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The motion of Martian glaciers and volcanic activity

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Abstract

The role of density of the heat flow on the velocity of motion of Martian glaciers is investigated using numerical model. We find that for enhanced heat flow the motion could increase dramatically. Similar effect could be achieved by thick insulating thermally layer on the top of the glacier.

1. Introduction

The rheology of ice forming glaciers is complicated. Generally it is solid but for very slow processes it behaves like a viscous fluid with the viscosity given by:

$$\eta(\sigma,T)=\eta_0\sigma^{(1-i)}\exp\left(\frac{E}{RT}\right)$$

where η_0 is a constant, σ is the second invariant of deviatoric of stress tensor (σ is high for fast deformation), i is the power law index (i=1 corresponds to a Newtonian fluid, but rather i>3). $E=Eo+pVo$ is the activation energy of the dominant mechanism of deformation, where p is the pressure. R =8.314 [J K^{-1} mole^{-1}] is the universal gas constant [1, 2].

Parameters η_0, Eo, Vo and i depend on many factors; e.g. size of ice crystal, content of gases, etc. Note that E is proportional to the melting temperature.

2. Equations of our model

We model considered processes of glacier's flow using the following equations [3]:

$$\rho\frac{D\boldsymbol{v}}{Dt}=-\nabla p+\nabla\cdot(2\eta\boldsymbol{D})+\rho\boldsymbol{g}$$

$$\frac{\partial T}{\partial t}+\boldsymbol{v}\cdot\nabla T=\kappa\nabla^2 T$$

where t is time [s], $\boldsymbol{v}$ the velocity vector [m s^{-1}], $\boldsymbol{D}$ tensor of rate of deformation [s^{-1}], ρ density [kg m^{-3}], $\boldsymbol{g}$ gravity [m s^{-2}], T temperature [K], c specific heat [J kg^{-1} K^{-1}], κ coefficient of temperature diffusion [m^2 s] (note: $\kappa = k/(\rho\, c)$ where k is thermal conductivity [W K^{-1}m^{-1}]).

We consider 1 dimensional (1 D) model. It could be used for regions in the middle part of glaciers – Fig. 1.

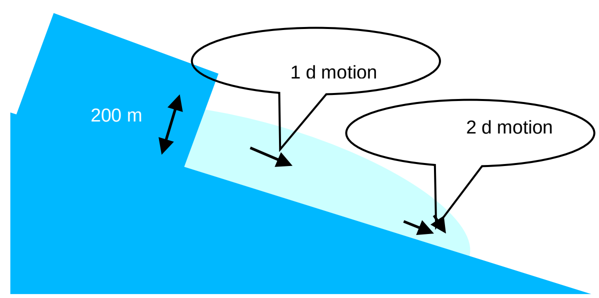

Figure 1: Sketch of flow regimes in a glacier. Note that 1D flow is a good approximation of the flow in the middle part of the glacier.

3. The role of geothermal heat flow

We observe dramatic increase of the velocity for some critical value of the heat flow density for limited heat flow (~0.2 W m^{-2}) – Fig. 2. Note that this value of heat flow is substantially less than for volcanic region (~20 W m^{-2}).

We found also that heat flow required for the fast motion depends on thermal conductivity of the glacier. For thick regolith layer of low conductivity on the top, the glacier could move significantly faster.

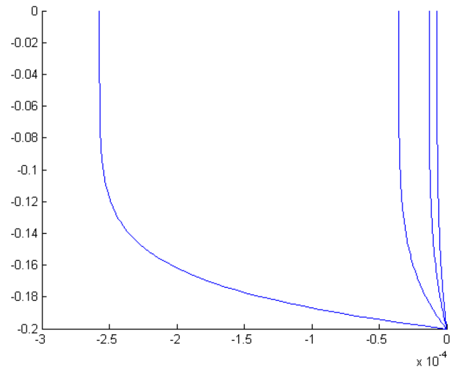

Figure 2. Effects of the heat flow variation for the velocity profiles. The vertical scale gives depth in m, the horizontal scale gives velocity in m s^{-1}. The profiles correspond the values of heat flow density of: 0.02, 0.05, 0.1, 0.2 W m^{-2}, respectively (the leftmost line corresponds to the highest heat flow).

4. Summary and plans

The velocity of glaciers depends strongly on the geothermal heat flow. For the average heat flow, typical for Mars, the flow velocity is rather limited. For enhanced heat flow (but still significantly below values typical for a volcanic area) the velocity could increase dramatically. The role of insulating layer of regolith will be the main subject of future research.

Acknowledgements

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References

[1] Durham, W.B., Kirby, S.H., Stern, L.A., 1998, Rheology of planetary ices. In: Schmitt, B., de Bergh, C., Festou, M. (Eds.), Solar System Ices. Kluwer Academic Publishers, Dordrecht, 63-78.

[2] Goldsby D. L., Kohlstedt D.L., 1997. Grain boundary sliding in fine-grained Ice-I, Scr. Mater. 37, 1399-1405.

[3] Czechowski L., The motion of martian glaciers and geothermic heat flow. Martian Cryosphere Workshop, Wrocław, February 10th, 2014.

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Geomorphological descriptions of seasonal processes on Mars: Linear Gullies and Recurrent Diffusing Flows on the intra-crater dunes fields

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Abstract

Linear Gullies are seasonal processes located on the intra-crater dunes fields. They are mainly located between 43°40'S and 52°2'S on dunes with a slight slope (~ 13°) facing SSW (mainly between 150°N and 260°N). The progression of Linear Gullies happens every years between the end of winter and the beginning of spring (between Ls 167.4° and Ls 216.6°), when the CO_2 finally defrosts on the dunes fields. Each year, a Recurrent Diffusing Flow spreads on Linear Gullies area from the end of winter (Ls 167.4°) to the beginning of autumn (Ls 21.9°), with a maximum activity between Ls 167.4° and Ls 192.3°. This flow takes an active part in the Linear Gullies creation/upkeep and could participate to the pits development. We highlight an albedo decrease of 42% during the pits activity. This important and very transient decreasing could be hardly explained by a dry movement only. We thus suggest that the Recurrent Diffusing Flows could be linked to the presence of a fluid or a liquid spreading in the shallow sub-surface. A link between CO_2 cycle and the Linear Gullies could be consistent with their development timing. Brines participation can't be excluded.

1. Introduction

Since 2006, HiRISE instrument provides recurring high resolution images of the Martian surface. Numerous seasonal processes have been observed but the origin of most of them is still unclear.

Linear Gullies (LG), present on intra-crater dunes fields, are long and narrow channels, more or less sinuous, with or without alcove and finishing by one or more circular depression(s) called "pit(s)" (Fig. 1D). No similar processes are observed on Earth and their presence on dunes is intriguing. LG on dunes fields were previously estimated to several million years [1][2]. However, recent studies have suggested that these processes are still active today and are probably seasonal [3].

Several hypotheses have been suggested for the formation of LG on dunes fields: (i) Water-supported debris flow [1][4][2]. (ii) Defrosting processes, glacial-like creep and rolling sand-ice (CO_2 and H_2O) aggregates [5], (iii) CO_2 blocs sliding [3], (iv) CO_2 sublimation [6].

Dark features, called "Recurrent Diffusing Flows" (RDF) (Fig. 1BC) in this paper, are often associated with LG on dunes (Fig. 1). They never have been studied precily, just mentioned [3]. The origin of these low albedo flows is still unclear and raises several problems [3].

The aim of this study is to: (i) Determine the relation between RDF and LG; (i) Make a precise, systematic and complete study of RDF and LG on dunes fields which have not been studied. (iii) Discuss hypotheses of RDF and LG formation.

2. Methods

The morphological study was mainly done by the investigation of HiRISE images as well as HiRISE Digital Terrain Models (DTM). We made a global research on Mars dunes and we studied HiRISE images available where LG are situated. Successive HiRISE images provide us a morphological and temporal monitoring. 344 groups of LG have been identified and 5034 observations of LG were made.

HiRISE Digital Terrain Models (DTM) provides information about the altitude and the slopes of dunes in two studied craters (Kaiser and Proctor). Slopes have been measured on each active area of LG and on dunes which not displaying any activities. 225 topographic measurements were realized.

We also use HiRISE data to investigate the variations of relative albedo of the RDF. Thanks to IDL/ENVI, representative regions were sampled in the RED (570-830 nm) HiRISE RDR products.

3. Observations

3.1 Distribution

These active processes are mainly located in a restricted latitudinal interval ranging from 43°40S to 52°2S. We focus our study on 6 dunes fields located in: Rabe, Kaiser, Unnamed (47°18; 34°15'E E), Proctor, Matara, and Hellespontus Montes.

3.2 Orientations and slopes

We observed that these seasonal processes occur only on the South-facing slopes of the dunes (between 90°N to 270°N) and mainly on the South-Southwest facing slopes (between 150°N and 260°N).
For dunes with LG/RDF activity, we obtain slopes on the highest part of the dunes (where the gully formation starts) of about 20° and 13° for the complete dunes. The average slopes of the complete dune are lower of at least 4° to 6° on inactive south facing slope than on active south facing slope. For the North facing slopes, no significant slope differences exist with the south facing dunes where seasonal surface activity occurs.

3.3 Timing

Within the 6 intra-craters dunes fields studied in details, the progression of LG happens every year between the end of the winter and the early spring (between Ls 167.4° and Ls 216.6°). RDF are present at the end of winter (Ls 167.4°) up to early autumn (Ls 21.9°). It’s mainly active between Ls 167.4° and Ls 192.3°.

3.5 Albedo

The average relative albedo between active diffusive flow and the surrounding unchanged dune is about 10%. In Matara crater, some very dark stain can be observed on HiRISE image (Fig. 1C). These spots are about 42 % darker than the surrounded virgin dune. They appear below a LG on a dune area which not display any changes in the previous images. On next image these dark stains are replaced by new pits. These very dark stains thus seem to be at the origin of the pits formation.

4. Summary and Conclusions

RDF take an active part in the creation or upkeep of LG. The pits formation could be linked to the presence of a RDF. These pits show a difference in albedo with the dune of 42%. This result is consistent with the presence of a fluid or a liquid. Brines appear to be a good candidate to interpret these phenomena. As LG activity begins each year during the thawing of CO_2, a link between LG and CO_2 is probable. The CO_2 is also a serious candidate.

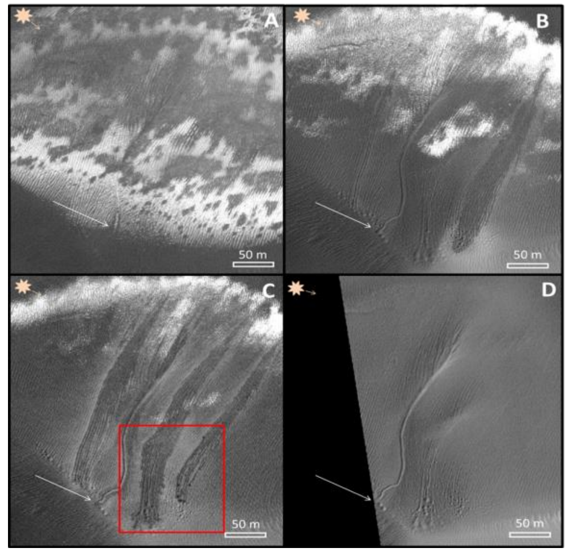

Figure 1: LG and RDF seasonal evolution. A) CO_2 frost on LG (HiRISE ESP_028616_1305); B) C) RDF spread (HiRISE ESP_028972_1300 and ESP_029038_1305); D) Creation of news LG (HiRISE ESP_029394_1300). The white arrow shows a reference point.

References

[1] Costard, F., Forget, F., Mangold, N., and Peulvast, J.P.: Formation of recent Martian debris flows by melting of near-surface ground ice at high obliquity, Planet. Sci., Vol. 295, pp. 110-113, 2002. [2] Mangold, N., Costard, F., and Forget, F.: Debris flows over sand dunes on Mars: Evidence for liquid water, J. Geophys. Res., Vol. 108, No. E4, 5027, 2003. [3] Diniega, S., Hansen, C.J., McElwaine, J.N., Hugenholtz, C.H., Dundas, C.M., McEwen, A.S., and Bourke, M.C.: A new dry hypothesis for the formation of Martian linear gullies, Icarus, Vol. 225, pp. 526-537, 2013. [4] Jouannic, G., Gargani, J., Costard, F., Ori, G.G., Marmo, C., Schmidt, F., and Lucas., A.: Morphological and mechanical characterization of gullies in a periglacial environment: The case of the Russell crater dune Mars, Planet. Space. Sci. Vol. 71, pp. 38-54, 2012. [5] Di Achille, G., Silvestro, S., and Ori, G.G.: Defrosting processes on dark dunes: new insights from HiRISE images at Noachis and Aonia Terrae, Mars, Planetary Dunes Workshop, April 29_May 2, 2008, Alamogordo, EU, 2008 [6] C. Pilorget, F. Forget.: CO_2 driven formation of gullies on Mars, 46th Lunar Planet. Sci., March 16-20, 2015, Texas, EU, 2015.

