Construction and validation of an integrated 3D geomodel for reservoir characterization – case study, offshore Angola

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This paper was prepared for presentation at the 9th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, 11-14 September 2005.

Abstract

WM field, offshore Angola produces significant quantities of oil from sandstones of the Upper Cretaceous Vermelha Formation. This sequence of mixed carbonate and interbedded siliciclastic sediments was deposited as a transgressive-regressive barrier island system. Approximately 97,5 m of conventional whole core was examined in order to define depositional facies and understand their relationships. Three principal facies were recognized: (1) inner shelf to shoreface sediments characterized by bioturbated, argillaceous, dolomitic siltstones, very fine-grained sandstones, and silty/sandy dolowackestones; (2) beach/barrier bar complex ranging from well-sorted, very fine-to fine-grained to poorly sorted, very fine-to very coarse-grained subarkoses and arkoses commonly containing planar cross-lamination; and (3) lagoon and tidal-flat sediments composed primarily of argillaceous dolomudstones and wackestones punctuated by dolomitic sandstones.

This integrated study used geophysical, geologic, and engineering data simultaneously to guarantee the accuracy in the models to be used for simulation purposes on a well by well basis, for matching the past dynamic performance, and to investigate the future reservoir management strategies such as remaining hydrocarbon reserves estimates, better understanding of water conformance, and to minimize the risks on implementing new production wells.

Introduction

Block 0 offshore Angola is a trend of fields located in the lower Congo Basin of West Africa (Fig. 1). Production in Block 0 is primarily from cretaceous mixed carbonate-siliciclastic sequences. which produces from a wide variety of littoral sandstones to vuggy dolomites. The WM field was discovered in 1982 by the Cabinda Gulf 44-5 well which was drilled as a step-out exploration well to appraise a structure north Block 0. The field is in 64 m of water and production began in 1986, with seven wells tied to one well jacket. Current production is only from the Vermelha formation.

The WM structure is a northward-plunging structural nose separated from Takula Field by a growth fault with a throw ranging from 213 to 335 m. The field has a maximum gross oil column of 114 m and is trapped by a seal formed from shales and siltstones of the overlying Lower Iabe Formation. Oil API gravity is 29.6°. The principal production lithology is very friable (poorly cemented to uncemented) dolomitic sandstones that have average porosities of 29 percent and permeabilities as high as 5 Darcys. Reservoir energy is provided by a very active water drive.

Regional Settings

The Geological evolution relevant to northern Angola's petroleum system began during the Early Cretaceous break-up of southwestern Gondwana. This break-up formed several lacustrine rift basins north of the Walvis Ridge during the Valanginian-Barremian (Early Cretaceous). Petroleum source rocks of the Bucomazi Formation were deposited in these Lacustrine basins. During the Apian (Middle Cretaceous), the sea intermittently flooded over the Walvis Ridge into what is now the Lower Congo Basin. During Albian-Cenomanian time, the West African shelf was the site of very variable mixed carbonate-siliciclastic deposition from at least as far south as central Angola (Tillement, 1987) to as far north as Nigeria (Oti and Koch, 1990), due to two major transgressive-regressive sedimentation cycles that occur ed from the lower Congo Basin to the Douala Basin (Seiglie and Baker, 1984). This was the setting at time of the Vermelha deposition.

Method

A Three-dimensional geologic model for the WM field was constructed as the first attempt to build a geo-cellular model of the field. The aim is to build a realistic model of geological facies distribution, as well as other petrophysical properties constrained to the geologic facies models. This geo-cellular model would be the starting point from which further work can be done.

Data used included Interpreted horizons, fault sticks, well markers, well traces with deviation surveys, well logs, and a 3D seismic survey of the area.

Structural Framework

The 3D structural-stratigraphic framework with appropriate layering (Proportional) was constructed. Four structural surfaces, Upper Vermelha, Pinda, Pinda 8 and Salt base formation were used to define the three main zones. These were then subdivided to create a fine layering using the above mentioned stratigraphic layering scheme to capture the reservoir heterogeneities.

The aerial grid dimensions were set at 50m x 50m for the I and J directions, and an average Z increment of 2 m resulted from the subdivision of the zones making a total of 57 layers. The model has a total of 1 886 643 cells.

Having been built in time, the 3D grid was depth converted using the velocity model created from stacking velocity.

Rock Property Modeling

The main objective of this task is to assign rock property values into the model, based on information from the well logs. It is initialized by first assigning values into every grid cell that is penetrated by the wells, based on the raw log values. A process known as Up-scaling of logs. The models to be constructed include:

1. Facies model
2. Porosity model
3. Permeability model

These models will aid in the understanding of the reservoir and will be used as drivers for dynamic purposes.

