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The formation of peak-ring basins: Working hypotheses and path forward in using observations to constrain models of impact-basin formation

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ABSTRACT

Impact basins provide windows into the crustal structure and stratigraphy of planetary bodies; however, interpreting the stratigraphic origin of basin materials requires an understanding of the processes controlling basin formation and morphology. Peak-ring basins (exhibiting a rim crest and single interior ring of peaks) provide important insight into the basin-formation process, as they are transitional between complex craters with central peaks and larger multi-ring basins. New image and altimetry data from the Lunar Reconnaissance Orbiter as well as a suite of remote sensing datasets have permitted a reassessment of the origin of lunar peak-ring basins. We synthesize morphometric, spectroscopic, and gravity observations of lunar peak-ring basins and describe two working hypotheses for the formation of peak rings that involve interactions between inward collapsing walls of the transient cavity and large central uplifts of the crust and mantle. Major facets of our observations are then compared and discussed in the context of numerical simulations of peak-ring basin formation in order to plot a course for future model refinement and development.

1. Introduction

Impact basins provide windows into the crustal and mantle structure and stratigraphy of planetary bodies. In order to infer the pre-impact locations of materials excavated and uplifted by basin-forming events, the processes controlling basin formation and morphology must be constrained. Peak-ring basins (exhibiting a rim crest and a single interior ring of peaks; Fig. 1c) provide important insight into the basin-formation process and into the development of peak-ring landforms. They are unique in morphology compared to complex craters with central peaks and smaller rim-crest diameters (Fig. 1a) and form the basis for understanding multi-ring basins, which occur at larger diameters (Fig. 1d). Other important crater types in this transition include protobasins, which possess both a central peak and a peak ring (Fig. 1b). There has been considerable debate on the processes controlling the formation of peak rings on the Moon and terrestrial planets (Pike, 1988; Melosh, 1989; Spudis, 1993; Collins et al., 2002; Grieve et al., 2008; Baker and Head, 2013). New image and altimetry data have permitted a reassessment of the origin of lunar peak-ring basins and their relationship to smaller complex craters and larger multi-ring basins (Baker et al., 2011a, 2012; Baker and Head, 2013). The morphometric properties of peak-ring basins on Mercury have also been described in detail (Baker et al., 2011b; Baker and Head, 2013).

Here, we synthesize these observations of lunar peak-ring basins and their implications for the physical processes operating during the formation of impact basins. We then describe two working hypotheses for the formation of peak rings that involve complex interactions between inward collapsing walls of the transient cavity and large uplifts of the crust and mantle that occur in the center of the basin. Major facets of the observations of peak-ring basins are then qualitatively compared and discussed in the context of current numerical simulations of peak-ring basin formation. The goal is to identify major gaps in knowledge between the empirical constraints summarized here and the predictions of current numerical models in order to plot a course for future model refinement and development. It is the hope that through more rigorous testing of numerical models with planetary measurements of impact craters and basins, we will greatly improve our

