An Integrated Approach from Seismic to Simulation in Offshore Green field: A Case Study

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Summary

Early life cycle of a field with limited well coverage possess inherent challenges in capturing reservoir heterogeneities in multiple geological plays. In such cases, seismic data with full field coverage can be utilized not only for mapping structural disposition but also for validating spatial distribution of reservoir facies in the static model prior to dynamic simulation.

B-192 is one of the marginal oil and gas fields in cluster-7 group of fields located in the Deep Continental Shelf of Bombay offshore basin. Major sedimentary sequence encountered in the field ranges from Paleocene to Recent. The upper Oligocene Panvel formation (L-VI) consisting of mainly limestone intervened with shale bands is underlain by thick limestone dominated Mukta formation of early Oligocene. Early Oligocene Mukta in turn overlies the Panna equivalent Basal Clastics of Paleocene to early Eocene age. Panvel (L-VI), Mukta and Basal Clastics are the main pay zones with very good production potential.

High resolution seismic coverage (3D Broadband seismic data) was available for the cluster and the same was utilized for facies modeling. After building a detailed structural framework model, facies model was built by using vertical proportion curves from well logs as 1D trend models to control the vertical distribution of the facies proportions along with 3D trend models based on seismic attributes (P and S - Impedance) for constraining the spatial distribution of the facies under the range defined by variogram models. Finally, facies model was used to constrain the property distribution in petrophysical modeling algorithm in PETREL E&P platform.

In simulation, fine scale model was initialized with available SCAL and PVT data. Permeability transform was generated based on well test data and scaled up to match the production behavior. A good history match was obtained at well level utilizing minimum modifiers thereby indicating representative saturation and porosity distribution.

The present study exemplifies practical workflow adopted in building a robust geological model for simulation in a carbonate green field emphasizing integration of 3D seismic attributes with well data to build a fine scale static model and fine tuning the geostatistical static property distribution conventionally based on log data. In simulation study, good history match at well level was achieved which gives ample confidence in firming up exploitation strategy for different pays.

Introduction

One of the most challenging task in the upstream hydrocarbon industry is to build a robust reservoir model that can not only give reliable estimates of the in place volumes, their distribution but also to predict the flow dynamics of the hydrocarbon reservoirs. A critical step to achieve these objectives is to create a geologically sound facies model mainly because the lithological characteristics of the reservoir rock and their spatial distribution control to a large extent the petrophysical properties like porosity, permeability and fluid saturations which in turn are paramount to assess the economic value of a reservoir, predict reservoir performance under different boundary conditions and optimize the development plans.

In the present study the field being in its early stage of development posed a major challenge in view of the scanty data (few wells logs, limited testing data and short production history). But acquisition of 3D broadband seismic data (Figure-1) with much better

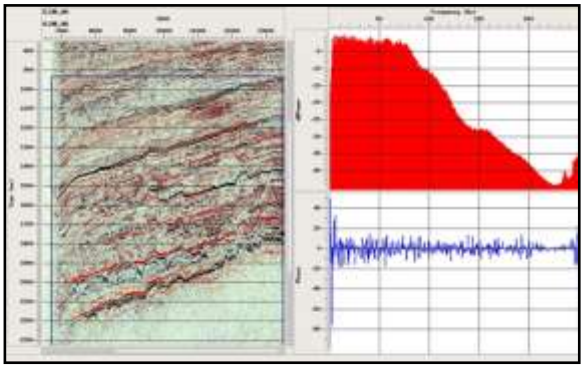

Figure 1: Spectrum of Broad Band Seismic Data (Peak frequency 24 Hz, Bandwidth: 2.5-90 Hz at -12 dB).

resolution as compared to earlier seismic data was a major game changer, as the seismic attributes from the data could now be used to distribute the properties in the inter-well region. The first step was to build a geologically and statistically reliable facies model which could capture the changes in spatial distribution and direction of continuity over the area of interest and then to use this facies model for populating the properties over the entire model area. This was achieved by using the stochastic facies modeling technique known as Sequential Indicator Simulation (SIS) available in Petrel to integrate the well data with seismic attribute based trend models to constrain the facies. This facies model was then used as a constraint for property modeling using Sequential Gaussian Technique (SGS) which is a stochastic technique often used in conditions where sparse data is present.

