corresponding excavation cavities. This difference indicates that collapse of the transient cavity must result in large inward and upward translations of the cavity floor. These new observations of geometric/morphometric 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. Comparisons of the geometric trends of the inner rings of Orientale basin with those of peak-ring basins are generally consistent with a mega-terrace model for the formation of multi-ring basins.

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1. Introduction

[2] Our understanding of the processes controlling the evolution of crater landforms on planetary bodies has relied on detailed morphologic and topographic analyses. It has been well documented on the Moon and the terrestrial planets that there is an evolution of crater morphologies with increasing size of the impact structure [*Baldwin*, 1963; *Hartmann and Wood*, 1971; *Howard*, 1974; *Wood and Head*, 1976]. At the largest crater sizes, complex craters exhibiting prominent wall terracing and central peaks transition to peak-ring basins characterized by a single interior ring of peaks. This transition then ends with the largest impact events, which form multi-ring basins displaying more than two concentric topographic rings. Although less numerous, additional basin morphological types in the transition from complex craters to peak-ring basins have been recognized. These include protobasins, with both a central peak and peak ring and ringed peak-cluster basins, which display ring-like arrangements of central peaks that are much smaller in diameter than those in peak-ring basins of the same rim-crest diameter [*Pike*, 1988; *Schultz*, 1988; *Baker et al.*, 2011a, 2011b]. Morphological measurements of the rim-crest and ring diameters of protobasins, peak-ring basins and multi-ring basins have provided much insight into the basin formation process [*Pike and Spudis*, 1987; *Pike*, 1988; *Alexopoulos and McKinnon*, 1994; *Baker et al.*, 2011a]. Measurements of the topographic properties of basins (e.g., depth, height of central peak and peak ring, wall height and width) have also been important in understanding the processes controlling the excavation and modification of the transient cavity during large impact events [*Pike*, 1977, 1988; *Melosh*, 1989; *Spudis*, 1993]. However, due to the limitations in the available data sets, the topographic characteristics of impact basins have historically been difficult to quantify accurately.

[3] The earliest comprehensive topographic characterizations of craters on the Moon have relied on image photoclinometry and stereo-photogrammetry [e.g., *Baldwin*, 1963; *Pike*, 1976]. More recent digital elevation models (DEMs) of the lunar surface provided by several laser rangers/altimeters have substantially improved our understanding of the topography of lunar craters. The Lunar Orbiter Laser Altimeter (LOLA) instrument onboard the Lunar Reconnaissance Orbiter (LRO) [*Smith et al.*, 2010] is currently providing global gridded topographic models of the lunar surface at a maximum resolution of 1024 ppd (∼30 m/pixel), a several orders of magnitude improvement over prior DEMs of the Moon (e.g., Clementine lidar DEMs at 8–30 km/pixel [*Smith et al.*, 1997] and DEMs from the Kaguya Laser Altimeter at ∼2 km/pixel [*Araki et al.*, 2009]). The improved resolution of LOLA is due to its relatively higher spatial density of altimetry measurements over the entire lunar globe, which is systematically improving with time in orbit. The availability of this vastly improved data set thus provides the opportunity to quantify more accurately the geometric properties of basins in the transition from complex craters to peak-ring basins and to multi-ring basins on the Moon.

[4] Here, we describe new techniques for calculating various geometric properties of basins from DEMs, such as those from LOLA. These techniques can be applied to any planetary body with high-quality DEMs and can be modified for different crater morphology classes. We concentrate on peak-ring basins and protobasins specifically, as these features have traditionally been poorly characterized due to the difficulties of obtaining accurate shadow measurements of their long-wavelength, subtle topography and because of their complex interior morphologies. Furthermore, recently updated catalogs of lunar and mercurian peak-ring basins and protobasins [*Baker et al.*, 2011a, 2011b] provide improved rim-crest and peak-ring diameter measurements that we can use as a foundation for further quantitative characterization. The goal of these analyses is to ultimately calculate a set of geometric properties for peak-ring basins and protobasins that can be used to test models of the peak-ring and multi-ring basin formation process.

2. Background on Lunar Topography Data

[5] The geometric properties of lunar craters and basins derived from topography of the Moon have been the subject of study for decades. Early comprehensive quantification of lunar crater topography used contour maps derived from photoclinometry of Earth-based telescopic images [*Baldwin*, 1963]. Subsequent orbital image data from the Lunar Orbiter in the late 1960s and images from the Apollo metric camera accompanying the Apollo missions in the 1970s, greatly facilitated new quantitative analyses of the topography of craters through photoclinometry and stereophotogrammetry (e.g., Lunar Topographic Orthomaps (LTOs), [*Schimerman*, 1973]). Measurements of the geometric properties of hundreds of fresh craters on the Moon using these improved data products were pioneered by R. J. Pike [e.g., *Pike*, 1976] and still provide the foundation for many current models of impact crater formation. However, due to the limited spatial coverage of Lunar Topographic Orthomaps and the large-scale, subtle topography of the largest craters, only the smallest craters with the best image coverage and illumination geometries could be analyzed. Thus, the geometric