

An Integrated Approach from Seismic to Simulation for Marginal Field Development to Scale Down risk: A Case Study of Offshore Carbonate Green field

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Keywords

Seismic Attributes, Impedance, Reservoir Modeling, Geo-cellular model, History match, Productivity Index

Abbreviations

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

Abstract

Early life cycle of a field with limited well coverage possess inherent challenges in capturing reservoir heterogeneities in a multiple pay geological setup. 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.

Uncertainty of data is more crucial in marginal fields due to limited sub-surface information viz. pressure, reservoir drive and fluid properties and present significant challenges in marginal field development.

This paper presents a field case study wherein data from seismic, petrophysics, geology, well-test and laboratory PVT analyses were integrated in a classical black oil simulation model to allow the evaluation of alternate development approaches.

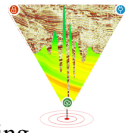
The field under study is one of the marginal oil and gas green field located in the Deep Continental Shelf of Bombay offshore basin. Major sedimentary sequence encountered in the field ranges from Paleocene to Recent. The Panvel (L-VI), Mukta and Basal Clastics are the main pay zones with very good production potential. 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. 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 trends models to control the vertical distribution of the facies proportions along with seismic attributes (P and S - Impedance) as 3D trend models for constraining the spatial distribution of the facies within the range derived from the 3D variogram models. Finally the facies model was used to constrain the property distribution in petrophysical modeling algorithm in PETREL E&P platform.

An integrated workflow was utilized to incorporate several seismic attributes extracted from the 3D-broadband seismic data to prepare a robust geo-cellular model. In simulation, the 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 proper saturation and porosity distribution.

Subsequently, development scheme was formulated by targeting the good hydrocarbon saturation locales and well inputs from the existing platforms were identified for further exploitation with additional facilities.

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 based on conventional log data. In simulation study, good



history match at well level was achieved which gives ample confidence in firming up exploitation strategy of different pays.

Introduction

Main purpose of building a reservoir model is to provide input to flow simulation studies with reliable estimates of fluid volume, its distribution and flow dynamics and to conceptualize development plan with minimum uncertainty. This in turn will help in assessing the economic value of the reservoir, predict its performance and prepare future development plans. To achieve these objectives it is essential 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. Hence, the most critical element in reservoir modeling is to first build a robust facies model which can then be used for geo-statistical distribution of the petrophysical properties in the reservoir 3D grid.

The field under study is a marginal carbonate field in the early stages of its life cycle located in the western offshore basin, India. The field (B) comprises 3 culminations viz. B-1, B-5 and B-8 having proved reserves in multiple pays (Figure-1). The hydrocarbon accumulation is confined in Panna, Bassein, Mukta and Panvel formations.

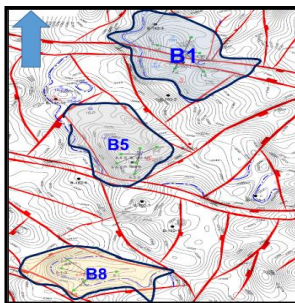


Figure-1: Location Map of B field

One of the inherent challenges of developing such green fields is the lack of availability of data in terms of low well density, petro-physical data, cores and a very short production history. In this case the field under study, having 3D broadband seismic data covering the entire field was compensated to some extent the lack of sub-surface data. First step was to build a geologically sound facies model by integrating all the available geological and

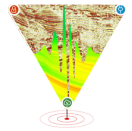
geophysical data. This was achieved by integrating the well data with probability trend models based on seismic attributes generated from inversion studies by using stochastic facies modeling technique known as Sequential Indicator Simulation (SIS) available in PETREL. Subsequently this facies model was used to constrain the distribution of petrophysical properties through Sequential Gaussian Simulation (SGS) technique in PETREL.

