ASSESSING THE MORPHOLOGY OF DOUBLE LAYERED EJECTA CRATERS AT EQUATORIAL REGIONS ON MARS.

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Introduction: Craters displaying fluidized layered ejecta blankets are unique to Earth and Mars and, to date, have not been recognized on any other terrestrial body (i.e. the Moon, Mercury and Venus) in the inner Solar System [1, 2]. The presence of volatiles in the subsurface or atmosphere are thought to help fluidize ejecta layers, causing them to flow [1, 3]. On Mars, three distinct morphologies of layered ejecta are recognized: single (SLE), double (DLE), and multiple (MLE) [4]. While SLE and MLE morphologies are common globally, DLEs are of particular interest because of their concentration in the northern latitudes (35 – 60°) [5]. They do, however, occur elsewhere on Mars, but in much lower numbers [5]. To date, few in-depth analyses have been done concerning these ‘outlier’ DLEs. Here, we assess the morphology of DLEs found at equatorial regions on Mars and compare them with more common DLE morphologies at northern latitudes (Fig. 1).

Methods: Thirty-three DLE craters were selected for analysis: 19 in northern latitudes (30 – 60°), and 14 near the equator (+/- 18° latitude). Crater sizes in each region correspond with one another and range from ~5 to 25 km in diameter. Equatorial DLEs are concentrated in the Tharsis region around Valles Marineris with the exception of 4 in Syrtis Major, while northern latitude DLEs are concentrated in the Vastitas Borealis, Arcadia Planitia, and Utopia Planitia regions. Java Mission-planning and Analysis for Remote Sensing (JMARS) software [6] was largely used for the analyses of DLE craters, along with the Robbins Crater Database [7]. The extent of each ejecta layer was measured by dividing the crater radius by the average radius of the ejecta layer and subtracting one to give an average run out distance measured from the crater rim. Sinuosity of each layer was determined using the lobateness (Γ) formula [8].

Results: Our results of northern latitude DLEs support previous observations (i.e. [9, 10]) of DLEs located at these latitudes while Equatorial DLEs are noticeably different from their counterparts. Results are presented and summarized below.

		Avg. ROD	SD	Avg. Γ	SD
N. L. DLEs	Outer L.	3.31 R	0.64	1.55	0.17
	Inner L.	1.56 R	0.16	1.29	0.17
E. DLEs	Outer L.	2.25 R	0.32	1.80	0.25
	Inner L.	1.47 R	0.20	1.59	0.19

Table 1: Average run out distances (ROD) are measured with R (crater radii). Average lobatness (Γ) values are given where 1 is circular. Standard deviations (SD) are listed for each.

