MORPHOMETRY OF LARGE CRATERS ON PHOBOS AND COMPARISON WITH OTHER BODIES.

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A few large craters on Phobos are anomalously deep in comparison to other small bodies and lunar highlands.

Introduction: Impact craters are widely used in planetary science to deduce valuable knowledge about Solar system bodies, their evolution, and surface processes. The first morphometric study of craters on Phobos [1] with images taken almost half a century ago had revealed unusually high depth (d) to diameter (D) ratios, up to $d/D = 0.24$ for some large craters. Here we take advantage of a modern high-resolution digital terrain model (DTM) of Phobos and confirm the presence of unusually deep large ($D \geq 2$ km) craters on Phobos.

Data: *Phobos.* We use a new Phobos DTM [2], produced based on new control point network [3] from photogrammetric processing of 176 images obtained by SRC camera onboard Mars Express. The effective spatial resolution of this DTM is typically 50-100 m, which allows detailed morphometry of craters larger than 1-2 km. Our GIS-based catalog of impact craters on Phobos (http://cartsrv.mexlab.ru/geoportal/) [4] contains 25 craters of $D \geq 2$ km; we exclude the unusually large Stickney and work with 24 craters. The largest crater in this population, Gulliver, has $D = 6.7$ km.

For morphometric measurements we need to know elevation differences between surface points. Unlike the planetary bodies, it is not readily evident, how to define elevation on small bodies. Here we use two kinds of "elevation". One is *geometric elevation*; it is a distance from the surface point to a reference surface along the normal to that surface. The reference surface was defined as shifted (with respect to the center of mass) triaxial ellipsoid that gives the best fit to our DTM [5]. Another one is *dynamic elevation*, which can be thought about as elevation above the geoid along local vertical; more accurately, it is the effective gravitational potential of the surface point divided by the mean surface gravity potential [6]. The effective potential is calculated as a sum of gravitational potential of a homogeneous body with the shape described by our DTM and the known mass, the centrifugal potential, and the martian tidal [7].

Moon. Classic works on lunar crater morphometry have mostly been done with mare craters, while obviously, highlands are more adequate for comparison with Phobos. We considered 38 craters with $D = 1.7$ - 10 km in a typical Nectarian-age farside highland area at 10ºN 160ºW. Selected craters span a wide range of preservation state. The craters were outlined with LROC WAC mosaic and elevations were taken from the DEM GLD100 produced from LROC WAC stereo images [8].

Eros. Depth and diameter of all 7 craters with $D = 1.7$ - 10 km on asteroid 433 Eros are taken from [9]. The depth of two largest craters has been measured with radar-altimeter-derived DEM; the other have been measured with photoclinometric method.

Results: *Crater depth*. Traditionally used morphometric parameter, crater depth d has been defined as elevation difference between the crater rim and the crater floor. For complex topography, where the rim and the floor do not have well-defined elevation, it is naturally to calculate d as elevation difference between the mean elevation of the rim and the lowest point inside the crater. This definition of d does not work well for both Phobos and lunar highlands: for 50% of Phobos craters and 68% of lunar highland craters, the lowest point of the crater is at the rim, and thus d does not characterize the actual crater depth at all. **Fig. 1a** shows the d – D scatter plot for the rest of the craters, where the lowest point somehow reflects the crater floor. The inclined line in Fig. 1a shows the classic [10] relationship $d / D = 0.20$ for *fresh* simple craters in lunar maria. Not surprisingly, our lunar craters fall well below this line, because there is no any really fresh crater in our population, although it is also possible that highlands craters are generally shallower than maria craters. Eros craters are also at or below this line, as discussed in [9]. Several Phobos craters, however, are above the line, that is deeper than their fresh lunar mare counterparts.

Mean crater depth. To remedy the situation with d, we introduce another measure to characterize crater depth, the mean crater depth d'. We calculate it as the difference between the mean elevation of the crater rim and the mean elevation of the crater as a whole. This works better; the resulting d' – D diagram in **Fig. 1b** is filled with shallow craters. Naturally, $d' < d$. For the craters in Fig. 1a, the ratio d' / d varies between 0.1 and 0.4 with the median about 0.30. To show Eros data on Fig. 1b, we arbitrarily assumed $d' = 0.30\, d$. For the shape of the fresh lunar mare craters we assume a bowl with a power-law profile and 35° maximum slope, which yields $d' = 0.47\, d = 0.093\, D$. Again, it is seen that several Phobos craters are significantly deeper than craters on Eros and lunar highlands and are close to the fresh lunar mare line.

Dynamic vs. geometric elevations. In **Fig. 2a** we compare the mean depth *d'* of Phobos craters calculated with dynamic and geometric elevations. With a single exception, the craters are the same or shallower with respect to the local vertical than with respect to the ellipsoid. This may indicate the role of gravity in crater degradation processes. **Fig. 2b** shows a similar diagram for the RMS variations *S* of elevation along rims. Unlike crater interiors, the rims do not tend to be smoother with respect to the vertical, and thus the trend in Fig. 2a is not a consequence of generally smoother dynamic topography.

Discussion: As we see in Fig.1**,** the clouds of relatively shallow, degraded craters on the lunar highlands, Eros and Phobos overlap well; typical depth of craters on other studied small bodies are similar [9]. Fig. 2 gives an indication that gravity plays a role in degradation of craters on Phobos, despite the fact that it is low.

However, the deepest craters on Phobos are noticeably deeper than craters on the lunar highlands and possibly on other small bodies. Four craters on Phobos (Hall, Reldresal, Todd and an unnamed crater) are anomalously deep, their depth reaching and exceeding that of fresh mare craters. Although morphologically these deepest craters are rather well preserved, they certainly do not show the crisp freshness of the lunar craters used to deduce the trend lines in Fig. 1.

A possible explanation for the anomaly is that Phobos is a coherent body, while the other studied small bodies are rubble piles. Therefore, on Phobos craters are excavated in purely strength regime with little subsequent modification due to weak gravity, while on other small bodies gravity significantly affects post-excavation modification of crater cavity, which produces shallower craters. On the Moon the craters of considered size are formed in purely gravity regime and also might be somewhat shallower than strength craters.

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