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Seismic reservoir characterization through pre-stack inversion of an area of Mahanadi offshore basin- a case study

Binode Chetia, Sunil K. Singh, P.K Chaudhuri, A.K. Tandon, & Anil Sood
GEOPIC, ONGC, Dehradun, Uttrakhand, India.
Presenting author, E-mail: Chetia_binode@ongc.co.in

Abstract

Mahanadi offshore basin is situated in the northern part of the East Coast of India. Area 'A' of Mahanadi Offshore basin was taken up for pre-stack inversion study to de-risk the identified prospects. So far, over twenty wells have been drilled in Mahanadi Basin with sporadic occurrences of hydrocarbon. All hydrocarbon bearing sands of Miocene sequence are found to be thin while thick ones are brine filled in most of the wells. Wells 1, 2, 3 and 4 are gas bearing. The slope fan deposits were proven to be gas bearing in Well 1.

Pre-stack inversion was carried out using elastic logs of these wells and angle stacks of seismic data. To delineate gas sand in this area, polygon of most probable gas sand was selected from the cross plot of P-impedance and Vp/Vs extracted from inversion results at the well locations. Most likely locales for gas sand accumulation at different stratigraphic levels have been worked out in 3D volume and mapped.

Based on this analysis of prospect evaluation, two prospects, namely A and B are found to be having desired characteristics suggesting gas filled reservoir.

Introduction

Mahanadi offshore basin is bounded by the Bengal Basin in the NE and Krishna-Godavari in the SW. The study area 'A' is comprised of total 510 Sq.Km, **(Fig: 1)**. The bathymetry of this part of the Basin is 200 to 1200m. The seismic data used in this study are Q marine PSTM data, processed with residual amplitude compensation.

Over twenty wells have been drilled under exploration activity in this basin but commercial success has remained elusive till now. Majority of drilled wells have evidence of gaseous hydrocarbon accumulation of biogenic origin in shallower Mio-Pliocene section. Few wells encountered gaseous hydrocarbon of mixed origin in deeper level. So far thin hydrocarbon bearing sands and thick brine sands have been found in most of the wells.

First ever hydrocarbon discovery in this offshore basin was from Mio-Pliocene channel-levee complex. Miocene gas sands were encountered in Well-1 and 2 while Paleogene gas sands were encountered in Well-1 & 3. Gas bearing sands encountered in Well-1 are proven to be the slope fan play. Thickness map of the slope fan prospect suggests maximum thickness towards further south of Well-1. Bright seismic amplitudes are also observed around the locations.

Gas sand can be discriminated from brine sand and shale through P-impedance versus Vp/Vs cross plot to quite a good extent, **(Fig: 2).** However, discrimination is poor when logs are filtered in seismic frequency band as the gas sands are very thin. Pre-stack inversion was carried out using the Well- 1, 2, 3 and 4. To delineate gas sand from inversion result in this area, gas sand polygon is selected from cross plot of extracted P-impedance and Vp/Vs at well locations. The inversion results show medium P- impedance and low Vp/Vs ratio as characteristics of pay sand. Thin individual pay sands may not be detectable, however vertical cluster of such sands is likely to get detected using inversion volumes as observed from the analysis.

Locations A and B appear to be favourable from hydrocarbon point of view. Geo-body extraction from the inversion volume using gas sand polygon delineated the extension of most likely occurrence of gas sand.