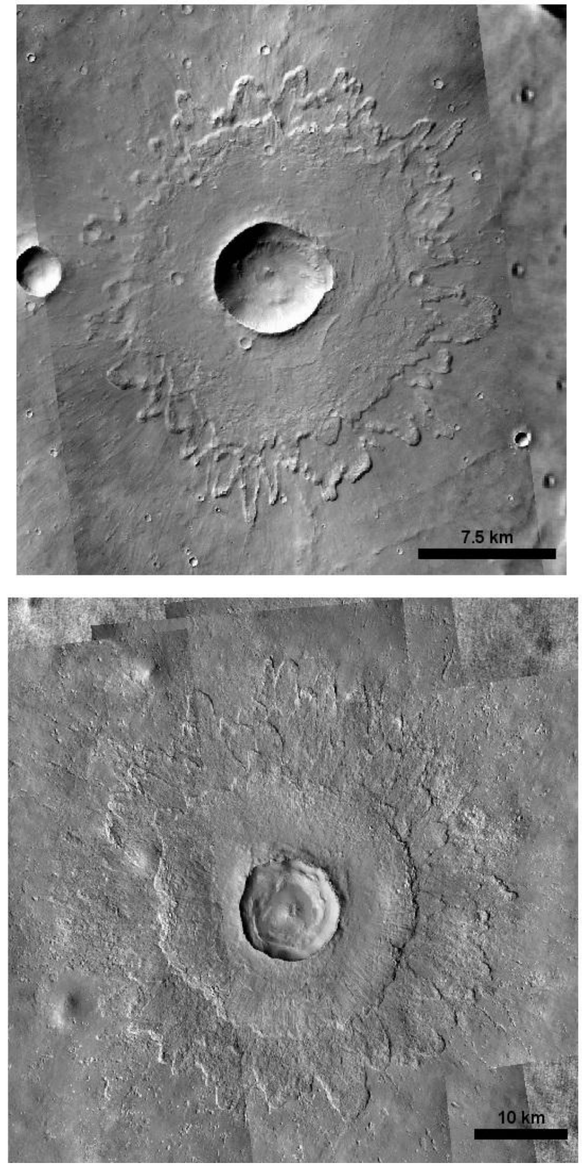

Figure 1: Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) images of typical DLE craters. *Top:* Unnamed equatorial DLE (301.04° E, -10.21°). *Bottom:* Northern latitude DLE Steinheim (190.66° E, 54.57°).

Northern Latitude DLEs: In terms of area, northern latitude DLEs tend to be larger than the equatorial ones. The extent of outer layers range from 2.3 – 4.8 R, while inner layers range from 1.3 – 1.8 R where R is crater radii measured from the rim. The extent of each layer does not necessarily grow in a linear fashion with crater size, especially for the inner layers. Inner layers tend to be more circular (less lobate) than outer layers with an average lobateness value of ~1.29, where 1 is circular [8]. The average lobateness value of outer layers equals ~1.55.

Equatorial DLEs: The most striking difference of equatorial DLEs from northern latitude DLEs is the sinuosity of each layer. Average lobateness values of ~1.59 and ~1.80 were recorded for the inner and outer layers, respectively, each registering higher than both layers of northern latitude DLEs. As previously stated, DLEs in equatorial regions are less extensive than those at higher northern latitudes. Outer layers extend only out to 1.6 – 2.7 R, while inner layers range from 1.2 – 1.9 R.

Discussion and implications: Based on our results and observations, it is possible that the DLEs observed in equatorial regions could be classified as a sub-class of DLE. Although two distinct layers are clearly visible, the morphologies of each layer varies from those observed at northern latitudes. The sinuosity of equatorial DLE craters is much greater than northern latitude DLE craters, especially inner layers and may be due from a surplus of volatiles at depth. In addition, run out distances of equatorial DLEs' outer layers are much less than those at northern latitudes. We suggest the differences in equatorial and northern latitude DLEs could potentially be due to varying emplacement processes.

It has been previously suggested that subsurface volatiles help fluidize ejecta deposits of DLE craters [1]. Reservoirs of ice may lie within 1.2 km of the surface in northern latitudes, whereas reservoirs may lie as close as 600 m at equatorial latitudes (+/- 30°) [5]. Varying depths at which reservoirs reside may affect the observed lobateness values and morphologies. Results from this study support that varying concentrations of volatiles as a function of latitude may also affect the observed DLE morphologies.

It is generally acknowledged that the different layers of layered ejecta structures are emplaced in two (or more) separate stages where fluidity of the ejected material is thought to vary [9, 8, 2]. It has been proposed that the first layer emplaced will be affected by a reservoir of volatiles more than the second layer [8] (e.g., layer will be more sinuous). This implies that for both equatorial and northern latitude DLEs, the outer layer is emplaced first due to higher lobateness values. However, Barlow and Bradley [11] hypothesize DLE morphologies are the result from impact into a layered target material containing varying concentrations of volatiles. Alternately, the inner layer may be comprised of a higher volume of melt component with respect to the outer [2], which is also closely linked to the target stratigraphy.

It is possible that equatorial regions have a higher frequency of volatile-rich layers (or perched aquifers) at depth, while northern regions have a series of volatile-rich layers concentrated only near the surface. The amount of volatiles in each region is unknown, but would presumably be more abundant in northern latitudes where there have been extensive ice deposits throughout much of Mars' latter history [12]. The overall thickness of volatile-rich layers in the north may be relatively large, whereas regions near the equator may consist of multiple thin layers of volatiles extending to depth. Assuming at least some amount of volatiles exist at depth in equatorial regions can explain why lobateness values are so high for inner layers of ejecta deposits. A surplus of volatiles would allow both ejecta layers to become sinuous.

At northern latitudes, it is proposed that the outer layer is deposited first, while the inner layer is emplaced as a landslide mode assisted by surficial snow or ice [13]. Assuming craters are completely circular, and rim slopes are equal circumferentially, the inner layer would extend radially at equal lengths downslope from the rim, producing the low lobateness values observed for this layer in northern latitude DLEs. The outer ejecta layer would be the only layer directly affected by volatile content.

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