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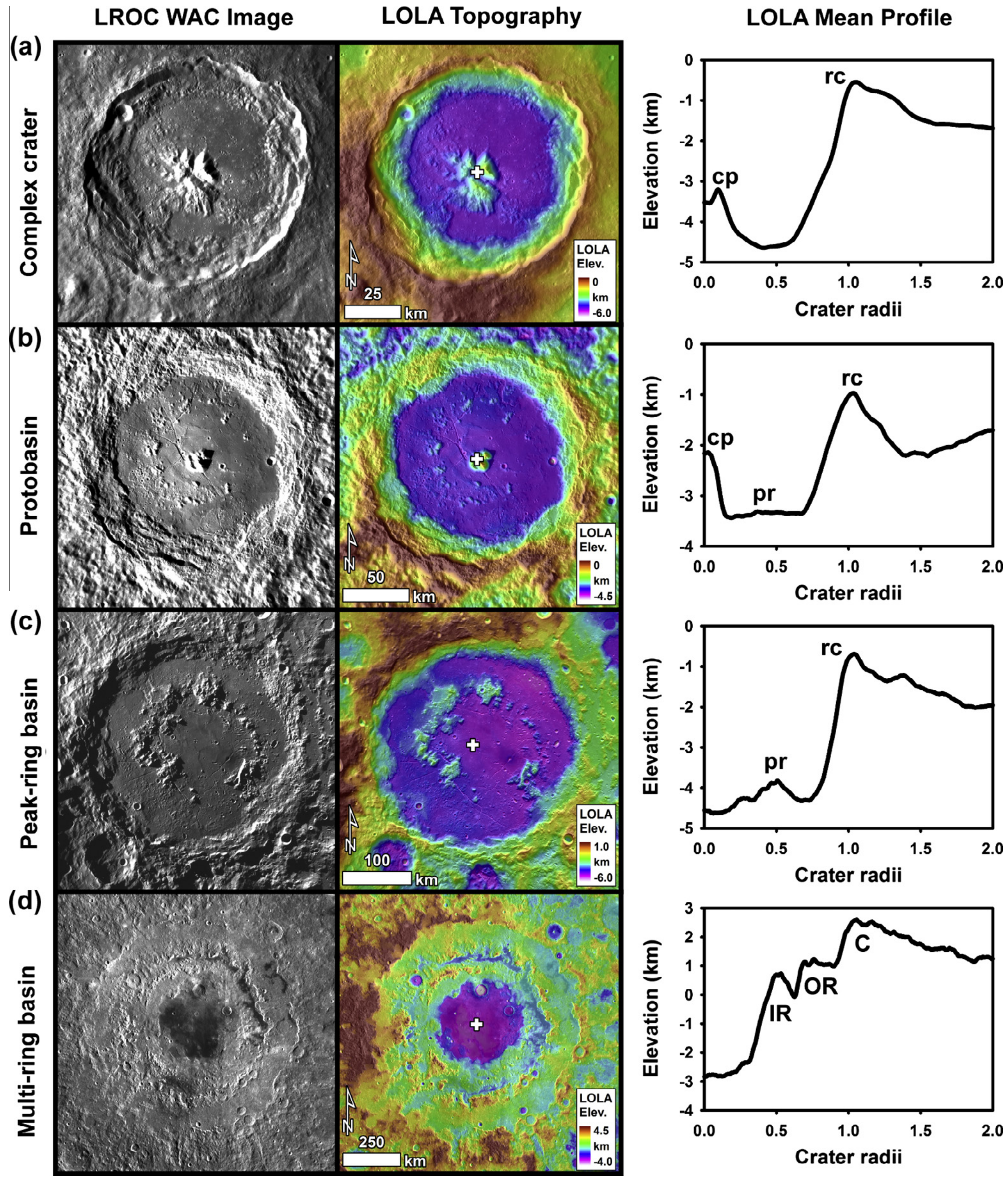

Fig. 1. The morphological transition from complex craters to multi-ring basins on the Moon. The left panels in each row show LROC Wide Angle Camera (WAC) global mosaic images. The middle panels show LOLA gridded color topography overlain on an LROC WAC global mosaic. The right plots are vertically exaggerated, radial topographic profiles for each crater or basin, presented as the mean of 360 radial profiles beginning at the center of the structure (+ mark in each map) and extending out to two crater/basin radii. (a) The complex crater, Theophilus (98 km; 11.40°S, 26.33°E), exhibiting a central peak (cp) and rim crest (rc). (b) The protobasin, Compton (166 km; 55.92°N, 103.96°E), exhibiting both a central peak (cp) and a low-relief peak ring (pr) and a rim crest (rc). (c) The peak-ring basin, Schrödinger (326 km; 74.90°S, 133.53°E), exhibiting a single ring of peaks (pr) and rim crest (rc). (d) The multi-ring basin, Orientale (930 km, 19.40°S, 265.50°E), exhibiting at least three topographic rings (IR = Inner Rook ring, OR = Outer Rook ring, and C = Cordillera ring) (Head, 1974). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

understanding of the fundamental processes that form peak-ring basins on the terrestrial planets.

2. Summary of recent morphometric observations

New topography and image data from the Lunar Reconnaissance Orbiter (LRO) Lunar Orbiter Laser Altimeter (LOLA) and Lunar Reconnaissance Orbiter Camera (LROC) have provided the opportunity to re-evaluate and expand previous efforts (Pike and Spudis, 1987; Williams and Zuber, 1998) to constrain the morphometric characteristics of peak-ring basins on the Moon. Recent work by Baker et al. (2011a, 2012), and Baker and Head (2013) have updated the catalogs of peak-ring basins and protobasins on the Moon (Table 1) and used LOLA gridded topography data to measure a number of morphometric characteristics of these basins. The Moon has 17 cataloged peak-ring basins and three protobasins (Table 1), which is among the fewest per square kilometer on any body in the inner Solar System. By comparison, Mercury has the largest populations, currently at 110 peak-ring basins and 70 protobasins (Baker et al., 2011b; Baker and Head, 2013). Measurements of their rim-crest diameters place the fifth-percentile onset diameter of lunar peak-ring basins at 227 km, which is the largest of planetary bodies in the inner Solar System (Baker et al., 2011a). Onset diameters of peak-ring basins follow a moderate inverse dependence on gravitational acceleration at the planetary body (Pike, 1988; Baker et al., 2011a), although improved correlations are observed when gravitational acceleration is combined