**Revealing the Reservoir in a High NTG Environment using Seismic Inversion: Case Study from Bhagyam Field, Barmer Basin, India**

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**Keywords**

Structural Interpretation, Seismic Inversion, Reservoir Mapping, Acoustic Impedance, Static Modeling

## Summary

Lower bandwidth of 3D seismic data always reduces the limits of visibility and its capabilities to detect relatively thinner layers. Moreover, a high NTG environment further masks deterministic acoustic impedance contrast between the two lithologies which results in almost no normal incidence reflection. It is extremely difficult to interpret the intermediate level horizon in such a condition. This paper highlights a case study of Bhagyam field which has been on production since 2012. Main reservoir units are FB1 and FB3 which comprises around 95% of STOIIP. Also, FB1 alone holds ~70% of STOIIP. FB1 reservoir unit has been sub-divided into three zones based on detailed log correlation and depositional understanding of the reservoir units. Dynamic data and Time lapse saturation (RST) data suggests that these three zones possess variable sweep efficiency and connectivity (Figure 1). Hence, it was important to capture this information in the static model. Seismic inversion volume has been used to constrain the structural interpretation mainly at zone level horizons. This paper highlights the benefit from the clearer signature of the reservoir seen in acoustic domain as compared to amplitude domain, due to the removal of complex wavelet effects in the inversion process.

## Introduction

Bhagyam oil field, discovered in 2004, is situated in the northern part of the Barmer Basin, Rajasthan, India. The Bhagyam field is formed by a tilted fault structure, dipping ~15 deg towards East and bounded by a normal main bounding fault (MBF) in the West. The crestal part of the field is intersected by low angle gravity collapse faults, and there are also some

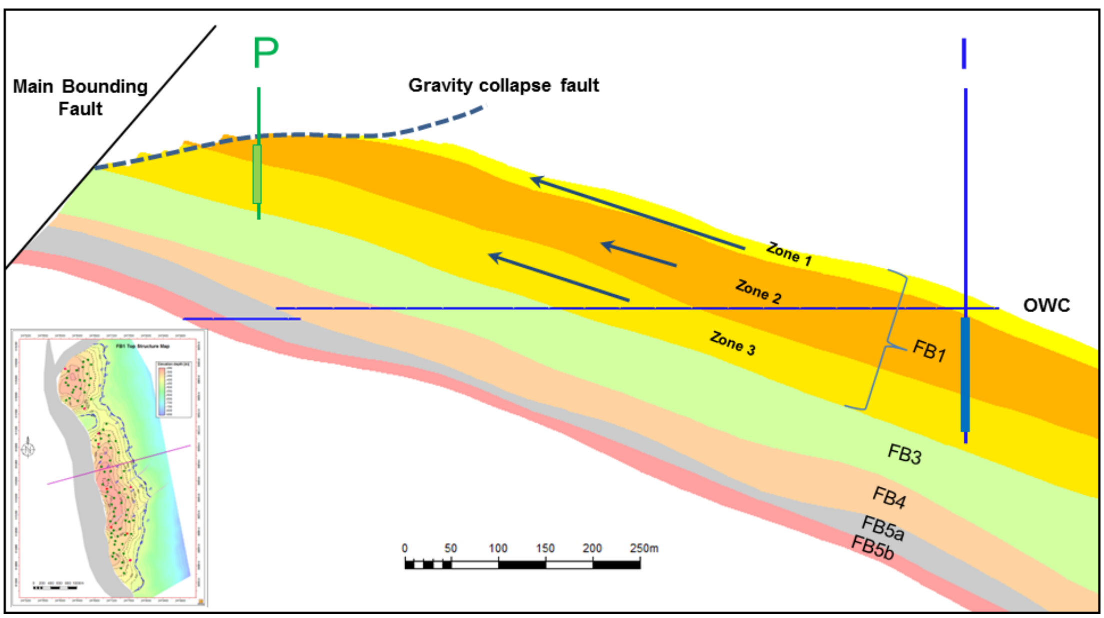


Figure 1 Dip section from static model explaining various reservoir units, reservoir zonation scheme and structural setting.

