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Application of AVAZ and VVAZ study to predict fractured reservoir using Full-Azimuth Seismic data- A case study in a field of Cauvery Basin, India

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Summary

Various petroliferous provinces of Cauvery basin have produced hydrocarbon from fractured basement. The discovery of Madanam field has given impetus to basement exploration in view of its contribution to the total hydrocarbon production of Cauvery basin. Natural and Induced fractures play vital role in determining the hydrocarbon producibility from basement. An accurate knowledge of fracture networks is critical for the optimization of the development of naturally fractured reservoirs, since intensity and orientation of fractures significantly affect fluid flow in the reservoir rocks. Assorted techniques are available in the industry to characterize these fractures present within the basement. A growing interest in P-wave azimuthal velocity and amplitude variation has been observed in the last few years. This work proposes a novel approach i.e. azimuth dependent analysis for sweet spots identification within the basement. Fractures and stress may cause the Earth to become anisotropic, which is seismically noticeable using Azimuthal gathers. The changes in reflection time visible at far offset on different azimuth due to presence of anisotropy and its effect is being analysed in Velocity Variation with Azimuth (VVAZ) and Amplitude Variation with Azimuth (AVAZ) study. Extracted Fracture intensity and their orientation from these analyses are highly agreeable with recorded image logs (FMI) in wells.

Introduction

Cauvery Basin is the southernmost petroliferous basin of India which evolved in Late Jurassic during rifting and drifting of Indian Plate (B. S Josyulu et.al 2013). Narasimhapuram-Tirukalar area lies in the eastern flank of Pattukottai-Mannargudi rejuvenated to explore the basement potential as the presence of adjacent established Basement fields like Neduvasal-Vadatheru and Mattur-Pundi (Figure 1). Tectonically, Basin is divided into a number of sub parallel horst and grabens in NE-SW direction. A number of E-W trending shear zones affected the basement of Basin. The stratigraphy of Cauvery Basin ranges from Late Jurassic to Recent. The Late Jurassic Early-Cretaceous syn-rift sediments (Andimadam Formation) rest on the Precambrian Basement. Shales within Andimadam Formation overlying the basement are established as the main effective and matured source sequence in entire Cauvery basin. Basement charging is mostly through up dip migration from juxtaposed source rock in the entire Cauvery basin while downward migration may also be possible due to differential stresses between Overburden and basement (Lavendra Kumar et.al. 2015). Basement towards Narasimhapuram-Tirukalar area is juxtaposed with source rock (Figure 2) which encourages exploring the basement potential. The shale above fractured basement act as seal rock, however exceptions to top shale over basement in the Pundi and Pandanallur wells which produced hydrocarbon. Hence the fractured basement overlain by massive basement also acted as seal in Cauvery basin.

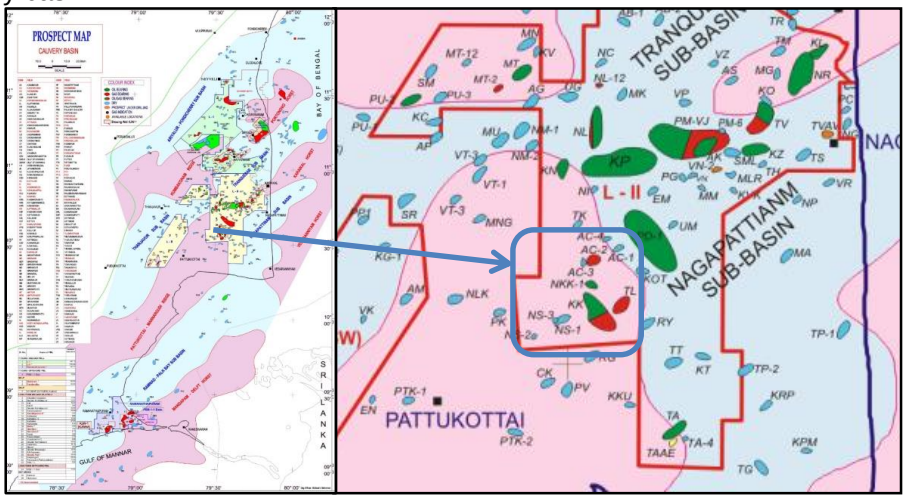

Figure 1: Prospect map of Cauvery basin showing the study area along the Pattukottai-Mannargudi ridge

