EXPERIMENTAL INVESTIGATION OF SAND TRANSPORT MECHANISMS BY BOILING LIQUID WATER UNDER MARS-LIKE CONDITIONS AND POTENTIAL IMPLICATIONS FOR MARTIAN GULLIES AND RSL.

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Introduction: Active flow processes are currently ongoing at the surface of Mars, for example within gullies or RSL (Recurring Slope Lineae). The physical processes involved in their formation and current activity have not been unambiguously identified. One possible candidate is liquid water [1,2], but under current martian conditions liquid water is transient and can only be present in limited amounts [3,4,5]. However the surface temperature can locally exceed the melting point [6,7] on present-day Mars, leading to rapid boiling of liquid water. So far, little attention has been paid to the role of boiling in sediment transport processes. Recent study has highlighted that boiling water can drive unusual transport mechanisms leading to an enhanced transportation volume [8]. In our work [9,10] we conduct a series of experiments under low pressure to investigate the transport capacity of boiling liquid water under martian-like surface conditions. The experimental observations are then compared to physical laws in order to identify the important parameters driving the transport and scale our results to martian gravity to apply them to martian features.

Experimental set up and protocol: The experiments were performed under martian-like pressure (~9 mbar) in the Open University's Mars Chamber (Fig. 1). The test bed is a rectangular tray filled with a 5 cm thick layer of fine silica sand. It was set to an angle of 25° which is in the range of observed slope angles of martian gullies and RSL [7,11]. The water outlet was positioned at the top of the slope and controlled with a valve from outside. We choose to investigate the influence of two parameters on water boiling intensity and sand-transport: the sand (T_s) and water temperature (T_w). We performed experiments with 9 combinations of 3 different temperatures, 278 K, 288 K and 297 K for sand and water, respectively. These temperatures are consistent with temperatures measured at the surface of Mars [6,7]. Each combination has been performed as triplicates for a total of 27 experiments. The sand and the water were initially pre-cooled if necessary. The pressure was lowered by two vacuum pumps to the initial pressure of ~7 mbar. When the pressure and temperature reached the desired values, water was released for duration of ~60 s with a mean flow rate of 11 m s^{-1}. We maintained the low pressure inside the chamber for several minutes after the flow ceased to observe any further transport processes. We constantly monitored the sand temperature, water temperature, pressure, and humidity. The evolution of the test bed was recorded by two webcams inside and a camera outside the chamber. Before and after each experiment the test bed was photographed using multiple observation angles in order to produce digital elevation models and calculate the volumes of transported sand.

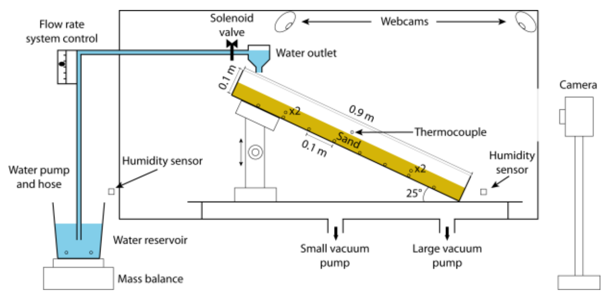

Figure 1: Diagram of the experimental set up [10].

Experimental results: For all performed experiments water was boiling. Even from observational data it is clear that the intensity of boiling was mainly driven by sand temperature while water temperature had only a minor influence. As sand temperature increases, the total volume of sand transported is increased by a factor of ~9 while for different water temperatures it is rather constant (Fig. 2) [10].

For all experimental configurations we observe transport of sand directly by overland flow and by the formation of pellets (sand-water mixture) as water interacts with sand [9,10]. At $T_s \geq 288$ K the boiling is more vigorous and we observe additional dry processes, including sand ejection and avalanches of dry sand. In addition the size of ejected pellets (millimeters to centimeters) increases significantly. The volume attributable to each mechanism changed as the sand temperature increased. At $T_s = 278$ K, the majority of the sand is transported by overland flow while at $T_s \geq 288$

K the majority is transported by mechanisms associated with boiling water, *i.e.* ejected pellets and dry processes. We observe that the gas ejected by the boiling water is strong enough to create an air cushion at the bottom of pellets leading to their downslope levitation rather than rolling as observed at T_s = 278 K. Additionally, the produced gas is also able to eject single sand particles and drive dry avalanches. These processes can persist several minutes after the end of liquid water flow. Water temperature plays a role in the duration of these dry processes which are longer at lower water temperature [10].

