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Multiples or Residual Moveout: The Presence of Which Noise Type in Seismic is Worse for Wide Angle AVO Inversion

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Summary

The quality of reservoir properties estimated from seismic data depends on the quality of input seismic data and favorable rock physics relationships. The seismic data, input to amplitude-versus-offset (AVO) inversion, is assumed to have gone through amplitude friendly seismic data processing. But, even after careful processing, there are always some noise present in seismic data, and the two commonly noise types present in processed seismic data are multiples and residual moveout. These noises will affect seismic inversion for rock property like impedance, and therefore reservoir property prediction from seismic. Out of these two noise types, the presence of residual moveout is worse for prestack seismic inversion and is also more difficult to attenuate from seismic data. Residual moveout of 10ms at the far angle of 60 degrees in seismic angle gather is common and this residual moveout is more problematic than multiples. We can reduce the effects of residual moveout on seismic inversion by not using far angles data but that will affect the quality of inverted rock properties, especially shear impedance and density. I will discuss the effects of these noises in wide angle AVO inversion with a synthetic seismic data example.

Introduction

Amplitude-versus-offset/angle (AVO/AVA) inversion of prestack seismic data provides spatial distribution of rock properties (e.g., impedance, density), which can be used along with an appropriate rock physics model to estimate reservoir properties (e.g., porosity, volume shale). It is the rock physics relationship derived from well logs that dictates which one or more rock properties (P-impedance, S-impedance, and density) is/are needed to estimate reservoir properties. The quality of estimated reservoir properties from seismic data depends on the favorable rock physics and high quality inverted rock properties. For lithology and fluid information, P-impedance is not sufficient and S-impedance (or elastic impedance) is needed. Extracting S-impedance and density reliably from P-wave data is not trivial (Cambois, 2000) and it requires long offsets (higher angles) seismic data. The quality of AVO inversion for rock property (impedance) depends on 1) the quality of input seismic data, 2) a good wavelet, 3) a good quality low frequency model, and 4) a robust inversion method. The quality of input seismic data is the most important in reliably estimating impedance.

The presence of noise in seismic data will produce unreliable rock property from seismic data and therefore poor estimation of reservoir properties. There can be varieties of noises present in seismic data, e.g., random noise, inherent noise due to offset to angle conversion, multiples, and residual moveout (Cambois, 2000). It is easy to attenuate random noise for example by (partial) stacking, but, coherent noise like multiples and residual moveouts are difficult to attenuate. I will focus on the two most common noise types, present in seismic data even after extensive data processing, i) multiples and ii) residual moveout, and compare their effects on inverted data. In this paper, I will use a one-dimensional prestack synthetic seismic example to discuss noise effects on prestack seismic inversion.

Synthetic seismic computation

Prestack synthetic seismogram can be computed by convolving angle dependent earth's reflectivity to a source wavelet (Yilmaz, 2001, P.168). This will be a one-dimensional synthetic seismogram. In equation form,

$$S(t,\theta) = R(t,\theta) \otimes w(t) + n(t, \theta) \qquad (1)$$

where, $S(t, \theta)$ is seismogram at incidence angle θ, $R(t,\theta)$ is the earth's reflectivity series at incidence angle θ, $w(t)$ is a wavelet, $\otimes$ is the mathematical sign for convolution and $n(t,\theta)$ is the noise term. Let's assume that there is no noise in the seismic to start with ($n(t, \theta) = 0$), and subsequently add various noises to study the effects of noise in seismic data to prestack seismic inversion. To focus on the noise issue, I used a simple bandpass filter as a wavelet. The reflectivity series can be computed by AVO P-reflectivity formulation. In this paper I used linearization of Zoeppritz provided by Aki and Richards (1980) for the angle dependent P-reflectivity.

Various noise types $n(t, \theta)$ can be modeled and added to the synthetic seismi $S(t, \theta)$. Random noise can be generated based on the signal-by-noise ratio. In the absence of any coherent noise, isotropic angle gathers after normal moveout should be flat. Since coherent noise, like multiples and residual moveout, will have different moveout compared to the primary reflection; coherent noise can be generated by creating a seismic response with a moveout different than primary and adding to the noise free seismic.

