Geological Process Response Model to Synthetic Seismic Response in South of Mumbai High, Western Offshore Basin

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Abstract

Geological Process Modelling (GPM) is a quantitative tool to forward model depositional and stratigraphic processes of erosion, transport and deposition of clastic sediments and carbonate growth and redistribution on a grain size scale while honouring physics-based flow dynamics. Using the rock physics properties, synthetic seismic volume is generated, which allow analysis of stratigraphic features and their seismic expression on different scale. The well and seismic consistent forward stratigraphic model can provide new insights into the characteristics of sub-surface reservoirs over conventional geological models. GPM Modelling was carried out in the south of Mumbai High area for both clastic i.e., Panna Formation and carbonate i.e., Devgarh and Bassein formations wedging out against the Basement around Bombay High. In Panna Formation, Source provenances were defined and distribution of sand through time and space was determined by combination of different processes such as diffusion (weathering and gradient based transport), steady flow (Channel transport), sea wave, and carbonate growth. For Bassein Formation, carbonate ramp model was simulated with dominantly four depositional environments i.e., basinal, shoal, lagoonal and supratidal, based on the water depth, wave energy and clastic sediment input rate. Subsequently, diagenetic model was also simulated and residence time of each carbonate facies in different diagenetic zones. The simulated models were sampled into 3D grid and results were validated with the drilled wells in terms of facies and porosity. Further, elastic properties of the sediments were populated in the 3D grid and a synthetic seismic volume was generated in depth domain which showed good qualitative match with acquired-processed PSDM seismic volume and validated the modelled stacking of various depositional cycles and wedge outs limits. Well and seismic consistent forward stratigraphic model provided key insights on the character, geometry, and limits of sandstone units within Panna and Devgarh formations and porosity likelihood areas within Bassein Formation. Modelling results also suggested to shift focus from facies wedges to porosity wedges within Bassein Formation. Post modelling, results of exploratory wells corroborated with the forward stratigraphic model. Well-A targeting up-dip porosity wedge corridor within Bassein Formation encountered 30m of pay and flowed commercial oil and gas rates, another exploratory well-B targeting thin sandstone reservoirs within Devgarh carbonates corroborated with the modelled results in terms of sand thickness and facies character.

Introduction

Recently there has been an increasing insight into reservoirs because of high-resolution seismic data and borehole imaging techniques. As a result more complexities are being revealed than previously anticipated. Furthermore, with more data there has been a growing need to integrate, both across data types and geoscience domains. Traditionally, understanding reservoir presence and quality has been done either at the basin-scale or field level separately. The present work is grounded on observations from subsurface data and present-day sedimentological processes, requiring many assumptions. Therefore, whilst these individual approaches have proved adequate in the past, with the ever-increasing complexity in both structural and stratigraphic plays, it is essential that both approaches be more closely linked. At one end of the spectrum, seismic stratigraphic interpretation has often been detached from the consideration of the physical processes which were responsible for the deposition of the sequences. At other end of the spectrum, geological models invoked to understand geological processes do not offer scope to be tested.

Geological process response model to synthetic seismic response provides insight into geological process and seismic reconstruction and process matching at well level helps in validation of simulated geological models at both basin and field scale. The combination of both leads to a better understanding of reservoir presence and facies association. These integrated processes/workflows are demonstrated using an example from the Mumbai Offshore Basin, India, for both clastic and carbonate.

Mumbai Offshore Basin Geology

Mumbai offshore basin is a pericratonic basin along the western continental margin of India (Fig.1).

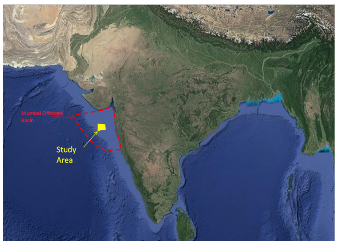

Fig.1: Map Showing Mumbai Offshore Basin and study area.