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Mapping the northern plains of Mars: origins, evolution and response to climate change – a new overview of recent ice-related landforms in Utopia Planitia

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Abstract

An International Space Science Institute (ISSI) team project has been convened to study ice-related landforms in targeted areas in the northern plain of Mars: Acidalia Planitia, Arcadia Planitia, and Utopia Planitia. Here, over western Utopia Planitia, ice-related landforms were identified and recorded in a sub-grid square. The end result of the mapping is a "raster" showing the distribution of the various different types of landforms across the whole strip providing a digital geomorphological map (Fig. 1).

1. Introduction

In the northern plains of Mars, the main questions this project aims to answer are:

1) *"What is the distribution of ice-related landforms in the northern plains, and can it be related to distinct latitude bands or different geological or geomorphological units?"*

2) *"What is the relationship between the latitude dependent mantle (LDM) and (i) landforms indicative of ground ice, and (ii) other geological units in the northern plains?"*

3) *"What are the distributions and associations of recent landforms thought to be indicative of thaw of ice or snow?"*

Rather than traditional mapping with points, lines and polygons, we used a grid "tick box" approach to efficiently determine where specific landforms (see [4] for details). Here, we describe our mapping in Utopia Planitia.

Western Utopia Planitia (UP) shows an assemblage of possible periglacial landforms: scalloped depressions [5-10]; spatially associated small-sized polygons [6-11]; polygon-junction pits [7, 12]. There seems to be a general agreement that these relatively recent landscape features are indicative of a permafrost that is probably ice-rich [8]. However, the Gamma Ray Spectrometer detected only a small percentage of water-equivalent hydrogen (4 % wt of ice) content in the near-surface of UP (depth < 1 m) [13] but ground-ice is predicted to be stable at these latitudes at depth > 1 m [14]. Interestingly, UP lies in the area of the young latitude-dependent mantle thought to have been emplaced during obliquity variations of Mars [15].

Questions concerning the distribution of periglacial landforms and characteristics of the ice-rich permafrost in UP remain unanswered.

2. Method

We conducted a geomorphological study of all landforms in UP along a strip from 25°N to 75°N latitude of 250 km wide (Fig. 1). The goals are to: (i) map the geographical distribution of the ice-related landforms; (ii) identify their association with subtly-expressed geological units and; (iii) discuss the climatic modifications of the ice-rich permafrost in UP. Our work combines a study with CTX (5-6 m/pixel) and MOLA, supported by higher resolution HiRISE (25 cm/pixel) and a comparison with analogous landforms on Earth. The mapping strips were divided into grid of squares for each study area, each approximately 20×20 km [4].

3. Results of the grid mapping

The mapping shows that the scalloped depressions, pits and 100 m polygons occur over a broader area than previously shown (from 40°N to 65°N on Fig. 1). Coalesced scalloped depressions of several km in diameter are concentrated near 50°N. Different impact craters are observed with CCFs (see [16] for details). We also observed that the thumbprint terrains, high-albedo mounds of different diameter (see [17] for details) and km-scale polygons are mostly seen in the southern UP (from 30°N to 40°N on Fig. 1).

Based on their correlated distribution at regional scale but also at local scale where they are associated spatially, several assemblage of landforms can be defined. The scalloped depressions, pits and 100 m polygons are spatially associated at local scale because interrelated, pits cross-cut polygons that are degraded by scallops and at regional scale because same area between 40°N to 50°N. The mantling deposits and the textured terrains are found at the same latitudinal band. The thumbprint terrains, high-albedo mounds of different diameter and km-scale polygons are mostly seen between 30°N to 40°N.

4. Summary and Conclusions

Our knowledge of the distribution of ice-related landforms in UP was improved. Based on their spatial association, there are different assemblages of landforms. Their distribution is not only related to latitude but also on topography, geological context. The next step is to define unit : based on assemblage of landforms, albedo and/or crater counting. The differences/similarities of the key 3 regions in the northern plains reflect their complex geological history.

Acknowledgements

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References

[1] Malin, M. C. et al. (2007) 112. [2] Balme, M. et al., (2015) LPSC #1384. [3] Hauber, E. et al., (2015) LPSC #1359. [4] Ramsdale, J. et al., (2015) LPSC #1339. [5] Costard, F. and Kargel, J.S. (1995) 114, 93-122. [6] Lefort, A. et al. (2009) 114, E04005. [7] Morgenstern, A. et al. (2007) 112, E06010. [8] Séjourné, A. et al., (2011). [9] Soare, R.J. et al. (2007) 191, 95-112. [10] Ulrich, M. et al., (2010) JGR 115, E10009. [11] Seibert, N.M. and Kargel, J.S. (2001) 28, 899-902. [12] Séjourné, A. et al. (2011) LPSC 2010 #2113. [13] Boynton et al., 2002. [14] Mellon et Jakosky, 1995. [15] Mustard et al., 2001. [16] Skinner, J. et al., (2015) LPSC #1700. [17] Orgel, C. et al., (2015) LPSC #1862.

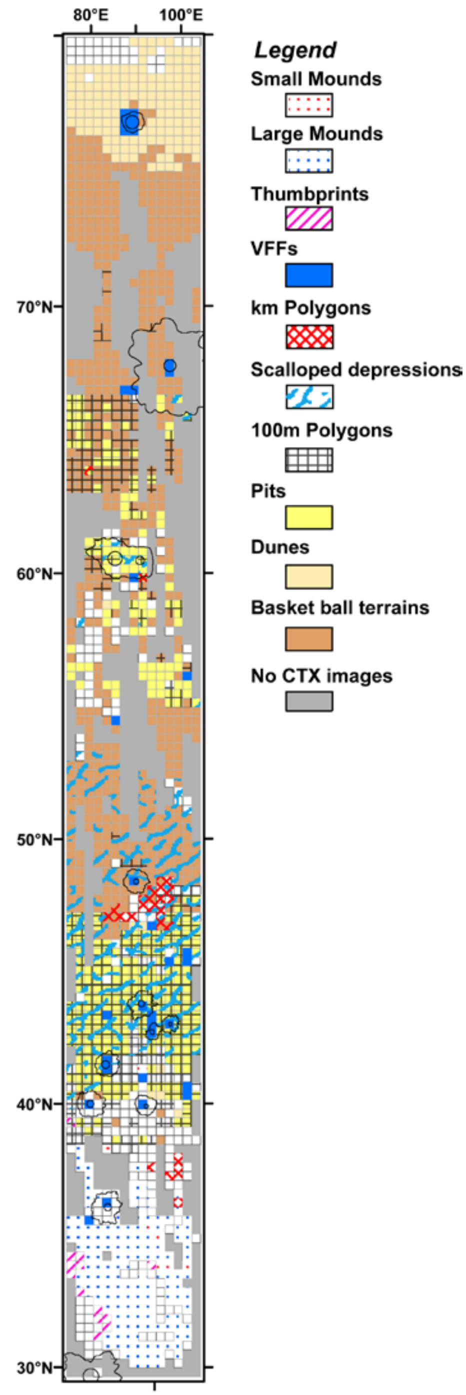

Figure 1: Geomorphological grid map of the ice-related landforms in western Utopia Planitia

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Ice composition at active Mars Gullies

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1. Introduction

Current activity at gullied sites includes occurrence of bright/dark deposits within pre-existing gullies, channel widening/lengthening, and formation of new channels [e.g., 1]. Whether present-day gully formation and modification mechanisms are representative or not of all gullies formation pathways remains an open question [e.g., 2]. This activity is observed during winter / spring seasons in relation with surface ice which strongly suggests that condensed volatiles are a key factor controlling present-day gully modifications [e.g., 1]. CO_2 ice, the main component of seasonal ice, is thought to be the main driver of current gully activity [e.g., 1], which could imply that gullies are not primarily formed by liquid water, as previously thought. However, CO_2 ice has not yet been detected at all currently active gullies [1, 3]. In this study, we perform an extended survey of near-infrared observations of active gullies to identify the presence and composition of seasonal ice.

2. Observations

We use the available datasets from the OMEGA and CRISM imaging spectrometers to detect ice at the exact location of reported active gullies. CO_2 and H_2O ice are identified as a function of solar longitude (L_S). Ice can be detected even if dusty or transparent. Observations without ice also provide reliable clues about the actual lack of ice onsite due to the high signal to noise ratio of both spectrometers, the high spatial sampling of CRISM (20 m per pixels), and the elevated sensitivity of near-IR spectroscopy to thin amount of surface ice (down to a few micrometers thick for water ice) [4].

3. Discussion

The available dataset is sufficient to characterize the presence of ice during winter and spring seasons with a time sampling of typically 10° of L_S. At equatorward latitudes (30°S – 35°S), we frequently only observe the formation of a thin layer of water ice during winter, without detection of CO_2 ice. Activity at these locations is generally restricted to the formation of new bright/dark deposits [1]. At poleward latitudes, where new channels have been detected [1], we observe a more complex history of seasonal ice formation and sublimation. During winter, mm to cm thick layers of CO_2 ice contaminated by H_2O ice are observed. During spring, this layer sublimates and a water ice layer is sometime observed afterward during a few ° or tens of ° of L_S. Changes are sometimes reported to occur at that time, while water ice is the only component of seasonal ice.

4. Conclusions

This ongoing work suggests that all gully activity may not be caused by CO_2 ice, in particular activity restricted to new deposits at the most equatorward latitudes. On the other hand, the most impressive gully changes, including new channel formation, do occur at location and time where/when CO_2 ice is indeed largely condensing in winter. However, even at these sites, water ice only timeframes are observed, and may coincide with some of the reported activity.

References

[1] Dundas, C. M., Diniega, S. & McEwen, A. S., Long-term monitoring of martian gully formation and evolution with MRO/HiRISE. Icarus, 251, pp. 244-263, 2015.

[2] Dickson, J. L., Head, J. W. & Kreslavsky, M.. Martian gullies in the southern mid-latitudes of Mars: Evidence for climate-controlled formation of young fluvial features based upon local and global topography. Icarus, 188(2), pp. 315-323, 2007.

[3] Vincendon, M. et al. Near-tropical subsurface ice on Mars. Geophysical Research Letters, 37(1), p. L01202, 2010.

[4] Vincendon, M., Forget, F. & Mustard, J.. Water ice at low to midlatitudes on Mars. Journal of Geophysical Research, 115(E10), pp. E10001, 2010.

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Earth-like aqueous debris-flow activity on Mars at high orbital obliquity in the last Ma

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1. Introduction

At present Mars is very cold and dry and its thin atmosphere makes liquid water at its surface exceptionally rare. However, climatic conditions differed during periods of high orbital obliquity in the last few millions of years [4]. In these periods liquid water was probably more abundant, as testified by the presence of numerous mid-latitude gullies, which are small catchment-fan systems. Obliquity on Mars has varied between 15^0 and 35^0 in the last 5 Ma, in cycles of approximately 120 Ka [3]. The obliquity threshold for snow and ice transfer from the poles to lower latitudes is estimated at 30^0 [1], whereas the threshold for melting and associated morphological activity is probably higher but unknown [5].

Key questions that remain unanswered are how much water could potentially melt during these high-obliquity periods? And how frequent was the aqueous activity within the gullies? Here, we address these questions by quantifying debris-flow size, frequency and associated liquid water contents on Mars, in the very young Istok crater in Aonia Terra (Fig. 1) (0.1-1 Ma; best-fit age: ~0.19 Ma [2]).

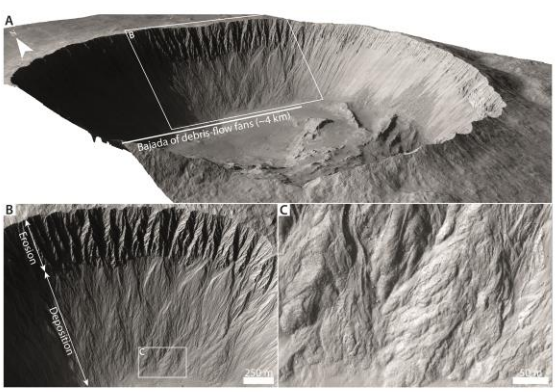

Figure 1: Istok crater. (A) Bajada of remarkably pristine debris-flow fans on the pole-facing slope (45.11^0S; 247.2^0E). (B) Eroding alcoves supply sediments to the downslope bajada of fans. (C) The fans are composed of debris-flow deposits [2].

2. Debris-flow and liquid water volume and frequency

The pole-facing slope of Istok crater hosts a bajada, a series of coalescing fans, with abundant debris-flow deposits, which are among the best preserved found on Mars to date [2].

Debris flows contain approximately 20 to 60 percent water by volume. They form deposits with paired levees and distinct depositional lobes that often incorporate large boulders. We use the distinct morphology of these deposits to estimate individual debris-flow volumes from a HiRISE DEM with a sampling distance of 1 m. Estimated individual debris-flow volumes roughly range from 400 to 5100 m^3 (Figs. 2A-C).

