MARTIAN IMPACT CRATER EJECTA TOPOGRAPHY AS MEASURED BY THE MARS ORBITER LASER ALTIMETER (MOLA).

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The morphology of the ejecta deposits associated with martian impact craters appears to correlate with changes in target mechanical properties, possibly associated with subsurface volatiles [1-8]. With the availability of Mars Orbiter Laser Altimeter (MOLA) topographic transects for a significant sample of impact craters largely in the Northern Hemisphere of Mars, it is now possible to consider detailed geometric aspects of ejecta blankets,and whether this new information supports the target volatile hypothesis. Here we consider the topology of ejecta blankets using the MOLA-derived topographic cross-sections as boundary conditions. Our initial emphasis is on characterization so that one and two-dimensional flow models can be used to investigate ejecta blanket emplacement and modification.

MOLA sampled 165 impact landforms during its initial data acquisition operations in Sept. - Nov., 1997 [9]. Of these, approximately 17 craters were effectively bisected with the MOLA topographic profiles acquired, an another 30 were within ~ 20% of the centerline. Using these craters, we have carefully measured the volume of the topographically-defined continuous ejecta blanket (CEB) using numerical integration of the MOLA profile data, as well as a radial ejecta thickness function (te) defined as follows:

$$te = a(x/Ra)^b \qquad (1)$$

where x is the dependent or radial variable, Ra is the apparent crater radius from the rim crest, and a and b are fit constants determined on the basis of the best non-linear least squares fit to the topography of the ejecta from the rim rest to the edge of CEB (i.e., usually about 1-1.2 crater diameters). McGetchin et al. [12] first used this approach to consider ejecta thickness for terrestrial and lunar craters and Melosh [1] points out that simple ballistic ejecta emplacement would suggest a value for b of -3.0 +/- 0.5. Because of the limited availability of high vertical and spatial resolution topographic data for Mars (and even for Earth in many cases), investigations of the significance of the te function for craters as a function of target properties, age, and other factors has escaped detailed treatment. Here we consider the radial ejecta thickness function te as constrained by suitable MOLA topographic profiles. The objective is to assess whether radial ejecta thickness characteristics for fresh craters could be used to test the hypothesis that ejecta topology is ultimately controlled by target properties (and impactor energy) [1,13]. In addition, the overall flank slope of the ejecta blankets considered here has been computed, as well as the ratio of CEB volume (Vej) to that of the apparent crater cavity (Vc) : Vej/Vc, which for fresh craters should be correlated with ejecta productivity or with degree of final crater cavity infill (or fallback).

Our earlier work with MOLA data suggests a general correlation of crater cavity geometry (i.e., cross-sectional shape) with diameter and hence energy. Examination of the patterns in the other parameters that describe ejecta blankets reveals a much great degree of variability. Although ejecta flank slopes appear to cluster with the most general dichotomy of crater morpholoy: simple versus complex, it is clear from MOLA observations that ejecta blankets exhibit much great variation than crater cavities. For example, a near-centerline MOLA profile of the 95 km diameter crater *Mie* in Utopia Planitia, indicates that ejecta blanket slopes, as measured from the rim crest to the edge of the CEB, are between 1.25 and 1.4 degrees, and the exponent on the radial ejecta thickness function (b in Eqn. I above) is -1.0. The balance between the volume of ejecta and the apparent volume of the crater interior for Mie (Vej/Vc) is 0.78, within the range expected for larger lunar craters such as Tycho [10,11]. However, a 45 km diameter, un-named crater at 46 N, 0 E in Amazonis Planitia that was bisected with a MOLA transect suggests a very different behavior, with ejecta flank slopes of ~ 0.5 deg., an exponent b of -6.7 (and as high as -25), and a Vej/Vc ratio of 1.46. Even if one corrects for the volume of the central peak structure, the Vej/Vc ratio is 1.25, well beyond that anticipated for typical lunar craters. McGetchin et al. [12] suggested a -3.0 exponent (b) in Eqn. I in part due to the availability of explosion cratering data. For Mars, the observed variation in the b parameter is too wide to be a random effect. Indeed, only one high-latitude rampart crater sampled by MOLA indicates an exponent of -3.0 (i.e., in terms of the small subset of craters bisected perfectly). Many of the most pristine simple craters display te function exponents in the -8.5 and steeper regime. This suggests that near-rim pile-up of ejecta, as well as perhaps some rim structural uplift, is responsible. Another alternative is that such steeper ejecta thickness functions indicate enhanced down-ejecta mass wasting which acts to steepen the topography of the ejecta blankets. However, larger, lobate ejecta craters display much flatter ejecta thickness functions, with exponents less than -2.0. If fluidization is a late stage element of the ejecta emplacement process, then it could serve to flatten and extend the topographic expression of ejecta blankets.

