Repercussions of available long offset, random noise and impedance contrast on AVO analysis

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Summary

The amplitude variation with offset (AVO) or angle of incidence (AVA) is sensible to several factors that may affect the feasibility of doing this kind of analysis. This work measures how the available long offset, level of random noise and the impedance contrast affect the estimation of the AVO parameters such as intercept, gradient and curvature. A low impedance oil sand, with a Class III AVO anomaly, constitutes the geological framework. Fluid replacement modelling was used in order to extent the analysis to three different impedance contrast scenarios: gas, oil and water filling the pore space.

Introduction

The maximum distance between source and receiver (offset) is a relevant parameter when designing a seismic survey. Cordsen et-al (2000) state that the maximum offset depends on the depth to the deeper targets to be imaged, and they emphasize, along with Galbraith (2004), on the impact of the processing mute. This work introduces other criterion that can be used when designing a seismic survey: recording the maximum offset needed to perform AVO analysis. On the other hand, random noise also affects AVO response. Downton and Lines (2001) studied the impact of random noise in AVO inversion and proposed a methodology to know the feasibility of applying this technique in the presence of noise. Cambois (1998) recognized that noise can lead to misinterpretation of the background shale trend when applying AVO attributes such as fluid factor. We analyzed the simultaneous effect of maximum offset and level of noise in AVO analysis, specifically on the estimation of intercept (I), gradient (G) and curvature (C) parameters. We also addressed how the AVO response changes as the impedance contrast decreases.

Theory and/or Method

The method of analysis is as follows: Firstly, fluid replacement modelling, based on Gassmann theory {Gassmann (1951), Smith et-al (2003)}, was used to generate new velocity and density logs by substituting the original fluid (oil) by gas and water, while holding all other rock parameters (matrix composition, porosity, thickness) constant. Secondly, seismic gathers were generated by modelling amplitude variation with angle of incidence, applying the Zoeppritz equations and the convolutional model of the Earth. The third step was to apply the Wiggins reformulation of the Aki-Richards (2002) approximation as used by Russell and Hampson (2006) to estimate the intercept, gradient and curvature for each time of the synthetic gather:

$$R_p(\theta) = R_{AI} + G\sin^2\theta + R_{VP}\sin^2\theta\tan^2\theta \qquad (1)$$

Where R_{AI} is the intercept, G is the gradient, R_{VP}, is the curvature..

$$R_{AI} = \frac{1}{2}\left[\frac{\Delta V_p}{\overline{V_p}} + \frac{\Delta\rho}{\overline{\rho}}\right] \qquad G = \frac{\Delta V_p}{2\overline{V_p}} - \frac{4}{\gamma^2}\frac{\Delta V_S}{\overline{V_S}} - \frac{2}{\gamma^2}\frac{\Delta\rho}{\overline{\rho}} \qquad R_{VP} = \frac{\Delta V_p}{2\overline{V_p}} \qquad \gamma = \frac{V_s}{V_p}$$

An important assumption is that Equation 1 fits the amplitude versus angle curve.

The AVO parameters, derived from gathers with no noise and angles up to 45 degrees, were taken as reference to measure the effect of reducing angle of incidence and varying the signal to noise ratio (Fig. 1).

Because of the random nature of noise, the experiment was repeated several times for each level of noise and angle, in such way that we can calculate the relative error and the standard deviation which is representative of the dispersion degree of the estimations.

Finally, the standard deviation as a function of angle and noise was plotted for gas, oil and water scenarios. These kind of plots allow comparing the effect of different impedance contrasts in AVO analysis, and can be used for deciding the maximum offset when designing a seismic survey.

Examples

Fig. 1 shows the synthetic seismic gathers constructed by using a zero-phase Ricker wavelet and applying Zoeppritz equations. No noise was introduced in this case. The top and base of the sand of interest are highlighted at 1844 and 1867 ms, respectively. The gathers are constituted by angle traces from 1 to 45 degrees.

