3D P-wave Anisotropy Analysis Technique to Fracture Detection in a Colombian Limestone Reservoir

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Abstract

Fracture detection technique based on 3-D P-wave seismic dataset has been a powerful tool for fractured reservoir characterization in recent years. However, as the most economical method of fracture detection, the accuracy and resolution of this method has been doubted sometimes. The major aspect of this paper is to prove the effectivity of this method.

Traditionally, fracture information comes from well data, in particular image log and core. The purpose of this article is to prove that P-wave azimuthal anisotropy technique not only can describe the fracture character in thin limestone reservoir to regions between the wells but also can get result with good accuracy and resolution. The results indicated that the final fracture orientation and intensity got from 3D P-wave azimuthal anisotropy are extremely consistent with FMI/CMI data from drilled wells.

Introduction

Our study was conducted in an oil field located in the Catatumbo basin at North-Eastern Colombia and it corresponds to an anticline encased between two regional faults in NS strike. The reservoir is limestone of the Lower Cretaceous with very low porosity (1%~4%) and permeability (0.01~0.1mD). Because of these critical petrophysical properties, fracture characterization is very important to understand storage space, directions of flow and areas of commercial oil production.

This paper attempts to describe how to best use azimuthal anisotropy technique based on 3D P-wave data to detect and characterize fractures in the whole study survey, without limitation of well location. The results show very good correlation with well data.

Core idea of methodology

The theory that fracture development can cause amplitude variation with offset and azimuth (Shen et al., 2002) has been universally accepted by now.

It has been proved that thin pores (fractures) have much greater effects on velocities than rounded pores at the same porosity and that a very low porosity (less than 0.01 percent) of thin pores could decrease the P- and S- wave velocities (Kuster and Toksoz, 1974) and generates seismic anisotropy. Further, Study shows that vertically aligned fractures can cause anisotropy of seismic attribute on offset seismic data (Lynn et al., 1995). That means how to detect azimuthal amplitude variation with offset and relate it with fracture properties is essential issue of predicting fracture development.

To identify the effects of fracture properties on the azimuthal amplitude variation, the forward modeling can be very useful to set relationship between seismic attribute and fracture characteristic and establish a vector which can present fracture properties directly. By combining P- and S-wave velocities, rock density and related geological information, the rock physics model can be constructed accurately.

After modeling wave propagation in fractured reservoirs to rock physics model, the accurate azimuthal AVO response can be obtained (Fig. 1 upper).

In order to describe and understand directly and visually, an anisotropic ellipse as a vector, which can present fracture orientation and intensity, can be fitted by different values of each azimuth in same incidence angle (Fig.1 lower).

Application steps and result

Rock physical forward modeling

Theoretical petro-physical model is designed to investigate lithological variation azimuthal P-wave anisotropy response by using forward modeling of mutual medium fluid exchange wave equation (Zha et al., 2005). The problem about how to definite the anisotropic orientation by the elliptic axis also can be solved by analyzing the relationship of anisotropic orientation with amplitude directional elliptic of different incident angle.

The forward modeling result from one well with a good set of electrical logs (Fig.2) indicate that the target layer can cause obvious anisotropy response and the maximum axis of anisotropy ellipse can present fracture orientation.

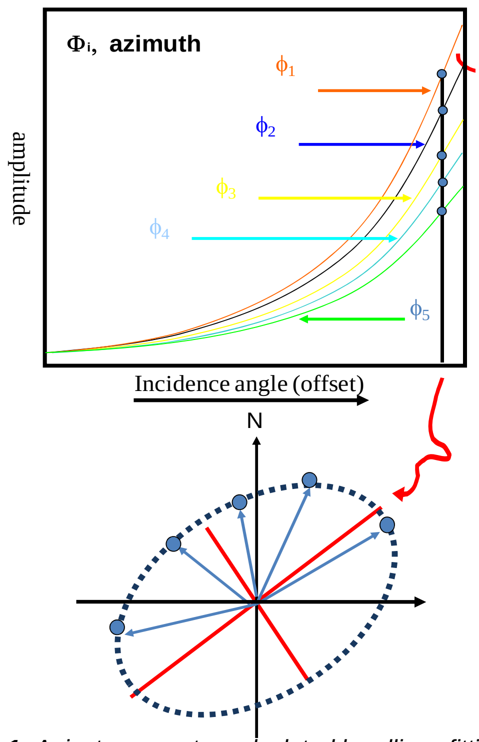


Fig.1- *Anisotropy vector calculated by ellipse fitting (The axis: orientation of anisotropy; the ratio of major and minor axis: intensity of anisotropy.)*

