LUNAR ASYMMETRY: COINCIDENCE OF THE DEGREE-1 AND DEGREE-2 FEATURES DUE TO A RAYLEIGH-TAYLOR INSTABILITY AND REORIENTATION. V. Perera and I. Garrick-Bethell, Department of Earth and Planetary Sciences, University of California, Santa Cruz, CA 95064. vperera@pmc.ucsc.edu.

Introduction: In a number of ways the nearside and the farside of the Moon are different. On average, the topography of the farside is higher, which is usually attributed to the farside crust being thicker than the nearside [1]. In addition, most mare and heat producing elements are concentrated on the nearside [2]. Furthermore, this asymmetry is made more pronounced by the Moon's center of mass (COM) being about 2 km closer to the Earth than its center of figure (COF) [1].

A number of hypotheses have been proposed to explain some or all of the Moon's farside-nearside differences. For instance, Wood [3] proposed that a series of impacts, which has a higher probability of occurring on one side (due to gravitational lensing and the leading edge effect), distributed material preferentially onto one side of the Moon. Alternatively, there are several internal thermal and compositional events that may have caused the asymmetry. Lingenfelter et al., for example, proposed that crustal thickness variations due to large-scale convective upwelling and downwelling early in lunar history caused the asymmetry [4]. Here we will explore the impact and internal origins hypotheses using a new observation of the near-coincidence of two long wavelength features on the Moon. We find that an impact origin of the lunar dichotomy appears less consistent with this coincidence but that an internal mass redistribution plausibly by a degree-1 Rayleigh-Taylor (R-T) instability [5] may be more consistent with observations.

The COM/COF offset: Assuming a reference sphere is used, the line connecting the COM and the COF passes through (8°N, 203°E) on the farside and (8°S, 23°E) on the nearside [1]. Because the Moon's long wavelength internal structure affects the COM/COF offset, understanding the origin of the COM/COF offset will provide greater insight into understanding the lunar asymmetry.

The degree-2 feature of the farside: It has been shown that the farside topography closely follows a degree-2 or $\cos^2(x)$ function [6,7]. This degree-2 topography is likely caused by degree-2 variations in crustal thickness formed by spatial variations in tidal heating at the base of the crust during the magma ocean epoch [6,7]. Degree-2 topography is not obviously expressed on the nearside possibly due to internal thermal and compositional differences [6] that are also related to nearside volcanism. The peaks of the degree-2 topography are expected to be the primordial sub- and anti-Earth points and aligned with the primordial minimum moment of inertia axis (A-axis). Presently, the center of this degree-2 terrain on the farside is located approximately at (0°N, 215° E) [6,7], which suggests that the A-axis has reoriented by about 35° (Fig. 1).

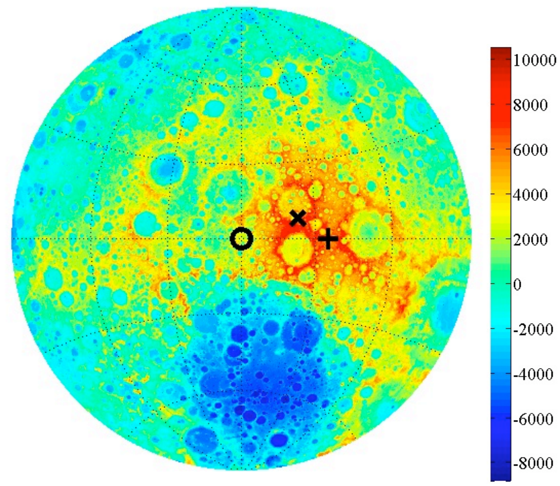

Figure 1: Farside topography (in meters) with the center of the degree-2 terrain (+), COM/COF offset line (X), and anti-Earth point (O). LOLA data (8 pixels per degree).

Coincidence of the COM/COF and degree-2 features: Interestingly, the COM/COF offset line and the peak of the degree-2 terrain are located within 14° of each other (Fig. 1). There are several possible explanations for their close proximity: 1) it is a coincidence, 2) the event that formed the COM/COF offset eventually controlled the orientation of the degree-2 structure, and 3) the event that formed the degree-2 structure controlled the orientation of the COM/COF offset. The latter two possibilities will be explored here.

COM/COF affect on lunar orientation and impact origin of the dichotomy: The Moon's orientation is controlled predominantly by its principal moments of inertia (see also [8]). Earth's gravity aligns the A-axis with the Earth-Moon line. Is it plausible that a large impact basin(s) or other formation(s) could both produce the Moon's degree-1 crustal structure and alter the Moon's moments of inertia such that the resulting COM/COF offset is nearly coincident with the resulting A-axis as observed? In the case of an impact, the likely affect on the moments of inertia would be for the resulting maximum moment of inertia (C-axis) to pass through the center of the basin such that the most energetically favorable orientation would place the basin at a pole [9]. Because the impact-formation model for the present degree-1 structure would place the center of a large, nearside basin nearly coincident with the present *A*-axis this is a less plausible model for the lunar dichotomy.

