9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-255

Reservoir Characterization of Pay Sands Encountered in Malleswaram Area – An Inversion Case Study

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Summary

Rift-fill play of Early Cretaceous age have emerged out to be most important exploration targets in the Krishna-Godavari basin in particular offshore area, as a number of similar play has been established. Recently, commercial oil bearing reservoirs of multi-stacked channel sands were encountered in well-C from Nandigama-Arenaceous unit equivalent to rift-fill sequence. This has necessitated studies to delineate the reservoir. An inversion study has been undertaken with an objective of delineating the reservoir's lateral and vertical distribution for further probing such reservoir facies in and around the area. The study interval is confined to upper part of Nandigama-Arenaceous unit which host the oil bearing reservoirs. The hydrocarbon reservoirs in this sequence comprises of multi-stacked channel sandstones with a net pay thickness of around 100 m. The study covers an area of 100 sq.km located within the Bantumilli graben of west-Godavari sub-basin, On-land in Krishna-Godavari Basin Tectonically the study area falls in between the Kaza high in the North- west and Bantumalli high in the south-east. The KG Basin evolved through three stages of rifting (Proterozoic Proto-rift, Gondwana rifting, final rifting by break up of Gondwana land) followed by drifting of the separated part of the Gondwana land.

The study involves Petrophysical analysis, Rock physics modeling, seismic pre-stack inversion and Geological analysis to bring out an integrated reservoir model.

With conventional seismic reflection data it is difficult to map the reservoir extension due to wavelet and tuning effects. As the inversion output give the layer properties it is envisaged that mapability of the reservoir will improve. Further, with simultaneous inversion as we get both p- and s- impedance the capability for identification of reservoir facies is enhanced considerably.

Well log data was conditioned by editing noisy zones and filling data gaps by generating synthetics from other available logs. Seismic data were conditioned by attenuating noise in near offsets and correcting for residual NMO. Low frequency model was generated by interpolating filtered logs using stratigraphy information. The simultaneous inversion combined with the low frequency data gave Vp, Vs, and density volumes. The reservoir zone, corresponding to producing pay of well-C, is characterized by high P- impedance and low Vp/Vs. From the Vp and Vs data, zones corresponding to high P-impedance and low Vp/Vs is captured in 3D which gives the probable reservoir extension.

Keywords*: Seismic inversion, reservoir characterization, rift- fill sequence*

Introduction

Consequent upon the discovery of hydrocarbons from rift-fill sequence in nomination blocks of ONGC and also discoveries in the contiguous blocks operated by private partners, rift-fill sequence has assumed greater importance. In West-Godavari Sub-basin the Cretaceous and older (Upper Jurassic) sequences are the known hydrocarbon habitats. Exploration to probe hydrocarbon potential in such sequences in areas such as Malleswaram, Nandigama, Endamuru, Vygreswaram, Gokarnapuram etc. has resulted in discovery of both gaseous and liquid

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hydrocarbon and augmenting of Inplace reserves. Interestingly, in Malleswaram area, well - C, for the first time has established commercial liquid hydrocarbon from multistacked channel system of Nandigama-Arenaceous unit equivalent to rift-fill sequence resulted in accretion of substantial reserves. Thus, well-C has given impetus to carry out reservoir characterization to understand its lateral extension. An inversion study (Pendrel, 2006) is attempted to understand the lateral and vertical distribution of the reservoir for further probing of such reservoir facies.

2. Regional Tectonic setting and Basin Evolution

The Krishna-Godavari (KG) basin is a peri-cratonic poly history basin along the east coast of India and extends into offshore. The origin of KG basin is related to three stages of rifting. The Proterozoic Proto-rift (NW-SE) accommodated Purana group of sediments. This was followed by Gondwana rifting superimposed on the NW-SE trending Proterozoic graben which accommodated the sediments of Lr. Gondwana (Talchir to Chintalapudi S.st.). The final rifting (NE-SW) took place during the break up of Gondwana land (Late Jurassic-E. Cretaceous) and was followed by drifting of the separated part of the Gondwana land. The drifting was accompanied by SE tilting of the basin that heralded the open sea conditions and deposition of transitional, deltaic, inter deltaic and deep water sediments

In the on-land part, the West Godavari Sub Basin, delimited in the south by Matsyapuri – Palakollu Fault has proved to be the potential area for commercial hydrocarbons from the Upper Jurassic to Upper Cretaceous sediments. In the area of study south of Kaikalur - Lingala high, Nandigama and Suryaraopeta are gas and oil fields (Rao, 2001).

