EXPERIMENTAL SIMULATION REVEALS THAT MUD BEHAVES LIKE LAVA UNDER MARTIAN CONDITIONS.

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Abstract: Here we present results of mud experiments performed inside a low pressure chamber to investigate the mechanisms of sedimentary volcanism on the cold martian surface. Our results show that mud propagates under the martian environmental properties with a different behavior than on the Earth surface. Results show that Mars low atmospheric pressure and temperatures cause rapid freezing of the mud flow's surface. This newly formed "protective crust" effects the propagation of the mud flow resulting in a behavior in some aspects similar to the pahoehoe lava flows on Earth. These findings open new scenarios for the interpretation of the flow-related morphologies on Mars.

Introduction: Ever since the presence of methane in the martian atmosphere was first reported [1,2], mud volcanism has been hypothesized to be the possible release mechanism [3]. Therefore the surface expressions of this phenomenon were sought in remote sensing data. Hypothesized martian mud volcano fields (or in broader terms, any kind of subsurface sediment mobilization) have been identified at various sites based on morphologic and morphometric similarities with terrestrial analogues [4-6]. However, a mud-volcano origin interpretation is not straightforward in several of these localities as similar-looking landforms could be related to igneous volcanism activity [7,8]. To make progress in the debate as to whether the martian cones and associated flows are formed by igneous or mud volcanism, it is necessary to understand the process(es) controlling these phenomena and to understand if they are analogous or not to those observed on Earth. While the physics behind igneous volcanism on Mars is relatively well studied and understood [e.g., 9,10], this is not the case for sedimentary volcanism. There is a lack of basic knowledge about the behavior of a mixture of clay-sized particles and water at low atmospheric pressure, temperature and gravity, both from the theoretical and empirical point of view. This represents an obstacle both to attempt numerical models of martian sedimentary volcanism [e.g. 11], and more broadly, to answer the question of whether sedimentary volcanism can operate on the surface of Mars at all. To overcome this gap we performed analogue experiments in a low pressure chamber.

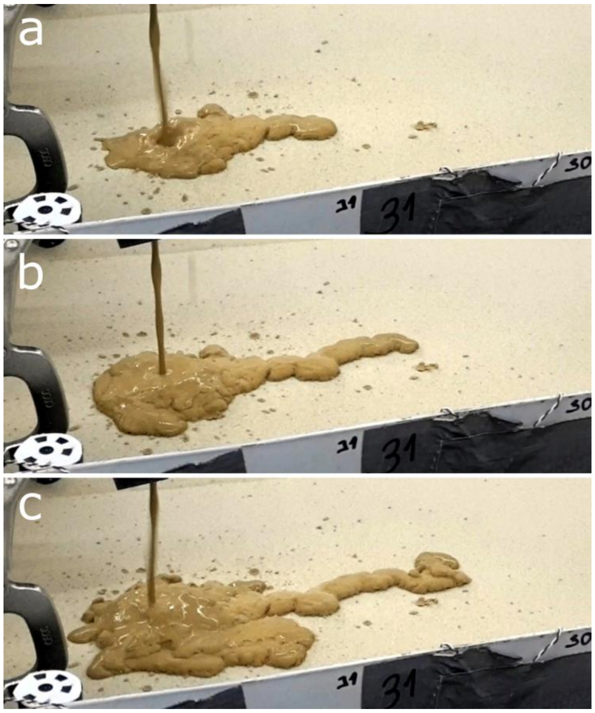

Figure 1: A sequence of images capturing the propagation of mud under an atmospheric pressure of 7 mbar and over a cold surface. See the text for details.

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 ~200µm) bed cooled to a temperature of ~-20°C together with the reservoir containing 500 ml of low viscosity mud at room temperature hanging ~5 cm above the tray. The tray was inclined by 5° to force the mud to move once emplaced on the surface. The mud was then released from the container under the reduced (~7 mbar) pressure and the movement of the mixture was observed and recorded by three cameras from different angles. Each experimental run was performed in triplicate to confirm the reproducibility of the results. Moreover, comparative experiments under terrestrial pressure were also performed. The temperature of the mud during propagation was monitored by a grid of thermocouples (n=5) distributed inside the tray.

