TESTING THE GLACIAL SUBSTRATE MODEL FOR DOUBLE-LAYERED EJECTA CRATERS ON MARS. D. K. Weiss and J. W. Head, Department of Earth, Environmental, and Planetary Science, Brown University, Providence, RI 02912, U.S.A. (david_weiss@brown.edu)

Introduction: The martian layered ejecta craters appear to be fluidized when compared to the ballistically emplaced ejecta of their lunar and mercurian counterparts: [1]. The unique ejecta morphology associated with layered ejecta craters is typically attributed to subsurface and/or surface volatiles [1-19], and/or atmospheric-vortex interactions [21-25].

Double-layered ejecta (DLE) craters are a particularily unusual subclass of the wide variety of layered ejecta craters on Mars which include single-layered ejecta (SLE), multiple-layered ejecta (MLE), low-aspect-ratio-layered ejecta (LARLE), and pedestal craters. DLE craters are located in the mid-high latitudes in both hemispheres [15,19]. DLE craters range from ~1 to 35 km in diameter (~8 km on average) and exhibit two ejecta facies. The inner facies is characterized by radial grooves, transverse fissures, and an annular depression at the base of the rim [1,15,19]. The outer facies exhibits smaller, more sinuous grooves, and an anomalously high runout distance. Typical martian craters exhibit ejecta mobility (EM; ratio of ejecta runout distance from the rim crest/crater radius) values of ~1-2 [1-5,26]. DLE craters exhibit anomalously high EM values compared with other martian layered ejecta morphologies, displaying an average EM of ~3 for the outer ejecta facies, and ~1.5 for the inner ejecta facies [5].

DLE craters have been hypothesized to form through (1) interaction with the martian atmosphere [21,22]; (2) the incorporation of volatiles from within the target [5-9,14]; (3) some combination of these factors [5,14,17]; (4) a base surge [7,14, 27]; (5) impact melt overtopping the crater rim [9,28], (6) impact into a subsurface ice layer [15]; (7) impact into a volatile-rich substrate followed by a landslide of the near-rim crest ejecta [29]; or (8) impact and penetration through a surface snow/ice layer, followed by a landslide of near-rim ejecta off the uplifted rim-crest [19]. The latter hypothesis [19] suggests that the landslide of the inner ejecta facies and the long runout distances of the outer facies are explained by ejecta sliding on a lubricating (low friction) icy surface layer (Fig. 1).

In the latter two landslide scenarios, (7) and (8) above, for DLE inner ejecta facies formation, the grooves on the DLE inner facies are analogous to longitudinal grooves formed on the surfaces of terrestrial landslides [30], particularly those that slide on snow and ice [30,31-33]. We use recently improved frictional models [33] to test the landslide hypothesis.

Landslide modeling: DLE inner facies have runout distances of ~2-20 km and initial (rim uplift) heights on the order of ~10-100 m. Can landslide scaling laws be

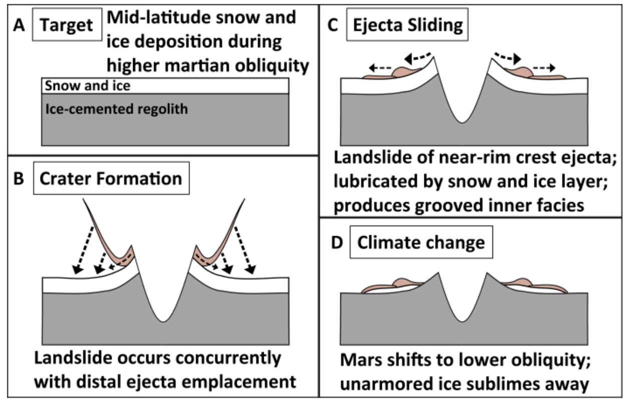

Figure 1. Glacial substrate model for DLE craters [19].

reconciled with those large runout distances despite low sliding angles and initial landslide heights? Are the speeds sufficient to form and preserve the grooves, which simultaneously require vertically unmixed flow, low degrees of movement perpendicular to the primary flow direction, and low values of basal friction [31,33,35]? In such a hypothesized landslide process, did the landslide occur on snow/ice (i.e., glacial-substrate model [19]) or rock [29]? In order to address these questions, we model the runout and sliding speeds of a landslide of near rim-crest ejecta. We use the equation of motion for a landslide center of mass (COM) (e.g. [35]) in cylindrical coordinates using the structural uplift height function of [36] and a new frictional weakening law [34]. On the basis of this model, the landslide COM is predicted to have peak COM sliding speeds between ~17 to 62 m s^{-1}, and average landslide COM speeds between ~10 and 34 m s^{-1} (Fig. 2) depending on crater diameter, over a wide range of friction coefficients and structural uplift geometries. Our model predicts landslide durations of 75-400 s. We find that across the parameter space, the runout distance of the inner ejecta facies COM is predicted to range from 0.7-1.4 R from the rim crest

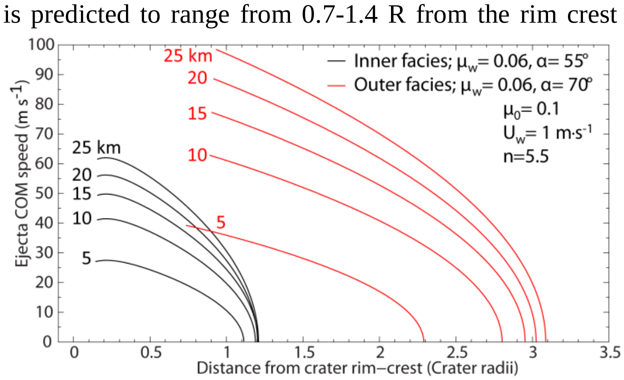

Figure 2. Inner and outer ejecta facies model results.

after correcting for crater collapse (friction coefficient, μ=0.05-0.07), and is thus in good agreement with observations (measured inner facies COM distances are 1±0.3R). The high EM values of the DLE inner facies, despite low sliding angles and low initial heights, is a predicted consequence of the lubricating snow and ice substrate (Fig. 1) and moderate emplacement speeds [4,19].