Exploration and exploitation from basement play has unique challenge because of unconventional nature of reservoir. Reservoir quality and production from basement depends on the presence of connected open fracture network. Various attributes like DFN, Ant-track are being used for the fractured basement characterization. There is no single technique that works best all the time sometime combination of different approaches gives the better results in fracture prediction. In the same line, this study adding one unique attribute through a novel approach i.e. azimuth dependent analysis for sweet spots identification within the basement.

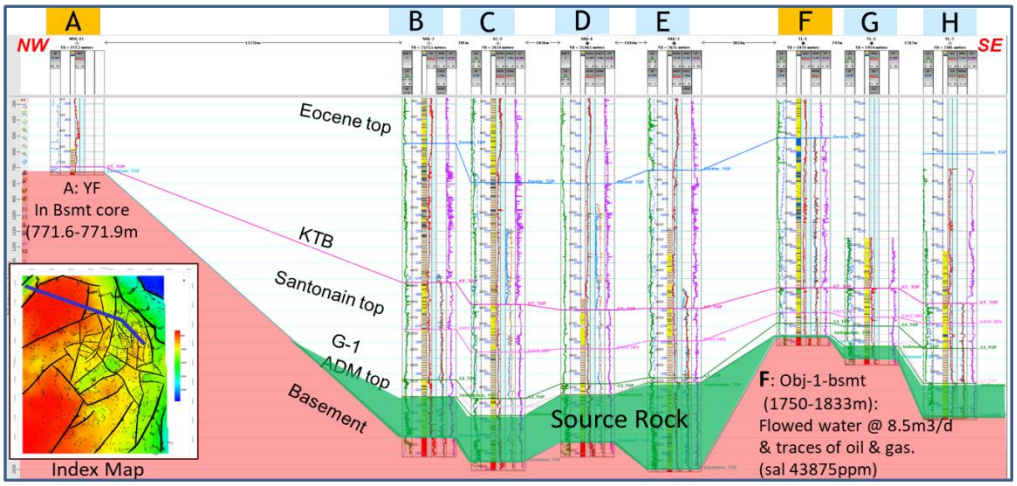

Figure 2: NW-SE Log Correlation Profile depicting the juxtaposition of source rock with basement towards well A

Methodology

Growing interest in unconventional plays, azimuthally dependent seismic analysis is becoming increasingly important. The ability to perform full azimuth angle domain migration (B R de Ribet et. al. 2015) has made it possible to perform azimuthally dependent analysis of seismic data. Seismic data offers an indirect measure of the effects of fracturing through azimuthal variation in P-wave velocity and amplitude. Stack data is having limitation as remnant noise on stack data can also severely affect the fracture definition. The input data to VVAZ/AVAZ are migrated gathers, in which the migration was performed using isotropic velocity. This way the anisotropic component is still present in the data, which is seismically observable at far offset on different azimuth (Figure 3). The presence of anisotropy and its effect is being analysed in VVAZ and AVAZ study.

