ANOMALIES OF THE LUNAR REGOLITH STRUCTURE IN THE VICINITY OF APOLLO-15 LANDING SITE: RESULTS FROM PHOTOMETRIC ANALYSIS OF CLEMENTINE UVVIS IMAGES.

M. A. Kreslavsky[1,2] and ***Yu. G. Shkuratov***[1], [1]Kharkov Astronomical Observatory, 35 Sumska, Kharkov, 61022, Ukraine; [2]Dept. Geol. Sci., Brown University, Providence RI 02912-1864, USA, misha@mare.geo.brown.edu

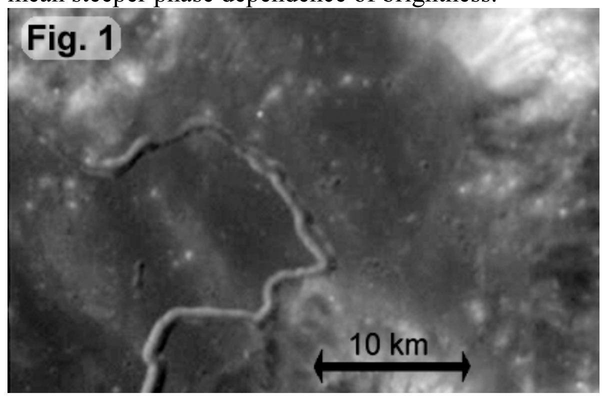
Introduction: Brightness of the lunar surface depends on the illumination/observation geometry. This dependence, often referred as the photometric function, is controlled by the regolith structure at wide range of spatial scales. Anomalies in the photometric function indicate anomalies in the regolith structure.

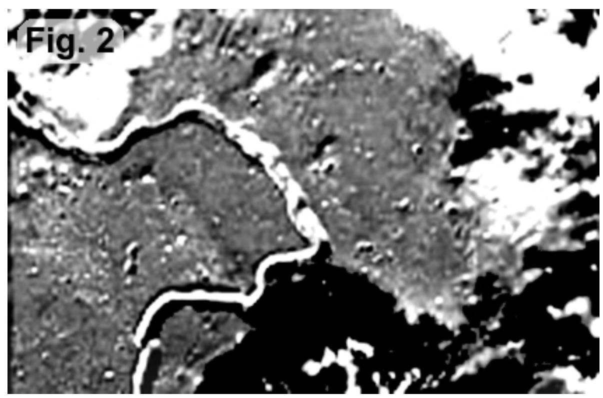
Source data: In this work we used a series of 52 images of a vicinity of Apollo-15 landing site taken with Clementine UVVIS camera in orbit 299. Illustrations (Fig. 1-3) were made using the red (B) filter images; results for the other 4 filters are qualitatively the same. The sun was at SE 54° above the horizon. The spacecraft moved from S to N almost through the local zenith. The first image in the chosen series was taken from 45° above the horizon from S; the last one was taken from 65° above the horizon from N. The image taken almost from the zenith is shown in **Fig. 1**. The phase angle changed in the range of 26° - 55° trough the series. Image resolution changed in the range of 100-200 m per pixel due to difference in distance from the spacecraft to the scene and perspective distortion.

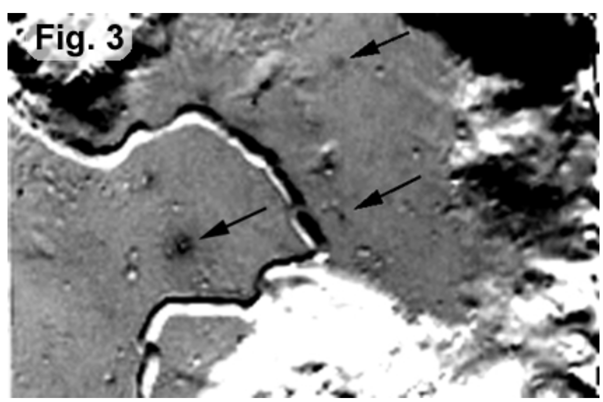
Data processing: We performed a standard calibration procedure [1] excluding the photometric correction and absolute calibration and obtained images calibrated in arbitrary units proportional to the observed surface brightness. Then we geometrically transformed images to compensate difference in scale and perspective distortion and coregistered all images. Since the camera pointing information was not accurate enough, we had to apply an heuristic matching algorithm to coregister the images with accuracy of 0.3 pixel. We calculated the illumination/observation geometry for each pixel of each frame. Thus, for each pixel in the area where all images overlap, we obtained 52 measurements of brightness obtained at 52 observation conditions. We approximated the dependence of brightness on the observation conditions with Akimov's [2] photometric function:

$$Ae^{-\eta\alpha}\cos\tfrac{\alpha}{2}\,\frac{\left(\cos(l-\tfrac{\alpha}{2})\right)^{\nu\alpha+1}-\left(\sin\tfrac{\alpha}{2}\right)^{\nu\alpha+1}}{1-\left(\sin\tfrac{\alpha}{2}\right)^{\nu\alpha+1}}\,\frac{(\cos b)^{\nu\alpha}}{\cos l},$$

where the phase angle α, the photometric latitude b and longitude l are the tree angles describing the illumination/observation conditions, and albedo A and parameters η and μ are the three adjustable parameters (see [3] for details and discussion). In this way we obtained maps of estimates of μ (**Fig. 2**) and η (**Fig. 3**). Brighter shades in these maps denote higher values of the parameters; in particular, in Fig. 3 brighter shades mean steeper phase dependence of brightness.







