NEW MORPHOLOGICAL CATALOG OF MERCURY CRATERS

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The new Morphological catalog of Mercury craters was created at the Sternberg Astronomical Institute of Moscow State University in collaboration with Moscow State University of Geodesy and Cartography based on MESSENGER spacecraft data. This catalog includes information about coordinates, diameters, and morphology of 12365 craters with diameters ≥10 km. The catalog was created using data from the Mercury Crater Catalog prepared at Brown University (USA) and a global mosaic of Mercury's surface images from the MESSENGER spacecraft. Analysis of the new Morphological catalog showed that most Mercury craters with diameters ≥10 km have smoothed or partially destroyed rim crests and flat floors. The article provides a detailed description of the morphological features of Mercury craters. Table 1 shows the percentage ratio of craters with various features on Mercury and the Moon. It was found that there are significantly more well-preserved craters on the Moon than on Mercury. Most Mercury craters have terraces and slumps on their inner slopes (65%, unlike 7% of lunar craters). The relationship between craters of varying degrees of rim preservation, craters with terraces and slumps depending on their diameters is presented in detail.

Keywords: Mercury, catalog, craters, morphology

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INTRODUCTION

Images of Mercury's surface were obtained from two spacecraft: Mariner-10, which made three approaches to the planet during 1974-1975, and MESSENGER, which operated in Mercury's orbit from 2011 to 2015. As a result of the Mariner-10 mission, more than 2800 photographic images of the planet were obtained, and maps of 45% of its surface (western hemisphere) were created. Earlier studies comparing the morphology and shape of craters on Mercury and the Moon focused mainly on characteristics of the internal structure, such as central uplift, crater depth, rim height, terraces on the slopes (Head III, 1976; Oberbeck et al., 1977; Pike, 1988). One of the first catalogs of craters in the western hemisphere of Mercury based on Mariner-10 data was published in 1977 (Lipsky et al., 1977). In 2011, catalogs of craters covering the entire surface of Mercury were published (Fassett et al., 2011; Herrick et al., 2011). In each catalog, the authors typically used their own system of morphological parameters. The catalog created at the Geophysical Institute of the University of Alaska (Herrick et al., 2011; 2018) included the following morphological characteristics in addition to coordinates and crater dimensions.

1. Preservation state: fresh, standard, and degraded.
2. Rim and slope structure: circular, scalloped, presence of terraces.
3. Interior form: simple, flat-floored, presence of central peak, central ridge, multiple peaks, peak ring, proto-basin, and peak ring.
4. Ejecta: bright ray system, butterfly-wing ejecta, dark ejecta.
5. Additional features: elliptical shape, floor pits, depressions, bright deposits inside the crater, dark deposits inside the crater, shadowed part of the inner crater surface, pits on the central uplift, pits in the center of the floor, and other features.

In 2004, the Catalog of Mercury Craters (http://selena.sai.msu.ru/Kozl/Publications/Mercury/Hermes.xls) was created at the Sternberg Astronomical Institute of Moscow State University, which included information on coordinates, dimensions, and morphological descriptions for ~6500 craters with a diameter of ≥10 km. The Mercury Atlas (Davies, 1976) and the Topographic Map of Mercury at a scale of 1:5000000, compiled by the US Geological Survey using data from the Mariner-10 spacecraft, were used to create this catalog. As a result of this mission, about 45% of Mercury's entire surface was photographed, predominantly the western hemisphere. The morphological description of craters included: the degree of rim preservation, the presence of terraces and collapses on the inner slope, the presence of a central peak, pit, ridge on the floor, the presence of cracks and chains, the nature of the crater floor, the presence of lava on the floor, the presence of a ray system, and the character of the surrounding terrain (plain, elevation, or transition zone). The accuracy of crater diameter measurements was 2 km on average. Analysis of this catalog showed that the average crater density on the surface for the western hemisphere of Mercury is 193 per 1 million km^2, which is approximately half the average crater density on the Moon. It was noted that the largest number of craters on Mercury belongs to the 3rd and 4th preservation classes. The percentage of well-preserved craters on the Moon is higher than on Mercury (Sitnikov et al., 2004; Kozlova et al., 2005).

The MESSENGER (MErcury Surface, Space ENvironment, GEochemistry and Ranging) spacecraft was launched in 2004 in the USA. After three close encounters with the planet, the spacecraft reached Mercury's orbit, where it operated from March 2011 to April 2015. The main objectives of the mission were: determining the chemical and mineralogical composition of surface rocks, mapping the surface, studying the internal structure of Mercury, detailed studies of individual terrain features most important for understanding the history of the planet's geological development. During its operation, the spacecraft transmitted about 270 000 images of Mercury's surface to Earth, covering more than 99% of the planet's surface, including the eastern hemisphere, which was not photographed during the Mariner-10 spacecraft mission. The obtained images confirmed that almost the entire surface of the planet is covered with impact craters. The images had higher resolution and were taken under better lighting conditions than those delivered by Mariner-10, which allowed for improved description of crater morphology. MESSENGER spacecraft data were used to create the New Morphological Catalog of Mercury Craters.

CRATER MORPHOLOGY DESCRIPTION SYSTEM

The New Morphological Catalog of Mercury Craters (Catalog of Mercury Craters based on MESSENGER spacecraft data for the website.xlsx (live.com) , open access) contains morphological descriptions of 12,365 craters with diameters ≥10 km (Fig. 1). Data on coordinates and diameters of 8,775 craters with diameters >20 km were obtained from the Mercury Crater Catalog created at Brown University, USA (Fassett et al., 2011). Coordinates and diameters of the remaining 3,590 craters were obtained using a global mosaic of Mercury's surface images from the MESSENGER spacecraft: https://astrogeology.usgs.gov/search/map/Mercury/Messenger/Global/Mercury_MESSENGER_MDIS_Basemap_LOI_Mosaic_Global_166m with a resolution of 665 m/pixel and the first global digital terrain model of Mercury with a resolution of ~222 m/pixel (Johnson, Hauck, 2016). The positions and diameters of the craters were determined automatically using the ArcGIS package. The accuracy of determining the coordinates of these craters was 0.1°.

