OBJECT MODELS WITH VECTOR STEERING

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ABSTRACT. A new type of geometry in object models is presented. The new object type is called backbone objects. The objects have a piecewise linear centre line, and are able to follow the direction of a three dimensional vector field locally in lateral and vertical direction. How well the objects follow the vector field is determined by three parameters. Use of different coordinate systems and mapping between the systems make it possible to generate Gaussian random fields that follow the direction of the objects. The Gauss fields can be used to model petrophysical variables.

We have tested the new object geometry on modelling of turbidite reservoirs. Turbidites are gravity driven mass flows, and local geometry and orientation are strongly controlled by local topographic variations. The local behaviour of the turbidites is modelled by conditioning the backbone objects to a vector field with the wanted local orientation.

KEY WORDS: facies modelling, Backbone objects, local orientation, turbidites.

1. INTRODUCTION

Object models are widely used for facies modelling when the reservoir consists of objects of different facies within a background of some other facies. See for example Deutsch & Wang (1996), Holden, Hauge, Skare & Skorstad (1998), Viseur, Shtuka & Mallet (1998) for modelling fluvial channels and Syversveen & Omre (1997) and Lia, Tjelmeland & Kjellesvik (1996) for more general models.

Lia et al. (1996) describes a general model for object based facies architecture. The model has great flexibility in modelling trends in intensity, size and shape of the objects. The model is also able to condition on complex well observations. But the model lacks flexibility in local orientation of the objects. It is possible to have trends for rotation and dip of objects, but the trend is a global control of the object, and can not change direction locally according to the trend.

In this article, we look at an extension of the marked point model described. A new type of objects, called the backbone objects, is introduced. They are able to orient locally according to a vector field in both lateral and vertical direction. Petrophysical variables can be modelled as Gaussian random fields where the trend and correlation structure follow the local orientation of the objects. We will only describe the extensions of the model in this article. Other details about the model and the simulation algorithm are found in Lia et al. (1996).

We show how the extended model can be used to model a turbidite reservoir. The orientation of turbidites vary locally, due to local topographical variations. Therefore the backbone objects are suitable for the modelling.

2. Backbone objects

In this section, we describe the parametrisation and geometry of the backbone objects.

The main difference between backbone objects and the objects described in Lia et al. (1996) is the orientation of the objects, see Figure 1. For the objects in Lia et al. (1996), the orientation is given as two angles, one for rotation and one for dip. Rotation and dip can vary in space. 3D cubes for trend and variance for rotation and dip are defined. The object's rotation and dip are drawn from two Gaussian distributions with mean and variance taken from the 3D cubes at the object's reference position. The backbone objects are able to locally change orientation in space, and follow a vector field. In the following, we describe the parametrisation and geometry of the backbone objects and explain how the objects change direction in space. Different coordinate systems are needed for the description, and we start by defining them.

2.1. **Coordinate systems.** The whole reservoir is mapped into the simulation box coordinate system. The object model is defined in this system. This is a rectangular box, with left handed orthogonal coordinate system with z coordinates increasing with increasing depth.

When simulating petrophysical variables for the reservoir, we want the correlation structure to follow the local orientation of the backbone objects. In addition, we want trends depending on location within the object. To be able to do this, we introduce a local coordinate system for each object. Each object has its own local left handed orthogonal coordinate system, where the the x-axis is along the centre line of the object and positive z direction is downwards. The location of origo is at the centre of the object. The objects including the petrophysics are simulated in the local system and mapped to the simbox system. See Section 3 for a description of the transformation between coordinate systems.

