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AVO and Constrained Sparse Spike Inversion for reservoir characterization of an area in Mahanadi Offshore Basin

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Summary

AVO and inversion techniques became very popular in the oil industry in recent days. Although AVO technique can be used for direct detection of hydrocarbon, however it suffered from ambiguities caused by lithology effects, tuning effects and overburden effects. Seismic inversion is the process of transforming seismic reflection into a quantitative rock-property description of a reservoir. Apart from general interpretation, these studies are done to extract additional information from seismic data.

The present study area is from Mahanadi offshore basin. Over twenty wells have been drilled under exploration activity but commercial success has remained elusive till now. Majority of drilled wells have evidence of gaseous hydrocarbon accumulation in thin sands. In most of the gas bearing wells drilled so far thin sands are found to be hydrocarbon bearing while thick ones are brine sands. The aim of this study is to look for the probable locale of larger hydrocarbon bearing sands, if any within Mio-Plio sequence of the study area.

Keywords: *Inversion, Mahanadi Offshore*

Introduction

The importance of seismic inversion and AVO techniques has been growing steadily over the last few decades. These studies when integrated with conventional interpretation are essential to add value to hydrocarbon exploration and development projects. Inversion and AVO studies are the means to extract additional information from seismic data. There are various seismic inversion techniques and algorithms suitable for different input data scenario and objective of study. Pre-stack inversion technique to discriminate lithology and fluid is applied for this study. The amplitude character of seismic reflections varies with offset due to changes in the angle of incident which is evident in pre-stack CMP gathers. The Amplitude Versus Offset (AVO) behavior of reservoir rock is useful to detect the presence of hydrocarbon saturated reservoirs. This study area is in Mahanadi offshore basin which is situated in the northern part of the East Coast of India, Fig: 1. The bathymetry of study area is 1100 to 1390m. Wells A & B were drilled in this study area in structural closure and encountered thin gas sands within Miocene. Objective of this integrated study is to discriminate gas sands from the rest of the clastics. On the basis interpretation few prospective locations were identified. Time migrated pre-

stack data are used as basic input to Constrained Sparse Spike inversion (CSSI) and AVO analysis. Inversion and AVO analysis were carried out independently for the 3D seismic volume using the Well A and Well B. To delineate gas sand in this area, gas sand polygon is selected from cross plot of inversion derived Pimpedance and Vp/Vs at Well A. Due to bad well to seismic ties and unstable wavelet extraction, Well B was used as blind well for validation. As observed from the analysis, the thin individual pay sands may not be detectable; however vertical cluster of such sands is likely to get detected using inversion volumes.

Based on the AVO modelling result at well position, seismic signatures corresponding to gas sand were searched in the adjoining area. Intermediate range of P-impedance and low Vp/Vs as observed in gas sand is also used for delineating most likely pay sands. Both AVO and inversion studies were combined to arrive at the final location.

Geo-body extraction from the inversion volume using gas sand polygon of Well A are used to delineate the most probable gas sand within the zone of interest.

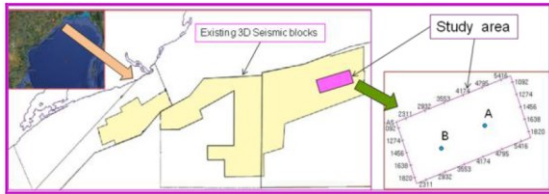


Fig. 1. Base map showing the study area of Mahanadi Basin with Well A and B.

AVO Modeling of Well A

In Well A, three zones within TWT 3625 to 3740ms of pure brine sand were selected for Fluid Replacement Modelling (FRM) and AVO synthetic generation. FRM was performed in the three brine sand zones by replacing brine with 50 percent gas. P-velocity and density reduced at gas filled zones. S-velocity increases slightly due to decrease in density. Consequently, the P-impedance of FRM log decreased more as compared to S-impedance. However, Vp/Vs of FRM curve decreased substantially. AVO synthetic modelling was carried out in the FRM zones of Well A using Zeoppritz equation. Synthetic gather of Gas saturated sand indicates flat amplitude response with angle while the brine sand shows decreasing amplitude with angle in zone 1 & 2. However, PSTM gather is affected by noise. FRM synthetic gather of zone 3 gas sand shows slight increase in amplitude with angle while the insitu synthetic shows no change, Fig: 2.

To discriminate the sand and shale, cross plot of Pimpedance (AI) vs. Vp/Vs ratio was taken for the above three brine sand within TWT 3525 to 3850ms of Well A. The same cross plot shows P-impedance and Vp/Vs to be decreasing substantially after FRM, Fig: 3.