3. Geology of the area

Major tectonic elements present in the study area include Kaza Horst, Kaikalur-Lingala Horst, and SW plunging Tanuku - Bantumilli high, Gudivada and Bantumilli grabens. (Fig. 1). The NW flank of the Bantumilli high, where the present prospect is located, is gentler as compared to the SE flank towards Lakshmipuram. Similarly, the Kaikalur high has steeper SE flanks as compared to gentler NW flanks where Kaikalur – Lingala fields are located. The SE faults extend from Basement to Basalt levels suggesting continued tectonic activity till Paleocene. Bantumilli graben in this area shows typical half graben geometry filled with coarser to finer clastic rocks of Fluvial to marginal marine environment over Archean basement. These sediments are also known as Nandigama Arenaceous unit. End of rift-fill is marked by Aptian - Albian sedimentation of High Gamma High Resistivity (HG-HR) shale unit. This HG-HR sequence of Lower Cretaceous (Aptian-Albian) age is bounded by regional unconformities at top and bottom.

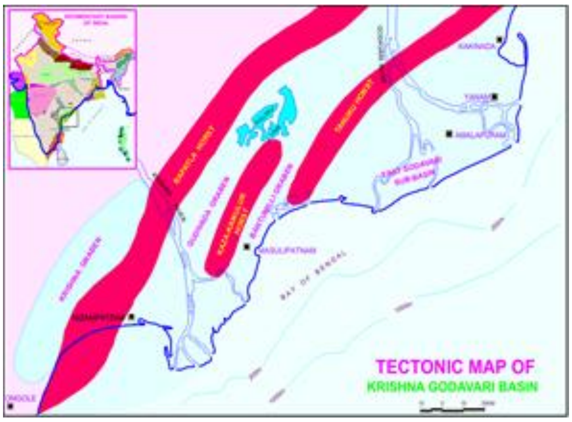

Fig.1: Major tectonic elements of KG basin

4. Stratigraphy

The oldest sediment penetrated in the study area is the rift-fill sediments named as Nandigama-Arenaceous formation (Upper Jurassic - Early Cretaceous) which is a good reservoir facies in the area. This formation is overlain by the transgressive Raghavapuram Shale formation (Early Cretaceous) which is the regional seal and also prominent source rock. This sequence is followed by Tirupati sandstone formation (Upper Cretaceous) and basaltic trap Razole Formation (Paleocene). A thin bedded Eocene Limestone overlies the Razole formation and subsequently deposited by the younger formation, Nimmakkuru Sandstone (Pliocene – Recent).

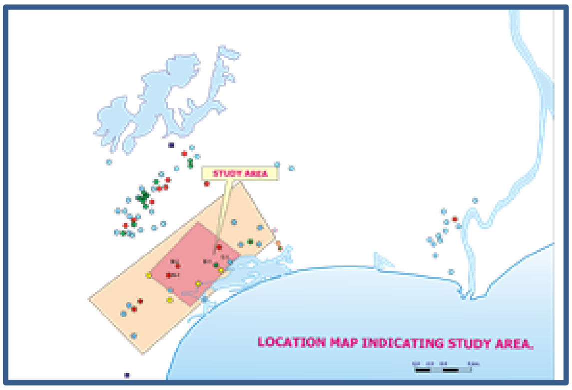

Fig. 2: Location map indicating study area in KG basin

5. Input Data

Four wells (A, B, C & D) are drilled in the study area (Fig. 2). of which three (C, A & D) have penetrated the rift-fill sediments of interest and produced oil, feeble gas and water respectively from the zone considered in the study. Well completion & Formation Evaluation reports, Production testing details, Sedimentological reports, log curves of the four wells are considered. In two wells, C & B both P & S-sonic are recorded, while in other two wells A and D only P- sonic is available. The study area is covered with 100 Sq.Km of 3D seismic data The seismic horizons corresponding to top of Basement and top of hydrocarbon bearing zones in well-C are used for generating the low velocity model for inversion.

