

ARECIBO S- AND P-BAND RADAR CHARACTERIZATION OF PUTATIVE ANCIENT IMPACT MELTS WITHIN MARE CRISIUM. E. G. Rivera-Valentín¹, H. M. Meyer¹, S. S. Bhiravarasu², C. D. Neish³, M. C. Nolan⁴, A. K. Virkki⁵; ¹Johns Hopkins University Applied Physics Laboratory, ²Space Applications Centre, Indian Space Research Organization, ³Dept. of Earth Sciences, University of Western Ontario, ⁴Lunar and Planetary Laboratory, Univ. of Arizona, ⁵Univ. of Helsinki.

Introduction: Impact shocked material records the timing of cratering events, providing insights into a body's bombardment history, as well as the dynamical evolution of the Solar System. Thus, identification of impact melt, particularly produced during ancient basin formation, can inform strategies for in situ sample science. In their work, [1] identified locations of potential exposures of impact melt related to the formation of the Crisium basin on the Moon (see Fig. 1). The features were identified as kipukas with hummocky/fractured textures located near Crisium's inner ring. Additional constraints from Clementine showed the units are of non-mare composition. Follow up work by [2], though, noted that not all the features may be melt, while others if present, may have been modified by ejecta.

Young lunar impact melt can be characterized in radar imagery due to its lobate appearance, as well as high backscatter and circular polarization ratio (CPR), which may indicate "roughness" at the decimeter-scale [3]. Even extremely old (> 3 Gyr) craters, like Tsiolkovskiy, may preserve this high CPR signature [4]. The high CPR associated with lunar impact melt may be due to a surficial layer of shattered glassy material causing double-bounce backscatter [5]. Recently, [6] proposed new polarimetric analysis techniques to improve radar characterization of planetary surfaces, which were supported by [7]. Thus, we revisit the putative Crisium impact melt exposures using S- (12.3 cm, 2380 MHz) and P-band (70 cm, 430 MHz) Arecibo radar observations to further test the hypothesis that these are melt-related features.

Observations: Here we use bistatic S- and P-band radar observations reported in [3,8] where Arecibo Observatory was the transmitter and the Green Bank Telescope (GBT) was the receiver. During a typical observing run, Arecibo would transmit a circularly polarized beam of light and GBT would receive echoes in both the same circular (SC) and opposite circular (OC) polarization as transmitted. Resultant delay-Doppler images were calibrated for thermal noise, beam pattern, and total power then projected onto selenographic coordinates. Final spatial resolutions were sub-1-km (~ 400 m in S-band and < 900 m in P-band). Data from these observations were obtained from the NASA Planetary Data System Geosciences node. Over Mare Crisium, the radar incidence angle, without accounting for local scale topography, varies between 40° - 60° . At these angles, the radar returns in both polarizations have a dominant component of volume scattering [9].

Analysis: We first produced a CPR map ($\text{CPR} = \text{SC/OC}$). To enhance contrast between features of interest, we used a quantile-based color mapping (Fig. 1). The five studied putative impact melt exposure locations from [1] were then cross referenced with the radar products. The putative impact melts are located in terrains with CPR values within the interquartile range of Crisium basin. All the studied potential melts have $\text{CPR} < 1$, which is unlike most other lunar impact melt [10].