The first step in rock property modeling phase is the facies modeling. This constitutes a vital first step in producing a realistic property model, as it captures the large-scale heterogeneity inherent in the geology. For all engineering studies, it is also vital that the facies model captures the connectivity of the system. Therefore, spatial, conceptual and statistical assessments play equally important roles.

For facies modelling of the WM field, Sequential Indicator Simulation (GSLib), a stochastic modelling technique whereby the result is dependant upon: Upscaled well log data, defined variogram, random seed, trends in 1,2 or 3D, etc was applied since probability trend maps were used to control the probability of certain facies occurring in certain areas. Also, the large project area combined with a small number of control points, stochastic modelling was suggests to be the most appropriate method in property distribution. This family of techniques aim to provide a range of equally probable models on which prognoses, etc may be based.

During data analisys, variogram did not indicate any horizontal relationship for all zones together or for individual zones. One conclusion that can be drawn from this is that aerial connectivity varies horizontally within distances less than the average well spacing.

A vertical variogram does however indicate a vertical distance relationship ranging from eight to fifteen meters with a nugget commonly at around 0.5.

Since the variogram did not provide any indication of horizontal ranges, to assess the aerial distribution of the reservoir, well tops net fraction attributes were calculated and gridded (convergent) for the three lithologies present in the facies log curve.

Petrophysical modelling was used to populate the facies bodies with realistically distributed property values of e.g. porosity and permeability. The process starts by upscaling the well logs using the upscaled facies log as a bias. Bias is necessary to prevent contamination of upscaled cell values by for example porosity values that do not belong to the facies in that cell (i.e, in an upscaled cell which has the facies value of “sand” should only contain porosity which occur within the sand facies in the input log).

For this study, Sequential Gaussian Simulation (SGS) a stochastic method that honours well data, input distributions, variograms and trends, was performed in populating values between the well logs in the model.

Multiple realizations of the porosity model have been generated. The reliability of the porosity models is based on similar premises to the assessment of facies modeling.

In computing permeability the initial plan was to apply the transform equation directly in the modeled properties using the properties and cut-offs as per facies. However, the resulting permeability property proved to be too pessimistic i.e., low permeability values were obtained in areas were moderate to high values were known to be (Sandy-dolomite and Sand), eventually less fluid flow was also observed in contrast to that obtained from the DSTs’.

The transform equation was eventually applied at log scale.

Permeability=0.066*Exp(0.342*phi), Phi in percent

The resulting permeability log was cut by 10md before scaling up the well logs (geometric averaging method) and distributed using SGS. The same distribution settings (i.e. variogram, etc) were used as for porosity. Porosity was also used as secondary variable, with correlation coefficient of 0.7 for the sandy lithology and 0.6 for sandy-dolomites.

Results

Results have been assessed by two essential methods:

-Human eyeball, is essential to qualify all results against the conceptual model

-QC of input/output statistics, is essential for quantitative assessment

The small number of control points allows (even necessitates) leeway in the statistical comparison. It should also be noted that trend maps take second place to the log data and variogram in stochastic modelling; therefore a perfect fit to the trend values should not be expected.

The Uvermelha area provides a good area for sense-checking the appearance of the facies models. This area contains the highest concentration of well, and is therefore the area were sedimentary body correlation is most robust.

To assess the conformance of trends seen in net fraction, average facies maps for each property in each reservoir zone were generated. These maps provide a 2D view of the 3D property by averaging the values stacked below each node in the 2D grid. As such, the discrete values 0, 1 and 2 of which the facies properties are composed, are rendered as a continuum of values, which represent the probability of encountering facies bodies in X, Y locations.

Trend maps are seen to have a positive effect on the distribution pattern of sand in SIS. The impact of these maps on the resulting properties is well observed with the way sand is distributed along the defined sand barrier trend polygon. The influence of the variogram range is seen in the “coagulation” of values into pods.

As was the case with facies modelling, deterministic decisions have been taken in the predominantly stochastic modelling of petrophysical properties. Conditioning of most of these properties to facies is an intuitive step, which nonetheless imposes decisions made in facies modelling on the spatial distribution. Additional constraints were placed on the spatial and statistical distribution of these properties, and as was the case of with facies modelling these are considered to be robust.