6. Methodology

6.1 Data QC & Feasibility study

Data QC and feasibility study were carried out. The following is the observations of this study:

- A few missing and noisy zones are observed in the log data. Density data was affected at a few places due to caving.
- The reservoir zone is characterized by high P impedance and low Vp/Vs.
- Near offset seismic data was found to be affected by noise.
- Considerable residual move out exist which need to be corrected.

It is concluded from the feasibility study that if the data is properly conditioned then it would be possible to identify and map the reservoir zone characterized by high P impedance and low Vp/Vs.

6.2 Well log conditioning

Sonic and density logs for all the wells (Fig. 3 & 4) were conditioned to enable generation of synthetics and proper ties with the seismic data. The data gaps in sonic and density logs were filled with synthesized logs based on resistivity and gamma ray logs. In addition, wherever density data is not reliable, the data was generated using synthetic log generator. From Fig. 3, it may be seen that the corrections have removed outlier / affected data. Spikes, gaps and missing information in sonic logs were corrected and patched. Depth matching was carried out for all the logs.

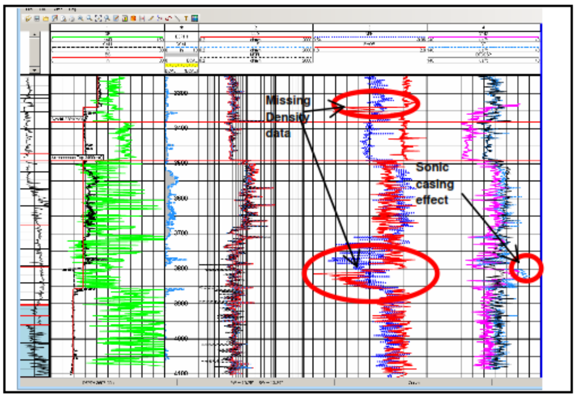

Fig. 3: Raw logs of well - C. The logs had to be conditioned by generating missing portions

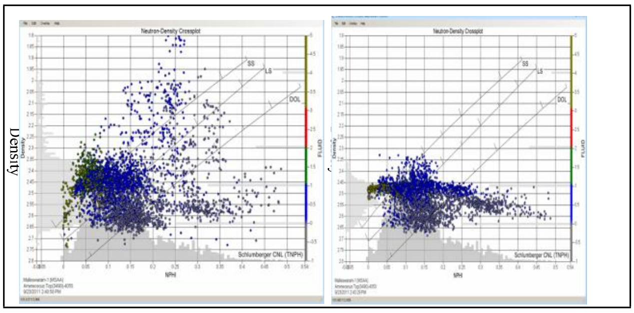

Fig. 4: The density - porosity crossplot before and after editing

6.3 Conditioning of Seismic data

The 3D seismic gather data was examined prior to inversion

(Fig. 5a). Certain deficiencies were observed in the data viz., (i) noise in the near offsets, (ii) rapid fall in amplitude from near to far offsets and residual move out.

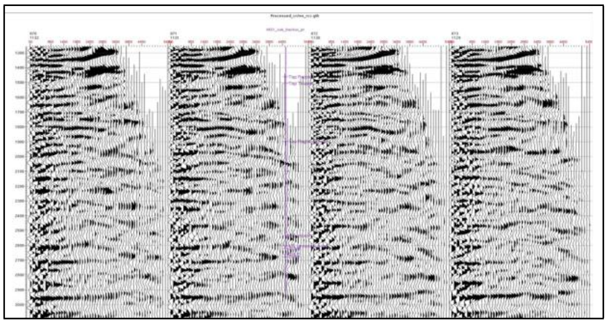

Fig. 5a: NMO Corrected gathers before conditioning

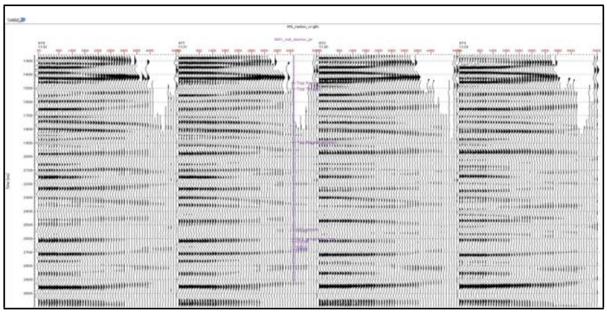

Fig. 5b: NMO Corrected gathers after conditioning

Seismic gather data was conditioned by noise removal using radon transform and residual static corrections. Fig. 5a & b show gather data before and after conditioning respectively. Data was restacked into 5 angle sub-stacks for carrying out Simultaneous Inversion.