2.2. **Geometry and parametrisation.** As described in Lia et al. (1996), each object is characterised by its marks, which are position, shape, size (length, width, thickness), and orientation. The shape of the backbone objects is specified by a prototype shape in the object's local coordinate system, where the width may vary along the centre line of the object. The width is specified as trend functions symmetrical around the centre line with 1D Gaussian random fields added. See Figure 2 for an example of shape trend in xy plane. The object may also have a thickness profile. As in the original model, in order to condition correctly on

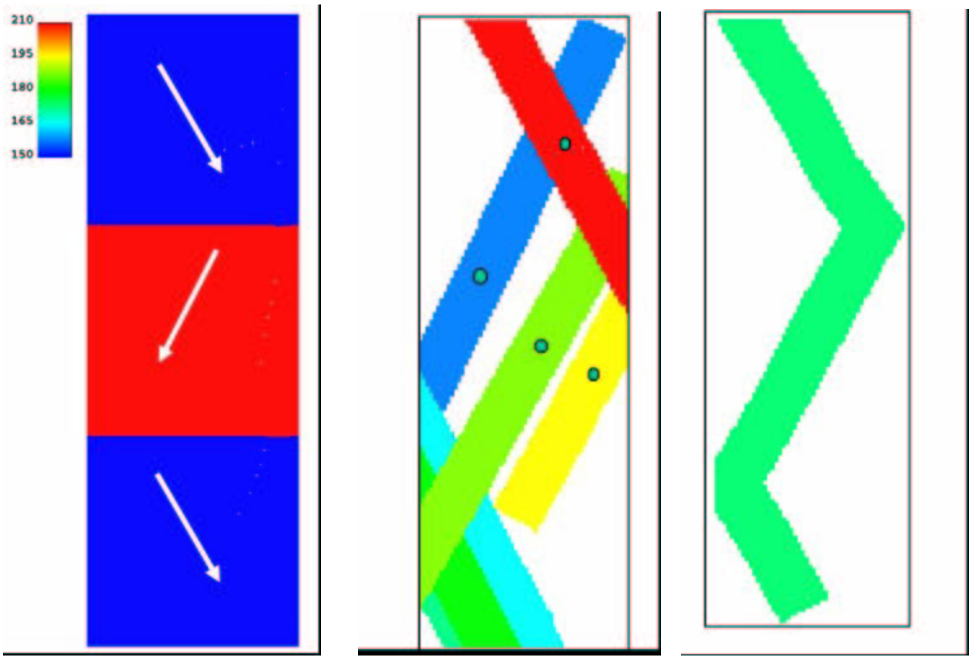

FIGURE 1. Illustration of the difference between backbone objects and conventional object shapes. To the left, an example of a vector field for rotation. In the middle, a realization from a conventional object model. The dots are the objects' the reference points. To the right, an example of a backbone object, locally oriented according to the vector field.

well observations, Gaussian random fields are added to the top and bottom of the object in the object's local coordinate system. Each object has a reference point which can be located anywhere in the object. The object is placed in the simulation box by drawing the position of the reference point.

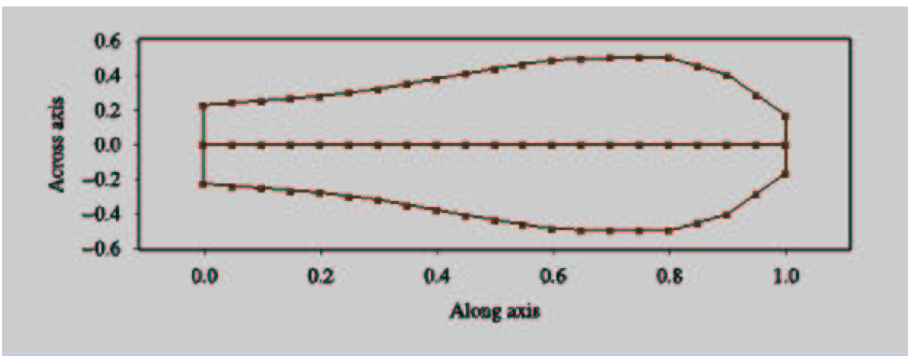

FIGURE 2. Example of backbone parametrisation in xy plane in local coordinate system. Only trend function is shown.

The next step is the orientation of the object in the simulation box. For backbone objects, the parametrisation of orientation is complex. The object is divided in pieces of equal length along the centre line, and each of these pieces can have different rotation and dip angle. Each of the pieces will then be able to orient according to the local value of a vector field. The flexible centre line is the object's "backbone".

