PS Object-Based Modeling of Wara Formation (Middle Cretaceous) in Greater Burgan Field (Kuwait): An Innovative Approach for a Better Reservoir Characterization*

Jean Michel Filak[1], Reham Al-Houti[2], Laila Dashti[2], Deryck Bond[2], Merlon Banagale[2], Barbara Luneau[3], and David Molinari[4]

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[1]Kuwait Oil Company, Ahmadi, Kuwait (JFilak@kockw.com)
[2]Kuwait Oil Company, Ahmadi, Kuwait
[3]Schlumberger, Denver, CO, United States
[4]IFP Middle East Consulting, Bahrain, Bahrain

Abstract

The Wara Formation is one of the main reservoirs of Greater Burgan Field, producing under primary depletion since the late 1940s. A major water flood has recently begun and prior to this, a large-scale pilot (Early Wara Pressure Maintenance Project EWPMP) was initiated. As part of the scope of this study, representative geological models were built to capture reservoir heterogeneities, which is crucial in building a dependable simulation model. An innovative workflow combining geological, petrophysical and dynamic data, has been developed to generate a range of geological models that will be selected for dynamic simulation. Five cored wells have been reviewed, to establish the markers used for the geological modeling and to define core-based depositional environments. Six Rock-Types, calibrated on cores, integrating RCA porosity-permeability data have been identified in 56 wells. The Wara Formation has been deposited in fluvio-deltaic to estuarine environments. Six depositional environments have been defined on cores, dominated landward by bay head fluvial delta passing into tidal estuarine mouth bars and sandy estuarine bay. They have been extended to 111 wells based on log signatures. Based on analogs (ancient and modern), aspect ratios for sand body shapes were used in addition to the well controls to constrain the distribution of depofacies. Variations in sand body's size were used to generate poorly, fairly and highly connected sand bodies, with a range of models. The final sand body distributions were validated using pressure data to match some pressure breaks in the reservoir. Then Rock-Types and petrophysical properties distributions were generated in the pre-defined geological framework, using a sequential indicator simulation approach (SIS). The object-based modeling (OBM) approach combines aspect ratios and depositional trends to constrain the petrophysical properties distribution. A range of models has been generated reflecting the geological settings and capturing the reservoir heterogeneities. Modeling complex reservoir heterogeneities in clastic environments is a challenge in the oil industry. An accurate sand body distribution is crucial for a good representation of the reservoir behavior in both static and dynamic models. The proposed modeling workflow combining geological, dynamic and petrophysical data, is a good alternative for geological models of similar depositional environments, to assess the complexity of such reservoirs.

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Reham Al-Houti(1), Jean Michel Filak(1), Laila Dashti(1), Deryck Bond(1), Merlon Banagale(1), Barbara Luneau(2), David Molinari(3).

Institutions: 1. Kuwait Oil Company, Ahmadi, Kuwait. 2. Schlumberger, Denver, United States. 3. IFP Middle East Consulting Bahrain.