The evolution of the Mumbai Offshore basin took place through distinct phases of tectonic activity, i.e., Synrift stage involving the Deccan event and sedimentation of Paleocene sediments. Contemporaneous intracratonic failed rifts, the rift between India and Laxmi Ridge & between Laxmi Ridge & Seychelles and different stages of collision of Indian plate with Eurasian plate have modified the structural grain of Mumbai Offshore Basin. The westerly tilt of the basin started right from Early Oligocene as is evidenced from increased clastic content. The hard collision during Mid. Miocene and renewed spreading along the Carlseberg Ridge created enough compressive force to reshape most of the areas of Mumbai Offshore Basin. The fault pattern is primarily guided by three major trends i.e., NE-SW, ENE-WSW, and NNW-SSE. The Basin has a thick sedimentation record starting from Paleocene to Recent. The area is widely covered by a basaltic floor except for small inliers having granitic Basement. The Basement is unconformably overlain by the sequence of trap-wash and clastics sequence of Paleocene to Early Eocene in age together makes the Panna Formation. However, Early Eocene carbonates in the study area belong to the Devgarh Formations. Panna/Devgarh Formation is overlain by carbonates of Bassein Formation of Middle to Late Eocene Age (Fig.2).

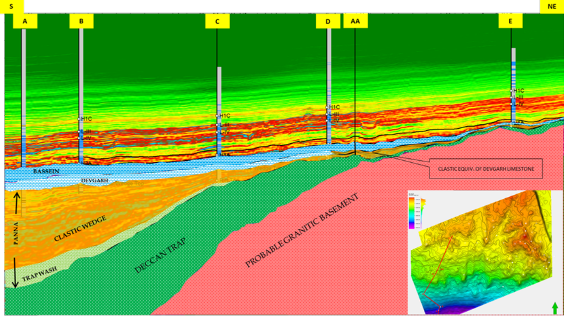

Fig.2: A cross section of Acoustic Impedance in the study area depicting Panna, Devgarh and Bassein formations wedging out on Basement (Deccan Trap/granitic Basement).

Geological Process Modeling

Geological process modeling (GPM) also called as stratigraphic forward modeling was used in the study area to model the processes of erosion, transport, and deposition of clastic sediments, as well as carbonate growth and redistribution based on quantitative deterministic physical principles (Acevedo et. al, 2014; Tetzlaff et. al, 1989; Minami et. al, 2003; Pickering et. al, 2001). The results show the geometry and composition of the stratigraphic sequence because of sea-level change, paleogeography, paleoclimate, tectonics, and variation in sediment input. In its scope, GPM is like detailed sequence stratigraphy. However, the latter has been developed based on observations and inferences, mostly from seismic data, and conceptual models that specify what stratigraphic relationships should be expected under certain conditions (such as sea-level rise and fall, or variations in sediment input). GPM on the other hand, is based solely on numeric modeling of open-channel flow, currents, waves, and the movement of sediment. The observed stratigraphy is the result of modeling a physical system.

Estimation of Subsidence through time

Original basement configuration at the initiation of sediment deposition and estimation of tectonics, thermal subsidence, and sediment compaction is important as it guides the sediment transport and thickness. To estimate these parameters 3D geomechanical restoration was carried out (Fig.3).

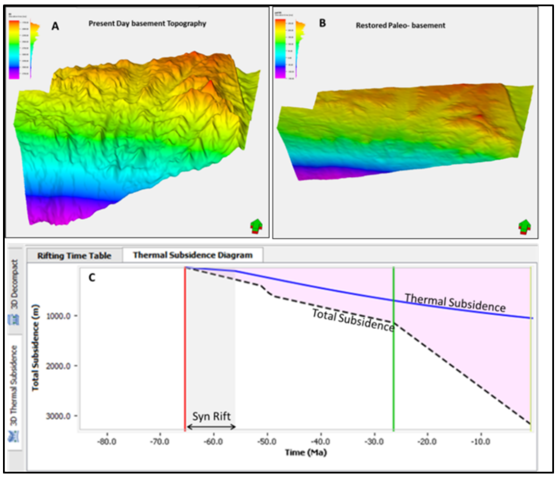

Fig.-3: Comparison of present day (A) and paleo- Basement (B) topography obtained through 3D geomechanical restoration. Modeled total and thermal Subsidence shown in (C).

