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Characterizing structural and textural subsurface patterns using spectral induced polarization: Effects of saturation

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Groundwater is a vulnerable resource that is endangered by pollutants and contaminants. Soil is an important protective buffer for groundwater and, therefore, the understanding of flow and transport processes in soils is very important. However, the prediction capabilities of unsaturated flow and transport models in the vadose zone are often limited due to an insufficient knowledge about the structural and textural heterogeneity of the soil. To obtain more information about soil structure, texture and heterogeneity, as well as hydraulic parameters, non-invasive electrical methods may be employed in field-scale studies. To investigate the potential of the approach, a laboratory measurement setup was developed which allows combined electrical and hydraulic measurements. The latter are conducted via a multi-step outflow device. Various pressure steps are applied to a saturated sample and the outflow is recorded. When equilibrium is reached, spectral induced polarization (SIP) measurements are conducted before the next pressure step is applied. The electrical measurements are carried out with a high-accuracy impedance spectrometer. Combined electrical and hydraulic measurements were conducted on packed sand-clay mixtures. The measured resistivity magnitude and phase spectra and their dependence on water content are clearly different for each mixture. For pure sand, the phase values increase with decreasing water content over the entire frequency range and a phase peak is present for low water content. The increasing phase is due to the increasing resistivity and an associated increasing chargeability of the sample. The phase spectrum of a sand-clay mixture with 5 % clay shows the same behaviour like the pure sand; however, the shift of the phase peak to higher frequencies is much stronger. This shift suggests that relaxation time and length become smaller with decreasing water content, which is related to the smaller pores that are active at lower water content. The sand-clay mixture with 20 % clay shows a significantly different behaviour. At full saturation, the phase spectrum exhibits a weak peak at about 0.2 Hz. With decreasing saturation, first a distinct phase peak is formed at about 0.02 Hz; then phase values decrease, and simultaneously a shift to higher frequencies occurs. The phase values are also much smaller than for the other mixtures. This unique dataset is used to investigate relationships between electrical and hydraulic properties.