EPSC Abstracts
Vol. 6, EPSC-DPS2011-826, 2011
EPSC-DPS Joint Meeting 2011
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Processes of formation of debris flows on the Russell dune under a periglacial environment (Mars)

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Abstract

The presence of gullies on sand dunes is rare on Earth, and their discoveries on Mars and the origin as well as mechanical properties of fluid necessary to the formation of gullies remains currently misunderstood. This study focuses on morphology of gullies over the Russell megadune (54.5°S; 12.7°E). The aim of this study is to better constrain the origin as well as the mechanical properties of the fluid involved into the debris flows. A new HiRISE DTM allowed to better characterize 3D geometry of these morphologies. It makes it possible to measure mass balance for one gully and estimate the eroded and deposited volume. It allows us also to estimate erosion and sedimentation rates along the channel. A series of cross-sections on a gully allowed us to estimate flow velocities, flow discharge and physical parameters such as viscosity, Reynolds number and yield strength (Fig. 1). Based on terrestrial methods ([1], [2], [3], [4]), this approach aims to understand the flow dynamic necessary for the formation of gullies on Martian dunes. Finally, we discuss a model of formation for the Russell's gullies under a periglacial environment.

Results

The results reveal that flow velocity and viscous flow discharge (Table 1) decrease from upstream to downstream because of the slope and the hydraulic radius decrease. At the same time, we observe a decrease of viscosity induced by the relative increase of fluid concentration during the flow advance (Table 1). Even if the fluid concentration increases over time, the absolute quantity of fluid is decreasing (Table 1). The mass balance realized along one gully showed that the erosion is bigger in the uppermost part of the dune at the higher slope [5]. The calculated erosion rates confirm this trend, we can observe a slightly decrease of the values during the flow progress (Table 2). The erosion rate decreases because of the flow velocity slowing down in relation with the slope decreases (we also can link the decrease of the erosion rate over time with the increase in fluid concentration, Table 1). Less solid material is incorporated from upstream to downstream and it generates a decrease of the viscosity during the flow advance (which can explain a fall in the available erosive energy of the flow, Table 1 and 2). The fact that the flow is supersaturated in solid material is highlighted by the fact that an increase in the liquid flow discharge will increase the erosion rate (Table 1 and 2). The sedimentation rate is relatively constant over time (Table 2) and it is not easy to establish quantitative relation between the sedimentation rate and the others physical parameters of the flow. The evaporation rate seems unstable over time and rapidly varies (Table 2) probably in relation with the complex fluid stability conditions on Mars.

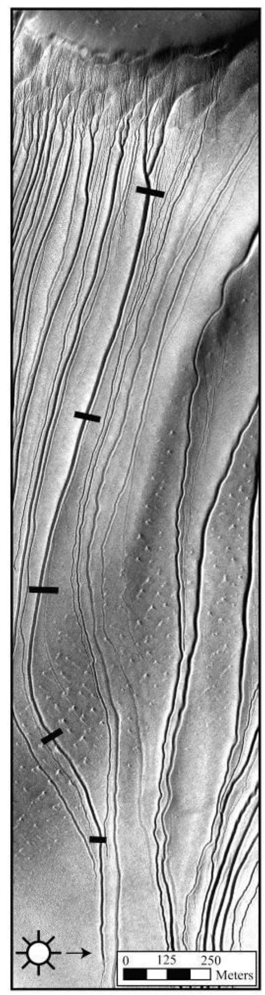

Figure 1: Position of the five cross sections studied along the gully. HiRISE image PSP_007229_1255 on the left. Image credits NASA/JPL/University of Arizona.

Table 1: Summary of the viscosities, velocities and discharge calculated along the studied gully.

Longitudinal distance (m)	Viscosity (Pa.s)	Reynolds number	Fluid concentration (%)	Velocity ($m.s^{-1}$)	Total discharge ($m^3.s^{-1}$)	Duration time (s)
340 ± 0.5	569 ± 56	604 ± 12	29 ± 0.5	12.4 ± 0.8	425 ± 71	27 ± 1
857 ± 0.5	504 ± 52	409 ± 1	30 ± 0.5	9.4 ± 0.7	420 ± 83	82 ± 5
1251 ± 0.5	322 ± 42	452 ± 1	34 ± 0.7	7.2 ± 0.8	183 ± 48	131 ± 11
1574 ± 0.5	319 ± 48	660 ± 29	34 ± 0.7	9.4 ± 0.8	153 ± 35	167 ± 34
1846 ± 0.5	97 ± 31	756 ± 92	42 ± 1.3	4.1 ± 0.7	29 ± 13	230 ± 45

Table 2: Summary of the calculated yield strength, sedimentation rate, erosion rate and evaporation rate.

