Development Wells Optimization using Seismic Guided Reservoir Characterization and Flow Based Connectivity Simulation- A Case Study from Saurashtra Shallow Water Block, Western Offshore Basin, India

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Clastic Reservoir, P-Impedance, Vp/Vs, Sand Dispersal, Geo-Cellular Model, Streamline Simulation

Summary

Delineation of the reservoir sands in multi stacked sand shale intercalation zone is extremely challenging owing to discrete nature, sub-seismic resolution at places and abrupt lithological variation both spatially and temporally. This multiplies in manifold uncertainties associated with the modelling of subsurface architecture. Thus standalone seismic driven approach may not be apt to characterize the reservoirs as it would lead to very conservative estimation of facies distribution since at places sands being thin would remain undetected by this approach. Therefore to tackle such thin pay sands a hybrid workflow has been formulated by integrating stochastic and deterministic approach. Seismic based deterministic characterization followed by updation of the model employing well based stochastic algorithm, effectively captures the sand dispersal pattern in this kind of reservoir. To ascertain the connectivity between the wells and optimization of development well spacing streamline simulation was carried out which clearly depicted the necessity of repositioning the wells and also the unswept areas. This paper brings out methodology to effectively delineate characterize the thin sand shale intercalated reservoirs and way to finalize the development scheme in areas of high uncertainty.

Introduction

Present Study area is situated in the Saurashtra shallow water Block in the west of, C-37 field of ONGC Ltd. In the northern side the boundary is approximately parallel to the Saurashtra coast from Diu to Jafraham town of Gujarat, India (Fig.1). Average water depth in this area ranges from 17 to 37m.

The study area is within the continental shelf, situated on the rising flank of the Saurashtra Homocline. In northwest and west, Diu Arch is present as a NNW-SSE trending SSE plunging basement high. The Diu depression is to the south and Daman Low to the southeast. The region has undergone Rifting followed by passive continental margin tectonic history with the structural style being dominantly controlled by basement faults. However, inversion tectonics has also played a major role in modifying the existing structural style. The basement architecture of this area has been evolved by the process of Rift-Drift of the Indian Plate. Extensional stresses that were active during the rift phase created number of Horst-Grabden features associated with normal faults in the Dharwarian trend i.e., NNW-SSE. A major strike slip fault trending ENE-WSW divides the area into two parts with homoclinal dips towards the north of this fault and inversion structures towards the south of this fault.
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Sedimentation initiated in this area started with deposition of Paleocene to Early Eocene Panna Formation above the Deccan Traps of Upper Cretaceous age. Belapur and Diu Formations were unconformably overlain by Panna Formation in the entire area above which Lower Oligocene Mahuva Formation was deposited after a hiatus. Daman Formation of Late Oligocene age is unconformably deposited above Mahuva, which is clastic sequence and are hydrocarbon bearing. Daman Formation is overlain by Mahim, Tapti and Chinchini formations which are dominantly shaly facies. The generalized stratigraphy is shown in the Fig.3.

Accumulation of Dry Gas in commercial quantity was established in Daman Formation of Late Oligocene age in this area. Daman Formation is comprised of multi-stacked sands bodies with thin shale interbeds and occasional limestone deposition in tide influenced deltaic environment. In this area Daman Formation represents the transition environment between pure clastic of Saurashtra Peninsula and Cambay Basin towards North and North East direction and carbonates of Mumbai Offshore Basin towards South and South West direction. So far 8 exploratory wells have been drilled in this area out of which 3 wells are gas bearing. Based on the results of the exploratory wells 2 well head platform with 10 development wells was planned to exploit these reservoirs.

The primary gas bearing sands in study area are DPS-2 and DPS-1 with some marginal gas accumulation in Sand-60, Sand-50 and Sand-25 (ONGC Unpublished Report, 2018).

Primary challenge in this area is the delineation of the reservoir sands within multi stacked sand shale intercalation zone. These thin discrete sands are unresponsive to certain seismic attributes, sub-seismic resolution at places and show abrupt lithological variation both spatially and temporally. This imposes uncertainties associated with the modelling of subsurface architecture. Thus standalone seismic driven approach may not be effective to characterize the reservoirs.

This paper deals with effective delimitation of the thin pay sands for risk reduction and for optimizing the development well placing through Geo-Cellular Modelling and Streamline simulation of clastic reservoirs.

Methodology adopted

Standalone seismic driven approach may not be apt to characterize the reservoirs as it would lead to very conservative estimation of facies distribution since at places sands being thin would remain undetected by this approach. Therefore to demarcate the limit of
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extensions of thin pay sands a hybrid workflow integrating stochastic and deterministic approach has been formulated. In this workflow facies modeling was carried out first by seismic based deterministic approach modeling followed by updation of the model employing well based stochastic algorithm to effectively capture the sand dispersal pattern. To capture the uncertainty several realizations were made and different scenarios pertaining to P50, P90 were selected. Porosity model was prepared for the P90 case facies model. Saturation model were prepared using porosity saturation relationship observed in the log. As Gas Water Contact was not observed in any of the exploratory wells, so two cases were considered for saturation modeling. Base Case saturation model was prepared by considering the lowest known gas limit observed in the wells and Extreme Case was prepared by considering bottom most limit of facies extension within each zone. These scenarios provided the estimate of maximum and minimum Initial Gas In Place (GIIP) volumes that may be considered for the development scheme preparation. Next step was to finalize the development wells position. To ascertain the connectivity and optimization of development well spacing streamline simulation was carried out. It clearly depicted the necessity of repositioning the wells to target the unswept areas.

