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Dynamics of freezing and thawing of water in saturated sand and soil: Magnetic resonance imaging study

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Magnetic resonance imaging (MRI) of the freezing and thawing process was performed on a series of repacked samples of sand, soil, and sand-soil mixture. The freezing/thawing is performed in the sample container placed inside the vertical bore MRI scanner within the 66 mm inner diameter of the radiofrequency coil. The sample container was vacuum insulated from the sides and bottom to allow for the minimum thickness of the insulation layer. The vacuum was constantly maintained by a vacuum pump. The sample assembly was built from PMMA and other nonmetallic - MRI compatible materials. A porous material in the sample container was cooled at the top by the flow of cold gaseous nitrogen released from the liquid nitrogen stored in the Dewar flask. The cooling took place across the glass plate positioned at the top of the sample in the headspace above the sample. The temperature of the gas that was delivered to the headspace and leaving the headspace was monitored. Additionally, the temperature was monitored in the headspace above the glass disk and directly in the glass disk by fiber optics temperature probes. A 4.7 T magnet at the FZJ was used for MRI. Multiple-Slice Spin-Echo and Zero Echo Time pulse sequences were utilized. The contrast between the frozen and unfrozen water is given by the difference in T1 and T2 relaxation times. The time-lapse 3D imaging was done during the entire course of the experiment. Once the freezing front reached the bottom of the sample, the thawing process was induced. The small changes in sand structure as a consequence of volumetric ice-water changes were studied. The spatiotemporal analysis of the freezing front advancement and frozen water volume has been performed. The data are available for the development of two-phase ice-water simulation models.