THERMOKARST ON MARS? INSIGHTS FROM A SURVEY OF RIMLESS DEPRESSIONS.
J. S. Drake, School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85287 (jdrake@mars.asu.edu).

Introduction: Circular and elliptical depressions, distinct from impact craters by their steep walls, lack of visible rims or ejecta, and flat floors, have been known to exist on Mars for over thirty years. Since their initial discovery in Chryse Planitia by [1], these features have been identified in Viking imagery at several locations, including Lunae Planum, Utopia Planitia, and Ares Valles [2],[3],[4]. More recently, narrow-angle MOC and HiRISE imagery has been employed in the study of the features, resulting in the discovery of several new sites of interest, and permitting the examination of previously identified areas in unprecedented detail [5], [6], [7].

Multiple interpretations concerning the origin of these features have been suggested, including aeolian deflation, periglacial processes such as thermokarst, and various combinations thereof [7] [8]. This study endeavors to discriminate between these competing hypotheses, where possible, by undertaking a geomorphic investigation of rimless depressions on Mars using a combination of THEMIS VIS/IR and MOC imagery, supplemented by MOLA altimetry.

Data and Methods: The region of study, covering the planet from +50º to -60º laitude, was broken up into 396 tiles ten degrees on a side, each of which was then used as the basis for a query of the THEMIS database of images (online at global-data.mars.asu.edu). Each of the matching images was then transformed to a simple cylindrical projection, co-registered with its neighboring images, and cropped to the boundaries of the tile. The resulting mosaics formed the basis for this study, each of which was typically made up of approximately 150 individual THEMIS images. Once all promising locations within a tile had been identified, additional data products were retrieved to facilitate the study of each site in more detail. These included THEMIS visible and MOC imagery (if avaiable), and MOLA altimetry.

Results: The global distribution of the features is strongly constrained by latitude, with over forty percent of all occurrences lying between 40º and 50ºN. Equally striking is the depressions' uneven longitudinal distribution within that zone. For example, a relatively high concentration of pits has long been known to exist near Utopia basin, from approximately 70º to 140º longitude. Beyond this region, however, the density of the features is highly variable. The distribution peaks near 45º N, declining steadily with decreasing latitude. The equatorial regions exhibit the lowest densities of the pits. The density of the depressions increases slowly to the south of 15ºS, but never approaches the levels present in the northern hemisphere.

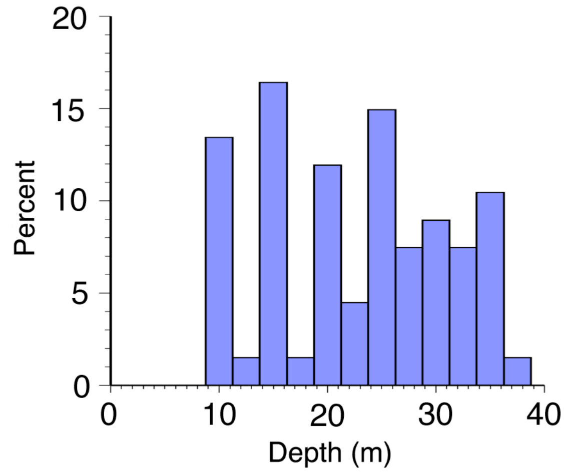

Fig. 1. The depths of rimless depressions in Utopia Planitia are strongly stratified.

A histogram of pits measured by MOLA reveals that their depths are strongly stratified, alternating between abundance and paucity roughly every 2.5 meters as shown in Fig. 1. Beginning in the lower twenty meter range, the number of depressions exhibiting intermediate values begins to increase steadily, however, until by thirty meters in depth the distribution is mostly uniform. Such stratification is consistent with the layered morphology of many of the depressions in Utopia. Though the layers are not themselves resolvable in the MOLA dataset due to their close horizontal proximity, such a stratified distribution provides evidence of their vertical spacing.

While layering most often occurs within depressions, it was observed in other contexts as well, and not only in Utopia Planitia. Figure 2 shows a layered sequence observed near the western edge of Hellas basin, in which multiple strata are clearly visible. Although this exposure may not have formed through the same process as the nascent depressions that occur nearby, their presence within the same deposit leaves little doubt that the two features are closely related.

