A multi-azimuth VSP experiment for fracture orientation detection in HMD field Algeria

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This paper was prepared for presentation at the 9th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, 11-14 September 2005.

Abstract

Natural micro-fractures are very important in the control of production in the hydrocarbon reservoirs. The presence of the vertical fractures in the rock mass causes the split of the incident shear wave into two approximately orthogonal components with different velocities. Shear wave splitting analysis permits the estimation of fracture orientation.

In the offset VSP experiment, converted SV waves are generated with varying strengths at particularly all depths. Consequently, the converted Sv waveforms partially overlap with direct P waveforms makes the separate event analysis difficult and inaccurate.

In this paper, an automatic picking technique was used to accurately compute travel time of P and Sv down-wave. The polarization angles are determined from particles motion analysis. The interval velocities Vp and Vs were than computed using the travel time inversion technique.

In this study, an attempt was made to determine the orientation of natural fractures using shear wave splitting technique and P wave velocity anisotropy from four offset VSP data acquired with different azimuths in the same well.

Introduction

The characterization of the fractured reservoirs in HMD field is a challenging task because of the complexity of the fracture geometry. While the fractures are the single most important future controlling fluid flow in the reservoirs with poor porosity, good knowledge about fractures strike may significantly increase oil recovery.

Various methods exist that help determining the fractures orientation (anisotropy) such as VSP. The resolution of the subsurface anisotropy using multi-components VSP experiment depends critically on the geometric distribution of raypaths sampled. Raypaths at inappropriate azimuths and incidence angles may not contain enough information about the anisotropy. In this paper, we have used two approaches to investigate the fractures orientation which are the shear wave splitting and P wave velocity variation with incidence angles.

Stratigraphy

The reservoir under investigation is sandstone (about 90m) in which the upper part is saturated by oil with a poor porosity. The prevailing stress field at reservoir's depth cause micro-fractures associated with faulting. To investigate this fault, four fixed offset VSP were acquired.

Acquisition and data processing

The 3C geophone was used to record the complete seismic wavefield propagating from different offsets and azimuths using a P-wave vibrator as energy source. Conventional processes were applied to construct the subsurface image, and special processes which maintain the amplitude variations in order to determine the rock properties. The data were horizontally oriented to the direction of maximum direct P-wave arrival energy (fig. 1).

The particle motion analysis was performed to determine the P and SV waves polarization information, used later to maximize the P and SV down waves energy in the vertical plan.

Shear wave splitting identification

The VSP have the advantage of recording the full seismic waveform propagating in the subsurface at a short interval witch makes them ideal tools for detecting the anisotropic zone.

The observed SV waves were generated by mode conversion of incidence P wave on subsurface interface of high impedance contrast. It is well known that shear-wave splitting from PS converted waves contains information on subsurface fractures and azimuthally anisotropy. The fracture orientation is determined from the particle motion's direction of fast shear wave (S1).

The analysis method involves:

- Selecting a shear-wave event.
- Rotating the horizontal seismograms into radial and transverse components.
- Maximizing the P and SV wave in the vertical plan.
- Picking the shear-wave's arrival times.
- Computing the polarization's direction using the particle motion diagram in the horizontal plan (Hs, Ht).
- If a second split shear wave is identified, the time delay is measured.

In this case, we have used the downgoing Sv events generated by two strong conversion interfaces (Aptien and Lias S1).

Figure 2 shows the polarization diagram for Sv wave generated by Lias S1 interface for selected depths above, within and below the reservoir. After analyzing the particle motion of the two selected events for different azimuths we observed that the SV wave has kept the usual direction of propagation (source –receivers) and that its second component didn't appear.

Even though the geological information confirms the presence of the vertical natural micro fractures, the shear wave splitting couldn't be identified. The result above leads us to investigate the anisotropy through the P wave velocity variation with offset.

P wave velocity anisotropy

Since we couldn't identify the shear wave splitting over all azimuths, we tried to determine the fracture's orientation using the P wave velocity anisotropy. To investigate this later, we have studied the P wave velocity variation with azimuths using the anisotropic ratio (Kabaili and Schmitt 1996):

$$(V_{\max} - V_{\min}) / V_{\max} ;$$

Where V_{max} is the maximum velocity assuming equal to oblique velocity derived from offset VSP using the incidence angles of direct arrivals and V_{min} is the vertical velocity calculated from zero offset VSP.

The incidence's angles estimated from hodogram vary with depth because of changing geometric relationship between the source and receivers and of refraction of the downgoing P wave as it passes through media with different velocities. We have compared the theoretical incidence's angles computed from a synthetic model using the velocity derived from zero offset VSP and the hodogram angle of incidence estimated from experiment offset VSPs.

