Reservoir Characterization of Mandhali Sands through Stochastic Modeling: A Case Study from Sobhasan Complex, Cambay Basin

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Summary

Sobhasan Complex comprises of Sobhasan, West Sobhasan, South Sobhasan, Mewad, South Mewad and Kherwa fields and is located in the Ahmedabad-Mehsana tectonic block. Sobhasan is the major field, discovered in 1968, in this Complex. Mandhali, Sobhasan, BCS and Kalol pays are prolific producers and entrapment situations vary from four-way closures to fault closures and lateral pinch-outs.

Geo Cellular Modeling (GCM) of the various pays of Sobhasan Complex was recently completed using advanced algorithms in both Structural and Stratigraphic modeling. Combined 3D structural model was created using Volume Based Modeling algorithm in Petrel to handle the stratigraphic as well as structural traps combining both seismic and well based information. Reservoir facies were interpreted with GR and PHI using the Artificial Neural Network process. This was subsequently utilized along with porosity and water saturation logs to propagate in the previously created 3D model using stochastic modeling techniques like Sequential Indicator Simulation (SIS) aided with geostatistical analyses like 3D variogram modeling. The conceptual facies model was first prepared using object modeling input with the Petrel based algorithm which was then used to bias the other petrophysical property distribution both laterally and vertically using Kriging and Gaussian Simulation (GRFS) methods. The uncertainty in areas far from wells was handled using the Monte Carlo Uncertainty and Optimization technique to determine the P10, P50 and P90 volumes for each of the stratigraphic zones. The study resulted in identifying locales having high hydrocarbon saturation within the known pool limits. This will help in optimal positioning development locations leading to efficient exploitation of hydrocarbon reserves.

Introduction

Cambay Basin is a narrow, elongated rift graben extending from Surat in the south to Sanchor in the north. Major cross-trends have divided this basin into five tectonic blocks. NNW-SSE trending Mehsana Horst is a prominent tectonic feature in the Mehsana tectonic block of North Cambay Basin and Sobhasan Complex is situated to its east (Fig: 1). Sobhasan Complex is flanked by Warosan low in the west and Nardipur low in the east. Hydrocarbon accumulations have been found in sands ranging in age from Paleocene to Middle Eocene, i.e. within Mandhali, BCS, Mehsana, & Kalol pays which are deposited extensively in the area and are separated from each other by shale layers of varying thicknesses. Highly variable spatial & temporal facies variations of these pay sands make their mapping a challenging task. More than 400 wells have so far been drilled in Sobhasan Complex. Integrated 3D Geo Cellular Modeling incorporating seismic, well and reservoir data has been carried out to make an accurate model of reservoir heterogeneity, formulation of

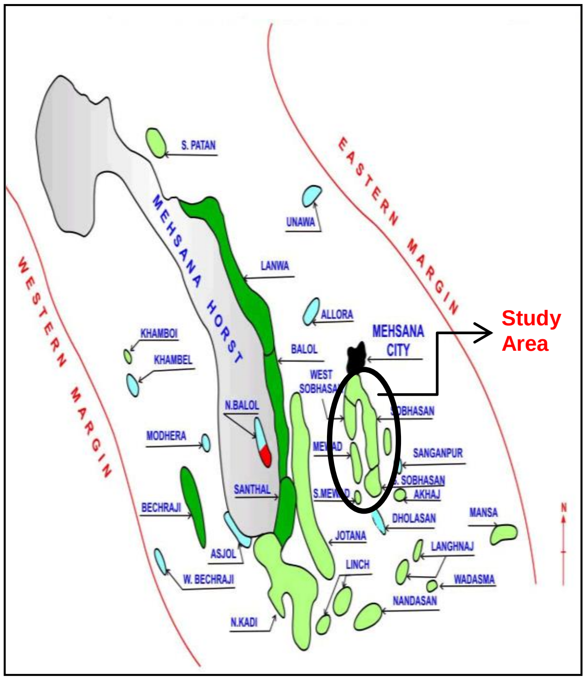

Fig 1: Index map showing Location of study area

exploitation strategy, infill drilling and improving the recovery of Sobhasan Complex fields. Though GCM was carried out for all pay sands, studies pertaining to Mandhali pays only are discussed in this paper.

General Geology and Stratigraphy

Sobhasan structure is a doubly plunging anticline whereas Sobhasan Complex comprises of Sobhasan field and five satellite fields / extensions of Sobhasan itself.

