Qualitative application of broadband seismic data for optimized performance prediction: A Case Study of Offshore Carbonate Green field

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Keywords
Impedance, Reservoir modeling, Geo-cellular model, History match, Productivity Index, Forecast

Abbreviations
SCAL:Special core analysis, PVT:Pressure-volume-Temperature, GCM:Geo-cellular model, GOR:Gas oil ratio, MDT:Modular dynamic Tester, FBHP/BHP:Flowing bottom hole pressure, SBHP:Static bottom hole pressure, OWC:Oil water contact, SWATINIT:Initial water saturation, STOIIP:Stock tank oil initial in-place, PBU:Pressure build up study, HCPV:Hydrocarbon pore volume, PIGN: Effective porosity, Sw:Water Saturation

Abstract
This paper presents a field case study wherein integration of 3-D broadband seismic data led to a robust geological model capturing reservoir heterogeneity resulting in improved performance forecast and optimization of field development strategy.

The field under study is one of the marginal oil and gas green field in western offshore basin. Accumulation of hydrocarbons is mainly in carbonates of Early Miocene, Oligocene and Late to Middle Eocene age (Ratnagiri, Panvel, Heera, Mukta and Bassein formation), and to a lesser extent, in Paleocene-Eocene sands within Panna clastics. With limited well data available as the field being in its early stage of development, it became essential to integrate seismic driven reservoir facies characterization for filling critical knowledge gaps in populating properties in the inter-well region.

An integrated workflow was utilized to incorporate several seismic attributes extracted from the 3D-braodband seismic data to prepare a robust geo-cellular model.

The model constructed helps explain the reservoir fluid flow behavior in the already producing area and captures reservoir heterogeneity pinpointing locales of leftover oil pockets, plan for infill locations and work-overs and optimize long-term development strategy of the field. 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. The integrated approach of utilizing the seismic Impedance volume for preparing facies model which in turn constrains the property distribution is able to capture the reservoir heterogeneity as reflected in the pressure match particularly the drawdown match during simulation study.

Subsequently, development scheme was formulated by targeting the good hydrocarbon saturation locales left at the end of history and well inputs from the existing platforms were identified for further exploitation with additional facilities.
In summary, the applied methodology i.e. qualitative integration of broadband seismic data to prepare a robust GCM followed by reservoir simulation study is a rational approach in marginal field development to minimize subsurface uncertainties and gives ample confidence in its predictability.

Introduction
The objective of this study is to conceptualize development plan through simulation study for improved recovery based on a geo-cellular model constrained to seismic data for a green offshore carbonate field in western offshore basin of India. The field under study is a marginal carbonate field (B) discovered in 1991 located in the western offshore basin, India which is in early stages of its life cycle.

Geological Background of study area:
The field comprises 3 culminations viz. B-1, B-5 and B-8 having proved reserves in multiple pays. The hydrocarbon accumulation is confined in Panna, Bassein, Mukta and Panvel formations. The structure is bounded by faults on the eastern and western limbs and is also affected by cross faults of a later

generation trending NE-SW both in the south as well as the north. Two major producing reservoirs are Mukta and Panvel formation. Early Oligocene limestone reservoir of Mukta Formation is developed throughout the field and un-conformably overlies the Bassein Formation. Late Oligocene limestone reservoir of Panvel Formation is underlain by Mukta Formation comprises of hard and compact limestone with shale alternations having two layers designated as Pay-1 and Pay-2. The location map of B-field culminations is shown in Figure-1. Commercial production from the field started in Sep-13 and reached to peak oil production to 16,500 bopd in Apr-15 after commissioning of evacuation facility. As of now, field has recovered about 6% and presently, it is producing oil at the rate of 5200 bopd with 45% water cut and GOR of 120 v/v. One of the inherent challenges of developing such green fields is the lack of availability of data in terms of low well density, few logs and cores and a very short production history. In case of the field under study lack of data was compensated to some extent by the availability of 3D broadband seismic data covering the entire field. First step is to build a geologically sound facies model by integrating all the available geological and geophysical data.

