# The lunar great circle basins' relationship between their diameters and distances from Orientale

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**Abstract**

Several of the Moon's largest basins show correlations between their locations and diameters. These include Orientale, Mare Imbrium, Mare Serenitatis, Mare Crisium, Mare Smythii, Mare Tsiolkovsky and potentially others. All of these basins lie along a lunar great circle and their diameters decrease starting at Mare Imbrium and moving eastward across the surface of the Moon to Mare Tsiolkovsky. This pattern appears far from random which is contrary to what might be expected under the interpretations of the late heavy bombardment scenario, which is thought to have been a millions-of-years-long cratering event. In this research, an explicit relationship is presented which relates a basin's diameter to its distance from Orientale. This relationship possesses a coefficient of determination of 0.979. This adds further support to the idea that these basins are not randomly distributed and that some causal relationship exists between them.

## Introduction

The Moon is thought to have formed about 4.5 billion years ago (4.5 Ga). Around 600 million years later (~3.9 Ga) a significant geological event occurred to the Moon as indicated by several studies. It was around this time that many of the largest impact basins formed. Crustal rocks indicate that the entire surface of the Moon was shocked and broken into smaller pieces [1]. Lava flowed on the surface of the Moon and some melt rocks that cooled during this timeframe exhibit properties of magnetism, indicating that they solidified in a strong magnetic field, which may have been the Moon's. This is an exciting finding because whatever triggered this spike in lunar activity may have been of such magnitude to restart the Moon's magnetic field, which is no small feat. After this spike in activity to about 3.2 Ga, it appears that the Moon was cooling as most of the lava flows solidified during this timeframe. This spike in activity around 3.9 Ga is often referred to as the lunar cataclysm.

In order to explain the cause of the lunar cataclysm, contemporary lunar science has devised the late heavy bombardment hypothesis (LHB). LHB states that a massive swarm of plantesimals, asteroids, comets, etc. impacted the Moon and by inference, the Earth and the rest of the inner solar system. This swarm of impactors is proposed to have been generated by one of several potential mechanisms: perhaps the gas giants migrated at this late of a date so as to destabilizing asteroid fields and send them flying towards the inner solar system, or perhaps Uranus and Neptune did not form until around this time [2,3]. Some scientists predict that a planet existed between Mars and the asteroid belt and when its orbit became unstable, it plunged into the sun, throwing asteroidal material towards the inner solar system [4]. Other hypotheses exist as well.

In understanding the cause of the lunar cataclysm, the spatial properties of the largest basins on the Moon prove useful. Several correlations have been shown to exist. The locations of Orientale and Mare Imbrium, Serenitatis, Crisium, Smythii and Tsiolkovsky can roughly be described by a great circle across the surface of the Moon. It is also observed that the diameters of these mare-filled basins decrease when starting at Mare Imbrium and moving eastward to Mare Tsiolkovsky. These findings are interesting because the late heavy bombardment hypothesis is thought to have lasted millions of years in duration and a more random distribution of these basins might be expected, yet a random distribution is not what is observed as many of the large lunar basins are found lined up and organized by their diameters. At least one study has determined that there is less than a 2% probability that the largest basins are randomly distributed over the surface of the Moon [5]. In this research, an explicit correlation was searched for which relates a basin's diameter to its location.

## Methods

Several studies have pointed out the general trends in the lunar great circle basins' locations and diameters, but explicit correlations have yet to be shown. In the research presented here, an explicit trend between a basin's location and its diameter was searched for. The data used in this study came from a simple literature search to identify the locations (latitude and longitude) and diameters of the basins that lie on the lunar great circle. This includes Orientale and Mare Imbrium, Serenitatis, Crisium, Smythii and Tsiolkovsky. The locations of these basins were plotted on the surface of the Moon and connected by geodesics (to approximate the lunar great circle) as shown in Figure 1.

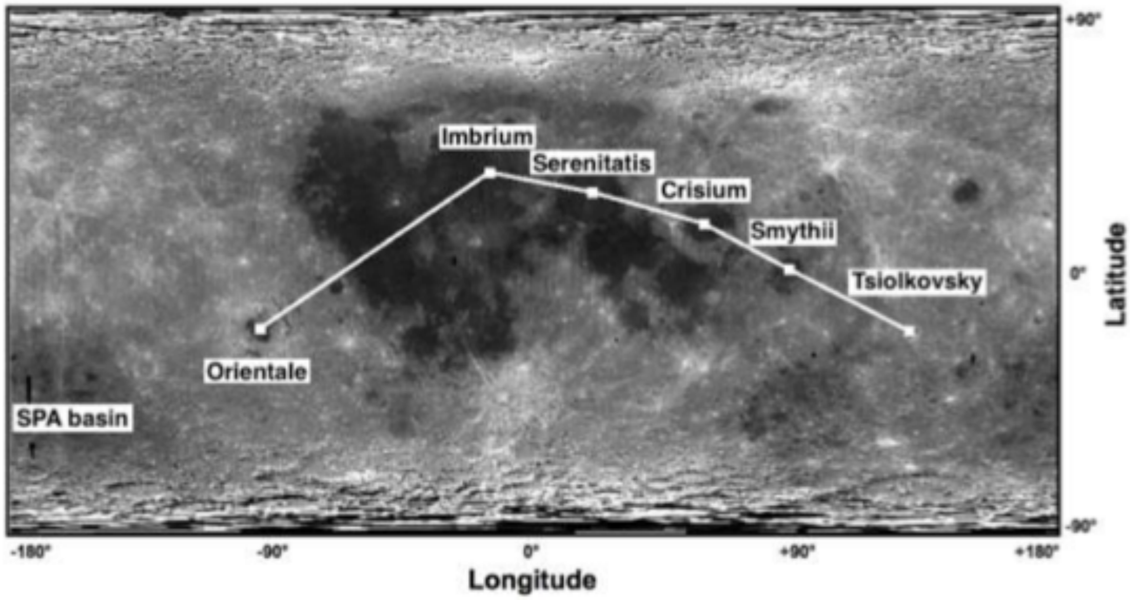


**Figure 1: Approximate great circle pattern on the Moon that includes Orientale and at least five other mare-filled basins. These basins are connected by geodesics to approximate the great circle pattern. [6]**

Using the distance formula for spherical surfaces, the lengths of the geodesics between each consecutive basin were determined. This data is shown in Table 1 along with each basin's diameter and location. Using these distances and the diameter of each lunar basin, a series of attempts to match mathematical functions to these values was undertaken while trying to minimize the coefficient of determination.