Longitudinal distance (m)	Yield strength (Pa)	Sedimentation rate ($dm^3.s^{-1}$)	Erosion rate ($dm^3.s^{-1}$)	Evaporation rate ($mm.s^{-1}$)
340 ± 0.5	306 ± 281	18 ± 9	26 ± 8	1.1 ± 3.3
857 ± 0.5	1145 ± 247	12 ± 4	14 ± 4	4.0 ± 3.3
1251 ± 0.5	849 ± 241	19 ± 7	16 ± 6	12 ± 3.3
1574 ± 0.5	2044 ± 310	12 ± 7	15 ± 6	5.5 ± 3.3
1846 ± 0.5	637 ± 181	78 ± 31	86 ± 31	7.4 ± 3.3

Discussion

The daily mean temperatures on the surface of Mars are lower than 0°C. Even if spacecraft observations and models have shown that the surface temperature above 0°C are common during summer, only the first millimeters of the ground can be warned above the melting point of water. Using the estimated deposition and fluid concentration, we have estimated that a large amount of liquid water is necessary to generate the Russell debris flows (between 6.200 and 11.200 m^3). A previous study showed that during high obliquity of Mars, the surface temperature has been above 0°C over enough long periods making possible the melting of near surface ice [5]. We propose a possible scenario for the gullies formation on the Russell dune during high obliquity period: a) The sand/silt dune (grain size 18 µm < d < 1334 µm, [5]) composed of 30-40 % ice-rich permafrost is entirely frozen during winter (Fig. 2a); b) At early spring, surface temperatures begin to growth (warmer on the high slopes, [6]). Melting of near surface ice and formation of a ~1 m seasonal active layer occured ([7]; [8]). A fluid reservoir ~300-1500 m^3 take place on the top of the dune. Liquid water slowly migrates on the permafrost table to the scarp under the dune crest (Fig. 2b). The fluid pressure increases and a debris flow is initiated when the critical shear stress is reached near the shelf break [2]; c-1) The triggering of a debris flow and the formation of a scar below the dune crest happened (Fig. 2c); c-ii) Meltwater coming from the active layer is incorporated in the plug of the debris flow and water concentration increase during its progression (Fig. 2c). Liquid water contained in the active layer near the path of the debris is incorporated in the flow (Fig 2d); d) The flow stop because of evaporation of all the liquid water contained in the debris flow.

Acknowledgements

This work is supported by "Programme National de Planétologie", CNRS-INSU, France. We thank the HiRISE team and and the Orsay Planetary Picture Library (http://fototek.geol.u-psud.fr/) as well as the HRSC Team for the data provided.

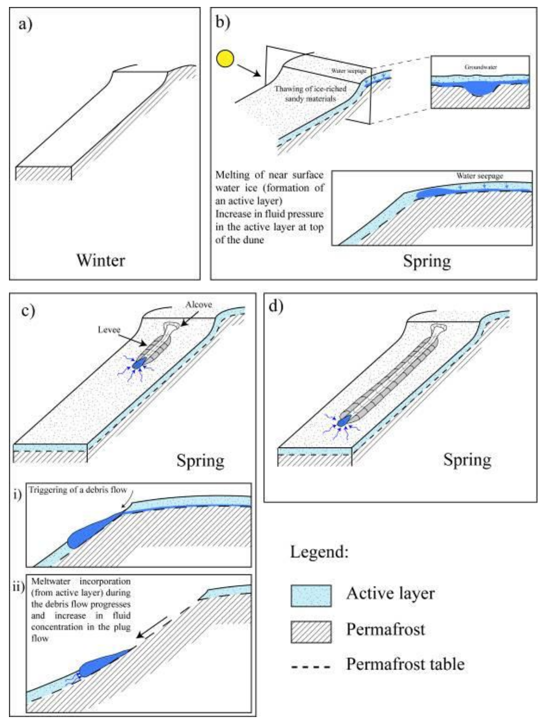

Figure 2: Scenario for the formation of debris flows during high obliquity period on the Russell dune.

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