MEASURING MERCURIAN CRATERS TO DEVELOP AN UNDERSTANDING OF MERCURY’S TARGET SURFACE

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ABSTRACT

In this study measuring the morphologies of fresh impact craters on Mercury, I worked with my mentor to identify the diameter of transition at which Mercurian craters cease to be simple structures and become complex. Our principle objective was to use the transition diameter to gain a better understanding of the target cohesiveness of Mercury’s surface. Findings in previous research derived transition diameters, which first suggested that Mercury’s surface is very hard/cohesive (Pike, 1981) but later indicated Mercury’s surface is nominal, similar to the Moon and Earth (Pike, 1988). We used newly obtained topographic data from MESSENGER (Mercury, Surface, Space, Environment, Geochemistry, and Ranging) to measure the craters and wanted to know what conclusions up-to-date information draws about Mercury’s surface strength. To gain some perspective, we also compared our measurements of the Mercurian craters to those of Lunar craters we found in our project last semester. Results of this study determined that the target cohesiveness of Mercury is the same globally, regardless of surface age. In addition, our measurements produced a transition diameter that leads us to infer Mercury’s is close to an average target.

INTRODUCTION

The shape, structure, and size comprising the morphology, of impact craters on terrestrial bodies reveal much about the surfaces and surface conditions of their planet or moon. In this study we applied this concept to Mercurian craters in order to improve our understanding of Mercury’s target strength. Target strength, surface strength, and cohesiveness are some of many terms, which refer to the ability of a planet’s surface material to hold together and withstand collapse. This is reflected in the morphologies of impact craters. To decode the information about surface strength from the morphologies of crater, we measured their diameter and depth dimensions.
Figure 1: The dimensions of a crater.

Figure 1: An illustration of a crater profile (a cross-section directly through a crater) showing the basic dimensions of a crater. The **diameter** of the crater is the horizontal distance measured from one rim peak to the other directly across it. **Depth** is the vertical distance between the averaged elevation of the crater rim and the floor (fluctuating floor elevations may need to be averaged as well). **Rim flank**, also known as flank width, is the horizontal distance from a peak on the rim directly to its break in slope. The **rim height** is the vertical measurement from the elevation of the break in slope to the elevation of the rim.

In his 1976 study measuring dimensions of lunar craters, Richard J. Pike, discovered that fresh craters, which are the youngest, being less than 1 to 2 billion years old, possessed a distinct trend when ratios between the diameter and depth of each crater were plotted. He also found that the trend showed a change in slope as a result of increase in diameter of the craters. At smaller diameters there was a well-defined, very linear trend. As the sizes of the craters increased to a certain diameter, the slope decreased and the trend became scattered. Figure 4 shows this occurrence in the diameter-to-depth plot of fresh lunar craters we measured last semester.

The trend of the diameter-to-depth plot corresponds to the morphologies of sub classifications of fresh craters: simple and complex. In addition to the Moon, many other terrestrial bodies that experience cratering, including Mercury, have simple and complex craters. Simple craters are small (in diameter). Their morphology is typically bowl-shaped with rounded floors and steep, sharp rims (French, 1998). They are quite deep with respect to diameter and on a plot, as the diameters of simple craters increase, so will the depth. Figure 2(a) and 2(b) exhibit the characteristic structures of simple craters. The steep-sloped, linear nature of the diameter-to-depth trend reflects the morphology of simple craters.

Figure 2: (a) is an illustration of a simple crater profile. It is shaped like a bowl with steep rims and a round floor. (b) is an LROC image of lunar simple crater Sinus (~11.7km diameter).
Complex craters are, by contrast, large. The trend of complex craters on a diameter-to-depth plot is not well defined and has a small slope because as they increase in diameter their depth increases very minimally. Characteristically they are shallow in relation to diameter. They have interesting features like a central peak, terraced walls, and flat floors (French, 1998).

![Figure 3](image1.png)

**Figure 3:** (a) is an illustration of a complex crater profile. Notice that, compared to the simple crater in 2(a), it is much wider but similar in depth. Its also has a flat floor, step-like terraced walls, and a central peak (bump in the center). (b) is a MESSENGER spacecraft image of Mercurian complex crater Balzak (~68.8km diameter).

In this study of Mercurian craters, we wanted to create a diameter-to-depth trend for Mercury in order to determine the diameter at which the simple craters shift to complex, indicated by the break in slope. Figure 4 is a plot of diameter-to-depth of lunar craters showing a clear break in slope indicating the diameter at which simple transition of the measured craters to complex morphology. This diameter is called the transition diameter. The transition diameter varies depending on the conditions that are responsible for forming simple or complex craters.

![Figure 4](image2.png)

**Figure 4:** Plot of diameter to depth of fresh lunar craters. There is a well-defined trend at smaller diameters, reflecting the morphologies of measured simple craters.

The ultimate force dictating the formation of either simple craters or complex craters is gravity. Simple craters possess their characteristic morphology of steep rims and deep interiors because of their small size--gravity cannot act on them. Larger craters, on the other hand, are more likely to break down under gravitational forces, creating the complex morphology of shallow interiors and terraced walls due to rim collapse. Principally, the greater the gravity, the more affect it will have on smaller and smaller craters. Therefore, with high gravities, the transition diameter will be lesser because complex craters are generated at reduced diameters.

