Supplementary information on the paper titled: "Spectral induced polarization characterization of non-consolidated clays for varying salinities – an experimental study".

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1. SIP measurements on additional samples.

   Spectral induced polarization (SIP) measurements on the beige montmorillonite sample, and the Boom clay sample, at three different salinities (de-ionised water, ~10^{-2}, and ~1 mol/L NaCl).

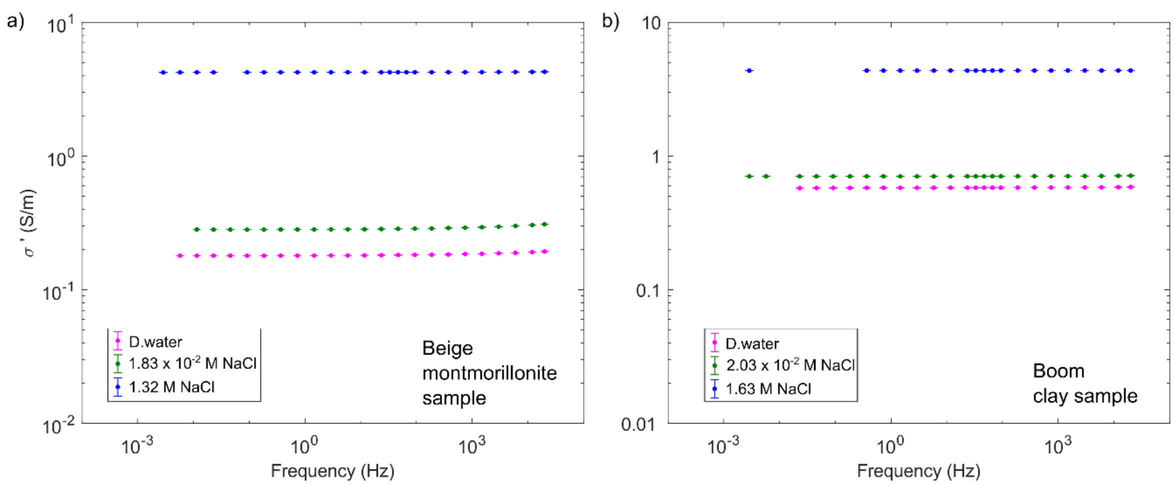

Figure S1: Real part of the complex conductivity per salinity of: a) beige montmorillonite sample, and b) Boom clay sample. The calculated salinity values at which the SIP measurements were collected are presented in the legends of each subplot. Dots with errorbars represent the SIP measured data.

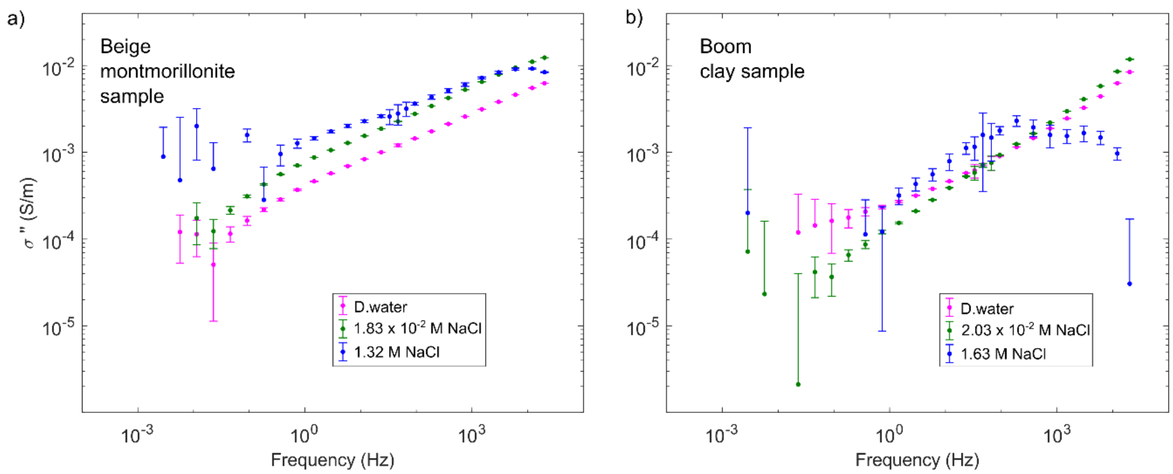

Figure S2: Imaginary part of the complex conductivity per salinity of: a) beige montmorillonite sample, and b) Boom clay sample. The calculated salinity values are presented in the legends of each subplot. Dots with errorbars represent the SIP measured data.