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ABSTRACT

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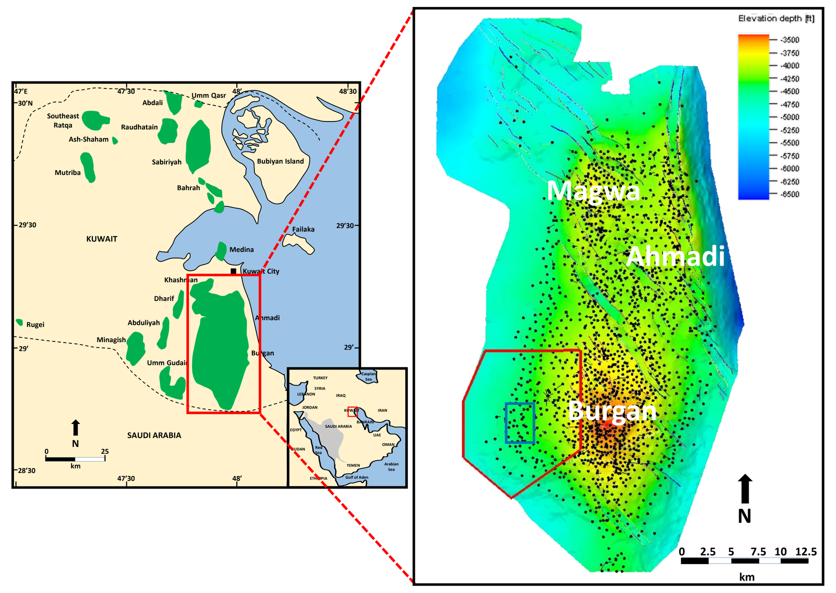
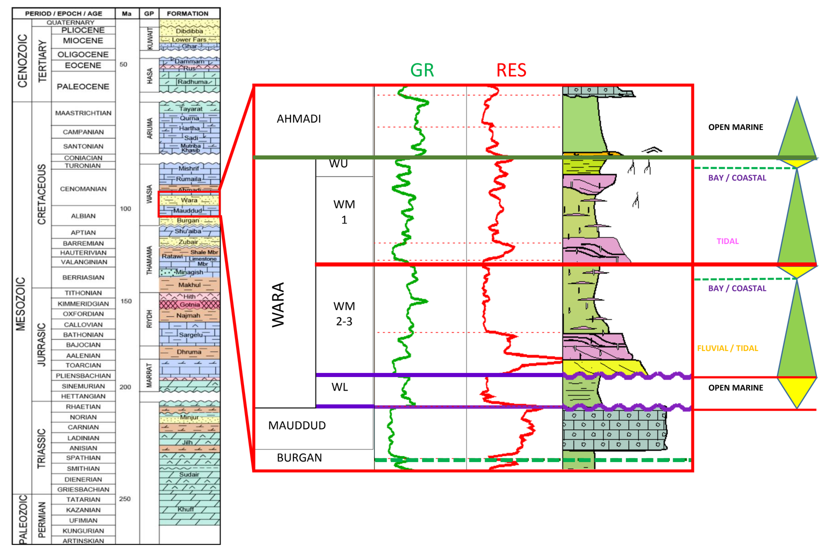
GEOLOGICAL SETTINGS

