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P- and S- wave attributes in monitoring shale gas reservoirs

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Summary

Microseismic methods are usually employed to locate fracture network induced during hydraulic fracturing of a shale gas reservoir. Injection of hydraulic fluids in shales alters the rock properties. P- and S-wave characteristics of the shales are modified in terms of velocity anisotropy and attenuation. These changes are in turn reflected in the observed microseismic signals. In this paper, I have shown how P- and S-wave amplitude and frequency attributes are affected due to attenuation caused by hydraulic fluids injected into the shale reservoir. I have used full waveform synthetic seismogram for this purpose. Elastic parameters of Barnet shale is used in the modeling. It is observed that though amplitude and frequency both decrease with increasing attenuation, it is the relative change in P- and S- wave amplitude and frequency that can be utilized to characterize attenuation in the shales.

***Keywords**: Shale gas, Anisotropy, Attenuation, Amplitude, Frequency*

Introduction

Shale gas reservoirs are commonly produced by massive scale hydraulic fracturing which in turn creates permeable pathways in the impermeable shales. Fractured volume of the rock is mapped using microseismic signals captured by multicomponent geophones installed either in the boreholes or on the surface (Maxwell, 2011; Eisner et al., 2011; Abaseyev et al., 2009; Vikhoreva et al., 2011).

In the process of hydraulic fracturing of shales, huge amount liquid along with proppant is injected into the shales thereby changing the viscoelastic property of the rock. Thus, highly fractured area of the reservoir would be more attenuating compared to its less fractured or unstimulated part of the reservoir. Eaton (2011) obtained attenuation parameters for P- and S- waves using spectral ratio method from microseismic data in Canadian shales.

Shales are treated as a transversely isotropic (TI) medium because of layering of clay minerals forming the rock. Thomsen (1986) listed anisotropic parameters for various shales. Anisotropy in combination with attenuation is studied with the help of full wave synthetic seismograms on Barnet shales. Amplitude characteristics are studied using the radiation pattern (Sinha et al, 2011) and frequency characteristics using time-frequency maps (Sinha et al, 2005).

Methodology

Plane wave propagation in an anisotropic medium is described by the Green-Christoffel equation (Musgrave, 1970).

$$(\Gamma_{ik} - \rho v^2 \delta_{ik}) u_k = 0$$

where $\Gamma_{ik} = C_{ijkl} n_j n_l$. is the density and u_k is the displacement (polarization) vector. C_{ijkl} is a fourth rank tensor for the elastic constants and n_j and n_l are direction cosines.

Attenuation in a medium is included as a quality factor (Q) as below (White, 1965):

$$C^*_{ijkl} = C_{ijkl} + i\frac{C_{ijkl}}{Q}$$

In general Q can be anisotropic; however, the same values of Q to P- and S-waves are chosen in order to investigate amplitude attenuation with respect to Q.

In order to generate full waveform synthetic seismograms, I have used reflectivity method (Kennett and Kerry, 1979; Fryer and Frazer, 1984). A layer matrix approach is followed, where columns of the layer matrix represent upgoing and downgoing waves for each wave types and rows represent Cartesian components of polarization and

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traction vectors. It facilitates the task of solving the boundary value problem of wave propagation throughout a stack of welded layers.

For synthetic seismogram modeling purposes, I have used following elastic parameters (Table 1) with Type I and Type II as alternating layers. Furthermore, for radiation pattern Type I is used with varying attenuation coefficients.

Cs	Type I	Type II
C_{11}	21.26	59.4
C_{33}	17.63	42.42
C_{44}	5.32	15.27
C_{66}	8.99	19.7
C_{13}	6.97	15.82
ρ	2.34	2.37

Table 1: VTI elastic coefficients (in GPa) and density (gm/cc) used for multilayer modeling with reflectivity method.

Spectral decomposition based on continuous wavelet transform, TFCWT (Sinha et al. 2005) is used to analyze frequency characteristics of the seismogram. The primary reason to use TFCWT is that it preserves the entire signal character, unlike matching pursuit decomposition.

Results and Discussions

A series of microseismic data recorded from Barnet shale hydraulic fracturing are shown in Figure 1. As expected S-wave amplitude is much higher compared to P-wave amplitude. From radiation pattern modeling, amplitude variation with changing values of Q is shown in Figure 2. We observe that for the values of Q below 100, P- and S-wave amplitude become comparable and for Q = 10, the P-wave amplitude even becomes greater than the S-wave amplitude.

