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Integrated Fracture Identification with Z-VSP and Borehole Images: A study from Cambay Basin

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Summary

Cambay basin in Western India has long been on production from various stratigraphic formations of clastic sedimentation. The production has been on decline and the exploration campaign is focusing more on the tight silty formations in the basin these days. Fractures do play an important role in such reservoir to provide the secondary porosity and flow conduit. The shear splitting from Zero-offset Vertical Seismic Profiling (Z-VSP) has been observed in a couple of wells in the study area which can be attributed to natural fractures. Borehole images by virtue of their high resolution (1.2 inches from Oil Base Micro Imager, OBMI) capture the sub-seismic events of fractures with their orientations. After calibrating the fractures on borehole images with the shear splitting this methodology was used for identification of fractures in other intervals where borehole images were not acquired or had poor data quality due to hostile logging conditions. Such integrated application of Z-VSP and Borehole images is key to successful identification of fractures which could be used to ant-track on seismic volume.

Introduction

Borehole measurements like formation imaging and vertical seismic profiling provide a detailed insight into the understanding of fractures not resolved on traditional seismic analysis. Borehole imaging of formations by virtue of its high resolution capabilities plays a vital role in identifying the fractures and their orientation. Being near well bore measurement, these findings need to be validated with sonic logs and vertical seismic profile. The most prominent effect of aligned vertical (or near vertical) fractures on seismic waves is the splitting of shear waves (Thompson, 2002) and this study compares the intervals of shear wave splitting with the borehole images.

An attempt has been made to understand the distribution of fractures in a field in the Cambay basin of India. Cambay basin is a proven petroliferous basin and has been on production since long. The basin is a complex Tertiary rift graben filled with more than 7 km thick sediments above the Deccan Trap of Cretaceous-Tertiary boundary (Figure 1). This rift is bounded by north-south trending boundary faults both on the eastern and western margins, the former being the more severely faulted than the latter.

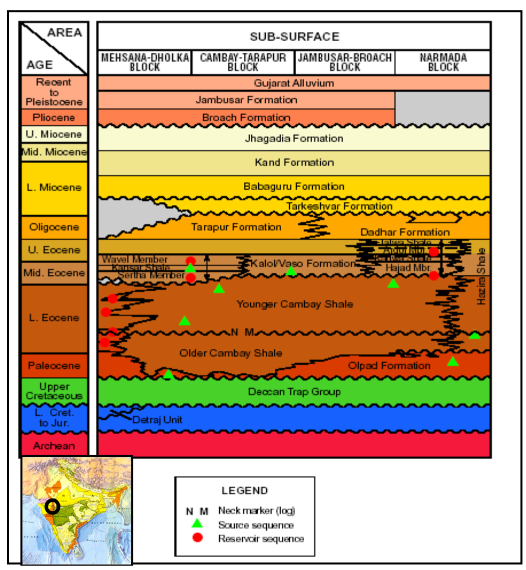

Figure 1: Study Area of Cambay Basin with Generalized Stratigraphy

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Right lateral strike-slip faults trending NE-SW divides the rift basin into sub-basins. The fault and fracture trends obtained from the image logs follow both the regional trend of the Cambay rift basin. Paleocene Olpad Formation sands are the targets in this basin and fractures play a very important role in providing the much needed permeability through such formations. Two wells were studied and the study confirmed the presence of fractures and provided their orientation for further interpretation in the Olpad Formation**.**

Data Acquisition

VSP Data

The Z-VSP data was acquired using an array of four shuttles each spaced by 15.12m and having triaxial GAC sensors The tool used was VSI*-Versatile Seismic Imager Tool, as the downhole seismic tool. A two gun cluster was used as an energy of source to acquire the survey. The source was positioned at a distance ~ 65m. The downhole data quality was good with high signal to noise ratio. Also, mode conversion (P2S) was observed and were more dominant in the horizontal components.

Bore Hole Imaging Data

Borehole images were acquired with OBMI (Oil-Based Micro Imager) since the drilling mud was synthetic oil-based. The data quality has been affected in some intervals due to the borehole rugosity and it is imperative to do the interpretation with the help of quality flags.

