
Introduction: On present-day Mars, high-concentration brine can transiently exist as liquid [1, 2]. Once liquid brine forms on a slope, it may flow downward, creating morphological features. Such morphological features may include recurring slope lineae (RSL) [1].

Geomorphologic features formed by repeated brine flows on Mars could be different from those formed by fresh water flow on Earth in terms of precipitates of salts and flow rate of brine. Precipitated salts within soil after evaporation would prevent infiltration of subsequent brine flow. In our previous study [3], we performed laboratory experiments on repeated brine flows on slope covered with glass beads. The results show that precipitation of salts within glass beads layer prevents infiltration of subsequent brine flow, forming surface runoff [3]. 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 [4]). Our previous study suggests that, owing to the precipitation of salts within glass beads layer, surface runoff occurs effectively even under low flow rate conditions, leading to formation of elongated features on the slope [3].

However, surface runoff is forced downward by gravity. Under low gravity conditions, such as Mars, this downward force becomes relatively weak compared with capillary force that causes infiltration of water into soils. In our previous study [4], we performed experiments at slope angle of 33°. Nevertheless, to reproduce the same downward force on a slope with 30° (typical slope angle of RSL) on low-gravity Mars, the slope angle needs to be ~10° on Earth. Thus, the slope angle would be an important parameter that could determine the flow features.

In the present study, we focus on the effects of slope angle on morphological features due to brine flow. We perform laboratory experiments to observe morphological feature of repeated flows of MgCl₂ solution on a slope with angles of 10° and 33°. Based on the experimental results, we discuss the effect of slope angle on morphological features formed by repeated cycles of flow and evaporation of brine on Mars.

In addition, if RSL relate to brine activity, repeated flow and evaporation of brine should result in precipitation of salts within soils on the slope. In fact, the presence of hydrated salts on a few RSL sites has been suggested by Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) onboarded on Mars Reconnaissance Orbiter (MRO) [5]. However, the mineralogical and chemical compositions of salts on RSL are poorly constrained due to the high signal-to-noise ratios in the CRISM spectra [5].

In the present study, we also discuss whether the salts precipitated within soils are detectable in CRISM spectra when geomorphologic features are formed by the repeated brine flows.

Methodology of Laboratory Experiments: We performed laboratory experiments using the experimental setup of our previous study [3]. In the laboratory experiments, solutions were introduced into a 33° or 10° slope 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 [4]. We employed MgCl₂ solutions with 5 mol/L in the experiments. The slope was set in a glovebox, where temperature was set to be ~27°C and relative humidity was maintained ~38% using an air drier connected with the glove box. After a flow of a solution for 5 minutes, the slope was moved to an electric oven at temperature of 45°C for drying over 18 hours. Then, the dried slope was again set in the glove 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 glove box was used to observe the flow features of solutions on the slope.

Results of Experiments: Figure 1 shows morphological features of flow of MgCl₂ solution on a slope at 10° and 33°. For a comparison, we show our previous result of ultrapure water flow onto a slope at 33°. Ultrapure water infiltrate into the glass beads layer almost radially, whereas repeated flows of MgCl₂ solution form elongated features (e.g. Fig. 1(a,b)) [3]. In the first flow on slope with 33°, the MgCl₂ solution infiltrates into the glass beads layer almost concentrically [3]. However, in the subsequent flows, surface runoff also appears together with infiltration of the solution into the glass beads layer [3]. Due to the surface runoff, the flow feature of the MgCl₂ solution becomes elongated downward over the cycles of flow and evaporation (Fig. 1(b)) [3]. The aspect ratio of the elongated features may include r...
flow features reaches up to ~2.7 after the five cycles of flows of MgCl₂ solution.

