Application of G&G concepts in 3D Geocellular modeling

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Abstract

3D Geocellular model (GCM) involves data integration through application of G&G concepts and experiences. Conceptual G & G models describe essential features of geological situations, explain the primary processes of the petroleum system, and provide important information about reservoir characteristics of the field under study. These conceptual models are being used as the key input for 3D reservoir Modeling. A fully integrated GCM consists of three stages: construction of structural model, designing facies & petrophysical model and volumetric estimation. These processes require integration of geological, geophysical, petrophysical, reservoir along with production data into a comprehensive model describing the physical features of the geologic system. Data driven model without proper G&G concept never completes as a realistic reservoir model, fails in predicting HC Inplace, recoverable reserve and production forecast with high degree of accuracy.

This paper briefly describes the process of integrating G&G data to make conceptual model and its application in building Geocellular Model. The importance of integrating Data with concept in the 3D reservoir models has been demonstrated through an example of siliciclastic Mid Eocene reservoir of Gandhar Field, Cambay Basin. This reservoir has distinct internal sedimentary distribution and stratigraphy which leads to high subsurface uncertainties. The study shows how conceptual G&G model helps in integration/interpolation of input data through geostatistical principles in static 3D reservoir model. Applicability of conceptual model & appropriate geostatistical technique have been validated through QC, result of infill wells from reservoir & production performance data. Therefore, the successful application of appropriate G&G conceptual model is critical for better 3D reservoir characterization and Modeling which enables to identify and rank the key reservoir uncertainties and assess their impact, establish interdependency of spatial property distribution, make volumetric assessments, optimize recovery efficiency and obtain reliable production forecasts.

Key words: Geological & Geophysical (G&G), Geo cellular Model (GCM)

Introduction

3D Geocellular Model is a synthetic earth model involves G & G data integration which is used as predictive tool for HC Inplace, recoverable reserve and production forecast with high degree of accuracy in E&P business.

Some of the most common uncertainties in the Geocellular Model are: the limited data and its quality, multiple possibilities of the geologic interpretations, reservoir geometry, areal extent and thickness variations which lead to uncertain reservoir characterization. Despite the effectiveness of stochastic simulation in recent years, most of the stochastic models suffer due to lack of geological understanding. Most of these 3D reservoir models do not incorporate the G&G concepts qualitatively. As a result, there is mismatch between actual and synthetic model in both brown as well as green fields. In some cases, geoscientific and engineering data are not enough else geostatistical techniques are not appropriately utilized. All these aspects contribute to poor assessment of subsurface uncertainties and it remains a key issue for any 3D reservoir Modeling (J. Cavero et al., 2016). Data driven model without proper G&G concept never completes as a realistic reservoir model, fails in predicting HC Inplace, recoverable reserve and production forecast with high degree of accuracy.

Objective

Preparation of conceptual G&G model interpreting paleo-depositional settings, structural elements, sedimentary system, reservoir areal extent & thickness, porosity and permeability and integrate them to build realistic 3D reservoir model.

Methodology

An integrated GCM consists of at least three stages: construction of structural model, designing of facies & petrophysical model and volumetric estimation. This quires incorporation of the proper conceptual G&G model in the integrated 3D reservoir Modeling work-flow through use of appropriate geostatistical techniques. G&G knowledge is used as a guide to construct the 3D reservoir model(s) at different stages.

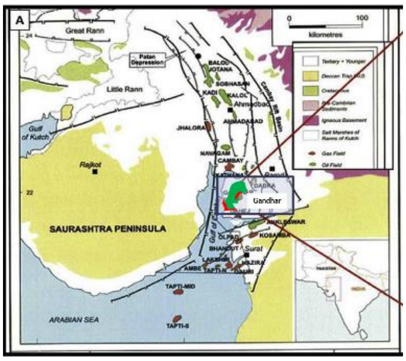


Figure 1a): Study area within Map of Cambay Basin

GCM-An effective tool to build reservoir Model

Geocellular Model (GCM) provides the best mechanism for linking all the existing data. It estimates the intrinsic dependencies between the input parameters, and provides quantification or visualization of the spatial correlation and variabilityof the uncertainty. Now a days, efficient 3D simulationhas become an essential part of normal explorationand production activities. To demonstratethe application of conceptual model, an example of a siliciclastic reservoir, deposited in fluvial-deltaic sequences, is illustrated.