Results and analysis: A contrasting shadow-like pattern of mountains (Apennines) and a channel (Rima Hadley) does not reflect real variations of the photometric function parameters and should be disregarded in the analysis. These strong variations of the estimates are caused by steep surface slopes, which were not taken into account when we calculated the observation geometry. The same is the case for a number of black/white objects are associated with resolved craters, pits, and knobs. Several bright unresolved craters also produce small contrasting unreal features in the map of the parameters due to difference in the actual resolution of the source images used as well as minor (~1/2 pixel) imperfections in the coregistration. Only a few diffuse features on the flat mare surface are real anomalies of the photometric function.

The map of the parameter μ of the disk dependence of brightness (**Fig. 2**) shows almost no real features. Faint variations are related with a ray seen (Fig. 1) inside the Rima Hadley loop.

The map of the parameter η of the phase dependence of brightness (**Fig. 3**) shows several distinctive diffuse features in the flat surface. The most pronounced feature is a diffuse halo shown with the **left arrow** in Fig. 3. It is associated with an impact crater shown with the arrow in **Fig. 4** (taken from Lunar Orbiter V frame 105M). The well-expressed inner part of the diffuse halo has a radius of 0.7 km; a faint extension of the halo can be traced up to 2 km from the center. Smaller and less pronounced halo (the **upper arrow** in Fig. 3) is also associated with an impact crater (the arrow in **Fig. 5;** the same LO frame). Both craters are fresh, because they have sharp slope breaks (Fig. 4, 5) and are bright (Fig. 1) due to the regolith immaturity. The haloes extend much farther from the crater centers than the increased albedo (immature soil). There are some other fresh craters of comparable size in the scene, which do not have any halo in Fig. 3, for example, the crater in the upper left part of Fig. 4.

A small dark spot (**lower right arrow** in Fig. 3) is not associated with any fresh crater but exactly coincides with Apollo 15 landing site. This object is very small, and we cannot prove with absolute reliability that the dark spot is not an occasional result of some superposition of noise realizations in the images used, however our screening of all the images, absence of similar spots in the scene and exact coincidence of the spot with the landing site made us sure that this is a real feature.

Discussion: At the phase angle range in effect, the steepness of phase dependence of brightness is thought to be controlled predominantly by the shadow-hiding mechanism. In the frame of this mechanism, for the same albedo the lower values of η (darker shades in Fig. 3) correspond to a regolith surface, which is flatter at scales of 0.1 – 10 mm [e.g., 4]. At these scales, the regolith structure is controlled by microimpacts. The uniform value of η corresponds to a saturation of the microimpact effect. Anomalies in η mean relatively recent local damage of the regolith structure.

For Apollo 15 landing site, the damage within the radius of 50-150 m around the landing site is probably caused by the lander jet.

For the fresh impact craters, we think about several agents causing the regolith structure damage. (1) Shock and/or seismic and/or sound waves from the impact could shake the regolith and change the fluffy structure. (2) Distal ejecta could be dense enough to influence the structure but too thin to mix the regolith and expose the immature material. In these cases the fresh craters without the anomalous halo exist because the time scale of establishing of the equilibrium structure is shorter than the time scale of regolith maturation and the time scale of crater form softening. (3) Gas that surrounds icy projectiles could affect the structure. Additional study is necessary to evaluate plausibility and/or importance of these factors.

Conclusion: Our results show that photometric studies of the lunar surface at 10-100 m resolution are of great interest. They can help, e.g., to study recent impactor population in the Solar System, or to search for sites of recent seismic activity in the lunar crust.

References: [1] McEwen A. et al. (1998) *LPS XXIX*, #1466. [2] Akimov L. A. (1988) *Kinematika i Fizika Nebesnykh Tel, 4*, 3-10 (in Russian) [3] Kreslavsky M. A. et al. (2000) *JGR 105*, 20281 - 20295 [4] Hapke B. (1993) Theory of reflectance and emittance spectroscopy, Cambridge Univ. Press, N.Y..

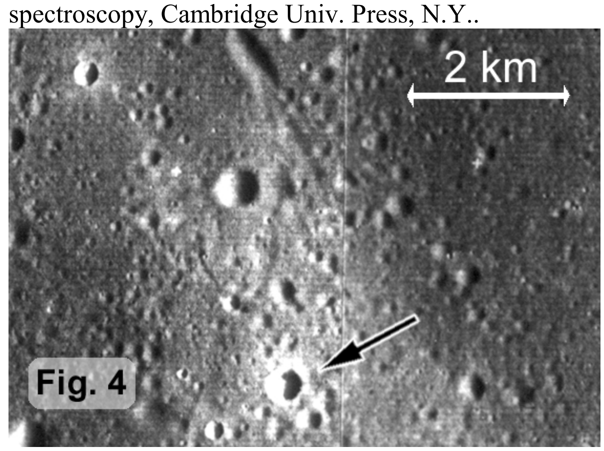


Fig. 4

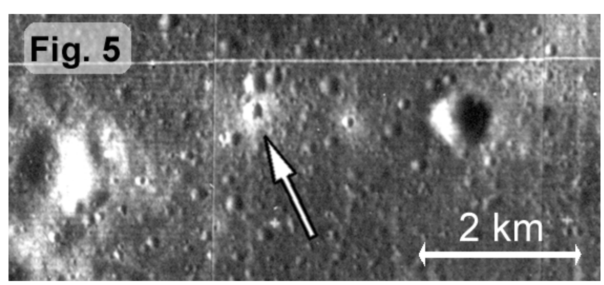


Fig. 5