INFERENCES ABOUT THE EARLY MOON FROM GRAVITY AND TOPOGRAPHY.

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Recent spacecraft missions to the Moon [1,2] have significantly improved our knowledge of the lunar gravity and topography fields and have raised some new and old questions about the early lunar history [3]. It has frequently been assumed that the shape of the Moon today reflects an earlier equilibrium state and that the Moon has retained some internal strength. Recent analysis indicating a superisostatic state of some lunar basins [4] lends support to this hypothesis.

On its simplest level the present shape of the Moon is slightly flattened by 2.2 ± 0.2 km [5] while its gravity field, represented by an equipotential surface, is flattened only ~0.5 km [6]. The hydrostatic component to the flattening arising from the Moon's present-day rotation contributes only 7 m. This difference between the topographic shape of the Moon and the shape of its gravitational equipotential has frequently been explained as the "memory" of an earlier Moon that was rotating faster and had a correspondingly larger hydrostatic flattening [7–9]. To obtain this amount of hydrostatic flattening from rotation alone, and accounting for the contribution of the present-day gravity field, the Moon's rotation rate would need to be about 15 times greater than at present, leading to a period of under 2 days. Maintaining its synchronous rotation with Earth would require a radius for the Moon's orbit of order 9 Earth radii (R_{Earth}).

Unfortunately, our confidence in the observed lunar flattening is not as great as we would like. The uncertainty of 0.2 km may not properly reflect the limitations of the Clementine dataset, which did not sample poleward of latitudes 81°N and 79°S. Also, the large variation of topography (± 8 km) that is seen on the Moon dwarfs our estimate of the flattening. Further, the lunar south pole is on the edge of, or possibly inside, the massive, deep South Pole-Aitken Basin. Thus, polar radii [5] could be underestimated. This would yield a smaller flattening, which would imply a greater lunar rotation period and orbital radius. However, basin compensation states [4] and analyses of support [9] and relaxation [10] of topography at long wavelengths point to a lunar shape that has retained a flattening from an earlier, faster rotation period.

Complementary information about the Earth-Moon distance during the distant past can also come from the shape of the equator (Fig. 1). The present shape of the lunar equator is dominated by an ellipticity (2, 2 terms) of ~770 m, coupled with a 1.7 km degree 1 term that represents the offset of the center of figure of the Moon from its center of mass. This offset has been interpreted as a possible planetary scale variation in crustal thickness [11, 3] with the farside thicker than the nearside, but its origin and relationship to the Earth is not clear. The topographic ellipticity is oriented approximately 45° to the east of the Earth-Moon line and its amplitude is much larger than the 116 m ellipticity of the lunar geoid. It is possible that this distortion is also part of a lunar "memory", in this case of an earlier tidal distortion.

If the Moon behaved like a perfect fluid then the present nearside tidal bulge would be about 10 m. For the tide to approach 770 m, the Moon must have been over 4 times closer to Earth (~15 R_{Earth}) than it is at present and would have a rotation period of only about 3.5 days. In this orbit the effective permanent tide at the lunar poles would be about 650 m, which would decrease the flattening and increase the distance of the Moon required to obtain the requisite rotation. Combining the tidal effect estimated from the equatorial ellipticity and the rotation leads to a lunar period of nearly 3 days at a distance of slightly more than 13 R_{Earth} (Fig. 2). If the Moon exhibited some rigidity it would mean a reduced tidal effect and imply a somewhat smaller Earth-Moon distance. Thus, it seems that both the observed flattening and the ellipticity of the equator require a Moon that was much closer to the Earth, at a distance of 13 to 16 R_{Earth}, when the Moon "froze in" its present shape.

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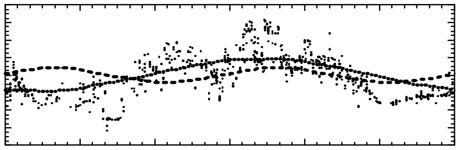

Fig. 1. Lunar radii within 1° of the equator. The values are subtracted from a mean of 1738.0 km. The solid line shows the (1,1) term of the spherical harmonic topography field [5] and the dashed line shows the (2,2) term.

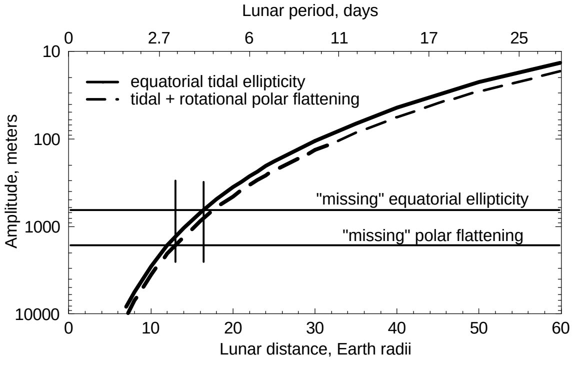

Fig. 2. Rotation and tidal effects on the lunar flattening and equatorial ellipticity.