Integrated Study for Reservoir Characterization of D-18 Block of DCS Area of Mumbai Offshore Basin, India

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Key words Data enhancement, log normalisation, acoustic impedance, seismic facies, correlation map

Abstract

3-D seismic attribute analysis and seismic inversion in integration with petrophysical properties has been qualitatively and quantitatively used in reservoir characterization of D18 area by integrating the drilled wells. This article describes the science and art of seismic inversion and, how oil and gas industries are using it to reduce the risk in oil and gas exploration, development and production operations. The case study of D-18 block situated in Mumbai Offshore Basin (water depth 90m) has been taken to fine tune reservoir image and its characteristics. First well was drilled at crestal part of structure during year 1985 and produced oil and gas at depth range 2800-3000m within Mukta formation. Subsequently other wells were also drilled and reservoir boundary of field is defined.

Significant upside potential, pertaining to shallower Panvel formation and deeper Bassein formation were interpreted as oil and gas bearing based upon review of log and structural configurations in addition to study of main reservoir of Mukta formation with data enhancement, structural interpretation, seismic inversion and facies analysis.

1. Introduction

Most of the big offshore basins world over, such as the North Sea, the Gulf of Mexico and Mumbai Offshore Basin in India is entering into their mature age and now we have to concentrate on marginal fields which are on the border line between of commercial and non-commercial depending on availably of reliable data base, logistics and infrastructure/facilities surrounding it. Thus the understanding of a field as marginal varies from province to province and is broadly based upon cost of development and the fiscal framework. The marginal fields are unevenly distributed throughout the Mumbai offshore basin, some are surrounding the main producing fields but majorities are isolated in nature. The distances of marginal fields from the existing platforms range from a minimum of 5 km to a maximum of 40 km. Among Offshore fields in Mumbai High offshore Basin, Block D-18 (Figure 1) was considered as top priority and

![Location map with geological cross section passing through well showing fluid distribution](image)

Figure 1: Location map with geological cross section passing through well showing fluid distribution

most sought by Oil and Gas Company during bid for disinvestment of small and marginal fields of India. The 3-D seismic data and all available logs were taken for the study with application of data enhancement; structural mapping and petrophysical analysis integrated with seismic.

2. Method and Process

(i) Data enhancement

Despite great improvements in acquisition and processing techniques in recent years, seismic data still suffer from its limited resolution problem. In present case, seismic inversion was carried out
over PSTM seismic data enhanced for higher resolution from 35 Hz to 75 Hz, using ‘Statistical Deconvolution using zero phase’ and Spectral blueing with objective to visualise the reservoir layers in better way. Phase shift of -90 degree was applied to stack data to make an interpretation ready volume similar to “run sum” or relative inversion in which layer boundaries are on zero crossing. In present case, in house data enhancement (Fig. 2) was carried out to achieve these criteria as fast track data enhancement with application of inbuilt software. Post stack data was considered as most suitable for study as it is considered noise free due to averaging of gather data.

(ii) Log editing and processing

Attempt was made to reprocess and normalise the log data (Fig. 3) to minimize uncertainty before using the data for synthetic seismogram (Fig. 4) as log are severally affected by borehole condition in few case. The spikes and noise were removed during process of trimming off the spikes.

Figure 4: Synthetic seismogram, acoustic impedance log, derived HCM and facies log, seismic and acoustic impedance section passing to well W1

direct correlation with reservoir quality and minimize the uncertainty of production behaviour, Reservoir Quality Index (RQI) and Hydrocarbon Mobility (HCM) were computed based on resistivity logs. There is no doubt about the presence of hydrocarbon in Marginal field D-18.

(iii) Structural mapping and Seismic inversion

Figure 5: Depth map along Surface of Middle of Mukta formation showing areal extents for low, average and high case based on fluid contacts.
After well to seismic correlation and refinement of data, seismic horizons along Upper, Middle, Lower Mukta, Bassein and Panvel formation were tracked and maps were generated for assessment of prospects and correlation with seismic inversion. One of map for Mukta middle is shown in Figure 5. Polygons for low, mid and high case are drawn with different colours for volumetric computation.