Integrated Static Geological Model: Workflow

The following workflow (Figure-2) was adopted to successfully integrate data from different sources and of different scales to build a 3D static model which could effectively capture the reservoir heterogeneities and reduce inherent uncertainties related to fluid volumes and flow dynamics.

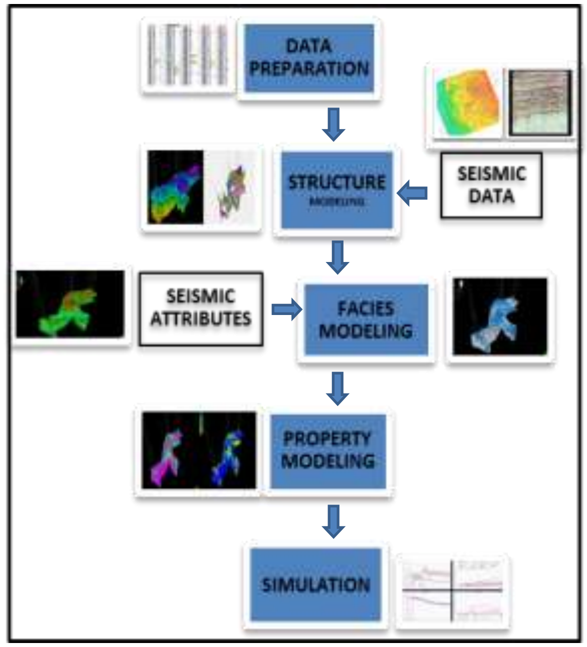

Figure 2: Workflow for building an integrated 3D static model

Seismic Data

3D seismic survey is one of the primary tools for identifying the exploration targets. Seismic data so far has been extensively used to identify the geometry of the reflectors and ascertain their depths. However, seismic inversion can be used for reservoir characterization which in turn helps in filling critical knowledge gaps in populating formation properties between the well derived data control. In the present study, structural and stratigraphic model was initially built from the available 2D/3D seismic interpretation, then various well based cross plots between Vp/Vs vs. P-Impedance, PIGN vs. P-Impedance and S-Impedance vs. P-Impedance were generated within the different pay windows. The purpose of the cross plots were to extract the well based hydrocarbon bearing range from the available pre-stack volumes like effective porosity volume, Vp/Vs volume, P-Impedance volume, S-Impedance volume etc. Cross plots generated between Vp/Vs vs. P-Impedance was not able to segregate the hydrocarbon bearing zone and the water bearing zone (Figure-3)

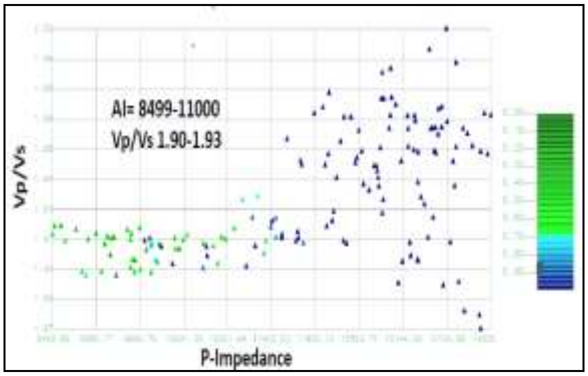

Figure 3: Cross plot of Vp/Vs versus P-impedance

The Vp/Vs range captured for hydrocarbon bearing zone 1.90-1.93 is same as that of the non-hydrocarbon zone. Hence the Vp/Vs volume could not be used for fluid characterization. Similarly, cross plots between PIGN vs. P-Impedance were generated and after detailed analysis of the cross plots and prestack volumes (Vp/Vs and effective porosity), it was observed that the well based ranges captured for hydrocarbon bearing zone in the cross plots are either on the higher or lower side as compared to the prestack volumes. However, cross plots generated between S-Impedance and P-Impedance was able to segregate the pay zones and non-pay zones for different plays. Based on these ranges of P/S impedance values two broad categories as reservoir and non-reservoir facies were identified (Figure-4)