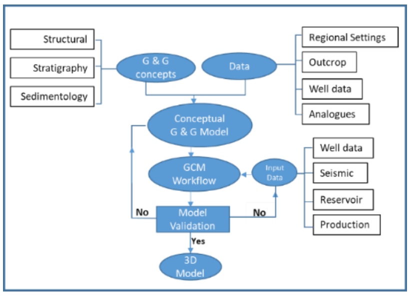


Figure 1b: The workflow of integrated GCM.

Geocellular Model of Gandhar Field, Cambay Basin

Cambay Basin is a pericratonic rift basin along western continental passive margin of India and Gandhar Field is located in South Cambay Basin (Fig.1a). The basin experienced different stages of extensional tectonic episodes, essentially confinedto Cenozoic era and related stratigraphic evolution.The stratigraphic setup principally facilitates the maturation of Lower Eocene source facies i.e. CambayShale and distribution of various play style within prime reservoir clastic facies of Ankleshwar formationof middle Eocene age. Hazad Member lies in bottom part of Ankleshwar formation having development of 13 stacked reservoir sandstone units (GS-0 to GS-12) within the Hazad Member, each containing a separate hydrocarbon pool separated by intra-formational shales.

Hazed pays are deposited on a fluvial/tide dominated delta and comprises a sequence of fine to coarse-grained, argillaceous sandstones and siltstones, interbedded with grey to greenish grey shales that are locally carbonaceous. Hydrocarbon is mainly controlled by strati-structural entrapment as up-dip pinch-out.

Gandhar field has reached at matured phase of production where comprehensive reservoir model is really essential to access the remaining potential of field for formulating a development strategy. Prior to making Geocellular Model (GCM), focus is given for preparation of conceptual G&G Model.

Conceptual G&G Model

During initial phase of model building, conceptual models are built based on G&G data & concepts. These conceptual models represent geological objects spatially in terms of their physical features based on evidences and or analogues. They incorporate possiblescenarios of structural/stratigraphic configurations, depositional systems, geochemical factors, thermal evolution and distribution, seal and trap evolution etc. Construction of conceptual model is in fact a non- linear and complex process which involves applicationof geological rules and geologist's experience and in turn helps to build a geologically consistent 3D reservoir model (Fig.1b).

Building of a fully integrated conceptual modelinvolves at least four stages: construction of structural, stratigraphic, sedimentary and diagenetic facies models. Depending on the complexity of the field, it can relate to the components for each geological entityto specific objectives and to a set of key uncertainties that are required to be analyzed.

The major challenges in building the Conceptual Geological Models lie on the availability of the input data/information (e.g. core, logs, seismic, analogues, etc.) from different disciplines with the variable scale of resolution (micro to mega) and associated uncertainties, lack of enough geological knowledge, proper data integration, geologic interpretation for the quantification of vertical and lateral reservoirheterogeneities.

Structural component

This component incorporates the spatial positions of major boundaries of geobodies, faulting, folding, and erosion etc. to define the framework of the traps, seals and reservoirs. These structural components might have control on the sedimentation trends as depositional systems are guided by peleo-depositional settings. Integration of regional tectonic setting, outcrop evidences, structural configuration from 2D/3D seismic, play and analogues fields and geologic data from wells define the possible structural scenarios for area under study. Velocity is one of the key parameters which affect the seismic imaging of the subsurface in time or depth. Velocity uncertainty together with reservoir top/ base interpretation uncertainty can have high impact on the structuralconfiguration, gross and net reservoir thick-ness away from well control areas and hence gross rock lume estimation. Depending on the velocity uncertainty combined with prior geological knowledge,

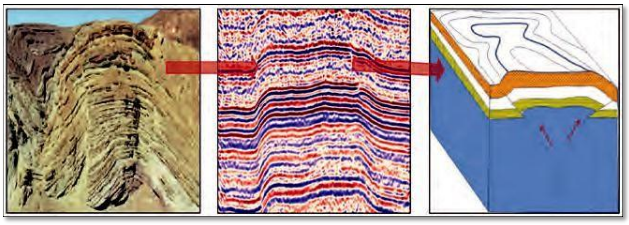


Figure2: Illustration showing the tectonic factors, structural framework and elements to define the type of traps. A real structural object from the outcrop (Source: Wilson, 2010) is used as analogue to make correlation with 3D seismic data for creating the 3D structural framework of geological model

single or multiple structural scenarios can be defined. For this example, using enhanced 3D Pre-stack Time Migrated (PSTM) seismic data, well-to-seismic tie and VSP data at key wells, seismic interpretation was carried out for defining the structural configuration of the study area. The interpreted reservoir top and base time horizons were depth converted using a 3D velocity model built integrating Check-shots/VSP and seismic velocities. The conceptual structural model (Fig.2) was interpreted as normal faults bounded by a structure generated by extensional regime which has undergone inversion tectonics. Due to good number of drilled wells and available velocity data, the structural component does not carry high uncertainties. Therefore, the only single structural framework was used as input in creating the 3D static model.

