AN INVESTIGATION OF THE PHYSICAL CONSTRAINTS ON ARANEIFORM MORPHOMETRY

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Introduction: Araneiforms are an exotic class of feature native to the Martian south polar terrain [3, 6] which are unlike anything seen on Earth. They are negative topography features comprised of dendritic, tortuous troughs emanating from a central depression and their long axis can exceed 1 km. Due to the large size of some araneiforms [2] and hence the energy budget required to erode them, the dilation and recession of the seasonal CO_2 ice deposit is proposed to be responsible for their gradual formation *over time* [3, 6, 7]. However, the *radial* class of araneiforms of the south polar cryptic region and surroundings have not been observed to form or extend in the present day [7].

Here we present an alternative hypothesis; that the radial araneiforms of the South Polar Layered Deposits (SPLD) formed in a relic climatic period on Mars and that the contemporary fan and spot activity in their environs is due to recycling of seasonal dust deposits which settle in their negative topography. We present the first laboratory observations of araneiform formation by vigorous CO_2 sublimation dynamics under Martian pressure [5]. We detail the results of an ongoing survey designed to investigate the environmental factors that may influence araneiform morphometry and find that present–day ice thickness distribution does not appear to control landform morphometry. However, we find that inferred pressure gradient controls their level of branching in the form of (i) inferred vent spacing and (ii) inferred vent length. From this survey, we develop a more extended classification of araneiforms than previously offered.

Araneiforms and their surroundings are veneered in winter by CO_2 ice which sublimates in spring. The timing of seasonal fan and spot activity has been linked to the sublimation of this seasonal CO_2 ice [8, 3] and conceptual modelling has attributed a process known as 'cryoventing' to their formation [3, 6]. This concerns basal sublimation of the seasonal CO_2 ice induced by increasing solar insolation in spring and consequent pressure buildup and rupture of the ice overburden. This process is posited to erode and lift the loose regolith from beneath the ice in the form of a plume rich in ice and dust. In turn, the eroded material is deposited on top of the ice in the form of relatively dark albedo dust as (a) spots and (b) elongate fans when mobilised by katabatic winds.

Although this cardinal hypothesis of CO_2 sublimation on Mars is widely accepted, there is a paucity of empirical evidence due to the unavailability of ground truth observations or field analogs. Also, a major quandary associated with the hypothesis is that while fans and spots are observed to reappear, and while other smaller dendritic features in surrounding and lower latitudes [7, 1] form and extend annually, none of the radial araneiforms of the SPLD have been observed to form or grow during the last 6 Mars Years (MY) of sub–metre resolution imaging with HiRISE. This suggests one of three possible scenarios: (a) the araneiforms grow via multiple cryoventing events at a very slow rate and the extent to which they have grown in 6 MY is below image resolution [7], (b) the material of the SPLD is now consolidated and hence not easily eroded, (c) the araneiforms grew during a paleo–climate. Environmental variables such as atmospheric temperature and pressure, ice thickness and diurnal solar insolation intensity allowed an energy budget competent to erode the specifically radial patterns of high latitude araneiforms in one or few instances of cryoventing. If true, the araneiforms are coeval. This suggests that cryoventing at that time was a pressure–gradient limited process. The efficacy of the process would have been constrained by the number of active vents and their spacing. Widely spaced vents would result in higher pressure gradients and hence greater levels of branching and closely spaced vents would result in low pressure gradients and more diffuse flows of gas resulting in less branched araneiforms.