The Vej/Vc volume balance for pedestal type craters on Mars is particularly interesting. Such craters exhibit Vej/Vc ratios all in excess of 3.0, with many having ratios larger than 10. The exponent b in the te function for these perched craters is highly variable with several displaying values over -3.0. Indeed, the only craters illustrating volume balances in excess of 10 are of the pedestal variety, and such features typically display exponents such as -6.0. For example, a 4.6 km diameter pedestal crater at 16 N demonstrates a Vej/Vc of 3.1, while its non-pedestal counterpart nearby has a Vej/Vc of 0.7. The mean volume balance ratio (Vej/Vc) for the ~ 100 craters for which a reliable calculation can be conducted is 1.8, with a large standard deviation (4.7). Only 5%

of the craters sampled thus far show Vej/Vc values above 4.0, and virtually all of these are rampart or pedestal craters.

Most crater cavities reliably sampled by MOLA thus far reveal cross-sections that are well-approximated by inverted cones or parabolas (i.e., mean degree of polynomial or power function that best approximates the cavity is near to 1.4, where 1 represents a cone and 2 a paraboloid). However, the extraordinary diversity of ejecta blanket topologies fails to produce a clear statistical tendency when one considers either ejecta flank slope or the exponent b in Eqn. I. Indeed, if one restricts consideration to the approximately 20 craters that were essentially bisected by a MOLA topographic profile, then the ejecta thickness function exponent varies from -0.3 (complex crater at 3 S), to -24 for a simple crater at 35 N. Such well-known impact features as the crater *Mie* in Utopia Planitia display exponents near to -1.0, while fresh-appearing transitional craters (15.5 km crater in Isidis at 12.8 N) suggest a te function exponent of -0.7, both of which indicate a very shallow fall off in ejecta topography from the rim crest. However, pristine simple craters in the Northern volcanic plains such as the 5. 8 km crater at 21 N, displays a te function exponent of -12, and the complex, lobate ejecta crater in Amazonis at 46.5 N (c.f. Fig. 3 in Smith et al. [9]) has an exponent that varies from -7 to -25. This natural variability in the behavior of ejecta thickness is independent of crater diameter and does not correlate with the systematic behavior of crater depth, cavity geometry and rim height that is clearly observed (i.e., such parameters correlate with crater diameter and hence energy). Thus, we interpret the variability in ejecta topology as measured from the te function and using the general flank slope of the ejecta, to be an indication of the variability of target mechanical properties and hence volatile concentrations. When one further examines the local vertical roughness of the ejecta blankets of a variety of impact craters on Mars using the RMS optical pulse width parameter measured by the MOLA instrument, a general increase in perceived local roughness (both footprint scale slopes and other roughening agents such as blocks) is observed as one moves from the distal ejecta up to the rim crest.

In summary, we have observed the topographic characteristics of nearly 100 martian impact crater ejecta blankets and have noted the extreme variability in their geometries. There is no systematic variation in the radial ejecta thickness function as one extends from the rim crest to the edge of the CEB (see Eqn. I), nor are local slopes correlated with many aspects of their morphology. As further MOLA topographic observations of these features are acquired and first order fluid mechanical models for ejecta emplacement are considered, a clearer pattern of how ejecta thickness and topography relate to the martian impact crater process is anticipated.

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