Integration of Geostatistics and Well Test to Validate a Priori Geological Models for the Dynamic Simulation: Case Study.

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Abstract

To estimate the economics of marginal development with large uncertainties due to a reduced appreciation, wells performances should be evaluated as precisely as possible. This cannot be achieved without a correct quantification of the heterogeneities governing the dynamic processes. In this perspective, geostatistical models have to be built using, as usual, static data, but also dynamic data: well test response should be taken into account as constraint for the geostatistical modelling in an integrated study combining geological and dynamic considerations. A refined 3D geological model built using the geostatistical object method is validated by dynamic data when completely matching the corresponding well test response. The petrophysical values assigned to each facies are found by the matching process.

The Boubute field is a marginal structure appraised with one well, containing hydrocarbons in the Z Formation. This formation is characterised by heterogeneities coming from different depositional environments, with large uncertainties on the sizes and shapes of sedimentary bodies. Because of this geological complexity, the geostatistical approach constrained by well test data is performed. A good match is obtained with 20 x 60 m reservoir bodies while supposed much bigger initially. It allowed to perform a full field simulation on the upscaled model with sensitivity cases. An effect of acceleration of the production due to better Productivity Index (PI) and a second effect of production mechanism due to the percentage of good facies is observed on these sensitivity cases.

The integration of dynamic data to constrain geostatistical modelling is thus of great interest to provide supplementary information in this kind of development study and should, especially in the appraisal phase, be used when possible to validate a priori static models.

Introduction

The appraisal phase is a very important time in a life of a field, especially when the range of reserves uncertainty is close to economic viability. The uncertainties on the HIP and the reserves are often due to the presence of heterogeneities in the reservoir. The distribution of such heterogeneities is difficult to predict but conducts the well performances. In such a context all the data, either of static or dynamic nature, providing information about the reservoir model of heterogeneities should be integrated in the reservoir modelling to reduce the range of uncertainty of the field production. In this perspective, different geostatistical techniques have been developed during the last ten years for modelling heterogeneities, quantifying uncertainties and integrating data of different kind: seismic as well as sedimentology, diagensis or well tests. Furthermore, the fields which provide such kinds of economic viability problems are usually small structures, where the appraisal phase is reduced because of the associated costs. Only few data are thus available to define the optimal development of the field: The seismic at large scale, the logs and the cores at small scale. Both these data are of static nature. Only the Well Test is a technique which provides dynamic information at a medium scale. Only some of the main characteristics of it are usually used in a classical study: distances to limits, permeabilities, skin or partial penetration. In the case of large uncertainties on the geological model, the whole pressure response should be used to validate the a priori geological scenarios, by integrating the dynamic data to constrain geostatistical realisations.

The aim of this study is to evaluate the reservoir connectivity and productivity potential of a very heterogeneous field in a small structure. This is performed through a geostatistical modelling of the reservoir, based on the geological scheme of deposition. Each
sedimentological scenario is validated by comparing a well test forward simulation of the model with the available well test data. After matching, dynamic simulations are performed on the upcaled geostatistical model with sensitivity cases on different parameters, in order to estimate the economics of the possible developments of this field (see fig. 1).

Geological and Petrophysical data.

Geological context.

In the blocks around the field, several well tests have to be interpreted with one or more no flow boundaries. These « boundaries » can be attributed to lateral sedimentary evolutions with modifications of the reservoir characteristics by pinching out (or thickening) of the individual permeable aeolian beds.

Based on log and core data, the reservoir model for the Z formation around the field area can be summarised as:
- a vertical succession of decimetric to metric thick playa, fluvial, deltaic sheet flood and aeolian facies deposited in 4 main «drying-up» sequences. The 4 resulting reservoir sequences are separated by metric to pluri-metric thick shaly to silty intervals corresponding to playa lake deposits;
- the sediments composing the sequences were deposited along planar and sub-horizontal surfaces. The sequences themselves are correlatable but individual beds within show limited lateral extent especially for the aeolian and fluvial facies (plurimetric to hectometric range);
- there is very little fracturing and faulting apart near the blocks margins and for scattered seismic to sub-seismic scale faulting.

Description of the heterogeneities.

**Facies determination in each layer.** The main Z formation depositional environment deducted from core analysis are aeolian, fluvial, playa and desert lake. On the basis of lithology, grain size, sedimentary structures and on phi/K plots, 4 main facies groups have been differentiated to represent the overall reservoir architecture of the formation interval:
- dune sands,
- sandsheet sands,
- fluvial channel fill or sheet flood sands and conglomerates,
- playa/ desert lake silts and shales.

