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Elastic impedance for gas sands discrimination and risk mitigation – A case study in deep water of Mahanadi Basin

Nepal Singh*, Shweta Bankhwal, S. Das, R.S. Waraich, Shyam Mohan,
ONGC Ltd. Dehradun, India

Abstract

Deepwater environment of Mahanadi basin in the Mio-Pliocene window is dominated by mud prone channel system. Sandstone reservoir of channel-levee complexes in this window are transported from the shelfal environment in the north to the basinal part in the south. Stratigraphic features of channel-levee complexes in the study area of deep water of Mahanadi basin are mapped by seismic amplitude in the Mio-Pliocene window because of the acoustic impedance contrast between reservoir and non-reservoir facies. Different inversion attributes are modeled and cross-plotted using the rock physics model of well 'A'. Elastic impedance at far angle 30 degree EI(30) with the cut-off value of 740 is identified as most important attribute for distinguishing gas bearing sand from the brine sand and non reservoir facies. EI(30) volume is generated by inverting the far angle stack (30 degree) data using model based algorithm. Channel features identified based on the seismic amplitude are tested with inverted EI(30) attribute with the fixed cut-off value and found to have anomalous values. A location 'B' is identified based on this criteria and tested with reflection signal polarity (opposite to seabed) and AVO effect which later proved to be gas bearing. This paper illustrates how a systematic study of Elastic Impedance at far angle can help in identifying a successful exploratory location thereby mitigating the commercial risk.

Introduction

Mahanadi basin is located in the northeastern part of eastern passive continental margin of India. Tectonic setup of the basin is the resultant of NNW-SSE trending Gondwana trend and ENE-WSW trending Eastern Ghat trend (fig. 1). Deepwater environment of Mahanadi basin comprises sediments ranging from cretaceous to Miocene and post-Miocene. Channel system transported clastics from the shelf environment in the north to deep basinal part to the south and forms isolated sandstone bodies within the channel complex. Present study focuses the tertiary channel-levee complexes mapped by the seismic reflection amplitude slice within the Mio-Pliocene window of the study area in the deep water environment and are the target zone for gas accumulation. Deciphering the well defined configuration and reservoir continuity within the channel is the key to exploration success. Present study has brought out a methodology for defining the channel geometry and reservoir continuity and also the reservoir fluid discrimination within the channel. Elastic impedance at 30

degree angle EI(30) is utilized successfully to discriminate the gas bearing sand from shale/brine sand within the channel and hence addresses the aspects of risk mitigation

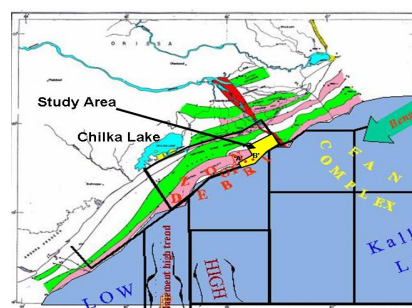


Fig 1. Tectonic map Mahanadi Basin .



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Seismic Reflection Amplitude

PSTM stacked and far angle stacked (30 degree) volumes with bin dimensions 12.5m×25m are used to identify exploratory and appraisal locations in the deep water block. Seismic horizons are interpreted within the Mio-Plio window and are used to extract RMS amplitude map. Channel system are found to exhibit strong seismic reflection character due to the contrast in acoustic impedance between reservoir and non-reservoir facies. RMS seismic amplitude slice from the target window demonstrates the geometry and setting of the channel system (Fig. 2). Within this channel-levee complex there exist lithology and hydrocarbon related amplitude anomalies. Spectral decomposition within the same window is used to get an idea of thickness variation within the channels which acts like a conduit for hydrocarbon. A discovery well 'A' drilled within the channel in the Mio-Pliocene window in the study area, strike gas.

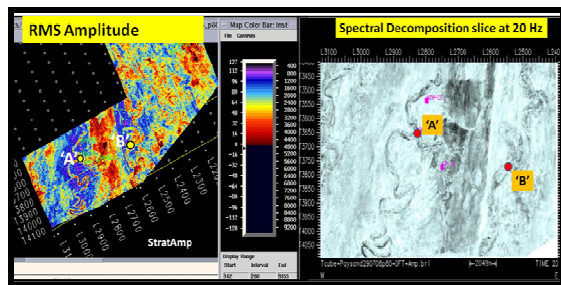


Fig2. RMS amplitude map and spectral decomposition slice.