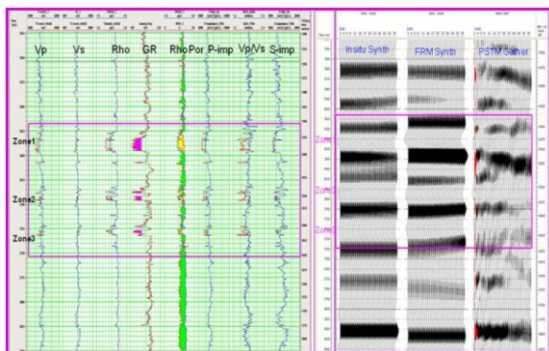


Fig. 2. FRM logs (brine replaced with 50% gas) and In-situ logs of Well A. FRM elastic logs are coloured red at three brine sand zones (left panel). Right hand side showing In-situ, FRM synthetic gathers and PSTM gather.

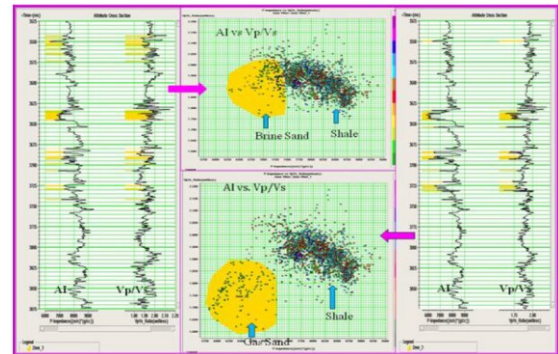


Fig. 3. Cross plot between AI vs. Vp/Vs ratio within TWT 3400 to 3850ms showing brine sand and shale clusters before (top & right) and after (bottom & left) FRM.

Rock Physics Analysis on Gas Sand of Well A

A cluster of seven thin gas sand at depth level 3900 to 4120m was selected for rock physics analysis and FRM modelling in Well A. P-impedance and Vp/Vs cross plot within this interval shows three distinct cluster of clean gas sand, tight sand and shale. Cross plot of FRM logs (after replacing gas with 20% water) within the same interval is showing three distinct zones of clean sand, tight sand and shale. Modelled synthetic gather with and without FRM for the above level shows no change in amplitude with angle in gas sand as well as water filled sand in shallower part. However in the deeper part it shows increase in amplitude both for gas and brine sand. As the individual gas sands are too thin, the response is a composite one, Fig:4.

Change of rock physics property with change in fluid is noticeable, but not as substantial as to give rise to strong AVO effect. The AVO response from brine sand are showing decreasing amplitude with angle. AVO response for gas sand is showing flat amplitude or little increase in amplitude with angle. Therefore, conventional AVO analysis in this area may not be very effective for delineating gas reservoir even if it is sufficiently thick. Individual gas sand is too thin to give rise to any perceptible AVO response. Only in case, there is a cluster column of several gas sands as in Well A, it may show Class III AVO response.

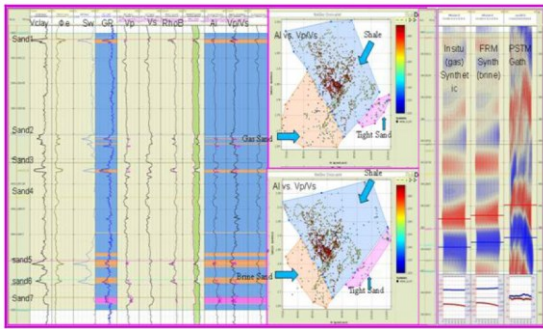


Fig: 4. Original logs (blue) and FRM (red) logs (left). Cross plot between AI vs. Vp/Vs before (middle top) and after (middle Bottom), FRM show three distinct zones of clean gas sand, tight gas sand and shale. Synthetic gather with and without FRM (left).

Strategy for pay sand delineation from inversion results

P-impedance and Vp/Vs cross plot is the best combination to delineate the extension of gas producing sand in this area. So within the inverted zone, cross plot of Well A between P-impedance and Vp/Vs of original log was taken. Then a polygon is drawn to select the gas sand from P-impedance and Vp/Vs ratio, Fig: 5. The cross plot of P-impedance and Vp/Vs ratio was taken from inversion derived logs (inverted) also at well position. However gas sand polygon is selected from this cross plot by slightly modified above well log derived polygon which is finally used to delineate gas sand, Fig: 6. Relatively thicker gas sands like 6, 7, 8, 9 and 10 are being identified as a cluster.

