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

Introduction: Previously we had used the global imagery from Viking to compile a database of oblique impact forms with diameter D > 5 km for the northern hemisphere of Mars [1,2]. We 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 [3,4]. The martian planforms are very different from those produced in the presence of a dense atmopshere in the laboratory and on Venus [4,5]. 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 [2].

Since last year's *Workshop on the Role of Volatiles and Atmospheres on Martian Craters* [2] I have focused on looking at oblique impacts with THEMIS imagery and MOLA altimetry. Here I summarize some of the observations.

Updates from the THEMIS imagery: We looked in detail at the oblique impact forms in our database 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. Figure 1 shows the improvement in resolution shows a typical example of the improvement in resolution from the Viking to THEMIS imagery.

Some of our general observations are as follows:

- We saw no differences between crater types in the transition diameters for interior complexity (e.g., onset of central peaks, terracing).
- Other than radial ridges in some of the butterfly craters (discussed below), there were no consistent deviations from an axially symmetric crater interior for the different crater forms.
- We saw no occurrence of different crater forms being preferentially single-layered, double-layered, or multiple-layered according to the classification scheme of [6]. We reclassified many of the craters in [7] 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 ([8] also noted reclassifying many craters with the THEMIS imagery).
- For all but the craters with a "butterfly" ejecta planform, the rims are circular.

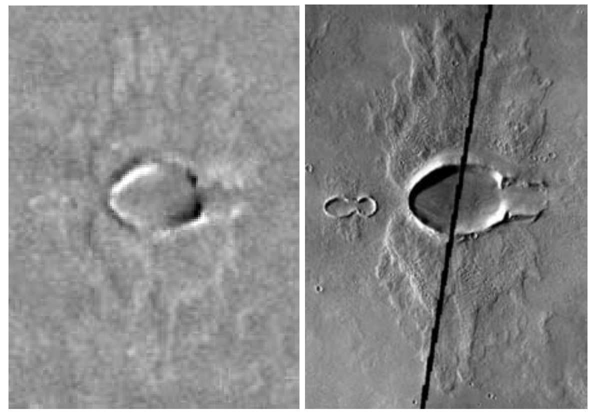

Figure 1. Crater at 40.5 N, 222.5 E, D = 12 km, shown in Viking (left) and THEMIS (right) imagery. This butterfly crater has a small uprange (to the left) companion crater interpreted to result from impact of a fragment from the primary meteoroid. Both the main crater and its companion show evidence of "ricochet" material forming a nearly separate downrange crater. Note that the ricochet craters do not appear to have an associated rampart.

Butterfly craters: There were a few 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, to interrupting development of a downrange rim, 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. Butterfly craters always have an uprange rim, but in some cases they lack a downrange rim in the area we interpret to be affected by ricochet.

There are also interesting changes with increasing crater diameter that are observable in the butterfly craters. The ejecta lobes of the two smallest butterfly craters (D < 10 km) have very irregular boundaries. 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 2 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. 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) that we interpret as resulting from the impact of a fragment of the primary meteoroid.

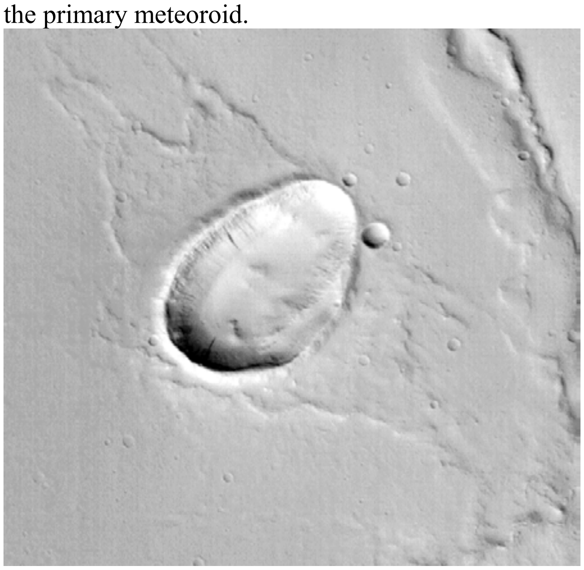

Figure 2. HRSC image of apparently pristine butterfly crater with a short ejecta blanket (21.6 N, 280.8 E, D = 7 km).

