IDENTIFICATION AND MEASUREMENTS OF SMALL IMPACT CRATERS IN THE LUNOKHOD 1 STUDY AREA, MARE IMBRIUM.

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Introduction: Lunar Reconnaissance Orbiter Narrow Angle Camera (LROC NAC) [1] has recently obtained several very high resolution (0.46-1.6 mpx) images of the area of the Lunokhod 1 studies [2]. The stereo pair M150749234/M150756018 was used to produce the DTM with 0.5 m horizontal resolution and 0.5 m vertical accuracy [3]. In this work we use some of these LROC NAC images and the mentioned DTM as well as the derived from it topographic map with the 1 m altitude contours. Below we consider a problem of identification of small impact craters on the LROC NAC images taken at different Solar Elevation Angles (SEA) and measured depth (H) / diameter (D) ratio (H/D) for the subpopulation of craters with D = 72-345 m. Then we made topographic profiles through several of these craters having different morphological prominence and then discuss the results.

Identification of craters on the images taken at different Solar elevation angle: Four images have been used: M127169138 (SEA = 46.3^{o}), M150749234 (24.7^{o}), M147210569 (8.4^{o}), and M133575171 (5.3^{o}), with resolutions of 0.463, 0.518, 0.74 and 0.465 m/px, all resampled to 0.725 mpx (Figure 1).

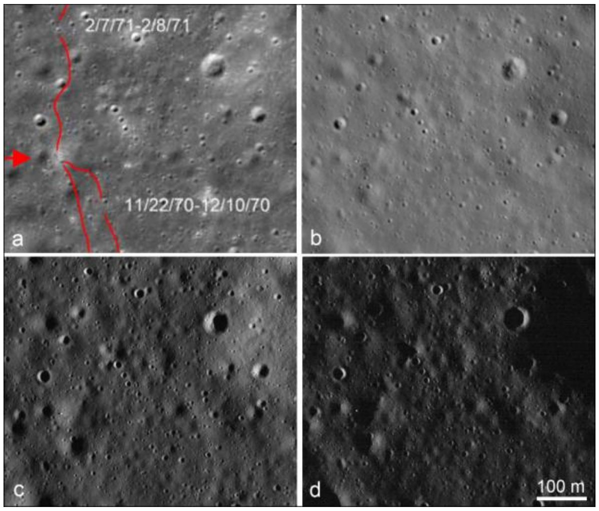

Figure 1. Portions of LROC NAC images M127169138 (a), M150749234 (b), M147210569 (c), and M133575171 (d), Red line shows the Lunokhod 1 route, red arrow shows the place where Lunokhod 1 landed.

The mappers, using Photoshop and alternatively Adobe Illustrator tools, outlined craters with D $\geq$72 m starting with images with the highest SEA and then, without reference to the previously mapped craters, again outlined craters on the images with the lower and lower SEA. As one could expect on the images with the lower SEA, more craters have been mapped comparing to those with higher SEA. For example, on the image with SEA = 5.3^{o} 127 craters have been mapped, while on the image with SEA = 46.3^{o} showing the same area, only 67 craters were identified. Subsequent checking of the crater presence and accuracy of diameter determination on the topographic map with the 1-m contours lines showed that on the first of these images 11 of 127 craters have been identified erroneously (they are clusters of smaller craters and noncrater depressions), while on the second one, all 67 mapped craters have been confirmed, but a significant fraction of existing craters was missed. Then we compared results of this mapping with those of mapping in GIS using the CraterTools program [4] and found that even on the image with SEA = 5.3^{o} in our counts using Photoshop we missed 4 craters. Simultaneously we found that the GIS-based mapping made on the image with SEA = 24.7^{o}), also missed a some number of craters. Our results agree with the results of other works on this topic [5-8].

The corrected (for erroneously identified and found using GIS craters) density of craters as a function of solar elevation angle is shown in Figure 2.

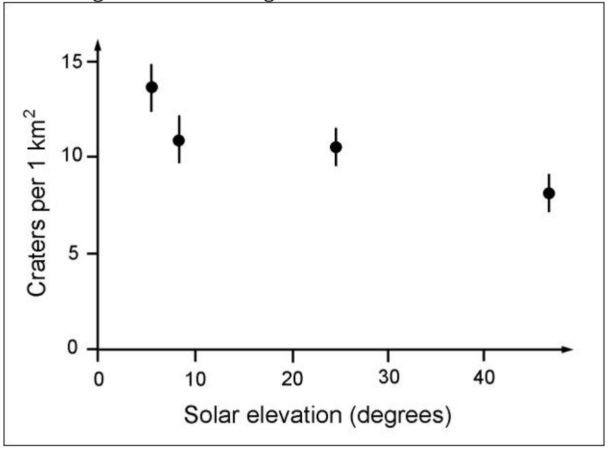

Figure 2. Density of craters mapped on the LROC images taken at different Solar elevation angle.

The above consideration shows that crater identification and mapping is better accomplished using images with the lower SEA, but this increases a probability of wrong crater identification and checking the results on the detailed topographic map can help to avoid false identification.

Measurements of depth/diameter ratio: For 120 validated craters with D $\geq$72 m we have measured the depth/diameter ratio (H/D). This was accomplished using the mentioned topographic map with the 1-m contours lines. The measurement results are shown in Figure 3.

