POSSIBLE ASSOCIATIONS OF GRABENS AND BASAL SLIDING OF ICE STREAMS ON MARS.

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Introduction: This abstract relates to the author's Equatorial Ice Sheets on Mars Project [1]. Mangala Valles (Fig. c) is possibly the easternmost major trough of a western equatorial trough system of over 20 troughs spread along the western crustal elevation dichotomy of Mars [2]. Ice sheets may have blanketed the slopes of the elevation dichotomy, and individual ice streams may have eroded the troughs. Ice sheets may have eroded the other examples presented here, which are near Elysium Mons. The mantling at Deuteronilus Mensae [1, 3] may give insight into the coverage of these ice sheets.

Basal Sliding: Glacial erosion is most significant where basal sliding occurs. Sliding is induced by water, which lubricates and may be accompanied by friction-reducing pore pressure. Polythermal ice sheets may be the best analog for Mars glacial trough erosion because they are cold-based where thinner, such as at ice sheet margins, but are warm-based where thick enough [4].

The erosion of glacial troughs may have occurred through Mars history when and where climate and landscape were mutually conducive to the generation ice sheets thick enough to allow for basal melting. Melting of basal ice occurs where the pressure melting point of ice is met, which is generally within a couple of degrees below 273 K. Even where the average annual surface temperatures are below freezing, deeper ice can be warmed by geothermal heat, frictional heating generated by basal sliding and internal deformation, and through heat transfer by water. The driving force behind ice flow is gravity related to slope or spreading ice. Ice flow by deformation occurs across an entire ice sheet, but sliding may only commence within favorable landscape features where the greater ice depth allows for higher velocities and warmer bases.

Frictional heating is higher where ice deformation and sliding are stronger, and ice temperature generally increases with depth. This means that portions of ice sheets situated in preexisting channeling or graben and other depressions are more likely to experience basal melting compared to thinner ice to the sides. Ice streams will exploit landscape features if they are favorably oriented, and they may even form the basis of an eventual trough system. As erosion continues, subglacial troughs may lengthen, widen, deepen, and even connect, providing positive feedback through increasing frictional heating and ice depth. As examples, the erosion of Dao Vallis and Kasei Valles may have been strongly influenced by structural faulting [5, 6].

Graben Morphology: Two contrasting landscape features are located to the west of Elysium Mons in Elysium Planitia (Fig. a) and may provide insight into grabens and trough erosion. An ice sheet may have once covered the entire region, but erosion was not uniform and may have been enhanced where faults provided favorable avenues for ice flow. A possible glacial trough system to the east is well-developed with streamlined islands and glacial through troughs. The angular graben network to the west may have provided avenues for ice to flow, but erosion was more restricted. The angularity of a graben network may have inhibited ice flow and so was not eroded greatly. It is possible that the trough system was underlain by a simpler and favorably oriented fault system that afforded avenues for ice flow or provided access to groundwater that promoted basal sliding. Alternatively, the difference may reflect spatial ice sheet variations of thickness or other factors.

Groundwater and Local Topography: In the case of Athabasca Valles (Fig. b) and Mangala Valles **(**Fig. c**),** trough erosion is seen to commence near grabens that are oriented near perpendicular to flow direction. Because these grabens afford no physical advantage for flow, another factor may be at work. The grabens may have been near enough to the threshold of basal melting to initiate sliding or to impede the upslope migration of sliding. Groundwater can play an important role in glacier dynamics both because of the lifting force of pore pressure, which can increase sliding velocities, and by providing water for sliding and heat transfer. One possibility is that groundwater flow focused at the graben [7] spread beneath ice sheets and induced sliding.

Topography can also control where an ice sheet is warm-based, and it is possible that ice at the base of the grabens was at the pressure melting point owing to greater ice thickness. The grabens could have supplied meltwater eventually capable of migration to the base of the ice sheets through cracks in the ice, along the ice-rock interface, and through the ground with the help of localized heat transfer. One gram of refreezing water can raise 160 grams of ice by 1 ˚C. Water may have migrated along the ground-ice sheet interface to the degree that sliding was initiated. The heat then generated by the sliding friction, which is comparable to geothermal flux [4], could sustain and expand the area of basal sliding.

Conversely, stagnant ice filling the grabens would support less friction and impede headward erosion by preventing the headward progress of basal sliding. Along these lines, upslope topography can impede headward erosion, and it is noteworthy that a large crater is located directly across the graben from the head of Mangala Valles (Fig. c). The walls of craters act as ramparts to ice sheets and deflect flow around them and are often at the heart of many streamlined islands.