Methods: *Laboratory Experiments:* We performed a suite of experiments of CO_2 block placement on a series of granular beds of discrete grain size ranges under Martian atmospheric pressure at the Open University Mars Simulation Chamber. Our aim as (a) establish whether cryoventing activity could erode araneiform morphologies, (b) assess the role of substrate grain size and (c) evaluate the role of vent width on araneiform morphology. A CO_2 block measuring $20 \times 10 \times 2\,cm$ was drilled at its centre and a 'claw' attached to a pulley was slotted into its sides. The block was suspended above a level granular bed. Coded markers were carefully measured and placed within the scene for later 3D modelling of the features produced. The chamber was closed, evacuated and pressure was lowered to 6 mbar. The block was then lowered and allowed to sublimate as it came in contact with the relatively warm granular surface. The *Leidenfrost Effect* was utilised in order to simulate the stage at which insolation became intense enough to cause basal sublimation beneath the block in contact with the granular bed in each case, as in our previous Earth–based experiments [4]. This experiment was performed in duplicate across discrete grain size ranges between 150–600 μm for vent diameters of both 3 and 5 mm. Images were taken at a variety of angles following each experimental trial and 3D topographic models were developed

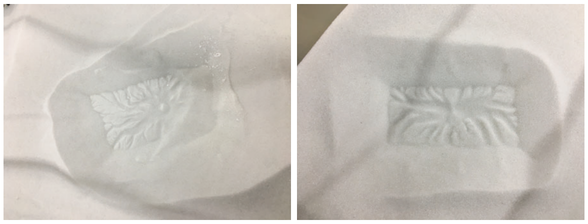

Fig. 1: Araneiforms developed on granular beds of (a) 150-250 μm and (b) 250-425 μm when a CO_2 block with a central vent of 5 mm in contact with the granular surface was allowed to sublimate in each case.

by Structure from Motion [9] using Agisoft Photoscan Software and later measured using ArcMap 10.4.

HiRISE Survey: HiRISE images ESP_049046_0985 (Inca City), PSP_004907_0945 (Oswego) and ESP_013833_0980 were selected for three sites at latitudes and longitudes -81.459, 296.281, -85.464, 83.558 and -81.813 and 76.170 respectively. Collectively, the 112 araneiforms surveyed represent 'thin', 'fat', 'classic' and 'starburst' araneiforms. We used ArcMap 10.5 to test for evidence of a pressure–gradient limited process by investigating the relationship between the level of branching of araneiforms and (a) inferred vent spacing, (b) inferred vent width to araneiform extent ratio and (c) inferred ice thickness. Based on our lab observations of araneiform centres originating at vent locations and similar araneiform centre width to vent diameter, we approximated original vent locations as the centre of each araneiform and vent diameter as roughly equal to the width of the central depression of each araneiform. Using the *measure* tool in ArcMap 10.5, we measured the distances between centres of each araneiform morphology type on Mars and their individual central diameter. We then counted the number of junctions on each araneiform branching system and plotted these data using Matlab 2015a.

Results We report the first observations of plume action and consequent erosion of substrate to form araneiforms and deposit the eroded material on top of the incident ice as a spot. On the laboratory scale, the level of branching of araneiforms and the area of substrate they covered increased with decreasing (a) grain size and (b) vent width, indicating a role of pressure gradient on araneiform morphometry. We report an initial trend for araneiforms on Mars whereby the level of branching of araneiforms increases with inferred vent (a) spacing and (b) width–also indicative of limitations on morphometry posed by pressure gradient. However we did not note a latitudinal gradient in araneiform morphometry and so our hypothesis of limitations posed by inferred ice thickness is inconclusive. We caution that assumptions were made during our survey based on small–scale laboratory

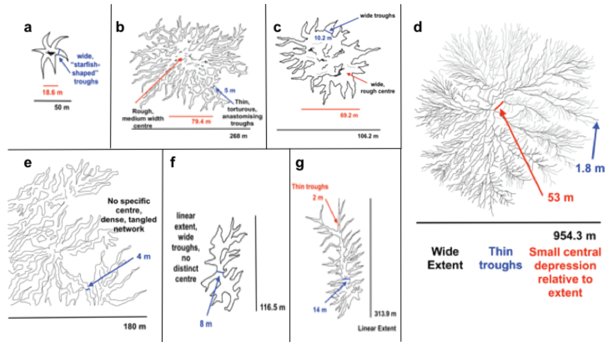

Fig. 2: Araneiform Classification. (a) Baby araneiform. $< 50\,m$ in diameter and their troughs are few and "spiky" in form. (b) Classic araneiform. These have many tortuous, anastomising troughs. (c) Fat araneiform. These are $> 50\,m$ in diameter and have low full extent to central depression ratios. (d) Lace terrain. This has no distinct centre and often covers multiple km of terrain. (f) Rake araneiforms. These are linear and have no distinct central depression, but have wide troughs. (g) Linear araneiform. These are linear with thin tortuous troughs.