We estimated the total number of debris flows by comparing the volume of a single, modal-sized, debris flow to the total volume of sediment eroded from the catchments. In total, around 28000 modal-sized debris flows were needed to form the entire bajada and ~1900 debris flows originated from each catchment. From this we calculated the cumulative time above a specific obliquity threshold for melting and then determined the debris-flow frequency within the gullies, expressed as their return period. Debris-flow return periods ranged between 4-15 yr on the bajada, and 64-221 yr in the catchments for a conservative obliquity threshold for melting of 30^0. A melting threshold of 35^0, implies return periods of 0.2 to 0.8 yr for the bajada and 3 to 12 yr for the catchments (Fig. 2D-E).

Using the known range of water concentrations of terrestrial debris flows in combination with the measured debris-flow volumes in Istok crater, we estimate the amount of liquid water required for each flow. The associated liquid water volume yields a minimum estimate of snow/ice deposition and subsequent melting within the alcoves. Between 3 and 9 mm of liquid water uniformly spread over an average-sized alcove is required for the formation of modal-sized debris flows, and 16 to 50 mm of liquid water is required for the formation of large, 95 percentile-sized debris flows. The actual thickness of the snow/ice layer must have been much larger due to the porosity of the snowpack, potential sublimation and evaporation losses, and the fact that uniform melting over an entire alcove will generally not occur. Therefore, we estimate that centimeters to decimeters of snow must have accumulated in the alcoves to form the observed debris-flow deposits.

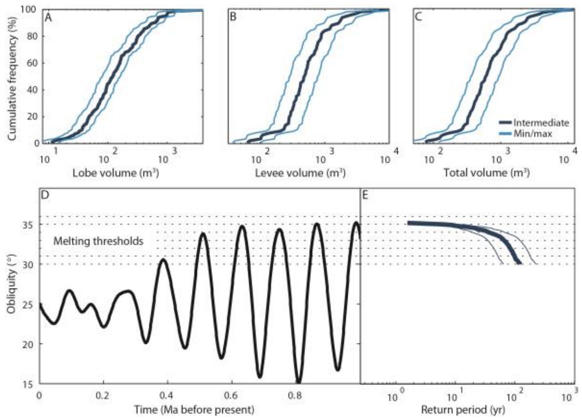

Figure 2: Debris-flow return periods and size in Istok crater. (A-C) Cumulative frequency distributions of lobe, levee and total debris-flow volume, respectively. (D) Obliquity in the last Ma on Mars, and potential thresholds for melting on mid-latitude pole-facing crater walls. (E) Debris-flow return periods averaged per catchment [6].

3. Discussion

The surprisingly short debris-flow return periods at high orbital obliquity in Istok crater are very similar to those in various environments on Earth [4] (Fig. 3). Current climatic models do not explain the amounts of liquid water needed for the formation of the debris flows in Istok crater [5]. This implies that melting of snow/ice in high-obliquity periods must locally have been much larger and more frequent than currently predicted by these models.

4. Conclusions

- Debris flows occurred at Earth-like frequencies in Istok crater during high-obliquity periods in the last million years on Mars.
- Local accumulations of snow/ice within gullies were much more voluminous than currently predicted
- Melting must have yielded centimeters to decimeters of liquid water in catchments.
- Recent aqueous activity in some mid-latitude craters was much more frequent than previously anticipated.

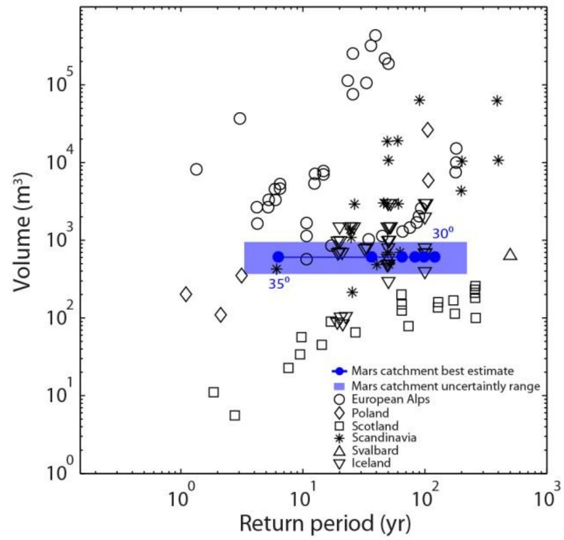

Figure 3: Comparison between debris-flow volumes and return periods in Istok crater, Mars [6], and examples from Earth [4].

References

[1] Head, J. W., Mustard, J. F., Kreslavsky, M. A., Milliken, R. E., & Marchant, D. R. (2003). Recent ice ages on Mars. Nature, 426(6968), 797-802.

[2] Johnsson, A., Reiss, D., Hauber, E., Hiesinger, H., & Zanetti, M. (2014). Evidence for very recent melt-water and debris flow activity in gullies in a young mid-latitude crater on Mars. Icarus, 235, 37-54.

[3] Laskar, J., Correia, A. C. M., Gastineau, M., Joutel, F., Levrard, B., & Robutel, P. (2004). Long term evolution and chaotic diffusion of the insolation quantities of Mars. Icarus, 170(2), 343-364.

[4] Van Steijn, H. (1996). Debris-flow magnitude—frequency relationships for mountainous regions of Central and Northwest Europe. Geomorphology, 15(3), 259-273.

[5] Williams, K. E., Toon, O. B., Heldmann, J. L., & Mellon, M. T. (2009). Ancient melting of mid-latitude snowpacks on Mars as a water source for gullies.Icarus, 200(2), 418-425.

[6] De Haas, T., Hauber, E., Conway, S.J., Van Steijn, H., Johnsson, A., Kleinhans, M.G. (In Prep). Earth-like aqueous debris-flow activity on Mars at high orbital obliquity in the last Ma. Nature Communications.

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Sedimentological analyses of Martian gullies: the subsurface as the key to the surface

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1. Introduction

Martian gullies are composite landforms that comprise an alcove, channel and depositional fan. They are among the youngest landforms formed by liquid water on Mars, and therefore of critical importance in resolving the planet's most recent hydrologic and climatic history. Water-free sediment flows, debris flows and fluvial flows have all been identified in gullies. These processes require very different amounts of liquid water, and therefore their relative contribution to gully-formation is of key importance for climatic inferences. Many authors inferred that most gullies were formed by fluvial flows because the surface morphology of most gully-fans lacks evidence for debris-flow processes [3,4]. Paired levees, distinct depositional lobes and large boulders all characteristic of debris-flow deposits, are only recognizable on a few fans but are generally not reported [4]. Nevertheless, the morphometric attributes, such as slope-area relations, the steep depositional slopes and channel sinuosity, do suggest a formation by debris flows [1].

On Earth, fans on which primary processes of aggradation have been long inactive are exposed to prolonged weathering and erosion. These secondary processes often dominate fan surfaces due to the long return periods of primary processes, although they generally have a minimal effect on fan aggradation [2]. As such, secondary processes might have modified the surface of Martian gully-fans and hinder identification of primary depositional processes based solely on surface morphology.

Here, we aim to constrain the formative processes of Martian gullies based on outcrop sedimentology (as deposits are generally reworked at their surface but not internally). Secondly, we aim to resolve the apparent discrepancy between genetic interpretations from gully-fan surface and morphometry.

2. Results

This work is based on the analysis of 51 HiRISE images widely distributed over the southern midlatitudes [4]. The resolution of HiRISE images does not allow for fully detailed sedimentological analyses of incised sections; only large boulders (>0.5 m) and layering patterns can be resolved. As such, the presence or absence, and distribution of boulders and large-scale layering within stratigraphic sections are used for process interpretation of gully-fans on Mars.

We show that many gullies dominantly formed by debris flows, based on this sedimentological analysis of outcrops in gully-fans. For gully-catchments which mainly comprise bedrock, the great majority (96%) of outcrop exposures in gully-fans fed contain sedimentological evidence for debris-flow formation. These exposures contain many randomly distributed large boulders suspended in a finer matrix and in some cases lens-shaped and truncated layering (Figure 1). Moreover, mobility analyses show that these boulders cannot have been transported by fluvial flows or rockfalls over typical gully-fan slopes. Similar sedimentological features are rare in gully-fan exposures mainly fed by catchments comprising abundant latitude dependent mantle deposits (LDM; a smooth, often meters-thick deposit consisting mainly of ice and dust), wherein boulders are largely absent. These LDM-fed gullies may have formed by fine-grained debris flows, but this cannot be determined from outcrop sedimentology alone because of the lack of boulders in these systems. The fan surface morphology, in contrast to the subsurface, is dominated by secondary, post-depositional, processes, mainly weathering, wind erosion, and ice-dust mantling (Figure 1). These processes have removed or severely reworked the original, primary, debris-flow morphology over time. This explains the controversy between previously published morphometric analyses implying debris-flow formation and observations of gully-fan surfaces, which are often interpreted as the product of fluvial flows because of the absence of surficial debris-flow morphology. The inferred debris-flow origin for many gullies implies limited and ephemeral liquid water during gully-formation.

3. Conclusions

- Stratigraphic-sedimentological analyses show that the majority of Martian gullies are likely formed by debris flows.
- Large boulders and truncated layering are common diagnostic features for debris flows in vertical sections along incised channels in Martian gully-fans.
- The original gully-fan surface morphology is generally heavily modified and masked by secondary processes, such as weathering, wind erosion and ice-dust mantling.
- The surface morphology is therefore generally not representative for the dominant formative mechanisms of gully-fans.

References

[1] Conway, S. J., Balme, M. R., Murray, J. B., Towner, M. C., Okubo, C. H., Grindrod, P. M., 2011. The indication of Martian gully formation processes by slope-area analysis. Geological Society, London, Special Publications 356 (1), 171-201.

[2] De Haas, T., Ventra, D., Carbonneau, P. E., Kleinhans, M. G., 2014. Debris-flow dominance of alluvial fans masked by runoff reworking and weathering. Geomorphology 217, 165-181.

[3] Dickson, J. L., Head, J. W., 2009. The formation and evolution of youthful gullies on Mars: Gullies as the late-stage phase of Mars most recent ice age. Icarus 204 (1), 63-86.

[4] Reiss, D., Hauber, E., Hiesinger, H., Jaumann, R., Trauthan et al., 2011. Terrestrial gullies and debris-flow tracks on Svalbard as planetary analogs for Mars. Geological Society of America Special Papers 483, 165-175

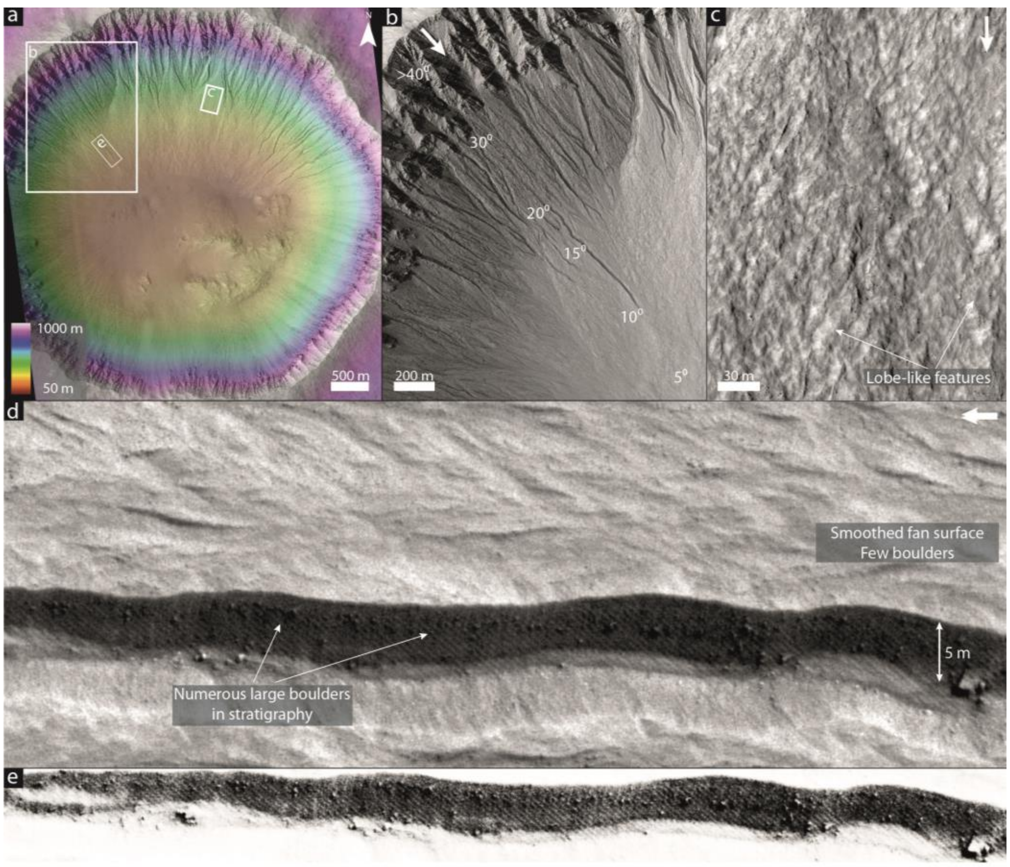

Figure 1: Morphometry, morphology and stratigraphy of gullies in Galap crater. (a) Overview. (b) Detail of northwestern slope showing gradients of catchment and depositional fan. (c) Detail of proximal fan surface. (d,e) Example of stratigraphic section, showing many large boulders dispersed in a finer matrix. This is typical for debris-flow deposits. Note the contrast with the surface deposits where there are far less boulders and no debris-flow morphology. Arrows denote downslope direction. HiRISE image PSP_003939_1420.

