Scalloped Depression Development on Malea Planum and the Southern Wall of the Hellas Basin, Mars. M. Zanetti[1], H. Hiesinger[1], D. Reiss[1], E. Hauber[2], and G. Neukum[3]. [1]Institute für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany. [2]Institute of Planetary Research, German Aerospace Center (DLR), Rutherford Str. 2, 12489 Berlin, Germany. [3]Freie Universität Berlin, Maltese Str. 74 -100, 12249 Berlin, Germany. (ZanettiM@uni-muenster.de)

Introduction: Scalloped depressions are an erosional surface morphology characterized as a type of dissected mantle terrain by Milliken and Mustard (2003) [1]. The are characterized by an asymmetrical north-south profile which shows a steep pole-facing scarp, a flat floor, and a gentle equator-facing slope which grades into the surrounding terrain [1,2]. They are found in latitude-dependent, ice-rich surface mantles in both the northern and southern hemispheres, with large concentrations in Utopia Planitia and Malea Planum [1, 2]. The mantle material is presumably composed of atmospherically derived dust and water ice, and is thought to be related to obliquity driven ice activity as recently as 2.1-0.4 Mya [3]. Previous researchers, [e.g. 1,2,4-7] have attributed the formation of scallops to the sublimation of interstitial ice. Morgenstern et al. [6] suggested that the asymmetric profile of scallops can be explained by enhanced solar insolation on the equator-facing slope which leads to enhanced sublimation of interstial ice and thereby increases the area of the depression. By this process they can also grow and coalesce to form large degraded areas [6].

Our previous work surveyed the southern hemisphere using HRSC images for the presence of scalloped terrain, and determined that almost all scalloped terrains are in the Malea Planum region near the southern wall of the Hellas basin [7]. We also mapped the distribution of scalloped terrain between 50° and 70° E and 50° and 70° S. The results of the map showed that the scalloped terrains contour the southern wall of the Hellas basin between the elevations of 1000 m and –2000 m, and that the ice rich mantle is thickest in this region [7]. In this work we explore the solar insolation hypothesis using HiRISE and THEMIS-IR images. We also propose a hypothesis for the nucleation and development of scallops based on observations from HiRISE of cracks in the mantle.

Solar Insolation Model: Studying the Amphitrites and Peneus Paterae volcanic complex located in Malea Planum, Plescia [5] noted the presence of scallops and suggested their formation could be related to a collapse phenomenon of the dust mantle by enhanced solar insolation on the smooth southern slopes. Relating this idea to the scalloped terrains of Utopia Planitia in the northern hemisphere of Mars, Morgenstern et al. [6] proposed that the difference in solar insolation between equator-facing and pole-facing slopes could explain the N-S asymmetry of the scallop profile, as well as explain the difference in hemispherical orientation, where northern hemisphere scallops have steep scarps on the southern side of the scallops and vise a versa. They proposed that through enhanced solar radiation of the equator-facing slopes, more interstitial ice from the dust mantle can sublime to the atmosphere, which creates void space into which the remaining dust collapses making the depression larger [6]. It is important to note that the dusty lag deposit created by removing the pore ice will create and insulating layer which can significantly slow down or stops the sublimation process [8]. Mustard et al. [4] suggested that eolian processes, such as dust devils were the most capable mechanism for dust removal. Based on the modeled slope winds of Siili et al., [9] Zanetti et al. [7] suggested that strong wind gradients due to the slope of the Hellas basin were capable of removing the insulating surface lag.

Data and Methods: High resolution HiRISE images of the scalloped terrain of Malea Planum were used to investigate small scale features. Daytime infrared images from THEMIS-IR were used to show the temperature gradients within the scallops, and were referenced to CTX and HRSC images.

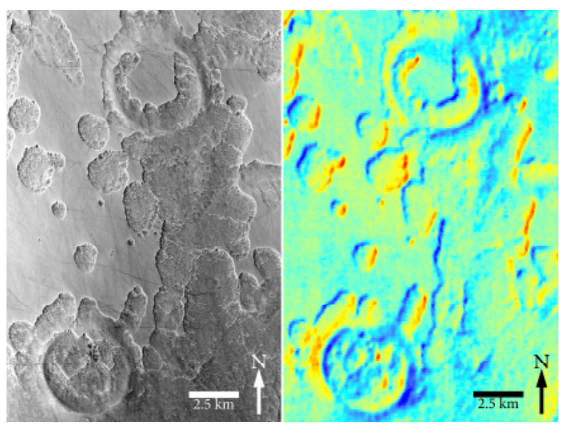

Figure 1: THEMIS-IR image (at right) of an area of scalloped terrain. Equator facing slopes are relatively warm (red), pole facing slopes are relatively cold (dark blue). (THEMIS-IR I17273005RDR; L_S: 318.9, Time: 15.73; CTX image P08_004274_1221_XI_ 57S308W)

Evidence from THEMIS-IR: Figure 1 shows a comparison of a 5 m/pixel CTX and a THEMIS-IR image of an area of scalloped terrain just north of Peneus Patera in Malea Planum [centered at lat. 57S, long. 308W]. The CTX image shows two ~ 4.5 km craters which had been completely mantled over, and are undergoing erosion by the scallop process. The THEMIS-IR image shows the uneven heating of the scallop margins by solar insolation. Red areas in the image are relatively warmer than the dark blue areas. The image (taken at ~15:45) shows that throughout the day, the equator facing slope of the scallop receives more energy than the colder pole-facing scarps. This is evidence in support of the solar insolation model described above.

