A Seismic Workstation Solution to Bakken AVO

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GeoConvention 2012:Vision

Summary

AVO should provide a way to identify "sweet spots" for Bakken production, but to date this approach has not been successful because of inadequate seismic resolution preventing an identifiable Bakken Reservoir event from being present on the CMP gathers used for AVO. This paper demonstrates a way to address this resolution problem through the use of a match filter with the operator designed on stack data using a seismic workstation which is then applied to gather data at the processing centre.

Introduction

The Bakken formation consists of a central clastic reservoir bounded above and below by very rich organic shale member source rocks which provide the oil that fills the central reservoir clastic member. Any well drilled into the Bakken will encounter oil but for many years the low permeability and low porosity of the central reservoir member prevented economic extraction of this large oil reserve. The advent of horizontal drilling and multistage hydraulic fracturing has turned the Bakken into an economic prospect and because of the Bakken's large prospective areal extent it has become a critically important North American oil resource.

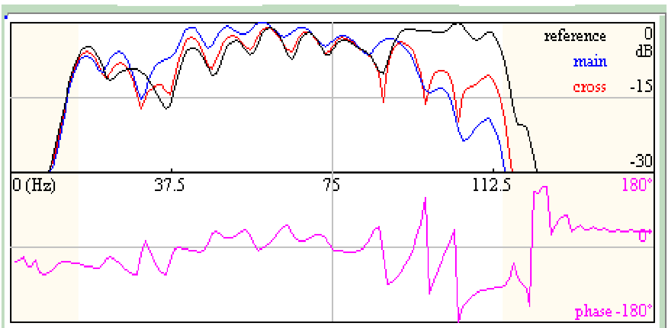
As more and more wells are drilled into the Bakken it is becoming apparent that drilling technology alone is not a 100% guarantee for an economically successful Bakken oil well because of reservoir variability. Typically the best Bakken production comes from reservoirs that have some natural fracturing and where no natural fracturing is present even the best multistage frac may not result in adequate flow rates to fully meet economic criteria.

The problem is therefore to identify fractured Bakken Reservoir, and a simple solution to this problem would typically be found in AVO analysis. P waves and S waves respond very differently to fractures. Fractures have a profound effect on S waves because of the dramatic reduction in shear strength but have very little effect if any on P waves because the compressive strength remains more or less the same. AVO is essentially a measure of interference between P and S waves at a reflector and since fractures change S waves AVO should provide the ability to distinguish between fractured and unfractured Bakken reservoir thereby identifying the better production areas.

Theory and/or Method

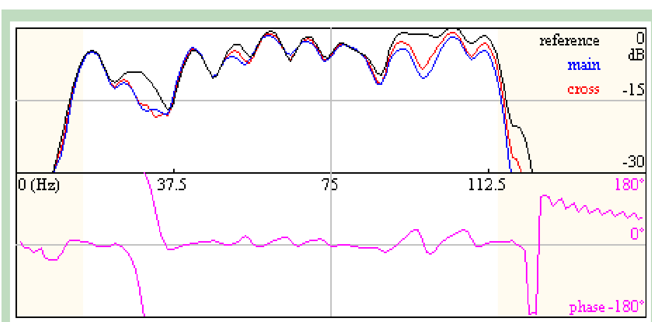
There is a vast amount of both 2D and 3D seismic data available that could be used for AVO analysis of the Bakken if the resolution of the trace gathers from this seismic data was sufficient for this application. The Bakken formation is comprised of a high acoustic impedance reservoir unit sandwiched between upper and lower organic rich shales with very low acoustic impedance easily providing an adequate reflection coefficient of approximately 0.35 magnitude at both the top and base of the Bakken reservoir unit to result in a Bakken Reservoir reflection on CMP gathers. The problem is resolution because the Bakken Reservoir may only be 12m thick requiring useable frequency of 100 Hz within the trace gathers and this is not typically present on most of this existing seismic data. (12m with an interval velocity of 4800m/s has a ¼λ resonance corresponding to 100 Hz.)

