2O_3 of individual analytical spots.*

Water Contents in Standard Glasses: The FTIR measurements showed that the OH contents (expressed as ppmw H_2O) in our pieces of GOR128-G, GOR132-G, and KL2-G are 153, 138, and 68 ppmw H_2O, respectively, roughly half of the reported values [16]. The 1σ standard deviations of 3 to 4 analyses of each glass are 6, 10, and 10 ppmw H_2O, respectively. The FTIR spectra of ML3B-G are abnormal, and thus this reference glass is not used as a standard for later studies. The MORB glass contains 258 ppmw H_2O with a 1σ standard deviation of 11 ppm of 4 analyses. These results imply that the analyses in Liu et al. [5] may have overestimated OH contents by a factor of 2.

Water Contents in Lunar Soils: The study of Liu et al. [5] largely focused on one lunar soil, Apollo 11 soil 10084. Two grains from an Apollo 17 soil 70051 and one grain from an Apollo 16 soil 64051 were included in [5]. The <250 μm fractions of soil 10084 and 64501 are both mature (I_s/FeO of 78 and 61, respectively [17]), where soil 70051 is likely sub-mature (I_s/FeO = 30-59) [17, 18]. I_s is an arbitrary unit, proportional to single-domain metallic iron grains.

Liu et al. [5] verified the presence of OH in agglutinitic glasses in lunar soils. The measured OH contents display a large range from 27 to 470 ppmw H_2O, with the D/H values range from ~2 x 10^{-5} to ~1 x 10^{-3} (Fig. 1). Most of these D/H values can be explained by the mixing of spallation-induced D with solar-wind H [5]. One sample (10084agg2) shows D/H values comparable to those in chondrites and comets. Liu et al. [5] also speculated that the OH contents in bulk soils correlate with their agglutinate contents.

Discussion: The major goals of continuing the study of Liu et al. [5] are: 1) To determine whether the OH contents of lunar soils are related to their compositions and maturities; 2) To evaluate the contribution of different sources to OH in lunar soils. These data will form a solid basis for an accurate estimate of the water budget on the surface of the Moon.

There is no clear dependence of OH contents in individual grain on the bulk soil maturity (Fig. 2). However, the agglutinitic glass is very heterogeneous in its nanophase iron (np-Fe^0) contents. The amount and size of these iron grains may reflect the local 'maturity' of the glass itself. High-resolution back-scattered electron images are being collected to examine any relationship between np-Fe^0 and OH contents.

The agglutinitic glass was formed by melting of fine fraction soils [19-22]. Compositions of these glasses reflect the minerals being assimilated. For example, higher CaO + Al_2O_3 values indicate more plagioclase, which was reported to correlate with surface absorbed OH [23]. There is a weak dependence of OH contents in [5] on the CaO + Al_2O_3 content of the glass in 70051 and 64501, but no similar correlation was observed in 10084 (Fig. 2). Obviously, more data on soils of different compositions are needed to determine possible compositional effects.

The resemblance of the D/H value in grain 10084agg2 to those of chondirtic and cometary water supports the meteorite input for surface water on the Moon. Meteorite fragments are not uncommon in lunar soils and lunar breccias (e.g., [24-25]). They usually appear as metal fragments with schreibersite [$(FeNi)_3P$] and occasionally cohenite [$(Fe,Ni)_3C$] (Hunter and Taylor [26] and Misra and Taylor [27]). Chondritic fragments are relatively rare, but have been suggested: a carbonaceous chondrite in Apollo 12 soil [28-29], an enstatite chondrite in Apollo 15 [30-31], a chondritic fragment (carbonaceous or ordinary) in lunar meteorite regolith breccia PCA 02007 [32-33]; and an olivine-rich sphere with barred-olivine texture in lunar meteorite breccia Dhofar 1428 (Zhang et al. [34]). The chondritic sources of fragments were verified by Joy et al. [25]. Investigation of meteorite input to water in lunar soils will help to understand the uptake rate of meteorite water in lunar soils.

Ongoing Measurements: With the new set of standard glasses, we are re-examining the OH contents in samples used in Liu et al. [5] and new soil samples. These results will improve our understanding of the distribution of water in lunar soils and contribution of different sources. Results will be presented at the conference.

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