Geophysical Research Abstracts
Vol. 13, EGU2011-4607-1, 2011
EGU General Assembly 2011
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Feasibility of estimation of vertical transverse isotropy from microseismic data recorded by surface monitoring arrays

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Hydraulic fracturing is a technique for increasing the reservoir permeability and consequently the production rate of natural gas and oil. It involves injecting high-pressured fluids into the reservoir formations to open existing or to create new fractures. This process induces microseismic events. Before starting the injection operations, perforations are shot in the stimulated well to create openings through the casing and establish communication between the wellbore and the reservoir. These perforations can be used to invert seismic velocities as their positions are known with a high precision.

Hydraulic fracturing treatments can be monitored with surface star-like arrays of receivers centered at the wellhead (Duncan and Eisner, 2010). Arrival times recorded at the surface from microseismic events or perforation shots can be inverted to estimate their origin times and locations, as well as the velocity, the Thomsen anisotropy parameter δ (Thomsen, 1986) and the anellipticity coefficient η (Alkhalifah and Tsvankin, 1995) of a vertically transversely isotropic (VTI) medium. We consider the P-wave traveltime inversion for homogeneous VTI media. This is a well established inversion technique in active seismic (e.g., Grechka and Tsvankin, 1998; Grechka, 2009). The inversion algorithm minimizes the sum of time residuals from the difference between the picked arrival times and traveltimes computed with the nonhyperbolic moveout equation given by Alkhalifah and Tsvankin (1995) in the form

$$t^2(x) = t^2(0) + \frac{x^2}{V_{NMO}^2} - \frac{2\eta x^4}{V_{NMO}^2\left[t^2(0)V_{NMO}^2 + (1+2\eta)\,x^2\right]}, \tag{1}$$

where, for microseismic applications, $t(0)$ is the one-way vertical time, x is the offset (surface projection of the source-receiver distance) and V_{NMO} is the normal-moveout velocity. The latter relates to the P-wave vertical velocity V_{P0} and to Thomsen parameter δgs

$$V_{NMO}^2 = V_{P0}^2(1+2\delta).$$

For passive seismic monitoring, the measured arrival time $t_a(x)$ is given by

$$t_a(x) = t_t(x) + t_0, \tag{2}$$

where $t_t(x)$ is the traveltime in the subsurface and t_0 is the origin time. The above formulation assumes a homogeneous VTI medium, which is an acceptable approximation for effective anisotropy of horizontally layered sedimentary rocks (Grechka and Tsvankin, 1998).

Measured arrival times can be affected by picking noise. Moreover, the locations of perforation shots are known with a limited precision, which depends on the accuracy of a well-deviation survey (e.g., Bulant et al. 2007). The vertical P-wave velocity can be obtained from active seismic (e.g., check shots) and it can also contain errors. In this study, we investigate the sensitivity of this inversion technique to inaccuracies in the input parameters.

We compute synthetic arrival times by ray tracing and perturb them with Gaussian noise. Inversions of these noisy arrival times show high sensitivity of the anellipticity coefficient η and Thomsen parameter δ to the noise level, whereas the origin times are estimated accurately. Large offsets of the receivers and their greater number along each line improve the anisotropic parameters estimation. The root-mean-square of the time residuals appears to provide a good indication of the quality of the inverted anisotropic parameters.

Uncertainties in both the vertical velocity and the source depth strongly influence the origin time, the anellipticity parameter, and Thomsen coefficient δ resulting from the inversion procedure. The root-mean-square of the time residuals can be low even when the three inverted quantities are grossly incorrect, which emphasizes the importance of using accurate vertical velocity and source depth for the inversion.

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