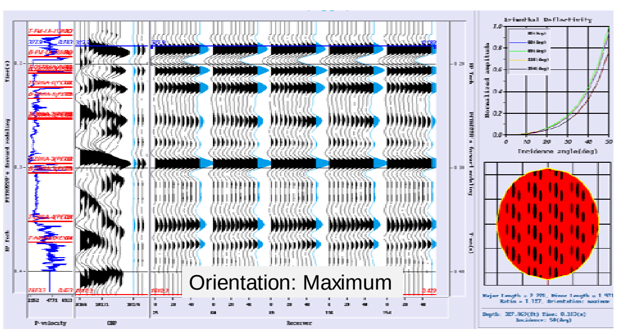


Fig. 2- *Forward modeling result of one well*

Sensitive parameter optimization

Optimization most sensitive parameter is a key step to determine the accuracy of fracture prediction result. The high fracture density can cause the seismic scatting and loose energy in high frequency components. This kind of variation is extended when take the offset seismic data with different azimuth into consideration. So the offset-dependent dynamic seismic attributes are used to characterize the seismic attenuation induced by the fractures and its heterogeneity. For this particular case, the relative impedance was chosen as the sensitive parameter to estimate fracture detection. Figure 3 shows calculated relative impedance sections of each different azimuth seismic data.

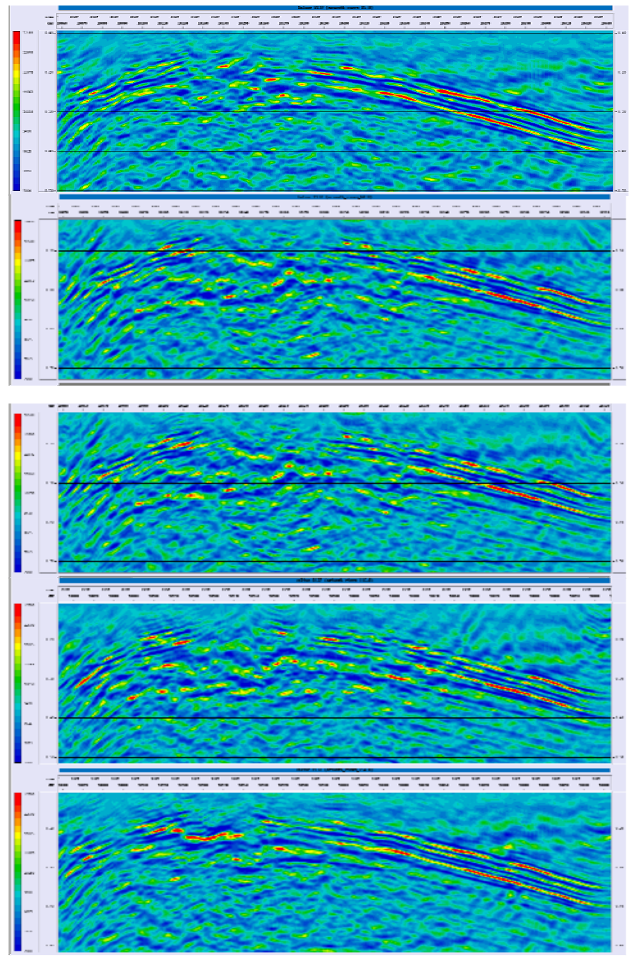


Fig. 3 *- Relative impedance sections of five azimuth cubes (From above downward, the azimuth range is 0~49°, 48~76°, 75~103°, 102~129° and 128~180°)*

Fracture characterization

The theory has proved that it is possible to get fracture development properties by using 3D P-wave seismic data. However, to characterize fracture orientation and intensity is a big challenge in aspect of accuracy and resolution. In order to decrease the uncertainty and multi-solutions problem of seismic data as much as possible, the quality control has to be done for step by step, such as azimuth trace gather division, forward modeling, attribute calculation and so on.

In this case, it is observed that significant relative impedance changes around producing wells in such low porosity and permeability limestone reservoir is caused by the seismic scattering due to the occurrence of high fracture intensity. Optimizing sensitive parameter helped to improve the reliability of result. The drilled and production data is the only information can be trusted to represent reservoir properties, so they were used to verify the fracture prediction results. Using production well locations as a priori, the fracture intensity map calculated from relative impedance of five different azimuthal seismic gather provided the best calibration to reservoir production (Fig. 4).

Though because of the seismic data limitation, the calculated fracture intensity result cannot be quantified as image log and core. The significance of this approach is that it realized to predict fracture development characteristic of whole 3D survey and give guidance of exploration in quality and half-quantity.

