Mascon Basins

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Definition

Large basins across the lunar surface have observable positive gravity anomalies within the interiors, referred to as mass concentrations, or "mascons." Some near-side mascons can be explained by flexural support of the mare basalts within the basins, like Orientale, that have excessive mascons. There are also some basins that exhibit masons but lack mare basalts. Lunar gravity and topography data are most often used to determine the morphology and gravity anomalies of the mascons.

Morphology and Formation

Results from several observations have discovered these positive gravity anomalies associated with large circular basins, including Apollo (Arkani-Hamed 1998), Lunar Orbiter (Muller and Sjogren 1968), and the Gravity Recovery and Interior Laboratory (GRAIL) spacecraft (Zhao et al. 2021). From these data, elastic layer models are created to determine the elastic layer thickness of the Moon required to support the mascons (Solomon and Head 1980; Melosh 1978).

Mascon basins (list in Table 1) are surrounded by annuli of negative gravity anomalies, forming a sort of bull's-eye morphology (Sjogren and Smith 1976; Neumann et al. 1998; Melosh et al. 2013), likely due to a ring of thickened, sub-isostatic crust originating as ejecta (Andrews-Hanna and Stewart 2011). These thickened crusts would be upward loads on the lithosphere, causing flexure. That is, a positive topographic load would produce a downward flexure, and vice versa (Arkani-Hamed 1998). This could also suggest that non-mare mascons may be a secondary effect of flexural uplift (Andrews-Hanna 2013). Negative gravity anomalies observed at the lunar highlands surrounding the basins also implies mass deficiencies (Arkani-Hamed 1998). The annuli of negative free-air gravity are estimated to be ~ -200 mGals (Trowbridge et al. 2020).

The variations in the spatial effective lithosphere thickness during early mare volcanism are likely from large-scale inhomogeneities in the thermal structure of the lunar crust and mantle (Solomon and Head 1980). The current hypothesis on how mascons formed are as follows: (i) Large impact that excavates near-surface material and deposits the ejecta as an encircling topographic rim; (ii) surrounding area collapses due to differential pressure at the base of the excavated zone, attaining isostatic equilibrium; (iii) such a structure creates a negative gravity anomaly, indicating excess mass concentrations (mascons) in the basins; and finally (iv) excess mass of the ejecta and thickened crust beneath are expected to create the positive gravity anomalies.

The growth of the lunar lithosphere beneath mare basins are a natural consequence of the cooling. As the mantle heated from the impact beneath the impact cooled, the pressure gradient from the exterior to the interior drove viscoelastic flow toward the basin center, creating an uplift, and achieving a super-isostatic state with a thickened crust (Melosh et al. 2013). Cooling also increases the melt density through contraction, further increasing the gravity anomaly at the basin center (Melosh et al. 2013). Primary variables controlling gravity signatures of mascon basins are the lunar thermal gradient at impact time, impactor energy, crustal thickness, and the extent of mare in-filling (Melosh et al. 2013).

Spectra and gravity field observations of lunar mascons are observed from Clementine data (Arkani-Hamed 1998). Models of mascons require viscous decay and elastic support of the lithosphere to support the basin geology. An elastic layer of thickness ~50 km would be required to support Serenitatis, Nectaris, and Imbrium mascons, ~35 km for Crisium, ~30 km for Humorum and Smythii, and ~20 km thickness for Orientale (Arkani-Hamed 1998). An average viscosity of 10^{26} Pa s was estimated for the Moon in the past 3 Gyr, assuming mascon topography basins created through viscous deformation of the interior and about 10^{24} Pa s during mascons formation period (Arkani-Hamed 1973).

Types of Mascons

All mascon basins display a variety of associated tectonic features, such as linea rilles and/or mare ridges, each having some form of horizontal crustal tension or compression, respectively (Solomon and Head 1980). Crisium, Nectaris, and Smythii basins have mare ridges, but no rilles. Linear rilles appear to be restricted to lunar ages > 3.6 ± 0.2 Byr (Solomon and Head 1980). Most mascons can be explained by the flexural support of mare basalts within the basins (Solomon and Head 1980), though this does not explain all mascons. Some basins exhibit mascons but lack any mare fill (Neumann et al. 1996), such as Hertzsprung, Korolev, and Mendel-Rydberg.

Orientale basin is surrounded by an annulus of thickened, though sub-isostatic, crust (Andrews-Hanna 2013). The flexural uplift of the annulus caused the positive gravity anomalies within the basin center. The uplift exceeded ~2 km, increasing the central gravity anomaly by ~200 mGal, which explains a significant fraction of the Orientale mascon, and is an archetype for non-mare mascons (Andrews-Hanna 2013). A non-mare mascon component has a central gravity anomaly at ~180 mGal relative to the mean anomaly outside the basin, leading to mare thicknesses up to 4 km (Bratt et al. 1985). These non-mare mascons were previously hypothesized to arise from a dynamic rebound of the basin floor and underlying mantle following the impact (Neumann et al. 1996). However, this process would require a sufficiently thick lithosphere to exist pre-impact (Andrews-Hanna 2013).

Crisium (Figure 1) does not have an extensive ring structure as seen in Orientale. Most of the mare fill is deep in the central depression (Solomon and Head 1980). The topography of the mare is dominated by an annulus of elevated topography. It sits above uplifted mantle material, which contributes to a mass excess beneath the basin (Byrne et al. 2015). Byrne et al. (2015) have also hypothesized that mare-filled mascon basins share similar tectonic characteristics, mainly by deep, underlying thrust faults.