Structure contour and isopach maps are as essential as a stratigraphic correlation for interpreting basin history. They may or may not contain much direct paleogeographic information, but they are required in order to illustrate basin shape and orientation and basin-fill geometry.

Stratigraphic component

Identifying the stratigraphic sequences variability and complexity, their hieratical orders and stacking patterns require more specific data and the robust methodologies to make flexible stratigraphicinterpretation (Catuneanu, 2011).

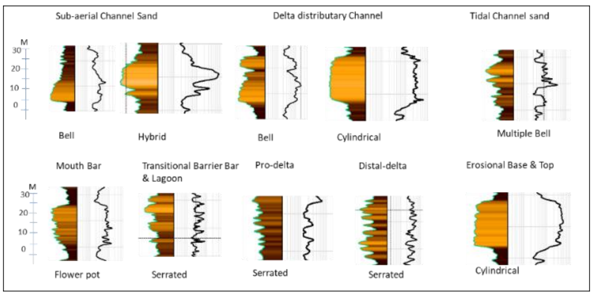


Figure3: Log shapes suggesting of depositional environment of Hazad Sands, Gandhar Field

Establishing the linkbetween lithology and stratigraphic sequences is primarily essential. Additionally, the stratigraphic sequences types and their areal distribution are alsothe most critical information required for defining the 2D/3D geological models.

Interpretation of depositional environments from Electrologs (Gamma ray & SP Logs) have been used successfully in conjunction with other diagnostic criteria. Due to high data density of drilled wells, paleogeography reconstruction becomes easy in basinal scale. Shifting of facies belts in response to a rise/fall in relative sea-level are depicted in dispersion pattern of sediments and log features resemble the change.

Various log motifs of Gandhar Field pertaining to Hazad members were studied in details in context of sequence stratigraphy and they have shown progradational, retro-gradational and aggradational pattern (Fig.3). The sand distribution in the Gandhar field is maximum for the GS-9 level (maximum procreation), whereas the GS-9 to GS-12 sandstone units show a gradually declining sand distribution indicating the onset of rise in relative sea-level.

Sedimentary components

Regional sedimentary trends, 2D/3D seismic data, analogues and public databases are used to interpret the sedimentary trends including facies and their association.

Facies interpolation is most critical process of Geocellular Modeling as stochastic simulation cannot correctly capture the channel geometries of fluvial systems and may produce unreasonable geological features in the stochastic facies model. Equiprobable simulation outcomes need to be explained geologically to get a realistic facies model. Therefore, conceptual facies model is used as input in Facies Modeling of GCM. Quantitative as well qualitative interpretation of well logs help in making conceptual model which was carried out for Hazad sands of Gandhar Field.

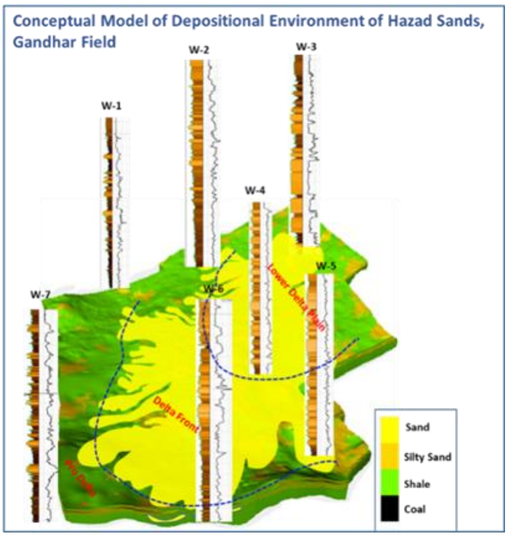


Figure4: Conceptual model for regional depositional environment of Hazad sands, Gandhar Field.

