Secondary Crater Morphology with Distance from Primary Crater

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Introduction

As material from outer space interacts with the moon's gravitational pull and impacts the moon, ejecta is thrown from the impact. Secondary craters are caused by this random rain of primary impact craters throughout time. The ejecta thrown from the primary crater is dependent on several functions: velocity/energy, impact angle, projectile type, and target type (McEwen and Bierhaus). It is important to take all of these functions into consideration when studying secondary craters.

Because the crater, Copernicus, is well studied, the decision was made to take a deeper look into its secondary craters. Copernicus is a large primary crater with a diameter of 96.07 kilometers (JMARS). Since it is so large, it has an abundance of secondary craters that can reach to the outskirts of Mare Imbrium. Copernicus is a great model to study because there is an abundance of secondary craters at varying distances.

Copernicus (-20.079 E, 9.621 N)

Question

Does the distance from the primary crater affect the morphology of the secondary craters?

Methods

First, a primary crater was selected that was large with distinct secondary cratering. Based on this criteria, Copernicus, located on the nearside of the Moon, was selected. Copernicus is positioned in Mare Imbrium and Sinus Aestuum (-20.079 E, 9.621 N). Because Copernicus is on lunar mare, it is easy to see the lighter ejecta rays against the dark mare. Mare are plains of dark basaltic material making up 30% of the near side of the Moon (Taylor). It was essential to study a primary crater in lunar mare to know how far its ejecta rays extended thereby, showing the extent of the secondary craters.

Next, a large physical map of Copernicus was printed to have a better visual of the primary crater and its surrounding area as reference. Concentric circles were drawn around the primary crater's central point, 100 kilometers apart (Fig. 1). The circles allowed us to group secondary craters within similar distances from the primary crater to better compare and contrast data. The secondary craters were then observed. To isolate and measure each crater, the Java Mission-planning and Analysis for Remote Sensing (JMARS) and Lunar Reconnaissance Orbiter Camera (LROC) Quickmap applications were used. These applications use the Lunar Reconnaissance Orbiter Camera data. By using these applications, the secondary crater's depth, diameter, morphologies, and their exact distance from Copernicus was determined.

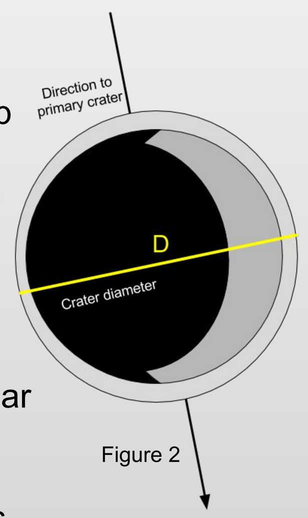


Figure 2

To find the diameter of the secondary craters, a measuring tool was used in JMARS to bisect the crater perpendicular to the direction of the primary crater to calculate its breadth (Fig. 2). LOLA 512ppd Topography v2 data, was used to determine the depth of the secondary craters. A line was again drawn over the secondary crater in the same manner to reveal its topography (Fig. 3).

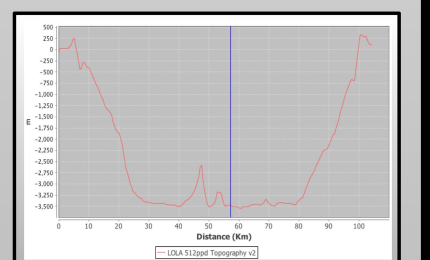


Figure 3

After collecting the data for each secondary crater, the data was entered into a spreadsheet to be analyzed. To know where each individual crater was and to establish organization of the data collected, a specific identification was given to each crater sampled and all data was recorded in a spreadsheet. Attached to the name was its latitude and longitude. We took a screenshot from the JMARS map of each specific crater and used it to describe the crater's shape. By analyzing the crater's appearance using characteristics such as; circular, sharp, oblong, and irregular, Pictures and morphology descriptions were both used to compare secondary craters at specific distances.

Results

Graph 1 illustrates data collected on the secondary crater depth in relation to the distance the craters are from the primary crater. As expected, the data shows, in general, that the further away a crater is, the more shallow the crater becomes. Interestingly, between 150-190 km, depths of the secondary craters varies more widely and even increases, ranging between 78 to 1261 km (Table 1), before becoming more shallow again at 200 km.