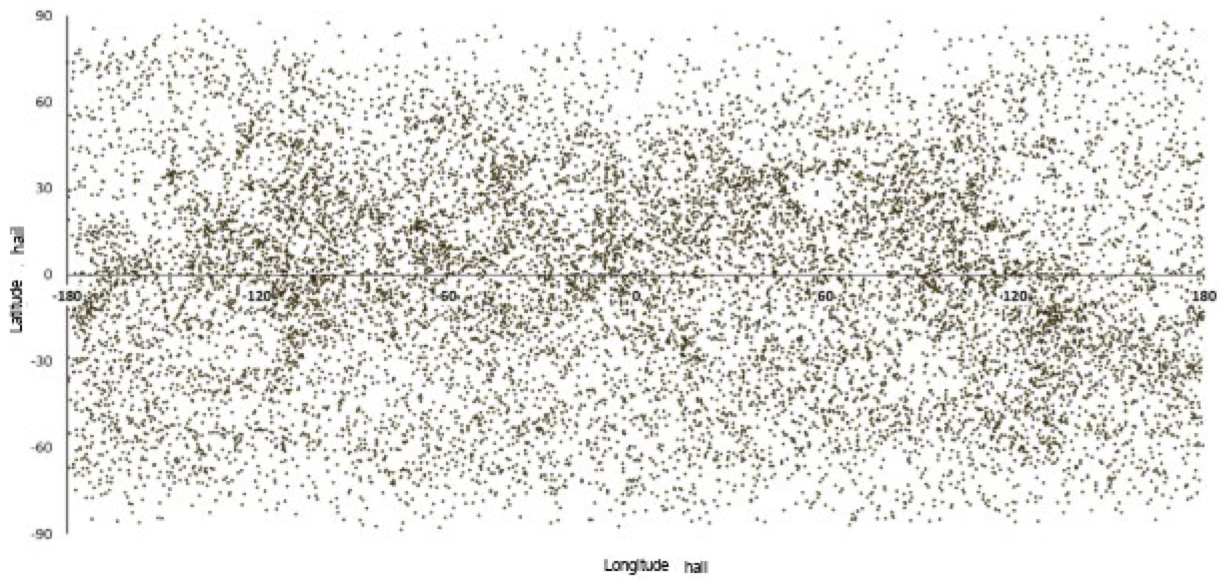


Fig. 1. Distribution of craters with $D \geq 10$ km included in the new Morphological catalog across Mercury's surface. The average density of craters with diameters ≥10 km on Mercury's surface is 165 craters per 1 million km^2.

When creating the new Morphological catalog of Mercury craters based on MESSENGER spacecraft data, a crater morphology description system developed at SAI MSU was used. This system, with some variations, was previously used to create morphological catalogs of craters on the Moon (Rodionova et al., 1987), Mars (Rodionova et al., 2000), and Mercury (Sitnikov et al., 2004). To describe the morphology of craters, 10 morphological features were used: 1) clarity or degree of preservation of the rim; 2) presence of terraces and collapses on the inner slopes of craters; 3) presence and character of the crater rim; 4) presence of hills, peaks, central and ring ridges on the crater floor; 5) presence of chains of small craters and cracks on the floor; 6) character of the crater floor; 7) presence of lava on the floor; 8) presence of a ray system; 9) character of the underlying surface; 10) peculiarities of craters. Each feature included a number of sub-features (Table 1).

Figure 2 shows the distribution scheme of well-preserved Mercury craters of the 1st and 2nd preservation classes. The distribution density of these craters is lower than that of craters of the 3rd and 4th preservation classes, shown in Figure 3. The density of craters of the 1st and 2nd preservation classes is 28.8 craters per 1 million km^2. The density of craters of the 3rd and 4th preservation classes is 113 craters per 1 million km^2.

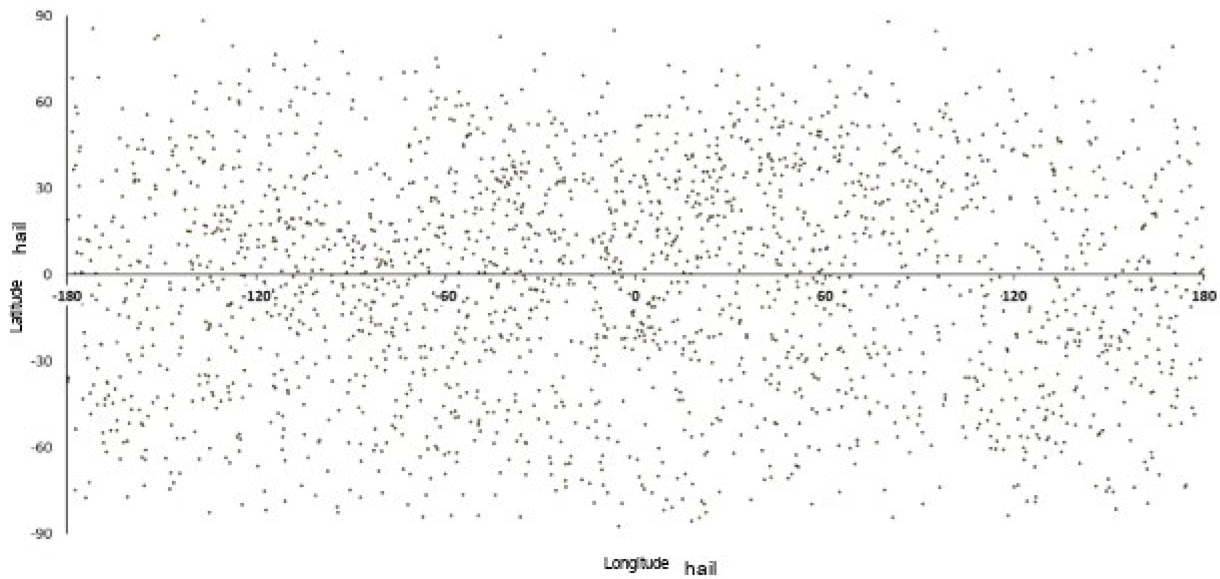


Fig. 2. Distribution of craters of the 1st and 2nd preservation classes on the surface of Mercury.

