LETTERS TO THE EDITOR

PHYSICAL SCIENCES

Influence of Lunar Mascons on its Dynamical Figure

THE recent discovery of large mass concentrations (mascons) beneath the lunar circular maria from Lunar Orbiter tracking data[1] raises the question of whether mascons can influence the dynamical figure of the Moon. A convenient way to describe the lunar figure is in terms of the moments of inertia about the three principal axes, where C is about the axis of rotation, A is about an axis along the lines of centres of the Earth and the Moon, and B is about an axis tangent to the orbit. It is well known from observation that $C > B > A$ and that their differences exceed by about an order of magnitude the predicted values from hydrostatic equilibrium and tidal distortion. There is a one-to-one correspondence between large mascons and circular maria[1]. But the circular maria have a non-uniform distribution over the lunar surface, with a tendency for locations toward the equator and toward the sub-Earth point. These locations are in the correct sense to suggest that mascons are responsible for the non-equilibrium contribution to the inequality $C > B > A$.

A quantitative estimate of the contribution of the mascons can also be made. Assuming the mascons beneath the six large circular maria (Maria Imbrium, Serenitatis, Crisium, Orientale, Humorum and Nectaris) are the sole cause for the differences in moments of inertia, it is possible to derive the contribution from each mascon by the expressions $A = mr^2 (1 - \cos^2\Phi \cos^2\lambda)$, $B = mr^2 (1 - \cos^2\Phi \sin^2\lambda)$; and $C = mr^2 \cos^2\Phi$, where m, r, Φ and λ are the mascon mass, distance from the lunar centre, and selenographic latitude and longitude, respectively. The relative mascon masses can be estimated from the Lunar Orbiter acceleration data[1] or from crater diameter–energy scaling laws[2]. Assuming that the values for r in all cases are similar, the sums of the differences in moments of inertia attributable to mascons are: $C - A \simeq 1{\cdot}2\ m_I r^2$ and $B - A \simeq 0{\cdot}3\ m_I r^2$, where m_I is the mass of the Imbrian mascon. Because $C - A$ is not sensitive to the unknown mass of the Mare Orientale mascon whereas $B - A$ is, and because observations of lunar $B - A$ are not as accurate as those of $C - A$, I shall discuss only the case for $C - A$. The approximate range of values for the non-equilibrium component[3] is $1{\cdot}1 \times 10^{-4} \lesssim (C - A)/M_{☾}R_{☾}^2 \lesssim 2{\cdot}4 \times 10^{-4}$, where $M_{☾}$ and $R_{☾}$ are the lunar mass and radius, respectively. Therefore, $1 \times 10^{-4}\ M_{☾} \lesssim m_I \lesssim 2 \times 10^{-4}\ M_{☾}$ for mascons within a few hundred kilometres of the lunar surface to account for the asymmetry in C and A.

It is difficult to estimate the mascon masses from the Lunar Orbiter acceleration data because of the unknown depths and distributions of the mascons. Conel and Holstrom (unpublished work) have constructed two models which roughly fit the profile of accelerations across Mare Serenitatis: a disk near the surface and a sphere at depth 200 km, each corresponding to $m_I \simeq 5 \times 10^{-5}\ M_{☾}$. This value is of the same order as that predicted from the lunar asymmetries, and there would be even closer accord for models including the lunar farside according to preliminary results M. J. Campbell has obtained from expanding the coefficients of the lunar gravitational potential; the suggestion of a large mascon near the centre of the lunar farside disk is particularly interesting. The results of this analysis will be published later.

Two other types of lunar asymmetries might also be explained by mascons: the observations that the lunar centre of mass is displaced to the north of its geometric centre[4] and that the Moon is dynamically pear-shaped with a "bulge" at latitude 30° north (as deduced from the negative value for the third zonal harmonic, C_{30}, in the expansion of the lunar gravitational potential[5,6]). Both effects could be produced by mascons beneath Maria Imbrium, Serenitatis and Crisium, all of which are located near latitude 30° north.

I therefore suggest that mascons beneath the circular maria produce the asymmetries in the Moon's dynamical figure. The idea that these asymmetries are due to density inhomogeneities has been suggested before in terms of the formation of the Moon from objects with randomly varying density[3,7]. The present proposal is that these inhomogeneities are due to mascons.

It is also interesting to apply this problem to the planets. In the case of Mars it is well established that the optical oblateness is more than twice the dynamical oblateness. The most satisfactory explanation for this discrepancy would seem to be that the material in the polar regions is of higher density than that in the equatorial regions[8]. There are several large circular bright areas on Mars with a non-uniform distribution toward the poles. It is thus tempting to propose that mascons beneath these areas would account for the differences in oblatenesses, in analogy with the lunar case. In the case of Mercury it has been suggested[9] that there is an asymmetry in its equatorial moments of inertia, such that the axis of least moment of inertia, A, points toward the Sun at each perihelion passage. Three "relatively circular" dark areas appear on maps of Mercury[10,11] near the proposed A axis; thus there is again a suggestion that mascons produce dynamical asymmetries. On the other hand, the Earth and Venus[12] show small asymmetries, so it is possible that isostatic compensation interfered with the survival of their mascons. A more detailed study of the relation between mascons, circular basins and the dynamics of the Moon and planets will be published later.

I thank C. Sagan and M. J. Campbell for stimulating discussions. This work was supported by a grant from the US National Aeronautics and Space Administration.

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Received October 20, 1968.

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Huntite, Dolomite, Magnesite and Polyhalite of Recent Age from Tuz Gölü, Turkey

INVESTIGATIONS of sediments from the hypersaline environment of the Tuz Gölü, a seasonal salt lake in Central Anatolia, Turkey (Fig. 1), showed that huntite, $CaMg_3(CO_3)_4$, dolomite and magnesite are often present in the