

# 3D Modeling Of Turbiditic Channels Within Lobes From 2D Models

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**Abstract**—In this work we present the 3D modeling of turbiditic channels inside lobes using 2D images obtained through geostatistical multiple-point methods. We are assuming that these images can be interpreted as projections on the  $xy$  plane of the phenomenon. The proposed method consists of creating the turbidite lobe using the model proposed in Cardona’s work, [1]. Then the 2D images of the channels are projected onto the surface of the lobe. Finally, successive erosions of the image are layered and used to generate the volume to the channel system. This process has great importance in research and economics, because in the Brazilian oil exploration, about 90% of the reservoirs are turbiditics and they are difficult to study [2].

**Resumo**—Neste trabalho apresentamos a modelagem 3D de canais turbidíticos no interior de lobos, usando imagens 2D que são obtidas por métodos geostatísticos multipontos. Nós estamos supondo que estas imagens podem ser interpretadas como projeções no plano  $xy$  do fenômeno. O método proposto consiste em criar o lobo turbidítico usando o modelo proposto por Cardona [1]. Depois, as imagens 2D dos canais são projetadas sobre a superfície do lobo. Por último, são feitas sucessivas erosões da imagem que são usadas para dar volume ao sistema de canais. Esse processo é de grande importância nas pesquisas e na economia, pois na exploração petrolífera brasileira, cerca de 90% das reservas encontradas são do tipo turbidítica e elas são difíceis de serem estudadas, [2].

## I. INTRODUCTION

The main source of the hydrocarbons being explored in Brazil is located in the so called turbiditic deposits, which correspond to around 90% of the national reserves [2], [3]. These deposits are known for being complex and heterogeneous with an intricate geometry [3]. Thus the main advantage of the method presented in this work is being able to introduce more information to the studied reservoirs, such as developing the Brazilian oil scene [4].

The turbiditic lobe consists of a body of channels with high hydrocarbon reserves, and to model it we use the model presented on Cardona’s work [1].

Having in mind its importance, there’s a need to estimate both the geometry and the productivity of reservoirs in areas not yet studied. Because of that, several techniques are used, being highlighted *multiple-points geostatistic models* such as the ones presented in the works of Grajales, [5], Honarkhah, [6] and Arpat, [7]. These model use the so called *Training Image*, which is a conceptual image that in theory contains all the possible structures present in the modeled phenomena.

In our case, the training images used present a particular geometry.

The results from the previous methods for this kind of phenomena are 2D images. To generate the three-dimensional channels we build them inside of the turbiditic lobes following three main steps: *erosion*, in which successive erosions of the training image are made; *projection*, in which the eroded images are projected onto the surface of the lobe; and *superposition*, in which the projected images are layered, generating the volume of the desired channels.

## II. OBJECT-BASED MODELLING OF THE TURBIDITIC LOBES

In this section, the method presented by Cardona [1] about the turbiditic lobe generation is briefly explained. In the simulation, three lobes were generated, but we’ve used only one of them to model the channel system in this work. For more details about the lobe modeling refer to Cardona’s work [1].

Before the simulation, we need to understand the parameters that are used on its construction: length, width and thickness.  $B - spline$  curves are used to limit the volume of the lobe. The curves on the  $xy$  plane are  $B_{right}$  and  $B_{left}$ , defining the width of the lobe, the curves on the  $xz$  plane are  $B_{sup}$  and  $B_{inf}$ , defining its thickness. The curves are defined in relation to  $x$ .

Finally, the volume of the lobe is generated by these four  $B - Spline$ .

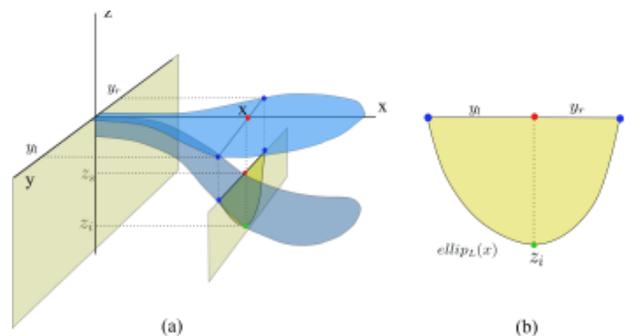


Fig. 1. Elliptical quadrants determining the asymmetric depth.

