THE IMPACT ANGLES OF DIFFERENT CRATER FORMS ON MARS. R. R. Herrick and K. Hessen (Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058; Herrick@lpi.usra.edu).

Introduction: Previous surveys have been conducted of the Venusian and lunar impact crater populations in an effort to empirically determine the onset angle of various oblique impact forms. Those surveys showed a general consistency with predictions from small-scale experiments [1,2,3]. That previous work also showed that in the presence of a dense atmosphere the onset angle increases for various phenomena, and ejecta is carried downrange in a turbulent cloud. A weakness of the previous surveys was the small numbers of craters sampled. Venus has a young surface and the dense atmosphere prevents small craters from forming. Space weathering and gardening on the mooon make it difficult to discern the distal ejecta for all but the most recent impacts. On Mars there are hundreds of well-imaged craters located on flat surfaces, and ejecta blankets are easy to distinguish because they are emplaced as ramparts. We have surveyed Martian craters over a large size range to empirically determine the angles for which various phenomena occur.

Procedure: Using Viking imagery we surveyed a total of 466 impact craters in the northern plains of Mars from 1 – 128 km in diameter. Craters over 5 km were analyzed using the global MDIM at a resolution of 231 m/pixel, and the smaller craters were analyzed using the high-resolution MDIMs at 58 m /pixel. Five distinct ejecta planform types were observed. Assuming that increasing ejecta asymmetry indicates decreasing impact angle, the categories in order of decreasing impact angle are as follows:

- **Symmetric** craters have circular crater shapes and no obvious impact direction. The ejecta blanket is equal in size and shape in all directions.
- **Offset** craters have circular crater shapes. They have asymmetric ejecta blankets that have either a lack of (but not absence of) ejecta in the uprange direction or a surplus of ejecta in the downrange direction. The crater rim is not centered in the ejecta blanket, it is offset in the uprange direction.
- **Forbidden Zone** craters have circular crater shapes. These craters have asymmetric ejecta blankets with an absence of ejecta in the uprange impact direction, often in the shape of a V. They may or may not have a surplus of ejecta in the downrange impact direction.
- **Crossrange Lobe** craters can have either circular craters or craters that are slightly elongate in the impact direction. Ejecta material is mainly concentrated perpendicular to the impact direction in two crossrange lobes. Small amounts of ejecta still appear uprange and downrange of the crater.
- **Butterfly** craters are often, but not always, elongate in the impact direction. Two distinct forbidden zones appear uprange and downrange of the crater. All of the ejecta is located perpendicular to the impact direction in a "butterfly wing" pattern.

These categories are essentially the same as those illustrated in a preliminary study [4]. Schultz and Lutz-Garihan conducted a global survey of Martian craters that searched for only the most highly oblique impacts [5]. Their highly oblique impacts fall into the "cross-range lobe" and "butterfly" categories. Because we required a well-preserved ejecta blanket, all of their Category 1 preservation-state craters are in our survey, and a few Category 2 and 3 craters are in our survey. There were 22 craters in their survey that overlapped with our survey; 18 were too degraded for us to use, 2 were cross-range lobe, and 2 had butterfly ejecta patterns.

Results: Table 1 summarizes the results for our survey along with previous survey results for Venus and the moon [2]. We show results for all the craters, and craters divided by diameter into those above and below 8 km in diameter. In one column of Table 1 we assign impact angles based on the well known formula that the percentage of impactors below a given angle θ is $\sin^2\theta$ [6]. When applied to a crater distribution the actual impact angle is probably overestimated, as the $\sin^2\theta$ dependence does not account for any decrease in crater size with decreasing impact angle.

Table 2 shows the survey broken into factor of 2 diameter bins.

Conclusions: In terms of both the planforms of the ejecta blankets and the percentage of craters with each planform, the Martian craters are much more similar to lunar craters than Venusian craters. This suggests that the atmosphere plays a minimal role in the excavation process for Martian craters. The observations seem to require that the air shockwave associated with the incoming projectile does not affect ejecta emplacement.

Our survey is consistent with [5,7] that show about 5% of the craters having planforms attributable to the lowest impact angles, similar to the lunar survey but higher than predicted by [1]. Ejecta planforms for smaller craters on Mars are similar to larger craters, but our survey shows a distinctly lower percentage of craters with nonsymmetric planforms. Further analysis is required to explain this observation.

References: [1] Gault D. E. and Wedekind J. A. (1978) *Proc. LPSC 9th,* 3843-3875. [2] Schultz P. H. (1992) *JGR, 97,* 16,183-16,248. [3] Herrick and Forsberg-Taylor (2003) *Met. and Plan. Sci., in press*. [4] Herrick R. R. and Shanteau R. L. (2001) *LPSC XXXII*, abs. #1909. [5] Schultz P. H. and Lutz-Garihan A. B. (1982) *Proc. LPSC 13th, JGR, 87*, A84-A96. [6] Shoemaker E. M. (1962) *Physics and Astronomy of the Moon*, 283-251. [7] Bottke W. F. et al. (2000) *Icarus, 145,* 108-121.

Table 1. Angular distribution of crater forms.

Category	Count	Fraction of Craters	Onset angle Cum% = $\sin^2\Theta$	Expected onset angle
Martian craters - All				
butterfly	6	0.01	7	
crossrange lobes	15	0.03	12	
forbidden zone	35	0.08	20	
offset	119	0.25	38	
symmetric	291	0.62	90	
total	466			
Martian craters > 8 km diameter				
butterfly	4	0.01	6	
crossrange lobes	14	0.04	13	
forbidden zone	29	0.09	22	
offset	94	0.28	40	
symmetric	196	0.58	90	
total	337			
Martian craters < 8 km diameter				
butterfly	2	0.02	7	
crossrange lobes	1	0.01	9	
forbidden zone	6	0.05	15	
offset	25	0.19	31	
symmetric	95	0.74	90	
total	129			
Venusian craters > 30 km diameter				
fly-wing	5	0.04	12	10
quadrant missing	17	0.14	25	20
notch	31	0.26	42	30
offset	30	0.25	56	50
symmetric	37	0.31	90	90
total	120			
Clementine - mare craters > 5 km diameter				
butterfly	3	0.03	11	5
forbidden zone	16	0.19	28	20
offset	21	0.24	43	45
symmetric	46	0.53	90	90
total	86			

Notes: All angles with respect to horizontal; expected angle from experimental work in [1,2]; data for lunar and venusian craters from [3].

Table 2. Distribution of Martian ejecta planforms divided by diameter ranges.

Diameter (km)	total # of craters	symmetric	offset	forbidden zone	crossrange lobes	butterfly
1-2	21	16	3	1	0	1
2-4	19	15	2	1	0	1
4-8	89	64	20	4	1	0
8-16	216	134	54	19	6	3
16-32	105	52	37	7	8	1
32-64	13	7	3	3	0	0
64-128	3	3	0	0	0	0