Geophysical Research Abstracts
Vol. 16, EGU2014-3409, 2014
EGU General Assembly 2014

Modeling of flow and solidification of liquid water during unidirectional freezing in porous media

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Flow and phase change of liquid in porous media are fundamental processes in earth science and soil physics. Particularly in cold region or periglacial environment, the flow and solidification of pore water in the ground simultaneously occur and their collective interactions control the growth of ice lenses and upward displacement of surface called as frost heave. In the nucleation and growth of ice lenses, the homogeneous mixture of soil particles and pore water is transformed to the heterogeneous structure due to the water redistribution and the particle migration. Unfrozen water that is adsorbed to the particle surface or confined to capillary regions plays an important role in the formation of ice lenses and its behaviors have been investigated from a perspective of premelting dynamics (e.g., Worster and Wettlaufer 2006). In the porous media below the nominal melting temperature, intermolecular forces that act between particles and ice through the liquid thin film produce the net thermomolecular force that is responsible for the particle separation form the ice lenses(Dash et al. 2006). Although the mechanisms of ice lens formation have been investigated by many researchers, still large uncertainties remain and more experimental constraints are required. Here we present experimental results of ice lens formation, particularly focusing on the role of grain size and compare the model by Rempel et al (2004).

We have performed the unidirectional freezing experiments using water-saturated glass beads that have uniform structures. Since the flow of water in porous media depends on the particles size and pore throat size (Darcy's law), we have prepared various sizes of glass beads from submicron to submillimeter. Our experiments reveal the clear relationships between the host particle sizes and nucleated location and lens thickness. Part of this work is already published in Saruya et al, PRE but we extended to smaller sized regime. We compared our experimental results to the numerical predictions that were modified to our experimental conditions based upon Rempel et al. (2004). The comparison between the experimental results and numerical predictions emphasizes the importance of kinetics due to the flow in liquid thin film and implies the kind of dominant van der Waals interactions that controls the behavior of liquid thin film.