The data presented in Figures S1 and S2 have been filtered with a 5% filter. That is, if the error in the measured amplitude exceeds 5%, we remove the data point.

2. Differentiation of clay minerals.

To compare datasets (red and green montmorillonite samples, kaolinite sample, and illite sample) we calculated a normalized measured conductivity difference ($\Delta\sigma'_N$ and $\Delta\sigma''_N$) between each clay type at 1.46 Hz, for the real and the imaginary conductivities. We calculated Δx_N as:

$$\Delta x_N(f = 1.46\ Hz) = 100 \times \frac{x_1 - x_2}{\frac{x_1 + x_2}{2}}, \qquad (1)$$

where x_N, x_1 and x_2 represent either the real or the imaginary part of the conductivity at 1.46 Hz. Equation 1 is performed for either the real or the imaginary conductivities at 1.46 Hz. Moreover, x_1 and x_2 represent the measurement of an individual clay type at 1.46 Hz.

In the paper we presented the table of the salinity ~10^{-2} mol/L (M) NaCl salinity. Here, in the tables 1, 2, 3, and 4, we present the $\Delta\sigma_N^*$ values for the salinities: de-ionised water, ~10^{-3}, ~10^{-1}, and ~1 M NaCl.

a) De-ionised water:

Table 1: $\Delta\sigma'_N$ and $\Delta\sigma''_N$ (in %) for the initially de-ionised water clay mixtures. The calculations are made using the complex conductivity at 1.46 Hz, the real part ($\Delta\sigma'_N$) is on the lower left triangle (in bold), and the imaginary part ($\Delta\sigma''_N$) is on the upper right triangle (in italics). MtG represents the green montmorillonite sample, MtR the red montmorillonite sample, Ka the kaolinite sample, and Il the illite sample.

	MtG	MtR	Ka	Il
MtG	0.00	*14.00*	*149.08*	*112.30*
MtR	**-21.73**	0.00	*142.51*	*102.32*
Ka	**-96.92**	**-79.37**	0.00	*-63.25*
Il	**-115.92**	**-100.52**	**-26.42**	0.00

b) ~10^{-3} M NaCl salinity:

Table 2: $\Delta\sigma'_N$ and $\Delta\sigma''_N$ (in %) for the initially 10^{-3} M NaCl clay mixtures. The calculations are made using the complex conductivity at 1.46 Hz, the real part ($\Delta\sigma'_N$) is on the lower left triangle (in bold), and the imaginary part ($\Delta\sigma''_N$) is on the upper right triangle (in italics). MtG represents the green montmorillonite sample, MtR the red montmorillonite sample, Ka the kaolinite sample, and Il the illite sample.

	MtG	MtR	Ka	Il
MtG	0.00	*16.31*	*143.23*	*138.88*
MtR	**-4.80**	0.00	*134.79*	*129.93*
Ka	**-97.78**	**-94.09**	0.00	*-8.65*
Il	**-105.49**	**-101.98**	**-10.39**	0.00

c) ~10^{-1} M NaCl salinity:

Table 3: $\Delta\sigma'_N$ and $\Delta\sigma''_N$ (in %) for the initially 10^{-1} M NaCl clay mixtures. The calculations are made using the complex conductivity at 1.46 Hz, the real part ($\Delta\sigma'_N$) is on the lower left triangle (in bold), and the imaginary part ($\Delta\sigma''_N$) is on the upper right triangle (in italics). MtG represents the green montmorillonite sample, MtR the red montmorillonite sample, Ka the kaolinite sample, and Il the illite sample.

	MtG	MtR	Ka	Il
MtG	0.00	*1.85*	*162.12*	*138.28*
MtR	**-8.66**	0.00	*161.48*	*137.31*
Ka	**-9.87**	**-1.21**	0.00	*-54.24*
Il	**-44.89**	**-36.59**	**-35.41**	0.00

d) ~1 M NaCl salinity:

Table 4: $\Delta\sigma'_N$ and $\Delta\sigma''_N$ (in %) for the initially 1 M NaCl clay mixtures. The calculations are made using the complex conductivity at 1.46 Hz, the real part ($\Delta\sigma'_N$) is on the lower left triangle (in bold), and the imaginary part ($\Delta\sigma''_N$) is on the upper right triangle (in italics). MtG represents the green montmorillonite sample, MtR the red montmorillonite sample, Ka the kaolinite sample, and Il the illite sample.