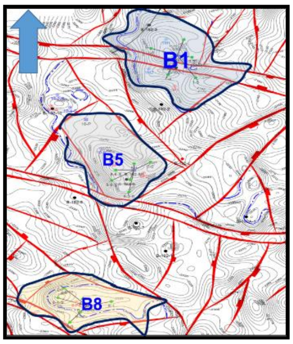


Figure-1: Location Map of B field

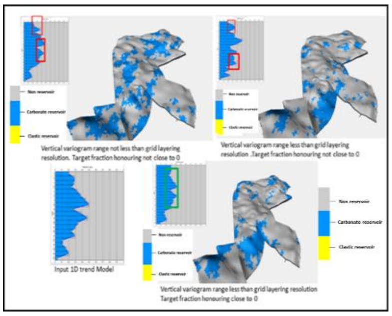
Integrated Reservoir Study:

Geological Modeling: Main objective of building a reservoir model is to provide input to simulation studies with reliable estimates of fluid volume, its distribution and flow dynamics leading to assessment of economic value of the reservoir, predicting its performance and preparing future development plans. To achieve these objectives it is imperative to capture the reservoir heterogeneity in terms of spatial distribution of petrophysical properties like porosity, permeability & fluid saturation which in turn are dependent on the lithological characteristics of the reservoir rocks & their spatial distribution arising due to transportation, deposition as well as diagenetic processes.

As no unique method can be used for capturing the reservoir heterogeneity, an integrated approach was adopted wherein the standard workflow was followed to prepare the structural framework using faults and horizons picked from the 3D seismic volume. Facies model generated was used to constrain the distribution of the Petrophysical properties.

Facies Modeling

In the present study, facies model was generated by using well log data and Seismic driven probability trend models as soft constraints using Sequential Indicator Simulation technique. Trend models can be built by integrating data from different sources and scales and can be defined as 1D Trend (Vertical Proportion Curves), 2D Trends (Horizontal probability maps), or 3D Trends (Probability volumes) (Figure-2). (Reference-1)



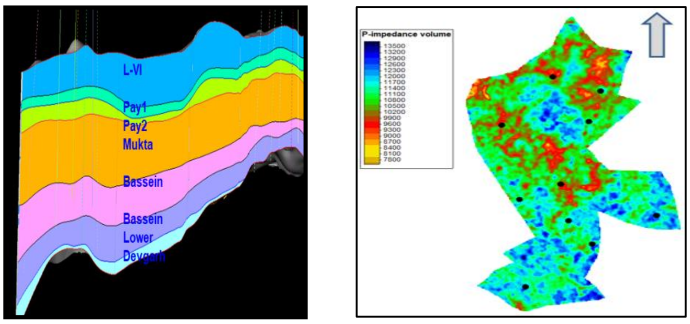
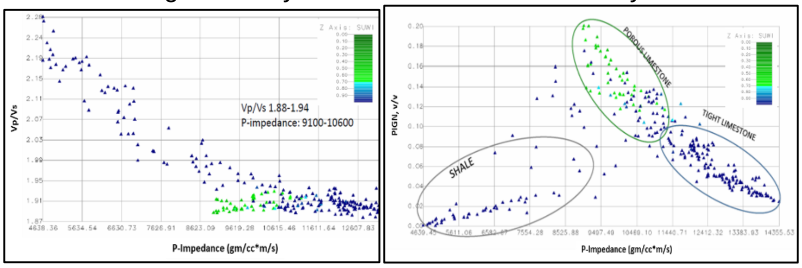


Figure-2: Facies distribution based on Variogram model

Figure-3: Stratigraphic zones in GCM & Seismic attributes (P-Impedance) map

In the GCM, 8 horizons have been modelled which comprises of 7 stratigraphic zones (Figure-3). It consists of 140 vertical layers having a grid size of 50m*50m. 3D static model from the structural modelling workflow was populated with discrete properties from processed well logs and distributed with constrained facies to capture the heterogeneity.

