Identification of Surface Hydrogen Enhancements Within Shackleton Crater at the Moon's South Pole. R. S. Miller[1] and D. J. Lawrence[2], [1]University of Alabama in Huntsville (richard.s.miller@uah.edu), [2]Johns Hopkins Applied Physics Laboratory.

Introduction: Enhanced hydrogen abundances have been identified within the Moon's Shackleton Crater using fast neutron data from the Lunar Prospector mission. This enhancement is unique and is the result of a rigorous statistical analysis used to evaluate the spatial distribution of hydrogen at lunar poles. The fast neutron derived hydrogen concentration is 850±144 ppm H. This is statistically equivalent to the abundance derived independently using epithermal neutrons (888±33 ppm H), implying the hydrogen lies at or near the surface. In contrast, other permanently shadowed regions are likely buried under >10 cm of hydrogen-poor regolith. Shackleton crater is ~30 K warmer than other South Pole permanent shaded craters, suggesting that thermal processes may control the vertical migration of hydrogen within Shackleton and inhibit hydrogen migration within colder craters.

Background: A recent reanalysis of lunar neutron datasets from NASA's *Lunar Prospector* (LP) and *Lunar Reconnaissance Orbiter* (LRO) missions used a robust statistical approach to characterize the abundance distributions of hydrogen at the lunar poles [1]. Hydrogen enhancements derived using epithermal neutrons showed broad asymmetric distributions with a footprint averaged abundance of 106±11 ppm H at each pole [1]. In contrast, the fast neutron dataset showed a single, highly localized, statistically significant feature spatially coincident with Shackleton Crater. The uniqueness of this signature has motivated the extended analysis presented here.

Data: This work focuses on the LP dataset since it consists of a well-understood suite of instruments capable of neutron and γ-ray spectroscopy across a wide range of energies. *Lunar Prospector* orbited the Moon for approximately 1.5 years beginning in January 1998. Initially placed into a 100 km circular, polar orbit, it was lowered to 30 km for the final 6 months of the mission. The LP-NS included two identical ^{3}He proportional counters, one covered with Sn and the other with Cd [2]. Although both detectors were sensitive to epithermal neutrons (0.4-100 eV), only the Sn-covered detector was sensitive to (thermal) neutrons with energies below the Cd cutoff at 0.4 eV.

Fast neutrons (0.6-9 MeV) were detected using the scintillator-based LP-GRS [2]. This instrument incorporated a borated plastic scintillator as a charged-particle veto surrounding a BGO crystal for γ-ray detection. Fast neutrons were identified using a double-pulse signature: neutron moderation and signal generation in the plastic scintillator, followed by neutron capture and the detection of a characteristic 478 keV γ-ray via ^{10}B(n,α)^{7}Li.

To maximize the effectiveness of neutron observations it is important to be close to the emitting source. Therefore only data acquired during the 220 days of low-altitude (30 km) operations are used for the analysis presented here. This includes epithermal (LP-epi) and fast neutrons (LP-fast) accumulated in 8 and 32 second intervals, corresponding to 1.8×10^6 and 4.4×10^5 sample intervals, respectively. All data were obtained from the *Planetary Data System* (PDS) public archive; data reduction details for these datasets can be found elsewhere [3, 4].

Analysis: A likelihood approach is employed to characterize consistency with a desiccated hypothesis [5]. It incorporates relevant observational details (e.g. exposures), as well as the inherent uncertainties governing particle detection. The resulting statistic is used to evaluate the statistical significance of a given neutron observation; multiple spatially resolved observations enable the generation of significance, and ultimately hydrogen abundance, maps.

In-situ measurements can be used to estimate the desiccated, or null, hypothesis. However, because polar hydrogen excesses and local elemental abundance variations may potentially influence this hydrogen-free estimate, an new definition of this null hypothesis is defined and applied here. It is based on mid-latitude 'highlands' and is rigorously defined to mitigate systematic effects. This highlands-based approach produces spatial distributions similar to those reported previously [1], albeit with higher statistical significance. Epithermal neutrons show a broad circumpolar distribution with an extension into the Cabeus region. In contrast, the fast neutrons show a localized high significance feature coincident with Shackleton Crater.

Shackleton: The Shackleton detection is indicative of a spatially unresolved feature. In other words, while it is spatially co-located with the crater, supplementary analyses demonstrate that the detection is consistent with the spatial resolution of the (uncollimated) LP-GRS instrument at 30 km altitude.

It is well established that neutron deficits such as the ones detected at Shackleton are indicative of enhancements of hydrogen abundances [6]. Forward-modeling is sued to account for geometric effects and detector response, and when combined with neutron yield-to-hydrogen abundance conversions give 850±144 ppm H from fast neutrons and 888±33 ppm H from epithermal neutrons. The consistency between these two independent determinations implies that the hydrogen lies at or near the surface of Shackleton Crater. Supplemental analyses using thermal neutrons and γ-rays further supports the hydrogen-enhancement hypothesis.

Discussion. Is Shackleton Crater special? If so, what makes it special? These are particularly intriguing questions because no other equivalent detections can be identified elsewhere on the lunar surface even though many regions have been observed with similar exposures and detection sensitivities. A key supporting clue comes form the DIVINER instrument about the *Lunar Reconnaissance Orbiter*. It shows that Shackleton Crater has a nominal maximum temperature of ~95K, compared to other PSRs at ~65K [7]. This disparity in temperature appears to be relatively unique, perhaps indicative of the key defining characteristic. We will discuss the potential impact of this thermal environment on hydrogen migration within Shackleton, discuss the relevance of this result to other observational signatures, and identify open areas of study.

References: [1] Miller R. S. et al. (2012) *JGR, 117,* E11007. [2] Feldman W. C. et al. (1999) *Nucl. Instrum. Methods., A422,* 562-566. [3] Maurice S. D. (2004) *JGR, 109,* E07S04. [4] Lawrence D. J. (2006) *JGR, 111,* E08001. [5] Miller R. S. (2012) *JGR, 117,* E00H19. [6] Feldman W. C. et al. (1999) *Science, 281 (5382),* 1496-1500. [7] Siegler M. (2012), private communication.