In the reservoir zone, we have found that the theoretical incidence's angles are more vertical than the observed angles. The difference between the theoretical and the observed angles depends on the azimuth. This anomaly can be attributing to the azimuthally anisotropy. To confirm this assumption we must compare the vertical and oblique P wave velocities.

The vertical component of velocity at the receiver array for a given source position was calculated directly from the arrival times of the zero offset VSP. Meaningful interval velocities from offset VSP can only be computed if we have a good idea of the incidence's angles. Supposing that there are no severe lateral variations, the oblique component of velocity was computed using the travel time inversion technique, where the incidence's angles were automatically estimated.

Figure 3 illustrates that the oblique and vertical velocities converge in most investigated depths except in the reservoir zone. The results are summarized in Table 1. We denote that the incidence's angles increase with the offset, consequently, we can attribute the anisotropy ratio's variation to the azimuthally anisotropy. The rose-plot (figure 4) help us to determine the preferred fracture direction witch correspond to the most important anisotropy ratio. In our case, the preferred direction of wave's propagation on the rose plot is about 168°.

VSP	Azimuth	Offset	Angle	Anisotropy ratio
A	72°	1300	29°	05.75
B	300°	2500	45°	14.03
C	220°	2200	43°	07.80
D	175°	2300	38°	27.05

Table 1: P wave velocity anisotropy ratio and incidence'sangles vs. azimuth.

Conclusion

Even though the geological information confirms the presence of the vertical natural micro fractures, the shear wave splitting couldn't be identified. This is probably due the geometry witch is inadequate for this problem (very large offsets).

Although the B, C and D offsets are practically equal (similar angles of incidence), the ratio corresponding are different. Consequently, the velocity variations are rather related to the azimuth. As a conclusion, the reservoir is an azimuthally anisotropic model and the direction of fracturing plane is perpendicular to the direction of maximum anisotropy ratio (azimuth =165º).

References

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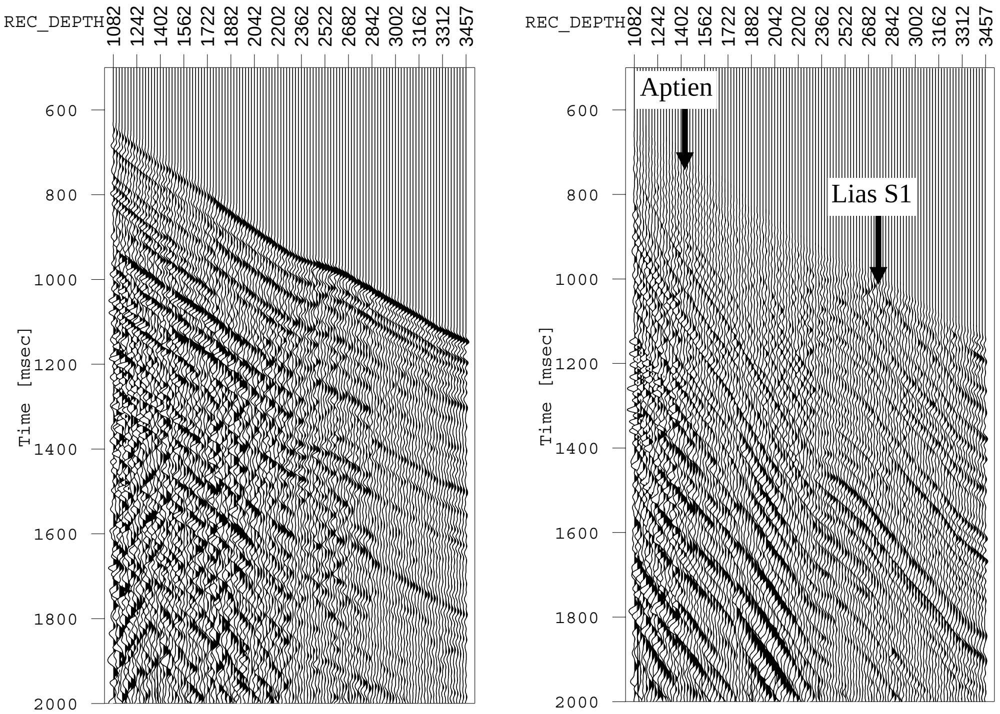

