AVO Processing Calibration

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Abstract

Over the years AVO technology has been deployed in both efficient and inefficient ways in different sedimentary environments, normally functioning as a lithology indicator and sometimes as a direct hydrocarbon indicator. Several factors may be regarded as responsible for the unsuccessful applications. However, the most basic one, the propemess of the processing sequence to the problem at hand, is sometimes underestimated. The ambiguity of the AVO technique and the presence of coherent noise in the data are other major factors. In this study, I developed a method to check the consistency of the AVO measurements produced by different processing sequences on a noise contaminated data. An extense reprocessing work has been employed in a marine seismic dataset, where an amplitude anomaly is related to the presence of high porosity sands saturated by light hydrocarbons. The sandstone reservoir is encased in marine shales. The anomaly is localized and is characterized by a decrease in density and Poison's ratio in the reservoir zone. The AVO signature is modeled and the corresponding normalized reflection coefficient curve is used to check the amplitude responses produced by different processing sequences. As a result of such calibration procedure the best processing sequence can be selected and it can be used for all seismic lines in the same area.

Introduction

Multiple attenuation is a key step in any marine processing sequence and plays a major role on the success of AVO technique. However, one of the most important questions to be answered when applying multiple attenuation techniques in the context of AVO, is: how off are the seismic amplitudes resulting from a specific processing sequence from the seismic amplitude that resembles the reflection coefficient response of a reservoir ?. In this work I will focus on three important issues of AVO processing of marine datasets: the processing calibration, the role of multiple attenuation and the order for the application of such process in a processing sequence. A reprocessing work was carried out on a marine seismic dataset with the primary objective of checking the bias introduced by processing on a known AVO anomaly. This anomaly is related to a sandstone reservoir embedded in marine shales. The reservoir contains light hydrocarbons, which were responsible for a significant drop in density and Poisson's ratio with respect to the encasing shales.

The AVO processing sequence calibration was achieved through the analysis of the normalized amplitude response of each processing sequence, which were compared with the theoretical response of the reflection coefficient at top and base of the reservoir. The best processing sequence should be the one that simultaneously optimizes both seismic amplitude preservation and attenuation of coherent noise (multiples and reverberations), producing AVO attributes similar to those obtained from seismic modeling.

Amplitude preservation throughout seismic processing can be difficult to achieve. However, the success of AVO technique considerably rely upon the processing sequence employed. When seismic anomalies are extremely large, AVO effects stand out and sometimes the bias introduced by processing algorithms may not be sensed at all. Small amplitude anomalies, many times associated with the presence of liquid hydrocarbons normally show very small expression and can be completely lost or destroyed by bad data pre-conditioning. In such cases, AVO processing calibration is recommended as a tool to minimize amplitude bias.

Seismic Amplitude Anomalies

Observation of amplitude anomalies in amplitude preserved stack sections can be very common. In some cases, the anomalies are related to large acoustic impedance contrasts, which can be solely due to lithologic contrasts. In other cases, the anomalies can be an indicative of changes in the reservoir pore fluid, which in turn can lead us to find hydrocarbons. The classic case of the later (called *bright spots)* typically occurs when low impedance gas sands are encased in high impedance shales. In some areas, however, the contrast in acustic impedance between the gas sand and the encasing rocks is small. This type of reservoir may comprises the so called class 11 sands (Rutherford and Williams, 1989), in which the contrast of elastic properties of the media involved produces a phase reversal at relatively short incidence angles. In such cases, traditional stack sections may not be able to detect this type of AVO anomaly. Partial stack analysis can help to indentify these anomalies, but coherent noise may become a major problem. The difficulties in detecting such anomalies emphasizes that a rigorous amplitude and phase preservation scheme must be carried out in the processing stage.

Eventually, one can idealize a whole family of AVO signatures, including those that are represented by amplitude decay with offset and yet are associated with hydrocarbons. There is no general rule to directly find hydrocarbons from amplitude anomalies alone, simply because the method is highly ambiguous, and also because there are hidden problems in the processing sequence that can compromise the AVO signature. Only after an extensive amplitude calibration work one can gain confidence in the AVO analysis so as to use it as a predictive tool

AVO Signature

Figure I shows a composite of sonic (P and S), density and Poisson's ratio logs in a zone that includes the high porosity sandstone reservoir encased in shales. Reservoir thickness is around 15 in (above seismic resolution limit). The density log clearly reflects the change in porosity with depth. The reservoir is saturated with light oil (280 API).

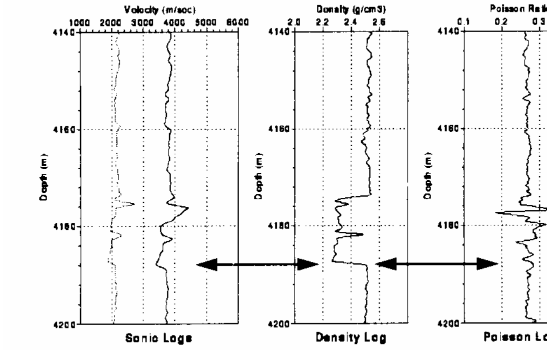

Figure I - Composed P and S-wave sonic, density and Poisson's ratio logs. The base of the reservoir is indicated by arrows.