Geo-Cellular Modelling

Facies Model: Facies modeling was carried out by using bipartite approach. At the onset the relationship between facies and different seismic attribute e.g. P-Impedance, Vp/Vs was attempted for each pay sand. Posterior Probabilities of sand with P-Impedance and Vp/Vs was chalked out (Fig.4a and Fig.4b) Sand facies based on the P-Impedance and Vp/Vs input was modelled deterministically in the first stage. Connected volumes property was generated and used to filter out single cells and minor connected volumes (less than 10000K m3 bulk volume) that were not attached to the main channel bodies. This was done to clean the sand-shale probabilities, highlight the main sand bodies and remove noise. Subsequently a smoothing process and normalization was applied, keeping the probability of 1 in the central parts of the filtered sand bodies (thickest parts) and gradually decreasing outwards (Fig.5). This seismic driven sand model has limitation vis-à-vis conservative estimation of sand as in many places owing to sub seismic resolution, pay sands were not captured. This limitation was overcome by updating the model using well based stochastic algorithm. 100 realizations were made using the input probability and P50& P90 cases were prepared. Sand thickness map of P50 and P90 is placed at Fig.6a and Fig.6b.
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It is evident from the sand thickness maps that there is not much difference in both the maps therefore P90 case was selected for next phase of modeling.

Fig.6a: Sand thickness map of P50 case.

Fig.6b: Sand thickness map of P90 case.

Porosity Model: Porosity model was conditioned to seismic data using collocated co-krigging since P-Impedance shows linear and inverse relationship with effective porosity (PHIE). Gaussian Random Function Simulation (GRFS) using collocated co-krigging was performed taking P-Impedance as the secondary variable (Ghosh et al. 2018). 100 realizations were made and arithmetic mean of all the realizations was taken as the representative effective porosity model. Average effective porosity map of DPS-2 pertaining to P90 facies model is placed at Fig.7

Fig.7: Average effective porosity map pertaining to P90 case of facies model.

Saturation Model: As Gas Water Contact (GWC) was not observed in any of the exploratory wells, so two cases were considered for saturation modeling. Base Case saturation model was prepared by considering the lowest known gas limit observed in the wells and Extreme Case was prepared by considering bottom most limit of facies extension within each zone. Segment wise Height above contact volume was prepared by taking log based and segment wise extreme fluid contacts for each zone (Ghosh et al. 2019). Saturation modeling was done through krigging algorithm conforming to local grid using porosity saturation relationship observed in the log (Fig.8).

Fig.8: Porosity vs Saturation relationship observed in the logs.

Streamline Simulation

Basic of Streamline Simulation is that it measures the connectivity estimated from fast tracer type flow simulations. Time taken to reach tracer from connected pore volume to wells qualify the connectivity, e.g. high time implies poor connectivity. Streamline models provide us with a
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tool rapid screening of 3D reservoir models with insight of unswept areas and need of well placement optimization. Interaction of flow with reservoir heterogeneity can be visualized easily using streamline models. Streamlines are intuitively appealing and provide a natural means for dynamic reservoir characterization (Dutta-Gupta and King, 2007).

To initialize the streamline simulation model permeability needs to be modeled first. Permeability was modeled using poro-perm transformation employing general formula of

\[ k = a\phi^b \]

Value of constant and exponents of different sands is placed Table-1

<table>
<thead>
<tr>
<th>Sand</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPS-2</td>
<td>4000000</td>
<td>6.2964</td>
</tr>
<tr>
<td>DPS-1</td>
<td>8000000</td>
<td>6.7187</td>
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<tr>
<td>Sand-25</td>
<td>292054</td>
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<td>Sand-50</td>
<td>1060340</td>
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</tr>
<tr>
<td>Sand-60</td>
<td>1862385</td>
<td>5.0887</td>
</tr>
</tbody>
</table>

Table 1: Exponent and constants used for permeability modelling

Permeability in horizontal direction was kept equal i.e., \( k_x = k_y \) and vertical permeability was kept 10% of horizontal permeability, i.e. \( k_z = k_x / 10 \).

The model was initialized and streamline profiles were generated for base case and extreme case (Fig.9 and Fig.10).

Results and Discussion

It was clearly brought out that streamlines clearly depict the unswept zones for both the cases at the southern part of the field. Base case depicts there is large portion of undrained region but situation improves in the extreme case. In the Base case northern most development well was not participating at all but this well was participating in the other case. Also there was a huge area in the north and some patches in the south that need additional wells for optimal exploitation of the reserves. This clearly depicts that the uncertainty at the northern part of the structure is very high and the northern most location may be repositioned at the southern part where streamline distribution shows undrained portion.

Conclusions

- Hydrid workflow integrating seismic and well input is the most suitable methodology to model thin pay sands of discrete appearance and sub seismic resolution.
- To understand the uncertainty it is always advisable to prepare multiple geological model and prepare different probability cases.
- In the same line dynamic simulation should also be carried out on multiple models.
- Streamline simulation is very effective way to understand the well connectivity and determine unswept areas.
- It helps in optimizing the development well placement and caters the need of additional well, if any, requirement in a very effective way.
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