PEAK-RING BASINS ON MERCURY: NEW MESSENGER DATA AND IMPLICATIONS FOR BASIN FORMATION AND MODIFICATION.

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Introduction: While there has been much progress in understanding the transition from complex craters to multi-ring basins in the past decades [e.g., 1-4], there are many outstanding questions that remain to be resolved with improved modeling and analysis of current and future planetary remote sensing datasets. These questions include: 1) What is the formational mechanism for the onset of transitional morphologies such as peak-ring basins, 2) How are basin rings emplaced with respect to the transient crater rim, 3) Are there variations in ring emplacement style throughout the inner solar system? Analysis of the characteristics of peak-ring basins (Fig. 1) is critical to understanding these questions, as they represent transitions between complex craters and multi-ring basins. Peak-ring basins, or two-ring basins, consist of an outermost basin rim crest with an interior ring of peaks or massifs (Fig. 1A). While they are present on all of the terrestrial planets [e.g., 4], Mercury has the highest density of peak-ring basins [1], and thus provides an important dataset for analyzing the questions surrounding basin formation.

Pike [2] outlined the main morphological characteristics of peak-ring basins on Mercury using image data from Mariner 10. He recognized that protobasin morphologies, exhibiting a central peak and an interior ring of peaks, are particularly well developed on Mercury. The presence of both a central peak and an interior ring suggested that the formation of the interior ring of a peak-ring basin cannot be due to a simple enlarging of a central peak [2]. Peak-ring basins also have a lower onset diameter on Mercury than other planetary bodies at about 120 to 132 km [1,2], suggesting that differences in gravity and impact velocity may have an effect on the resulting basin form.

Recent image data from the MESSENGER spacecraft flybys of Mercury have doubled our image coverage of the planet, providing nearly complete global coverage of Mercury’s surface. Many peak-ring basins, e.g., Eminescu [5] and Raditladi [6], have been recognized and can be studied and mapped in detail. This new dataset provides the opportunity to evaluate past and present observations of peak-ring basins and models of basin formation and evolution with increasing basin size. Observations of post-emplacement modification of basins are also important for recognizing how various geological processes have operated on Mercury through space and time.

We are assessing MESSENGER flyby data to compile a database of peak-ring basins on Mercury, the transitions from complex crater to basin to multi-ring basin, and processes of modification of fresh peak-ring basins.

Models of basin formation: Previous models of the transition from central peak craters to protobasins to peak-ring basins has considered a number of processes, including discontinuities of the target structure, a simple progression or expansion of central peaks with crater size, uplift of an inflection in the excavation crater profile, an impact velocity-related process, or gravity-induced uplift or collapse of the transient crater cavity [7]. A recent model by Cintala and Grieve [8], further developed by Head [9], combines a variety of recent insights on the structure of the transient cavity [3,4] and of impact melt production with increasing crater/basin size [e.g., 10]. In this model, a crater-like cavity filled with impact melt forms in the center of the transient crater and is bordered by a zone of solid target material that has experienced peak shock stresses just short of melting. As the energy of the impact increases, the melt cavity grows in size to penetrate down into the displaced zone (the area below the growing transient cavity that compresses and moves laterally away from the sub-impact point) and melts lower target material. As the transient crater rebounds, the melt cavity and bordering zone of peak shocked target material moves laterally inward and upward. Since the peak shocked target material is concentrated on the border of the weaker central melt cavity, a peak ring is predicted to form rather than a central uplift. Multi-ring basins are formed [9] when the melt cavity grows with increasing basin size to penetrate past the displacement zone and into deeper crustal material. As rebound occurs, the displacement zone is dislocated along listric faults, forming mega-terraces outward from the transient crater rim that are displaced toward the weak central melt cavity.

Testing basin formation models with peak-ring basins on Mercury: The details of the Cintala and Grieve [8] peak-ring and Head [9] basin formation models may be tested on Mercury from examination of the morphological characteristics of peak-ring basins. Quantitative characteristics of the basin rim and peak-ring diameters (Fig. 1A) are important in evaluating the role of the melt cavity in producing peak rings. Observations of Mariner 10 data of Mercury and data from the Moon have suggested that peak rings increase in diameter relative to the basin diameter with increasing basin size [1]. This phenomenon is predicted by the Cintala and Grieve [8] and Head [9] models and is in the process of being examined with the new image coverage from MESSENGER. Characterization of the spatial and volumetric dimensions of melt within peak-ring basins will also help to evaluate the significance of melt production in influencing peak-ring formation.