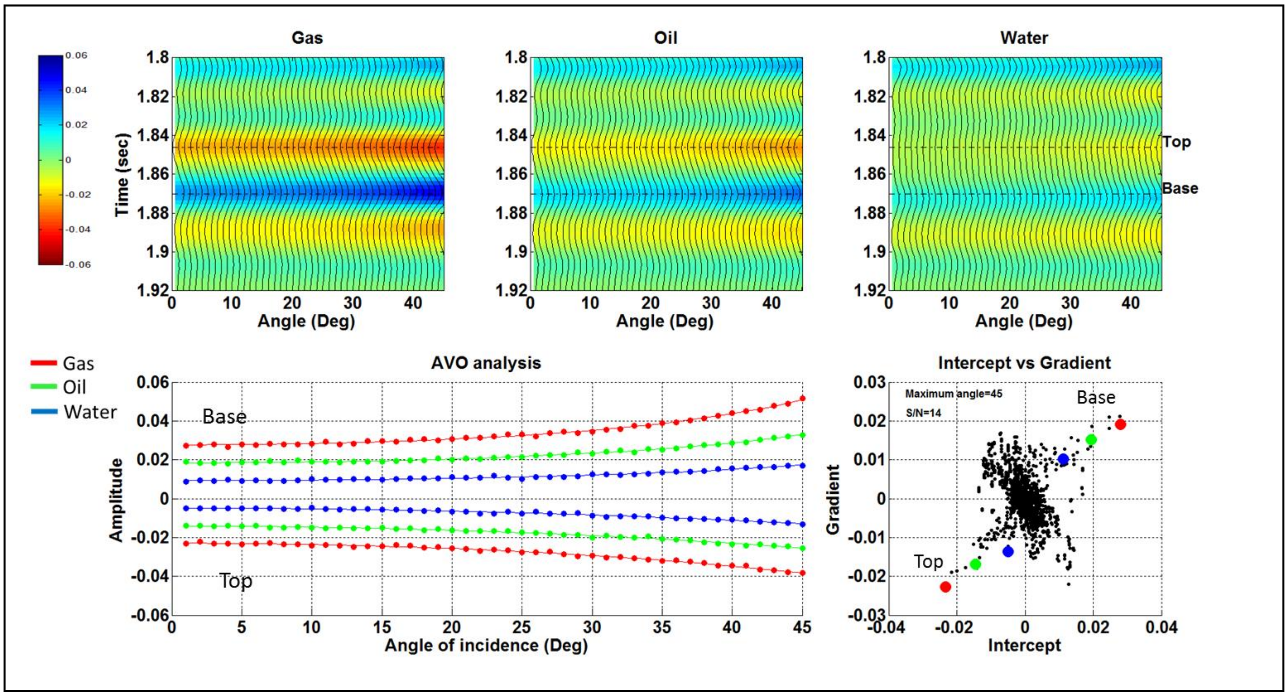

FIG. 1. AVO modelling and analysis of the AVO response applied to gas, oil and water scenarios.

Fig. 2 shows the dispersive effect of noise on intercept versus gradient crossplots for different levels of noise, while keeping constant the maximum angle of 45 degrees.

The impact of reducing the angle of incidence on the intercept vs gradient plot is shown in Fig. 3. A signal to noise ratio of 12 was kept constant.

Fig. 4 shows the standard deviation matrix constructed by varying S/N from 1 to 15 and maximum angle available from 10 to 45 for the three AVO-parameters and the three fluid scenarios. The error cut off of 20% was selected considering the abrupt increase in error beyond this point. These plots provide a criterion to decide the maximum offset when designing seismic surveys, taking into consideration a specific impedance contrast and the expected level of noise. For example, if we anticipate a S/N=5 and an impedance contrast similar to the gas scenario, we would design a maximum angle of 35 degrees and expect maximum errors below 20%. If we expect an impedance contrast such as the oil case, we would either need to acquire angles of 40 degrees or to improve the S/N by processing, so that we obtain similar errors. If we design a seismic survey considering the higher impedance contrast, we are already covering scenarios with lower impedance contrast. Long offsets contribute to stabilize the estimation of the AVO-parameters. For these examples, it is recommendable to acquire angles larger than 40 degrees when the expected S/N is lower than 4.

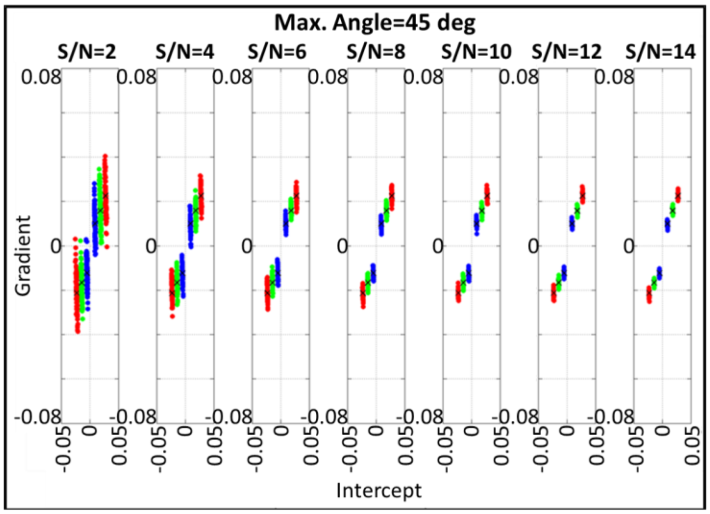

FIG.2 Effect varying level of noise on intercept vs gradient plot. The maximum angle of 45 degrees was kept constant

