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Author **LIENDON ZEITE , ONGC , India**

Co-Authors **MADHUKAR SINGH, SOUMITRI S. DASH, ANINDA GHOSH, K. VASUDEVAN**

Dimension of Shallow-marine Sand bodies using High-resolution Sequence Stratigraphic Framework for Estimation of Hydrocarbon Volume in B-127, B-59 and B-157 Fields, Mumbai Offshore, India.

Abstract

Shallow-marine sandstone deposits are host to a considerable percentage of the world's hydrocarbon reserves. An understanding of dimension, geometry and orientation of sand bodies in a shallow-marine setting is essential for estimation of hydrocarbon volumes and to optimize development and production schemes. However, defining a high-resolution dimension of shallow-marine sandstone bodies – both qualitative and quantitative – remains a big challenge for exploration geoscientists. The Panna Formation in B-127, B-59 and B-157 fields of Mumbai offshore, India, comprises of discrete sand bodies interlayered with silts, shales and coals/carbonaceous matter deposited in an overall marine transgressive system. High-resolution sequence stratigraphic framework is implemented to understand the facies dispersal and lithological heterogeneity of these sand units within Panna Formation. Well-based sand isolith maps were prepared for different zones within 3rd order parasequences. A 3-Dimesional sand trend was generated for B-127 and B-59 area using the sand isolith maps combined with VPC (Vertical Proportion Curve) derived from actual lithofacies encountered in wells. Using this trend in a static model supported by a robust seismic data interpretation, a facies model is generated which captures the inherent vertical as well as lateral heterogeneity of different reservoir units. The hydrocarbon volumes thus estimated using this facies model gives a good end result with a high confidence level.

Introduction

An understanding of dimension, geometry and orientation of sand bodies in a shallow-marine setting is essential for estimation of hydrocarbon volume that is present and the percentages that is recoverable, and to optimize development and production schemes (Reynolds, A.D., 1999). The B-127, B-59 and B-157 fields of north-west Mukta area, Mumbai offshore, India are located at a distance of approximately 150 km northwest of Mumbai city along the rising flank of Dahanu Low and have been taken up for development of Panna pays as a part of cluster scheme (Fig 1). The area is bounded by Mumbai High to the West, B-58 high to the East, Dahanu Low to the North and B-57, B-126 structures (Mukta Platform) to the South.

Panna Formation consists of discrete sand bodies interlayered with siltstone, shales and coals/carbonaceous matter deposited in an overall marine transgressive system deposited during Late Paleocene and Early Eocene age. Panna sedimentary column varies from 20 to 2000 m in the Basinal side north of the present area. Due to the nature of thin sands associated with coal seams in Panna Formation, 3-D seismic lack sufficient resolution to image individual discrete sand units.

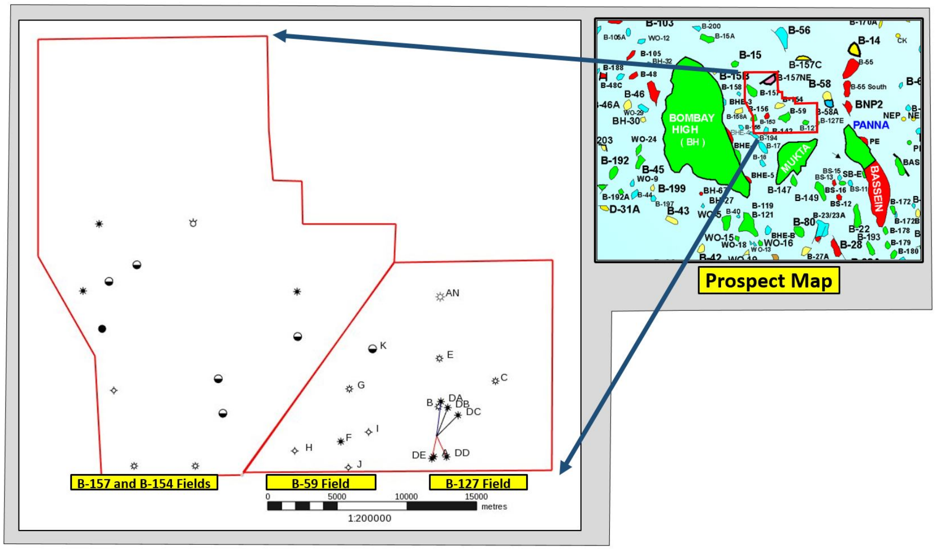

Fig 1. Base map of B-127, B-59 and B-157 fields of Mumbai offshore, India.

