3-D MORPHOMETRY OF MARTIAN SECONDARY IMPACT CRATERS FROM ZUNIL & GRATTERI

W. A. Watters (**wwatters@wellesley.edu**), A. C. Radford; Dept. Astronomy, Whitin Observatory, Wellesley College

We present a statistical study of shape characteristics measured from 3-D elevation models of secondary impact craters on Mars, focusing on clusters of secondaries from the geologically recent impacts that formed Gratteri (D = 6.9 km) and Zunil craters (D = 10.4 km). We find that proximal secondaries (downrange distance r < 250 km, impact velocity v < 1 km/s) are sufficiently well-preserved to exhibit the expected features of low-velocity splash craters. More distal secondaries (r > 600 km, v > 1.5 km/s) exhibit mean depth/diameter approaching values typical of fresh primary craters.

Characterizing the shapes of fresh and modified secondaries may assist with understanding the contribution of secondaries to the cratering record and the estimation of surface ages [1]. Secondary craters on Mars and the Moon can be used to test ideas about how impact crater morphology depends on impact energy [2]. Secondaries can also be used to estimate rates of modification in different materials and geological settings, since any given population of secondaries formed at the same time [3].

Methods. Populations of secondary impact craters were identified in THEMIS images as belonging to distinct crater rays radiating from Gratteri and Zunil craters [3, 4, 5], and captured by overlapping HiRISE images [6]. Elevation models were generated from cropped HiRISE stereo images of the craters using the Ames Stereo Pipeline [7] after the images were radiometrically calibrated, mosaicked, and map-projected using USGS's ISIS software. Crater rim crests were traced automatically using in-house Python scripts that find the maximum elevation along radial profiles, bridging discontinuities by following ridges of local maxima.

We compute the distributions of four quantities: (1) “Tallest rim azimuth”: the azimuth of the line connecting the geometric center of the rim crest outline to the tallest position on the rim. In low-angle splash craters, this azimuth normally points downrange [8]. (2) “Bottom-center azimuth”: the azimuth of the line connecting the geometric center of the rim crest outline to the crater's lowest point. In low-angle splash craters, this azimuth points uprange [Ibid.]. (3) Major axis orientation: the orientation (-90° to 90°) of the major axis of an ellipse that has been fitted to the rim crest outline. In splash craters, rim planforms are usually aligned with the direction to the source crater. (4) We also compute the average crater depth/diameter ratio (d/D), where the depth is maximum crater depth (below ambient surface) plus the average rim height.

Results. Figures 1 through 3 show rose histograms for the three directional quantities described above as measured for a cluster of N = 370 secondary craters in a ray emanating from Gratteri Crater, where a thick dashed line indicates the direction to Gratteri itself. In this cluster, all three distributions have an excess of counts in the direction anticipated for splash craters [8]: that is, the morphological signature of the impact azimuth has been preserved, in a statistical sense.

Fig. 4 shows d/D computed for different clusters of secondaries as a function of increasing downrange distance from Gratteri and Zunil. As expected, d/D increases with downrange distance r. If the most distal population on this plot has been correctly identified as Zunil secondaries (PSP_006762_1840), neglecting atmospheric drag and assuming ejection angles of between 30° and 45° we find that d/D approaches 0.2 for impact velocities as small as v ~ 1.5 km/s.

The deepest craters in Fig. 4 (largest d/D) describe an “envelope” of the d/D vs. r relation. If such a relationship can be established for the most pristine secondary craters in typical surface materials, then this along with estimates of source crater age might be used to estimate an upper bound on local rates of crater modification in the recent past.

Rays of secondary craters present a natural experiment that can be used to examine how d/D and other shape characteristics depend on downrange distance (and impact velocity) [2]. The relationships discussed earlier for the proximal (r < 250 km) Gratteri secondary craters are not clearly visible in the Zunil populations, some of which are only slightly more distal. This may be a consequence of the slightly larger expected impact velocity, or may relate to the effect of materials in which the craters formed or else the different amounts of time elapsed since the source crater formed, or different rates of erosion and burial.

Going forward, this work will address the dependence of downrange distance for other shape characteristics such as planform asymmetry, rim roughness, and cavity and ejecta shape and volume. With the advent of LROC stereo imagery, a similar analysis can be carried out for relatively fresh lunar secondaries in future.

References: [1] Calef, F.J. et al. *JGR* 114, 2009; [2] Pike, R.J., D.E. Wilhelms, *LPSC 9*, pp. 907, 1978; [3] Preblich, B.S., et al., *JGR* 112, 2007. [4] McEwen, A. et al., *Icarus* 176, pp. 351, 2005; [5] Tornabene, L. et al., *JGR* 111, 2006; [6] McEwen, A. et al., *Icarus* 205, pp. 2, 2010; [7] Moratto, Z., et al., *LPSC 41*, abs #2364, 2010; [8] Roberts, W., *Icarus* 3, pp. 348 (1964)