**Definition of the main geometrical reservoir parameters.** The reservoir body dimensions and orientation are essentially deducted from sedimentological studies and Elf’s internal reservoir data base.

An aeolian preservation mode is proposed to explain this lateral bed discontinuity and heterogeneity: (dune ramp model of Rubin and Hunter, (1) and Langford, (2)): the pinching out of the aeolian deposits results from lateral facies migration i.e. dunes and inter-dunes climb while migrating and preserve underlying dune deposits within a given interval (fig. 2).

With this model, four aeolian layers are recognised in the well, generally at the top of drying-up sequences (playa-fluvial-aeolian succession).

**Identification of the aeolian dune type:** A precise analysis of the aeolian facies succession and dipmeter recordings has clearly identified the dune and inter-dune facies as belonging to a barchan type desert environment.

The dunes are crescentic in form and probably isolated at time of deposition (fig 2). They are composed of dune sets and sandsheet facies both of which are modelled simultaneously as they belong to the same « object ».

The paleo-wind direction is from the east whereas the associated fluvial system is running towards the north, parallel to the aeolian dune crests.

**Size and composition of the individual aeolian sand bodies (« object »):** Considering the relative dune thickness and based on Elf’s internal reservoir geometry data base, on aerial photos and on outcrop measurements, a preliminary 500 x 100 m sand body dimension is chosen for the modelling of the dune facies in the reference case. Iterative work between the well test matching results and the actual DST response led to the reduction of these dimensions (120 x 120 m, then 80 x 80 m, then 60 x 40 m).

The barchan shape is finally represented by a 6 cell geometric « object » with the sandsheet facies lying in front of the dune deposits (fig 3). The comparison of the sedimentological data on the 4 reference wells in the area shows that the maximum individual dune and sandsheet thickness in the Bouboute area is 0.9 m.

**Internal aeolian layer geometry:** The aeolian horizons are made of dune « ramps » composed by an overlapping and inter-bedding of the bottom part of the dunes and associated sandsheets with inter-dune playa shales and fluvial incisions. Hence, the internal
architecture results from lateral facies migration i.e. dunes and inter-dunes climb while migrating and preserve underlying deposits of fluviatile and playa. (fig 3). The climbing angle can reach up to a few degrees (3 to 4°).

Thus, in the modelled aeolian sequence, barchan shaped « blocks » composed of dune and sandsheet facies are trending in a north-south direction while migrating upward in the sequence towards the east. These blocks are separated by north-south trending fluvial channels and playa deposits (inter-dune or « matrix, fig 3).

**Facies frequency**: Without extensive well data to support the facies frequency determination i.e. the ratio of dune vs sandsheet facies in the four previously defined aeolian horizons, this parameter has been estimated by looking at the aeolian frequency occurrence throughout the Bouboute area and at outcrop data and aerial views of barchan type present day environments.

The initial overall proportions for constructing the four aeolian sequences are presented Tab 1.

In the inter-dune (also referred to as the matrix of the aeolian sequences), fluvial channels are also stochastically generated in the NS direction and a frequency of 30%.

**Petrophysical characteristics.**

The petrophysical characteristics (phi, K, Sw) for each facies group in each layer is taken from log and core analysis of the well. The measured porosity, permeability and saturation ranges are given in Tab 2.

Based on the above reservoir characteristics and previously calculated facies proportions, the reservoir model is expected to be mostly sensitive to the aeolian bodies geometry and distribution. In the following, emphasis is put on the geological data used as input for guiding the stochastic modelling of the aeolian horizons.

**Geological modelling process for the Bouboute area:**

Based on the above results, a refined 3D geological model is built for well test forward simulation purpose using an in-house modelling software called GESTAT (stochastic modelling package), (ref. 3). In a second step, the dynamic behaviour of the generated geological model and the one from the actual Z formation reservoir of Bouboute will be compared by using a numerical well test analysis software (gridded model). The methodology is schematised in the figure 1.

This reservoir building and well test simulation processes involved the following steps:

- refined layering of the reference well,
- facies determination in each layer,
- petrophysical characteristics attribution to the main facies (phi, permeability, Sw),
- definition of the geometrical reservoir parameters (aspect ratio of main aeolian sand bodies, orientation, frequency),
- geostatistical (object based) modelling of aeolian sand bodies,
- 3D reservoir model construction.

