Global Hydrogen Abundances on the Moon. David J. Lawrence[1], Patrick N. Peplowski[1], Jack T. Wilson[1], and Richard C. Elphic[2]; [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD; [2]NASA Ames Spaceflight Center, Moffett Field, CA; (David.J.Lawrence@jhuapl.edu).

Introduction: We present new analyses of orbital neutron data from the Lunar Prospector (LP) mission where we use updated corrections for rare-earth-elements (REEs) and link these new corrections with previously published sample-site hydrogen (H) concentrations. Our revised analysis has led to a full global map of neutron-derived H abundances. This map confirms previous identifications of H-bearing materials at the lunar poles and variations due to solar-wind implanted H. We identify additional lunar nearside locations with enhanced H, and show that lunar evolved materials with enrichments of incompatible trace elements are preferentially enhanced with H abundances. This map also confirms the presence of enhanced H abundances at the Aristarchus Plateau pyroclastic deposit, which provides the first evidence that this H extends to the subsurface (i.e., is not a surficial effect).

Global Hydrogen Map: Lawrence et al. [1] presented a map of near-global H abundances, but did not include abundances in nearside Th-rich regions due to uncorrected effects of rare-earth elements causing variations in the epithermal neutron data. Here, we use a spatially reconstructed map of LP epithermal neutrons [2], and implement a procedure similar to [3] that corrects the epithermal neutron data for non-H neutron absorption effects. Fig. 1 shows the results of an analysis where simulated epithermal neutron count rates were benchmarked to values based on Apollo sample sites. This correction quantitatively accounts for non-H variations, which are then removed from the data.

The fully corrected map of global H abundances is shown in Fig. 2. The abundance scale was derived using a hybrid approach where non-zero abundances were calibrated using sample soil and regolith breccia data for each Apollo landing site [4]; the low end of the abundance scale is anchored by assuming the maximum counting rate has a H abundance of 0 ppm.

Discussion: With this global map, we now have a complete inventory of the significant bulk H reservoirs on the Moon. This map confirms locations of bulk H enhancements that have been previously identified and characterized. These are the H enhancements at both lunar poles [5], which are indicated in both Fig. 1 (low epithermal neutron counts at low neutron absorption), and the high H abundances poleward of 80° in Fig. 2. The identification of bulk solar wind H that spatially corresponds with surface maturity [6] is also seen in the latest data (Fig. 3). Global data equatorward of 80° latitude show a mean H abundance of 47 ppm, whereas for regions with low optical maturity, the mean abundance is ~20 ppm H lower. As described below, new information about two other types of H enhancements is revealed in the global abundance data.

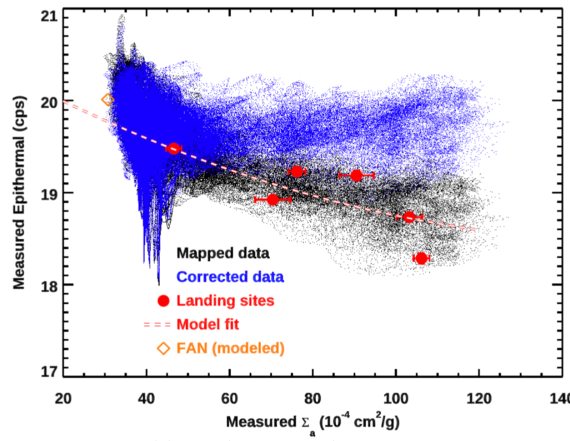

Fig. 1. LP epithermal neutron data versus neutron macroscopic neutron absorption, Σ_a [3]. Original data are black and Apollo landing site values are red. A fit derived using model-based count rates is shown by the dashed line. Corrected mapped data are shown in blue.

H enhancements in KREEP-rich regions: Fig. 3 shows that H abundances in the most KREEP-rich regions (as indicated by Th abundances > 8 ppm) are enhanced by 14-35 ppm H over average, non-polar materials (see also Th contours in Fig. 2). Within the global dataset, there is no correlation between H and Th. However, in higher-Th regions (Th>6 ppm), we find a correlation coefficient of >0.7 between H and Th. These observations lead to important implications regarding KREEP-rich materials and our understanding of lunar formation models. In a study of lunar formation models, [7] stated that a KREEP-signature and water should be positively correlated if water was processed through the Moon's original magma ocean. However, their review of sample measurements did not show a water enhancement in KREEP-rich materials, which led [7] to suggest that incompatible trace elements were decoupled from water in lunar compositions. The results given here, however, show a positive correlation of water in KREEP-rich materials, which implies that some fraction of water was processed through the original magma ocean. The 14–35 ppm H KREEP enhancement (or equivalently 126–315 ppm H_2O) seen with the global data may be a current-day tracer of the original water that was present in the lunar magma ocean.

