TuMod – Stochastic Modeling of Turbidite Sedimentation

Petter Abrahamsen, Bjørn Fjellvoll, and Ragnar Hauge
Norwegian Computing Center

John Howell, Tore Even Aas
University of Bergen

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What is a turbidite?

- A turbulent flow of water and sediment
- Can move 10’s of km
- Moves fast ~ 20km/h
- Erodes and deposits
- Comes to rest at ocean floor
- Triggered by earthquakes, waves, instabilities, …
The Monterey Channel

Palo Alto

Monterey

30km
So what is a deep marine deposit?

- A stack of turbidite sands with hemipelagic clay in between.

Ainsa quarry (May 2007)
Why new approach?

► Process models:
  ▪ Realistic geometry.
  ▪ Cant use well and seismic data.
  ▪ Slow.

► Object models:
  ▪ Simplistic geometry.
  ▪ Wrong interaction between turbidite events.
  ▪ Can condition on data.
Basic ideas in TuMod

► Combine process model with stochastic elements
► Mimic the sequence of deposition.
► Use simplified physical flow process to generate channel/lobe shapes fast.

► Multiple events (10-1000?) flows generated chronological.
► Minor stochastic element added to the physical process.
  - Allows us to honor data by intelligent trial and error.
Generating one turbidite

1. Centre line
   ► Run a single particle down the slope

2. Height
   ► Find height using 1D model for erosion and deposition
   ► Detect hydraulic jump

3. Width
   ► Simplified particle model for side lines: repulsion from centre line
   ► After hydraulic jump: change repulsion to attraction

4. Cross section shape

5. Adjust top and base using Gaussian random fields
1. Centre line of turbidite

Main idea:
Track a particle sliding down the slope

- Main forces on a fluid particle:
  - Gravity
    - Force the particle downhill
    - Depend on the density
  - Friction
    - Surface friction, currently set to zero
    - Fluid friction – stops otherwise very fast flow
  - Random component
    - Seabed uncertainty
  - Attraction to and repulsion from well observations

- Minor forces:
  - Coriolis
  - Ocean currents
Density and velocity determines sensitivity to topography

\[
\frac{\rho_{\text{turb.}} - \rho_{\text{water}}}{\rho_{\text{water}}} = 0.15
\]

\[
\frac{\rho_{\text{turb.}} - \rho_{\text{water}}}{\rho_{\text{water}}} = 0.05
\]

\[
\frac{\rho_{\text{turb.}} - \rho_{\text{water}}}{\rho_{\text{water}}} = 0.01
\]
2. Height: Deposition and erosion

- Using a method formulated by Leo C. van Rijn
  - 1D calculation along centre line.
  - Deposition rate:

\[
\frac{\partial h}{\partial s} = \frac{1}{\gamma_2} \left[ \gamma_1 (1-c_2) - (1-c_1)(\tau_1+\tau_2) - 2\rho_2 W_t W_b - \gamma_3 \frac{\partial c_2}{\partial s} \right]
\]

with:

\[
\gamma_1 = (\rho_s - \rho_w) h_2 c_2 g \sin\beta
\]

\[
\gamma_2 = (\rho_s - \rho_w) h_2 c_2 g \cos\beta - \rho_s u_2^2
\]

\[
\gamma_3 = 2\rho_2 h_2 (u_2)^2 + (\rho_s - \rho_w) (1-c_1) h_2 (u_2)^2 + 0.5(\rho_s - \rho_w) (1-c_1)(h_2)^2 g \cos\beta
\]

- Detects **hydraulic jump**.
  - Caused by dilution of sediment and reduced speed at basin floor.
Example

Blue is erosion
Red is deposition

Deposition
Erosion
Difference

Surface slope

Blue is erosion
Red is deposition
3. Width

~ 0° slope

~ 1° slope

$\frac{a_r}{l} = \frac{e_r}{l}$

$C_e$

distance to centre line

$f(x, y)$

edge, left line

edge, right line

$g_l$

centre line

$g_r$
Repulsion

- Force $\propto K / \text{(distance to centre line)}$
Closing the lobe

- Length, $L$, depend on mass at hydraulic jump

$r = \text{distance to centre line}$
4. Cross section shape

- Height of deposition
- Depth of erosion

Draping deposit

Filling deposit

Mixing these extremes
Physics is to stable!

- $2^\circ$ dipping plane
- Dips in X-direction
- 20 Events
Results: Event: 1, 10

Red = net deposition
Blue = net erosion
Results: Event: 15, 20

Red = net deposition
Blue = net erosion

Deep ditch

High pile

This pattern will continue for Event: 21, 22, …
Problem and solution

► Problem
  ▪ All events stack on top of each other.
  ▪ Sea floor is incredibly flat.

► Solution
  ▪ Turbidity current sends shockwave forward to find easiest path.
  ▪ Add antenna to turbidite flow.
New results: Event: 1, 10

Red = net deposition
Blue = net erosion
New results: Event: 15, 20

Red = net deposition
Blue = net erosion
Comparing end results

Red = net deposition
Blue = net erosion

Looking forward: On
Looking forward: Off
Another example
50 Events

Final realization

Red = net deposition
Blue = net erosion
Similar example: 70 Events
Filling

Filling accommodation space with shale between events using spill-point algorithm.
70 Events cont.
70 Events cont.
35 Events: Cross sections

From channel to abyssal plane
35 Events: Cross sections
Around hydraulic jump.
35 Events: Cross sections
Well conditioning

- Well conditioning in physics model
  - Sand observations are attractors.
  - Shale observations are repulsors.

- Additional conditioning with Gaussian fields
  - 1D field applied to left and right edge.
  - 2D field applied to top and bottom.

- Sequential solution
  1. Match observations laterally.
  2. Match observations vertically.
Physics conditioning – centre line

- Attracted to sand observations.
- Shale observations give force in opposite direction.
Active sand observations

Attraction to sand if $\delta_{sa, \text{max}}$ less than $\delta_{sa, \text{max}}^{\text{tol}}$
15 Events with wells

Well logs:
- Facies
  - Sand
  - Shale
- Body

Note stacking
15 Events with wells cont.
Well conditioning: 8 Events

2 wells:
Only shale in w1.
3 sand obs. in w2.
The Monterey Channel
Monterey, detailed simulation

Erosion dominates, no deposition
Monterey, TuMod simulation

Z scale: 1.0

Turbidite number is colour coded. Red is the last.

Erosion dominates
Petrophysics

- Standard approach for object models
  - Trends relative to object geometry
  - Anisotropy following objects
Summary

► Realistic geometries
  ▪ Includes important physics.
  ▪ A lot of flexibility.

► Conditioning to well data in place
  ▪ Rejection of bad proposals to be tested

► Complex model – a lot of parameters

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- Norwegian Research Council
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Future work

► Variation in deposition rate of sand and clay.
► Better depositional model for post-hydraulic jump.
► Erosion dependent on seafloor deposit (shale/sand).
► Adaptive gridding and up scaling (corner-point geometry).
► Iterative well conditioning.
  ▪ Discard turbidites that fit poorly.

Thank you for listening