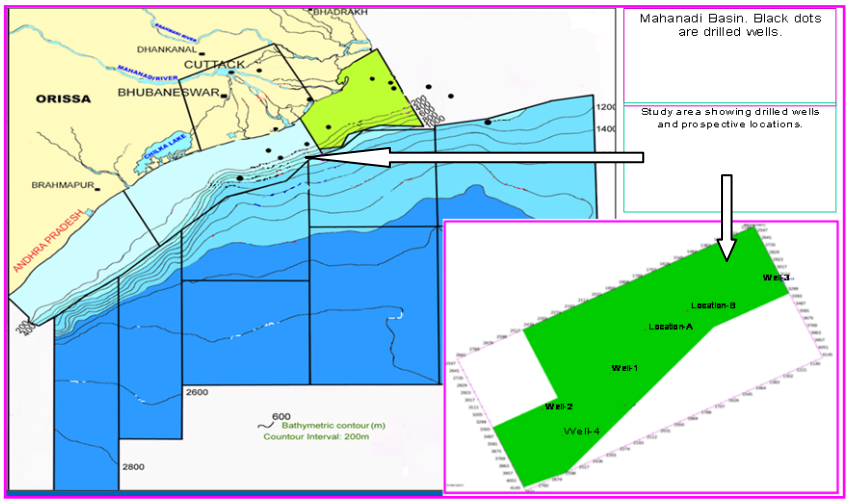

Fig: 1. Map showing the study area of Mahanadi offshore Basin with Well 1, 2, 3 & 4 and prospective locations A & B.

Rock Physics Analysis on Gas Sand

In Well-1, three gas sands of total thickness 8, 13 and 7m exist in Miocene sequence. Similarly based on wire-line log and MDT data of Well-3, two sand of thickness 1 and 2m were found to be gas bearing. However, in Well-2 & 4 no hydrocarbon bearing sand is observed in Miocene sequence. All the four wells are used for low frequency solid model building, wavelet extraction and rock physic analysis. The target zone for inversion is Miocene sequence. The effective gas sand thickness of this sequence is 1 to 3m only. P-impedance and Vp/Vs cross plot within this interval indicates the separation of gas sand from rest to a good extent. However, few brine sand are also getting captured along with the gas sand by the polygon due to partial overlapping of properties (**Fig: 2)**.

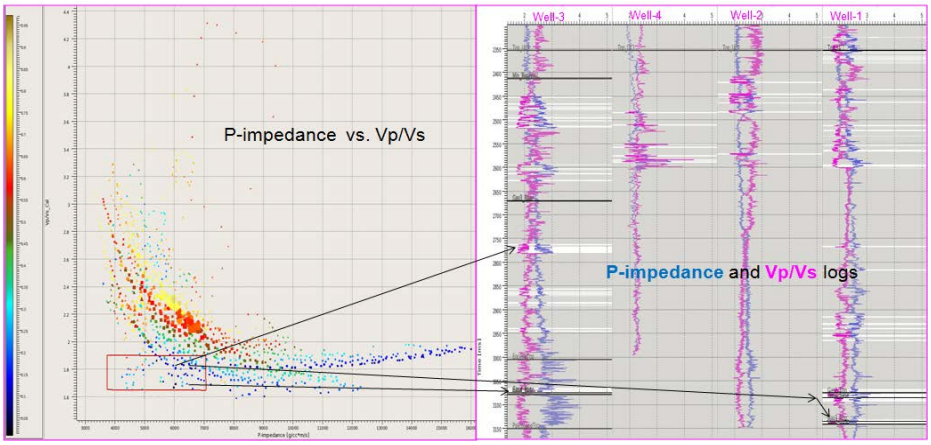

Fig: 2. P-impedance vs. Vp/Vs cross plot of the four wells, within inverted zone (left). Corresponding logs are highlighted by the polygon of the cross plot. Magenta=Vp/Vs, blue=P-imp (right).

Feasibility Study from wells

Within the inverted zone, cross plot of P-impedance versus Vp/Vs of two wells filtered in seismic frequency band was taken and a polygon is drawn to isolate the contribution from the gas sand which are showing with highlighted gas sand in P-impedance and Vp/Vs logs, **Fig: 3.** Now the cross plot of similar logs extracted at well position from inversion volumes was taken. Gas sand polygon is selected from this cross plot by slightly modifying well log derived polygon**.** Relatively thicker gas sands are getting identified and logs are highlighted by the gas sand polygon, **Fig: 4**.

