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OBJECT BASED SIMULATIONS IN FLUVIAL ENVIRONMENT AT THE RESERVOIR SCALE AND AT A LOCAL SCALE.

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ABSTRACT

Object-based approaches are commonly used to reproduce large-scale heterogeneities in oil reservoirs, such as channels and crevasses in fluvial environment. These bodies are often non uniformly distributed in the studied domain. Their locations can be deduced from additional data, such as seismic, which is interpreted in terms of proportions of the reservoir facies. According to the fact that the reservoir facies will be reproduced by the objects, their shape, distribution and number have to be consistent with the proportion map. In this paper we propose a method to obtain, from the proportion of the studied facies, the non stationary distribution and the number of the objects to be simulated over the volume, the shape and size of the objects being fixed a priori.

INTRODUCTION

Classically, the non stationary distribution of a given facies is given by the 3D distribution of the lithofacies proportions, deduced from wells and seismic data. In object-based methods, this matrix of proportions represents the non stationarity of the objects in terms of their size parameters and their distribution. In this work, we only consider the variability associated to the object distribution, assuming that its shape and size have been previously determined.

In terms of the parameters of the Boolean model, this non stationarity is reproduced by a regionalized Poisson intensity. The problem to be solved is how to fit this intensity knowing the 3D proportion matrix and to obtain the corresponding number of objects to be simulated. To do that, we propose a method based on a deconvolution operation. This method was first proposed in 1D by ([7] Schmitt, 1996) and generalised to 2D by ([2] Benito, 2002).

After a brief presentation of the method for estimating these two parameters (the Poisson intensity and the number of objects), two different applications are presented. The first example concerns fluvial reservoir at the reservoir scale. An outcrop provides the proportion of this facies as well as its non stationarity on the plane perpendicular to the fluid flow. To illustrate this example, data from the Permian series of Utah are used.

In the second example we move down to the channel scale. We obtain simulations of heterogeneities whose distribution is non stationary in 3D. This approach is useful to represent the non stationary distribution of shales or sands inside the channel at a local scale, for instance.

METHOD DESCRIPTION

Inference of the Poisson intensity by deconvolution

The Boolean model is defined as:

$$X = \bigcup_{x \in \wp} A(x); \qquad x \in D > \mathbf{u\ \ g\ \ 3} \tag{1}$$

where $\wp$ is a Poisson point process of intensity θ, $A(x)$ are the objects or primary grains introduced at the Poisson point x and D is the studied domain. The $A(x)$ are compact non empty sets in D whose characteristics do not depend on their position.

In our particular case the available information, provided by wells and seismic surveys, is the proportion over the field of the studied facies which will be modelled by the Boolean model X. This proportion gives the probability of the indicator facies on this support, $p(y)$, that is, the probability that a point y of the space belongs to the Boolean model X. This proportion is related both to the regionalized intensity function $\theta(y)$ and to the primary grain by a convolution operation, as in (2). The characteristics of the object are introduced through $p_0(y)$, the probability associated to the primary grain, that is, the probability that a point y of the space belongs to the object implanted at the origin $(y = 0)$. In this approach, the primary grain is determined using additional information, such as analogues outcrops.

$$p(y) = 1 - \exp(-\int_D \theta(u) P(A(u) \cap \{y\} \neq) \varnothing du) = 1 - \exp(-\int_D \theta(u) P((u - y) \in A) du) = 1 - \exp[-(\theta * p_0)(y)] \quad (2)$$

The regionalized intensity can be then obtained directly by the deconvolution of expression (2). This deconvolution is solved by using Fourier transforms and a classical method of signal processing, the Wiener filter. The deconvolution process is extensively treated in ([1] Benito, 2001).

The practical application of this approach has certain pecularities that need to be addressed. One is interpreting the result of the deconvolution in terms of intensity, which involves the correction of its negative values. That has been solved by simply smoothing the result of deconvolution. Another one is defining the calculation support to provide sufficient accuracy when describing the objects through p_0. For that, we must work on a fine grid. As the support of $p(y)$ is related to the studied domain, it is usually calculated on wide blocks and it has been necessary to subdivide them into smaller blocks. These points are discussed more extensively in ([2] Benito, 2002).