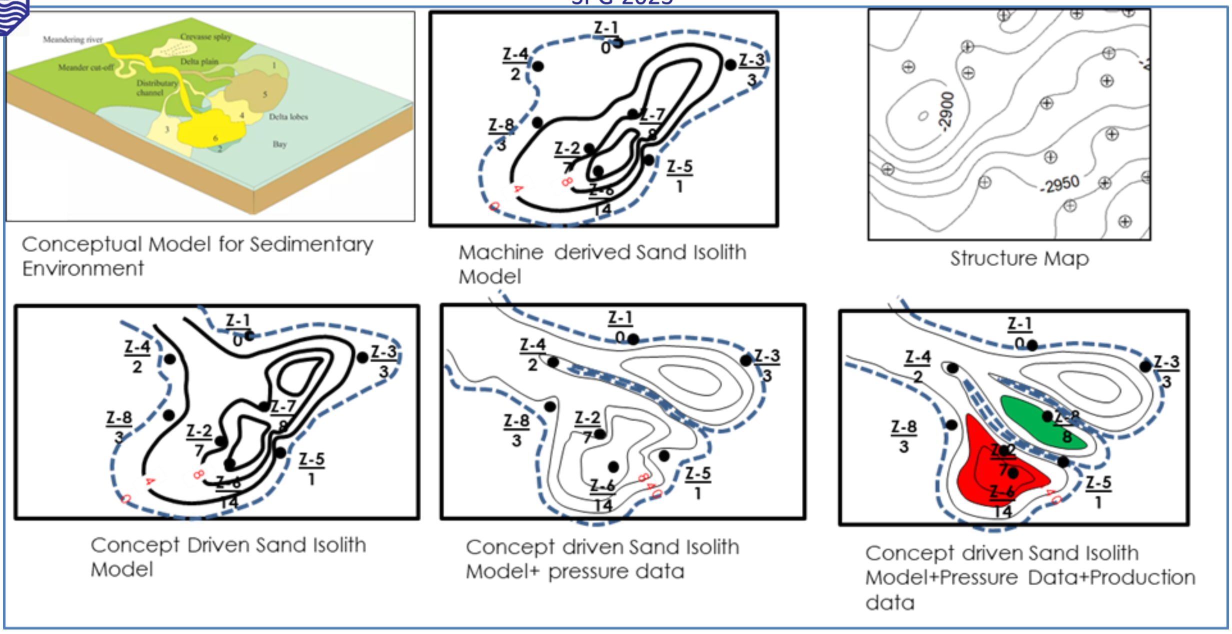


Figure5: Conceptual sand Isolith Model of Hazad sands, Gandhar Field.

Conceptual model of Hazad sands depicts that the sediments of the Hazad Member were deposited by proto-Dadhar/proto Narmada river systems from east and northeast, respectively, forming aconstructive delta as interpreted from the sand thickness maps (Fig.4). The paleogeographic reconstructions made within the Hazad Member suggest a paleoslope towards the west. Sands gradually shale out towards west, an upper delta plain is envisaged towards the eastern part, at the inferred basin margin, where the facies association shows dispersal of immature to submature fluvial sediment. Sedimentation took place mainly in lower delta plain and delta front contexts, in form of distributary channels, inter-distributary bays, mouth bars and delta lobes with effects of tides coming from the south (open sea). The lower delta plain and delta front deposits passed basin ward into prodelta clay/shale.

While facies model is prepared using above regional conceptual model, each sand lobe is conceptualized based on well data, pressure data & production data. Machine derived isolith model is based on quantitativevalue. Sand count of different wells for a particular zone may be same, but log motifs/pattern may indicate to different sand lobes. Software never understands qualitative interpretation. Mathematical contours are drawn on equal value. However, realistic model needs data like structure, reservoir & production data to explain the fluid properties & contacts. These micro level interpretations need to be integrated in GCM for field development (Fig.5)

Post depositional geological processes (diagenesis) components

Diagenesis has been identified as one of the most complicated and lesser addressed components. Sometimes, it is even completely ignored while building the 3D geological model. Detailed petrographic analysis together with burial history helps to define the most important diagenetic processes that might have affected the reservoir quality. Core analysis, outcrops and offset analogues can also provide useful trends for diagenetic processes. Based on core samples, it is assumed that the diagenetic processes have affected the reservoir homogeneously. Therefore, only one scenario for this component can be considered. Based on the above G&G analysis, conceptual model is used as inputs for building the geocellular model (GCM).

Building of Geocellular Model (GCM)

G&G data like well coordinates, deviation data, log data, seismic data, well markers, and fluid contacts areloaded into the project. 3D model starts with building of structural model using interpreted faults and horizons using pillar gridding process. Property Modeling is the process of filling the cells of the grid with properties such as facies, porosity and water saturation. Multiple geological realizations were carried out in the Modeling process to reduce the geological uncertainty. Finally, the volumetric calculations for all realizations are calculated and ranked to determine the reservoir potential and reserves (Fig:6).