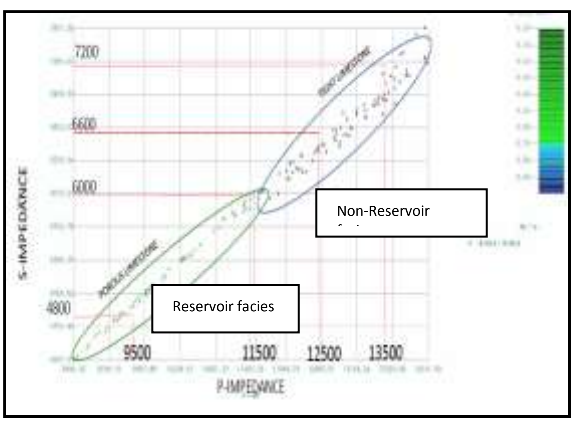

Figure 4: Cross plot of Vp/Vs versus P-impedance

Window slices for P-Impedance and S-Impedance corresponding to different pay zones was generated to know the lateral extension of reservoir facies (Figure-5)

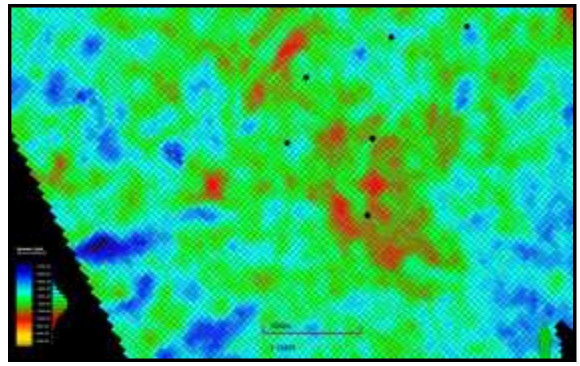

Figure 5: P-impedance slice showing lateral extension

These impedance ranges were then used as trends to guide the facies population within the model.

Facies Modeling

Facies modeling is a means of distributing discrete facies throughout the model grid by using different modeling approaches such as 'Object Based Modeling' or 'Pixel Based simulation' techniques. The facies model provides the link to the sedimentological-depositional model of the reservoir, which ultimately characterizes the volume, spatial distribution and dynamic behavior of hydrocarbon reservoirs. Being a natural phenomenon resulting from geological processes the facies may show large scale trends in spatial distribution and connectivity over the area. To obtain a geologically reliable facies model these trends should be accounted for. This can be achieved by creating a probability trend model by optimally combining all the available geological and geophysical data.

In the present study, probability trend models were created by optimally combining all the available geological and geophysical data and these trend models were used as a constraint in the stochastic facies modeling technique known as sequential indicator simulation (SIS). The trend models used were defined in the form of vertical proportion curves

(1D trend), horizontal probability maps (2D trend), and probability volumes (3D trend) (Figure-6)

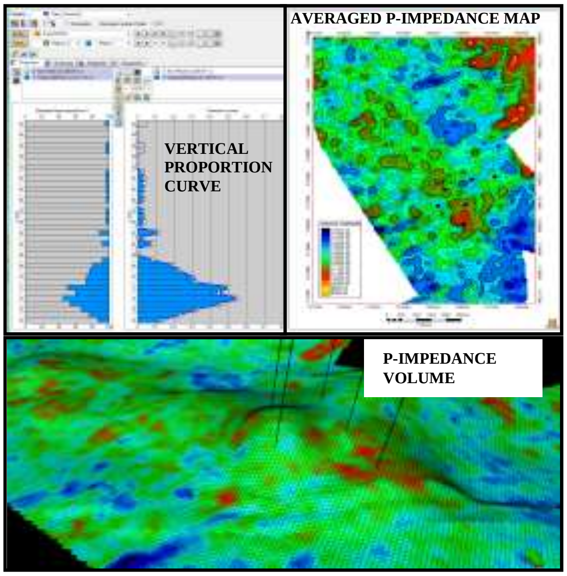

Figure 6: Examples of 1D and 2D probability trend models, for a facies property containing two facies codes (reservoir and non-reservoir).

1D Trend Model

Based on the conceptual sedimentological model, estimates of vertical facies proportions and input well data, the vertical proportions of each facies for each layer of the zones of interest were computed and used to constrain the vertical distribution of the facies. Further, to fully honor the vertical facies distribution obtained from the vertical trend model the vertical range of the facies obtained from the variogram analysis was kept less than the vertical resolution (layering) of the 3D grid, with target honoring value close to zero during facies modeling in PETREL.