So we considered the polygon of extracted Pimpedance and Vp/Vs ratio for delineating most probable gas sand in this area. The thin individual pay sands may not be detectable, but cluster of such sands is likely to get detected using inversion volumes as observed from this analysis.

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. Both Well A and Well B are used for well to seismic tie and wavelet extraction. Five partial stacks are generated from angle gathers of range 2 to 36degree. Well to seismic tie and wavelet extraction were performed within two way time level 3200 to 4400ms for all the angle stacks. The wavelets of Well A are similar and stable for all angle stacks and synthetic to seismic correlation is also good. The energy of extracted wavelet

is concentrated near zero. Phase of the wavelet near seismic bandwidth is also near zero and constant within seismic frequency bandwidth. However, it is not so for Well B. So the stable wavelets of Well A are used for better inversion process.

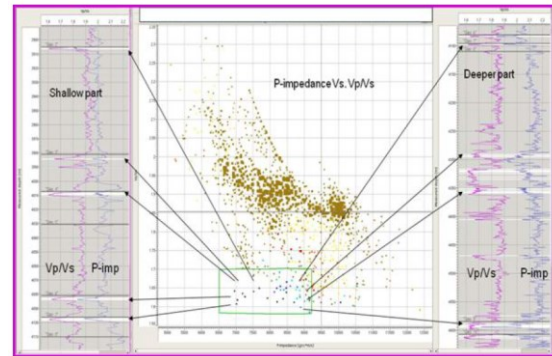


Fig: 5. Cross plot of Well A within the zone of inversion, showing medium P-impedance and low Vp/Vs (within polygon) from gas sand. Corresponding logs are shown in left & right panels.

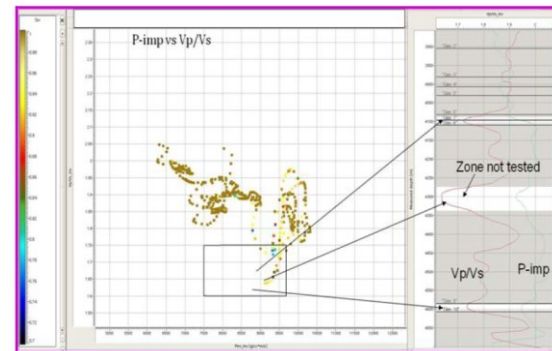


Fig: 6. Cross plot of extracted logs of P-impedance and Vp/Vs from inversion results at Well A. This Polygon is used to select probable gas bearing zones in inversion (left). Corresponding logs are on right.

It needs to optimise the inversion parameters before running the CSSI. Optimum elastic parameters are determined by minimizing an objective function which contains multiple terms called misfit functions. CSSI was run after fixing the inversion parameters.

The inverted P-impedance and Vp/Vs logs at Well A & Well B when overlaid on P-impedance and Vp/Vs sections indicates reasonably good match. The well Pimpedance and Vp/Vs logs and inversion derived logs at Well A show reasonably good match. In Well B, although P-impedance



show good match, but Vp/Vs shows poor match as the variation in Vp/Vs log with depth is unrealistically low, Fig: 7.

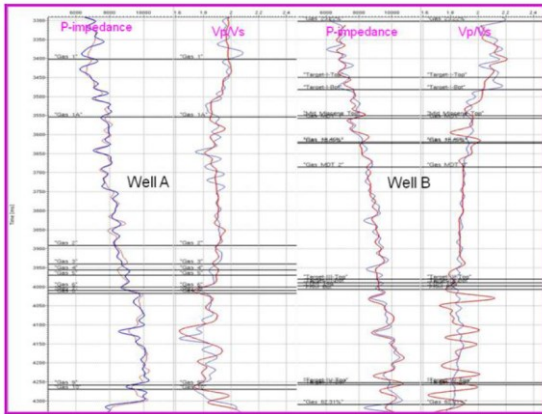


Fig: 7. High cut filtered original log (blue) and extracted (red) Pimp & Vp/Vs log of well A & B.

AVO and Inversion analysis at and around Well A

As shown in Fig: 8, positive P*G attribute is not very obvious for class II/III type of AVO due to alignment issues of seismic event, but AVO anomaly is clearly observed around Well A at TWT of about 4000ms from the cluster of three gas sand. The pick analysis of angle gather around the well indicates increase in amplitude with angle, Fig: 9.

