Exploring Lunar Crater Density Over Different Latitudes

Background

Characteristics of craters at different latitudes can tell us about lunar geology and behaviors of solar system objects. I studied whether the crater database provided by Robbins 2018 shows variations in crater density at different latitudes. Suspected ice deposits at the lunar poles could affect crater characteristics (Hayne et al. 2015), making any variation between polar and non-polar craters an important piece of evidence in this search. Additionally, knowing where and how asteroids impact the moon can tell us about asteroids that may exist in different parts of the solar system (Robertson et al. 2021). Lemelin et al. 2022 mapped mineral composition near the poles, an area that is difficult to mineralogically map due to illumination conditions. Robertson et al. 2021 predicted that the flux of asteroid collisions would be 55% higher at the lunar poles than at the lunar equator.

Robbins (2018) published the most extensive lunar crater database to date, containing all craters larger than 1-2 km in diameter. This cataloging was done via tracing, with minimal automation. Three different projections were used for crater rim identification. Equidistant cylindrical was used for the equator (demarcated at 35 degrees latitude), Mollewide for the range between 35 and 60, and polar stereographic for the poles.

Additional work was done by Nelson et al. (2014), who published a file mapping the lunar maria using JWST data. The maria mapping was done at latitudes between 64.7°N and 66.5°S.

Methods

I categorized each crater from the Robbins (2018) database into Maria or Highlands using the shapefile provided by Nelson et al. (2014) using the R programming language. Due to computational limitations, I used a subset of the Robbins database with only craters with a diameter larger than 10 km. The data was already in a clean format, so the only data cleaning I did before calculating density was removing 8 craters that did not have elliptical fits. I inspected the data by looking at a summary of minimum, first quartile, median, mean, third quartile, and maximum value for each variable in the dataset, and then made several plots to visualize the data. The database has circular and elliptical fitting of the crater. I used the elliptical fit coordinates of each crater. The maria have a lower crater density, meaning that the location of the maria could affect findings across latitudes. I rounded the latitude of each crater to the nearest 5° and counted the number of craters at each 5° latitude bin. I chose 5° because it created 36 bins, which is a reasonable number of bins for a histogram, and because it divides 180° evenly. The area calculations were done by categorizing points spaced at every 1° latitude and 1° longitude into the maria or highlands. This method may introduce some inaccuracies. It was chosen for computational simplicity. I normalized the number of craters in each region (maria or highlands) within each latitude bin by the total area of each biome within each bin, giving me an area normalized density.

Results

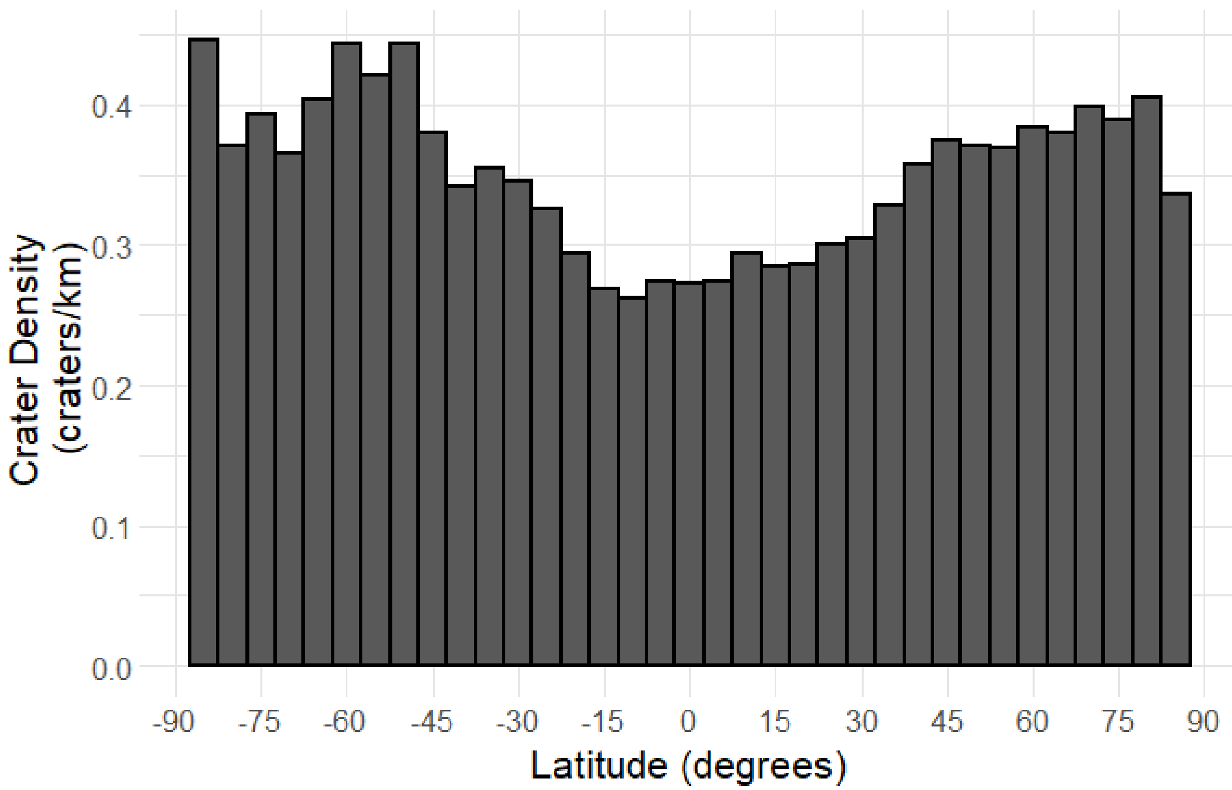

Figure 1. Histogram of crater densities across latitudes for the entire lunar surface. This graph shows a distinct dip in crater density near the equator relative to higher latitudes.