2D/3D Trend Model

In view of the limited well data, the laterally dense secondary seismic attribute (P-impedance/S-impedance) data derived from the seismic data inversion was used to provide information regarding lateral variation of the facies (Figure-7)

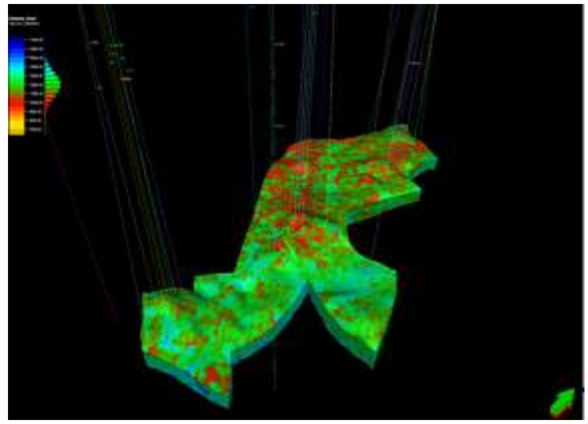

Figure 7: P- impedance 3D volume

For the seismic P impedance data to be used for reservoir characterization, a good correlation must exist between the log derived P impedance and seismic P impedance. In the present study the correlation was not good at places (Figure-8) and also as the seismic data is much coarser than the layering of 3D grid it was decided to use the seismic data only as a trend to guide the lateral distribution of the facies. Hence the seismic attribute data was incorporated in the trend model as 2D maps of the averaged seismic attribute and also as 3D seismic attribute cube for defining the lateral distribution while the vertical variation of the facies was guided by the 1D trend model (Vertical Proportion Curve).

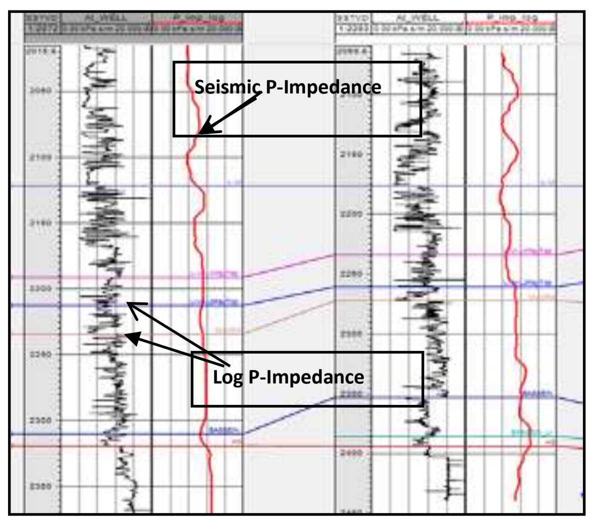

Figure 8: Log derived P-impedance and Seismic P-impedance

Anisotropy range, orientation and connectivity was defined by the variogram parameters (Figure-9) the

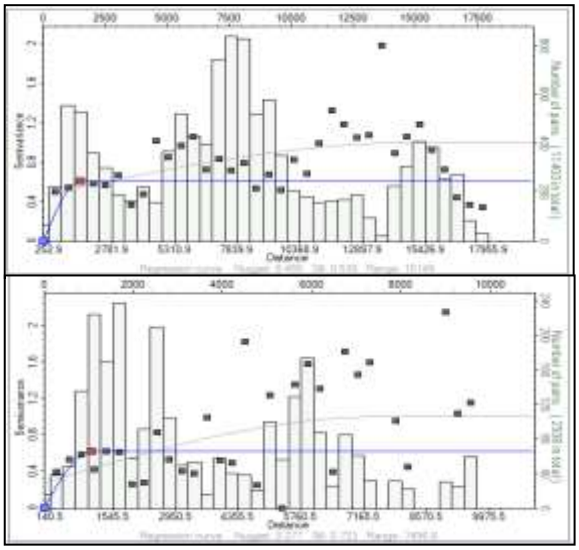

Figure 9: Major and Minor variogram ranges

resulting facies model was able to capture the spatial distribution and direction of continuity over the area of interest as seen from the facies encountered at well locations (Figure-10)