Development of Scalloped Depressions: In Malea Planum, the ice-rich dust mantle contains polygonally patterned ground which we interpret to be sublimation and sand-wedge polygons described by [10]. The mantle is expected to consist of the ice-rich dust material capped by an insulating ice free dusty lag deposit that is in equilibrium with the atmosphere [1,3,4,8], and models from Mellon et al., [8] suggest that ice is available within ~10 cm of the surface in most of the scalloped region. The mantle is smooth and typically uniform in its distribution and thickness where scallops are found. Thus, an important question is, how does this smooth, flat surface develop into the degraded scalloped terrain. Using high resolution HiRISE images we have found what we interpret as the nucleation points and the evolution of scallops. Scallops seem to form from small cracks (less than a meter width), which possibly form from thermal contraction of the mantle material. If the cracks are sufficiently deep, they penetrate into the ice-rich layer below. If temperatures and humidity levels are such to create a local disequilibrium, the interstitial ice of the mantle will sublime from the subsurface, and the crack will grow larger. However, as the sublimation of the icy material continues the dust lag that develops can threaten to stop the sublimation. This material can be removed by the eolian mechanisms mentioned before. If the process is not halted by this negative feedback loop, the influence of solar insolation on the scallop nucleus crack begins to develop.

Figures 2a and 2b show our interpretation of this progression. Figure 2a shows a number of small cracks in the basketball textured mantle. The feature at the center of the image is interpreted to be a small scallop nucleation crack that has deepened and has begun to take on the characteristic teardrop shape N-S asymmetry of larger scallops. Also in Fig. 2a a small horizontal crack (bottom right) can be seen to penetrate the wall of a much larger scallop (dark feature along right side). This suggests that the cracks can penetrate the subsurface deeply enough to reach the ice layer below. A number of smaller shallower cracks can also be seen in Fig. 2a. Figure 2b shows a curvilinear series of small depressions surrounding cracks a few meters in width. We interpret this to show the early coalesce of small scallops into a longer chain. Coalescence along longer cracks will increase the amount of ice available for sublimation and thus increase the rate of formation of scalloped depressions. Scallops probably also form after small impacts strike the mantle surface penetrate into the icy layer, exposing the ice and allowing for sublimation. We have observed a number of possible impact craters in the HiRISE images of Malea Planum that appear to have been modified by the degradation process. As this process continues, the crater is completely eroded leaving a scallop shaped depression, that can continue to grow. This has obvious implications for determining the age of the mantle unit because fresh craters seem to be relatively short lived.

References: [1] Milliken R.E. and Mustard, J.F., (2003), *6th International Conference on Mars*, #3240. [2] Lefort et al.., (2008), submitted to JGR. [3] Head et al.., (2003) *Nature*, 426, 797-802. [4] Mustard et al., (2001) *Nature*, *412*, 411-414. [5] Plescia, (2003) *LPSC 2003*, #1478. [6] Morgenstern et al., (2007) *JGR*, *112*. [7] Zanetti et al., (2008) *LPSC 2008*, #1682. [8] Mellon et al., (2004) *Icarus*, *169*, 324-340. [9] Siili et al., (1999) *Planetary and Space Science, 47*, 951-970. [10] Marchant, D.R., and Head, J.W., (2007) *Icarus*,*192*,187-222.

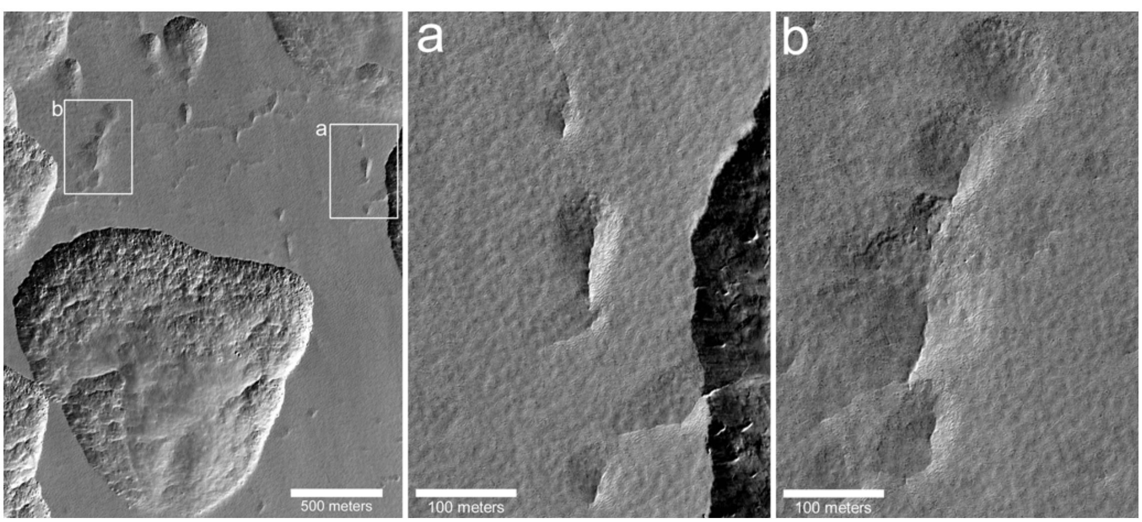

Figure 2: HiRISE image of scalloped depressions. The pole-facing scarp and gentle equator facing slope of the large scallop (~1 km diameter) are well defined. a) A small crack in the mantle has developed a teardrop shape, and begins to resemble a scallop. In the lower-right of the image a crack can be seen which penetrates deeply into the subsurface. b) A chain of depressions has formed along a long crack. Dust can be seen to infill some of the cracks (HiRISE image PSP_005342_1225; centered at Lat: -57.3, Long: 54.3: 50 cm/pixel).