Number of objects to be simulated

To achieve the simulations, it is necessary to know not only the distribution of the primary grains, that is, the Poisson intensity, but also the average number of objects to be simulated in the domain ***D***. This is directly given by the expression (3):

$$E[N(V)] = \int_D \theta(y) dy \quad (3)$$

Two different situations are presented in the following examples. In the first one, at the reservoir scale, we work on a cliff where the channel facies presents a non stationary distribution on the plane of the cliff. Then, the Boolean simulation only involves this plane of non stationarity and the whole process is performed in 2D. The second example, at a local scale, is related to a porous volume. The distribution of the studied facies in this volume is non stationary in 3D.

CASE STUDY 1: RESERVOIR SCALE

This example deals with the simulation of fluvial deposits at the reservoir scale. A regional transect provides the proportion of this facies and indicates a non stationary distribution on the plane of the cliff. The proportion map is then calculated on this plane of non stationarity and is considered to be representative of the whole unit, as the channels are more or less parallel and cross the entire unit. The Boolean simulation is performed in 2D.

The case study comes from the Permian continental series of the Paradox Basin in Utah (Cutler and Cedar Mesa Formation). One regional transect has been constructed from fifteen outcrops and several photo mosaics ([5] Eschard, 1997, [6] Lerat, 1999). Only one of the nine litho-units identified is considered in this work and the Boolean model is used to simulate the facies corresponding to fluvial channels.

To do this, fifteen vertical proportion curves have been calculated from the outcrops. The proportion map has been obtained by kriging ([3] Benito, 2002). The proportion map (figure 1) shows that this unit is characterised by an important variation in the presence of the channel lithofacies decreasing from NE to SW where it almost disappears. We can also see the changes in proportions from one level to another along the vertical direction.

The channel facies in this plane corresponds to the intersection of the channels with the plane of non stationarity. This lithofacies is simulated by semi-ellipses of 600 m wide and 3-5 m deep ([4] Clément, 1999). To perform the deconvolution, the probability associated to the objects, p_0, has been calculated by approximating the semi-ellipses of variable size to the smallest rectangles that contain them. This considerably simplifies the expression of p_0, making the whole process more rapid to perform while giving a good approximation of the intensity we are looking for. As the objects to be simulated are semi-ellipses, the number of primary grains to be introduced in the simulation has to be corrected. The approximated average number of semi-ellipses to simulate is proportional to the average number of rectangles, the constant of proportionality being the ratio between the surface of the rectangle and the surface of the semi-ellipse.

The intensity obtained after deconvolution (figure 2) gives the distribution of the primary grains in the volume of simulation. We can observe that the maximum values correspond to the highest values of proportion and conversely with the minima.

An example of the simulations obtained using this approach is shown in figure 3. Only the vertical section XZ is presented, knowing that the channels cross the whole unit. The distribution of the channels reproduces that of the corresponding facies indicated on the proportion map (figure 1). We observe the decreasing presence of channel from NE to SW, which separates two regions in the field. This approach allows us to treat the whole unit without splitting it up.

The proportion map computed on this simulation is presented in figure 4. The general aspect satisfies the initial proportions, within the intrinsic variability of simulations. However, the intermediate values in the initial proportion map (between 0.10 and 0.50) are not so well reproduced in the proportion of the simulation.

In this case, the proportions obtained from several simulations slightly over-estimate the initial global value of channel proportion in the unit: 45-48% for an initial value of 44%, which can be considered satisfactory enough.

CASE STUDY 2: LOCAL SCALE

We now apply this approach to the simulation of heterogeneities having a non stationary distribution in 3D at a smaller scale. This approach can be used to reproduce heterogeneities inside the channel, when there is a non stationary distribution of the shales and sands, for instance. The whole process is similar to the previous case, but now the intensity is obtained in 3D. The volume of simulation is $52\times40\times8$ m^3. The heterogeneities are represented by rectangles of varying size: 2-4 m wide, 2-6 m long and 0.2-0.5 m deep.

Figure 5 shows the distribution of proportions of the heterogeneities to be simulated, in red. Here, every small block contains one single vertical curve of proportion, that is, the proportion of the facies in every vertical level in a block of horizontal size 4×4 m^2. It is possible to appreciate the non stationary distribution of this facies: from West to East, the proportion increases from the highest levels to the lowest, with the appearance of two distinct zones in the middle region. In the western side, the highest levels disappear. In general, the proportions decrease from South to North, particularly at the lowest levels. In the northern region, the proportions of these lowest levels even disappear. We can identify a region in the NW in which no presence of the facies of interest has been detected.

The process is the same as previously: the deconvolution between the initial matrix of proportions and the probability associated to the primary grain gives the corresponding matrix of intensity and the number of objects to be simulated. Figure 6.a. shows an example of such simulations. We can appreciate the non stationary distribution of the objects as indicated by the initial matrix of proportions.