The generated lobe is represented in a 3D grid. Each cell of the grid is marked with either 2 or 0, where 2 infers that the cube's center is inside the lobe and 0 that the center is found outside the lobe. To determine the state of each cell, the center  $(px, py, pz)$  is analyzed according to the: *B-Spline* curves and the elliptical quadrants, segments that delimit the lobe (See Figure 2). The function used in the analysis is not presented in this article because it isn't relevant to the proposed work. For more information refer to chapter 3 in Cardona's work [1].

The grid size has to be big enough to preserve the geological formations presented by the models, but small enough to optimize the time spent on simulating the lobes.

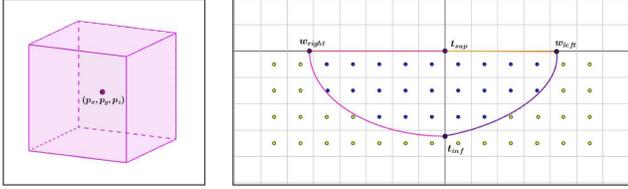


Fig. 2. Testing the center of the cells

### III. METHODOLOGY

In this section we explain the methodology behind the work. The 2D models of the turbiditic channels used in modeling are binary images obtained from a multiple-point geostatistical simulation on Grajales' work [5]. We divide this section in four parts: erosion of the 2D channels, scaling and rotation of the channel's image in the  $xy$  plane, projecting the channel on the lobe's surface and, at last, modeling the channels' volume inside the turbiditic lobes.

#### A. Erosion of the 2D channel model

It consists of analyzing, for every point in the training image, the following scenario: The function  $ti(p)$  determines whether  $p$  is black, -1, or white, 0, that is, whether it contains information on the channel or not. let  $p$  be an  $(x, y)$  point so that  $ti(p) = 1$ .  $p$  is a contour point, namely an extremity point, if  $ti(u_j) = 0$  for at least one  $u_1, u_2, u_3, u_4$  position (see Figure 3).  $p$  has, then, at least one neighboring white dot.

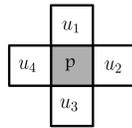


Fig. 3. Structuring element used in the erosion process.

To make the erosion of the channel system we remove all the contour points found in the last step. This way, as we repeat the process several times, a sequence of eroded images is generated and used to derive the volume of the channels, as seen in section III-D. (The erosion of two images can be seen in Figures 4 and 5)

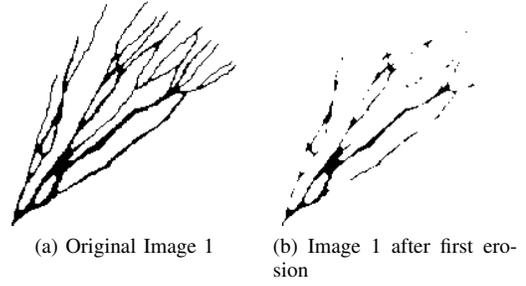


Fig. 4. Training Image and its first erosion

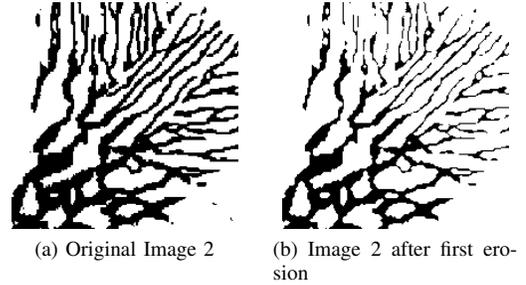


Fig. 5. Training Image and its first erosion

#### B. Scaling and rotation

1) *Scaling*: In our method, we first need a grid and an image on the same scale. For that we call the original image  $Im$ . The size of the image is  $d_{Im} = (d_{Imx}, d_{Imy})$  and the number of cells in the grid is  $n = (n_x, n_y)$ . The first step is to calculate  $d_x$  and  $d_y$ , as in the 1 equation.

