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Volumetric Changes of Mud on Mars: Evidence from Laboratory Simulations

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Abstract

We present results of experiments performed inside a low-pressure chamber designed to investigate whether the volume of mud changes when exposed to a Martian atmospheric pressure. Depending on the mud viscosity, we observe a volumetric increase of up to 30% at the pressure of ☐6 mbar. The reason is that the low pressure causes instability of the water within the mud, leading to profuse bubble formation that increases the volume of the mixture. This mechanism bears resemblance to the volumetric changes associated with the degassing of terrestrial lava or mud volcano eruptions caused by a rapid ascend along the conduit and associated pressure drop.

Introduction

Subtle mounds have been discovered in the source areas of Martian kilometer-sized flows and on top of summit areas of some domes (Fig. 1; [1-2]). These features have been suggested to be related to subsurface sediment mobilization, opening questions regarding their formation mechanisms. Previous studies hypothesized that they mark the position of feeder vents through which mud was brought to the surface [1-2]. Two theories have been proposed: (a) ascent of more viscous mud during the late stage of eruption and (b) expansion of mud within the conduit due to the instability of water under Martian conditions.

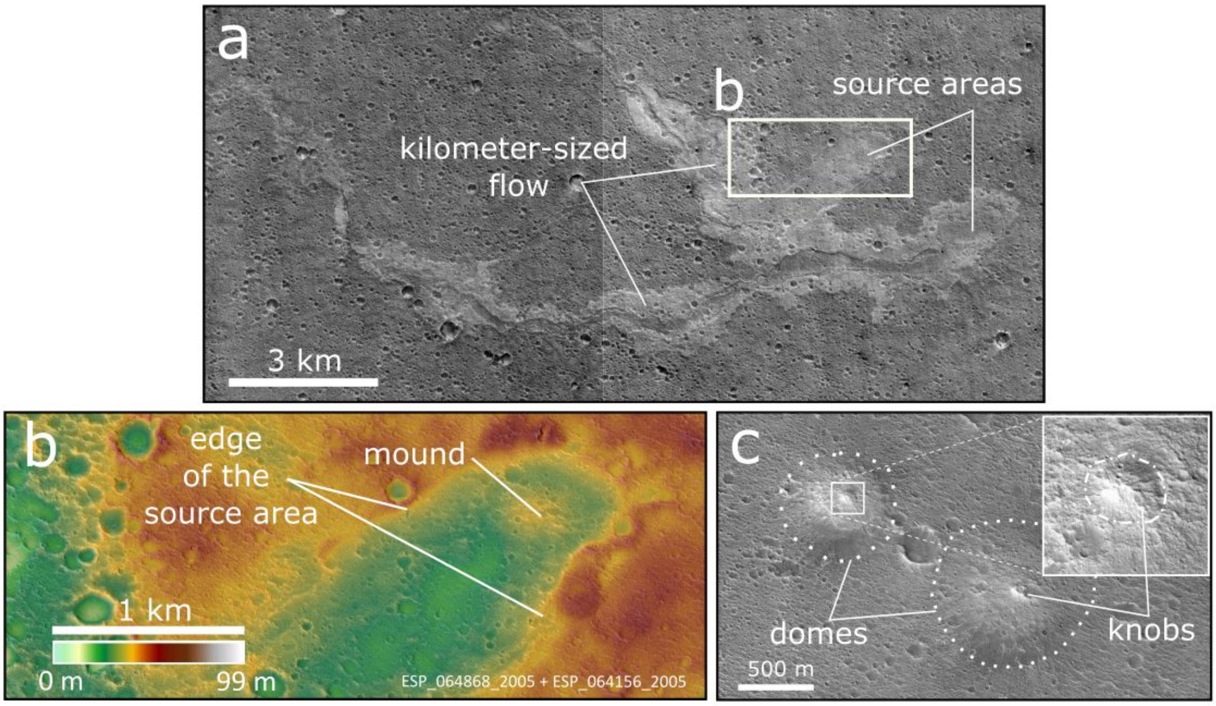

Fig. 1. Examples of Martian mounds and knobs.

Mud volcanoes on Earth release mud with a wide range of viscosities [3]; likewise similar variations are also expected in the mud extruded on other planetary surfaces. So far, experimental studies have been conducted only for low viscosity mud under low pressure conditions [4-5], and the behavior of more viscous muds under such conditions remains unclear. To overcome this knowledge gap, we completed analog experiments, to investigate the behavior of various viscous muds under martian pressure conditions.