Methodology and Workflow

Multicomponent VSP Data Analysis

Zero Offset VSP (Z-VSP) has traditionally been used as post-drill analytical tool with its main deliverables being velocity information along the well. In case of Z-VSP in vertical well most of the compressional energy comes in vertical component (Z) and horizontal components (X and Y) contain shear and mode converted shear information (if observed). That's why most of the Z-VSP processing is done by using only vertical component.

However, if horizontal components contain siginificant shear information, then this can be utilized for other applications e.g. shear splting analysis, shear velocity extractions etc. This mode conversion can not be ignored for data acquired in onshore environment.

In the present case study data was acquired in land environment and siginficant mode conversion (P2S) has been observed. This led to the processing of all the three components to analyze the shear splitting and the causative factors for such response. Shear splitting is a common phenomenon in a fractured rocks of reservoir units. When a shear wave enters the fractured system with its polarization angle oblique to the fracture, it splits into two polarized waves – fast and slow (Figure 2). The fast shear (S1) wave polarizes along the fracture, and the slow wave (S2) polarizes at a right angle to the fracture direction.

Estimation of shear splitting can be better and easily performed, when data from at least two different azimuth sources is available. But if sufficient mode conversion is observed in the data recorded with a single azimuth fixed source shear splitting analysis could be performed with success.

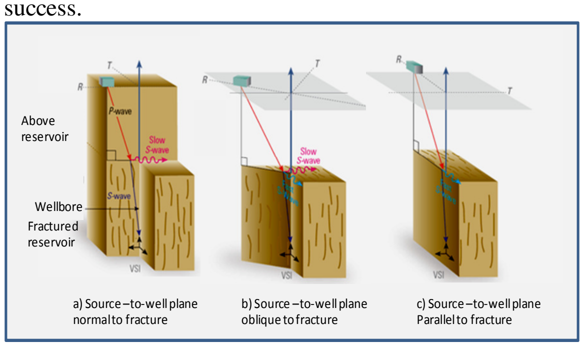

Figure 2: Shear wave splitting concept with varying source position.

The shear splitting analysis required multicomponent data and starts with rotataion to radial (along the P-wave arrival) and transverse components. The horizontal components (X and Y) can be orient to radial and transverse components using polarization and hodogram technique Once the data is rotated, the separated shear waves are processed by conventional techniques to obtain the fast and slow shear interval velocities (Johnston, 1986).

In the present case study Parameteric Decompositin technique has been used to do the shear splitting analysis.

The goal of this processor is to decompose multicomponent seismic data (VSP) in anisotropic medium into S1 and S2 waves and to provide information about their velocities and arrival angles as a function of depth.

Figure 3 shows the workflow used in the present case study. In this technique the data is modeled in a given time window as a superposition of several events and is defined by its local velocity, angle of incidence and polarization. At the depth of interest, three-component data at several (two or more) neighboring depth levels are modeled as the superposition of several waves with locally planar wavefronts. Local wave field inversion (or decomposition) is viewed as a parametric least-squares minimization problem.

The input waveforms (Figure 4) show the data derived from different components. The difference in slopes on the waveforms after parametric decomposition nicely illustrate the shear splitting (Figure 5)