The 3D block of proportions computed on this simulation (figure 6.b.) respects the general characteristics of the initial proportions, except that it is more erratic, as it was expected. An important point to be noted is that, as in the previous case, the global value of proportions in the whole volume is recovered in all the simulations performed, although a slight over-estimation can still be observed: the initial global value of the proportion of the studied facies being 18%, the global value of the proportion of the simulations is 21-22%.

The importance of the distribution of the objects is highlighted in the study of the porosity, for example. We can see that by calculating the connected components on the Boolean simulations. A connected component is the union of all the pixels that can be connected using a path through the concerned facies. Figure 7.a displays the five biggest components in the previous simulation. The largest component, labelled 1 (in red), represents 71% of the total volume occupied by the objects. Figure 7.b also shows the five biggest connected components in a stationary simulation. In both examples, the global proportion value of the model, that is, the global porosity value in the block, is the same. In this stationary case, the biggest component only takes 11% of the total volume occupied by the objects. This clearly illustrates the fact that the porosity not only depends on its global value in the volume, but also on the distribution of the facies in the block.

CONCLUSION

The method presented in this paper makes it possible to estimate the Poisson intensity of the Boolean model from a 2D or 3D matrix of proportions. This enables us to reproduce a general non stationarity in the distribution of the facies to be simulated at a large or at a local scale. The number of objects to be introduced in the volume is then naturally calculated from this intensity. The simulations obtained respect both the initial matrix of proportion and the global value of proportion over the whole volume, when the objects are small compared with the volume. However, several problems must be still analysed, for instance, the impact of the relationship between the size of the objects and the size of the domain, the introduction of a regionalized distribution of the object sizes…

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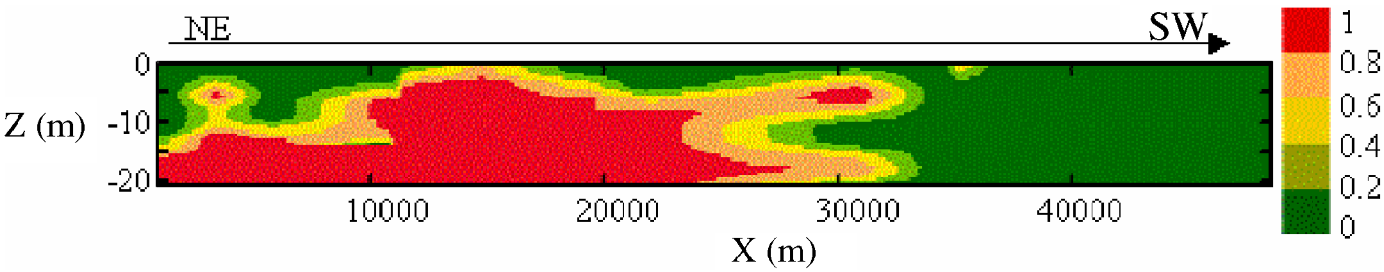

Figure 1. Proportion map (initial data)