	MtG	MtR	Ka	Il
MtG	0.00	*-41.04*	*154.93*	*154.20*
MtR	**14.82**	0.00	*169.10*	*168.57*
Ka	**20.47**	**5.69**	0.00	*-1.82*
Il	**4.40**	**-10.44**	**-16.11**	0.00

3. Repeatability test

In Figure S3 we present an example of repeatability test. We made two identical sample holder structures, made a green montmorillonite batch with de-ionised water. From the batch, we obtained two samples to be tested independently. We present the SIP signature of the test, and also the percentage difference (as in equation 1 of this supplementary information) of the real and imaginary parts of the electrical conductivity.

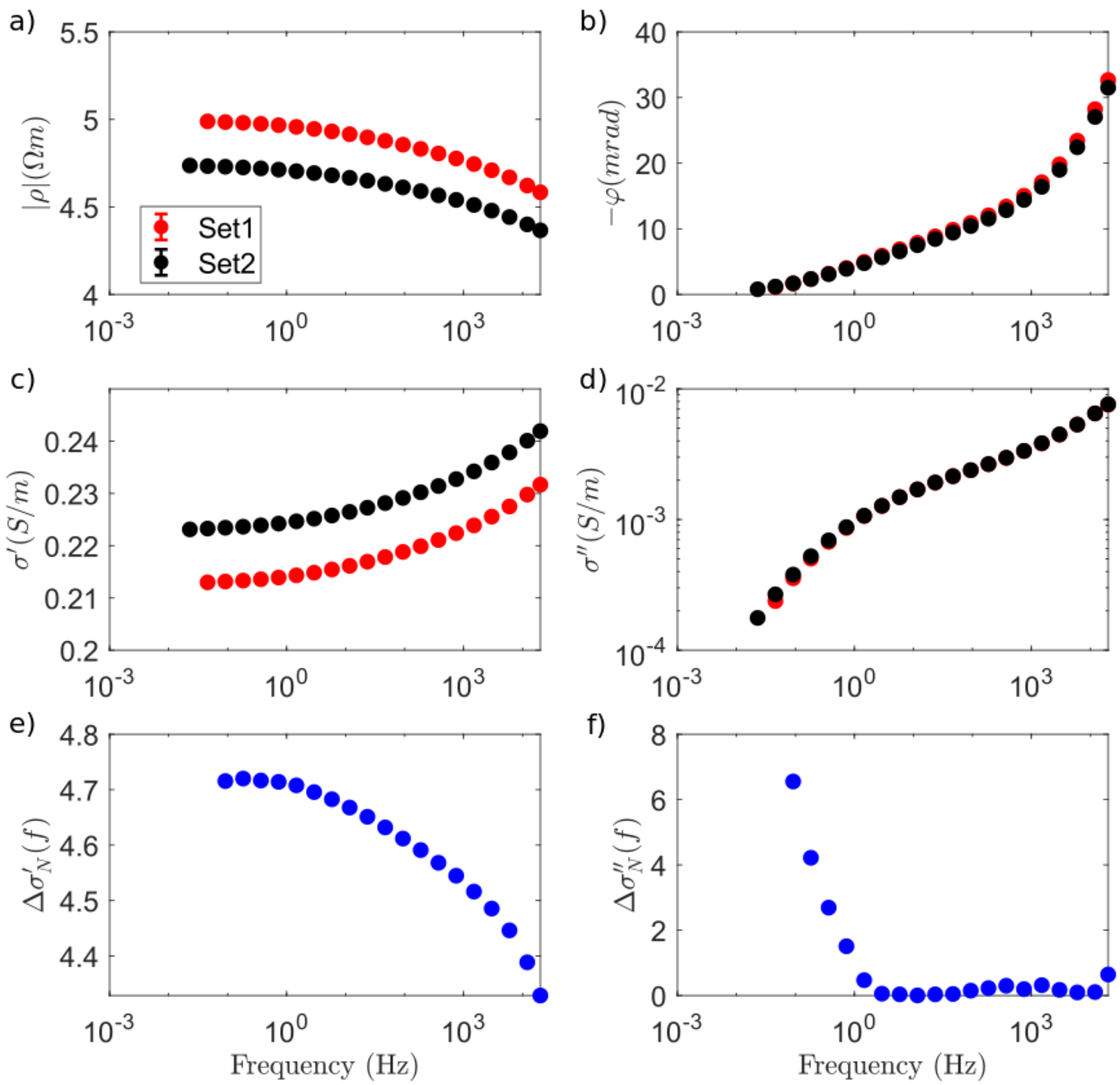

Figure S3: SIP repeatability test for a green montmorillonite using de-ionised water, with two datasets and their a) amplitude, b) phase, c) real conductivity, d) imaginary conductivity, e) percentage difference for the real part of the conductivity, and f) percentage difference for the imaginary part of the conductivity.

