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Volatile Retention on the Lunar Poles and on Asteroid Vesta as Derived from Radar Surface Roughness Observations

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Abstract

Planetary regoliths of airless bodies have different physical mechanisms to capture and retain exogenic volatiles. On Asteroid Vesta, large areas of relatively smoother terrain (at centimeter-decimeter scales) are found to overlap with areas of heightened subsurface hydrogen concentrations [H], but unlike the Moon, show no correlation with surface age—suggesting that impact cratering processes alone cannot explain the regolith's cm-dm surface texture. Instead it was hypothesized that Vesta's surface may have been smoothened in these areas at cm-dm scales by the release of buried water-ice after heating, melting and upward flow along impact fractures, leading to the erasure of small-scale surface textures [1].

Recent observations suggest that impacts can generate localized transient water flow that, in turn, may smoothen the surface at small scales [2]. In this study, we will search for smooth surfaces coupled with heightened [H] in the polar areas of the Moon at different incident angles as observed by the Lunar Reconnaissance Orbiter (LRO) Mini-RF (both monostatic and bistatic modes) and by Chandrayaan-1 Mini-SAR in S- and X-band. This will constrain the different mechanisms of volatile retention in the desiccated regoliths of different airless bodies, especially on Vesta and the Moon.

1. Introduction

Airless, desiccated bodies were thought to have depleted their initial water content during formation, but new observations continue to suggest that water-ice can survive in places previously thought dry, including the poles of Mercury and the Moon within permanently shadowed craters (e.g., [3,4]). One technique particularly well-suited to assessing potential water-ice occurrence is radar remote sensing, as it can be used to characterize the electrical and textural properties of the surfaces and shallow subsurfaces of planetary regoliths [5]. The assessment of wavelength-scale surface roughness, in particular, can provide unique insights into the physical processes that govern the texture of desiccated surface at cm-dm scales (i.e., using X- and S-band frequency observations), such as cratering history, impact gardening mechanisms, and surface erosion by solar wind and diurnal thermal weathering.

On the Moon, one of the primary smoothening mechanisms is regolith gardening, leading to the observed correlation between older surfaces and cm-dm-scale smoothness (e.g., [5]). On Asteroid Vesta, however, the same correlation was not observed using Dawn bistatic radar data, suggesting that while Vesta and the Moon share similar cratering histories and regolith gardening mechanisms, cratering processes alone cannot explain Vesta's surface texture at the cm-dm scale [1]. Instead, large smoother areas are found to overlap with heightened [H] mapped by Dawn's Gamma Ray and Neutron Detector (GRaND) [6] supporting the hypothesis that buried water-ice accessed by impact fracturing may have played a role in shaping Vesta's surface [1, 7].

In this study, we will investigate the relationship between cm-dm-scale surface roughness on the Moon with known sites of heightened [H] derived from LRO's Lunar Exploration Neutron Detector, LEND [8], and compare with surface ages to disentangle the role of dry impact gardening processes with volatile occurrence on shaping the surface texture of an airless, desiccated body.

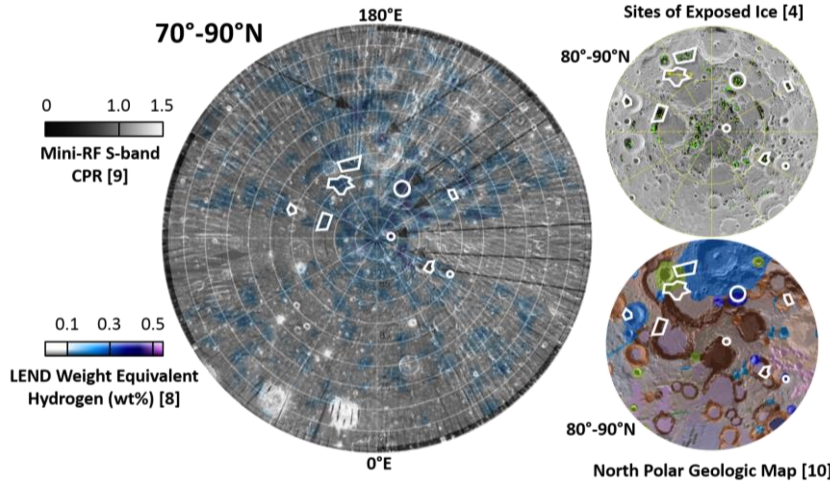

Figure 1: Potential areas of interest (outlined in white) where heightened hydrogen concentrations overlap with weak radar backscatter near the lunar north pole. *On left:* Mini-RF S-band CPR mosaic adapted from [9], overlain by a map of hydrogen concentrations measured by LEND, adapted from [8]. *On right*: Sites of exposed ice adapted from [4], and geologic mapping adapted from [10].

2. Surface Roughness Retrieval at Different Incidence Angles

Surface smoothness at wavelength scales is characterized by low radar backscatter returns (i.e., appearing radar dark) due to strong quasi-specular reflection and weak diffuse scatter. However, apparent surface roughness also depends on the angle of incidence. Hence, in order to reduce the ambiguity associated with accurately identifying smoother surfaces, we will compare circular polarization ratio (CPR) radar images of the lunar surface that are acquired at three different viewing geometries and at different frequencies, i.e., using radar observations by Mini-RF (monostatic and bistatic at S- and X-band) and Mini-SAR at S-band frequency.

3. Correlating Mini-RF and LEND Observations

Figure 1 shows preliminary sites of interest (outlined in white) near the lunar north pole where low CPR values (suggesting smoother surfaces) coincide with locally heightened [H] and with sites of exposed ice [4]. We will assess whether localized volatile occurrence plays a role in the shaping of the lunar regolith surface at the cm-dm scale by comparing CPR values within the above-mentioned sites to relative surface ages inferred from geologic maps [10]. Older surfaces are expected to have lower CPR values. In turn, by disentangling the mechanisms governing the Moon's cm-dm surface texture at the poles, we aim to better understand the role of exogenic volatiles in shaping surface regolith texture on other airless, desiccated bodies.

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