The flows of the MgCl₂ solution on slope with 10° slope also generate the ligulate feature extending downward (Fig. 1(c)). In the first-time flow, the MgCl₂ solution infiltrates laterally into the glass beads layer. In the second-time flows, the only infiltration of the MgCl₂ solution occurs following the flow feature of the first-time flow. In the third-time flow, surface runoff appears on the slope together with the infiltration flow. Upon the repeated cycles of flow and evaporation, the flow feature of the MgCl₂ solution extends downward, although clear elongated features are not generated even in the five cycles of flows (the aspect ratio; ~0.6) (Fig. 1(c)).

Effect of Slope Angle on Morphological Features: Our results suggest that, even on a 10° slope, our suggested flow mechanism [3] works. The precipitated salts prevent the infiltration flow, generating surface runoff. Consequently, the flow features get elongated. However, the flow features on a 33° slope are narrow streaks, whereas those on a 10° slopes are ligulate. A possible reason for no clear elongated features on the 10° slope is that gravity is not predominant on both of the infiltration flow and surface runoff. Therefore, isotropic diffusion due to capillarity makes the infiltration flow in the first and second-time flows spread widely. In terms of surface runoff, the friction force between the MgCl₂ solution and glass beads may be more effective than the gravity force. Thereby, the surface runoff is difficult to flow downward.

Detectability of Precipitated Salts on RSL: Next, we assess whether the precipitation of salts can be detected and identified on RSL with a spectrometer equivalent to CRISM’s spatial resolution. First, a mixing spectrum was calculated by linear combination of the measured spectra of powdered basalt and MgCl₂·2H₂O salt. We obtained the mixing spectra for various mixing ratios of basalt to MgCl₂ as (a) 50 : 50, (b) 70 : 30, (c) 80 : 20, (d) 90 : 10 and (e) 95 : 5. Then, we added artificial random noise with a Gaussian distribution to the mixing spectra in order to reproduce the noise levels of the CRISM [5]. To discriminate between the signal and noise, we used a band detection algorithm for the mixing spectra with the noise based on the previous study [5]. Finally, we calculated band depths for detected absorption bands whether they exceed the detection errors of CRISM.

Figure 2 shows the mixing spectra with artificial noise together with the smoothed spectra and the 7th order polynomial-fit continuum curves. Our results show that the mixing spectra exhibit absorption bands at (a) ~1.47 and 1.98 µm, (b) ~1.45 and 1.97 µm, (c) ~1.47 and 1.98 µm, (d) ~1.41 and 1.97 µm and (e) ~1.96 µm, whereas pure MgCl₂·2H₂O salt has absorptions at ~1.46 and ~1.98 µm. Considering that 95% confidence interval of the noise, a band depth needs to exceed 3% for definite detection. Due to the noise, the band depths of absorptions at around ~1.97 µm do not exceed 3% for the basalt-to-MgCl₂ ratio of (d) 90 : 10 and (e) 95 : 5 with CRISM (Fig. 2). On the other hand, band depths exceed 3% for the mixing spectra with the basalt-to-MgCl₂ ratio greater than 80 : 20.

Our results show that if the volumetric MgCl₂ salt contents are higher than 20%, the band depth can be identified with the noise levels of CRISM (Fig. 2). Based on our previous experiments [3], precipitation of salts fills pores within the glass beads and reaches up to ~30% of glass beads in volume. Given that typical width of RSL (0.5–5 m) is about 1/3 of the spatial resolution of CRISM (~18 m), effective salt contents in a field of view of CRISM would be ~10% or less. Thereby, salts are unable to be detected with CRISM from the current orbit of MRO unless most of a field of view is occupied with RSL [5]. To identify possible MgCl₂·2H₂O salts on one streak of RSL, effective salt content need to exceed 20%. This means that a spatial resolution of a spectrometer equivalent to CRISM needs to be ~5 m or lower. To achieve this high-spatial resolution, an orbital altitude of a spacecraft needs to be 1/3 or less of that of MRO (the current orbit: ~260–320 km from the surface). Such observations from low orbital altitudes may be achieved by an orbiter with elliptical orbits or during aerobraking upon orbital insertion in future spacecraft missions to Mars.