SECONDARIES OF LUNAR CRATER TYCHO: DEPENDENCE OF THEIR MORPHOMETRIC CHARACTERISTICS V.S. DIAMETERS. A.T. Basilevsky[1], N.A. Kozlova[2] and B.A. Ivanov[3], [1] Vernadsky Institute, RAS, Kosygin Str. 19, 119991, Moscow, Russia, [2]Moscow State University of Geodesy and Cartography (MIIGAiK), 105064, Moscow, Russia, [3]Institute for Dynamics of Geospheres, RAS, Moscow, 117939.

Introduction: Although processes of formation and evolution of small impact craters of the Moon are generally well known [e.g., 1-5], there are topics in this problem, which need additional studies and secondary craters formed by impacts of ejecta of the primary craters provide for that useful opportunity.

Description of the data: Here we consider two groups of secondaries of the 85-km lunar crater Tycho which age is 109 ± 4 Ma [6], so this is the age of its secondaries. One group of 8 craters with diameters from 240 to 670 m, located on the mare floor of Taurus-Littrov Valley, and another group of 4 craters of 1000 to 1400 m in diameter, located in Mare Nectaris, both considered to be secondaries of Tycho [7,8,9]. The first group is ~2250 km and the second one is ~1450 km from Tycho so the velocities of the secondary-forming impacts for the angle of ejection from 45 to 15^{o} were correspondingly 1.45–1.55 and 1.3-1.4 km/s [5, formula 6.13]. These values are significantly lower than a typical velocity of primary meteoritic impacts on the Moon, 17.5 km/c [10], that should affect the initial geometry of these craters. As it was shown in several works [see e.g., 11,12] secondary craters typically are shallower than the primary craters of the same size.

For the considered 12 craters there were measured relative depth (*d/D*) and maximum angle of inner crater slopes (*Slope*, degrees). Data for and technique of these measurements are described in [13,14,15] and their results are presented in Figs. 1, 2 and 3.

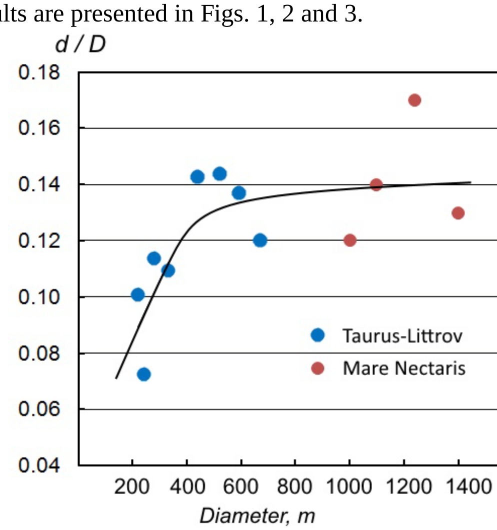

Fig. 1. Relative depth of the considered secondaries as a function of their diameter.

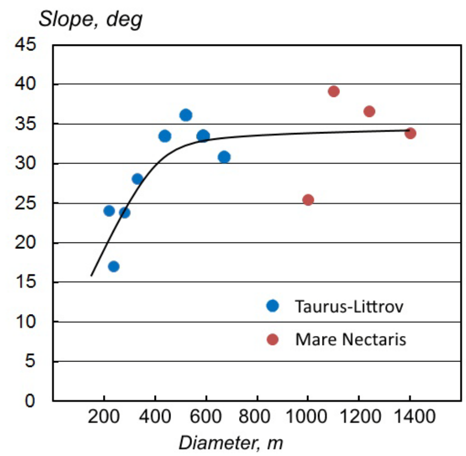

Fig. 2. Maximum angle of the inner slopes of the considered secondaries as a function of their diameter.

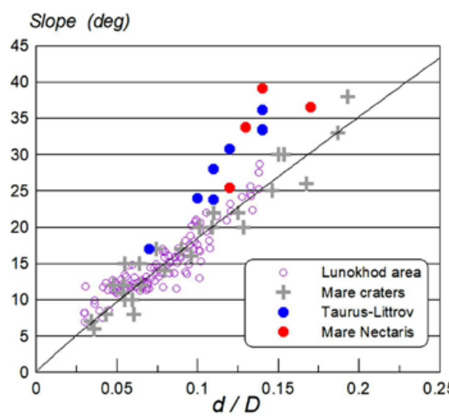

Fig. 3. Maximum *Slopes* vs. *d/D* of the considered secondaries in comparison with primary craters [16,17]. The approximating curve for primary craters after [17].

Data analysis: Three major features are seen in Figures 1, 2 and 3: 1) Along with the craters' diameter increase the crater's relative depth and maximum angle of their inner slopes increase; 2) For individual secondary craters the deviations of the considered parameters from the trend curves are rather large. 3) The *Slope* v.s. *d/D* dependence for the considered secondaries differs from that for the primary craters.

1) Assuming that within the considered diameters' range craters at the moment of their formation have similar *d/D* and maximum *Slope*, increase of these parameters along the *D* increase means that for the time of existence of the considered secondaries (~100 Ma), smaller craters made the larger portions of their potential lifetime com-

paring to those of the larger craters. For craters ~200-400 m in diameter the averaging trends of the d/D(D) and Slope(D) are close to linear. Then from ~ 400 to 700-800 m they bend to curves. And for the larger craters they again become close to linear but with the smaller slope.