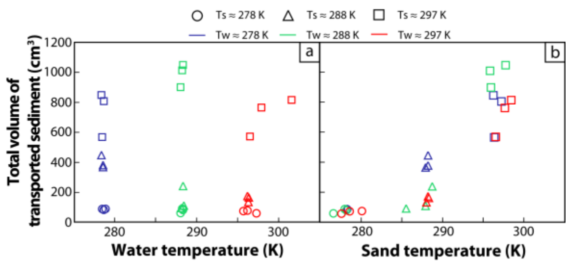

Figure 2: Transported sediment volume versus (**a**) water temperature and (**b**) sand temperature [10].

Transport mechanisms due to boiling and martian gravity scaling: Sand temperature is the main parameter controlling the boiling intensity because surface temperature drives the heat flux [12,13]. As liquid water is unstable it turns into gas and we observe single sand particle ejection and pellet levitation. In both cases the two forces in competition are the weight of the object W and the force exerted by gas production F_e (Fig. 3).

For sand ejection, we calculate conditions for which we obtain a velocity of the gas exceeding threshold transport velocity U_t to entrain particles. For our given experimental conditions U_t ~6 m s^{-1} meaning that at T_s = 278 K grain ejection is very unlikely while at $T_s \geq 288$ K the gas velocity far exceeds the threshold and grains are ejected as observed in our experiments. The lower martian gravity decreases the transport threshold velocity to U_t ~2.5 m s^{-1}. But according to atmospheric characteristics of Mars, the gas speed remains lower than this value for T_s = 278 K and still exceed the threshold velocity for $T_s \geq 288$ K. However, if ejection does occur on Mars, the ejection velocity of the sand grains should be similar to that obtained in our experiments and the ballistic trajectory would be enhanced by a factor of 2.6 compared to Earth [10].

Pellet levitation is made possible by the rapid gas production at the base of the pellet via boiling. Computational results (Fig. 3) show that the increase of sand temperature leads to an increase in the duration of levitation of about several seconds and also a larger size range can potentially be lifted. In addition we found that the levitation process under weaker martian gravity is enhanced by a factor of ~7 and is able to transport larger objects for a longer time. This process should be efficient even at temperatures close to the saturation point [10].

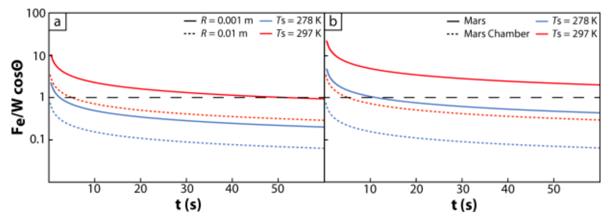

Figure 3: Evolution of the ratio Fe/W cosθ during time for different **(a)** sand temperatures and radius R of pellets, and **(b)** sand temperatures and gravity values (Mars and Earth). The slope angle is set to θ = 25°. Levitation occur when the ratio exceed 1 (dashed black line) [9].

Conclusion: Our experiments and scaling calculations reveal that if liquid water is present at the surface of Mars, boiling could play an important role in understanding the recent changes in martian gullies or RSL for which water is a candidate fluid [9,10]. We find that sediment transport by boiling is characterised by grain ejection, granular avalanches and levitating pellets, which according to our scaling calculations are more effective transport processes under martian gravity [9,10]. Among the two parameters tested, the sand temperature is the main driving parameter for transport via boiling while water temperature plays a minor role [10]. We highlight that boiling is an important agent of sediment transport, which should not be neglected when analysing and modelling water flow features on Mars.

References: [1] Malin and Edgett (2000) *Science*, *288*, 2330-2335. [2] Conway S. J. and Balme M. R. (2016) *EPSL*, *454*, 36-45. [3] Hecht M. H. (2002) *Icarus*, *156*, 373-386. [4] Diniega S. et al. (2010) *Geology*, *38*, 1047-1050. [5] Dundas C. M. et al. (2012) *GRL*, *37*, L07202. [6] Haberle R. M. et al. (2001) *JGR-Planets*, *106*, 23317-23326. [7] McEwen A. S. et al. (2011) *Science*, *333*, 740-743. [8] Massé M. et al. (2018) *Nature Geoscience*, *9*, 425-428. [9] Raack J. et al. (2017) *Nature Communication*, *8*, 1151. [10] Herny C. et al. (2018) *GSL*, accepted. [11] Raack J. et al. (2015) *Icarus*, *251*, 226-243. [12] Cengel Y. A. and Ghajar A. J. (2014). [13] Diniega S. et al. (2013) *Icarus*, *225*, 526-537.