



Solute redistribution during saline water evaporation in porous media and its effects on the onset of salt crust formation

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Evaporation from porous media is a key phenomenon in the terrestrial environment and is linked to soil salinization, degradation and weathering of building materials. Column-scale experiments could extend our understanding of the complex processes affecting saline water evaporation. In this context, the current study aims at investigating solute accumulation near evaporating surfaces and the resulting implications for time to salt crust formation. Previous numerical studies with REV-scale simulations predict the development of local instabilities due to density differences during saline water evaporation in case of saturated porous media with high permeability, eventually causing density-driven downward flow through fingering. To experimentally investigate this process on the column-scale, we performed evaporation experiments on two types of porous media: medium sand (F36) and fine sand/silt (W3) saturated with NaCl solution. The intrinsic permeability of the two packings differed by two orders of magnitude, i.e. $29 \times 10^{-12} \text{ m}^2$ for F36 and $0.56 \times 10^{-12} \text{ m}^2$ for W3. Using magnetic resonance imaging (^{23}Na -MRI), we monitored solute accumulation at the surface and subsequent downward redistribution of salt in time-lapse scans during evaporation with a continuous supply of water from below (wicking). Results showed key differences between the enrichment patterns of Na for the two types of porous media. Density-driven downward flow only occurred in F36, initially manifested by fingering, and resulted eventually in redistribution of Na throughout the sample. For W3, solute accumulated at the thin region at the surface with a thickness of a few mm. Despite similar average evaporation rates for both porous media, the concentration at the top reached the saturation limit (6.13 mol/L) for W3, whereas it remained relatively low (2.5 mol/L) for F36 due to the redistribution. This different behavior suggests that time-to-crust formation is longer for higher permeability porous media under similar evaporation conditions applied in our experiments.

To investigate crust formation in more detail, additional column-scale evaporation experiments with wicking conditions were performed on three sands WS1, WS2 and WS3 with particle sizes ranging between 0.1 to 0.3 mm, 0.3 to 0.5 mm and 0.71 to 1.0 mm, respectively. To achieve well-controlled evaporation conditions, experiments were performed in a wind tunnel maintaining a constant wind speed of 5 ms^{-1} . Surface time-lapse imaging with a digital camera was performed to observe the onset time of crust formation as well as the resulting crust morphology after initiation. The results showed that for the relatively coarser WS2 sand, onset of crust took twice as long (40

hours) in comparison to the finer WS1 sand (20 hours). The significantly larger particle size of WS3 sand led to air entry, partially saturated conditions and an almost instantaneous crust formation. The crust formation affected also the evaporation rate of each sand, which is attributed to the formation of a new porous layer (crust) and its wetting-drying dynamics. These findings encourage further investigation into effects on crust development for heterogeneous porous media, redistribution and precipitation of different salt types, and the coupling of experimental results to numerical modelling.