The centre line of each piece will be the corresponding centre line piece of the object ($z = 0$ in the local coordinate system), and angles between pieces are measured as angles between centre line pieces. The vector field which each piece is conditioned on defines the trends for mean for rotation and dip of the object. We also have trends for variance of rotation and dip.

Two parameters specific for the orientation of backbone objects are given. The first is an approximate piece length, and together with the object length, this defines the number of pieces. The second is a stiffness parameter, which determines the flexibility of the object.

The piece length should be sufficiently short for adapting well to the vector field, and as large as possible for computational reasons.

The stiffness parameter is defined as the standard deviation of the angle between two pieces, and is independent of the variance of rotation and dip. We let β_i be the rotation angle for piece number i, and $\gamma_i = E(\beta_i)$. The stiffness parameter controls how far the change in direction $\beta_2 - \beta_1$ could be from the mean $\gamma_2 - \gamma_1$. The likelihood for β_2 from the stiffness definition is Gaussian, and given as

$$l_\alpha(\beta_2) = const * \exp(-(\beta_2 - (\beta_1 - \gamma_1 + \gamma_2))/\sigma_\alpha)^2 \tag{1}$$

where σ_α is the stiffness parameter. Here we assume constant stiffness parameter, but generally, the stiffness parameter can be given as a trend function. Similar equations yields for the dip, but in the following we only look at the rotation parameter. We assume that the angle between pieces is Gaussian distributed. The vector field defines a Gaussian distribution for the rotation, and the angles for different pieces are independent. The likelihood for β_2 from the vector field is given by

$$l_\beta(\beta_2) = const * \exp(-(\beta_2 - \gamma_2)/\sigma_\beta)^2 \tag{2}$$

Conditional independence of the stiffness and the vector field gives that the conditional distribution for β_2 is Gaussian. By multiplying the two likelihoods given in Equation 1 and 2, we find the conditional mean and variance for β_2 as

$$E(\beta_2|\beta_1, \theta_1, \theta_2) = \gamma_2 + \frac{\sigma_{\beta_2}^2}{\sigma_{\beta_2}^2 + \sigma_\alpha^2}(\beta_1 - \gamma_1) \tag{3}$$

and

$$Var(\beta_2|\beta_1, \theta_1, \theta_2) = \frac{\sigma^2_{\beta_2} * \sigma^2_{\alpha}}{\sigma^2_{\beta_2} + \sigma^2_{\alpha}} \tag{4}$$

where θ_1 is the stiffness and θ_2 is the vector field. We see that mean is a weighted combination of the means from Equation 1 and 2. For the reference piece of the object, that is, the piece containing the reference point, the variance of the orientation is only decided by the vector field variance. The stiffness parameter has influence on the orientation of the rest of the pieces, given the reference piece. If the stiffness parameter is small, and the variance of the vector field is large, the object will not follow the vector field well. But all pieces follow the direction of the reference piece, and objects are smooth in shape. With a large stiffness parameter, and large vector field variance the deviance from the vector field will vary from piece to piece, anf objects become wiggly. With small vector field variance, the effect of the stiffness parameter is less visible. See Figure 3 for an illustration. The objects have a rectangular shape with mean number of pieces equal to 10. The vector field for rotation trend varies from 1 degree to the left, and increases linearly to 60 degrees at the right. Two different constant values are used for the vector field variance and the stiffness parameter. The values are 5 and 25 degrees for both, and the figure shows realisations with the four combinations of these parameter values. The variance is given by Equation 4, and the upper right and lower left realisation have the same variance. But we see that the realisations are quite different, because the vector field variance and the stiffness parameter are different.

3. Transformation between coordinate systems

During simulation, we sometimes operate in the object's local coordinate system, and sometimes in the global simulation box system. The parametrisation of the object is simpler in the local system, particularly the Gaussian fields for top, bottom and edges. Well conditioning is therefore done in the local system. Each piece of the object has its own orientation, hence the transformation between the coordinate systems is very complex.