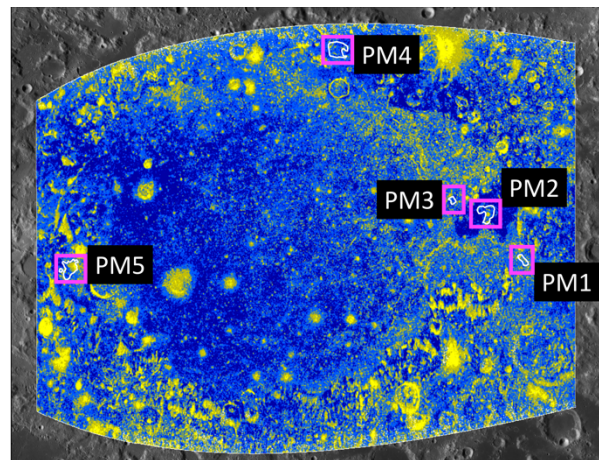


Figure 1: Arecibo S-band CPR map overlain onto an LROC WAC image of Mare Crisium (17°N , 58.8°E). The locations of the putative melt deposits are outlined in magenta and annotated with the naming convention used here. CPR color mapping is quantile-based by clustering values into quartiles from yellow (high, $\text{CPR} > 1$) to dark blue (low, $\text{CPR} < 1$), with the lighter blue representing the inter-quartile range.

For each of the putative melt (PM) regions, the SC and OC radar backscatter coefficients in both frequencies were sampled after masking out the interiors of radar-bright craters. This was done to concentrate on the melt deposits outside of crater rims. Besides the studied PM, we also sampled the central Crisium basin, again after masking large, radar-bright craters. Additionally, we compared values to the ejecta deposits of Picard (22 km) and Yerkes V (3.7 km) craters.

In Fig. 2 we show the median and interquartile range for the SC and OC radar backscatter coefficients of the studied PMs and context regions. In both frequencies, PM 5 is distinguishable from the background context terrain due to its radar brightness. Additionally, PM 5 is more similar to Yerkes V in P-band than S-band, indicative of a larger block-size distribution over the terrain.

In both frequencies, PM 2 is indistinguishable from the context terrain, which may suggest that it is not impact melt. While PM 4 is distinguishable from the context terrain due its lower radar return in S-band, in P-band it is indistinguishable. Similarly, while PM 1 and 3 are indistinguishable from Crisium in S-band, they are distinguishable in P-band. These differences may suggest different depths or roughness scales for the features.

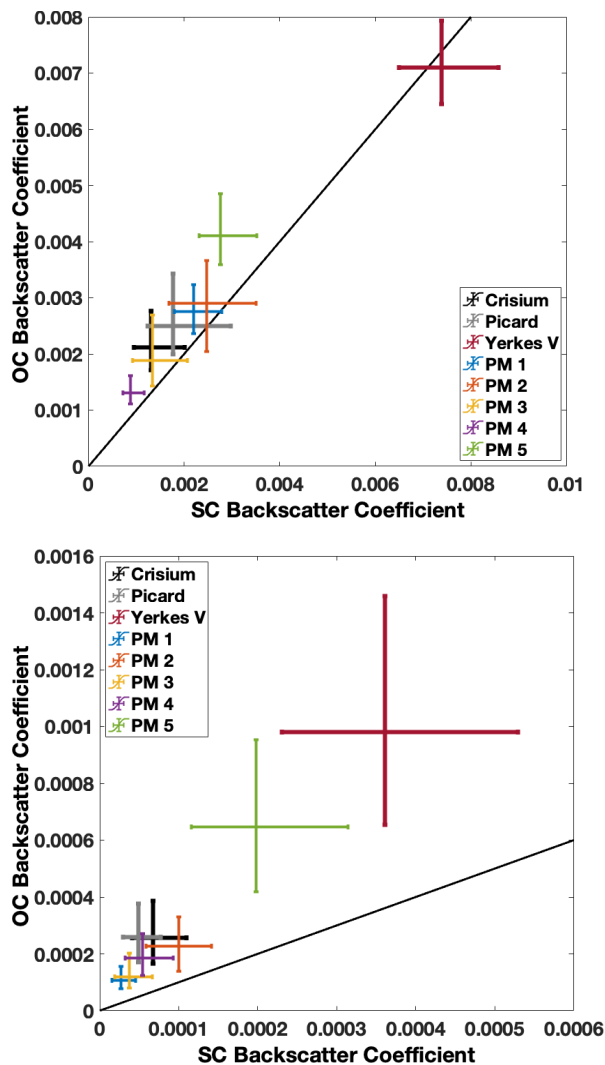


Figure 2: The median (center) and interquartile range (bars) of the SC and OC radar backscatter coefficients for the studied regions for (top) S- and (bottom) P-band. The black solid line denotes the one-to-one (i.e., CPR = 1) relation, where beneath the line CPR > 1 and above CPR < 1. All PMs have CPR < 1.

