DOUBLE-LAYERED EJECTA CRATERS (DLE) ON MARS: ASSESSING A GLACIAL SUBSTRATE MODEL AS A FACTOR IN THEIR ORIGIN. D. K. Weiss[1] and J. W. Head[1], [1]Department of Geological Sciences, Providence, RI 02912, U.S.A. (david_weiss@brown.edu)

Introduction: Martian impact craters possess unusual ejecta characteristics relative to ballistically-dominated ejecta seen in lunar and mercurian impact craters: martian lobate ejecta deposits appear to have been fluidized during their emplacement [1-5]. Of the martian impact craters, double-layered ejecta (DLE) craters, located in the mid-high latitudes of Mars in both hemispheres [5,7], and characterized by two ejecta layers that possess a radial texture extending from the crater rim to the outer edge of the ejecta deposit, are particularily enigmatic.

The major features of DLE craters include (Fig. 1): 1) regional, mid-latitude dependent distribution [5], 2) lack of secondary craters [5], 3) anomalously steep outer rim crest [5], 4) grooved radial texture [5,6], 5) apparent overthrusting of inner lobe over outer lobe [7], 6) unusual annular depression at base of rim structural uplift and enhanced annular topography at distal edge of inner lobe [5], 7) sublimination pits on outer rim, 8) unusual texture on outer rim crest, 9) association with other crater types [6,8], 10) association with glacial and ice-related features [5,9-14]. Many of the unusual characteristics of DLE craters have been hypothesized to be related to: 1) the presence of the martian atmosphere [15-18], 2) the presence of regolith volatiles within the target materials [5,9-14], 3) a base surge developed by the collapse of an explosion column [5], or some combination of these factors [5,14]. Here we explore a fourth hypothesis, a *glacial substrate model*, which attributes many of the unusual characteristics of DLE craters (Fig. 1) to be due to the presence of surface snow and ice (glacial deposits) that existed periodically in mid-high latitude regions due to spin-axis/orbital variations [19,20] (Fig. 2a).

Evidence for Glacial (Snow and Ice) Substrates: Recent work synthesized in [20] has shown that non-polar regions have sometimes been covered with snow and ice typically 50 meters thick, and sometimes more [20-27]. In the *glacial substrate model* (Fig. 2), a layer of surface snow and ice ranging from 50-200 meters thick, predicted and detected by a variety of studies [20-27], existed in the region at the time of the impact and influenced the emplacement of the ejecta to explain many of the characteristics of DLE craters.

Testing the hypothesis: We outline nine basic characteristics of DLE craters (Fig. 1) and test these against the *glacial substrate model* to assess its plausibility and usefulness for futher analysis.

1. Latitude dependence. DLE craters are primarily located in the latitudinal bands 25°-60° N and 30°-50° S [5], where a variety of studies have detected the existence of surface snow and ice during extended periods of the Amazonian [20].

2. Lack of secondary craters. The lack of secondary craters surrounding DLE craters has been explained by the fragmentation of ejecta blocks due to: 1) volatiles within the regolith ejecta blocks, 2) volatiles within the target material, or 3) crushing of ejecta blocks by dynamic pressure in high-velocity outflow of gas during ejection [5]. Alternatively, if secondary craters were emplaced when a glacial substrate was present, their small size and relatively shallow depths would likely prevent their preservation subsequent to the sublimination loss of the glacial substrate during a different climate regime.

3. *Rim crest.* The anomalously sharp, narrow nature of the observed crater rim crest [5] suggests that the rim crest has experienced modification. If ejecta emplaced on the rim crest slid downwards on a lubricated glacial substrate, the rim crest would appear tapered.

4. *Radial striations.* DLE craters exhibit radial striations that extend from the crater rim to the outer edge of the ejecta deposit and are suggested to result from radial scouring of wind vortices by the advancing ejecta curtain [5, 15-18]. However, radial striations are also common in terrestrial and martian landslide material [28-30]; some [30] have suggested that the ejecta layer flowed as a basal glide and that multi-layered ejecta (MLE) and DLE morphologies are caused by a landslide of the outer rim material. In our scenario, we interpret the radial striations in the context of a landslide and suggest that the sliding of the outer rim material was enhanced by the underlying snow and ice layer, resulting in preferential slumping at the edge of the structurally uplifted rim (Fig. 2c).

5. Overthrust. The inner ejecta layer has been shown to overlie the outer ejecta layer [7] and radial outward flow is interpreted to have led to an overthrusting of the outer layer by the inner layer. In line with suggestion that DLE craters form from a landslide [30], we suggest that the overthrusting event was a landslide of outer rim material enhanced by structural uplift and sliding off the ice-lubricated surface layer (Fig. 2c).

6. Low annulus elevation. We observe that a low annulus at the base of the uplifted rim crest lies at an elevation that is very close to that of the outer ejecta layer (Fig. 1). If uplift-induced landsliding occurred due to a glacial substrate, one might expect to see a topographic low at the base of the structural uplift in the proximal part of the landslide area.

