**Experimental study of the complex electrical conductivity of Fontainebleau sandstones**

P. Kessouri[(1)], W.F. Woodruff[(1)] and A. Revil[(1),(2)]

(1) *Colorado School of Mines, Dept. of Geophysics, Golden, CO, USA*
(2) *LGIT, UMR C559, Université de Savoie, 73376 Le-Bourget-du-lac Cedex, France*

Fontainebleau sandstones possess remarkable properties that make them an interesting object to study. Indeed they are composed of pure silica grains (~ 99.8 %) and have a narrow grain size distribution (ranging from 150 to 300 μm with a mean grain size of 250 μm). Moreover, the silica grains can be more or less cemented by silica precipitation, so that the Fontainebleau sandstones have a large porosity spectra ranging from 3 to 30 %. Their study thus represents a good way to test the single influence of porosity in the complex electrical conductivity modelling and measurements.

A set of 67 Fontainebleau sandstones core samples has been studied in terms of complex electrical conductivities, surface conductivities but also porosities. To measure the surface conductivity, the DC electrical conductivity of the samples at 7 different water salinities (from $1.7\ 10^{-3}$ to $18.7\ \mathrm{S\ m^{-1}}$) was measured by a 2 electrodes device working at 4 kHz. The complex electrical conductivity was measured for a water salinity of $6.4\ 10^{-2}\ \mathrm{S\ m^{-1}}$ using a 4 electrodes system linked with the ZEL-SIP04-V02 impedance meter working at frequencies ranging from $10^{-2}$ to $10^{4}$ Hz. On this study we will only use the results at 0.1 Hz, this frequency having a good signal-to-noise ratio. The porosity was measured either using the formation factor and permeability measurements or using mercury intrusion measurements.

In Fig. 1, the intrinsic formation factor $F$ ($F = a\phi^{-m}$ for a saturated medium with a porosity $\phi$ where $a$ is the tortuosity factor and $m$ is the cementation exponent) is compared to the apparent formation factor $F_a$ ($F_a = \sigma_w / \sigma$ where $\sigma_w$ represents the water electrical conductivity and $\sigma$ is the electrical conductivity of the medium). For low water conductivities, until 1000 $\mu\mathrm{S\ cm^{-1}}$, there is a clear variation between the two formation factors. This variation shows the influence of the surface conductivity on the measurements. Until now, the surface conductivity of clay-free sandstones is generally neglected in the modelling. Taking into account these new data, the surface conductivity of clean sandstones needs to be taken into account, especially for low water conductivities, typically in fresh water aquifers contexts ($80 < \sigma_w < 1000\ \mu\mathrm{S\ cm^{-1}}$).

Moreover, the surface conductivity can give some information on the rock state properties. The bulk tortuosity $\alpha$, defined as the intrinsic formation factor $F$ multiplied by the sample porosity $\phi$, is one of these properties. Indeed, for the Fontainebleau sandstones, a linear relationship exists between the log of the measured surface conductivities and the log of the bulk tortuosity (Fig. 2a). A similar relationship is observed between the measured quadrature conductivity and the bulk tortuosity (Fig. 2b). The same bulk tortuosity of the pore space can thus be used to evaluate the bulk and surface conduction processes. An interesting relation can also be found between the quadrature and the surface conductivity of the sandstones. These relationships are important because they can significantly improve the estimation of porosity, formation factor and salinity using IP measurements at only one water salinity.

