F-22 4D-4C AVOA AT TEAL SOUTH

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Introduction

P-P and P-S wave amplitude variation with offset and azimuth (AVOA) effects are studied for the first time in multi-component, time-lapse seismic data. The data considered are from the Phase I and II ocean bottom cable (OBC) surveys of the Teal South experiment in the Gulf of Mexico. The objective in this work was to analyse the potential of P-wave and converted wave AVOA to detect time-lapse signatures beyond the resolution of conventional approaches.

AVOA analysis has significant sensitivity to azimuthal anisotropy (which may be induced by alignment of fractures or porosity) and pore-fill/saturation (e.g., Hall and Kendall 2000). Thus observations of AVOA can be used to characterise sub-seismic scale fracturing, identify compartmentalisation and assess fluid-flow. In a marine setting, ocean bottom seismic acquisition provides the wide azimuthal coverage necessary for AVOA studies and true 3D imaging. Furthermore, permanent installation of 3D-4C ocean-bottom receivers allows monitoring of time-lapse stress/fracture effects, in combination with fluid movement, that may be induced by production. At Teal South the 4500' sand reservoir was initially over-pressured so some degree of compaction is expected that may lead to changes in local stress distributions that could be detected using AVOA analysis. Such information may, in many situations, be utilised to optimise production through the guiding of directional drilling or water-injection and identification of in-fill targets. Modelling of the expected AVOA and time-lapse signatures is presented to assess the feasibility of the approach and enable interpretation of the results. The processing procedure is outlined with the initial results from time-lapse P-wave AVOA analysis providing anisotropy orientation and magnitude maps for the 4500' sand and a control horizon.

Teal South field and 4D-4C data

The Teal South experiment, managed by the Energy Research Clearing House in Houston, aimed to study the practicalities of permanent deployment of ocean bottom sensors (considering issues such as repeatability and data quality) (Ebrom et al., 1998). The OBC acquisition involved two phases with a 2-year interval. Phase I was shot in July 1997 with a 25m x 25m shot grid over 9km^2 using 4 East-West lines of 6 receivers at a line interval of 400m and a receiver interval of 200m (see Figure 1). Phase II was acquired in April 1999 with the same acquisition extended with a shot grid area of 12km^2 and 3 additional N-S lines of 4 receivers to the East of the original lines. Legacy 3D towed streamer data were acquired in 1995.

The reservoirs of interest are turbidite sands distributed between 4000' and 8000'. This work concentrates on the 4500' sand that was initially overpressured and showed a clear time-lapse response between the towed-streamer and the Phase I OBC datasets. However, conventional processing and analysis of the P-P and converted wave data of the Phase I and II OBC surveys has revealed an insignificant time-lapse signature. In this period, between Phase I and II of the OBC acquisition, the reservoir changes involved: a pressure decrease from 19.5 MPa to 15.1Mpa, with the rock stress being 36MPa; a saturation (Sg:So:Sw) change of 0.00:0.70:0.30 to 0.05:0.65:0.3; a change in fluid properties from a density of 797kg/m^3 and V_P of 1240m/s to values of 761 kg/m^3 and 1140m/s respectively.