Surface strength also plays a role in producing either simple to complex craters. It essentially counteracts the effect of gravity on craters. More cohesive targets are comprised of material that holds together well, and can therefore maintain craters at larger diameters. As a
proof of concept my mentor and I experimented with constructing craters in wheat flour, which is very coherent, and beach sand, which is far less cohesive. We used our fingers and cups to make holes in both materials. We found that we could not make simple structures in the sand without collapse, even using a pencil eraser (about 0.75cm). However, in the flour, we could make very large simple craters, exceeding 1 foot in diameter without collapse. Thus, transition diameter increases with stronger targets.

To evaluate the cohesiveness of Mercury’s surface we used gravity and transition diameter. Because gravity is constant and calculated very precisely on other bodies of the solar system, we compared it to the transition diameter we found by measuring the craters to develop a diameter-to-depth trend. Figure 5 shows the scheme of gravity with respect to transition diameter we used to infer our assessment of Mercury’s target surface. The solid line represents average target strength, like that of the Moon and Earth. It also represents what we estimate transition diameter to be based on the amount of gravity. Hence, as gravity increases, transition diameter will decrease. If a transition diameter is above the line for a, we infer it to be affected by a very cohesive surface. If transition diameter is below the line, we infer it to be affected by a weak target surface.

Figure 5: Diagram of gravity versus transition diameter that we used to infer the strength of Mercury’s target surface.
Figure 6: Images of different surfaces of Mercury obtained by Messenger spacecraft. (a) Shows a smooth plains surface. Note the smooth, flat terrain and relatively small number of craters. (b) Shows an intercrater plains surface. Note that this terrain is rough and irregular with a relatively large amount of craters.

To get a better understanding of target strength of Mercury, we wanted to determine if the intercrater plains and smooth plains types of terrain that make surfaces possess different target strengths. Smooth plains are the young surfaces of Mercury, as evidenced by their flatness and lack of large quantities of impact craters. Figure 6(a) shows this type of surface. Intercrater plains, by contrast, are very old given their rough nature and vast number of craters accumulated over time. Figure 6(b) shows this surface. We hypothesized that being very young and less bombarded, the smooth plains craters would have greater depth in relation to diameter, indicating that they are a very strong target surface. Intercrater plains, we predicted, have less target cohesiveness due to billions of years of cratering and be shallow in relation to diameter.

METHOD

In order to develop a plot of diameter vs. depth of Mercurian craters that allows us to observe and infer the transition diameter most accurately, we chose to include more craters into our population of Mercurian craters to be measured. We currently have data for approximately 120 craters on Mercury, which is about 70 more than proposed, ranging in size from 5 to 140km in diameter instead of 5 to 30km. We also mentioned that the Mercury Laser Altimeter (MLA) would be used in our measurement process, however, sources for the topographical information have not worked. Therefore we use the Gaskell Elevation Model to measure topography.
RESULTS

**Diameter-to-Depth Trend of Fresh Mercurian Craters**

*Figure 7:* Plot of our diameter measurements in kilometers to depth in kilometers for fresh Mercurian craters.

**Diameter to Depth Trends of Intercrater Plains v. Smooth Plains Craters**

*Figure 8:* Graph of the depth-to-diameter ratios of fresh Mercurian craters showing the distribution of intercrater and smooth plains craters. The blue diamonds represent intercrater plains craters and red circle represent smooth plains craters. Note that the distribution lacks notable separation between either trend.
Figure 9: Plot of diameter-to-depth in kilometers displaying the trends for fresh lunar craters and fresh Mercurian craters. The intersecting arrows represent the slope of the simple trend (pointing right) and the complex trend (pointing left). The vertical arrow indicated the derived transition diameter at the intersection of slopes. It points to about 11.7 kilometers.

Figure 10: Display of our assessment of Target Strength based on our derived transition diameter of 11.7km and the gravity of Merucry, which is 3.7m/s².
DICUSSION

We found that our measurements of the depth and diameter dimensions of Mercurian produce a depth-to-diameter trend that is very ambiguous in terms of the slope change separating the simple and complex craters, compared to what we observed with lunar craters. Figure 7 shows that trend. Based on slope measurements, we found the transition diameter at 11.7km. Figure 9 shows how we determined the transition diameter. Our earlier data suggested that the transition diameter is at 18.6km, however, looking at the craters around the break in slope, we found that they are complex at much smaller diameters. Based on the known diameter of Mercury, which is 3.7m/s^2, and our derived transition diameter for Mercurian craters, we inferred that the surface of Mercury is an average target because it falls very close to the line representing nominal cohesiveness. In terms of target strength relative to aged surfaces of Mercury, i.e. the intercrater plains, and relatively young surfaces, i.e. the smooth plains, as figure 8 shows, there is no differentiation among the diameter-to-depth ratios of craters from either surface. Therefore, the surface strength on Mercury is the same globally.

CONCLUSION

Impact crater morphologies reveal much about the surface they are on. Measuring craters on Mercury helped us to better understand the target strength and cohesiveness of Mercury’s surface. Using crater diameter and depth we developed a trend, from which we determine the transition diameter of simple to complex craters or Mercury is 11.7km. Given the Mercury’s gravity we infer that Mercurian surface material is of average strength. We have also determined that globally, surface strength on Mercury is the same between intercrater and smooth plains.

REFERENCES