Graph 2, displaying the secondary crater diameter in relation to the distance from the primary crater, also indicates a fairly linear relationship between decreasing secondary crater diameter with increasing distance from the primary crater. As noted in the depth data, there is also significant variability in the secondary crater diameters between 100 to 200 km; however, there isn't an obvious jump at 150 km with the diameter data as there is illustrated in the depth data.

Variation in the morphologies of secondary craters observed in this study are not distinctive. Most of the sampled secondaries are circular in shape with no defining features (Table 2). The cross-section views indicate they are all simple craters without the central depression features of complex craters. Closer inspection of Table 2 shows sharp contrasts in shadow widths for craters in the 100-200 km range versus craters in the outer ranges. This is indicative of steeper walls and correlates the depth data recorded in Table 1.

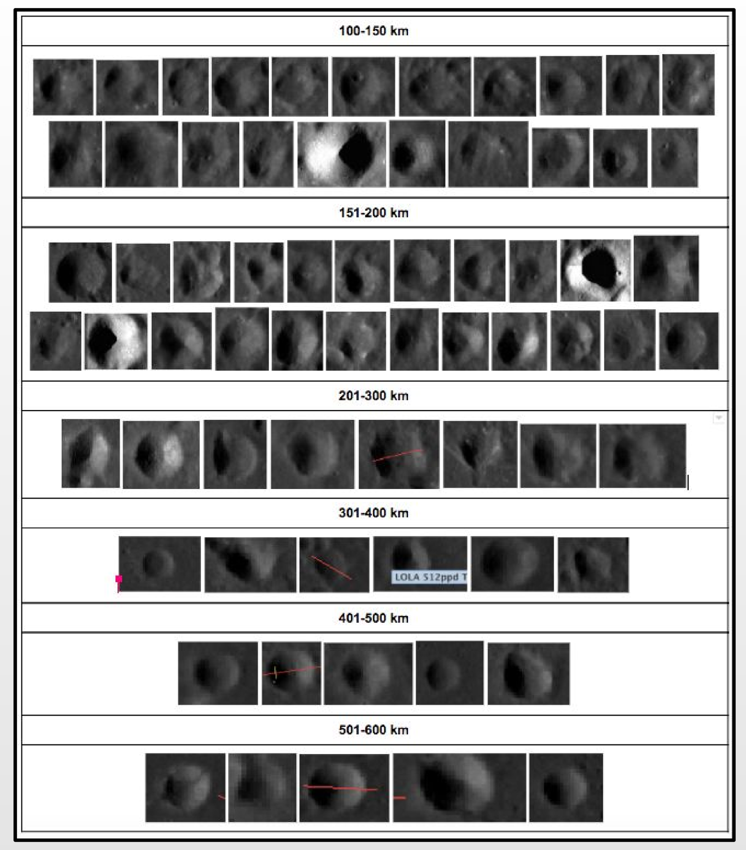


Table 2. Images of secondary craters by distance.

*The number of secondary craters sampled varied because the further the craters were, the more difficult to confidently identify them as secondaries.

Number of Secondary Craters Sampled*	Distance to Primary Crater (km)	Sample Crater Depth Minimum (m)	Sample Crater Depth Maximum (m)	Average Crater Depth (m)	Median	Sample Crater Diameter Minimum (km)	Sample Crater Diameter Maximum (km)	Average Crater Diameter (km)	Median
25	100-150	158	669	410.614	395	1.859	5.808	3.081	2.9675
22	151-200	78	1241	503.955	429	1.724	5.41	3.192	3.1985
10	201-300	188	631	382.7	381.5	1.82	3.74	2.727	2.863
8	301-400	19	429	115.125	77.5	1.41	2.4	1.913	1.965
6	401-500	39	352	154.333	113	1.5	1.9	1.707	1.705
6	501-600	100	303	183.167	169.5	1.06	2.31	1.68	1.7

Table 1. Number of craters sampled, distance to primary crater, sample crater minimum and maximums, averages, and medians.