**Geostatistical modelling.**

In such a geological context where the objects to be modelled have to be very precisely described and the stacking pattern very well controlled, the most appropriate geostatistical modelling is the object method, also called Marked Point Process Modelling. Indeed, the sedimentary body shapes such as barchan types or the location of the sand-sheets regarding to the location of the dune facies, can be specified in a much better way in the framework of object based modelling method than what could be done in variogram-based techniques like in ref. 4.

In this geostatistical modelling technique (ref. 5), the objects, are, in a first step, described in terms of

- geometry (shapes, respective location of all the facies),
- dimensions (width, length, thickness, sinuosity...),
- proportions (frequencies, occurrences),
- interactions between objects (stacking effect, dispersion, erosions...).

The locations of the objects in the field, as well as their geometrical parameters, are randomly allocated for each object, placed in the reservoir but constrained by some parameters of the modelling which are supposed to be respected such as : well data facies description, facies proportions, stacking pattern/interactions....

**Simulation grid and modelling parameters.**

In order to model the field finely enough, with a reasonable low number of blocks, the parameters are chosen as such : block size (m) :
hx=10, hy=20, number of blocks : Nx = 251, Ny = 341. Nz and hz depend on the aeolian layer. 
The shapes of the objects are firstly drawn in two 2D sections. These 2D sections are secondly mixed together, as explained in ref.4 to create a 3d object. The horizontal 2D sections of dune facies are presented fig 3. 
In this model the four dune/sand-sheet layers are modelled with these barkan type objects. 
The geometrical parameters of the 3D objects are presented above in the geological part, as well as the facies proportions.

Modelling methodology.

The dune and sand-sheet deposit model can actually represent a base pattern with one vertical block high, duplicated several times in the climbing angle direction. In this repeatable scheme, paths of fluvial can cross the structure parallel to dune crests, randomly placed in the repeatable architecture of climbing aeolian deposits. An example is given fig 4 with a horizontal section of an aeolian layer. 
To model this complex geometry, the procedure has been divided into two parallel steps (Fig 5).

- A simulation is performed for each of the four aeolian sequences, independently, in only one vertical block size of 10 cm (Fig 5.1.). This simulation contains only dune and sand-sheet facies in the matrix. The matrix is at this step undefined but can be either of fluvial or of playa type, as explained below. The 2D simulation grid is multiplied several times and all the 2D grids are concatenated together to get the 3D grid with a translation of one horizontal block in the paleo-wind direction to simulate the climbing angle of the inclined aeolian deposits (Fig 5.2.).
- Parallel to this simulation of the potential reservoir facies (dune and sand-sheet in un-differentiated matrix), a simulation of the matrix facies is performed. The fluvial facies is then modelled like random occurrences in a playa matrix (Fig 5.3.).
- For each aeolian layer, the reservoir facies simulation and the non reservoir facies simulation are merged together (Fig 5.4.) with the following hypothesis :
  - the dune and sand-sheet facies are kept.
  - the matrix is replaced by the fluvial or playa facies.
All the simulations are 100% honouring the well data. After having simulated all the layers independently, the grids are concatenated together with the grids representing the homogeneous underlying beds of playa, desert and fluvial deposits, in order to model the real sequence. 
The fig 6 displays the whole Z formation reservoir modelling. 
The layers are not equally scaled since all the homogeneous underlying beds (playa, fluvial) are only represented, in a deterministic way, with a unique vertical block. 
Though, the aeolian sequences (dunes and sandsheets in playa or fluvial matrix), stochastically modelled are at a correct 10 cm scale in z axis.

Sensitivity studies : Geometries, climbing angle.

Some sensitivity tests on the proportions of reservoir facies as well as on the climbing angle or the dune dimensions, have been performed, to compare their well test signatures and the real one, as explained in paragraphs below.

Preparation of the modelling for the Well Test Matching.

Since, for the Well Test Matching, the description of the field has to be in petrophysical terms, the facies assignments in the grid are changed into porosity, lateral and vertical permeability and water saturation. Although the Well Test matching supposes a modification of these parameters, some rough initial parameters, coming from log and core analysis, have to be assigned before the matching. They are given Tab 3.

Well Test matching.

Presentation of the well test matching.