Table I shows the basic elastic parameters obtained for reservoir and shales. The acoustic impedance contrast produces a negative reflection coefficient at the top, and a positive reflection coefficient at the base of the reservoir. The Poisson's ratio (d) drop at the reservoir zone indicates that absolute amplitude should increase with offset for the top as well as the base of the reservoir.

Table I -Elastic Parameters used in the Model

Layer	Rock	Vp (m/s)	Vs (m/s)	Vp/Vs	ρ (g/cm^3)	σ
1	shale	3810	2150	1.77	2.51	0.27
2	sand	3717	2252	1.65	2.31	0.21
3	shale	3810	2150	1.77	2.51	0.27

Figure 2 shows the plane interface non-normal reflectivity model obtained for na incident P-wave at the top (lower curve) and base (upper curve) of the reservoir. This model is very simple, since it only represents the energy reflected off the interface between two elastic media and does not incorporates propagation effects (transmission, attenuation, etc.). However, considering that P-wave anisotropy is small at limited incidence angles and that propagation effects are somewhat corrected during processing, the model can be used to compare with the reflection strength found in the data.

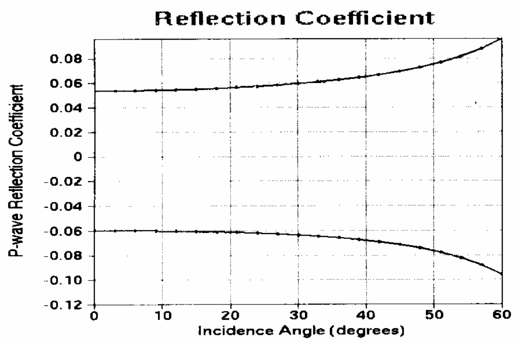

Figure 2 - Non-normal reflectivity model obtained for an incident P-wave at the top (lower curve) and base (upper curve) of the reservoir. The curves indicate that the AVO product section (Intercept * gradient, or Ro * G) will show positive responses for both top and base of the reservoir.

AVO Processing

The goal of true amplitude processing is to obtain reliable data for AVO analysis. The biggest issue in AVO processing is to combine algorithms and processing parameters in a well balanced way, creating the minimal amount of amplitude bias.

Table II summarizes the major effects on seismic amplitudes and the most common processing algorithms used to compensate these effects. Some amplitude corrections are made in the deterministic way, whereas others are purely statistical corrections, assuming the impossibility of knowing the complete earth model. The later are especially important for land data processing, where surface consistent corrections play a major role (Ramos, 1993). In such cases, the surface consistent amplitude corrections helps to validate the AVO data. For marine data, the most significant effect usually comes from the surface consistent deconvolution. Figure 3 shows the processing flow employed in the marine data used in this work. Strong sea floor multiples interfere in target zone. In order to attenuate the multiples, parabolic radon filtering was applied. The order of application of radon filtering with respect to the amplitude correction processes was critical in this case.

Calibration and Results

The processing flow of Figure 3 shows that sequences I through 7 and 13 did not involve any effort to attenuate multiples. The analysis of the CDP gathers corresponding to these sequences and the amplitude versus offset curves for the base of the target zone, showed that the multiples and reverberations caused amplitude oscillations in the amplitude data. A quadratic fit of the observed amplitude values for each offset was carried out for each processing sequence tested. This fit was based on the small offset approximation for reflection coefficient:

$$R(x) = R_0 + R_1 . x + R_2 . x^2 \ , \qquad (1)$$

with coefficients given by:

$$R_0 = \frac{1}{2}\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\rho}{\rho}\right) = \frac{1}{2}\frac{\Delta Z_p}{Z_p} \ , \qquad (2)$$

$$R_1 = \frac{1}{2}\left(\frac{\Delta\alpha}{\alpha}\right) - 2\left(\frac{\Delta\mu}{M}\right) \ , \text{ and} \qquad (3)$$

$$R_2 = \frac{1}{2}\left(\frac{\Delta\alpha}{\alpha}\right) . \qquad (4)$$

In these equations: x = sin 20, a is the average P-wave velocity, g is the average shear- modulus, M is the average plane wave modulus, Zp is the average P wave acoustic impedance and 0 is the average angle of incidence and transmission. The symbol A represents changes across the interface of the corresponding elastic parameter.

