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Experimental Simulation Reveals That Mud Behaves Like Lava Under Martian Conditions

Petr Brož[1], Ondřej Krýza[1], **Ernst Hauber**[2], S.J. Conway[3], J. Raack[4], M.R. Patel[5,6], M.R. Balme[5], A. Mazzini[7], and M.E. Sylvest[5] (1) Institute of Geophysics of the Czech Academy of Science, Prague, Czech Republic, petr.broz@ig.cas.cz (2) Institute of Planetary Research, DLR, Berlin, Germany (3) CNRS UMR-6112 LPG Nantes, France (4) Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Germany (5) School of Physical Science, STEM, The Open University, Milton Keynes, UK Open University, Milton Keynes, United Kingdom (6) Space Science and Technology Department, STFC Rutherford Apple-ton Laboratory, Oxford, UK (7) Centre for Earth Evolution and Dynamics (CEED), University of Oslo, Norway.

Abstract

Here, we present experimental results performed inside a low pressure chamber at cold temperatures to investigate the mechanisms of mud propagation on Mars. Our results show that low viscosity mud under such conditions propagates differently than on Earth, because of rapid freezing and the formation of an icy-crust. The protective crust means the mud flow propagates in a similar manner to pahoehoe lava flows. Our findings open new ways of interpreting flow-like morphologies on Mars previously attributed to igneous volcanism, but also to better understand the physics behind cryovolcanic extrusions across the icy bodies within the Solar System.

1. Introduction

Ever since the presence of methane in the Martian atmosphere was first reported [1,2], mud volcanism has been hypothesized to be a possible source [3] and its surface expression has been sought in remote sensing data. Possible Martian mud volcano fields (or any sign of subsurface sediment mobilization) have been identified based on similarities to terrestrial analogues [4-6]. However, their identification on Mars is not straightforward because similar-looking landforms can result from igneous volcanism [7,8] and the behavior of extruded mud (and resultant morphologies) under Martian conditions is poorly constrained. 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.

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 cooled to a temperature of ~-20°C together with a container 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.

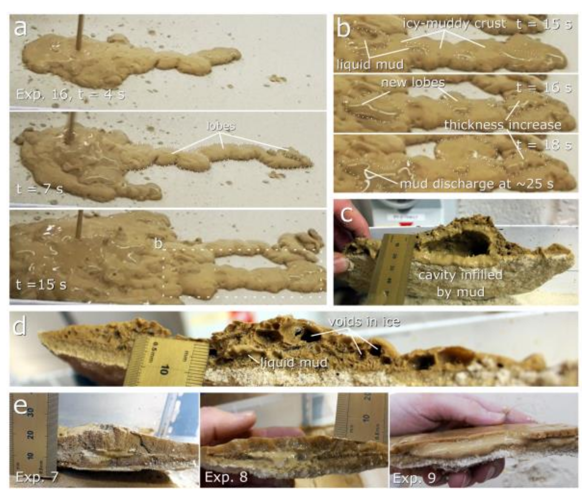

Figure 1: Example of the development of a mud flow in a low pressure environment (panels a, b) and details of their interior structure, sampled once the chamber was de-pressurized (c, d, e). Note the presence of liquid mud within the structure.

3. 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 substrate 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.

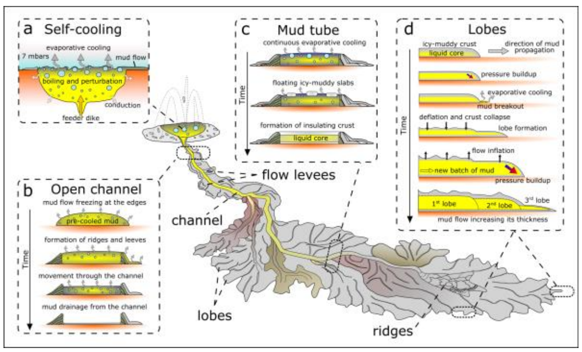

Figure 2: Schematic showing the hypothesized development of a low viscosity mud flow at the surface of Mars.

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 resembling levees in flows with a yield strength 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. 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. 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 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 (Fig. 1c,e) and the enveloping icy-muddy crust contained a large quantity of variously sized bubbles (Fig. 1d).

4. Conclusions

The experiments show that if mud is extruded in a low pressure environment on a cold surface, the mixture will rapidly freeze 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 behaviour 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 behaviour should also affect the final morphologies at larger-scale (Fig. 2) 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 P/T conditions.

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