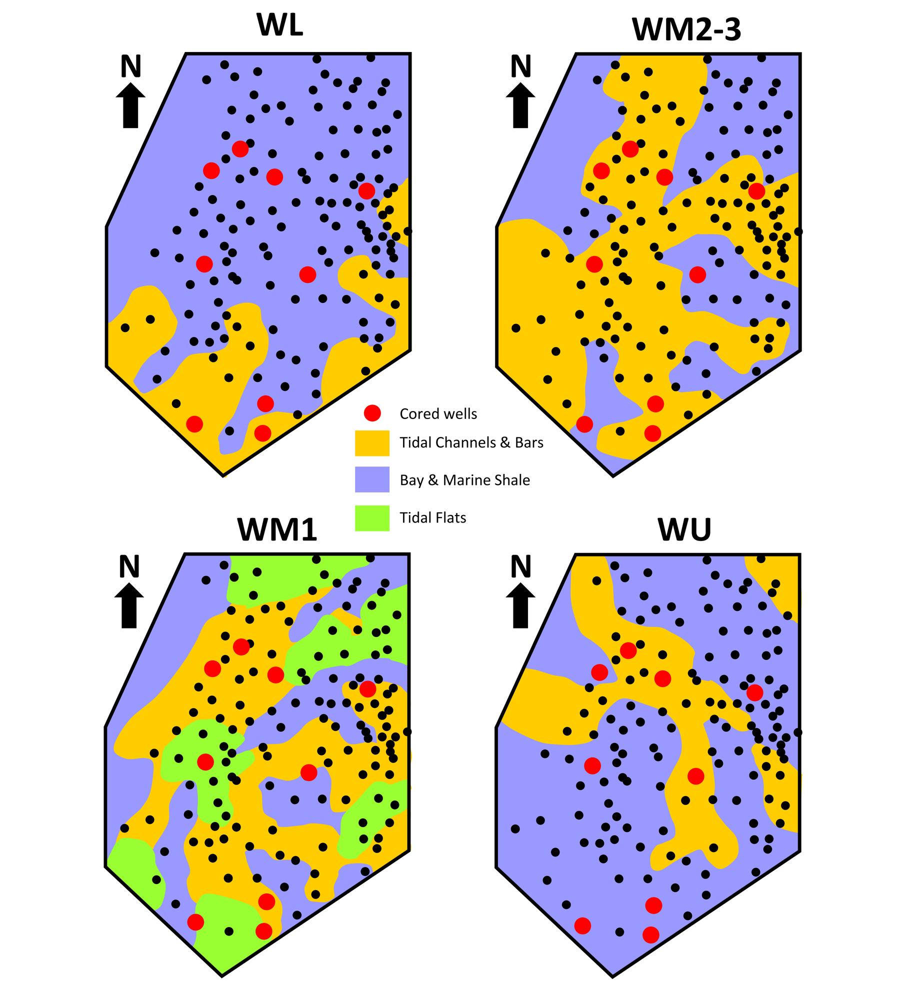




The EWPMP area is located in the southwestern part of Burgan field, in Figure 1, as shown on a structural map of Wara formation. As can be seen the study area is relatively extensive and contains a significant "buffer area" around the area of the injection wells (within the small blue rectangle). Also shown is the location of the Greater Burgan field in the State of Kuwait.

The Wara reservoir is one of the four main reservoirs in Greater Burgan field. It is separated vertically from the remaining reservoirs by extensive carbonate and shale intervals (Mauddud formation and Wara Shales unit). However, extensive faulting does allow communication between the Wara sand and the Burgan Sands below. The Wara Formation is characterized by three (3) third-order cycles, deposited in tidal/coastal settings. The variability inherent to the depositional style leads to a complex reservoir scheme. The Lower unit (WL), defined as the "Wara Shales" consists in an extensive shale interval deposited in marine settings that provide good sealing capacities. Small, laterally strongly variable and heterogeneous fluvial-tidal dominated units (sands, silty sands and silts) are representative of the Middle Wara WM2-3 and WM1 Formations, separated by an extensive shale barrier corresponding to a regional flooding event (MFS_intra_Wara). The Upper Wara section (WU) exhibits transgressive and more open marine settings, showing a general transgressive trend toward Ahmadi Formation above.

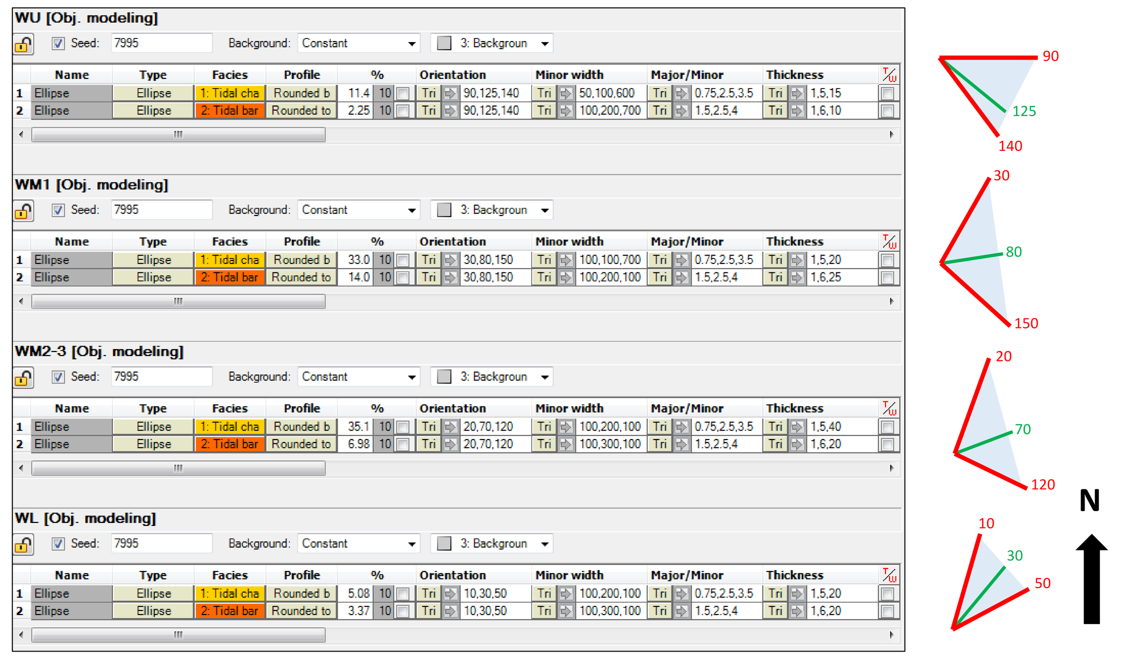
CORE / LOG_BASED DEPOFACIES MAPS FOR WARA UNITS



Log and cored-based depositional environment maps were created for the WL, WM2-3, WM1 and WU units. In each well penetrating these units, the dominant depositional environment was selected. For example, a well containing 50% of tidal channels, 30% of tidal bars and 20% of tidal flats, will be interpreted as dominantly deposited in tidal channel.

