FLOW FEATURES ON MARTIAN LAYERED EJECTA: Joseph M. Boyce, Peter Mouginis-Mark, and Lionel Wilson, Hawaii Institute of Geophys. & Planetology, University of Hawaii, Honolulu, HI, 96822: jboyce@higp.hawaii.edu.

The cause of fluidization of Martian ejecta has important implications to the geologic and biologic history and evolution of Mars because of the possible role of water in the target. In an effort to gain further insight into the processes and conditions (the presence of water) governing that flow, we characterize the morphology of flow features on Martian layered ejecta. We suggest that such an insight is possible because ejecta flow, like flow in other geophysical materials composed of fragmented debris, is controlled by the physics of granular flow. Hence, similar to the flow features on other geophysical flows, those on ejecta record intrinsic processes of free-surface granular flows [1 - 6].

Flow features such as linear grooves and ridges transverse and radial to ejecta flow occur on all layered ejecta and show systematic differences with crater type, ejecta layer, and distance from the rim. To a first order, the flow features on single layer ejecta (SLE) craters are similar to those of multi-layer ejecta (MLE) craters, but both are different from those on double layer ejecta (DLE) craters. Specifically:

1. <u>Radial Features</u>: Relatively straight r**adial grooves** are found on all ejecta layers except the outer ejecta layers of DLE craters which are typically **sinuous troughs** commonly bounded by a levee-like ridge (Fig. 1) similar to those on desert fans [7]. The straight grooves on SLE and MLE deposits superficially resemble

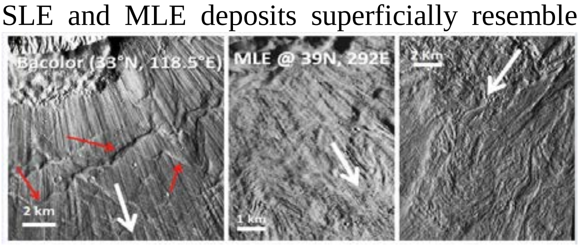


Fig. 1. Straight groove on the inner ejecta layers of a DLE (left) and MLE crater (center), and the sinuous radial flow features on the outer ejecta of Bacolor. White arrows show ejecta flow direction, and red arrows point to graben-like troughs.

those on the inner ejecta layer of DLE craters, but a morphometric analysis suggests that they are not the same. We have measured the width and length of grooves on the inner ejecta layers of various sizes of fresh SLE, MLE and DLE craters. This was done in sample areas at radial distances from (1) the rim to 0.5 R, and (2) 0.5 R to 1.0 R. We have found that while the average width (Fig. 2, top left) of grooves increases with crater size on all types of craters, it changes little outward on SLE and MLE ejecta. This is similar to grooves on rock avalanches that traverse glaciers [1]. In contrast, the average width of grooves substantially increases outward on the inner ejecta layer of DLE craters. On all types of craters, the number of grooves in each radial zone increases (Fig. 2 top right) with crater size, but the area covered (Fig. 2, bottom) by grooves (normalized to the area of that zone or NGA) in a radial zone decreases with crater size. However, the functions describing these trends for SLE and MLE craters are similar to one another, but differ for DLE grooves.

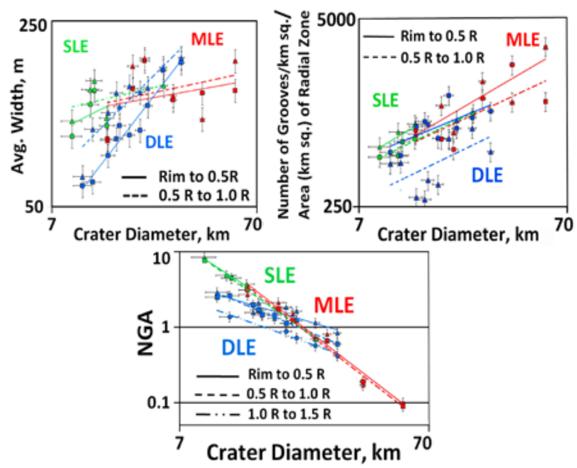


Fig. 2. Graphs showing grooves measured outward in 2 radial zone [crater rim to 0.5 R (triangles and solid lines), and 0.5 R to 1.0 R (squares and dashed lines)] on the inner ejecta layers of SLE, DLE and MLE craters. At top left is the average groove width, top right is the area density of groove, and at bottom is the NGA (normalized groove area). Lines are best fit linear regression curves

In addition, on all ejecta layers except the inner layer of DLE craters, radial grooves typically are deflected by pre-existing topographic features (Fig. 3).

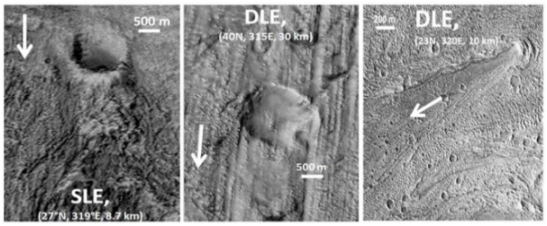


Fig. 3. The effects of small pre-existing crater on radial grooves development. Arrows show ejecta flow direction.