$$d_x = \frac{d_{Imx}}{n_x}; d_y = \frac{d_{Imy}}{n_y} \quad (1)$$

Thus, the scaled image is such that  $\overline{d_{Im}} = (\overline{d_{Imx}}, \overline{d_{Imy}}) = (d_{Imx} \cdot d_x, d_{Imy} \cdot d_y)$  so that  $(\overline{d_{Im}}) = n_i$ .

and the scaled image is such that  $\overline{d_i} = (\overline{d_{ix}}, \overline{d_{iy}}) = (d_{ix} \cdot d_x, d_{iy} \cdot d_y)$  so that  $(\overline{d_i}) = n_i$ .

2) *Rotation*: Now consider the scaled image  $\overline{I}$ . To be able to design it, it must be aligned with the lobe. For this the vectors  $\overline{V_L}$  and  $\overline{V_I}$  are defined as being the directors of the lobe and of the Image, respectively. The function  $\phi_\theta(\overline{I}) = \overline{I}_\theta$  defined as a rotation of  $\theta^\circ$  with  $\theta$  being the necessary angulation for the superposition of the directors is then applied

#### C. Projection on the surface of turbiditic lobe

A prime number is attributed to each region of the turbiditic lobe generated in the simulation. So, to the lobe it's attributed the number 2, then the number 7 is chosen to represent the cubes that belong to the channel system. In case the point belongs to both, it's value is 14, the product of the primes in the intersection.

With that in mind,  $\overline{I}_\theta$  is projected onto the superior B-Spline surface in this part. For that, for each  $(x, y)$  point of  $\overline{I}_\theta$ , a value of the coordinate  $z$  is associated so that  $z = B_{sup}$  for its corresponding  $x$  and  $y$ . This way the point  $(x, y, z)$  is in

the surface of the lobe ( $B - Spline thickness_{sup}$  curve) and the corresponding cube in the grid is marked with the number 7.

On the second step it's analyzed whether the point  $P_c(x, y, z)$  is contained inside the lobe or not. If it's inside, the cell is marked with a corresponding color ( $n$ ) different from the one previously associated (see Figure 2). So the following  $CO(p)$  function is defined:

$$CO(p) = \begin{cases} 2, & \text{if } P_c \text{ is inside the lobe} \\ 7, & \text{if } P_c \text{ is inside the channel} \\ 0, & \text{otherwise} \end{cases}$$

#### D. Volume modelling of the channel system

Finally, the results from the aforementioned steps are used to model the volume. Let  $I_N$  be the eroded image  $N$  times. The aforementioned steps are then applied to  $I_0, I_1, \dots, I_N$ . However, by projecting  $I_k$ , a unity  $z$  is projected below  $I_{k-1}, \forall k, 1 \leq k \leq N$  so that the image  $I_N$  doesn't exceed the boundaries of the  $B - Spline$  lobe curves.

Thus, the eroded images will be layered on the  $z$  axis inside the  $Thickness_{sup} - Thickness_{inf}$  interval of the lobe, creating a 3D model from a Training Image, delimiting the volume by the  $B - Spline$  curves of the object as previously explained.

z

## IV. RESULTS

We have obtained, using the aforementioned methodology, a three-dimensional model of the channel system inside the lobe. In this section we show two examples of the proposed method.

### A. Example 1

First, we use the figure 4 as the channel system. Figure 6 presents three successive erosions of this image so to make clear the disparity between the original image (with contour) and the subsequent image (without contour), and so on.

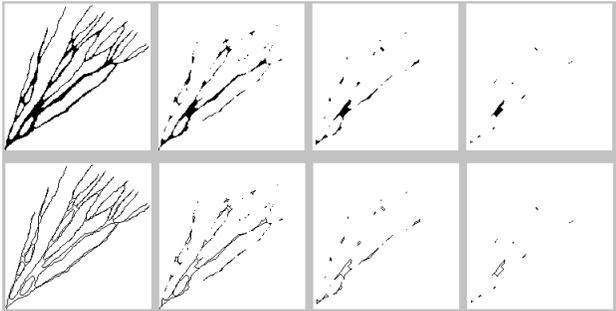


Fig. 6. Example 1: Successive erosion of the channel system

Now we can see in Figure 7 and in Figure 8 the generation of the channel's depth by layering the images, method mentioned in sub-section III-D. In this example the frames 7a and 8a illustrate the first layer of eroded images. On the other hand, the frames 7b and 8b illustrate the third layer of images.

