MORPHOLOGY OF LARGE IMPACT CRATERS AND BASINS ON VENUS: IMPLICATIONS FOR RING FORMATION.

Jim S. Alexopoulos and William B. McKinnon, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO 63130.

A nearly complete examination of the Magellan radar data for the Venusian surface reveals 72 unequivocal peak-ring craters and 4 larger structures that we interpret to be multiringed. This report updates our earlier studies and that of the Magellan team. The general morphology of peak-ring craters, decreasing ring diameter ratio trends with increasing crater diameter, and the general size-morphology progression from complex central-peak crater to peak-ring crater on Venus and the terrestrial planets suggest similar processes of peak-ring formation. Observations are consistent with a model of dynamic collapse, downward and outward, of an unstable central peak to form a ring. We interpret the four larger ringed structures (Klenova, Lise Meitner, Mead, and Isabella) to be morphologically similar to the Orientale Basin on the Moon, and thus true multiringed basins.

Peak-Ring Craters Four distinct peak-ring crater types, ranging in diameter from ~30 to 110 km, have been identified on Venus. The most common forms (types A and B), which comprise ~85% of all peak-ring craters, are generally characterized by an outer, well-defined radar-bright rim, and a continuous or partial bright inner ring of concentrically arranged peaks/ridges. Less common are types C and D. Type C are characterized by a continuous ridge-like inner ring that exhibits scarp-like attributes, whereas type D are characterized by a central region with isolated but closely clustered peaks that have a concentric ring outline.

The onset diameter to peak-ring craters on Venus was initially defined at ~40 km [1–4]. However, the complete Magellan images indicate that the onset diameter may be closer to ~30 km (Fig. 1). The inner rings of these smaller peak-ring forms are comprised of small, isolated, and concentrically arranged peaks that define both a complete and partial ring, and thus are not as distinct as the coherent ring mountains of larger peak-ring craters.

Our measurements indicate that crater-rim to peak-ring diameter ratios (D_{out}/D_{in}) are a function of crater diameter (Fig. 1). At smaller crater diameters (~30 to 35 km) ring ratios are relatively large, reaching up to ~5.2. These smaller peak-ring forms likely represent transitional forms between complex craters with central and multiple peaks and well-developed peak-ring craters. At diameters of ~40 to 70 km, ring ratios are generally larger than 2, and reach up to ~4.5. With increasing craters diameters of up to ~110 km, Venusian peak-ring craters generally show decreasing ring diameter ratios that reach, and fall below, 2.

Ring ratios also vary among the different peak-ring craters. Type A have ring ratios that range from ~1.7 to 4.9, with ~64% having ratios ≤2.5. Although type B show a similar range of ratios (~2.1 to 5.2) as type A, ratios are relatively larger (~48% have ratios ≤3.0). Type C occur over a large diameter range (~52 to 102 km), but they exhibit the most distinct ring ratios, extending over a very narrow range, from ~1.8 to 2.1. Type D exhibit a relatively wide range of ring ratios from ~2.5 to 4.0, albeit over a diameter range of only a few km (near 45 km).

There are ~22 peak-ring craters with ratios of ~2 or less, 16 of which exhibit an inner ring of isolated and concentrically arranged massifs (types A and B); i.e., they have a distinct (or partial) peak ring. The 6 others are the type C peak-ring craters, which exhibit very bright radar returns from continuous ridge-like inner ring segments.

Multiringed Basins Three larger ringed craters, Klenova, Lise Meitner, and Mead (with diameters of ~144, 149, and 270 km, respectively) are different in morphology from the peak-ring forms. Based on ring morphology, relative ring spacing, and ejecta placement, we originally interpreted these structures to be morphologically similar to the Orientale Basin, and thus multiringed basins [1–3]. A fourth crater, Isabella (~170-km-diameter), we interpret to be a degraded multiringed basin. A cycle 2 Magellan image of Meitner confirms our initial interpretation [1–3], and also reveals the presence of radar-bright returns on the darker floor, possibly from remnants of an inner peak ring. Topographic profiles of Mead clearly show a step-down topography to the basin center across each ring, the inward facing nature of the scarp-like rings, and an outward tilt of the region between the rings. These structural attributes are analogous to those observed for Orientale, and are consistent with models [5, 6] that predict ring-faulting, megaterrace collapse, and inward rotation of lithospheric blocks.

