ASPECTS OF A DEPRESSION ON ELYSIUM MONS, MARS, USING HiRISE IMAGERY

A THESIS SUBMITTED TO
THE GEOLOGY AND GEOPHYSICS DEPARTMENT

MAY 2016

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I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Scott Rowland for his mentoring and endless help, Dr. Steve Martell for his help figuring out interpretations of the structural behavior of the depression, my wife, Trista McKenzie, for her endless support, and Danny Powell for pretty much always being in a good mood when I was yelling at Matlab.

Abstract

A depression on the southern flank of Elysium Mons offers a unique opportunity to study the aspects of lava flows and depressions on the second largest volcano on Mars. Using a combination of High Resolution Imaging Science Experiment (HiRISE) images and Mars Orbit Laser Altimeter (MOLA) data it was possible to examine the morphology of a 7 km x 2 km x .5 km lava flows exposed in outcrops on the southern flank of Elysium Mons as well examine the origin of the depression itself. The lava flows show no evidence of interaction with groundwater, a common trait of flows near similar depressions elsewhere on Elysium Mons. Two theories for the formation of the depression were explored. The first was the possibility that it is a graben. The depression's long axis is circumferential to the volcanic centre and apparent postdating of the lava flows indicate that it may have a formational history dissimilar to similar structures elsewhere. Another possibility is that the depression formed by collapse into a subsurface fissure generated by trans-tension between two pressure ridges 2 km and 4 km away. Additional studies into Earth-based analogues and higher resolution topographical data will allow for a more definitive understanding of this feature.

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CHAPTER 1. INTRODUCTION

Elysium Mons is one of the largest volcanoes on Mars, and the central component of a three-volcano hot-spot system of the Elysium volcanic region. Elysium Mons was heavily studied following the Viking 2 mission in 1976. Of particular interest were features that were indicative of interaction with ground and ice water as well as morphology unique on Mars, such as exposed major diking. Due to the unique importance of the northwestern flank, the southern edifice of Elysium Mons is relatively understudied.

The Mars Global Surveyor (MGS) and Mars Reconnaissance Orbiter (MRO) satellites carried onboard instruments that have allowed for an expanded understanding of the Martian surface. Mars Orbiting Laser Altimeter (MOLA) and High Resolution Imaging Science Experiment (HiRISE) data allow for accurate altimetry of the surface of Mars with very small errors. HiRISE imagery of a depression on the southeastern flank of Elysium Mons reveal a cross section of Martian lava flows perpendicular to the eruptive centre. By combining HiRISE imagery with MOLA

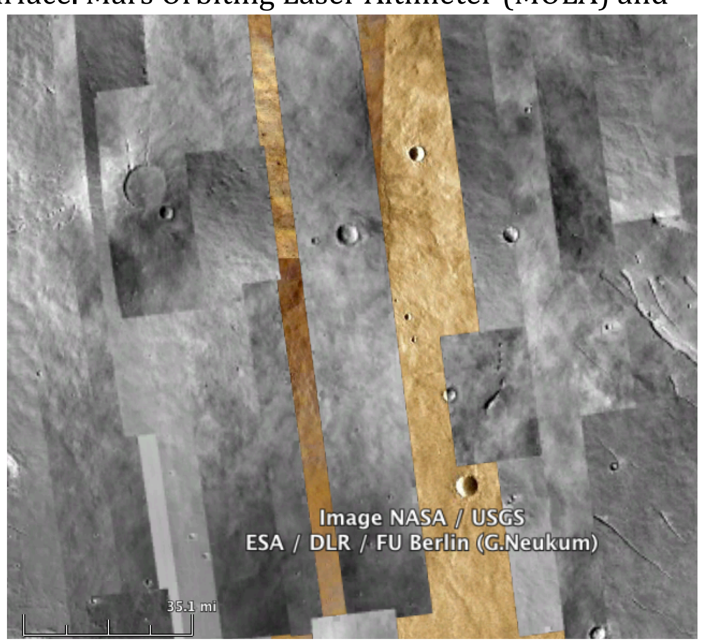

Figure 1. Location of the depression on Elysium Mons, caldera in upper left

altimetry, a more accurate understanding of the depression can be developed with regard to surface topography and the eruptive history of Elysium Mons.