After adding the third image below the others an increase in the volume of the channels becomes apparent.

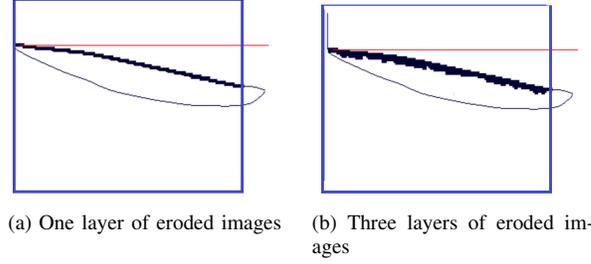


Fig. 7. Increase in the volume in example 1 through the addition of three eroded images

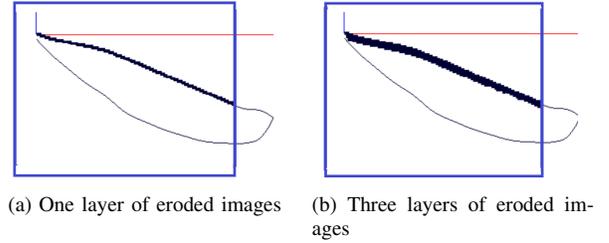


Fig. 8. Increase in the volume in example 2 through the addition of three eroded images

In Figure 9 we can see the result obtained when the volume of the lobe is filled simultaneously to the channel system modeled in its interior, leading us to our expected goal.

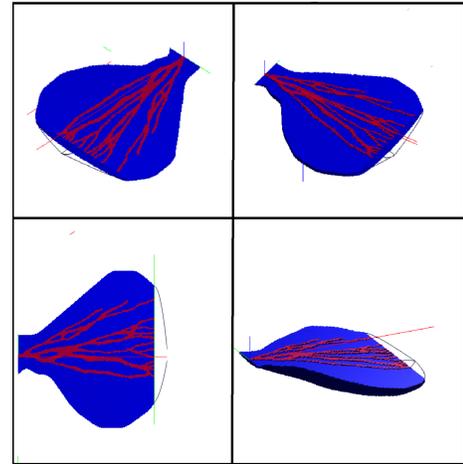


Fig. 9. 3D model of the channels on the lobe's interior.

### B. Example 2

Now, the figure 5 is used as the channel system to be modeled inside the turbidite lobe. Figure 10 show three erosions of this image, removing one contour at a time.

Finally, we can observe in figure 11 the turbiditic channels 3D modeled inside the lobe.

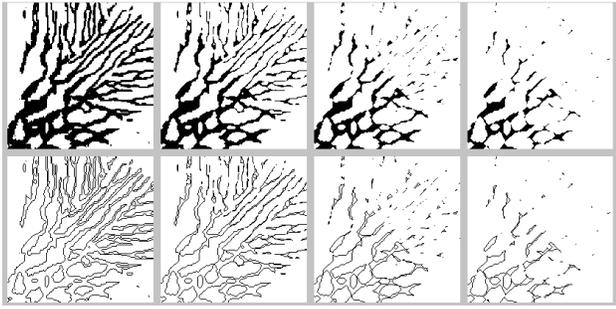


Fig. 10. Example 2: Successive erosion of the channel system

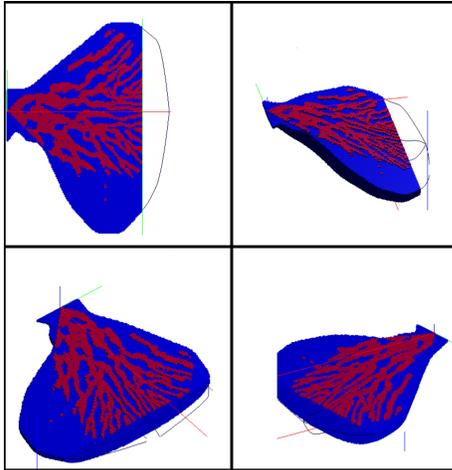


Fig. 11. 3D model of the channels inside the lobe.

