Seismic constraints in a stochastic reservoir model and flow fluid simulation

[1]Azpiritxaga, I., [1]Correa, A., [1]Hernandez, E, [2]Galli, A.; [3]Ravenne, C., [1]Jimenez, Z., [1]Castillo, C., [1]Gedler, G., [1]PDVSA, Caracas, Venezuela; [2]Ecole des Mines de Paris, Fountainebleau Francia; [3]IFP, Paris, Francia

Abstract

Proper reservoir characterization is essential for optimum hydrocarbon recovery. Reservoir architecture and rock quality is usually based on well and seismic information. Well information from logs; cores, sidewall samples, and cuttings provide a good vertical characterization of the reservoir, whereas seismic information extends this knowledge in lateral dimension. Geostatistical tools provide the link between the well and seismic data.

The first approach is to perform a calibration between seismic and well stratigraphy. Attribute calculation is done for each horizon; geostatistical techniques are applied to build a quantitative relationship between rock quality and attributes. This relation is then incorporated into a Gaussian Stochastic Model in order to characterize the reservoir and a flow fluid simulation is performed.

To establish a quantitative relationship between seismic attributes and rock quality properties, a cross validation using Kriging with external drift was applied. Pseudo-petrophysical property maps are generated for unit resulting from the combination of attributes. Each unit is correlated with different attributes stemming from vertical and lateral rock quality variation.

These relations are introduced into a non-stationary stochastic model and an improvement in the definition and distribution of sand bodies is obtained comparing the models with and without seismic constraints. Based on cross validation techniques, at least 20% improvement can be obtained. Also a history match runs are performed and a more accurate history match is obtained using seismic. This methodology indicates that seismic constraints are essential to establish a stochastic reservoir model and the flow fluid simulation to decrease reservoir uncertainty.

Introduction

This methodology was applied in VLA-8-Block I, Eocene-C6 reservoir to optimize secondary oil recovery. VLA8-Block I field is located east of Icotea fault in Lake Maracaibo, Western Venezuela (Fig.1).

Eocene-C6 reservoir, in this field, began production in 1953, and it has been waterflooded since 1964. By December 1998, this reservoir had produced 46.2 MMSB with 123.5 MMB of injected water.

Information from 14 well logs, 2 core descriptions and 23 Km2 seismic cube were used to build the stochastic geological model and a production/injection history of 45 years was included for 22 wells (15 producers and 7 injectors) in the flow fluid simulator.

Two different approaches were undertaking for the reservoir characterization of Eocene C-6. The first one using only well information on the stochastic Gaussian model (Stationary), and the other one using beside the well data, seismic attributes as constrains in the model (Non-stationary). These models were scaled up in different grid sizes to evaluate the cell size effect on the dynamical simulation and history match runs were made with the stochastic models and the results were compared with the field performance.

Stochastic Geological Model

Eocene-C6 reservoir characterization was performed in a stationary stochastic geological model and using seismic as constrain in a non-stationary model.

