SPACE WEATHERING AND THERMAL PROPERIES OF FRESH CRATERS ON THE MOON.

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Introduction: Space weathering processes on the Moon control the production of the regolith and the alteration of its optical properties [1]. Larger impacts produce new regolith from bedrock and smaller impacts work to comminute it to finer particle sizes [e.g. 2]. Solar wind sputtering and micrometeorite impact vaporization combine to cause regolith spectra to both redden and darken [e.g. 3]. Two data sets exist that are sensitive to these two processes. Thermal images of the Moon, taken during eclipse, are sensitive to the particle size distribution of the surface (the amount of rocks). Optical Maturity (OMAT) parameter images, on the other hand, are sensitive to the amount of agglutinates and nanophase iron produced as a result of surface exposure to space weathering processes. Analysis of these images offer new insights into the state of the lunar regolith and its evolution.

Methods: In order to assess maturity, we produced OMAT parameter images from Clementine UV-VIS data [4, 5]. This parameter is sensitive to the optical effects of space weathering, with higher OMAT values indicating a less optically mature surface. To study the particle size distribution, we used a set of thermal infrared images (8.35-9.13µm) acquired with the AEOS 3.67-m telescope at the Air Force Maui Space Surveillance System on July 28, 1999 when the southern portion of the Moon was eclipsed by the Earth's shadow. An array of 73 × 73 individual images of 200 × 200 pixels were taken, with a resolution of ~300 m/pixel. During an eclipse, the fast plunge into darkness allows for measurements of variations in thermal inertia across the surface as rock units cool at different rates depending on their thermal properties. Grain size, bulk density, thermal conductivity and rock abundance all affect the thermal behavior, but of these, rock abundance has the strongest effect, and even a small change in the abundance of rocks on the surface will have a drastic effect on the surface temperature [6]. Thus the eclipse brightness temperature is used here as a proxy for the blockiness of a surface. A calculation of skin depth shows that the eclipse data is sensitive to ~cm-scale particles.

Qualitatively, the distribution of thermal and optical maturity anomalies is very similar. Both show a large number of anomalies (thermal and maturity) associated with small (10^2-10^3 m) craters in mare regions, and few anomalies in the highlands (Fig. 1). We quantified this by determining the density of craters 3-km and larger that appeared as both maturity and brightness temperature anomalies in Mare Humorum and in a highlands area centered at a latitude and longitude of –33.6°, 28.5° (south of Nectaris Basin). Crater counts and size determinations were made on images obtained by Clementine at 2.7 µm [7] where crater rims are more easily visible. In order to investigate the particle sizes of more distal ejecta and the effects of large craters on regolith, we also examined the thermal and optical maturity properties of the ejecta of Tycho, an 85-km Copernican-age crater [8] in the southern highlands.

Results: We generally see a 1:1 correlation between areas that appear as maturity anomalies (optically immature) and brightness temperature anomalies (blocky) (Fig. 1). In mare areas, a multitude of small craters are detected, as was

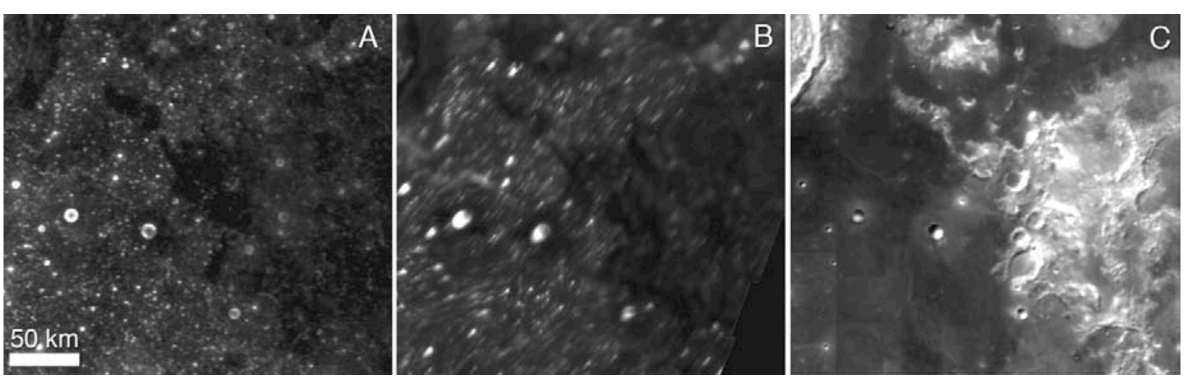

Fig. 1. Mare Humorum and surrounding highlands as seen in A) OMAT parameter image; B) Eclipse brightness temperature image; C) Clementine 2.7-µm image. Note correlation of OMAT and eclipse, and the drop-off of small-crater maturity and thermal anomalies in highlands areas.