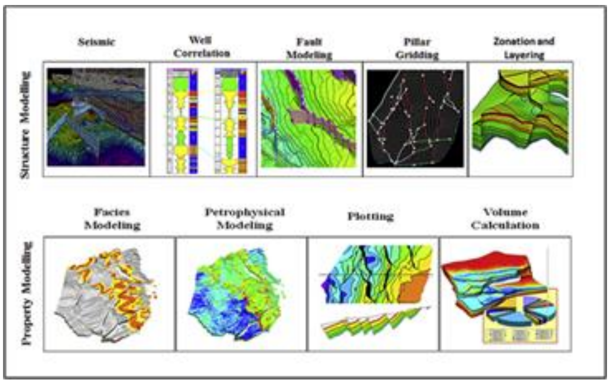


Figure6: The workflow of Geocellular Model (GCM).

uctural Modeling

Structural mapping of horizons and faults is the most important part of structural Modeling process. Data from a variety of sources viz. well logs, seismic and field analogue are integrated. Commonly, accuracy is required for preparing a depth map through seismic-well tie, seismic time interpretation, gridding, time-to-depth conversion and residual mapping. Inaccuracy in top and base surfaces of reservoir pay affects the rock volume during reserve estimation.

In Gandhar field, some wells have missing sections (Fig.7a & b) observed in electrolog motifs, especially in inclined wells which are drilled from the down- thrown to up-thrown side and repeat sections are observed if well is drilled from up-thrown to down thrown of a Normal fault block. Three wells W-1, W-2 & W-3 are located at close distance apart and missing section has been observed in W-2 along zone between GS-9 & GS-7 i.e GS-8. This has resulted in lesser isopach thickness in well W-2 which has created squeezing the Zone in structural Modeling. However, this has been modified subsequently in Modeling. Fault cut wells need to be re-adjusted in isopach mapping.

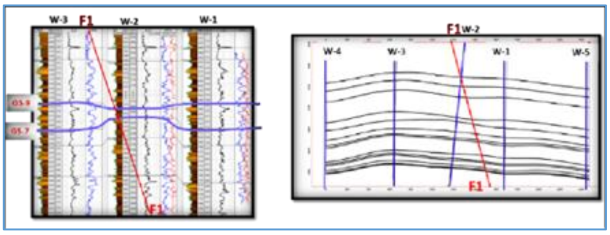


Figure7a: Electrolog correlation of Gandhar wells showing missing section in fault cut well b) cross section showing less thickness against well W-2 dueto missing section

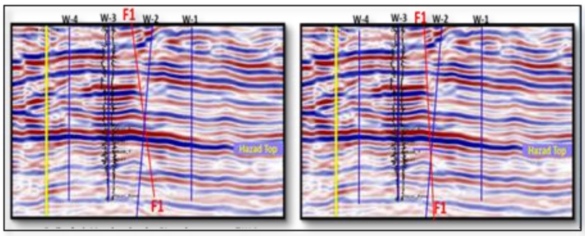


Figure8a: Earlier fault Mapping shows F1 cutting across well W-2 above Hazad Section. b) Modified fault showing F1 cutting across in well W-2 below Hazad Section.

As faults are interpreted in seismic, hence orientation of fault planes need to be properly adjusted with missing sections of wells to avoid section mismatch in horizon Modeling(Fig.8a & b). Balancing fault throw with horizons also need to be taken care for getting accuracy in depth surfaces to avoid twisting/dragging of surfaces and making cell angle very high. Locations of Wells, deviation profiles &log data are important in structural Modeling which induce errors in structural surfaces.

Fault sticks are interpreted in seismic sections and are incorporated into pillar gridding process. Pillar girding generates a 3D grid from the fault model. The result from the pillar girding is the "Skeletal Framework" consisting of a top, middle, and base skeleton grid.The make-horizon process incorporates horizons into pillar grid and the vertical layering is carried out to define vertical resolution of a 3D grid. The number of layers in each zone is considered to optimize the number of cells to capture reservoir heterogeneity by representing actual percentage of Lithofacies. Various ways of layering the zones are1: Following top, 2: Following base, 3: Proportional layering from reservoir Top to Base which can be made based on regional concept of reservoir geometry and respective 3D grid layering is used for further Modeling. 3D Seismic data considered in the interpretation has provided some possible evidences tosupport the layering process (Fig.9).As property Modeling follows layering geometry, properties also vary according.