Vp/Vs vs. P-Impedance plot (Figure-4) shows the same range for hydrocarbon & non-hydrocarbon zone (Reference-1), hence Vp/Vs volume has not been used for fluid discrimination. PIGN vs. P-Impedance with saturation in z-axis plot (Figure-4) indicates the porous limestone falls in the range of 0.12 to 0.20 for PIGN & 9100-10600 for P-Impedance. P-Impedance volume was filtered to the range obtained from reservoir characterization study (Reference-1) for each horizon and using these P-impedance volumes as a constraint to model for facies distribution laterally (Figure-5). The vertical distribution of the facies was governed by the vertical proportion curves obtained from data analysis while the ranges obtained from the variogram analysis controlled the connectivity over the area.



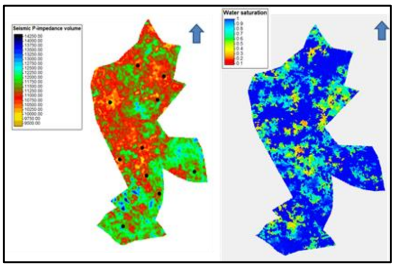


Figure-4: Cross plots of Vp/Vs vs. P-Impedance and PIGN vs.P-Impedance   Figure-5: Distribution of P-Impedance & Sw

Simulation Model Preparation:

Taking inputs from the geo cellular model, reservoir model was constructed with rock and fluid properties as follows.

Fluid Model (PVT):

Fluid model was created using laboratory data obtained from the PVT analysis of the fluid samples from the wells of B-5 & B-8 blocks and verified with standard correlations. For the blocks without lab data, PVT tables generated using standard correlations and validated with the testing GOR and API of crude samples.

Permeability Modelling and Relative Permeability and Capillary pressure curves:

Porosity-permeability (PORO-PERM) cross plot has been generated based on available core data of discovery well B5 (Bassein, Mukta & Panvel pay) and scaled up to match the well productivity and pressure. The PORO-PERM transform (core data) was validated with the available buildup and MDT permeability data. (Reference-2)

Initialization:

Full field simulation for the entire field was done on ECLIPSE 100 simulator considering 3-phase black oil Model. Model initialization involves distribution of initial water saturation in each grid cell for estimation of initial hydrocarbon volumes in the model. The reservoir is subdivided into fourteen equilibrium regions in order to account for the varying OWC for different pays for different structure. The model was initialized with the saturation distribution using the SWATINIT method and the PVT model as discussed above. The model is found to be in capillary gravity equilibrium with above conditions. The initialization indicated field level agreement between the model STOIIP and the estimated volumes.

History Match of the Integrated Model:

Prime objective of history match is to calibrate the simulation model to replicate field production behavior and generate reliable production forecast for various production and development scenarios. Simulation model matches the history needs to be geologically and physically valid. Most important factor in history match is the material balance of the model and needs to corroborate with the recorded static pressure. Good history matched model need minimum modifiers for a reliable production forecast.

History matching was carried out for initial 4 years of production With well production constraint set to instantaneous surface oil rate and lower BHP limit of 60 bar whereas water injection constraint set to surface water rate and maximum BHP of 260-300 bar. Well completion data was incorporated for producers & injectors using their deviation data and initial perforation details. Well intervention in the form of re-perforation, zone transfers and cement squeeze were captured date wise and modelled as per actual. A satisfactory history match was achieved at field level (Figure-6) along with reasonable history match at Block and layer level. The use of integrated modeling approach helped to achieve a judicious history match without any modifiers.

History Match in B-1 block:

This block is having 5 active wells for history match, with 3 completed in Panvel & 2 in Mukta.

