Improving understanding of the information content in induced polarization data: the value of empirical observations based on extensive, validated original datasets

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There has been a recent surge in the publication of mechanistic formulations to describe the induced polarization response in terms of grain or pore based polarization mechanisms. In the POLARIS model, the importance of the mobility ratio i.e., the ratio of the mobility of the counterions in the Stern layer ($\beta_{(+)}{}^{S}$) to the mobility of the counterions in the diffuse layer ($\beta_{(+)}$), in reliably predicting induced polarization (IP) responses of porous media has recently been emphasized. The POLARIS model predicts two distinct values for this ratio, one for clean sands and one for clayey material. The mobility of the counterions at the surface of sand (silica) is assumed comparable to the mobility of the counterions in the diffuse layer, whereas in clay minerals the mobility of the counterions in the Stern layer is assumed to be much smaller (~1/350) than in the diffuse layer. Recent publications have presented a limited amount of data in support of this argument, where sands are predicted to show an approximately two orders of magnitude increase in polarizability relative to clays with the same cation exchange capacity, a prediction that is not easily reconcilable with the majority of measurements in the literature. This strong difference in the mobility ratio for silica sands and clayey materials implies that any relationship between the surface conductivity and the quadrature conductivity will differ for clayey materials versus clean sands.

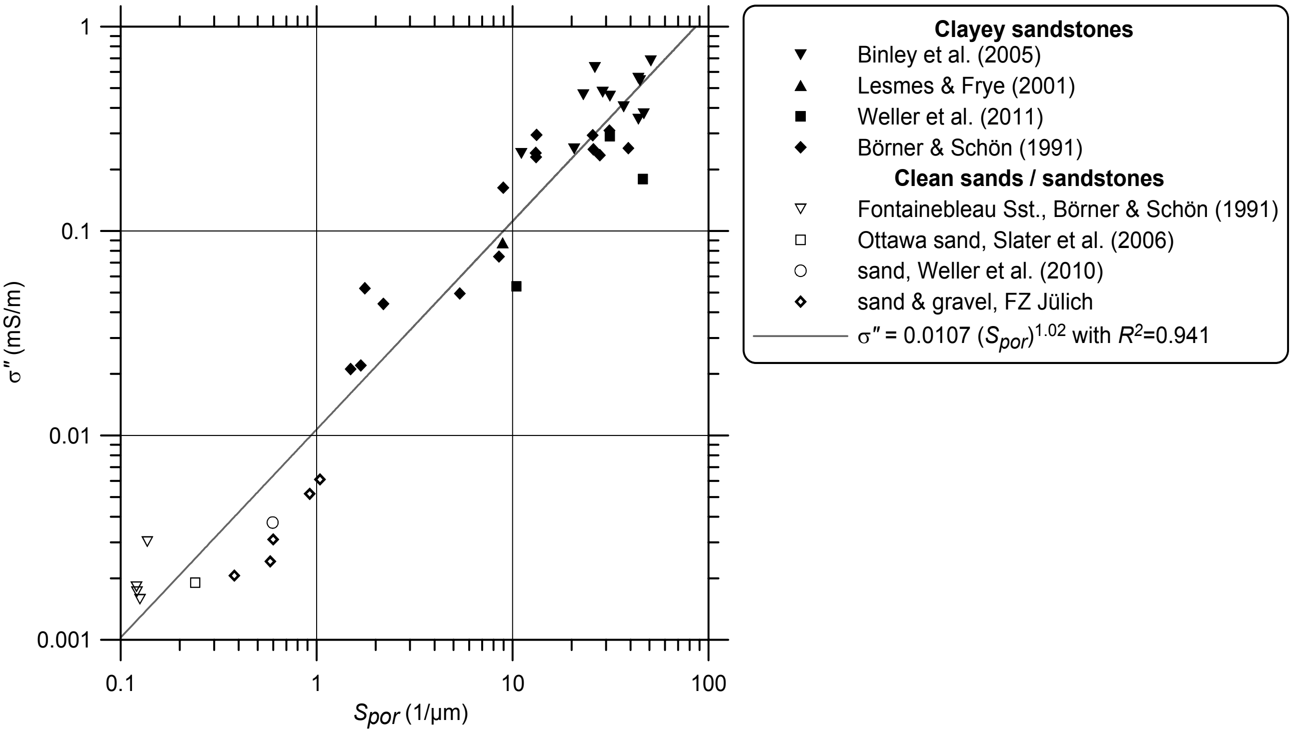

Fig. 1: Relation between imaginary part of conductivity (σ'') measured at a frequency of about 1 Hz and the specific surface per unit pore volume (S_{por}) for 42 samples originating from six laboratories. The data of the clean sand samples (F33, F34, F36, KH, and filter gravel) was kindly provided by Alexander Huisman, Forschungszentrum (FZ) Jülich, Germany. The samples have been saturated with natural water (Binley et al. 2005; samples F33, filter gravel) or a sodium chloride solution (all other samples) with a fluid conductivity of about 100 mS m^{-1}.

However, using a database composed of 63 sandstone and unconsolidated sediment samples covering nine independent investigations (including clayey, silty and clean material), we have identified a single strong, linear relationship between the real part of surface conductivity determined from multi-salinity resistivity measurements and the imaginary conductivity measured with IP at a frequency of about 1 Hz (coefficient of determination of 0.911). This finding implies a more or less fixed ratio between quadrature conductivity and surface conductivity for our samples despite the wide range of mineral composition. Furthermore, the POLARIS model describes this