Frontiers + Innovation
2009 CSPG CSEG CWLS CONVENTION • CALGARY, ALBERTA, CANADA

Comparing Post-stack AVO Inversion to Prestack Inversion for Estimating Rock Properties

Paul F. Anderson*
Apache Corporation, Calgary, AB
paul.anderson@apachecorp.com

Summary

Inversion of seismic data to rock properties is not a new method, however there are a wide variety of methodologies available one can use to achieve those estimates. The number of potential AVO equations one has access to now exceeds what many would consider useful. The problem then becomes, which of the several methods should be applied, given a specific exploration or development goal? While it is likely that each example must be reviewed upon its own merits, below is a comparison of two such methods for estimating rock properties from seismic data. Specifically a comparison of the workflow proposed by Goodway et al. (1997) to the method proposed by Hampson et al. (2005) will be discussed in the context of identifying reservoir quality sands within Mannville-age fluvial channels (Larson & Anderson, 2006). It will be shown that given the same input, while both geologically "accurate" (as much as the geophysical method can be), the prestack inversion does produce a result which is of more value to an interpreter.

Introduction

As part of a research effort at the University of Calgary, a project was undertaken to evaluate the differences in predicting rock properties, specifically Vp/Vs ratio, from seismic data by two different methods. Method 1, follows a workflow similar to that proposed by Goodway et al (1997), whereby prestack gathers are inverted for conventional AVO attributes (e.g. Rp & Rs from Fatti) which are then "post-stack inverted" for accoustic and shear impedance. Method 2 follows that proposed by Hampson et al, whereby this workflow is simplified into a single inversion step. What follows is a comparison of the results using the different workflows.

Post-stack inversion method

The process of estimating Vp/Vs ratios with a post-stack inversion method follows the procedure outlined by Goodway et al (1997). In this paper, the authors propose starting with prestack data and performing an amplitude variation with offset (AVO) inversion of these gathers, in order to estimate the P-wave and S-wave reflectivities. One such method is the approximation to the Knott-Zoeppritz equations, proposed by Fatti et al (1984), where AVO is estimated by fitting the amplitudes from each time sample of the gather to an equation that relates the reflectivity at a given angle (offset) to P-wave and S-wave reflectivities.

The gathers, as delivered by the processor, required additional processing applied in order to help improve the inversion results. This consisted of a mute function applied to the data, as well as a 3x3 superbin, in order to improve the signal to noise ratio at each offset, through partial stacking (Ostrander, 1984). In order to convert from offset domain to angle domain for the CMP gathers, the stacking velocity was used to perform a 1-D pseudo-depth conversion, which when used with the offset of the traces within each CMP, produces the angle for each sample. A maximum angle of 30 degrees was used for the AVO inversion, as farther angles begin to exhibit problems with normal move-out removal (e.g. VTI-anisotropy).

Upon extraction of the AVO attribute volumes, post-stack inversion was performed upon each attribute. While these reflectivity volumes can be useful in themselves, it is often helpful to follow the next step and invert the reflectivity volumes to impedances. This can often aid the process of calibrating the seismic data to well control. Using well log information, we can build background P-wave and S-wave impedance models which we can then be used to invert the corresponding AVO attributes following standard practices for acoustic impedance inversion.

A single well log was used to build the impedance models. This well contained measured conventional and shear sonic logs, in addition to a conventional logging suite. This well was then used to build the low-frequency background model to be used for the post-stack inversions to impedance. The same parameters were used for both the P-wave and S-wave impedance inversions, with two exceptions:

1. shear log used for S-impedance model

2. independent wavelets for each inversion

The consistency between the models was done so as to minimize the computational differences between the inversion results, so we can infer that the differences seen are geologically influenced.

Prestack inversion with P-wave seismic data

The procedure for prestack inversion of P-wave seismic data followed the workflow presented by Hampson et al (2005). The concept is intended to arrive at the same point as the workflow provided above, using fewer steps and in a more integrated fashion. One of the less favorable aspects to the post-stack inversion method described above is the inversions for P-Impedance & S-Impedance, with the exception of the models, are independent of one another. Non-correlated noise can cause problems because the signal to noise ratio of the P-wave reflectivity and S-wave reflectivity is often different, the resulting inversion can respond to this in independently on each section. By performing the inversion prestack, we are able to solve for P-wave impedance and S-wave impedance simultaneously, thereby treating errors equally on both volumes.