Panvel pay: Negligible water production in wells of Panvel Pay, no oil cut observed in history match (Figure-7). Oil production rate indicates two states of flow regime which is mainly due to facies variation. No modifiers are used to match the different production trends, which validates the methodology adopted for property distribution in GCM using seismic attributes. Satisfactory pressure match and the pressure trend indicate that reservoir is operating under depletion case i.e. no external energy support. However few observed pressure points show less than 100ksc reservoir pressure which is not supported by the well performance, lower pressure indicates well are not stabilized during PBU which further substantiates the patchy facies variation in Panvel pay.

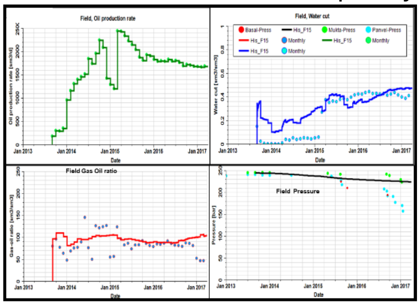


Figure-6: Field level history match plot

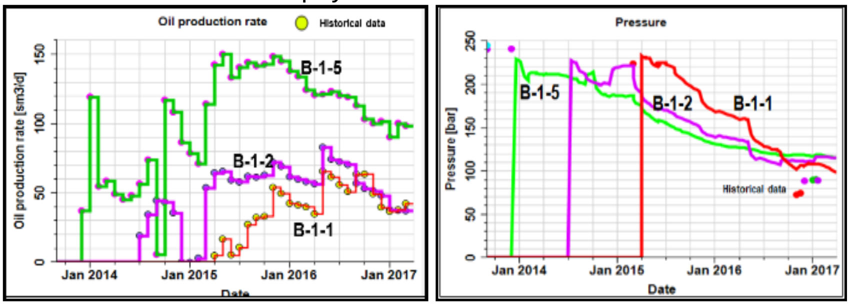


Figure-7: History match plot of Panvel pay in B-1 block

Mukta Pay: Two wells are completed in Mukta and are producing with 30-40% water cut (Figure-8). The pressure and water cut trends indicates the wells follow similar flow regime, however the wells are located on either sides of the NNW-NNE fault, indicating the fault to be non-sealing. Pressure depletion w.r.t to recovery (~4.5%) and water production in wells completed in Mukta formation points to the presence of weak aquifer. (Reference-2)

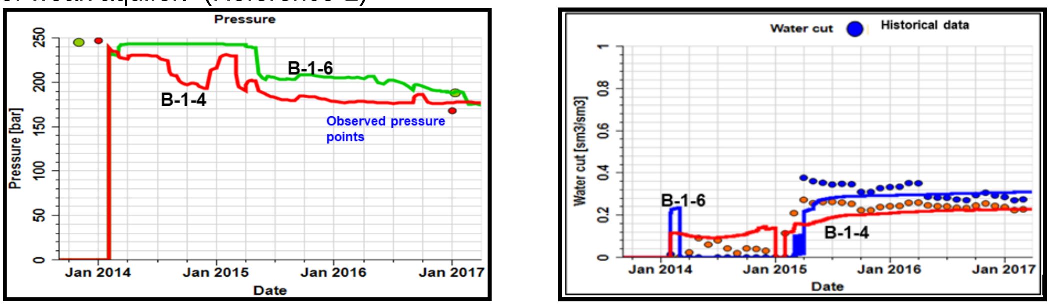


Figure-8: History match plot of Mukta pay in B-1 block

History Match in B-5 block:

B-5 block is the most prominent block in the filed with 60% of the total oil production. Total 6 wells are active in this block and 4 wells are completed as dual string producer (Panvel/Mukta & Panvel/Panna).