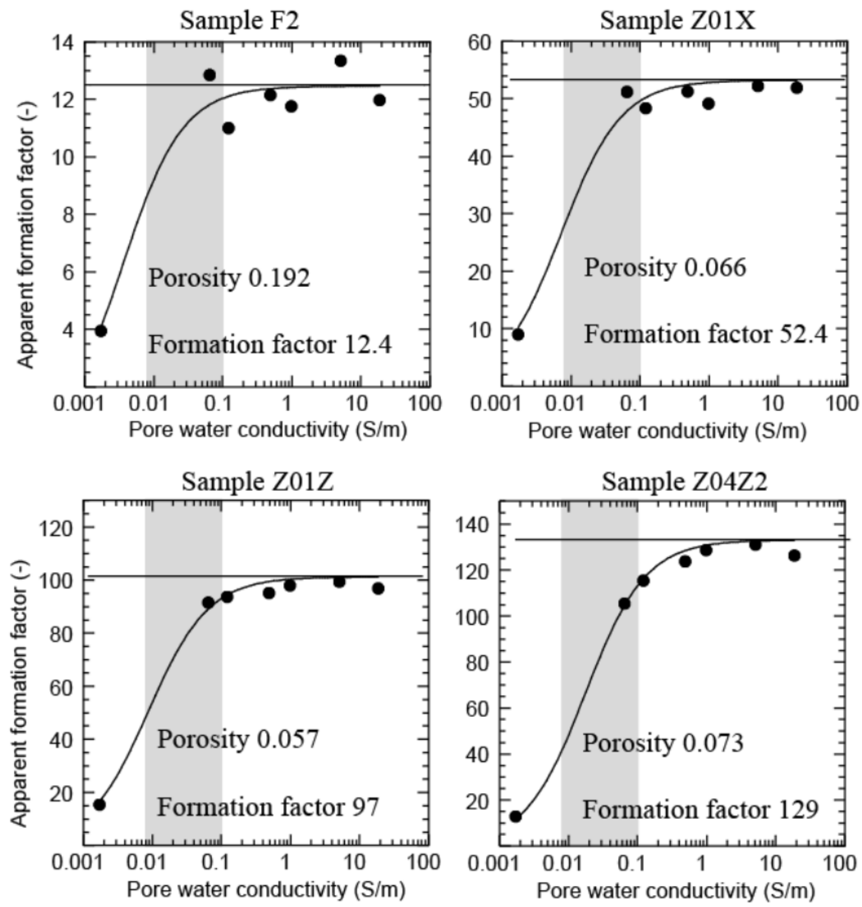


*Fig. 1: Relationship between apparent formation factors $F_a$ (defined as the ratio of the conductivity of the pore water by the sample conductivity) and intrinsic formation factors F ($F = a\phi^{-m}$ for a saturated medium with a porosity $\phi$ where a is the tortuosity factor and m is the cementation exponent). The horizontal line identifies the value of the intrinsic formation factor F while the continuous line identifies a fit with the equation $\sigma = \sigma_w/F_a+\sigma_s$ in terms of apparent formation factor. The grey areas correspond to typical conductivity values of fresh water aquifers (80 to 1000 $\mu S\ cm^{-1}$).*

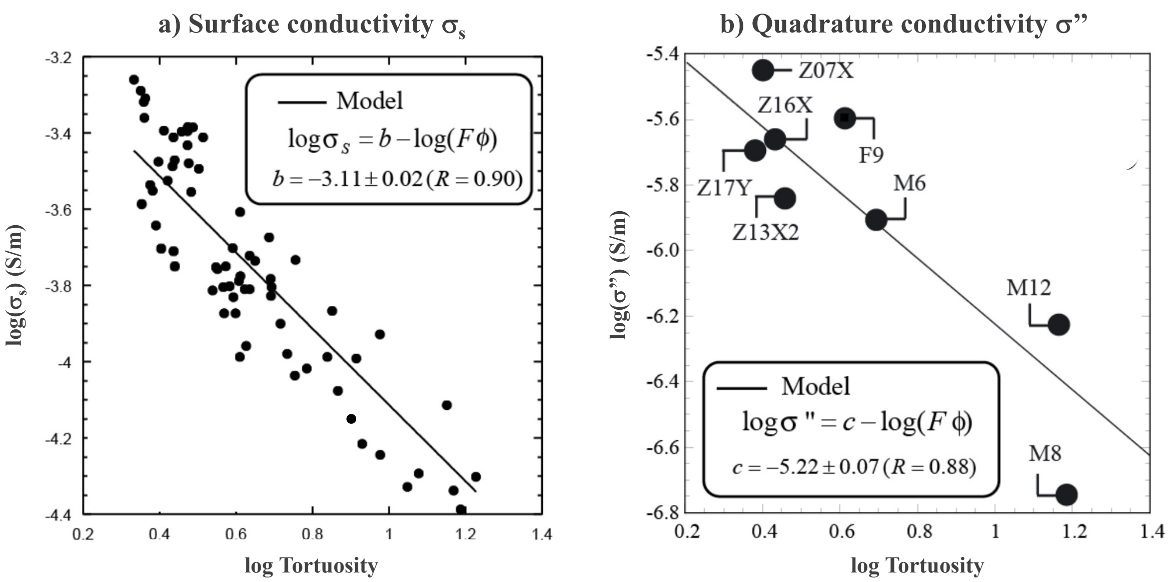


*Fig. 2: a) Surface conductivity $\sigma_s$ and b) Quadrature conductivity σ" versus bulk tortuosity of the pore space ($\alpha = F\phi$ with F the formation factor and $\phi$ the sample porosity). The straight lines correspond to the best fit of the model equation.*