Methods

We performed a set of experiments using the Mars Simulation Chamber at the Open University (UK), in which we inserted a two-part test bed that contained a reservoir which was able to accommodate 600 ml of mud and a □10 cm thick layer of frozen icy-sandy infill as the surrounding (Fig. 2). The temperature of this infill was around -20°C before experiment started. No active cooling of the icy-sandy infill was used, hence the infill slowly warmed up. All experiments were completed before the temperature of the icy-sandy infill reached the melting point of the water ice. The temperature of the mud when poured into the container was either 0.5-3°C (further refer as "cold") or 13-22°C ("warm").

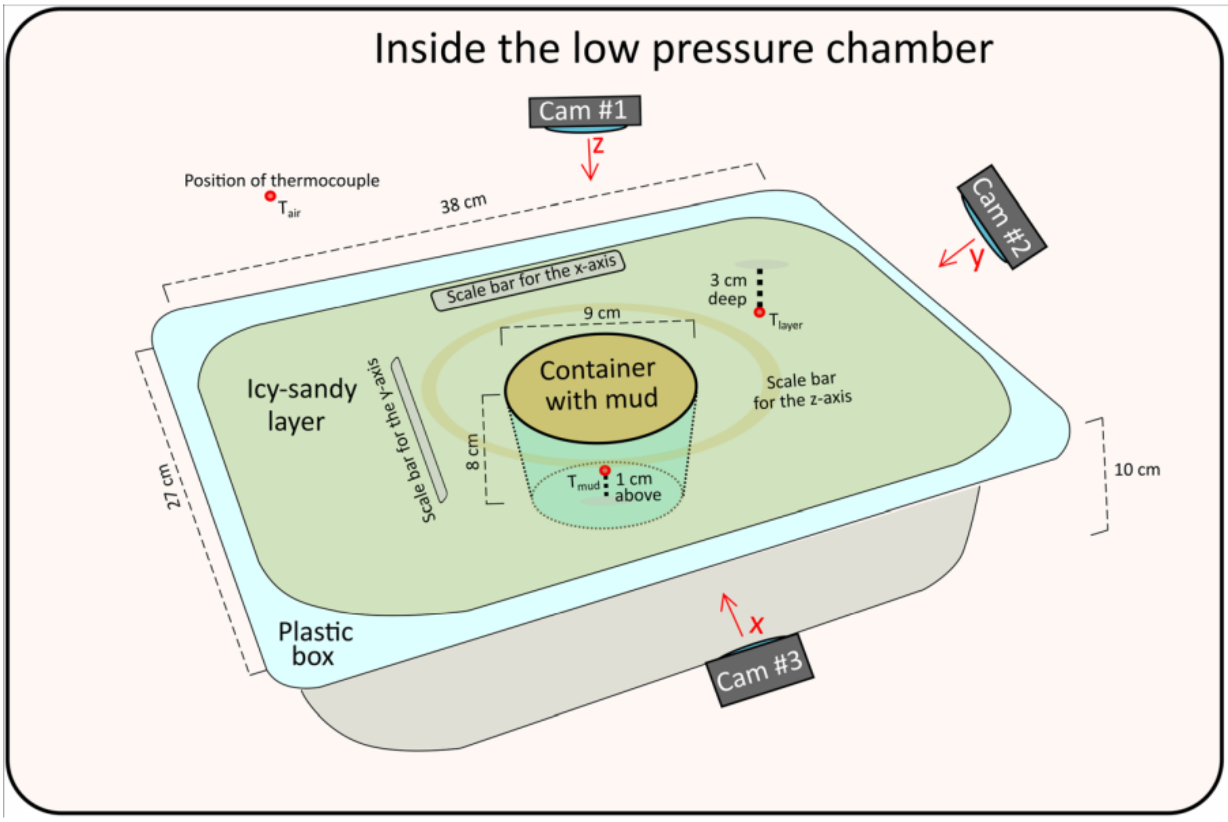

Figure 2. Schematic illustration showing the experimental setup inside the Mars Simulation Chamber.

