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Anatomical and morphogenetic analysis of seismoelectric conversion patterns at geological units

B. Kröger and A. Kemna
University Bonn, Germany (kroeger@geo.uni-bonn.de)

Characterisation of the hydraulic properties of a reservoir, such as porosity and permeability, and their spatial distribution plays an important role in many subsurface geophysical investigations. A fully developed seismoelectric exploration method is very appealing since it would offer the potential to directly determine these parameters in field-scale applications. In fluid-saturated rocks, seismic waves can generate electromagnetic fields, due to electrokinetic coupling mechanisms at the fluid-mineral interface. Using numerical modelling, we investigated the spatio-temporal occurrence and evolution of the seismoelectric effects that occur in spatially confined lithological units. Such geometries may represent clay lenses embedded in an aquifer or petroleum deposits in a host rock.

For the modelling, we use a simplified time-domain formulation of the coupled physical problem and its efficient implementation in a 2D finite-element framework. Two occurring seismoelectric phenomena are investigated: (1) the co-seismic field associated with the seismic displacement at each point and (2) the interface response generated at layer boundaries. To gain insight into the morphogenetic field behaviour of the seismoelectric effects, we run numerical simulations using several material parameter set-ups for various target geometries. Accordingly, we varied both the thickness of the confined units and the value of the electrical bulk conductivity in the considered media. The analysis of the seismoelectric effects revealed an important difference in the generation of the interface response at either electrically conductive or resistive units. We find that the contrast in the electrical bulk conductivity between the host rock and the target geological unit controls the shape and structure of the seismoelectric conversion patterns. Our results show that the seismoelectric interface response captures both the petrophysical and geometrical characteristics of the converting geological unit. The considered models indicate the general potential of using the seismoelectric interface response for reservoir characterisation in hydrogeological or hydrocarbon exploration studies.