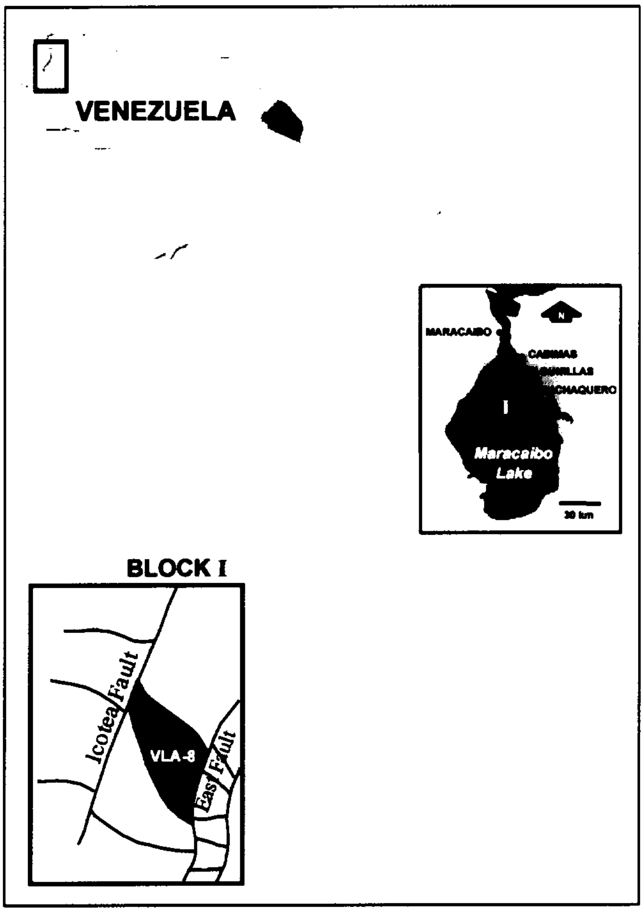

Fig. 1. Location Map

The Eocene C6 reservoir bellows to the C member of Misoa Formation. It has an average thickness of 500 ft. The structure of Block I is a very gentle homocline (7°) dipping SE, limited to west by Icotea strike-slip fault dipping 70° SE and to the east by a normal fault dipping 50° E. Two normal faults limited the north and south of the VLA-8-Block I field.

Eocene-C6 reservoir is a highly heterogeneous reservoir; two genetic units were defined in C6, limited by three maximum flooding surfaces (MFS C6, C6i, and C7). These two units called Upper (C6-C6i) and Lower (C6i-C7) were deposited in a tidal dominated delta in distal and proximal environments respectively (Fig.2).

Each environment has a specific vertical and lateral sedimentary facies distribution. Upper Genetic Unit is characterized by a very well sorted, medium to fine grain sandstone deposited in a distal part of a tidal dominated delta. Sandstone bodies are elongate tidal bars oriented NW-SE intersected by muddy tidal flat deposit. The Lower Genetic Unit is characterized by cross bedding coarse and medium grain sandstone deposited in the proximal part of a tidal dominated delta. Sand deposits are funnel tidal channels trending NW-SE. These two Units were correlated a long the 14 wells of the field to build the stratigraphic model.

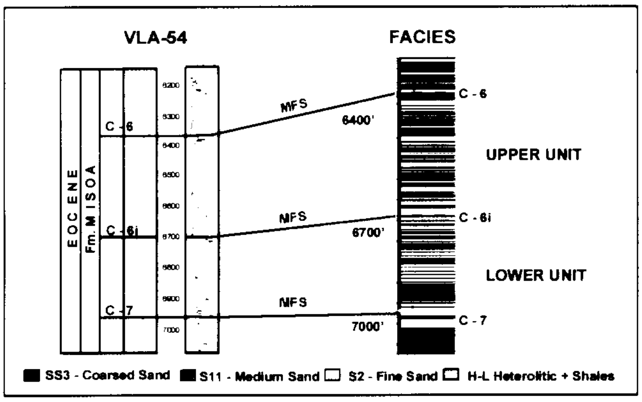

Fig. 2. Eocene-C6 Genetic Units

To establish the seismic stratigraphy model, the first approach was to perform a calibration between well and seismic, using synthetic seismograms to match seismic markers and well stratigraphy.

Once defined the Upper (C6- C6i) and Lower (C6i-C7) genetic units in seismic. Seventeen attributes distributed in 9 amplitude, 4 frequency, 2 phase, 1impedance and 1 thickness from time were calculated for each Unit. Six attributes in the Upper Unit and seven in the Lower Unit had found to be non-linearly correlated. The attributes were also divided into their spatial components resulting in 18 attributes for the Upper Unit and 22 for the Lower Unit. To establish a quantitative relationship between seismic attributes and rock quality properties, a cross validation-using Kriging with external drift was applied, using the seismic data as the external variable and well data as the hard variable. Pseudo-proper (%sand, ϕ, K, Vsh, and RQI) maps were generated for each unit resulting from the combination of attributes .

The attributes that correlated best with the sand percentage in the Upper Unit were component 2 of the average absolute value of amplitude (aaa2) and the component 3 of the thickness (thc3). The best attributes for the Lower Unit were the thickness (thc) and the ratio of positive to negative sample (rpn). These relations were introduced into a non-stationary stochastic model and an improvement in the definition and distribution of sand bodies was obtained comparing the models with (stationary) and without seismic constraints (Non-stationary) (Fig 3). Comparing the dimension of both stochastic realizations, the sand bodies extension of the lower unit in the model with seismic is 2.2 Km and in the well model is 500 m. If we compare these dimensions with modern environments, the model with seismic looks more realistic. Seismic information introduces in the reservoir model the lateral dimension required to define the reservoir architecture.

Dynamic Reservoir Model

Each stochastic model, stationary and non-stationary, was simulated in a fine grid (Nx=50, Ny=50, Nz=750, Dx=50, Dy=50, Dz=1) and upscaling into four different grids varying the Dz in 14, 24, 31 and 44 (Nx=67, Ny=68, Dx=50, Dy=50) and exported to flow fluid simulation software format.