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Thermokarst, mantling and Late Amazonian Epoch periglacial-revisions in the Argyre region, Mars

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1. Introduction

Metre to decametre-deep depressions that are rimless, relatively flat-floored, polygonised and scallop-shaped have been widely observed in Utopia Planitia (*UP*) [e.g. 1-5] and Malea Planum (*MP*) [6-8]. Although there is some debate about whether the depressions formed by means of sublimation or evaporation, it is commonly believed that the terrain in which the depressions occur is ice-rich. Moreover, most workers assume that this "ice-richness" is derived of a bi-hemispheric, latitudinally-dependent and atmospherically-precipitated mantle that is metres thick [2,4,6-10].

Here, we have three aims: (1) report/discuss the presence of Late Amazonian Epoch depressions in the Argyre region (Fig. 1) that are morphologically similar to those in *UP* and *MP;* (2) show that the depressions in the Argyre region comprise two disparate types; and, (3) suggest that if these disparities are mirrored in *UP* and *MP*, then the hypothesized synonymy between "ice-rich" terrain and an "icy" mantle perhaps ought to be reconsidered.

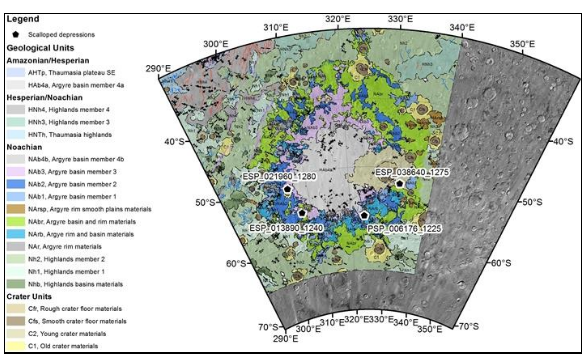

Figure 1 - Geological-unit map of the Argyre region, adapted from [11]. The brown pentagons represent thermokarst-like depressions that are commonplace in *UP* [e.g. 1-5].

2. The geological context

The Argyre basin lies in the southern hemisphere of Mars. It was formed by the impact of a large body ~3.9 Gya. Despite its age the basin, associated rim-materials and marginal highlands show geological modifications and revisions by a wide-range of processes - tectonic/volcanic, fluvial, aeolian, glacial and periglacial - possibly through to the present day [11]. For example, in addition to the thermokarst-like depressions discussed below, other putative periglacial-landforms thought to have originated in the Late Amazonian Epoch have been identified in the region: a) low and high-centred polygons [12]; b) sorted polygons [13-14]; c) open-system pingos [15]; and, d) gelifluction lobes [14].

Having studied all of the available HiRISE images (*n*=1101) that cover the Argyre region (290-360^{0}E, 30-70^{0}S; *n*=1101) we have identified two different types of possible periglacial-depressions.

3. Type 1 (in-ground) depression

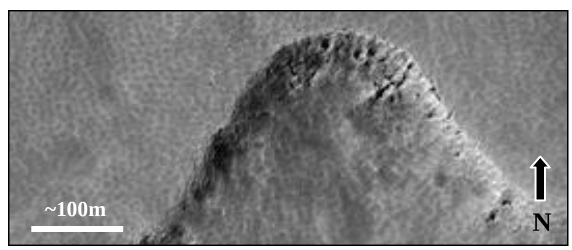

Figure 2 - Polygonised "Type 1" depression in *AP* (HiRISE ESP_013890_1240; 307.523^{0}E, 55.615^{0}S). Note the clustered pitting in adjacent polygon-junctions at the northern rim of the depression.

Type 1 depressions display various plan-forms: elongated, rounded, drop-like, elliptical and, sometimes, scalloped. Depression-length (long axes of the depressions defined by the outermost closed contour line) ranges from ~85-1000m; widths range from ~50-500m. Depression margins are continuous, sharp albeit rimless and well-defined; depression sides lack deep gravitational-slope processes or fan deposits at the floor. Generally, the floors are flat or slightly concave up.

In all instances, depression-margins, -sides, -floors and even the terrain beyond the depressions themselves, are incised by small-sized (~5m) and non-sorted polygons. Many of these polygons show relatively-dark centres surrounded by light-coloured metre to sub-metre troughs. Sometimes, polygon-junctions within the depressions are pitted; where this pitting is clustered, it occurs amongst adjacent junctions (Fig. 2).

Invariably, the depressions are embedded in terrain that is barely cratered. If present, boulders are infrequent and, often, are underlain by the small-sized polygons.

The Type 1 depressions are distributed radially on/along the southern rim of the *AP* impact-basin (Fig. 1) in four geological units (cf. Fig. 1: NAbr, NArb, impact-associated materials; C1 and C2, crater-impact materials that postdate the Argyre impact event) [11]. The radial distribution of the depressions occurs in a tight latitudinal-band (~52^0-57^{0}S).

4. Type 2 (on-ground) depression

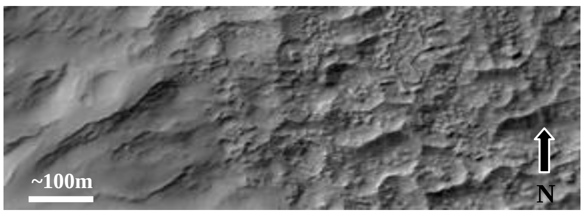

Figure 3a - Mantled terrain (on the left) dissected by small, rimmed and irregular “Type 2” depressions or pits (centre/centre-right) Note the smoothness and un-polygonised texture of the former (HiRISE PSP_007648_1440; 322.285^{0}E; 35,714^{0}S).

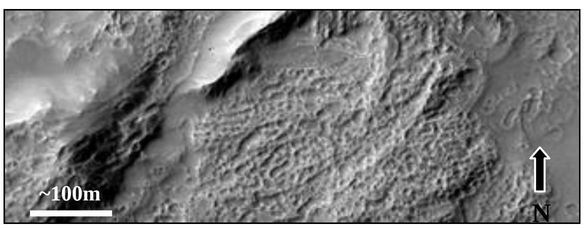

Figure 3b - Mantled terrain (on the left), pitted densely (centre-centre-tight) by “Type 2” depressions (HiRISE PSP_007033_1455; 321.183^{0}E, 35.000^{0}S).

Type 2 depressions are shaped irregularly, often with raised edges or rims, and lack marginal troughs (Fig. 3a-b). Invariably, the distribution of these depressions is dense (Fig. 3a-b). Individual depressions range in diameter from metres to decametres; collectively, the depressions are expansive (showing surface coverage on a kilometre-scale) and ubiquitous (observed from 315-354^{0}E and from ~31-50^{0}S), unlike Type 1 depressions whose distribution across the Argyre region is sparse. Generally, the floors are concave up. Most type 2 depressions exhibit no *in situ* polygonisation.

In all cases the Type 2 depressions are nested in mantle-like material that blankets the underlying topography and bedforms. The latter becomes visible if and only when the mantle exhibits discontinuity or dissection. Thus, bouldering is observed only where mantled terrain is absent (cf. boxed-in area, Fig. 4).

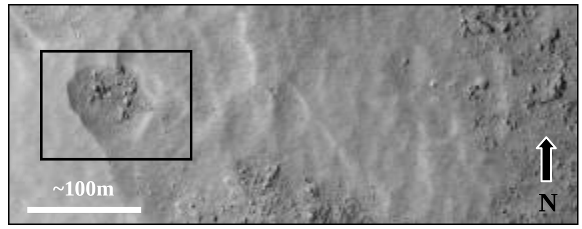

Figure 4 - Boulders observed in hollows where mantled material is being lost, possibly by sublimation (HiRISE ESP_021960_1280; 305.499^{0}E, 51.706^{0}S).

5. Discussion

In discussing the origin and development of the putatively periglacial and possibly “thermokarstic” Martian-depressions, previous workers have not differentiated between depressions that are “in-ground” (Type 1) and “on-ground” (Type 2).

Here we have highlighted the two depression-types and suggest that these stratigraphical and morphological differences could be indicative of origins and, consequently, of host materials that are dissimilar.

Acknowledgements

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References

[1] Costard, F.M., Kargel, J.S., *Icarus* 114 (1) 93-112, doi:10.1016/j.icar.1995.1046, 1995. [2] Morgenstern, A. et al., *JGR* 112 (E06010) doi:10.1029/2006JE002869, 2007. [3] Soare, R.J., et al., *EPSL* 72 (1-2) 382-393, doi:10.1016/j.epsl.20080510, 2008. [4] Lefort, A., et al., *JGR* 114 (E04005) doi:10.1029/2008JE 003264, 2009. [5] Séjourné, A., et al., *PSS* 59, 412-422, doi: 10.1016/j.pss.2011.01.007, 2011. [6] Lefort, A., et al., *Icarus* 205 (1) 259-268, doi: 10.1016/j.icarus.2009.06.005, 2010, [7] Zanetti, M., et al., *Icarus* 206, 691-706, doi:10.1016/j.icarus.2009.09.010, 2010. [8] Wilmes, M., et al., *PSS* 60, 199-206, doi:10.1016/j.pss.2011.08.006, 2011. [9] Mustard, J.F., et al., *Nature* 412, 411-414, 2001. [10] Milliken, R.E., et al., *JGR* 108 (E6) 5057, 2003. [11] Dohm, J.M. et al., *Icarus* 253, 66-98, doi:10.1016/j.icarus.2015.02.17, 2015. [12] Soare, R.J. et al., *Icarus* 233, 214-228, doi:10.1016/j.icarus.2014.01.034, 2014. [13] Banks, M. et al., *JGR* 113 (E12015) doi:10.1029/2007JE002994, 2008. [14] Soare, R.J., et al., *46th Lunar Plan. Conf.* 1218, 2015. [15] Soare, R.J., et al., *EPSL* 398, 25-36, doi:10.1016/j.epsl.2014.04.044, 2014.

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Clastically-sorted polygons and pre-(ice-dust) mantle periglacialism in the Argyre region, Mars

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1. Introduction

Here, we present three new findings that point to multiple episodes of Late Amazonian Epoch periglacial revisions in the Argyre region **(Fig. 1)**:

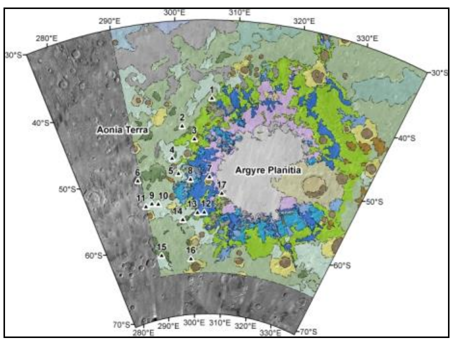

Figure 1: Sorted-polygon locations, on the basin rim and adjacent highlands. Adapted from a geological-unit map of Argyre in [1].

1) Small-sized (~15-25m in diam.) and sorted-polygons (*SPs*) **(Fig. 2)** are observed. The morphology of the *SPs* is consistent with the work of clastic sorting, cryoturbation and mobile liquid-water that has undergone freeze-thaw cycling [2-4]. Heretofore, there have been no region-wide reports of *SPs* in the southern hemisphere [5].

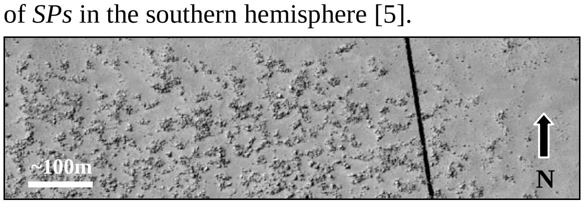

Figure 2: Sorted (partially-enclosed) polygons (*HiRISE* PSP_005597_1250; 54.797^{0}S, 291.489^{0}E; site 1 in **Figure 1**).

2) The collateral presence of gelifluction-like lobes, gullies putatively incised by the flow of water, and small-sized non-sorted polygons (perhaps formed by thermal-contraction cracking) in the general area where the *SPs* are located.

3) Stratigraphy showing that the *SPs* have been exhumed from a light-toned and possibly ice-rich mantle that, in turn, is incised by non-sorted polygons (*NSPs*). This underlines the possibility of pre- and post-(ice-dust) mantle periglaciation.

2. Sorted and non-sorted polygons

The *SPs* are observed at seventeen locations in eastern Aonia Terra (*AT*), immediately to the west and southwest of the floor of the Argyre impact-basin **(Fig. 1)** They comprise relatively-dark metre to multi-metre boulders that encircle, often incompletely, zones that are lighter of tone and without resolvable clasts **(Fig. 2)**. A few polygons show margins comprised of individual boulders; most margins, regardless of their radial symmetry or completeness, display multiple boulders. Some boulder margins are imbricated.

The distribution of the *SPs* is irregular. Sometimes, the polygons appear in the midst of dense-boulder-fields and are contiguous; elsewhere, the polygons are relatively isolated and in the midst of sparse boulders. Typically, the density of polygon distribution decreases proportionately as the boulder coverage of the terrain lessens and the surface coverage of the light-toned mantle increases **(Fig. 2)**.