Methodology

Sequence stratigraphic framework was adopted using electro-log correlations of twenty-five exploratory and five development wells to understand the regional facies distribution as well as lithological heterogeneities of different sand units within Panna Formation. Three 3rd order sequences S1, S2 and S3 from bottom to top are mapped within Panna Formation. The pay sands of B-127, B-59 and B-157 fields lie within the topmost/youngest sequence, i.e., S3, which has been subdivided into TST and HST packs (Jose Anthony et al, 2015). Six flooding surfaces – S3-FS-1, S3-FS-2, S3-FS-2A, S3-FS-2B, S3-FS-3 and S3-FS-4 – and a maximum flooding surface – S3-MFS – are correlated from bottom to top demarcating transgressive sands within S3 (Fig 2 and 3).

Micro-depositional environments inferred on the basis of facies association, log motifs, core analysis, sedimentological and biostratigraphic data have revealed sequence S3 to have been deposited primarily in backshore, foreshore, shoreface and offshore environments with increase of bathymetry from basin margin to basin ward i.e. from south to north (Fig 4).

The typical facies belt indicates coal-shale-sand-silt in backshore, coal-thick sand-shale in foreshore, thin sand-thick shale with almost no coal in offshore bars in deeper bathymetry. The log motif is blocky in foreshore, thin serrated for sand bodies deposited in shoreface environment and coarsening upward in offshore bars (Jose Anthony et al, 2015).

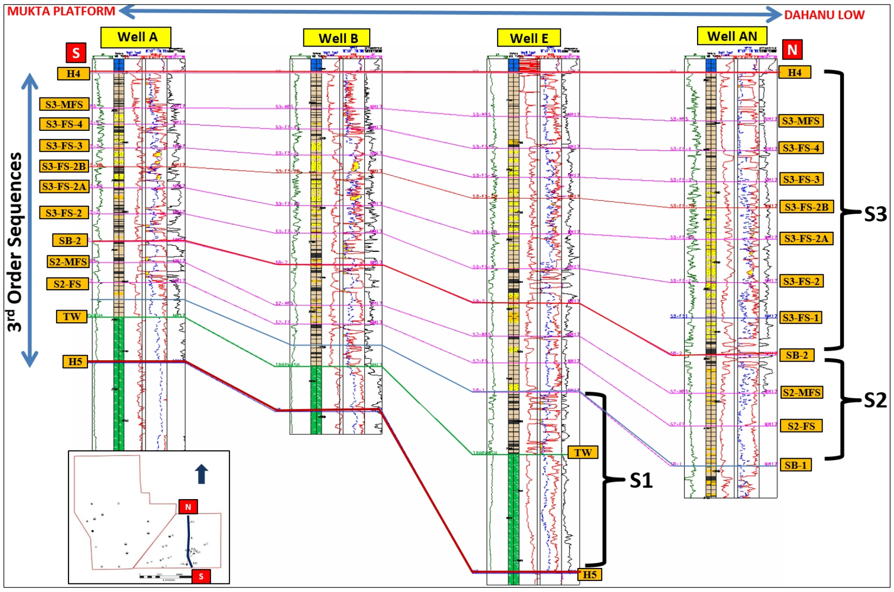

Fig 2. Sequence stratigraphic log correlation showing three 3rd order sequences along wells A, B, E and AN.

