Integrating seismic data to downscale uncertainty for better decision making: A Case Study

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Summary
Delineation of reservoir subsurface structure, reservoir continuity and lateral extent along with inherent uncertainty in reservoir properties are of significant importance to gauge economic viability, determine future exploration opportunities and optimize field development. Integration of seismic and well data along with recent advances in seismic processing, interpretation and geostatistics are capable of providing not only improved reservoir characterization but also better delineation of subsurface structure and reservoir compartmentalization however complications may arise due to the difference in scale of seismic and well data. Also in case of limited well coverage it is difficult to predict the characteristics and heterogeneity of the field. Seismic data alone cannot provide the complete solution hence it is vital to integrate seismic data and its attributes, well data and all other available information to achieve the objective of minimizing uncertainty and obtaining a geologically meaningful and predictive reservoir model. Notwithstanding their inherent limitations, seismic attributes can be used as soft constraints leading to better and fewer equally probable geological models with enhanced confidence and improved prediction of interwell reservoir properties.

This paper describes a case study of a marginal offshore carbonate field in its early stage of development with very scarce data to demonstrate the approach for integrating seismic attribute maps and variogram from the wells to capture lateral and vertical heterogeneities for building a robust 3-D geological model. Recently acquired 3D Broadband seismic data covering the entire area of study was used to generate the structural framework which resulted in significant changes in the structural configuration leading to substantial changes in distribution and estimation of in-place volumes. The next step was to generate a geologically sound facies model essentially because petrophysical properties like porosity, permeability and fluid saturations are largely dependent on the lithological characteristics of the reservoir rock and their spatial distribution. A two-step approach was adopted wherein averaged seismic attribute maps were used to create facies probability maps which in turn were applied as trends to guide the facies population laterally within the model. Additionally the vertical variogram from wells were utilized for capturing the vertical heterogeneity followed by populating the facies model with reservoir properties using appropriate simulation techniques available in PETREL software. The resulting 3-D reservoir model honors both the geostatistically created zone-average seismic attribute maps and the vertical heterogeneity at the well locations and has the potential to be used as a more cost-effective method for optimized field development through the use of seismically constrained reservoir characterization. Few examples presented demonstrate the applicability of integrating seismic data for downscaling uncertainty and making effective decisions on field appraisal.

Introduction
The fields under study together form the Cluster-9 group of fields located in BH-DCS block of Bombay offshore Basin at a distance of about 20 to 40 kms to the south-west of producing Bombay High field in water depth of 80-88m (Figure-1).

Figure 1: Location map of Cluster-9 Fields
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The Upper Cretaceous Deccan Trap basalt forms the basement in the area. The sedimentary sequence of about 3 km thickness comprises of two distinct cycles of sedimentation represented by Carbonates and Clastics deposition. In the area of study Hydrocarbon accumulations in Bombay High-DCS block are found mainly in Panna, Bassein, Mukta, Panvel, Bombay and Ratnagiri formations in wedge out prospects (Figure-2).

About 36 exploratory wells have been drilled in this cluster spread over a number of independent structures (Figure-3).

These fields are offshore carbonate fields in the early stage of development and pose many challenges in deciphering the structural configuration and reservoir heterogeneities mainly due to inadequate well coverage. Also being carbonate fields with heterogeneous nature, subtle facies changes and low impedance contrast it becomes more challenging to characterize as compared to the siliciclastic reservoirs. Seismic data together with well data can help in understanding the structural composition and heterogeneities, which are critical for construction of a reliable geological model. Seismic data can be utilized qualitatively not only for prediction of the structural configuration of the field but can also validate the spatial distribution of reservoir facies in the static model. While quantitative interpretation can be used for estimating physical properties such as porosity or permeability.

3D broadband seismic data having enhanced resolution as compared to the earlier seismic data was acquired over the entire area of interest which provided improved understanding of the structural disposition along with better control on distribution of properties in the inter-well region (Figure-4).

A two-step approach was successfully applied to build a geologically sound and reliable model wherein the seismic attributes were used to guide the population of facies within the model laterally while the vertical heterogeneity was addressed through vertical variogram from wells and subsequently this facies model was used to constrain the distribution of properties. The model obtained was able to estimate the volumes accurately and capture the changes in spatial distribution and direction of continuity of the reservoir properties over the area facilitating assessment of the economic value of the reservoir, prediction of reservoir performance under different boundary conditions and formulation of an optimized development plan.

Geomodelling

Firstly a 3D structural framework in depth was constructed using horizons and faults picked in time and converted to depth using a velocity model derived from seismic velocities and calibrated to the well logs.
The objective of building a model with necessary details to characterize vertical and lateral heterogeneity at the well, multi-well, and field scale, required the model to be finely layered with relatively small XY cell dimensions. Accordingly a 192498120 million cell model was built having 570 layers of 1.5 m average thickness and a grid dimension of 100 x 100 m the small XY-cell dimensions facilitated extraction of portions of the model for local reservoir simulation.