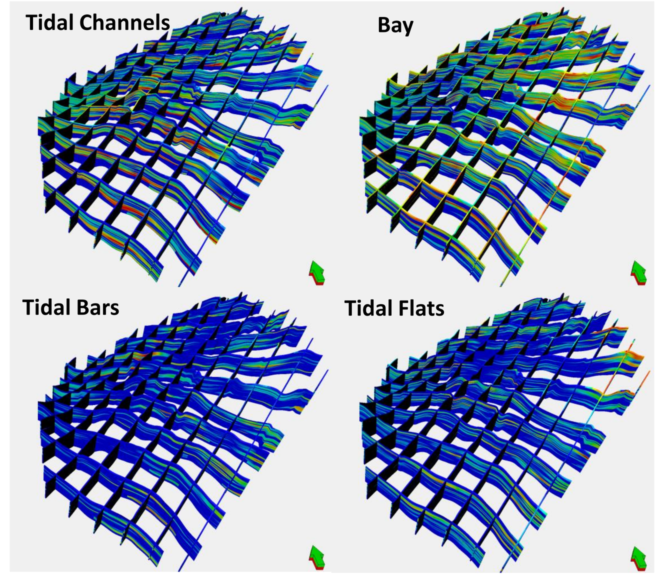
DEPOFACIES OBJECT GENERATION

To better capture the geometry and the shape of sandstone bodies and shale, the Wara reservoir has been modeled using an object-based modeling (OBM) approach, based on analog aspect ratios and depositional trends from previous studies. In this approach, the depositional environments and their vertical and lateral distributions are used to constrain the petrophysical property distribution. In the OBM, aspect ratios for tidal bodies and sand body shapes are used in addition to the well control to constrain the distribution. The selected object shapes mimic the expected sand body morphology. A tidal bar tends to be elongated with a broader base and narrower top. It will be represented as an ellipse with rounded base geometry. Tidal channel and flats shapes are represented with an ellipse with rounded top as geometry. Bay-fill, tidal flat and transgressive sandstones are defined as background.



The Wara depofacies object has been discretized to be used as an input for modeling. The average method "most of" has been selected as well as for the Wara Depofacies log.