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N-S and E-W trending intra-field faults. The main reservoir is late Cretaceous-Early Paleocene fluvial deposits of Fatehgarh formation. Older units of the Formation are dominated by braided channel facies, whereas younger units are meandering fluvial channel deposits; overall, all reservoir units show high NTG sand content. The Fatehgarh Formation is divided into four reservoir units: FB1, FB3, FB4, and FB5. The FB1 unit has been further divided into three subunits based on the gross log motifs namely FB1-Zone1, FB1-Zone2 and FB1-Zone3. Zone 1 is a cleaning upward sequence and deposited in fluvial to lake environment. On the other hand, zone 2 is mainly dominated by single-storey sinuous meandering channel system. However, lowermost part of FB1, which is zone 3, is dominated by multi-storey braided river channel system which is expected in a fluvial to lake environment (Figure 2).

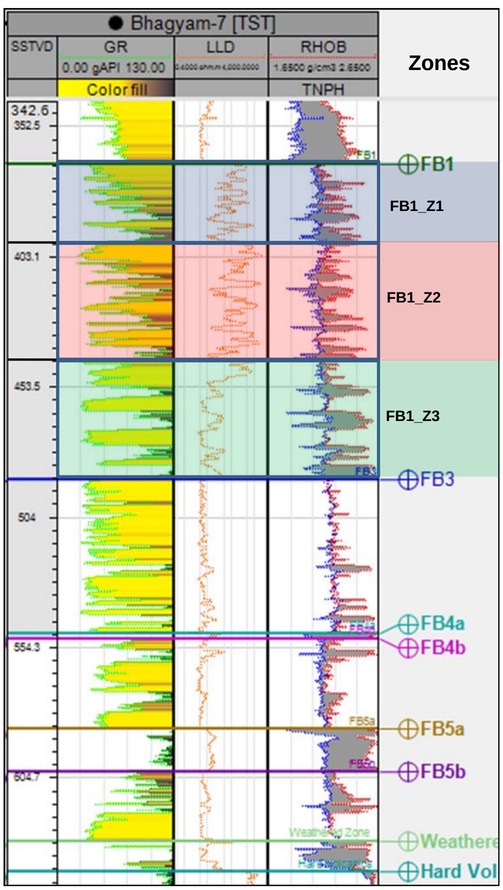


Figure 2 FB1 zonation scheme highlighted in the type log from well B-07; Zone 1(Blue), Zone 2(Red) and Zone 3 (Green)

## Associated Challenges

The early breakthrough of water in the crestal producers and steep rise of water-cut in all the producers during the early field life, is one of the key challenges. Moreover, despite the high NTG system there are areas where reservoir sands do not communicate, resulting in conformance issues. Few producers where Zone 3 occupies the major part of pay have witnessed high water cut due to the better connectivity of this zone. Based on the above understanding some of the water shut-off jobs which have been implemented in the field have shown good results. Time lapse saturation (RST) data has been thoroughly reviewed which also indicates that uppermost zone 1 and lowermost zone 3, has very high sweep efficiency and connectivity as compared to zone 2 (Figure 3).

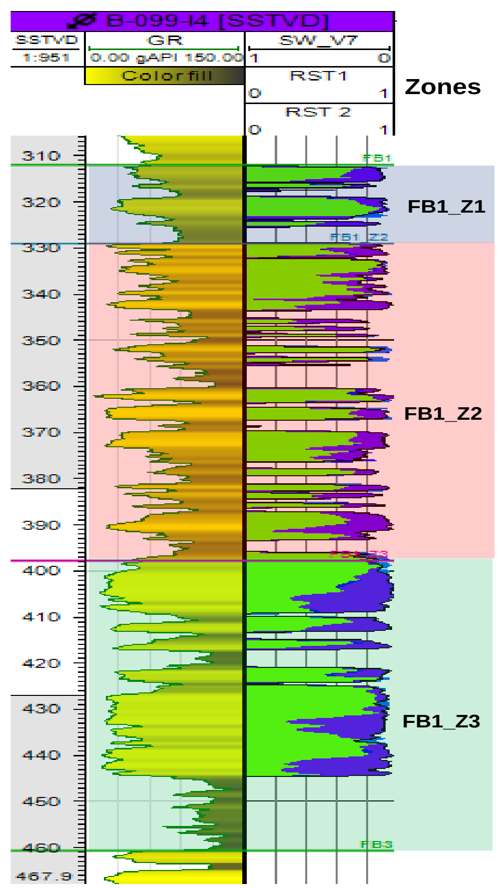


Figure 3 Time Lapse Saturation data (RST) highlighting variable sweeps in FB1 sands

Lower connectivity and sweep efficiency is expected from zone 2 as it has been deposited in mainly single-storey meandering channel system where sands are intercalated by remnant of shale units. Detailed mapping of these zones is important to understand field connectivity. Also, to improve the accuracy and predictability of the dynamic model, it is required to populate properties in various zones as per their depositional environments. Hence, it was required to input these intermediate level surfaces (Zone 1, 2 and, 3) in the static model to improve the accuracy of reservoir property modelling.

