QUANTITATIVE CHARACTERIZATION OF IMPACT CRATER MATERIALS ON THE MOON: IMPLICATIONS FOR THE ROLE OF TARGET MATERIAL.
J. T. Wang [1, 2, 3], M. A. Kreslavsky [2], J. Z. Liu [1, *], J. W. Head [4], and M. M. Kolenkina[5], [1]Center for Lunar and Planetary Sciences, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550081, China (wangjuntao@mail.gyig.ac.cn and liujianzhong@mail.gyig.ac.cn), [2] Earth and Planetary Sciences, University of California – Santa Cruz, Santa Cruz, CA 95064, USA, [3] University of Chinese Academy of Sciences, Beijing 10049, China; [4]Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA, [5]MExLAB, Moscow State University of Geodesy and Cartography (MIIGAiK), Moscow, Russia.

Introduction: Impact craters are the most abundant landform on the surface of the Moon. Properties of a newly formed craters are controlled by two groups of parameters: parameters of the projectile and parameters of the target [1]. Properties of the target can also affect crater degradation process. The parameters of projectiles vary in a random way, therefore, in large crater populations the effects of the projectile parameters are averaged out. This allows us to study the effects of the target material by examination of large crater populations. In this work we report our results for large ($D > 40$ km) craters. We mapped the crater material subunits and obtained their quantitative attributes, such as topographic roughness, night-time regolith temperature and rock abundance. Then we analyzed regional differences in these attributes that can be caused by target material difference.

Terranes: The term "terrane" refers to a regional unit of consistent properties, composition and topographic texture [2]. The obvious highland-mare dichotomy is not suitable for target material classification for large craters: (1) large craters obscure the original target, therefore, it is difficult to reliably assign a mare or highland target to a large crater; (2) mare-forming lavas are relatively thin with respect to the transient cavity size for large craters and do not necessarily dominate the target material.

Jolliff [2] subdivided the Moon into three major terranes, the Procellarum KREEP Terrane (PTK), the Feldspathic Highlands Terrane (FHT), and the South Plot-Aitken Terrane (SPAT), according to their geochemistry and petrologic history. Other authors also subdivided the lunar surface according to typical geophysical (crust thickness) and topographic characteristics and suggested three regional units with similar, but not the same outlines [3, 4]. We merged those results and chose some "average" outlines (Fig. 1). Because our terrane definition is not identical to [2], we chose different names: Mare terrane, Highlands terrane, and South Pole-Aitken (SPA) Terrane, respectively. *Highland terrane* is characterized by high elevations, thick crust, and felsic composition with a low amount of iron, and occupies the central and northern farside. *Mare terrane* is characterized by lower elevations, thinner crust and a high abundance of KREEP elements. Almost all maria belong to Mare terrane, but it also includes a significant area of the nearside highlands. *SPA terrane* has the lowest elevation, the thinnest crust, and slightly elevated Fe abundance in comparison to the Highland terrane. Its outline generally coincide with SPA basin.

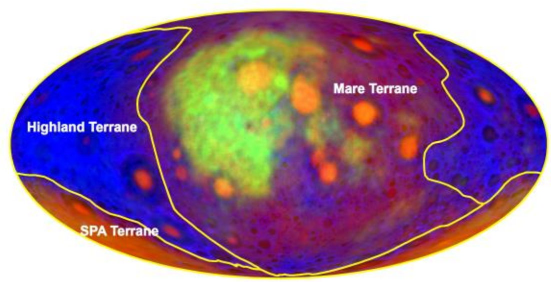


Fig. 1. Boundaries of three terranes we select. The base map [3] is RGB color composite of Bouguer gravity anomaly (red), Combined Th and Fe abundance (green), and elevation (blue). Mollweide projection centered at the nearside center.

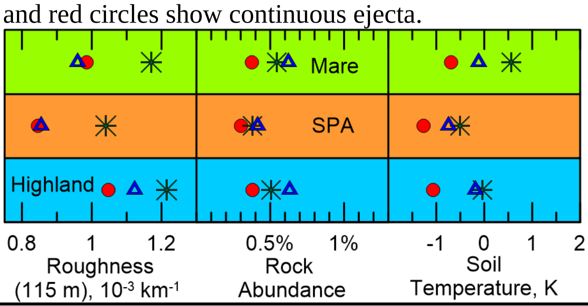
Data: We selected craters ($D > 40$ km) from the 2015 version of LPI lunar crater database [5] which have stratigraphic age. Since Mare terrane underwent an extensive volcanic resurfacing in the Imbrian period, it has a significantly smaller population of old craters. To exclude this age bias, we analyzed craters of younger stratigraphic ages only: Copernican, Eratosthenian and Late Imbrian.