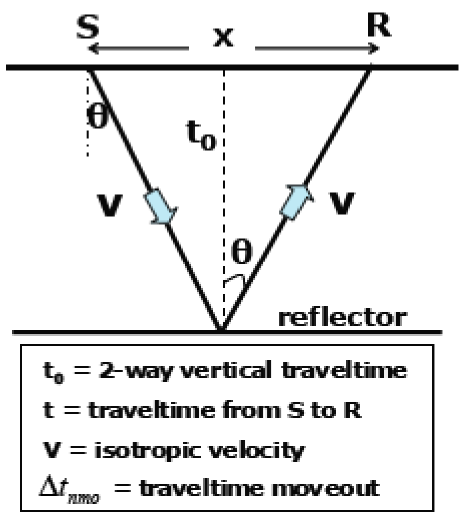

Figure 1: 1-D reflection model in an isotropic medium.

Figure 1 shows a 1-D reflection model, where x is the distance between a source S and a receiver R, V is an isotropic seismic velocity. Equation (2) is the traveltime equation in offset and equation (3) is the equation of offset in terms of angle for the one-dimensional earth model shown in Figure 1. See chapter 3.1 in Yilmaz (2001) for detail discussion on traveltime equation and moveout. By putting offset from equation (3) to traveltime equation (2) we get moveout equation in angle domain (Figure 4). In the angle domain moveout equation (4), the first term on the right side of equation is a scalar in time unit (t_0), which shows the moveout for the farthest angle in seismic data. Figure 2 shows the moveout plot with scalar value of 100ms and far angle of 60 degrees. In this example (Figure 2), the moveout is 100ms if seismic angle gathers are up to 60 degrees; the moveout will be lower for near angles and no moveout at zero degree. In the prestack seismic (AVA) inversion, we should first estimate the maximum angle that will be optimum for inversion (Washbourne and Herkenhoff, 2007).

$$t^2 = t_0^2 + \frac{x^2}{v^2} \qquad \text{---- (2)}$$

$$x = vt_0 \tan\theta \qquad \text{---- (3)}$$

$$\Delta t_{nmo}(\theta) = \underbrace{t_0}_{\text{scalar}}\underbrace{\left(\sec\theta - 1\right)}_{[0,\,1]} \qquad \text{---- (4)}$$

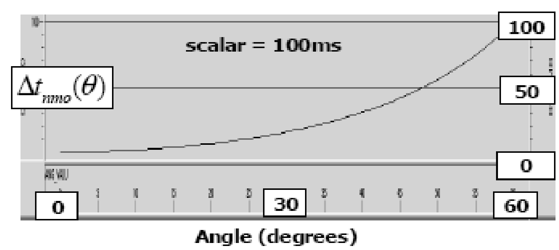

Figure 2: Moveout with angle of incidence. The moveout is 100ms at the far angle of 60 degrees.

Multiples and residual moveout in seismic data can be generated by creating moveout in the data as explained above with appropriate moveout scalar and amplitude of noise data (multiples and residual moveout) compared to seismic primary energy. Figure 3 shows an example of seismic data with multiples. The moveout at far angle of 60 degrees is 100ms and amplitude of the multiples is a scaled version of shallow seismic response.

Prestack seismic (AVO) inversion

Inversion consists of retrieving model parameters (rock properties) from observed seismic data by minimizing the misfit function between observed and modeled seismic data (Tarantola, 1987). AVO inversion is performed by simply fitting seismic amplitudes in offset/angle and time. The input data to AVO inversion is normal-moveout-corrected seismograms as shown in Figure 3. An AVO inversion essentially maps the seismic data into fractional changes in rock properties, which can be further processed (inverted) to derive rock (layer) properties.