4. Relationship between imaginary conductivity at a frequency of 1.46 Hz and surface area per unit pore volume

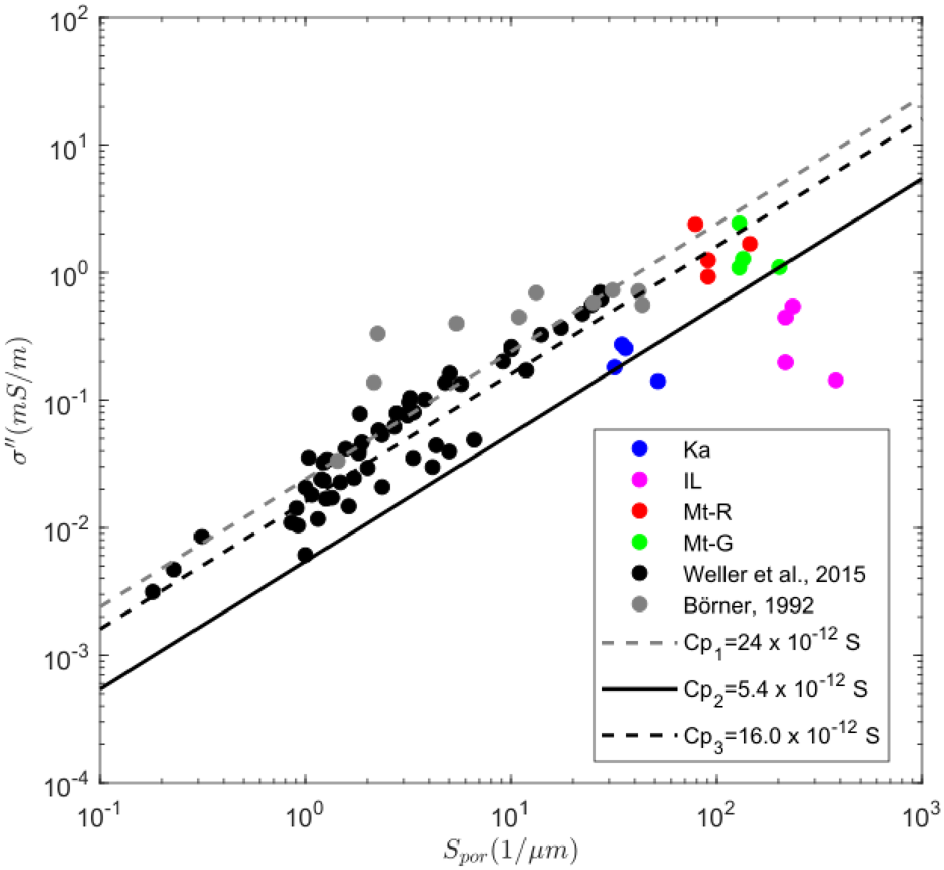

Figure S4: Relationship between σ'' and surface area per unit pore volume (Spor), obtained by BET measurements. We compare our data (in color), to that presented in Weller et al. (2015) and Börner (1992).

In Figure S4 we compare our dataset with that of Weller et al. (2015) and Börner (1992). We present only data points where the surface area per unit pore volume (S_{por}) was measured using the BET method. Weller et al. (2015) propose the relation $\sigma'' = C_p S_{por}$, they find the value of Cp_1 for their dataset. We found a value of Cp_2 for our dataset only, and a value of Cp_3 for all of the datasets together (see figure S4, for the values of Cp). The data extracted from Weller et al. (2015) corresponds to the data presented on their figure 1, consisting only of sand-clay mixtures. The sand-clay mixtures of Weller et al. (2015) vary in clay content from 0.023% and 1.85%. The difference between clay content between the data presented in Weller et al. (2015) and this study could explain the slight difference between the fitted values of Cp.

Data acknowledgment:

The data used in this study will be available at the doi:10.5281/zenodo.4050345 after acceptance of the paper.

References from the Supporting Information

Börner, F. D. (1992). Complex conductivity measurements of reservoir properties. In P. F. Worthington & C. Chardaire-Rivière (Eds.), *Advances in core evaluation: Reservoir management: Reviewed Proceedings of the Society for Core Analysis Third European Core Analysis Symposium* (pp. 359–386). Hardwood Academic.

Weller, A., Slater, L., Huisman, J. A., Esser, O., & Haegel, F. H. (2015). On the specific polarizability of sands and sand-clay mixtures. *Geophysics*, *80*, A57–A61. https://doi.org/10.1190/GEO2014-0509.1