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Can equivalent circuit models be used for the complex conductivity of clayey materials?

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Workshop session: “Tackling ambiguity: Towards a more reliable interpretation of IP signals”

Is the first and presenting author a student? No

Introduction

Clays are very abundant minerals in the Earth’s crust and express a high conductivity response that can be measured at the scale of the geological formation by electrical and electromagnetic methods in geophysics. However, these minerals have a complex microstructure that renders difficult the quantitative petrophysical interpretation of electrical field measurements. In this study, we have developed a new approach to interpret measured spectral induced polarization (SIP) spectra on clay materials in terms of microstructural and electrical double layer properties including surface conductivity using an extension of the mechanistic model developed by Leroy et al. (2017) considering interlayer space and Maxwell-Wagner polarizations.

Modeling strategy

With a minimum set of physical-chemical parameters to be optimized, i.e., the fraction of the counter-charge and cation mobility in the Stern layer, number of stacked solid layers per particle, and clay aggregate size distribution, a fitting procedure is considered. Its aim is to reproduce the measured laboratory SIP spectra in the mHz to kHz frequency range on kaolinite, illite and montmorillonite muds at different NaCl concentrations reported by Mendieta et al. (2021).

Results and discussion

We find that the interlayer space conductivity of Na-montmorillonite (Na-Mt) suspensions should not be neglected and that the surface conductivity concept may not apply to the diffuse layer of clays like Na-Mt because the thickness of the diffuser layer can be higher than Na-Mt particle thickness. We show that Archie’s first law is enough for computing the electrical conductivity of clay muds when water conductivity is modeled considering the diffuse layer contribution (Figure 1). We also test the validity of the petrophysical model of Weller et al. (2013) based on equivalent circuit modeling that is commonly used to interpret laboratory and field SIP measurements on clays in terms of mineralogy, state and transport properties. Our model shows a frequency dependence and a slightly salinity dependence and confirms most of the assumptions of the petrophysical induced polarization model of Weller et al. (2013) for the surface conductivity of clay muds except when they contain a significant fraction of Na-Mt because, in this condition, imaginary surface conductivity may not be approximated by measured imaginary conductivity.

Conclusions and perspectives

Our modeling approach allows extracting surface conductivity from complex conductivity measurements in a more realistic way than petrophysical models based on equivalent circuit

modeling. It needs more physical parameters to be adjusted than equivalent circuit models but shows that equivalent circuit model assumptions may not be valid in all situations like when the sample contains a large fraction of Na-Mt where Archie's first law may still apply and their interpretation in terms of surface conductivity are frequency dependent and slightly salinity dependent. Our study is a step forward to better understand the high conductivity response of clays from geophysical electrical measurements. The next step will be to use a purely numerical model to compute the complex conductivity of clay materials whose geometrical parameters will be constrained by high-resolution characterization measurements.

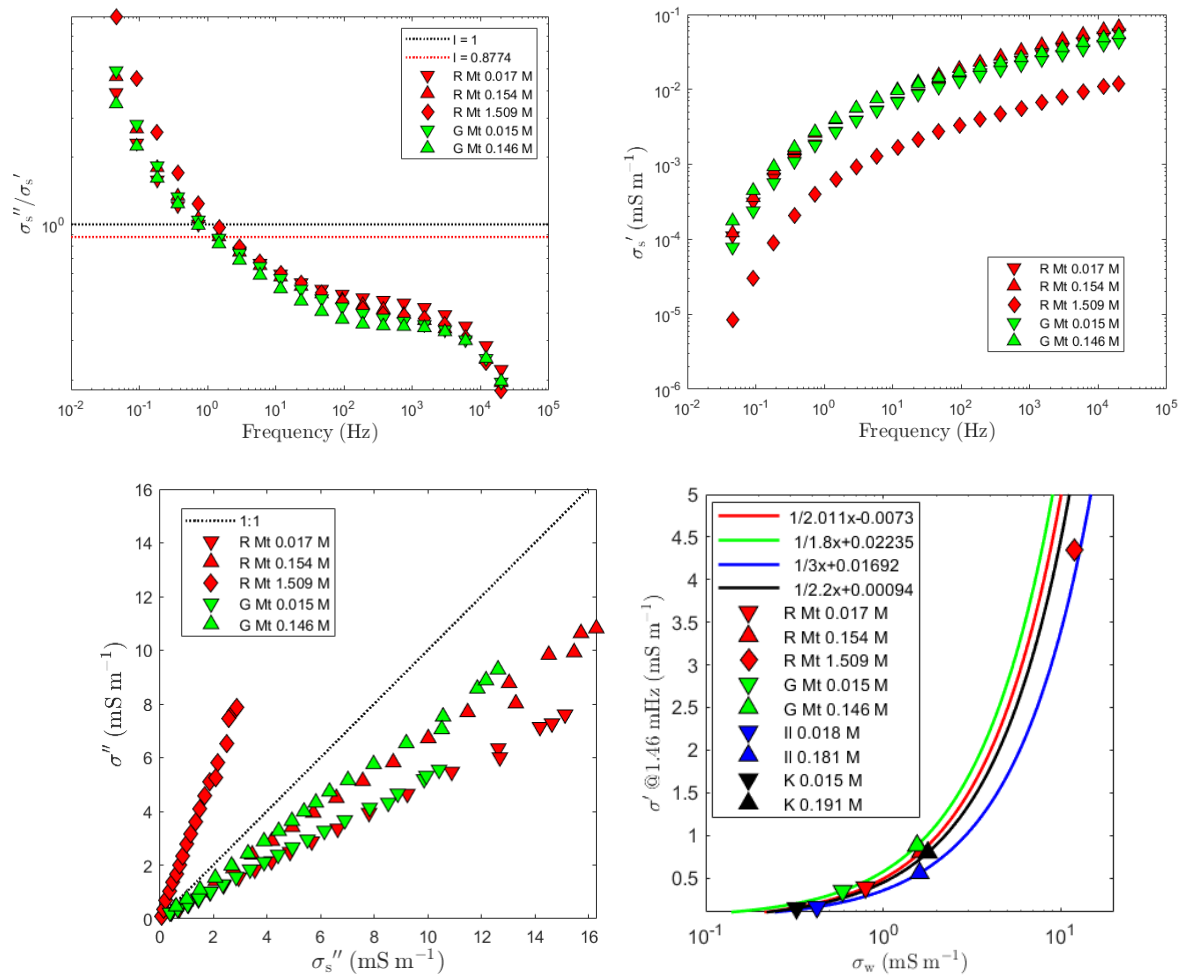


Figure 1: Top and left bottom, imaginary and real components of the modeled surface conductivity and measured imaginary conductivity of clay muds as a function of salinity (NaCl concentration) and frequency. Bottom right: real part of the measured complex conductivity as a function of the modeled water conductivity at different salinities.

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