A set of eight grids was exported in a dynamic reservoir simulation format. Four corresponds to the stationary model a four to the non-stationary model.

Oil in place values was obtained by initialization of the models. For the model without seismic (stationary) OOIP values range between 212.9 and 218.9 MMSB. Better results were obtained for the model with seismic (non-stationary); in this case, OOIP varies between 220.9 and 223.7 MMSB. The history match improves in the non-stationary model and when the number of layers

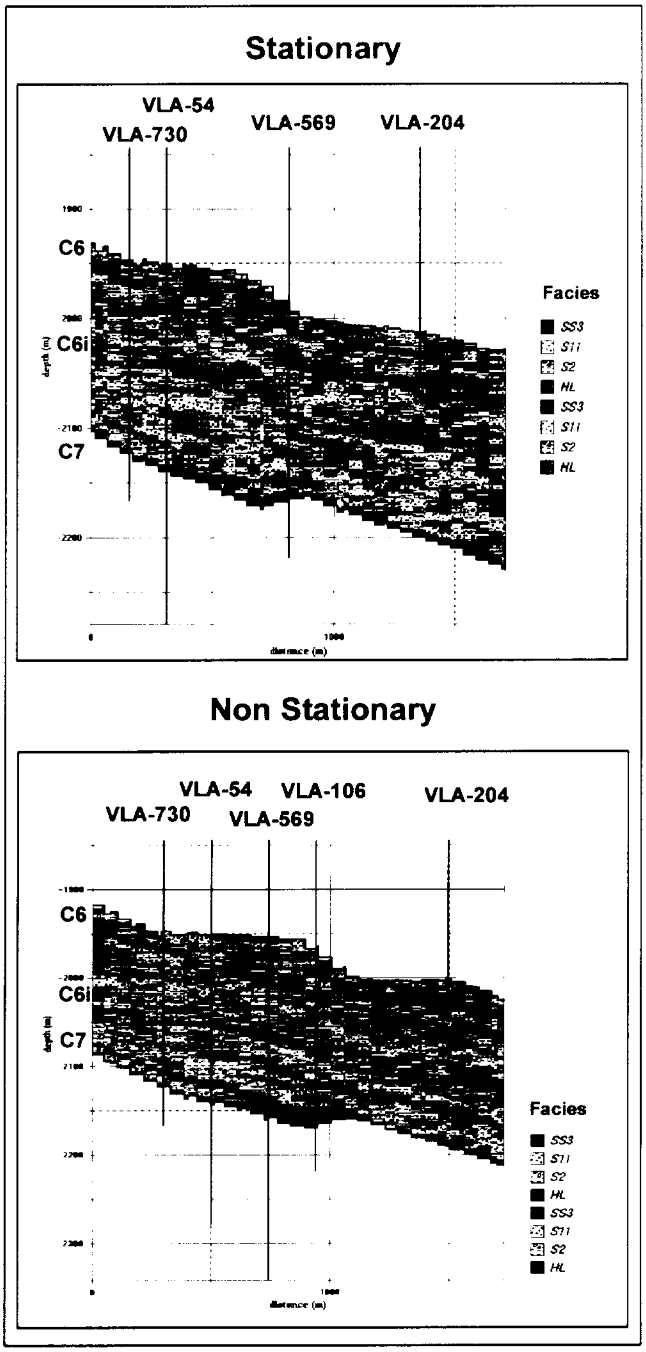

Fig. 3. Stochastic Models Comparison

increases. These results are due to a better lateral sand properties distribution given by the seismic attributes and a improve in the production/injection assignment within the layering in the vertically more detailed model (Fig. 4).

The flow fluid simulation performance is affected by the size of the upscaled grid. As expected the larger the grid the longer the run. However, there is a difference in the CPU time required for runs depending on the model. Non-stationary model having a better sand definition, and being laterally more continuous shows a faster convergence than the stationary model.