The history of similar depressions on Mars has led to an understanding of their structural formation. They are found on Elysium Mons in the Northwest oriented circumferentially to the volcanic centre. On other Martian volcanoes they are more commonly radial to the volcano or can be associated with features such as dikes. The southeastern Elysium Mons graben studied here is at a 45° angle between two wrinkle ridges which circumscribe Elysium mons, and the depression itself is relatively shallow at 500 m compared to other depressions on Mars. The depression is 7km long along the long axis, 1km wide in the northeast, and 2km wide in the southwest. The interior of the depression is filled with talus, leaving the upper portion of the lava flows exposed as a cliff. There are several hypotheses for the origin of the Elysium Mons depression, examined here.

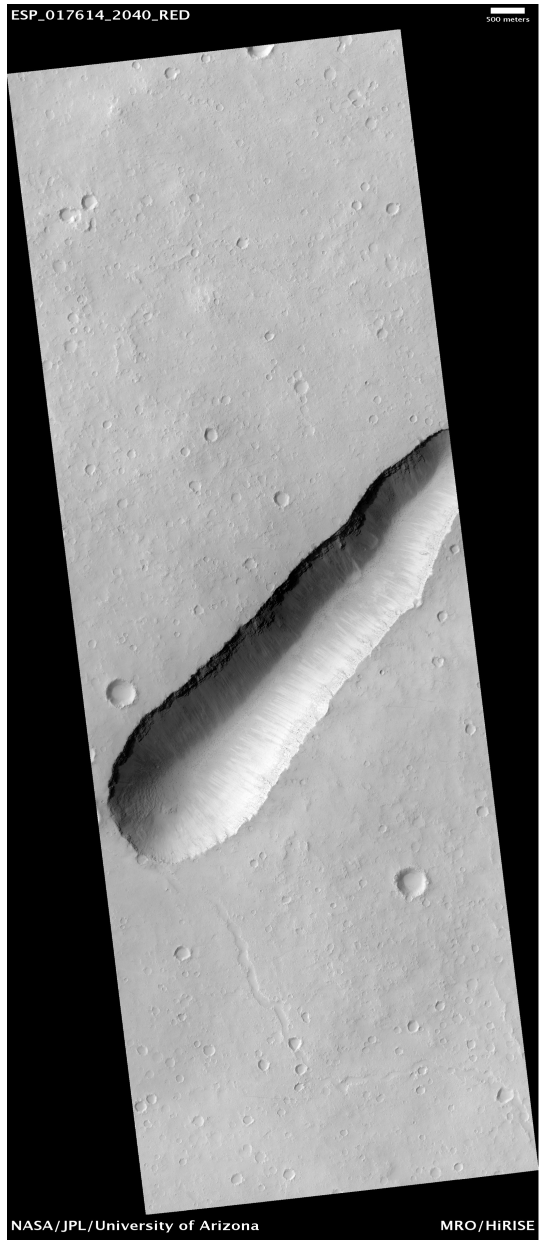

Figure 2. HiRISE image of the depression, scale bar is 500m. (NASA)

CHAPTER 2. METHODS

Data were taken from HiRISE via the University of Arizona's HiRISE Science Experiment web page (hirise.lpl.arizona.edu). A high resolution image of the depression was collected in April, 2010. The image is a .JP2 file with full geospatial tagging. MOLA data were obtained from the Washington University at St. Louis MOLA Precision Experiment Data Record (PEDR) database. A request for data was submitted using the maximum and minimum latitudes and longitudes of the HiRISE image of the depression. Errors in the coordinate system used to mark up the image for importation to mapping software prevented analysis using the image in ArcGIS, so it was imported into Matlab and the MOLA points overlaid onto the HiRISE image. (Glaze et al., 2003), (Mouginis-Mark & Rowland, 2008).

