UNDERSTANDING THE LUNAR WATER CYCLE BY IN-SITU ASSESSMENT OF REGOLITH HYDRATION IN AREAS OF VARYING SOLAR-WIND EXPOSURE. David T. Blewett¹,* , Dana M. Hurley¹, Jasper S. Halekas², Brett W. Denevi¹, and Benjamin T. Greenhagen¹. ¹Planetary Exploration Group, Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 USA; ²Dept. of Physics and Astronomy, University of Iowa, Iowa City, IA 52242 USA. (*correspondence author: david.blewett@jhuapl.edu)

Introduction: Volatile compounds cold-trapped in the polar regions of airless bodies in the inner Solar System are valuable repositories for both scientific and practical exploration exploitation. The reason for the marked differences between the polar deposits on the Moon and those on Mercury is an outstanding question in planetary science. In order to understand the origin of the polar water ice on the Moon, it is necessary to determine the relative contributions of exogenic sources (impact delivery of icy or hydrated material), production (OH or H₂O generated in the regolith from implanted solar-wind protons), and endogenic sources (release of magmatic volatiles internal to the Moon). Fortunately, the Moon has provided natural laboratories in which the process of hydration can be studied. Areas of crustal magnetism, known as magnetic anomalies [e.g., 1], provide partial shielding of the surface from exposure to solar-wind ions. A rover mission to a magnetic anomaly could assess regolith hydration by measuring the strength of the OH/H₂O absorptions near 3-μm wavelength in areas of greater and lesser solar-wind exposure that are conveniently located at relatively close geographic proximity. Microscopic examination of the regolith would reveal the specific soil constituents (minerals, glass) that are most susceptible to H implantation.

Magnetic Anomalies: The Moon does not at present have a global, internally generated magnetic field. However, the lunar crust does contain areas of magnetized rocks. The crustal magnetic anomalies are correlated with unusual, high-visible-reflectance markings referred to as lunar swirls [e.g., 1–7]. The local magnetic fields produce disturbances in the Moon’s interaction with the solar wind [e.g., 8, 9]. Described as "mini-magnetospheres", the disturbances have been detected through analysis of the flux of neutral atoms [10], electrons [11], and solar-wind protons [12]. It is known from orbital remote-sensing data that the high-reflectance parts of swirls exhibit weaker hydroxyl absorptions at 2.82 μm than do the background [13, 14], consistent with a lower flux of solar-wind protons reaching the surface, or a difference in retention. Figure 1 shows a 2.8 μm band-depth map for the Airy swirl and magnetic anomaly.

Lunar Hydroxyl: A major point of debate is whether the hydration observed globally on the surface of the Moon is available to migrate through the lunar exosphere to the polar regions. Before humans ever stepped foot on the Moon, Zeller and colleagues [15] predicted that the bombardment of regolith with solar-wind protons would induce the formation of hydroxyl on the lunar surface. This prediction has been confirmed with remote sensing observations of the Moon in the 3-μm region where OH and H₂O produce absorption bands [16, 17]. However, the distribution of hydration in latitude and local time is debated according to the manner in which phase functions and correction for thermal emission are applied to the data [18–20]. One interpretation is that there is a diurnal variation of the amount of hydroxyl in the regolith, which implies that the hydroxyl is transient in the lunar regolith.

With the benefit of lunar samples returned by the Apollo program, Arnold [21] proposed that the observed reduction of Fe³⁺ in regolith silicates by implanted protons may have produced ~1 × 10⁻⁷ g of water in the gas phase over the last 2 × 10⁷ yr. This water, upon release from the regolith, has the potential to migrate to cold traps in the lunar polar regions, where it could accumulate as ice. Migration models [22] predict that 0.04% of incident protons are ultimately delivered to the lunar polar regions as water molecules. This corresponds to the delivery of an equivalent water-ice layer 40 cm thick spread across the permanently shadowed regions in the last 2 × 10⁷ yr. Clearly, the Moon lacks such a coherent ice layer now. But the question remains as to where the pipeline is interrupted: in the release of H₂O from the surface, in the delivery to the cold traps, or in the retention at the cold traps after delivery.

In-Situ Study: Exploration of a lunar magnetic anomaly by a landed spacecraft offers a wealth of scientific opportunity [23, 24]. A rover payload [25] could address major planetary science questions including the origin of the magnetic anomalies, the nature of solar-wind interactions that lead to the formation of the mini-magnetosphere stand-off regions, the relative importance of ion and micrometeoroid bombardment in the space weathering of silicate surface materials, and the origin of lunar swirls. In addition, the rover could examine key issues about the formation and retention of OH in the regolith by taking advantage of the variations in solar-wind flux that reach the surface within and around a magnetically shielded area. This will better define the role that the solar wind has in producing water
through interaction with the lunar regolith, and thus, the potential importance of the solar wind as a source of water being fed to lunar cold traps.


Figure 1. Top: Moon Mineralogy Mapper (M3) reflectance image at 750 nm of the area of the Airy swirl and magnetic anomaly, located near 3° E, 18° S. Bottom: M3 image of band depth at 2850 nm for the same area as the top reflectance image. Darker tones in the bottom band-depth map correspond to weaker OH absorption. The high-reflectance portion of the swirl has weaker OH absorption than does the background. Width of scene ~7.5 km.