Despite the influence that aeolian processes are known to have on the morphology of terrestrial thermokarst, and the fact that some observers have ascribed a purely aeolian origin to the Martian depressions (e.g. [9]), a comparison of the features' distribution with evidence for such activity shows little correspondence between the pits and either dune fields or regions where global circulation models predict aeolian shear stresses in excess of the saltation threshold as computed by [10]. A similar lack of correlation is evident between the features' distributuion and the wind streaks mapped by [11].

Interpretation: Though the pits are generally distinct from impact and volcanic features, it is more difficult to differentiate between the hypotheses of aeolian and periglacial origin. Both deflation and the melting or sublimation of ground ice have the potential to produce the morphoogy and distribution observed for the features, and both have been proposed as mechanisms for their formation, either alone (e.g. [3],[9]) or in combination with one-another [12]. One clue to the origin of the features is the observation that their latitude distribution is highly concentrated in bands consistent with the “dissected mantle terrain” (DMT) described by Mustard et al. While it is difficult to envision aeolian processes being constrained in such a manner, however, this does not in itself disprove the theory, as the aeolian erosion of a preexisting latitude-dependent deposit could account for such a pattern. While dissected mantle terrain as a whole is uniformly distributed throughout the Martian mid-latitudes [13], however, the distribution of rimless depressions is far less longitudinally contiguous.

Both numerical models and geomorphic features provide evidence that winds capable of causing deflation are ubiquitous throughout much of the territory in which dissected mantle terrain occurs. If aeolian erosion of the mantled terrain were exclusively responsible for the depressions, they should be similarly widespread, yet they are not. This contrast is particularly striking than in the Southern hemisphere, where dunes, wind streaks, and high modeled shear stresses all occur in conjunction with extensive mantled terrain, yet are accompanied by a conspicuous absence of rimless depressions.

Though this evidence points towards a periglacial origin for the depressions, it does not fully explain their formation as it leaves open the debate between melting and sublimation as the primary genetic process. While the latter interpretation has been preferred by many (e.g. [13]) due to its compatibility with the instability of liquid water under the present Martian climatic regime, other investigators (e.g. [12], [5]) have concluded on the basis of geomorphic evidence that ponding of meltwater occurred on the Martian surface in the recent geologic past. In this scenario, the layers that occur within many of the Utopian depressions represent terraces formed by the erosive action of standing water. Despite the reported similarity between the layering in Martian depressions and erosional benching in terrestrial thermokarst, however, the observed stratification of depths appears to refute the notion that the morphology is the result of erosional processes; such activity would be unlikely to occur at consistent depth intervals across the entire region. Further refuting the lacustrine interpretation is the presence of erosional features, distinct from the rimless depressions, which show similar layering patterns (Fig. 2). While inconsistent with erosion by meltwater, both of these observations fit in with the notion that the layers represent pre-existing stratigraphy. This interpretation, in cojunction with evidence for the features’ periglacial origin, suggests that multiple episodes of volatile deposition may have occurred in the recent geologic past, with sufficient separation between them to result in the discrete layering observed today.

Fig. 2. Though distinct from rimless depressions, this exposure exhibits similar layered stratigraphy. THEMIS VIS mosaic at 40.66ºS, 48.23ºE.

References: [1] Carr M. H. and Schaber G. G. (1977) *JGR, 82,* 4039–4054. [2] Thelig E. and Greeley R. (1979) *JGR, 84,* 7994-8010. [3] Costard F.M. and Kargel J.S. (1995) *Icarus, 114* 93–112. [4] Costard F. (1987) *Z. Geomorph. N.F., 31* 243-251. [5] Page D.P. (2007) *Icarus, 189,* 83-117. [6] Chapman M.G. et al. (2003) *JGR, 108,* 1-20. [7] Soare R.J. et al. (2005) *Icarus, 174,* 373-382. [8] Ghatan G.J. et al. (2003) *JGR,* 108(E5), 5045, doi:10.1029/2002JE001972. [9] Carr M.H. and Head J.W. (2003) *JGR, 108,* E5, 5042 doi:10.1029/2002JE001963. [10] Haberle R.M. et al. (2003) *Icarus, 161,* 66-89. [11] Thomas P. et al. (1981) *Icarus, 45,* 124-153. [12] Soare R.J. et al. (2007) *Icarus, 191,* 95-112. [13] Mustard J.F. et al (2001) *Nature, 412,* 411-414. [14] Milliken R.E. and Mustard J.F. (2003) *Sixth International Conference on Mars,* Abstract # 3240.