Three different viscosities were used (Fig. 3) and they are further refer as "low", "medium" and "high." The mud mixtures were prepared by mixing deionized water with 1% w/w of dissolved magnesium sulfate salts (MgSO4) and clay content varying depending on the required viscosity. Magnesium sulfate salt was added to the water to achieve Earth's average river salinity, which enables the suspension of submillimeter clay particles within low viscosity mixtures. During the experiment, the pressure was gradually reduced from 1 bar to 5-7 mbar to achieve the martian surficial pressure. Two different speeds of pressure drops were utilized, namely the pressure was reduced within a timeframe of minutes (rapid) or more than an hour (slow).

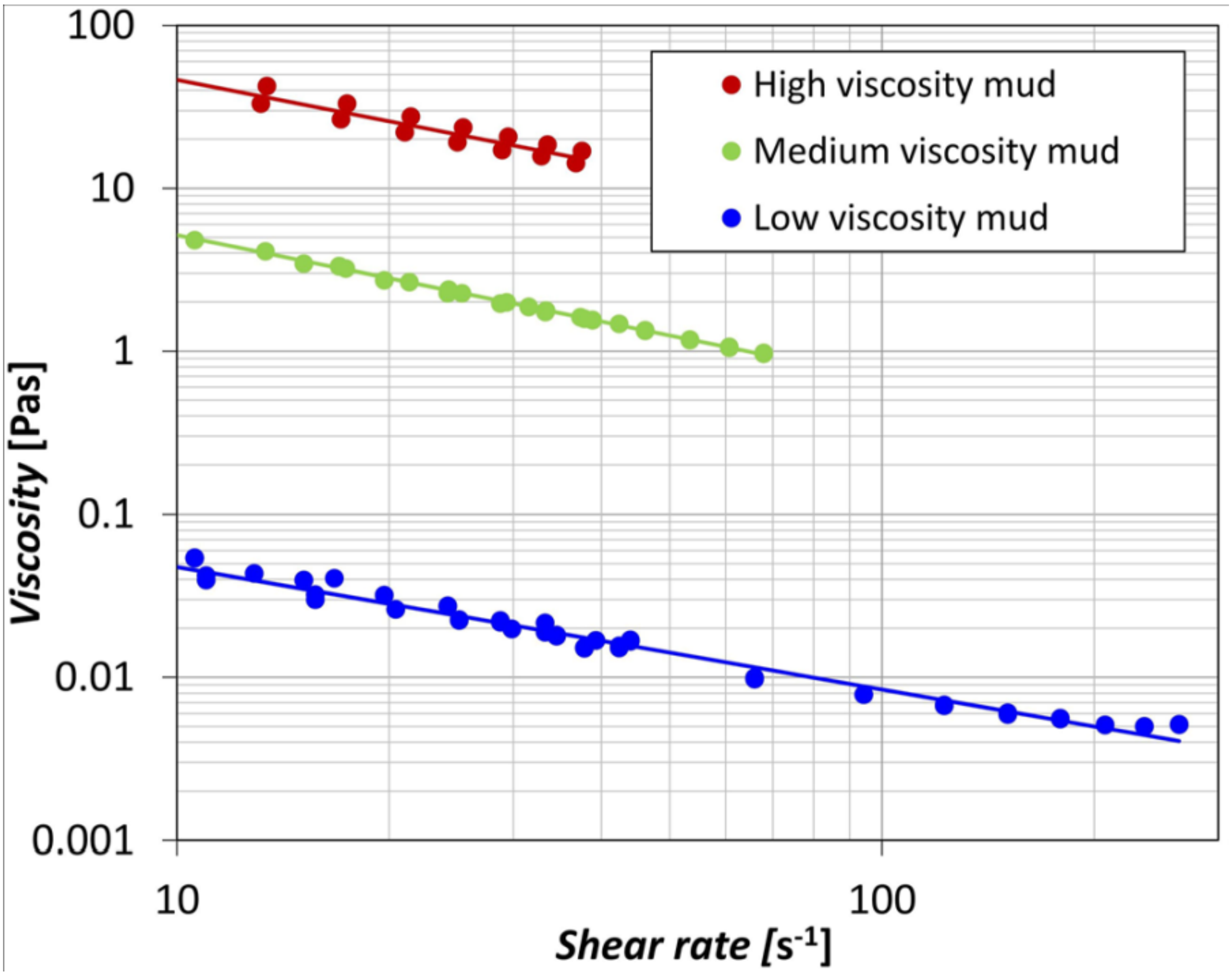

Figure 3. Viscosity curves of "low", "medium" and "high" viscosity aqueous bentonite.