6.4 Log correlation

Electrolog correlation of the Nandigama-Arenaceous unit was attempted for the four wells falling in the study area. Arenaceous unit has been further sub-divided into three sub- units (Fig.6). The Unit-III is penetrated in wells A, C & D, while the equivalent unit is not drilled in well - B. It is interesting to note that, Unit-III is gas bearing in A and oil bearing in C which is stratigraphically at a shallower level. Further in D, the equivalent unit is water bearing although it is shallower with respect to C. The inference is that these reservoirs are isolated in nature and may be time equivalent. This is further substantiated by the different high pressures recorded in these wells. The sealing nature of fault which separates C and D might have played a role in D being water bearing despite its stratigraphically much shallower level.

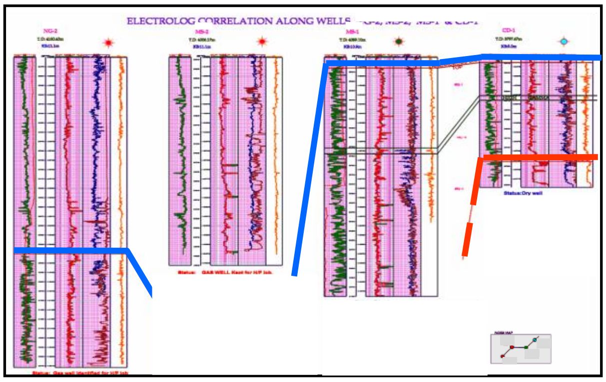

Fig. 6: Electrolog correlation of wells A, B, C & D

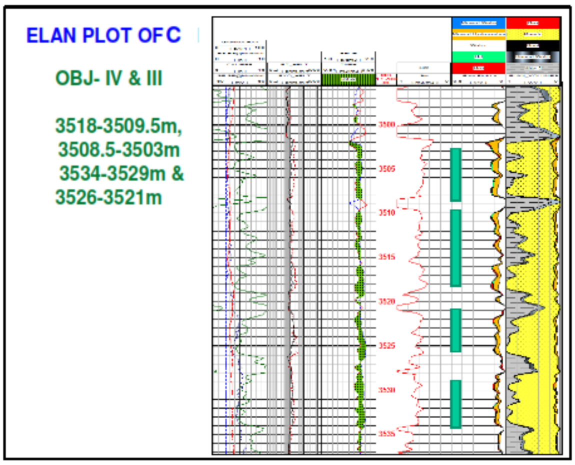

Fig. 7: Elan plot of the Oil bearing zone in Nandigama- Arenaceous Unit-III, well – C

Out of the three wells which penetrated zone of interest under study, well-C produced liquid hydrocarbon from Unit-III of the Nandigama-Arenaceous sequence. The log motif of the oil producing zone is depicted in Fig. 7. This zone is characterized by Resistivity of 12-20 ohm-m, Porosity: 10- 15% & Oil saturation: 45-55%. It produced 48m3 of oil & 11,200 m3 of gas through 6 mm bean.

6.5 Petrophysical study

Using the conditioned logs, petrophysical evaluation of the zone of interest (Basement Top to Arenaceous top) was done based on deterministic method. The attribute logs such as acoustic impedance, shear impedance, VP/Vs ratio were generated and used to produce cross plots colour-coded by Litho log. Fig. 8 shows a cross plot between P-impedance and Vp/Vs. A fair separation such as varying matrix content (e.g. sand and shale) and fluid saturation (hydrocarbon and brine) is obtained within a zone of interest. This indicates that generation of these attributes through seismic inversion will help in the mapping of geobodies. Similarly Fig. 8 shows that sand and shale are discriminable in SI-AI domain and further between hydrocarbon-bearing Sand, Shaly- Sand and Shaly intervals. It is also important to note intercalations of silty sand and shale occurs within the hydrocarbon bearing sands which will affect seismic resolution of hydrocarbon bearing facies. Therefore use of these seismic attributes for mapping hydrocarbon-bearing sands should take into consideration these lithological factors and the thickness of the sands which may be below the seismic resolution.