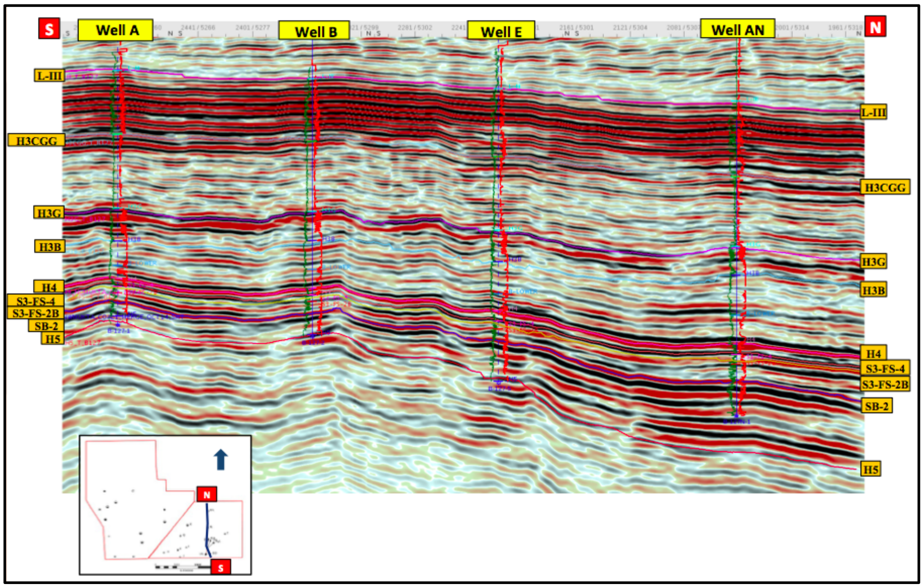

Figure 3. Arbitrary seismic section showing flooding surfaces along wells A, B, E and AN.

Well-based sand isolith maps within flooding surfaces S3-FS-2 and S3-MFS (Fig 5) were prepared. As a part of development scheme, five development wells namely, DA, DB, DC, DD and DE were drilled in B-127 area around wells A and B which further enhanced the accuracy of the model in portraying the spatial-temporal distribution of hydrocarbon bearing sands.

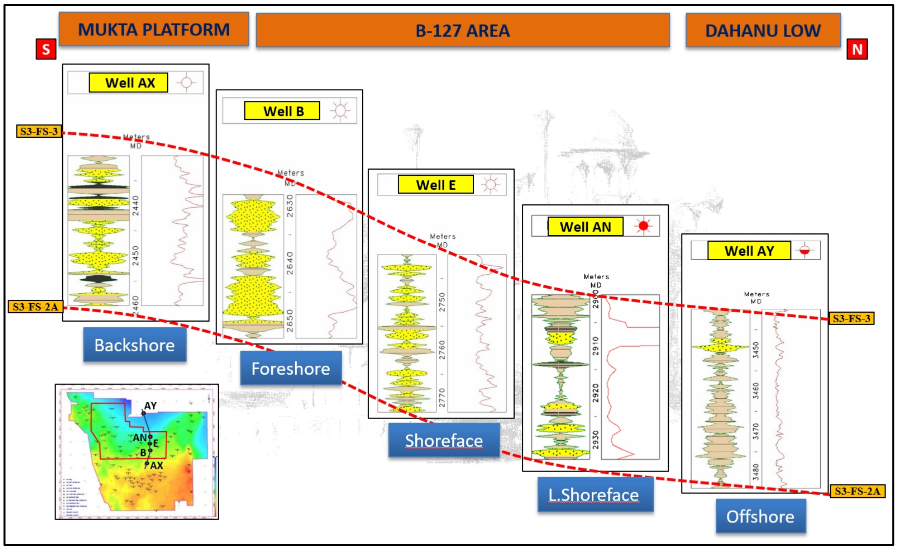

Fig 4. Log motif of depositional sub-environments.

Discrete sand bodies in the form of shore parallel bars due to the action of longshore currents are prominent. Reservoir facies are best developed as longshore sand bars close to the paleo-shoreline of each lower order sequence in almost east-west direction due to the effect of longshore currents (Fig 5).

The lateral and vertical dimensions of these sand bodies are in the range of 3000-14500 m in length, 2000-10000 m in width and 2-20 m in thickness and is in concordance with collected data from ancient successions (Reynolds, A.D., 1999).

Discrete sand bodies within the same genetic parasequences are time equivalent bodies. The occurrence of oil in structurally shallower area and gas/condensate system in structurally deeper area indicate the existence of discrete pools though occurring within same genetic parasequences. This reservoir heterogeneity has been brought out in the sand isolith maps. All these sand isolith maps also depict the shifting of paleo-shoreline from north to south as reflected from shifting of sand line progressively landward from bottommost to topmost parasequences.