Integrated Approach for Static Geological Model:

As no single 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. In a green field with very sparse well data the facies model based on facies proportions obtained from upscaled well logs may not be representative of the actual facies distribution as most of the wells are likely to be drilled in the better part of the reservoir. Hence to honor the input well data and account for the spatial distribution and continuity of reservoir facies, probability trend models were created from well logs and seismic derived attributes and used as a soft trend to guide the facies model. Finally the facies model generated was used to constrain the distribution of the petrophysical properties. This approach of integrating multiscale multi-disciplinary data for predicting the reservoir presence was able to capture the reservoir heterogeneity to a large extent with higher confidence thereby reducing the inherent uncertainty.

Seismic Data

The 3D broadband seismic data with a frequency bandwidth in the range of 2.5 to 90 Hz at -12dB acquired over the entire study area was used not only for mapping the structural disposition of the reservoir but also to generate several seismic attributes for better reservoir characterization. To address the challenges of reservoir heterogeneity in the inter well region a comprehensive approach based on identification of key geological markers, seismic to well ties, detailed facies mapping, seis-facies analysis, pre/post stack inversion and attribute analysis was adopted. Various well based cross plots between V_p/V_s versus P-Impedance, PIGN vs. P-Impedance and S-Impedance vs. P-Impedance were generated for different pay windows to extract the well based hydrocarbon bearing ranges. A representative cross plot between V_p/V_s vs. P-Impedance was not able to segregate between hydrocarbon bearing and water bearing zones



(Figure-2). V_p/V_s range captured for hydrocarbon bearing zone i.e. 1.88-1.94, is same as observed for the non-hydrocarbon zone. Hence the V_p/V_s volume could not be used for fluid differentiation. The cross plots between PIGN vs. P-Impedance with saturation in z axis was generated (Figure-3), After detailed analysis of the cross plots and prestack volumes (V_p/V_s and effective porosity), it was observed that the well based ranges captured for hydrocarbon bearing zone in the cross plots are not represented in the prestack volumes, which appear to have grossly under predicated the effective porosity. However, cross-plot generated between P-Impedance and S-Impedance is able to segregate the pay zone and non-pay zone for different pay windows. Based on these ranges of P and S impedance values hydrocarbon bearing porous limestone and tight carbonate were identified as reservoir and non-reservoir facies (Figure-4). The average maps for P-impedance and S-impedance corresponding to different pay windows were generated and used as input in probability trend models for facies modeling (Figure-5). (Reference-1)

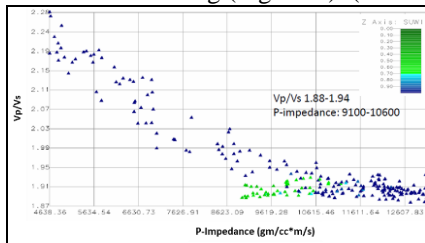


Figure-2: Cross plots of V_p/V_s vs. P-Impedance

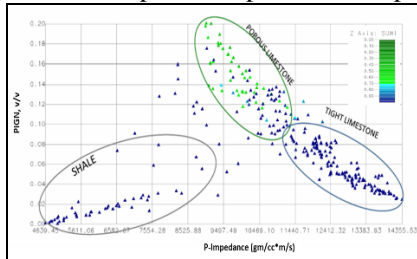


Figure-3: Cross plots of PIGN vs. P-Impedance

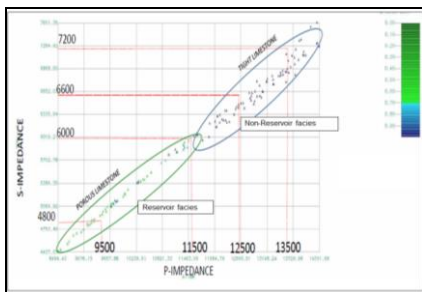


Figure-4: Cross plot of P vs. S-impedance

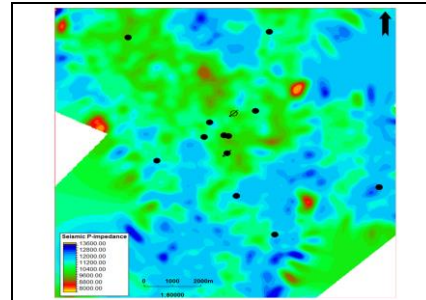


Figure-5: Average P-Impedance map showing lateral extensions of reservoir

Facies Modeling

Facies modeling is used to populate Geocellular grids with discrete property value. Properties can further be distributed into the reservoir 3D grid volume. The facies model should be able to capture the trends i.e. the gradual change in spatial distribution & direction of continuity which may have been introduced as a result of geological process of transportation, deposition or diagenesis. These trends can be accounted for by using probability trend models created by integrating all available data. 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-6). (Reference-1)