The same gathers used for the AVO extraction above were used as a starting point for the prestack inversion. Using the stacking velocities, the offset gathers were converted to angle gathers, where angles between 5° & 30° were used. In order to maintain consistency, the background model used for the post-stack inversions was also used for the prestack inversion. Because the algorithm is somewhat different, parameterization is not the same as in the case of the prestack inversion, as we are optimizing the inversion for seven prestack traces at each CMP location, instead of one post-stack trace twice (once for each post-stack inversion). To do so, the prestack inversion requires a background trend between P-wave impedance and S-wave impedance, as well as P-wave impedance and density. The inversion then solves the angle-dependant reflectivity model that minimizes the error on the angle gathers as deviations from the input model. These deviations from the model are then added back to the model and the process is repeated, generally with significantly more iterations than typically done with a post-stack inversion to reach what is hoped to be a global minimum. Using the model built previously, background relationships between P-Impedance, S-Impedance and Density from four wells were used to define the background relationships.

In order to account for frequency content differences from near to far angles, near angle (5°) and far angle (25°) wavelets were extracted using the same parameters as the wavelets derived from the post-stack inversion. This allows the wavelet to account for frequency dependant changes in the angle gathers that are not attributable to geology (frequency decay with offset, wavelet stretch from NMO-removal, etc.). In this case, a full-phase wavelet was extracted using the “Roy White” algorithm within HRS-STRATA software to account for frequency-dependant phase variations.

Discussion

Figure 1 shows a comparison of the different Vp/Vs ratio methods for the same cross-line. Inserted into each section is the Vp/Vs ratio calculated from depth-time relationships for comparison. One comment that can be made immediately is that each of these volumes has different frequency content. The amplitude spectra of these Vp/Vs ratios are displayed in figure 2. Given that the input seismic data all possessed the same filters, it is interesting to note the differences in the spectra. Based upon the inverted Vp/Vs ratio, the high frequency content does appear to be noise. It is possible that we have accidentally demonstrated one of the potential pitfalls with the post-stack inversion technique. Specifically, he post-stack inversion is minimizing the error on the reflectivity estimates by iteratively changing the reflectivity of each sample. Since the inversion for P-Impedance and S-Impedance are decoupled, we may have a situation where the P-wave inversion may put a reflector at sample n, but that same geologic event may occur on the S-wave inversion at a slightly different sample (n-1 or n+1). When we then ratio these two attributes, we produce high frequency artifacts.

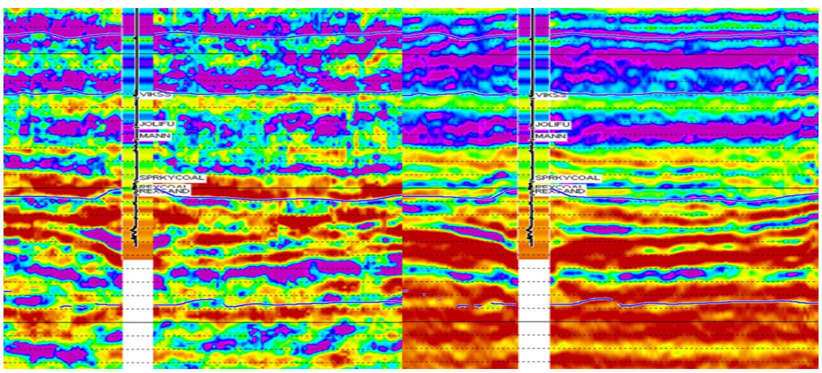

Figure 1: Comparison of Vp/Vs ratios calculated from AVO + post-stack inversion (left), prestack inversion (right). Vp/Vs ratio from logs at Well D has been inserted in colour and the SP log as the trace.

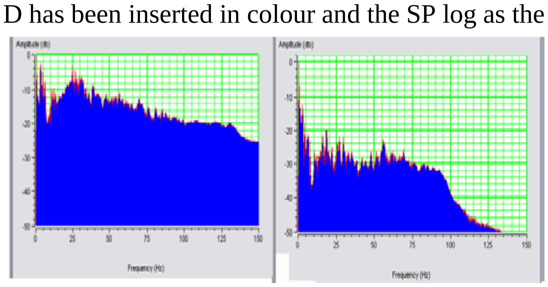

Figure 2: Amplitude spectra of the Vp/Vs ratio volumes taken from 10 inlines around well F. The left image shows the amplitude spectrum from the AVO + post-stack inversion has significantly more high frequency energy than the prestack inversion (right).