I performed a least square AVA inversion with wide-angle prestack seismic data (from 0^0 to 58^0 angles) and the output is reflectivities in time. The output reflectivities are: P-impedance reflectivity (Ro), S-impedance reflectivity (Rsi), and density reflectivities (Density) as described below; where Vp, Vs and ρ are P- and S-wave velocity and density respectively, Δ shows difference in rock properties between two layers, and symbol ˆ shows average rock properties across interface.

$$\frac{\Delta(V_P\rho)}{\hat{V}_P\hat{\rho}} = \text{P-impedance reflectivity}$$

$$\frac{\Delta(V_S\rho)}{\hat{V}_S\hat{\rho}} = \text{S-impedance reflectivity}$$

$$\frac{\Delta\rho}{\hat{\rho}} = \text{Density reflectivity}$$

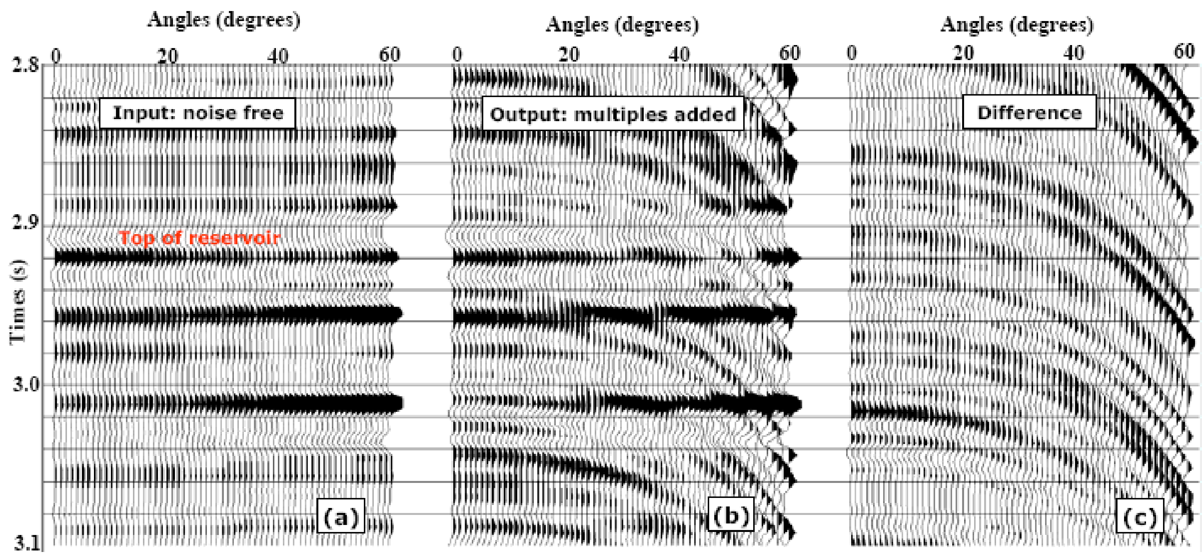

Figure 3: Synthetic seismic angle gather data example: noise free data (a), with multiples added (b) and the difference between the two (c), which is the multiples added to noise free data. The moveout is 0ms at zero angle and 100ms at the fat angle of 60 degrees. The amplitude of multiples is a scaled version of shallow seismic data.

Results of AVA inversion

Figure 4 shows the list of input seismic data to AVA inversion in the left and a comparison of output reflectivities on the right. The x-axis in Figure 4 is the serial number (SL. NO.) of the input seismic data. The plotted reflectivities in Figure 4 are the mean of root mean square (RMS) amplitudes over 400ms data around reservoir for P-impedance, S-impedance, and density reflectivities. These amplitudes are scaled with respect to the inverted output using the noise free seismic data (SL. No. 1 in Figure 4) to compare the effects of various noises. In Figure 4, the deviation in reflectivity amplitude from one (corresponding to noise free data inversion), for a type of input seismic data, represents the amount of error in inversion due to presence of noise associated with seismic data.