The steps needed to perform model based inversion of seismic data are briefly known as: log preparation, wavelet estimation, seismic to well ties, horizon tracking, initial model building, inversion and its QC. For computation of absolute acoustic impedance, low frequency information was taken from sonic log of drilled wells. Interpretation of the seismic amplitude volume for the Mukta, Bassein and Panvel formations is relatively straightforward because events are marked by strong acoustic impedance contrast.

The computed values of Reservoir Quality Index $RQI = \sqrt[3]{\frac{\sqrt{\text{Reservoir Volume}}}{\text{Non-Reservoir Volume}}}$ and Hydrocarbon Mobility $HCM = \frac{Fw}{Fmd}$ in the form of log were superimposed on acoustic impedance to integrate the results directly with seismic and extend the reservoir quality and its mobility areally beyond wells. Shallow resistivity factors ($F_s = \frac{\text{LLS}}{R_{mf}}$) and deep resistivity factors ($F_d = \frac{\text{LLD}}{R_w}$) were computed from shallow and deep resistivity logs where $R_{mf}$ and $R_w$ are mud filtrate and formation water, $k$ is permeability and $\bar{\rho}$ is effective porosity. In the present case HCM range ($0.25 < HCM < 0.75$) is valid for reservoir and 1.0 for water.

Due to non-availability of gather data, pre-stack seismic inversion and AVO analysis could not be done and discussed here.

Figure 6: Acoustic impedance section extracted from volume along well W1 superimposed with logs showing reservoir facies with low acoustic impedance within carbonates.

Although, there is acoustic impedance contrast at reservoir levels, it does not appear itself as reliable and spatially consistent amplitude events in normal seismic. But acoustic impedance volume is able to show the boundaries. Acoustic impedance section (Figure 6) passing through well W1 and acoustic impedance map of middle Mukta is shown in (Figure 7) with colour bar on left side showing low (reservoir facies) and high acoustic impedance values (non-reservoir facies). The computed values of Reservoir Quality Index $RQI = \sqrt[3]{\frac{\sqrt{\text{Reservoir Volume}}}{\text{Non-Reservoir Volume}}}$ and Hydrocarbon Mobility $HCM = \frac{Fw}{Fmd}$ in the structure.

(iv) Seismic attributes

Structural attribute as variance cube analysis (Fig.8) was also attempted as faults and fluid movement is part of reservoir characterization and play important role in trapping and accumulation of hydrocarbons. It is based on analysis of similarity and non-similarity of adjacent traces in seismic cube. Amplitude variations will be larger in case of faults disturbed zones and geobodies whereas it will be very small in case of undisturbed zone. Fault boundary from 3 direction of structure is clearly identified in time slice extracted from variance cube near reservoir at around 2500ms. Zone of similarity is marked with dark blue polygon and fault boundary with black color which indicates that reservoir zone is not much affected by compartmentalization due to faults.
Figure 8: Time slice within reservoir of Mukta formation extracted from variance cube showing fault boundary for the structure

(v) Seismic facies analysis

Further, seismic facies maps were generated to integrate reservoir facies using unsupervised (indirect) and well based supervised (direct) classification using pattern recognition of wavelet patterns.

Figure 9: Seismic facies map showing the heterogeneity within reservoir facies. Outer area from fault boundary shows different facies

Five traces were taken around the well and averaged out to remove noise and generate super trace for the supervised facies classification. The clustering of seismic traces is done on the basis of these super traces. Classification based on pattern recognition is then performed and traces were grouped in separate classes as per their similarity. Each class is assigned with a different color code. Eight wells were selected varying in facies from the study area and 8 classes of super traces were initiated for classification of seismic facies map with optimum window from reservoir top.

In general, reservoir facies with class 3, 4, 5, 6 and 7 and non-reservoir facies with cluster 1, 2 and 8 could be identified. Even the reservoir facies indicates the heterogeneity by subdivision of 5 classes due to variations of mudstones, packstones and grainstones in carbonate rock. In the study area, depositional environment are almost same with minor fluctuations of water depth required for carbonate deposition. Thus, the study in the present setup is not much fruitful for prediction of environment as it could have been for clastic reservoir.

