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Application of Shear-wave Splitting Analysis to Fracture Characterization for a Shaunavon Tight Oil Reservoir

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Summary

Shear-wave splitting analysis has been used to assess natural fracturing within a tight oil reservoir, after first correcting for anisotropy present in the overburden. Though the amount of splitting is relatively small, we did observe an anomalous region with higher time delay between the fast and slow shear waves. This was most clearly mapped by interpretation of the P-S1 and P-S2 migrated images. We find that hydraulically-fractured wells located on this anomaly correlate with higher production rates.

Introduction

Fracture and stress characterization play an increasingly important role in today's hydrocarbon business, with the focus on unconventional or "resource" plays. The characteristic of these plays is that they require some form of stimulation, such as hydraulic fracturing, to improve recovery. This has spurred interest in new technologies such as microseismic, for fracture monitoring. It also has brought about a change in focus for our expectations of information from surface seismic. Instead of the focus being exclusively on the structure and on amplitude information, we are now – in addition - aiming to extract information on stress fields and/or pre-existing fractures for optimal placement and orientation of fraccing wells.

Recently, attention has been given to fracture characterization using P-wave analysis either with azimuthal travel-time variations or with azimuthal AVO. These are fairly standard approaches that can be applied on many conventionally acquired seismic datasets, given adequate offsets and azimuths. A third approach, and the focus of this paper, is only available when multicomponent data have been acquired so that shear waves are recorded. This approach exploits the fact that shear waves become polarized in the presence of azimuthal anisotropy. This polarization effect leads to "shear-wave splitting" in which two separate shear waves, S1 and S2, are recorded from the same reflection with orthogonal polarizations and with a time delay which indicates the amount of anisotropy. The polarization of the S1 mode is generally assumed to be parallel to maximum stress or parallel to fractures for a single fracture set. An advantage of using shear-wave splitting to map fractures, over P-wave based methods, is that other effects such as heterogeneity are less likely to masquerade as anisotropy, since the travel paths for S1 and S2 are almost identical.

Theory and Method

The analysis for shear-wave splitting has two key steps. First, a pre-stack least-squares analysis of the transverse component amplitudes (Bale et al., 2005) is used to ascertain the azimuth of the fast shear direction and the time delay between fast and slow shear waves. Second, the gather is rotated to the S1-S2 coordinate system, and is stacked to generate S1 and S2 traces. These traces are then correlated to determine the total time delay between S1 and S2 signals.

Generally we assume that there will be anisotropy effects in the overburden as well as at the target level. There can be multiple layers each with a different orientation of the anisotropy. The effect is that the shear waves from depth can become split multiple times as they propagate back to the surface receivers. To make sense of the anisotropy at target, these overburden effects must first be corrected for using a layer-stripping approach. For each overburden layer, a time-variant shift is applied to the S2 shear wave so it matches the S1 time, and thus allows recombination of the split waves into new radial and transverse datasets, corresponding to an equivalent isotropic layer with S1 velocity. This is then repeated for each overburden layer. At the target level, the result is output as S1 and S2 oriented data, suitable for further analysis.

The overburden correction described above, as well as allowing target level splitting analysis, has an additional benefit. It provides an improvement to the PS image, as it removes the time delays present within the radial PS gathers, so that they can be imaged more coherently (Whale et al, 2009). This is shown in Figure 1, which compares the converted-wave (PS) imaging for part of one line of the dataset with and without correction for shear-wave splitting effects. The corrected data (1b) shows improved signal to noise and continuity compared to the uncorrected data (1a), as indicated by the red ellipses.

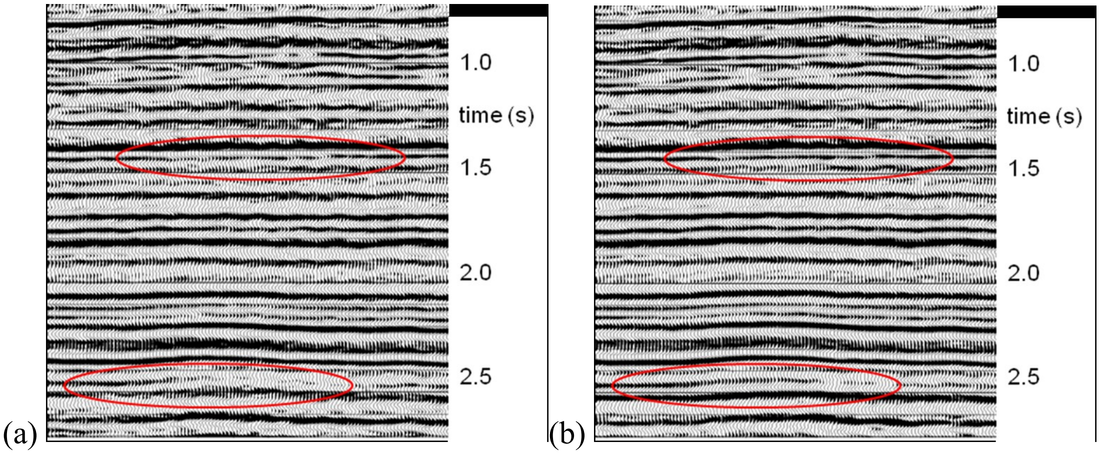

Figure 1: Migrated image of Shaunavon PS (radial) data: (a) with no correction for overburden shear-wave splitting; and (b) with correction for overburden shear-wave splitting.