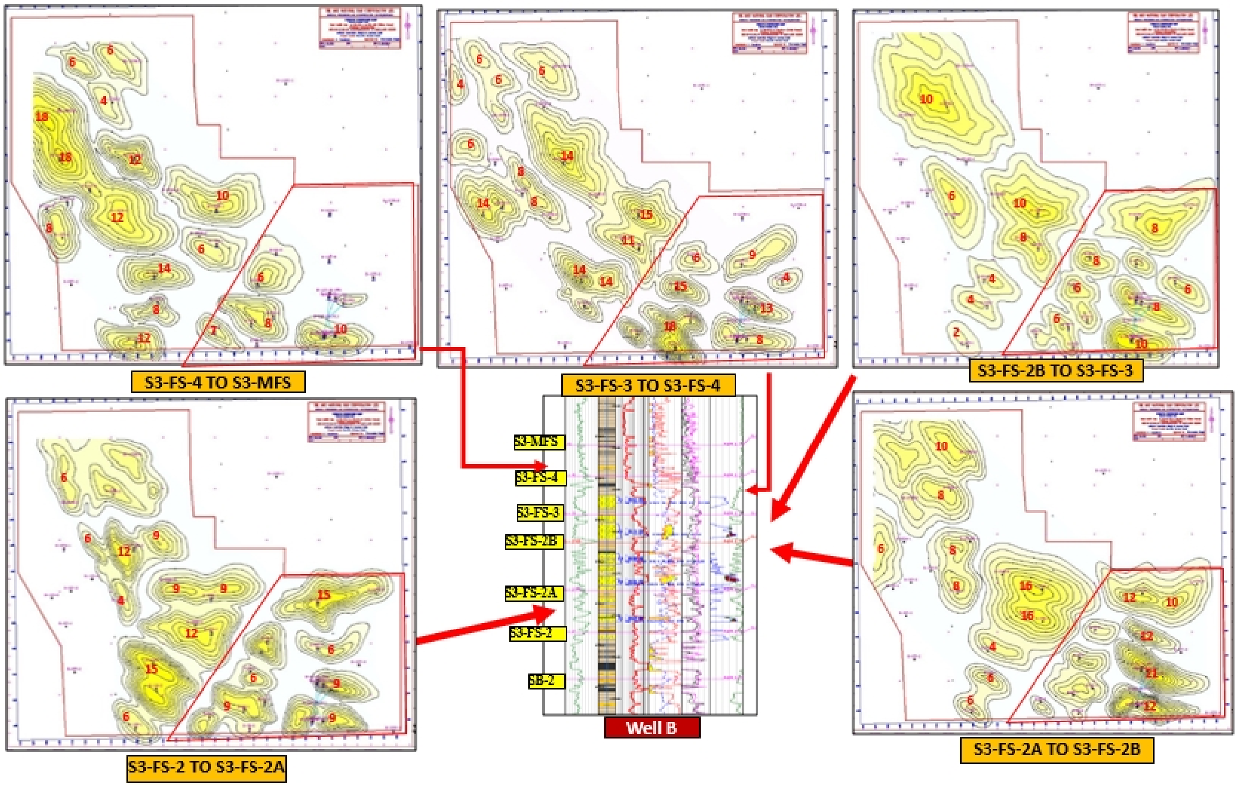

Fig 5. Sand Isolith Maps between S3-FS-2 to S3-MFS showing B-127 and B-59 fields (enclosed in polygon)

For visualizing the dimension of sand bodies, sand-isolith maps for B-127 and B-59 area were normalized and converted into 2-Dimensional trends for each zone (Fig 6). 2-Dimensional trend for SB-2 to S3-FS-2 was generated using VPC (Vertical Proportion Curve) from wells. A 3-Dimensional sand trend was generated using the normalized sand-isolith maps combined with VPC derived from actual lithofacies encountered in all the exploratory and development wells.