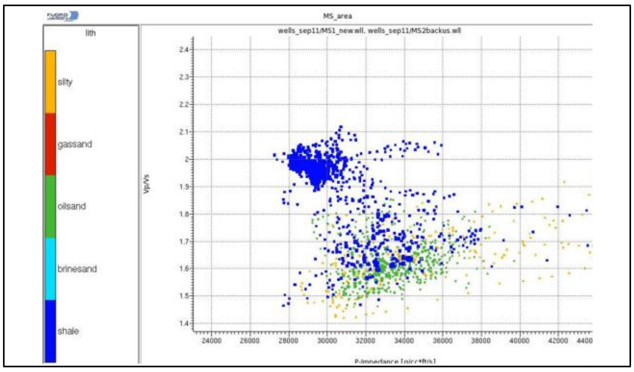

Fig. 8: Crossplot between P-impedance and Vp/Vs from well logs; a reasonable discrimination of reservoir (green) and non-reservoir (blue) facies is observed.

6.6 Inversion

Simultaneous deterministic inversion has been attempted with three angle stacks (out of the five) to obtain absolute P- and S- impedances from calibrated seismic data. This is a quick and robust technique to obtain the rock properties from reflectivity data. Fig. 9 shows the inversion workflow.

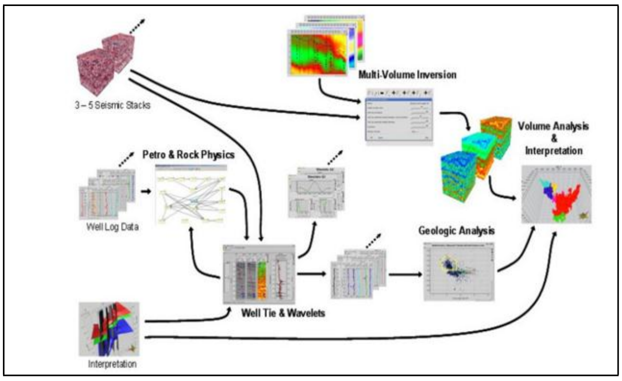

Fig. 9: Workflow for Inversion

A low frequency model was generated from filtered impedance logs interpolated taking into account the stratigraphic variation of the sub-surface (Fig. 10).

The inversion results are found to be encouraging. The match of acoustic impedance and Vp/Vs derived from the inversion and the well log is generally very good with respect to both reflector placement and absolute values (Fig. 11).