Insights from post-emplacement modification: Modification by superposed impacts and impact materials (Figs. 1B-C), tectonism (Fig. 1A), and infilling by volcanic material (Fig. 1D) obscures recognition of key morphological characteristics of peak-ring basins, but they may also provide clues to the spatial and temporal evolution of geological processes on Mercury. Superposed impact craters (Fig. 1C) provide windows into the composition and thicknesses of melt and basin-fill material. Superposition of crater ejecta (Fig. 1D) provides markers for relative age determinations. Multispectral images from the Mercury Dual Imaging System (MDIS) have provided evidence that a significant portion of the surface on Mercury has been resurfaced by volcanism [11]. Many basins are filled by differing volumes of smooth plains material (Fig. 1B); evaluation of whether these smooth plains represent volcanically emplaced layers is a goal of ongoing analyses. The embayment of small craters, if volcanic in origin, may provide estimates of volcanic deposit thicknesses [12]. Furthermore, tectonic processes including wrinkle ridge (Fig. 1A,D) and lobate scarp formation appear to have operated early in Mercury's history and have occurred after emplacement of smooth plains material [13]. Recognizing these relationships within basins will help to constrain the relative ages and emplacement histories of these features.

Future goals and objectives: We are in the process of characterizing and analyzing the morphological and morphometric characteristics of newly imaged peak-ring basins on Mercury (e.g., Fig. 1). Elevation data from the Mercury Laser Altimeter and image-derived topographic models of Mercury's surface will greatly aid in these analyses. This work will provide useful insights on the questions surrounding basin formation on planetary bodies, and will help to evaluate the evolution of various geological processes operating on Mercury.

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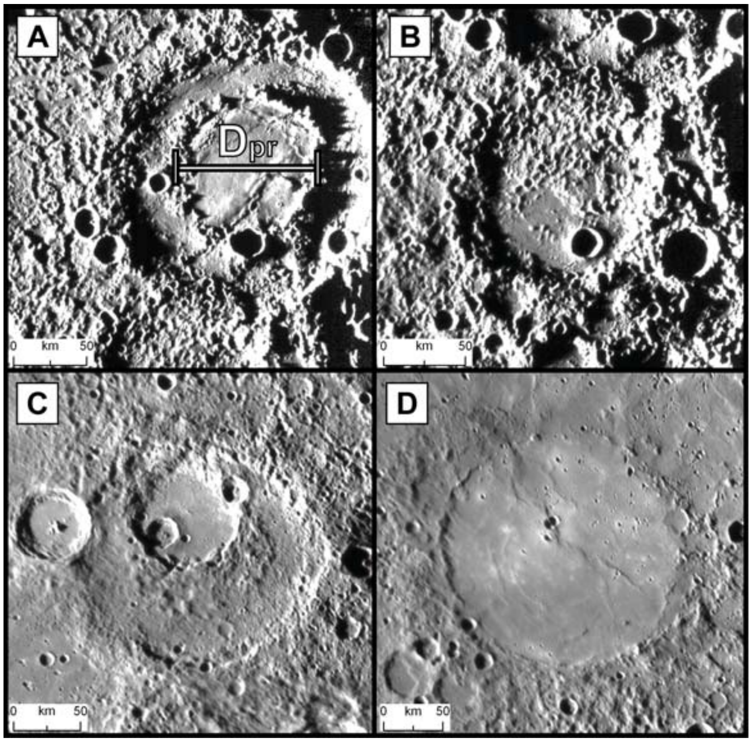

Fig. 1. Examples of peak-ring basins on Mercury, as imaged by the MESSENGER MDIS instrument during the recent spacecraft flybys of Mercury:

A) Example of a well-formed peak-ring basin with a lobate-scarp-like feature transecting the interior smooth fill material. Key to the understanding of basin formation is the diameter of the interior peak ring (D_{pr}) relative to the basin rim diameter. Basin centered at 3ºN, 87ºE.
B) The interior of this basin is infilled by ejecta (rugged terrain), obscuring recognition of a peak-ring structure. Basin centered at 0.5ºS, 86ºE.
C) A basin highly modified by superposed impact craters. A hint of a peak ring is observed in the middle of the image but is difficult to distinguish from impact material of the superposed crater. Basin centered at 29ºN, 76ºE.
D) A basin nearly completely filled by smooth material that is continuous with the surrounding plains toward the top of the image. Wrinkle ridges have modified the interior fill. A volcanic origin has been favored for similar plains material on Mercury [11,12]. Basin centered at 38ºN, 73ºE.