In order to validate or invalidate the geostatistical modeling described in the previous part, this model has been tested in term of Well Test matching. To achieve a correct response, different characteristics for each facies determined by the geology are optimized using the gradient method (see reference 6). The pressure response of the build up is given in all figs. 7 to 11. It is important to note that the points are not given in terms of pressure (bars) but in term of pseudo-pressure as usually in analytical gas well test interpretation. The pseudo-pressure used in this case are the ones used in the classical gas well test interpretation. 
The structure of the geostatistical model (grid size, number of blocks) has been described in the previous part. In addition to the initial
gridding, a grid refinement around the well has been done to reduce the size of the well cells. It allows then the reproduction of the well test pressure response. In deed, a large cell at the well would correspond to a too large capacity in the first cell and the wellbore storage would then be impossible to match.

**Well Test Matching.**

Several geostatistical models have been tested during this study. The well test analysis allows the modification of the geostatistical modelling. For example, some of the models have been invalidated by the well test matching because it was clear that the information input in the geostatistical model was incompatible with the pressure response. Only a few matches are presented here.

First, the well test model optimises some of the parameters like permeabilities per facies and the global skin. But, to match the well test, a good start point should be given to the model. This start point has to be chosen with the Geology.

The first model tested, as explained in the geostatistical part corresponds to high dune dimensions with a unique climbing angle in all the aeolian sequences (see match, fig 7). After optimisation, the « best » match is then given in fig 9 with the corresponding petrophysical parameters.

After study, it appeared that this model could not correspond to the real pressure response and it was impossible to change the parameters in a good way to obtain a correct match. This can be explained by the fact that the dunes in the aeolian sequence 4 were too large, because 90 cm were observed at the well. This was the consequence of the completion profile and of the fact that most of the production comes from this sequence. The pressure response is then directly linked to this sequence distribution. It was therefore impossible to obtain the first climb-up on the derivative curve at about 500 s. This climb up corresponds to a close limit as for example the end of the first dune observed at the well.

The same analysis has been made for the climb-up at about 500 s while the dune size has been tested during the well test matching. Fig 7 gives good examples of different matches obtained for different size of dunes. Largest dunes cannot fit the well test at this time. The first limit was too far from the well.

After correction of the climbing angle and of the dune size to solve this problem, the new model has been tested. The corresponding match is then given in fig 8 with its corresponding petrophysical parameters.

This match is not good enough to represent correctly the hump observed on the derivative curve at around 5 000s. The reason of this bad match at this time was not very clear but after study it appears that two different phenomena are stacked at this time : the first one corresponds to a climb up due to a change of permeability (from a good permeability zone in a dune to a bad permeability one around this dune) and the second one corresponds to an exchange between layers (the hollow in the derivative curve at about 30 000s is the consequence of this exchange between layers). All these phenomena have been understood with different tools among of which one of the most important was a analytical well test analysis software which allows to test lots of different cases with appropriate analytical solutions (ref. 7).

However, it was not possible with the used parameters to separate explicitly these two phenomena. To achieve this, the fluvial facies should be separate in two under facies : the first one corresponding to the fluvial facies between the dunes in the aeolian sequences and the second one corresponding to the fluvial facies layers.

After separation was realised, a correct match was obtained. It is shown fig 9.

The difference observed in the vertical permeability between the same facies but in different layers (as for example the fluvial facies within the aeolian sequences and the fluvial facies only) can be explained by a scale effect i.e. the vertical permeability is not observed at the same scale in both cases. This phenomenon is described more precisely in reference 5.

**Sensitivity to the percentage of dunes in the aeolian sequences**

To test the model in term of gas production, many sensitivity runs have been performed in order to appreciate the uncertainty around the chosen model. In this aim, the percentage of dunes in the aeolian sequences has been tested in term of gas production. Two new matches are presented for the two different cases studied : 20 % and 40 % of dunes in the aeolian sequences.

The two matches are presented fig 10 and 11.

Because the well test matching process does not yield unique solution, it is possible to obtain different values for all the different parameters. However, the values drawn from the models shown provide a good order of magnitude for the actual values.

**Preparation of the modelling for Eclipse simulation, Upscaling.**

Because of the too high number of grid blocks in the geostatistical modelling, an upsampling phase has been necessary to run the Eclipse
simulator. The refined grid settled around the well and used for the well test matching step is still kept for the Eclipse simulation. Thus only the part of the reservoir modelling which is not involved in the well test response is upscaled and integrated in the Eclipse simulation as a coarse grid (see Fig 1).