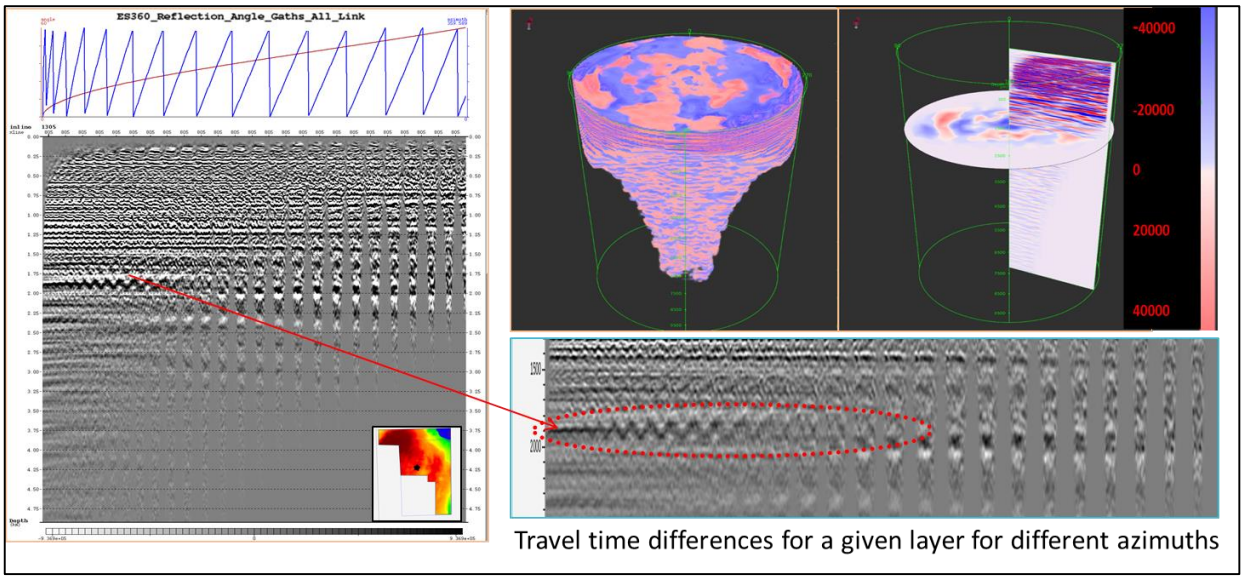

Figure 3: ES360 reflection angle gather shows the sinusoidal effect due to travel time differences at a given layer for different azimuths

VVAZ Analysis:

P-wave velocity parallel to the fractures is more than across the fractures. These differences give the velocity variation with azimuth (Satinder Chopra et.al. 2019). The first step of VVAZ analysis is to extract the effective residual anisotropic velocities; Relative Residual Velocity (Alpha Slow), Delta Alpha which is the difference between alpha slow and alpha fast, and the azimuth in slow velocity direction. In other words, the residual velocity field that is analysed in VVAZ has three components (α, Δ α and φ).

In addition to these parameters, a by-product of the analysis is a "reliability" measurement. For each sample reliability is calculated. The reliability is very important tool and become stable as long as there is a large enough anisotropic component in the data. If a layer is isotropic, anisotropic analysis becomes unstable and would be unreliable. Hence, VVAZ analysis produces four effective parameters Alpha Slow Effective, Delta Alpha Effective, Azimuth slow effective and anisotropic Reliability (Figure 4). Alpha slow indicates fractured area, Delta Alpha measures fracture intensity and Reliability parameter indicates the confidence level of fracture intensity

Workflow:

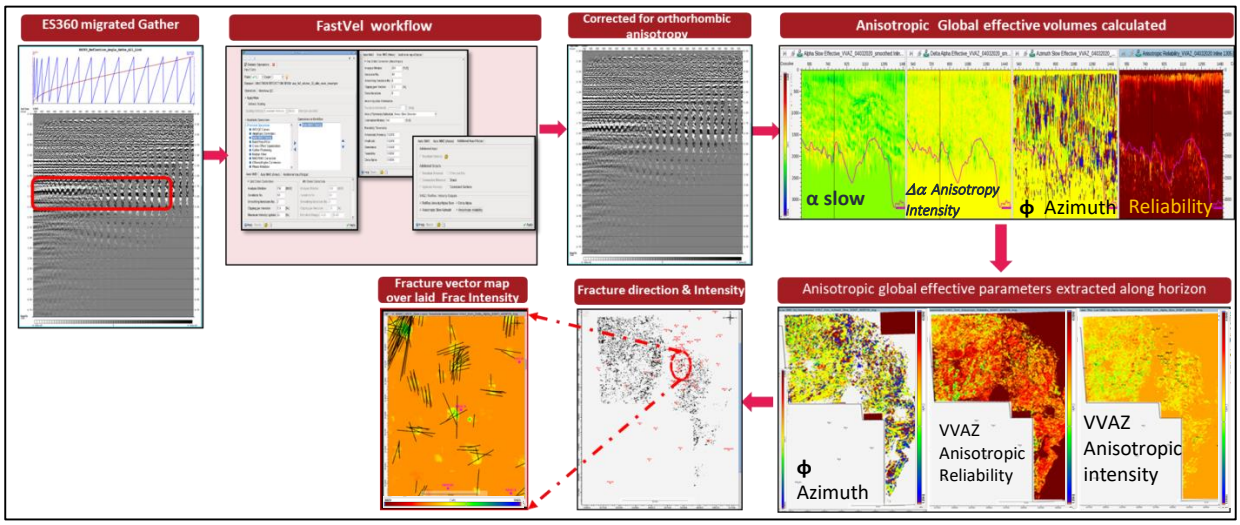

Figure 4: work flow adopted for VVAZ analysis

AVAZ analysis:

AVAZ is an alternative analysis to VVAZ, which is based on the amplitude variations as a factor of angle and azimuth (similar to AVO/AVA analysis in the isotropic case) (GalenTreadgold et. al. 2008) .However, It is important to note that AVAZ and VVAZ analyses measure a different property. VVAZ measures the effective parameter which is some average that involves the overburden while AVAZ is a local analysis, affected only by the layer anisotropy. The input for AVAZ is migrated gathers, in which VVAZ effects have already been removed by flattening the gathers through Trim statistics. The AVAZ analysis determines the Anisotropic Gradient which is the equivalent to Delta Alpha in the velocity case. Reliability for AVAZ and VVAZ is similar. Eventually, this analysis produces Anisotropic Gradient, Anisotropic Orientation and Reliability (Figure 5).

Workflow:

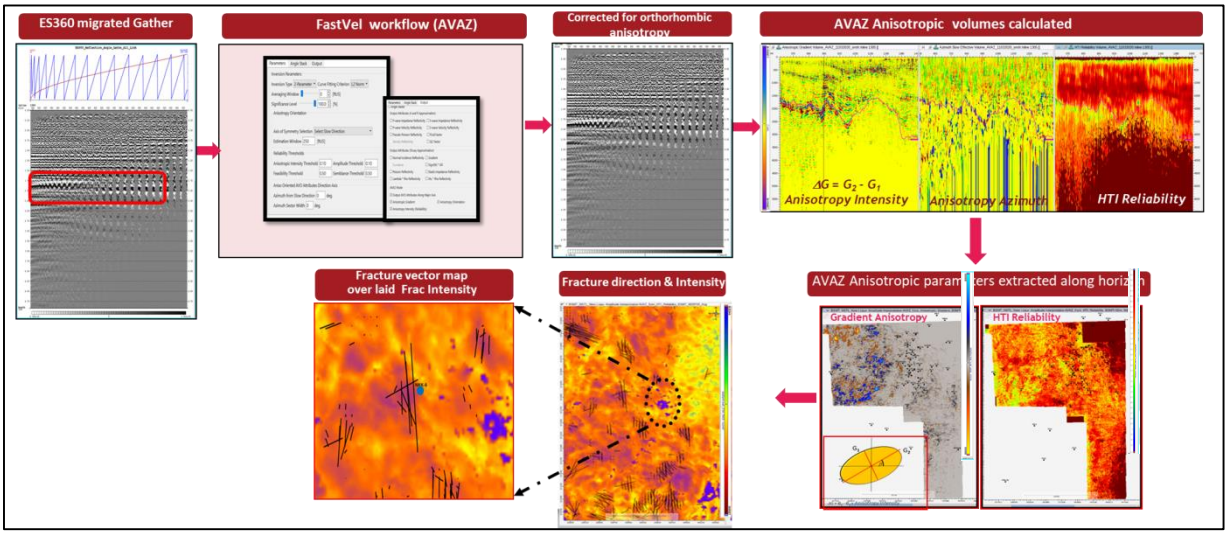

Figure 5: work flow adopted for AVAZ analysis

Discussion

Results of VVAZ analysis:

Effective parameter sections of Alpha slow, Delta Alpha, Azimuth, and Reliability derived through VVAZ analysis; depicting more fracture towards western side near to basement (Figure 6).