Figures 4 through 6 show the values of the coefficients Ro , R, and R2 obtained from quadratic fit through the normalized seismic amplitudes, for each processing sequence. Because the signature for the reflection coefficient at the base of the reservoir is represented by a parabola up to 0 = 450, it is expected a similar behavior for seismic amplitudes adequately processed, which means that positive values of Ro and R2 should be observed. The coefficient R, only indicates the position the parabola vertex with respect to x = 0 and has little effect on the amplitude response. Negative values of R2 are in general associated with amplitude decrease with offset or with strong oscillations in the amplitude data (typically caused by multiples), which affect the quadratic fit. This is the case of sequences I through 7, where multiples were not attenuated. Sequence 13, shown in the same position of sequence 7 in Figure 3, differs from 7 because the computation of weights in the statistical processes was done using data radon filtered, but these weights were applied in the data without radon filtering. This procedure improved the estimation of weights, but application of these weights to data con-

Table II - Factors and Corrections for Seismic Amplitudes and Major Processing Algorithms Employed

FACTOR	**CORRECTION**	PROCESS
Reflectivity	No	
Source Directivity	No	
Array Effects	Possible	RAC 3
FACTOR	**CORRECTION**	PROCESS
Source and Receiver Coupling	Yes	SCAC2
Near Surface Velocity Variations	No	
Geometric Spreading	Yes	GEOSP'
Attenuation and Phase Distortions	Partially	SCDEC4, SW 5, Inverse Q filter
Transmission Losses	Possible	RAC3
Velocity Anisotropy Above Target	No	
Waveform Interference (Tuning)	Possible	
Short Period Multiples	Yes	Predictive Deconvolution
Converted Waves / Long Period Multiples	Yes	NMO; RADON6; FK Filter
Reflector Dip and Curvature	Yes	DMO; Prestack Migration
Processing Effects (e.g. NMO stretch, etc.)	Possible	

I GEOSP (Geometrical Spreading Correction)
2 SCAC (Surface Consistent Amplitude Correction)
3 RAC (Residual Amplitude Compensation)
4 SCDEC (Surface Consistent Deconvolution)
5 SW (Spectral Whitening)
6 RADON (Parabolic Radon Filter)

taminated by multiples proved to reinforce amplitude oscillations introduced by such noise.

The effect of residual amplitude compensation on the amplitudes was observed comparing data from sequences 2 and 3. In this case, there were a significant amplitude reduction in the short and mid offset ranges (up to 1500 in), which can be seen by the drop in Ro for sequences 3 through 7. The reduction is actually caused by the fact that the residual amplitude compensation is actually attempting to reverse the amplitude decay trend that still exist after geometrical spreading correction.

Sequences 10, 12 and 14 had the multiple attenuation through parabolic radon filtering applied at the very end of the flow. In these cases, amplitude scatter with respect to the quadratic fit was small, resulting in better correlation coefficients, especially for sequences 12 and 14, which were also submitted to spectral balancing. The process with largest effect on reducing amplitude scattering was surface consistent deconvolution. A detailed analysis of the amplitudes in the CMP gathers for events above and below the target zone revealed that sequences 12 and 14 have introduced an excess of correction for far offset traces.

Sequence 8 showed radon filtering right after the deterministic processes. This sequence showed considerable scatter of amplitudes, which was reflected in R2 < 0 (Figure 6). This result indicates the need of applying the surface consistent statistical processes. Sequences 11, 9 and 15 had parabolic radon filtering (for multiple attenuation) applied before all statistical processes. This procedure produced data with superior quality for surface consistent algorithms and therefore improved their outputs. Spectral balancing applied to sequence 15 resulted in very small amplitude scatter for quadratic fit. However, a carefull analysis of the CMP gathers that were output of this sequence showed an excess of correction at long offsets.

Sequences 9 and I I showed satisfactory results. However, because of the application of residual amplitude compensation before the statistical processes, sequence 9 showed slight overcorrection for long offsets at almost all reflectors (similarly to sequences 12 and 14). The result obtained with sequence I I has an AVO signature quite close to the reflection coefficient curve for the base of the reservoir (Figure 2). This sequence was then used to compute AVO attribute sections.

Figure 7 compares the maximum normalized amplitudes for sequences 9, 11 and 15 and the normalized reflection coefficient at the base of the reservoir. Computation of incidence angles was made through ray tracing using a velocity model derived from CMP and well data. There is a good correlation between amplitudes from sequence I I and the forward model of reflection coefficients.

Conclusions

This work shows that in the presence of strong multiples and reverberations AVO processing sequence requires especial care. Attenuation of such strong coherent noise must precede surface consistent statistical processes.

Depending on the attenuation and transmission losses, the processing sequence of noise contaminated data may not require statistical processes without surface consistence. The main reason for avoiding these processes is due to violations in their basic premisses in the presence of strong coherent noise. However, when signal-to-noise ratio and geological setting are favorable these processes may be perfectly applicable.

There is a clear dependency between seismic data quality and the processing sequence to be used in order to preserve relative amplitudes. The calibration process presented here is a control tool that allows fine tuning of the amplitude changes, allowing the definition of the best processing sequence, so that it can be used for all seismic lines in the same area.

Finally, this work demonstrates that AVO should be used with caution as exploration tool, but it can be used more safely as a reservoir maping tool, in areas where the calibration processing is possible.

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Acknowledgments

I would like to thank PETROBRAS for permission to publish this work. I am also grateful to the colleagues Angela Vasquez and Marcos Antonio Amaral for the enormous help in data processing. Adelson Oliveira and Andre Gelio for useful discussions during the course of this work.