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Reservoir Characterization through Stochastic Modeling in Complex Tectonic Regimes: A Case Study from Gamij Field, Cambay Basin

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Abstract

The Gamij field is flanked by Walod Low in the West and the basin margin of Cambay basin to the East. Cambay basin is an intra-cratonic, NNW-SSE trending narrow, elongated, rift basin located in the NW margin of Indian Precambrian Shield. This basin is bounded by step-faults in the Eastern & Western margins. The major cross-trends have divided this basin into five tectonic blocks from south to north. Sediment thicknesses gradually decrease from the low in the west to the basin margin in the East. The hydrocarbon is housed in several compartments in various sands. Besides structural accumulations, the aerial limit of hydrocarbon entrapment also is in the form of fault seals and pinch outs laterally.

The complex combination traps encountered in this field were thus subsequently modeled in the present study using the latest advanced algorithms in both Structural and Stratigraphic modeling. The existence of the thin bedded reservoir facies was validated by well correlations which were then integrated with seismic interpretation of the tectonic faults. Structurally, Gamij is a rollover anticline against the N-S trending basin margin major fault (F-9). These faults have influence on migration and accumulation of hydrocarbons in the Gamij field. The 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.

The reservoir facies were interpreted with GR and PHI using the Artificial Neural Network Process. The facies was subsequently propagated along with porosity and water saturation logs in the previously created 3D model using stochastic modeling techniques like Sequential Indicator Simulation (SIS) aided with geostatistical analyses using 3D variogram modeling. The facies model was prepared first using conceptual 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. Regions of high hydrocarbon accumulation were identified within the previously broad areas and high accumulations in some zones were recognized which have subsequently been validated by the newly drilled wells.

Introduction

Gamij field, located 15 Km WNW of Ahmedabad city in the Ahmedabad-Mehsana Tectonic Block of Cambay Basin covers an area of more than 300 square km. Gamij field was discovered in 1982. Subsequent exploration/development effort of the field indicated K-VI, K-VII to be extensive over the field having good potential of oil production even from relatively low resistivity log response. The field was put on production in 1994.

Hydrocarbon accumulations have been found in sands ranging in age from Paleocene to Middle Eocene, i.e. within Olpad, YCS, Chhatral and Kalol Formations (K-III to K-X). Although Chhatral, K-VI & K-VII sands are deposited extensively in the area and are separated from each other by shale layers of varying thicknesses, their highly variable spatial & temporal facies make their mapping a challenging task. Presently, Chhatral member within Younger Cambay shale holds a major component of the hydrocarbon of Gamij field. With the acquisition of 3D seismic data in 2001, the exploration and development activity in the field received a boost and more than 130 wells have been drilled till date. It has thus been considered for integrated 3D Geo-Cellular Modeling to incorporate seismic, well and reservoir data to make an accurate model of reservoir heterogeneity.

General Geology and Stratigraphy

Gamij field is flanked by Walod Low in the West and the basin margin of Cambay basin to the East. Sediment thicknesses gradually decrease from the low in the west to the basin margin in the East. The Olpad sediments were deposited under lacustrine environment during the Paleocene in the half-grabens on Deccan Traps 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, the Cambay Shale is divided into Older & Younger Cambay Shale, separated by the Neck-Marker; an unconformity marker present regionally that can be identified in electro-logs as well as on seismic data. The Cambay Shale is grey to dark grey, fissile & laminated. The Cambay Shale thickness is around 350m in the western part of the study area but thins out towards the Eastern margin to about 100 m. Pay-zones consisting of sandstone/siltstone, encountered at the lower part of Younger Camber Shale (undifferentiated Mandhali & Mehsana members in the presently studied area) and Chhatral member within the upper part of Younger Cambay Shale consist of siltstone and thin layers of sandstone developed within an argillaceous sequence.

After a hiatus that was marked by tectonic activity, the deposition of Kalol Formation, of Middle to Late Eocene age, marks a regressive phase in the area. The Kalol Formation overlies the Cambay Shale and consists mainly of mature, fine grained, moderate to poorly sorted sandstone / siltstone and silty shale with several coal bands out of which, K-X & K-IX coals are regionally mappable.

