Preliminary Assessment of the Morphometry of Martian Impact Crater Ejecta Deposits and their Implications, Joseph M. Boyce and Peter Mouginis-Mark, Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu HI 96822

We are continuing characterization of the geometry of flow-related features of the fluidized ejecta of fresh Martian craters to be used in concert with dynamical models of granular flow as a basis for developing new models and testing current models of fluidized ejecta emplacement. Granular flow studies have shown great promise for understanding the causes of ejecta flow on Mars [1, 2] because 1) the fragmental nature of ejecta [3] makes ejecta, by definition, a granular flow, and 2) recent major advances in granular flow dynamics have been made in understanding rapidly moving granular materials. Below we briefly discuss examples of features being studied, including *radial structures, secondary crater, transverse structures, and ramparts*.

Radial Structures: Radial furrows and ridges are common on ejecta deposits of all types of fluidized ejecta craters (Figures 1). They

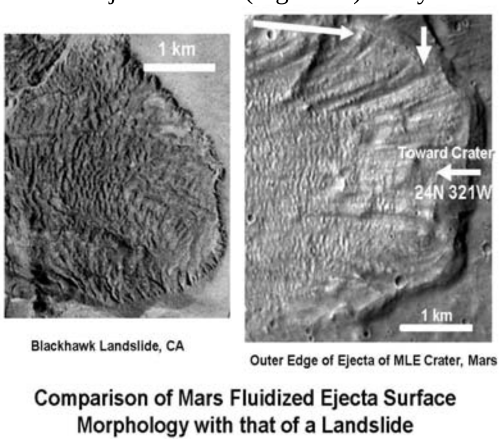

Figure 1 Blackhawk landslide (left), and the outer ejecta layer of a Martian MLE crater (right) showing furrow parallel to the flow. Both show transverse ridges.

generally differ with crater type and even between layers on the same ejecta blankets [5,] suggesting differences in flow conditions. On the ejecta of single-layer ejecta (SLE) and multi-layer ejecta (MLE) craters radial furrows tend to curve around obstacles, and widen as they approach the outer edge of the ejecta lobes, analogous to the geometry of radial structures on long run-out terrestrial landslides [6]. This suggests that, in places, these structures may have formed by "shear" [6, 7] and in others, by "divergent flow" [8]. In contrast, on double layer ejecta (DLE) crater ejecta, closely-spaced, straight grooves and ridges, similar to those produced at Mount St. Helens by supersonic flow of a blast surge [10], extend radially across the inner ejecta layer, cutting all other flow features [4]. However, in laboratory experiments [11, 12] similar patterns also form in rapidly flowing dry granular materials, and are the result of instabilities (similar to Gortler vortices) generated by high flow-rate, and high granular temperatures (caused by surface roughness). The high granular temperature causes the granular equivalent of convection, resulting in longitudinal vortices (similar to Rayleigh-Benard instabilities) that produce straight ridges [11, 12]. Consequently, this mechanism does not require supersonic gas to carve the straight features of DLE craters, as does the model of [10], but might be done without volatiles.

Secondary Craters: All types of fresh layered ejecta craters have secondary craters and crater fields, although secondary craters are rare around DLE craters [5]. This is possibly caused by comminution of ejected blocks resulting from water in the target materials [13]. In addition, extensive small secondary-like craters chains and clusters occur on ejecta layers of MLE craters. This is counter to most models that predict most debris that produces secondary craters should impact before the emplacement of the ejecta blanket. The presence of these small craters suggests that either the blocks that produced them have extraordinarily long flight times, or that these are not secondary craters.

Transverse Structures: Sets of closely spaced transverse ridges and troughs are common on the ejecta of SLE and MLE craters (Figure 1, 2).

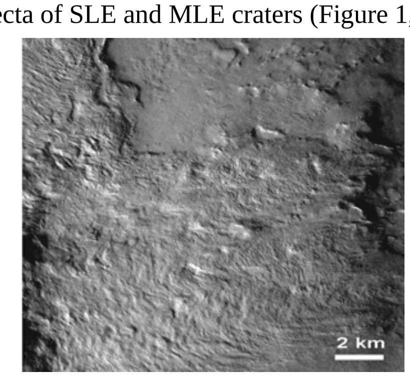

Figure 2. Wavy pattern of transverse ridges and troughs

These features are morphologically similar to features on terrestrial long run-out landslides [6] and those studied theoretically [14] and in laboratory experiments in both wet and dry granular materials [15, 16, 17, 18,]. These studies suggest that such features are caused by rolling wave-like instabilities, like in classic fluids, but modified due to the specifics of the friction law of granular flows [15, 16, 18]. These friction forces lower the stability threshold below the onset of the flow, so that such features should form even near the rim of fluidized ejecta craters. This is consistent with observations [6, 16] and the suggestion that these features may only require a non-zero yield stress condition to form [12, 17], without other perturbations [14].

In plan view, the wavy or chevron-like geometry of these features may be produced by shear, like some of the radial features. In contrast, [20] have suggested that, based on experimental data, chevron-like features form near boundaries on relatively slow granular flows (Figure 2). These features are produced by vortices induced directly by shear between frictional walls and the main flow, in the granular analog of the fluid boundary layer. However, at this point it is not clear how this mechanism would operate in the open geometry of an ejecta flow.

Ramparts: The hallmark feature of Martian layered ejecta craters is the terminal rampart at

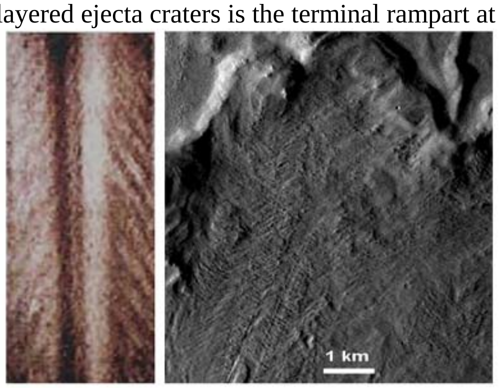

Figure 3. Chevron shaped features (left) formed on the surface of flows of grains in experiments in narrowly confined chute (flow is from the top) produced by friction along the edges (from *Conway et al.,* 2003). showing furrows cutting across and in some places displace or deform closely spaced sets of small transverse ridges and troughs (*crater is toward bottom and terminal rampart ridge is shown at the top).*

the outer edge of each ejecta layer [24]. Ramparts of MLE and SLE crater ejecta layers typically are narrower and higher compared with those of the inner layer of DLE craters [5, 22, 23, 24]. Ramparts may be the equivalent of the terminal ridges common on both wet and dry flows of granular materials [16, 25, 26, 27], are thought [16, 25, 27] to be the result of segregation and accumulation by kinetic sieving of large grains into a band at the leading edges of flows. Because the large grains have higher friction owing to their angularity, they are pushed up from behind into ramparts by the more fluid body of the flow behind. It has also been suggested that the size of ramparts is a function of the proportion of fluid phase in the flow, with lower, broader ramparts corresponding to proportionally more fluid in the flow [30] because fluid facilitates recirculation of course debris back into the flow. This more broadly distributes the course debris in the band back into the flow, hence resulting in low, broad ramparts. However, for wet flows, deflation of the body from dewatering behind the rampart tends to enhance the relief of the rampart [16].

Other factors (e.g., geologic setting) may also be important in rampart geometry, such as the presence of an easily erodable surface that increases the fiction with the surface, causing materials to pile up behind the leading edge, and hence produce more massive ramparts [2, 31].

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