UNDERSTANDING THE PHYSICAL EVOLUTION OF THE LUNAR REGOLITH USING LRO DATA.

J. B. Plesica, The Johns Hopkins University, Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723; jeffrey.plescia@jhuapl.edu.

Introduction: The lunar surface is covered by a layer of fragmental debris – the regolith – produced over billions of years by the physical disintegration of the surface materials by micro- to macroscopic scale impacts [1]. To first order, the process is mechanical, unlike the chemical processes that produce soils on the Earth. Because the lunar regolith is ubiquitous, it is the prism through which virtually all aspects of the Moon are seen. The regolith is also the surface on which lunar operations will be conducted and may serve as a resource. Thus, a detailed understanding of its properties and its evolution are necessary.

Background: Our understanding of the origin and evolution of the regolith is derived from remote sensing data (orbital and Earth based) and from in situ samples and analysis (Apollo and Luna). The physical, chemical, and mineralogic properties are summarized by [1-7]. While a general understanding of the physical properties exists [3], much remains poorly defined.

Questions: A series of questions can be posed for the regolith, some can be addressed by data from the Lunar Reconnaissance Orbiter (LRO) and from the Japanese Kaguya, Indian Chandrayaan-1, and Chinese Chang’e missions.

What is the variation in thickness of the lunar regolith? How does thickness vary with surface age, maturity, and composition.

Are there significant local variations in regolith thickness in the mare or highlands; if so what does this imply for regolith formation?

Is the regolith in areas of permanent shadow fundamentally different from regolith elsewhere?

Can a fossil regolith be located?

How do rays from recent impact events modify the regolith such that they are visible and what is the mechanism for the disappearance of rays?

What Do We Know: Regolith analysis began with data from Ranger, Lunar Orbiter (LO) and Surveyor. Ranger and LO provided variable resolution images allowing the regional properties to be defined; Surveyor and Apollo provided higher resolution local views.

Regolith Thickness: Mare regolith is estimated to be a few meters thick; the highlands megaregolith is considerably deeper, up to tens of meters thick. Original estimates of regolith thickness were made using crater morphology [8-10]. The model assumed the crater morphology changes from simple to concentric or flat floored when the crater excavates to the top of an underlying strong layer (i.e., bedrock). The diameter at which blocks first appeared was also used to estimate thickness. Later, Apollo seismic data [11] and radar data have also been used to estimate the thickness [12]. Using such methods, regolith was estimated to be 8.5 m thick at the Apollo 14 site; 12.2 m at the Apollo 16 site, and 7-32 m at the Apollo 17 site.

Wilcox et al. [13] show that such a simple model may not always be applicable. For example, similar diameter craters can have different morphology, some have blocks whereas others do not. These differences indicate that the regolith formation process is complex.

Rocks: Craters which excavate into bedrock will distribute blocks. As the regolith is thinner on the mare than in the highlands, blocks will be excavated at relatively smaller diameters (shallower depths) on the mare. Block populations around fresh craters and on the intercrater areas have been measured [13-20]. Using LO images, blocks around craters >30-100 m typically are 1-3 m. Apollo and Surveyor sites have rocks >30 cm of 100 m^2. At Apollo 16, rocks >10 cm range from <1% at Sta. 1 to ~16% near WC crater. [13] found 10% of craters 50-100 m have blocks; 100% of craters >300 m have blocks on the mare. Some correlations between surface and orbital data have been made; radar data have also been used to assess surface block populations, although in a statistical sense.

Crater Size Frequency: The size frequency distribution of craters has been measured with orbital data (LO and Apollo) to diameters of a few meters and
from Surveyor images to cm scale [24-31]. LROC data will allow data to diameters of perhaps 2-3 m at numerous locations to be collected allowing for a better understanding of the small projectiles flux, local variations in the surface ages, and the extent to which surfaces are saturated with craters at diameters <200-300 m [32].

**Ejecta Thickness:** Ejecta thickness can be measured using the LOLA data or geometric or photometric topography from images. This will allow better constraints on ejecta thinning as a function of radial distance and azimuth, and the net bulking of the regolith by the impact process.

**Morphometry:** Various morphometric relations (e.g., depth / diameter, rim height / diameter, etc.) will be developed using both the LOLA and stereo topography data. This will allow existing data bases [33-39] to be examined and extended to much smaller diameters than was previously possible.

**Slopes:** Previous studies [40-41] show that slope distributions are a function of the baseline over which they are measured. LOLA data can be used to address slope variations at scales ranging from the distance between shot points (25 m) to kilometers. Topography derived from stereo can be used to address the slope distribution to baselines of ~1 m.

**New Data:** LROC narrow angle (NAC) targeted observations provide images with ground surface distances (GSD) of 0.5 m/pixel. These images allow very high spatial assessment of the parameters noted above. However, the amount of surface covered by NAC is very limited. Therefore, targeted observation and a statistical sample are critical. Stereo imaging data from Kaguya and Chandrayaan-1 (GSDs ~5-10 m/pixel) are also important. LOLA and altimeters from the other missions provide very high resolution (horizontal and vertical) topography. In addition, LOLA data provide estimates of surface roughness and albedo. These data, supplemented by geometric and photometric stereo, will provide critical topographic data.

Radars on Chandrayaan-1 and LRO will image permanently shadowed areas and provide data on surface roughness and volume scattering. Instrument resolution is too low to resolve individual blocks, but the data do provide a statistical estimate.

**Maturity:** Over time, the regolith matures due to space weathering – exposure to radiation and the effects of micrometeoroid bombardment [7]. Color images have been used to estimate the optical maturity of the regolith [43-44]. LROC wide angle camera, as well as the spectral instruments form other missions, will provide better calibrated data that can be correlated with high resolution images of the surface and other data sets to better understand the maturation process.

**Summary:** LRO and other missions will provide a suite of key data sets at varying resolution and coverage to address problems of the lunar regolith. For the instruments with high spatial resolution (LROC, radar) targeted observations are critical to ensure the relevant data are collected. Using these data sets, the processes by which the regolith forms, evolve and mature will be better understood. Spatial variations in the physical properties of the regolith that will affect surface activity (landing, construction, mining, roving) will be better defined to allow better planning and system design.

**References:**