EVIDENCE FOR POSSIBLE LOW-DENSITY REGOLITH AT THE LUNAR POLES. B. J. Thomson[1], P. D. Spudis[2], P. O. Hayne[3], J. T. S. Cahill[4], G. W. Patterson[4], C. D. Neish[5], T. W. Thompson[3], E. Heggy[6], and A. M. Stickle[4], [1]Center for Remote Sensing, Boston University, 725 Commonwealth Ave., Boston MA 02215 (bjt@bu.edu), [2]Lunar and Planetary Institute, Houston TX, [3]NASA–Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, [4]John Hopkins University Applied Physics Lab, Laurel MD, [5]University of Western Ontario, London, Ontario, Canada, [6]University of Southern California, Los Angeles, CA.

Introduction: The lunar polar regions represent unique environments that are substantially dissimilar from the more equatorial lunar terrains sampled to date. Low insolation results in persistently low temperatures near the poles [1], particularly permanently shadowed areas. While much attention has been paid to the potential of shadowed regions to capture condensable volatile species [e.g., 2, 3-5], polar terrain outside of shadowed regions nevertheless experiences relatively low-temperature thermal environments. Here we report on global trends of Mini-RF radar data that exhibit unexpected characteristics in the polar regions, suggesting unique physical properties of polar regolith.

Observations: The Mini-RF instrument on the Lunar Reconnaissance Orbiter (LRO) collected monostatic imaging radar data between July 2009 and December 2010. These data include >98% of polar terrain between 70 to 90° N and S latitude, as well as ~66% of the terrain between 70°N to 70°S. Global trends in radar properties and correlations with optical, thermal, and gamma ray data have been examined previously [6], but the emphasis has been on the equatorial region. The focus here is on regional-scale differences between polar and equatorial terrains.

The global mosaic of Mini-RF S-Band data was downsampled via averaging to 32 ppd in latitude and across all longitudes, creating a pole-to-pole profile of CPR (circular polarization ratio) data versus latitude for all areas observed by Mini-RF (**Fig. 1**). Polar S-Band data from Chandrayaan-1 Mini-SAR instrument are also included. This spatial downsampling suppresses the influence of recent impact craters, which have distinct high returns but only occupy a small fraction of the surface area. Peak values of CPR occur in northern mid-latitudes between 15–45°N; values generally fall off with increasing distance from this zone. A distinct downward trend is evident moving toward either pole. The north and south polar regions (>85 to 87° N or S latitude) have typical CPR values ~0.4, compared with values of ~0.5 or greater elsewhere.

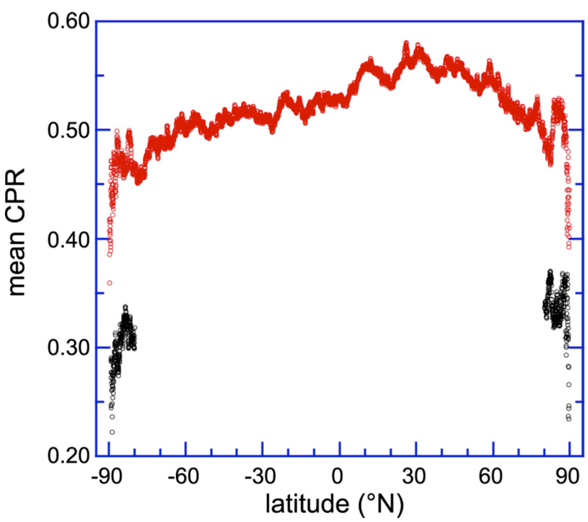

Figure 1. Profile of mean S-Band CPR (circular polarization ratio) versus lunar latitude for LRO Mini-RF data (red points) and Chandrayaan-1 Mini-SAR data (black points).

In our examination of polar maps of CPR, it is evident that regions with low CPR are not limited to areas of permanent shadow. Furthermore, the pole versus equator difference (~20%) is roughly comparable with the difference between the mare and highlands [6]. Both polar regions are highlands terrain, yet they exhibit atypical characteristics. These observations are consistent with prior examination of the lunar regolith in the large, flat-floored south polar crater Cabeus (the target region of the LCROSS impact), which was observed to have CPR values comparable to or below the average of nearby southern lunar highland terrain [7].