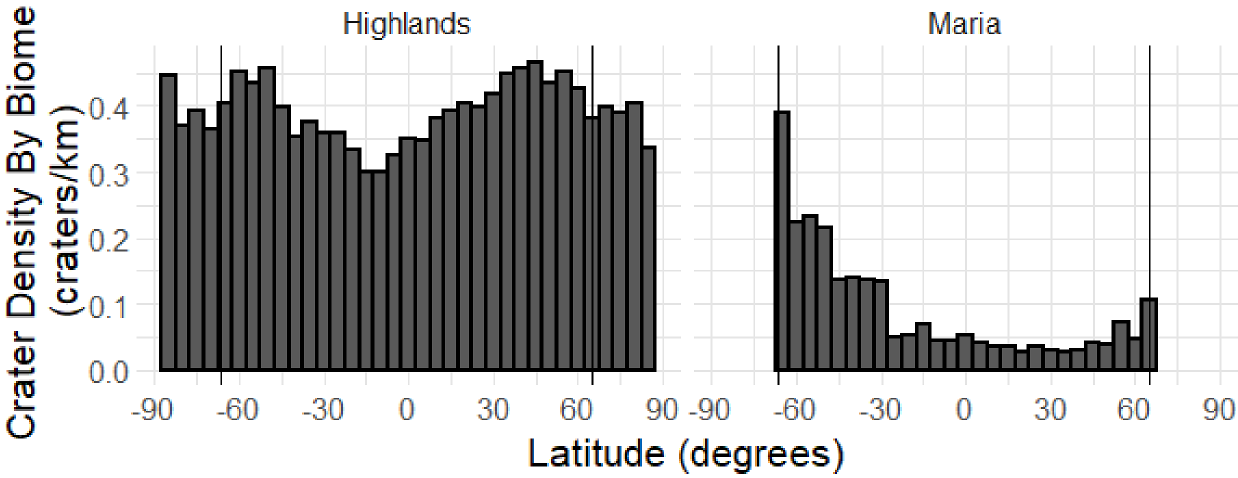

Figure 2. Histogram of crater densities across latitudes for the two lunar regions.. This graph shows a distinct U shaped density distribution in the maria, and a less distinct M shaped distribution in the highlands. Vertical lines are shown at 64.7°N and 66.5°S, the limits of the maria shapefile, meaning that all area outside these limits is categorized as highlands.

Crater density appears to be higher near the poles than near the equator over the full lunar surface, as shown in figure 1, and in both the maria and the highlands, as shown in figure 2. The full lunar surface appears to show a distinct change in density across lunar latitudes, The mean and standard deviation of the densities over the full lunar surface are 0.350 and 0.054 respectively. However, the mean crater densities are 0.392 and 0.092 craters per kilometer for the highlands and the maria respectively. There is a larger area of maria near the lunar equator, so this pattern may be influenced by the lower crater density of lunar maria than highlands.

Looking at each biome individually should remove the distribution of biomes as a complicating factor. In the highlands, there appears to be density peaks around 50° north and south, with lower density at latitudes closer to the poles. This is complicated by the maria shapefile only going to about 65° north and south, meaning that any maria closer to the poles than that is categorized as highlands in my code. The shapefile only contains the areas classified as maria, implying that all other areas are highlands. However, if there are any areas of actual maria outside of the range of the shapefile, those would be misclassified as highlands. This risk is mitigated by the fact that the bulk of the maria are situated away from the poles.That being said, this classification issue may help explain why the density of craters in the highlands seems to dip near the poles. The dip could also be representative of fewer asteroids impacting at the poles. In the maria, the difference in density near the poles is more substantial, with a standard deviation of 0.087 vs 0.045 for the highlands. However, there are so few maria near the poles that the density becomes subject to small number statistics. The mean crater densities are 0.392 and 0.092 craters per kilometer for the highlands and the maria respectively. The exact numbers may be slightly different due to inaccuracies in my method of area calculation, but the broad trends should remain the same. The distribution of densities in the maria seems to form a U shape. However, that U shape is not symmetric, with a substantially higher density at 65°S than 65°N. Because the maria has a lower mean density, there are likely fewer craters overlapping and obscuring other craters. Therefore, the maria density distribution may be more representative of actual asteroid flux.

Conclusions

From this data, I can conclude that the higher asteroid flux predicted by Robertson et al. 2021 may be reflected in the database provided by Robbins 2018. Given the noise in the data and the incomplete maria shapefile, I can not confidently claim a specific difference in asteroid flux, and more work is necessary to evaluate how close the Robertson prediction is to the actual difference in crater densities. Additional work I recommend includes expanding the maria shapefile to cover the full lunar surface, using the full Robbins database, and calculating precisely how much denser craters are near the poles than at the equator.

Bibliography

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