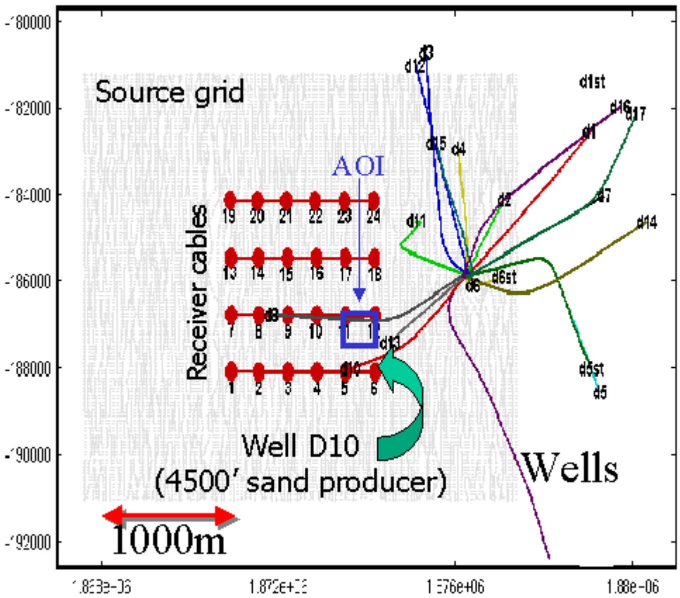

Figure 1 Teal South Phase I 4D-4C OBC data acquisition set-up plus well locations and 4500' sand position. Also shown in is the area of interest (AOI) for the AVOA analysis.

Modelling

To assess the potential of AVOA analysis as a time-lapse monitoring tool at Teal South forward modelling of the expected AVO and AVOA signatures has been carried out. Initially simple models have been used with a single set of fractures in the reservoir sandstone that is overlain by shale providing a negative impedance contrast at the interface. The effective elasticity of the fractured sandstone is represented using an effective medium method (using an extension of the Schoenberg and Sayers (1995) approach as outlined in Hall and Kendall (2000)). Figure 2a shows the modelled AVO for different azimuths from the fracture strike direction. From these results it can be seen that the converted wave AVOA has a greater azimuthal character than the P-wave.