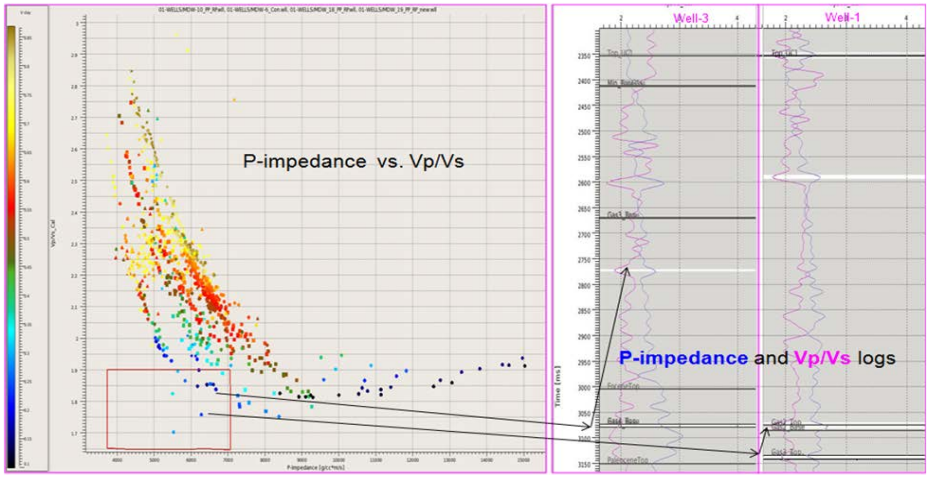

Fig: 3. P-impedance vs. Vp/Vs cross plot of two wells filtered in seismic frequency band, within inverted zone (left). Corresponding logs of the wells are highlighted by polygon the cross plot. Magenta=Vp/Vs, blue=P-imp (right).

Wavelet extraction, Inversion & QC of Results

Wavelet is the core of seismic inversion. The inferred shape of the seismic wavelet strongly influences the inversion process. All the four wells are used for well to seismic tie and wavelet extraction for four angle stacks used for inversion. Wavelets extracted from the four angle stack are stable within seismic frequency band**.**

After well to seismic ties, wavelet extraction and QC, of four angle stacks for the wells indicate that wavelet amplitude of Well-3 is very low as compared to other wavelets. The amplitude of seismic data near Well- 3 is also low. That may be the reason of low amplitude wavelet.

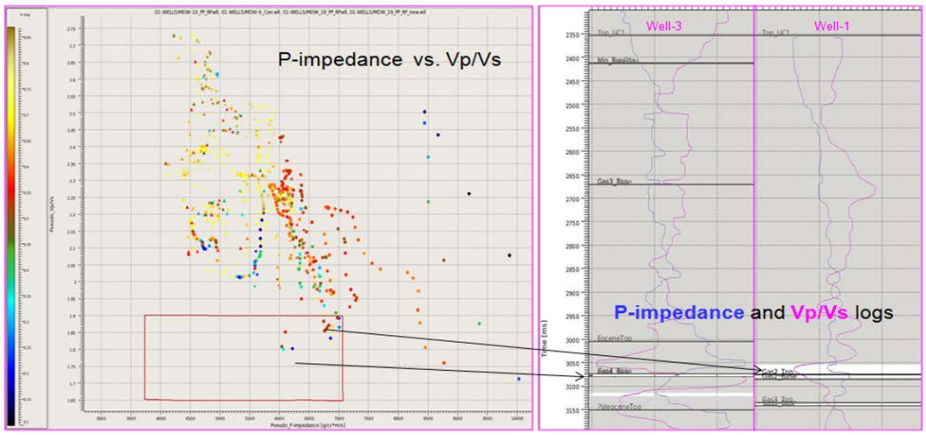

Fig: 4. Inversion extracted P-impedance vs. Vp/Vs cross plot of two wells. Polygon is for most probable gas sand. The same logs of gas wells highlighted by polygon of the cross plot. Magenta=Vp/Vs, blue=P-imp.

So to compensate for the low amplitude wavelet in Well-3, we used the amplitude weighted spatial wavelet interpolation process which balances the amplitude of wavelet over the area.

The well P-impedance, S-impedance and Vp/Vs logs show reasonably good match with corresponding extracted logs from inverted volume at Well-1, 2, 3 and 4 implying relatively good quality of pre stack inversion is, **Fig: 5.**

Inversion analysis

As mentioned above, effective gas sand layers within the inverted zone are only 1 to 3m thick which is responsible for poor delectability of pay. The best attributes for gas sand detection are P-impedance and Vp/Vs taken together. The cross plot of P-impedance vs. Vp/Vs, filtered in seismic requency band was generated and polygon was drawn to isolate most likely gas sands which are relatively thicker or occur in a cluster of several thin sands.

