THE MORPHOLOGY OF CRATERS ON MERCURY: RESULTS FROM THE MESSENGER FLYBYS

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Introduction: Topographic profiles obtained by the Mercury Laser Altimeter (MLA) and stereo topography and shadow-derived estimates of topography from the Mercury Dual Imaging System (MDIS) on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft were used for investigations of the relationship between depth and diameter for impact craters on Mercury. The data provide new observational constraints on factors that might influence the shape of both well-preserved fresh and degraded craters on Mercury.

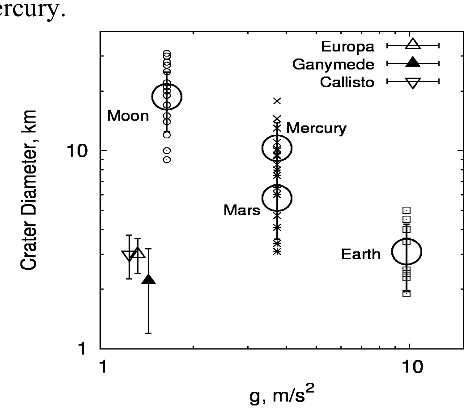

Figure 1. Diameter at which craters transition from simple bowl-shaped to complex forms as a function of surface gravitational acceleration for the Moon, Mercury, Mars, Earth, Europa, Ganymede, and Callisto [6, 7]. Large symbols are the geometric means of a variety of variables considered (e.g., onset of terracing; small symbols) when assessing this transition; see [6] for details.

Background: A variety of factors are known to influence the formation of impact craters on planetary surfaces. The most important include the strength of the target [1]; the mass, velocity, and impact angle of the projectile [e.g., 1-4]; and the surface gravitational acceleration [e.g., 5]. The crater dimensions traditionally used to investigate these influencing factors [e.g., 6] include the crater diameter, D, defined as the diagonal distance between rim crests, and the crater depth, d, defined as the difference in elevation between the average height of the rim crest and the deepest point in the crater.

By carefully measuring these parameters for the freshest observed craters on several planetary surfaces including Mercury, Pike [6] demonstrated that the gravitational acceleration at the target body surface plays a major role in the transition from simple bowl-shaped craters to complex craters possessing terraces, central peaks, and flat floors. His study also revealed that despite the similarity in surface gravity between Mars (3.72 m/s^2) and Mercury (3.70 m/s^2), the crater diameter at which this transition occurs, D_t, is nearly a factor of 2 greater on Mercury than on Mars (Fig. 1). Pike [6] suggested that the cause might be differences in the strength (cohesion) of the surface of Mercury relative to Mars, which is richer in volatiles and perhaps weaker. Schultz [8] posited that differences in impact velocity may be an additional contributor to the observed difference in D_t. On Mercury, the mean impact velocity is expected to be ~43 km/s [9], whereas on Mars it is 12-15 km/s [9].

Assessing the shape of craters on Mercury not only yields information on how the impact conditions on Mercury might differ from those on Mars, but also provides a quantitative basis for assessing crater modification by other impact or by endogenic processes. Providing such a framework is particularly important in the case of Mercury, where new results indicate the presence of widespread volcanism in large impact basins and intercrater plains [e.g., 10, 11]. Modification of some craters by subsequent impact (e.g., ejecta infilling, impact erosion, and seismic shaking) continues to influence the shape of craters as well, but possibly to a lesser extent than previously thought [e.g., 12]. Careful analyses of topographic observations and images of craters at a range of states of preservation may provide a quantitative route to assess how these processes alter the surface of Mercury, possibly leading to insights into the thermal evolution of this planet.

This study has two objectives: (1) to gain additional insights on why D_t on Mercury is so much greater than on Mars, and (2) to provide a framework for quantifying how craters on Mercury have been modified subsequent to formation.

Approach: We obtained measurements of craters with three techniques. The first and most accurate approach combines MLA and MDIS data. For craters encountered by the MLA footprint, MLA profiles provide a direct measure of d, whereas MDIS data provide D (Fig. 2). The second approach uses MDIS narrow-angle

