translation of the transient crater rim crest was relatively greater than inward translation during mega-terracing. In addition, non-proportional scaling and growth of the excavation cavity for multi-ring basin forming events could also result in the observed shallow depths.

[68] Third, mega-terracing will also reduce the height of the rim wall as the rim-crest elevation is decreased and material is compressed into the peak ring. This process will also act to decrease the h_{wall}/d ratio and increase the h_{floor}/d ratio. The reduction in the h_{wall}/d ratio of the Outer Rook ring is readily observed in Figures 10c. Expulsion of impact melt from the central portions of the basin and deposition of this melt between the Inner Rook and Outer Rook rings (section 6.5) could also act to reduce these parameters. A high h_{floor}/d ratio of about 0.5 is also observed, which is slightly greater than extrapolation of the trend of peak-ring basins (Figure 10d) and is consistent with mega-terracing or re-distribution of impact melt.

[69] Finally, the reduction of the transient crater rim-crest elevation from mega-terracing also should result in an extreme increase in the h_{pr}/d ratio, especially if the increasing h_{pr}/d trend observed for peak-ring basins (Figure 10b) is maintained for multi-ring basins. While the h_{pr}/d ratio is greater for Orientale than for the largest peak-ring basins ($\sim$0.8 compared to $\sim$0.6), this value for Orientale is less than that predicted from extrapolation of the peak-ring basin trend (this trend predicts values approaching 1.0) (Figure 10b). Thus, it appears that the peak ring of Orientale (i.e., the Inner Rook ring) has a reduced height compared to what our peak-ring basin observations would predict. A possible reason for this smaller peak-ring height is that there is a physical limit to the height of peak rings at multi-ring basin scales, possibly related to greater gravitational instability and failure of the slopes of the ring's massifs. Little terracing of the Inner Rook ring is observed, however [*Head*, 1974], suggesting that wall failure may not be contributing to this reduction in peak-ring height.

7. Conclusions

[70] Using new high-quality topographic data provided by the Lunar Orbiter Laser Altimeter, we have developed a new technique for measuring and calculating the geometric properties of impact basins on the Moon. This new method meets a number of criteria that are important to consider in any topographic analysis of craters. These criteria include using many data points over a complete range of azimuth, being systematic so that the analysis can be readily reproduced by others, avoiding subjective biases, avoiding areas that have been obviously affected by post-impact processes, and being robust with respect to the statistical techniques used for the calculation. In particular, our data more completely capture the azimuthal variation in topography that is characteristic of large impact structures. Several new geometric trends for peak-ring basins are observed:

[71] 1) *Basin depth:* There is a factor of two reduction in the depth to diameter ratio in the transition from complex craters to peak-ring basins (Figure 9a), consistent with previous observations of impact basins on the Moon. Our depth measurements suggest that there may be a steeper trend in depth and diameter than previous studies; however, the small sample size precludes a confident interpretation of this trend. The depth/diameter ratio for peak-ring basins (Figure 10a) decreases with rim-crest diameter, which may be the result of continued reduction in cratering efficiency or increase in magnitude of floor uplift.

[72] 2) *Wall height, width, and slope:* Wall height and width increase (Figures 9d and 9e), while slope decreases (Figure 9f) with increasing rim-crest diameter. The ratios of the wall width and wall height to basin depth decrease (Figures 10c and 10e) and may reflect burial of the toes of wall slump blocks from re-distribution of impact melt during collapse of the transient cavity. Expulsion of impact melt from the central portions of the basin may help explain the observed increase in the floor height to depth ratio (Figure 10d) and is consistent with observations of central depressions within the largest peak-ring basins on the Moon and Mercury [*Baker et al.*, 2011b].

[73] 3) *Peak-ring height:* The height of the peak ring increases with increasing rim-crest diameter in a manner similar to central peak heights in complex craters, although at larger crater diameters (Figure 9c). The peak-ring height to basin depth ratio also increases (Figure 10b), suggesting that floor uplift is even larger in magnitude in the largest peak-ring basins. No correlation is found between the peak-ring elevation and distance to the rim wall within a single basin (Figures 11a and 11b), suggesting that rim-wall slumping does not exhibit a large control on the topography of peak-ring basins. There is a slight correlation between rim-crest height and peak-ring height within peak-ring basins (Figure 11c), which indicates that the pre-impact surface is important in determining the final topographic characteristics of peak rings.

[74] 4) *Offset of peak rings*: Peak rings are offset from the center of the basin by an average distance of 13 km (Table 6 and Figure 12a). From the limited number of peak-ring basins analyzed, overall we find little evidence of substantial enhancement of the peak-ring elevation in the direction of peak-ring offset (Figure 12a). This may in part be a function of offset magnitude or peak-ring preservation, as most of the peak rings in peak-ring basins on the Moon are only partially complete or have been modified by superposed impacts.

[75] 5) *Basin volume*: The volumes of peak-ring basins are, on average, $\sim$40% smaller than the volumes predicted by geophysical estimates of the dimensions of their corresponding excavation cavities (Figure 13). This difference indicates that collapse of the transient cavity must result in large inward and upward translations of the cavity floor, which must be physically explained in any model for basin formation.

[76] These new observations of the geometric properties of protobasins and peak-ring basins place some constraints on the processes controlling the onset and formation of interior landforms in peak-ring basins. Reduction in the depth to diameter ratio relative to complex craters could be due to a combination of non-proportional scaling of excavation cavity dimensions at the onset of peak-ring basins and increased uplift of the basin floor. Increased impact melting and re-distribution of this melted material within the interior of the basin could account for the decreasing ratio of wall height to depth and ratio of wall width to basin radius. More rigorous tests of the processes controlling peak-ring formation should include detailed comparisons between these new geometric relationships with proposed models of peak-ring