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Experimental study of sediment transport processes by liquid water and brine under Martian pressure

Meven Philippe[1], **Susan J. Conway**[1], Jan Raack[2], Sabrina Carpy[1], Marion Massé[1], Manish R. Patel[3], Matthew Sylvest[3]
[1]Laboratoire de Planétologie et Géodynamique UMR6112, CNRS, Université de Nantes, France
[2]Institut für Planetologie, Westfälische Wilhelms-Universität, Münster, Germany
[3]School of Physical Sciences, Open University, United Kingdom
Contact: meven.philippe@gmail.com

1. Introduction

Martian slopes host several downslope movement morphologies, including Recurring Slope Lineae (dark linear flows – [1]) and gullies (mass-wasting sediment movements composed of an alcove, a channel and a depositional fan – [2], Figure 1). Both of these morphologies have been observed to be active today [1, 3] (Figure 1). Many hypotheses have been put forward for the process(es) that could trigger both their activity and formation. Gullies have been proposed to be formed by debris flows, slush flows, CO_2-gas-based flows and dry granular flows, amongst others [4]. RSL have been hypothesized to be formed by flowing water/brine [5], dry flows [6], or other more exotic mechanisms.

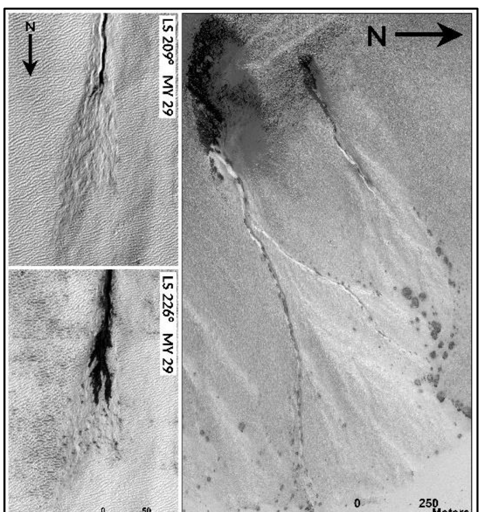

Figure 1: *Left: seasonal change in a gully channel and fan during the Martian year 29. Dark deposits cover a large part of the depositional fan. From HiRISE images ESP_011963_1115 (top) and ESP_012319_1115 (bottom). Right: two gullies systems, each one showing an alcove, a channel and a depositional fan. From HiRISE image PSP_003287_1115.*

A few experiments have already been performed to study how liquid water transports sediments under Martian conditions [7, 8, 9]. They found transport processes related to boiling with no terrestrial equivalent, such as grain ejection or pellet "levitation" on water vapour cushion. Our experiments expand on this work by comparing boiling water and brine flows in both qualitative and quantitative ways. We performed over 30 experiments in the Mars Simulation Chamber (MSC) of the Open University (UK), using water and 19wt% $MgSO_4$ brine and five sand temperatures (0, 5, 15, 17.5 and 20°C). We chose an $MgSO_4$ brine because this salt is found on Mars [10] and easy to work with.

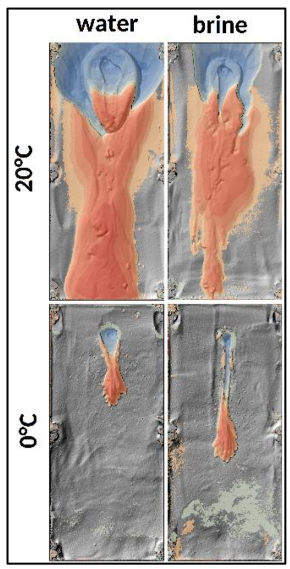

Figure 2: *Four examples of experiments performed with water and brine at 0°C and 20°C. The difference in height is superposed on the hillshaded DTMs. Erosion is in blue and deposition in red. No colour represents zones were the difference in height is very low (+/- 0.5mm).*

2. Method

We used a tray filled with 5 cm of fine sand inclined at 25° in the MSC at pressures around 7-9 millibars. An outlet poured 1min-liquid flows (water or brine) from 5cm above the sand at the top of the tray. Temperature was recorded under, within and on the sand. We also used a pressure sensor, two air humidity/temperature sensors and two webcams. An amount of ~575g of water was used for each run and introduced at the top over 1 minute. Photographs were taken before and after each experiment in order to produce 1 mm/pix DTMs with the Structure from Motion technique [8, 9] (Agisoft Photoscan software). These DTMs were used to compute the amount of sediment moved and locate the erosion and deposition zones (Figure 2).