The synthetic seismograms were generated for a multilayered model with Q equal to 100 and 10. Only radial components of the polarization vector are shown for the two models (Figure 3a). A spectral decomposition map of trace 1 is plotted in Figure 3b and partly enhanced to plot as Figure 3c. A spectral decomposition map for trace 2 is plotted in Figure 3d. Note that for Q values of 100 and 10, the dominant frequency is around 100 Hz and 50 Hz, respectively, as shown by small arrows on frequency axes in Figures 3c and 3d. This clearly shows that with increasing attenuation, dominant frequency decreases. Furthermore, by comparing Figures 3b and 3d, we can say that radiation energy shifts from S-wave to P-wave as attenuation increases.

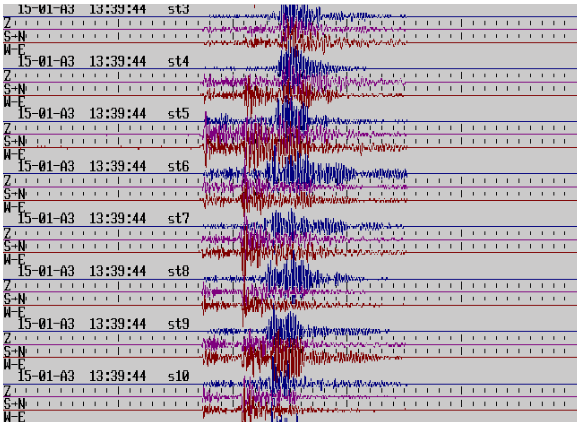

Figure 1: Example of microseismic data for a number of multicomponent geophones. Vertical component is in blue color and two horizontal components are in purple and red colors.

Conclusions

From full waveform synthetic seismogram modeling, we observe that attenuation in the range of 10 to 100, amplitude and frequency characteristics of seismic signals are affected significantly to be observed. Shales are reported to have quality factor (Q) in this range. Thus, amplitude and frequency attribute analysis of microseismic data can help delineating the extent of fracturing in shales. This approach can also be useful in heavy oil studies.

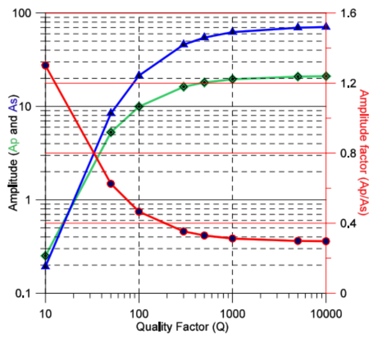

Figure 2: Change in P- and S-wave amplitudes with respect to attenuation (inverse of Q) are plotted in green and blue colors, respectively. Amplitude factor is the ratio of P- and S-wave amplitudes and is shown red color.

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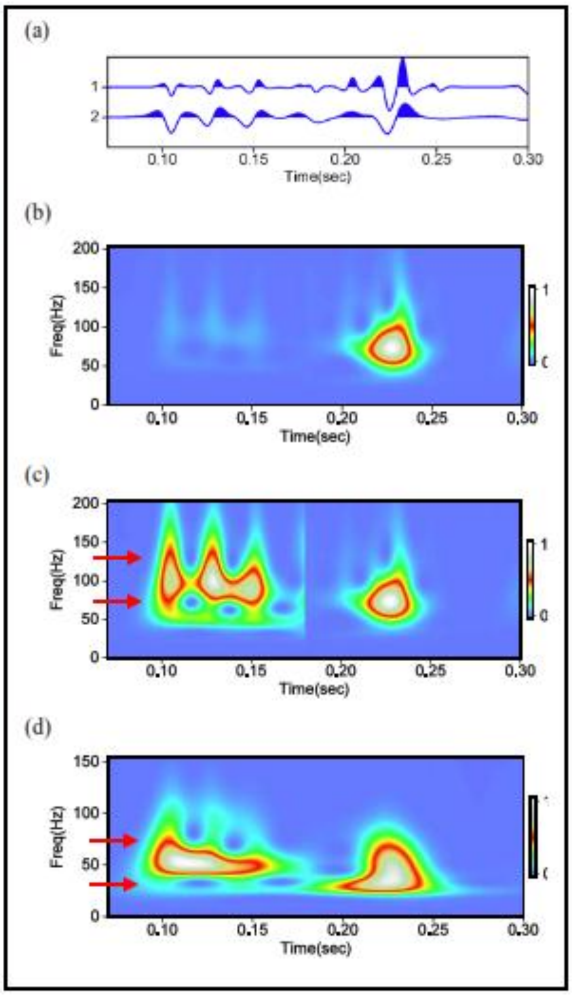

Figure 3: (a) Synthetic seismograms for Q = 100 (trace 1) and Q = 10 (trace 2) (b) Spectral decomposition of trace 1 and partly enhanced amplitudes between 0 and 0.18 sec (c). (d) spectral decomposition of trace 2.