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Quantitative measurement method for impact basin characteristics based on localized spherical harmonics

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ABSTRACT

Characteristics of impact basins are important fundamental knowledge for assessing basin forming impacts and their influence on surficial and interior structural evolutions for lunar and planetary bodies. To estimate impact basin characteristics based on spherical harmonic expressions of topographic figures, we propose a quantitative method that we apply it to actual lunar topographic data. The estimated basin locations (center) are almost coincident with those determined by visual inspection. However, the numbers of ring structures differ from previously reported ones. The relation between the ring height and the ring diameter coincides well with those reported previously. Some older basins show discrepancies in the height/diameter relation, which probably reflect the degree of degradation by subsequent small impacts. We recognize a power law relation between the diameters of a ring and a neighboring ring structure. That relation suggests that the formation, volume and modification of the melt-cavity control the formation and size of peak-ring and multi-ring structures. These relations, which are thought to reflect the mechanism of the collapse stage of basin formation impact, provide helpful constraints for elucidating the long-standing problem of how multi-ring impact basins are formed.

1. Introduction

Impact cratering, especially when associated with large impacts such as basin-forming impacts, is an important driving force affecting surficial and interior structural (down to the upper mantle) evolutions of the Moon, planets, and satellites with solid surfaces. During cratering, the surface materials of target bodies are vaporized, melted, and displaced from their original positions. Underlying deep structures are excavated. The cratering processes of small simple craters have been well elucidated based on laboratory experiments (e.g., Oberbeck, 1971; Yamamoto et al., 2009; Hermalyn and Shultz, 2011), geological and geophysical surveys of terrestrial craters (e.g., Shoemaker, 1960, 1963; Pilon et al., 1991; Grieve and Therriault, 2004), and numerical simulations (e.g., Melosh et al., 1992). The scaling law based on the reconstruction of collapsed complex craters (e.g., Croft, 1980, 1985) and the extrapolation of trends from laboratory hypersonic impact experiments (e.g., Holosapple, 1993) have been used to estimate the dimensions of the transient and excavation cavities. Additionally, numerical modeling of basin-forming impacts (e.g., Collins et al., 2002, 2008; Ivanov, 2005) has been conducted. Nevertheless, basin-scale impact cratering remains poorly understood.

Morphological change with increase of diameter is recognized for lunar craters of which diameters are greater than 50 km (Hare and Grieve, 1982). With increasing diameter in complex craters, the central peaks transition into peak-rings, thereby reducing the resulting height-to-diameter ratio. This transition suggests that the collapse of large central peaks determines the peak-ring crater morphology (Hare and Grieve, 1982). The gravitational instability of large rebounds (Croft, 1981) and interaction of the transient cavity with the lunar Moho (Williams and Greeley, 1997) are proposed as driving forces affecting the building of peak rings. A further diameter increase shows an additional transition such as peak-ring to multi-ring structures. Several models have been proposed for multi-ring structure formation: collapse of the mantle rebound (Melosh, 1989), dynamic collapse by inward dipping normal fault systems (Croft, 1981), and their combined effects (Spudis, 1993). Recently, Head (2010) proposed a new model (nested melt-cavity model) as a collapse of impact melt cavity and transient cavity built peak-ring, and multi-ring structures. The nested melt-cavity model combines three components of the cratering process (excavation cavity, displaced zone and melt cavity) and provides a basis for ascertaining the characteristics of the transition from complex

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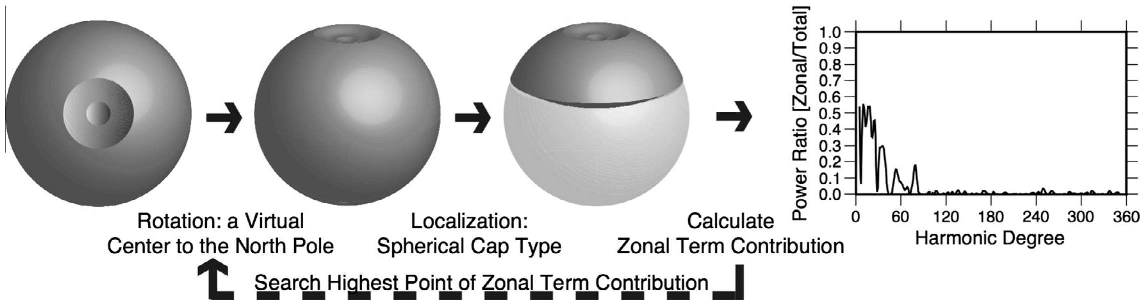

Fig. 1. Schematics diagrams showing the proposed procedure used to estimate impact-basin characteristics based on localized spherical harmonics.

craters to multi-ringed basin based on differential melt scaling (Cintala and Grieve, 1998). Small impact events did not produce a substantial volume of melting materials, so the resulting structure reflects only the excavation cavity and displaced zone. Larger and/or faster impact events produce amounts of melting materials and melt cavities nested in the displaced zone. Because of the strength difference between the melted material of melt–cavity and rocks of displaced zone, the collapse of such cavities produces peak-ring basins. With increasing impact size, the melt cavity expands and penetrates to below the basement of the displaced zone, which creates a strength discontinuity at the basement of the displaced zone and the inner, much weaker melt cavity wall, which is filled by melted materials. Then the collapse of the expanded melt cavity along faults at the basement of the displaced zone forms a multi-ring basin. In short, according to the nested melt-cavity model, the ring structure size is controlled by the scale and velocity of basin-forming impacts. Basin characteristics, such as the height/diameter ratio of basin rings and ring diameter ratio of neighboring rings, probably reflect the mechanisms of the collapse stage of transient cavity of basin formation. It is therefore the first important step to determine accurate characteristics of impact basins, such as the location of the center, the size and the ring height, and to elucidate the impact basin structure.