The four crater material subunits [6]: central peak material (CP), crater floor material (CF), crater wall material (CW), and continuous ejecta (CE, also named crater rim material), were mapped based on images and topographic data from LRO mission. We used topography data obtained by Lunar Orbiter Laser Altimeter [7] (LOLA) to calculate roughness at 115 m, 230 m, 460 m, 920 m and 1.8 km baseline. The roughness measure we chose is the "interquartile range of profile curvature" [8]. We also used the thermophysical properties [9] of crater subunits derived from the DIVINER Experiment onboard LRO: rock abundance and night-time regolith temperature (with the global latitudinal trend subtracted).

Diversity of crater material properties among three terranes: Fig. 2 shows the median values of roughness and thermophysical properties for three crater subunits (CE, CF, and CW), and three terranes. Although within each terrane the properties vary in a wide range due to the difference in crater degradation degree [10] and individual variations, there are consistent trends seen in Fig. 2.

Topographic roughness. Topographic roughness shows a generalized overview of the typical surface textures. Not surprisingly, crater walls (CW) with their significant topography are rougher than generally flat CF and CE at all scales and on all terranes (Fig. 2). At long baselines (not shown in Fig. 2), CW of Mare terrane craters are systematically rougher than CW in Highland and SPA terranes. This can be explained by a higher mechanical strength and a higher resistance to degradation of competent volcanic material of maria in comparison to a weaker heavily fractured highlands megaregolith. Since roughness decreases with crater age [8,10], a higher resistance to degradation would cause a higher characteristic roughness. This effect is partly similar to a higher abundance of very steep slopes in mare craters noted in [11].

Fig.2 Roughness measure at 115 m baseline, the mean rock abundance, and the median normalized night-time regolith temperature for three terranes. Green asterisks show crater walls, blue triangles show crater floors, and red circles show continuous ejecta.



At short baselines, the SPA craters appear smoother than craters on the other terranes. This trend occurs for all crater material subunits (Fig. 2). This effect is rather strong, and we do not see any observational biases that could explain it. Typical background roughness (outside of the young crater materials) in the SPA region is also lower than in typical highlands [8], which is likely to be a related phenomenon. So far we do not have any convincing explanation for this effect. The absence of such an effect (for CW, CE, and the background) at long baselines suggests that SPA smoothing is caused by surficial processes, therefore, it is unrelated to the crustal thickness. The compositional difference between SPA and Highland terrane is minor and is not a likely reason for the observed effect.

Rock abundance and soil temperature. The thermal infrared measurements provide a means of understanding the physical properties of the upper decimeters of the regolith. The youngest, Copernican age craters in Mare terrane have a much higher rock abundance and soil temperature than the other terranes (not shown). We interpret this to be due to contribution of the competent volcanic material of maria, which, being impacted, produces more rocks and coarse soil particles than heavily fractured megaregolith of the highlands. In contrast to the youngest craters, the median rock abundance calculated over the entire population considered have similar values for all crater materials and all terranes (Fig. 2), which is consistent with a short lifetime of rocks [12]. Soil temperature in Mare terrane is slightly higher (Fig. 2). In [10] we found that the soil temperature of pristine craters takes a longer time to disappear, therefore Eratosthenian and Late Imbrian craters still “remember” the originally coarse soil in Mare terrane. The difference in mechanical properties between mafic materials of the maria and felsic materials of the highlands might also play some role.

Craters in SPA terrane show a slightly lower rock abundance and soil temperature than in Highland terrane; this occurs for all crater material subunits. This trend is likely to be related to the same enigmatic trend that we observe in roughness.

Conclusion: Using quantitative measurements, we observe some effects of the target material on impact crater properties. The observed increase of rock abundance in craters found in mare materials might be used as supplementary evidence for the detection of cryptomeria. The significant difference between crater properties in SPA and the Highlands is under further investigation.

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