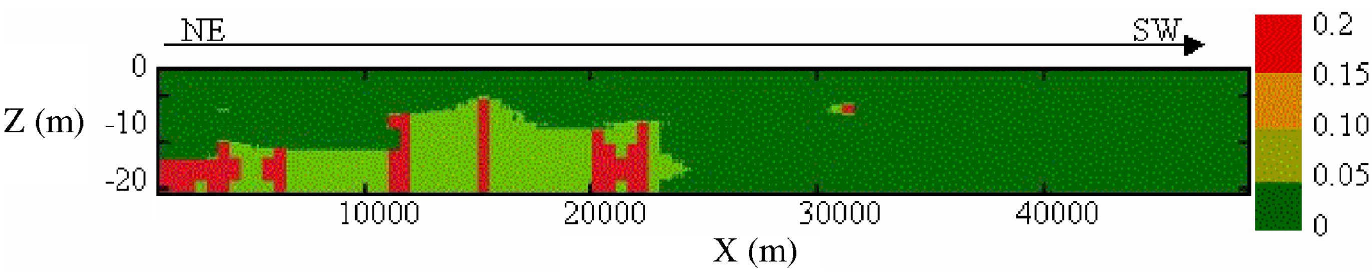

Figure 2. Intensity map obtained from deconvolution

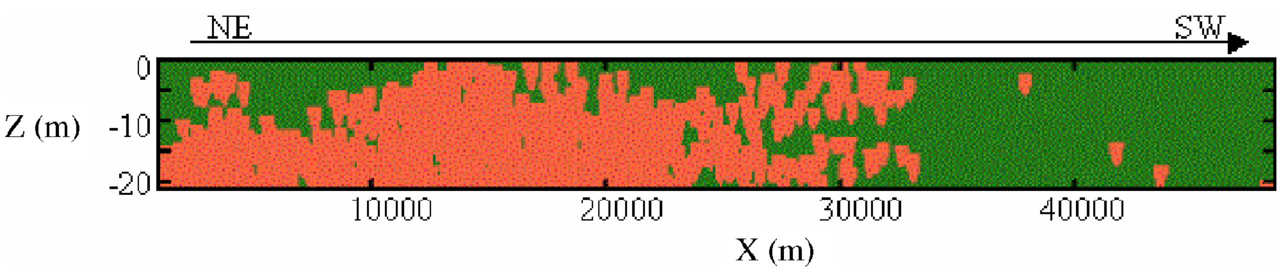

Figure 3. Section XZ of an example of simulation obtained with the intensity calculated.

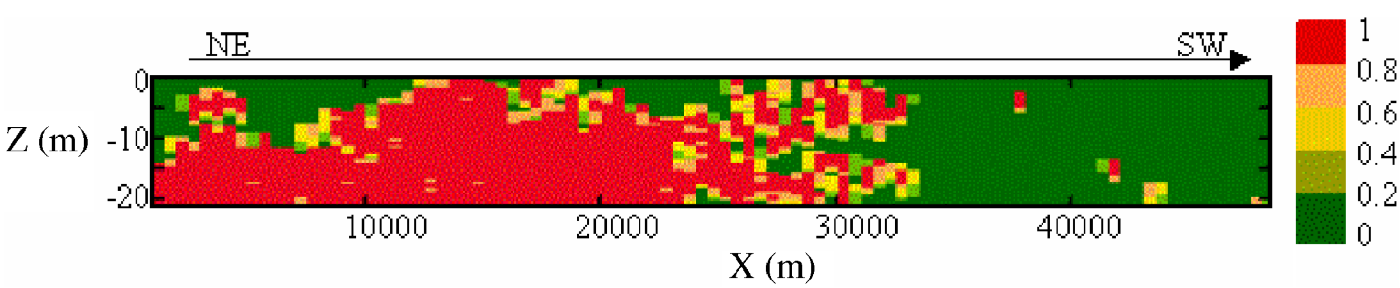

Figure 4. Proportion map computed on previous simulation.

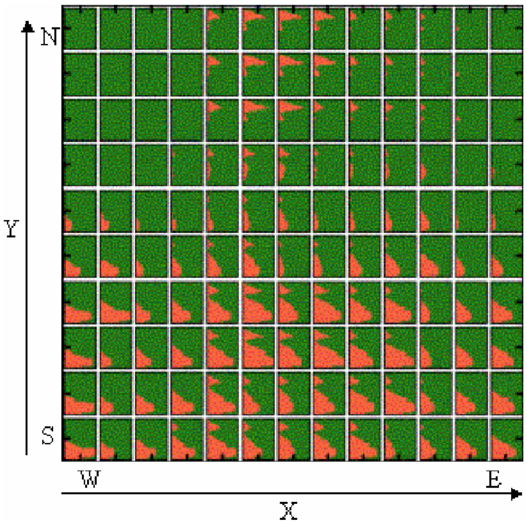

Figure 5: Initial vertical curves of proportions.
In red, the facies to be simulated.

