SCATTERING PROPERTIES OF LUNAR GEOLOGICAL UNITS REVEALED BY THE MINI-SAR IMAGING RADAR, CHANDRAYAAN-1 MISSION.

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Understanding the nature and range of radar backscattering properties of non-polar areas of the lunar surface is critical to a better understanding of the poles and their deposits. The lunar surface is covered with fine-grained unconsolidated debris (the regolith) that overlies bedrock. Some of this debris is coarse-grained, including larger blocks and boulders. Surface roughness affects the manner in which radio waves are reflected from planetary surfaces. Understanding how different terrains on the Moon reflect radio frequency (RF) energy was the task of this study.

The Mini-SAR is a fully polarimetric imaging radar aboard the India lunar orbiter Chandrayaan-1. It has collected S-band (λ=12.6 cm) SAR images of both poles and several non-polar areas [1]. One important parameter to characterize the surface backscatter of the Moon is the circular polarization ratio, the ratio of the power of the received signal in terms of the same sense transmitted versus the opposite sense [2, 3]. Circular Polarization Ratio (CPR) values were obtained from a variety of locations on the lunar surface. These data can be correlated with mapped geological units, allowing us to determine both typical and atypical reflection properties for each terrain. Utilizing this knowledge of radar backscatter from the well studied non-polar units will help us to better infer the geological make-up and surface properties of the less studied and more poorly known polar units of the Moon [3].

Method: Mini-SAR image strips were registered to regional basemaps of Lunar Orbiter IV or Clementine images. Other resources, including high resolution digitized Apollo rectified pan frames, Lunar Topographic Orthophotomaps, and USGS lunar geologic maps were compiled and co-registered with both the respective uncalibrated SAR data and regional basemaps. With each resource on a separate layer, the areas of previously defined geologic units underneath the SAR strip were re-mapped in higher resolution and redefined, as necessary.

Calibrated CPR strips were overlain on geological maps (Fig. 1). Small areas (on the order of hundreds of pixels to a few thousand pixels) were selected to represent each geologic unit present in the CPR coverage. Statistical data from the selected area were collected, determining the mean, median and deviation CPR values of each geological unit covered by the radar (Fig. 2). These collected values were then averaged to yield estimates of the average CPR of geological units in the area of SAR coverage.

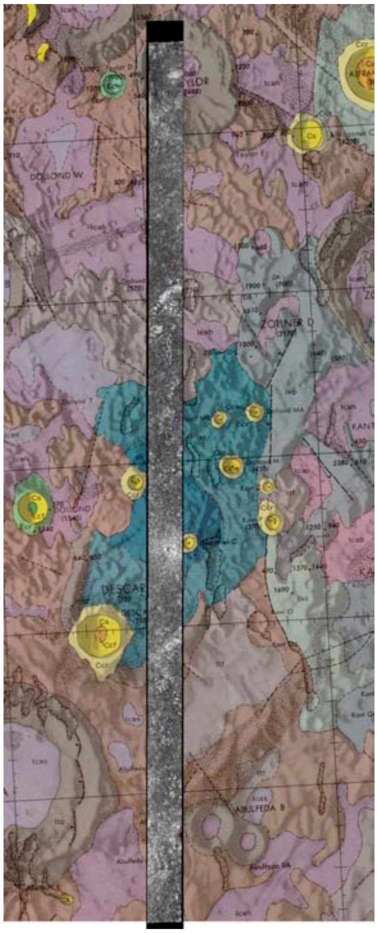


Fig. 1. Mini-SAR CPR image near Apollo 16 landing site on the USGS 1:1M geologic map [6]. SAR strip is about 11 km wide.

Data for multiple non-polar areas were collected with the aim of building a CPR and backscatter property database from which to infer general lunar surface properties and the dependance of CPR on the geological age of terrains. Averaged mean CPR values of each geological unit were derived from the individual mean CPR measurements. This value was then plotted against its respective geologic unit, with the geologic units organized by relative age, from oldest to youngest. Finally, we analyzed these relations for systematic trends associated with the scattering behavior based on the geological unit.