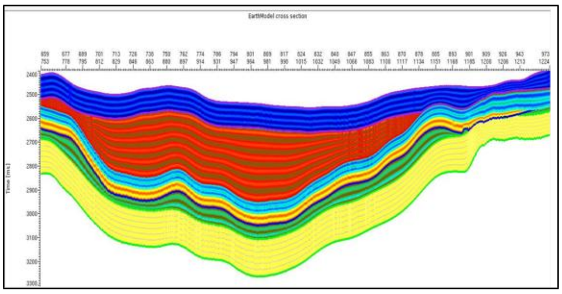

Fig. 10: Section showing the low frequency model input to the inversion

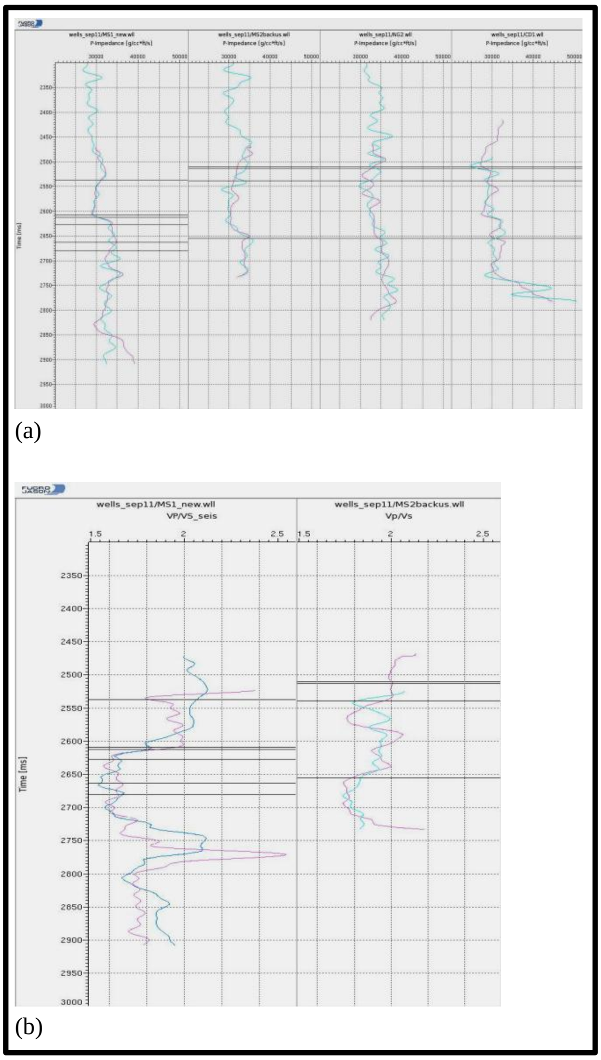

Fig. 11: Comparison of inversion results and initial model data at well locations. (a) & (b) show P-Impedance and Vp/Vs ratio respectively. Blue - inverted trace, red – filtered log curve (starting solution).

The P-impedance obtained from inversion correlates well with that derived from well log with a correlation coefficient = 0.9 (Fig12).

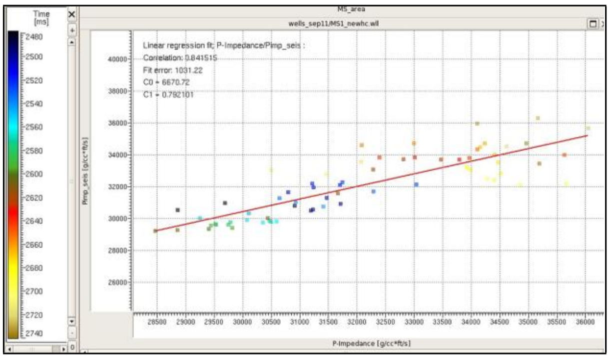

Fig. 12: Correlation of P-impedance derived from well log (X axis) & seismic (Y-axis)

In Fig. 13 the P- impedance Vp/Vs obtained from inversion are shown in (a) and (b) with the log derived values superimposed. The good match between inversion and log derived results further validate the results of this study.

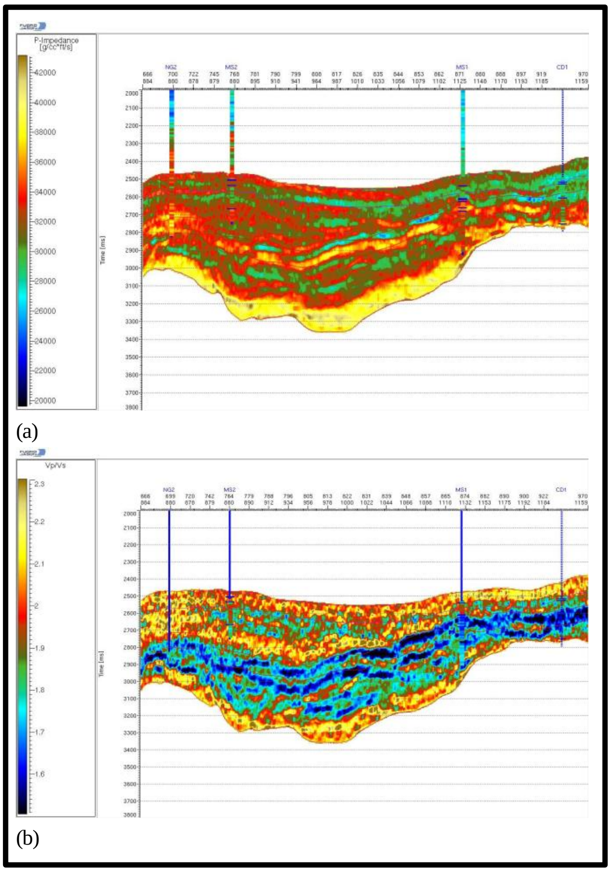

Fig. 13: P-impedance from inversion is shown in (a) and Vp/Vs is shown in (b) with the well derived values superimposed. Very good match is observed between log derived and inversion results

