THE ROLE OF SALT PRECIPITATION FOR MORPHOLOGICAL FEATURES DUE TO BRINE FLOW ON MARS.

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Introduction: On present-day Mars, pure liquid water is thermodynamically unstable due to the low temperatures and pressures, however high-concentration brine can, at least transiently, exist as liquid on the surface owing to the freezing point depression [1, 2]. In fact, seasonal changes in temperature and humidity at Gale Crater, Mars, measured by NASA's Curiosity Rover indicate that liquid perchlorate brine becomes temporally stable [2]. Given the common presence of perchlorate salts on Martian surface [3], liquid brine formation could occur widespread on present-day Mars [2]. Once liquid brine forms on a slope, it may flow downward, creating morphological features. Such morphological features may include recurring slope lineae (RSL), which are narrow dark streak features appeared on steep slopes during warm seasons [1, 4].

Geomorphologic features formed by brine flow on Mars could be different from those formed by fresh water flow on Earth for the following reasons. First, cycles of flow and evaporation of brine on Mars should result in precipitation of salts within soil. Salt precipitation would decrease porosity within soils, which may, in turn, prevent infiltration of subsequent brine flow into the soils. Second, brine can be formed by melting of subsurface ice or deliquescence on present-day Mars [1, 5], whereas fresh water flow on Earth occurs mainly due to precipitation or groundwater upwelling. Consequently, the flow rate of brine on Mars is expected to be very low (e.g., several mm/hour in the case of melting ice sheet [6]). Third, the eutectic concentration of brine has high kinetic viscosity (e.g., 6.0 mm^2/sec for a solution of 5 mol/L $MgCl_2$ at 25 ºC [7]) (c.f. 0.9 mm^2/sec for pure water at 25ºC [7]). The high viscosity of brine decreases the capillary pressure within soils, possibly preventing effective infiltration [8]. Finally, liquid brine sometimes becomes metastable under the conditions on present-day Mars [5]. Since an achievement of these four conditions are rare on Earth [1, 9], laboratory experiments are important to understand characteristics of morphological features formed by brine flow on Mars.

The previous laboratory experiments investigate the behavior of metastable liquid brine within soils on a slope [5]. They also reproduce a low flow rate of brine via ice melting [5]. Although they find a hybrid flow mechanisms of metastable brine (i.e., a combination of evaporation and liquid flow) [5], the flow features are almost radially spread from the brine source, which is inconsistent with RSL.

In the present study, we focus on the effects of salt precipitation and high viscosity of brine on morphological features due to brine flow. We perform laboratory experiments to observe flows features for three types of liquids (pure water, ethylene glycol solution, and $MgCl_2$ solution) on a slope. The three types of liquids have different properties in terms of salt precipitation and kinetic viscosity. Evaporation of ultrapure water and ethylene glycol solution leaves no significant amounts of precipitations; whereas, evaporation of $MgCl_2$ solution leaves $MgCl_2$ salts within soils. Additionally, both of ethylene glycol and $MgCl_2$ solutions have similar, high kinetic viscosities (7.0 mm^2/sec [10] and 6.0 mm^2/sec, respectively), compared with ultrapure water (0.9 mm^2/sec). In repeated cycles of flow and evaporation of these solutions, we observe motions and behaviors of the flows. Based on the experimental results, we discuss the characteristics of morphological features formed by repeated cycles of flow and evaporation of brine on Mars.

Methods: In the laboratory experiments, solutions were introduced into a steep slope (angle = 33°) covered with a thin layer (layer thickness = 3 mm) of pulverized glass beads (grain size = 45–250 μm). The flow rate was controlled with a peristatic pump at a constant flux of 0.15 ml/minute, comparable to the flux due to melting of ice sheet on Mars [5]. We employed three types of solutions in the experiments; ultrapure water (kinetic viscosity: 0.9 mm^2/sec), a solution of ethylene glycol with 50 wt.% (kinetic viscosity: 7.0 mm^2/sec), and a solution of $MgCl_2$ with 5 mol/L (kinetic viscosity: 6.0 mm^2/sec). The slope was set in a glovebox, where temperature was set to be ~25℃ and relative humidity was maintained ~37% using an air drier connected with the globe box. After a flow of a solution for 5 minutes, the slope was moved to an electric oven at temperature of 45ºC for drying over 18 hours. Then, the dried slope was again set in the globe box for the subsequent flow of the solution. The cycle of flow and evaporation was repeated more than five times for each solution. A digital video camera in front of the globe box was used to observe the flow features of solutions on the slope.

To examine precipitation of $MgCl_2$ salt within the glass beads layer, we collected a ~10 mm^3 of solidified glass bead samples from the flow features after the experiments. The collected samples were analyzed using Scanning Electron Microscopy and Energy Dispersive Spectroscopy (SEM-EDS), aiming to identify surface materials. The collected samples were also analyzed using a micro X-ray Computed Tomography (XCT), aiming to measure the porosity.