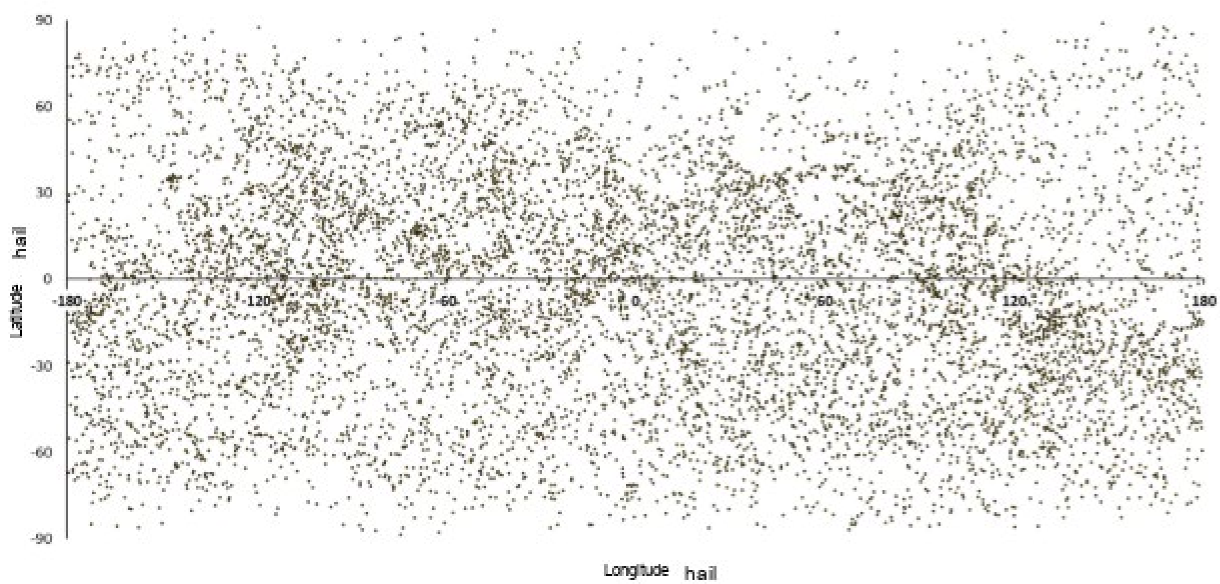


Fig. 3. Distribution of craters of the 3rd and 4th preservation classes on the surface of Mercury.

Three types of surface are present on Mercury: plains, highlands, and intercrater plains. In the work (Leake, 1982), the similarity between the intercrater plains of Mercury and the transition zone between highlands and maria on the Moon is shown. Therefore, in the Morphological catalog, we used the term "transition zone" to denote the intercrater plains of Mercury. The transition zone is widespread on Mercury, unlike on the Moon.

When creating the catalog, the CraterTools module of the ArcGIS package was used (Kneissl et al., 2011). To more accurately localize craters and outline their edges, as well as better examine their internal structure, an additional layer was used – a hillshade, built on the basis of a digital elevation model (DEM). Digitization of craters was carried out by sectors. The number of craters varies in sectors due to different crater densities. For example, in the territory of sheet H-9, more than 390 craters were digitized, and on H-2 – about 210. As a result, unlike the catalog (Fassett et al., 2017), the new Morphological catalog significantly supplemented craters with diameters from 10 to 20 km.

The craters of the new catalog were divided into five classes depending on their degree of preservation. Craters with a sharply defined rim were classified as 1st class preservation craters (Fig. 4); craters with a clear rim were classified as 2nd class; 3rd class craters had a smoothed rim and flat bottom; 4th class included craters with a destroyed rim, and 5th class – crater ruins. This division by preservation classes is largely similar to that used in the work (Wood et al., 1977), which examined the morphology of 537 Mercury craters with diameters ≥30 km. The freshest well-preserved craters were classified in the work (Wood et al., 1977) as 1st class preservation, the most destroyed – as 5th class. In the morphological description of craters in the new catalog, a feature such as the character of the crater rim was added. This is due to the fact that many craters on Mercury have a powerful outer rim. Also, a tenth feature – "peculiarities" – was added to the description of crater morphology, including the presence of dark material inside or dark halo around the crater (Fig. 5); presence of pits in the crater; intersection of the crater by an escarpment; elliptical shape of the crater; presence of a ring ridge. In addition to data on crater morphology, the catalog contains information about their depth. To determine the depth of craters, data from the MLA height altimeter of the MESSENGER spacecraft were used (Feoktistova et al., 2021).