Table 1. The first two points of MOLA data used to calculate the MOLA laser's track across the depression

long_East	lat_North	topography	MOLArange	planet_rad	Ephermis Time	UTC	Orbit
148.79236	23.6505	3140.7	398040.64	3396200.15	22642567.81	2000-09-19T13:35:03.630	16860
148.7916	23.6453	3182.03	397995.92	3396242.56	22642567.91	2000-09-19T13:35:03.730	16860

The margin of error for MOLA's timing is smaller than the margin of error for the laser's firing timing. (Neumann et al., 2001). As the HiRISE track was limited to 56 points, the distance of the MOLA track divided evenly using the linspace function in Matlab. A topographic profile was generated by plotting the distance against the MOLA altimetry data. The overall distance calculated using the Haversine equation and averaging the topographic change between the two endpoints. Two topographical profiles were generated, one with a 2:45 ratio of vertical exaggeration and the other true to scale. Slope was calculated by taking the angle of the slope of two points overlapping the talus flow. A MOLA point at the edge rim of the depression and the adjacent point on the talus was subdivided into percentages of slope face and talus. Talus angle was assumed to be consistent and the rock face slope was calculated by creating a point at the end of the talus slope from the horizontal distance and previously calculated angle. The remaining horizontal and vertical distances were used to calculate a slope for the cliff face.

Individual lava flows were traced in the southwestern portion of the depression. These were outlined in the GNU Image Manipulation Program (GIMP). Flows were only outlined as far as could be definitively followed without a portion obscured by talus. The southern face of the depression was angled into the sun in HiRISE imagery, the resulting overexposure means that a meaningful study of the flows could not be completed. Behavior of the flows exposed in the walls of the depression were contrasted with other flow sequences studied on the northern and northeastern flank of Elysium Mons. (Mouginis-Mark, 1984). Flow sequences believed to be due to dike movement in the northern flank of Elysium were selected for a similar radial distance from the caldera centre and the prevalence of similar

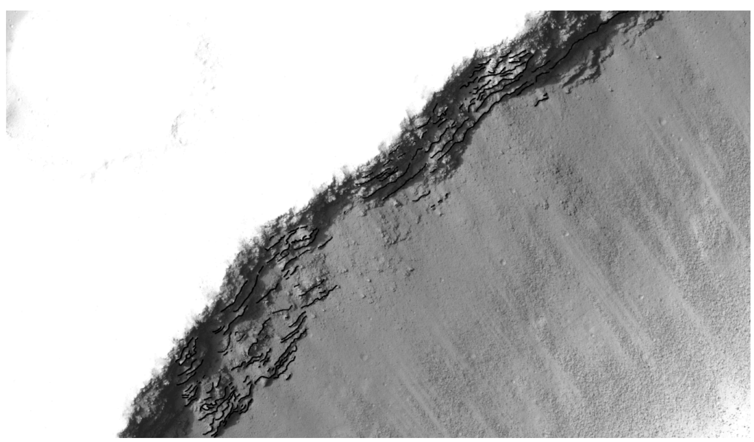

Figure 3. A portion of lava flows outlined in GIM

depressions. This broadly controls for rheological similarities across propagating lava on the volcano’s surface. (Platz and Michael, 2011).

Comparisons of the depression to similar depressions and grabens on Mars and on Earth was done by selecting several representative depressions with similar behavior as the flows observed in the depression studied here. These depressions are dissimilar in origin from each other, allowing for possible sources and scenarios for the depression's formation. (Glaze et al., 2003), (Mouginis-Mark & Rowland, 2008). These were then contrasted with the structural environment, history, and possible geochronology of the depression. With these data it was possible to develop multiple theories for the origin of the depression.