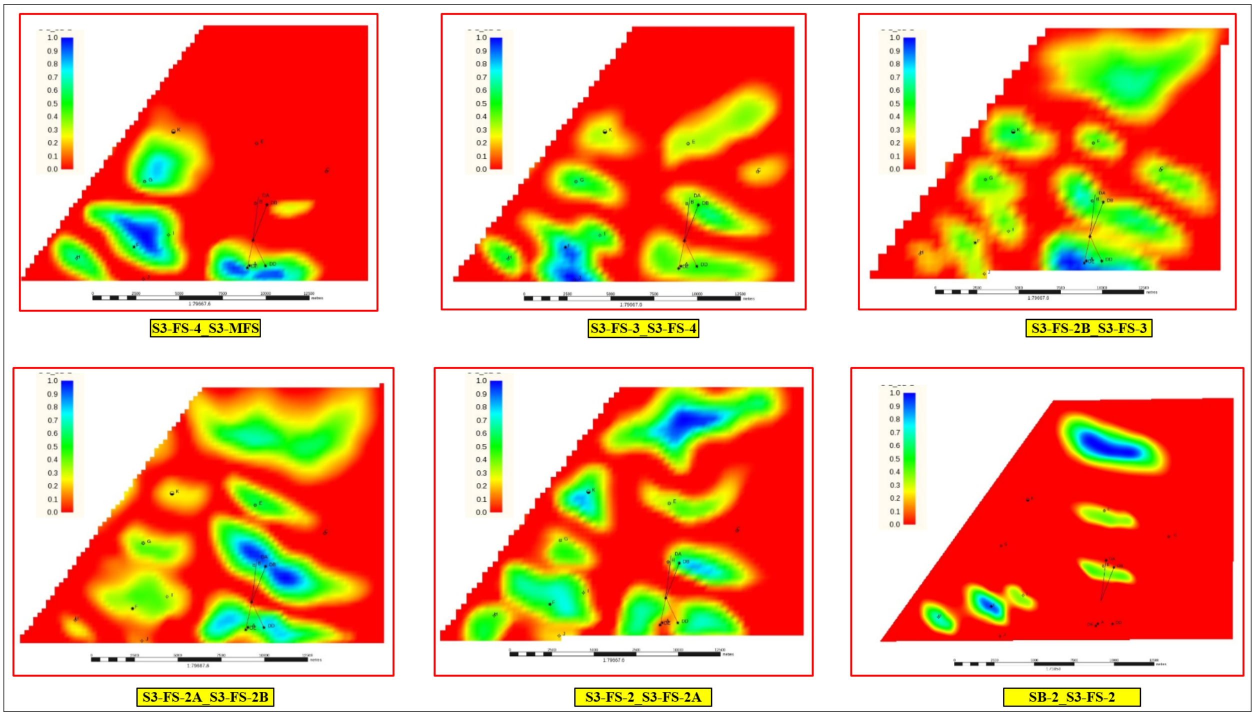

Fig 6. Normalised Sand Isolith Maps between S3-FS-2 to S3-MFS for use in 3D sand trend.

Geo Cellular Model was made for Panna Formation for B-127 and B-59 fields using five interpreted faults and four seismically mapped horizons were used as inputs. Using these interpreted seismic horizons as references, six interlayered horizons were also generated using well picks as hard data for defining the structural disposition of nine zones/ reservoir units in the grid model. Corner-point gridding method with proportional layering (consisting of 50*50m horizontal grid spacing and 1m vertical resolution) was adopted for the present model.

Facies was upscaled using and classified into two types – Reservoir (sand) and Non-reservoir (all non-sand facies) (Fig 7). Vertical Proportion Curve (VPC) derived from well data, which represent the vertical variations in the volume fraction, is used as the 1D trend (Fig 7). Variogram analysis of sand bodies did not yield good results due to the discrete nature of the sand facies in each zone. The indicator variogram parameters i.e., anisotropy directions and range were fixed taking into account the orientation and variation in facies model for each zone for both reservoir and non-reservoir facies.

Using the 3D sand trend and vertical proportion curve (VPC) as inputs, facies model for nine zones in Panna was populated using Sequential Indicator Simulation method with Simple Kriging. The workflow adopted is shown Fig 7. Facies model was populated in 292 layers from H4 (Panna Top) to H5 (Basement). Facies model shown in Fig 7 represents one layer in zone S3-FS-2A to S3-FS-2B. This zone has 20 layers.

Using upscaled effective porosity logs and the facies model as trend, porosity model was generated with Sequential Gaussian Simulation method (Fig 8).

Based on sand model integrating with distribution of HCs, the modeled B-127 and B-59 area has been subdivided into six segments -1, 2, 3, 4, 5 and 6 keeping E-W trending faults as barriers (Fig 9). Each segment encompasses hydrocarbon bearing zones having a particular hydrodynamic setting. Two segments, 1 and 2 in B-127 area have been demarcated on the basis of facies discontinuity and different hydrodynamic conditions. For each zone the Lowest Known Gas (LKG), Lowest Known Oil (LKO) and Oil Water Contact (OWC) were identified from the individual processed well logs. Saturation models for each segment were generated using saturation-height trend method and interpolating the upscaled SUWI logs (Fig 10).

