GRAIL GRAVITY ANALYSIS OF PEAK-RING BASINS ON THE MOON: IMPLICATIONS FOR THE CRATER TO BASIN TRANSITION. David M.H. Baker[1], James W. Head[1], Gregory A. Neumann[2], David E. Smith[2,3], Maria T. Zuber[2,3], and Roger J. Phillips[4]. [1]Department of Geological Sciences, Brown University, Providence, RI 02912 USA, Email: David_Baker@brown.edu; [2]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA; [3]Department of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139 USA; [4]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302 USA.

Introduction: Recent morphological measurements of peak-ring basins (large impact craters exhibiting a single interior ring) on the Moon [1,2] are helping to improve our understanding of transition from craters to large basins on planetary bodies. Linking these morphological observations with the three-dimensional structure of peak-ring basins, however, requires information about crustal structure derived from geophysical measurements.

Recent high-resolution measurements of the lunar gravity field by the twin Gravity Recovery and Interior Laboratory (GRAIL) spacecraft [3] now provide the opportunity to analyze the gravity and crustal structure of complex craters and peak-ring basins in detail. We use these gravity measurements and compare them to our morphometric observations [1,2] to begin to construct a more comprehensive understanding of the structural changes that occur in the transition from craters to basins on the Moon.

Methods: We made measurements of topography, free-air gravity anomalies, and Bouguer gravity anomalies for all 17 peak-ring basins and 3 protobasins in the catalog of [1]. Topography was measured using LOLA 128 ppd global gridded data. Gravity was measured using GRAIL 16 ppd global gridded gravity anomaly products (gravity model GL0420A) expanded from spherical harmonic degrees 6 to 360. Circles fit to the basin rim crests were used to locate the centroid of each basin. For each dataset, radial profiles separated by 1° azimuth (360 total) were measured from each centroid and then averaged to form a single profile (Fig. 1b). The gravitational effects of mare fill were not removed in the current analysis. With this correction, the magnitudes of the anomalies will decrease for those basins with mare, however the general trends presented here should remain.

Topography: Peak-ring basins exhibit unique profiles that are distinct from complex craters. Peak-ring heights range from 300 m to 3 km above the center of the basin [2]. Surrounding the peak ring is an annulus that is higher in elevation than points interior to the peak ring (Fig. 1b). The lowest elevations are in the center of the basin, creating a cavity-like profile bounded by the peak ring (Fig. 1b). Peak-ring diameters are around half the diameter of the rim-crest [1].

Free-air anomaly: Most of the 17 peak-ring basins show central free-air anomalies that are elevated with respect to the average floor anomaly (Fig. 1b), with seven showing positive free-air anomalies. Surrounding the elevated free-air anomaly is an annulus of negative or more negative gravity anomalies (Fig. 1b). The gravity anomaly again becomes positive in many basins, creating a "bulls-eye" gravity pattern recognized in previous studies [4,5]. Protobasins do not show any clear patterns in free-air gravity anomalies, with most of the variations due to topography.

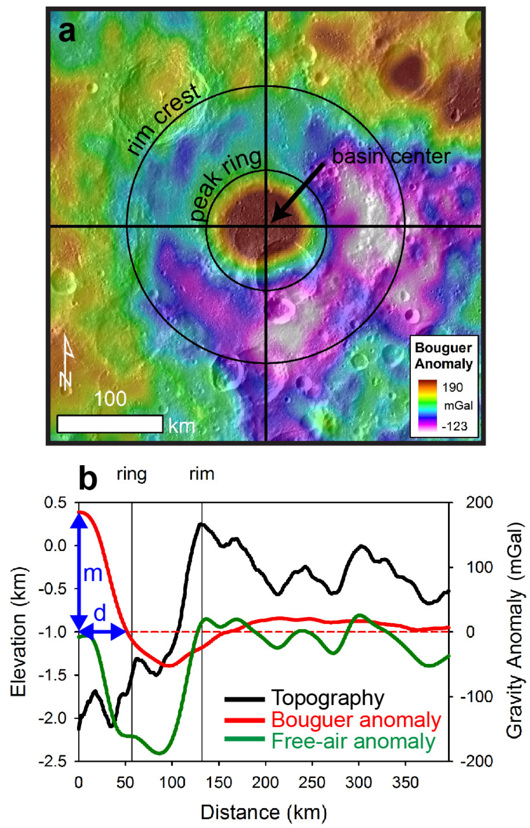


Fig. 1. The topography and gravity characteristics of Milne (264 km, 31.25°S, 112.77°E), showing characteristics typical of peak-ring basins on the Moon. a) Map of Bouguer gravity anomalies with overlays of circles fit to the rim crest and peak ring. b) Radially averaged profiles of topography and free-air and Bouguer gravity anomalies. Blue arrows and labels illustrate measurements of the maximum strength (m) and diameter (d) of the central Bouguer anomaly.

Bouguer anomaly: All 17 peak-ring basins show positive, circular, central Bouguer anomalies, which have been observed for many of the peak-ring basins by prior workers [e.g., 4,5], although at coarser spatial resolution. The maximum values of these central Bouguer anomalies increase linearly as a function of basin diameter from 25 mGal to 480 mGal (excluding Moscoviense and Coulomb-Sarton, which have extreme values for their diameters at 685 and 393 mGal) (Fig, 2a). Extrapolation of this trend predicts an absence of a positive Bouguer anomaly at a diameter of about 170 km. This is consistent with the typical lack of regular, central positive Bouguer anomalies in complex craters (maximum diameter = 205 km) [6] and protobasins (maximum diameter = 170 km). The diameters of the positive Bouguer anomalies also increase with basin size from about 50 km to 292 km in diameter (Fig, 2a). Surrounding the central positive anomalies in nearly all peak-ring basins are annuli of negative Bouguer anomalies (Fig. 1b). The strength and spatial patterns of these negative annuli are more irregular than the central anomalies but are a common characteristic of peak-ring basins. Beyond the negative annulus, anomalies are typically near zero with minor variations from basin to basin (Fig. 1b).