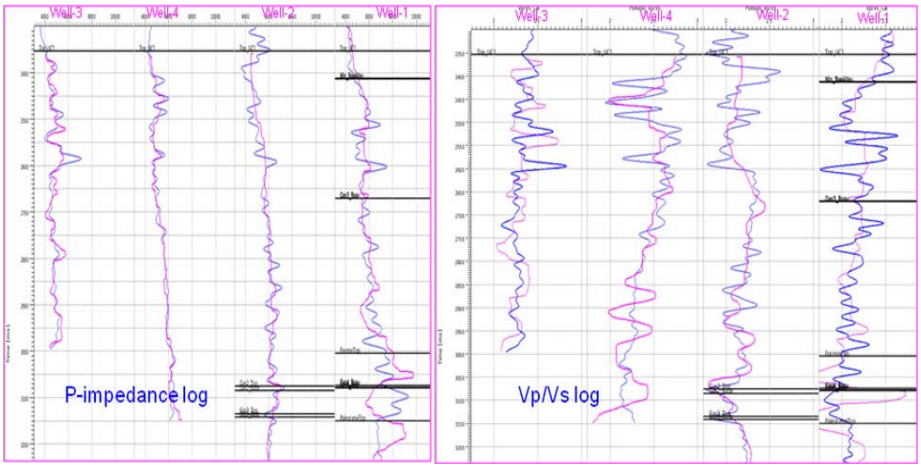

Fig: 5. High cut filtered original P-impedance and Vp/Vs log (blue) and extracted log (magenta) of Well-1, 2, 3 & 4.

Within the inversion zone, only Well-1 and 3 have three and two gas sand zones respectively. Polygon selected from these wells indicates low Vp/Vs ratio and medium P-impedance for gas sands. Then same polygon is used in extracted P-impedance vs. Vp/Vs cross plot after slight adjustment to include the gas sand. This polygon is finally used for "most probable gas sand" detection from the inverted volumes.

Analysis around Well- 1, and location A & B

Cross plot of P-impedance and Vp/Vs ratio is taken from the inverted volumes. The Polygon derived for gas sand is used to capture pay zone in and around the drilled wells and prospective locations**.** The pay sand at TWT of about 3050ms, highlighted by most probable gas sand polygon is shown in section view of P-impedance and Vp/Vs of Well-1(**Fig: 6)**. The areal distribution of this can be observed through the stratigraphic slice of P-impedance and Vp/Vs, (**Fig: 7)**. The P-impedance and Vp/Vs section, passing through location A is shown in the same figure. The stratigraphic slice at about TWT 2845ms indicates the areal distribution of the same, (**Fig: 8)**. Similarly most probable gas sand polygon capture the fan like feature passing through location B as shown in the stratigraphic slice of P-impedance and Vp/Vs, **(Fig: 9)** .

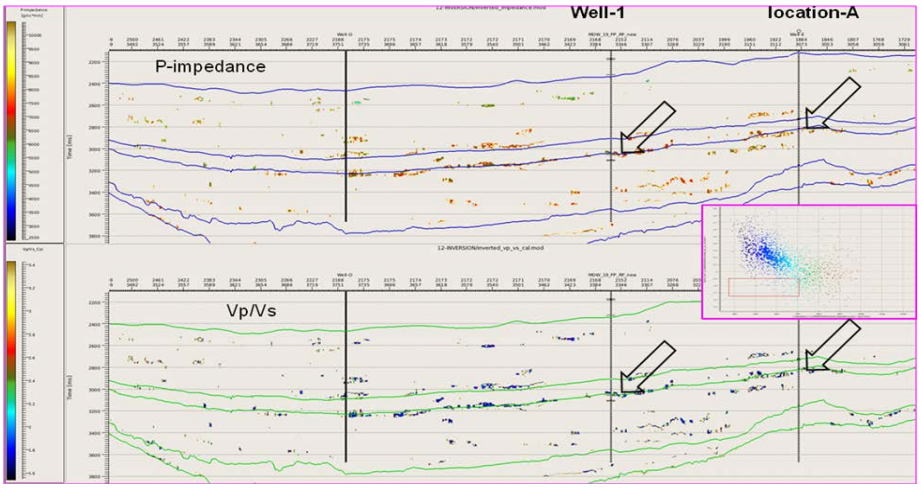

Fig: 6. P-impedance and Vp/Vs section through Well-1 & location A, highlighted by polygon of most probable gas

