REORIENTATION OF THE MOON DUE TO SOUTH POLE-AITKEN BASIN EJECTA. L. Ong[1] and H. J. Melosh[2], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721 (long@lpl.arizona.edu), [2]Dept. Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907.

Introduction: Early in lunar history, a giant impact excavated deep into the lunar crust and ejected enough material to cover the surface of the Moon. The current location of the South Pole-Aitken basin near the South Pole and centered at the sub-Earth longitude implies that the impact fundamentally affected the lunar shape and orientation. We show that the massive ejecta blanket resulting from the South Pole-Aitken basin impact redistributes enough lunar mass to produce the observed disequilibrium lunar shape. This new mass distribution alters the moment of inertia of the Moon and reorients the lunar surface relative to the axis of rotation, placing the basin in the position where we observe it today.

Lunar Shape: In the late 18th century, Laplace discovered that the Moon's shape, described by its radius along three axes, is not at equilibrium. The expected shape is the result of rotational flattening and tidal stretching and is determined by the Moon's orbital radius and rate of rotation. Previous studies have investigated and dismissed the hypotheses that the disequilibrium shape is the result of degree-2 convection [1], lunar impact basins [2], and lunar mascons [3].

Recently, an early high-eccentricity orbit has been proposed as a mechanism for producing the disequilibrium lunar shape [4,5]. For tidal stretching to cause the observed lunar shape, a high-eccentricity orbit is necessary because Laplace showed that the ratio of the axis lengths (B-A)/(C-A) is constant with respect to the Moon's orbital radius for circular orbits. However, this hypothesis requires the freezing of a tidal bulge when tidal heating is expected to be highest due to the large eccentricity of the orbit.

The South Pole-Aitken Basin: We propose an alternative hypothesis, that the South Pole-Aitken basin ejecta produced a massive global blanket that changed the shape and mass distribution of the Moon. South Pole-Aitken basin is the oldest confirmed impact basin in the solar system. It is the largest impact basin on the Moon and measures approximately 2600 km in diameter. Its location near the South Pole implies that the impact redistributed the mass of the Moon, resulting in a new moment of inertia and causing a major reorientation of the rotational axis of the Moon relative to its surface.

Hydrodynamic impact simulations of the SPA basin-forming impact show that the transient crater collapses and rebounds immediately [6]. The large basin diameter together with lowered viscosity due to impact heating suggest the basin became isostatically equilibrated within 100-500 Ma [2], but the surrounding impact ejecta blanket could be flexurally supported by the cold underlying lunar crust. As a result, no gravity anomaly is expected from the basin itself, though the impact ejecta blanket produces a positive mass anomaly on the surface.

The mass redistribution caused by the basin and ejecta results in the reorientation of the Moon such that the new maximum moment of inertia is aligned with the rotation axis (assumed to be perpendicular to the orbital plane). For a ring of uncompensated mass produced by the ejecta blanket, the impact point and basin are reoriented towards the lunar poles. Thus, the current location of SPA is consistent with our hypothesis that the basin-forming impact and ejecta blanket played a major role in establishing the current lunar orientation.

Modeling reorientation due to SPA formation:

Tidal Bulge. We assume the impact occurred after the establishment of a fossil tidal bulge. The orbital radius of the Moon has gradually increased since lunar formation due to tidal dissipation. The shape of the tidally-distorted Moon is a function of the tidal forces and hence of the orbital radius [7]. If we assume the tidal deformation of the Moon was frozen into place in early lunar history, we can describe this fossil tidal bulge as a function of the Moon's mean radius (a), mass (m), Earth's mass (M), and the Earth-Moon distance at the time the fossil bulge was established (c). The lengths of the principal axes of the triaxial ellipsoid are [7]:

$$A = a\left(1 + \frac{35}{12}\frac{M}{m}\frac{a^3}{c^3}\right)$$

$$B = a\left(1 - \frac{10}{12}\frac{M}{m}\frac{a^3}{c^3}\right)$$

$$C = a\left(1 - \frac{25}{12}\frac{M}{m}\frac{a^3}{c^3}\right)$$

We assume current values for a, m, and M, but we treat the orbital radius at the time of bulge formation as a free parameter. We test fossil tidal bulges frozen at distances from 10^5 km to the current Earth-Moon distance of 3.8×10^5.

Ejecta Blanket. We model a global, symmetric ejecta blanket centered on an impact point. We superpose this ejecta blanket on a fossil tidal bulge calculated above to produce different gravity harmonic coefficients dependent on the location of impact.

