Recent Radar Imaging Observations of the Moon: New Views of Pyrocastics, Mare Basalts, Impact Crater Deposits, and the Lunar Subsurface.

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Introduction: Recent radar data sets have provided new information about a wide variety of lunar science topics. Radar waves are capable of penetrating into the surface and imaging buried rocks and buried structures. Longer wavelength radar waves are capable of traveling farther into the regolith, and they are also less sensitive to smaller rocks. Radar is also sensititve to the density and composition of the surface and near-subsurface through the dielectric permittivity.

In the last decade radars have provided polarimetric imaging of the lunar surface at multiple wavelengths: Arecibo and the Green Bank Telescope at 70 cm and 12.6 cm wavelength [1,2], and Mini-SAR on Chandryaan-1 and Mini-RF on the Lunar Reconnaissance Orbiter at 12.6 cm and 4.2 cm [3]. The use of polarimetry data, such as the Circular Polarization Ratio (CPR), has provided a means to investigate the roughness of volcanic deposits and crater ejecta.

Lunar Pyroclastics: Fine-grained pyroclastic deposits are typically dark in radar images due to their smooth surface and lack of embedded rocks. They also often have very low CPR values. Radar data of pyroclastics at both 12.6 and 70 cm wavelength have led to new mapping of deposit extent, and to the identification of new deposits, including some associated with domes and rilles [4]. On the Aristarchus plateau, radar penetrates through the pyroclastic ash to reveal shallow buried flows; low-CPR, radar-dark regions of the pyroclastic deposit are deeper, rock-poor regions [5].

Mare Basalts and Cryptomare: The lunar Mare consist of layered basalt flows of varying age and composition. Radar is very sensitive to the $TiO2$ content of the mare basalts, due to an increased loss tangent that attenuates the radar wave. Radar backscatter at 70 cm exhibits strong variations with minor changes in flow $TiO2$ content when the fractional abundance of ilmenite is low (< 4%– 5%) and the radar can penetrate to the substrate [6]. Mapping changes in radar brightness across Mare Serenitatis clarified boundaries between major buried lava flow complexes, and revealed linear features inferred to be collapsed lava tubes [7]. The improved delineation of units also helped to reconcile inconsistencies between regional stratigraphic relationships and crater-count age dating.

Cryptomare units – mare basalts covered by highlands material – represent an additional component of the early volcanic record of the Moon. The deep probing allowed by the 70 cm wavelength radar has added significantly to our understanding of these ancient lava flows. For example, areas east of the Orientale basin where highland material was mapped at the surface from multi-spectral methods had much lower 70 cm radar echoes than expected [8]. These areas are connected with mare-contaminated highland material mapped by [9] near the edge of Oceanus Procellarum, showing that the cryptomare units must extend a long distance beneath the Orientale ejecta.

Impact Cratering and Age Dating: The age of the regolith affects the radar backscatter and polarization properties, because comminution of blocky ejecta over time reduces the average block size and smooths the surface. The effects of aging are particularly apparent in radar images of impact ejecta. Lunar craters of Early Imbrian age or younger typically have radar dark haloes that appear farther from the rim than the blocky continuous ejecta, which appear bright in radar images [10]. Radar and infrared comparisons have revealed that large surface rocks break down faster than expected, but that shallowly-buried rocky ejecta can remain undisturbed for long periods [11,12]. The radar properties of ejecta blankets offer a new means of dating lunar craters [12].

Recent observations have also revealed previously unrecognized buried impact melt flows [1,13,14]. A survey of Mini-RF data led to a significant reassessment of how melt is emplaced; a larger number of small craters have melt flows than was expected and pre-existing topography appears to play a dominant role in the emplacement of melts [14]. Impact melts are also some of the roughest features on the Moon, despite appearing smooth in optical images [1,14].

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