Geographic Factors: Three primary geographic factors are elevation, latitude, and slope orientation to the sun. Meteorological conditions will determine the amount of precipitation at a given location , which will result in geographic asymmetries of accumulation. Likewise, surface air temperatures will determine the upper settings of temperature profiles and may determine whether or not basal melting will occur. Regional slope is another factor in determining where sliding occurs because precipitation and surface air temperature are elevation-dependent factors.

The relationships between the graben and the possible glacial troughs on the flanks of Elysium Mons (Fig. d) likely reflect one or more elevation-dependent factors. The ground surface has been modified and numerous possible glacial troughs have been eroded below a threshold elevation. These often have their origins in grabens. As perhaps occurred with the previous examples, it may be that ice sheets on the flanks of the volcano preferentially eroded troughs where suitably oriented structural troughs existed. Given that Elysium Mons is a volcano, geothermal heat flow could have been a significant factor during the period of erosion. Groundwater may have issued to the surface beneath the ice as thermal springs and promoted basal sliding, as well as mineralogically modifying the surface.

Similarly, Mangala Valles is located on the elevation dichotomy and elevation was very likely important in determining where sliding would occur. Mangala Valles is somewhat unique amongst the elevation dichotomy troughs in that the graben Mangala Fossa is positioned precisely at its head and is perpendicular to the slope. The existence of many other troughs on the dichotomy suggests that the graben may not have been essential in the formation of Mangala Valles. Mangala Fossa may simply have been near enough to the elevation-controlled threshold of basal melting to initiate sliding or to set its upslope limit.

References: [1] Arfstrom, J. D. (2012) Comp. Clim. Ter. Pl. Ab., 8001 (poster paper at ResearchGate). [2] Arfstrom, J. D. (2019). 10.13140/RG.2.2.23286.34882 [3] Baker, D. M. H. & Head, J. W. (2015). https://doi.org/10.1016/j.icarus.2015.06.036.
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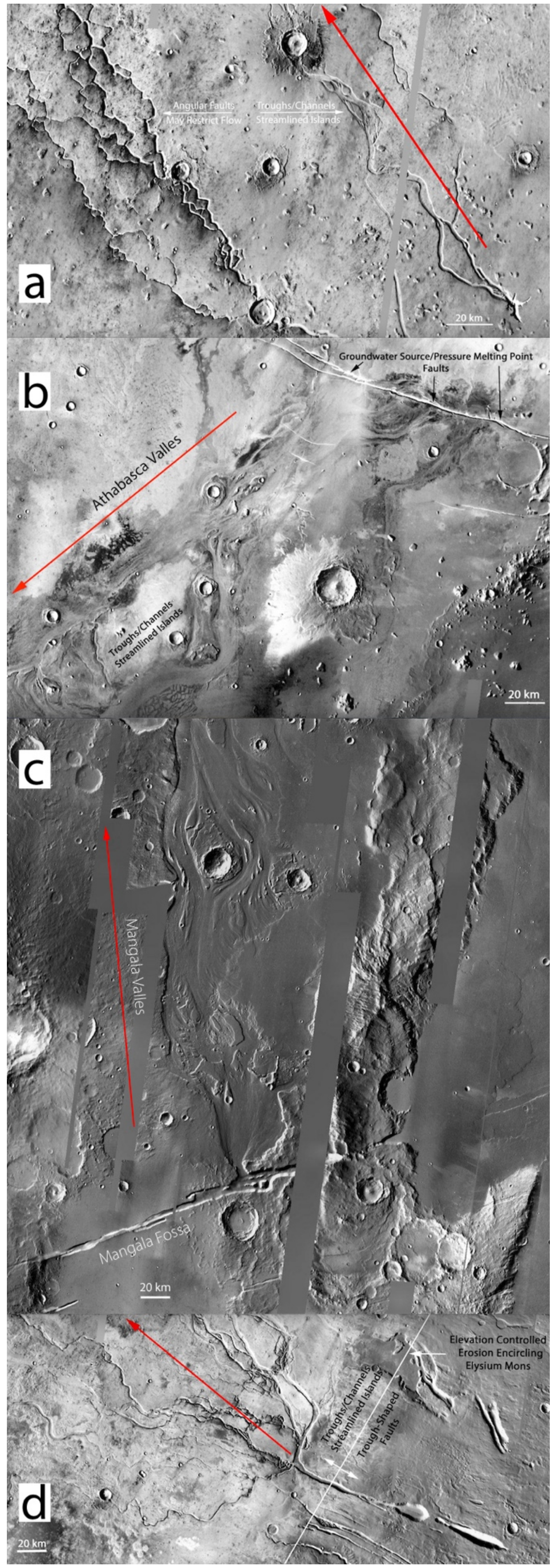

Figure: North is up for all images and red arrows indicate flow direction. Themis IR. See [2] for context. **a)** Area west of Elysium Mons. **b)** Athabasca Valles. **c)** Mangala Valles. **d)** Western flank of Elysium Mons.