UBIQUITY OF "ELEPHANT HIDE" TEXTURE ON THE MOON. *M. A Kreslavsky*[1], *N. V. Bondarenko*, and *J. W. Head*[2], [1]Earth and Planetary Sciences, University of California – Santa Cruz, Santa Cruz, CA, 95064, USA, mkreslav@ucsc.edu, [2]Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA.

Introduction: It has long been known that on the Moon regolith-covered slopes, both moderately steep and gentle, have a specific subtle decameter-scale texture dubbed "elephant hide" or "leathery" texture [e.g., 1 - 3] (Fig. 1). We prefer the descriptive term "elephant hide" texture (EHT), rather than the term "creeps" [3] which is genetic in nature and is not necessarily indicative of the nature of the process.

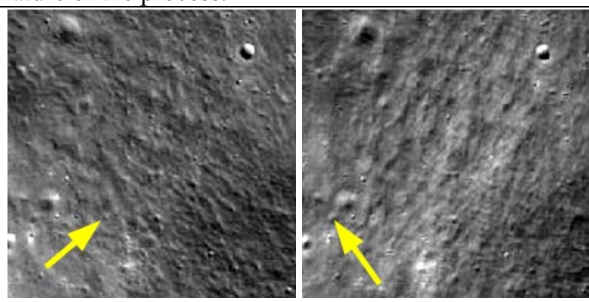

Fig. 1: Portions of two LROC NAC images of the same scene taken under different illumination directions (shown with yellow arrows). The scene is 1 km × 1 km. 52.9°N 179.4°E.

Detectability of EHT and its apparent anisotropy strongly depend on illumination geometry. At high sun and low phase angle EHT is usually invisible. Its appearance and apparent anisotropy change with the change of illumination direction (Fig. 1). It has been demonstrated [4,5] that oblique illumination can cause strong false visual impression of anisotropic, lineated surfaces, especially on the lunar regolith surface. EHT, however, is not a visual illusion: (1) in some places topographic variations related to EHT appear is high-resolution digital terrain models (DTM) derived from stereo pairs; (2) we studied several stereopairs in a stereoscope and ensured that there was discernable topography associated with the EHT; (3) in a few test sites, photoclinometric topography reconstruction from three images taken at different illumination directions [6] reveals EHT-related topography. Thus, EHT is certainly not a purely observational artifact, there is a true topographic texture at the surface, however, its appearance in the images is strongly affected by oblique illumination. This makes EHT difficult to analyze and explains the lack of systematic studies. The only such study we are aware of is [3], where it is shown that EHT is ubiquitous and occurs on all surveyed slopes down to ~5° steepness. The EHT formation mechanism is essentially unknown. Here we present our preliminary observations regarding EHT ubiquity and occurrence and briefly discuss constraints on possible EHT formation mechanisms.

Observations: We applied a Monte-Carlo-style approach to study occurrence of EHT in 3 latitudinal zones (60°S – 50°S, 5°S – 5°N, 50°N – 60°N) on the lunar far side using LROC NAC images [7]. Such an approach enables robust statistical treatment of EHT occurrence not biased by systematic variations in illumination conditions in the images. Within each latitudinal zone we calculated topographic slopes at 0.5 km baseline and curvatures at 1 km baseline using the GLD100 topographic data set [8]. We randomly selected 500 image samples (3 km × 3 km) in each zone from nadir-looking images with better than 3 m/pix sampling so that (1) slopes at sample centers are uniformly distributed between 2° and 22°, (2) local curvature is not too high (to exclude strong variations of slopes in the sample) and (3) local incidence angle (accounting for the local slope) in the center is 75° – 77°. The latter factor ensures that there is no bias in EHT identification due to different illumination conditions. Image samples were extracted by an automated computer procedure, which projected them into local equirectangular projection with 3 m/pix sampling, rotated them so that illumination direction was the same, and put them in a random order. One of us (MAK) screened the whole set of 1500 sample images not knowing slope and latitude of each scene (to avoid biases) and noted whether EHT in the central part of the sample (1 km in diameter) is present, absent, or uncertain. The latter category included scenes where slope was apparently non-uniform in the 1-km central part of the scene and/or EHT was patchy. 120 samples were excluded because their center happened to be in shadow.