All the underlying beds of playa and fluvial, deterministically modelled, are only represented by one single vertical block per bed. Boundaries Conditions and No Boundaries Conditions have been tested and the results have been compared, even if diagonal terms cannot be integrated in Eclipse. The diagonal terms are found to be negligible.

**Full Field Model**

Flow simulations are performed on the models previously defined through a geostatistical approach validated by well test data, to assess the dynamic behaviour of the wells in field conditions. Sensitivity on different parameters are performed to quantify the uncertainty on the recovery.

**Input data.**

Input data are of different types:

**Geology and petrophysics.**

The first input of the model is the top map of the structure. The layering of the reservoir has been given in the geological study. It is the same layering as in the well test matching. The other static properties such as the porosity, the permeability and the water saturation have been introduced after upscaling.

**Fluid properties**

The gas PVT has been defined in the model by tables corresponding to the Formation Volume Factor ($B_p$) and the gas viscosity ($m_p$). Because all the different facies (aeolian, fluvial and playa) and the cells after upscaling have different $S_{w}$ (seen on the logs), the corresponding Kr-Pc curves have to be adjusted for each case. It is the reason why the End Point Scaling option has been used for all the cells of the model. Only one curve is given at the beginning of the model, a table of all end points (the connate gas and water saturations, the critical gas and water saturations and the maximum gas and water saturation) thus characterises each cell, so that the relative permeability curve and the capillary pressures can be calculated for each cell.

The Water Gas Contact (WGC) has been set at 3940 m MSL.

**Well production constrains**

The full field model simulation has been performed with the exploration well characteristics. The well perforations are located as found in the well test matching.

The perforation skin is one of the parameter matched with the well test analysis and a value of -0.5 has been found. However, this value corresponds to a clean well without any stimulation. In fact, this well will be stimulated when it will be put in production; so this value should not correspond to the future real value. By comparison with the corresponding wells in the region, it seems to be correct to have a perforation skin after stimulation (fracturation) between -4.0 and -5.0. The model should represent such a low value.

Unfortunately, it is not possible to introduce this kind of perforation skin in the Eclipse model. To get a correct approximation of this parameter, a radial better permeability zone has to be introduced in order to take into account the fact that the connection between the well and the reservoir has been stimulated.

In our case, and after a short perforation skin match, the horizontal permeability around the well has been multiplied by a factor of 20 in a 20 m x 20 m block around the well. This modification of the permeability around the well did not change the well test response but gives a perforation skin of around -4.5.

The second parameter to characterise this connection between the well and the reservoir was the turbulence factor. This parameter had been estimated in the well test conditions. However, the conditions of the test are different from the future conditions. The stimulation that will be performed on the well should reduce this parameter too. This factor has then by reduced by a factor of 10 so that the value of turbulence factor introduced in the model is 4.02 x 10^{-7}.

The control of the well and its production is performed by the Well Head Pressure.

A swing factor of 110% has been used in all the simulations in order to adjust the real potential of the well.

Finally, pressure drop in the tubing has been introduced by table.

**Initial Gas In Place**

The first result of this simulation concerns the Initial Gas In Place (IGIP). It is comparable with the previous results obtained.

**Reference case**

With the hypotheses displayed above, a 10-year simulation has been run. The results of this simulation are graphically displayed: a plot of the different flows between layers in order to clearly understand the production mechanisms (fig 12).
The cumulative gas production gives a global recovery factor of 40% after 10 years. The aeolian sequences with the best permeability drain the gas from other sequences of the reservoir. Most of the Initial Gas In place are in the fluvial sequences, which supply the aeolian drains. But the contribution of the playa layers to the global result is not negligible. A quick look at the 2nd Playa sequence from the bottom gives a good idea of its role. Without any vertical communication within this unit, the gas in the 1st Fluvial layer from the bottom would not be produced through the 1st aeolian sequence (down).

A good summary of the production mechanism could be:
- The aeolian sequences are drains
- The gas capacity is in the fluvial sequences
- The vertical permeability of the playa sequences is not negligible since it permits gas to flow from the fluvial layers to the aeolian drain.

Sensitivities
As it had been said in the well test matching paragraph, the match found with this well test is not unique, even if it was quite difficult to get one precise match. It is thus important, to understand the production mechanism and extrapolate its result to other cases, to run sensitivity cases on this field.