In order to quantify volumetric changes of the mud samples, we used semi-manual and automatized image analyses using the PIV (Particle Image Velocimetry; [6]) and photogrammetry methods.

Results and discussion

Results revealed a significant volume increase during the experiments with slow depressurization, high mud viscosity and low initial mud temperature (Fig. 4). The volumetric change occurs due to the formation of water vapor bubbles, which are temporarily trapped within the mud. This phenomenon occurs since the bubble buoyancy is insufficient to overcome the drag force within the viscous material. Hence, these bubbles remain trapped in the mud allowing their gradual growth up to centimeter-scale sizes. During their volume increase, they push the mud out from the container resulting in horizontal and vertical propagation of the mud over cm-scales. In those experiments where the mud bulge freezes due to the evaporative cooling, the internal structure is kept in (or beneath) the icy crust. Our experimental approach reveals that mud with identical characteristics features different morphologies depending if its extrusion occurs on Earth or Mars pressure conditions.

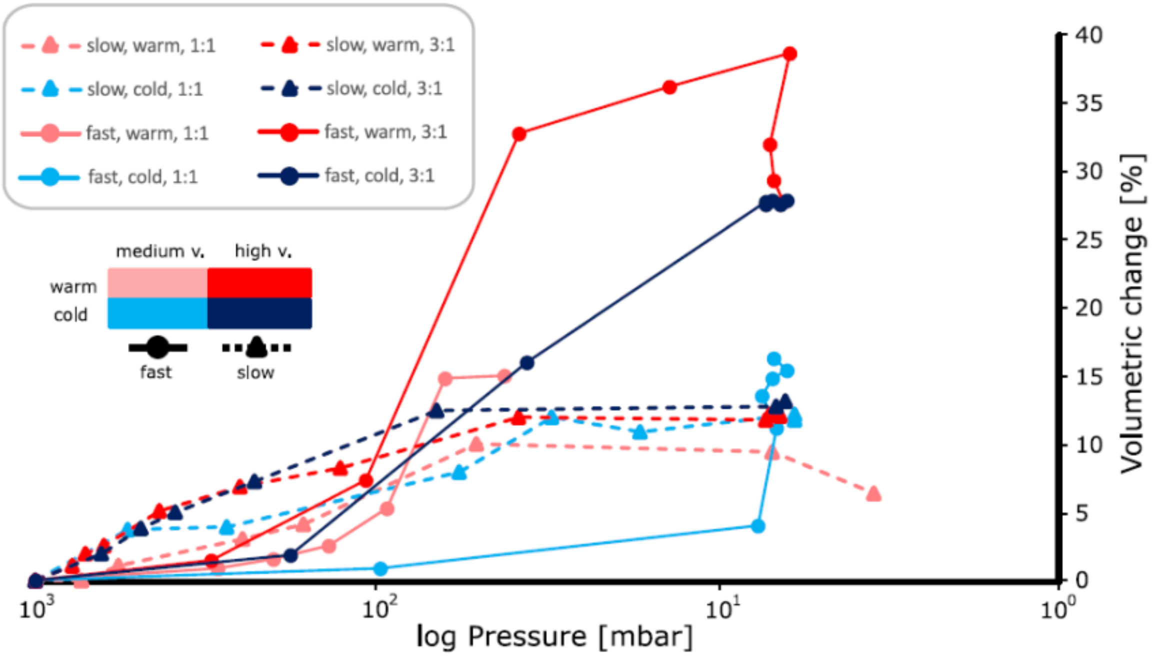

Figure 4. Results of volumetric change measurements.

As the surface gravity on Mars is nearly three times smaller than that on Earth, we performed numerical calculations to reveal to which depth the mud undergoes boiling. We reveal that the depth of boiling would be nearly three times larger on Mars, reaching meters for sufficiently warm muds. As a consequence, the boiling and associated volumetric changes observed during our small-scale experiments may apply to meter-scales for Mars natural conditions . This suggests that the observed mounds and knobs associated with putative martian sedimentary volcanoes might indeed be related to mud volumetric changes in response to surface exposure. We also show that mud flows on Mars, and elsewhere in the Solar System, could behave differently to those found on Earth since mud dynamics are affected by the formation of bubbles in response to the different atmospheric pressures.