extensive dataset, composed of a wide range of samples including coarse filter gravels, with an assumed single mobility ratio equal to 1/350. Even in the event that the mobility ratios are distinctively different for clay and quartz, our empirical findings indicate that they do not strongly affect the ratios between quadrature conductivity and surface conductivity. Similarly, we find a single strong relationship between imaginary part of conductivity measured at a frequency of about 1 Hz and specific surface per unit pore volume (S_{por}) for 42 samples originating from six laboratories spanning three orders of magnitude of S_{por} covering clean sands (including pure quartz sand), filter gravels, and Fontainebleau sandstones to clayey sandstones as demonstrated by Fig. 1. This finding is inconsistent with the proposed concept of large differences in the mobility ratio between sands and clays. In summary, if differences in the mobility ratios between clay and quartz do exist, experimental evidence suggests that such differences are not important for determining relationships between IP parameters and physical properties.

The strong empirical relations identified in our work can be readily used to significantly improve estimates of formation factor, water salinity and specific surface area in well logging and hydrogeophysical studies. We therefore suggest that, whilst mechanistic models are valuable for providing insights into the possible origin of IP responses, robust empirical petrophysical relations (similar to the classic Archie Law) that satisfy the widest possible range of available datasets may ultimately provide a more reliable means to relate IP measurements to fundamental physical properties of soils and rocks over a wide range of material types.

References

Binley, A., Slater, L.D., Fukes, M. and Cassiani, G., 2005. Relationship between spectral induced polarization and hydraulic properties of saturated and unsaturated sandstone. *Water Resources Res.*, 41, W12417.

Börner, F.D. and Schön, J.H., 1991. A relation between the quadrature component of electrical conductivity and the specific surface area of sedimentary rocks. *Log Anal.*, 32, 612-613.

Lesmes, D.P. and Frye, K.M., 2001. The influence of pore fluid chemistry on the complex conductivity and induced-polarization responses of Berea sandstone. *J. Geophys. Res.*, 106, 4079-4090.

Slater, L.D., Ntarlagiannis, D. and Wishart, D., 2006. On the relationship between induced polarization and surface area in metal-sand and clay-sand mixtures. *Geophysics*, 71, A1-A5.

Weller, A., Slater, L., Nordsiek, S. and Ntarlagiannis, D., 2010. On the estimation of specific surface per unit pore volume from induced polarization: A robust empirical relation fits multiple data sets. *Geophysics*, 75, WA105-WA112.

Weller, A., Breede, K., Slater, L. and Nordsiek, S., 2011. Effect of changing water salinity on complex conductivity spectra of sandstones. *Geophysics*, 76, F315-F327.