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Modelling electromagnetic responses from seismic data

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The paper considers the problem of recovering subsurface resistivities from controlled source electromagnetic (CSEM) data. CSEM data obey a diffusion equation in a conducting earth. Methods used in the processing of seismic data, which obey the wave equation, do not apply to CSEM data and there is no theory that allows resistivities to be extracted directly from CSEM data.

The conventional approach is to perform iterative forward modelling, or inversion. Synthetic data are created using the data acquisition configuration and a subsurface resistivity model. The model is adjusted until the synthetic data fit the measured data. However, there are many different models that fit the data equally well and it is a problem to select the range of most likely models. Constraints are required. Seismic data yield complementary information, which can constrain the range of possible resistivity models that fit the data.

We present a methodology to estimate resistivities from seismic velocities. We apply known methods, including rock physics to transform velocities into resistivities, depth trends to account for depth-dependent rock parameters, structural information to include lithology variations, and uncertainty analysis to estimate the error of the data, the physical parameters, and the model itself.

The result of applying this methodology to data in the neighbourhood of the CSEM data is a range of background resistivity models that is consistent with the known seismic velocities. We successfully apply our methodology to real data from the North Sea. We use a well log from a well in a field nearby to calibrate our model, and well logs from our study field to verify our transform. The transform proves robust at depths where we have well control, but uncertainty remains in the shallower and deeper sections.

We use these background resistivity models to calculate synthetic electromagnetic responses, and compare them with measured multi-transient electromagnetic data. Our initial resistivity model represents the horizontal resistivities, as we calibrate our transform with resistivity measurements from (almost) vertical well logs, which measure horizontal resistivity. Since the study area contains horizontally-layered sediments in the shallow part, this allows the shallow section to be approximated by a one-dimensional (1D) model. CSEM data at short source-receiver offsets are sensitive to the shallow layers. Allowing the shallow layers to be anisotropic in 1D inversions of the measured CSEM data improves the agreement of the synthetic and real data. The shallow section of the background resistivity model is improved and an estimate of the anisotropy is obtained. Separate step response and impulse response anisotropic inversions are used to determine the most accurate anisotropy factor.

This approach yields a detailed background resistivity model from seismic velocities. We believe this is far better than the usual approach of a uniform resistivity background, or a resistivity background from fast, unconstrained 1D inversions. The next step is to create in this way a three-dimensional resistivity background model, and compare the resulting CSEM responses to the measured CSEM data.