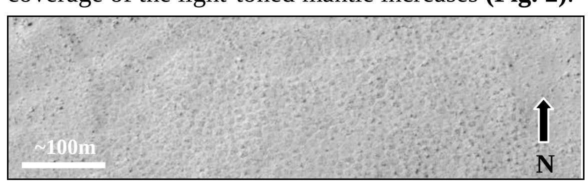

Figure 3: Non-sorted polygons (*HiRISE* PSP_005597_1250; site 1 in **Figure 1**).

Distinctly, clusters of small-sized (~5-10m in diam.) and non-sorted polygons **(Fig. 3)** are ubiquitous in the light-toned terrain where the sorted polygons are not observed and in transitional terrain where the distribution of sorted polygons is increasingly sparse. Polygon margins measure ~25-50cm in diameter and polygon centres are slightly elevated (relative to their margins.

Immediately to the east of the *SP* sites, lobe-like features are observed on the north (equator-facing) inner-wall of an impact crater **(Fig. 4).** From a plan view, the lobes display long and short axes parallel and normal to the slope wall, respectively, with downslope segments being wider than the upslope ones. The lobes also display lateral coalescence, forming crenulated terrace-fronts. The apexes of these assemblages are synonymous with their long-axes and the side by side distribution of the two lobe assemblages gives them a saw-tooth appearance. The slope-side lobes and lobe assemblages also drape non-sorted polygons, of the type described above.

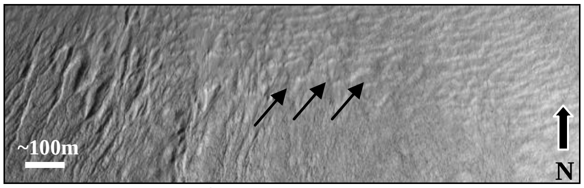

Figure 4: Possible gelifluction lobes. (*HiRise* ESP_028857_1255; 295.217^{0}E, 54.245^{0}S; site 6 in **Figure 1**).

There are multiple locations in our study region where gullies are observed within impact craters; typically, they are ~4km in length and originate from rocky out-crops ~50m below the crater rim. They occur on north/northeast-facing slopes and incise a polygonally-patterned mantle that covers the rest of the crater wall. The alcoves are up to 1km wide, narrowing downslope, and are bounded laterally by steep incisions. The channel portion of these gullies often is braided and/or leveed. The depositional fans show multiple superpositions and often are incised by channels or channel segments.

The lighter-toned material encircled by the *SPs* also forms a wide-ranging, relatively uniform and ~metre-thick mantle that blankets the terrain [6-7] wherever the sorted polygons and associated boulder-fields are not observed (Fig. 2). When mantle patches and the *SPs* are contiguous, the former show a slightly higher elevation than the latter.

3. Discussion

Absent of boots on the ground and the ability to dig a soil pit or trench, validating a periglacial hypothesis that assumes the vertical and highly localized displacement of clasts to metres of depth must be indirect. Towards this end, we have identified a three-feature landform assemblage in *AT* that is spatially collateral with the sorted polygons. Collectively, the assemblage points to periglacialism, freeze-thaw cycling and the availability of mobile liquid-water.

(1) The key morphological characteristics of the crater-wall lobes are consistent with slope-side gelifluction on Earth (Fig. 5). Gelifluction is a type of mass-wasting induced by three key variables: (a) the availability of liquid water at or near the surface; (b) the presence of a near-surface permafrost-table that prevents the downward movement of moisture and promotes soil saturation; (c) soil composed of fine-grained and silty material that can remain wet longer than coarse-grained material and facilitate the downhill creep of slope masses [12].

(2) A number of key traits point to the possibility of the gullies in our study region having been formed by "water-rich" debris flows, e.g. levees, discontinuous channel segments and cutoffs, channel sinuousity, steep incisions and multiple small fan-shaped deposits. Moreover, the equatorial orientation of the observed gullies and crater-wall lobes could be a marker of insolation-driven mobilisation of near-surface water-ice in *AT*.

(3) The light tone of the mantle in *AT*, the uniformity of its distribution and its mid-latitudinal location, are characteristics shared with the widely reported and possibly "ice-rich" latitude-dependent mantle; the latter is thought to have formed by means of atmospheric precipitation and surface accumulation in response to a period of high obliquity in the very recent past [e.g. 13-14]. Thermal-contraction polygons do not require an ice-rich medium to form. However, mantle incision by these *NSPs* does point to the possibility of cryotic processes having been at work in their formation subsequent to the emplacement of the mantle.

The slightly higher elevation of the mantle than the *SPs*, along with the similarity of tone be-tween the mantled terrain and the polygon centres (possible mantle-remnant material), suggests that clastic polygon-formation could have predated the mantle.

4. Conclusion

We have identified a multi-feature-landscape assemblage that possibly benchmarks the relatively-recent presence of mobile liquid-water (gelifluction lobes and gullies) and of ice-rich terrain (mantle and thermal-contraction polygons). Against this backdrop we infer that the *SPs* in *AT* are the work of periglacial processes. We also report that the newly identified *SPs* and *NSPs* are separated, stratigraphically and geochronologically, by the mantle. This suggests, contrary to the dominant paradigm in the discipline, that Late Amazonian Epoch periglaciation on Mars is not synonymous with the accumulation or subsequent ablation of mantle material.

5. References

[1] Dohm, J.M. et al. *Icarus* 253, 66-98, 2015. [2] Taber, S., *The mechanics of frost heaving…*, 1930. [3] Washburn, A.L. *Periglacial processes & environments*, 1973. [4] French, H.M., *The periglacial environment*, 2007. [5] Banks, M. et al.,*JGR*, 113, E12015, 2008. [6] Mustard, J.F. et al. (2001). *Nature* 412, 411-414, 2001. [7] Milliken, R.E. et al. *JGR* 108, E6, 505, 2003.

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Preliminary grid mapping of fluvial, glacial and periglacial landforms in and around Lyot crater, Mars

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Abstract

Lyot crater, a 215 km diameter, Hesperian-aged martian impact crater, contains many landforms that appear to have formed by glacial, periglacial and fluvial processes [1-3]. Around Lyot are large channels potentially formed by groundwater release during the impact event [1,3]. Hence, the landscape of Lyot crater appears to record the action of both ancient water sourced from underground, and more recent water sourced from the atmosphere. We have used a grid mapping approach [5] to describe the distribution of these landforms and landscapes in and around Lyot crater. These data are presented here and potential avenues of future work discussed.

1. Introduction

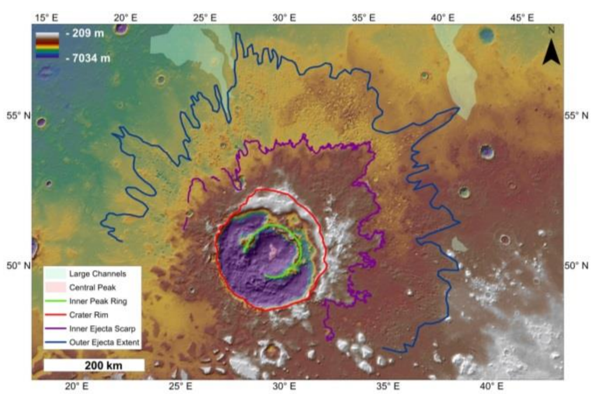

Figure 1: MOLA topography map showing Lyot crater with ejecta extents and large channels marked.

Lyot crater (50°N, 30°E) is located in the northern hemisphere of Mars, north of Deuteronilus Mensae [1-3,6] (Fig. 1). Lyot has an ejecta blanket consisting of both an inner continuous ejecta sheet, and an outer, more hummocky ejecta [1,3,6]. Large outflow channels that cover an area of ~300,000 km^3 and extend >300 km beyond the ejecta margin can be seen to the north, west and east of Lyot [3]. Lyot crater includes many geomorphic features which indicate prior fluvial activity [1–4] and possible periglacial and/or glacial activity [1,2,4].

2. Grid Mapping Method

Grid mapping employs a gridded "tick box" approach to record the presence or absence of particular landforms in a certain area [5]. A 6m/pixel Context Camera (CTX) mosaic of the study area was divided into a grid of 1680 squares, each 20 x 20 km in size. Alternating squares across the study area have been viewed, and each selected landform has been described as either "present", "dominant", "possible", "absent" or "no data". In this way a coarse-resolution map has been created which shows the distribution of the different landforms across the area. Below we outline some of our mapped landforms which are important indicators of the history of water in and around Lyot crater.

3. Key Geomorphological Features

3.1 Fluvial Valley Networks and Channels

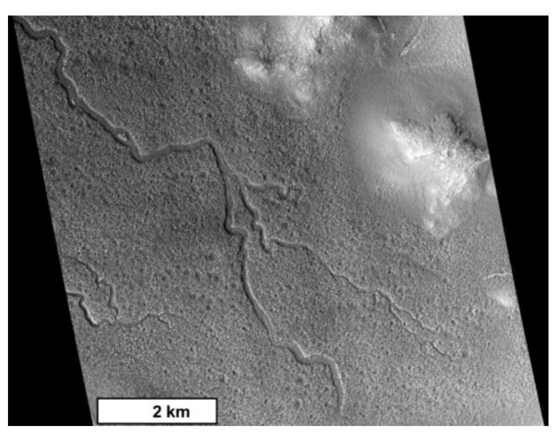

Figure 2: HiRISE image showing a rare contributory channel from the south east of Lyot crater.

Fluvial valley networks and channels are commonly found throughout the interior of the crater and within the inner ejecta blanket [1,4]. Channels are generally small (up to hundreds of metres across and up to tens of kilometres in length) and unbranching. Several channels have fans at their termini which vary from broad smooth surfaces, to smaller dissected fans [2]. Ages derived from impact crater size-frequency statistics for the networks place them as Mid/Late Amazonian in age [2,4]. Their distribution and morphology could be consistent with both an atmospheric and groundwater source.

3.2 Glacier Like Forms (GLFs)

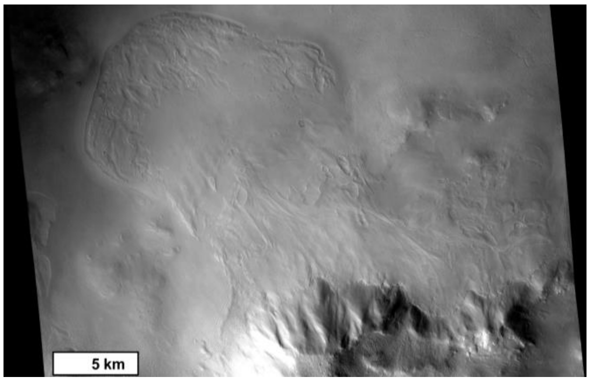

Figure 3: HiRISE image showing a GLF from the southern rim of Lyot crater.

GLFs are lobate features with convex-outwards and convex-upward profiles, and occur mainly in the south of Lyot crater along north-facing slopes of the rim and peak ring [1,2]. Some fluvial channels have been associated with GLF's, but not enough to indicate potential proglacial fluvial activity [1]. Their orientation is consistent with climate-driven deposition of water ice.

3.3 Polygonal Networks

Polygonal networks are common, and are limited to the north and south east regions of the outer ejecta [1]. Networks are commonly associated with mantling deposits in the outer ejecta blanket [1,4]. Some polygonal networks are enigmatic due to the presence of clasts which demarcate the edges of the polygons [1]. The location of these features, only within the ejecta, indicates that the conditions for formation are only met within this area/material [1].

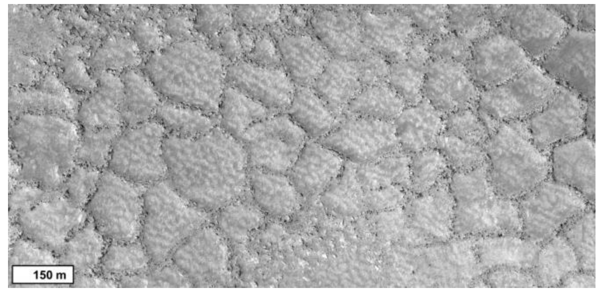

Figure 4: HiRISE image showing a clastic polygonal network from the outer ejecta to the east of Lyot crater.

4. Summary and Further Work

Lyot crater contains fluvial landforms and possible periglacial and/or glacial landforms that indicate the presence of liquid water in a recent period of Martian history. The distribution of these landforms indicates that the conditions for the formation of water may only be met in certain areas. In particular, there appears to be a genetic relation between polygonal networks and outer ejecta material. Cratering mechanics indicate that the impact event which formed Lyot crater could have penetrated the martian cryosphere [6]. As such ejecta material may represent cryospheric material deposited onto the martian surface [6]. To further explore this, the impact event that formed Lyot crater will be modeled using hydrocode impact modelling. This will provide an insight into the conditions for formation of the crater, and a means of testing if subsurface ice could have been released onto the surface as a result of the impact event.

References

[1] Balme, M. R., Gallagher, C. J. and Conway, S. J. EGU 2013. Abst: EGU2013-11032.