The thickness of the blanket (*t*) is computed according to the empirical model formulated by Housen *et al.* [8] modified to include antipodal focusing [9]:

$$t = 0.0078r\left(\frac{d}{r}\right)^{-2.61}\left(\frac{r}{Rsin(r/R)}\right)$$

where *d* is the distance from the center of the crater, *r* is the transient crater radius, and R is the radius of the Moon. We assume a transient crater diameter of 2100 km.

We allow the position of the impact to vary relative to the tidal bulge, and an ejecta blanket thickness is calculated individually for every impact position in our model. This thickness is then converted to redistributed mass by multiplying by the surface area represented by the cell and by the assumed ejecta density of 2.6 g cm^{-3} [10].

Moment of Inertia and Reorientation. We calculate the moment of inertia of the Moon as a function of the fossil bulge and imposed ejecta blanket mass distribution. The surface of the Moon is then reoriented relative to the axis of rotation using solid body rotation so that the maximum moment of inertia is parallel to the rotation axis and the minimum moment of inertia lies along the Earth-Moon plane. We then calculate the degree-2 gravity harmonic coefficients and compare the modeled coefficients to the observed disequilibrium shape.

Results: The superposition of impact ejecta on a fossil tidal bulge agrees with the observed degree-2 gravity coefficients to within 6% when the fossil tidal bulge formed at a distance of $2x10^5$ km (Fig. 1). The best fits to the observed lunar shape occur for impacts along the limb of the Moon, i.e. 90 degrees from the sub-Earth point. This is consistent with the most likely impact location on the Moon, the apex of motion. Current results from this model also predict the post-reorientation location of the basin to be located near one of the lunar poles, and to be centered at either the anti-Earth or sub-Earth longitude, in agreement with the current location of South Pole-Aitken basin.

Conclusion and Future Work: As a result of the massive global ejecta blanket produced by the South Pole-Aitken basin, the Moon experiences a major reorientation that places the impact basin near the South Pole where we observe it today. We will improve our model to take asymmetric ejecta blankets resulting from oblique impacts and the lunar Mascons into account.

Asymmetric ejecta blankets The most probable impact angle is 45° (or lower for large impactors where the curvature of the lunar surface is significant), and so the SPA basin-forming impact was likely oblique, as also indicated by its elliptical shape. Oblique impacts produce asymmetric ejecta blankets, with higher concentrations of ejecta in the downrange direction for impacts between 60° and 20° from the horizontal and a "forbidden zone" uprange where little or no ejecta is deposited [10,11].

Mascons Large positive mass anomalies (mascons) on the lunar near side contribute to the degree-3 and higher order gravity anomalies [3]. We will account for post-reorientation mascon formation in future comparisons of higher-order gravity anomalies with our model output.

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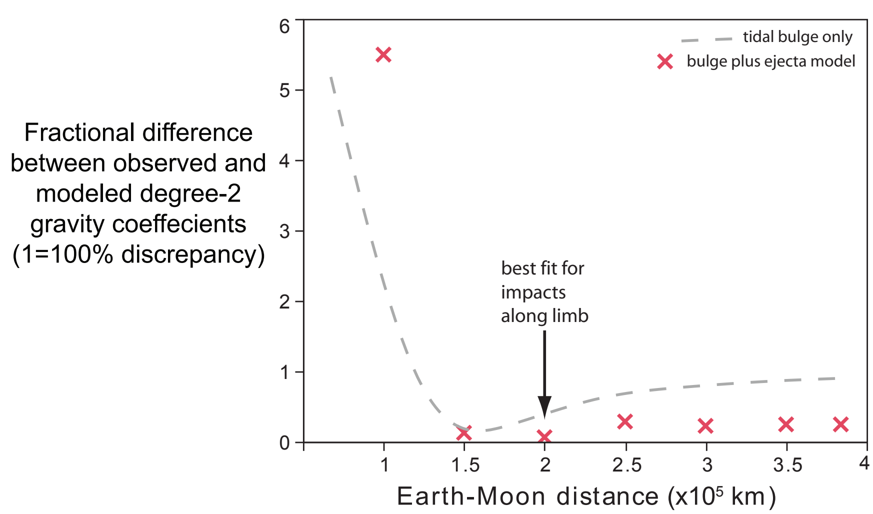

Fig. 1: Fractional difference between modeled degree-2 gravity coefficients and observed coefficients for tidal bulge alone (dashed line) and tidal bulge superposed with basin ejecta (crosses). The best fit occurs for impacts along the limb after a fossil bulge has frozen at a distance of $2x10^5$ km.