When transforming a point from the simulation box system to the local coordinate system, we do as follows:

- Find which piece the point belongs to, as described later.
- Do a rotation and translation, such that origo is in the centre of the centre line of the actual piece, and rotation and dip angles are zero.
- Transform to a non-orthogonal coordinate system, called NonOrto. See Figure 4.
- Transform to the local coordinate system by "stretching" out the object.

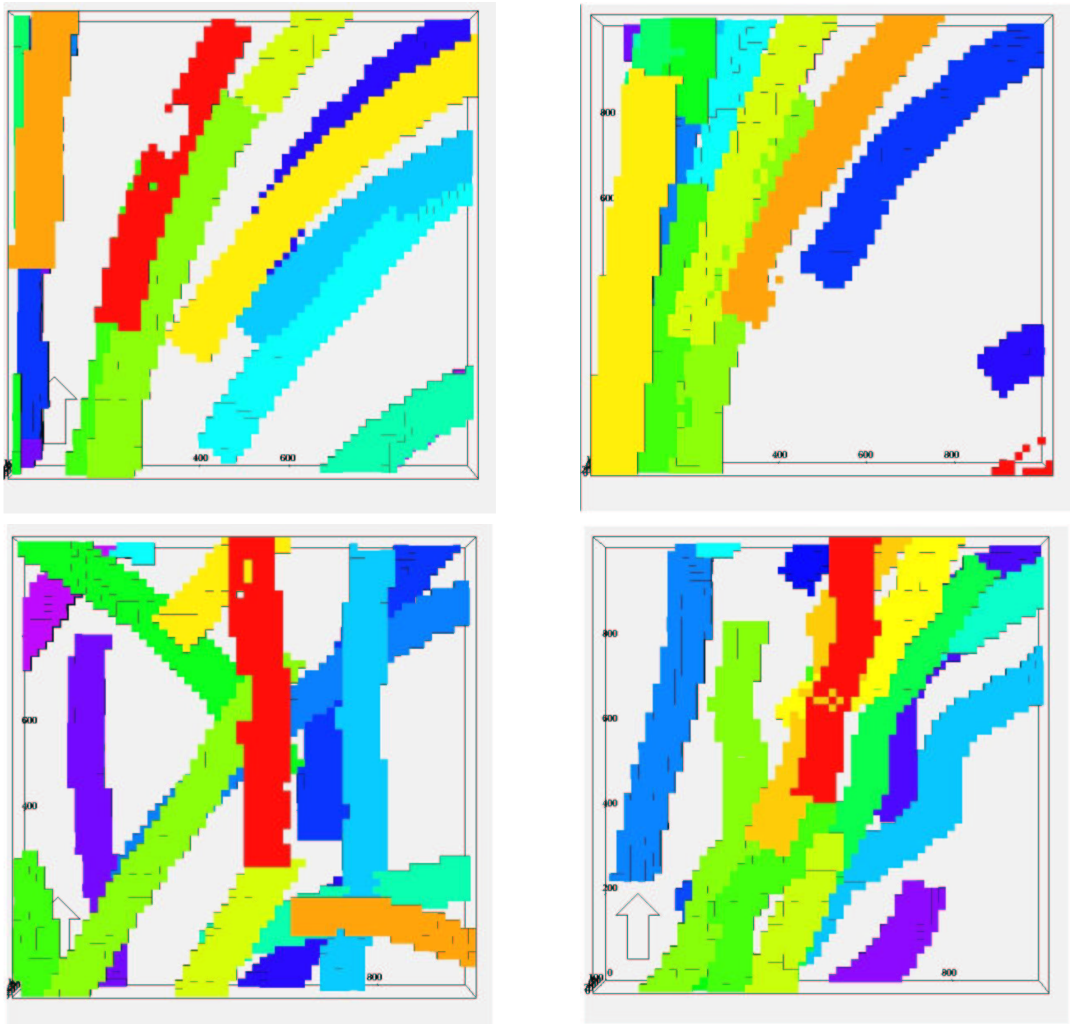

FIGURE 3. Effect of stiffness parameter and variance of vector field. Upper left: Small stiffness parameter and small variance. Upper right: Large stiffness parameter and small variance. Lower left: Small stiffness parameter and large variance. Lower right: Large stiffness parameter and large variance.