Another interesting difference noted is that the Vp/Vs below the zone of interest is quite different. Below the target zone, the geology abruptly changes from a clastic succession to a carbonate one at the Paleozoic uncomformity. As a result, one would expect the Vp/Vs to show that difference as we would expect the clastics to have a nominal Vp/Vs above 2 and the carbonates to be less than 1.9. It is interesting to note that while both of the impedance inversions used the same background model, only the prestack inversion was able to identify this transition. While not completely understood, one possible theory is the Paleozoic unconformity can be masked by interbed multiples in this area. It is possible that this noise may have had a larger impact on the post-stack inversion workflow as compared to the prestack inversion flow (it should be noted that is simply conjecture at the time of writing this abstract).

Conclusions

In summary, two different inversion methods were tested and evaluated based upon their ability to estimate Vp/Vs ratios from well logs data.

1. Amplitude variation with offset (AVO) with two post-stack inversions
2. Prestack inversion of P-wave data

Based upon the results presented here, prestack inversion appears to be the best method to estimate Vp/Vs ratios from seismic data. Revised processing of the P-wave data to incorporate farther offsets/angles may help to constrain the inversion results, perhaps even allowing an inversion for density. This would require higher-order move-out corrections or other brute-force methods to implement (e.g. time-variant trim static).

It has been noted that the AVO plus post-stack inversion flow has potential pitfalls, which appear to have been encountered with this data set, due to the fact that we are solving for related parameters in an unrelated fashion, which has resulted in artifacts (high-frequency noise on subsequent products like Vp/Vs ratio).

Acknowledgements

Special thanks to the staff at Apache Corporation for providing the data and encouragement to continue pushing this data volume to its limits, specifically to David Monk Ron Larson & Heather Joy. Also to, CGGVeritas Hampson-Russell for software support and extensive code debugging for the joint prestack inversion presented above, especially to Janusz Peron, Keith Hirsche and Graham Carter. Thanks also go to VGS Seismic for providing publication rights on the P-wave seismic data. As this work was done as part of my Master degree with CREWES at the University of Calgary, I would be remiss if I didn't also recognize the help and support provided to my by my thesis supervisor, Dr. Larry Lines.

References

Aki, K. & Richards P.G., 1980, Quantitative Seismology, v. 1, sec 5.2

Anderson, P.F. & L.R. Lines, 2008, A comparison of inversion techniques for estimating Vp/Vs from 3C3D seismic data. CREWES Annual Report.

Anderson, P. F., and R. Larson, 2006, Multicomponent case study - One company's experience in Eastern Alberta: Recorder, **31**, 5–10.

Fatti, J.L., Smith, G.C., Vail, P.J., Strauss, P.J., and Levitt, P.R. 1994**,** Detection of gas in sandstone reservoirs using AVO analysis: A 3-D seismic case history using the Geostack technique. Geophysics, **59**, 1362-1376.

Gidlow, P. M., Smith, G. C., and Vail, P. J., 1992, Hydrocarbon detection using fluid factor traces, a case study: How useful is AVO analysis? Joint SEG/EAEG summer research workshop, Technical Program and Abstracts, 78-89.

Goodway, B., Chen, T. and Downton, J., 1997, Improved AVO fluid detection and lithology discrimination using Lame petrophysical parameters; 'λρ', 'μρ', & 'λ/μ fluid stack' from P and S inversions, 67th Ann. Internat. Mtg: Soc. of Expl. Geophys., 183-186.

Hampson, D. P., B. H. Russell, and B. Bankhead, 2005, Simultaneous inversion of pre-stack seismic data: 75th Annual International Meeting, SEG, Expanded Abstracts , 1633-1637.

HRS-STRATA User Manual

Ostrander, W. J., 1984, Plane-wave reflection coefficients for gas sands at nonnormal angles-of-incidence: Geophysics, **49**, no.10, 1637-1648