Panvel Pay: 4 oil production strings and 2 water injector strings are considered for history matching. Wells are producing under depletion drive, Pressure depletion from initial value of 249ksc to recent levels of about 165-170ksc is observed. In History match, no oil rate cut was observed and good static pressure match was also observed, without using any modifier in static as well as dynamic model. Negligible water production observed in the wells also indicates absence of active aquifer support. To match the pressure in B-5-5 & 6 area (Figure-9) either volumetric support or aquifer support is envisaged, however in view of insignificant water production observed and the modeled water saturation distribution guided by facies model (seismic attributes) not providing any volume support ,in dynamic model pore-volume modifiers had to be used in this area, supported by the material balance study.

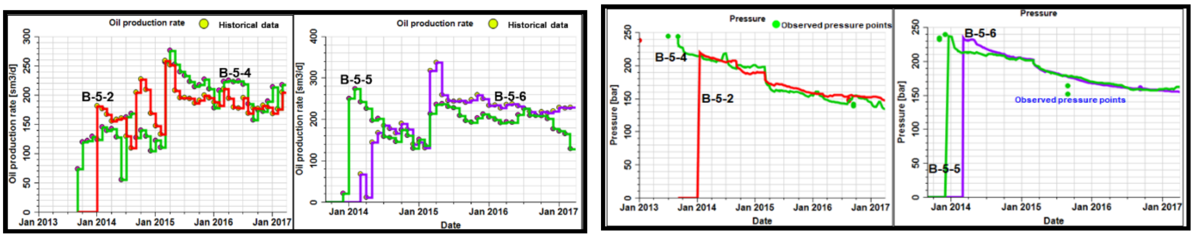
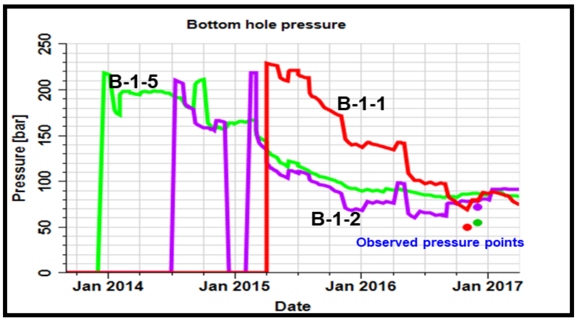


Figure-9: History match plot for Panvel Pay in B-5 block

Mukta Pay: 4 oil production strings and 2 water injection strings are considered for history matching. Wells are producing under depletion drive, no oil rate cut was observed and good pressure match was also observed. Negligible water production observed in the wells also indicates no aquifer support.

Integration of seismic data to build a robust facies model capturing the heterogeneity has resulted in satisfactory history match not only for production rate (Oil, gas & water) and static pressure (SBHP) but is also able to match the flowing bottom hole pressure (FBHP). Good agreement of FBHP data for Panvel pay of B-1 & B-5 block (Figure-10 & 11) with the historical pressure points indicates that the use of 3D broadband seismic data for preparation of GCM helped in construction of a robust dynamic model. In B-1 block the FBHP match for Panvel Pay indicates all the 3 wells are producing with a similar range of drawdown. In B-5 block, in wells B-5-6 and B-5-5 the drawdown is comparable whereas the wells B-5-2 & B-5-4 are analogous which justifies the different permeability regimes in the model.



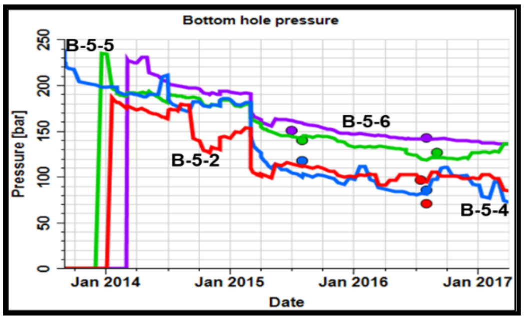


Figure-10: FBHP match model vs. actual of B-1 block (Panvel)   Figure-11: FBHP match model vs. actual of B-5 block (Panvel)

A satisfactory productivity index match i.e. good match of flow rate, SBHP & FBHP without use of any modifiers, supports the integration of seismic data in achieving a reliable history match and preparation of a production forecast for green field development.

