Introduction: Previous understanding of lunar ejecta has derived from mapping based on visible-wavelength images and reflectance spectroscopy, both yielding information about surface textures and lithologies, and Earth-based radar, which provides insight into the subsurface distribution of volume scatterers (i.e., large blocks). New data from the Lunar Reconnaissance Orbiter (LRO) provide additional information about the physical properties of impact ejecta and their relationship to the lunar regolith. In this presentation, we report on systematic investigations of ejecta properties using data from the LRO Diviner thermal radiometer and the LRO Mini-RF radar experiment.

Blocky ejecta: Earth-based radar observations have shown that most nearside lunar craters show annuli of high radar return, high circular polarization ratio (CPR) material generally accepted to correspond with blocky continuous ejecta blankets [1-4]. The high radar returns originate from a volume of regolith meters (for 12.6-cm wavelength radar) to tens of meters (70-cm radar) in depth, and it is not possible on the basis of these data alone to determine how much of this signal arises from rocks on the lunar surface. The LRO Diviner thermal radiometer, provides a means of estimating the surface rock abundance, expressed as the fraction of a given field of view occupied by rocks large enough to remain warm through the lunar night [5]. Diviner rock abundance values for all but the youngest nearside lunar craters’ ejecta are generally indistinguishable from the low values that characterize the background lunar regolith (e.g., Fig. 1). Thus, most of the blocky ejecta detected in Earth-based radar images reside in the subsurface, mantled by at least tens of centimeters of thermally insulating, fine-grained regolith material. Recent work has established a relationship between ejecta block abundance and time, with rock abundance decreasing as a power-law function of crater age [6].

In the current work, we add analysis of LRO Mini-RF radar data to our investigation, which provide a means of extending our exploration to regions not mapped in Earth-based radar datasets. In addition, we analyze multiple wavelengths of Earth-based radar data, in order to use the differences in effective scatterer size and penetration depth to further constrain subsurface ejecta block sizes.

Figure 1. Crater Kaiser C (36.5S, 9.6E; d=12 km): a) Arecibo 12.6-cm CPR overlain in color on OC image (spatial resolution: 80m/pixel); b) MRF 12.6-cm CPR overlain on total power image (15 m/pix); c) Arecibo 70-cm CPR overlain on OC image (400m/pixel); d) Diviner derived rock abundance (0 to 3%). Radar CPR values approaching 1.0 denote high block abundance within radar penetration volume.

Fine-grained ejecta: Earth-based radar also shows that most nearside lunar craters have low-return, low-CPR haloes that appear distal to the blocky continuous ejecta; these are interpreted as block-poor, fine-grained deposits [1-3]. Comparison of radar-dark halo spatial extents in 12.6-cm vs. 70-cm wavelength radar observations indicates that the fine-grained material is on the order of several meters thick and does not thin significantly with distance from the crater [4]. Diviner rock abundance values for these radar-dark regions are appreciably lower than those of the surrounding regolith, confirming that radar-dark haloes are in fact depleted in large blocks.

In addition to rock abundances, Diviner nighttime data also yield temperature values for the rock-free regolith fraction [5]. Matching those temperatures to
the results of 1D thermal models [7, 8] constrains the bulk density of the upper meter of the regolith. Application of this method to radar-dark halo regions shows lower bulk densities than for the surrounding regolith, consistent with depletion in small surface rocks and/or larger buried rocks (and in contrast to elevated bulk densities for blocky ejecta regions, consistent with higher abundances of small and buried rocks). We attribute the small but appreciable bulk density differences observed for nearside mare craters (e.g., Euler: Fig. 2) to the absence of small rocks, and estimate that radar-dark haloes are depleted down to mm-sized particles.

Buried impact melt: Radar datasets can reveal the nature of buried features such as impact melt flows [9, 10]. For example, analysis of the polarimetric characteristics of these features provides information about their wavelength-scale roughness, and comparison of radar returns at multiple wavelengths can be used to estimate quantities such as roughness more quantitatively than is possible using a single wavelength. The burial depths of such features are difficult to constrain using radar data alone in the absence of knowledge of the dielectric properties and population of volume scatterers. Shallow features, however, may produce thermal signatures, detectable in Diviner data, that allow constraints on the maximum burial depth.

Ejecta evolution: Together, these datasets and their intercomparisons can provide quantitative information about how material is emplaced during the impact process. In addition, they provide a means of quantifying the rates of evolution of various impact products, on the surface and in the subsurface.