Results of Shear-wave Splitting Analysis

Shear-wave splitting analysis was applied to seismic data over a field producing from the Middle Jurassic Shaunavon formation. The Shaunavon consists of an upper and lower member; the lower member is a carbonate mudstone while the upper member is made up of interbedded limestone, sandstone and shale (Marsh and Heinemann, 2005).

Figure 2 shows the results of this analysis at two levels, one (a) corresponding to the overburden, and a second (b) corresponding to the Shaunavon level. The amount of splitting shown in Figure (2a) was significant in places, and had clear spatial variation both in strength and orientation. Correction for this resulted in the improvement shown in Figure 1. Apart from a few anomalies at the Shaunavon level (Figure 2b), the study area is fairly isotropic, which is verified by dipole sonic well logs nearby. In the NE quadrant there appears to be a clear trend varying from E-W to N-S in a circular arc. There is also indication of a fracture swarm slightly SW of the center. However, we have less confidence in this anomaly, as it is associated with a lower value of the QC attribute – based on similarity of the S1 and S2 data – which is shown as the background gray scale in Figure (2b).

An alternative approach to extracting the reservoir fracture information was also pursued. This involved imaging both S1 and S2 data without correcting for the time delay. The top of the Gravelbourg formation (a marker defining the base of the Shaunavon) was then interpreted for both S1 and S2, and the difference in two-way-time calculated to give a Δt. This gives similar results to the shear-wave splitting analysis attributes as described above, but has the advantages of being based directly on interpretation, and being performed in the migrated domain. The results of this procedure are shown in Figure 3.