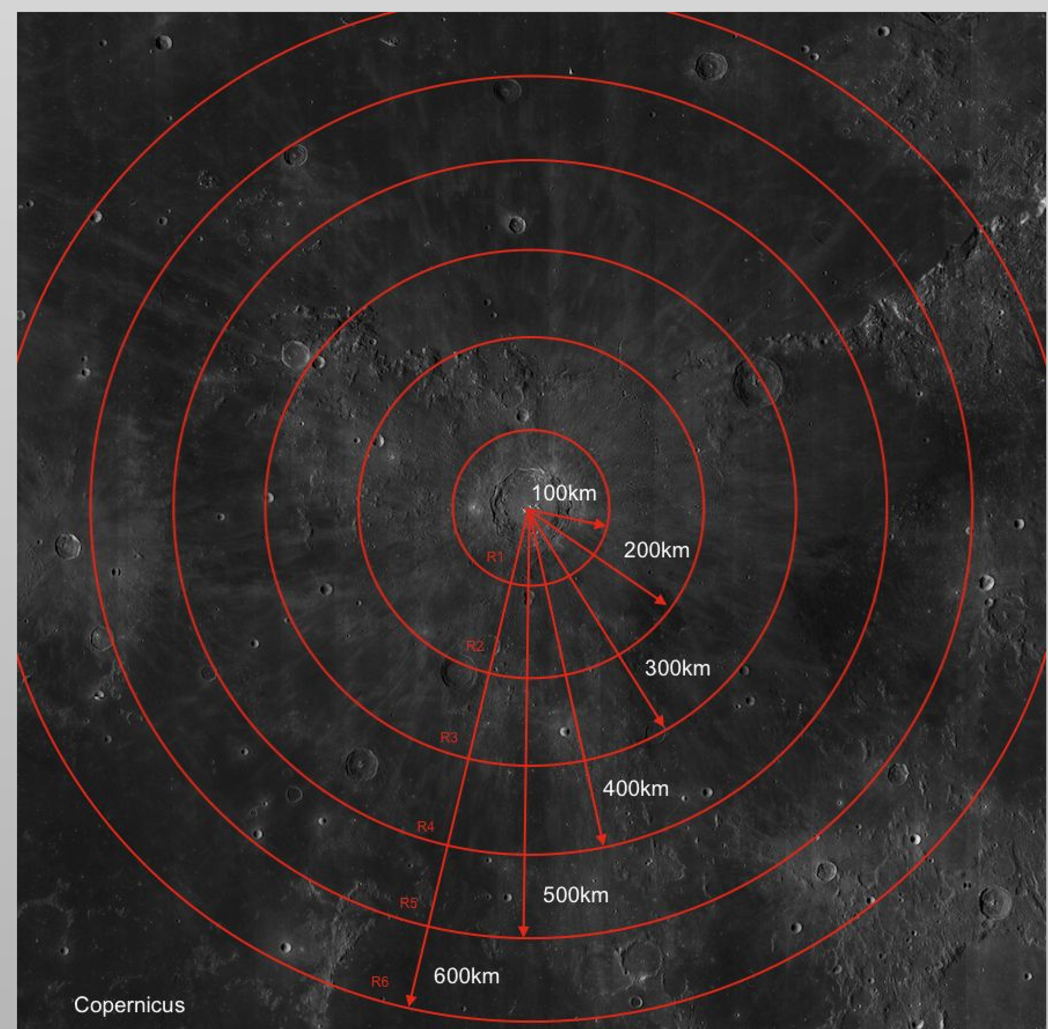
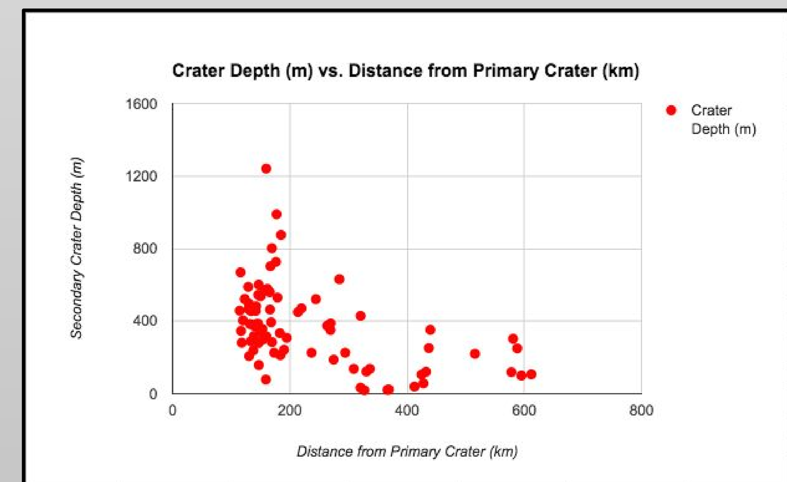
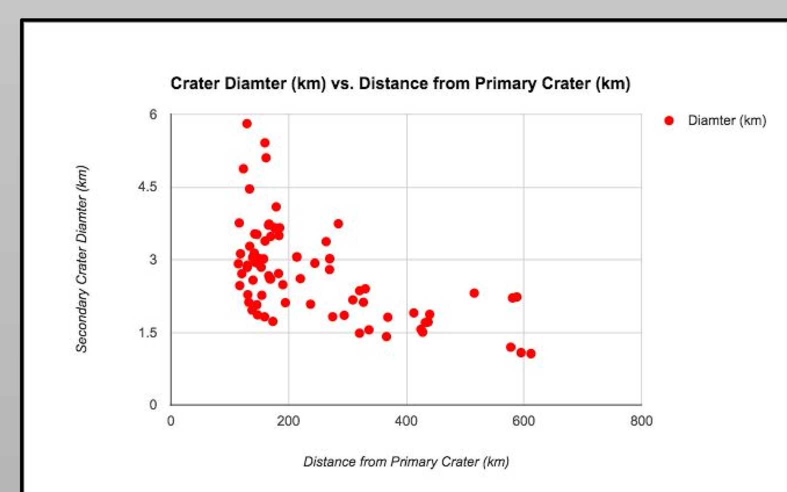