[2] Dickson, J. L., Fassett, C. I. and Head, J. W. GRL. 36. Doi:10.1029/2009GL037472. 2009.

[3] Harrison, T. N., et al. GRL. 37. Doi:10.1029/2010GL045074. 2010.

[4] Hobley, D. E. J., Howard, A. D. and Moore, J. M. JGR 119,128 – 153. 2014.

[5] Ramsdale, J., Balme, M., Conway, S., and the ISSI Team. EGU 2015. Abst: EGU2015-14884.

[6] Russell, P. S. and Head, J. W. GRL. 29. Doi:10.1029/2002GL015178. 2002.

EPSC Abstracts
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Mapping Mars` Northern Plains: Origins, Evolution and Response to Climate Change – A New Overview of Recent Ice-Related Landforms in Acidalia Planitia

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1. Introduction

Many young landforms in mid- and high-latitudes on Mars are thought to be related to ice [1], but their exact distribution and origin are still poorly understood. In an attempt to determine their extent and identify possible spatial relationships and genetic links between them, we mapped their distribution across a N-S traverse across Acidalia Planitia (AP) (Fig. 1), following the method described by [2]. The general characteristics of Acidalia are similar to that of Utopia Planitia (see companion abstract by [3]).

2. Data and Map Products

We employed a grid mapping approach based on CTX images [2], which enables mapping large areas at small scales. Our resulting maps show a binary ("yes" or "no") distribution of specific landforms in each grid cell (~20 × 20 km), but allows for some ambiguity (another class is "possible", where no unambiguous decision was possible). We also document where no data were available ("NULL") and where a landform is dominant. Examples of resulting maps are shown in Fig. 2.

3. Observations

We mapped individual landforms that may have been formed in association with ice or water, including polygonal terrain, gullies, and mantling material (the full list of landforms is provided by [2]). The following paragraphs give a short overview on the distribution of selected landforms.

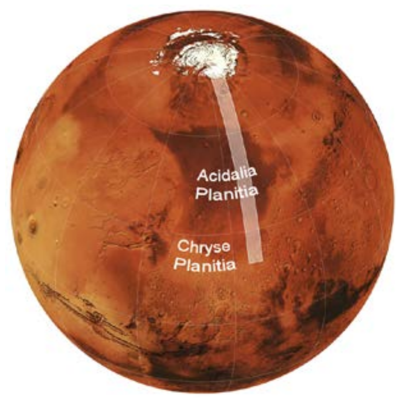

Figure 1. Traverse across Acidalia Planitia (from 20°N to~80°N). Width of traverse is 300 km.

Mantling deposits. Mantling deposits are ubiquitous and occur basically everywhere between ~43°N and almost the margin of the north polar cap. As their surface may appear smooth if undegraded, and their texture (if degraded) can be difficult to detect at CTX scale, unambiguous detection of mantling deposits is often complicated. Moreover, the quality of CTX images in the northern lowlands is not always perfect. Therefore, we classified the occurrence of mantling deposits in the majority of grids as "possible".

Gullies. Gullies were observed within a limited latitude range between ~32°N and ~54°N (Fig. 2b). They predominantly occur in Acidalia Mensae (outcrops of highland material [4]) and Acidalia Colles (knobs that can be several hundred meters high [4]). Although gullies were found in several impact craters, their clustering in Acidalia Mensa and Colles is likely due to the high relief compared to the northern lowlands in general. First gully orientation analyses in the Acidalia Mensa/Colles region between ~44-54°N show a strong equatorward orientation, in agreement with results of previous studies in this latitude region [5,6]. Note that recurrent slope lineae [7] have been detected in Acidalia [8], but are not further discussed here because they can only be confirmed in multi-temporal HiRISE images..

Small-scale polygons. Due to CTX resolution we focused on first-order polygon networks that are tens to approximately hundred meters in size. Small-scale polygons are observed between ~60°N to ~70°N in agreement with previous studies [8,9] (Fig. 2c). They occur predominantly as oriented orthogonal networks in crater interiors and depressions and as random orthogonal patterns on plains.

Viscous Flow Features (VFF). The VFF as originally coined by [11] here embraces all meso-scale landforms indicative of creep of ice and debris, either confined as valley fill or inside impact craters as concentric crater fill or as lobate aprons that are commonly distributed within a well-defined latitude belt between 45°-60° [e.g., 12]. As VFF movement is predominantly controlled by slopes (rather than internal deformation), these features are observed only in higher-relief areas of the Acidalia Mensae and Colles. Their morphology is not well pronounced, partially subdued and covered, and most features are restricted to debris aprons distributed circumferentially around small knobs.

Thumbprint terrain (TPT). TPT is characterized by curvilinear arrangements of pitted cones [13]. It is wide-spread in the northern lowlands and especially in Isidis Planitia. In our study region, TPT appears north of about 30°N in the most distal parts of the Chryse outflow channels and shows a transition zone with the LPMs (see below) at around 36°N. It is not observed north of ~39N° [14]. TPT is arranged in clusters and linear or arc-shaped chains. TPT cones have smaller basal diameter then the LPMs.

Giant Polygons. Giant polygons with a spacing of ~5 to ~10 km were already detected in Mariner 9 images [15]. The delineating troughs have average depths of ~30 m [16]. Together with the LPM (see below), the giant polygons have been considered analogous to fluid expulsion features in terrestrial sedimentary basins [17,18]. They characterize the study area from to 35 N° until 61 N° and completely disappear in the Acidalia Colles region [14]. Their spatial distribution overlaps with that of the LPM.

Large Pitted Mounds (LPM). These are dome-like features, commonly with a summit pit or crater, which have a greater basal diameter than the TPT cones. LPM are located in the northern part of AP, arranged in clusters and associated with the giant polygons [14,19]. Their morphology is changing from domical to pancake-like shapes around 48 N°. LPM completely disappear at ~63N°. North of 39°N, only LPMs without TPT can be observed.

4. Summary and Conclusions

Grid mapping proved to be an efficient way to map small-scale landforms over wide areas. The distribution of possible ice- and water-related features in AP is clearly latitude- and topography-dependent. For some features (e.g., TPT, giant polygons), it is very similar to that in Utopia [3]. Next steps will include the comparison of our results with those obtained for Utopia [3] and Arcadia [20] Planitiae, and with a morphologic inventory of impact craters in the three study areas [21], compiled in the same project.

Acknowledgements

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References

[1] Lasue, J. et al. (2013) *Space Sci. Rev., 174,* 155-212. [2] Ramsdale, J. et al. (2015) *LPSC, XLVI,* Abstract #1339. [3] Séjourné, A. et al. (2015), *LPSC, XLVI,* Abstract #1328. [4] Tanaka, K.L. et al. (2003) *JGR-Planets, 108,* 8043. [5] Bridges, N.T. and Lackner, C.N. (2006) *JGR-Planets, 111,* E09014. [6] Kneissl, T. et al. (2010) *Earth Planet Sci. Lett., 294,* 357-367. [7] McEwen et al. (2011) Science, *333*(6043), 740–743. [8] Dundas, C.M. et al. (2015) *LPSC XLVI,* Abstract #2327. [9] Mangold, N.. (2005) *Icarus, 174,* 336-359. [10] Levy, J.S. (2009) *JGR-Planets, 114,* E01007. [11] Milliken, R.E. et al. (2003) *JGR-Planets, 108,* 5057. [12] Hauber, E. et al. (2008) *JGR-Planets, 113,* E02007. [13] Lockwood, J.F. et al. (1992) *LPSC, XXIII,* 795-796. [14] Orgel, C. et al. (2015) *LPSC, XLVI,* Abstract #1862. [15] Mutch, T.A. et al. (1976) *The Geology of Mars,* Princeton Univ. Press. [16] Hiesinger, H. and Head, J.W. (2000) *JGR-Planets, 105,* 11999-12022. [17] Allen, C.C. et al. (2013) *Icarus, 224,* 424-432. [18] Salvaore, M. and Christensen, P. (2014) JGR-Planets, 119, 2437-2456. [19] Oehler, D.Z. and Allen, C.C. (2010) *Icarus, 208,* 636-657. [20] Balme, M. et al. (2015) *LPSC, XLVI,* Abstract #1384. [21] Skinner, J.A. et al. (2015) *LPS XLVI,* Abstract #1700.

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Reassessing the global gully distribution on Mars

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Abstract

Gullies on Mars are kilometer-scale erosion-deposition systems that resemble water-carved gullies on Earth [1]. Trends in their distribution and orientation with latitude have led many authors to associate these features with an exogenic climate trigger [e.g., 2]. There is a renewed debate [e.g., 3] about whether these features are caused by the sublimation of carbon dioxide ice or by melting of surface/near-surface ice – each of these formation mechanisms should produce different latitudinal trends. A new study of these features has resulted in a near complete global map [4], which allows us, here, to reassess their distribution and give a set of criteria which any model of gully-formation must explain.

1. Gullies and steep slopes

Gullies on Mars are found on sloping terrain, most commonly on impact crater walls, but also on mesas, valley-walls, central peaks, polar pit walls [e.g., 5]. Gullies are generally found to originate on slopes > 20° [6,7].

It is known that the frequency of steep slopes generally decreases towards the poles [8,9]. The general decrease of gully-density from the mid-latitudes to the poles is thought to be partly explained by the decrease in the number of steep slopes [6], however this has not been quantitatively assessed.

Here we reassess the distribution of gullies taking into account the presence or absence of steep slopes. Firstly, we compare the global gully-density map of Harrison et al. [4] with the frequency of slopes > 20° from the global MOLA gridded data over a 250 km-span (Fig. 2). Secondly we look in more detail at two study areas, one in Terra Cimmeria and one in Argyre Planitia.

2. Global trends

The boundary between frequent steep-slopes and infrequent steep-slopes on the slope-density map (Fig. 1) matches well with the drop-off in density of gullies in the southern hemisphere. Local minima in steep-slope-frequency are matched by local minima in gully-density (labelled A). One notable exception is the lack of gullies east of Hellas (labelled B), which cannot be explained by a lack of steep slopes. The equatorward extent of gullies is sometimes mediated by the steep-slope-frequency (labelled A), but in most cases is not – therefore spatial variations in this boundary need to be explained by another variable (possibly climate-related).

In the northern hemisphere gullies are less common, yet the low density of gullies is not entirely explained by a low frequency of steep slopes. Notable zones with low gully densities, but high frequency of steep slopes are labelled "B" on Fig. 1, including Phlegra Montes, Eastern Deuteronilus Mensae, western Ascuris Planum. The lack of gullies in all regions labelled "B" corresponds exactly to the locations of lobate debris aprons and viscous flow features mapped by Squyres [10].

The polar pit gullies located around the south pole of Mars are also somewhat anomalous as they do not have a high density of steep slopes. Previous work has found that these gullies have lower slopes than the global population [7] and may be formed solely by CO_2-processes [11].

3. Local trends

In our smaller-scale regional studies around Argyre Planitia and Terra Cimmeria, we mapped the gully-clusters as polygonal outlines [12] on 6 m/pix Context Camera (CTX) images. From this mapping we were able therefore to examine the distribution of gullies by only considering the MOLA pixels that had greater than 10° slope (Fig. 2), rather than simply density per area, as in previous studies. Both areas show important differences from the density shown in Fig. 1 and the southern hemisphere frequency distribution of Dickson and Head [13] based on data of [14] superposed on Fig. 2.

Firstly, for the Terra Cimmeria site there is no peak in gully-density at 37.5°S (as shown in Fig. 1 and [13]), rather gullies have an even distribution across the whole latitude band (therefore there is no steady decline in gully-forming potential towards the pole). Secondly, there is a distinct lack of gullies in the 27-42°S region in Argyre where gullies should be most common and indeed without considering the slopes are relatively dense in Fig.1.

4. Summary and Conclusions

From these analyses we conclude that any model of gully-formation would have to explain the following:

- The onset of gully-forming processes at ~30°N/S and the undulations in that boundary.
- The uniform density of gullies over the whole 30-55° latitude band in highland areas.
- Local paucity (e.g. N Argyre) and local hotspots of gully occurrence (e.g. E Terra Cimmeria).
- The trends in orientation of gullies with latitude reported in other works [4–6,14,15].

Acknowledgements

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References: [1] M.C. Malin and K.S. Edgett, *Science*, (2000), 288,2330–2335. [2] F. Costard *et al.*, *Science*, (2002), 295,110–113. [3] C.M. Dundas, S. Diniega and A.S. McEwen, Icarus, (2015), 251,244–263. [4] T.N. Harrison *et al.*, *Icarus*, (2015), 252,236–254. [5] M. Balme *et al.*, *JGR*, (2006), 111,doi:10.1029/2005JE002607. [6] J.L. Dickson, J.W. Head and M. Kreslavsky, *Icarus*, (2007), 188,315–323. [7] S.J. Conway *et al.*, *Icarus*, (2015), 253,189–204. [8] M.A. Kreslavsky, J.W. Head and D.R. Marchant, *PSS* (2008), 56,289–302. [9] M.A. Kreslavsky and J.W. Head, *J. Geophys. Res.*, (2000), 105,26695–26712. [10] S.W. Squyres, *JGR* (1979), 84,8087–8096. [11] J. Raack *et al.*, *Icarus*, (2015), 251,226–243. [12] A. Britton, S. J. Conway, and M.R. Balme, *EPSC*, (2013), Abst#345. [13] J.L. Dickson and J.W. Head, *Icarus*, (2009), 204,63–86. [14] J.L. Heldmann and M.T. Mellon, *Icarus*, (2004), 168,285–304. [15] T. Kneissl *et al.*, *EPSL*, (2010), 294,357–367.