The NonOrto system is a non-orthogonal system for a single piece, constructed as follows: First define end planes, which are border planes between pieces. These are the set of points with equal distance to the centre of the centre lines on each side. The centre line is marked with CL in Figure 4. At the ends of the object, this plane is orthogonal to the centre line. The end planes for the middel piece are marked with dotted lines in Figure 4. The intersection of the end planes defines a line called L in the figure. The lines across the object represent constant x-values.

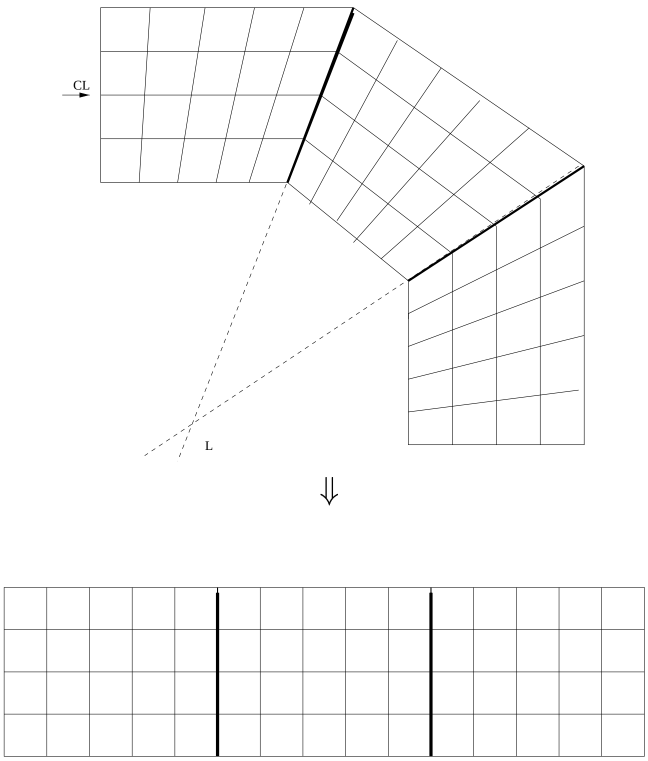

FIGURE 4. Object in NonOrto and local coordinate system. Thick lines are borders between pieces, thin lines are borders between grid cells. CL is the center line, also called the "backbone" of the object.

The x-coordinate of a point is defined by the intersection between CL and the plane given by the point and the line L.

A point is defined if it is located inside the "fan" defined by the end planes. If the point is in multiple fans, its coordinate is given from the centre line closest to the point. Objects with undefined points will be rejected during simulation.

In each piesce, the y- and z-coordinates are measured along axes which are orthogonal to each other and the local centre line. Ideally, we would like the z-axis to be in the plane defined by this centerline and the z-axis of the simulation box. This would give the most logical interpretation of object thickness, top and bottom. However, this would lead to inconsistency in the endplanes, since the z-axis from two neigbouring pieces would not correspond if not either the dip or the rotation is the same for both pieces. To avoid this, the y-z plane is rotating around the x-axis. In the middle of the piece, the z-axis has our ideal orientation, whereas it is rotated towards the endplanes in such a way that the z-axes from neighbouring pieces match in the endplanes, and have the same rotation from the center of the piece. The y-axis follows this rotation, so it is at all times orthogonal to the z-axis and the centerline.

The last step from NonOrto to the local system is to adjust the x-coordinate such that zero is in the middle of the object, and not in the middle of the selected piece. Note that this final coordinate system is treated as orthogonal when needed, it is only non-orthogonal seen from the simulation box.

All steps are easily reversed, and we go from the local system to the simulation box by doing all the steps in the opposite order.

4. Modelling turbidite reservoirs

Turbidites are deposits from turbidity currents, which are downslope movements of dense, sediment-laden water, see for example Tarbuck & Lutgens (1990). The local geometry and orientation of the turbidites are therefore strongly controlled by local topographic variations. The local characteristics of the turbidite bodies make the backbone objects suitable for the facies modelling.