Production Forecast and Optimization:

The history match model as elaborated above was used for production forecast and placement of inputs for generating various development scenarios.

B-1 block development strategy:

Hydrocarbon Pore Volume maps are generated considering the available saturation at the end of history match and the prospective areas are identified for further development.

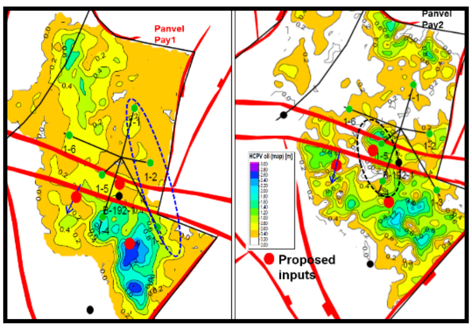


Figure-12: HCPV maps for Panvel Pay1 & 2 of B-1 block

The HCPV maps (Figure-12) indicate the patchy development of Panvel pay-1 & pay-2 in the NE direction which corroborates with the performance of the wells (B-1, B-2) having lower production rate as compared to B-5 (Ref. Figure-7). Well performance vs. product map (Phi-He-So) indicates, 3D broadband seismic guided facies model has captured the property distribution judiciously. For additional development, 4 new inputs targeting Panvel & Mukta have been conceptualized with 3 oil producers and 1 water injector to provide pressure support. This development strategy is expected to improve the recovery of B-1 block to about 16 % from 3%.

B-5 block development strategy:

As explained earlier, B-5 is the highest producing block in the field and is the only block in which water injection is being continuing for Panvel pay as secondary recovery method.

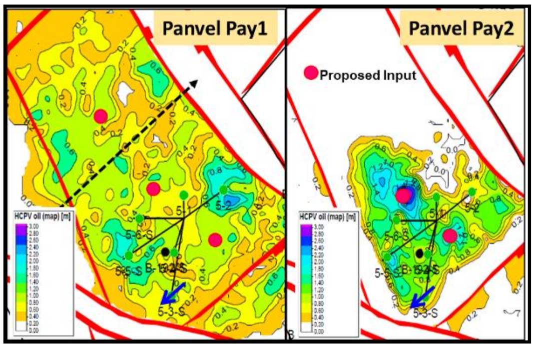


Figure-13: HCPV maps for Panvel Pay1 & 2 of B-5 block

The HCPV map (Figure-13) showing the development of Panvel pay2 limited towards the NW direction by the lowest known oil (LKO) which is replicated in the model and validated by history match and the development of Panvel pay1 towards NW direction beyond the LKO of Pay2. After achieving satisfactory history match, the additional development plan was conceptualized with new inputs & additional facility of 6-Slot Bridge connected platform. 3 new oil producer inputs are envisaged targeting both Panvel & Mukta pays from new platform. For achieving maximum recovery dual completion strategy was adopted. With all the conceptualized inputs the envisaged recovery for B-5 block is anticipated to be about 21% from current recovery of 7%. (Reference-2)

Based on the performance prediction using the simulation model, the investment proposal was approved by the management. Coincidently, after creation of facilities, the drilling of wells have yielded improved production from the field which has re-affirmed the confidence in modelling methodology.

Conclusions

The proposed qualitative integration of seismic data with simulation model resulted in minimizing the inherent uncertainties giving ample confidence in the adopted workflow.

The methodology was evaluated in a complex marginal carbonate field in the western offshore basin of India, where the integration of seismic impedance data led to generation of an improved simulation model consistent with observed seismic and well production history data.

The simulation study based on the integrated model contributes significantly towards understanding the static and dynamic reservoir properties and improves the predictability of the model to estimate long-term production forecasts leading to optimized development and management.

The adopted methodology can be applied for development of green fields to scale down subsurface uncertainties making the reservoir model reliable for future forecast.

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