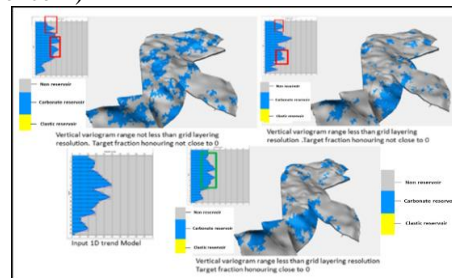
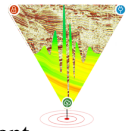


Figure-6: Facies distribution based on Variogram model

Geo-cellular Model: In the GCM, 8 horizons have been modelled which comprises of 7 stratigraphic zones. 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. (Reference-1)



Simulation Model Preparation:

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 & Relative Permeability:

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 STOIPP 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 event. A satisfactory history match was achieved at field level (Figure-7) 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.

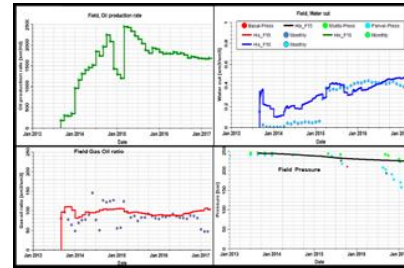


Figure-7: Field level history match plot

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-8). Oil production rate indicates two different flow regimes which are 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. Moreover, lower pressure indicates well are not stabilized during PBU which further substantiates the patchy facies variation in Panvel pay.

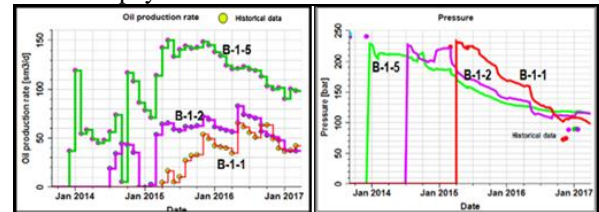
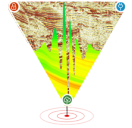


Figure-8: History match plot of Panvel pay in B-1 block

Mukta Pay: Two wells are completed in Mukta and are producing with 30-40% water cut (Figure-9). 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)

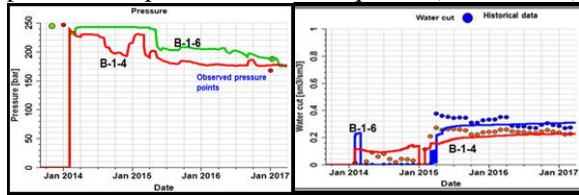


Figure-9: History match plot of Mukta pay in B-1

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: All the wells were considered for history matching. Being initial phase, wells are producing primarily 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-10) 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 volumetric support, in dynamic model pore-volume modifiers had to be used in this area, supported by the material balance study.

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-11 & 12) 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.