Fluid Replacement Modeling

Discovery well 'A' drilled in the study area is used for fluid replacement modeling assuming Gassman's relations (Gassman, 1951). Effect of fluid within the reservoir sand on the seismic response is analyzed using the rock physics model and petro-physical properties of the formations encountered in the well. Invasion correction is applied to correct the sonic and density logs through fluid replacement modeling (FRM) in the target zone by replacing water saturation S_{xo} with S_w . Elastic property logs are shown along with gas saturation before and after FRM in the figure 3. It is observed that brine sand impedance is more than the shale impedance and gas sand impedance is less than the shale impedance. This indicates that sand is not

soft in this area and hence gas sand will be identified by class II type AVO anomaly and with opposite polarity to that of seabed on stack section. Change in EI(30) within the gas bearing zone is more pronounced than that of acoustic impedance Z_p (figure 3) which implies that amplitude of far angle stack will be more than that of near angle stack showing the AVO effect within the zone.

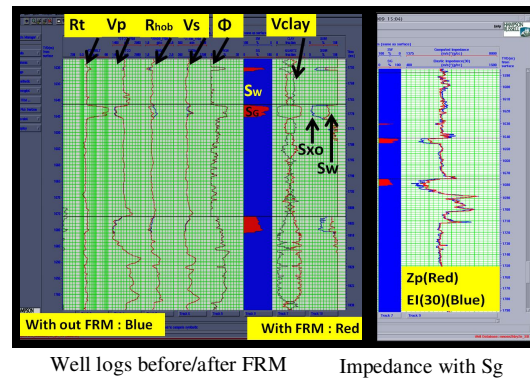


Fig3. Well logs before and after fluid replacement modeling along with gas saturation log.

Cross-plotting of inversion attributes

Different post-stack and pre-stack inversion attributes modeled from the well logs are cross-plotted with the petro-physical properties of the reservoir and best pair of attributes are identified to discriminate the gas sand from brine sand and non-reservoir facies. Acoustic impedance Z_p is cross-plotted with elastic impedance EI(30) and with gas saturation colour code of the points in the figure 4(a). EI(30) with 740 m/s cut-off is the best attribute to discriminate gas bearing sand from shale/brine sand within channels. EI(30) values from 740 to 1000 value discriminates non-reservoir shale facies while brine sands are found to have EI(30) value more than 1000 (fig. 4b).



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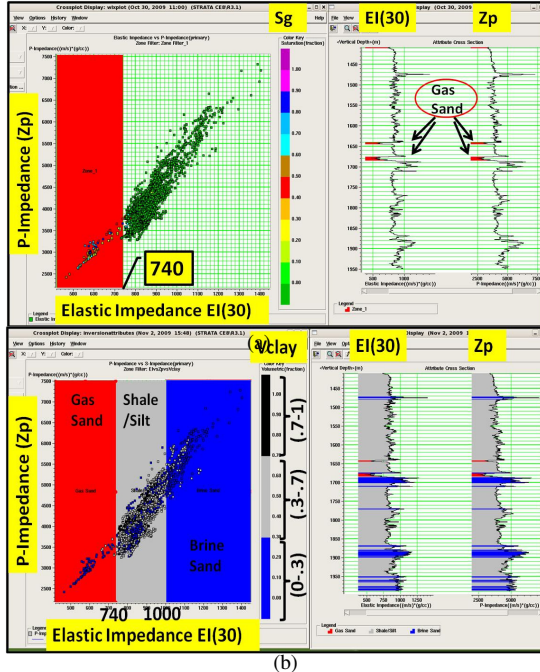
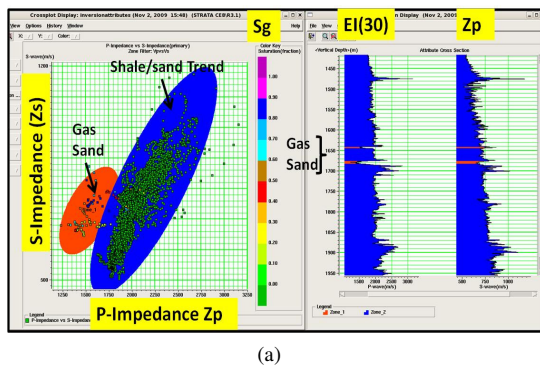
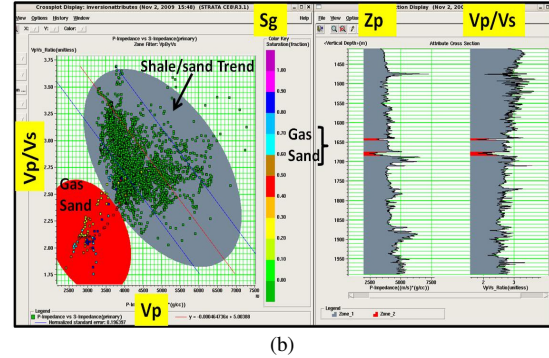


Fig4. Cross-plotting of (a) EI(30) vs Zp with color of symbol represent the gas saturation; (b) EI(30) vs Zp with symbol color represent the volume of clay;

Shear impedance Z_s vs Z_p and V_p/V_s vs Z_p cross-plot also indicates that gas sands separate from shale/brine sand (fig. 5 a&b). Since brine sands and shales are following almost same trend and hence are not separable.