It is still possible that a basin that controlled the degree-1 structure formed *after* the degree-2 crustal structure had already been established by other processes. However, the COM/COF offset alignment with the degree-2 structure would then be both fortuitous and require special constraints on the basin's own contribution to the global moments of inertia. Alternatively, we will explore the possibility that the degree-1 structure arose from internal mass redistributions that aligned with the Earth-Moon line.

Rayleigh-Taylor Instability: Parmentier et al. [5] suggested that a dense late-crystallizing layer of ilmenite-rich cumulates could have migrated towards one hemisphere of the Moon in a degree-1 R-T instability (Fig. 2B). This displaced mass would have had its own moments of inertia and changed the global moments of inertia as it formed. There seems to be no physical mechanism that would initially cause the displaced mass to move in any preferential direction. However, the new global moments of inertia after mass movement will reorient such that the *new A*-axis points towards the Earth-Moon line. If the global moments of inertia before the mass movement were established by the rigid crust, perhaps during its crystallization, and the displaced subsurface mass is free to move under the rigid crust, then it is possible that the *A*-axis of the mass plus crust will both align and point towards the Earth (Fig. 2C). This combined reorientation would place the displaced mass underneath the primordial sub- or anti-Earth point. The freedom of movement required for reorientation of the mass under the crust is likely possible if the mass was ever able to undergo movement by a R-T instability.

Conclusions: The above mechanism provides a means to move dense, titanium-rich minerals and heat producing elements to one of the sub- or anti-Earth points. It does not, however, completely explain the COM/COF offset since it is likely that crustal thickness variations and other effects combine to produce the internal density distribution that gives rise to the COM/COF offset. However, the model offers a new insight into the unique location of the COM/COF offset and places denser and more radiogenic material in one hemisphere. This placement may lead to a different thermal and volcanic history on the nearside.

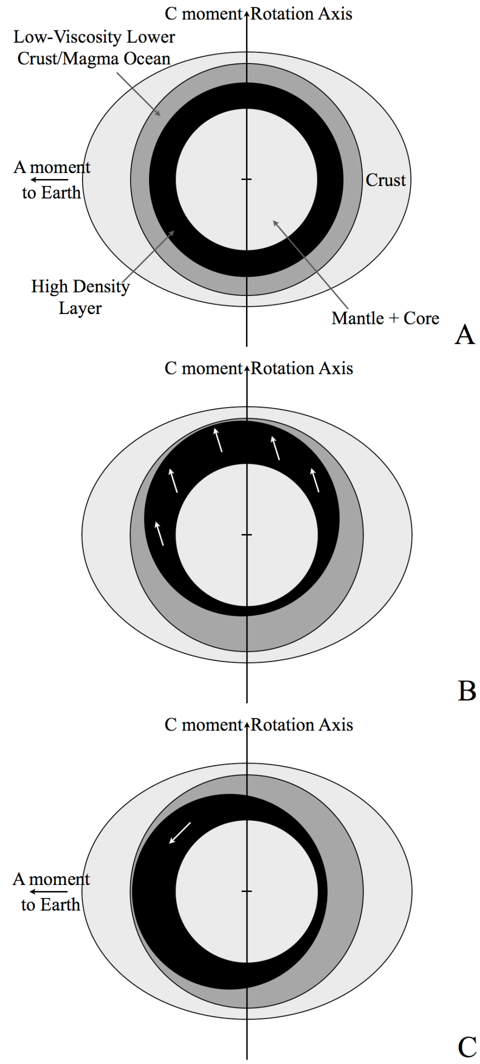

Figure 2: A) Prior to R-T instability. **B)** R-T instability occurs without a spatial preference. **C)** Due to energy dissipation, the dense material will move towards the Earth-Moon line in order to maximize the moment of inertia about the *C*-axis and conserve angular momentum resulting in the final configuration shown. Figures not to scale.

References: [1] Smith, D. E. et al. (1997) J. Geophy. Res., 102, 1591. [2] Jolliff, B. L. et al. (2000) J. Geophy. Res., 105, 4197-4216. [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] Garrick-Bethell, I. et al. (2010) Science, 330, 949-951. [7] Garrick-Bethell, I. et al. this volume. [8] Aharonson, O. et al. (2010) AGU Poster, P51C-1464. [9] Melosh, H. J. (1975) Earth and Planetary Science Letters, 26, 353-360.