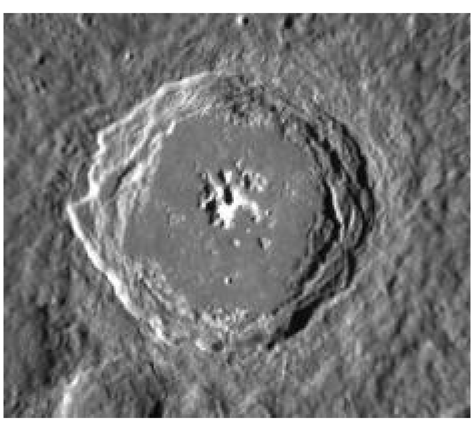


Fig. 4. Balzac crater (10.6° N; 144.7° W) of 1st class preservation (image obtained by MESSENGER spacecraft https://messenger.jhuapl.edu/Explore/Images.html#of-mercury).

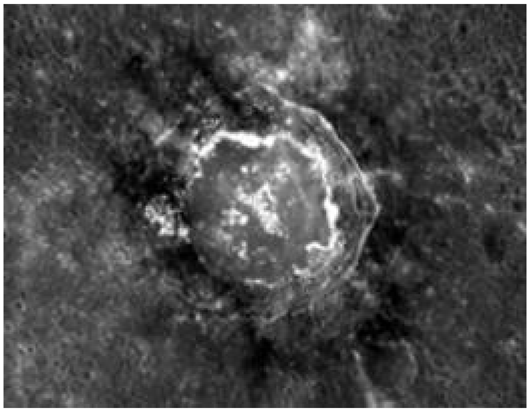
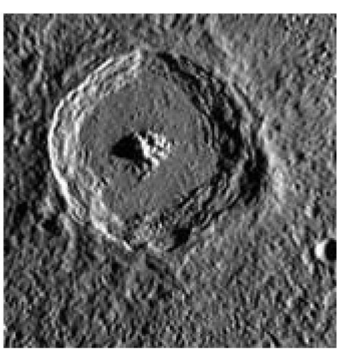


Fig. 5. Suess crater (7.7° N; 33.2° W) with dark halo (image obtained by MESSENGER spacecraft https://messenger.jhuapl.edu/Explore/Images.html#of-mercury).

Table 1. System of Morphological Description of Craters

Morphological Features	Designation	Semantic Meaning	% of Craters	
			Mercury	Moon
Preservation Class	1	very distinct rim	2.3	19.1
	2	distinct rim	15	27.3
	3	smoothed rim	37.3	26.9
	4	destroyed rim	31.2	20.9
	5	completely destroyed rim	14.2	5.8
Terraces and Collapses	0	no terraces and collapses	3.8	90.3
	1	unclear	31.3	2.3
	2	terrace	22	3.2
	3	collapse	14.4	2.7
	4	terrace and collapse	2.3	1.3
	5	many terraces	24.5	0.2
	6	many terraces and collapse	1.7	0
Rim Character	0	no rim	4.1	0.1
	1	unclear	7.3	0
	2	rim	78	95.4
	3	massive rim	10.6	4.5
Central Uplift (hills, peaks, ridges)	0	none	14	54.2
	1	unclear	46.4	24.6
	2	hill	5.3	4.6
	3	many hills	21.1	8.3
	4	peak	1.9	3.2
	5	peak and hill	0.9	0.1
	6	peak and many hills	4.4	0.6
	7	many peaks	0.7	1.5
	8	many peaks and hill	0.04	0
	9	many peaks and hills	3	0.1
	10	ridge	0.4	2.4
	11	ridge and hill	0.1	0.1
	12	ridge and many hills	0.6	0.3

	13	ridge and peak	0.02	0.1
	14	ridge and many peaks	0.1	0.1
Chains and Fractures	0	no chains and fractures	5.8	60.1
	1	unclear	52.2	26.1
	2	crater chain	18.7	11.9
	3	many chains	22.9	0.1
	4	fracture	0.2	1.1
	5	chain and fracture	0.2	0.6
	6	many chains	0.1	0.1
	7	many chains and fracture	0.01	0
Floor Character	1	unclear	10.4	21.5
	2	smooth floor	26.4	7.5
	3	rough floor	63.1	71.5
Lava on the Floor	0	no lava	1.1	68.7
	1	unclear	49.8	20.4
	2	lava on the floor	37.1	10.8
	3	entire floor flooded with lava	12	0.1
Ray System	0	no ray system	98.7	99.7
	1	unclear	0.1	0
	2	ray system	0.8	0.3
Underlying Surface Character	1	plain	18.2	3.2
	2	highland	36.5	94.2
	3	transition zone	45.5	2.6
Special Features	0	no special features	98.4	
	1	pit or pits on the floor	0.2	
	2	escarp	1	
	3	dark halo	0.2	
	4	ring ridge	0.7	
	5	elliptical crater shape	0.2	



An example of encoded crater description in the catalog is shown for the Alencar crater (Fig. 6): 4259 -63.5 103.5 120 2.4 2 5 3 9 0 3 2 0 3 0. This means that the crater has number 4259 in the catalog, crater coordinates: 63.5°S; 103.5°W, crater diameter - 120 km, crater depth - 2.4 km, the crater belongs to the 2nd preservation class, there are many terraces on the crater slopes, the crater has a massive external rim, there are many peaks and hills on the crater floor, there are no crater chains or fractures on the floor, the crater has a rough floor, there is lava on the floor, no ray system, the surface underlying the crater is a transition zone between highlands and plains, the crater has no special features.

Fig. 6. Alencar Crater (63.5°S; 103.5°W) (image obtained by the MESSENGER spacecraft https://messenger.jhuapl.edu/Explore/Images.html#of-mercury).