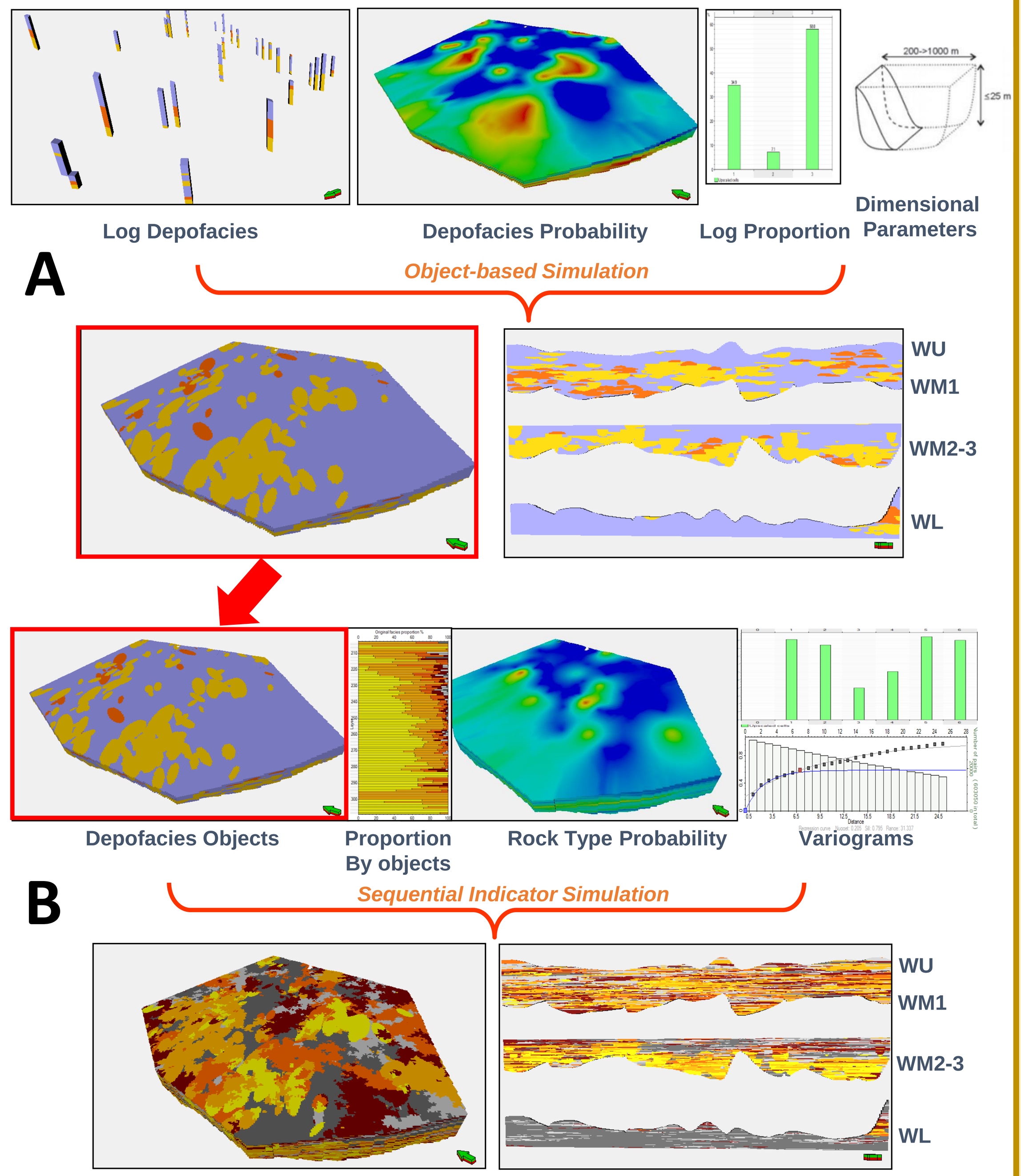
DEPOFACIES PROBABILITY CUBES



Depofacies probability cubes were generated including: tidal channels, tidal bars, estuarine bay fill, tidal flats, transgressive sandstones and marine shales. The depofacies probability cubes used the detailed log interpreted depositional facies as input. The summation of the four cubes equals 100% at each cell. The upscaled depofacies objects and the trend probability cubes were used as input to guide the body geometries in the grid as a result of the object-based modeling.

Triangular distributions have been used for the orientation and dimension parameters of the sand body shapes. The orientation of the bodies, the thickness range and the width / aspect ratios have been defined for each zone, based on an analysis of the probability maps.

WORKFLOW



The workflow developed for this study consists in four major steps.

A: Depofacies objects derived from cores and logs were simulated using an Object-based modeling approach.

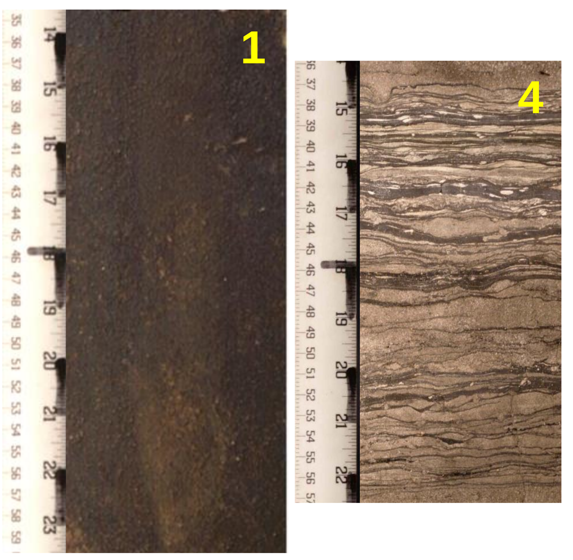
B: Facies and properties were then simulated using a classic Sequential Indicator Simulation (SIS) constrained by both Rock-Types defined at well location, as well the probability cubes of each depositional environments.