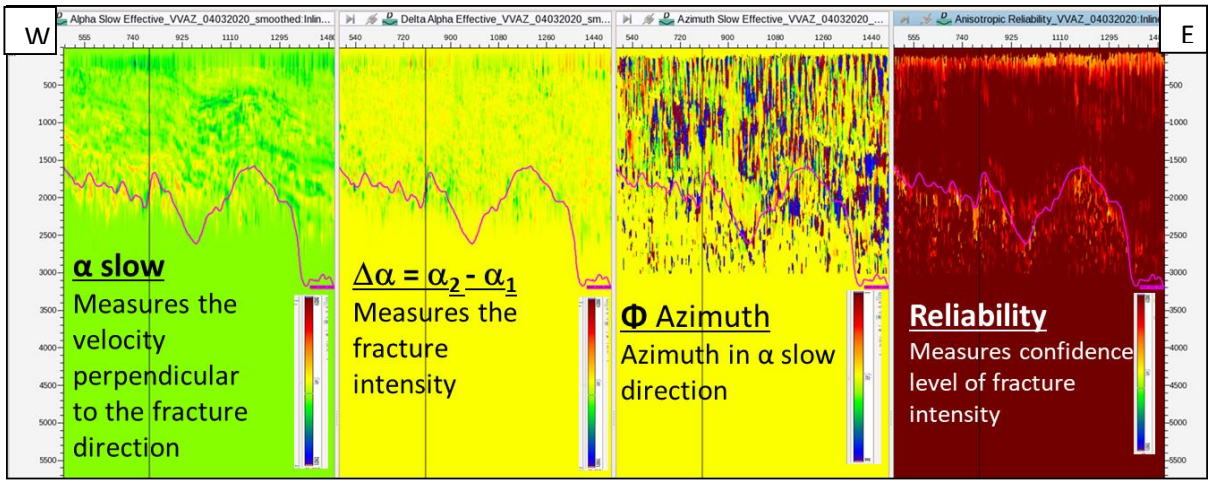

Figure 6: Effective volumes derived from VVAZ analysis ()

Extracted Fracture Intensity and Reliability for the different windows from basement shows high fracture zones towards the south of Narasimhapuram with high reliability. It is also observed that Fracture Intensity and Reliability parameter reduces as we go deeper into the Basement. Areal plots of these effective parameter shows that Fracture distribution is in localized pattern with moderate to poor connectivity in the most of study area (Figure 7).

