EJECTA MOBILITY OF LAYERED EJECTA CRATERS ON MARS: ASSESSING THE INFLUENCE OF SURFACE SNOW AND ICE DEPOSITS.

D. K. Weiss[1] and J. W. Head[1], [1]Department of Geological Sciences, Brown University, Providence, RI 02912, U.S.A. (david_weiss@brown.edu)

Introduction: Martian impact craters often exhibit unique ejecta morphologies relative to ballistically-dominated ejecta observed in lunar and mercurian impact craters [1,2]: martian lobate ejecta deposits frequently have distinctive ejecta deposit boundaries rather than an ejecta deposit of gradational thickness and morphology, and appear to have been fluidized during their emplacement, although there is no consensus on the mode of fluidization [1-7]. It has been noted that there exist major differences among the ejecta mobility values of layered ejecta craters (EM; ratio of ejecta facies radius from the rim/crater radius) (Fig. 1; 2a) [1,4,8-10]. Understanding the nature of the EM of layered ejecta craters may provide some insight into the conditions in which the impact occurred. The large values and variations in the EM of layered ejecta craters have been variously explained as being due to: 1) variations in volatile-rich target structure [8] or abundance [3,9]; 2) differences in ejecta particle size [11]; 3) variations in target softness [12]; or 4) a base surge [13-15]. Of the layered ejecta craters (Fig. 1), impacts hypothesized to form in decameters-thick surface ice deposits are a particularly unusual subclass, consisting of perched (Pr) craters [16], pedestal (Pd) craters (Fig. 1c & d) [17], and more recently proposed, double-layered ejecta (DLE) craters (Fig. 1b) [18]. In this study, we test the hypothesis that the fluidized nature and high EM of these craters can be accounted for by ballistic deposition followed by ejecta sliding on the lubricating icy-substrate target surface; in this scenario, the low friction ejecta-ice interface serves to enhance sliding distances, and thus EM. We begin by investigating the rim diameter, EM, and substrate thickness relationships between the different martian layered ejecta populations, and then attempt to model the ejecta deposition and sliding process.

Low-aspect-ratio layered ejecta (LARLE) craters: One class of layered ejecta crater is the low-aspect-ratio layered ejecta (LARLE) crater (Fig. 1a), which displays large and variable EM values (EM=1.5 – 21.8; average 7.1; Fig. 2a & b) and a highly sinuous distal ejecta edge [14,15]. Previous investigators [14,15] report that a LARLE crater can exhibit either SLE or DLE morphology, which is surrounded by the LARLE deposit, and that LARLE crater rim crest diameters are typically larger at higher latitudes. LARLE craters exhibit an identical latitudinal-dependent distribution to that of Pd craters [15]. They [14,15] suggest that LARLE craters are genetically related to Pd craters based on the latitudinal and morphological similarities. As such, LARLE craters are suggested to form in a "fine-grained ice-rich mantle deposit" [14,15], and the high EM and high ejecta sinuosity is attributed to 1) the collapse of the ejecta column, generating a suspension-driven gravity current [13,15], or 2) a base surge [15], in which the primary ejecta re-impacts outside the crater cavity and material surges outward through saltation enhanced by a high volatile component of the ejecta material.

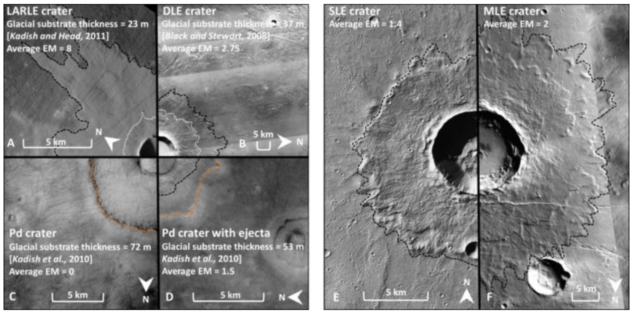

Figure 1. Ejecta deposits of six types of martian craters: A) LARLE crater with DLE morphology, B) DLE crater, C) Pd crater, D) a Pd crater exhibiting an ejecta deposit within the pedestal. E) SLE crater, F) MLE crater.