ROCK_TYPES DEFINITION

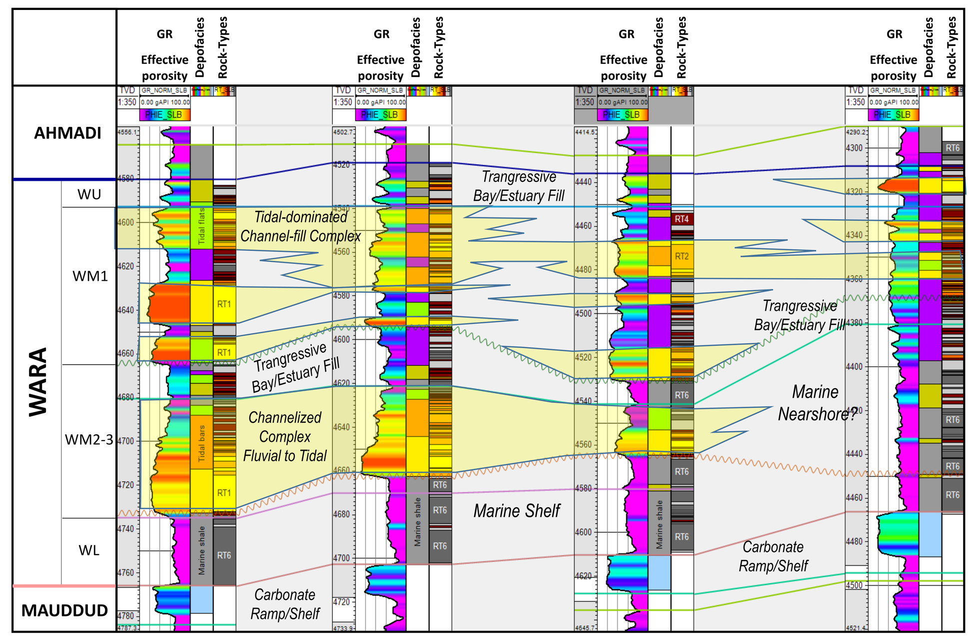
Rock-Types have been generated for 56 wells using standard methods used in studies of similar reservoirs in the Upper Burgan. Based on Routine Core Analysis data from 9 cored wells, R35 pore throat size distributions have been generated using Porosity-Permeability data calibrated on MICP PSD data at 35% Shg saturation (wherever applicable). Rock-Types were interpreted using Winland pore throat distribution curves per cored well. Geological facies from cores were used during all the process to ensure a good correspondence between the geological and the dynamic data.

Porosity-Permeability relationship have been defined per Rock-Types to be used for the property modeling. The resulting permeability estimates were then calibrated against permeability height estimates form PTA.

Rock Type	Dominant Geological Facies	Dominant Flow facies	Average Shale Volume	Average Effective Porosity	Permeability Range (mD)
1	a) Sandstone b) Argillaceous Sandstone	FF1 FF2	0.05	28%	K > 1000
2	a) Sandstone b) Argillaceous Sandstone	FF2	0.18	22%	400 < K < 1000
3	a) Bioturbated Sandstone b) Argillaceous Sandstone	FF3	0.3	16%	80< K < 500
4	a) Sand Dominated Heterolithics b) Glauconitic Sandstones c) Pebbly Interclastic Sandstone	FF3 FF4 FF5	0.41	11%	10< K < 100
5	a) Shale Dominated Heterolithics b) Siltstones c) Carbonaceous Sandstones	FF4 FF5	0.55	5%	1< K < 50
6	a) Bioturbated Shale	FF6	0.75	0.5%	K < 2