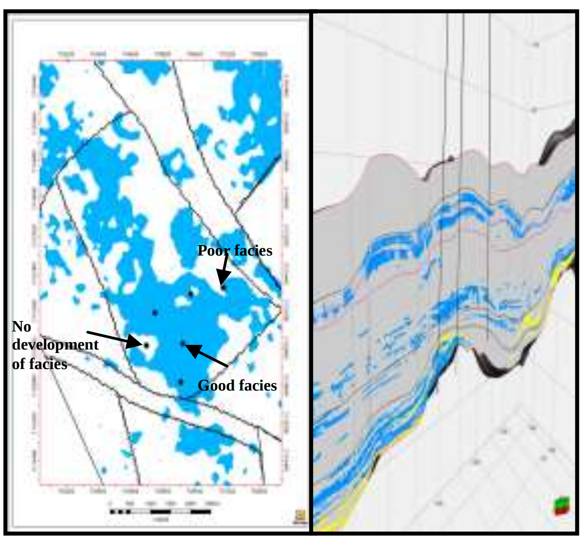

Figure 10: Spatial distribution of Facies

The porosity and water saturation obtained from processed log data of 21 wells was upscaled to the 3D grid and the properties were populated throughout the grid by using SGS technique in Petrel property modeling with earlier facies model guiding the property distribution (Figure-11) leading to generation of multiple equi-probable models of reservoir properties. The fine scale static model was taken up for further simulation studies without upscaling in either vertical or horizontal direction.

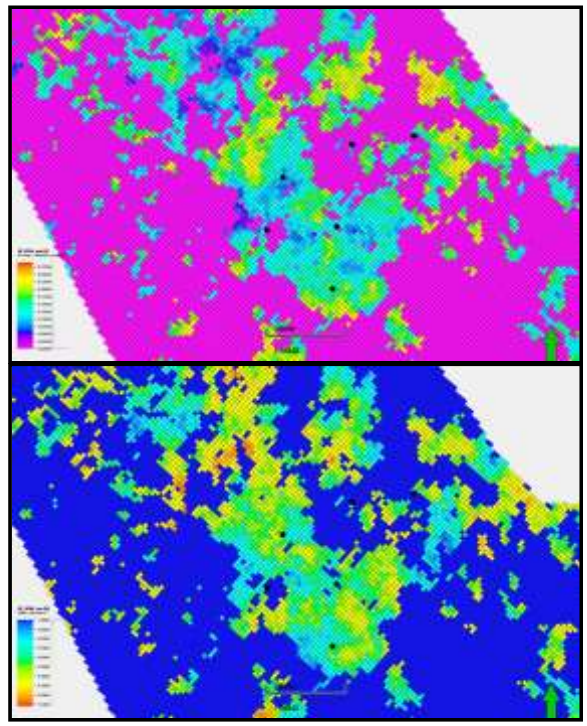

Figure 11: Porosity and Saturation distribution

Dynamic Simulation

Model initialization on the fine scaled grid was done with available PVT and SCAL properties. All the reservoir plays viz. Panvel, Mukta and Basal Clastics are modeled as under saturated fluids. Saturation model with in-place volumes close to 50 MMt is based on the porosity and saturation trends of the static model which corroborates well with observed production trends in 21 wells considered in history match till Mar-17 (Figure-12).

Minor scaling up of Phi-k transform and capillary data was required to match pressure and water production trends. In prediction mode, there is no significant oil cut when the model is run on liquid rate control thereby validating the property population in static model. Additional recovery of about is 6% is envisaged over BAU case (RF: 12%) from 10 new inputs up to Mar-2030.

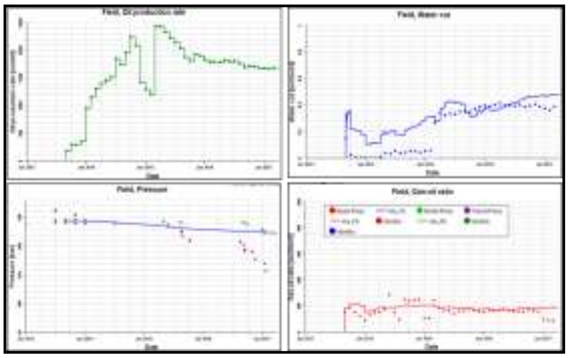

Figure 12: Field level History Match

Conclusions

1. Successful integration of diverse data at different Scales from different domains like geology, geophysics, petrophysics, reservoir engineering etc. leads to a robust static and dynamic reservoir model.

2. Use of seismic data to constrain the model heterogeneities significantly improves the reservoir characterization wherein the plays are both in carbonate and clastic domains.

3. Probability trend models used represent soft constraints i.e. they only guide the distribution of the facies within the 3D grid. However even probability trend do have a strong impact on the results and hence should be used with caution.

4. Adopted workflow has led to better predictable reservoir simulation model of highly heterogeneous plays overcoming constraints of limited data control inherent in green field development to a large extent.

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