WATER ANOMALIES AT RUGGED LAVA FLOWS ON THE MOON. S. Li[1], G. J. Taylor[1], R. Lentz[2], D. H. Needham[3], L. Gaddis[4], and T. Shea[5]. [1]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i. [2]Hawai'i Sea Grant, University of Hawai'i. [3]Exploration Science Strategy and Integration Office, NASA Science Mission Directorate. [4]Lunar and Planetary Institute. [5]Department of Earth Sciences, University of Hawai'i. shuaili@hawaii.edu

Introduction: Knowing the hydration level of the lunar interior is critical for understanding the formation and evolution of the Earth-Moon system. The paradigm about the hydration status of the lunar interior shifted away from a "bone" dry lunar interior after the detection of lunar interior water from Apollo returned volcanic glasses [1]. Orbital detections of excess hydration features at 10 of 11 examined large pyroclastic deposits suggested that water from the lunar interior quenched in volcanic glasses during fire fountain eruptions may account for the elevated hydration level in comparison to the surrounding background [2, 3], which reinforces a wet lunar interior. However, magma ocean modeling results suggest that the lunar interior should be mostly dry and only a few heterogeneously "wet" spots exist [4]. Studies of Apollo impact melt and mare basalt samples also indicate that the lunar interior is highly depleted in volatiles [5]. Further investigations are necessary to better understand the depletion of hydration in the whole lunar interior.

Lava flows sourced from the lunar interior in the mare region provide windows to investigate the hydration level of the melt. It is known that the melt must have gone through severe degassing (> 90%) during ascent and emplacement on the lunar surface, which means that the chance of water retention in the melt sourced from the lunar interior is small. If any excess hydration is observed in lava flows, in comparison to the surrounding background on the lunar surface, there must be additional sources of water. Solar wind implantation, impact delivery, and the lunar interior are thought to be three major contributors to the lunar surface hydration [6], of which solar wind implantation is the most ubiquitous process on the lunar surface; the other two processes are more localized. The impact-delivered hydration can be linked to craters and ejecta formed via impact. If excess hydration is only associated with volcanism (e.g., pyroclastic deposits and lava flows), it may strongly indicate an interior origin.

Data & Methods: In this study, we examined the hydration levels of the mare region using the water content mapped from the Moon Mineralogy Mapper (M^3) data [7]. High spatial resolution (~15 m/pixel) albedo and band ratio image data from the Multiband Imager (MI) onboard the KAGUYA mission were used to assess the geomorphology and chemical information of regions showing water anomalies. Earth-based 12 cm and 70 cm radar data were used to understand the subsurface structure, particle size, and possible chemical variations, which is important for characterizing lava flows [8]. We used the TiO_2 abundance map derived from the LROC WAC data [9] to examine the TiO_2 variations in our study region that may show strong effects on the radar circular polarization ratios (CPR) [8].

We used the water map derived from the M^3 OP2C data on the global lunar surface in our previous studies [7]. The OP2C data are 280 m/pixel and were mostly (>90%) acquired near the local noon [10]. All M^3 data were thermally corrected with our empirical thermal model that was developed from the spectral features of over 600 Apollo and Luna samples. Our thermal model was also validated with the independently measured temperatures by the Diviner radiometer onboard LRO [10]. We used the Multiband Imager (MI) level 3 MAP products (~ 15m/pixel) in our study region to understand the geomorphology and chemical information. All MI data have been calibrated to a standard viewing geometry and are downloaded from the KAGUYA (SELENE) Data Archive. The spectral bands of MI data at 414, 749, 901, 950, and 1001 nm were used. The Earth-based 12 cm and 70 cm and Mini-RF S band radar CPR image data were downloaded from the NASA PDS Geoscience node.

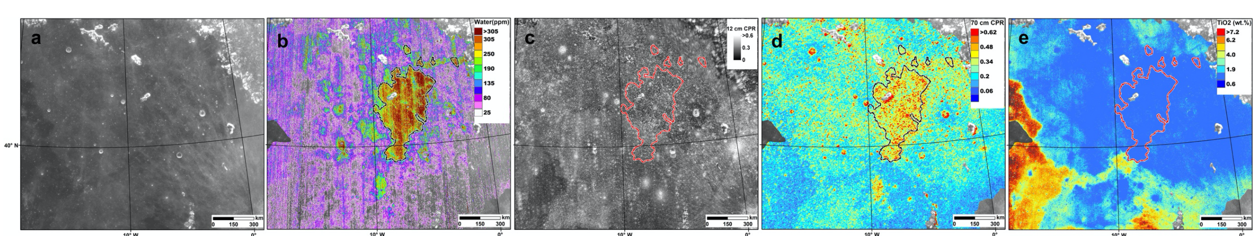

Fig. 1. a. LROC WAC albedo map of the region near Mons Pico in the mare Imbrium; b. map of absolute water content at the same region, derived from M^3 data in [7]; c. Earth-based 12 cm radar CPR map; d. Earth-based 70 cm CPR map; e. TiO2% map derived from the LROC WAC data in [9]; dashed halo lines in b, c, d, and e outline the water anomaly.