On the basis of these results, the incorporation of seismic attributes into the reservoir characterization impacts the

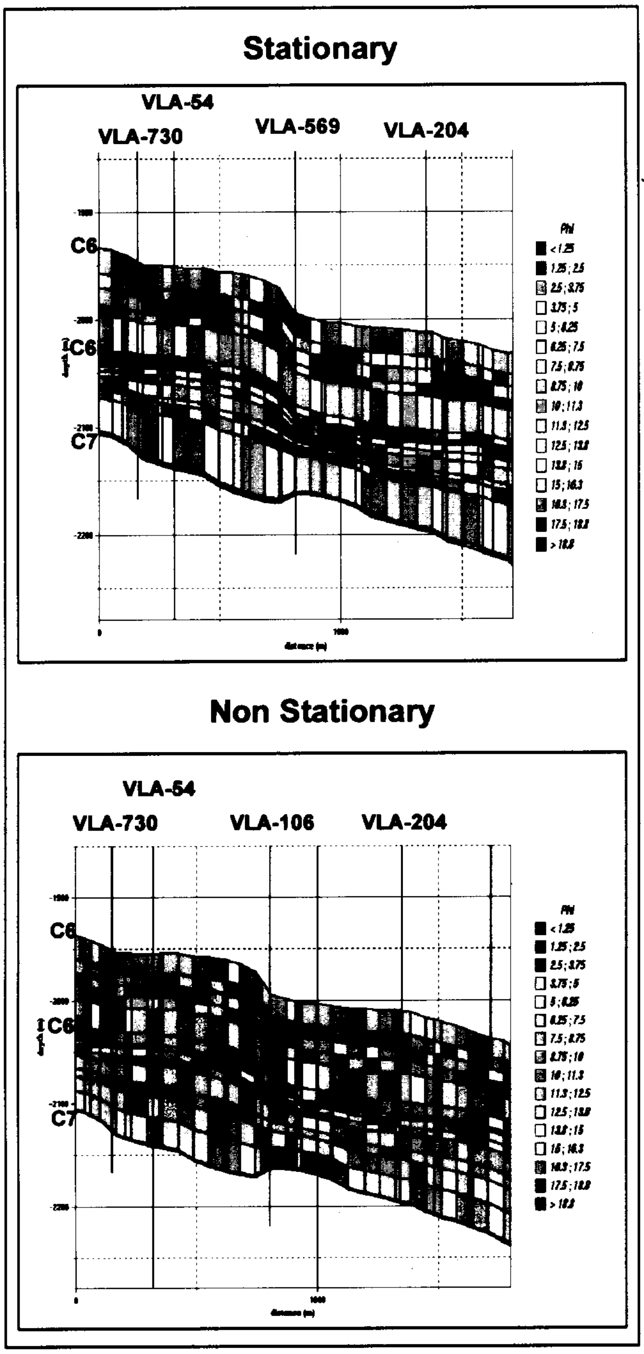

Fig. 4. Sands Petrophysical Properties Upscaling

performance of the fluid flow simulation and the history match quality. Additionally, the size of the upscaled grid must be selected accordingly to the level of heterogeneity present in the reservoir.

As a final result, a new development plan for C6-reservoir was establish base in the flow fluid simulation using the non-stationary stochastic geological model. This plan proposed a new product and two injector wells to optimize the reservoir recovery (Fig.5).

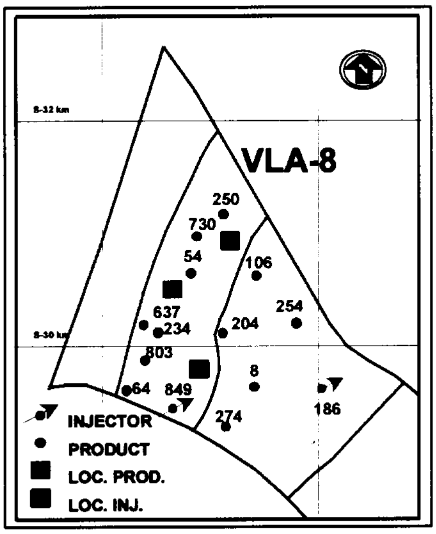

Fig. 5. C6 Reservoir Development plan

Conclusions

- A qualitative relation was established between rock properties and seismic attributes.
- Rock properties in each genetic unit correlate with different set of attributes stemming from vertical and lateral rock quality variation.
- The sand percentage quality map was incorporated to a Gaussian stochastic model to define reservoir arquictecture.
- Seismic incorporation in a reservoir stochastic model introduced the lateral dimension in the reservoir.
- 20 % of improvement in sand body definition was obtained comparing models with and without seismic.
- This improvement results in an accurate history match and OOIP calculation.
- One new product and two injector wells were proposed to improve the recovery in this deplete reservoir.
- This study indicates that seismic constrains are essential to better understand and decrease uncertainty in the characterized the reservoir.

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