Conclusions

In assessing the probable geology of the field, stochastic modeling algorithms represent the best estimate. However the nature of this simulation is that it will underestimate connectivity in low net layers

The property simulations performed in this study are highly probabilistic, the number and position of control points mean that risk is inherent in each simulation. However, every effort has been made to produce a realistic picture of the geology.

In order that connectivity is captured accurately in all layers, further work should be done and the simulation results will hopefully give some indications on how to proceed.

References

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Fig. 1 Map showing the area of study (Pimenta, 2005)

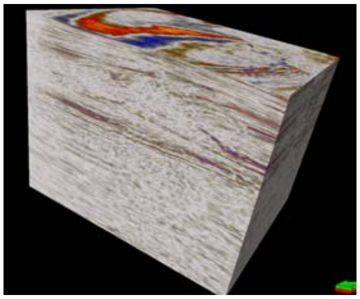


Fig. 2 3D Seismic Cube of the Field

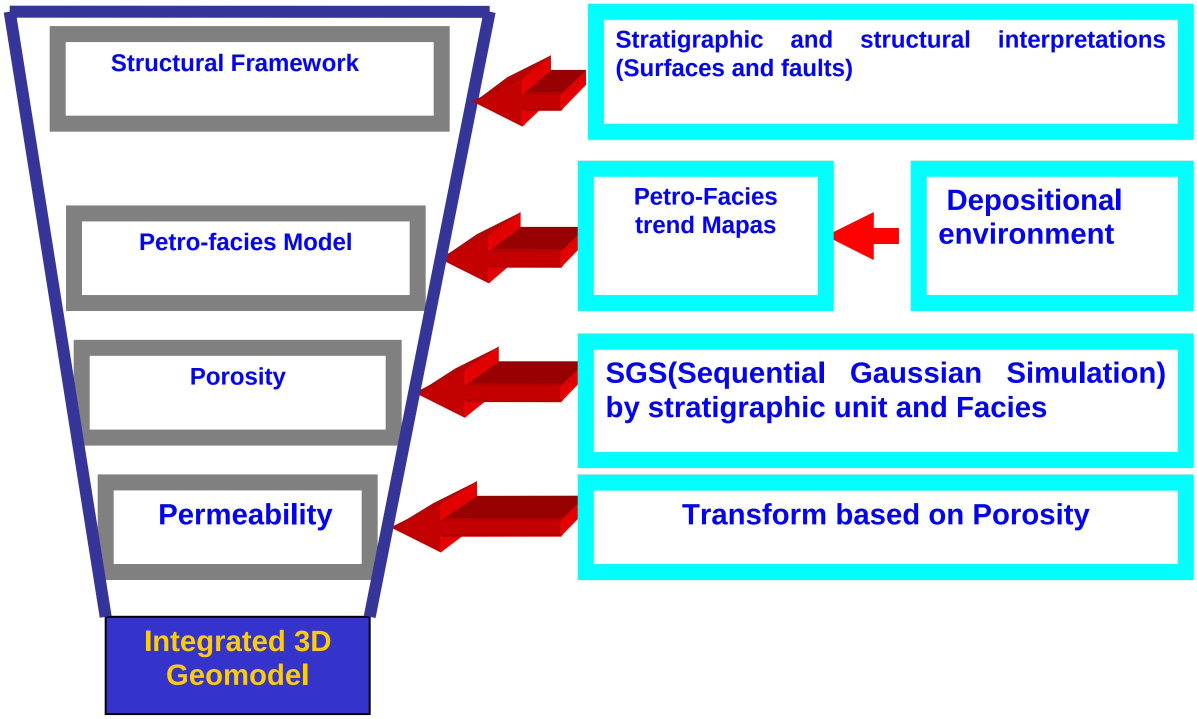


Fig. 3 Workflow detailing the modeling procedures

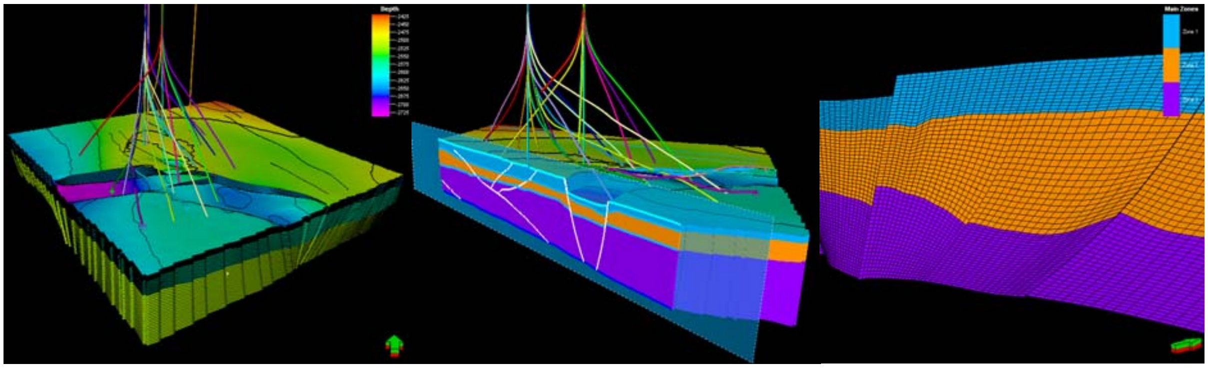
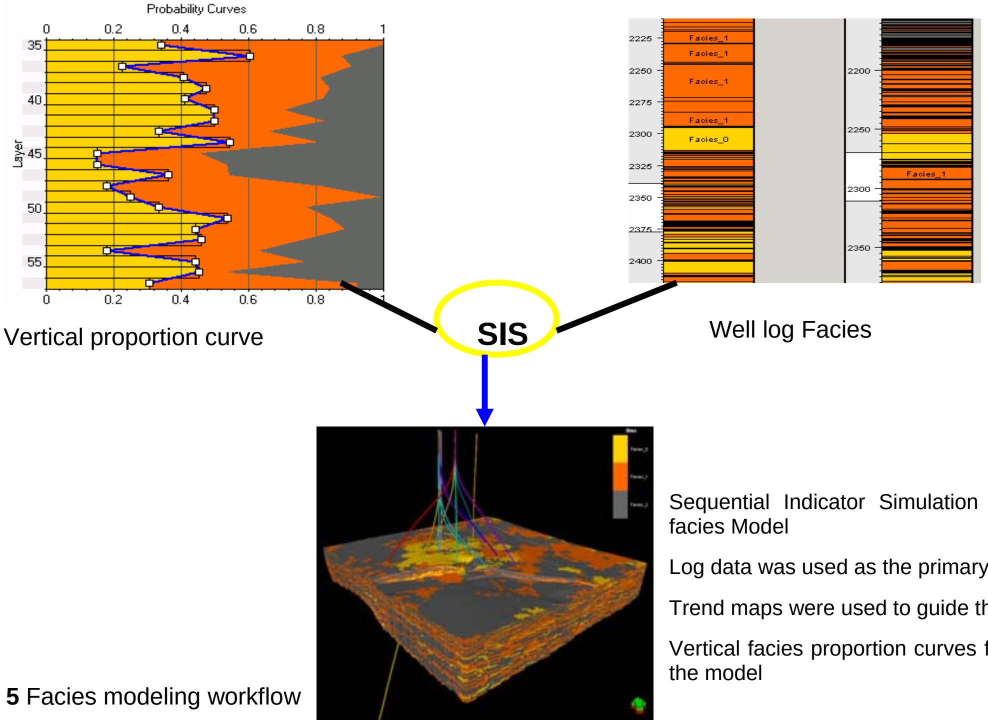