## Methodology

Earlier these zone level intermediate surfaces were captured in the model solely based on well markers and derived true stratigraphic thicknesses, which doesn't capture the lateral thickness variation between the wells accurately. The quality of the 3-D seismic data covering Bhagyam field is "fair to good" over the majority of the field, but "poor" at the crest adjacent to the main bounding fault, which poses a significant challenge to mapping. To achieve the objectives, and delineate FB1 zone level horizons, we performed post stack seismic inversion on this challenging seismic dataset. The seismic inversion data facilitates the mapping of reservoir horizons with much higher confidence in areas where the PSDM amplitude data is ambiguous, contaminated with noise.

Initially, rock-physics analysis and feasibility studies have been done using petrophysical logs and elastic properties. Various cross plots of petro-elastic properties, have been derived to understand the best possible lithology discriminator. P-impedance found to be a good discriminator of sand and shale (Figure 4). However, there was a tapered lithological separation in the depth trend plot of acoustic impedance. To overcome that it was decided to use band limited P-impedance volume for interpretation. Also, density parameter differentiates sand and shale units of the Bhagyam field whereas clear separation was not seen with elastic parameters like Vp/Vs. 1D inversion analysis and forward modeling results shows that composite response from various zones can be detected at the seismic resolution level.

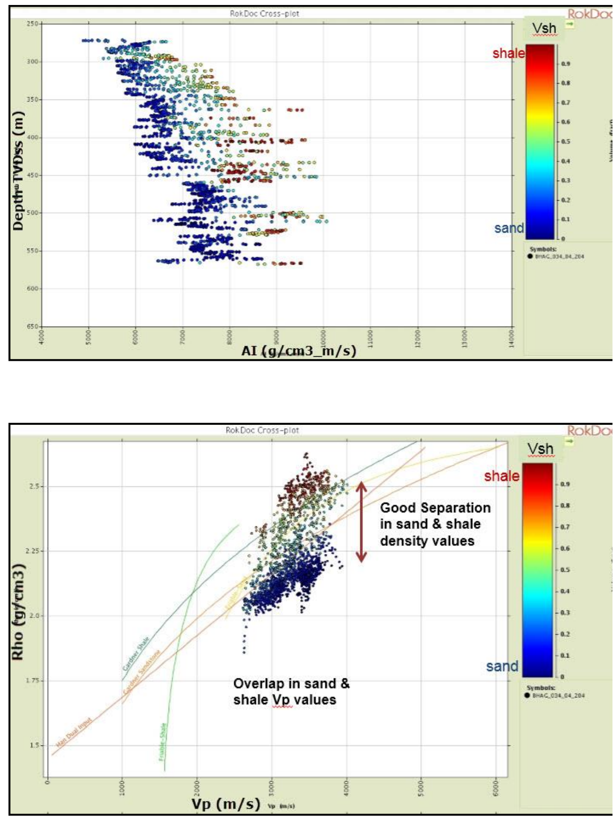


Figure 4 Rock physics analysis and cross plots shows that acoustic impedance (top) and density (bottom) are good discriminators of lithology i.e. sands and shales

Also, synthetic seismograms obtained for different wells, showed "good to fair" correlation with actual seismic in the northern part of the field where seismic data quality was relatively better. A deterministically derived wavelet using seismic and well log data was used for post-stack seismic inversion.

After QCing input data, and appropriate seismic inversion parameters, an acoustic impedance volume was obtained from seismic inversion. Better defined structural and stratigraphic features shows the supremacy of inversion volume over conventional seismic volume (Figure 5). Also, the inversion for P-impedance gave high-quality results that correlated strongly with values measured in the drilled wells.

