EJECTA "WIND" FROM THE LUNAR CRATER TYCHO. V. Korokhin[1], Y. Shkuratov[1], A. Basilevsky[2], V. Kaydash[1], G. Marchenko[1], U. Mall[3], and G. Videen[4]; [1]Institute of Astronomy, V. N. Karazin Kharkiv National University, 35 Sumska St, Kharkiv, 61022, Ukraine, [2]V. I. Vernadsky Institute, Russian Academy of Science, Moscow 117975, Russia, [3]Max Planck Institute for Solar System Research, 37077 Göttingen, Germany, [4]Space Science Institute, 4750 Walnut St. Suite 205, Boulder CO 80301, USA.

Introduction: Crater Tycho is a young (~100 Ma, [e.g., 1]) lunar crater with a prominent system of light rays extending for thousands of kilometers. The rays are believed to be produced by ejecta from the crater [e.g., 2]. Lunar orbital missions provide multispectral, high-resolution data that may be used to determine the characteristics and, thus, the origin of the rays. We use LROC WAC and other data to study an area related to Tycho's ray system. It is 68.2 x 65.6 km, located in Oceanus Procellarum at a distance ~1000 km from Tycho and includes the old crater Lubiniezky E almost fully flooded by mare lava (Fig. 1). The scene center coordinates are 27.48°S, 15.83°W. A brightness WAC image of the area under study is shown in Fig. 2a, revealing NW-trending rays from Tycho. They resemble traces of aeolian transportation and deposition, which are characteristic of Mars and Venus, but the Moon has no atmosphere. So we study the "wind" traces in detail.

Source data: In [3] we have proposed a new technique to construct seamless mosaics of the lunar surface using LROC WAC images [4]. For instance, the normal albedo A_0 map at $\lambda = 415$ nm shown in Fig. 2 was calculated with the technique [3]. This allows a more reliable prognosis of TiO_2 abundance in the regolith using the Lucey's method [5]. A map of the TiO_2 content for the studied area is presented in Fig. 3a.

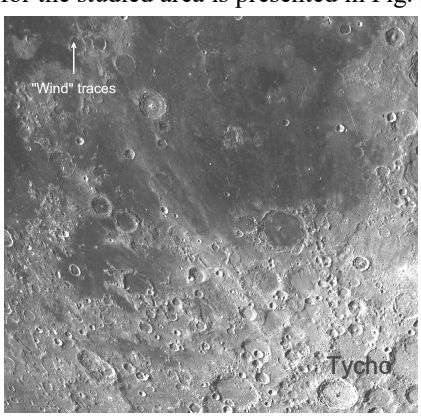

Figure 1. The crater Tycho and area under study; the image is adopted from http://target.lroc.asu.edu/q3/

We constructed a topography map with elevations using SLDEM2015 data [6] (Fig. 2b) to compare with the albedo distribution. We exploited also Clementine UVVIS data to retrieve FeO (Fig. 3b) and maturity degree (Fig. 4a) maps [7]. The latter was constructed with the calibration published in [8]. Applying the approach presented in [3], we calculated the parameter of the slope η of the approximating phase function $f(\alpha)=A_0\exp(-\eta\alpha^{0.6})$ [3,9,10]. Due to multiple light scattering in the lunar regolith, the slope inversely correlates with albedo; deviations from the correlation characterize optical roughness variations [9-11].

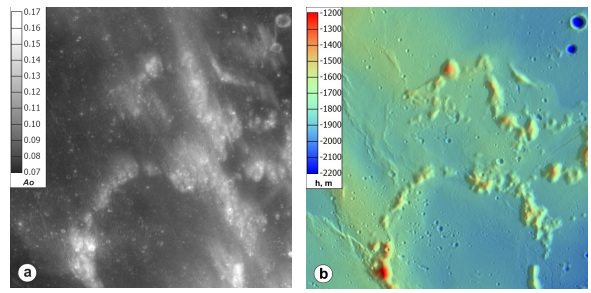

Figure 2. (a): the A_0-map at λ = 415 nm and (b): topomap

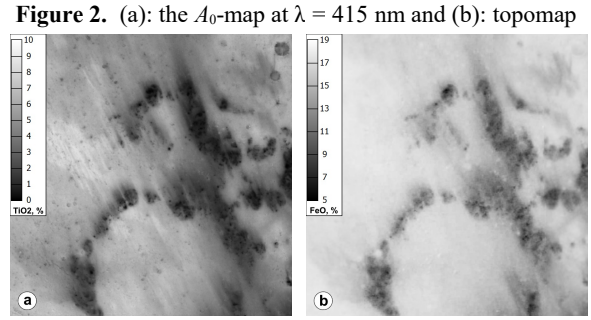

Figure 3. (a): the TiO_2 (LROC WAC) and (b): FeO (Clementine UVVIS) abundance maps

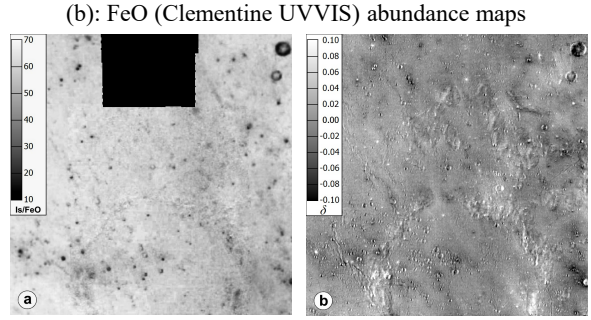

Figure 4. (a): maps of maturity degree I_s/FeO and (b): the optical roughness

Description: Comparing Figs. 2a and b, one can see that a portion of the bright features seen in Fig. 2a represents knobs that are protrusions of parts of the flooded crater Lubiniezky E, while other bright fea-

tures are rays of Tycho. Figs. 3a and b are maps of TiO_2 and FeO, which show that the surface of the knobs is significantly depleted in these components suggesting that the knobs are composed from the highland material.