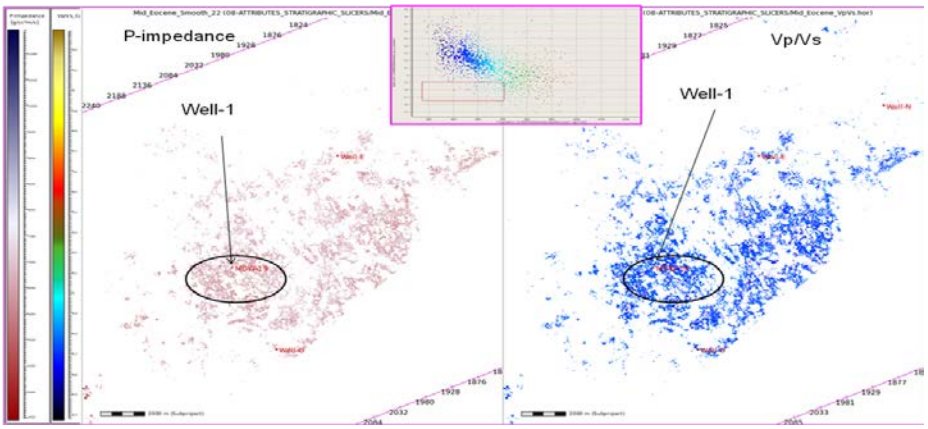

Fig: 7. Stratigraphic slice of P-impedance and Vp/Vs, highlighted by gas sand polygon about TWT 3050ms at Well-1 gas producing layer.

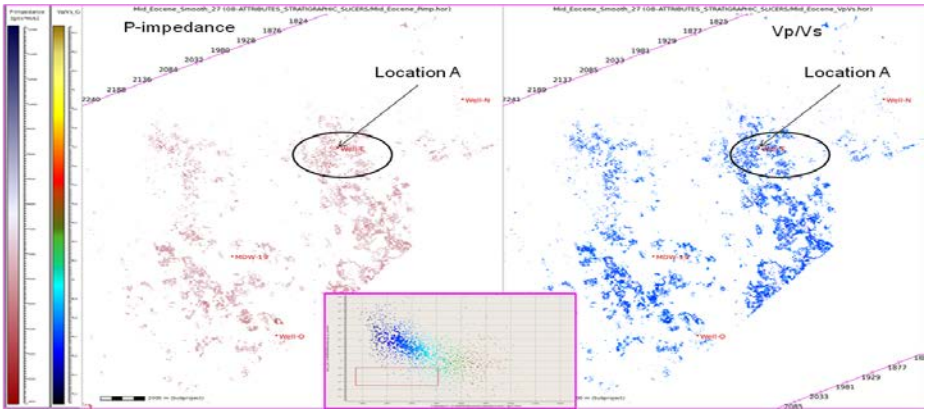

Fig: 8. Stratigraphic slice of P-impedance and Vp/Vs, highlighted by gas sand polygon about TWT 2845ms at location A.