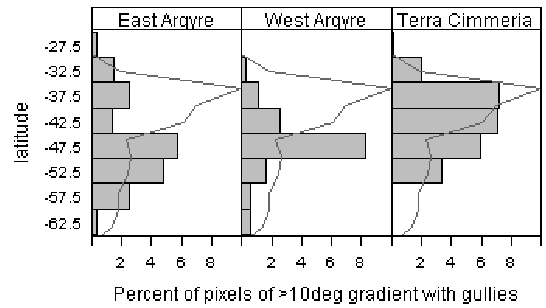

Figure 2: Latitudinal distribution of gullies on slopes >10° in the three study areas shown in Fig.1. In grey the normalized southern hemisphere frequency of gullies from [13], based on [14].

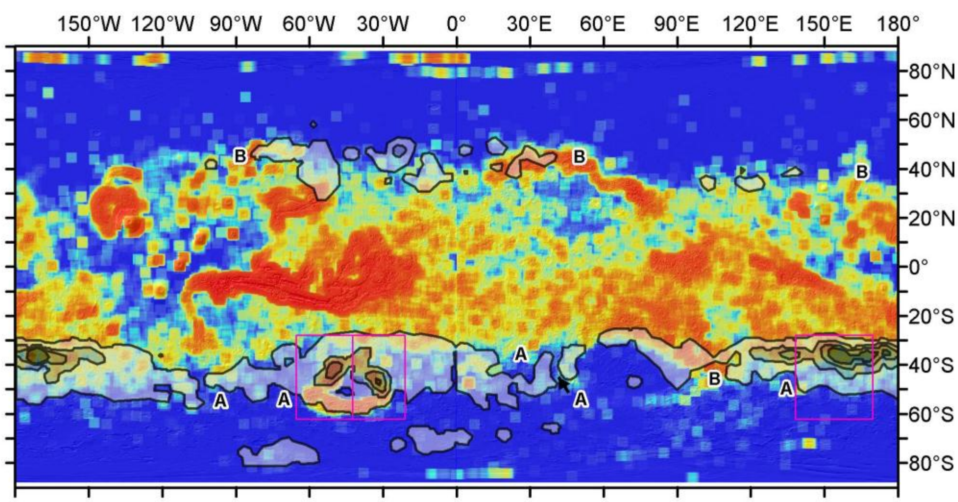

Figure 1: Map of density of steep slopes overlain by the gully-density map taken from [3], red indicates high density of steep slopes and blue indicates few steep slopes. Gully density increases with darker shades within the contours. Locations labelled "A" have low steep-slope density and low gully-density; those labelled "B" have a lack of gullies, yet a high steep-slope density. Areas outlined in pink are the locations of the regional study sites.

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Mapping Mars' Northern Plains: Origins, Evolution and Response to Climate Change - An Overview of the Grid Mapping Method and Results from Arcadia Planitia.

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1. Introduction

As part of an International Space Science Institute (ISSI) team project studying the northern plains of Mars we use geomorphological mapping to compare ice-related landforms in the three northern plains basins: Arcadia Planitia, Acidalia Planitia [1], and Utopia Planitia [2]. The main questions are:

1) *"What is the distribution of ice-related landforms in the northern plains, and can it be related to distinct latitude bands or different geological or geomorphological units?"*
2) *"What is the relationship between the latitude dependent mantle (LDM) and (i) landforms indicative of ground ice, and (ii) other geological units in the northern plains?"*
3) *"What are the distributions and associations of recent landforms indicative of thaw of ice or snow?"*

Increased coverage of high-resolution images of the surface of Mars enables identification of increasing numbers and varieties of small-scale landforms which can form the observational basis for understanding the history of an area. The combination of improved spatial resolution with near-continuous coverage increases the time required to analyse the data. This becomes problematic when attempting regional or global-scale studies of metre-scale landforms. Here, we present an approach for mapping small features across large areas that was formulated for the ISSI project and the results from Arcadia Planitia (Fig. 1).

2. Assessment of the Method

Rather than traditional mapping with points, lines and polygons, we used a grid "tick box" approach to determine where specific landforms are. The mapping strips were divided into a 15×150 grid of 20 km squares. In an ArcGIS shapefile, a new column attribute was added for each landform/surface type. CTX and THEMIS daytime images were then viewed systematically for each sub-grid square and the landforms were recorded as "present", "dominant", or "absent" in each sub-grid square. Where relevant, each square was also recorded as "null" (meaning "no data") or "possible" if there was uncertainty in identification (but where the mapper felt that there was some evidence to suggest that the landform was present). The result is a series of coarse-resolution "rasters" showing the distribution of the different types of landforms across the strip. The Grid mapping (Table 1) is efficient: for each sub-grid, only the presence or absence of a landform needs to be ascertained, and no detailed digitising is needed removing an individual's decision as to where to draw boundaries and improving repeatability.

Pros	Cons
Rapidity, ensures all areas are covered, actively marking negative results. At full CTX resolution.	If a landform needs to be added later, it would require going back over the whole dataset.
Reproducible and scalable with group efforts. Transitions between colleagues are easier than traditional mapping.	Hard to discriminate between a single dominating landform in a sub-grid, and many landforms covering perhaps 25% of the sub-grid.
Allows large datasets to be published in a series of smaller maps.	Tedious to implement.
Comparable data for several strips across an area.	
Several landforms can be mapped at once.	
Only basic mapping and GIS skills needed.	

Table 1. Pros and Cons of the grid mapping method.

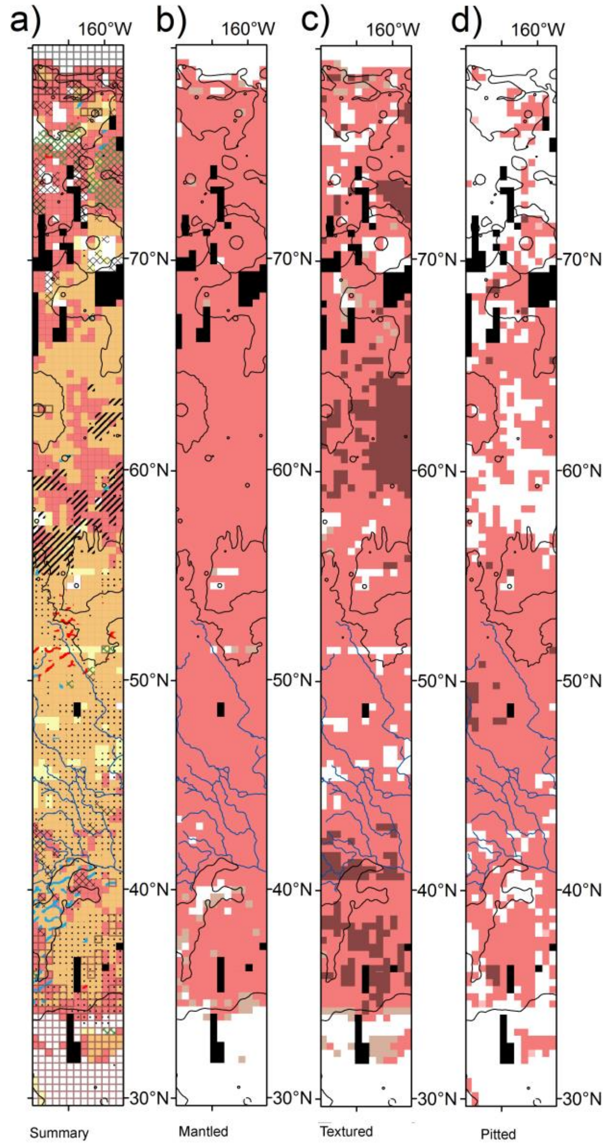

Fig. 2. Summary and example data from Arcadia Planitia grid-mapping. a) summary of all landforms and surface types, b) "mantled" designation, c) "textured" morphological type terrain, and d) "pitted" morphological type terrain. Background map takes simplified contacts from [3] and additional mapping (e.g., of channel-like features) from this study.

References: [1], Hauber et al., (2015) *LPSC XLVI*, Abstr. #1359 [2] Séjourné et al., (2015) *LPSC XLVI*, Abstr. #1328, [3] Tanaka, K. L., et al., (2005) Geologic map of the northern plains of Mars.

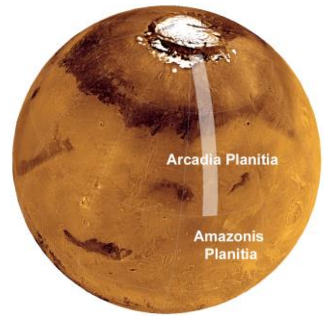

Fig. 1 Arcadia Planitia Study area. The swath is 300 km wide and extends from 30° to 80° N.

3. Results

Fig. 2 shows summary results from Arcadia Planitia; results of particular note are 1) "textured" surfaces are ubiquitous down to about 35°N, and match the distribution of a topographic mantle. 2) Small pits are common in the south and middle of the swath, but become less common in the north. 3) 100m-scale polygons are found mainly near the north of the study area, in contrast to results from Utopia [3]. Also, unlike Utopia, there are very few scalloped depressions. 4) Small mounds – morphologically similar to erosional remnants – correlate with albedo and relief patterns that form a branching network between 40° and 50°N. This could suggest that there was once an extensive, erosional fluvial system in this region.

4. Conclusions

Grid mapping provides an efficient and scalable approach to collecting data on large quantities of small landforms over large areas and has produced a rich dataset. Future studies will compare the landform maps with roughness, elevation, slope, geological, sub-surface RADAR, and climate data. Also, the three mapped strips will be contrasted with one another in order to assess whether the dominant control on landform/surface type is latitude (i.e. climate or insolation strength) or substrate.

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Veiki-moraine-like landforms in the Nereidum Montes region on Mars: Insights from analogues in northern Sweden.

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1. Introduction

Mars is a cold hyper-arid planet where liquid water is extremely rare [1]. Most water is instead locked in a number of frozen reservoirs such as the polar caps, latitude-dependent near surface ground ice and as glacier ice. Previously, numerous studies reported on glacier landforms such as viscous flow features and lobate debris aprons where water-ice is believed to be present under insulating debris cover [2]. This notion was confirmed by SHARAD measurements [3]. However, very little is known about glacial landforms in which water is an important factor. Most studies have focused on moraine-like ridges that are associated to gully systems in crater environments [4], glacier landforms at the equatorial volcanic province [5] and drop-moraines from CO_2 glaciers [6]. Here we report on unusual irregular ring-shaped landforms within a mountain complex in Nereidum Montes, Mars. These landforms are well-preserved and may suggest recent ablation of a debris-covered, cold-based glacier. These martian ring-shaped moraine-like landforms show a striking resemblance to the Veiki moraine in northern Sweden. Veiki moraines are believed to have formed at the lobate margins of a stagnant ice-sheet during the first Weichselian glaciation as it sharply ends to the east [7]. The Veiki-moraine is characterized by ridged plateaus that are more or less circular and surrounded by a rim ridge. The newly acquired national LiDAR data over Sweden enable us studying these landforms in unprecedented detail. They also enable us exploring geomorphological similarities between Earth and Mars in large spatial contexts. This study aims to increase our understanding of glacial landforms on Mars by comparison to terrestrial analogues. Questions addressed are: (1) how morphological similar are the Martian landforms to the Veiki moraine of Sweden? (2) How does the moraine-like landform relate to other, well-preserved, glacial landforms within the mountain complex? (3) Do the moraine-like landforms indicate the maximum extent? (4) Was any meltwater involved and are the preserved landforms ice-cored?

2. Data and Methods

For our study we use HiRISE (25 cm/pxl), CTX (6 m/pxl), MOLA topography and point data. CTX images have been processed using ISIS 3.0. The terrestrial analogues are covered by LiDAR. The LiDAR data have a point density between 0.5 to 1.0 points/m^2, with a footprint of 0.5 m and a scan angle of 20°. Accuracy of the z-axis is typically better than 0.1 m on flat surfaces.

3. Observations

The martian moraine-like landforms (MLL's) are located at the end of a valley that are open in the eastward direction. In plan form the overall morphology has a distinct lobe shape (Fig. 1 A) and cover an area of approximately 80 km^2. Individual MLL's form irregular open and enclosed ridges (Fig. 1B). By shadow measurements ridges are 10-15 m in height. Ridges show a high concentration of boulders and clasts (Fig. 1 C). The outer lobe border is mainly made up of fractured mounds. The Veiki moraines in northern Sweden show a similar irregularity of landforms forming ridged plateaus and enclosed depressions (Fig. 1D).