For the most part this 100 Hz is resident within the seismic data but it is typically below optical resolution because of phase misalignment and noise contamination. The following figure compares the amplitude spectrum of a synthetic trace with a zero phase Ormsby wavelet of 12/16 to 115/125 Hz bandwidth with seismic data filtered at the low end to 12/16 with an open upper end. Below this amplitude spectrum is a phase plot of the difference in phase between the zero phase wavelet of the synthetic and the processed seismic wavelet.



It is clear that the seismic trace amplitude spectrum (main) in blue does in fact contain the requisite 100 Hz energy but this is down by 15dB as a result of the phase distortion above the 85 Hz level as depicted on the phase plot.

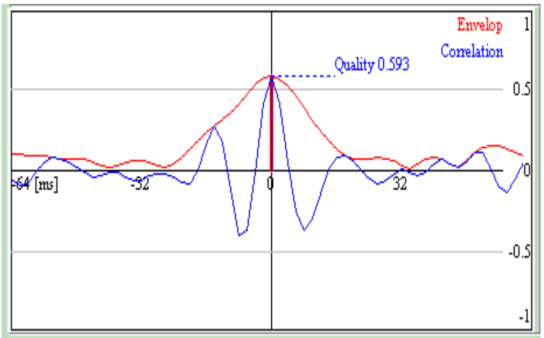
A match filter is a simple convolution operator designed on the difference in amplitude and phase spectra which applied to a target trace will convert the wavelet of that trace to the wavelet of the reference trace. Using the synthetic trace as a reference trace the wavelet in the target seismic trace can be converted to match that of the synthetic trace as demonstrated by the following figure which is the above spectra after the application of a match filter.

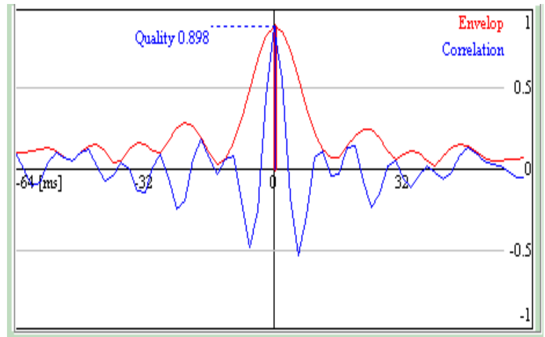


The cross correlation between the reference trace and the target trace demonstrates the improved resolution after the application of the match filter as demonstrated by these cross correlations before (on the left) and after (on the right) the application of the match filter .

Cross correlation before Match Filter application

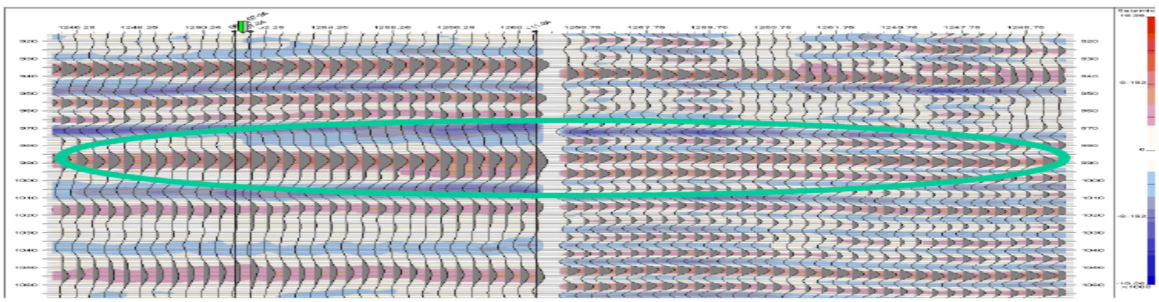
Cross correlation after Match Filter application