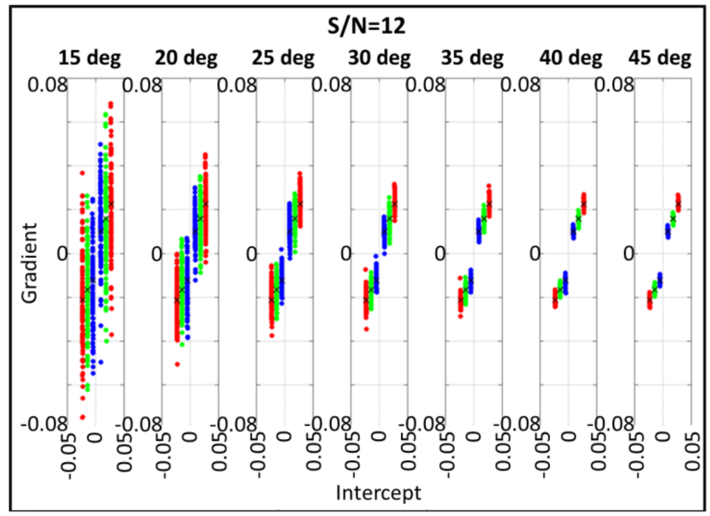

FIG. 3. Effect of reducing angle of incidence on intercept vs gradient plot. S/N=12 was kept constant.

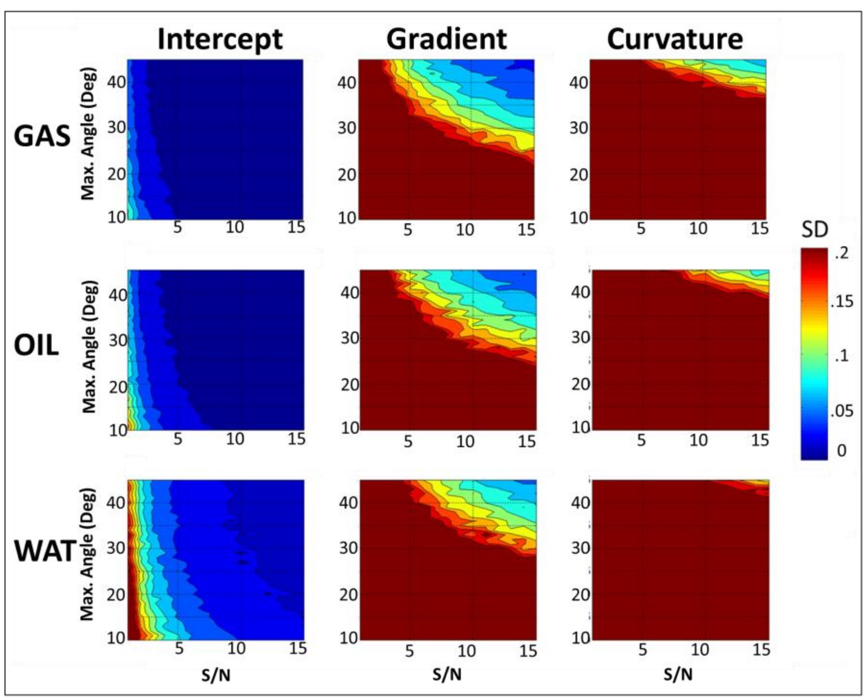

FIG. 4. Simultaneous effect of noise and maximum angle available on AVO-parameter estimation

Conclusions

Random noise and available long offset are variables that affect the estimation of AVO-parameters. We are able to observe the impact of these factors by repeating the parameter estimation several times and calculating the relative error and its standard deviation. In general, when the standard deviation is larger than 20%, the parameter estimation becomes unstable.

We observed that the intercept is practically not affected by increasing S/N or reducing offset. On the other hand, gradient estimations are strongly influenced by both noise and maximum available offset. For the gas scenario, we are able to estimate the gradient with an error of 20% by using an angle range from 1 to 22 degrees in the condition of high S/N=15. If we reduced the S/N, we would need larger offset to conserve the error of 20%. When we have S/N lower than 4, we may need angle traces larger than 40 degrees. The most heavily affected is the curvature estimation. When we have S/N=15, we need angles greater than 36 degrees in order to have errors under 20%. We need dramatically larger angle traces as S/N decreases; for example, for S/N=5 we require angles of 45 degrees so that the error is under 20%.

We observed that the error tends to be higher if the target has lower impedance contrast, such as the cases of oil or water filling the pore space. This information may be useful when designing a seismic survey for monitoring changes of fluids in time-lapse studies.

This methodology can also be used to check the feasibility of applying AVO analysis with old seismic data.

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