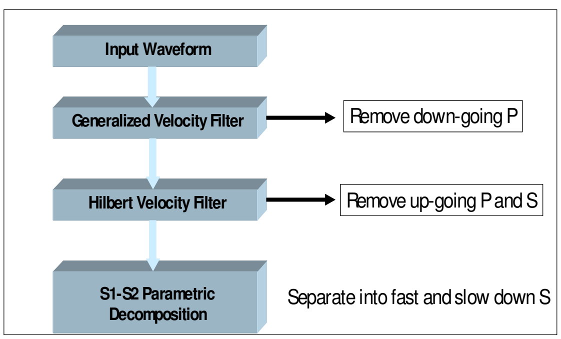

Figure 3: Workflow for shear splitting from Z-VSP data

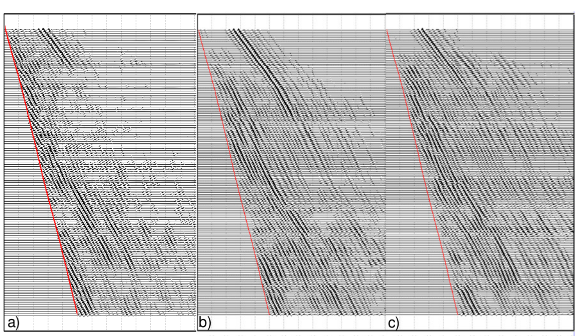

Figure 4: The input data for Parametric Decomposition a) Vertical Component b) Radial Component and c) Transverse Component.

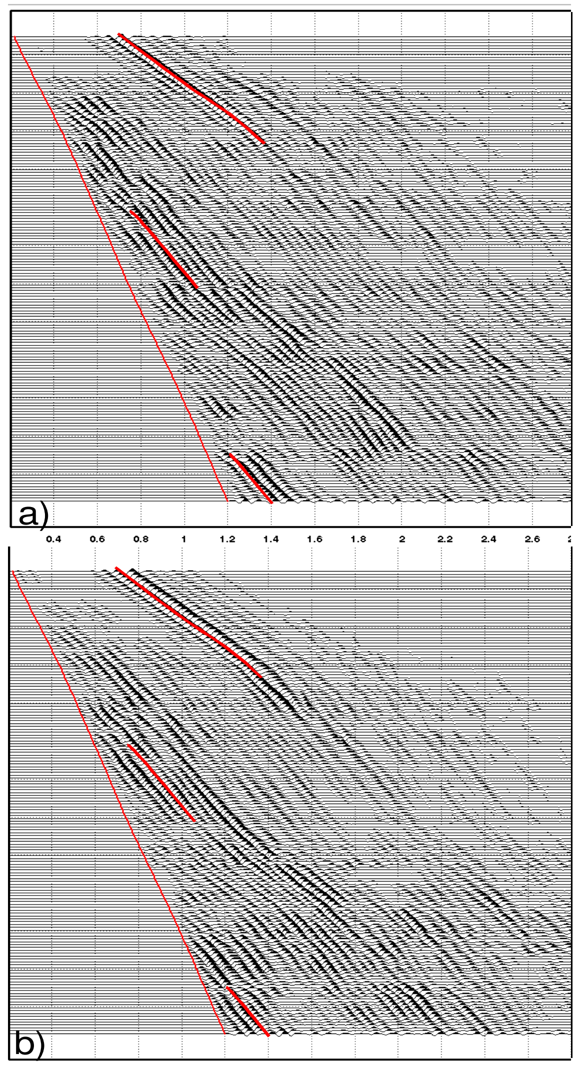

Figure 5: The difference between the slopes of the shear can be appreciated in a) S1 and b) S2 wavefields after parametric decomposition

Borehole Imaging Analysis

The borehole images are 2D, unwrapped representation of the 3D borehole and borehole crossing; planar features are represented by sine waves at abrupt resistivity contrasts. A resistivity contrast is represented by color variation on the images and therefore inferences are made that relate to the textural characteristics of the respective lithology are made based upon the resistivity contrast.

Two types of normalization are performed, static and dynamic. In static normalization a preferred spectrum of colours are distributed over the data interval. This technique provides a good overall representation of the data, highlighting major resistivity variations (Figure 6). Higher resolution normalization is achieved through the process of dynamic normalization, where a preferred spectrum of colours is distributed over a 1m-window length. A sliding window method is applied to the whole data interval.

