Evidence for lunar true polar wander, and a past low-eccentricity, synchronous lunar orbit

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Abstract. For nearly 200 years, the nature of the Moon's shape has remained a mystery. The observed lunar figure is significantly more deformed than it should be, given its present orbital and rotational state[1]. This excess deformation has long been ascribed to a "fossil figure," frozen into place when the Moon was much closer to the Earth[2,3,4]. However, the observed figure requires an initially large eccentricity or non-synchronous spin-orbit state[5,6], which seem at odds with our understanding of the Moon's formation and evolution. In this work, we use GRAIL gravity data[7] to investigate whether lunar impact basins and mascons have any contribution to the observed figure. We find that the South Pole-Aitken (SPA) basin and its associated global ejecta blanket account for a significant fraction of the observed lunar figure, while most other impact basins and mascons are negligible. Removing the contribution from SPA reveals a fossil figure that is misaligned with respect to the present-day rotational and tidal principal axes – suggesting a past episode of lunar true polar wander driven by the formation of SPA. Correcting for this reorientation reveals a lunar figure consistent with the Moon forming in a low-eccentricity, synchronous orbit. Constraining these past orbital and rotational states is important for improving our understanding of the formation, dynamical evolution of the Moon.

[1] Laplace, P.-S. *Oeuvres comptetes de Laplace*. (Gauthiers-Villars, 1878).
[2] Sedgwick, W. F. On the oscillations of a heterogeneous compressible liquid sphere and the genesis of the Moon; and the figure of the Moon. *Messenger Math.* **27**, 159-173 (1898).
[3] Jeffreys, H. Certain hypothesis as to the internal structure of the Earth and Moon. *Mem. R. Astron. Soc.* **60**, 187-217 (1914).
[4] Lambeck, K. & Pullan, S. The lunar fossil bulge hypothesis revisited. *Phys. Earth Planet. Interiors* **22**, 29-35 (1980).
[5] Garrick-Bethell, I. Wisdom, J. & Zuber, M. T. Evidence for a past high-eccentricity lunar orbit. *Science* **313**, 652-655 (2006).
[6] Matsuyama, I. Fossil figure contribution to the lunar figure. *Icarus* **222**, 411-414 (2013).
[7] Zuber, M. T. et al. Gravity field of the Moon from the Gravity Recovery and Interior Laboratory (GRAIL) mission. *Science* **339**, 668-671 (2013).