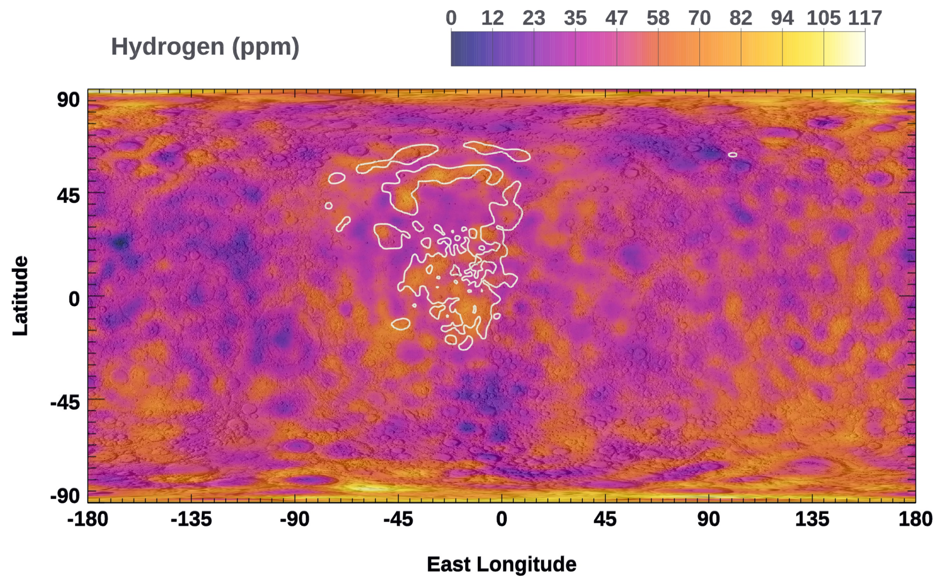

Fig. 2. Global map of H abundances. Crater overlays are shown, and white contours show boundaries of 6 ppm Th.

given in spectral reflectance results for surficial OH/H_2O [8,9]. These data provide evidence that the hydrogen enhancements extend to the subsurface, indicating the hydrogen is intrinsic to the pyroclastic deposits (not exogenic) and thus associated with volatiles within lunar magma source regions.

H enhancement in Aristarchus Plateau: The volatile species of OH/H_2O have been detected in various pyroclastic deposits widely spread across the lunar nearside using spectral reflectance data, including the Aristarchus plateau [8], which is the largest pyroclastic deposit on the Moon. These observations support the idea of significant water-bearing magma source regions within the lunar interior. Fig. 4 shows a local map of H abundances in the Aristarchus crater and plateau region, and there is a clear H enhancement that is spatially coincident with the Aristarchus plateau. The inferred maximum hydrogen abundance of 50–68 ppm (or 450–612 ppm H_2O) is quantitatively consistent with the values

Summary: Using model-based corrections of neutron data benchmarked to Apollo sample data, we have generated a global map of lunar H abundances. With this complete inventory of mapped bulk H abundances, we have not only confirmed H enhancements in previously known locations, but have identified likely endogenic H enhancements in KREEP-rich materials and the Moon's largest pyroclastic deposit at Aristarchus plateau.

References: [1] D.J. Lawrence et al., *Icarus*, 255, 127, 2015; [2] J.T. Wilson et al., *J. Geophys. Res*., 123, 1804, 2018; [3] P.N. Peplowski et al., J. *Geophys. Res.*, 121, 388, 2016; [4] L. Haskin and P. Warren, *Lunar Sourcebook*, pp. 357, 1991; [5] W.C. Feldman et al., *Science*, 281, 1496, 1998; [6] P.G. Lucey et al., *J. Geophys. Res*., 105, 20377, 2000; [7] L.T. Elkins-Tanton & T.L. Grove, *Earth and Plan. Sci. Lett.*, 307, 173, 2011; [8] R.E. Milliken & S. Li, *Nat. Geo*., 10, 561, 2017; [9] T.D. Glotch et al., *Planet. Sci. J.*, 2, 10.3847/PSJ/abf.

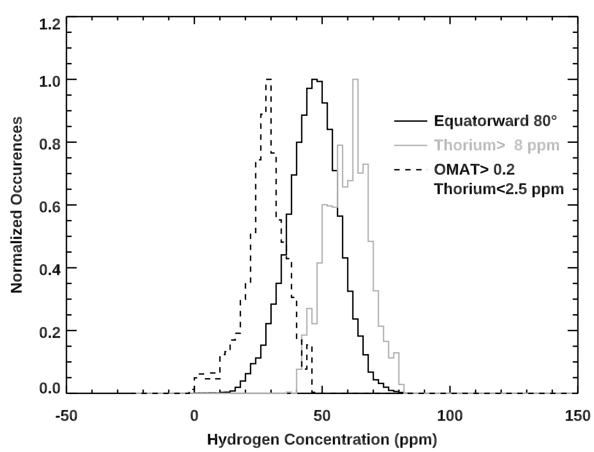

Fig. 3. Normalized histograms of H abundances in different lunar regions (OMAT = optical maturity parameter from [6]).

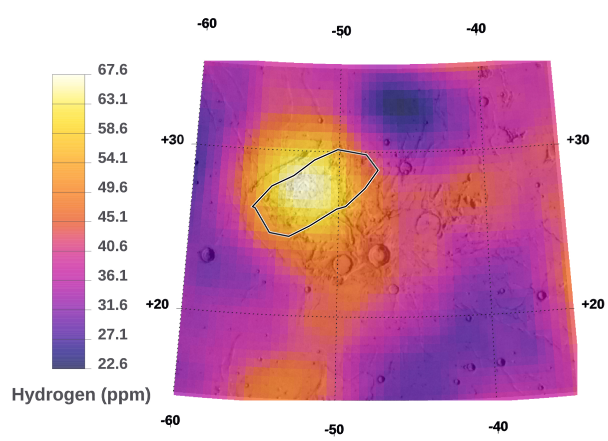

Fig. 4. Hydrogen abundances in the Aristarchus region. Black outline indicates the boundary of the Aristarchus plateau that has enhanced OH/H_2O abundances based on spectral reflectance data [8,9].