Evidence for a Thick, Discontinuous Mantle of Volatile-Rich Materials in the Northern High-Latitudes of Mars Based on Crater Depth/Diameter Measurements: Joseph M. Boyce, Peter Mouginis-Mark, and Harold Garbeil, All of the Hawaii Institute of Geophysics and Planetology, University of Hawaii, Manoa, Honolulu, HI, 96822. jboyce@higp.hawaii.edu.

Introduction: The ultimate goal of this study is to provide insight into the erosion and depositional history of Mars. This study focuses on the surface history of the northern high-latitudes of Mars suggested by depth/diameter (d/D) relationships of craters found within that region. Variation in d/D relationships across this latitude zone suggests the presents of a blanket of materials in the lowlands covering both crater floors and the surround plains north of 45° N. The technique described by [1] was applied to the 1/64° MOLA database in six sample areas (Utopia, Acidailia, North Polar basin, the lowlands north of Protonilus, and the highlands of northern Deuteronilus, and Tempe Terra) in order to search for spatial variations in d/D. Depth and Diameter for a total of 1023 craters, ranging from about 2 km to over 100km diameter were measured in sample areas. Unlike previous d/D studies that only measured depth from the crater rim to its floor (d_R/D), the difference in elevation between the surface surrounding the crater and the crater floor was also measured for each crater (d_s/D).

Background: The morphologies of fresh Martian craters include features both similar and dissimilar to fresh crater morphologies found on the other terrestrial planets. However, the basic sequence of changing morphologies with increasing diameter from simple to complex to multi-ring basins originally described for the moon [2], and Mercury [3,4] applies to Mars as well [5,6,7,8, 9]. Differences observed in the Martian crater morphology (e.g., fluidized ejecta, pitted-central peaks, size of simple crater to complex crater transition) from those on other planets are primarily second order-variations, due to the influence of the Martian environment [10]. On Mars, some variations are produced as an initial morphology of the crater [11]. For example, [9] has suggested that the fresh crater d_R/D relationship may be different for craters in the north polar region because of target material effects. However, other variations are clearly the result of modification of the initial crater shape by surface process such as erosion or deposition [8, 9,12]. To a first order, the origin of such variation can be determined by comparing fresh crater morphologies produced when the crater (in an area) to the crater(s) in question. Further, different types of surface processes also produce characteristic, though not unique, changes to the shapes of craters. With the aid of photogeologic analysis these process can generally be inferred, providing insight into history. This technique is similar to that used by crater counters to infer the surface processes that effect the shapes of their size frequency curves.

We have extended these earlier studies, measuring d_R/D and d_S/D for craters in the Utopia basin. We found that the crater population in Utopia basin exhibits an anomalous ds/D relationship. The floors of craters in Utopia basin were found to be generally at the same elevation as the surrounding terrain [12]. This behavior was ascribed to the deflation of a regional mantle of fine-grained, ice-rich sediment similar to that described by [13, 14]. We suggested that the mantle had been produced from an ancient ocean.

Results: We have expanded our previous study of the Utopia basin to three additional northern high-latitude lowland sample area as well as two areas in the northern high-latitudes highland (all north of 45° N). This study focuses on craters in the 3km to 13km diameter range because 1) small craters are most abundant and hence provide the greatest statistical confidence, and 2) MOLA data is ill-suited for the accurate measurement of d/D of craters smaller than a few kilometers. Consequently, this size range is a balance between these two constraints.

The data show that the northern high-latitude region of Mars can be divided into two major regions of similar d/D relationships (note: polar materials were excluded from this study). The first, the highlands terrain north of 45°N, where the d_R/D and d_S/D relationships (Figure 1 and 2) are similar to those for craters found in mid- and high-southern latitude regions (i.e., depth increases with diameter). The second region, the northern lowland plains, where the d_S/D relationship is markedly different from d_sD in any other region on Mars, while the d_R/D relationship is similar to d/D relationships found in all other parts of Mars [8, 9,12]. Like for the Utopia basin, a plot of the d_s/D relationship for craters in the high-latitude northern lowlands plains follow a nearly horizontal regression line (slope ~ 0) on d/D plots. This indicates that the crater floors and the surrounding terrain are at nearly the same elevation. In addition, few craters in this size range show fresh crater d_S/D relationships suggesting that the mechanism that caused this relationship most likely is geologically young. Though we have less statistical confidence in the d_S/D relationship for craters larger that ~13km diameter and have not presented this data here, it should be noted that the data suggest there may be a slight increases in depth with increasing size.