observations. We require a more rigorous understanding of grain size and sediment induration at the SPLD. In addition, past climatic conditions are required to be modelled at a landform-scale that is sufficient to better understand the constraints on araneiform formation. Further modelling and analog laboratory experiments will prove useful to our understanding of these features and the reasons for their possible dormancy today.

References

[1] M. C. Bourke and A. Cranford. Seasonal furrow formation on Mars polar dunes. In *Fifth International Conference on Mars Polar Science and Exploration*, volume 1623 of *LPI Contributions*, page 6059, September 2011.

[2] C. J. Hansen, N. Thomas, G. Portyankina, A. McEwen, T. Becker, S. Byrne, K. Herkenhoff, H. Kieffer, and M. Mellon. HiRISE observations of gas sublimation-driven activity in Mars' southern polar regions: I. Erosion of the surface. *Icarus*, 205:283–295, January 2010. doi: 10.1016/j.icarus.2009.07.021.

[3] H. H. Kieffer, P. R. Christensen, and T. N. Titus. CO_2 jets formed by sublimation beneath translucent slab ice in Mars' seasonal south polar ice cap. *Nature*, 442:793–796, August 2006. doi: 10.1038/nature04945.

[4] L. E. Mc Keown, M. C. Bourke, and J. N. McElwaine. Experiments on Sublimating Carbon Dioxide Ice and Implications for Contemporary Surface Processes on Mars. *Scientific Reports*, 7:14181, October 2017. doi: 10.1038/s41598-017-14132-2.

[5] L.E. Mc Keown, M.C. Bourke, J.N. McElwaine, M.E. Sylvest, and M.R. Patel. The Formation of Araneiforms by Carbon Dioxide Venting and Vigorous Sublimation Dynamics Under Martian Conditions. *Scientific Reports*, submitted.

[6] S. Piqueux, S. Byrne, and M. I. Richardson. Sublimation of Mars's southern seasonal CO_2 ice cap and the formation of spiders. *Journal of Geophysical Research (Planets)*, 108:5084, August 2003. doi: 10.1029/2002JE002007.

[7] G. Portyankina, C. J. Hansen, and K.-M. Aye. Present-day erosion of Martian polar terrain by the seasonal CO_2 jets. *Icarus*, 282:93–103, January 2017. doi: 10.1016/j.icarus.2016.09.007.

[8] N. Thomas, G. Portyankina, C. J. Hansen, and A. Pommerol. HiRISE observations of gas sublimation-driven activity in Mars's southern polar regions: IV. Fluid dynamics models of CO_2 jets. *Icarus*, 212:66–85, March 2011. doi: 10.1016/j.icarus.2010.12.016.

[9] M.J. Westoby, J. Brasington, N.F. Glasser, M.J. Hambrey, and J.M. Reynolds. 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*, 179:300 – 314, 2012. ISSN 0169-555X. doi: 10.1016/j.geomorph.2012.08.021.

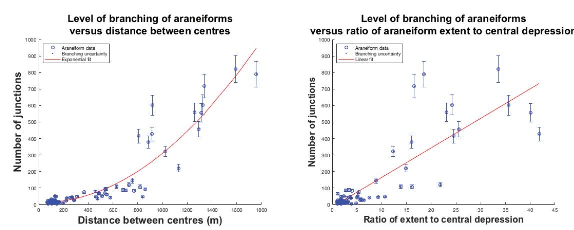

Fig. 3: Branching of Martian araneiforms with vent (a) spacing and (b) diameter.