WHAT HAS BEEN THE INFLUENCE OF LARGE GRAVITY ANOMALIES ON THE POSITION OF THE LUNAR POLE?

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Introduction: The lunar spin pole, the point of intersection of the lunar rotation axis with the lunar lithosphere, appears to have been stable for billions of years [cf. 1]. This stability is a result of the present-day distribution of lunar mass with almost zero change occurring. This could not always have been the case, as evidenced by the presence of large anomalies in the lunar gravity field, particularly the mascons [2, 3]. Although these mass concentrations are << 10^{-3} of the total lunar mass, they would have influenced the position of the point of intersection of the rotation pole with the lunar lithosphere.

Recently, the interpretation of the distribution of hydrogen at the lunar poles suggests that the pole is now about 5 degrees away from its position when the hydrogen was implanted in the polar regions (Figure 1) [4, 5]. If true, what could have caused this movement of the pole?

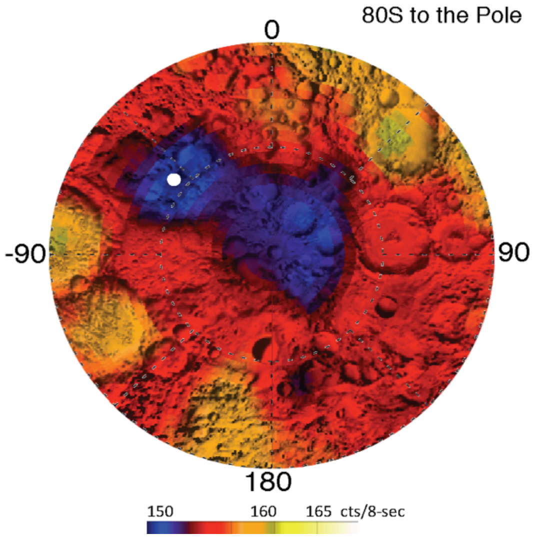

Figure 1. Epithermal neutron counts from Lunar Prospector [4]. The small white spot marks the location of the center of the distribution [5].

We investigate the magnitude of possible lunar polar wander due to several large gravity anomalies, SP-A, Crisium, Imbrium and Orientale, by extracting the gravitational signature of these features from the lunar gravity field to derive their possible influence on the position of the lunar principal axis. We use an alternative approach to modeling basin masses from previous studies of the role of basins on the global lunar mass distribution [6, 7], in particular by considering the relative timing of impact events and the implications for C(2,0).

Approach: At the time of formation of the largest basins, the impact is likely to have caused a rapid motion of the pole followed by a slower movement as a result of the infusion of denser mantle material into the basin and a rebound of the lithosphere. From the resulting gravity anomaly for each impact basin, we estimate the low-degree gravity field associated with each impact and derive the implied change in the position of the principal axis from:

$$\boxed{\delta Lat = \sqrt{C_{21}^2 + S_{21}^2}/C_{20}}\ ;\ \boxed{\delta Lon = S_{21}/C_{21}}$$

where the degree-2 and order (0,1) gravity coefficients are unnormalized and the changes in latitude and longitude, δLat and δLon, are in radians. For clarity, note that the C(2,0) coefficient is the coefficient for the entire Moon, not just that induced by the mascon.

The gravity anomaly locations and the dimensions of the central region are obtained from a GRAIL-LOLA Bouguer gravity model [8] and the magnitudes from a GRAIL free-air gravity model [9]. For the Imbrium, Crisium, and Orientale basins, the magnitudes corresponded to the free-air value at the Bouguer center; for the South Pole-Aitken (SP-A) basin the free-air magnitude was the median over the Bouguer field of the basin. The gravity field for each anomaly was computed to degree and order 180, and the degree-2 zonal coefficient for each individual anomaly used to estimate the change in pole position is shown in Table 1.

					Pole Position	
	Lat. deg	**Lon. deg**	**FA Grav. mGal**	**C2,0 normalized**	**Lat. deg**	**Lon. deg**
Moon				-2.032e-04	90.0	
Orientale	-20.1	265.2	194	-8.440e-06	87.5	85.3
Imbrium	37.0	341.5	265	2.334e-06	82.5	341.5
Crisium	16.8	58.4	260	-1.648e-05	79.2	58.4
SP-A	-53.0	191.1	-42.5	-2.905e-05	87.6	191.1
Sum, C2,0 excl. Moon				-5.165e-05		

Table 1. Changes in pole position and un-normalized gravitational flattening due to the individual selected basin gravity anomalies.

The accumulated effect on C(2,0) of removing all the anomalies is to reduce the gravitational flattening by is approximately 25% of the present lunar C(2,0) (top line) indicating the potential effect of the individual impacts on the lunar flattening. Specifically, these calculations do not consider the effect of long-term viscous relaxation, but rather apply the gravity signature of the relaxed basin.

The order of the anomalies in Table 1 is the reverse order in which they occurred and is important because each impact moved the pole but also changed the gravitational flattening of the Moon. From early on, impacts probably increased the lunar flattening to what it is today and contributed to a motion of the pole that has been preserved to the present.

All of the large basins and gravity anomalies are known to be > 3.8 Ga [10, 11] and any surface evidence of a change in pole position, such as tectonic structures arising from surface lithospheric stresses, has been erased by subsequent impacts. But the lack of evidence does not imply that there were no changes in the pole position, only that if such changes occurred the evidence has not been preserved. Figure 2 shows the geophysical locations of the pole before each impact. The blue dotted line represents results using the present-day lunar flattening, and the red line shows the modification when C(2,0) is updated after each impact. Obviously, the order of the impacts matters.

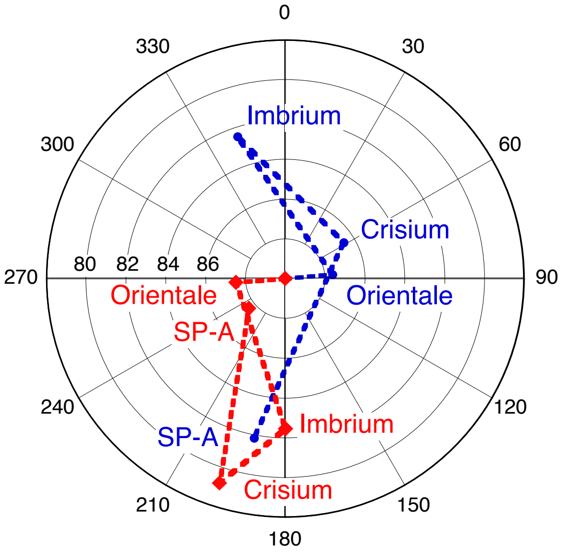

Figure 2. Location of the lunar spin pole resulting from each impact. The spin pole positions in blue are the results of the impacts if they occurred today on the present Moon. The red locations are those same impacts when removed from the present Moon in the order of occurrence, beginning with Orientale ending with SP-A.

Summary: The largest impacts caused changes in the location of the lunar spin pole due to mass redistribution associated with basin excavation and removal/transport of crust, and uplift of dense mantle. Preliminary calculations indicate that these impacts were a major influence on the rotation of the Moon and contribute to the stability we see today.

With a full accounting of the largest impacts, including longer-term mass redistribution effects associated with basin relaxation, and their contribution to the position of the lunar pole, it may be possible to work back to better understanding the flattening of the Moon before the time of heavy bombardment when all the major impact basins are included.

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