3. Results

Consistent with the experiments of [7, 8, 9] we observed boiling for the experiments with sand temperatures of 15, 17.5 and 20°C. Boiling caused grain ejection, forming a depression at the top of the slope and grain avalanches along the tray. We also observed: pellet levitation, channel formation and percolation. The grain avalanches dominate the sediment transport at these temperatures. We observed more sediment transport by boiling for water than for brine, and boiling lasted longer after the flow stopped.

At sediment temperatures of <5°C, transport occurs via channel erosion and deposition (Figure 2) with some mm-sized pellets produced. The volumes of eroded sediment at ~5°C are slightly larger with the brine than with water, but taking the error into account the difference is not significant (Figure 3). Around 0°C the water starts freezing, unlike the brine which remains stable. Additionally the previous trend is reversed and water transports more sediment than brine (Figure 3). We also observed morphological differences between water and brine flows (Figure 2): with cold sediment (0 & 5°C), brine channels are longer and thinner than the water channels.

4. Discussion

Extrapolated to Mars, transport of sediment by boiling liquid would be a very efficient way to produce downslope mass movements such as gullies. Our data show that a given water release can move twice its weight of sand at ~15°C and around 3.5 times its weight at ~20°C. Brine is slightly less efficient: at 15°C, the ratio is slightly under 2 and goes up to ~2.3 for hotter slopes (20°C). The reduced gravity on Mars would make these processes even more efficient [8]. In contrast, in case of a cold sediment the difference between water and brine in terms of transported volumes is much smaller. Our results suggest that studying the volume of sediment moved by a process will not be an effective way to distinguish between water and brine flows on cold Martian slopes. It still should be noted that at these temperatures morphologies formed by water and brine flows are very different (Figure 2).

5. Conclusions

- On "warm" substrates, brine flows are more stable, boil less and so transport less sediment than pure water (Figure 3).
- On "cold" substrates, the difference between brine and water is less marked, and counter-intuitively near 0°C brine transports less sediment than water (Figure 3).
- On "warm" substrates the morphological differences between water and brine flows are not obvious, but on "cold" ones they are clearly marked: brine form very long and thin channels when water form short and wide ones.

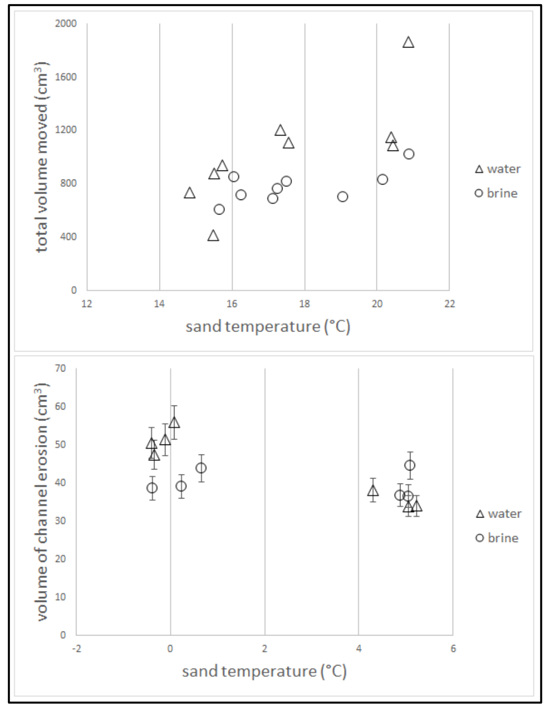

Figure 3: *Total volume moved in the experiments at 15, 17.5 and 20°C (top) and volume of channel erosion in the experiments at 0 and 5°C (bottom) against average sand temperature during the experiments. Errors on the total volume moved are very small and fall within the symbols.*

Acknowledgments

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