Another key feature of turbidity flows is the segregation of grain sizes within flows, which results in systematic spatial trends in petrophysical parameters. The trends are in three directions - proximal to distal, from axis to margin laterally and from top to bottom vertically. The use of object model allows the trends to be preserved in the reservoir model. Petrophysical properties can be simulated separately for each turbidite body using Gaussian random fields in the local coordinate system defined along the backbone.

A typical geometry for turbidite reservoirs are lobe-like bodies which are thick and narrow at the proximal end and become thinner and wider distally. We can construct backbone objects with such a shape, see Figure 5.

Turbidites have their origin at the same location, and spread out in a fan shape. The location of bodies in an object model is taken care of by the intensity trend. The objects' reference points are placed proportional to the intensity trend. By choosing an intensity trend with very high values in the area we want the objects to start, and small values otherwise, and place the reference point at the proximal end of the objects, we get the wanted location.

The fan shape is taken care of by the vector field for rotation trend. The vector field is constructed from flow lines, which can be extracted from the structural interpretation of the reservoir, isochore information or directly from seismic data.

4.1. **Simulation example.**

We use the object model with backbone objects to model a turbidite reservoir in the Gulf of Mexico. A vector field for rotation trend is constructed based on the isochore and geological knowledge, see Figure 6. The flow lines are also shown in the figure. Angles vary between 160 and 320 degrees. The variance of the rotation is held constant equal to 8.0 degrees. There is no

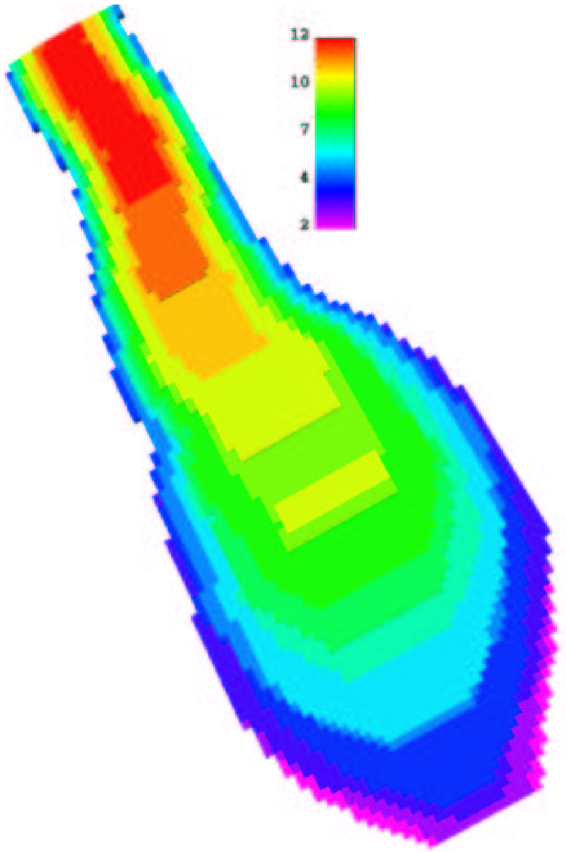

FIGURE 5. Example of shape of turbidite. The colour scale shows thickness of object.

trend in dip, and the mean dip is set to zero and the variance is 0.001 degrees. The stiffness parameter is set constant equal to 15.0 degrees. The intensity field has a high value in the area where the flow lines start, see Figure 6, and very small values elsewhere. The shape of the objects is shown in Figure 5. The mean object length is 6000, and mean piece length is 100.

Synthetic well data are generated by simulating an unconditional realisation, and collecting observations at the well positions. A realisation of the turbidite reservoir conditioned to synthetic observations from six wells is shown in Figure 7. We see that the objects start in the high intensity area, and spread out according to the vector field.

Finally, we illustrate how petrophysics can be modelled within each object. Figure 8 shows an example of a porosity realisation. A Gaussian random field is simulated on a single turbidite object. We see how the trend follows the shape and orientation of the object.