## V. CONCLUSION

In figure 12 we can see the channel from figure 4 projected onto two distinct grids, that is, on Figure to the left we have used a (260,260,260) grid while using a (400,400,400) grid on Figure to the right. The difference in the level of details is clear, however, the time it took was a drawback seen that increasing the grid size requires a greater amount of small cells, making the process slower by a few minutes.

In this article we presented a method with which to generate 3D models of turbiditic channels inside the lobes by using 2D images taken from multi-point geostatistical simulations. The idea behind the method is to adjust the image to fit within the boundaries of the lobe, projecting the image onto the surface delimited by the B-Spline curve. The volume was derived from layering the erosions of the image, varying the z coordinate one unity at a time.

The small thickness of the modeled channel is due to the restricted amount of erosion we use in this procedure. However, we can increase the number of erosions, or simply repeat the same erosion several if the imaging is very clear, this way we are able to obtain a channel with more volume. In Figure 13 we have the same channel system of example 2, but this time each erosion was projected twice instead of only once.

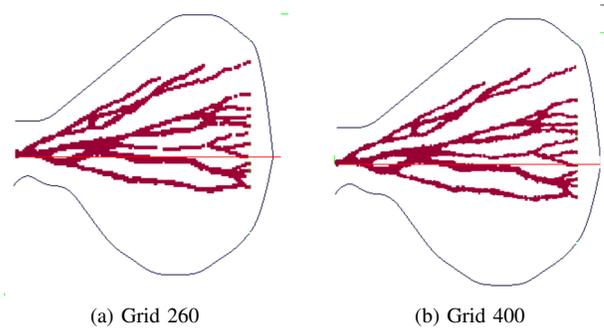


Fig. 12. Difference between a grid of 260 and a grid of 400.

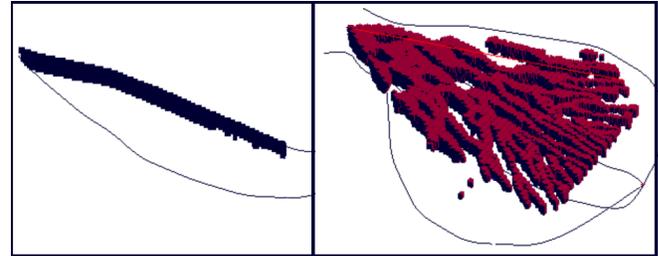


Fig. 13. Increase the depth of the channels

## ACKNOWLEDGMENT

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## REFERENCES

- [1] Y. A. Cardona, "Object-based modelling of turbidity lobes using non parametric b-splines," Dissertação de Doutorado, Pontifícia Universidade Católica do Rio de Janeiro, 2016.
- [2] F. M. de Lima, "Análise estratigráfica dos reservatórios turbidíticos do campo de namorado." Dissertação de Mestrado, Universidade Estadual Paulista, 2004.
- [3] L. M. S. de Lima, "Modelagem geoestatística de atributos geológicos em reservatórios turbidíticos," Dissertação de Mestrado, Instituto de Geociências da Universidade Estadual de Campinas, 2015.
- [4] S. Pessini, "Simulação estocástica baseada em objetos: aplicação aos depósitos turbidíticos do campo escola de enamorado," Dissertação de Mestrado, Instituto de Geociências da Universidade de São Paulo, 2013.
- [5] V. L. V. Grajales, "Image based simulation methods for depositional systems modeling," Dissertação de Doutorado, Pontifícia Universidade Católica do Rio de Janeiro, 2017.
- [6] M. Honarkhah and J. Caers, "Direct pattern-based simulation of non-stationary geostatistical models," Master's thesis, Math Geosci 44: 651 - 672, 2012.
- [7] B. Arpat, "Stochastic simulation with patterns," Doctoral dissertation, Stanford University, 2005.