Cross plot of inverted P-impedance and Vp/Vs ratio is taken from Well A within inverted time window. The Polygon derived for gas sand of Well A is used for selecting medium P-impedance and low Vp/Vs from section along Well A, showing the zone of medium P-impedance and Vp/Vs at TWT of about 4000ms (where AVO anomaly is also seen), Fig: 10. Areal distribution of this can be observed through the stratigraphic slice of Pimpedance and Vp/Vs highlighted with gas sand polygon, Fig: 11.

AVO and Inversion analysis at other locations

Class III types of AVO anomaly are observed at around IL1357 / XL3800 (*location C*) about TWT 4190ms. Inversion result is also indicative of probable presence of gas sand, Fig: 12. AVO anomalies are observed more or less continuously on this event in relatively large areal extent which also passing through IL1235/XL3725

(*location D*) about TWT 4175ms. Inversion analysis also shows probable presence of gas sand in relatively large areal extent. Similarly analysis of location F at IL 1761/XL2872 at TWT 4100ms shows class III type AVO anomalies and medium P-impedance and Vp/Vs, Fig: 13.

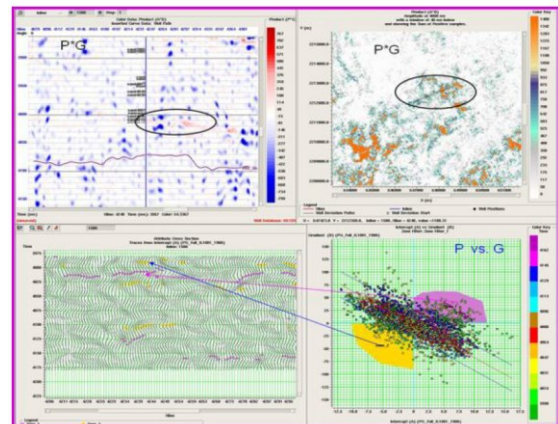


Fig: 8. P*G section of IL1580 (top left) and P*G slice (sum of positive sampling) (top right) of 40ms time window below 4000ms. Cross plot at well location is showing very little AVO anomaly.

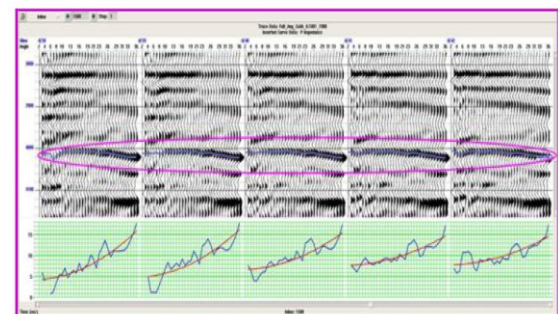


Fig: 9. Pick analysis of few gathers at TWT 4000ms at and near Well A, showing increase in amplitude with angle.

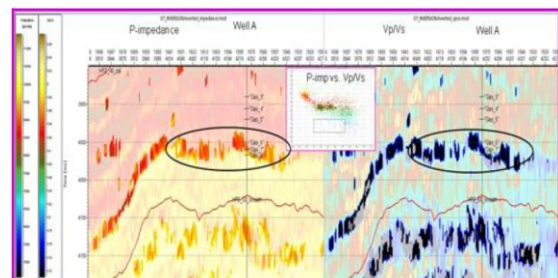


Fig: 10. P-impedance and Vp/Vs section of line segment along Well A, showing the zone of medium P-impedance and Vp/Vs at TWT of about 4000ms (gas sand 6, 7 & 8).

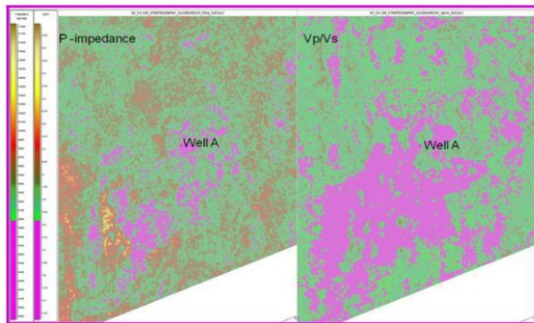


Fig: 11. Stratigraphic slice of P-impedance and Vp/Vs highlighted with gas sand polygon from P-impedance and Vp/Vs at TWT of about 4000ms at Well A.