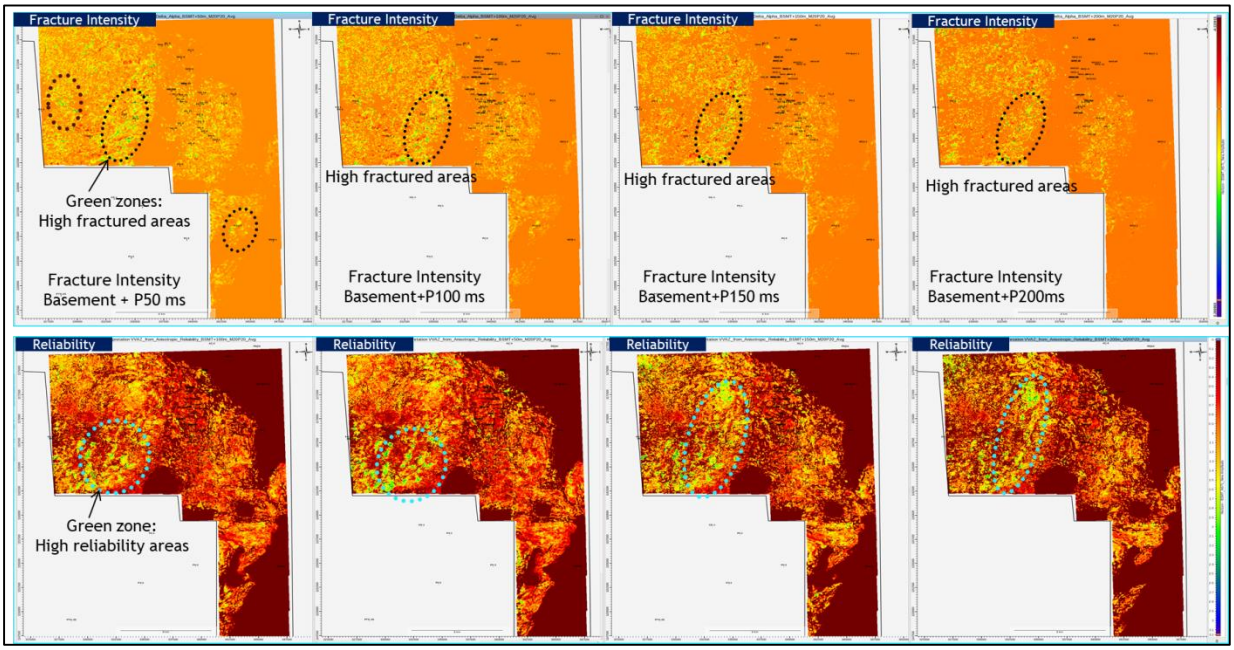

Figure 7: Effective volumes horizon slices derived from VVAZ analysis (Alpha slow, Delta Alpha, Azimuth, and Reliability)

Fracture orientation extracted from VVAZ analysis has been calibrated with image logs (FMI) in wells. Vector map overlaid with fracture intensity shows that fractures are oriented NW-SE direction which is corroborated with the FMI recorded at well M. this analysis depicts that fracture density decreases with depth within the basement (Figure 8)

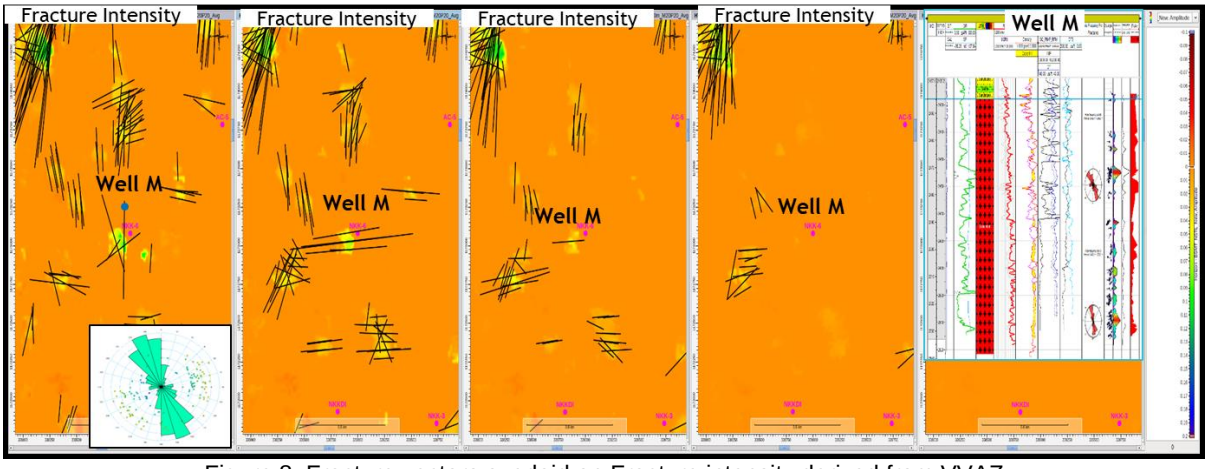

Figure 8: Fracture vectors overlaid on Fracture intensity derived from VVAZ

Results of AVAZ analysis:

AVAZ analysis provides the Anisotropic Gradient, Azimuth and Horizontal Transverse Isotropy volumes (HTI: Reliability). Anisotropic gradient measures fracture intensity which is increasing near to Basement towards the Narshimhapuram area (Figure 9).