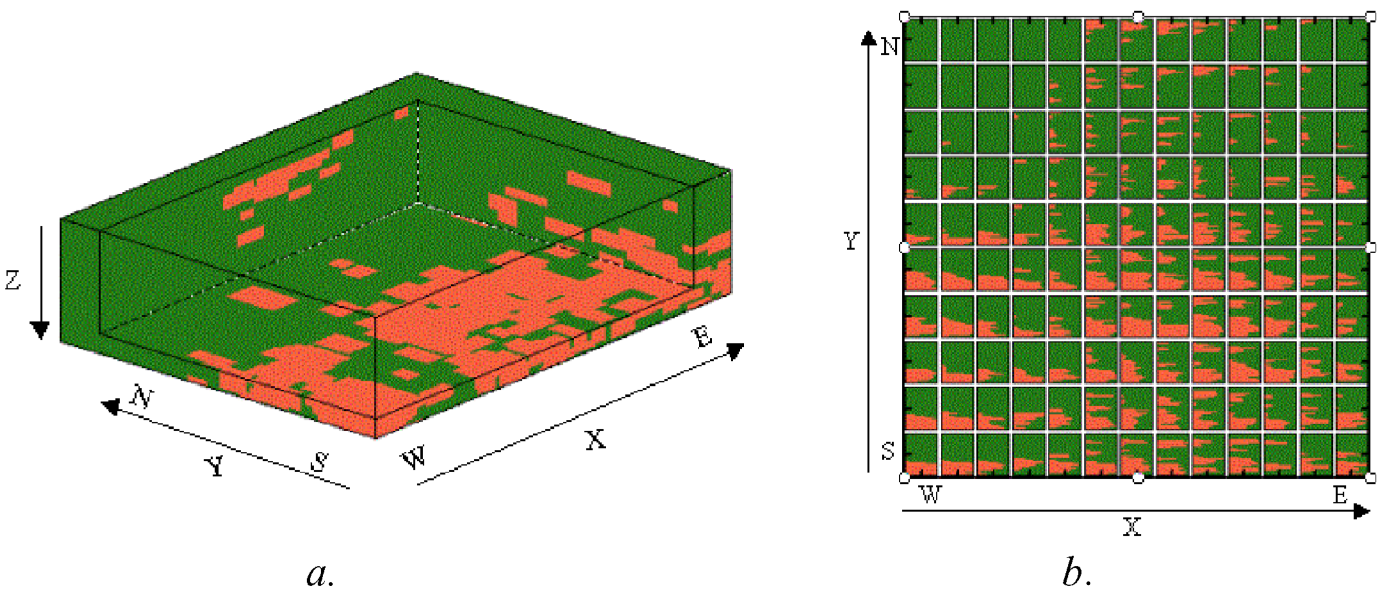

Figure 6: An example of simulation (a.) and the 3D block of proportions computed on it (b.) . In red the facies simulated.

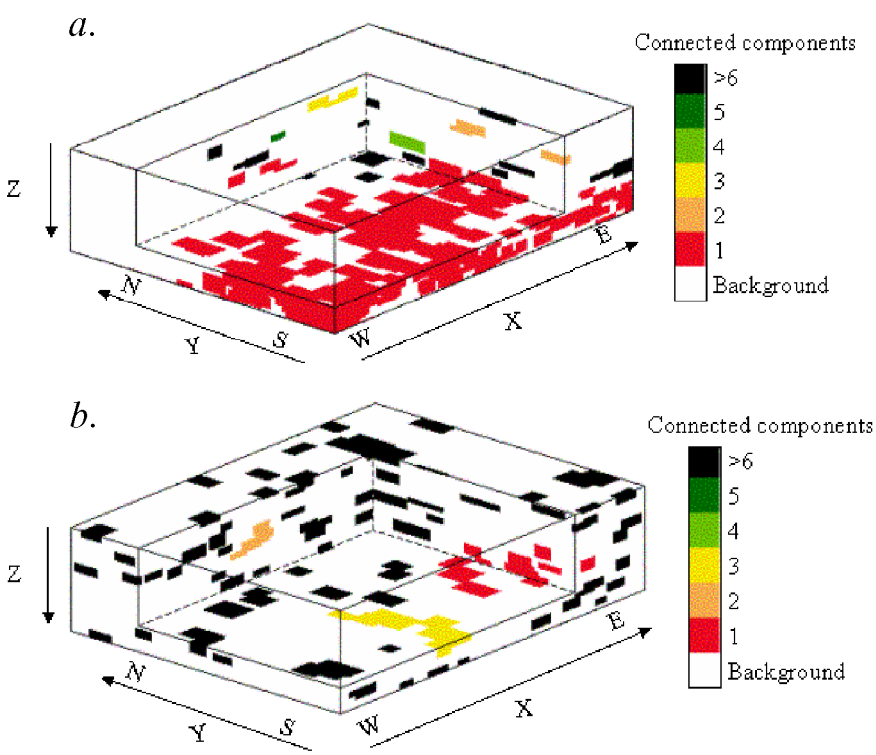

Figure 7: Connected components of the previous non stationary simulation (a.) and of a stationary simulation (b.). The global proportion of the model is identical in both cases. Only the five biggest components are presented, labelled from the biggest to the smallest, the rest of them are grouped in label 6.