In addition to collection of d/D data, we have conducted a preliminary examination of craters in the northern lowlands using Viking, MOC and THEMIS images. Similar to previous observers (e.g., [13] [14]), we have found that smooth, layered materials mantle the floors of most craters and surrounding plains in the anomalous d_S/D region. On the floors of larger craters these deposits may form discontinuous isolated mesas while on the surrounding plain these deposits are typically patchy and discontinuous, resulting in the formation of a great variety of landforms on the northern plains (e.g., knobs, irregular mesas, closed depressions and various forms of patterning). Many of these landforms have been interpreted as developing from the action of ground ice [14,15]. The mantle appears to be up to several hundred meters thick and in some places nearly fills craters a few kilometers across. The mantle also appears to be layered suggesting they may have formed as sedimentary deposits in a low energy environment such as an ocean, lake or from the atmosphere. Most crater appear to be in the process of being exhumed from beneath the mantle, with only a few fresh craters found to be superposed on the mantle.

Interpretation: In order for the observed d_S/D relationships to have developed in the northern lowland plains a mechanism must be found that can explain why crater floors are at about the same elevation as the surrounding terrain. While at the same time, this mechanism must also explain why the distance from the crater floors to their rim increases with crater size. In addition, the mechanism must explain why nearly all craters are effected in the northern lowland plains, but none appear to be affected in the northern highlands. We suggest that deflation of an ice-rich mantle covering the northern lowland plains best explains the data and is the most likely cause of the anomaly, though such mechanisms as viscous relaxation, surface creep or deposition from the atmosphere, might conceivably explain some of the observations [15, 16,17]. We favor our model because 1) sublimation and deflation of a several hundred meters thick ice-rich mantle would produce the observed d/D relationships, and 2) the anomalous d_S/D relationship is found only in the northern lowland plains, but absent in the northern highlands. This latter relationship argues against surface creep or viscous relaxation because ground ice needed for these mechanisms to work is stable and expected to be present in both the northern lowlands and northern highlands [14, 15]. As a result craters in both these areas should show the effect of these process, but they are absent in the northern highlands. Similarly, processes that would deposit the mantle from the atmosphere should also operate in both regions. However, because the anomalous d_S/D relationship is limited to the northern lowlands but not observed in the northern highlands this process also appears to be ruled out.

We suggest that the erosion style of the mantle has produced the observed d/D relationships. There is ample evidence for a mantle blanketing the northern lowland plain that is made of layers of volatile rich fine-grain materials [14,15]. We contend that sublimation of ice from this mantle and the subsequent removal of its fine-grained sediments by the wind would result in uniform erosion across its surface. Consequently, as the mantle (assuming it was initially deposited of approximately uniform thickness in any particular area) erodes and its elevation decreases all points on its surface would stay at the same relative elevation with respect to one another, both inside and outside of the craters. As a result, the topography of buried craters would be progressively exposed, analogous to the way they would be exposed if submerged in a lowering body of water. This process would result in the development of d_s/D relationship where d_s values are nearly zero no matter the value of D. At the same time, because rim height is typically a function of crater size, the rims of the largest crater should emerge first from beneath the deflating mantle's surface. As deflation continues and the surface elevation of the mantle decreases locally, rims of smaller and smaller craters will also emerge. As this process continuous, the larger craters, with their higher rims, will rise higher above the deflating mantle than do the smaller ones with their lower rims. This process results in the development of a d_R/D relationship where d_R increases with increased D.

Origin of the Mantle: Our model suggests that the observed d/D relationship of craters found in the northern lowland plains is caused by the erosion of a geologically young mantle composed of several hundred meters of ice-rich sediments. What are the ways such an ice-rich sedimentary mantle could be produced? The observed layering in the mantle is consistent with deposition of sediments in a low energy environment such as provided by a large body of standing water (i.e., ocean) or from the atmosphere. An atmospheric origin appears to be ruled out by the distribution of the mantle, but expected for an origin involving an ocean [18, 19]. In addition, the relative youth of the deposit is inconsistent with an origin related to an ocean whose water was derived from floods delivered down the large outflow channels [18,19]. However, the recent work of [14] (water from a local source) and [20] (water from a global aquifer) have proposed mechanisms that provides large amounts of water from the subsurface at nearly anytime. The details of these models must be developed further in order to decide which fits or data best and therefore favor.