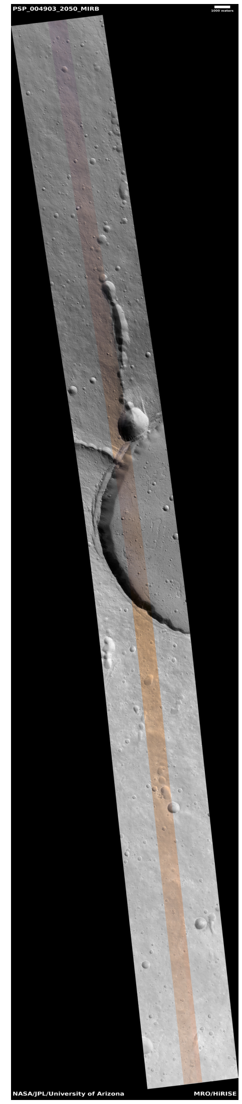

Figure 4. HiRISE example of a dike-formed depression (Nasa, 2010)

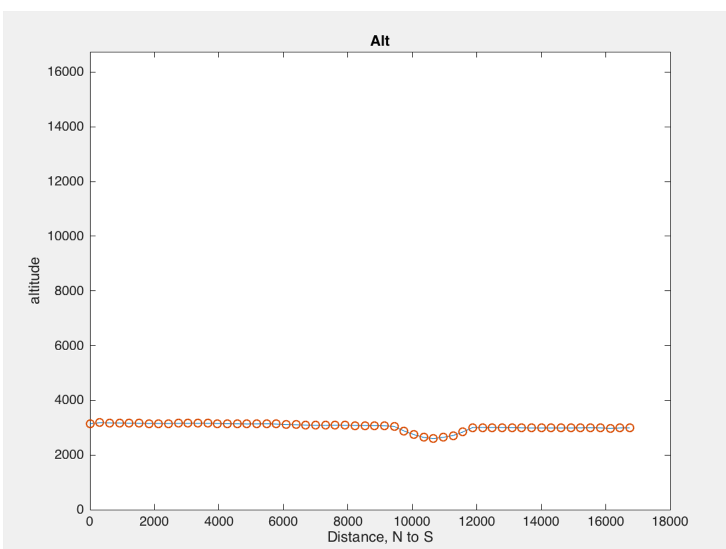

Figure 5. MOLA track with no vertical exaggeration, actually NNE to SSW

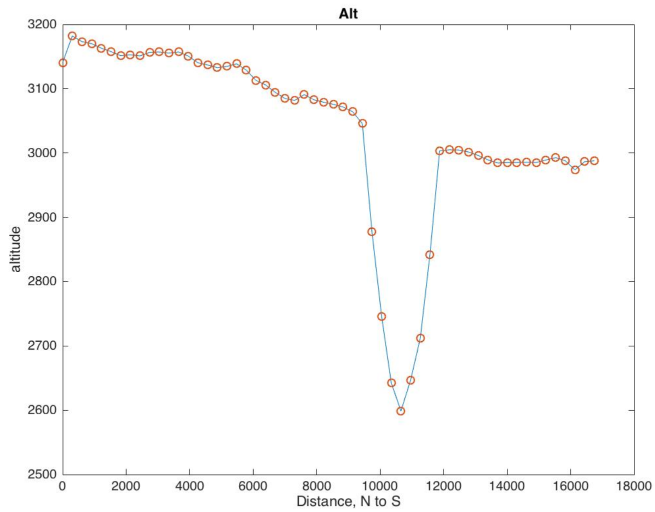

Figure 6. MOLA track with 2:45 exaggeration, actually NNE to SSW

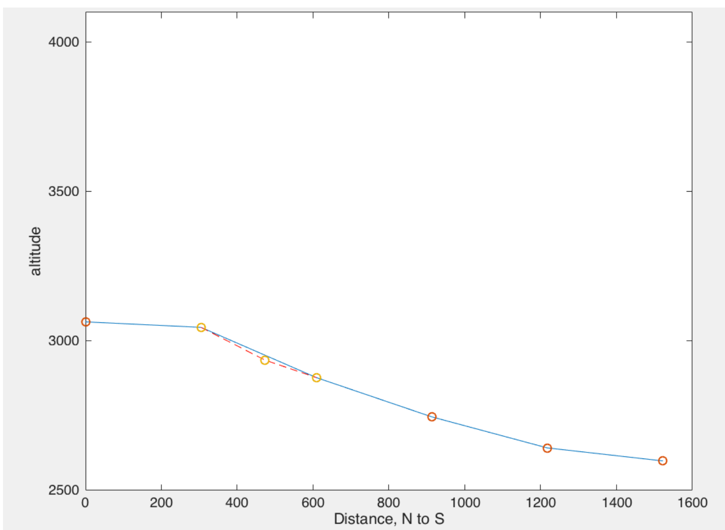

Figure 7. MOLA track for the north face of the slope, with the boundary between the talus and the cliff face marked and calculated slopes in dashed lines., actually NNE to SSW. No vertical exaggeration.