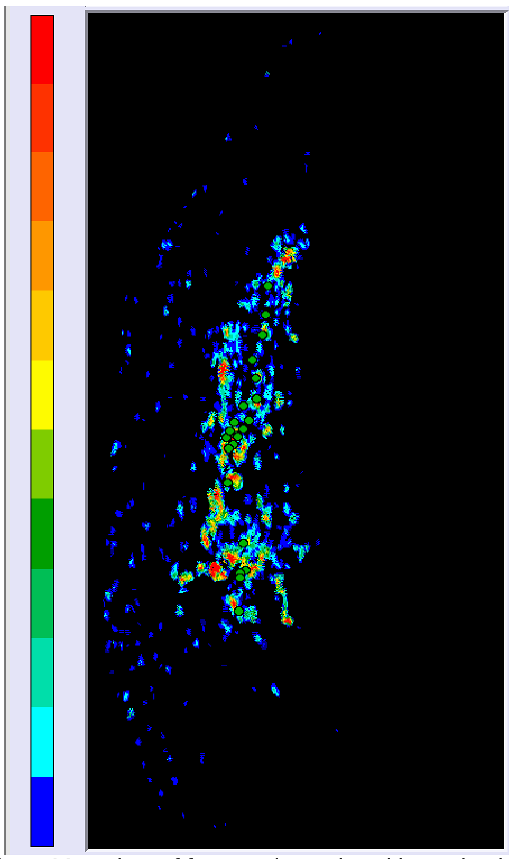
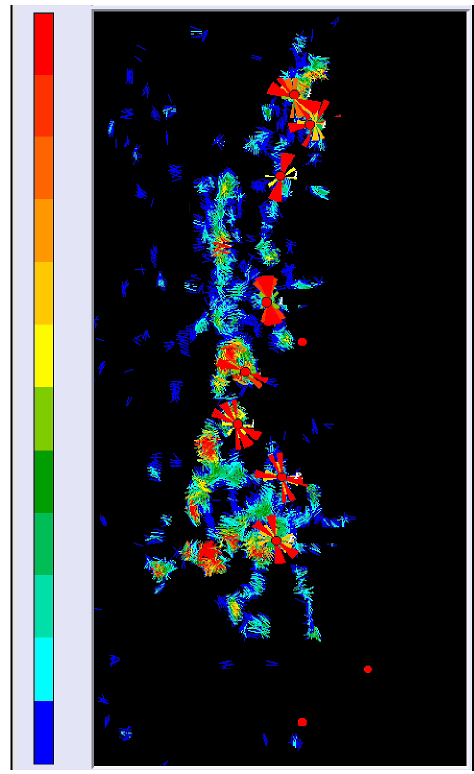
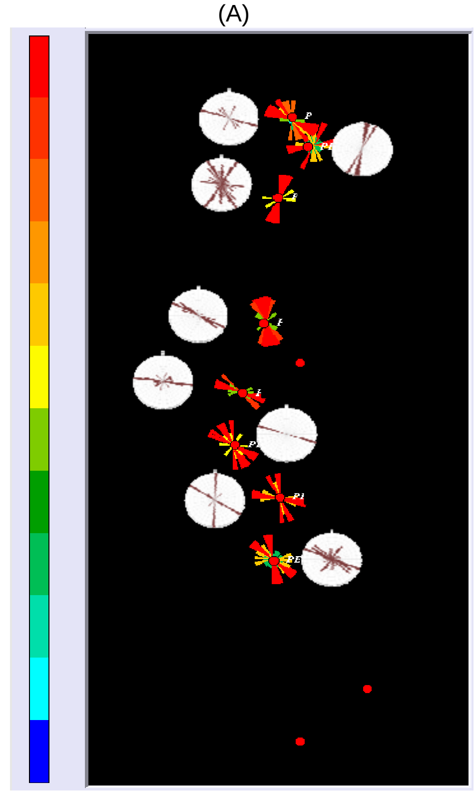


Fig.4- *Map view of fracture intensity with production well location*
(red color means high fracture intensity; green circle shows production well location)

The fracture orientation is another very important factor of controlling hydrocarbon flow direction. Seismic data have wider spatial coverage than the well data, while well logs have spatial limitation but with high resolution and accuracy. In order to verify the reliability of prediction results, the image log was taken as examination standard. In this field there are 11 wells with image logs information, They are well distributed through whole our study area from north to south (Fig.5A). The comparison between the orientation from well data and seismic data gives confidence and approve reliability of per-stack anisotropy detection result. The rose diagrams of Fig.5 A come from fracture orientation predicted from seismic data at each well location. Though comparing with image log result (rose diagram in white circle of Fig.5 B), it is definitely proved the accuracy and reliability of predicted result.



(A)



(B)

Fig.5- *Map view of fracture orientation and comparison with FMI/CMI result*
A: fracture prediction result
B: comparison between predict result and FMI/CMI

Conclusions

Natural fracturing is a very important factor controlling exploration and development of hydrocarbons, which is a complicated geological phenomenon determined by geological and geomechanical process. In this paper, we have demonstrated an advanced methodology to characterize fracture (intensity and orientation) using 3D P-wave seismic data and the results showed good accuracy and resolution correlate with well data.

Forward modeling by using log data provided a guide for fracture analysis. Sensitive parameter optimization is pre-condition to confirm the accuracy and reliability of predict result. By comparing the results with well data, this case proved that the detailed fracture characteristic can be extracted from 3D seismic data and this technique is viable for predicting fracture between wells & ahead the drilling.

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