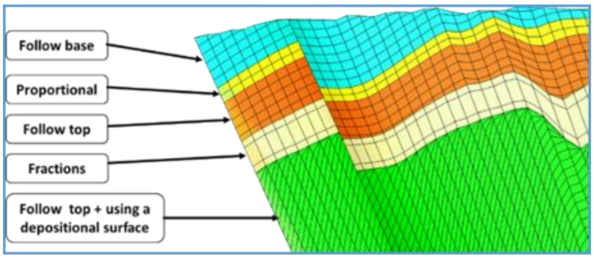


Figure 9: Various ways of layering the zones based on regional concept of reservoir geometry

Property Modeling

Property modeling involves filling grid cells with petrophysical properties such as facies, porosity, permeability, and water saturation. Therefore, these processes are dependent on the geometry of the existing grid. When interpolating between data points, the geostatistical modeling process propagates property values along with the grid layers.

To build realistic property models one need different inputs from Geophysics, Geology, Petrophysics and Reservoir engineering. A model builder integrates all available data types.

- The deterministic model gives the main framework (structural-stratigraphical model)
- The statistical information such as histograms, variograms , correlation and trends give the property variation on themodel
- The conceptual model is very important because of the use of analogs (outcrops, neighboring fields, etc.) bridging the gap between reservoir geology and 3D numerical reservoir Modeling activity.

A combination of conceptual and statistical information may allow the user to choose key parameter values and to indicate upper and lower bounds for such key parameters when little data exists in the project area (e.g. object orientation, size, shape, correlation lengths and so on)

Reservoir's development controlled by geological processes cannot be predicted through classical tistical method, whereas Geostatistics can be applied to explain the spatial & temporal variability through variograms, semi-variograms & kriging techniques. Prediction of the spatial occurrence of rock properties via stochastic modeling has been proved to be a better approach in designing facies and petrophysical model. Correlated seismic attributes aid in fine tuning the model by bridging the gaps in sparsedata.

Variogram is a method of analysing and describing the spatial changes in intrinsic properties based on the principle that samples close together are more similar than samples far from each other. In addition, data transformation enables the user to make the data stationary and standard normally distributed, which are requirements of many of the standard geostatistical algorithms. Data driven variogram model, sometimes gives error in estimation of range of major axis. In order to reduce uncertainty in variograms, well data can be supplemented with the geological knowledge of the reservoir by studying the energy level of the depositional environment, grain texture as well as depositional space. These three attributes are used to determine the relative distance of continuity of the lithofacies and need to be incorporated in the variogram modeling (Fig.10 a,b,c)

Geostatistical Modeling processes have also inherent uncertainties. Applicability of processes are also reservoir specific and focus should be given on G&G Knowledge/interpretations and stochastic models need to be validated through G&G data integration.

Facies model

Facies model is carried out to understand geological processes and to capture facies architecture, such as reservoir connectivity and high level heterogeneity. It honors descriptive facies information: shape, size, orientation, proportion, distribution andstatistics. Facies modeling is a means of distributing discrete facies throughout the model grid. Sequential indicator simulation (SIS) is one of the most commonly used methods to model litho facies because of its capabilities in integrating various data. In addition, directional settings such as variograms and trends of conceptual model are also honoured in facies modeling process.

Currently, there are three approaches used to generatea stochastic facies model which are multipoint geostatistics, pixel-based and object-based. The multipoint geostatistics technique is an emerging stochastic simulation method that generates facies models utilizing a training image (i.e. an identical analogue). The main drawback of this method is that the produced facies model is not conditioned to data at well locations. Hence, this method is more suited to reservoirs with very limited or sparse well data. The pixel-based technique is very flexible because it can be used to model different depositional environments, however, it cannot correctly capture the channel geometries of fluvial systems and

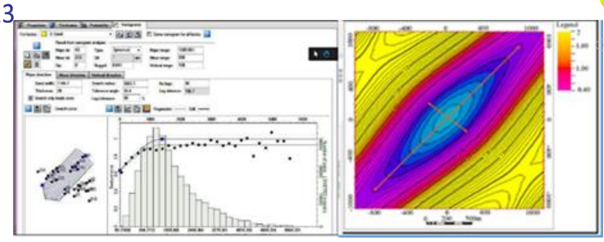


Figure10 a) Variogram Model for property Modeling b) Variogram map to show major & minor axis.

may produce unreasonable geological features. The object-based technique is commonly used for modeling a variety of channel depositional settings designed to modelstraight to sinuos channels.

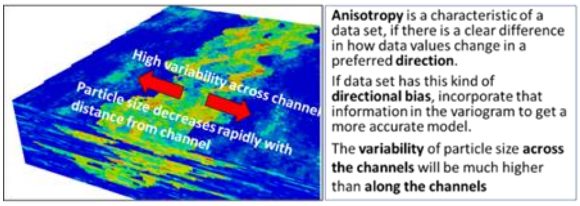


Figure10 c) Illustration showing grain size variation in a channel body.

