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Characterization of electrical properties of Beauce Limestones (O-ZNS, France) from SIP measurement.

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Introduction

Water needs is tremendously and continuously increasing, driven by climate change and world population growth. In this context, hydrogeophysics can provide insightful non-intrusive information about groundwater activities. This study considers the Beauce aquifer (O-ZNS platform, France), where its lacustrine limestone vadose zone is characterized by multi-scale heterogeneities. They are defined by the overall complex pore structures and enhanced by diagenetic reactions and weathering processes. This leads to uncertainties for electrical properties estimation, which could be used to predict hydraulic parameters compulsory for flow models and helping aquifer management. In this study, we used complex conductivity measurement combined with other petrophysical analysis in order to relate these properties and ultimately infer the influence of weathering/fracturing on their prediction.

Material and methods

The vadose zone of Beauce aquifer is an extremely complex porous and fractured medium mainly composed by lacustrine limestones (i.e., Beauce Limestones). This vadose zone can be subdivided in two layers: (1) the soil and the unconsolidated limestones and (2) the consolidated limestone on which we focus this study. In order to investigate rock with different (micro) structures, we further subdivided this consolidated limestone into four different facies (A, B, C and C') from which a total of 16 sample were cored. Spectral Induced Polarization (SIP) measurements (Binley and Slater, 2020) were carried out on 8 samples (of 4 cm diameter and ~10 cm length) with the SIP-LAB-IV apparatus using a 4-electrode setup (Jougnot et al., 2010). SIP measurements were performed on fully saturated samples at three different NaCl concentrations with the following conductivities (at 25 °C) 21.4, 86.9 and 956 mS/m, respectively. The sample have been also characterized in term of porosity, permeability and acoustic velocities, together with microstructural analysis.

Results and discussion

We first considered a single frequency (1.46 Hz) to compute the formation factor (FF) and surface conductivity from in-phase conductivity. Yielding to formation factor from 86 to 378 and surface conductivity ranging between 0.0008 and 0.022 S/m. A cementation exponent (m) was then calculated according to Archie's law. Afterwards, we defined for each samples, the ratio between the two component of the complex surface conductivity (σ_{surf}^*) as introduced by Börner et al (1996). The result is then compared (figure 1) to that of the datasets used by Weller et al. (2013). Beauce Limestones ratio values vary from 0.08 to 0.45 and are globally higher compare to those found by Weller et al. (2013) (0.01 to 0.13) and Börner et al. (1996) (0.01 to 0.15) for silicoclastic materials.

The second interpretation approach considered the entire spectrum of complex conductivity and interpreted from fitting a double Cole-Cole model. In general, the SIP spectra are well fitted, especially the quadrature conductivity where the fitting is almost perfect. In total, 7 fitting parameters among which chargeability (M) and relaxation time (τ) are obtained and analysed. Both chargeability and relaxation time show some discrimination according the four defined facies.

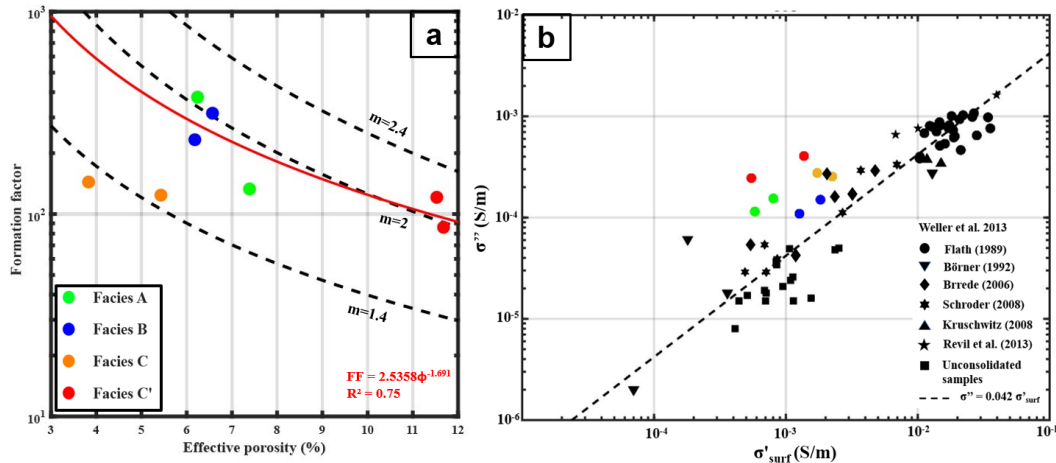


Figure 1. Cementation exponent of Beauce Limestones. a) Plot of FF versus effective porosity: dashed lines: Archie's models with different cementation exponent. Red line: Winsauer (1952)'s model. b) Relationship between quadrature conductivity and surface conductivity for Beauce Limestones compared to siliciclastic dataset from Weller et al. (2013). The quadrature conductivity and surface conductivity were defined at frequency of 1.46 Hz and water conductivity of 86.9 mS/m.

Conclusion and perspectives

The SIP method provides interesting and relevant parameters that are related to pore structures and transport properties, helping us to better characterize carbonate samples than using only the real part of the electrical conductivity. The next step of this work is to predict Beauce Limestones permeability. By using on one hand, the first approach element (FF , m and σ_{surf}^*) and on the other hand the fitting parameters (M , τ) based on petrophysical models more often limited to silicoclastic rocks (Binley and Slater, 2020). The influence of the complex pore structure of our weathered and fractured limestones will be also studied. Finally, we will assess a possible relationship between these complex electrical properties and acoustic velocities.

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