DETAILS OF THE MOST OBLIQUE MARTIAN IMPACT CRATERS R. R. Herrick, Geophysical Institute, University of Alaska Fairbanks, 903 Koyukuk Dr., Fairbanks, AK 99775-7320 (rherrick@gi.alaska.edu).

Introduction: In previous work the global imagery from Viking was surveyed to compile a database of oblique impact forms with diameter D > 5 km for the northern hemisphere of Mars and to infer the impact angles represented by those different forms [1]. That work found that, although the craters have ramparts indicative of surface flow, the planforms of the ejecta are similar to the dry-vacuum ballistic patterns for experimental and lunar craters [2,3]. The Martian planforms are very different from those produced in the presence of a dense atmopshere in the laboratory and on Venus [3,4]. The impact angles at which the Martian planforms occur also matched closely with those observed in dry-vacuum conditions [1]. These results suggested that Martian crater ejecta are first ballistically emplaced. Ramparts then form as a result of modest, post-emplacement flows that preserve the basic ejecta planform [1]. Here I focus on some of the details of the oblique impacts as observed with THEMIS imagery and MOLA altimetry.

Methodology: We looked in detail at the oblique impact forms using THEMIS visible and infrared imagery. The former typically provides about 20% coverage of a crater at ~20 m resolution, while the latter has nearly universal coverage at ~100 m resolution (Viking imagery is ~250 m resolution). The daytime IR imagery closely resembles a panchromatic visual image, and that data were the most valuable in our analysis. It is necessary to coregister and overlay the individual MOLA footprints with the imagery in order to observe whether such features as the rim or floor have been adequately sampled. In some cases, particularly for the smaller craters, the sampling by MOLA was inadequate to fully evaluate important details such as downrange versus crossrange rim heights or whether interior slopes vary relative to impactor direction.

General results: For all observables there were no apparent deviations from an axisymmetric form for the crater rims or interiors except for "butterfly" craters. These observables include topographic parameters such as depth and rim height. In other words, while the ejecta becomes increasingly asymmetric as impact angle decreases, the rim and interior are indistinguishable from the vertical case until the shape becomes noncircular. This is significantly different from lunar and Venusian craters, where the appearance of an uprange "forbidden zone" is accompanied by a significantly lower uprange rim [3]. Variations in impact angle produced no differences in the transition diameters for interior complexity (e.g., central peak onset, terracing). Also, although the planforms of the ejecta for oblique impacts were different, there was nothing unusual about the thicknesses of the ejecta layers or the ramparts for the oblique forms.

We saw no occurrence of different crater forms being preferentially single-layered, double-layered, or multiple-layered according to the classification scheme of [5]. We reclassified many of the craters in [6] from single-layered to double-layered after examination utilizing THEMIS imagery; in several cases erosional remnants from a second layer were evident in the THEMIS imagery but not in the Viking imagery ([7] also noted reclassifying many craters with the THEMIS imagery).

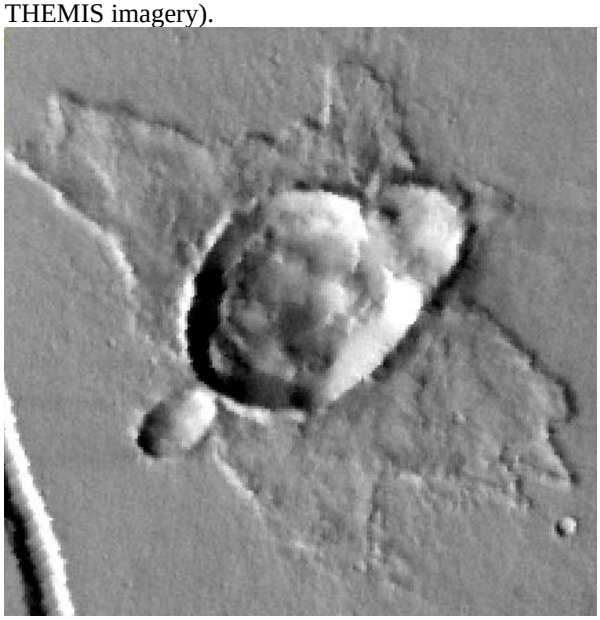

Figure 1. THEMIS daytime IR image of apparently pristine butterfly crater with a short ejecta blanket, uprange crater interpreted to be a companion fragment, and downrange end perhaps blown out by ricochet; projectile traveled towards upper right corner (13.2 N, 289.6 E, D = 10.5 km, rim-floor depth 900 m).

Butterfly craters: There were several particularly interesting observations for the handful of "butterfly" craters observed:

There appears to be a progression regarding what we interpret to be ricocheted material. Also sometimes referred to as impactor decapitation, some of the impacting material effectively skips off the surface after the first impact and then impacts a second time downrange. The progression is from the ricochet creating a nearly separate crater downrange (e.g., see abstract by Chappelow and Herrick, this volume), to interrupting

development of a downrange rim (Figure 1), to being entirely contained within the crater. There are no apparent ejecta flows emanating from the extension of the crater structure associated with the ricochet. Associated with the progression in rim planform is a transition from an avoidance zone that extends straight from the rim to the presence of a small lobe of downrange ejecta. This transition may reflect the influence of the ricochet material on the ejecta emplacement process.