The Kalol Formation is overlain by marine Tarapur Shale of Late Eocene to Oligocene age. Subsequent tectonic activity in the basin resulted in the development of a widespread unconformity. The deposition of enormous thickness of Miocene sediments took place as the Babaguru, Kand and Jhagadia formations. Sand and shale were deposited during the Pliocene, whereas During Pleistocene to Recent, the sedimentation was mainly fluvial represented by characteristic deposits of coarse sands, gravel, clays and kankar followed by finer sands and clays, comprising Gujarat Alluvium. (Fig. 1)

Tectonic Framework and Structural Styles

Cambay basin an intra-cratonic, NNW-SSE trending narrow, elongated, rift basin located in the NW margin of Indian Precambrian Shield. This basin is bounded by step-faults in the Eastern & Western margins. The major cross-trends have divided this basin into five tectonic blocks from south to north viz; i) Narmada-Tapti Block, ii) Jambusar-Broach Block, iii) Cambay-Tarapur Block, iv) Ahmedabad-Mehsana Block, v) Patan-Tharad-Sanchor Block**.** The study area falls in Ahmedabad-Mehsana Block in North part of Cambay Basin.

Ahmedabad-Mehsana tectonic block is demarcated by Nandasan fault in the north and Vatrak fault in the south. Gamij field is located SE of Kalol field, along eastern basin margin. Structurally, Gamij is a rollover anticline against the N-S trending basin margin major fault (F-9). This structure can be sub-divided into three sectors namely, i) Northern sector, ii) Central sector, iii) Southern sector which are separated by two cross trends F-21 and F-22. These faults have influence on migration and accumulation of hydrocarbons in the Gamij field.

Methodology

Gamij has twelve producing sands with varying aerial spread over the field. In order to prepare the integrated Geo-cellular model, the input data requirements are: horizon and fault surfaces in depth domain, processed well logs having reservoir properties, reservoir definition in depth correlated log data and production history. The seismic horizon and fault interpretation was undertaken on a depth migrated volume which provided the constraints for the well markers. Using the seismic and well based interpretations as well as well logs, the following methodology was followed for creation of an integrated 3D sealed reservoir model capturing the heterogeneity of the field.

Structural Modeling

Structural Modeling is the process of creating a sealed reservoir model in 3D comprising of the faults and horizon interpretations from the depth migrated seismic volume. The interpretations being all done in the depth domain velocity modeling was not required and the entire 3D structure was created in depth. After the framework was created incorporating the seismic and geological interpretations, it was further subdivided into smaller units called cells whose resolution was governed by the reservoir facies geometry in the particular zone. 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.

- **Horizon/Well Marker Interpretation:** In the present study, an attempt has been made to correlate the different pay units in all the 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 the present study 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.(Fig. 2)

- **Structural Framework**: 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 was very difficult to deal in traditional approach, has easily been resolved with creation of refined zone model displaying the complex tectonics.

- **Zones and Layering:** In the make horizon process the input surfaces already generated are inserted into the 3D grid. Eighteen number of surfaces were used in the make horizon process namely Kalol top, Oolite top, Oolite bottom; sand K-III top, sand K-IV top, sand K-V top, sand K-VI top, sand K-VII top, sand K-VIII top, sand K-IX top, sand K-X top, Cambay Shale top; Chhatral top, Chhatral bottom; YCS top, YCS bottom, Olpad top and Trap top.
  In the make horizon process eighteen stratigraphic surfaces were created. These eighteen horizons also define sixteen zones in between them. Model top is defined as Kalol top and the model bottom is Trap top. Totally sixteen zones in between the eighteen surfaces have between classified. Applying this process will enable sixteen zones in the model for all subsequent processes and computations
  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 unit of sixteen zones is divided into 248 fine layers. The sands Oolite, K-III to K-X, Chhatral, YCS and Olpad were layered proportionally

Property Modeling:

- **Data Analysis:** Subsequent to scale up 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 Simulation) and give a numerical description to these heterogeneities and to probabilistically predict geological uncertainties. The variogram results obtained from data analysis was used to populate the up scaled saturation (SUWI) and Effective Porosity (PIGN) by Kriging Interpolation method.

- **Facies Modeling:** The facies distribution depicts multilayered discreet heterogeneity in the Gamij field. Data analysis was carried out for all the seven facies i.e. sandstone, medium grained sandstone, fine grained sandstone, very fine grained sandstone, siltstone, shale and coal. For all the sixteen zones the 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.

- **Porosity Modeling:** Data analysis was carried out on the up scaled Effective-porosity (PIGN). An 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: 0.38 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.

- **Saturation Modeling:** As regards saturation, the Gamij field being a marginal field with a production history of 17 years. Data analysis was carried out on the up scaled Saturation (SUWI). An effect of 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. The model shows that, Chhatral and Kalol-VI pays are best developed both in terms of quality and aerial extent in the Gamij field. All twelve pay zones in this field are undersaturated reservoirs. The results from volumetric estimates were seen to be reasonable and an improvement over earlier estimates.