Large Non-Ringed Impact Craters To understand better the morphologic nature of the transition from complex central-peak to peak-ring crater, we have systematically analyzed 96 non-ringed impact craters with diameters $\gtrsim$ 30 km, or ~55% of all mapped craters within this size range (Fig. 2). These craters were classified as having a central peak or multiple peaks. Central-peak craters are abundant at diameters of ~30 to 40 km, become less frequent with increasing crater diameter, and then disappear at ~50-km-diameter. On the other hand, craters that

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display multiple-peak complexes are more abundant than central-peak craters at diameters of ~40 to 50 km and, as with central-peak craters, are not present above ~50-km-diameter. Three larger craters (with diameters of ~73, 63, and 60 km), which are in the size range of being peak-ring craters, are completely flooded and show no interior structure or inner ring. The Venusian data shows that complex crater morphology is a function of crater diameter (Fig. 2). With increasing crater diameter, craters generally evolve from ones with a single, central peak to forms with multiple-peak complexes, and then to peak-ring craters. Similar studies of complex central-peak craters on the Moon and Mercury [7, 8] claim that central peak complexity is irresponsive to crater size.

Interplanetary Comparisons The inner rings and crater rims of Venusian peak-ring craters are morphologically similar to the inner rings and crater rims, respectively, of peak-ring craters on the Moon, Mars, and Mercury.

The morphologic transition from complex central-peak crater to peak-ring crater is generally similar on the Moon, Mars, and Mercury, although Mars is more complicated [9, 10, 11]. The morphologic sequence with increasing diameter is craters with central peaks, to transitional forms with both a central peak and inner ring, and then to peak-ring craters [9]. Craters at or near the transition on the Moon, Mercury, and Mars exhibit both a central peak and inner ring of peaks. No craters with both a central peak and distinct peak ring have been unequivocally identified on Venus.

Ring diameter ratios for the Moon and Mercury reveal similar trends to Venus, indicating that ring ratios are generally a function of crater diameter. This trend in ring ratios is not clearly evident for Mars. The smaller ringed craters on the Moon and Mercury, with relatively larger ring ratios, are usually transitional forms with both a central peak and inner ring. Craters with both a peak and inner ring on Mars also have the largest ratios, although they are generally larger than most peak-ring craters there. On Venus, smaller peak-ring forms have complete and partial peak-rings, exhibit larger ring ratios, and thus are consistent with being transitional forms, but without a central peak.

Generally, with increasing crater diameter, ring ratios decrease to ~2 and less, central peaks disappear, and interior structures are dominated by a well-developed inner ring. These observations are consistent with peak ring formation being an extension of the central-peak collapse process.

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Fig. 1

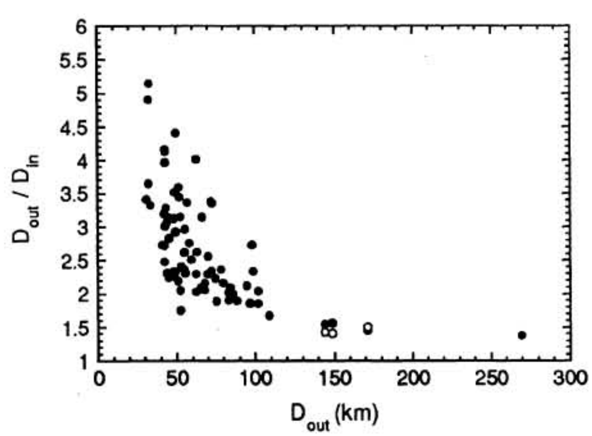

Fig. 2