Humorum basin exhibits a ring structure obscured by degradation, with a second basin ring that has major mare deposits concentrations, estimated to be emplaced ~3.6 Byr (Solomon and Head 1980). The Nectaris basin mascon is concentrated in the inner ring depression, within a well-developed ring structure. Imbrium has three major rings, an extensively flooded basin, central peak ring partially exposed, and an asymmetric load in the basin between the second and third rings (Solomon and Head 1980). Smythii is the most ancient of the mascon basins, with mare lavas concentrated in the central depression. Geologic mapping estimated exposed mare of Imbrian age > 3.0 Byr (Solomon and Head 1980). No linear rilles are observed, and mare ridges are concentrated in the northeastern part of the basin. Grimaldi is the smallest of the mascon basins, with an exposed surface of about 3.0 Byr (Boyce 1976). It also exhibits extensive linear rilles, especially to the western edge of Oceanus Procellarum.

Cross References

Lunar surface, Gravity field

Impact processes of the Moon

Moon: Overall Geology

GRAIL mission

References

Andrews-Hanna, J. C. (2013). The origin of the non-mare mascon gravity anomalies in lunar basins. Icarus, 222(1), 159-168.

Andrews-Hanna, J. C., & Stewart, S. T. (2011, March). The crustal structure of Orientale and implications for basin formation. In 42nd Annual Lunar and Planetary Science Conference (No. 1608, p. 2194).

Arkani-Hamed, J. (1973). Viscosity of the Moon. The moon, 6(1), 100-111.

Arkani-Hamed, J. (1998). The lunar mascons revisited. Journal of Geophysical Research: Planets, 103(E2), 3709-3739.

Boyce, J. M. (1976, April). Ages of flow units in the lunar nearside maria based on Lunar Orbiter IV photographs. In Lunar and Planetary Science Conference Proceedings (Vol. 7, pp. 2717-2728).

Bratt, S. R., Solomon, S. C., Head, J. W., & Thurber, C. H. (1985). The deep structure of lunar basins: Implications for basin formation and modification. Journal of Geophysical Research: Solid Earth, 90(B4), 3049-3064.

Byrne, P. K., Klimczak, C., McGovern, P. J., Mazarico, E., James, P. B., Neumann, G. A., ... & Solomon, S. C. (2015). Deep-seated thrust faults bound the Mare Crisium lunar mascon. Earth and Planetary Science Letters, 427, 183-190.

Melosh, H. J. (1978). The tectonics of mascon loading. In Lunar and planetary science conference proceedings (Vol. 9, pp. 3513-3525).

Melosh, H. J., Freed, A. M., Johnson, B. C., Blair, D. M., Andrews-Hanna, J. C., Neumann, G. A., ... & Zuber, M. T. (2013). The origin of lunar mascon basins. Science, 340(6140), 1552-1555.

Muller, P. M., & Sjogren, W. L. (1968). Mascons: Lunar mass concentrations. Science, 161(3842), 680-684.

Neumann, G. A., Zuber, M. T., Smith, D. E., & Lemoine, F. G. (1996). The lunar crust: Global structure and signature of major basins. Journal of Geophysical Research: Planets, 101(E7), 16841-16863.

Neumann, G. A., Lemoine, F. G., Smith, D. E., & Zuber, M. T. (1998). Lunar basins: New evidence from gravity for impact-formed mascons. New Views of the Moon: Integrated Remotely Sensed, Geophysical, and Sample Datasets, 59.

Sjogren, W. L., & Smith, J. C. (1976, April). Quantitative mass distribution models for Mare Orientale. In Lunar and Planetary Science Conference Proceedings (Vol. 7, pp. 2639-2648).

Solomon, S. C., & Head, J. W. (1980). Lunar mascon basins: Lava filling, tectonics, and evolution of the lithosphere. Reviews of Geophysics, 18(1), 107-141.

Trowbridge, A. J., Johnson, B. C., Freed, A. M., & Melosh, H. J. (2020). Why the lunar South Pole-Aitken Basin is not a mascon. Icarus, 352, 113995.

Zhao, G., Liu, J., Chen, B., Kaban, M. K., & Du, J. (2021). 3-D Density Structure of the Lunar Mascon Basins Revealed by a High-Efficient Gravity Inversion of the GRAIL Data. Journal of Geophysical Research: Planets, 126(5), e2021JE006841.

Figures and Tables

Table 1: list of mascons, w/ lat, lon, diameter

Lunar Basin	Latitude	Longitude	Diameter (km)
Mare Orientale	-19.87	265.33	294.15
Mare Crisium	16.18	59.10	555.92
Mare Humorum	-24.48	321.43	419.67
Mare Smythii	-1.71	87.05	373.96
Mare Serenitatis	27.29	18.36	674.28
Mare Imbrium	34.72	345.09	1145.53
Mare Nectaris	-15.19	34.60	339.39
Grimaldi	-5.38	291.64	173.49
Hertzsprung	1.37	231.34	536.37
Korolev	-4.19	202.59	423.41
Mendel-Rydberg	-50.0	266.83	630

Figure 1: Example of mascon "bull's-eye" morphology at Mare Crisium. Shown is data of Bouguer gravity degree 60 to 660 from GRAIL GRGM900C gravity model. Scale bar 100 km.