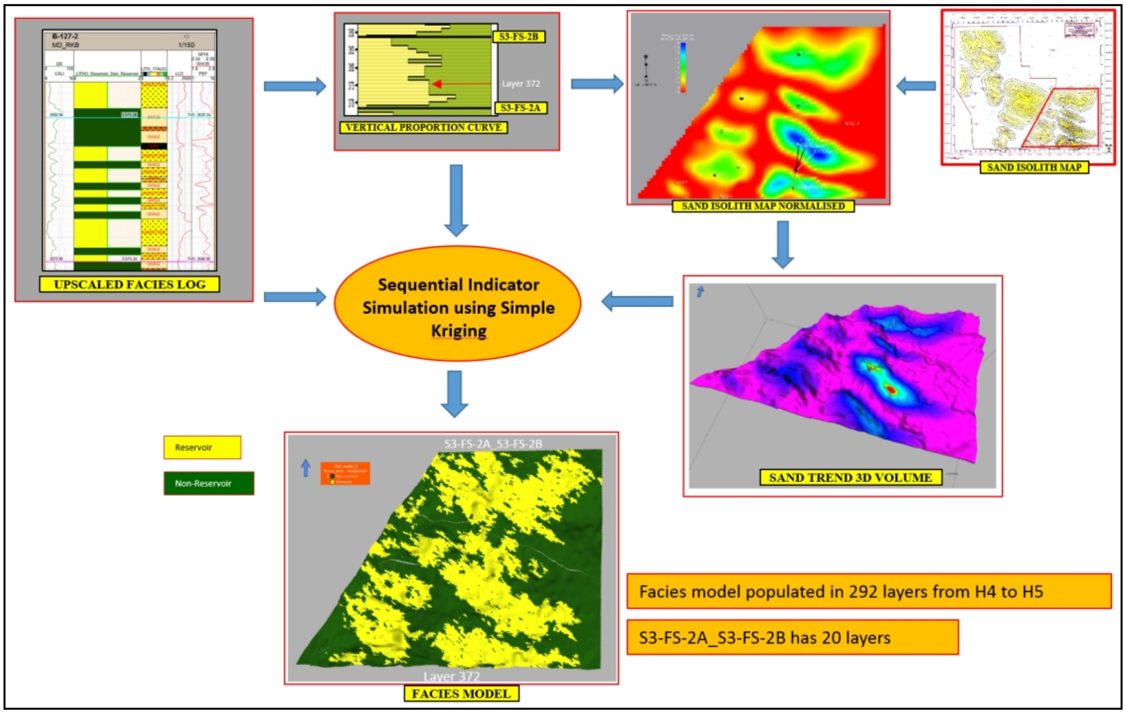

Fig 7. Workflow for facies model in GCM of B-127 and B-59 Area.

Result

Segment 1 and 2 in B-127 area exhibit different hydrodynamic conditions due to discrete nature of sands within zones S3-FS-2 to S3-FS-2A, S3-FS-2A to S3-FS-2B, S3-FS-3 to S3-FS-4 and S3-FS-4 to S3-MFS (Fig 5). The facies model generated using 3D sand trend display the inherent vertical as well as lateral heterogeneities of different reservoir units as brought out by the sand isolith maps at different zones with Panna Formation (Fig 7).

The volume estimated using this methodology gives a good end result with a high confidence level and can be an alternate way to predict hydrocarbon volumes from sand trend. The estimated hydrocarbon volumes in the static model for B-127 (Segment 1 and 2 estimated separately) and B-59 area using 3D sand trend-based facies model is very close to the oil and gas volumes earlier estimated from conventional isopay volume estimation method. With the help of this static model, the sub-surface point of a development well in B-127 field has been repositioned appropriately.