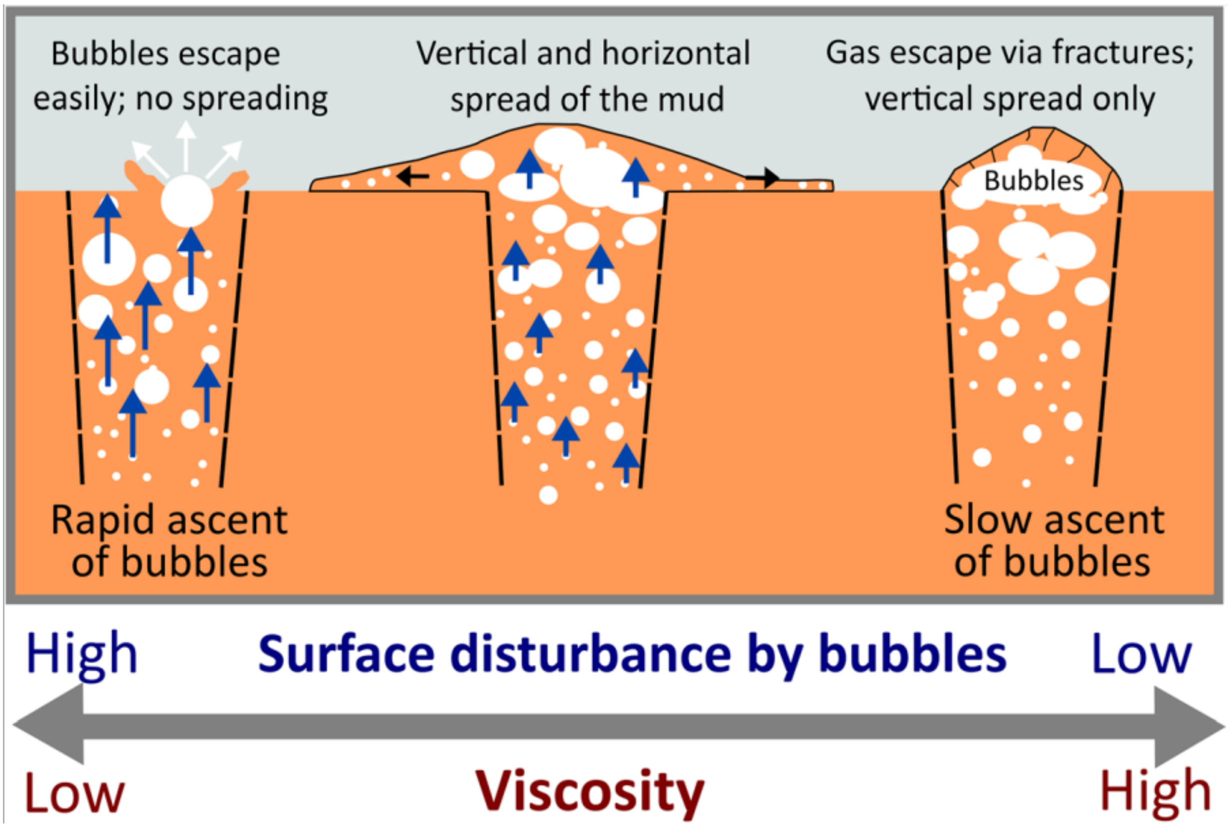

Figure 5. Simplified concept of gas migration and mud inflation due to the pressure drop.

Results of these experiments also suggest that other types of liquid, that are unstable in the low pressure environment, might behave similarly if their viscosity is high enough to prevent the bubble escape. The results presented herein also have implications for cryovolcanic phenomena on icy moons (e.g., Enceladus or Europa) or dwarf planets like Ceres.

References: [1] Komatsu et al., 2016. *Icarus*, *268*; [2] Brož et al., 2019, *JGR: Planets*, *124*(3); [3] Mazzini and Etiope, 2017, *Earth-Science Reviews*, 168. [4] Brož et al., 2020a, *Nature Geoscience*, *13*(6); [5] Brož et al., 2020b, *EPSL*, *545*; [6] Thielicke and Stamhuis, 2014, *Journal of Open Research Software*, *2*(1).