A 3D structural model comprising of horizons and faults from Paleocene to Recent was constructed. Geomechanical attributes (Young's Modulus, Bulk Modulus, Poisson's Ratio) were determined from well logs and assigned to the horizons. Geomechanical restoration based on a mass spring algorithm was performed for each surface, by iteratively minimizing the strain on the surface polygon, while attempting to retain its original shape. Basin has witnessed rifting in Paleocene; to estimate the effects of thermal subsidence a modeling based on the work of McKenzie (1978) was carried out. However, in this model only heat variation because of the asthenosphere upwelling is considered; there is no influence from radioactivity.

Sea level curve

The sea level curve is an important input in Geological Process Modeling as it controls the lateral and vertical variability of different facies. It also plays a very important role in defining different meteoric diagenesis zones in carbonate rocks, which are responsible for the secondary porosity creation. The sea level curve was prepared by integrating biostratigraphy data of clastic and carbonate intervals of drilled wells. Exxon global seal level curve trends were also used for unrepresented stratigraphic sections in the study area. Paleogene sediments wedge against the basement around the Bombay High and it provided opportunity to optimize the sea level curve by iteratively simulating and matching the stacking and wedge out limits of Panna, Devgarh and Bassein formations through synthetic seismic volume.

Panna and Devgarh Formation

To have better control on the process simulation Paleocene to Early Eocene was further subdivided into 4 zones wedging out on the basement (Fig.2). Zone-A formed by the erosion and deposition of the trap wash over basement. Zone-B comprises mainly shale, sandstone and coal forming the main clastic wedge. Zone-C and D represent the Devgarh limestone in distal part of the basin and clastic in the proximal. Sands in the proximal part are good reservoirs. Top of the Zone-C marks a maximum flooding surface and above it there is a clastic finger within the Devgarh limestone. Sand within Devgarh limestone was found to be hydrocarbon bearing in one exploratory well. GPM was carried out to assess thickness and distribution of sands within Panna and Devgarh formations.

Source provenances were identified for sand and shale and their properties were assigned in the model. Carbonate precipitation rates were also optimized through iteration for Devgarh limestone. Diffusion was used for erosion and downslope sediment movement. It simply assumes that sediment will move down slope at a rate proportional to the slope and to sediment characteristics (fine sediment will move farther than coarse sediment). Free surface water flow (rivers, longshore currents) was simulated through steady flow as there were no abrupt changes in the flow velocity and surface gradient. The wave action was also simulated using accepted formulas for wave celerity (the velocity of wave groups) to calculate wave trajectory (including refraction and diffraction), for a given set of wave sources as a function of wave amplitude, period, and depth distribution. Simulation results were iteratively optimized to match the facies and process from the drilled wells (Fig.4). Sand trend was taken from final optimized simulation to know the extent and thickness in various layers.

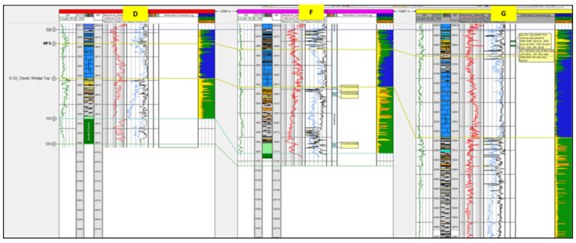

Fig.-4: Comparison of facies encountered in drilled wells with modeled facies (Right most track).

Parameters such as sediment input, sediment diffusion, transport coefficient etc. were estimated by iterative simulation through optimization of the values. In Panna Formation, distribution of sand through time and space was determined by combination of different processes such as diffusion (weathering and gradient based transport), steady flow (Channel transport), Sea wave energy, carbonate growth along with tectonics and subsidence.

Bassein Formation

Bassein carbonates were deposited in a carbonate ramp setup. Based on sedimentological studies Bassein formation was further subdivided into 3 zones, Zone-A and Zone-C represents carbonate deposition in mainly open shelf conditions, Zone-B was deposited in open shelf conditions with high clastic input. Ramp model was taken for simulation and based on the water depth, wave energy and clastic sediment input rate, four carbonate depositional environments, i.e., basinal, shoal, lagoonal and supratidal were defined and simulation was carried out with changes in the sea level, tectonics, and subsidence (Fig.5).