2. <u>Transverse features</u>: There are three principal types of flow features formed transversely to ejecta flow, i.e., 1) roll wave-like sets of ridges and troughs, (2) graben-like troughs, and 3) distal rampart ridges.

Roll wave-like features that resemble wave trains commonly develop on the ejecta layers of all types of ejecta deposits, except the outer layers of DLE craters. These appear to be roll waves similar to those on landslides and debris flows [e.g., 1 - 3, 9 - 11]. Their wavelengths are typically a few hundred meters, and are dependent on parent crater size and distance from the rim (Fig.4) (i.e., ejecta thickness [13]).

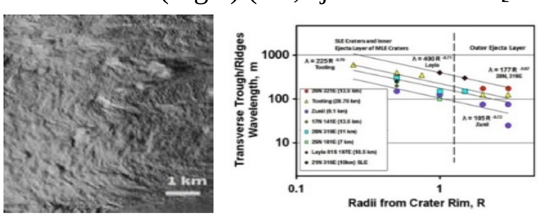
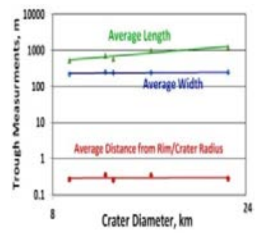


Fig. 4. Wavelength of roll waves with distance from the rim. Lines are best fit linear regression curves.

In map view, these features can also form sinuous patterns (Fig. 4 left), possibly a result of shear along the radial grooves.

Graben-like troughs develop transverse to ejecta flow on SLE and the inner layers of DLE craters (Fig. 1 left, red arrows), but are rare on MLE ejecta. In map view, these features occur as straight segments a few hundred meters to >1 km long (depending on crater size), but vary little in width, averaging ~ 250 m wide. They are most frequently located at about 0.4 R (Fig 5). Graben-like troughs commonly connect to form V-shaped patterns that point outward. Remarkably, on some DLE craters these troughs bound flat-topped blocks of ejecta that tilt back toward the crater rim.

Ramparts are typically found at the outer edge of each ejecta layer [9, 12] and are similar to those at the ends of many terrestrial geophysical flows (1 - 5, 14). The widths (Fig. 6) and heights of ramparts increase with diameter of the parent crater [14, 15]. The ramparts of the outer layers of DLE craters and SLE ejecta are slightly wider than ramparts of MLE craters, while the ramparts of the inner layer of DLE craters are markedly broader and relatively high (~ 0.13 of the parent crater depth) in comparison [14]. This is another indication of the uniqueness of DLE craters.



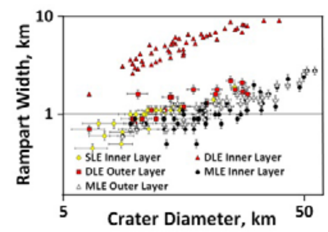


Fig. 5. Fig. 6.

Fig. 5. (left) Average width (blue), length (green) and distance (normalized to crater radius) from the rim (red) of graben-like troughs on the ejecta of SLE the three smallest craters) and DLE craters (the two largest). Lines are best fit linear regression curves. Fig. 6. (Right) Width of ramparts on SLE, DLE and MLE ejecta layers. Error bars are estimated measurement errors.

<u>Conclusions</u>: Our findings suggest that although all layered ejecta show abundant evidence of flow (and morphologic similarities to some geophysical flows), DLE ejecta shows fundamental morphologic differences from SLE and MLE ejecta that suggest important differences in flow processes and/or conditions during emplacement.

<u>References</u>: [1] Shreve, R., 1966, *Sci*. 154, 1639-1643; [2] Marangunic, C., and Bull, W., 1968, *Nat. Acad. Sci*., 383-394; [3] Barnouin-Jha, O., et al, 2005, *JGR*, EO4010, doi:10:1029/2003 JE002214; [4] Dufresne, A., and Davis, T., 2009, *Geomorph*., 105, 171-181; [5] DeBlasio, F., 2014, *Geomorph*., 213, 88-89; [6] Boyce, J. et al. 2014 *LPSC* 1428 [7] Whipple, K and Dunne, T., 1992, GSA, 104, 887-900; [8] Boyce, J. and Mouginis-Mark, P., 2006, *JGR*, doi:10. 1029/2005JE2638 [9] Baloga S, and Bruno, B. (2005), *JGR* 110, doi: 10.1029/ 2004JE002381 [10] Iverson R. and Denlinger R. 2001. *JGR*, 106 B1:537–552. [11] McKean, J., and Roering, J., 2004, *Geomorph*., 57, 331-351; [12] Carr et al., 1977 JGR 82:4055–4065; [13] Forterre, Y. and O. Pouliquen, (2002), *Fluid. Mech.*, 467, 361-387; [14] Boyce, J. M. et al., 2010, MAPS,45; 661; [15] Baloga, S. *et al.* 2005, *JGR* 110,doi10.102/ 2004JE00233.