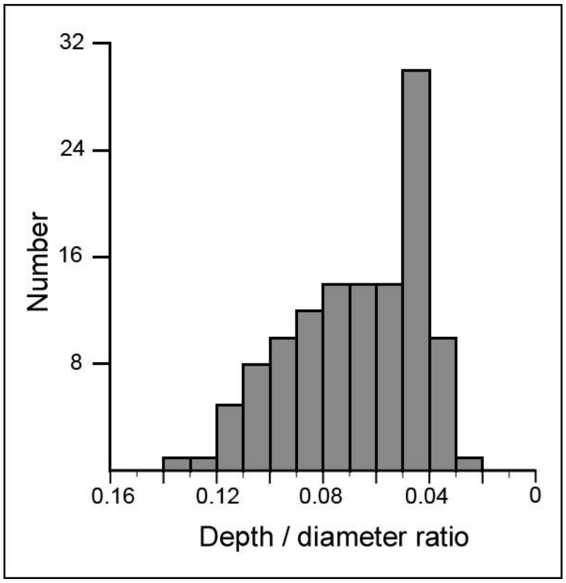

Figure 3. The depth/diameter ratio for 120 craters having D = 72-345 m.

The H/D for these craters vary from ~0.14 (morphologically most prominent) to ~0.02 (the least prominent). It was shown in previous work that small lunar craters form a morphological sequence from prominent and relatively deep to subdued and shallow. This sequence reflects the degree of crater degradation due to surface processes [e.g., 10-13]. The freshest craters were found to have H/D ~0.2-0.25 while the most degraded but still distinguishable on the images down to 0.05. The previous H/D measurements were not accurate, especially for the shallow craters, so our work provides more accurated data. The highest H/D for studied craters of the Lunokhod 1 area is ~0.14, that is noticeably smaller than that for very fresh well studied small craters, for example, in the Apollo 14 (Cone Crater) and Apollo 16 (South Ray and North Ray Craters), which have H/D = 0.2-0.25. Absence of so prominent craters among the sample of 120 craters of the Lunokhod 1 area suggests that their frequency in the area is smaller than ~1% that, in turn, means that the modification of the initial morphology with H/D = 0.2-0.25 occupies less that 1% of the potential lifetime of the craters of this size. We also measured H/D for 43 visually most prominent craters with diameters 30 to 72 m and found that their H/D varies from 0.11 to 0.17, none reaching 0.2-0.25. The total number of craters of this size range is ~400, so the absence in the studied subpopulation of craters with H/D = 0.2-0.25 suggests that their frequency in the study area is less than 0.2-0.3%. Thus, the modification of the initial morphology with H/D = 0.2-0.25 occupies less that 0.2-0.3% of the potential lifetime of the craters of this size.

Geometry of the crater depression: Using the DTM, topographic profiles through several craters having different morphological prominence have been made. Figure 4 shows the profiles through craters with H/D varying from 0.14 to 0.03 along with a profile through North Ray crater with H/D = 0.23 [14] for reference.

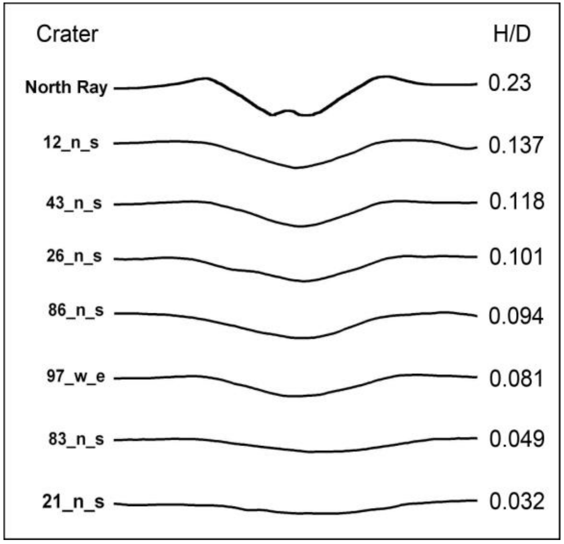

Figure 4. Topographic profiles through several craters of the Lunokhod 1 study area added with the profile through North Ray crater.

Figure 4 shows that in this morphologic sequence the crater relative depth (H/D), the crater rim relative height (h/D) and the maximum angle of crater inner slope (α) vary in the following way:

H/D	0.23	0.14	0.10	0.05	0.03
h/D	0.06	0.03	0.15	n.d	n.d
α^o	30	20	15	7	5

These changes in the crater geometric parameters can be considered in the context of surface processes responsible for crater morphologic degradation.

Conclusions: LROC NAC images provide a valuable information on different sides of the study of small lunar impact craters applicable to surface processes responsible for crater degradation and to the issues of characterization of the potential landing sites for future lunar missions.

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References: [1] Robinson M.S. et al. (2010) *Space Science Reviews,* 150, 81-124. [2] Vinogradov A.P ed., (1971) *Peredvizhnaya Laboratoriya na Lune. Lunokhod 1* Nauka, Moscow, 128 p. [3] Oberst J. et al. (2010) *LPSC XLI*, Abs. #2051. [4] Kneissl T. et al (2011) *Planet. Space Sci., 59*, 1243–1254. [5] Soderblom L.A. (1970) *JGR, 75*, 2655-2661. [6] Young R.A. (1975) *Proc. LPSC-6*, 2645-2662. [7] Wilcox B.B. et al. (2005) Met. Planet. Sci., 40, 695-710. [8] Ostrach L.R. (2011) LPSC-42, abs. 1202. [9] Trask N.J. (1966) *JPL Tech. Rep.* 32-800. [10] Florensky C.P., Taborko I.M. (1968) in *Physics of the Moon and Planets*, abs. 22. [11] Florensky C.P et al (1972) in *Sovremennye predstavleniya o Lune*, M. Nauka, 21-45. [12] Swann G.A. (1974) *LPSC-5*, 761-763. [13] Basilevsky A.T. (1976) *Proc. LPSC 7th*, 1005-1020. [14] Ulrich G.E (1981) *Geol. Surv. Prof. Paper 1048*. 45-81.