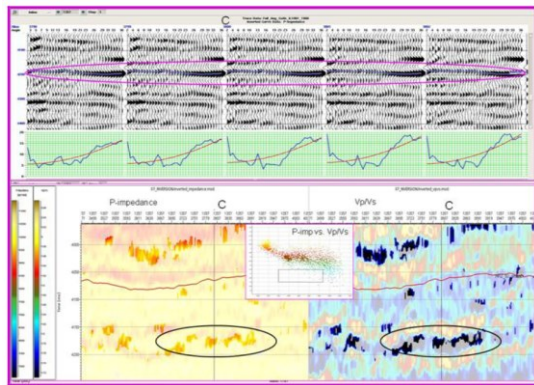


Fig: 12. Pick analysis of Few Angle Gather of IL 1357 (location C) near TWT 4190ms, showing increase in amplitude with angle (Top). P-impedance and Vp/Vs section along location C, showing the zone of medium P-impedance and Vp/Vs at TWT of about 4190ms.

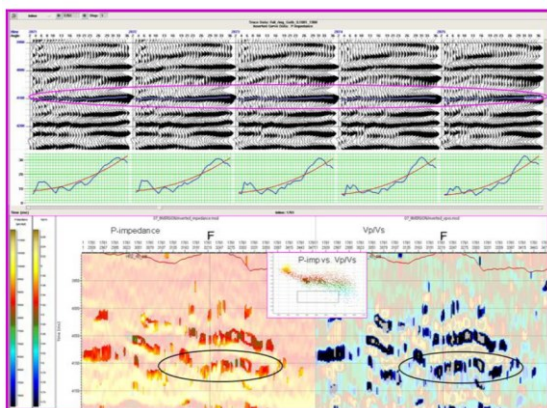


Fig: 13. Pick analysis of Few Angle Gather of IL 1761 near TWT 4100ms, showing increase in amplitude with angle (top). P-impedance and Vp/Vs section of IL1761/XL2872 along location F (bottom), showing the zone of medium P-impedance and Vp/Vs at TWT of about 4100ms.

Extraction of Geo-bodies

The most probable gas sand bodies are extracted from the inverted P-impedance and Vp/Vs volume using the gas sand polygon. Sand body of green colour is from the cluster of gas sand 6, 7 and 8 (within 4081 to 4115m depth) of well A, as shown in projected 3D view Fig: 14. The area of the body is about 24Sq.Km. The brown colour Geo-body of most probable gas sand is for location C and D of about 23Sq.Km. The blue colour geo-body is passing through location F and its total area is 17sq.Km, Fig: 14.

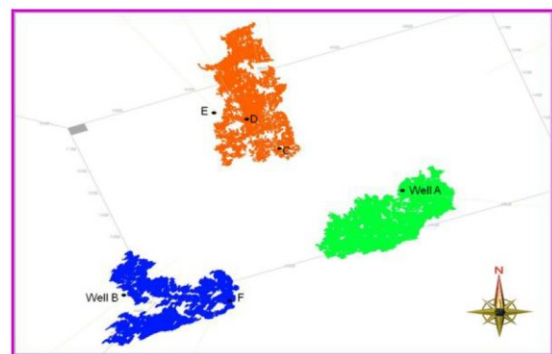


Fig: 14. Most probable gas sand bodies of relatively large size extracted from inverted P-impedance and Vp/Vs ratio volume.

Conclusions

In the study area change of rock physics property with change in fluid is noticeable, but not as substantial as to give rise to strong AVO effect for gas sand. Therefore conventional AVO analysis in this area may not be very effective for delineating gas reservoir even if it is sufficiently thick. Moreover, individual gas sand is too thin to give rise to any perceptible AVO response. Only in case, there is a cluster column of several gas sands as in Well A, it may show Class III response.

Gas sand polygon is selected from cross plot of extracted P-impedance and Vp/Vs from inversion volumes at Well A and it is used to delineate gas sand in this area. It is likely that it would be possible to detect the presence of thick and cluster of thin gas sands using combination of inverted P-impedance and Vp/Vs volumes. AVO analysis at around location D within TWT 3934 - 3956ms indicates class III AVO anomalies. The inversion also indicates probable presence gas sand. The observation is similar at location C within TWT 4166 - 4194ms. Inversion analysis also shows probable presence of gas sand in relatively large areal



extent. Same inversion results are observed at around *location F* about TWT 4078ms. Integration of AVO and Pre-stack inversion studies provided confidence in results of prospectivity analysis. However, for reducing uncertainty it is recommended to use these results along with other G&G analysis.

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