Results: Our global assessment of water anomalies in the lunar mare region suggests that lava flows near Mons Pico in the mare Imbrium, northwest of the mare Procellarum, north and center of the mare Serenitatis, east of the mare Crisium all exhibit elevated hydration levels in comparison to the surrounding background. A few patches of mare regions in Australe also show high water anomalies. The LROC WAC albedo map shows no albedo boundaries between high water anomaly regions and their surroundings. An example near Mons Pico is shown in **Figure 1**. **Figure 1a** shows that regions near Mons Pico are not different from surroundings in the LROC WAC albedo map. **Figure 1b** shows our water map at this region. It can be seen that the water content is mostly greater than 300 ppm, which is notably higher than the surroundings where no (or only a few 10s of ppm) water is mapped. The Earth-based 12 cm radar CPR map near Mons Pico shows no difference from surrounding mare regions (**Fig. 1c**). Interestingly, we find that all water anomaly regions show anomalously high 70 cm radar CPR, a relationship also clearly visible near Mons Pico (**Fig. 1d**).

Previous studies suggest that the radar CPR is dominantly affected by wavelength-sized boulders, the element Ti, and rough layer surfaces/interfaces [11]. The TiO_2 map derived from the LROC WAC data at this region (**Fig. 1e**) shows no clear difference in TiO_2 content between the water-anomaly region and the surrounding background. Interestingly, we did observe that the water-anomaly regions all show very low TiO_2 content, but since other low-TiO_2 regions show no water anomalies, a causal link seems unlikely. We also examined the band ratios of Multi-band Imager (MI) data and found that the water-rich region does show higher glass content than surrounding regions. It is unlikely that the glass is from impacts, because this mare region is much younger than surrounding mare units [12]. We assume that older units would have received more impacts, generating more impact glasses. A more likely source for the excess glasses is volcanic activity, which would imply that the elevated hydration level could be associated with volcanism.

MI data suggest that the thickness of the elevated hydration layer is around 15 m. We examined the size of craters that have penetrated through the hydration layer and excavated dry materials from the deeper subsurface. The excavation depth of these craters is used as the upper bound of the water-rich layer thickness. Higher resolution LROC NAC image data will provide better constraints on estimating the thickness of the water rich layer.

Discussion: Previous radar observations suggest that the 70 cm CPR anomaly at the region near Mons Pico could be either due to rugged lava flows or small reduction (~2 wt%) of TiO_2 content that cannot be seen by the 12 cm radar [11, 13]. However, it can be seen that the TiO_2 content is less than 1 wt% at the water-anomaly region and surroundings. Thus, the hypothesis of rugged lava flows in this region seems favored to explain the 70 CPR anomaly.

The lava flow at this region could be similar to pahoehoe flows on Earth. Inflation of melt during emplacement may have generated rugged interfaces that can enhance the radar echo after being broken down by impacts. MI data suggest that the lava flow could be around 15 m thick. The upper few m may have been gardened to fine regolith by impact and consequently cannot be sensed by the 12 cm radar. In contrast, the 70 cm radar can sense 5 – 7 m or even deeper where large chunks of rugged lava interfaces may still exist and enhance the 70 cm radar echo.

The observed elevated hydration features near Mons Pico cannot be introduced by thermal correction of M^3 data nor viewing geometry. Temperatures of less-hydrated regions would need to be >20 K higher than regions near Mons Pico to reproduce similar water absorptions in the M^3 data. This is physically impossible, because all M^3 data across the region were acquired near local noon. There is no reason to believe that the outlined region in **Figure 1** would be >20 K colder than the surrounding regions at local noon. Also, all M^3 data from our study region were photometrically corrected to a standard view geometry to derive their water content. It makes no sense that only the outlined region has photometry issue.

Conclusion: Enhanced hydration levels are observed in several mare regions. The water-anomaly regions do not show up in albedo, topography, TiO_2 content, and 12 cm radar CPR data. These water rich regions all exhibit anomalously high 70 cm radar CPR. High volcanic glass contents are also observed in some of these water rich regions. It suggests that the excess hydration may be sourced from the lunar interior and quenched in mare basalts in pahoehoe-like lava flows.

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