Conclusions:

An integrated study of Gamij Field has been carried out for reservoir characterization combining 3D seismic, petrophysical, geological, and reservoir data.
Integrated Geocellular Model (GCM) has been prepared for Gamij (Oolite pay, K-III to K-X pays, Chhatral, YCS and Olpad pay) pay sands for the first time using refined fault pattern and ELAN processed logs. All these 12 pays are undersaturated reservoirs.
In preparation of GCM, 18 surfaces, 47 faults, 43 segments, 16 zones, 248 layers and 1,17,73,056 cells were made to characterize horizontal and vertical distribution of porosity and saturation for all twelve pay-sands.
The structural configuration worked out on the basis of 3D seismic study was used in the present work. Several faults were mapped in Gamij. The fault pattern is used as one of the main input for the Geocellular Model.
On the basis of fault configuration, Gamij field is divided into forty three blocks / segments. Some of these blocks / segments are not in communication; faults are considered sealing in nature in such cases.
The in-place volumes estimation for Gamij field; for Oolite pay, K-III to K-X pays, Chhatral, YCS and Olpad pay sands was carried out and has resulted in an increase in the Initial Oil and Oil equivalent Gas volumes by approximately 28% over previous estimates. The accretion is mainly from Chhatral pays of Lower Eocene age.

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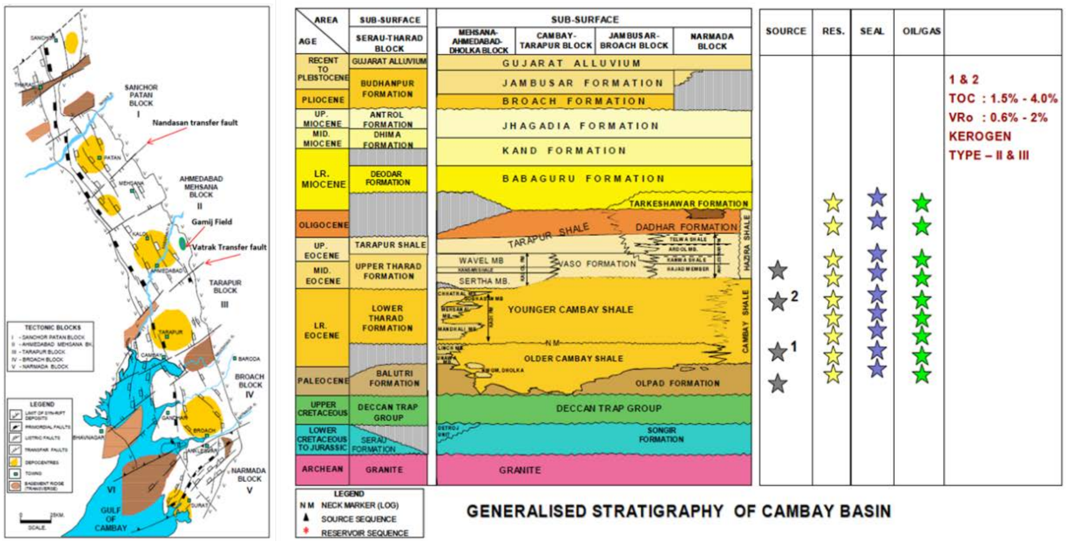