There are important differences between the TiO_2 and FeO distributions. The first one reveals low and high titanium abundance in the streaks trending NW. It is seen in Fig. 2a that the low TiO_2 contents are associated with the knobs and also extend to the NW (dark streaks) by distances up to a few km, while no extensions are observed towards other directions. Similar occurrences, although not so prominent, are seen in the FeO distribution. High titanium (bright in Fig. 3a) streaks, also of NW trending, are seen on the mare surface in the center-left of the image. There are no mare FeO-abundant streaks. The described occurrences can be interpreted that the upper part of reduced TiO_2 and FeO highland material of the knobs was mobilized and partly moved for some distance to the NW. Meanwhile in the mare surface within the observed brighter streaks (Fig.3a), the TiO_2 content increased, probably due to removing the very upper part of the surface layer and outcropping material more rich in this component.

The regolith maturity degree within the studied area (Fig. 4a) is almost without variations, except within the inner slopes of small craters. Comparisons of the map of the maturity degree I_s/FeO distribution (Fig. 4a) with the albedo and TiO_2 (Figs. 2a, 3a) maps suggest no correlation, which means that all the described features are old enough to reach the same level of maturity degree I_s/FeO, as their surroundings.

The distribution of optical roughness is shown in Fig. 4b. This was obtained from the correlation between η and A_0, which has the following regression equation $\eta = -1.97A_0 + 1.28$ and correlation coefficient -0.80. The deviation from the regression line does not appear abnormal. Darker tones in Fig. 4b correspond to areas with smoother structure on the scale of 100 μm – 1 cm [11]. In particular, we may see that optical roughness is low for the mentioned knobs tails.

Discussion: The described spatial distribution of TiO_2 and FeO content can be interpreted as indications of some process of directional surface erosion and deposition, which resulted in features resembling directional eolian erosion and deposition. But on the Moon there is no atmosphere and the question is what phenomenon could play the role of wind.

We think that such erosion and deposition could be caused in this case by the fine fraction of ejecta from crater Tycho. The Apollo 12 astronauts sampled a thin layer of fines consisting of pieces of light-gray glass in a small trench (Fig. 5). This area is within one of the light rays of the 93-km crater Copernicus and the sampled material is considered to be a fine fraction of ejecta from this crater [12]. Crater Copernicus is at a distance of 400 km from this place and to arrive here, the ejecta should have a velocity of 0.7-0.9 km/s [13]. Suspension of such fines reaching the surface with such high velocity could mobilize and erode some part of the surface layer, moving it down-range where it would be deposited.

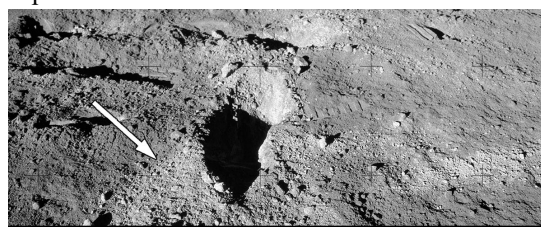

Figure 5. Trench at the Apollo 12 site in which a sample of Copernicus ejecta was taken. Arrow points to the lighter soil excavated from the trench. Part of image AS12-48-7052

The considered region in Oceanus Procellarum, having rays from crater Tycho located a distance ~1000 km, would necessitate ejecta arriving with a velocity of 1.1 to 1.3 km/s [13]. Suspension of the Tycho ejecta fines similar to sample 12033 could cause the directional surface erosion and deposition leading to the described situation.

Conclusions: The observed spatial distribution of the TiO_2 and FeO contents in the crater Lubiniezky E may be due to ballistical erosion/sedimentation caused by fine fraction of ejecta from crater Tycho. While these ejecta "wind" traces are observed in other places of the Moon, this phenomenon is not typical, since ejecta trajectories that may produce such traces should strike the surface at sufficiently grazing angles.

References: [1] Hiesinger H. (2012) *JGR (Planets) 117*. [2] Hawke B. Ray et al. (2004) *Icarus 170*, 1–16. [3] Korokhin V. et al. (2016) *PSS*, *122,* 70-87. [4] Robinson M. et al. (2010) *Space Sci. Rev.*, *150*, 81–124. [5] Lucey P. et al (1998) *JGR, 103,* 3701–3708. [6] Barker M. et al. (2016) *Icarus*, *273*, 346–355. [7] Lucey, P.G., (2004) *GRL 31 (8)*, L08701. [8] Pieters, C et al (2006) *Icarus* 184, 83–101. [9] Shkuratov Y. et al. (2011) *PSS, 59,* 1326–1371. [10] Shkuratov Y. et al. (2016) *Icarus* 272, 125–139. [11] Kaydash V. (2012) *JQSRT, 113*, 2601–2607. [12] http://www.lpi.usra.edu/lunar/samples/atlas/compendium/12033.pdf. [13] Melosh J. (1989) *Impact cratering: a geologic process*. Oxford Univ. Press NY.