Olpad sediments were deposited under lacustrine environment during the Paleocene in the half-grabens on Deccan Trap and represent the syn-rift stage of deposition in an expanding rift system. Basin subsidence at close of Paleocene resulted in the accumulation of a thick sequence of dark grey to black shale that was deposited in anoxic conditions along-with subordinate coarser clastics. Cambay Shale was deposited over Olpad Formation during Early Eocene in brackish to marine environment. Towards the basinal part, Cambay Shale is divided into Older & Younger units, separated by the Neck-Marker/ Y-Marker which is a fine sandstone, siltstone & coal section present regionally that can be easily identified in electro-logs as well as on seismic data. Younger Cambay Shale / Kadi formation has Mandhali, Mehsana and Chhatral members, in Northern part of Cambay Basin, consisting of siltstone and thin layers of sandstone developed within an argillaceous sequence. The Older Cambay Shale has unconformable relationship with Mandhali Member in the study area (Fig: 2). Mandhali Member consists of thick fine sandstone, interbedded with coal, silty & carbonaceous shale and has eight pay units, classified as Mandhali pays-I to VIII, in the oil fields constituting Sobhasan Complex. The Lower tongue of Younger Cambay shale separates overlying Mehsana Member from Mandhali Member. Mehsana Member comprises of thick coal seams, interbedded with fine sandstone & shale, and classified as sand Mehsana Sands-I to III. The Upper Tongue overlying Mehsana Member represents a transgression of sea after regressive phase of Mehsana Member. After a hiatus, the deposition of Kalol Formation of Middle to Late Eocene age marks a regressive phase in the area. The lithology, geometry of various arenaceous members and log motifs indicate that the Kalol Formation was deposited in a river dominated deltaic environment where slope is very gentle and the surface was almost levelled out. Kalol Formation is overlain by marine Tarapur Shale of Late Eocene to Oligocene age. Post Tarapur, deposition of enormous thickness of Miocene sediments took place in the form of Babaguru, Kand and Jhagadia Formations. These were overlain by the Broach formation of Pliocene age overlain by Jambusar and Gujarat Alluvium of Pleistocene to Recent age.

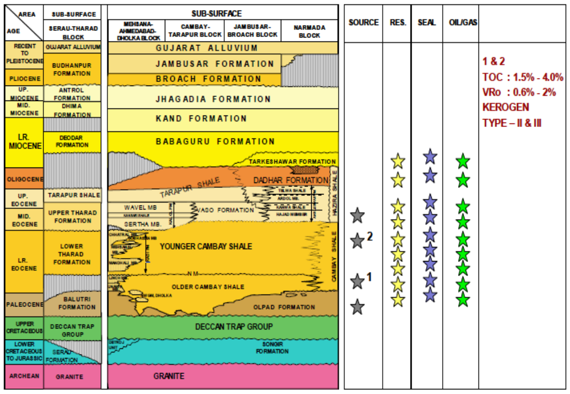

Fig 2: Generalized stratigraphy of Sobhasan field

Methodology and Discussion

Geo-cellular model of Sobhasan Complex was prepared with well tops, horizon & fault surfaces in depth domain, correlated log data, ELAN processed well logs having reservoir properties and production history as input data. Horizon and fault interpretation was undertaken on a depth migrated seismic volume which was constrained with well top markers. Using the seismic and well based studies, electrolog correlations were made to understand sand geometry as well as hydrocarbon distribution pattern. In Sobhasan Complex fields, the hydrocarbon bearing Mandhali Formation has been divided into eight units viz., MP-I to MP-8 which were further subdivided into 21 hydrocarbon bearing pay sub units. These units are MP-Ia, Ib, IIa, IIb, IIc, IIIab, IIIc, IIId, IVa, IVb, IVb2, IVc, Va, Vb, Vc, VIa, VIb, VIIa, VIIb, VIIc and VIII & IX taken together. These pay units have different reservoir properties over Sobhasan Complex area with varying spatial distribution (Fig: 3).