Fig 1. Tectonic Map of Cambay Basin and General Stratigraphy of the region

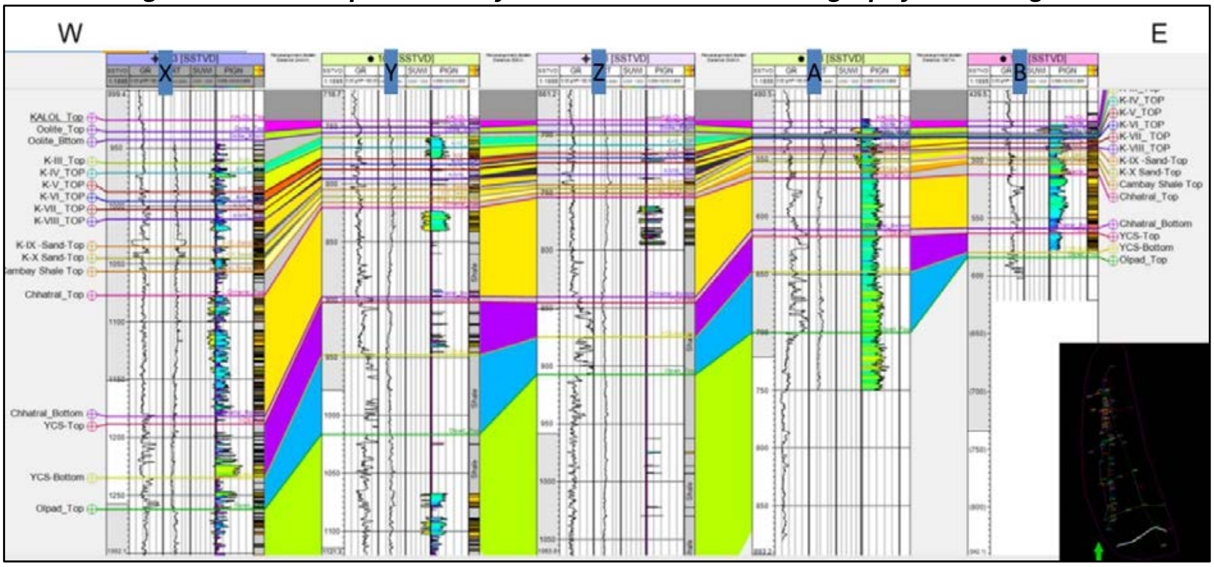

Fig 2. Electrolog Correlation of the sand units across the field

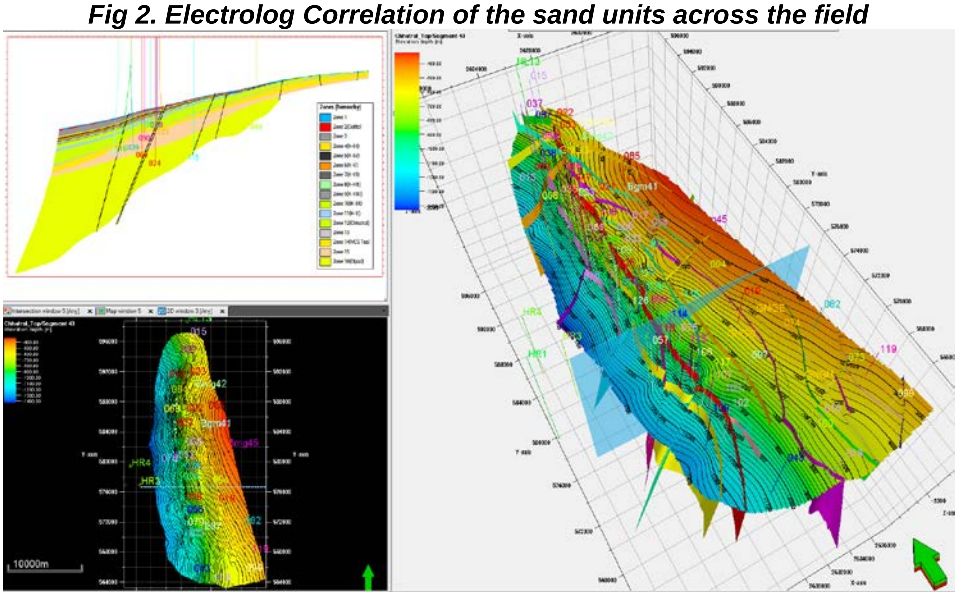

Fig 3. Structural Model showing Cross Section of Zones, Structural Map at K-III top with associated faults