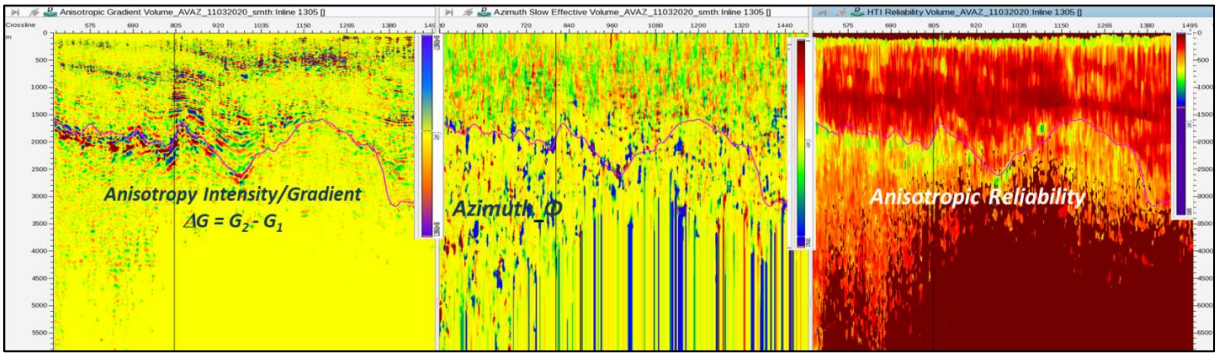

Figure 9: Effective volumes derived from AVAZ analysis (Anisotropic Gradient, Azimuth, Reliability)

Anisotropic Gradient and HTI Reliability for different windows from the basement shows better fracture intensity towards the south of Narshimhapuram with good reliability in comparison to the other part of study area (Figure 10). AVAZ analysis also brought out that Fracture Intensity and Reliability reduces as we move deeper into the Basement and Areal view of these anisotropic parameter shows that Fracture distribution is in localized pattern with moderate to poor connectivity in the most of study area.

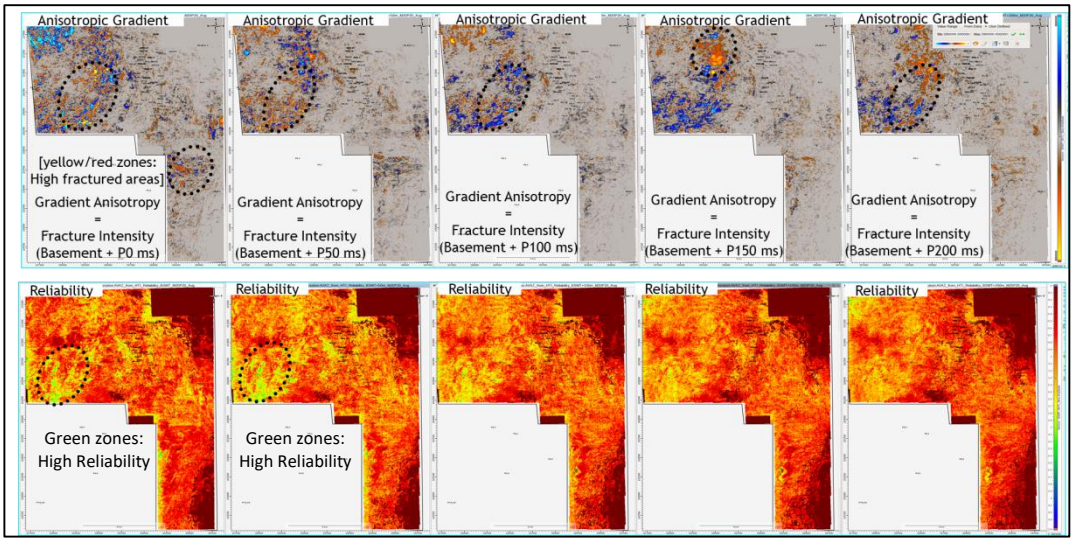

Figure 10: Effective volumes horizon slices derived from AVAZ analysis (Anisotropic Gradient, and Reliability)