The inverted density in this example is not reliable because density contrast is not enough, and therefore I will not focus on density output. Addition of random noise to seismic (SL. NO. 2 in Figure 4) is not much affecting inverted impedance data. From 3rd to 7th listed seismic data, in Figure 4, are for multiples with varying amount of amplitudes (scaled version of shallow seismic data) and consistent moveout of 100ms to far angles of 60 degrees. The presence of multiples in the input seismic data is little affecting inverted impedance data. However, the presence of residual moveout in seismic is worse for inverted impedance. The 8th listed seismic data in Figure 4 has residual moveout of 5ms at the angle of 60 degrees and it has more error in inverted impedance than inverted output

SL.NO	Type of input data to inversion	Comments
1	Noise free	
2	With random noise, S/N = 1	
3	Multiples, ampl. = 0.25	
4	Multiples, ampl. = 0.5	
5	Multiples, ampl. = 1, Near only	Complication
6	Multiples, ampl. = 1	
7	Multiples, ampl. = 2	
8	Residual NMO, dt_NMO=5ms	
9	Residual NMO, dt_NMO=10ms	
10	Residual NMO, dt_NMO=10ms Multiples, ampl. = 2	Most complicated

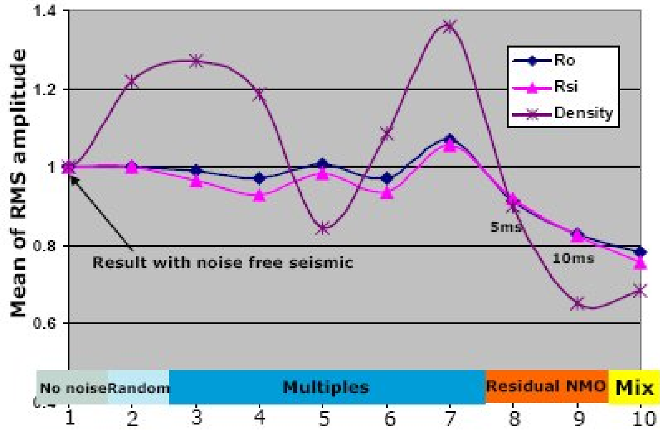

Figure 4: The list of input seismic data to wide angle AVO inversion on left and comparison of inverted reflectivities for various noise types present in input seismic is in right. The amplitude is mean of RMS reflectivities (Ro, Rsi, density) over 400ms data. The density is not reliable. Overall, the inverted output is worse in the case of seismic data contaminated with residual moveout than with multiples.

with multiples. The inverted result with residual moveout of 10ms in seismic data is worse than with residual moveout of 5ms in seismic data. In the last seismic example, I added both types of coherent noise to seismic: residual moveout of 10ms and multiples with amplitude of 2.0 with respect to shallow data. This last input seismic data to AVA inversion produce even worse inverted impedance.

Overall, the inverted P- and S-impedance reflectivities output with multiples added to seismic data, is closer to the inverted output with noise free data, than to the inverted output with the presence of residual moveout in seismic data (Figure 4). The effects of noise in AVO inversion is more for the S-impedance than for the P-impedance, because S-wave response is present in far angles and is prone to be affected by noises. The deviations in inverted reflectivities with noisy data from that of noise free output can be different if individual AVO outputs are scaled separately or if impedance reflectivities are converted to layer impedance.

Conclusions

Wide angle AVO inversion is required to reliably estimate both P- and S-impedance from P-wave data, because S-wave information are present in far angles data. Far angle data are normally of lower frequency and prone to be affected by various noises. The presence of noise, in seismic data input to prestack seismic inversion, affects the quality of inverted rock properties, which will affect the quality of reservoir property predicted from seismic data. I added multiples and residual moveout to a noise-free data to study the effects of noises in wide angle AVO inversion. The two most common coherent noises present in seismic data are: multiples and residual moveout. Out of these two, residual moveout (or a combination of residual moveout and multiples) is worse for prestack seismic inversion. The relative impedance amplitude for various seismic data can vary based on the scaling of individual AVO outputs and the type of measure of amplitudes to compare. This is an on-going research. Residual moveout in the real seismic data can be due to the presence of anisotropy (or other geology related) and poor seismic processing.

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