(a)



(b)

Fig5. Cross-plotting of (a) Z_s vs Z_p (b) V_p/V_s vs Z_p with symbol color representing gas saturation.

Based on analysis of Z_p vs EI(30)/ Z_s and V_p/V_s vs V_p in the figure 4&5 and since estimated shear impedance data are less reliable than elastic impedance (Whitcombe, 2002), it is clear that elastic impedance data at 30 degree is better attribute than others to discriminate gas sands from brine sand and shale, as well as brine sands from shales.

On the basis of reflection amplitude, fluid replacement modeling and cross-plots of different inversion attributes following criteria is developed for identifying gas bearing sands in the area

- Stratigraphic channel/splay feature.
- EI (30) with cut-off value of 740.
- Trough over peak polarity.
- Far angle stacked amplitude more than that of near angle (AVO effect)

Elastic Impedance Inversion

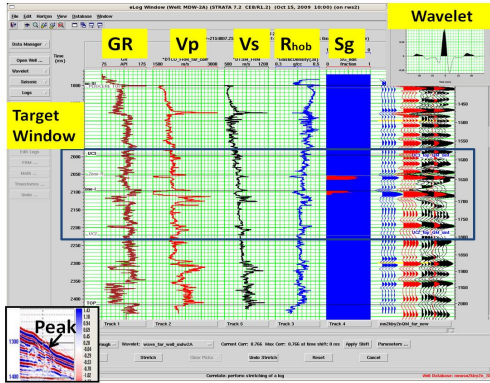
Partial angle stacks at far angle (30 degree) are analyzed to understand the AVO effect in the target window. Elastic impedance (PATRICK CONNOLLY, April 1999) inversion is carried out with the far angle stacks, well 'A' logs and interpreted horizons in the zone of interest in the study area. Well to seismic correlation is carried out for far angle stack and wavelet is extracted using well 'A' and is shown as inset in the figure 6(a). Wavelet is having European polarity displaying peak with increasing impedance. Seabed is represented as peak in the seismic section as shown in the bottom left corner of figure 6(a). Therefore gas sands will be represented as trough over peak on seismic section with opposite polarity to that of seabed.



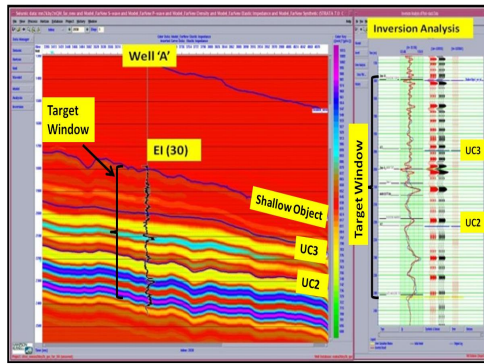
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Log correlation along with other synthetic trace is shown in the fig. 6(a).



(a)



(b)

Fig6. (a) Well to seismic correlation and wavelet extraction. (b) EI(30) model and post-stack seismic inversion analysis.

Three stratigraphic horizons (shallow object, UC3 and UC2) and well 'A' logs are used to build the initial impedance model for inverting far angle stack data (30 degree). Elastic impedance model along with post-stack inversion analysis within the target window is shown in the figure 6(b). Model provides low frequency impedance trend for generating absolute elastic impedance EI(30). Post-stack inversion analysis carried at well 'A' shows 99% correlation within the target window between inverted and actual EI(30) logs.

Model based inversion algorithm is used for inverting far angle stack volume using extracted wavelet and initial impedance model (figure 6b). Elastic impedance EI(30) is generated at far angle. Acoustic impedance Zp volume is also generated using model based inversion algorithm by inverting full angle stack volume.

Result and Discussion

Elastic impedance at far angle EI(30) section, acoustic impedance Zp section are shown along with seismic section passing through the discovery location 'A' (figure 7). It is evident from the section that gas bearing sands are having

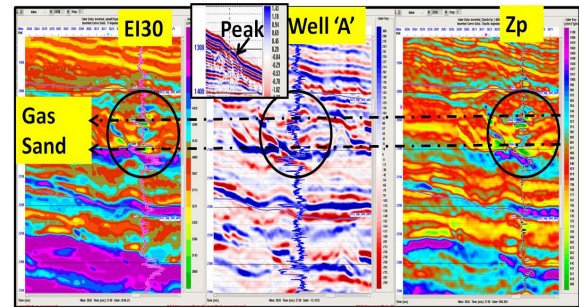


Figure 7. EI (30), Zp and far angle stack sections.

