Enhanced Understanding of Turbidities Gas Reservoir using Stochastic Seismic Inversion - A Case Study from Indian Offshore Basin.

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Summary
For better development of green fields having limited well information, stochastic inversion of 3D seismic data can be used as a tool to predict inter well reservoir properties. 3D Seismic data contains very useful information about reservoir properties laterally but lack vertical resolution while well logs provide very detailed information vertically but lack in spatial information. One method of integrating these two data sets is through stochastic seismic inversion. Stochastic inversion method integrates a broader range of data to produce multiple, equiprobable realizations of reservoir models at reservoir rock scale capturing reservoir heterogeneity. An AVA (Amplitude Variation with Angle) Stochastic seismic inversion workflow was successfully implemented to produce high-resolution detailed reservoir model for a Pliocene gas reservoir from Indian offshore basin.

This Pliocene gas reservoir is believed to be deposited as a turbidities channel-levee complex where the reservoir sand occurs as discrete sand bodies having limited areal extension. On a positive side as a shallow gas reservoir they exhibit class-III AVO (Amplitude Variation with Offset) anomaly, hence produce a clear separation on Zp (p-impedance) vs. Vp/Vs ratio cross-plot for reservoir and non-reservoir facies. Both deterministic pre-stack (it acts as a QC step for stochastic inversion) and stochastic inversion were carried out using 3D seismic data, well log data and available geological information for better characterization and modeling such complex reservoir.

Introduction
The Krishna-Godavari basin (KG basin) along the east coast of India covers the deltaic, inter-deltaic areas of Krishna and Godavari rivers and extends more than 200km into the deep sea. The offshore part of the basin represents a well-defined shelf to shelf-edge delta to deepwater depositional settings and has significant hydrocarbon potential both in the Tertiary delta as well as in the channel-levee-overbank play types in deepwater. The study area pertains to ONGC offshore block that has a multiple gas and oil reservoir. Location map of the study area is given in Fig-1.

Fig-1: Location Map of the Study Area.

The detailed 3D Seismic data interpretation and stochastic inversion study was taken up to characterize and model these Pliocene gas sand reservoirs. The lateral and vertical disposition of these sands is given in Fig-2. The reservoir characterization study for deeper oil and gas sands are done and reported previously (Mekap et al. 2017). In this article, an attempt has been made to characterize and model the youngest Pliocene gas reservoir (C-sand) through stochastic seismic inversion.

Methodology

Brief History and Sand description of the field

Exploration activity in the KG-Offshore basin is primarily based on seismic amplitude anomaly study.
In late 2000, Well C-1 drilled to test the amplitude anomaly shallower to both A and B sands, close to the Eastern boundary of the block has indicated gas on mini DST (Drill Stem Test). Later stage this well was tested conventionally and produced commercial quantity of gas. RMS (Root mean Square) amplitude map for this sand is given in Fig-3. Wells C-2 and C-3 drilled further to delineate the reservoir extension are proven to be gas bearing, but the well log and well test data indicated presence of separate pools. Hence, a detailed 3D seismic data interpretation and inversion study was taken up for better characterization of this reservoir. Well log correlation profile passing through Well C-1, C-2, and C-3 is shown in Fig-4.

Data Conditioning and Feasibility Study

As data quality have great impact on the output of the inversion, both the seismic and well log data (p-sonic, s-sonic and density logs) were thoroughly analyzed and conditioned. A comparison between the raw and conditioned p-sonic and s-sonic logs cross-plot is shown in Fig-5. After log conditioning a cross-plot between Zp and VpVs ratio at all three well location is generated and is shown in Fig-6. It is evident from the cross-plot that the gas bearing facies show a clear separation from the background non-reservoir facies trend. Zp and VpVs ratio values for gas bearing facies are in the ranges of 3000-4500 and 1.8-2.4 respectively.

Prior to seismic data conditioning synthetic gathers at the well position were generated and compared with the raw seismic gather. It is observed that raw seismic gathers do not contain noticeable multiple events and the AVO gradient analysis shows that up to 36° of incident angle the amplitudes of synthetic and raw gathers are consistent (Fig-7). Seismic data conditioning is done for random noise reduction and the process includes mute application, super gather...
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generation and trim static application. A comparison between the raw and conditioned seismic gathers at well location C-2 is shown in Fig-8. Thereafter the conditioned offset gathers were converted to angle gathers using RMS seismic velocity cube and 3 partial angle stacks (6-16, 16-26 and 26-36) were generated.

inversion requires low frequency initial model. In this case it is built taking 3 interpreted seismic horizons and filtered (upto 8Hz) elastic logs co-krigged with RMS seismic velocity. Thus the initial model, the angle stacks and their respective wavelets are used for deterministic simultaneous inversion to generate Zp, Vp/Vs and Density volumes. The seismic section, Zp volume and Vp/Vs volume from prestack inversion is shown in Fig-10.