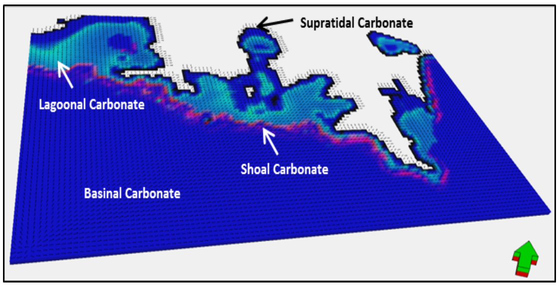

Fig.-5: Ramp model showing 4 depositional environments (Supratidal, lagoonal, Shoal and Basinal) for Bassein Carbonate.

After optimizing the simulated facies and environments with the drilled well data, diagenetic modeling was carried out to assess the role of meteoric diagenesis leading to secondary porosity creation. In diagenetic model, vadose, top of phreatic, phreatic and mixing zones were defined based on the sea level variation and topography (Fig.6).

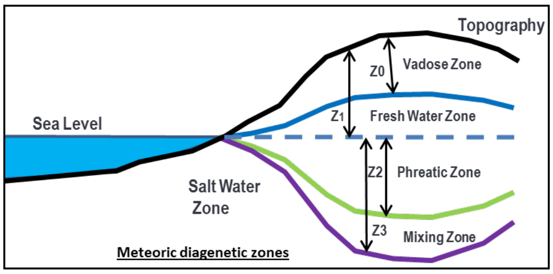

Fig.-6: Different zones of meteoric diagenesis defined with respect to sea level.

The digenetic model was simulated with varying sea level and tectonics through the defined geological time and residence time of different carbonate facies in each zone was calculated. The simulated models were sampled into 3D grid and results were validated with the drilled wells in terms of facies and porosity.

Synthetic Seismic

Generation of synthetic seismic cube from the simulated model gives opportunity for qualitative match with the acquired seismic data in terms of vertical and lateral stacking of different depositional packages and wedge out limits. A good match further adds confidence to the geological process model results. GPM model was further taken for reservoir elastic modeling (REM), where porosity, pressure, temperature, and pore fluid properties were incorporated in the elastic. REM helped in generating compressional and shear velocity volumes for synthetic seismic generation. Further a synthetic seismic volume was generated by convolving a wavelet similar to the acquired seismic. Synthetic seismic showed very good qualitative match with the acquired seismic (Fig.7), which helped in minimizing the uncertainty in input parameters optimizing the GPM results.

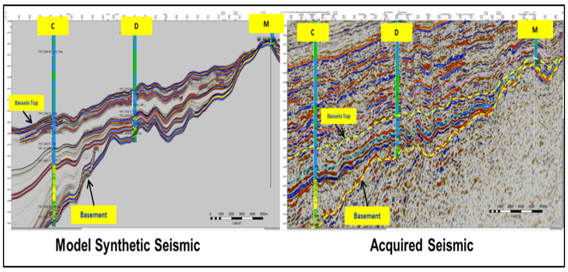

Fig.-7: A qualitative comparison between modeled synthetic seismic and acquired seismic showing good match.

Modeling Results

Geological process modeling provided geologically plausible and well and seismic consistent depositional model for Panna, Devgarh and Bassein formations. It also provided insight about time varying active sandstone provenances feeding the study area within Panna and Devgarh formations. Bassein carbonate simulations provided likelihood areas for Basinal and Shoal carbonates and its dissolution coefficients due to diagenesis leading to creation of secondary porosity (Fig.8).

