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Contribution of Stern layer and membrane polarization to spectral induced polarization of variably saturated sandy soils

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Spectral induced polarization is receiving increasing attention as a tool to map subsurface properties in a non-invasive manner. Although empirical correlations have been devised to link measurements to porous medium properties, such as the time constant of the Cole-Cole model to grain size distribution and hydraulic conductivity, a comprehensive process-based model is still missing. Two fundamentally different mechanisms have been proposed so far, (i) electrical double layer polarization, in particular of the Stern layer and (ii) membrane polarization. This latter mechanism is due to the accumulation of ions at the opposite sides of narrow pore-throats, which effectively act as ion-selective channels and lead to the formation of a membrane potential. Both mechanisms have so far shown the ability to explain to some degree experimental observations, although not in a completely convincing manner.

The goal of this work was to test whether the two process concur to the observed polarization of the porous medium or rather are mutually exclusive. The Hashin-Shtrickman Average (HSA) model of Brovelli and Cassiani (2010, 2011) was extended to compute the complex bulk conductivity of variably saturated porous media. Complex surface conductance was computed from EDL polarization theory, whereas membrane polarization affects pore-water conductivity.

The frequency-dependent HSA model was compared with the measured spectral induced polarization of variably-saturated sandy soils. A satisfactory comparison was found for most samples, in particular with water saturation above 0.8. It was observed that the two polarization mechanisms lead to separate phase peaks, which are related to the characteristic diffusion length and tortuosity of grains and pore-throats. When saturation is decreased, Stern layer polarization becomes the dominant mechanism, as the water phase is progressively less abundant and more disconnected. In addition, the measured polarization becomes more difficult to explain with the model, perhaps because additional mechanisms – such as the polarization of the air-water interface – come into play.