RESULTS OF THE NEW CATALOG ANALYSIS

The surface area of Mercury reaches 74796748 km^2. The average density of Mercury's craters according to our data is 165 craters per 1 million km^2. Statistical processing of Mercury's craters with a diameter of 10 km and larger showed that craters of the 3rd and 4th preservation classes (with smoothed or partially destroyed rims) predominate on Mercury. The proportion of such craters reaches ~69% of the total number of studied craters with a diameter of ≥10 km (Table 1). Fresh craters (1st and 2nd preservation classes) constitute only ~17%, and the oldest ones (ruins) ~14%. A significant number of Mercury's craters have terraces and collapses on the slopes (65% of craters), which is a distinctive feature of this planet. Almost 39% of craters have a central uplift, and only 11% of craters have central peaks (in the table, peaks are included in the central uplift). Central ridges are found in only 1.2% of craters, and 0.7% of craters have ring ridges. A significant portion of central uplifts is represented by hills: they are found in 26.5% of craters (Table 1). On the bottom and slopes of 40% of craters, chains of small craters can be seen. Most of Mercury's craters have an uneven floor, with about half of all craters being completely or partially filled with lava. Despite the widespread occurrence of scarps on the planet's surface, these formations cross only 1% of craters.

Fig. 7 shows the distribution of Mercury's craters by preservation class for the entire surface and for different regions of the planet: highlands, plains, and the transition zone between highlands and plains. As can be seen from the figure, craters of the 3rd preservation class predominate on the plains. The distribution of craters by preservation class for the entire surface of the planet is similar to the analogous distribution for the highlands.

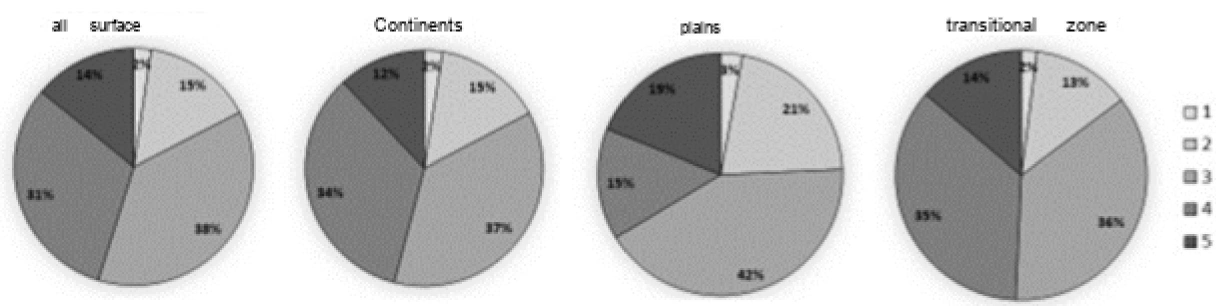


Fig. 7. Distribution of craters by preservation class for different types of underlying surface on Mercury. The numbers indicate the preservation classes of craters.

The distribution of craters by depth depending on the type of underlying surface is shown in Fig. 8. To exclude the influence of the lava layer on the final crater depth, we considered only those craters that do not have lava on the bottom. We only included well-preserved craters (1st preservation class according to the classification of this catalog). A total of 290 craters were studied: 66 craters on plains, 112 craters on highlands, and 112 in the transition zone. The diameter of most of the considered craters does not exceed 40 km. The depth values for the three types of underlying surface range from 0.07 to 3.9 km. The greatest depth of craters located in the transition zone reaches 3.9 km, the greatest depth of craters located on highlands is 2.7 km, and on plains - 3 km (Fig. 8). The ratio of crater depth (h) to diameter (D) for plains is within 0.006-0.53, for highlands h/D = 0.025-0.17, for the transition zone h/D = 0.015-0.13. Thus, the highest value of h/D is observed for craters located on plains. This conclusion does not agree with the conclusion made in the work (Kalynn et al., 2013) that differences in depth between craters located on different types of underlying surface are due to the porosity of the surface material. According to (Kalynn et al., 2013), craters located on lunar highlands are deeper than craters located on maria. In the work (Fassett et al., 2017), a similar conclusion was obtained for Mercury craters with a diameter of 2.5-5 km: craters located on Mercury's plains turned out to be less deep than craters on highlands.

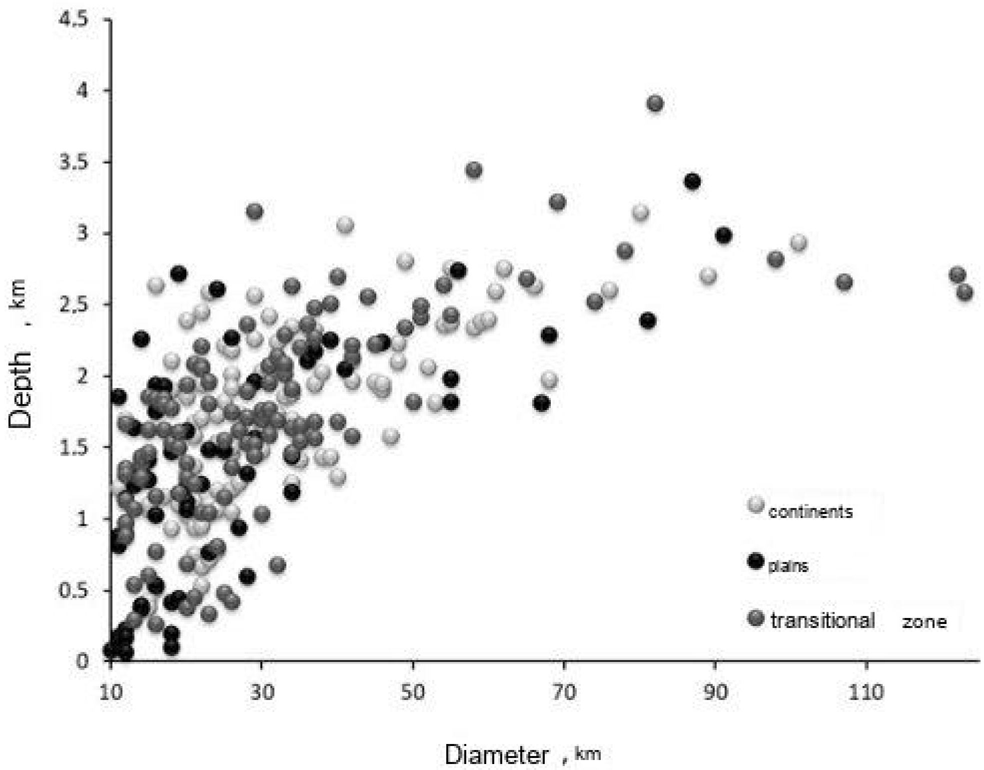


Fig. 8. Distribution of Mercury craters by depth depending on the type of underlying surface.