MOLA topography: In studying the oblique forms 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 only a few cases do MOLA tracks optimally cross the crater rim or floor in the crossrange or downrange direction, and in no cases for both directions in the same crater. This difficulty combined with erosional effects makes it difficult (impossible?) with MOLA data to assess how absolute fresh-crater geometry varies with impact angle (e.g., does the depth-diameter ratio change with decreasing impact angle). I hold out some hope that HRSC data may be useful for this, and it will certainly allow better assessment of crossrange rim height.

I am still organizing and clarifying the observations with the topography, but there are a few general observations:

- Except for possibly where ricochet has "blown out" the end of the crater, there is always some uprange and downrange rim, and in most cases this is a few hundred meters high. In one case, however, the uprange and downrange rim was only tens of meters in height.
- With the possible exception of a blown out end, I could detect no variation in interior slope relative to impactor direction.
- I have one good profile across a crater with a radial ridge (see above), and the ridge rises ~200 m from what appears to be the original floor surface for a crater with a major axis of 35 km (terrain-floor depth 700 m, rim-floor 1100 m).

References: [1] Herrick R. R. and Hessen K. (2003) *LPSC XXXIV*, Abs. #2122. [2] Herrick R. R. (2005) *The Role of Volatiles and Atmospheres on Martian Impact Craters*, Abs. #3019. [3] Gault D. E. and Wedekind J. A. (1978) *Proc. LPSC 9th,* 3843-3875. [4] Herrick R. R. and Forsberg-Taylor N. K. (2003) *Met. and Plan. Sci., 38*, 1551-1578. [5] Schultz P. H. (1992) *JGR, 97,* 16,183-16,248. [6] Barlow N. G. (2000) *LPSC XXXI*, Abs. #1475. [7] Barlow N. G. and Bradley T. L. (1990) *Icarus* 87:156-179. [8] Barlow, N. G. (2005) *LPSC XXXVI,* Abs. #1415.

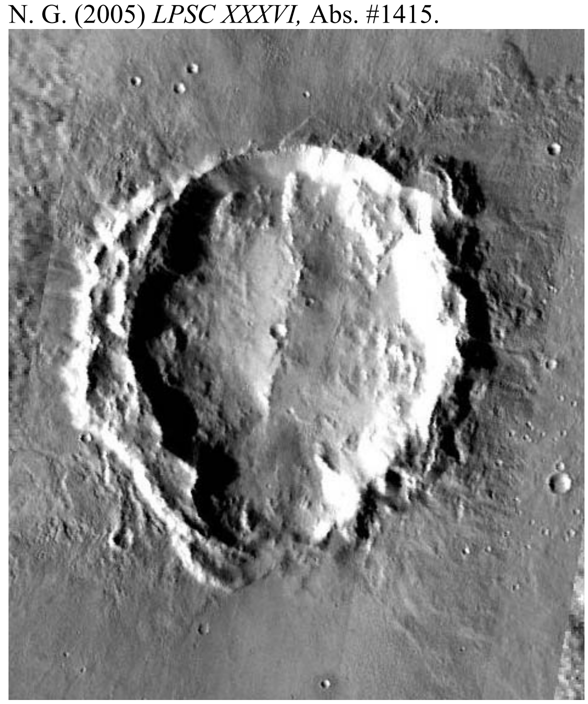

Figure 3. Interior of butterfly crater at 29.7 N, 87.3E, D=31 km. The interior ridge truncates against the crater wall but has no exterior surface expression.