Visual inspection of photographs and topographic data have been important tools used to estimate the location of the center and the impact basin size (e.g., Hartmann and Wood, 1971; Pike and Spudis, 1987; Wilhelms, 1987; Wood and Head, 1976). Recently, Head et al. (2010) produced a catalog of all impact craters

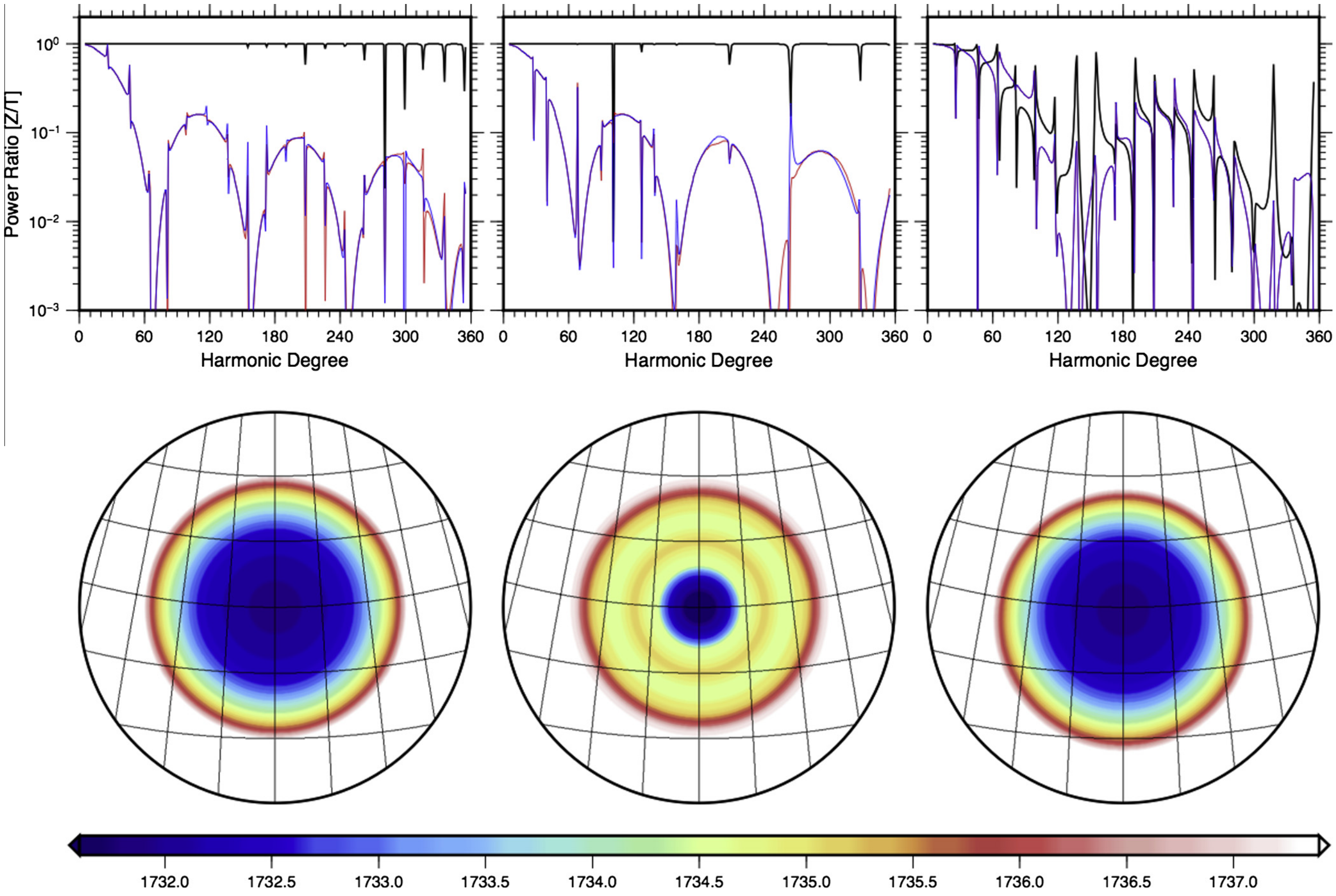

Fig. 2. Three synthetic topographies of a simple circular basin-like depression (lower left), a multi-ring basin-like depression (lower center), and an elliptic basin-like depression (lower right) of which a center or focus is located at (45°E, 45°N). Upper graphs respectively portray the zonal/total power ratios of those virtual centers of (45°E, 45°N), (45°E, 43°N), and (45°E, 47°N) cases in black, red, and blue lines. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)