Fracture orientation extracted from AVAZ analysis has been calibrated with image logs (FMI) in wells. Vector map overlaid with fracture intensity shows that fractures are mostly oriented N-S direction which is corroborated with the FMI recorded at well N. It was also observed that fracture density decreases with depth within the basement (Figure 11)

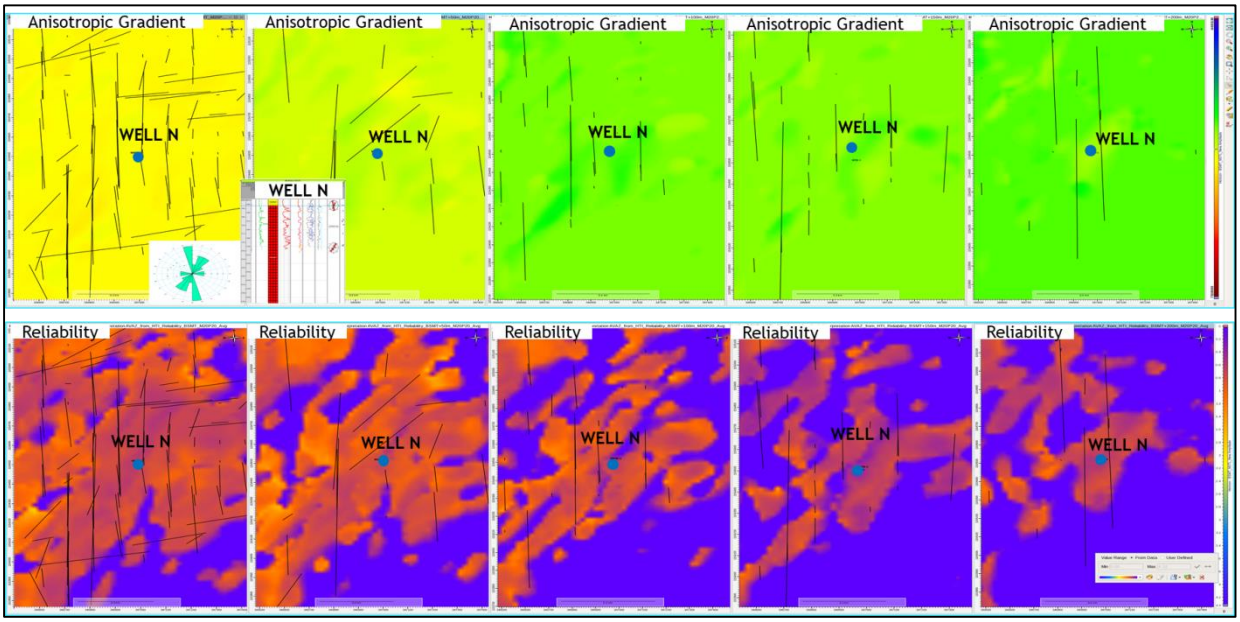

Figure 11: Fracture vectors overlaid with Fracture intensity derived from AVAZ

Conclusions

This work describes a new approach to capture the sweet spots within Basement in terms of permeable fracture zones. Robust implementation of AVAZ and VVAZ brought out fracture intensity and their orientation along with the reliability attribute which provided the confidence in fracture prediction. AVAZ/VVAZ analysis reveals that fracture density decreases with depth within basement in the study area and fracture distribution is in localized pattern with moderate connectivity. Results obtained from of this study corroborated with recorded image logs in wells, which encourages a wider use of this technique in fractured reservoirs.

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