low elastic and low acoustic impedance than the brine sand and shale and hence represented on the seismic section with trough over peak polarity opposite to that of seabed as shown in the figure 7. According to gas sand detection criteria, EI(30) is subjected to 740 cut-off. EI(30) with applied 740 cut-off criteria is scaled to zero and is shown in the map view in the figure 8 (a). After scaling to zero,



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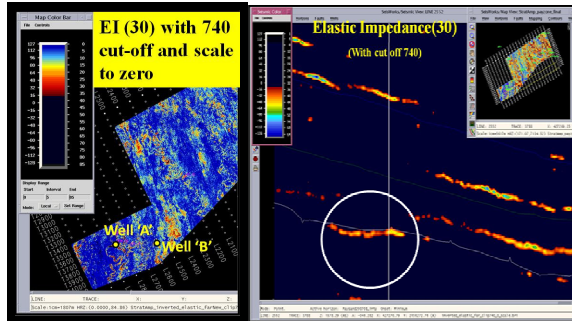


Figure 8. Elastic impedance (30) at 30 degree angle with the cut-off value of 740 and scaled to zero (a) Map view (b) Section view.

very low EI(30) values become higher values. Gas bearing sand bodies satisfying the cut-off criteria are identified along the channels and validated at the discovery location 'A'. No. of channel bodies satisfying this criteria are identified. Location 'B', identified within the channel, is shown in the figure 8. EI (30) section with cut-off value passing through the location 'B' is shown in the figure 8(b). Few sand bodies having lower EI(30) values are identified on this section. This location is tested for the other gas detection criteria such as peak over trough and AVO effects. Reflectivity section and EI(30) section along this location is shown in the figure 9.

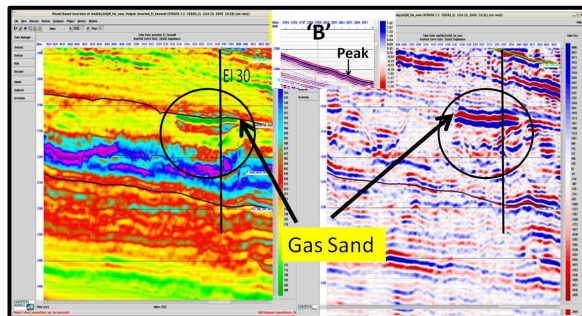


Figure 9. EI (30) and far angle stack section.

A primary target in the figure 9 is having very high amplitude sand body with in the channel cut and associated with the low elastic impedance EI(30) of the order of 690 value. On the reflectivity section it is having trough over peak (opposite to seabed polarity) as shown in the figure

9. This target is underlain by mild low EI(30) values (740 to 1000) which represents to shale. Shale values are then underlain by higher values (greater than 1000) values representing brine sand.

Identified location is tested with the fourth criteria i.e. AVO effect on the partial angle stacks. Amplitude of the sand bodies in the channel cut is having higher values on the far angle stacks than that on the near angle stack as evident in the figure 10.

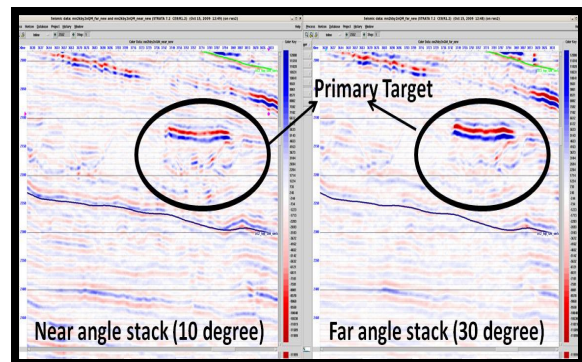


Figure 10. far angle stack and near angle stack section.

Channel sand body is satisfying all the gas identification criteria. Later on after drilling this channel feature strike gas bearing sand underlain by shale and water bearing sand.

Conclusion

Channel-levee stratigraphic features in the deep water of Mahanadi basin are mapped by seismic amplitude attribute in the Mio-Pliocene window because of acoustic impedance contrast between reservoir and non-reservoir facies. Based on fluid replacement modeling studies using the rock physics model of well 'A' and cross-plotting of inversion attributes, elastic impedance at far angle (30 degree) is identified as the most important attribute for discriminating gas bearing sand from the brine sand and non reservoir facies shale in the studied area. Identified channel feature on the seismic amplitude map is tested with the criteria of elastic impedance attribute with cut-off value of the order of 740, seabed opposite polarity and AVO effect. Location 'B' is identified fulfilling the above said criteria and proved to be gas bearing after drilling. Therefore a systematic study of Elastic Impedance at far



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angle can be used as a tool for identifying gaseous hydrocarbon in the area thereby mitigating the technical and commercial risk.

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