THE SIZES AND NATURE OF BASIN IMPACTORS ON MERCURY AND THE MOON. P. H. Schultz, Department of Earth, Environmental, and Planetary Sciences, Brown University, 324 Book Street, Box 1846, Providence, RI 02912; peter_schultz@brown.edu.

**Introduction:** Oblique impacts map out different stages of crater formation across the surface and can reveal the controlling independent variables. Laboratory experiments allow isolating these different stages and variables, even though they cannot directly simulate a large-scale event. One critical set of variables includes impact angle and impactor size. On the planets, crater morphology and ejecta distribution can be used to constrain the size of the impacting body, independent of scaling relations [1] and provide clues to the origin of the inner rings of large basins [2].

**Background:** At large scales, early stages of crater formation become more evident due to the reduced cratering efficiency [3]. For an oblique impact, surface expressions of an evolving flow field include a migrating source region of ejecta [4], non-circular elements in crater shape [5,6], and downrange scours by the impactor [1,7]. The Imbrium Sculpture illustrates each of these signatures [1]. For sufficiently oblique angles, fragments of the impacting body begin to fail soon after first contact such that the tops and sides of the impactor scour the surface beyond the final crater rim. Back-extrapolated trends of the resulting grooves either converge beyond the uprange rim or form sub-parallel sets converging far uprange. Based on experiments and 3D hydrocode models, the width of these grooves and scours near the uprange rim can be used to constrain the diameter of the impactor. This strategy yielded a diameter of the Imbrium impactor as at least 250 km, along with estimates of 110 km, 100 km, and 45 km for Orientale, Moscoviense, and Schrödinger, respectively [1]. Here we extend this approach to basins on other bodies, compare the derived impactor diameters with the measured interior peak ring diameters, and assess predictions based on scaling relations. The onset transition in interior morphologies (such as central peaks and rings) not only depends on gravity but also impact speed [8,9,10]. Consequently, such features should be expressed in the scaling relations as well.

**Selected Basins:** By definition, such a strategy can include only those craters formed by oblique trajectories with clearly expressed impactor signatures. Nevertheless, this subset establishes a benchmark for interpreting higher angle impacts. Stereographic projections centered on selected basins on Mercury provided the base maps for determination of downrange groove trends. The selected basins included: Caloris (1250 km diameter), Rembrandt (720 km), Beethoven (640 km), Tolstoj (490 km), Vivaldi (210 km), Dürer (190 km), Wang Meng (160 km), and Valmki (97 km). The morphologies of these basins exhibit strong contrasts. An estimate for the oblique impact crater Dantu (with an elongate central pit) on Ceres was also included.

**Results:** Mapped sculpture patterns on Mercury yielded the following sizes of the impacting bodies: Caloris (525 km diameter), Rembrandt (115 km), Beethoven (246 km), Tolstoj (197 km), Vivaldi (43 km), Dürer (86 km), Wang Meng (36 km), and Valmki (23 km). Such sizes may seem large but are generally consistent with extrapolated scaling relations (Fig. 1a). Scaling relations refer to impact diameters referenced to the pre-impact surface, i.e., the “apparent” diameter, rather than the final post-collapse diameter. Here, the rim-rim diameters of each basin was reduced by 25% to account for crater enlargement by slumping and another 25% in order to adjust to the pre-impact surface. Figure 1a reveals that lunar and Mercurian basins (and Dantu on Ceres) fall on the extrapolated scaling relation for non-porous gravity-controlled targets after making small (but reasonable) adjustments for impact speed and angle.

While the inner rings of two-ring basins are easy to recognize, the correct identification becomes problematic for multi-ring structures. For this study, it is assumed that the inner, oblong wrinkle ridge system of Imbrium and the inner oblong shelf in Orientale represent the inner ring. Even then, the multi-ring basins (Rembrandt, Orientale, and Imbrium) require a much higher speed, much lower angle, or a different transient diameter in order to be consistent with the peak-ring basins in Fig.1a. If the apparent transient crater diameter for Imbrium were placed between the Montes Alpes and oblong massif ring delineated by Montes Recti-Pico-Pito, the scaling relation would hold. For Orientale, the a working diameter would correspond to a position between Inner and Outer Rooke Mountains.

The derived impactor diameter also can be compared with the inner ring diameter (Figure 1b). An average ring diameter is not assumed; rather, the physically relevant diameter is orthogonal to the trajectory, as from inferred from the morphologic signatures (ejecta and crater structure). In general, the ring-impactor diameter ratio ($D_{IR}/a$) is about 2, but impactors larger than about 100 km are consistently above the extrapolated linear trend for smaller impactors.

**Discussion:** The correlation between the inner ring diameter and observationally determined impactor diameter (Fig. 1b) is consistent with the “footprint” model of inner ring formation [2,11]. In this model, the inner ring is related to dynamic uplift of the
displaced-downward crust. For an oblique impact at 30°, the downward-directed peak pressure is reduced by a factor of four. This reduced pressure increases the role of target strength at depth, even at speeds less than 15 km/s. At higher speeds (>20 km/s), energy plays a greater role and results in loss of expression of the downward-displaced zone and the formation of central peaks. In laboratory experiments, the ratio of the edge of the downward-displaced pit is also nearly constant as a function of (v sinθ), even though the diameter and depth of the crater changes. But it also depends on the impedance ratio between the impactor and target (Ip/It). Hence, the upward offsets for the inner rings of Schrödinger, Orientale, Rembrandt, and Imbrium in Fig. 1b could represent an effect of differentiated asteroids with a higher (Ip/It). Conversely, values of low (Ip/It), such as a cometary impact, should result in smaller and poorly expressed central rings.

Implications: First, lower speed impactors may be responsible for the apparent excess of the 200-350 km diameter basins on Mercury, consistent with the observed excess of basins per unit area in this size range relative to the Moon [12]. Second, most craters post-dating the Late Heavy Bombardment on Mercury (99%) and the Moon (90%) were formed at speeds > 15 km/s, consistent with the greater abundance of central peaks. But certain craters with small, broken inner rings (e.g., Eminescu) may represent comets impacting at the lower end of expected impact speeds. The unusual Hokusai crater [13, 14] could represent an unusually slow cometary impact (<10 km/s). Third, central pit craters represent an extension of the footprint model for smaller bodies where impactor momentum, penetration depths, and dynamic response were insufficient to produce an uplifted ring but did produce downward displacement. This is consistent with oblong central pits in oblique impacts and double pits in simultaneous impacts [8]. Fourth, the bi-modal distribution of impact speeds on Mars [15] would produce a population of craters of the same size with central peaks, central pits, and central rings in the same terrains [16, 17].