LUNAR SYMMETRY: THE TRUE SHAPE OF THE MOON? V. Perera and I. Garrick-Bethell, Department of Earth and Planetary Sciences, University of California, Santa Cruz, CA 95064. vperera@pmc.ucsc.edu

Introduction: The Moon is considered to be asymmetric in a number of aspects. Most of the maria and heat-producing KREEP elements are located on the nearside [1] while the farside on average has higher topography that is usually ascribed to it having thicker crust [2]. In addition, the Moon's center-of-mass (COM) is closer to the Earth by 2 km than its center-of-figure (COF) [2]. A number of explanations have been proposed in order to answer why the asymmetries exist and what caused the COM-COF offset [3-7]. Here we present results indicating that one of the asymmetries, the higher topography on the farside, might not be a fundamental asymmetry. We present a new map of the Moon that demonstrates that the Moon's fundamental shape may be symmetric and that the Moon's minimum moment of inertia axis has not shifted significantly since its formation.

Farside Shape: It has been shown previously that the farside of the Moon has a unique degree-2 or $\cos^2(x)$ shape that was proposed to be the result of tidal heating of the crust [8]. In order for this explanation to be valid, a degree-2 shape should be present on the nearside as well. However, such a shape is not immediately apparent. Therefore, it seems that either the farside degree-2 shape was caused by other means or the nearside degree-2 shape was present previously but now has been removed. A third possibility is that the degree-2 shape is present today on the nearside but is obscured by a choice of reference frame.

Reference Frames: Topography of a planet is often referenced to the planet's COM, due to the data being collected from a spacecraft that is orbiting about the planet's COM. If the planet does not have a large COM-COF offset the topography data that is referenced to the COM should aid in the characterization of the shape of the planet. However, the Moon has a COM-COF offset that is comparable to the difference between the mean near and farside topography. This suggests that transforming the topography to a COF frame may yield greater insight into the true shape of the body.

COF Frame and the SPA basin: In general, topography data referenced to the COM frame can be transformed to the COF frame by finding the location within the planet that minimizes the squared difference between the surface topography and the mean radius of the planet. On the Moon, however, there is also an important additional large-scale feature that must be considered before shifting reference frames. The South Pole-Aitken (SPA) basin is the largest basin on the Moon and makes up more than 12% of the Moon's surface area [9]. We assume here that this basin formed after the primordial shape of the Moon was established. Therefore, if we are to recover the primordial COF reference frame, we must not include SPA in the minimization. We used a circle of radius 1000 km centered at (-55°, 190°E) to mask out SPA. In Figure 1 the original COM-referenced map is shown along with the COF-referenced map obtained with and without SPA included in the minimization.

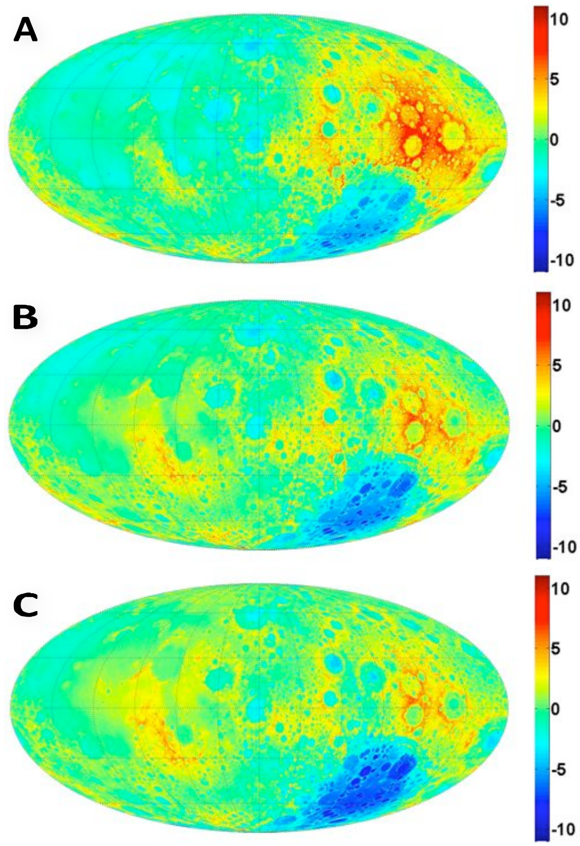

Figure 1: A) COM Frame **B)** COF Frame **C)** COF Frame ignoring the South Pole-Aitken Basin (depression in blue) in the minimization calculations. All maps are in the Mollweide projection with the nearside on the left and the farside on the right. Topography in km. LOLA data (4 pixels per degree) [10]

In comparing the two hemispheres of the Moon in each of the three cases above, it is clear that they are more symmetric in the COF frame, and most symmetric in the COF frame that does not include SPA.