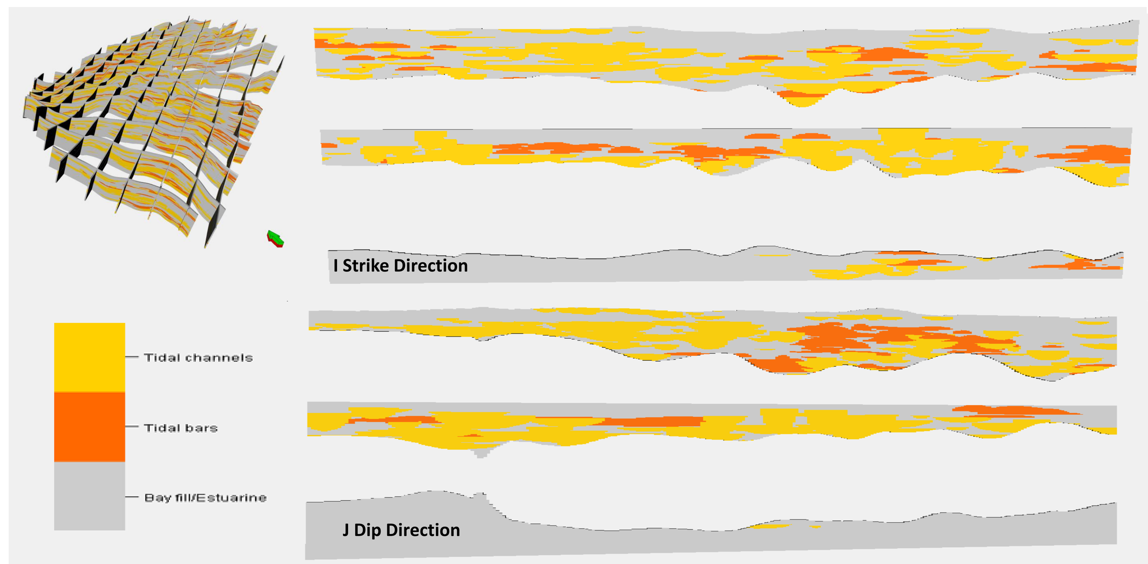
CORE-BASED / LOG-BASED DEPOFACIES DEFINITION



Depofacies	GR	Neut/Den	Major RT	PHIE	Association
Channel	low; ~< 30-32 API	cross-over; low density	1 & 2	highest; >20	sharp-based, fine upward
Bar	30-50 API	cross-over; low density; less than channels	2 & 3	moderate to high, >15	tend to overlie channels, aggrade upwards
Tidal Flats	Spiky, 30-50 API	variable cross-over to none	3, 4, 5, 6	low to moderate; 0-10	tend to overlie channels or bars, aggrade and fine upwards
Bay fill/Estuarine	high; > 40 API	low to moderate separation; med neutron	4, 5, 6	low to none; 0-10	tend to separate channel/bar complexes, variable log signature
Transgressive Sandstone	high <30-40	no, to low separation	4, 5, 6	low to none	Sharp-based, thin
Marine Shale	high; > 40 API	high separation; high neutron, low density	5 & 6	none	commonly present in WL and WU; distinguished by high neutron and separation

Based on the existing core descriptions, log-based Depositional Environments have been extended to uncored-wells The main conventional logs used there are the Gamma Ray, Neutron and Density logs.

OBJECT-BASED MODELING

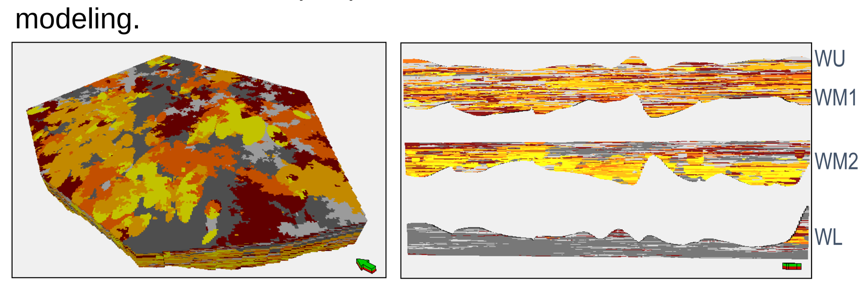


Cross sections in I strike direction as well as in J dip direction have been generated for a to quality check the sand body shapes and distribution.

PROPERTY MODELING (FACIES / POROSITY / PERMEABILITY)