These changes are probably due to changes in relative roles of the two major mechanisms of the crater degradation with time: One is the gravity-driven down-slope material movement: collapses and landslides when the slope angle is 20 to 40^o, and creep on the slopes of 10 to 20^o steep [e.g., 3, 18]. And another one is represented by the lateral redistribution of ejecta from small craters. This second mechanism became obvious in observations of the Apollo-15 and Lunokhod-2 close to edges of the Rima Hadley lava channel [19] and Fossa Recta graben [20]. It was noticed that at the distance of several tens of meters from the edge of the channel / graben the mare surface became inclined towards the depression, and the depression edge represents outcrop of the subregolith bedrock. It was concluded that from this "boundary" slope area small impacts eject the surface material both outward of depression and into it, but influx of the material into this area is mostly from the outward area and in very decreased degree from the depression. So this boundary area is a sourse of the material moving into depression.

Impact craters are depressions at which rims should be similar boundary segments serving as providers of the surface material into the crater depressions. Width of these segments and their productivity as a sourse of material filling the crater should be the same for craters of any size. So this mechanism should work more effectively for small craters and less effectively for the larger ones.

2) The data scatter seen in Figures 1 and 2 demonstrates that the local surface geometry and target mechanical properties may considerately affect the initial crater morphology and the crater degradation rate.

3) It is seen in Figure 3 that for the *d/D* >0.1, the secondary craters comparing to the primary ones have the steeper *Slope* v.s. *d/D* trend. This means that the new-formed secondaries are shallower than the new-formed primaries (agrees with [11, 12]) but steepnesses of the slopes of these two classes of the craters are similar. For the *d/D* values ≤0.1 these parameters become similar.

Discussion: The rolldown of curves at Figs. 1 and 2 could be considered from more general position. Following the model logic by M. Kreslavsky [13] we use the empirical curve for the crater slope decrease with the model time. The model includes an unknown (in this model) parameter – the dependence of a crater life time on its diameter. Assumong the direct proportionality of the life time to the crater diameter, and using as a proxy the slope/model time dependence for primary craters [16, 17] we can predict how the slope angle should decreases during the 100 Myr for various crater diameters (Fig. 4).

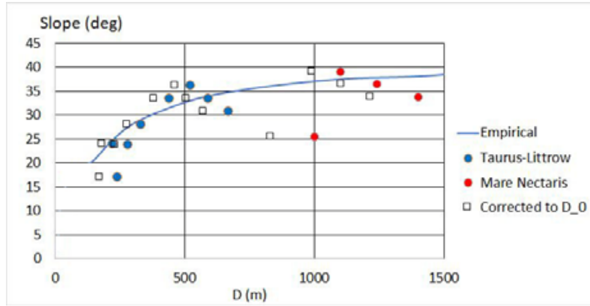

Fig. 4. The empirical model prediction of slopes for secondary craters, formed ~100 Ma ago. The normalized time to reach 11^o (approximately *d/D*=0.06 [17]) is assumed constant T_{11deg}/D = 5 Myr m^{-1}. Open symbols – same craters corrected for the crater widening after [17].

Fig. 4 demonstrates how the rolldown of curves at Figs. 1 and 2 could be mainly explained with a complex dependence of the degradation rate with the degradation level. Previously it was qualitatively demonstrated in [14] with a "sandblasting" diffusion model.

Conclusions: The above consideration shows some quantitative trends of the small craters degradation with time and allowed to suggest explanations for these phenomena.

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References: [1] Trask N. (1971) *USGS Prof. Paper 750D*. Washington, D.C., D138-D144. [2] Florensky C.P. et al. (1972) In: *Modern Concepts on the Moon*, Moscow, Nauka, 21-45 (in Russian). [3] Schultz P. H. (1976), *Moon Morphology*, Univ. of Texas Press, Austin, TX. 604 p., [4] Basilevsky A.T. (1976) *Proc. LPSC-7,* 1005-1020. [5] Melosh H.J. (1989). *Impact cratering: A geologic process.* Oxford Univ. Press. NY, 253 p. [6] Stoffler D. and Ryder G. (2001) *Space Sci. Rev. 96***.** 9-54. [7] Muehlberger W.R. et al. (1973) *Apollo 17 Prelim. Sci. Report. NASA SP- 330,* Washington, D.C., 6-1–6-91. [8] Lucchitta B.K. (1977) *Icarus, 30,* 80–96. [9] Hawke B.R. et al. (2004) *Icarus, 170,* 1-16. [10] Ivanov B.A., Hartmann W.K. (2007) In *Treatise on Geophysics, 10, Elsevier,* 207-242. [11] Pike R.J., Wilhelms D.E. (1978) *Lunar Planet. Sci.IX,* 907-909. [12] McEwen A.S., Bierhaus E.B. (2006) *Annu. Rev. Earth Planet. Sci. 34,* 535-567.[13] Kozlova N. et al. (2015) *The 6th Moscow Solar System Symposium, abs.6MS3-MN-04*. [14] Basilevsky A.T. et al. (2018) *PSS,* 1-10 (in press). [15] Basilevsky A.T. et al. (2018) *PSS*, submitted. [16] Basilevsky et al. (2014) *PSS, 92,* 77-87. [17] Ivanov B.A (2018) *Solar Sys. Res*., 52(1), 1-25. [18] Florensky C.P. et al. (1977) *Soviet-American Conference on Cosmochemistry of the Moon and Planets, NASA-SP-370*. 571-584. [19] Swann G.A. et al. (1972) *Prelim. Geol. Investigation of the Apollo-15 Landing Site, NASA-SP-289*. 5-1-5-112. [20] Basilevsky et al. (1977) *The Moon, 17.* 19-28.