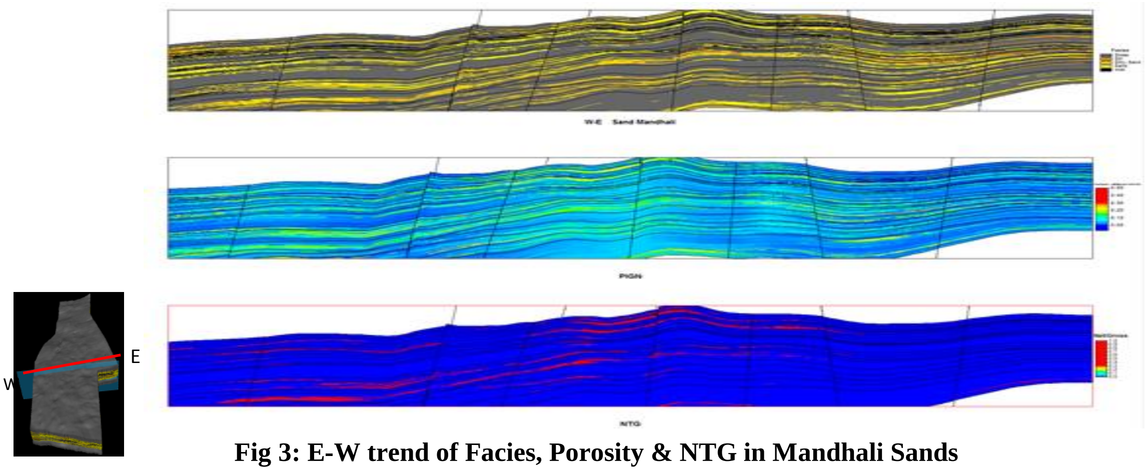

Fig 3: E-W trend of Facies, Porosity & NTG in Mandhali Sands

The following methodology was adopted for creation of an integrated 3D sealed reservoir model capturing the heterogeneity observed within the studied fields.

Structural Modeling

Structural Modeling, which is the process of creating a sealed reservoir model in 3D domain, is accomplished considering 21 horizon interpretations from the depth migrated seismic volume and 42 fault surfaces in depth domain. After the framework was created incorporating the seismic and geological interpretations, it was further subdivided into 38 smaller units called segments whose resolution was governed by the reservoir facies geometry in the particular segment. Thus the entire purpose of structural modeling was to subdivide the reservoir facies into smaller units in which the facies and petrophysical properties were to be modeled. (Fig 4).

Structural Framework: Mandhali sands have paucity of well data in deeper levels. Volume Based Modeling (VBM) was utilised in this case to handle the complex stratigraphic traps because of high variance in zone thickness moving towards the east. The VBM technology revolves around the concept of ‘implicit modeling’. This technique is very different from ‘legacy’ approaches and relies on the calculation of surfaces as ‘iso-values’ of a volume attribute which represents the gross stratigraphy of the model, usually denoted as an “implicit function”. In this case VBM provided the ability to create realistic models without needing to be concerned by the structural complexity present in the reservoir, i.e. fault configurations with crossing (X), synthetic/antithetic (Y), and non-conformable stratigraphy (presence of multiple unconformities that form complex truncation patterns).The issue of multiple non-conformable horizons, which is very difficult to deal in traditional approach, has easily been resolved with creation of refined zone model displaying the complex tectonics.

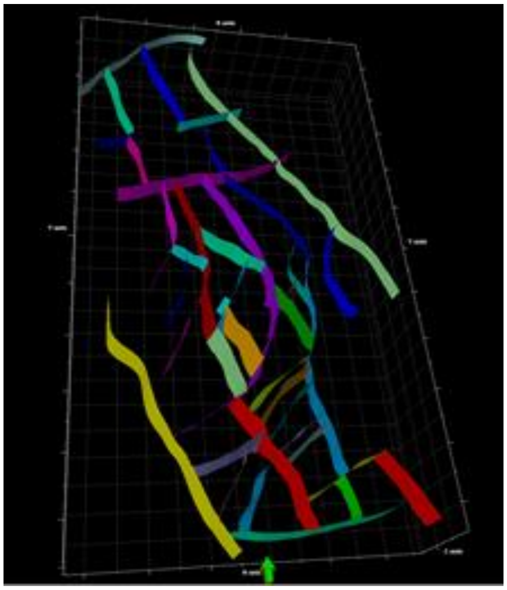

Fig 4: Fault Pattern at Mandhali level

Horizon / well marker Interpretation: In the present study, an attempt has been made to correlate different pay units in the all wells where the standard log suite is available. The pays are correlated and differentiated from each other on the basis of prominent shale markers. It is observed that within the pay units, thin shale has also developed. Therefore, the strategy adopted for correlating the different sand units has been to identify the shale layers which are developed in field scale and shale streaks which are developed locally. The field scale shale markers have been correlated as units spread laterally and the shale streaks correlated locally has been taken care while populating the reservoir properties in the fine-scale Geo-cellular model.