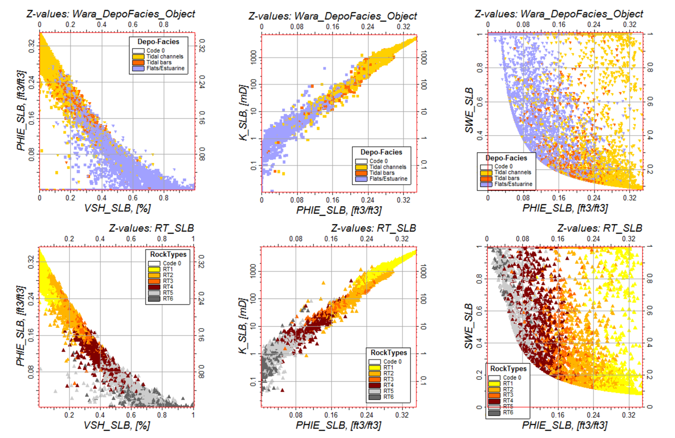
FACIES MODELING

The depofacies model described above constitute the main framework of the facies model. Sand body geometries/directions are used to populate and control the distribution of each Rock-Types. The distribution of each Rock-Types within the pre-defined Wara Object model (tidal bars, tidal channels and background), has been constrained using the proportion of each Rock-Types per objects as well as cubes of probability of each Rock-Types.. Sequential Indicator Simulation (SIS) have been used for the facies modeling.



POROSITY / PERMEABILITY MODELING

Gaussian random function (GRF) simulation was used to model the porosity, using the Rock-Types as a bias. Collocated co-kriging has been performed using the Rock-Types distribution and the porosity simulation results to constrain the permeability distribution.



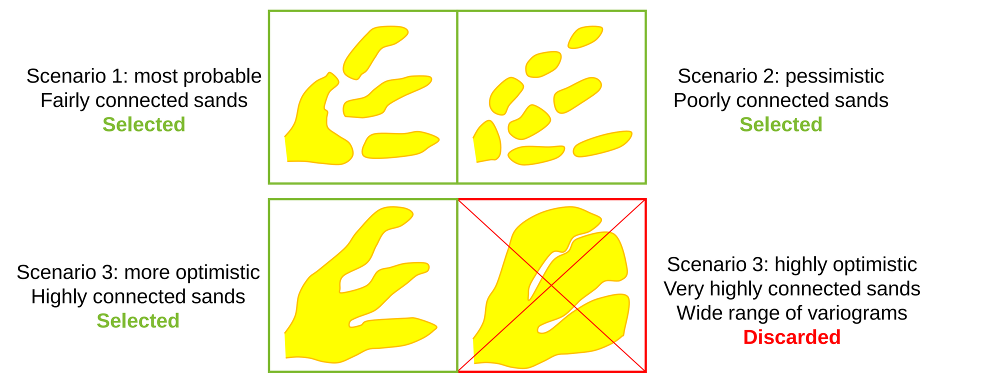
UNCERTAINTY ANALYSIS: GENERATION OF A RANGE OF GEOLOGICAL MODELS

Based on the knowledges of the reservoir geometry, a base-case has been generated and as has been described above.

Wide variations of geometries are expected in such type of depositional environments, alternate scenarios for the geobodies distribution have been considered.

Four scenarios were developed to assess the uncertainties related to this type of reservoir include:

- the first scenario (1) is the best-case, considered as the most probable according to compatibility with dynamic constrains (pressures, interference tests), It corresponds to fairly connected sands, with a realistic representation of the sand body geometries.
- a pessimistic scenario (2) characterized by poorly connected sands with narrow channels and smaller length of sand bodies, considers the possibility of isolated sand bars and channels, not always connected to each other, reflecting some observations done on well production profile of pressure changes in the reservoir,
- an optimistic scenario (3), with highly connected sands. In this scenario, the width and length of the channel has been extended to enhance and increase the sand body connectivity.
- on the extreme side, only for reference, a very highly optimistic scenario (4) was also considered with a wide range of variograms leading to very extended and connected sand bodies.



Scenarios 1, 2 and 3 have been chosen to generate multirealizations (100 realizations each). The full range of models has been screened through the integration of dynamic data (interference test campaigns, RFT, injection log data, tracer tests) to validate the communications between pair of wells.

CONCLUSIONS

Modeling complex reservoir heterogeneities in clastic environments is a challenge in the oil industry. An accurate sand body distribution is crucial for a good understanding and representation of the reservoir behavior in both static and dynamic models. The proposed innovative object-based modeling workflow that combines geological, dynamic and petrophysical data, used in this study may be a good alternative for geological models of similar depositional environments, to assess the complexity of such particular reservoirs. The approach that was adopted involved generating a large number of geological models that were broadly guided by the available data on connectivity and then screening out cases that were inconsistent with the detailed data on connectivity before embarking on relatively conventional AHM exercises.

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