COMPARISON OF MERCURY AND MOON CRATER MORPHOLOGY

We compared the morphology of craters on the Moon and Mercury. For this purpose, we used data from the New Morphological Catalog of Mercury Craters and the Morphological Catalog of Lunar Craters (Rodionova et al., 1987). The Morphological Catalog of Lunar Craters contains information about almost 15.000 craters with a diameter of ≥10 km. The data from this catalog were refined taking into account information obtained from recent missions, such as the LRO spacecraft. The morphological systems of both catalogs have minor differences: the Morphological Catalog of Lunar Craters lacks the "features" attribute. When comparing the morphology of lunar and Mercury craters, we used diameter intervals similar to those in the work of (Hartmann, 1968).

The comparison results are presented in Table 1 and in Figures 9 and 10. It was found that the proportion of well-preserved craters on the Moon is significantly higher than on Mercury (Fig. 9, Table 1). On the Moon, most of the well-preserved craters (1st and 2nd preservation classes) have a diameter in the range of 8-22.63 km. Most of the 3rd preservation class craters on Mercury belong to the diameter range of 8-45.25 km, while on the Moon such craters belong to the diameter range of 32-128 km. On both bodies, most of the 4th class craters have diameters in the range of 22.63-128 km.

The proportion of ruin craters (5th preservation class) on Mercury is twice as high as on the Moon. The main contribution to the number of 5th class craters comes from craters with a diameter in the range of 22.63-128 km. Most lunar craters (90.3%) have no terraces and slope collapses (Fig. 10). On Mercury, only 3.8% of craters are like this. The diameters of these craters lie in the range of 8-32 km. On both bodies, craters with terraces and slope collapses more often have diameters that lie in the range of 32-128 km.

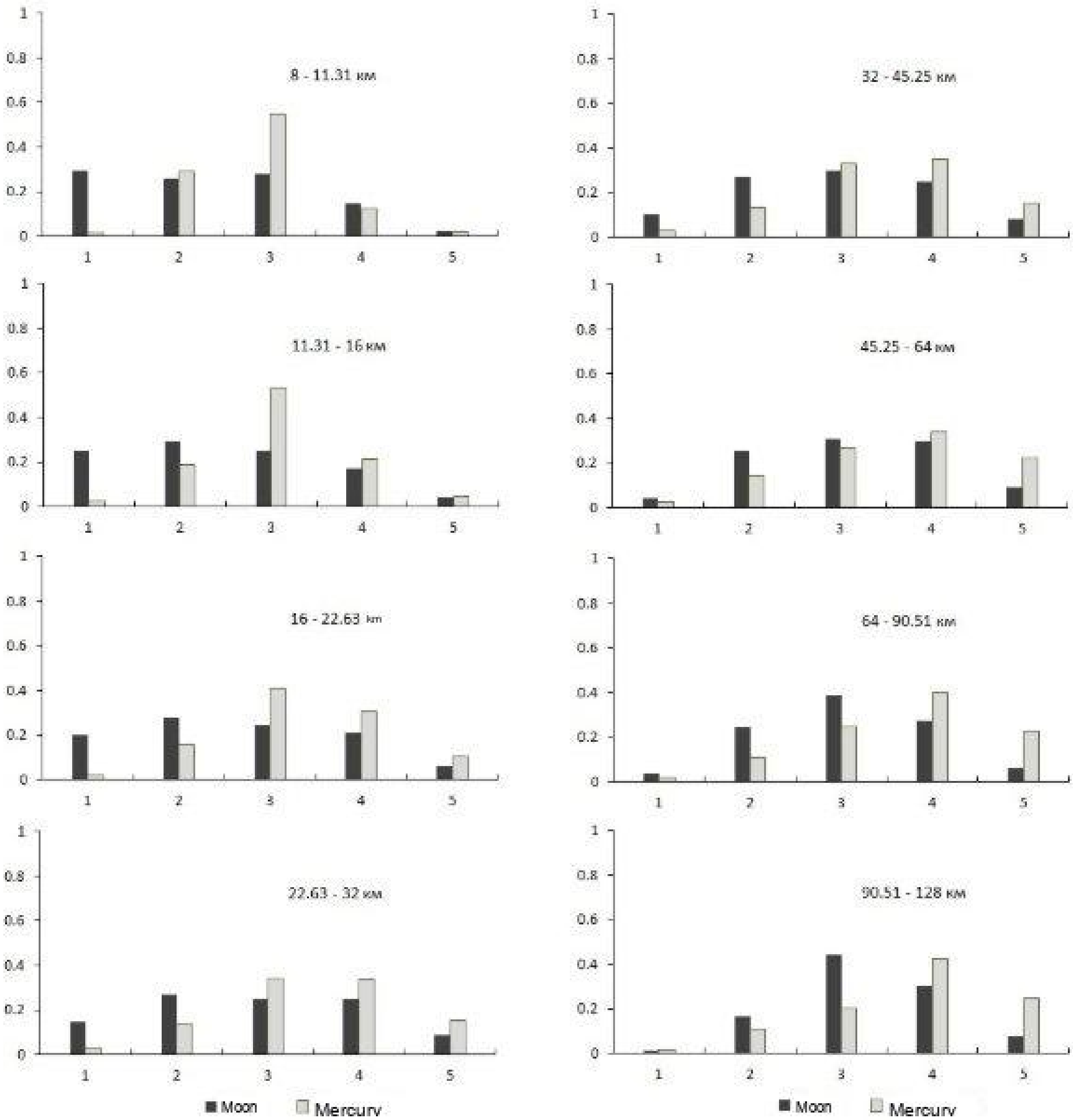


Fig. 9. Distribution of Mercury and Moon craters by preservation degree. The vertical axis shows the proportions of craters. The number of craters in a given diameter range is taken as 1.