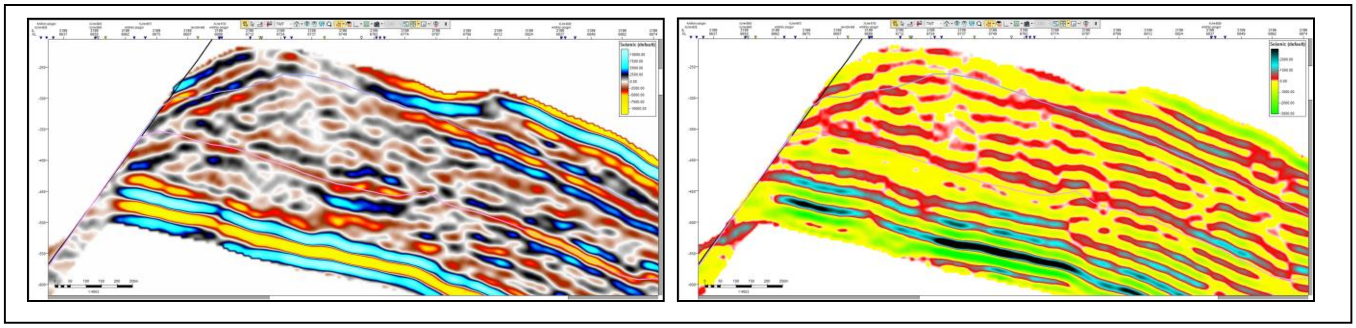

Figure 5 Seismic cross-section comparing amplitude data versus acoustic impedance data for structural interpretation; better defined reservoir features is one of the advantages of using seismic inversion volume for structural interpretation.

Band limited acoustic impedance volume was validated at different parts of the field using blind well data. Areas of higher confidence was demarcated with the help of well data validation and better quality seismic data. Detailed well correlation suggest that Zone 1 is relatively thicker continuous sand, presents mainly in the northern part of the field, same has been observed in band limited acoustic impedance volume as negative impedance values. The base of this continuous sand unit has been interpreted as Zone 2 surface. On the other hand, lowermost part, which is Zone 3, is a braided system.

There are thick shale units at bottom of zone 3. Composite response of these shale units can be seen in inversion volume as positive impedance values. Upper part of zone 3 contains relatively thicker and continuous sands, same has been interpreted as zone 3 surface in the inversion volume. It is clearly seen that geological understanding from well log data corroborates very well with the seismic inversion predictions. Seismic Inversion section in figure 6 describes the possibility that the zone 2 sands are intercalated by remnants of shale units, which is expected in single-storey meandering fluvial channel system.

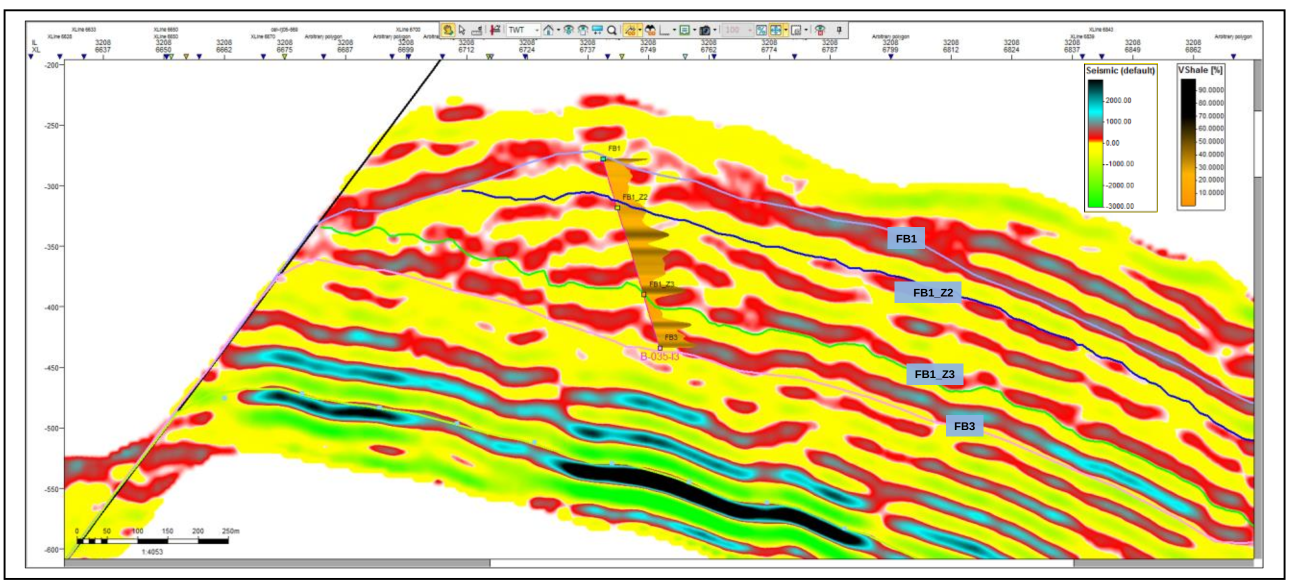


Figure 6 Dip section of Bandlimited P –impedance volume shows the good correlation with the values measured in log (filtered Vshale); Mapped Zone level surfaces are consistent with the geological understanding of the FB1 units.

