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Influence of Pore Structure on SIP Properties Deduced from Micro-Scale Modelling

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In geophysics frequency dependent complex resistivity measurements are called Spectral Induced Polarization (SIP). In other fields this method is known as Impedance Spectroscopy. In the last two decades many empirical relations were proposed which relate the frequency dependent electrical properties of water saturated rocks to structural properties such as pore radius and inner surface area, or to hydraulic conductivity. Unfortunately, these relations are not universal; they apply only for specific rock types and water compositions. In order to quantify the influence of inner rock structure (as well as of electrochemical water and rock properties) on the frequency dependent electrical properties we model the charge transport processes at the pore space using Comsol Multiphysics. In the frequency domain the effect of Induced Polarization (IP) is characterised by a phase shift between a measured electric current and an alternating voltage applied to the ground. A possible origin of this behaviour particularly for nonconducting rock minerals can be seen in the membrane polarization model as proposed by Marshall and Madden. This model describes a system of electrolyte filled pores. Different mobilities of cations and anions in the small pores cause a membrane effect and thus an electrical polarization. We aim to find a more realistic way of modelling the membrane polarization effect than using the simple Marshall and Madden model. The electric double layer, the origin of the Induced Polarization effect, is caused by surface charges located at the electrolyte rock interface. Thus, the EDL as a boundary effect is accounted for by reduced ion mobilities at the inner surface area. The governing equations and boundary conditions for a system of larger and smaller pores with applied voltage are expressed in frequency domain using a time harmonic approach, the electric current is determined to obtain information about amplitude and phase of the complex resistivity. The results are compared to corresponding theoretic and experimental results. The model is applied to study the influence of pore sizes and pore structure as well as of electrolyte properties like ion mobilities and concentrations.

We find two characteristic phase minima in the frequency range 1mHz – 100MHz. The dependence of the 'high frequency' minimum (f > 10kHz) on the electrolyte concentration and the dependence of the corresponding relaxation times on variations of the pore geometry are in good agreement with the classical Maxwell-Wagner theory. In contrast to this effective medium approach the simulations confirm the necessity of pore throats to obtain non-vanishing phase values. For large size differences of the smaller and larger pores a second 'low frequency' minimum (f < 10kHz) exists. Its relaxation time mainly depends on the length of the large pores of the system. Furthermore we find a decreasing phase amplitude with increasing electrolyte concentration not predicted by Marshall and Madden and similar models but confirmed by experimental results.

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