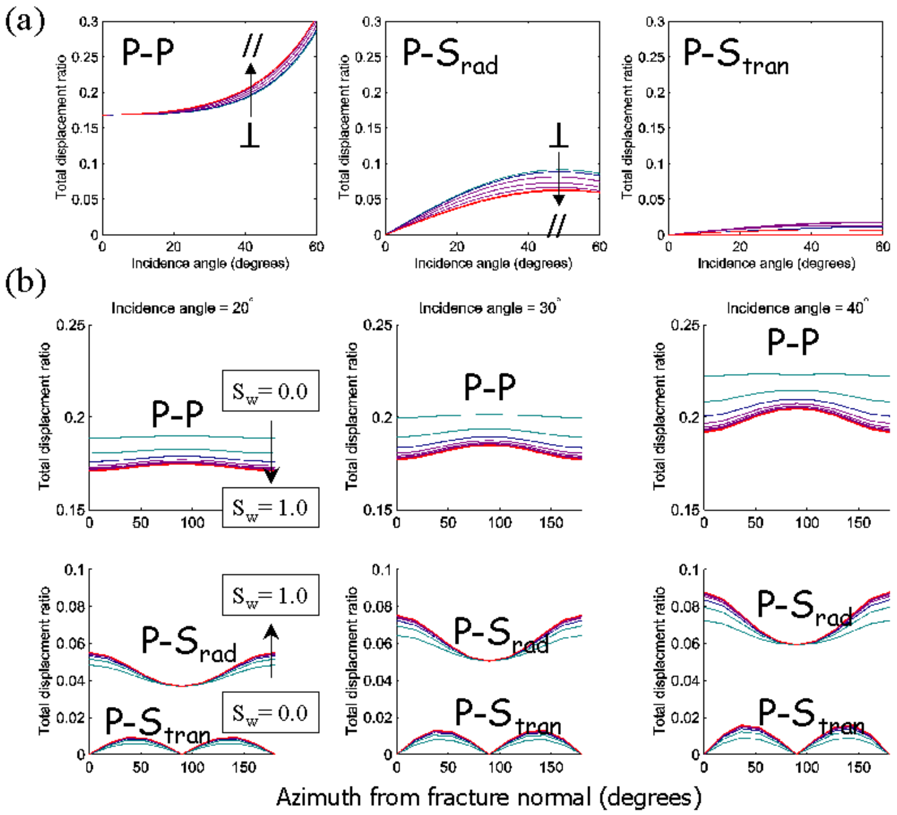

Figure 2 Predicted AVOA responses for the 4500' sand: (a) model parameters used in reflectivity and effective medium modelling; (b) AVO for a range of azimuths from the fracture strike direction (//) to the fracture normal direction (⊥); (c) AVAz for P-wave and converted reflections at the top sand with changing water saturation from 0.0-1.0 and at three P-wave incidence angles. The parameters used in the modelling are: overburden, Vp = 2740m/s, Vs = 1140 m/s, ρ = 2300 kg/m^3; Sand, Vp = 2210m/s, Vs = 1140 m/s, ρ = 2030 kg/m^3 ; single fracture set: aspect ratio = 0.001, crack density = 0.1.

Changes in saturation may be detected using AVOA techniques as demonstrated in Figure 2b for P-wave and converted-wave reflections. For this model an increase in the azimuthal variation of amplitude is observed with increasing water saturation. It is noted here that the "bulk" changes (seen as a dc-type shift in the AVAz curves) are greater for the P-wave than the converted waves highlighting the different sensitivities of the different modes. Thus multicomponent AVOA analysis has significant potential for monitoring of fluid changes at Teal South. Furthermore, production related pressure changes that will affect the aspect ratio of fractures and aligned porosity may be detected using anisotropy analysis. Geomechanical compaction may be associated with such pressure changes and can also give rise to opening and closing of fractures such that the degree and orientation of anisotropy may change. These pressure-related factors have also been modelled.

AVOA processing and preliminary results

The scheme applied in processing the OBC data for AVOA analysis (based on the previous work of Hall et al., 2000, and Reid and MacBeth, 2000) accounts for vector fidelity, source directivity and CMP offset-azimuth distribution. The data between the two surveys were matched such that only the original 24 receivers and Phase I shot area were considered (See Figure 1). P-wave analysis is relatively straightforward but converted wave processing requires a number of additional pre-processing steps prior to the AVOA, such as rotation analysis. Furthermore binning issues can have a significant effect on the resultant AVOA (Hall and MacBeth 2000). Both surveys were treated consistently to ensure adequate correspondence between P-P and P-S data as well as between the Phase I and II surveys.

Figure 3 shows preliminary time-lapse P-wave AVOA results for an area of the 4500' sand (indicated in Figure 1) and that for a shallower horizon, above the 4500' sand, where little time-lapse change is expected; this acts as a control horizon. Changes in AVOA magnitude between phase I & II at the control horizon are minimal and there is a reasonable consistency in the detected orientations. However the anisotropy tends to decrease from phase I to phase II in the reservoir (4500' sand). Based on previous modelling done at Heriot-Watt University (involving a more complete approach than the examples shown above), the observed changes at the 4500' sand are greater than would be predicted for the known whole-reservoir changes in pressure and saturation. Thus further modelling is needed to address this issue and it is expected that geomechanical compaction and localised pressure/saturation changes will be important factors. It is also noted that some anomalous values exist indicating a need for processing/picking refinement.

Conclusion

This work indicates that observations of seismic anisotropy (e.g., using AVOA) provide the potential to monitor small production-related reservoir changes through monitoring of the reservoir's stress-state. Furthermore a more quantitative assessment of time-lapse processes is possible permitting improved constraint on the reservoir simulation.

Modelling of the expected AVOA signature at Teal South shows that the P-S converted mode is a more sensitive indicator of the azimuthal anisotropy and P-P AVOA effects require greater offsets to observe the same magnitude of effect. However it is noted that P-P data are simpler to process than the P-S data which are more challenging in terms of both processing and interpretation due to binning issues and polarisation effects in the overburden. Initial data analysis reveals an azimuthal P-wave AVO signature with significant time-lapse changes. Extended AVOA processing and interpretation is in progress to include the complete reservoir interval and other horizons for both P-wave and converted phase data.