**Results**

A correlation between basin diameter and location was observed when Orientale was considered as the location from which all the other basins were measured. Each basin's distance from Orientale was calculated by summing the lengths of each geodesic between Orientale and the basin in question. This data is shown in Table 1. The diameter of Orientale was not considered in this analysis.

**Table 1: The basins' diameters, locations and calculated distances from Orientale. The Moon is assumed a sphere of radius 1737.1 km.**

| Lunar Basin | Diameter (km) | Latitude (degrees) | Longitude (degrees) | Distance from previous basin (km) | Distance from Orientale (km) |
|---|---|---|---|---|---|
| **Orientale** | Not used in analysis | -19.9 | -94.7 | 0 | 0 |
| **Imbrium** | 1145 | 34.7 | -14.9 | 2827 | 2827 |
| **Serenitatis** | 674 | 27.3 | 18.4 | 890 | 3717 |
| **Crisium** | 556 | 16.2 | 59.1 | 1189 | 4906 |
| **Smythii** | 374 | -1.71 | 87.1 | 999 | 5905 |
| **Tsiolkovsky** | 180 | 129 | -20 | 2446 | 8351 |

When each basin's diameter is plotted against its distance from Orientale, a pattern emerges which is shown graphically in Figure 2.

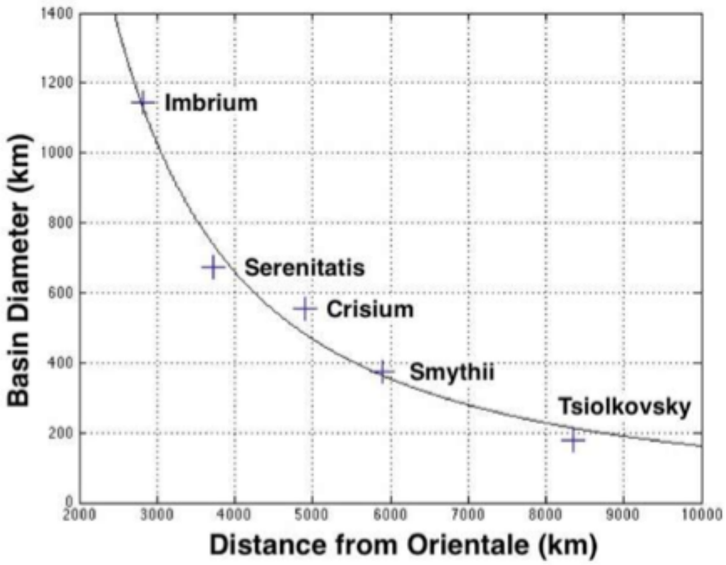


**Figure 2: Relationship between a basin's distance from Orientale and its diameter with the best-fit power function overlaid.**

When regression analysis is used to fit these points to a power function, a function that can accurately describe this trend is found:

$$D = 2.208*10^{8} * L^{-1.533}$$

where D is a basin's diameter and L is its distance from Orientale, both in kilometers. This power function has a coefficient of determination of about 0.979.

**Discussion**

A strong correlation has been shown between basin diameter and distance from Orientale for the basins that lie along the lunar great circle. These findings, coupled with observations and calculations of other scientists, support the idea that many of the largest lunar basins are not randomly distributed. It seems more likely that their exists some sort of causal relationship between these basins.

The late heavy bombardment hypothesis suggests a million-of-years-long cratering event formed many (if not all) of the basins mentioned in this research. If the impacts that formed these basins were spread out in time, however, then it would be highly unlikely that they would arrange themselves on a lunar great circle and be sorted largest to smallest with strong correlation. In order for this relationship to be present, one might imagine that a single event or impactor be the source, as this idea could support a causal relationship. Perhaps this event was a single impactor that broke up upon nearing the Moon similar to how comets may break up during impact and leave a row of craters. But even this idea encounters difficulties when considering the ages of these basins because their formation dates appear to be spread through time. Other interpretations should not be ruled out.

Furthermore, is there something unique about Orientale in this relationship? It would be odd if Orientale were in some way causally linked to the other large mare-filled basins because lunar science currently places Orientale as one of the youngest basins, forming much later than the other large basins. The exact reason for this is not certain at this time.

**Conclusion**

A correlation was found between several of the large basins that lie on the lunar great circle that relates a basin's diameter to its distance from Orientale. With a coefficient of determination of 0.979, the power function that describes the locations and diameters of these basins seems to imply a causal relationship between Orientale, Mare Imbrium, Mare Serenitatis, Mare Crisium, Mare Smythii and Mare

Tsiolkovsky. This relationship is not adequately accounted for by our current understanding of the late heavy bombardment hypothesis, which would more likely have produced a random distribution. As such, modifications to this hypothesis are recommended from these findings. Alternatively, other hypotheses that may account for this relationship should not be ruled out. Research should continue until a suitable, detailed hypothesis is established that possesses explanatory powers for the relationship presented here.

**References**

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