7. Lineated terrain.We observe lineated terrain, which is characterized by a linear pattern of parallel grooves located on the lower portion of the rim crest adjacent to the annulus in some DLE craters (Fig. 1). Lineated terrain is also observed in the inner parts of cold-based glacial features observed on the rims of craters and are attributed to glacial scouring and fluting [20, 31]. We suggest that the lineated terrain observed on the outer rim crest is caused by the scouring of the outer rim material during the landslide event (Fig. 2c) that created the inner ejecta layer and the radial striations.

8. Sublimination pits. We observe features interpreted to be sublimination pits [24] in the outer rim material of several DLE craters, from which we infer the presence of an ice layer. The presence of an ice layer at the boundary between the uplifted rim and inner ejecta layer is consistent with the scenario of the inner ejecta layer sliding outward enhanced by a preexisting snow and ice layer.

9. *Relation to other crater types.* DLE craters are linked in their areal distribution and potential glacial substrate [8] to other craters types, pedestal craters (Pd) [24], excess-ejecta craters (EEC) [6], and perched craters (Pr) [22, 8]) whose latitudinal distribution is similar to DLE craters. In the Pd/EEC/Pr [8] proposed model, these craters share the common theme of formation on a glacial snow and ice layer.

In summary, the *glacial substrate model* (Fig. 2) would involve the following steps: 1) deposition of a snow and ice layer to produce a glacial substrate (Fig. 2a). 2) Formation of an impact into this glacial substrate down into the regolith below the glacial ice substrate, excavation and emplacement of ejecta (Fig. 2b); the layered ejecta emplacement is potentially facilitated by the glacial substrate and secondary craters are formed primarily in the glacial substrate. In the latter stages of formation of the ejecta lobe, or at some time close therafter, the second lobe is emplaced in a landslide mode, enhanced by the glacial-substrate lubricated, structurally uplifted rim (Fig. 2c). This produces the sharp crater rim crest and the distinctive annular topographic low, and exposes the lineated terrain and leads to sublimation of parts of the exposed icy stubstrate. Following this emplacement, global climate change leads to surface ice instability and removal of the surrounding glacial icy substrate layer [20], destroying evidence of superposed secondary craters in this layer.

Conclusions: We conclude that a large number of martian DLE crater characteritics can be plausibly explained by the *glacial substrate model* for DLE formation and thus that it deserves further analysis in the context of the three currently favored factors, 1) Atmospheric effects [15-18], 2) Icy regolith substrate effects [5,9-14], 3) Base surge effects [5]. Together, or in some combination, these factors may explain the full range of enigmatic characteristics of DLE craters on Mars.

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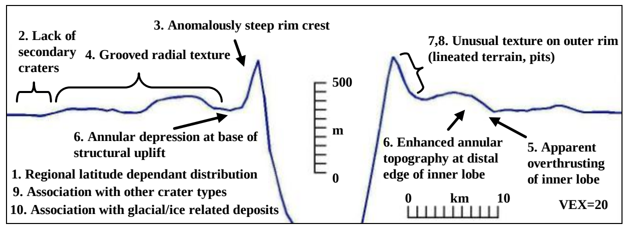

Fig 1. Major characteristics of DLE craters.

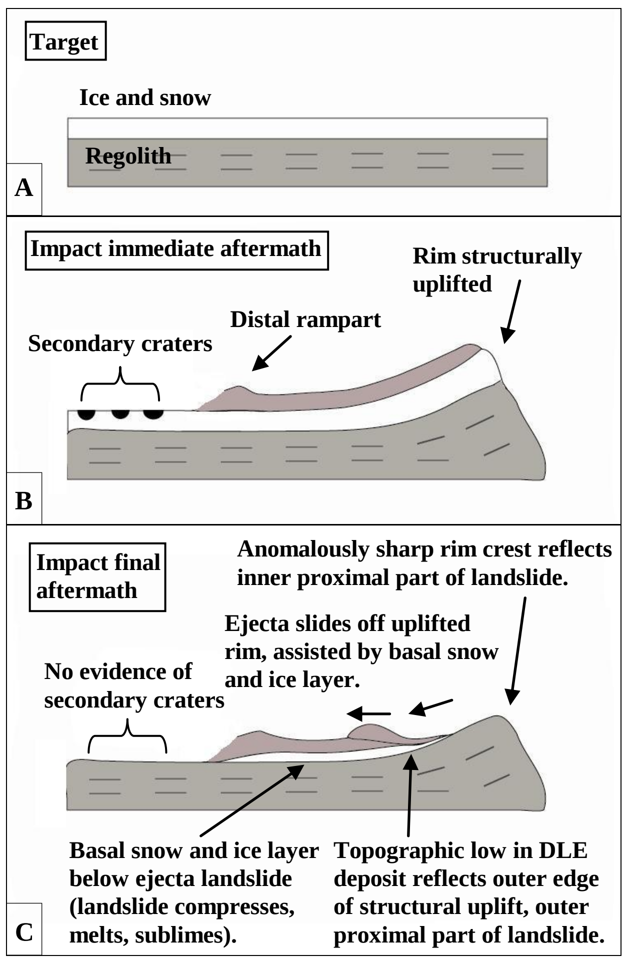

Fig. 2. *Glacial substrate model* for DLE craters.