7. Analysis of the Results

The Zone of interest lying within the Early Cretaceous sequence which comprises mainly 3 litho facies viz., sandstone, silty sandstone and shale. The dominant facies in the entire Early Cretaceous sequence is sandstone. The sandstones and silty sandstones are characterized by high gamma counts and high impedance values. The shales are characterized by high Vp/Vs and low impedance values in comparison to sand bodies. The Geobodies extracted show the reservoir sands (high P impedance and low Vp/Vs) encased in the shale and silty sand sequences (Fig.14).

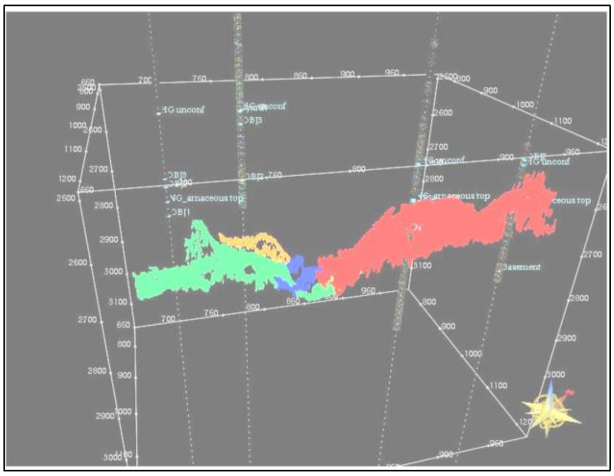

Fig. 14: Geobodies extracted from inversion results

The extracted Geobodies, which are potential reservoirs, identified from attribute study of the inversion volumes, appear to be associated with channel system.

It is observed that considerable details can be derived from the inversion results which can be used to fine tune or correct the existing interpretation or understanding of the geology and better delineation of reservoir sands.

8. Conclusions

The log correlation and relevant studies indicate that the reservoir encountered in the wells are isolated in nature and may be time equivalent as substantiated by difference in fluid types and pressure regimes of the reservoirs.

The cross plots between P-impedance and Vp/Vs derived for the target zone encompassing the pay sand indicate a reasonable separation between reservoir and non-reservoir facies.

The inversion results suggest that the hydrocarbon bearing sands of C and A are falling within the litho facies characterized by high P- impedance and low Vp/Vs. The morphology of the sand, extracted as a Geobodies using the multi-attribute cross plot of P-Impedance, Vp/Vs and windowed attributes of the same indicate sand deposited as channel/braided channel. (Fig. 15a, b & 16a, b).

The attributes derived from seismic does not show clear pattern of sand geometry (Fig. 15 &16).