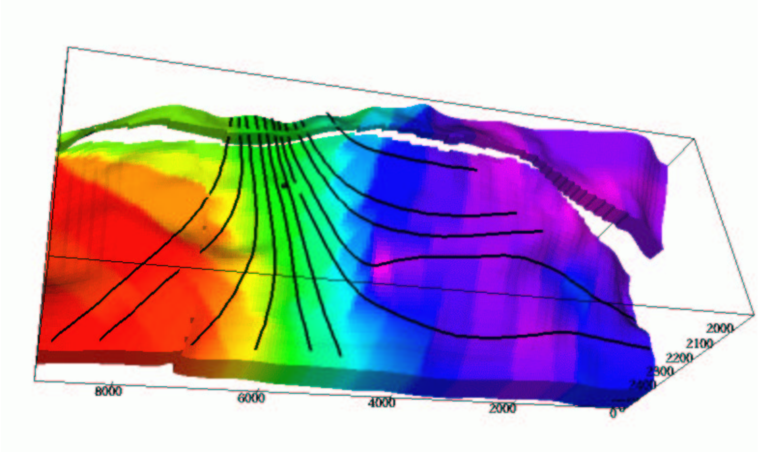

FIGURE 6. Vector field used for trend of rotation angle.

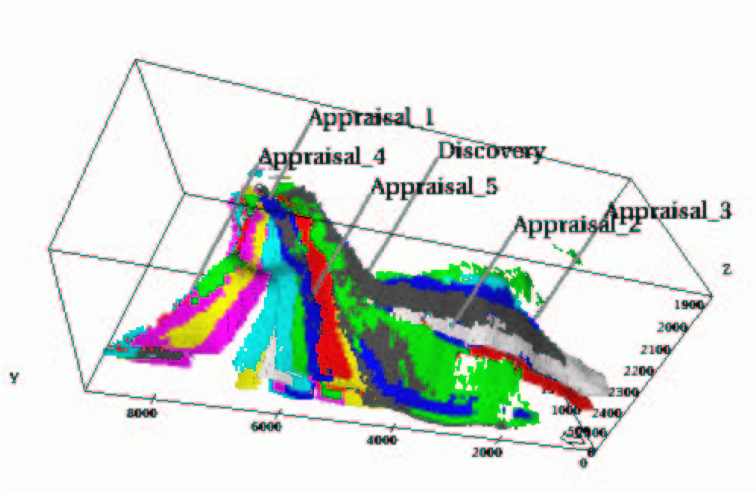

FIGURE 7. Facies realisation for the turbidite reservoir.

A more extesive example of turbidite modelling using Backbone objects is found in Hauge, Syversveen & MacDonald (2003).

5. Closing remarks

We have seen how to construct objects in an object model that are able to orient themselves locally according to a vector field. Three different parameters, that is vector field variance, stiffness parameter and piece length, determines how well the objects follow the vector field. Petrophysical variables may be simulated as Gaussian random fields that follow the shape and orientation of the objects. The ability of the model is demonstrated on a turbidite reservoir.

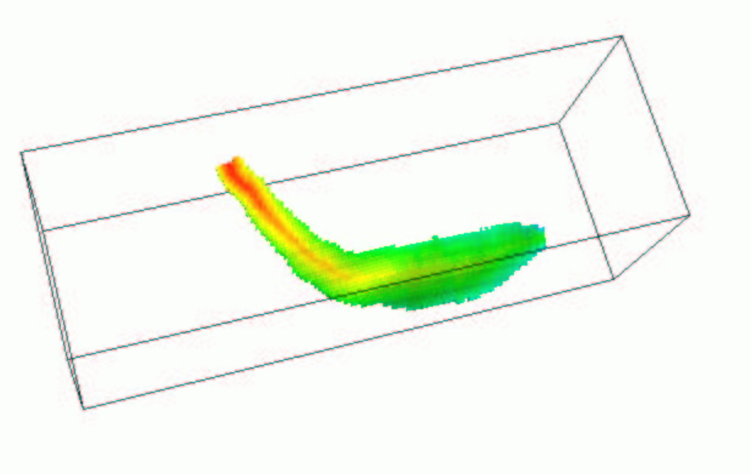

FIGURE 8. Porosity realisation for a single turbidite.

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