

Experimental study of ice lens formation in fine-grained particles, implication for martian environment

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Abstract

Ice lens is a pure ice layer formed by the migration of unfrozen water. Its existence is indicated in Mars. However, there exist unsettled issues about the mechanism of ice lens formation even on Earth. We performed unidirectional freezing experiment using glass beads. As a result of experiments, we have obtained clear and systematic relation ships between the ice lens and particle size and cooling temperature. In this presentation we report experimental results and discuss the martian case.

1. Introduction

By the high-quality exploration of Mars, various types of landforms that are similar to the periglacial landforms in Earth have been discovered. Besides these direct evidences for existence of pure ice layer has been obtained recently by Phoenix lander ([1]). The existence of such ice layer just below the surface would be a challenge for the near-surface environment of the present Mars. Zent et al. (2011) ([2]) considered the formation of the subsurface ice layer by the model of frost heave/ ice lens formation ([3]). Ice lens is formed by the migration and accumulation of unfrozen water. Unfrozen water is particular kind of water in mixture of fine grained solid particles / microporous material and ice below the bulk melting temperature, which is known to migrate in frozen soils from warmer side to colder to side to form segregated ice phase (ice lens). Although the mechanism of ice lens formation has been developed by various theoretical models, experimental checks are still not enough. In this presentation we report experimental results on ice lens formation and discuss the martian case.

2. Experimental procedure

We performed unidirectional freezing from bottom side and bottom cooling plate is directly attached to Peltier module. Our experiments were performed under closed system with respect to water. The bottom temperature was controlled stepwisely; i.e., there is no water reservoir and cooling temperature is constant. We observed the configuration of ice lens with various particle sizes and cooling temperatures. Also we measured temperatures during freezing experiment by thermocouples.

3. Results

Fig.1 shows the example of ice lens obtained by our experiment. The position is measured as the distance from the cooling plate at the center. The existence or nonexistence of ice lens is shown in Fig.2. The conditions that ice lens is formed were limited to specific area. At smaller particle sizes, ice lens is formed. It is evident that there exists a maximum limit of the grain size for the formation of ice lens (~ 50 micron).

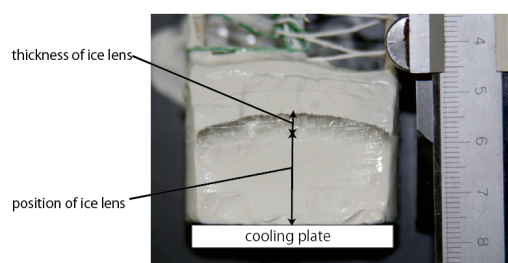


Figure 1: Example of ice lens obtained by our experiment. Horizontal dark zone is pure ice and other white zone is mixture of frozen water and glass beads.

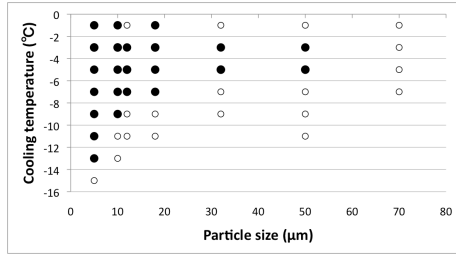


Figure 2: The phase diagram for formation of ice lens. White circles show no ice lens formation. In the particle size 5 micron and 10 micron extensive formation of ice lens was found. At particle size of 70 micron, no ice lens formation was found in any cooling temperatures.

Fig.3 and Fig.4 show the thickness of ice lens as a function of particle size and the position as a function of cooling temperature respectively. In Fig.3 the ice lens is thicker in smaller particle sizes. The solid line shows the particle size dependence of R^{-2} . As for the position of ice lens, lens is formed at farther position from cooling plate in lower cooling temperature. (In Fig.4)

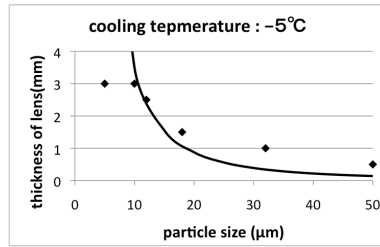


Figure 3: The thickness of ice lens as a function of particle size at cooling temperature -5°C . At smaller particle size, ice lens is thicker. The solid line shows the particle size R^{-2} .

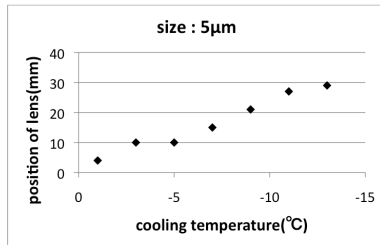


Figure 4: The position of ice lens as a function of cooling temperature at the particle size of 5 micron.

5. Discussion

The thickness of ice lens highly depends on the amount of unfrozen water ([4] WW model). The fraction of unfrozen water is proportional to R^{-2} ([5]). In our results, the thickness appears to be proportional to R^{-2} at particle size larger than 10 micron. This trend is consistent with particle size dependence of unfrozen water. On the other hand, the position of ice lens is controlled by critical freezing velocity (CFV). ([4]). When the velocity of freezing front becomes equal to CFV, ice lens starts to grow. We estimated the freezing velocity of the beginning of ice lens formation in specific experiment and obtained $0.6 - 0.7 \text{ micron / s}$. These values are close to the CFV in WW model (1 micron / s). Although our experimental results can be used to check physics of frost heave/ice lens formation the experimental situation is quite different from the martian case so that direct applications are limited. In the terrestrial environments, the ground water often plays a role of water reservoir for ice lens formation. On Mars, however, the water vapor in the atmosphere would be another important reservoir since the amount of H_2O of Mars is very limited. We should consider two different types of ice lens on Mars, groundwater origin and atmospheric origin. Vapor transport should control the ice lens formation in the extremely dry conditions like Mars. We are now developing our experimental system to fit the martian conditions.

References

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