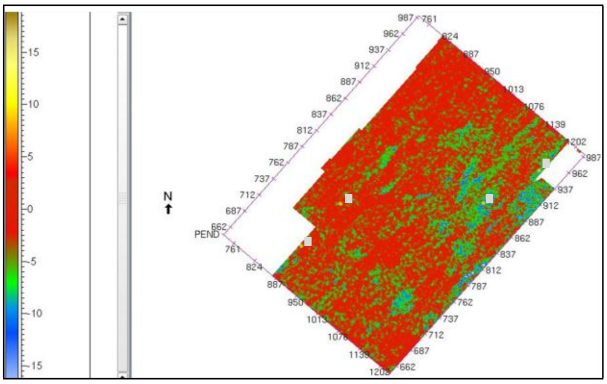

Fig.15: Windowed attribute derived from seismic data corresponding to Obj-I & II

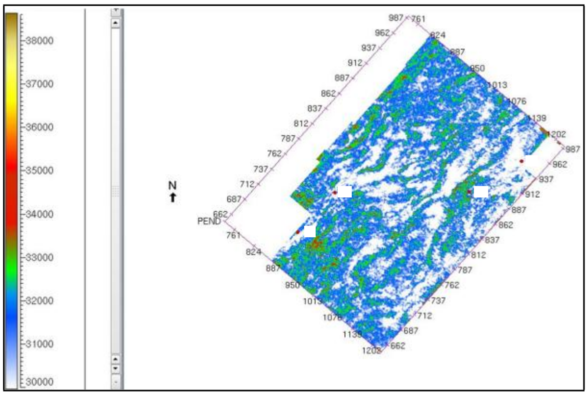

Fig.15a: P-impedance attribute map indicative of Obj I & II

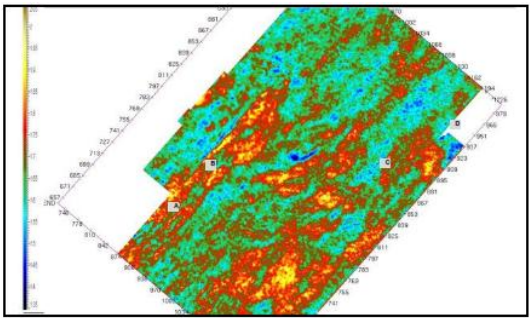

Fig.15b: Vp/Vs attribute map indicative of Obj I & II

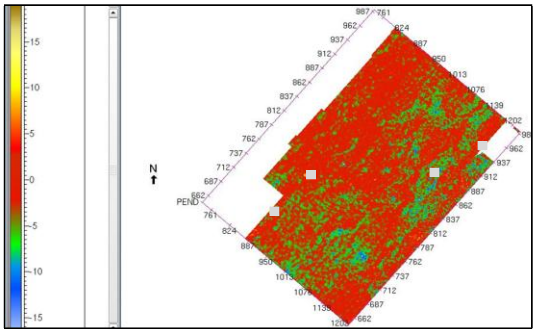

Fig. 16: Windowed attributed derived from seismic data corresponding to Obj-III- & IV

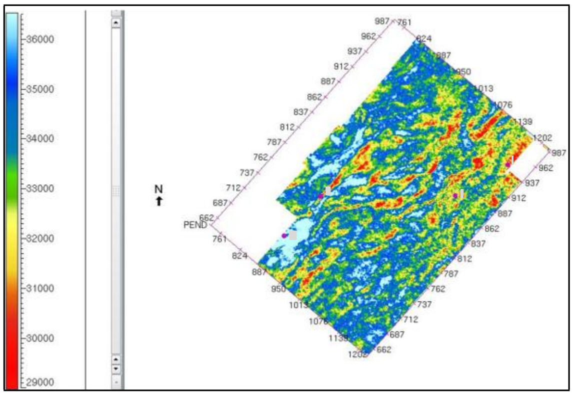

Fig.16a: P-impedance attribute map indicative of Obj III & IV

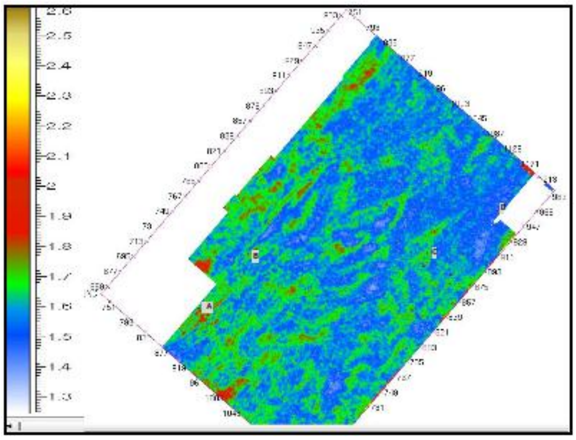

Fig. 16b: Vp/Vs attribute map indicative of Obj III & IV

Acknowledgements

We express sincere thanks to Shri. V. Rangachari, Executive Director-Basin Manager, KG Basin, for having inspired us to take up this project and also granting permission to publish this material. We are indebted to Shri. G. Karuppuswamy, GGM-Basin Co-coordinator for his encouragement to complete the project. Thanks are to Shri Y. E. R. Sastry, GM Block Manager, for his constant guidance during the course of this work and Shri. Kamaraju, DGM & his team members for all the necessary helps rendered while taking up the project.

References

Rao, G. N., 2001, AAPG Bulletin, v. 85, no. 9 Sedimentation, stratigraphy,and petroleum potential of KrishnaGodavari basin, East Coast of India

Paradigm 2010, Interpretation Report on Block KG PEL1A, Within K-G Basin,

Pendrel, J 2006 Seismic Inversion – Still the Best Tool for CSEG Recorder 5 p7-12