4. Discussion

The MLL's are located in close spatial proximity to other landforms such as protalus rampart glaciers and remnant cirque glaciers. The topography around the MLL's shows features that may be interpreted as roche moutonnées, bergschrunds (crevasses at the head of a glacier), arêtes, cols (saddle-like narrow depression formed by two head ward eroding cirques that reduce an arête) and cirques. If these interpretations are correct it shows an area with clear evidence of possibly current and former presence of glacier ice.

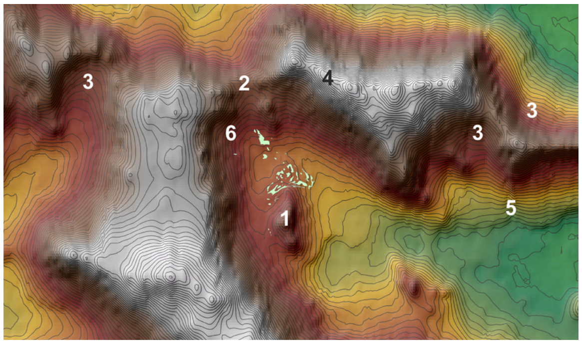

Figure 2: MOLA topographic map with 100 m contour lines and locations of possible glacial morphologies. MLL's in green dots (center). 1) Roche moutonnées. 2) Col. 3) Cirques. 4) Arête. 5) Protalus rampart. 6) Bergschrunds. Area located at the western part of Nereidum Montes.

The floor of the valley, adjacent to the MLL's shows a number of exhumed impact craters which probably represent the pre-glacial surface. The very few fresh looking impact craters point to a relatively young surface age post glacial recession.

5. Summary

We have identified an area in the Nereidum Montes region that shows clear evidence of glaciation, including possibly preserved glacier ice and glacial landforms. We have also found landforms strikingly similar to the Veiki moraines of northern Sweden. A better understanding of these features may provide important insight into Martian geologic and climatic history. This project is on-going and more work is needed to gain a better understanding of the sequential evolution of glacial landforms in this area.

Acknowledgements

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References

[1] McEwen et al. 2011, Seasonal Flows on Warm Martian Slopes. Science (5) 333. [2] Milliken et al., 2003. Viscous flow features on the surface of Mars: Observations from high-resolution Mars Orbiter Camera (MOC) images. JGR-Planets (E6) 108. [3] Holt et al.,2008. Radar Sounding Evidence for Buried Glaciers in the Southern Mid-Latitudes of Mars. Science (21) 322. [4] Arfstrom et al., 2005. Martian flow features, moraine-like ridges, and gullies: Terrestrial analogs and interrelationships. Icarus (2) 174. [5] Scanlon et al., 2015. PSS. [6] Head et al. 2006. Met & Plan Science (10) 41. [7] Lagerbäck, 1988. The Veiki moraines in northern Sweden-widespread evidence of an Early Weichselian deglaciation Boreas 17.

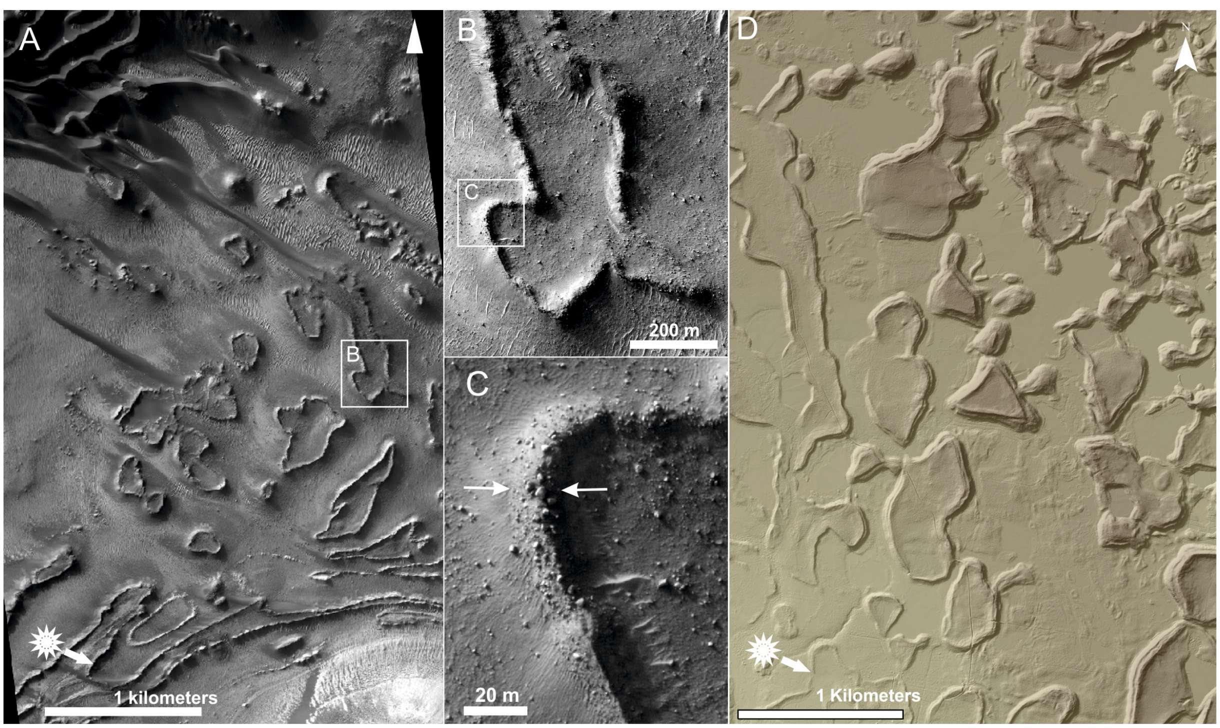

Figure 1. A) HiRISE image of multiple irregular MLL's forming a lobate pattern. B) Ridges form enclosed depressions with heights between 10-15 m. C) High clast concentrations at the ridges. D) LiDAR image of possible terrestrial analogues, called 'Veiki moraine' from northern Sweden.

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Small-scale lobes in the southern hemisphere on Mars: Implications for transient liquid water in the recent past.

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Abstract
We have catalogued small-scale lobes in the southern hemisphere on Mars. Small-scale lobes are restricted to crater walls and hillslopes but are morphologically distinct from viscous flow features (VFF) or other putative glacial landforms. Instead they show striking resemblance to terrestrial solifluction lobes. Previously it was shown by several authors that they are common in the northern mid and high latitudes. Here we show that they represent a hemispherical bimodal and latitude-dependent landform such as gullies and polygonal terrain. We hypothesize that they form by freeze-thaw activity and represent geomorphologic indicators for repeated transient liquid water close to the ground surface in Mars recent climate history.

1. Introduction
On Earth, solifluction is a common slow mass-wasting process in permafrost regions (Fig. 1). The main solifluction processes include frost creep, and/or gelifluction which occur within the seasonally thawing and freezing soil layer on top of permafrost [Matsuoka, 2001]. On Earth solifluction lobes are strong indicators of past or present freeze-thaw activity. As such they may represent a useful source of paleoclimatic information [Åkerman, 2005].

Figure 1: Examples of stone-banked solifluction lobes in Ugledalen, Svalbard. Lobes are approximately 10 m wide.

Previously, well-preserved small-scale lobes were reported in the northern mid-and-high latitudes on Mars by several authors [Balme et al., 2013 and references therein]. Based on morphology and integrated landform analyses [Gallagher et al., 2011; Gallagher and Balme, 2011], morphometry and Earth-analogue studies [Johnsson et al., 2012] the proposed mechanism is by solifluction. By implication, this suggests active-layer formation and transient liquid water close to the surface at repeated times in the recent climate history on Mars in contrast to general climate modeling [Kreslavsky et al. 2008].

Previously, small-scale lobes have only been observed at a few sites in the south using Mars Orbiter Camera (MOC) images [Mangold, 2005]. The first question we ask is therefore: what is the distribution of small-scale lobes on southern Mars as seen in HiRISE and CTX datasets? Secondly, is there a link to other mass wasting landforms that have been associated with melting of ice/snow such as gullies? And thirdly, how do the southern small-scale lobes compare to the northern counterparts?

2. Data and method
In this study we extend our search to the latitude band 40°S and 80°S on Mars. We have investigated all available HiRISE that were acquired between 2007 and 2013. A total of 2200 HiRISE images have been studied in detail. The Charitum Montes region contains a high concentration of small-scale lobes but HiRISE coverage is sparse. Here we used 20 CTX images for our mapping.

3. Observations and results
Like the northern counterparts, the observed small-scale lobes in the south show striking similarities to solifluction lobes on Earth (Fig. 2) and they are typically located in a context associated with thermal

contraction polygons and gullies. The small-scale lobes are tens to hundreds of meters wide with well-defined lobe fronts (risers). The risers are in the order of decimeters to a few meters high (<5m). Individual lobes overlap or occur as sheet-like landforms. They are restricted to crater walls and hillslopes and are not confined by valley topography. They lack attributes typically associated with creep/deformation of ice or ice-rich debris such as crevasses, compression ridges and furrows. Hence they are morphologically different from glacial landforms such as VFF [Milliken et al., 2003] and lobate debris aprons [e.g. Mangold 2003].

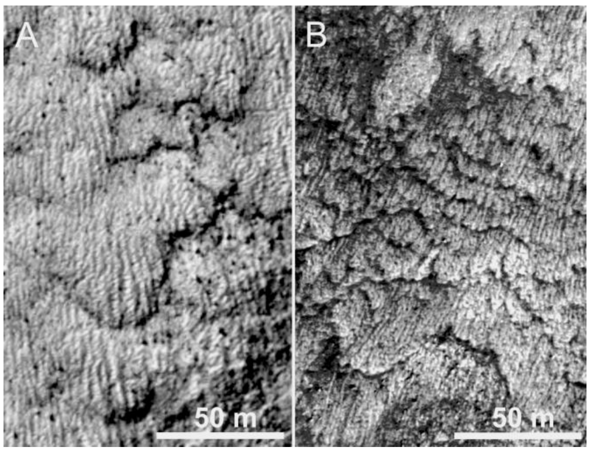

Figure 2: Comparison of lobes of similar scale on Mars and Earth. (A) Pole-facing small-scale lobes in a well-preserved mid-latitude crater on Mars. Note the stripe-like pattern superposing the lobes. (B) Solifluction lobes on a valley wall on Svalbard. Lobes are superposed by stone stripes.

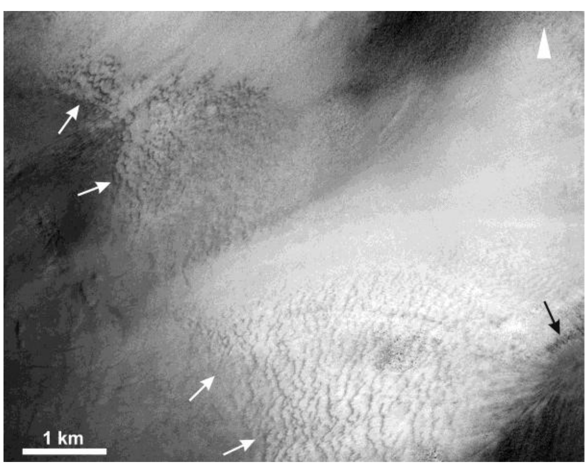

Figure 3: CTX image showing west-facing lobes in Charitum Montes. White arrows represent the lower boundary where lobes are observable. Black arrow points to summit in the area.

Particularly well-developed lobes are concentrated in the Charitum Montes region (Fig. 3), but lobes are also found elsewhere in the mid-latitudes, typically in well-preserved craters. We call these two populations: (1) crater lobes and (2) Charitum Montes lobes. The former show changes in aspect depending on latitude. Lower latitudes typically have pole-facing lobes and higher latitudes show a preference for equator-facing lobes. The Charitum Montes lobes are restricted to hillslopes of ancient terrain. They are well-developed and have modified large areas. They are typically restricted to west to north-facing slopes.

Our results show that small-scale lobes are widely distributed across the southern hemisphere of Mars. In the latitude band surveyed about 80 sites containing small-scale lobes have been found. They range in latitude between 40°S and 70°S. Their close spatial proximity and superposition relationship to gullies suggests that they may form under similar climatic conditions. Their close proximity to polygonal terrain suggests they form in an ice-rich substrate.

4. Summary and Conclusions

To date more than 2200 HiRISE images and 20 CTX images have been investigated for small-scale lobes in Mars' southern hemisphere. Results show that the small-scale lobes are distributed more equatorward than in the north. Like in the north morphometry and morphology suggest that they are distinct from permafrost creep. Although landforms indicative of freeze-thaw activity may be rare on flat terrain on Mars, there is growing evidence that freeze-thaw conditions may have been met on mid-and-high latitude slopes on both hemispheres. Small-scale lobes may therefore be strong indicators of past transient liquid water and be useful sources of paleoclimatic information on Mars.

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References: Balme et al., 2013. Prog. Phys. Geogr. 1-36. Gallagher et al., 2011. Icarus 211 (1), Gallagher and Balme, 2011. GSL 356. Johnsson et al., 2012. Icarus 218. Kreslavsky et al., 2008. Planet. Space Sci. 56 (2). Mangold, 2005. Icarus 174. Matsuoka, 2001. Earth Sci. Rev. 55. Åkerman, 2005. NJG 59.