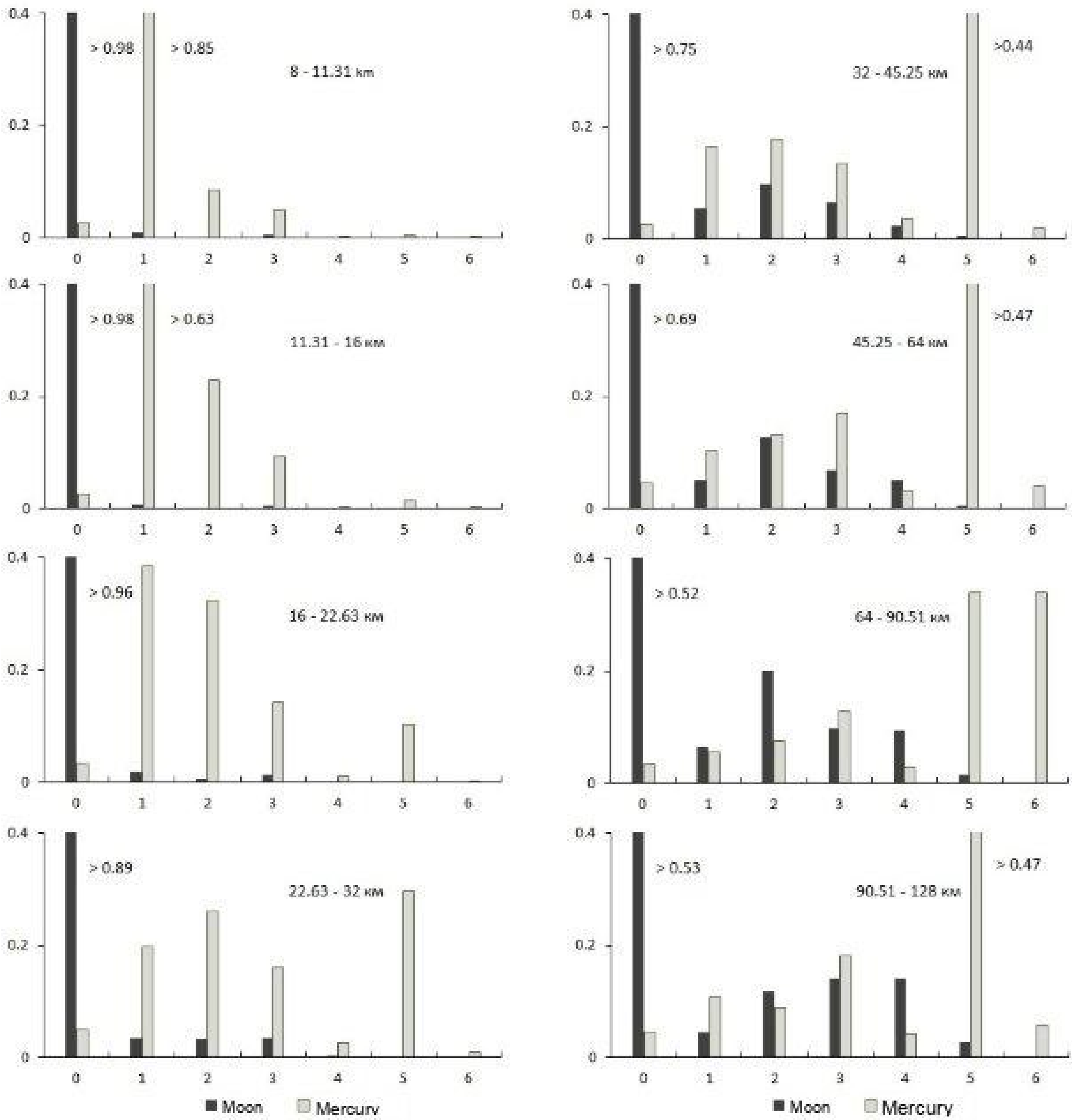


Fig. 10. Distribution of Mercury and Moon craters by the presence of terraces and slope collapses. The horizontal axis shows the feature sub-numbers according to Table 1. The number of craters in a given diameter range is taken as 1.

A significant portion of Mercury's craters (24.5%) has multiple terraces on their inner slopes. Most of these craters are found in the diameter range of 22.63-128 km. On the Moon, craters with multiple terraces are much less common: only 0.2%. The diameters of such craters on the Moon fall within the range of 64-128 km. The proportion of craters with massive rims and craters without rims on Mercury is much higher than on the Moon. More than half of the studied lunar craters do not have central peaks, while on Mercury such craters account for only 14% of the total number of craters with diameters ≥10 km. Craters with hills on the floor are more common on Mercury than on the Moon. The proportion of craters with central ridges on the Moon is higher than on Mercury. Most of the Moon's craters do not have crater chains and fractures on their floors. On Mercury, such craters make up only 5.8% (Table 1). Most craters on Mercury and the Moon have uneven floors. However, craters with flat floors are more common on Mercury. More than a third of Mercury's craters have lava on their floors, and 12% of craters have floors completely filled with lava. On the Moon, such craters account for only 0.1%. Most craters on both bodies do not have ray systems. The majority of lunar craters are located on the highlands (94.2%). On Mercury, the proportion of craters located on highlands is significantly lower (36.5%, see Table 1). Only 5.8% of lunar craters are located on maria and in the transition zone between maria and highlands. On Mercury, the proportion of craters on plains is three times higher (18.2%). Additionally, 45.5% of Mercury's craters are located in the transition zone.

