RARITY OF BOULDERS ON MERCURY: COMPARISON WITH THE MOON.
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Introduction: Boulders, meters-size blocks of solid rock, are seen in great numbers in high-resolution images of the Moon, Mars, and small bodies. The presence of boulders and their geological associations provide information about surface properties and modification processes on these planetary bodies. Here we report our preliminary results on boulder populations on Mercury and compare them to similar data analysis approaches on the Moon.

Survey: We visually surveyed images obtained by the Narrow Angle Camera (NAC) of the Mercury Dual Imaging System (MDIS) instrument [1] onboard the MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER) orbital mission to Mercury. We chose the highest resolution images (<2.5 m/pix sampling) acquired toward the end of the mission (Feb. – Apr. 2015). Individual images are small (0.25 Mpix), have a considerable amount of smear, low signal-to-noise ratio (because of the short exposures needed to keep smear reasonable), and do not overlap: the distance between them (~15 km) is much greater than the image size (~0.5 – 1 km). Such images cannot be used to produce mosaics, unlike the regular (10 – 20 m/pix) NAC operation regime. In a sense, the highest-resolution images are random samples of surface morphology. We screened ~3000 images, all images of the highest resolution and acceptable quality. These images are scattered in a region limited by 40 – 70°N and 210 – 320°E, which is occupied mostly by the intercrater plains. We noted all images in which we could identify individual boulders. Examples of MDIS images with boulders are shown in Fig. 1.

To compare the occurrence of boulders on Mercury with the Moon, we extracted similar random 0.25 Mpix samples from LROC NAC images [2] that have the same sampling, the same solar illumination incidence angle and are situated on highlands. Then we artificially degraded their quality by smearing (in the same direction with respect to the sun) and added noise to mimic MDIS NAC quality. Then we screened these image samples searching for boulders. Examples of degraded LROC images with identified boulders are shown in Fig. 2. So far, we have surveyed ~380 images.

Results: The majority of image samples on both bodies have no identifiable boulders. Boulders on both bodies often occur in clusters. Due to these two facts the mean boulder density (= the number of documented boulders / surveyed area) is not a good measure of the typical boulder abundance. The percentage of random image samples with boulders among the whole image set is a better characteristic of the boulder abundance. The table below shows that *boulders on Mercury are extremely rare in comparison to the Moon (~ 30× less)*. With the available images, it is impossible to distinguish between intact boulders and debris piles of disintegrated or partly disintegrated boulders, therefore such (partly) disintegrated boulders are included in our boulder count.

Planetary body	**Images total**	**Images with boulders**	**Percentage**
The Moon	379	54	14.3%
Mercury	2993	14	0.5%

Discussion: There are two principally different basic factors that can be responsible for very low boulder abundance on Mercury: (1) boulder production rate is lower, and (2) boulder obliteration rate is higher. We believe that both factors play a role, as discussed below, but in unknown proportion.

Boulder production rate is lower. On the Moon, excavation by meteoroid impacts is one of the sources of boulders. Fig. 1 suggests the same for Mercury: Fig. 1a is located on the floor of a large (~35 km) young crater. In Fig. 1b a boulder is associated with the rim of a small (~0.4 km) crater. The target material plays a significant role in boulder production: boulders are less abundant on lunar highlands than on maria [3] partly due to heavily fractured nature of the highland target material. On Mercury, the fractured nature of the heavily cratered intercrater plains may contribute to the lack of boulders, however, it hardly can be the only factor, because we observe a significant lack of boulders in comparison to highlands, a fractured target.

The surfaces of all large atmosphereless bodies are covered with loose, impact generated material, regolith. Indirect evidence suggests that the regolith on Mercury is thicker than on the Moon [4-6], which likely results from a higher micrometeoritic flux [7,8] and is consistent with a higher degradation rate of kilometers-size craters [9]. The smallest impact craters are made in the regolith and cannot produce boulders of this size. If the regolith is indeed thicker on Mercury, the smallest crater able to produce boulders would be larger. Since the crater formation rate on Mercury is on the same order of magnitude, the larger onset crater size means a lower boulder formation rate.