CHAPTER 3. RESULTS

I have considered two mechanisms for the formation of the depression. These two interpretations are not the only two possibilities for the depression but they represent two endmember hypotheses for which a reasonable body of evidence exists. Neither outcome can be definitively favoured over the other and therefore both will be presented as equally possible. First, the depression may be a graben, an extensional fissure opened up due to collapse of the slope of the volcano during the formation of wrinkle ridges. Alternatively, the depression may be a collapsed trans-tensional feature caused by underground trasns-tension.

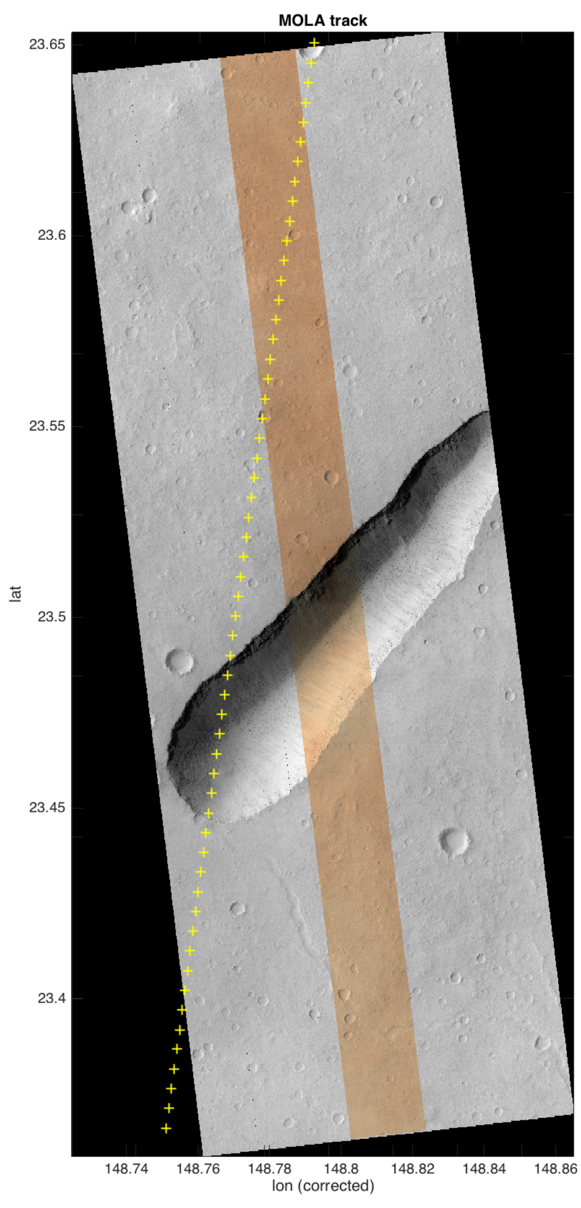

Figure 8. The MOLA track overlaid on the depression in Matlab.

Evidence for a graben interpretation is found in the morphology of the depression and its orientation relative to the caldera of Elysium Mons. The long axist of the depression is radial to the summit, following a trend of wrinkle ridges associated with the area the graben is observed and common on Martian volcanoes. Grabens on Mars form in a similar manner to many terrestrial grabens. On Elysium Mons, grabens have formed by collapsing material along the flank of the volcano as a byproduct of ground collapses brought on by overpressuring of surface material or vacating of underlying space. Grabens on Elysium Mons have also formed due to dike intrusions, where when dike-forming material vacates the space left behind collapses in. This is a process Mars unique to Elysium Mons, and only seen in the Northern portions of the system.