Three maps generated for upper, middle and lower Mukta indicates the facies variation occurs laterally and vertically from upper layer to lower layer and predict the prospectivity of layers. It became a valuable tool in developing the prospect in combination with seismic inversion and integration with well data. Facies map of Middle Mukta is shown in Figure 9 indicating the heterogeneity of reservoir from one well to other. Facies beyond main field is different from reservoir facies.

3. Data Analysis

Figure 10: Cross plot of acoustic impedance and porosity showing relationship

Top of Pays could be accurately correlated and refined using impedance data. Petro physical study was carried out by cross plotting different reservoir parameters with log based acoustic impedance with special emphasis to porosity (Figure 10). Porosity volume was computed from
acoustic impedance using simple inverse relationship of porosity with acoustic impedance (single attribute), multi-attribute analysis using algorithm EMERGE and finally with Geostatistical inversion to honour at well in the area. Porosity maps were generated for reservoirs layers within Mukta formation (Figure 11). Development of porosity is mainly due to dissolution of carbonate rock and more or less it coincides with structural high. Probability map (Figure 12) were prepared for porosity map to analyse the validity of maps which indicate a very good chance (above 60% ) to occur the predicted porosity away from wells. Acoustic impedance volume was finally used for the prediction of other petro physical properties. For this purpose, cross plots between impedance

Figure 11: porosity map for zone of middle Mukta based on acoustic impedance volume

Figure 12: Probability map for predicted porosity map of reservoirs

Figure13: Correlation coefficient map at wells showing very good correlation

values at different pay levels with gamma ray , porosity and fluid saturations were studied to establish relationship between seismic and reservoirs. Low Gamma ray with high acoustic impedance and low porosity indicates tight limestone facies. While low Gamma ray with low impedance and high porosity indicates porous limestone. But emphasis was given to porosity only as it is main factor for reservoir quality.

The quality control checking and validation of result was carried out by cross plotting the acoustic impedance value derived from logs and seismic derived acoustic impedance at all wells. The correlation map (Fig.13) indicated very good correlation of the order of around 60-70%.

4. Interpretation and results

The study could define the limits of Oligocene pays and also could separate tight carbonate zones and may be a good guide for further hydrocarbon exploration target. Acoustic impedance maps indicate that South-eastern part of study area is more interesting than North-western area. The Bassein formations (Figure 14) also look encouraging in term of porosity and other reservoir facies but it could not be good reservoir due to lack of cap rock above it.

Different clusters in facies maps indicate the loss of original porosity had occurred in flanks of structures due to cementation. The dry holes are also lying in different clusters from oil/ gas wells. Seismic facies map of Bassein formation indicates less heterogeneity in comparison to Mukta formation
The wedge out and pitchouts in the Panna clastics on the flank and especially over the Paleo-high appears to be promising. Structural mapping suggested the pinching out / wedging out of Panna formation towards the rising flank of basement. On the basis of analogy in surrounding area, Panna formation also seems prospective as per seismic inversion and attribute analysis in flank of structure. None of drilled well have tested the Panna formation except few have touched upper part of Panna formation with indication of gas. High resolution seismic inversion results integrated with seismic facies analysis, multi-attributes analysis and geostatistical analysis in addition to new resource estimation and development plan have brought out new picture of block. As per new rules of Government and improved fiscal regime, the marginal field D-18 looks economically viable.

### 5. Conclusions

Structure is broad terrace with anticlinal closure trending NW-SE direction and bounded by faults from three directions. On lap truncation and fault boundary against the carbonate platform provide the lateral barriers for the reservoir extension.

Seismic facies map indicates the heterogeneity within Mukta reservoir. Fault boundary and non-reservoir facies were identified as different clusters. Facies changes from carbonate platform to slope and carbonate ramp.

South-eastern part of area is more interesting than North-western area as per acoustic impedance maps. The Bassein and Panvel formations also look encouraging in term of porosity and other reservoir facies provided sealing cap rock exists over it.

Marginal field D-18 looks economically viable in comparison to of other offshore small and marginal field.

### Acknowledgements

The authors are grateful to Shri Kapil Garg, Managing Director, Oilmax Energy Private Limited for granting the permission to publish this paper in Conference of Society of Petroleum Geophysicists (SPG) 2020. They express their sincere thanks to Management of Oilmax Energy Private Limited for providing the facilities at the work center and other team members for their suggestions.

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