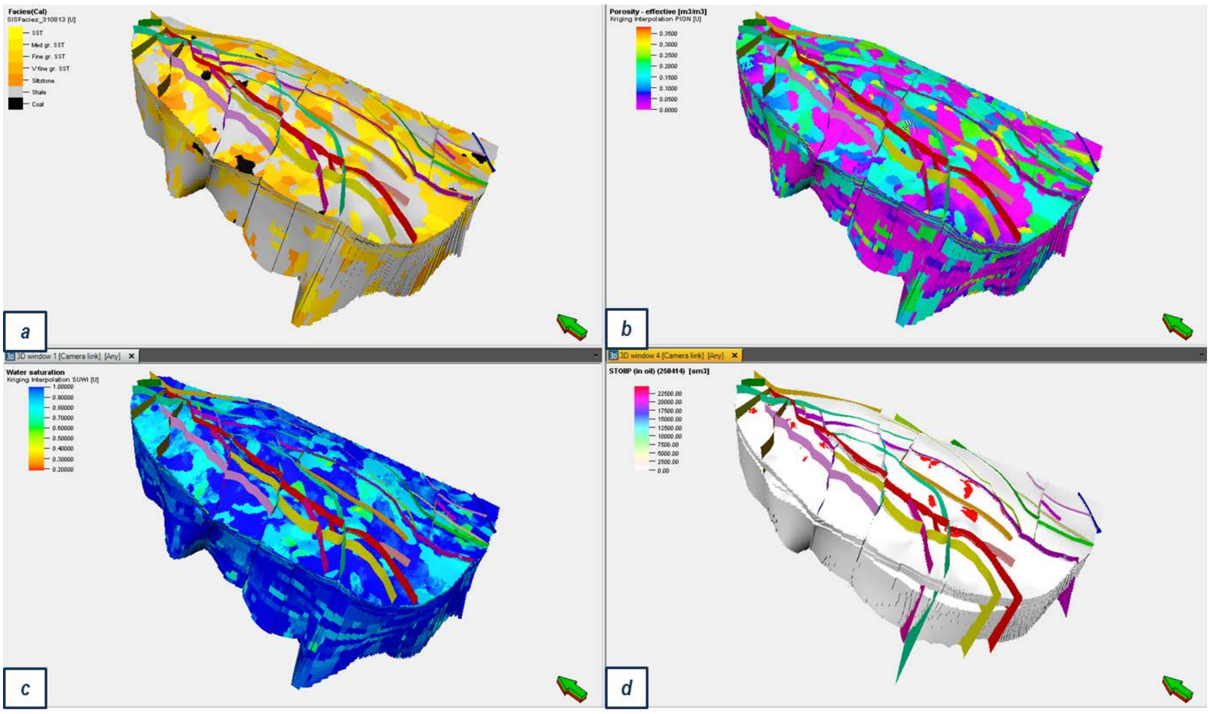

Fig 4. 3D Property Models of a) Facies b) Porosity c)Water Saturation d) Net to Gross

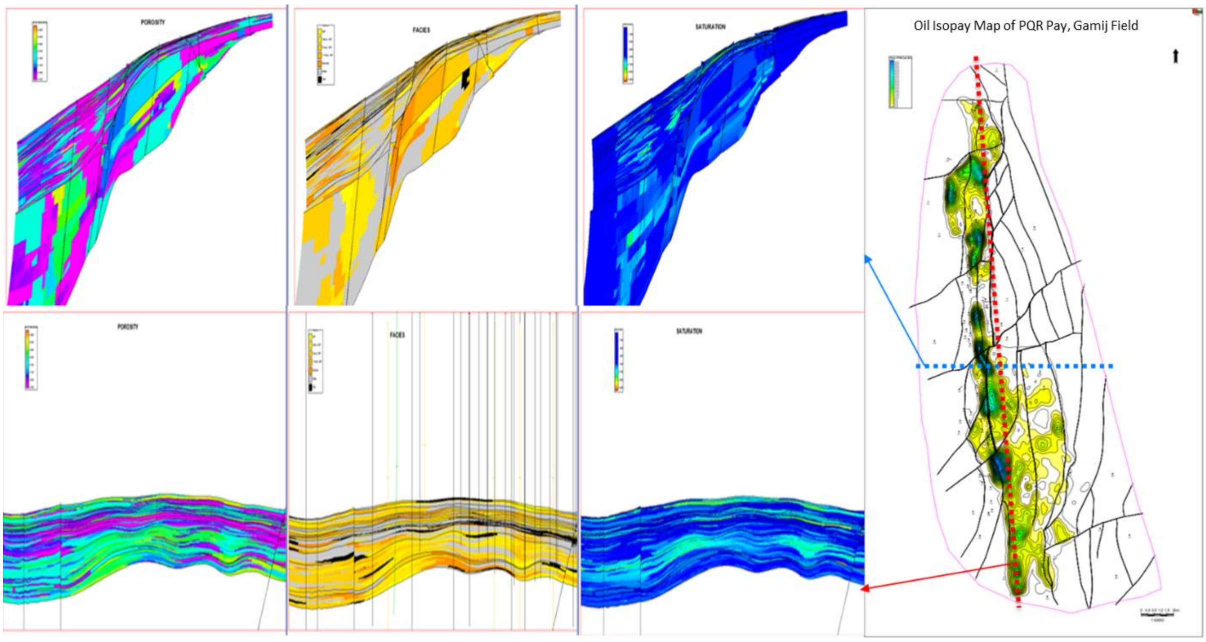

Fig 5. Sections showing Porosity, Facies and Saturation variation in the study area. The Map is given as reference.