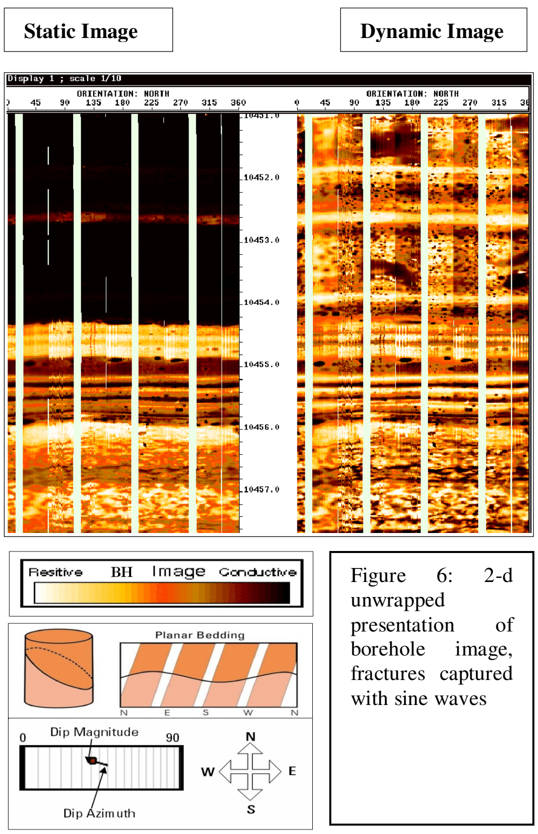

Figure 6: 2-d unwrapped presentation of borehole image, fractures captured with sine waves

Results

Fractures were identified from the processed image logs in a couple of wells. Fractures were defined as planar features identified in the image log that are cutting across the bedding planes without displacing them. As oil based mud used in the studied wells further classification of fractures, whether conductive or resistive, was not possible here. In OBM all fractures, open / closed with secondary mineral deposit seems resistive as the open fractures get filled with resistive mud.
Orientation of these fractures from both the wells dominantly follows the regional structural trend. Figure 7 and 8 show the general orientation of the fractures identified from the Well A and Well B respectively.

In Well A:

The fractures show bi-modality in their strike trend, one towards NE-SW and the other NW-SE.

Dip magnitude varies well within 35 – 65 deg

In Well B:

The fractures show a dominant strike trend towards NW-SE and few towards NE-SW.

Dip magnitude varies well within 35 – 70 deg.

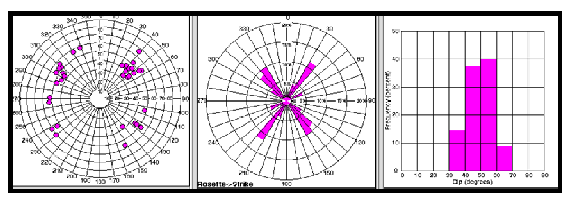

Figure 7: Fracture orientation in the well [Well A]: A. Stereographic pole plot, B. Strike rosette, C. Dip magnitude

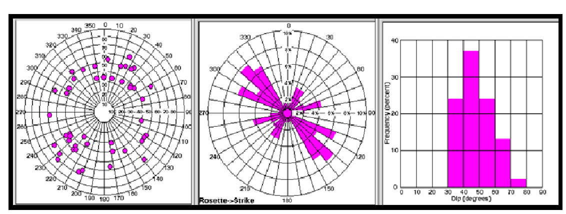

Figure 8: Fracture orientation in the well [Well B]: A. Stereographic pole plot, B. Strike rosette, C. Dip magnitude

Comparison between the locations of these fractures with the ZVSP revealed the presence of fractures/ fractures zone where shear splitting was observed on the Zero offset VSP. The presence of fractures on the images validated the finding on the VSP. This calibration of shear splitting with the occurrence of fractures in the tsubsurface led to the conceptualization of fractures where the image data was not acquired or was not of good quality due to hostile logging conditions.