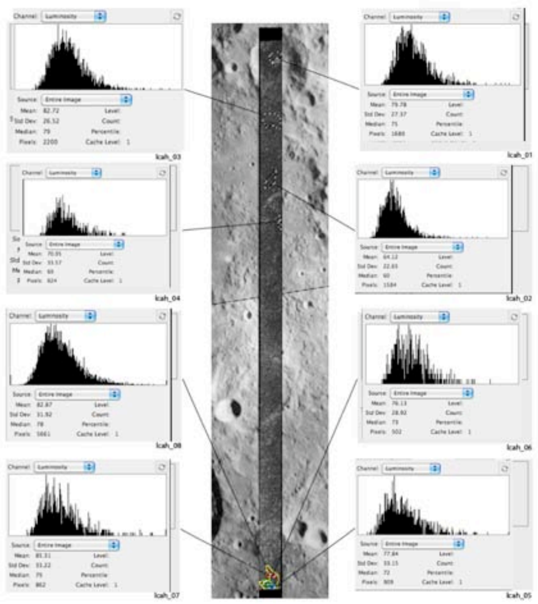


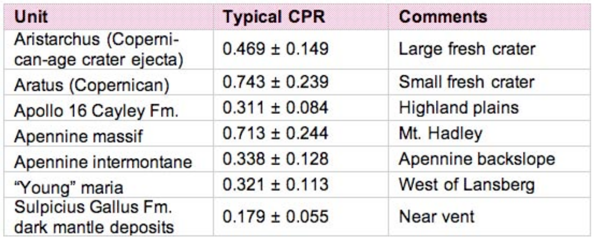
Fig. 2. Data collection from CPR image.

Discussion: We have found the highest CPR values associated with rougher and/or steeper surfaces. Typically, rough surfaces are associated with geologically young units, although (somewhat surprisingly), the pre-Imbrian large massifs of the Apennine Mountains show the highest values (Table 1). Young, fresh Copernican-aged craters have high average CPR values; younger, smaller craters display higher CPR than slightly older, large features. Both maria and highlands display relatively low CPR, ~0.3 for both "young" maria and Cayley plains near the Apollo 16 landing site. Generally, older geologic units are more subdued and therefore have a lower CPR value overall than younger units. The lowest CPR values we have found are associated with the dark, smooth mantling deposits associated with regional pyroclastics, such as near Sulpicious Gallus (Table 1). Our measured CPR value for these dark mantle deposits (0.179 ± 0.055; Table 1) agrees closely with published estimates from Earth-based S-band radar imaging (~0.18 ± 0.05; [5]).

Conclusions: CPR values vary according to geological unit and to the relative degree of unit freshness. Although a general increase in mean CPR is observed with increasing geological youth, several areas have been identified that run counter to this trend, where the CPR values are lower than expected. This could mean that the units are incorrectly mapped or it could mean that initial surface conditions of units are not all identical. The averaged mean CPR for mature mare and highlands areas studied is 0.32 ± 0.11. Such a value is slightly higher than the mean CPR suggested by Earth-based radar for the bulk Moon, ~0.2 [4], but corresponds to measurements of individual terrains from the Arecibo S-band radar [5]. Future work will include gathering more CPR data for more terrains around the Moon, examining these areas in the new high-resoloution images from LRO, and correlating them with estimates of surface roughness and maturity derived optically. Finally, these results allow us to better interpret and understand CPR variations in polar deposits, including the possible identification of ice deposits.

References [1] Spudis P.D. et al. *Current Science* (India) **96**, 533-539, 2009. [2] Hagfors, T. and J. V. Evans, *Radar Astronomy*, ed. J. V. Evams and T. Hagfors, 219-271, McGraw-Hill, New York, (1968). [3] Thompson T.W. et al. *Lunar Planet. Sci.* **XXXIX**, Lunar and Planetary Institute, Houston TX, 1023, 2008. [4] Ostro, S.J., (2002) in *The Encyclopedia of Physical Science and Technology*, 3rd Edition, vol. 12, Academic Press, pp. 295-328. [5] Carter, L. M., et al. *J. Geophys. Res.*, doi: 10.1029/2009JE003406 (2009, in press) [6] Milton D. J., USGS Map I-546, 1968.

Table 1. Some typical CPR values for selected geological units in the non-polar Mini-SAR coverage from Chandrayaan-1.



Unit	Typical CPR	Comments
Aristarchus (Copernican-age crater ejecta)	0.469 ± 0.149	Large fresh crater
Aratus (Copernican)	0.743 ± 0.239	Small fresh crater
Apollo 16 Cayley Fm.	0.311 ± 0.084	Highland plains
Apennine massif	0.713 ± 0.244	Mt. Hadley
Apennine intermontane	0.338 ± 0.128	Apennine backslope
"Young" maria	0.321 ± 0.113	West of Lansberg
Sulpicius Gallus Fm. dark mantle deposits	0.179 ± 0.055	Near vent