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Towards Seismoelectric Inversion: Sensitivity Analysis using Resolution Functions

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When a mechanical wavefield propagates through a porous, fluid-filled medium, a complex physical phenomenon called the seismoelectric effect can occur. Due to the presence of an electrical double layer at the microscale, coupling between the mechanical wavefield

and electromagnetic fields can occur. Pride (1994) has developed a set of governing equations that describes the seismoelectric effect using Biot's poroelasticity equations coupled to Maxwell's electromagnetic equations. Coupling effectively takes place at two locations:

1) Inside the seismic wavefield, copropagating with the seismic wave velocity and therefore referred to as the coseismic field. This field provides us with local information in the vicinity of the receivers.

2) At locations where contrasts in medium parameters occur (for example interfaces) an independently diffusing electromagnetic field is generated, referred to as the interface

response field or seismoelectric conversion. The seismoelectric method tries to take advantage of this subsurface coupling as a geophysical tool for exploration or monitoring purposes, as well as for borehole applications. Besides providing us with seismic resolution and electromagnetic fluid–sensitivity at the same time, several studies have also shown that seismoelectric fields can provide us with supplemental information about porosity, permeability and pore-fluid properties such as viscosity. The seismoelectric method can potentially be used for the detection and monitoring of oil/water contacts, several (near–)borehole applications and the monitoring of aquifers.

However, the seismoelectric effect is described by a combination of many (often mutually related) subsurface parameters. Therefore, inversion of seismoelectric data for a specific parameter is costly and solving for such a parameter uniquely might be even impossible. By carrying out sensitivity analyses prior to inversion, we can investigate whether the measured fields are actually sensitive to the parameter(s) of interest. In addition, sensitivity analyses can provide information about the optimal acquisition design or help us investigating time–lapse perturbations. We will start by explaining the theory of resolution functions using a seismoelectric example. We will derive the seismoelectric resolution function for inversion for a bulk density contrast. We will compute this resolution function as the least-squares solution to the normal equation. We will demonstrate the effectiveness of this method by first carrying out a purely electromagnetic sensitivity analysis for a point perturbation in conductivity. These results will be compared with literature results. As a next step, we investigate the electromagnetic sensitivity to point scatterers above and below highly conductive layers. Finally, we will present the results of the fully–coupled seismoelectric sensitivity analysis for a bulk density contrast, using single–frequency multicomponent line data.

Keywords: Seismoelectric, electromagnetic, resolution function, sensitivity analysis