First, these sensitivity cases are focusing on the effect of a global increase of the permeability on the production profile. Then, the characteristics of the fluvial facies will be modified in order to check its influence.

Sensitivity to the horizontal permeability
This first sensitivity case focuses on the effect of a global increase of the horizontal permeability. For this, the horizontal permeability ($k_h$) has been multiplied by a factor 1.5 in all the reservoir.

The total production after 10 years represents an increment of 20% compared to the reference case which can be explained by two different factors, the first one being an acceleration of the production mechanism and the second one by the fact that the poor layers (fluvial and playa) have a greater influence in this new case. This second hypothesis is clearly identified on a Pressure versus Cumulative production plot ($P(G_p)$) where the two different curves are not superimposed. The higher the horizontal permeability, the higher the recovery.

Sensitivity to the fluvial facies
All the parameters useful in a full field simulation could not have been determined by the well test interpretation because the information given by such a test is not extensive. As it has been explained in the well test interpretation part, some of the parameters has been estimated in a « base case », but can also vary in other interpretations.

This uncertainty concerns the Fluvial and Playa facies parameters. It is therefore interesting to check the sensitivity to those parameters in order to estimate the global uncertainty on the results.

Here, the horizontal permeability of the Fluvial facies has been multiplied by a factor of 2 in order to check the sensitivity to this particular facies.

The total production after 10 years represents a 10% increment compared to the reference case. This increase of reserves after 10 years seems to be quite important and must be taken into account in the uncertainty of the model:

As it had been explained previously, most of the Initial Gas In Place is in these Fluvial layers, and this permeability value is not well determined with the well test. The $P(G_p)$ curves confirm the point that this increase of production corresponds to an acceleration of the production mechanism: The bigger this value, the quicker the production.

New matches with different percentages of dunes.
All the previous cases have been performed with a constant percentage of dunes in the aeolian sequences (30%). This parameter was chosen in the geostatistical modelling. This paragraph will focus on the sensitivity to this input parameter.

To achieve this point, two new geostatistical models have been build (with a percentage of 20 % and 40 %). Those models have been then tested in a well test matching point of view. The results of these matches explained in the well test matching part, are different from the former interpretation, so that a new upscaling was necessary to get correct input tables in the model.

20% of dunes.
The results of the well test matching, displayed in fig 10 are in this case quite different from the previous ones. For example, it is clear that this interpretation gives an horizontal permeability for the fluvial facies seven times bigger than the previous one. As it was explained in the sensitivity to the fluvial facies paragraph, this should change the final results.

After upscaling, these figures have been introduced in the global model. The results of this run are displayed in fig 13 with a
comparison with the reference case.
The total production after 10 years represents a 25.0 % increment compared to the reference case. This difference is important but seems to be in the wrong way: The less dunes introduced in the aeolian sequences, the less connectivity and normally the less gas production. But, in this case, the matching parameters have been modified (as for example the horizontal permeability of the fluvial facies) so that this relation is no more straight forward. Two phenomena are observed, the first one reduced the production by the fact that less dunes are present, the second one increased the production with an increased horizontal permeability of the fluvial facies. At this point it is impossible to separate these two effects. The production mechanism is also poorer with this hypothesis from a P(Gp) point of view.

40% of dunes
The well test matching results of this new 40% dunes in the aeolian sequences are also different from the previous part. The influence of the fluvial characteristics is not negligible in this model.
After upscaling, these figures have been introduced in the global model, the results of this run are also displayed in fig 13 with the 20% and 30% (reference case) dunes plots.
The total production after 10 years represents a 30% increment compared to the reference case. As it has been said in the previous part, two phenomena can explain this result : the percentage of dunes and the horizontal permeability value of the fluvial facies.

Conclusions
This paper presents the modelling of an heterogeneous reservoir, with a validation of the geological scheme, modelled through a geostatistical approach, by well test data. We have seen by iterating on the geological model to match the well test, that the validation is quite restrictive decreasing the range of uncertainty and allows some sensitivity studies on the found most important different parameters of the model. The reference case has been found to have 60*40m reservoir bodies when supposed much bigger initially. The matching reduces also the uncertainties existing on the petrophysical values. The dynamic simulation has highlighted some mechanisms of production, seen also with the sensitivity cases, mainly that the aeolian layers are drains but the high capacity of the field is in the fluvial sequences.
Even if bad results of production are obtained with the simulation on 10 years, the sensitivity study has showed that the connectivity exists on the field, and that the reduced production problem comes from a low productivity. The next step should thus be the optimisation of the well architecture (multi-fracturing, acidification, complex well...) in order to increase the productivity.