Previously, we have examined anomalous small craters (typically <20 km in diameter) that have elevated CPR values in their interior only and noted that they are consistent with the presence of ice [3, 5, 8]. The observed CPR enhancements are modest enough, however, such that roughness effects cannot be ruled out [e.g., 9, 10]. Yet anomalous craters are overabundant in the polar regions [5, 11], suggesting that some subset of these craters may indeed be ice-bearing. These observations are not in conflict with the overall decrease in CPR in the polar regions, because the anomalous craters occupy a small area.

Interpretations and potential causes: For lunar highlands terrain, the signal recorded by Mini-RF typically represents the integrated return from from the uppermost ~10 wavelengths of the surface, or slightly more than a meter for an incident wavelength of 12.6 cm. The actual penetration depth depends on the loss tangent; penetration is less in high-loss material, particularly in regolith rich in Fe-Ti oxides [e.g., 12]. Penetration depths are generally less in mare than highlands due to their compositional differences.

What factors could plausibly explain the atypical polarization signature of the uppermost meter of polar regolith? Lower CPR values could result from: (1) reduced regolith bulk density in the column scattering the radar signal; (2) reduced decimeter-scale surface roughness (via a reduction in diffuse scatter); (3) a difference in silicate composition; (4) an increase in quasi-specular scattering from buried crater ejecta; or (5) a small percentage of condensed volatile species disseminated as fine grains rather than large chunks. We consider each of these options further.

Reduced roughness, silicate composition, and buried ejecta: In terms of roughness, there is nothing evident in maps of the hectometer to kilometer-scale roughness measured by LRO LOLA (Lunar Orbiter Laser Altimeter) [13] or SELENE Laser Altimeter and Terrain Camera data [14] to suggest that the polar regions differ from other highlands regions. Roughness at smaller spatial scales could affect the radar return, but there are limited measurements at this scale [e.g., 15]. Similarly, in terms of the composition of polar regolith, there are no obvious departures from typical equatorial highlands iron values as measured by gamma-ray spectroscopy data from Lunar Prospector [16] (excluding the effects of SPA at the south pole). Considering the third possibility of an increase in buried crater ejecta, there is little distinctive about the density of large craters at the poles (those with diameter ≥20 km in diameter) outside the influence of SPA [17].

Reduced bulk density: A lower overall bulk density of polar regolith could be manifested as a paucity of decimeter-scale rocks or as a reduced packing efficiency of finer material. Such low density was postulated for the LCROSS impact target, which produced a narrow ejecta plume, possibly indicative of "fluffy" or highly porous regolith [18]. High porosity has also been evoked to help account for the low UV albedo of the permanently shadowed regions [4]. The causes of such high regolith porosity are unclear, but might be related to either temperature effects of the polar environment or to unusual electrical properties of partially illuminated polar terrains.

Added volatiles: What would be the effects of the addition of a volatile species such as small ice grains or films to polar regolith? Thick deposits of slab ice can be ruled out as they would be evident as a high CPR signature, not a reduction in CPR [19]. A similar situation applies to small ice enhancements of ~5-10 wt% distributed as wavelength-sized chunks: they are predicted to result in modest increases in CPR [8], at least according to one model.

But if the amount of ice were small (i.e., <1 percent), an increase in bulk density could plausibly result from increased particle cohesion. The average porosity of the upper 30 cm of lunar soil approaches 50% [20]. An increase in particle cohesion in granular media results in the stabilization of (unoccupied) pore space in bound aggregates [21]; repeated overturn of a cohesive layer (tilling in the terrestrial literature [e.g., 22] or impact gardening on the Moon) can increase its bulk density relative to a less cohesive or cohesionless layer. So if there were ice present in quantities insufficient to result in a CPR increase due to the coherent backscatter opposition effect [23], but a sufficient amount to raise the regolith cohesion and lower the bulk density, a decrease in CPR could be the net result.

Potential implications: The interpretation that the observed decrease in polar CPR may be due to a lower bulk density (that could be result of volatile-induced cohesion or unrelated factors) is not offered as a firm conclusion, but instead as one potential hypothesis among many to be tested further. If variations in bulk density are responsible for the radar polarization signature, then we would also expect a decrease in average polar thermal inertia. This signature may be manifested in LRO-Diviner temperature data. Further, if neutron spectroscopic data could be interpreted as a function of bulk density of the uppermost meter of regolith, we would also expect a strong positive correlation between radar CPR and neutron-inferred bulk density.

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