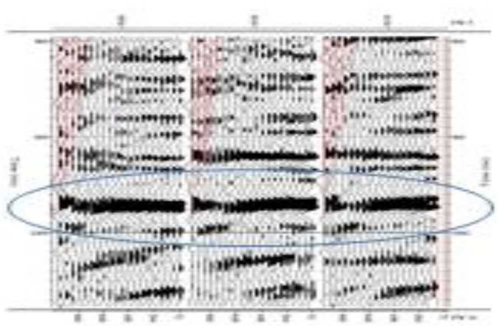


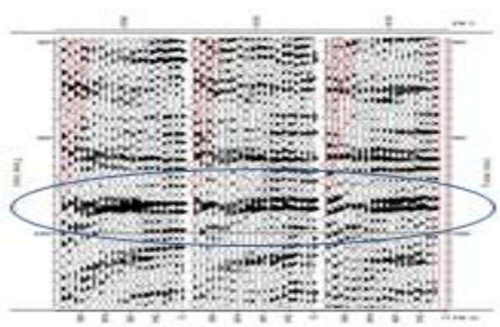
The plot below is the seismic data before and after the match filter demonstrating the enhanced resolution achieved by normalizing the the high frequency and aligning frequencies at zero phase with the match filter.

Seismic line before Match Filter *Seismic line after Match Filter*



Since a match filter operator only changes the wavelet a properly derived match filter operator should theoretically be just as applicable to gather traces as to stack data. This is easily demonstrated by the gathers from this dataset with and without the same Match Filter Operator applied.



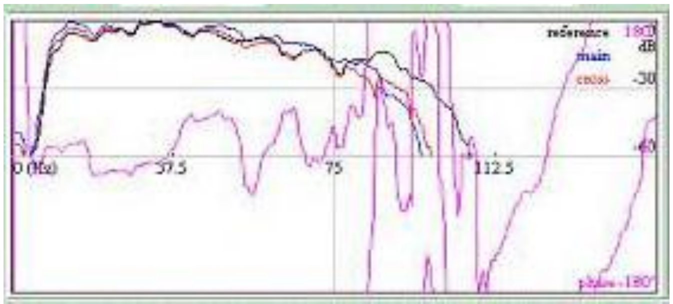


The design of the match filter operator is critical to the entire process of enhancing the resolution of the gathers and it is a multi-faceted interpretive process that is best done on a seismic work station.

The synthetic seismogram must first be stretched to perfectly align with the seismic trace.

Next the data must be tested to verify that there is useable requisite frequency resident within the data. This is done by correlating the data with a broad band synthetic trace and examining the resulting phase spectrum. The phase of useable reflection energy varies continuously but the phase of noise is erratic so the limit of the useable frequencies is easily determined at the point where the phase becomes erratic.

Frequency in seismic data above useable limit



This example shows the useable limit of the frequency to be around 85 Hz demonstrating that the frequency above 85 Hz is not useable.

Stacked seismic traces contain many components that are not present in synthetic traces such as variable amounts of NMO stretch, multiples, and other noise influences necessitating a certain amount of interpretation in selecting the optimum parameters for the match filter operator design and the design window. This interpretive selection of operator design parameters by necessity must be aided by appropriate diagnostic displays but these displays only serve as a guide with subjective interpretation playing a large role in the Match Filter operator design.

This is a departure from conventional practice in that the data processor is not directly involved in the operator design process and is only responsible for the mechanical application of this operator to the gather data and the subsequent AVO processing, with the onus for proper operator design falling on the interpreter.

Conclusions

Providing that there is sufficient useable frequency content for adequate resolution resident in the seismic data; a Match Filter operator designed on stack data and then applied to gather data should be capable of allowing AVO analysis that will aid in Bakken exploration. The process of Match Filter operator design is highly interpretive and is best done on a seismic workstation with Match Filter facilities and diagnostics incorporated into the seismic workstation programming.

Acknowledgements

Processing contributions provided by:

Ye Zheng, Ph.D., P.Geoph. Manager, Research & Development, Divestco Processing,

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