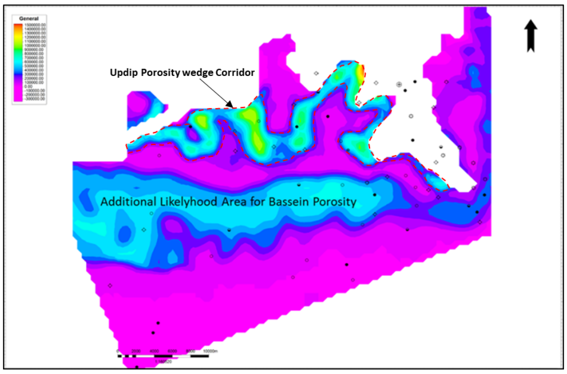

Fig.-8: Bassein carbonate simulations provided likelihood areas for Basinal and Shoal carbonates and their dissolution coefficients due to diagenesis leading to creation of secondary porosity.

GPM helped in assessing the thin sandstone reservoir within the Devgarh Formation (Fig.9) and one additional area for Bassein Formation (Fig.8), where

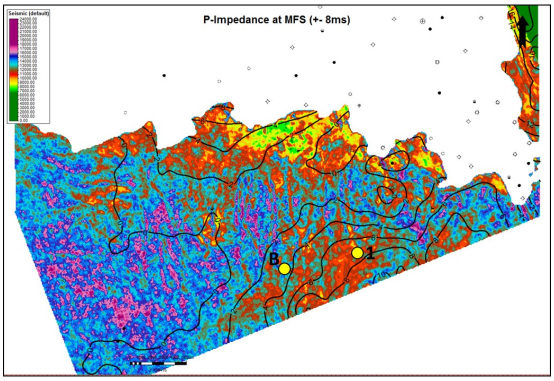

Fig.-9: GPM based Sand Isochore contours within Devgarh limestone overlain on the P-Impedance extracted at the MFS.

model suggested secondary porosity in Basinal and Shoal carbonates due to diagenesis. Subsequent drilling results of exploratory wells corroborated with the geological process modelling results, i.e., well-A targeting updip porosity wedge corridor within Bassein formation encountered 30m of pay and flowed commercial oil and gas rates (Fig.10),

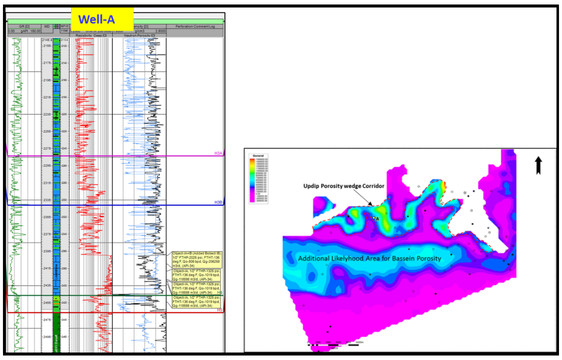

Fig.-10: Exploratory well-A encountered 30m of pay in updip porosity wedge corridor within Bassein formation.

another exploratory well-B targeting thin sandstone reservoirs within Devgarh carbonates corroborated with the modeled results in terms of relatively less sand thickness and poor facies w.r.t. to lead well-1 (Fig.11).

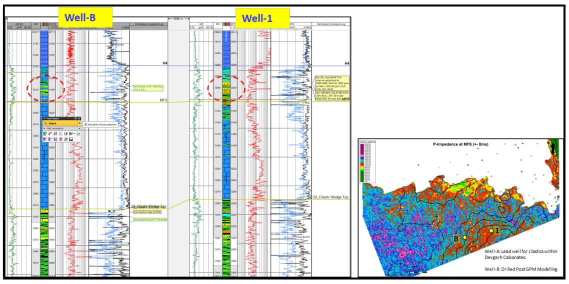

Fig.-11: Drilling results of exploratory well-B targeting thin sandstone reservoirs within Devgarh carbonates corroborated with the modeled results in terms of relatively less sand thickness and poor facies w.r.t. to lead well-1.

Conclusions

Geological process modeling provided a set of quantitative tools to forward model, tectonic and depositional processes responsible for deposition of Panna, Devgarh and Bassein formations. A good match with the drilled well and acquired seismic enhances the confidence on the modeling results. Based on the model provenance and extent of sandstone within the Devgarh formation was brought out and a new secondary porosity likelihood area was identified for Bassein formation for further exploration.

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