Stochastic modelling of deep marine deposits*

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Deep marine deposits are an important reservoir type. While existing object and trend based stochastic modelling approaches can capture some of the heterogeneity, the limited quantities of data result in a very broad spread of possible model outcomes. Furthermore, such modelling approaches fail to honour the key factors that control the distribution of reservoir sand, namely accommodation, sediment supply and basin topography.

Existing numerical process based modelling tools are capable of recreating flow and deposition from a single turbidite event. These tools are computationally expensive and while they capture the fine detail of a single event they are unsuitable for re-creating reservoirs comprised of the accumulated result of hundreds of individual flows.

A new simplified process based modelling tool capable of rapidly recreating the flow and deposition of hundreds of flow events is presented. The model accounts for seabed topography, gravity, friction, kinematics, ocean currents, sedimentation and erosion rates. Individual events start in a confined feeder channel and experience a hydraulic jump where the flow stalls and widens into a lobe. This method is combined with stochastic elements for inclusion of reservoir uncertainty and conditioning to well data.

Concept

The geometry of a deepmarine deposit is modelled by generating many individual events and stacking them on top of each other, thereby mimicking the actual sequence of deposition. Intermediate deposition of clay rich material, from hemipelagic material and numerous small clay rich mass failure events, are also modelled. These intermediate events can either be of constant thickness or filling available accommodation space.

Initial input is a bottom surface (seabed), well data and various physical parameters describing the physical process generating a turbidite. The goal is to generate a geologically sound realisation given the physical properties and the constraints imposed by surfaces and well data.

The basic idea is to have a simplified process model that can condition to well data. This combination of process model and exact conditioning makes a rigorous probabilistic specification very difficult. The lack of rigour allows the inclusion of realistic physical processes, but it requires robust algorithms since no properties are guaranteed from a theoretical model.

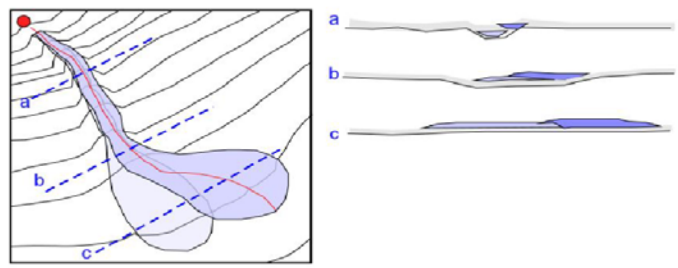

Figure 1: Principal sketch of two events with cross sections. Note that the position of the last event to the right is clearly dependent on the first event.

Overview of modelling approach

Our model for a single turbidite event has four key elements:

1. A centreline, along which the turbidite flows.
2. Two edge lines, defining the width of the turbidite.
3. A one-dimensional erosion/deposition model used along the centreline.
4. A cross-sectional shape extrapolating erosion and deposition from centre to edge.
5. A simplified geometry approach after hydraulic jump.

Numerical simulation of the centre line

First, the centre line of the turbidite is created. The main idea is to track a fluid particle sliding down the seabed,

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driven by momentum and gravity. The gradient of the surface is usually small so that dip angles are typically in the range 1-5 degrees. The main forces on this fluid particle are gravity and friction.

A real turbidity current sends a shockwave ahead to find the easiest path to proceed and it will therefore be attracted to the lowest local area in the forward direction. We model this attraction by adding an attraction force in the direction of steepest descent.

Using these forces, the movement of the particle can be easily and quickly computed. The centre of the turbidite follows this particle path. Due to momentum, the path will not follow the steepest descent, and may even pass small elevated areas on the seabed.