The depression is morphologically similarly to other grabens on the Martian surface. (Glaze et al., 2003), (Mouginis-Mark & Rowland, 2008). Grabens on Elysium Mons postdate surface lava flows, creating areas where the history of Elysium Mons eruptions can be readily examined. (Glaze et al., 2003). In the area around the grabens past geochronology work done through crater counts gives the age of surface flows, and it appears the depression is bisecting these flows. A channel structure emerging from the southwestern extremity of the depression further serves as evidence for the depression's formation postdating flows. (Platz and Gregory, 2011). Wrinkle ridges are associated with ground settling, and in the northwest of Elysium Mons there is evidence for the grabens formed from ground movement similar to the type seen here.

The presence of a chain of pits to the northeast of the depression and the presence of the nearby wrinkle ridges which frame it serve as counterpoints to the graben hypothesis. Chain of pits are frequently observed in areas where fractures have collapsed inward, and the wrinkle ridges are possible evidence for a trans-tensional formation history of the depression since the ridges themselves are formed from events that may impart regional strain.

Stratigraphy in the depression shows that the underlying structure of Elysium Mons is dominated by broad lava flows which are relatively thin compared to similar exposed sequences in the northwest. There is no evidence of dikes or any groundwater interaction, consistent with previous findings that interactions with surface ice were primarily constrained to the northwest and north flank of Elysium Mons. Individual lava flow sequences are thinner than those observed elsewhere on Elysium Mons, though due to the oblique angle of the MOLA track relative to the face of the depression this couldn't be quantified. (Mouginis-Mark et al., 1984)Estimates place individual flow sequences outside of the uppermost layers to be under 8 metres.

Figure 9. The Context Camera (CTX) image of the Elysium Mons depression, showing wrinkle ridges (NASA, 2010)

Alternatively, it is possible that the depression is a collapse feature that formed over trans-tensional subterranean fracturing. CTX images of the depression reveal that the wrinkle ridges near the depression end after passing the depression and that the depression is at a 45° angle to both wrinkle ridges. This may be an indicator that the depression is a surface manifestation of a deeper fracture associated with the wrinkle ridges and the surface material has partially collapsed into the fracture. However, as topography is poorly constrained the true slope direction is unknown. If the true slope regionally could be determined, then it would be possible to quickly ascertain the behavior of the depression relative to the surrounding rock and wrinkle ridges.

Figure 10. Morphologically similar depressions on Kīlauea. Compare to the CTX image of the Elysium depression. (USGS, 1999)

To the northeast of the depression is a chain of pits which are morphologically similar to the depression but along a line that is parallel to the two wrinkle ridges. This pit chain behavior is comparable to terrestrial collapse features observed on Kīlauea in Hawaiʻi. The behaviour of the depression relative to two framing wrinkle ridges is indicative of a trans-tensional origin rather than a purely extensional graben.

Key data are missing from the Martian altimetry record which could clarify the origin of the depression. Although MOLA points are all grouped together along orbits, it appears that there is a large gap in the data over the depression where there is an anomalously large space between tracks. Because of this it is impossible to get a true picture of the topographic setting of the depression. Knowing the regional slope would quickly answer one of the key questions about the behavior of the depression. Attempts to reconstruct the lava flow history across both sides of the depression were complicated by the angle of the sun relative to the HiRISE camera, as the southern face was overexposed and therefore the stratigraphic data were unavailable.

CHAPTER 4. CONCLUSION

With the available data it is difficult to determine the origin of the depression. Although it is similar to grabens on the Mars, the orientation of the depression relative to wrinkle ridges and the similarity to terrestrial analogues could indicate it is a collapse feature. The oblique angle of the MOLA track limited the available data for the lava flows, but it was possible to observe the structure of the flows. The depression's lava flows are thinner in range than those observed elsewhere on Elysium Mons with a similar radial distance, which may indicate a difference in rheology for southward-flowing flows.

Requests have been submitted to the University of Arizona HiRISE program for stereoscopic images of the region which contains the depression. With stereoscopic images it will be possible to accurately reconstruct the topography of the depression and its orientation relative to the overall slope of the volcano. This would enable additional study of the depression and further our understanding of the mechanical behaviour of volcanic surfaces and potentially wrinkle ridges on Mars.

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