Acknowledgements
The authors thank Elf Exploration Production for permission to publish this paper.

References
5. Early Quantification of Hydrocarbons in Place through geostatistical object Modelling and Connectivity computations by F. Petit, P. Biver, P. Calatayud, J. Lesueur and F. Alabert - 1994 SPE 28416
Table 1. Percentages of the different facies in the aeolian sequences.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Dune</th>
<th>Sand-sheet</th>
<th>Fluvial</th>
<th>Playa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeolian sequences 1 and 4</td>
<td>30%</td>
<td>20%</td>
<td>15%</td>
<td>35%</td>
</tr>
<tr>
<td>Aeolian sequences 2 and 3</td>
<td>20%</td>
<td>30%</td>
<td>15%</td>
<td>35%</td>
</tr>
</tbody>
</table>

Table 2. Petrophysical parameters of the different facies.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Porosity (%)</th>
<th>Permeability (mD)</th>
<th>Sw (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>aeolian dune</td>
<td>13.5 - 17</td>
<td>20 - 130</td>
<td>15 - 22</td>
</tr>
<tr>
<td>aeolian sand-sheet</td>
<td>8.0 - 17</td>
<td>1 - 20</td>
<td>15 - 26</td>
</tr>
<tr>
<td>fluvial channel fill/ bars</td>
<td>5.0 - 15.5</td>
<td>0.1 - 20</td>
<td>25 - 40</td>
</tr>
<tr>
<td>playa / desert lake</td>
<td>2.0 - 9.0</td>
<td>0.01 - 0.5</td>
<td>&gt; 50</td>
</tr>
</tbody>
</table>

Table 3. Petrophysical characteristics of the facies in the aeolian sequences defined for the well test matching.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Kv(mD)</th>
<th>Kh(mD)</th>
<th>Kv/Kh</th>
<th>Ph(%</th>
<th>Sw(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>dune</td>
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<td>12</td>
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<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>sand-sheet</td>
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<td>1.5</td>
<td>0.02</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
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<td>0.4</td>
<td>0.005</td>
<td>0.10</td>
<td>0.30</td>
</tr>
<tr>
<td>playa</td>
<td>0.0001</td>
<td>0.01</td>
<td>0.01</td>
<td>0.04</td>
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</tr>
</tbody>
</table>

Geostat refined grid → Upscaling → Assignment of PHI, K and SW per facies → Well Test Model for the matching → YES, validation of the a-priori model.

Geological modeling → Well Test matching → Full Field modeling

Eclipse coarse grid

Fig. 1- The validation of the geological model is done through a geostatistical approach when matching the well test response. After validation, the geostatistical model is upscaled for the dynamic simulation. A refinement around the well is kept.
Figure 2. Barchan type dune architecture and deposition model.

Figure 3. Aeolian dune object representation and modeled aeolian sequence architecture.

Figure 4. Geostatistical modeling. Horizontal section of an aeolian sequence.
Figure 5. Dune ramps geostatistical modeling process (up to down: steps 5.1., 5.2., 5.3., 5.4.).

Figure 6. Geostatistical Modeling. Cross Section of the whole Z formation. The four aeolian sequences (at 0.1m vertical scale) are interbedded with homogeneous modeled sequences of playa and fluvial deposits (not at scale, only sketched by one vertical grid block).
Figure 7. Well Test Matching. Build up and first models with 120*120 and 80*80 m dunes.

Figure 8. Well Test Matching of the reference case with 60*40 m dunes and 30% of dune facies. No optimization on petrophysics.
Figure 9. Well Test Matching of the reference case with 60*40 m dunes and 30% of dune facies. Optimization on petrophysics.

Well test match
20% of Dunes

Figure 10. Well Test Matching of the sensibility case with 60*40 m dunes and 20% of dune facies.
Figure 11. Well Test Matching of the sensibility case with 60"40 m dunes and 40% of dune facies.

Figure 12. Reference case. Production by layer after 10 years. The sum of the production is normalized at 100 and the sum of the exchanges is normalized at 1000.
Figure 13. Production profiles of reference case and sensibility cases on dune proportions.