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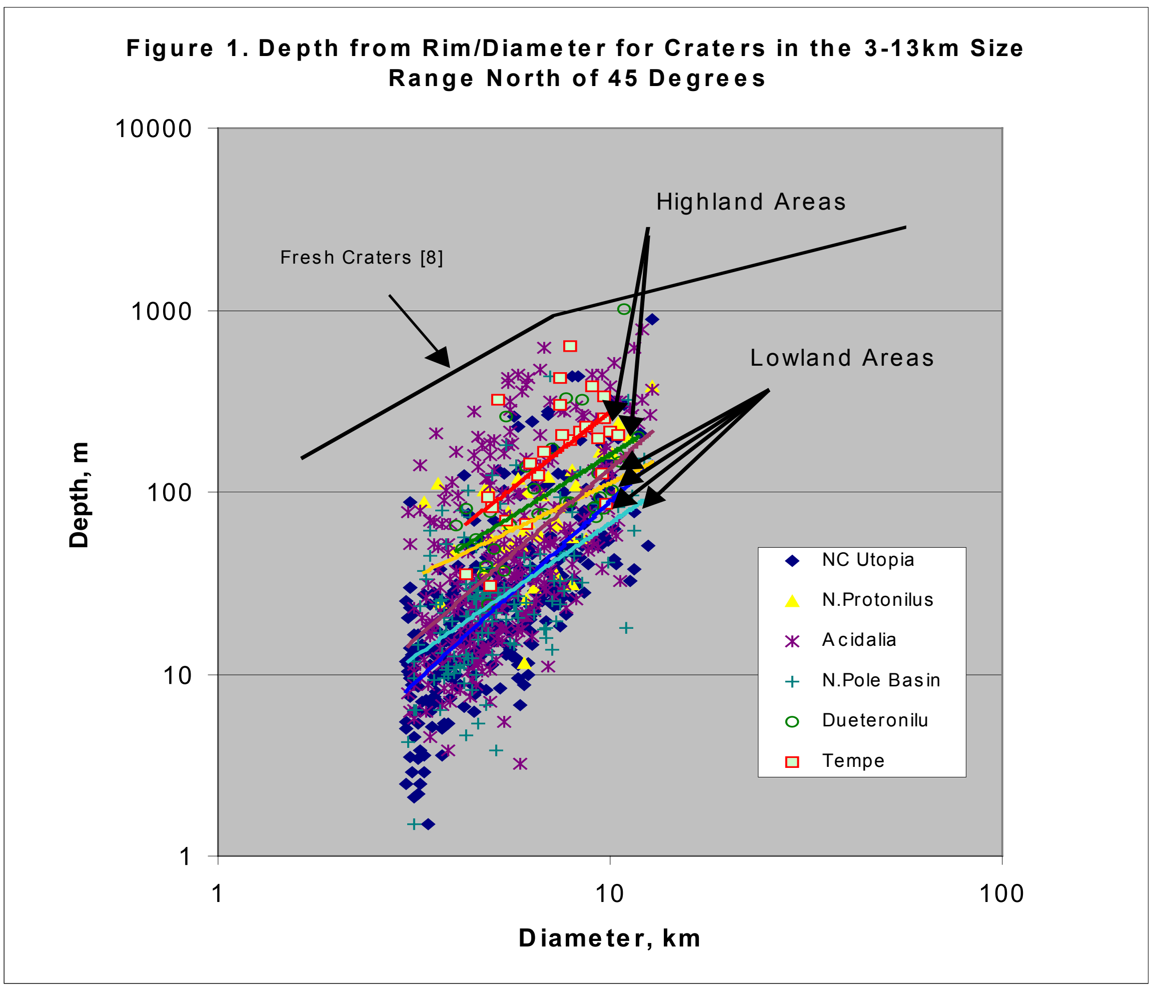
Figure 1: Plot of crater diameter against crater depth relative to crater rim for craters in the 3-13km diameter range. Lines through data points are regression lines for each area. A line represent d/D for all fresh craters from [8] has been include for comparison purposes.