Differences in the morphology of Mercury and Moon craters can be explained by the following reasons: 1) defects in surface images; 2) differences in surface properties during the period of crater formation; 3) influence of various processes on crater morphology: moonquakes and similar phenomena on Mercury, volcanic activity, tectonic activity (traces of this phenomenon are clearly visible on Mercury).

Comparison of morphological characteristics of Mercury and Moon craters was conducted earlier in a number of works (Wood et al., 1977; Cintala et al., 1977). In the work (Cintala et al., 1977), it was noted that the distribution of Mercury craters by the presence and character of terraces and central uplifts is similar to the analogous distribution for lunar craters located on maria, and differs from the analogous distribution for lunar craters located on the highlands. Based on this observation, the work concluded that the surface properties of Mercury's intercrater plains are similar to those of the lunar maria. In the work (Cintala et al., 1977), the influence of gravity on the formation of central uplifts in craters was analyzed. The authors concluded that the properties of the underlying surface have a greater influence on the formation of central uplifts than the gravity on the surface of the celestial body.

The surface of Mercury has been studied as a result of flights of only two spacecraft: Mariner-10 and MESSENGER. As a result, good quality images of the planet's surface were obtained, but for some areas such images are still insufficient. It is expected that the lack of images will be filled as a result of the work of the Bepi-Colombo spacecraft (https://sci.esa.int/web/bepicolombo/), which has already made three flybys of Mercury. The spacecraft Bepi-Colombo , launched on October 20, 2018, became the third mission designed to study Mercury. This is a joint project of ESA and JAXA. The Bepi-Colombo spacecraft will deliver two independent modules to Mercury, which will orbit the planet in different orbits: the Mercury Planetary Orbiter (MPO), developed by ESA, and the Mercury Magnetospheric Orbiter (MMO), developed by JAXA. The European module MPO will deliver 11 instruments to Mercury, including SYMBIO-SYS, which is an integrated system consisting of a stereo camera, high-resolution camera, and visible and near-infrared spectrometer. The data obtained from this instrument will allow researchers to map the entire surface of Mercury in the spectral range of 400-2200 nm. In addition, it is expected that the instrument will provide images of the planet's surface with a resolution of up to 400 m/pixel at perihelion. These images can be used in the future for a more accurate description of the morphology of Mercury's craters and refining our catalog. According to the plan, the spacecraft will reach its destination in 2025-2026. MPO will fly in a low polar orbit at altitudes from 480 to 1500 km with a period of ~2.3 hours. The MMO spacecraft will orbit in a highly elongated polar orbit: at the closest point of the orbit to Mercury it will be 590 km, at the farthest point - 11640 km. It is planned that the spacecraft will operate for a year, but with a fortunate set of circumstances, the mission could be extended for another year. The goals of the Bepi-Colombo mission are: to study the composition of Mercury's surface and its surrounding space; to assess the geological history of the planet's development; to study the chemical composition of the surface and its internal structure; to analyze the origin of the magnetic field and investigate its interaction with the solar wind; to map the prevalence of hydrogen-containing compounds and water ice in the polar regions. The MPO spacecraft will enter its final orbit on March 14, 2026.

Some morphological features of craters, such as terraces and collapses on slopes, could have formed at the moment of crater formation and may be related to the properties of the underlying surface at that time. This assumption is supported by the fact that there are more craters with massive walls and central uplifts (such as peaks, hills) on Mercury than on the Moon. These morphological features occur during crater formation and suggest that the properties of Mercury's underlying surface during the formation of some craters differed from the properties of the underlying surface on the Moon. Figure 9 shows that small craters on Mercury more often have terraces and collapses than craters of the same diameter on the Moon. A significant portion of small craters on both bodies formed later than large craters. Therefore, the presence of terraces and collapses on their slopes may mean that the processes that led to these features lasted longer on Mercury in geological terms and were more widespread than on the Moon. Such processes could include volcanic activity, tectonic activity, in particular, the formation of escarpments. The wider distribution of volcanic activity on Mercury is confirmed by the fact that 49.5% of the planet's craters have lava on the bottom (on the Moon, only 31% of craters have this) and 45.5% of Mercury's craters are located in the transition zone between continents and plains.

CONCLUSIONS

1. A New morphological catalog of Mercury's craters has been created. The catalog includes information on coordinates, sizes, depths, and morphological characteristics of 12,635 craters with diameters ≥10 km.
2. A significant portion of Mercury's craters shows signs of destruction: the presence of terraces and collapses on slopes, the presence of cracks and crater chains on the bottom.
3. Comparison of Mercury craters and lunar craters shows significant differences in crater morphology. On the Moon, there are more craters with a high degree of preservation and fewer craters with terraces and collapses on the slopes and lava on the bottom. Craters with multiple terraces and collapses on Mercury are much more numerous than on the Moon, and they are found in craters of smaller diameter. This circumstance, as we believe, is associated with tectonic processes that occurred on the planet. On Mercury, these processes were intense and large-scale. According to estimates from several studies (Strom et al., 2011; Jozwiak et al., 2018), the formation of effusive volcanic plains on the planet ended ~3.5 billion years ago, while explosive volcanism phenomena occurred in geologically recent periods of the planet's history: ~1.7 billion years ago and even ~280 million years ago. This is also evidenced by the significant number of craters with lava on the bottom on Mercury.

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