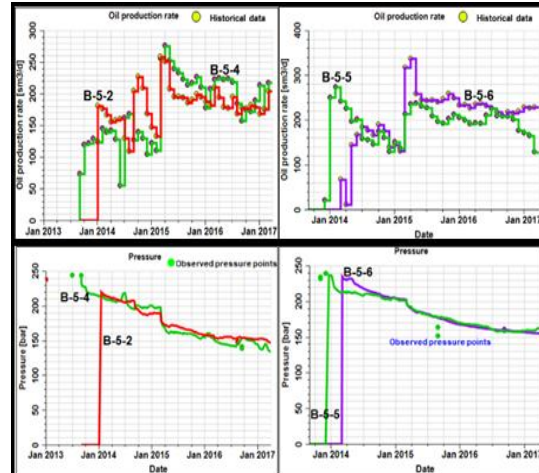


Figure-10: History match plot of Panvel pay in B5

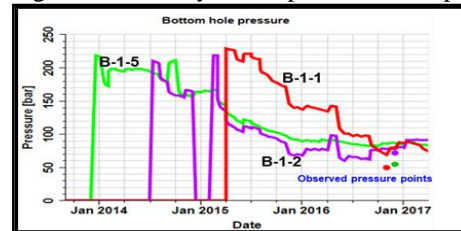


Figure-11: FBHP model vs. actual of B-1 (Panvel)

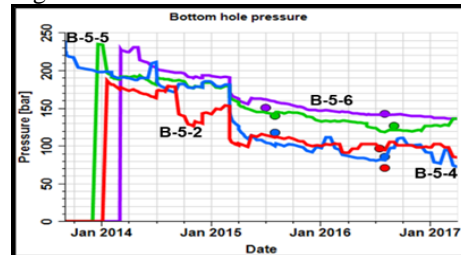


Figure-12: FBHP model vs. actual of B-5 (Panvel)

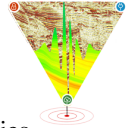
A satisfactory productivity index match i.e. good match of flow rate, SBHP & FBHP without use of any modifiers, supports the integration of seismic data in achieving a reliable history match and preparation of a production forecast for green field development.

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. The HCPV maps (Figure-13) 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-8). Well performance vs. HCPV map 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 significantly.

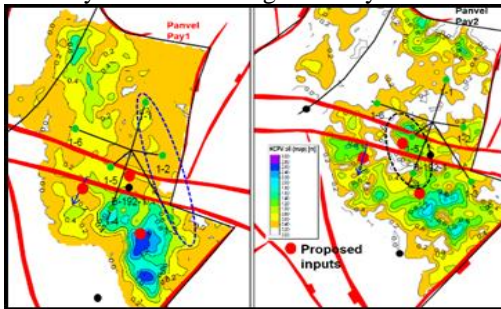


Figure-13: HCPV maps for Panvel Pay1 & 2 of B-1 B-5 block development strategy:

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 mode. The HCPV map (Figure-14) 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%. (Reference-2)

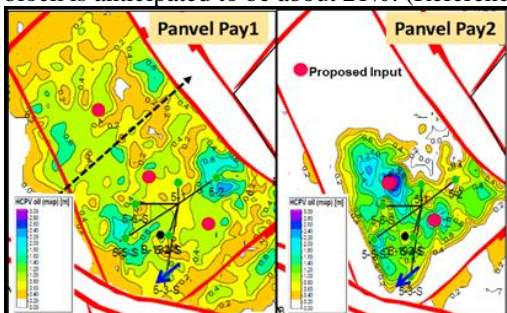


Figure-14: HCPV maps for Panvel Pay1 & 2 of B-5 block

Implementation status: After creation of facilities (1 Clamp-On, 1 WHP), the drilling of 6 new wells (2 B1, 3:B5 block) has yielded ~2400 bopd oil production against projected ~2800 bopd (~86% achievement) which has validated the study and provide confidence in the above applied workflow from seismic to simulation in reservoir modeling.

Results and Conclusions

The integrated approach has led to better predictable reservoir simulation model of a heterogeneous reservoir overcoming constraints of limited data control inherent in green field development to a large extent.

Integration of multidisciplinary multiscale data can help in building a robust static model. Use of seismic constrained facies probability maps significantly improves the reservoir characterization and enhances its reliability in predicting reservoir performance. 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.

Based on the study drilling of wells has yielded improved production and good correlation between production forecast & actual well production, provides a reliable validation point from the study.

In summary the paper shows, the applied methodology is a quick fit approach in marginal field development to minimize subsurface uncertainties and provides ample confidence in its predictability.

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