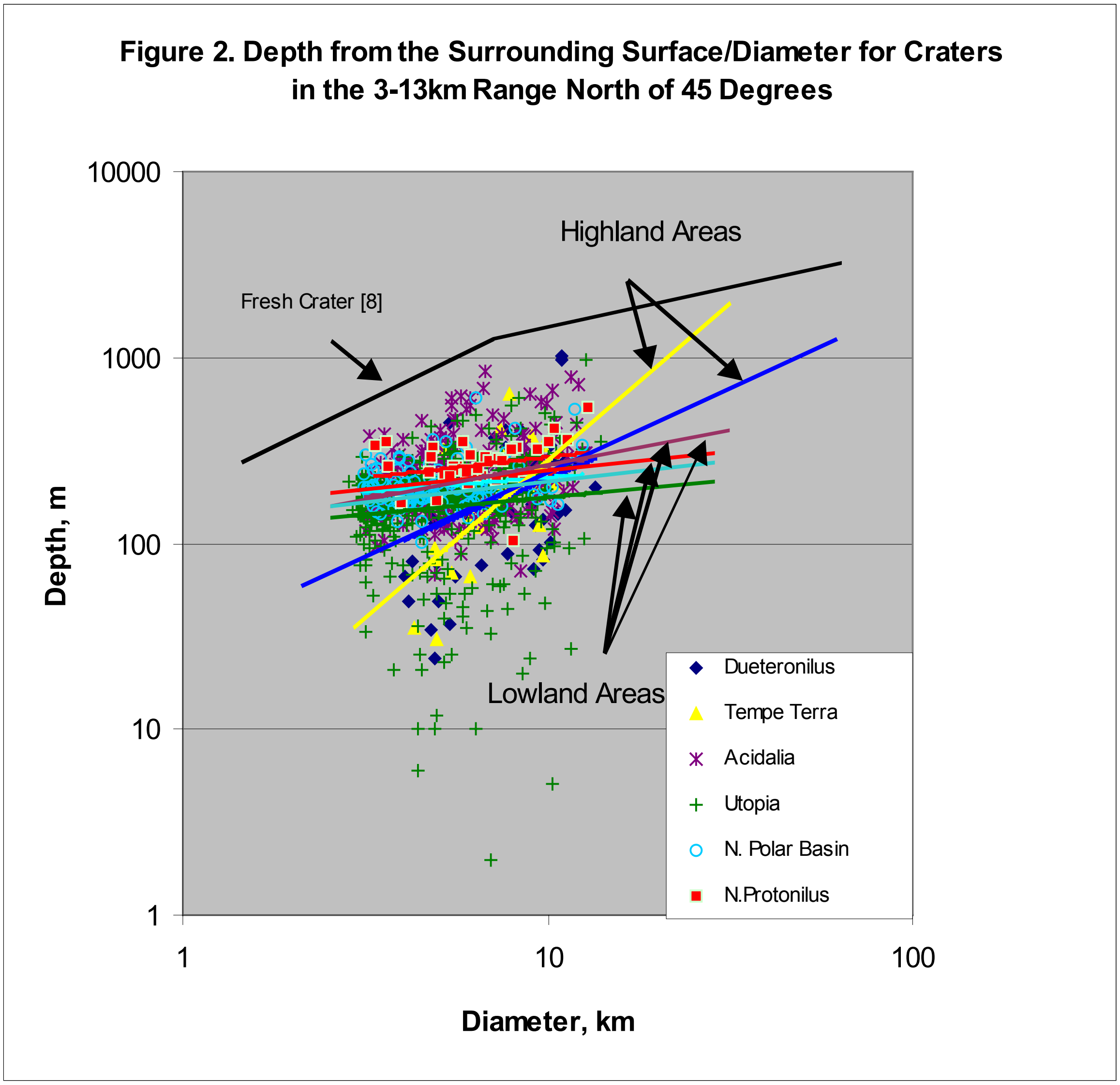


Figure 2: Plot of crater diameter against crater depth relative to the surrounding surface for craters in the 3-13km diameter range. All depth have had 200 m added to their value to make all measurements positive. Lines are the same as in Fig. 1.