Petrophysical Modeling

Petrophysical modeling of continuous properties generally include porosity, fluid saturations, and permeability. Porosity Modeling is run stochastically utilizing the sequential Gaussian simulation (SGS) method in conjunction with variogram models biased with facies model. Limitation of point data from drilled wells brings uncertainty in inter-wells properties which needs to be integrated with continuous data of seismic. Advanced seismic attributes must be tied up properly with wells to capture reservoir heterogeneity, anisotropy along with fluid characteristics. Seismic derived correlated acoustic Impedance (AI) can be used as secondary attribute to derive value of porosity (Fig.10d).

Unlike porosity, water saturation is a dynamic property which changes with hydrocarbon production from wells. Many literatures show different empirical and scientific efforts to produce robust saturations functions to address petrophysical properties of the rocks and fluid interaction. This study presents a simple and convincing saturation modeling approach to address strati-structurally controlled Hazad reservoirs, Gandhar field Sw logs of new wells were generated by applying saturation height function predicting initial hydrocarbon saturation in depleted part of the reservoir. Finally, Geostastistical Krigging method propagated the Sw values in making a realistic saturation model depicting structural controls and facies variation of the reservoir. The predictive qualities of the model have been verified by comparing the log derived water saturations with the “back-calculated” water saturations from the model at the well locations (Fig.11).

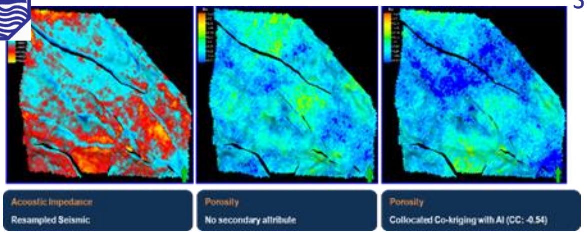


Figure 10 d: Porosity Modeling: Seismic acoustic impedance (AI) asSecondary Input.

Model Validation

Data and model validations are performed at every significant modeling step. First, when data have been imported to project, they should be under quality control (QC). Typical methods of data QC are to display them and to check statistics, histograms, cross sections etc. The essential steps during QC of structural grid include checking for crossing pillars because it is possible that negative cell volumes have been generated.

Geocellular model of Gandhar field was successfully validated by making synthetic log from facies and petrophysical model in well locations W-A & W-B which were not included for Modeling study (Fig.11).The correlation of predicted value with that from actual data at well locations W-A & W-B show very good match.