We conducted a comprehensive analysis of the global population of LARLE craters in the latitudes equatorward of ~75°N and ~75°S following the description from [14,15] and found a comparable number of LARLE craters, confirming the observations of [14,15]. Our analysis of LARLE craters indicates that 93% of the 170 craters examined exhibit DLE morphology: we interpret the outer LARLE deposit as the outer ejecta layer of a DLE (Fig. 1a). DLE craters, suggested to form in a surface ice layer by [18], also have large and variable EM (outer layer EM=0.57 – 9.2; average 2.9; Fig. 2a & b) when compared with SLE craters (EM=0.43 – 3.9; average 1.18; Fig. 1e; 2a & b) and multiple-layered ejec-

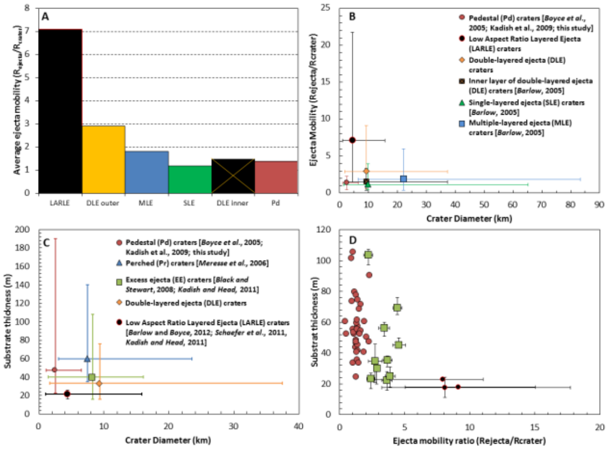

Figure 2. Data for several martian layered ejejecta crater populations. A) Average EM [10,14,15; this study]. B) Crater diameter and EM relationships. C) Crater diameter and icy substrate thickness relationships. D) Substrate thickness and EM plotted for Pd craters, EE craters (primarily with DLE), and LARLE craters.

ta (MLE) craters (EM=0.4 – 6; average 1.8; Fig. 1f; 2a & b). Some [17, 19] have classified several craters as excess ejecta (EE) craters (believed to form in surface-ice deposits [20]), which we classify more specifically as LARLE craters based on their high EM values and ejecta sinuosity. Based on the observation that: 1) numerous LARLE craters have DLE morphology; 2) LARLE craters share the same latitudinal-dependent distribution as Pd, DLE craters and other non-polar ice-related deposits; 3) the greater average diameter of LARLE craters at higher latitudes; and 4) our classification of several EE craters as LARLE craters, we suggest that LARLE craters may form in an ice and snow substrate much like DLE and Pd craters. The presence of larger LARLE craters at higher latitudes may indicate impact into a surface icy layer; one might expect thicker ice layers at higher latitudes (a trend observed for Pd craters [21]), and so smaller LARLE craters may not penetrate through a thick ice layer, leading to Pd crater formation. In this contribution, we test the hypothesis that ejecta sliding on a low-friction surface ice layer might be a contributor to the long runout distances observed.

Crater relationships: The LARLE crater rim crest diameter values span from the low end of Pd craters (1 km) to typical DLE crater sizes (15 km) (Fig. 2c). Pedestal craters impact into an average ~50 m ice sheet (Fig. 2c) and they may occasionally display ejecta within the margins of the pedestal (Fig. 1d). DLE craters impact into a ~40 m ice sheet (Fig. 2c) and display broader ejecta deposits. In contrast, LARLE craters typically form in thinner ice sheets (~20 m on average measured; Fig. 2c; likely thinner: LARLE deposits generally perched ~10 m above surrounding terrain [15]) and display laterally extensive ejecta deposits.

Differences in EM between crater classes could possibly arise due to ejecta velocity variations. In line with ejecta scaling laws [22-26], ejecta excavated at greater depth will have a lower average velocity than shallower ejecta originating near the surface and the center of the impact. In an impact into a surface ice layer, the near-surface, high velocity material is composed of the surface ice layer, and thus the high velocity ejecta material will experience significantly enhanced vaporization compared to impact into a rocky substrate, and thus will not interact with or accelerate the ejecta curtain. Additionally, the smaller grain size of ice particles (due to ice's low tensile stress) results in the preferential atmospheric deceleration of the unvaporized ice. Hence, enhanced vaporization and deceleration of icy ejecta material eliminates the highest velocity ejecta material from the advancing ejecta curtain. Therefore, as the surface ice thickness increases and the depth of penetration below the surface ice is reduced, the volume of icy material increases in relation to the volume of excavated regolith material, and more high-velocity ejecta (shallow icy material) is eliminated from the ejecta curtain.