Groove morphology: The average calculated inner facies COM speeds (~10-34 m s^{-1}) are ~16-56 m s^{-1} under terrestrial gravity, and thus are within the range of terrestrial landslides overriding glaciers which exhibit grooves (~26-64 m s^{-1};[37,38]). Grooves form through shear and splitting and can only be formed in the landslide when the flow is vertically unmixed [33]. Longitudinal grooves form when the primary flow direction speed is much greater than the lateral flow speed [33]. In the case of a near rim-crest landslide, azimuthal confinement from adjacent landsliding ejecta will prevent movement at right angles lateral to the primary flow direction. Cylindrical expansion in the landslide is thus accomodated by splitting, forming longitudinal grooves. This is consistent with the observation that wider grooves are present with increasing distance from the rim-crest [39]. Previous investigators [40] found that the inner facies of some DLE craters exhibited thinner grooves superposed on the longitudinal grooves and argued that this is inconsistent with groove formation in a landslide. Our examination of martian landslide groove topography in Ganges Chasma, however, shows that landslides often exhibit this morphology. The presence of grooves on the inner ejecta facies of DLE craters is thus consistent with a landslide origin.

Rampart formation: DLE craters exhibit subdued ramparts [5, 28] and fewer larger particles in the distal ramparts compared with single- and multiple-layered ejecta craters (Fig. 3). The low basal friction values of ejecta sliding on surface snow and ice deposits (μ=0.05-0.07) would inhibit the vertical velocity gradient in the flowing ejecta, reducing the efficiency of kinetic sieving, preventing large particle transport to the flow-front [39]. Larger particles dissipate pore pressure more rapidly, increasing friction and decelerating the flow-front to form ramparts. A prediction of the glacial substrate model is that DLE craters have subdued ramparts and fewer larger particles in the distal ramparts compared with single- and multiple-layered ejecta craters (Fig. 4); this is consistent with observation.

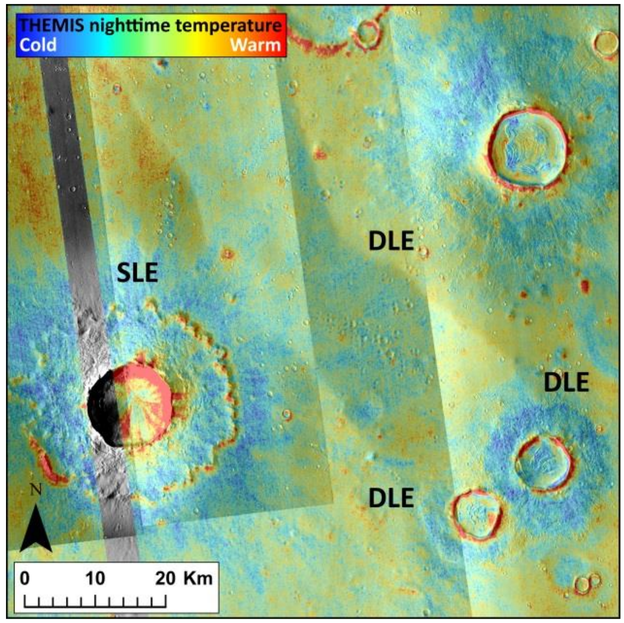

Figure. 3. DLE crater ramparts exhibit lower thermal inertia (smaller particles) than SLE craters.

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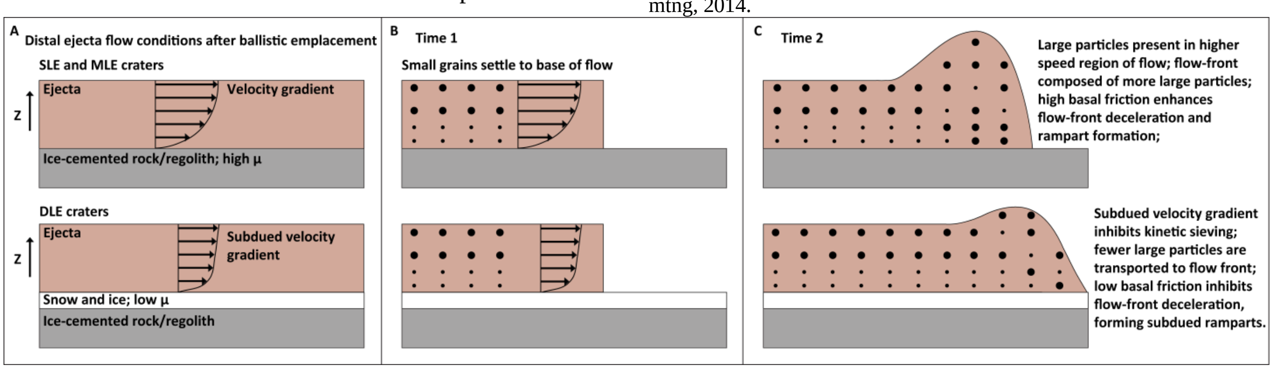

Figure. 4. DLE craters may possess subdued ramparts in the outer facies relative to the other layered ejecta craters due to sliding on snow/ ice. This reduces basal friction and inhibits kinetic sieving and flow-front deceleration.