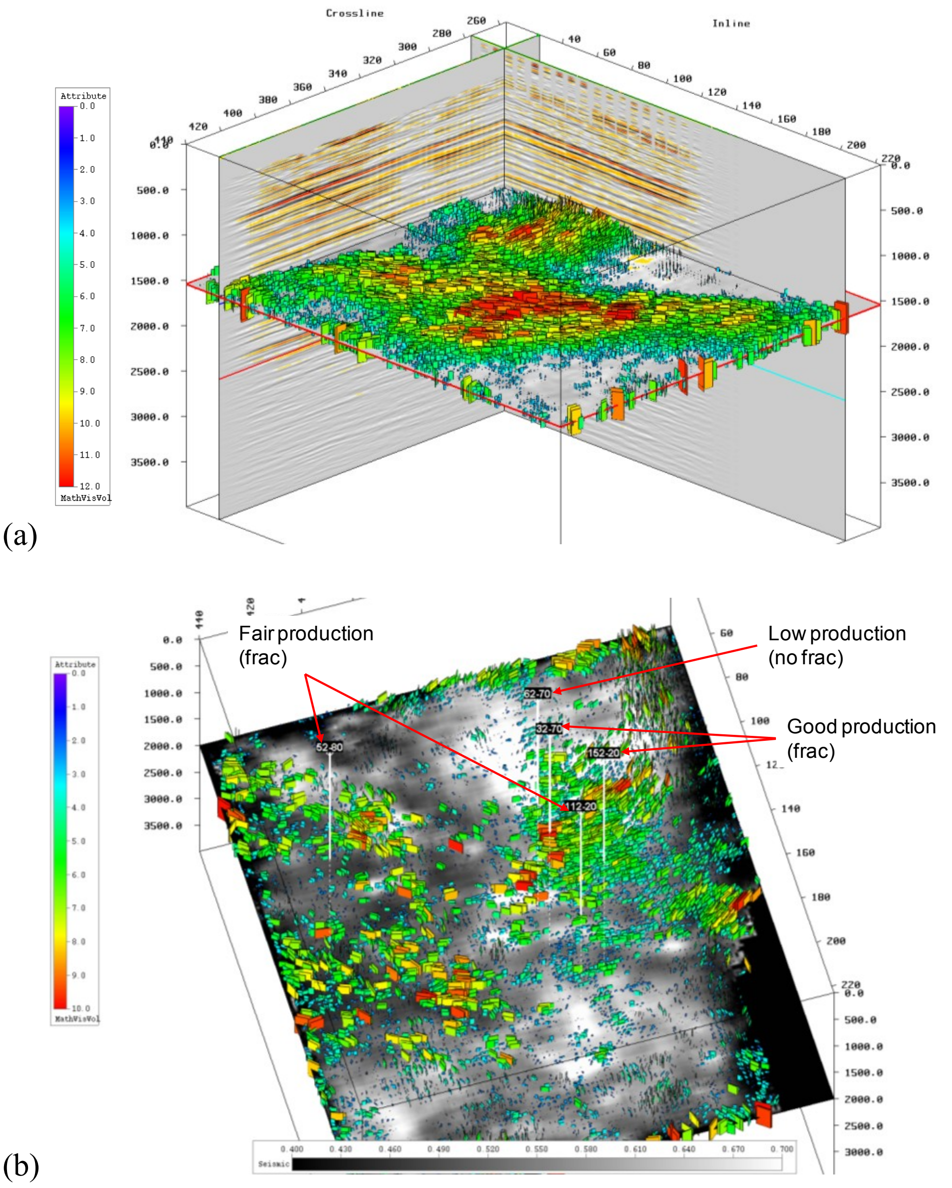

Figure 2: Results of shear-wave splitting analysis for anisotropy in overburden (a) and target level (b). The displays show oriented plates which represent simultaneously the orientation of the anisotropy (i.e. S1) and the S1-S2 time-delay, represented as both plate size and colour (warm colours correspond to higher anisotropy values). In (a) the background is the PS image; in (b) the background is a splitting QC which shows locations with *higher* confidence in the lighter gray shades.

Comparing this map to the output from the shear-wave splitting analysis (Fig. 2b), they show many similar characteristics. The NE quadrant shows a strong, coherent anisotropy anomaly. However, the fracture swarm seen SW of the center in the shear-wave splitting analysis is not as evident on the difference map.

To examine whether the anisotropy anomaly correlated to well production, certain comparable wells were analysed. In Figure 3, posted next to these wells are amount of Upper Shaunavon pay, if a hydraulic fracture ("frac") treatment was used or not and values for initial three month total fluid production in barrels. This value was used instead of oil produced to reflect well deliverability and initial 3 months used to avoid discrepancies due to variations in time on production.

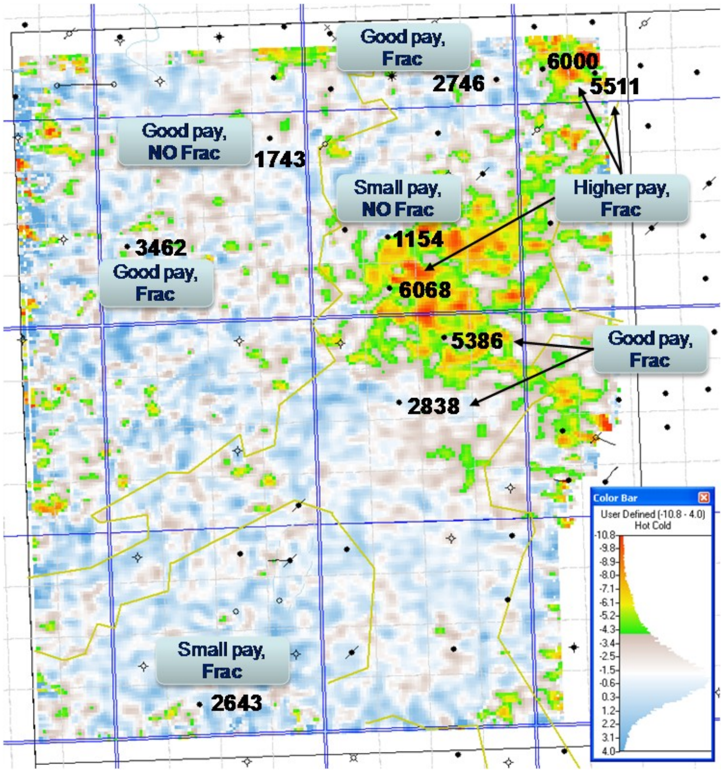

Figure 3: Anisotropy from time difference between P-S1 and P-S2 interpreted top Gravelbourg horizon (warm colours corresponding to larger time differences). Comparable wells with three month total fluid production figures are also shown. Note that there is a good correlation between areas of high shear-wave anisotropy and wells which responded well to fracturing.

As shown in Figure 3, the wells within the anomaly which had a frac tend to have higher production values than all other wells. The wells outside the anomaly which have a frac have higher production than wells without. One well inside the anomaly with a low production value had no frac applied. These results suggest that a frac applied to the wells within the anomaly have been aided by the stress field found here, making it more conducive to fracturing and that existing fractures (if any) have no effect on production.

Conclusions

Shear-wave splitting analysis from multi-component data demonstrated stress or fracture anomalies within an isotropic tight oil reservoir. By analyzing the S1 and S2 outputs, the time differences between these volumes produced a clearer image of the anomaly which was then correlated successfully to variable production patterns in the area. The data from this analysis can be used for future well treatments and placement of new horizontal wells.

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References

Bale, R. A., J. Li, B. Mattocks, and S. Ronen, S., 2005, Robust estimation of fracture directions from 3-D converted waves: 75th Annual International Meeting, SEG, Expanded Abstracts, **24**, 889–892.

Marsh, A. and Heinemann, K., 2005, Regional Stratigraphic Framework of Western Saskatchewan – Phase I: PTRC.

Whale, R., R. Bale, K. Poplavskii, K. Douglas, X. Li, and C. Slind, 2009, Estimating and compensating for anisotropy observed in PS data for a heavy oil reservoir: 79th Annual International Meeting, SEG, Expanded Abstracts, 1212–1216.