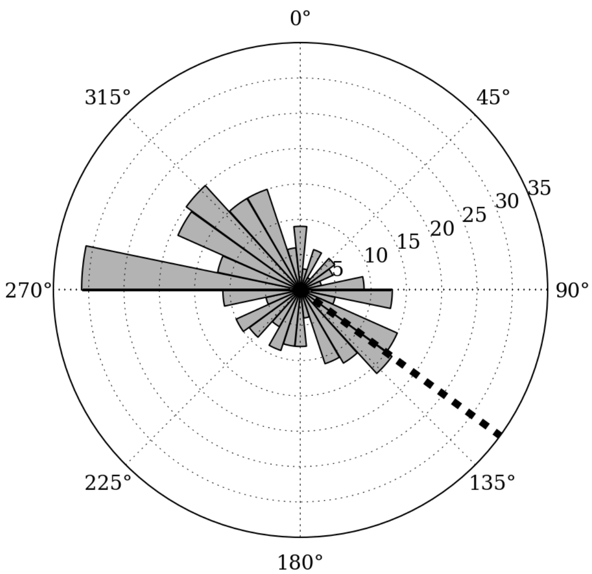

Fig. 1: "Tallest-rim azimuth": direction from geometric center of rim crest outline to the highest position on the rim. The rim is statistically taller in the downrange direction, as expected. (Population of 370 secondaries from Gratteri crater, HiRISE ESP_020922_1635.)

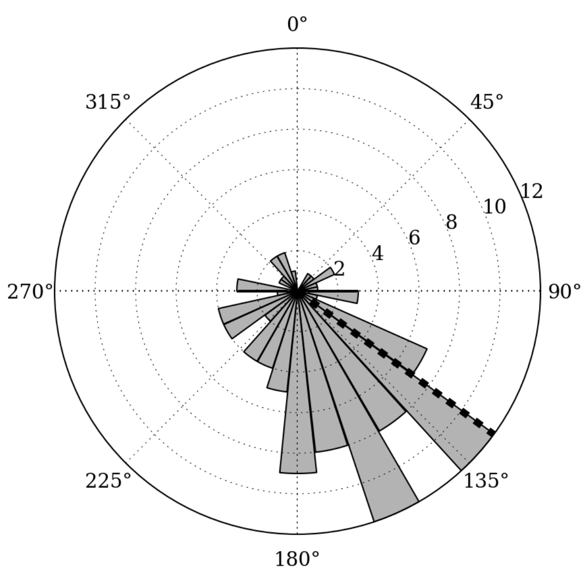

Fig. 2: "Bottom-center azimuth": direction from geometric center of rim crest outline to point of deepest crater cavity elevation (subset of population in Fig. 1). This rose diagram indicates that the craters are lopsided, with the deepest point uprange of the planform center, as expected for splash craters.

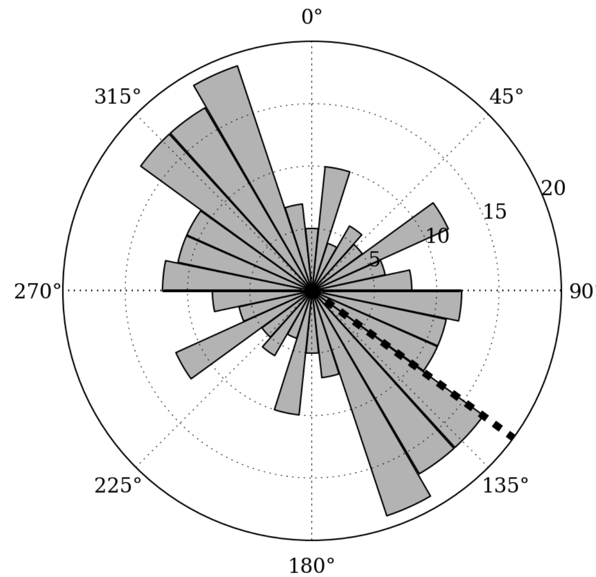

Fig. 3: Major axis orientation is preferentially aligned with the impact azimuth, as expected (subset of population in Fig. 1.)

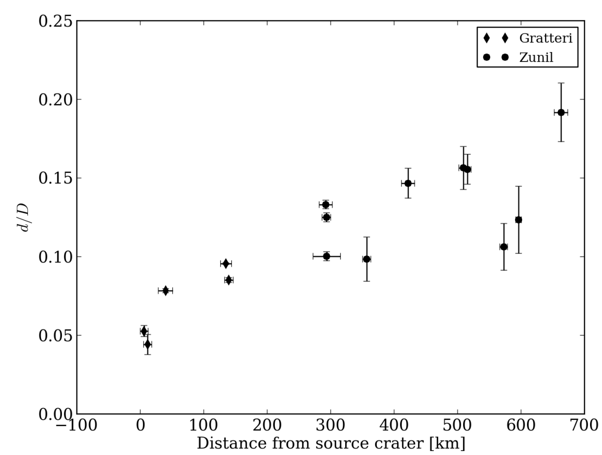

Fig. 4: Average depth/diameter for populations of secondary impact craters versus distance from source crater. A downrange distance of 250 km corresponds to an impact velocity of ~1 km/s, and 600 km to ~ 1.5 km/s. Vertical error bars represent uncertainty of mean values of *d/D*. Horizontal error bars represent standard deviation of downrange distances of craters in each population.