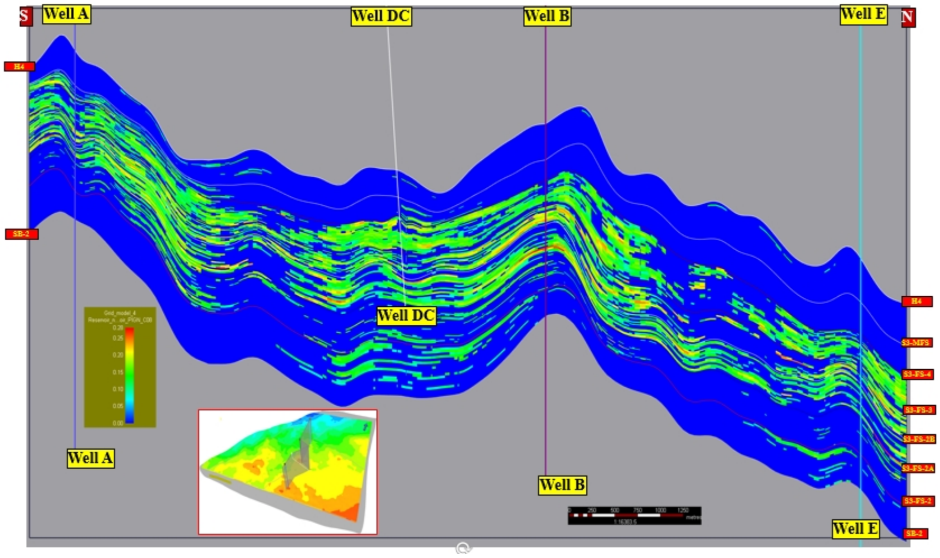

Fig 8. Regional cross-section showing porosity variation along wells A, DC, B and E.

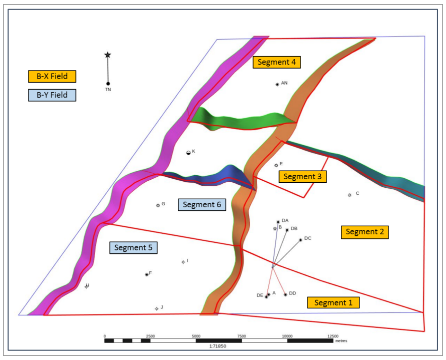

Fig 9. B-127 and B-59 Fields showing segments 1, 2, 3, 4, 5 and 6.

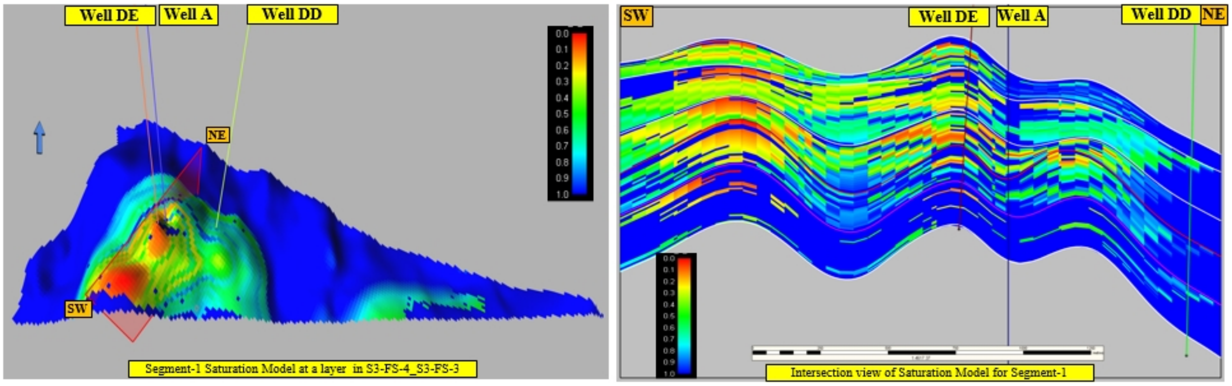

Fig 10. SUWI model and regional cross-section showing saturation variation in segment 1 (wells DE, A and DD).

Conclusion

A comprehensive workflow based on high resolution sequence stratigraphy and robust seismic data interpretation, has been suitably utilized for generation of sand isolith-based 3D sand trend for discrete sands in Panna Formation of B-127 and B-59 fields, Mumbai High, India. A facies model is created using this 3D sand body as a trend to visualize the facies and reservoir heterogeneity in a static model. The hydrocarbon volumes estimated from the static model show very close match with the already established reserve estimates using conventional methods. The static model may help devise better strategy for perforation of pay sand units in the development wells to be tested and placing of future infill locations in the best saturation area based on the new simulation model.

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