## Results

Comparison of inversion results with the well data confirmed good correlation between P-impedance and geological facies. For Bhagyam field, detailed reservoir mapping of the FB1 unit is very critical as it showed variable sweep efficiency and connectivity. Also, it holds significant amount of total STOIIP. Since the seismic data quality is better in the northern part of the field, hence, inversion results are more reliable in the northern part only. Therefore, the work is mainly focused in the northern part of the field with limited success in the southern part. Detailed interpretation of zone level surfaces shows lateral thickness variation between the wells, which was not appropriately captured in the well derived surfaces.

Zone 2 thickness map derived from horizon mapping complements very well with the thickness map derived from well data only (Figure 7). There is increase in thickness of zone 2 in the mid part of the field, which can be seen in both the maps. However, the details are very well captured in the thickness map derived from horizon mapping. Hence, it shows the advantage of the interpretation derived surfaces over well derived surfaces. Inversion volume also shows improved interpretability as compared to conventional seismic volume. Zone level surface mapping was not possible in the conventional seismic. However, it has been easily mapped in the inversion volume and established more confidence with the blind well QC's, specially, in the northern part of the field.

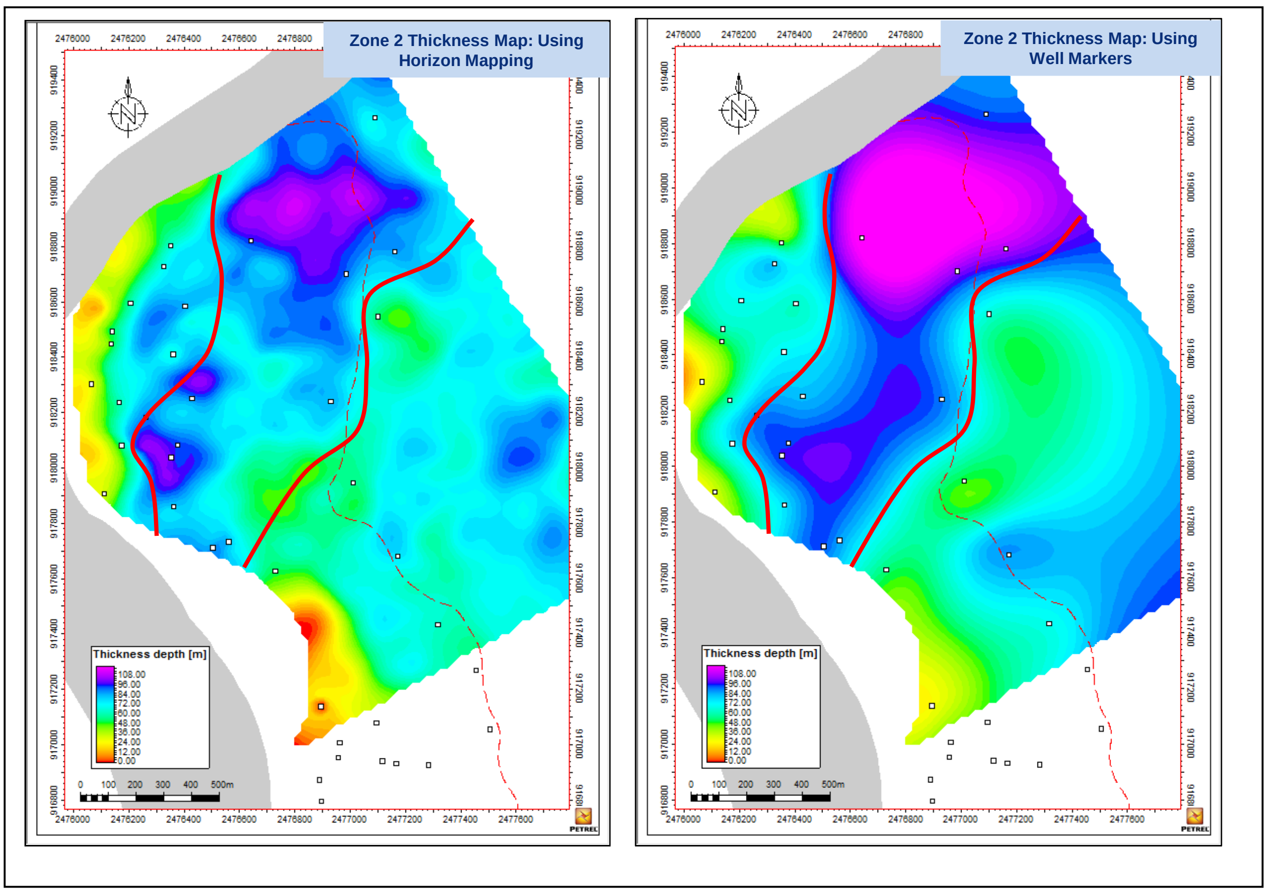


Figure 7 Thickness map of Zone 2 derived from zone level horizon mapping (left); well data only (right). Thickness variation between the wells (white dots) is more pronounced in left map, which shows the advantage of using seismic inversion volume

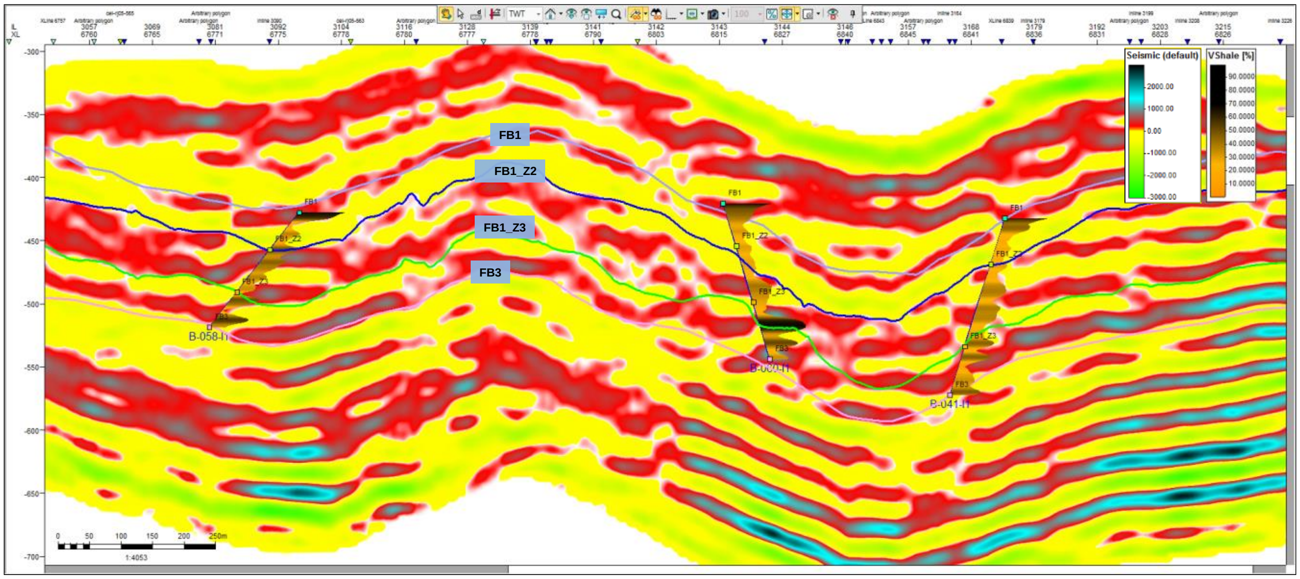


Figure 8 Band limited P impedance section along the three well (B-41, 58 and 60) shows the continuity of uppermost and lowermost sands; also, highlights the intercalation of sand and shale units in zone 2.

## Conclusions

Due to improved interpretability in the inversion domain, structural interpretation on the bandlimited inversion volume not only provides more confidence in the zone level reservoir picks, but also enables more precision than conventional amplitude data. Continuity of zone 1 and zone 3 sands corroborates very well with responses seen in producer wells. RST data also supports the high connectivity and better sweep efficiency which is in line with more continuous sands seen in upper and lowermost zones (Figure 8). Hence, mapping of these zone level surfaces will enhance the accuracy of the static and dynamic models. In the long run, it will improve the predictability of the reservoir model and will help in production optimization activities.

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