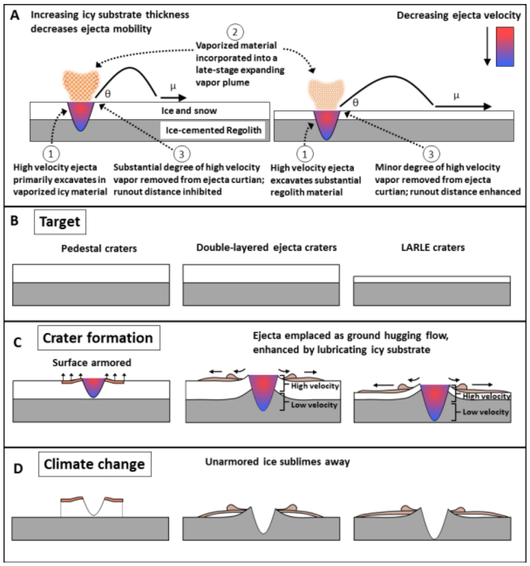

Figure 3. Interpreted sequence of events for Pd ([17]; left column), DLE ([18]; middle column), LARLE craters (right column).

Since the LARLE crater icy substrate is relatively thin, the excavated regolith (that immediately below the icy substrate) will exit the crater cavity at high velocities. In contrast, DLE craters typically form in a thicker ice sheet (~40 m), and so the regolith below the icy substrate is excavated from greater depth relative to the surface, and will exit the crater cavity at a lower velocity, thereby decreasing the EM; in this scenario, a substantial portion of the icy surface layer within the transient cavity is vaporized/decelerated upon impact. Fig. 2d shows that higher EM values are observed as a function of decreasing icy substrate thickness, which may indicate that with decreasing substrate thickness, more high-velocity ejecta is excavated and will contribute to the ejecta facies runout. We suggest that the thickness of the surface ice layer may be important in controlling the velocity of the ejecta that will contribute to the observed ejecta facies runout. We tested the idea that the morphologic differences between Pd craters, LARLE craters, and DLE craters might result from gradations in crater diameter and icy substrate thickness. We suggest that the proportion between the volume of icy material and the excavated regolith (i.e. depth of penetration below the icy substrate) is a controlling factor on the specific morphology that will be attained upon impact (Fig. 3a).

Acknowledgement: We gratefully acknowledge support from the NASA Mars Data Analysis Program NNX09A146G to JWH.

References: 1. Carr et al., JGR 82, 4055, 1977; 2. Schultz and Gault, JGR 84, 7669, 1979; 3. Gault and Greeley, Icarus 34, 486, 1978; 4. Mouginis-Mark, JGR 84, 8011, 1979; 5. Mouginis-Mark, Icarus 45, 60, 1981; 6. Woronow, Icarus 45, 320, 1981; 7. Boyce and Mouginis-Mark, JGR 111, E10, 2006; 8. Costard EMP 45, 265, 1989; 9. Barlow and Pollak, LPSC 33, 1322, 2002; 10. Barlow, Large meteorite impacts III, 433, 2005; 11. Schultz, JGR 97, 11623, 1992; 12. Wada and Barnouin-Jha, MPS 41, 1551, 2006; 13. Boyce et al., LPSC 43, 1196, 2012; 14. Barlow and Boyce, LPSC 43, 1253, 2012; 15. Barlow and Boyce, LPSC 44, 1196, 2013; 16. Meresse et al., MPS 41, 1647, 2006; 17. Kadish and Head, Icarus 215, 34, 2011; 18. Weiss and Head, GRL, in press, 2013; 19. Schaefer et al., GRL 38, 2011; 20. Black and Stewart, JGR 113, E2, 2008; 21. Kadish et al., Icarus 210, 92, 2010; 22. Wisotski, Planetary and Terrestrial Implications 1, 1101, 1977; 23. Maxwell, Planetary and Terrestrial Implications 1, 1003, 1977; 24. Cooper, Planetary and Terrestrial Implications 1, 11, 1977; 25. Housen et al., JGRL 88, 2485, 1983; 26. Richardson et a;., Space Science Reviews 117, 241, 2005.