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Violent Mud Propagation on Mars: Evidence From Laboratory Simulations

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Abstract

Here we present the results of experiments performed inside a low pressure chamber to investigate how mud would propagate over a 'warm' (~295 K) unconsolidated sandy surface under Martian atmospheric pressure conditions (~7 mbar). The results show that, flowing mud is capable of eroding down into the substrate. The gas released by boiling allows the mud to propagate into the subsurface and to form a subsurface flow which acts as a platform for further mud propagation over the surface. Escaping gasses can cause pockets of mud to levitate for a limited period of time (similar to [1,2]) and hence cause faster and further propagation than would be possible on Earth.

1. Introduction

Even though most of the Martian surface is cold today, locally warm surface temperatures can be achieved. Therefore sedimentary volcanism, if present on Mars [4-7], could represent a source of erupted mud in such warm regions. The extrusion of mud on cold Martian surfaces (i.e. sedimentary volcanism [3-6]) induces rapid freezing and the formation of a protective frozen crust on top of the mud flow, leading to a behavior similar to pahoehoe lava on Earth (see the EPSC abstract #122 for details). On the other hand, warm (i.e. non-freezing) surface temperatures (which can locally occur [7]) preclude freezing and in such conditions the mud propagation should be different. As the physical instability of water under current Martian atmospheric pressure leads to boiling [e.g., 1,2,8,9], this suggests that the propagation of a muddy mixture would also be different from our terrestrial experience.

2. Experimental setup

We used the Mars Simulation Chamber at the Open University (UK) into which we inserted a 0.9 × 0.4 m aluminum tray filled with a ~2 cm deep sediment (natural sand, ~200 µm) bed together with a reservoir containing 500 ml of low viscosity mud hanging ~5 cm above the tray. Mud and sand were at room temperature (~20°C). The tray was inclined by 5° or 10° to force the mud to move under gravity once poured on the surface. The mud was released from the container under reduced (~7 mbar) pressure and the movement of the mixture was observed and recorded by four cameras from different angles. Each experimental run was performed in triplicate to confirm the reproducibility of the results; comparative experiments under terrestrial pressure were also performed.

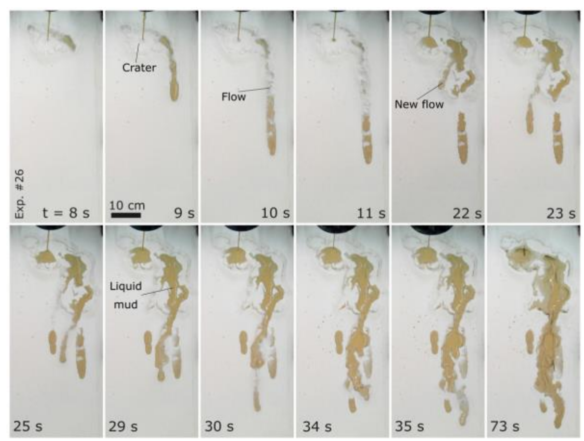

Figure 1: A sequence of images capturing the propagation of mud under an atmospheric pressure of 7 mbar and over a non-freezing 10° inclined surface. See the text for details.

3. Observations

Once the atmospheric pressure is reduced, the mud in the container starts to boil. The boiling intensifies as the pressure gets closer to the 12-14 mbar and continues all the way down to 7 mbar. When a pressure of 7 mbar is reached, the mud is manually released by tipping the container, letting it flow over the 'hot' (20°C) sandy surface. The contact of the mud with the 'hot' surface triggers explosive activity, which causes ejection of sandy grains to a height of several centimetres. The particles land both on the mud and on the surrounding sand. The deposition of the sand grains forms a small raised rim around the contact area resulting in a crater-like depression (Fig. 1). The explosive activity decreases with time. At the beginning the mud is not visible inside the crater area as it gets covered by a layer of loose sand which is repeatedly disturbed by bubbling (Fig. 1, 8 s). Within seconds, mud can be observed on the surface – not necessarily at the site where it was directly poured from the container – propagating inside the crater (Fig. 1). At the boundary between the mud and the sand layer, a large amount of millimetre-scale explosion pits formed, from which gas continued to eject particles for several minutes. This enabled a progressive expansion of the rim.