Zones and Layering: Twenty two surfaces were used in the make horizon process namely Mandhali top, MP-Ia, Ib, IIa, IIb, IIc, IIIab, IIIc, IIId, Iva, IVb, IVb2, IVc, Va, Vb, Vc, VIa, VIb, VIIa, VIIb, VIIc, VIII & IX. In Sobhasan Complex, Mandhali sands are well correlatable and these twenty two horizons defined twenty one zones in between them. In the make horizon process the input surfaces already generated are inserted into the 3D Mandhali grid. Layering is the process of creating the geological layer within each zone. The layers were created proportionally to capture the minimal variations in the log values. Each zone is divided into fine layers that are necessary in the subsequent processes of property modeling. In the present study the entire Mandhali unit of twenty one zones is divided into 385 fine layers in 50*50m 3D grid, making a total of 229*467*385 = 41173055 grid cells.

Property Modeling:

Data Analysis: Subsequent to scale up of well logs, the scaled up properties need to be propagated from the well location to the grid cells geo-statistically by assigning a value of the property into the grid node. Data analysis provides the geo-statistical means by which appropriate variogram is constructed in major, minor and vertical directions to study and capture the vertical and lateral heterogeneities through methods of simulation (Monte Carlo) and give a numerical description to these heterogeneities and to probabilistically predict geological uncertainties. The variogram results obtained from data analysis were used to populate the up scaled Effective Porosity (PIGN) and saturation (SUWI) processed logs.

Facies Modeling: Facies modeling was carried out subsequent to the data analysis of the facies created. Facies log was prepared manually for each well by comparing the raw logs with effective porosity & saturation observed in the processed logs. Five facies were identified and defined as follows:

Facies	**Facies Code**	**Porosity (PIGN) Range**
Sandstone	0	> 0.20
Med. grained sandstone	1	0.12 to 0.20
Siltstone	2	0.08 to 0.12
Shale	3	< 0.08
Coal	4	RHOB < 1.8

Table-1: Facies defined in the model and associated cutoffs

This facies distribution depicts multilayered discreet heterogeneity in tight Mandhali sands of the Sobhasan Complex fields. Data analysis was carried out for all the five facies i.e. sandstone, medium grained sandstone, siltstone, shale & coal for all the twenty one zones and spatial distribution results were obtained. The distribution so obtained was used for the facies modeling. The modeling was done zone wise using Sequential Indicator Simulation to calculate the best estimate of rock type by minimizing error variance.

Porosity Modeling: Data analysis was carried out on the up scaled Effective-porosity (PIGN). Effect of transformations on the data population was studied as regards Normal Score on both the properties and a value of Min 0.00 Max 0.30 for PIGN was estimated. The transform for 1D trend did not show much of correlation of the samples with respect to depth. The Normal Scored data were put to Variogram analysis. The Spherical Variogram model was used to fix-up the appropriate range in major, minor and vertical direction. Facies probability maps were used to constrain the model to honour the spatial positioning (Fig 5).

Saturation Modeling: Data analysis was carried out on the up scaled Saturation (SUWI). Effect of

