Permeability estimation based on elastic waveform inversion of microseismic data – A Feasibility Study

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Introduction

Microseismic usually provides us with information on the source locations, timing, and mechanisms of the natural or induced seismic events (Droujinine et al., 2011). The real challenge for microseismic is permeability estimation. There are at least two techniques for estimation of in situ rock permeability from microseismicity. The first technique, called *r-t* approach, derives the formation permeability from the rate of growth of a cloud of microseismic events triggered by the fluids injected from a point source (Shapiro et al., 2006). The second technique, called inversion approach, assumes fluid diffusion from the faces of an already created hydraulic fracture and is based on direct inversion of the 1D diffusion equation for the permeability (Grechka et al., 2010).
In this work we try the third approach for estimation permeability based on elastic full waveform inversion of microseismic records. That brings up the question of whether permeability information is present in seismic data (Pride et al., 2003). Recent tries (de Barros et al., 2010) in a full waveform inversion of seismic waves reflected in a stratified porous medium confirmed that permeability is the most poorly estimable parameter. Nevertheless, we try to use the simplest version of Biot's theory in order to establish dependence of a wave field on the rock permeability. We show that it is possible, in principle, to estimate the rock permeability by elastic full waveform inversion of microseismic records under the rather idealized conditions. We examine stability of the method to noise in a source wavelet and to errors in a velocity model.

Method

In order to solve the forward problem we firstly formulate elastic wave scattering by a point elastic heterogeneity in the Born approximation following to the work of Wu and Aki, 1986. The only difference is that we formulate such a problem in terms of velocity-density perturbations. At second step we establish linkage between the velocity perturbations and the rock permeability using Biot's theory. We use P- and S-wave velocities from the article of Ben-Menahem and Gibson, 1993, which correspond to the plane wave solutions of the spectral equation of motion of an isotropic poroelastic medium in terms of four independent scalar functions (Boutin et al., 1987). We use the real and imaginary parts of the frequency dependent velocities in the perturbed medium within the inclusion assuming that the velocities in the background medium are pure real and do not depend on frequency. As a result we obtain the wave field representations in the Born approximation that depend on the rock permeability. We use the 3D crosswell geometry with the irregular distribution of receivers. We put the inclusion between the horizontal and vertical wells so that the source-receiver distance for each pair would be in the range 200-300 *m*. When the focal mechanism is assumed to be constant in time during the rupture process, all of the components of the moment tensor have the same source time dependence. We use Ricker wavelet as a source function and the far-field terms of a double-couple solution in a homogeneous isotropic medium as a Green function (Aki and Richards, 1980). We assume that the location, timing, and mechanism of the induced event are exactly known. In addition, we use parameters of media used in the paper of Carcione et al., 2010.

We solve the inverse problem using both the grid search method (the direct minimization technique) and a quasi-Newton algorithm to minimize a misfit (cost) function between the observed and synthetic elastic (P + S) wave fields. Both techniques require conventional data preprocessing including trace normalization and time-domain gating of the observed displacements.

Results and conclusions

The estimation of poroelastic properties of reservoir rocks is a very important and topical problem. In this work we focused on the permeability estimation. Assuming that the input data were obtained during hydraulic fracturing experiments, our goal was to estimate the rock permeability using full waveform inversion of microseismic records. In this work we have successfully tried the elastic full waveform inversion of the rock permeability on the synthetic data in the Born approximation generated for the crosswell (the vertical and horizontal well) geometry with the irregular distribution of receivers. We used a quasi-Newton algorithm to minimize a misfit function between the observed and synthetic elastic (P + S) wave fields. We also used the grid search method to show a cost function behavior. Prior to inversion we used trace normalization and time-domain gating of the observed displacements. Assuming that the true permeability has a high value, we have done a set of numerical tests in order to study stability of the method to noise and velocity model errors. We have shown that our method is rather stable to noise, if the initial value of permeability is close to the exact one. However, even 5% errors in a velocity model can lead to method failure. It would be reasonable to fit a velocity model simultaneously with a permeability inversion.

Acknowledgements

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