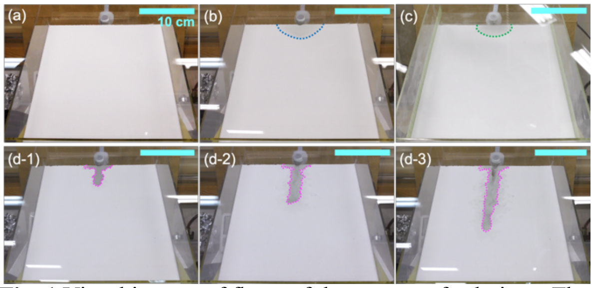

Fig. 1 Visual images of flows of three types of solutions. The dotted lines represent the rims of flow features. (a) The initial state of the glass beads layer. (b) A flow feature of ultrapure water. (c) A flow feature of ethylene glycol solution. (d) Time evolution of flow features of the $MgCl_2$ solution.

Results: At the relatively-low flow rate, both of ultrapure water and ethylene glycol solution infiltrate into the glass beads layer almost concentrically from the source of the solutions (Fig. 1). The flow morphologies of these solutions do not change in the cycles of flow and evaporation of the solutions. The width of the flow feature of ultrapure water is 1.3 times larger than that of ethylene glycol solution, since the capillary pressure of ultrapure water is higher than the ethylene glycol solution owing to the difference of kinetic viscosity.

On the other hand, the flow features of the $MgCl_2$ solution changes over the cycles of flow and evaporation (Fig. 1). In the first flow, the $MgCl_2$ solution infiltrates into the glass beads layer almost concentrically, similar to the behaviors of ultrapure water and ethylene glycol solution. However, in the subsequent flows, surface runoff also appears together with the infiltration of the solution into the glass beads layer. Due to the surface runoff, the flow feature of the $MgCl_2$ solution becomes elongated downward over the cycles of flow and evaporation (Fig. 1). Comparing with the results of ultrapure water and ethylene glycol solution, the elongated morphological features due to flow of $MgCl_2$ solution would result from precipitation of salt in the glass beads layer.

The results of SEM-EDS and XCT analyses for the collected samples shows that precipitated $MgCl_2$ salts coated over glass bead grains (Fig. 2). $MgCl_2$ salts also

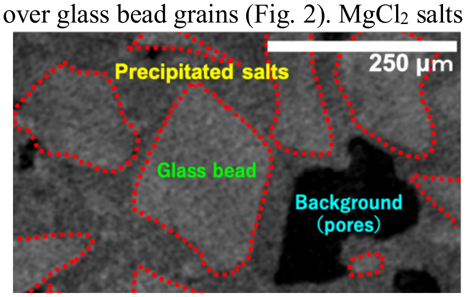

Fig. 2 A micro XCT cross section image of the solidified sample collected after five-time flows of $MgCl_2$ solution. The light gray areas surrounded by dotted lines represent glass beads. The surrounding dark gray areas represent $MgCl_2$ salts. The black areas represent pores within the soil.

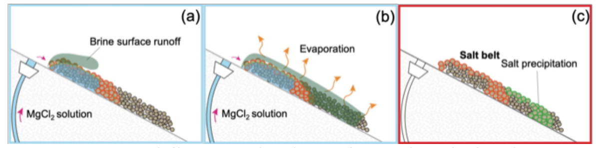

Fig. 3 Proposed flow mechanism of $MgCl_2$ solution in our experiments.

connect multiple glass bead grains via forming bridges and necks. Due to the precipitation of $MgCl_2$ salts within the glass beads, the porosity decreases from 45% to 15% over ten times of cycles of flow and evaporation. Although ~15% of porosity remains in the glass beads layer, almost all of these pores are isolated in a three-dimensional structure, suggesting that the precipitated $MgCl_2$ salt effectively prevents subsequent flow of the $MgCl_2$ solution within the layer.

Discussion: The formation mechanism of elongated morphological features due to flow of $MgCl_2$ solution is suggested as follows (Fig. 3). After evaporation of the $MgCl_2$ solution infiltrated into the glass beads layer, precipitation of $MgCl_2$ salt decreases the porosity and permeability of the glass beads layer. Subsequent flows cannot sufficiently infiltrate into the glass beads due to the low permeability. As the pore of the glass beads layer becomes saturated with the solution, surface runoff appears (Fig. 3a). After the surface runoff reaching the downstream edge of the previous flow, the solution infiltrates into unreached glass beads in the downstream (Fig. 3b,c). In every cycle of flow and evaporation repeats, the flow features elongate downward.

Our experimental results suggest that even at a low rate of liquid flow achieved on present-day Mars [5], repeated cycles of flow and evaporation of brine can effectively generate surface runoff, leading to formation of elongated flow features on a slope. The elongated features of RSL have not been explained thus far by any formation mechanisms triggered by liquid flows. RSL may be one of the candidates of such elongated flow features formed by cycles of flow and evaporation of brine, although the replenishment process of brine in the source regions remains largely unknown.

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