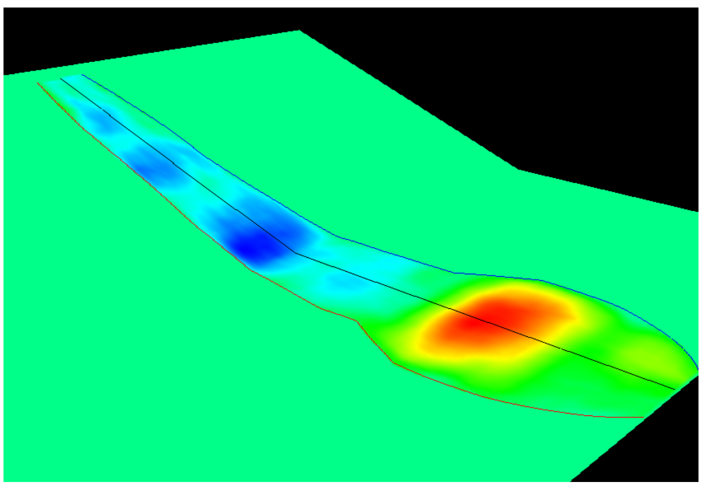

Figure 2: Example of turbidite from model

Width of turbidite

In order to determine the width of the turbidite, we model the path of two sidelines using a very simplified physics model. This model uses only two forces: Gravity, and repulsion from centreline, and looses all momentum between steps. The reasoning behind this is that the repulsion and lack of momentum models the outwards diffusion, while gravity balances this against local topography.

Height at the centre line

The height is found by using a 1D turbidity current model by Leo C. van Rijn (2005). A two-layer schematization of the turbidity current 1D flow is used, assuming almost constant values in each layer. The result is time- and layer averaged equations which describe the flow of sediment and water.

The 1D model is applied for erosion and deposition along the centre line. It assumes that the flow is in supercritical state, characterized by large velocities and low height of the flow. The transition from the supercritical to the subcritical (slow velocity, diluted, large flow height) is established by an internal hydraulic jump. After the hydraulic jump, the slow current widens into a lobe shape and the remaining mass is dumped. Using van Rijn's model gives the location of the hydraulic jump and a net deposition rate along the centre line. Figure 3 is the height input from the supercritical state used to produce the single turbidite pictured in Figure 2.

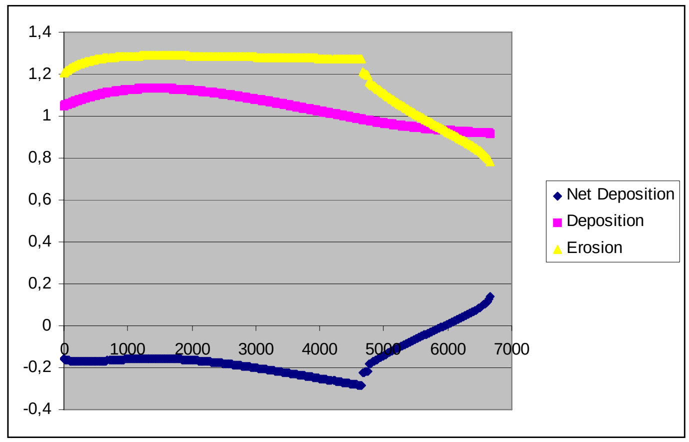

Figure 3: Deposition and erosion along centre line for turbidite in Figure 2.

Cross sectional shape

The cross sectional shape is found by fist multiplying the centre line erosion with a cross sectional trend shape, and removing this from the current surface. Deposition is then added in the same manner, by multiplying the deposition at centre with a trend shape, and adding it to the surface.

Width and height after hydraulic jump

After the hydraulic jump the detailed model for erosion/deposition is now longer valid and it is substituted by a simple approximation. This approximation is based on a trend curve, scaled to length depending on how much mass remains in the flow and the amount of deposition at hydraulic jump. The repulsion between edge and centre lines is initially increased and then changed to an attraction, to mimic a lobe.

Well conditioning

The well conditioning is done in two stages. First, the physical model for both centre line and edge lines are affected. This is done by adding attraction forces towards nearby sand observations, and repulsion forces from shale observations. In addition, 1D Gaussian fields along the sides, and 2D Gaussian fields on the top and bottom allows correction for small scale mismatches by kriging. This is similar to the approach in Pyrcz, Catuneanu and Deutsch (2005). An example of a turbidite sequence conditioned to a well is shown in **Figure 4**.