Figure 1. Copernicus with concentric rings drawn 100 km apart. Sample observations of secondary craters were taken from each ring.



Graph 1. Crater depth (m) plotted against distance (km) from primary crater.



Graph 2. Crater diameter (km) plotted against distance (km) from primary crater.

Literature Cited

Cohen, B. A. (January 2001). *Lunar Meteorites and the Lunar Cataclysm,* 1-8. Retrieved April 27, 2017.

Taylor, G. J. (December 1998) *Origin of th Earth and Moon,* 1-7. Retrieved April 27,2017.

JMARS. Computer software. *Https://jmars.asu.edu/*. Vers. 3.7.1. ASU, 2003. Web. 27 Apr. 2017.

LROC Quickmap. Computer software. *Http://target.lroc.asu.edu/*. Arizona State University, n.d. Web. 27 Apr. 2017.

McEwen, A. S., & Bierhaus, E. B. (January 2006). *The Importance Of Secondary Cratering to Age COnstraints On Planetary Surfaces,* 535-567. Retrieved April 26, 2017.

Berthoud, L., & Manderville, J. C. (May 1997). Distinguishing Between Oblique Incidence And Non-Spherical Projectile Impacts, 487-491. Retrieved April 26, 2017.

Taylor, G. J. (August 2006). Student Guide to Moon 101. *Wandering Gas Giants and Lunar Bombardment,* 1-7.

Discussion

After analyzing the secondary crater morphologies in Table 2, it was evident that there few difference in secondary crater shapes no matter the distance from the primary crater. It was originally thought that different features in each concentric circle would be apparent; however, this does not seem to be the case.

As McEwen and Bierhaus indicated in their study, the similarities or differences of morphologies do not depend on their distance from the primary; rather, they are dependent on the material thrown from the impact. The angle at which the primary crater impacts, associated with the depth at which the primary crater reaches, determines the type of material projected from the initial impact. The density in different terrain is what determines the depth of craters. Some areas on the moon may be less dense, making it more susceptible to deeper impacts (McEwan and Bierhaus).

The majority of the secondary craters in this study are found in the lunar mare; therefore, causing them to have impacted into the same material with the same densities. While the impact depths are the same, it causes the morphologies to be similar as well.

Conclusion

In conclusion, evidence in this study supports that the distance from the primary crater does affect the morphology of the secondary crater, as is apparent in both the depth and diameter data. However, the data also indicates the shape of the crater is not influenced by the distance from the primary crater as originally hypothesized.

Phenomena in the data showing the wide variability in crater depths and diameters between 100 to 200 km is interesting and further study would need to be conducted to determine why this occurred. Some factors like having more crater sample data within the 100-200 km range than other distances or the fact that secondary craters closer to the primary crater are usually more numerous and easier to identify or observe, may have contributed to this.

Future Studies

For more robust results, further studies should be conducted on more primary craters to determine why there may be a wide variability in the 100-200 km range. Is this unique to Copernicus? Or does it apply to other primary craters? There is a possibility that the mare in the 100-200 km is less dense than other regions, producing wider and deeper secondary craters.

In the future, newer technological methods using improved remote sensing could also lead to better identification and measurement techniques relating to secondary craters. This could also help scientists find more distinct patterns in secondary cratering relationships with primary craters.

Acknowledgements

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