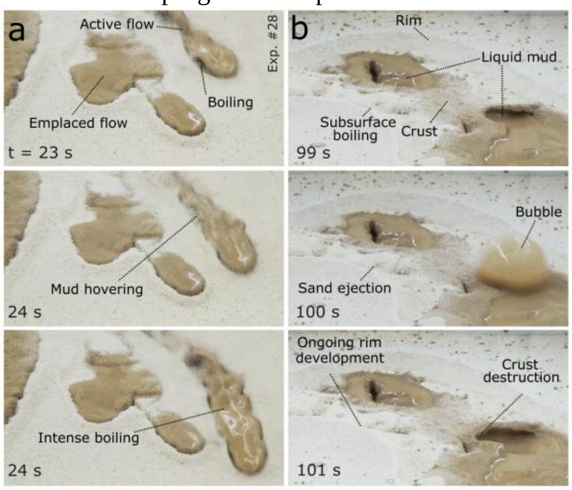

Figure 2: A sequence of images showing the levitation of the mud caused by boiling (a) and the sandy crust and repetitive explosions associated with small mud pockets (b).

Continued mud supply causes the flow to breach the sandy rim and a new lobe of mud advances over the warm sand (Fig. 1, 22 s). This flow front triggers new explosions as the mud propagates. The escape of gas at the bottom of the mud flow causes the lobe to vibrate vertically and to quickly propagate over the first few centimetres (Fig. 2a). Then the lobe stalls and small millimetre-scale explosions occur around its edge causing the formation of small ridges. Simultaneously fresh mud outpouring from the crater starts to propagate over the lobe's surface and accumulate at the front of the flow. Once enough material has accumulated to overcome the small ridges at the edges a new lobe forms and the process repeats until the supply of new mud is exhausted. The movement of mud through the lobes creates a trough with a curvy and irregular shape. This internal structure is supported by a hardened mixture of mud and sand. We also observed that the bottom of the trough is covered by fine-grained clay. Here, holes formed as the result of repetitive explosions caused by escaping gases were located above small subsurface pockets infilled by mud (see Fig. 2b). After several tens of minutes the chamber was decompressed and we inspected the interior of the mud flows by breaking them apart. Liquid mud was still present in the subsurface covered by sand. This implies that the sand partly acts as a protective layer insulating the mud from the surrounding desiccating environment.

4. Conclusions

Our experiments show that a warm and unconsolidated surface has a profound effect on the behaviour of flowing mud in a low pressure environment, because of boiling. This causes levitation of the mud over the surface for a short period of time as well as the erosion of the unconsolidated sandy substrate. Both mechanisms alter the mud propagation in a low pressure environment. Moreover, as Mars has a lower gravitational acceleration than Earth, we expect that these processes would be even more effective on Mars, because gravity does not change boiling rate, but the sediments can be more easily entrained [1,2]. The gas released should levitate mud for a more extended period of time, as also similarly suggested for wet sand [1,2], hence allowing the mud to propagate over larger distances than on Earth. Our work shows that the behaviour of mud and its propagation in a low pressure environment is strongly dependent on the surface temperature as freezing [see the EPSC abstract #122 for details] or rapid boiling would significantly change the final morphologies of resulting surface flow features

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References: [1] Raack et al. (2017), Nature Communications 8. [2] Herny et al. (2018) GSL Spec. Publ. 467 [3] Oehler and Etiope (2017), Astrobiology 17 [4] Skinner and Tanaka (2007), Icarus 187 [5] Okubo (2016), Icarus 269 [6] Komatsu et al. (2016), Icarus 268 [7] Hecht (2002), Icarus 156 [8] Conway et al. (2011), Icarus 211 [9] Massé et al. (2016) Nature Geoscience 9.