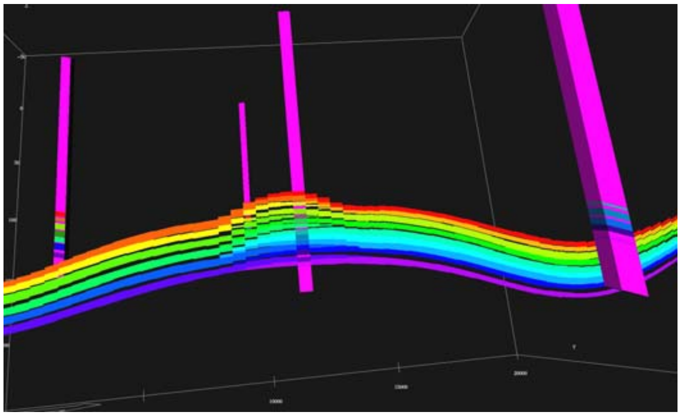

Figure 4: Example of well conditioning

Example: Synthetic slope with channel

The input surface is in this case a synthetic seabed, with an initial slope of 1-2 degrees. The picture in the top left of Figure 5 shows the original surface before turbidites are generated. The size of the area shown is 20 km by 20 km, and the height difference is approximately 250 m. Figure 5 shows the stacking of turbidite events on this surface, as well as a series of cross sections taken from the beginning of the channel to the abyssal plane. The z-scale in this figure is 20.

References

Leo C. van Rijn, 2005: Principles of sedimentation and erosion engineering in rivers, estuaries and coastal seas, Aqua Publications, The Netherlands, ISBN 90-800356-6-1, 2005.

Pyrcz, M. J., Catuneanu, O. & Deutsch, C. V. 2005: 'Stochastic surface-based modelling of turbidite lobes', AAPG Bulletin 89(2), 177–191.

Acknowledgments

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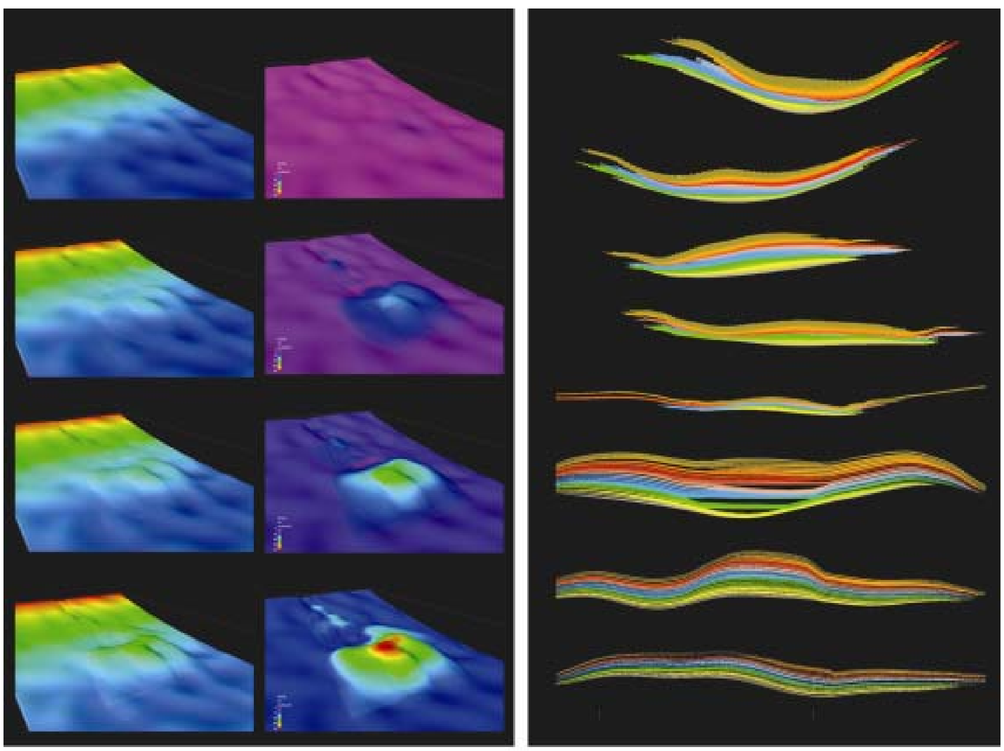

Figure 5: Turbidite sequence made by our model. The leftmost column shows the seabed after 0, 20, 40 and 70 events. The next column to the right shows accumulation of sand at the same stages. In the rightmost column, a series of cross sections along after the 35 first turbidite events are shown. The 4 upper cross sections are in the feeder channel, the two next are close to the hydraulic jump, and the final two are at the abyssal plain. The vertical exaggeration is approximately 20.