Observations: Once the atmospheric pressure is reduced, the mud starts to boil. The boiling intensifies as the pressure gets closer to the 12-14 mbar and continued all the way down to 7 mbar. The boiling causes the temperature of the mud to drop, so the mixture self-cooled to close to the freezing point regardless of the initial temperature. When a pressure of 7 mbar was reached, the mud was manually released by tipping the container, letting it could flow over the cold sandy surface. The contact of the mud with the cold surface caused rapid freezing at the bottom of the flow, but also on the edges of the flow (Fig. 1a). The freezing caused the formation of an icy-muddy crust which subsequently changed the way the mud propagated.

A narrow flow developed in contrast to the broad flows observed in experiments performed under normal pressure. This morphology occurs due to the formation of frozen bounding ridges that control the flow of the liquid mud inside a central channel. With time even the top of the mud flow started to solidify and a continuous crust formed all around the flow. However, the flow was still able to propagate (Fig. 1b). This implies the formation of a 'mud tube' (analogous to a lava tube) in which the mud was able to move to the front of the flow.

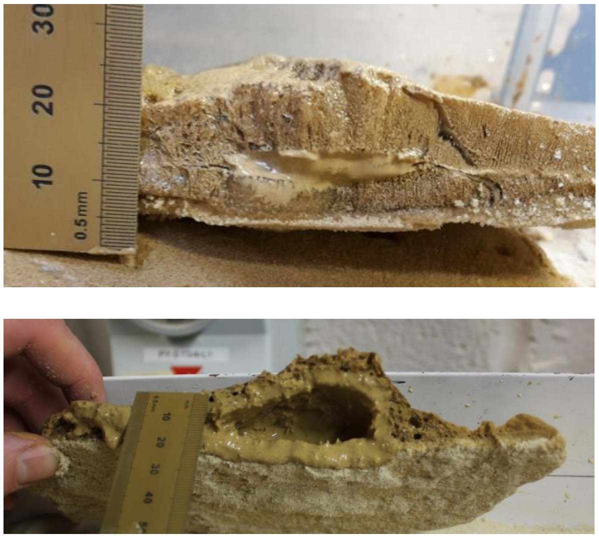

Figure 2: Details of the exposed inner structure of the two different frozen mud flows in which the liquid core was still present. Note the bubbles trapped in ice near the ruler.

The continuing flow of the liquid mud towards the front part of the flow increased the stress acting on the icy-muddy crust. This had two effects. Firstly, the mud was able to crack the crust and burst out to form new lobes (Fig 1c). The newly extruded material froze again and the process repeated itself until the liquid mud was not able to produce sufficient stress to breach the crust. The end of this process was most likely related to the lack of incoming fresh mud. Secondly, the incoming liquid mud increased the thickness of the mud flow by lifting the crust of the previous mud flow. The mud flow was hence inflating in a similar manner as pahoehoe lava flows. Once the source of mud was depleted, the propagation of the mud flow stopped. After several tens of minutes the chamber was returned to terrestrial pressure and we inspected the interior of the frozen mud flows by breaking them apart. Observations revealed that the flows had of an inner core of liquid mud (Figure 2) and the enveloping icy-muddy crust contained a large quantity of variously sized bubbles.

Conclusions: Experiments reveal that a low pressure environment changes the behavior of mud and hence the shapes of the resulting mud flows. The experiments showed us that if the mud is extruded in a low pressure environment on a cold surface, then the mixture rapidly freezes at the edges of the flow. As a result an icy-muddy crust is formed. This crust acts as a protective layer isolating the inner part of the mud flow from the "hostile" cold and low pressure ambient environment. This means that the mud can remain liquid in the core and flow for a prolonged period of time (depending on the thickness) and hence can propagate over larger distances. The behavior of the mud mixture in such environments appears to be similar to the propagation of low viscosity pahoehoe lava which is also protected by a cooled external crust surface insulating the lava flow from the surrounding environment. This has profound implications for the interpretation of many martian surface features whose origin by mud or lava is debated (e.g. 11). Our results suggest that the observed mud propagation behavior should also affect the final morphologies at larger-scale and therefore, that martian mud volcanoes may actually differ from their terrestrial counterparts. Therefore care must be taken when surface features are compared that formed under different PT conditions.

References: [1] Formisano et al. (2004), *Science 306* [2] Mumma et al. (2004), *BAAS 36* [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] Brož and Hauber (2013), *JGR-Planets 118* [8] Brož et al. (2017), *EPSL 473* [9] Wilson and Head (1994), *Reviews of Geophysics 32* [10] Brož et al. (2015), *JGR-Planets 120* [11] Wilson and Mouginis-Mark (2014), *Icarus 233.*

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