On the Moon, clusters of boulders are associated with hilltops and other convex relief forms. Apparently, diffusive transport moves lunar regolith from the hilltops exposing previously buried blocks and bedrock and thus producing boulders. We do not see examples of this kind in our Mercury boulder collection. The intercrater plains on Mercury are significantly smoother than the lunar highlands, therefore suitable hilltops may be less abundant and might not be sampled in our limited image set. Thus, the general smoothness of Mercury in comparison to the Moon [5, 10-12] may also contribute to a lower boulder production rate.

Boulder obliteration rate is higher. Boulders are destroyed by small meteoritic impacts, ground by micrometeoritic impacts [13], and cracked and disintegrated by thermal stresses [14]. The relative role of these processes is controversial. On the Moon the boulder survival time scale is ~ 100 Ma [13]. On Mercury the micrometeoritic flux is significantly higher than on the Moon [7,8], however, estimates of the ratio in these two papers are not consistent with each other. If micrometeoritic grinding is the dominant boulder obliteration mechanism, then the difference in the micrometeoritic flux is likely to be sufficient to account for the entire observed difference in boulder abundance.

Thermal stresses potentially responsible for boulder disintegration are proportional to the diurnal temperature amplitude [14], which is higher on Mercury due to its proximity to the Sun and longer days and nights. This difference could also contribute to a shorter boulder survival time and higher boulder obliteration rate on Mercury. Boulder material physical and chemical properties might also make boulders on Mercury more susceptible to micrometeorite grinding and/or thermal stresses.

Conclusions: Our analysis of boulder occurrence on Mercury is limited by quality and coverage of available high-resolution images. In particular, the images lack geological context: the resolution gap between the highest resolution image and the available lower-resolution context image is too wide, and the knowledge of camera attitude is insufficient to pinpoint location of the high-resolution sample. The forthcoming BepiColombo mission to Mercury [15] will provide such a context with SIMBIO-SYS/STC camera. The nominal highest resolution of BepiColombo images (~5 m/pix at low latitudes only with SIMBIO-SYS/HRIC camera) is only marginally suitable for studies of boulders. However, high image quality and wider coverage promise advances in understanding of their formation and degradation. In particular, if thermal stresses contribute significantly to boulder obliteration, an anticorrelation of boulder abundance with the "hot poles" of Mercury would be expected, and this could be tested with HRIC images. Observations from a lower orbit, beyond the nominal mission, would be extremely useful for boulder studies.

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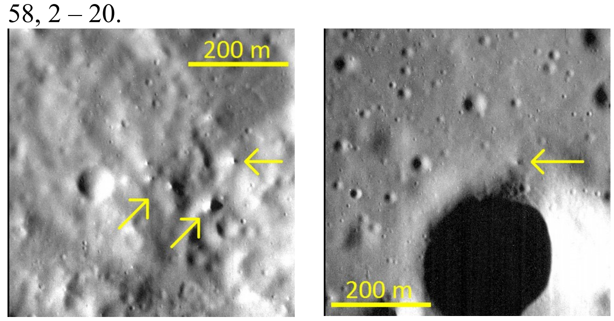
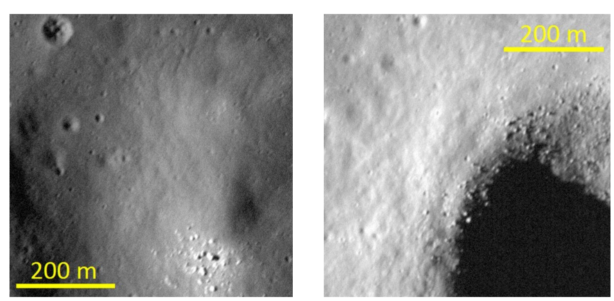


(a) CN1067123658M **(b)** CN1067302398M

Fig.1. Boulders on Mercury: (a) boulders on the floor of a young large (~35 km) crater; (b) one single boulder near the rim of small (~0.4 km) crater



(a) M1170070317LC **(b)** M1139300406RC

Fig.2. Boulders on the Moon: (a) cluster of boulders on a hilltop; (b) large accumulation of boulder on a crater rim