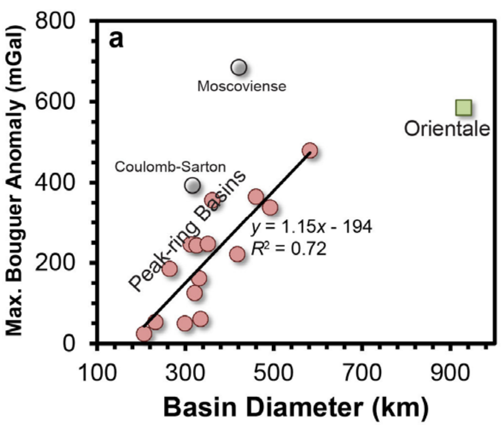
These patterns in peak-ring basins are similar to those in multi-ring basins, such as Orientale [7]. The strength and diameter of the positive Bouguer anomaly in Orientale follows the same general patterns as peak-ring basins (Fig. 2). Also distinct in Orientale is a negative Bouguer anomaly annulus.

Comparison with peak-ring morphology: The central Bouguer anomalies in peak-ring basins are largely confined to within the peak ring (Fig. 1b, 2b). Only in the largest basins (>~350 km) are positive Bouguer anomalies nearly equal to the diameter of the peak ring or exceed it by 20 to 30%. The negative Bouguer anomaly annulus reaches its minimum between the peak ring and rim crest (Fig. 1b), although it extends from the edge of the positive anomaly to slightly beyond the rim crest in many of the basins. In Orientale, the positive Bouguer anomaly is confined to within the Inner Rook ring. The negative annulus is confined to within the Cordillera ring.

Implications for the crater to basin transition: All peak-ring basins show positive Bouguer anomalies largely confined to within the peak ring, with most basins showing a negative Bouguer anomaly annulus extending to slightly beyond the rim crest of the basin. Multi-ring basins, including Orientale, show very similar gravity anomaly patterns, although with greater strength and larger spatial extents [7].

Based on our preliminary observations and those of [6], complex craters and protobasins typically do not show regular central positive Bouguer anomalies. The gravity anomaly patterns in these craters are more irregular and complex. These observations suggest that the formation of central positive Bouguer anomalies and associated negative anomaly annuli are fundamental characteristics of all basins (peak-ring basin to multi-ring basin) on the Moon. Thus, the transition from complex craters to peak-ring basins not only involves a change in interior landforms (central peak to peak ring) but also a change in crustal and mantle structure. Mechanisms for producing these gravity anomalies are still debated [e.g., 4,8,9], but a diameter threshold (~200 km) appears to be important for both the formation of peak rings and the observed gravity signatures of basins on the Moon. Determining possible relationships between peak-ring formation and the formation of positive Bouguer gravity anomalies is a goal of future research.

References: [1] Baker, D.M.H. et al. (2011) *Icarus 214*, 377–393. [2] Baker, D.M.H. et al. (2012) *J. Geophys. Res. 117*, E00H16. [3] Zuber, M.T. et al. (2013) *Science*, in press, doi: 10.1126/science.1231507. [4] Neumann, G.A. et al. (1996) *J. Geophy. Res. 101(E7)*, 16,841–16,843. [5] Namiki, N. et al. (2009) *Science 323*, 900-905. [6] Phillips, R.J. et al. (2012) *AGU Fall Meeting*, no. G32A-07. [7] Neumann, G.A. et al. (2012) AGU Fall Meeting, no. G32A-06. [8] Andrew-Hanna, J.C. (2012) *Icarus 222*, 159–168. [9] Kiefer,W.S. et al. (2012) *Early Solar Sys. Impact Bombardment II*, no. 4026.



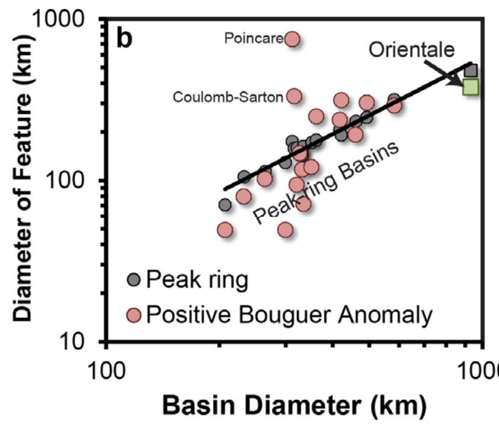


Fig. 2. Trends in central positive Bouguer gravity anomaly characteristics within peak-ring basins [1] and the Orientale multi-ring basin. a) The maximum Bouguer anomaly strength increases linearly with increasing basin size for peak-ring basins. Moscoviense and Coulomb-Sarton are excluded from the linear fit due to their extreme anomaly strengths resulting from their unique basin structures. Below a basin diameter of ~170 km, no positive Bouguer gravity is predicted. b) The diameter of the Bouguer anomaly also increases with increasing basin size. The diameters of peak rings [1] with a power-law fit (solid line) are plotted for comparison. Positive Bouguer anomalies are generally smaller that the diameters of peak rings. We assume a diameter of 930 km for Orientale, with a peak-ring diameter of 480 km (Inner Rook ring).