Well to seismic tie is performed for 7 wells and multi-well based wavelet for each partial stack are extracted. Well to seismic tie for well C-2 is shown in Fig-9. The model based deterministic simultaneous
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After AVA stochastic inversion, we performed seismic facies classification based on cross-plots of inverted elastic attributes, calibrated to log data. In this process, Zp and Vp/Vs form dipole sonic logs recorded at well were cross-plotted then a “hydrocarbon sand” cross-plot polygon was defined. Fig-13 shows hydrocarbon sand polygon drawn on Zp and Vp/Vs cross-plot and the cut-off values are taken in accordance with the well log cross plot shown in Fig-6. Each and every point of individual realization of the elastic properties are classified as hydrocarbon sand or non-hydrocarbon sand/shale depending on whether or not it falls inside the hydrocarbon sand polygon.

In this process equal number of seismic facies realizations is also generated. Once generated these facies realizations can be ranked using different criteria, in this case total hydrocarbon sand volume is considered. This enables us to select 3 realizations (out of 100 realizations) as P10, P50 and P90 scenario. Moreover, by counting in a particular cell the no of realizations classified as hydrocarbon sand, a hydrocarbon sand probability volume was also generated. This hydrocarbon sand probability volume represents the measure of uncertainty in seismic lithofacies prediction from stochastic inversion. To get hydrocarbon sand probability volume and most probable facies volume a probability distribution function approach (PDF) is used. Outputs of the stochastic inversion are shown in Fig-14 along with the seismic section.

The P50 realization of Zp and Vp/Vs ratio and hydrocarbon probability volume from above classification along with the seismic data were further converted into a porosity volume by multi-attribute regression analysis (EMERGE). This non-linear transform approach establishes the link between seismically derived elastic property and porosity through an optimized training correlation and error method approach at each well location. As the seismically derived elastic properties have a direct relation with the total porosity of the reservoir rock,
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The multi-attribute analysis was applied to Neutron porosity ($\phi_{\text{total\,MA}}$) and total clay volume ($V_{\text{CL\,MA}}$) separately. Fig-15 shows multi-attribute regression analysis process for prediction of VCL volume taking 5 wells as training set.

$$\phi_{\text{eff\,MA}} = (1 - V_{\text{CL\,MA}}) \times \phi_{\text{total\,MA}}$$

Then using transformation $\phi_{\text{eff\,MA}}$ the effective porosity volume was derived. The predicted petro-physical properties using multi-attribute regression analysis are shown in Fig-16. The hydrocarbon sand probability volume and effective porosity volume are finally depth converted using a robust velocity model. Subsequently the depth converted volumes are used in static reservoir model building. The whole process of seismic inversion and porosity prediction is further validated by blind well analysis at well C-4, which is drilled after the study is completed (Fig-17).

Discussion

For better characterization of a reservoir, it is important to know about the depositional process through which sand bodies were deposited. Prior to present study understanding was that the whole C-1 sand body is a single entity. In the present study it clearly emerges that these are two genetically and hydro-dynamically separate sand bodies. Well C1 is situated in a separate channel levee system whereas C-2 and C-3 are situated in slope failure turbidities deposit. The RMS Amplitude map shown in Fig-3 and RGB blended iso-frequency horizon slice shown in Fig-18 clearly indicate presence of different feeder channel and slump like turbidities deposit.
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In this pilot study, seismic interpretation and stochastic seismic inversion study provided vital insight about depositional process and petro-physical properties (clay volume and effective porosity) of C-1 gas sand reservoir.

The multiple solutions those are consistent with both the well data, seismic data and the prior geological information can be used for uncertainty quantification process in reservoir modeling process.

Conclusions

Seismic attributes analysis aided in bringing out representative extent of the sand body, which helped in better characterization of the reservoir.

Stochastic seismic inversion provides a tangible value addition by enhancing the resolution of the P-impedance, S-impedance and Vp/Vs ratio attribute. The petro-physical properties derived from these high resolution elastic attributes are very useful in updating the existing reservoir model and formulating a better exploitation strategy, thereby minimizing the economic risk associated with the deep offshore development activity.

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