Following [6], we also did a linear least squares fit (LSF) to the SC and OC backscatter coefficients for the studied terrains. In their work, [6] showed that the LSF slope helps to describe the abundance and morphology of wavelength-scale scatterers and the intercept is related to the bulk dielectric permittivity, which may vary

due to density differences and/or composition. In Fig. 3, the LSF slope and intercept for the studied terrains are shown relative to the Crisium reference values.

In both frequencies, PM 5 has a higher intercept than Crisium and a lower slope. This may suggest PM 5 has a higher bulk density than Mare Crisium with a regolith dominated by more and/or rougher scatterers. Differences in wavelength-scale scatterers associated with PM 5 may support the idea that the region has been recently modified by ejecta deposition [2]. PM 2 is mostly indistinguishable from Crisium in both frequencies except the P-band slope. This further suggests that PM 2 is likely not impact melt. Interestingly, PM 1 has a frequency-dependent intercept; the S-band intercept is higher than Crisium while the P-band is lower. This may indicate potential layering and/or surface contamination, since P-band radar senses deeper than S-band.

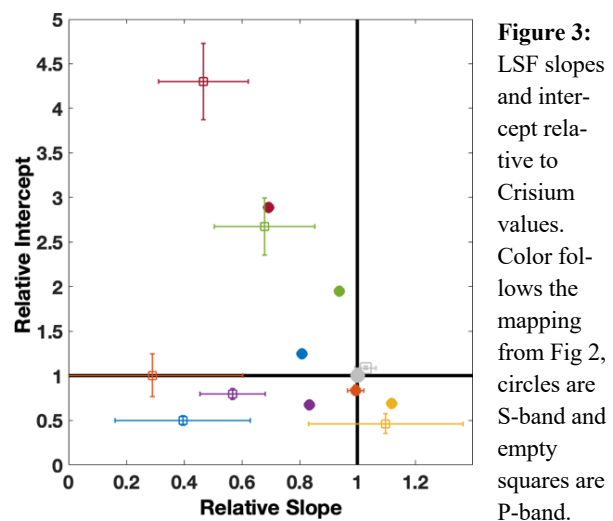


Figure 3: LSF slopes and intercept relative to Crisium values. Color follows the mapping from Fig 2, circles are S-band and empty squares are P-band.

Conclusions: Our radar analysis supports the idea that, if PM 5 contains impact melt, it has likely been modified by subsequent ejecta deposits [2]. On the other hand, PM 2 is likely not an impact melt due to its similarity with the properties of Mare Crisium. Indeed, all PMs exhibit CPR < 1, which is unlike most other impact-melt related features observed on the Moon [10].

References: [1] Spudis, P. D. and Sliz, M. U. (2017) GRL 44, 1260-1265. [2] Runyon, K. D. et al. (2020) JGRP 125. [3] Campbell, B. A. et al. (2010) Icarus 208, 565-573. [4] Greenhagen, B. T. et al. (2016) Icarus 273, 237-247. [5] Neish, C. D. et al. (2021) Icarus 361, 114392. [6] Virkki, A. K. and Bhiravarasu, S. S. (2019) JGRP 124, 3025-3040. [7] Rivera-Valentín, E. G. et al. (2022) PSJ 3, 62. [8] Campbell, B. A. et al. (2007) IEEE 45, 4032-4042. [9] Fa, W. et al. (2011) JGR 116, E03005. [10] Neish, C. D. et al. (2021) LPSC Abs. 2548.

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