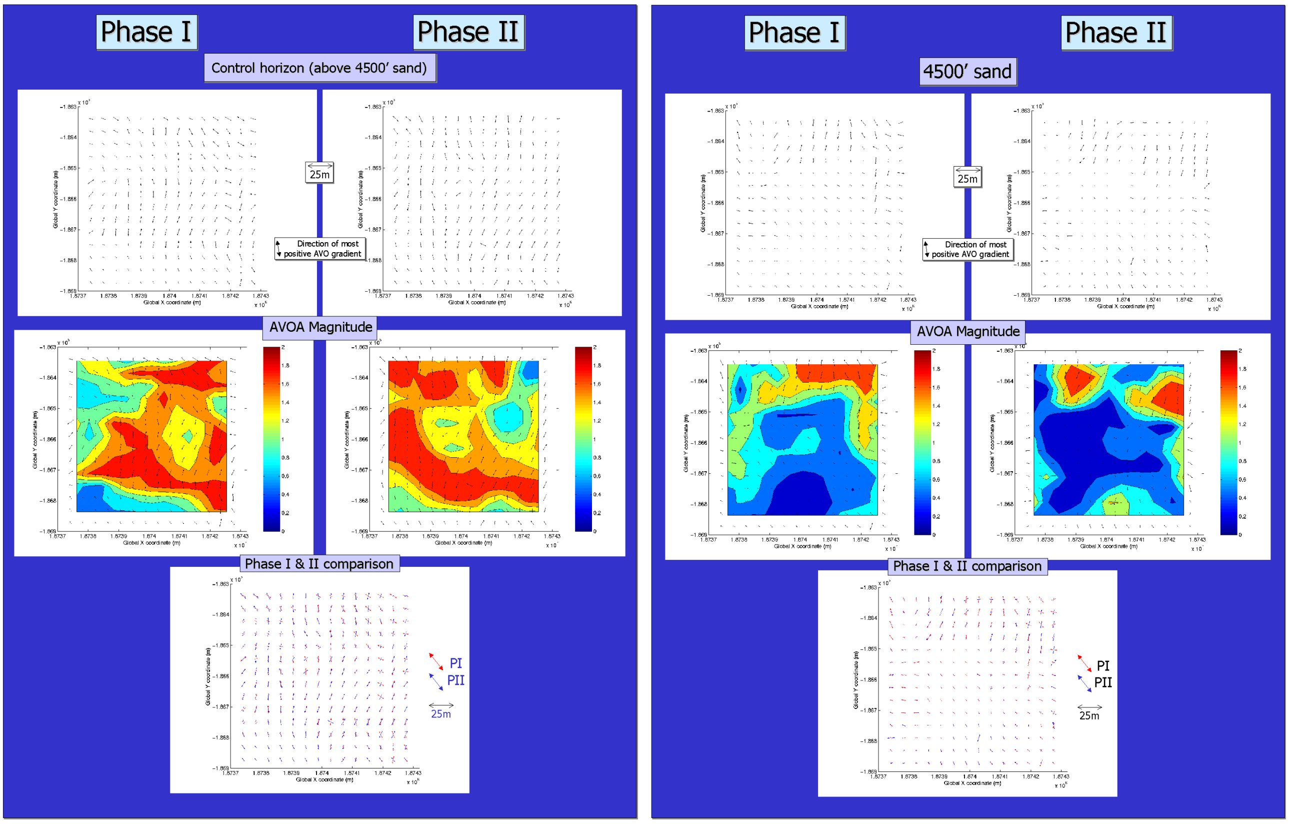

Figure 3 Preliminary P-wave AVOA results for Phases I and II for the area of interest highlighted in Figure 1. Two horizons are considered, the top 4500'sand and an overlying layer. The upper plots show the orientation of the most-positive AVO gradient. The middle plots show the magnitude of the azimuthal AVO anisotropy and the lower two plots show the change in the anisotropy between the two surveys with the two sets of AVOA results overlaid.

Acknowledgements

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