Next, the well logs were upscaled using appropriate averaging methods to assign values to cells in the 3D grid penetrated by the wells. Due to lack of sufficient well data the upscaled facies logs alone could not be used to create the facies model. Hence building a more realistic facies model necessitated the use of densely sampled seismic attribute data for better propagation of facies in the inter-well areas. Seismic impedance volume was generated by inversion of the available 3D seismic data. Since no correlation could be obtained between seismic impedance and petrophysical attributes at known well locations it could not be used directly as an input to modeling. Hence it was decided to incorporate seismic attribute maps as soft constraints to guide the distribution of facies spatially within the facies model while the vertical variability is defined by the well logs and vertical-variogram models.

Accordingly average seismic impedance maps were extracted from the seismic-impedance volume over required depth intervals (Fig. 5).

These averaged seismic impedance maps were converted to facies probability maps. These maps show relatively high probability at the well locations where good reservoir facies are present and low probability in case of absence of reservoir facies and honor the areal distribution of the facies (Figure 6).

However in order to capture the vertical variation in facies these maps were integrated with well log data and Vertical variogram models (Figure 7) using stochastic facies modeling technique known as sequential indicator simulation (SIS) available in PETREL software.
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Some variations may have been introduced as a result of difference in scale of seismic and well log data. This facies model was then used as a constraint for guiding the properties in the petrophysical modeling workflow available in PETREL software. Seismic constrained model provides a more detailed and accurate distribution of reservoir properties as compared to the well-based model (Figure 8).

Figure 8 Distribution of reservoir properties of well-based model compared with Seismic constrained model

Subsequently the resulting multiple equiprobable models of reservoir properties were subjected to reservoir simulation studies without upscaling in either vertical or horizontal direction.

**Reservoir Simulation**

Available SCAL and PVT data was used to initialize the model. While the well test data was utilized for generating the permeability transform which was further scaled up to match the production behavior. The reservoir simulation studies produced a good history match with the use of minimum modifiers validating the distribution of properties within the model and generated ample confidence in planning future development strategy for optimized production. Subsequently, development scheme was formulated by targeting the good hydrocarbon saturation locales left at the end of history match in the model and well inputs from the existing platforms were identified for targeting Panvel, Mukta and Basal Clastic reservoir with additional facilities.

**Examples**

Structural uncertainties may be introduced in the structural geological model due to input data quality or insufficient geological or geophysical information. These structural uncertainties may have a direct impact on exploration, development, and production, and in well placement decisions. Presented here is the case of structure B-10 where the acquisition of 3D seismic broadband data resulted in addressing the structural uncertainty and helped in planning well locations for developing the structure (Figure 9).

Figure 9: Structure contour maps of B-10 structure showing variation in structural configuration.

As per the earlier seismic data the geological model prepared showed the B-10 structure to be extending in the N-S direction and covering almost the entire fault block but when the new 3D seismic broadband data was used the structure was restricted to a very small area towards NW of well B-10 this also resulted in significant reduction of estimated volumes. The new structural model not only reduced the risk by addressing the structural uncertainty but also helped in preparation of an optimized development plan with better placement of wells.

Another example from B-1 structure demonstrates how integration of seismic data has led to significantly improved accuracy of reservoir model and helped to reduce uncertainties in predictions away from wells. The seismic attribute maps at different pay levels show the distribution of better impedance in the southern and western part of the structure which is also reflected in the facies model as seen from the average facies maps extracted at different pay zones (Figure-10)
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Production performance of the wells B-1-1 and B-1-2 further corroborates the fact that facies in this part of the reservoir is poor. Facies architecture across the B-1 field obtained from the seismically constrained model serves as an excellent guide in firming up the development locations and also for better reservoir management.

In structure B-5 the seismic broadband data was again able to reduce the structural uncertainty and demonstrated the structural configuration which was different as compared to the earlier interpretation thereby giving more realistic estimates of the in-place oil and better control in well placement (Figure-11).

Subsequently an exploratory well B-16 was drilled in this part for exploring the lower pays and encountered very good development of Bassein pay as anticipated by the average impedance map. This pay was tested and produced about 3000 BPD oil authenticating the distribution of properties as envisaged. This further validated the use of seismic constrained static model for predicting well locations for preparing the future development plan.

Conclusions

In early stages of field development, inadequate petrophysical data makes it difficult to reasonably assess the actual reservoir properties. However, assimilation of additional constraints, such as 3D seismic data and geological concepts, can significantly improve the accuracy of reservoir models and help reduce uncertainties in predicting the spatial distribution of petrophysical properties within heterogeneous reservoirs.

An integrated approach for incorporation of 3D seismic information in the geological model of a carbonate, oil reservoir is demonstrated resulting in a model capable of estimating reliably the in place volume, their distribution and predicting the flow dynamics of the reservoirs.

Integration of seismic data not only reduces the uncertainty in spatial distribution of properties but also provides better control on structural configuration minimizing the associated risks.
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Significantly improved reservoir description based on seismically constrained models can considerably improve the quality of the reservoir simulation and enhance its reliability to predict reservoir performance and make optimized development plans.

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