Discussions

The Zero offset VSP results were studied in well A and well B. The intervals shown for Well A (X000m – X050m, X070m – X090m) suggest shear splitting. Borehole image snapshots in the intervals (at X040m, X075m) confirm the findings as fractures were identified on borehole images as well. (Figure 9)

The same approach was taken for another Well B. The intervals on Zero offset VSP composite (X970m – X090m, X130m – X250m) suggest shear splitting. Borehole image snapshots in the intervals (X975m, X218m) suggest fracture population as well. (Figure 10)

The good correlation of shear splitting and fractures population on images led to believe that the logged section in intervals discussed above in the two wells has transected fracture planes. The same analogy was applied to another interval of well A where shear splitting is observed on Zero offset VSP composite, but the borehole image data has been affected adversely due to hostile logging conditions. In the conceptual modeling of such interval, present study provides the confidence of the presence of fractures in that particular interval (X470m – X505m, Figure 11).

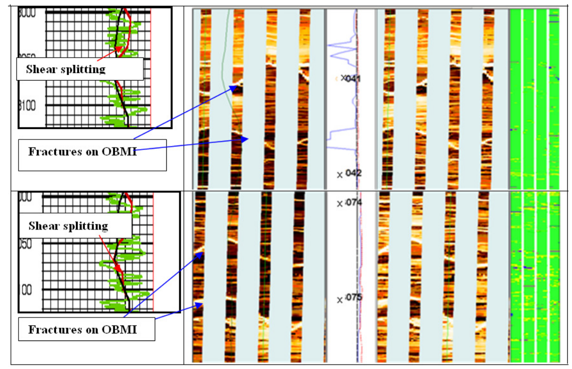

Figure 9: Comparison of the shear splitting in zero offset VSP and borehole images, Well A

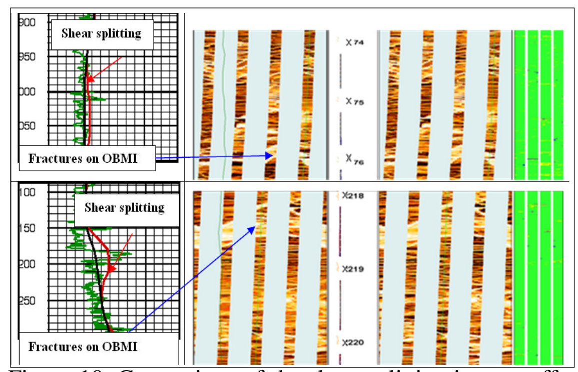

Figure 10: Comparison of the shear splitting in zero offset VSP and borehole images, Well B

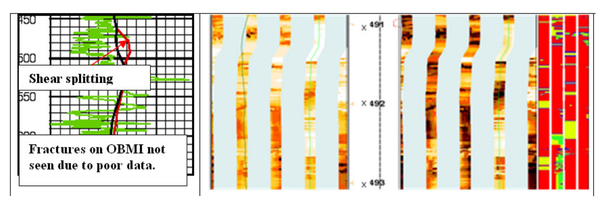

Figure 11: Conceptualization of fractures with shear splitting, where image quality is bad

The legend for the snapshots has been explained in Figure 12. The last track in the OBMI plot is quality flag, where red flag suggests that image quality is not worth interpretation. The green flag suggests good data quality.

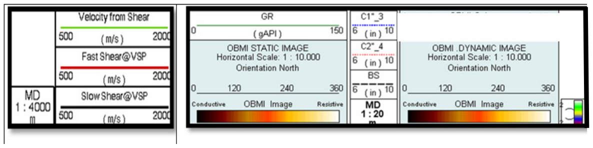

Figure 12: Legend for the snapshots used from VSP and OBMI images

Conclusion

The study provides a methodology for identifying fractured zones with the help of shear wave splitting from zero offset VSP. The shear wave splitting, observed in land wells zero offset VSP was attributed to the fractures and was validated with borehole images in the corresponding interval. The results provide a correlation to identify the fracture intervals where borehole image data quality was affected and hindered interpretation. Being first of its kind study in the Cambay basin, this approach provides a novel way of identifying the fracture intervals in the reservoirs.

Walk around VSP would provide a better control on azimuthal distribution of fractures orientation away from the borehole wall and could be coupled with the results of borehole images to comprehend a decent structural control on such reservoirs. Integration with advanced sonic analysis would reveal the fractures attributes of density and a measure of permeability through them.

References

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Acknowledgements

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