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Modelling the induced polarization of bentonite-sand mixtures

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Spectral induced polarization (SIP) has become an increasingly popular geophysical method for hydrogeological and environmental applications. These applications include for instance the non-intrusive characterization of the textural and interfacial physicochemical properties of bentonites used as permeability barriers in landfills or to store various types of contaminants including radioactive wastes. Bentonites are mainly constituted of smectites, which have very high specific surface areas (SSA) and cation exchange capacities (CEC). Therefore, these minerals have very high electromigration and polarization current densities responsible for very high in phase and quadrature conductivities, respectively. In addition, in diluted water, the diffuse layer of smectites occupies a large fraction of the pore space and may be therefore considered as part of the pore space.

In our approach [1], complex electrical conductivities of saturated unconsolidated bentonite and bentonite-sand mixtures are modeled at different salinities (NaCl) of the bulk pore water using a Donnan equilibrium model coupled to the revisited SIP model of Leroy and Revil [2]. Our complex surface conductivity model considers the DC contribution of the diffuse and Stern layers as well as the electrochemical polarization of the Stern layer coating the grains with different sizes. The macroscopic SIP model is based on the differential effective medium theory and considers the complex surface conductivity of the sand and smectite grains and the complex conductivity of the pore space. In our model, the diffuse layer of quartz sands occupies a small fraction of the pore space and is considered therefore as part of the surface of the grains.

Our SIP model predicts very well the low frequency (0.1 Hz - kHz) complex electrical conductivities of bentonite and bentonite-sand mixtures, except for very low frequencies (< 0.1 Hz) where membrane polarization may occur (Figure 1). The in phase conductivity of the sample with a high clay content (20 % in volume) increases slowly with salinity because of the very high DC surface conductivity of smectite. The observed large increase of the in phase and quadrature conductivity of the samples with the clay content (1, 20 and 100% in volume) is also predicted by our model. The quadrature conductivity of the samples with a high clay content is fairly independent on the pore fluid salinity because it is strongly connected with the SSA, CEC and Stern layer of smectite (Figure 1). The in phase conductivity of the sample with a low clay content (1% in volume) increases quickly with the salinity because of its low

DC surface conductivity. Its quadrature conductivity also increases quickly with salinity because of the formation of the Stern layer at the surface of quartz sand. Nevertheless, our SIP model can't predict the quadrature conductivity spectra observed at very low frequencies (< 10^{-1} Hz). The missing polarization mechanism may correspond to membrane polarization and there is an effort to be done to incorporate this contribution in a unified model.

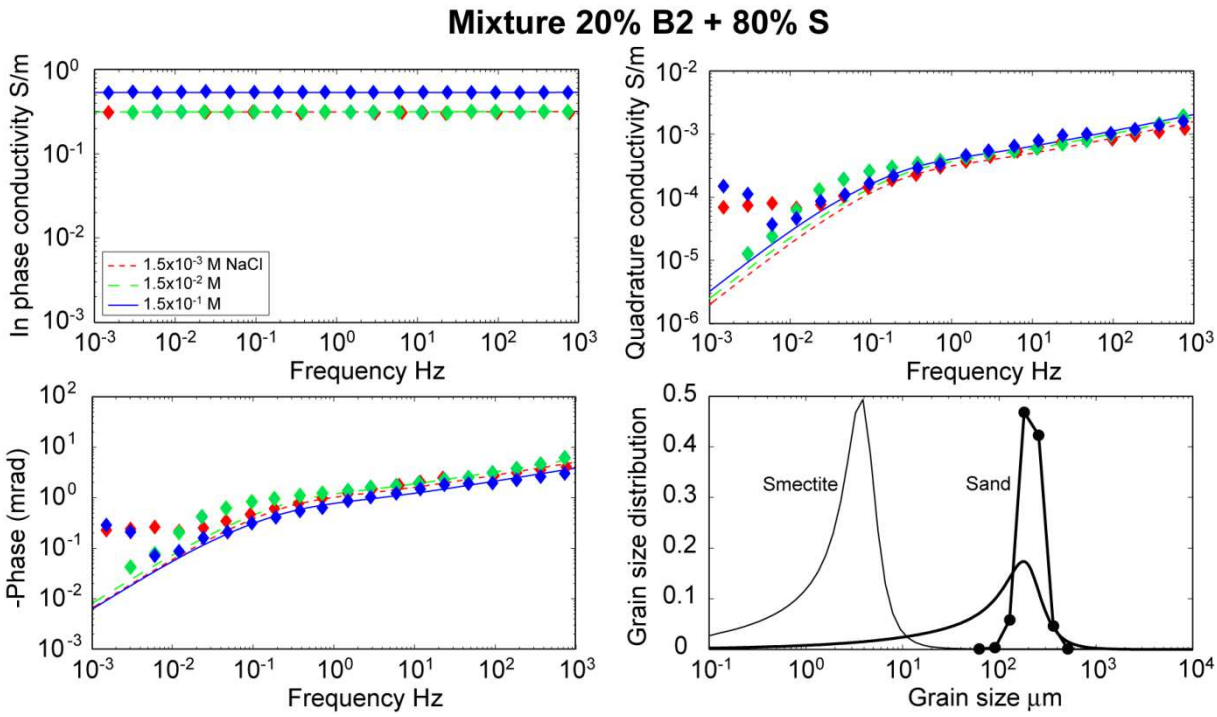

Figure 1. Comparison between theory (lines) and experimental data (symbols) for bentonite-sand mixture (20% clay content) at different pore water salinities (0.0015, 0.015, 0.15 M NaCl). The in phase and quadrature conductivities of the sample are dominated by the diffusion of sodium counter-ions in the Stern and diffuse layers of smectite because of the very high SSA and CEC of this material.

References

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Session 1 or Session 3. No preference for oral or poster