THE ROLE OF TARGET CHARACTERISTICS IN THE FORMATION OF IMPACT CRATER EJECTA MORPHOLOGIES AT HIGH LATITUDES ON MARS.  N. G. Barlow\textsuperscript{1} and J. M. Boyce\textsuperscript{2}. \textsuperscript{1}Dept. Physics and Astronomy, Northern Arizona University, Flagstaff, AZ 86011-6010 USA  Nadine.Barlow@nau.edu,  \textsuperscript{2}Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822  jboyce@higp.hawaii.edu.

Introduction: Ejecta morphologies surrounding fresh impact craters at the higher latitudes on Mars are distinctly different from those seen at lower latitudes. Equatorward of about 40\textdegree latitude on Mars, fresh craters are typically surrounded by single (SLE) or multiple-layer ejecta (MLE) morphologies whereas at higher latitudes several other ejecta morphologies dominate [1, 2]. These high-latitude morphologies are morphologically and morphometrically distinct from the lower-latitude ejecta deposits. Some of these morphologies are primary while others appear to be erosional forms. The four high-latitude impact crater ejecta morphologies are double layer ejecta (DLE), pancake (Pn), low-aspect-ratio layered ejecta (LARLE) and pedestal (Pd) craters (Fig. 1).

![Figure 1](image.png)

Figure 1: (Top left) 19.5-km-D DLE crater centered at 38.35\textdegree N 99.22\textdegree E. (Top right) 5.0-km-D Pn crater at 32.19\textdegree N 103.86\textdegree E. (Bottom left) 5.5-km-D LARLE crater centered at 68.27\textdegree N 266.36\textdegree E. (Bottom Right) 3.4-km-D Pd crater with marginal sublimation pits, centered at 62.4\textdegree N 99.4\textdegree E.

Double Layer and Pancake Craters: Double layer ejecta (DLE) craters are characterized by two complete ejecta layers [1] where the inner layer is less extensive, more circular in planform, has a broader distal rampart, and is thicker than the outer layer [3, 4]. We have recently begun calling these Type 1 DLE craters to distinguish them from those which are morphologically and morphometrically transitional between SLE and MLE (“Type 2 DLE craters”) [5]. Type 1 DLE craters are concentrated in the 30\textdegree-60\textdegree latitude zone in both hemispheres and display diameters between the 5 km lower diameter limit of this study and 115 km [2, 3, 6]. The morphology of their two ejecta layers are dramatically different. On the inner layer, a moat exists outside of the crater rim and a system of strong, straight, radial grooves and troughs extends continuously from the rim to the outer edge of this layer’s broad terminal rampart. The outer layer is uniformly thin and also exhibits strong radial grooving, but these grooves are narrower and can be quite curvilinear [3]. The average width of the straight radial grooves on the inner ejecta layers of Type 1 DLE craters are distinctly different compared to SLE, Type 2 DLE, and MLE craters (Fig. 2), suggesting different formation mechanisms [7]. The ratio of the ejecta length to the crater radius (ejecta mobility ratio, EM [6]) of the inner layer ranges from 0.4 to 3.3 with a median value of 1.5. The outer layer extends approximately twice as far as the inner layer, with EM values ranging from 1.4 to 9.8 (median = 3.1). Lobateness (\(\Gamma\)), which measures how the sinuosity of the ejecta deposit compares to a circle (\(\Gamma=1\) for circular deposit and is larger for increasing sinuosity) [8], ranges from 1.03 to 1.31 (median = 1.11) for the inner layer and from 1.05 to 1.93 (median = 1.15) for the outer layer.

![Figure 2](image.png)

Figure 2: Average width of radial grooves normalized to crater diameter. Groove width varies as a function of distance from the crater rim but Type 1 DLE craters are distinct from other ejecta types.