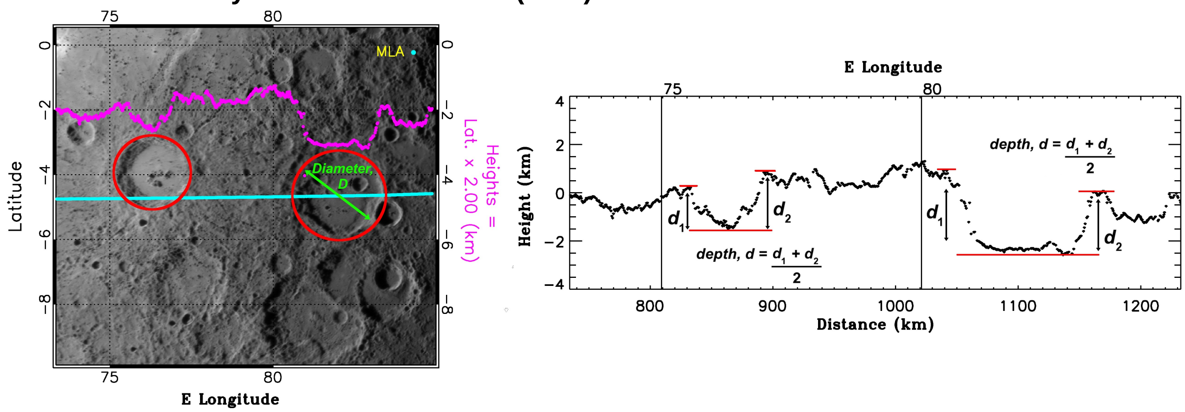

Figure 2: Two examples of how of how crater *d* and *D* were measured using MLA (straight line) and MDIS data. *D* is obtained by fitting circles to the crater rims, and *d* are measured as shown by the presented equations. The profile through the left crater measures for several MLA shots a flat surface in this crater, and should give a good estimate of its *d* given its flat appearance.

camera (NAC) images to measure the length of shadows from the walls of craters in order to estimate *d*. The technique employed [13] allows estimating *d* even when the shadow does not pass through the middle of simple bowl-shaped craters. *D* is measured by fitting a circle to the observed crater rim. Values of *d*/*D* measured using the shadow lengths compare favorably at the 92% confidence level with values for a dozen suitable craters measured with MLA. The third approach measures *d* from digital elevation models (DEM) obtained from geometric stereo and photoclinometric stereo. These models were found to be suitable primarily for obtaining *d* of large craters (*D*>20 km).

For each crater measured, the degradation state was determined using well-established criteria developed by Trask [see 12] for craters on the Moon and Mercury. By that scheme, class 5 craters are the freshest, whereas class 1 craters are the most degraded.

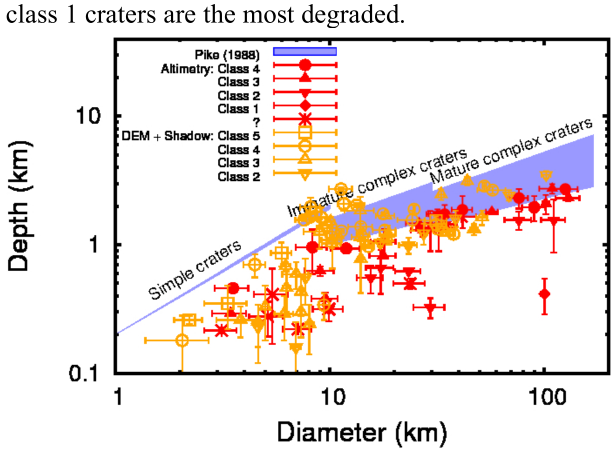

Figure 3. Depth to diameter measurements on Mercury from altimetry (combining MLA and MDIS - red) and stereo DEMs (only for *D*> 20km) and shadow length measurements (orange). Each crater is classified according to its degradation state (Type 5 = very fresh, Type 1= highly degraded). Type "?" are craters of in-determined degradation (poor image resolution).

Results: Measurements for over 100 craters are shown in Fig. 3. As in our previous report [15], the improved measurements continue to indicate that many of the freshest craters less than 10 km in diameter are shallower than the results of Pike [6] and are essentially identical to the results reported by [14]. Our new results confirm that small fresh craters on Mercury remain slightly deeper than small fresh bowl-shaped craters on Mars, despite the similarity in gravity on the two planets. The observed value of D_t as well as the depths of large craters (*D* > 14 km) follow trends that remain similar to those reported by Pike [6].

In addition to these comparisons, the MESSENGER data provide a quantitative measure of whether and how tectonics, impacts, or volcanic processes alter *d*. For example, these data reveal that several of the deepest craters on Mercury have been heavily influenced during their formation by their close proximity to major scarps. The scarps may have prevented lateral growth of the crater by confining the shock allowing for greater penetration. Furthermore, these data allow quantification of crater degradation effects through a combination of topography (including roughness) and imaging as seen with older crater floors that are typically rougher and frequently infilled.

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