論文の内容の要旨

論文題目　Numerical and experimental studies of ice lens formation with implication for interfacial melting
（アイスレンズ形成に関する数値的・実験的研究と界面融解への推察）

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When a homogeneous mixture of water and granular materials are frozen, pure ice layers known as ice lens are segregated out. They are formed by the migration and solidification of unfrozen water that is adsorbed to particle surface and confined to capillary regions. Growth of ice lens is responsible for the upwards displacement of the ground surface known as frost heave. The complicated interplay between heat and mass transport that causes ice lens formation and frost heave has been addressed by several theoretical models, but uncertainties still remain and require further experimental constraints and comparisons. Especially, the subject about the initiation of ice lenses has been remained uncertain because of the difficulty in theoretical treatment.

I performed a series of step-wise freezing experiments to observe the initiation and growth of ice lenses in fine granular materials. Freezing experiments demonstrate the clear relationships between the behavior of ice lenses, and the host particle size and the induced cooling temperature. Ice lenses are thicker with smaller particle sizes and the initial formation position is further from the cooled boundary with lower cooling temperatures. I compared the experimental results to numerical predictions of ice lens formation that are applied to the experimental conditions. Comparisons between the numerical predictions and experimental results emphasize the importance of water flow through the liquid thin film and suggest premelting in my experimental system is dominated by short-range electrostatic interactions. Particle size control based on the effective Peclet number indicates that ice lens growth in fine-grained porous media is constrained by low permeability in unfrozen region; by contrast, the restriction of thin film flow constrains the lens growth in coarse-grained porous media. Therefore, the ice lens growth is controlled by the balance between permeable flow and thin film flow, which leads to the high frost-susceptibility at intermediate-sized porous media. Beyond the fundamental experiments, I investigated the effect of salt on the initiation and

growth of ice lenses and the redistribution during unidirectional freezing. The nucleated position of ice lenses and final location of solidification front are displaced to lower temperature side associated with the solute rejection from solid ice phase.

The physical model can explain the vigorous frost heaving in the fine-grained soils that has been indicated by previous field survey, but the model predicts smaller frost heave at further smaller particle size. The model also proposes the importance of packing conditions and size distributions that are intrinsic in natural system. When assessing and predicting the susceptibility for frost heave in particular natural system including extraterrestrial phenomena, the physical model can be applied to the intrinsic situations.