also observed in Apollo 17 infrared scanning radiometer data [9]. In contrast, highlands areas show fewer maturity and brightness temperature anomalies. This is reflected in our counts of 3-km and larger craters detected in both maturity and brightness temperature images. There are approximately five times fewer of these craters in the eastern highlands study area (1.03×10^{-4} craters/km^2) than in Mare Humorum (5.06×10^{-4} craters/km^2).

In contrast to smaller craters, the ejecta of large craters do not appear as both maturity and brightness temperature anomalies. For example, the 85-km crater Tycho has an extensive ray pattern that is visible in the OMAT data, but is absent in the eclipse data (Fig. 2).

Discussion: The 1:1 correlation between maturity and brightness temperature anomalies implies a strong association between the abundance of cm-scale and larger blocks and the amount of optically immature material. The profusion of these anomalies in the maria suggests that cratering events frequently penetrate the mare regolith to expose optically immature and blocky (fresh) regolith from the basalt below. In contrast, the scarcity of small craters with maturity and thermal anomalies in the highlands implies that the highlands regolith is both deficient in cm-scale and larger rocks and is optically mature to the depth excavated (often >300 m [10]). This suggests that the Apollo 16 landing site, with its two fresh craters in close proximity, North and South Ray, may be anomalous with respect to soil properties relative to typical highlands. Thus caution should be applied when using Apollo 16 particle size distributions to estimate rock abundances at potential sample sites.

The lack of correlation between the thermal and maturity properties of the distal ejecta and rays of large craters suggests that these distal deposits are dominated by fine material, and that large cratering events are very efficient at comminuting ejecta to particles below cm-size. This provides an explanation for the deficiency of rocks observed in thermal images of the highlands and implies extensive reworking is not required to produce fine-grained regolith. However, the lack of maturity anomalies associated with small craters in the highlands suggests that the regolith has been extensively reworked and exposed at the surface until optically mature down to a depth proportional to the depth of fresh craters.

Conclusions: The correspondence between maturity and thermal images suggest a strong association between the optical maturity of a surface and its blockiness, except in the distal ejecta and rays of large craters like Tycho. A finding of five times more small-crater maturity and thermal anomalies in mare areas than in the highlands implies that highlands regolith is fine-grained and optically mature to great depth (100s of m). These findings suggest thermal images of the Moon can be used to infer regolith depth in the highlands. Global thermal data at 300 m/pixel will be available from the Diviner Lunar Radiometer Experiment on the forthcoming Lunar Reconnaissance Orbiter mission.

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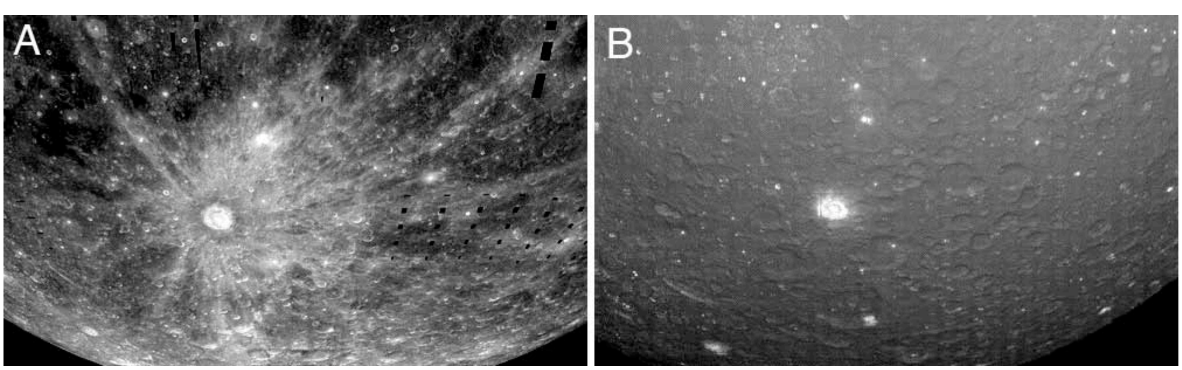

Fig. 2. A) OMAT image showing Tycho crater and immature rays. B) Eclipse image of Tycho, showing lack of thermal anomalies associated with rays.