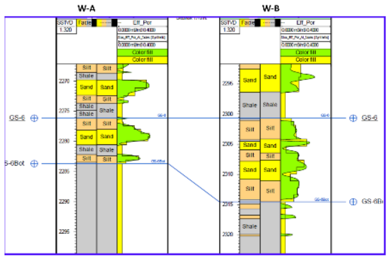
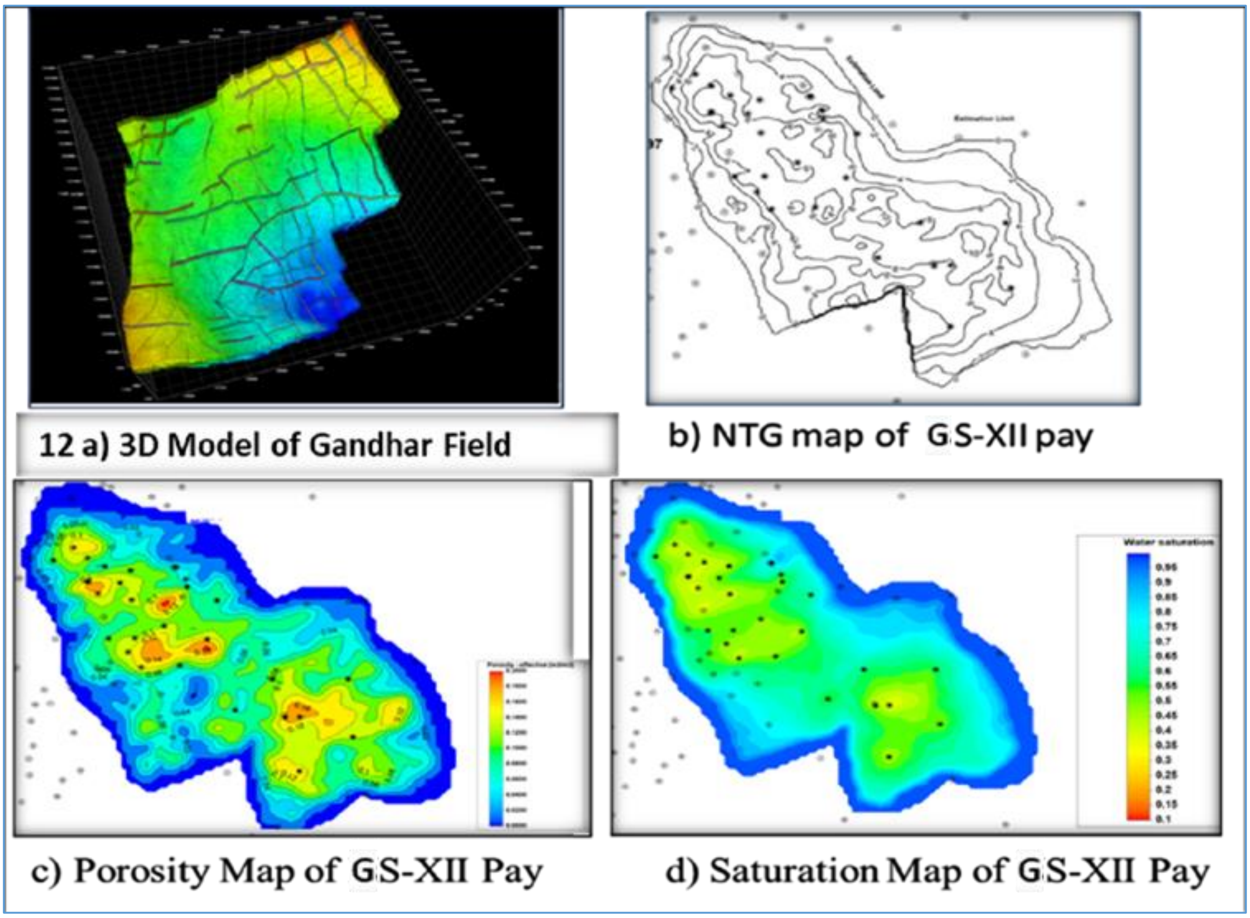


Figure11: Validation of model from synthetic log derived from facies and petrophysical Modeling.

Model has been validated with drilling of infill wells where actual structural & facies variances have shown very good match with predicted values.



Results and discussion

- **Volumetric Estimation**

Volumetric estimation was carried out by integrating the total number of cells above cut-offlimit. Bulk volume, net volume, pore volume & HC volumes were generated for GS-XII pay reservoir. This process adopted a mixed approach where input data are captured through stochastic/probabilistic method and estimation is deterministic. The best part of the estimation process is that errors in values of single cell never impact entire reservoir's estimation.

Rock volume has been calculated for the pay zone between Top & bottom surfaces. Net to Gross (NTG) for

Each cell has been estimated taking consideration of cut offVcl< = 35%, PHIE ≥8%;Sw<=80%.Values of porosity and oil saturation are taken from models. In addition, the oil formation volume factor (Bo), and oil–water contact (OWC) were taken for the volumetric calculation from structure map. Finally, OIIP of GS-XII pay has been estimated (Fig. 12 a,b,c,d).Volumetric estimation carried out in static GCM of Gandhar field was subsequently validated with the result of simulation study under dynamic modeling.

Conclusions

- Conceptual G&G model is a critical input for the structural, facies and property modeling in 3D static reservoir model building.
- It allows for bridging the gap between reservoir geology and 3D numerical reservoir Modeling activity.
- Applicability of conceptual model & appropriate geostatistical technique have been validated through QC, result of infill wells from reservoir & production performance data.
- GCM based on conceptual G &G model input identify and rank the key reservoir uncertainties and assess their impact, establish interdependency of spatial property distribution, make volumetric assessments, optimize recovery efficiency and achieve reliable production forecasts.

References

Catuneanu, O., Galloway, W., Kendall, C., Miall, A., Posamentier, H., Strasser, A. and Tucker, M. 2011. Sequence Stratigraphy: Methodology & Nomenclature. Newsletters on Stratigraphy, 44 (3), 173–245.

J. Cavero, N.H. Orellana, I.Yemez, V. Singh1 and E. Izaguirre, “Importance of conceptual geological models in 3D reservoir Modeling”, First Break, Volume 34, Issue 7, Jul 2016.

Wilson, M. [2010]. Anticline in the Barstow Formation (Miocene) at Calico Ghost Town near Barstow, California. Wikimedia Commons. USA, www.wikipedia.org/wiki/Anticlinal#/media/File:BarstowFormati onAnticlineMarch2010.jpg.