Figure 1: Vertical (left) and radial (right) component

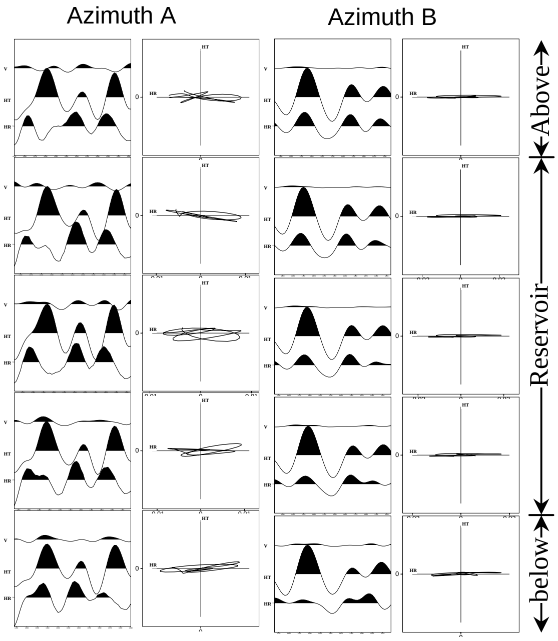

Figure 2: Polarization diagrams for Sv wave generated by Lias S1 interface

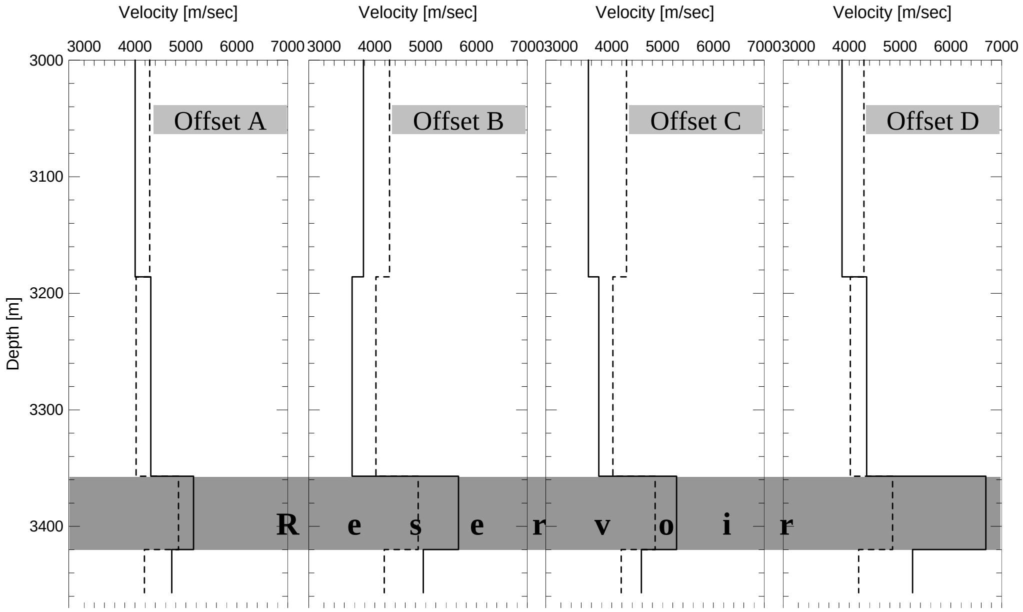

Figure 3: zero offset velocity (dashed) compared to oblique velocities (solid)

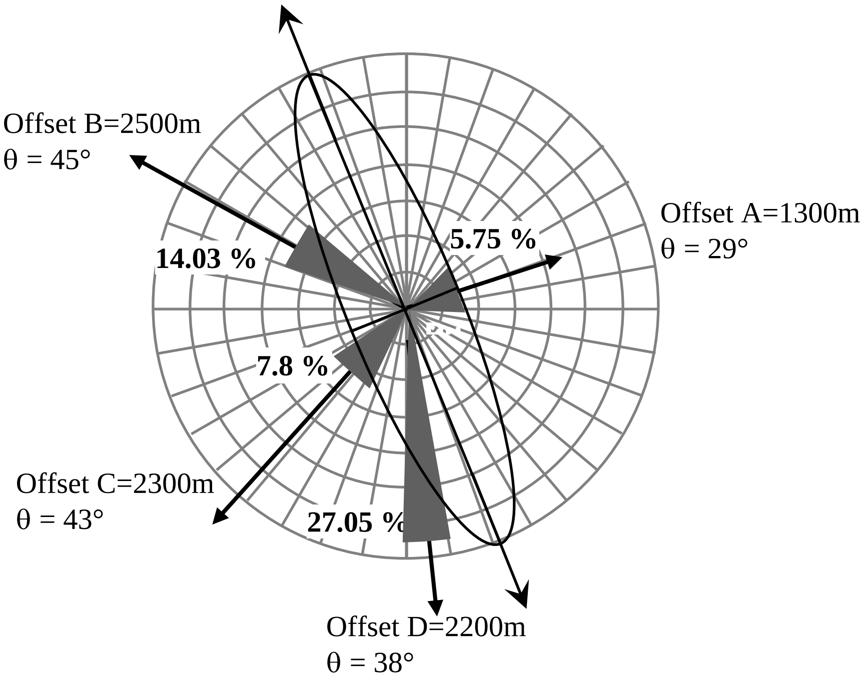

Figure 4: rose-plot representing the anisotropy ratio distribution vs. azimuth.