Pancake (Pn) craters are characterized by a single thick, low EM and \(\Gamma\) ejecta deposit. Based on morphology, [9] proposed that Pn craters were simply the inner ejecta layer of DLE craters where the outer layer was not detectable. Higher resolution images combined with morphometric measurements led Barlow [6] to confirm that Pn craters are simply eroded versions of Type 1 DLE craters where only the inner ejecta layer is resolved or present.

LARLE and Pd Craters: Another unusual ejecta morphology seen primarily around high-latitude im-
Impact craters on Mars is the LARLE morphology, which is characterized by a thin (<10 m) deposit extending beyond the normal layered ejecta blanket with EM up to 20 and terminating in a sinuous edge (median $\Gamma = 2.05$) [10]. We have identified 140 LARLE craters in the 1 to 12.2 km diameter range, primarily at latitudes poleward of 35°-40° in both hemispheres (Fig. 3).

Figure 3: Distribution of LARLE (black circles) and Pd (white triangles) craters across Mars. Most are found poleward of about 35°N and 40°S, with the exception of a few craters in the equatorial Medusae Fossae Formation (MFF).

Pedestal (Pd) craters are found in the same locations (Fig. 3) and diameter ranges as LARLE craters. They are characterized by the crater and layered ejecta blanket sitting atop an elevated plateau approximately circular in planform [10, 11]. Marginal scalloped pits along the base of some plateaus (Fig. 1) suggest an erosional process creates the pedestal on which the crater is found [12]. Pedestals are generally <60 m in height [11] and Pd craters have lower EM and $\Gamma$ values than LARLE craters [10]. Based on distribution, diameter range, and morphologic similarities, [10] has argued that Pd craters are eroded versions of LARLE craters.

**Formation Mechanisms:** The concentration of DLE, Pn, LARLE, and Pd craters within the fine-grained, ice-rich mid-latitude mantle [13] suggests that terrain properties are responsible for the formation of these unusual ejecta types. Several formation mechanisms have been proposed for Type 1 DLE craters, including excavation through layered targets [9, 14], debris flow [15], and impact into a glacial substrate followed by mass movement [16]. Based on our studies of the characteristics of the Type 1 DLE craters along with insights from terrestrial explosion studies [3], we argue that these morphologies result from emplacement of the inner layer in a manner involving both ballistic and flow processes. The outer layer is emplaced by a high-velocity outflow of materials by a base surge. The fine-grained, ice-rich nature of the mantle into which these craters form provides the vapor and particulate debris to enhance formation by this mechanism. Similarly, the extensive LARLE layer can be explained through emplacement by base surge like those produced by buried nuclear explosions and high-energy volcanic eruptions that generate a dusty, turbulent, dilute, suspension-driven gravity current which flows along the surface, depositing fine-grained material in a thin layer as it travels outward from the source [17]. On Earth, base surge deposits are quickly removed by wind, but the circulation of briny fluids within the LARLE deposits on Mars could produce a duricrust to retard erosion.

Pd craters are proposed to originate as LARLE craters which then undergo erosion of the outer extensive layer [10]. Obliquity-driven variations in ice-deposition and erosion in the mid-latitudes cause the mantle deposit to alternately thicken and thin as the tilt of Mars’ rotation axis changes [18]. As obliquity decreases and ice in the mantling layer sublimes, the surrounding region lowers in elevation. The duricrust of the LARLE layer prevents sublimation of the underlying ice and results in the crater and ejecta deposits remaining elevated above the surroundings. Ice sublimation occurs along the margins of the LARLE layer, gradually eroding the layer inwards and creating Pd craters [10, 12].

**Conclusions:** Several unusual impact crater ejecta morphologies at mid-to-high latitudes on Mars result from formation and degradation processes in fine-grained ice-rich materials. Thickness of these deposits relative to crater diameter (and thus excavation depth) can explain formation of Type 1 DLE versus LARLE craters. Pn and Pd morphologies are erosional versions of DLE and LARLE craters, respectively. The polar environment and obliquity cycles on Mars strongly influence crater formation and evolution at these high latitudes.