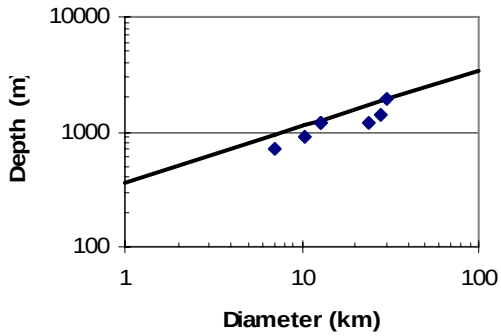

Figure 2. Rim-floor depths of fresh butterfly craters compared to global fresh-crater trend of [8].

Rim-floor depths for the butterfly craters were consistent with those for the general fresh crater population [8] (Figure 2). As with lunar and Venusian craters [3], we find the crossrange rim heights to be consistent with those for near-vertical impacts. However, unlike those bodies, there usually is an uprange and downrange rim in Martian butterfly craters. The uprange rim is always as high or higher than the downrange rim, and they are typically about half the crossrange rim elevations. Also, for a couple of craters with particularly favorable MOLA coverage we were able to discern an uprange steepening and downrange shallowing of interior slope, properties observed in experimental impacts [2] but not in lunar craters [3].

There are interesting changes with increasing crater diameter that are observable in the butterfly craters. The ejecta lobes of the two smallest butterfly craters (D < 11 km) have very irregular boundaries (e.g., Figure 1). This may be because we are seeing only the inner lobes of an eroded double-layered crater, and these should be more irregular than the outer lobes; however, the crater in Figure 1 appears to be relatively pristine. The three largest butterfly craters (D > 25 km) have an interior structure that includes a linear ridge that is subparallel to the major axis of the crater rim. At ~150 m in elevation these ridges are consistent with central peak heights for similar sized high-angle impact craters. In one case this interior ridge truncates at the crater wall, and yet there is no expression of the ridge exterior to the crater (Figure 3). This suggests that there is a sharp lateral transition from the interior collapsed/rebounded material in a complex crater to the undisplaced surrounding strata.

Finally, two of the butterfly craters appear to have small uprange companion craters (Figure 1 and abstract by Chappelow and Herrick, this volume) that we interpret as resulting from the impact of a fragment of the primary meteoroid.

Summary: The unusual rim topographies of Martian oblique impact craters relative to lunar, Venusian and experimental dry-vacuum craters are perhaps the most unexpected observations. They apparently reflect the influence of unique near-surface Martian crustal properties on crater excavation/modification, but the nature of that influence is unclear.

References: [1] Herrick R. R. and Hessen K. (2006) *MAPS 41*, 1483-1495. [2] Gault D. E. and Wedekind J. A. (1978) *Proc. LPSC 9th*, 3843-3875. [3] Herrick R. R. and Forsberg-Taylor N. K. (2003) *Met. and Plan. Sci., 38*, 1551-1578. [4] Schultz P. H. (1992) *JGR, 97*, 16,183-16,248. [5] Barlow N. G. (2000) *LPSC XXXI*, Abs. #1475. [6] Barlow N. G. and Bradley T. L. (1990) *Icarus* 87:156-179. [7] Barlow, N. G. (2005) *LPSC XXXVI*, Abs. #1415. [8] Garvin J. B. et al. (2003) *6th Intl. Conf. Mars*, Abs #3277.

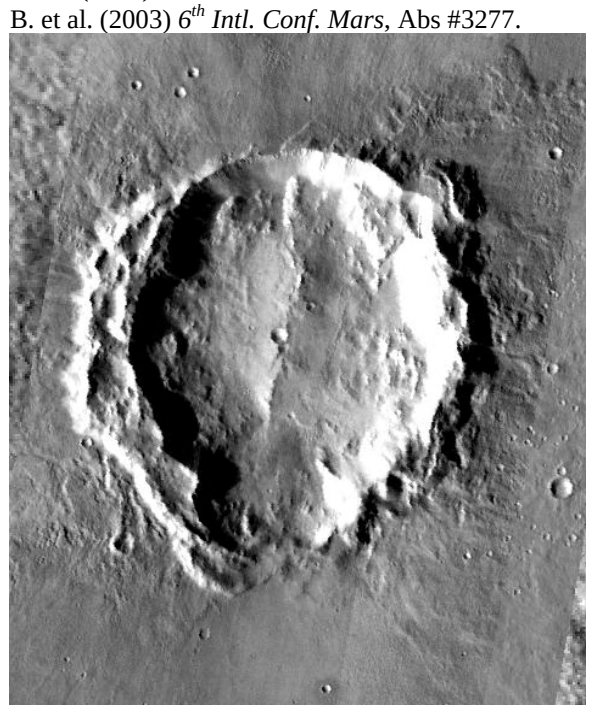

Figure 3. Interior of butterfly crater at 29.7 N, 87.3E, D=31 km. Projectile traveled top to bottom. The interior ridge truncates against the uprange crater wall but has no exterior surface expression. Rim-floor depth is 1950 m, central ridge is 150 m high, crossrange rim height is 800 m, uprange rim height is 400 m, and downrange rim height is 150 m.