Spherical Harmonic Analysis: In order to quantify the shape of the Moon without SPA, we performed spherical harmonic fits on the new SPA-

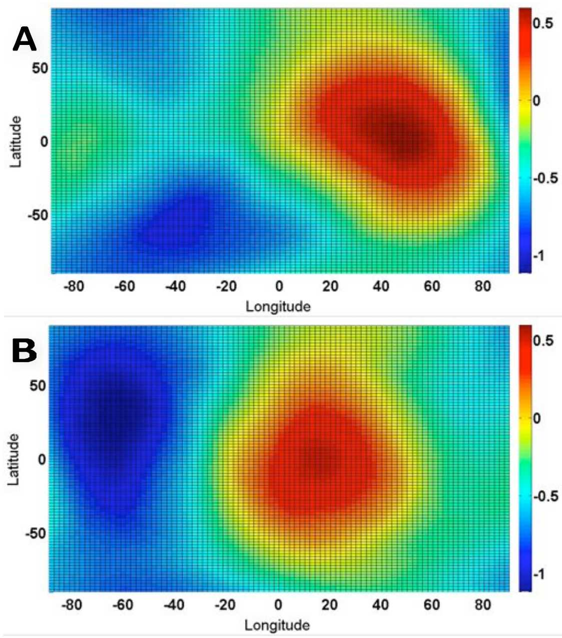

Figure 2: Spherical harmonic fitting for the C_{22} coefficient (in km) as a function of latitude and longitude variations in increments of 2 degrees (SPA ignored in both cases) **A)** COF Frame farside-only **B)** COF Frame nearside-only.

removed COF map. We were particularly interested in the C_{11}, C_{20}, and C_{22} coefficients. Least-squares fits to degree-1 and degree-2 were performed after shifting the map in latitude and longitude. A map of the coefficients was then generated for each new center latitude and longitude of the Moon.

Results and future work: Figure 2 shows plots of C_{22} coefficient values as a function of latitude and longitude for the COF Frame when spherical harmonics are only fit to either the nearside or the farside. In the case of perfect degree-2 topography the two C_{22} peaks on the nearside and the farside should be of equal magnitude and be opposite each other. We have found that the peak in the C_{22} coefficients on the two hemispheres for the SPA-removed COF map are comparable and both are shifted eastward. However, the two peaks are not perfectly opposite each other. We are investigating the potential origins of the eastward shift and the offset between the two peaks. A preliminary explanation for the eastward shift is that the Moon's minimum moment of inertia axis has shifted ~35 degrees westward. The ~32 degree offset between the two peaks may arise from geologic processes that took place after the primordial crustal topography was established.

We are also investigating the potential implications of the COF reference frame for inversions of crustal thickness.

Conclusions: In order to grain greater insight into the shape of a planet it is useful to transform spacecraft COM-referenced topography data to the COF frame. In the case of the Moon, by using the COF map and removing the effects of SPA, the previously inferred topographic asymmetry can be partly removed.

References: [1] Jolliff, B. L. et al. (2000) J. Geophys. Res., 105, 4197-4216. [2] Smith, D. E. et al. (1997) J. Geophys. Res., 102, 1591. [3] Wood, J. A. (1973) The Moon, 8, 73-103. [4] Lingenfelter, R. E. et al. (1973) The Moon, 7, 172-180. [5] Parmentier, E. M. et al. (2002) Earth and Planetary Science Letters, 201, 473-480. [6] Jutzi, M. et al. (2011) Nature, 476, 69-72. [7] Perera, V. et al. (2011) LPSC Abstract, 2750. [8] Garrick-Bethell, I. et al. (2010) Science, 330, 949-951. [9] Garrick-Bethell, I. et al. (2009) Icarus, 204, 399-408. [10] Smith, D. E. et al. (2010) Geophysical Research Letters, 37, L18204.