Fig. 4 WM field structural model with zone division

Facies Modeling workflow



Sequential Indicator Simulation (SIS) was used to build the facies Model

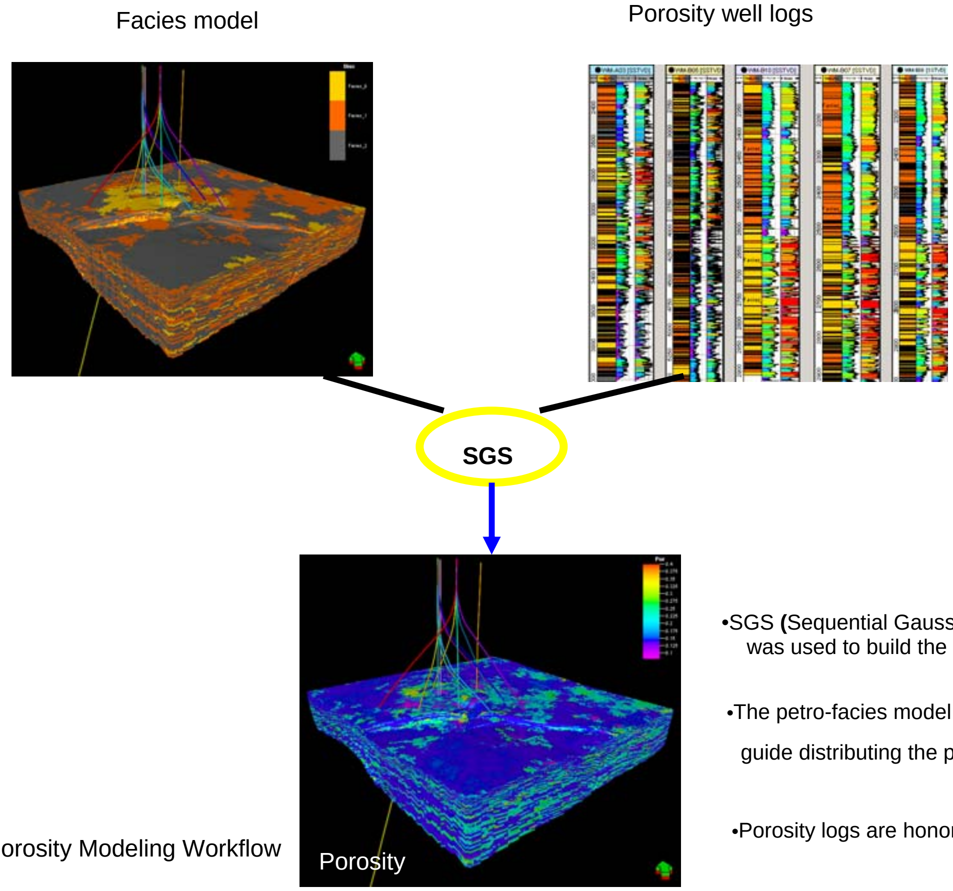
Log data was used as the primary source of information

Trend maps were used to guide the Facies distribution

Vertical facies proportion curves from well-log data was used in the model

Fig. 5 Facies modeling workflow

Porosity modeling Workflow



- SGS **(**Sequential Gaussian Simulation) was used to build the porosity model.

- The petro-facies model was used to guide distributing the porosity in the model**.**

- Porosity logs are honored in the model.

Fig. 6 Porosity Modeling Workflow

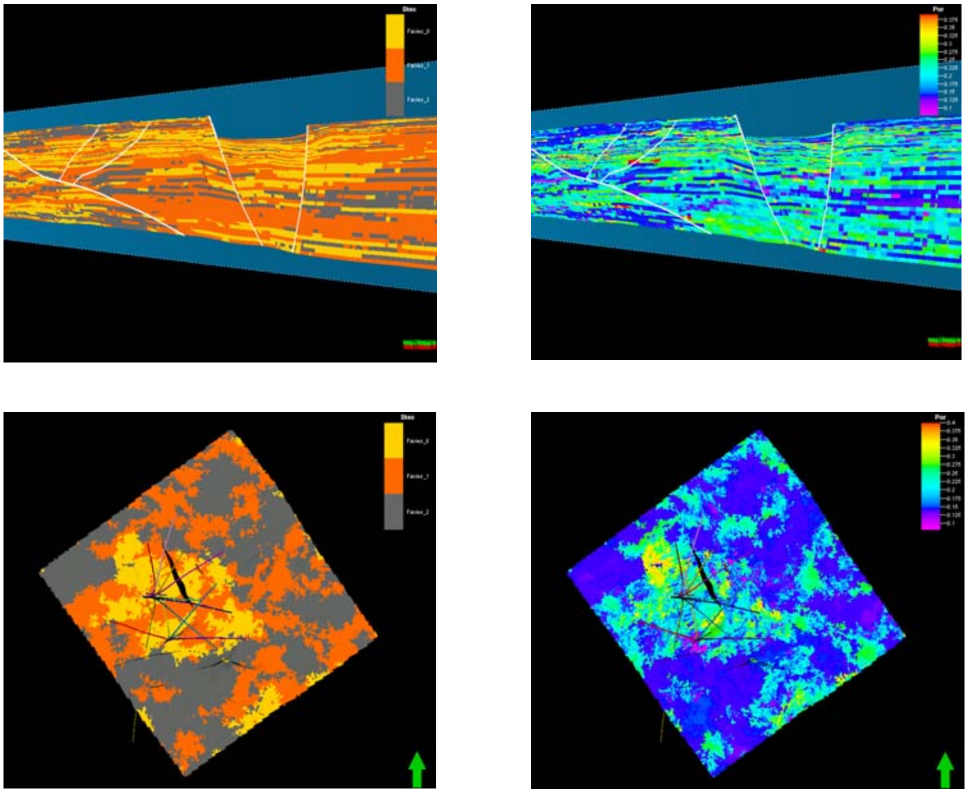


Fig. 7 Consistency in the facies and porosity models