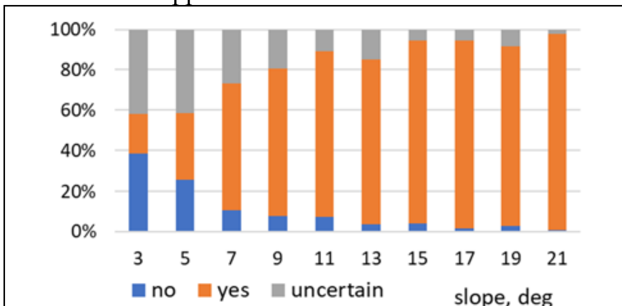

Fig. 2: Percentage of image samples with and without EHT as a function of slope

We find no differences between the latitudinal zones (within Poissonian 90%-confidence intervals for EHT occurrence percentage). Fig. 2 shows the distribution of outcomes with respect to slopes. It is seen that the majority of slopes steeper than 6° – 8° are covered with EHT. We individually checked the context and topography for all 39 cases where slopes are steeper than 8° and no EHT was noted. In 11 cases slope measurement are inadequate. 12 cases were related to distinctively young terrains: Copernican-age large craters and their ejecta, as well as extremely young small craters and their ejecta. In the remaining 16 cases (2%) the regolith seems thick and undisturbed, however EHT is either absent or extremely weak. 7 such cases are close to each other: they are on ejecta of the large Imbrian crater Compton. Another cluster of 3 cases is close to the farside center. In both regions steeper slopes still have EHT, however on 8 – 16° slopes it is absent or has an extremely low amplitude. Thus, EHT occurrence is not perfectly uniform.

Our analysis does not provide reliable information about EHT occurrence at slopes gentler than ~8°: the actual resolution and quality of the GLD100 topographic data is inadequate for the majority of scenes with gentle slopes. Not surprisingly we see a higher percentage of samples without EHT; however, details, for example, the onset slope and its possible variations, cannot be studied with this technique.

Possible formation mechanism: Association of EHT with slopes suggests that its formation is related to downslope regolith transport. In [1, 3, 9] EHT was attributed to downslope creep of the regolith without further explanation. However, regolith creep caused by micrometeoritic impacts and other minor surface disturbances is well described by topographic diffusion [10,11], a mathematical model in which time-averaged downhill material flux depends only on local slope. Simple theoretical analysis shows that topographic diffusion cannot generate any textures, even if the diffusion is non-linear (the diffusivity increases with the slope). Inclusion of non-local effects in the transport of regolith can in principle lead to formation of textures. We carried out a linear stability analysis of a mathematical model of a non-local regolith transport process in a rather general formulation [12] (to be described in detail elsewhere). We showed that spontaneous texture initiation in such models can occur only under unrealistic conditions. Non-local regolith transport can often be considered as anomalous diffusion [12]; it smoothens down all concave and convex topographic forms and does not generate any topographic textures.

Observations unambiguously show that decameter-scale craters are subdued and obliterated by regolith transport, which indicates that regolith creep indeed operates as (anomalous) topographic diffusion. Any EHT-forming decameter-scale topographic features would be subdued and obliterated at the same time scale as the decameter-scale craters. The observed ubiquity of EHT, therefore, indicates that some other process systematically generates the texture at rates sufficient to overcome the smoothing effect of topographic diffusion. The nature of this process remains unknown.

Attribution of EHT to regolith creep in [1,3,10] is likely intuitively based on visual impressions from landslides and earth flows in terrestrial environment that indeed produce rather chaotic decameter-scale textures. Such terrestrial processes, however, are not related to creep; they essentially involve detachment and slip at decameters-scale depth due to saturation of pore space with water, a process not possible on the Moon.

Seismic shaking has been suggested [2] as an EHT-producing factor without further explanations. From everyday life experience and from laboratory studies [13] it is known that shaking of granular materials indeed produces textures at their free surfaces; however, more detailed consideration shows that such textures are produced either by kinds of standing waves that can only occur in confined settings, or under external shaking with well-defined frequency [13]. Seismic shaking has a wide frequency spectrum and lunar regolith is not confined in the horizontal direction; therefore, texture formation due to shaking itself seems unlikely. In addition, shaking itself does not explain the absence of EHT on horizontal surfaces. Seismically-induced regolith slides are inconsistent with EHT morphology and ubiquity. In [14] some geologically recent regolith flow has been attributed to seismic triggering; its morphology has nothing common with EHT. Thus, although the potential role of seismic shaking cannot be completely excluded, the specific EHT formation mechanism remains unknown.

Lunokhod-2 rover traversed slopes (up to ~20°steep) with very well developed EHT. Measurements of regolith bearing capacity showed that the regolith on the slopes is weaker in comparison to horizontal EHT-free mare surfaces [15]. This observation may be relevant to understanding EHT formation.

Conclusions: The EHT formation mechanism is essentially unknown. Further observations of EHT characteristics and occurrence may provide hints as to the nature of EHT-forming processes. We plan to consider theoretically two types of physical processes as possible candidates: (1) highly non-local mechanisms of regolith transport possibly including particle sorting; (2) acoustic effects of impacts (sound frequencies 100s Hz – 10s kHz, that is acoustic wavelengths comparable or shorter than the regolith thickness) that might mobilize regolith at its base.

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