Geophysical Research Abstracts
Vol. 14, EGU2012-12939, 2012
EGU General Assembly 2012

Transient electrokinetic response of finely layered, fluid-filled porous media

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Transient electrokinetic coupling phenomena created at the microscopic scale by the passage of seismic waves through fluid-saturated porous media generate conversions between seismic and electromagnetic (EM) energy which can be observed at the macroscopic scale. Far from being a mere scientific curiosity, transient seismoelectric or electroseismic phenomena are especially appealing to oil and gas exploration and hydrogeology as they open up the (fairly unique) possibility to characterize fluid-bearing geological formations with the resolution of seismic methods. Indeed, electrokinetic effects are likely to reconcile the sensitivity of electromagnetic exploration methods to fluids with the high resolving power of seismic prospecting techniques for structural imaging, thus naturally bridging the gap between these two important geophysical investigation means. Accounting for the electromagnetic dimension of the seismic wave propagation, or conversely, accounting for the seismic dimension of electromagnetic wave propagation gives new insights into the microstructure and physico-chemistry of fluid-filled porous or fractured media.

We present full-waveform simulations of the coupled seismoelectromagnetic wave propagation in fluid-saturated, finely stratified porous media of interest to oil and gas exploration. Our simulation code uses the macroscopic governing equations derived by Pride [1994], which couple Biot's theory and Maxwell equations via flux/force transport equations. The synthetic seismoelectrograms and seismomagnetrograms are computed by extending the generalized reflection and transmission matrix method and by using a discrete wave number integration of the global reflectivity obtained in the frequency wave number domain. The theoretical signals clearly display the coseismic electric and magnetic fields travelling with the seismic disturbances as well as the seismic-to-electromagnetic conversions taking place at contrasts in solid and fluid properties. Our computer code also allows us to compute partial solutions to the full response, notably plane-wave solutions, and solutions in which particular wave conversions or multiple reflections are cancelled. Gradients of properties are simulated by considering stacks of thin layers.

We first investigate the sensitivity of the electrokinetic response to the mechanical and electrical properties of thin layers whose thickness is on the order of 1/20th of the incident seismic wavelength. Unlike seismic measurements, seismo-electromagnetic signals are shown to be sensitive to very thin heterogeneities, therefore yielding a "super-resolution" of the probed structures. Next, we consider stacks of thin strata representing a sandstone hydrocarbon reservoir in order to study its response to various water, oil and gas saturations including the capillary effects. These simulations underline the potential of electrokinetic conversions to improve the characterization of fluid-filled porous rock formations.