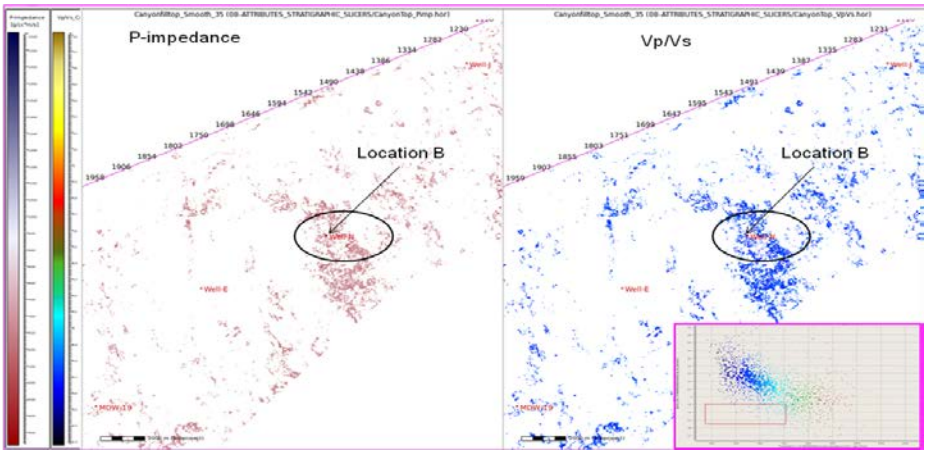

Fig: 9. Stratigraphic slice of P-impedance and Vp/Vs, highlighted by gas sand polygon at about TWT 3200ms at location B within canyon fill.

Extraction of Geo-bodies

The probable larger sand bodies extracted from the inverted volume is shown in 3D view, (**Fig: 10)**. Left limb of red colour sand body is passing through well Well-1 (at TWT 3050ms) and right limb is passing through the prospective location A (at TWT 2845ms) which is two fans like features. Another body of light blue colour which is passing through location B at about TWT 3200ms is also seen.

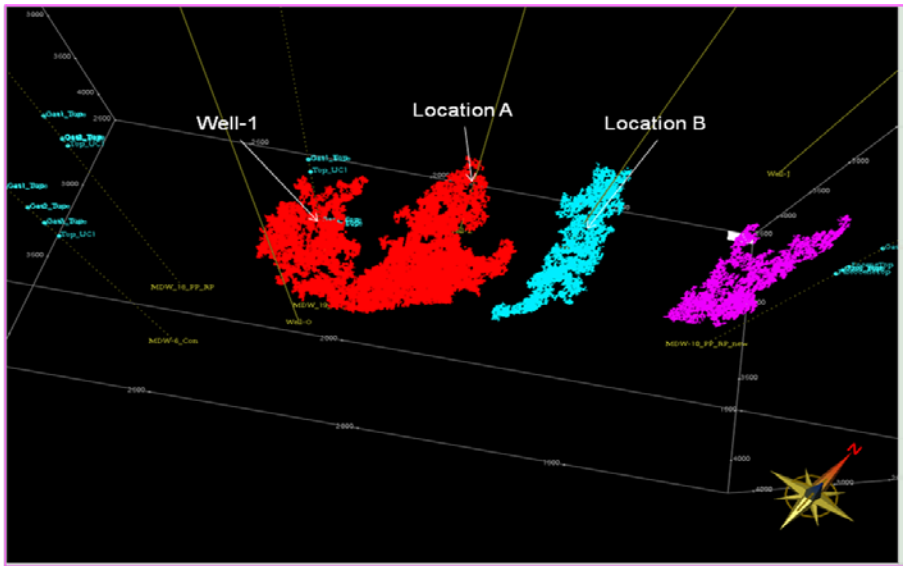

Fig: 10. 3D view of most probable bigger gas /brine sand body extracted from inverted P-impedance and Vp/Vs volume.

Conclusions

It is likely that it could be possible to detect the presence of relatively thick and vertical cluster of thin gas sands using combination of P-impedance and Vp/Vs volumes. Gas sand polygon is selected from cross plot of extracted P-impedance and Vp/Vs at four wells and it is used to delineate most likely occurrence of gas sand. Stratigraphic slices of both P-impedance and Vp/Vs have been generated within the zone of interest and used for detecting likely gas sand distribution at different levels.

Few prospective locations identified from G&G interpretation were investigated through inversion analysis. Well-1 was drilled on fan lobe and found to be hydrocarbon bearing at about TWT 3050ms. The feature with low Vp/Vs and medium P-impedance is clearly indicated by stratigraphic slice as identified by most probable gas sand polygon. Location A is also placed on similar feature. Another fan like feature at about TWT 3200ms is found to be present near location B.

In spite of all these studies, it is required to be further augmented by other G&G analysis before zeroing in the location for drilling as these results are partially affected by overlapping properties of pay and brine sands and thinness of reservoir sands. Detailed petrophysical study and improved seismic processing is recommended for more convincing results.

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