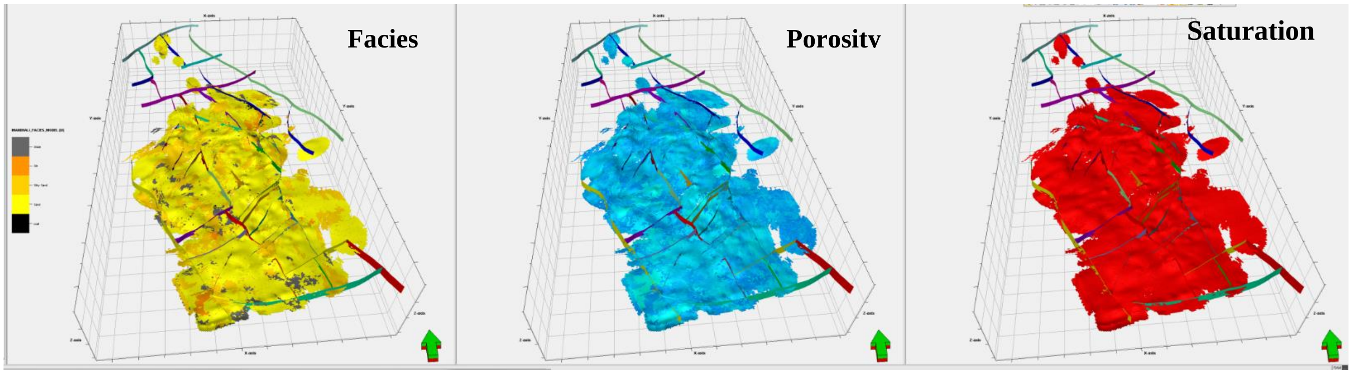

Fig 5: Property distribution in all pay sands of Mandhali

transformations on the data population was studied as regards Normal Score on both the properties and a value of Min 0.18 Max 1.00 for SUWI was estimated. In Sobhasan field, Kalol and Sobhasan pays are best developed both in terms of quality and spread. Mandhali sands are generally tight with depleted pressure and recovery is low inspite of hydro-fracturing for optimum exploitation.

In a large model, low values tend to be overestimated and high values underestimated. In the search for oil in place in a reservoir model.it is important to capture extreme values. Stochastic simulation methods were used for capturing heterogeneities of the subsurface by assessing its spatial variability based on well data and additional production data (Fig 6). Areas outside the estimated saturation pathways where similar trends are expected to extend assume importance and need to be analyzed for their suitability for further exploration.

NTG: Net to Gross property was prepared using calculator and by applying porosity and saturation cutoffs derived from lump plots.

The results thus obtained for each zone of Mandhali sands were analyzed and volume maps were prepared. These maps were also validated with available production data from Mandhali pay sands.

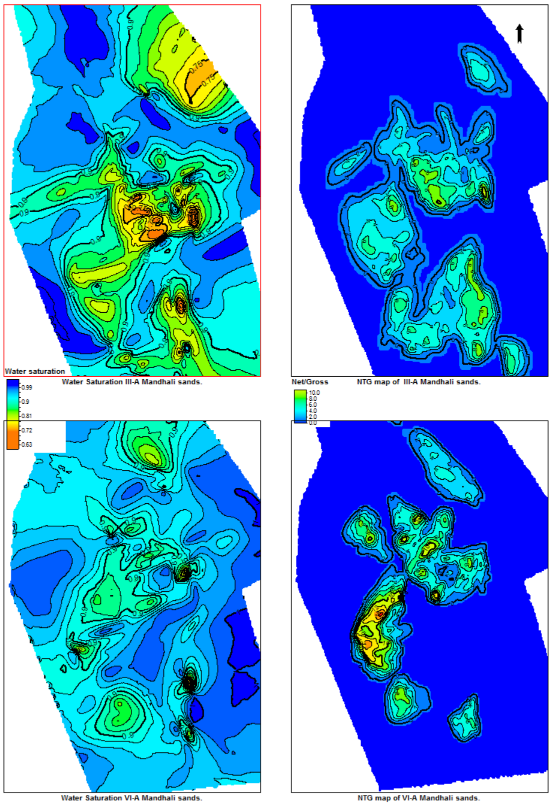

Fig 6: Sw and NTG maps of Mandhali sands IIIA and VI A

Conclusions:

An integrated study of Sobhasan Field has been carried out for reservoir characterization combining 3D seismic, petrophysical, geological, and reservoir data leading to the formulation of a Geo-Cellular Model (GCM) for Sobhasan Complex pay sands (Kalol, Mehsana, BCS & Mandhali pays) for the first time using refined fault pattern and ELAN processed logs. The structural and fault configurations were derived from 3D seismic data and reservoir properties from petrophysical and reservoir data from drilled wells.

In preparation of GCM for Mandhali sands, 22 surfaces, 21 zones, 385 layers were made to characterize horizontal and vertical distribution of porosity and saturation for all 21 pay sands utilizing more than 41 million cells. The study indicated an increase of 12% in-place reserves for Mandhali sands.

This integrated GCM will be used for simulation study. The lateral and vertical heterogeneity captured through this study serves to identify good sectors from bad ones in the previously estimated homogeneous area. This allows better placement of locations for infill drilling and to minimize quantum of bypassed oil. The results from this study are expected to result in formulation of suitable exploitation strategy for Mandhali sands including restoration of reservoir health and improvement in recovery factor.

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