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TuMod – Stochastic Modeling of Turbidite Sedimentation

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Hydro HYDRO

Statoil, nettverksmøte for geologi og geomodellering, strukturgeologi og sedimentologi, 30. – 31. mai 2007, Bergen

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 earth quakes, waves, instabilities,…

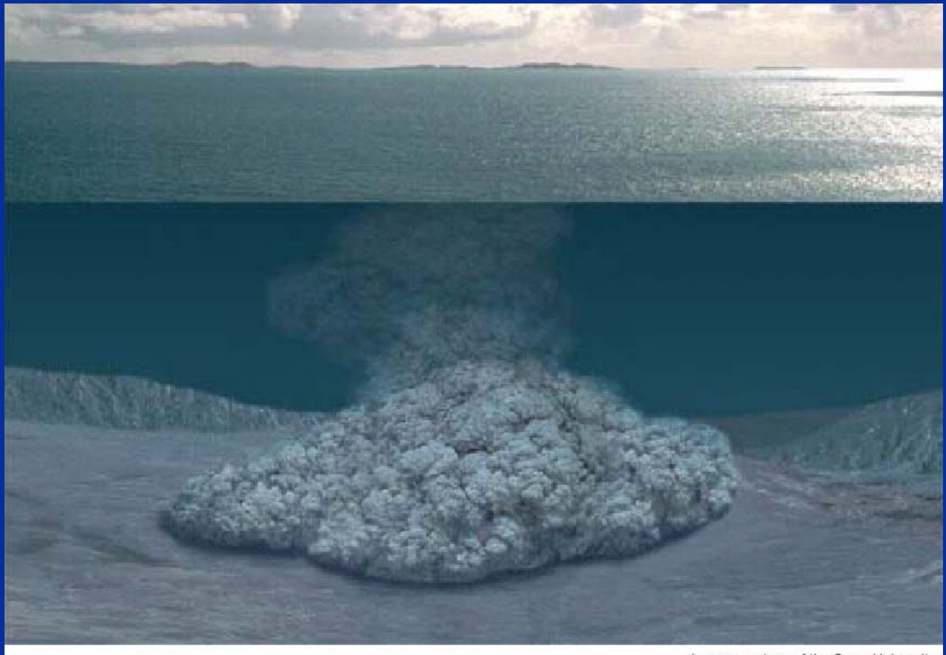
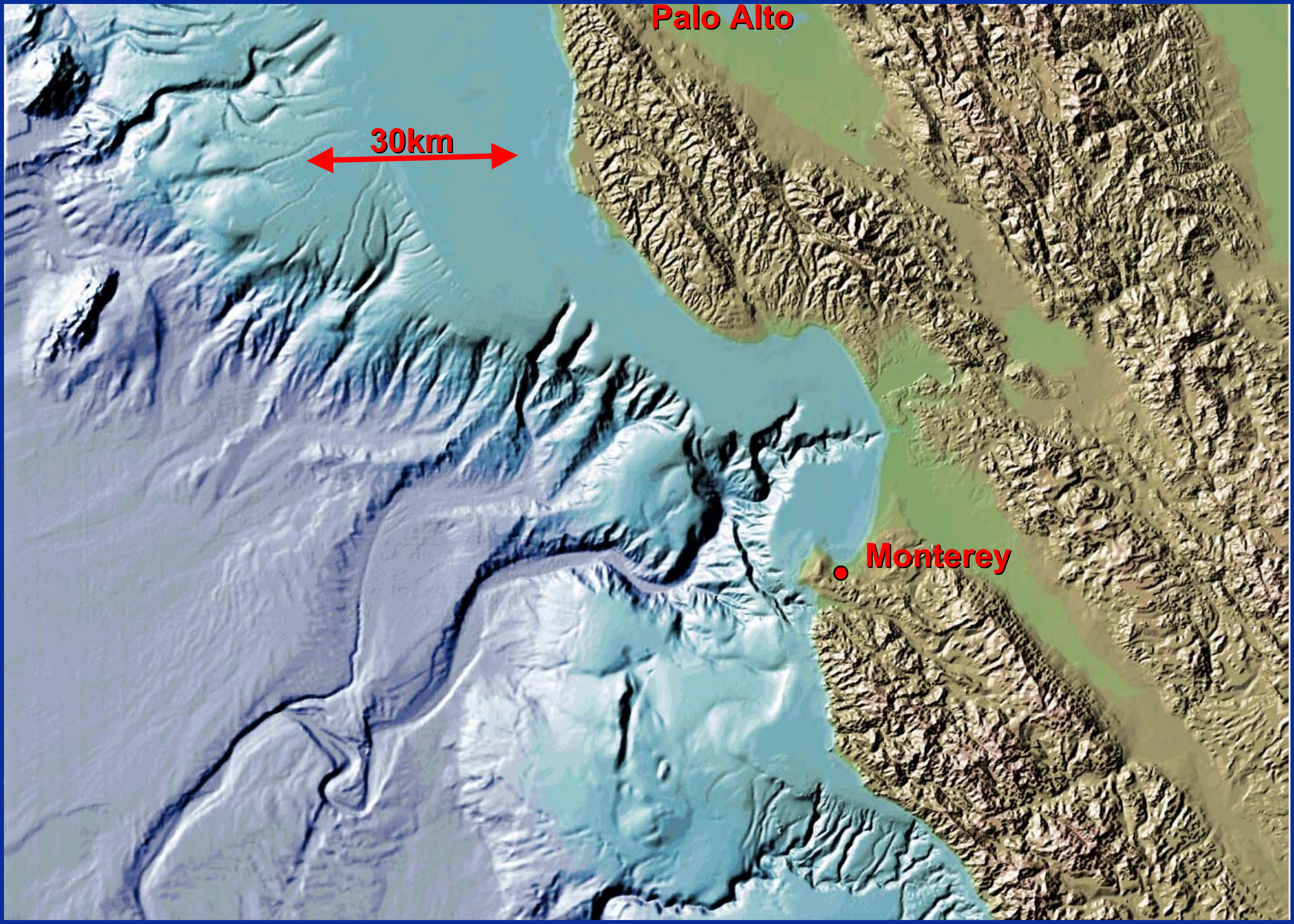


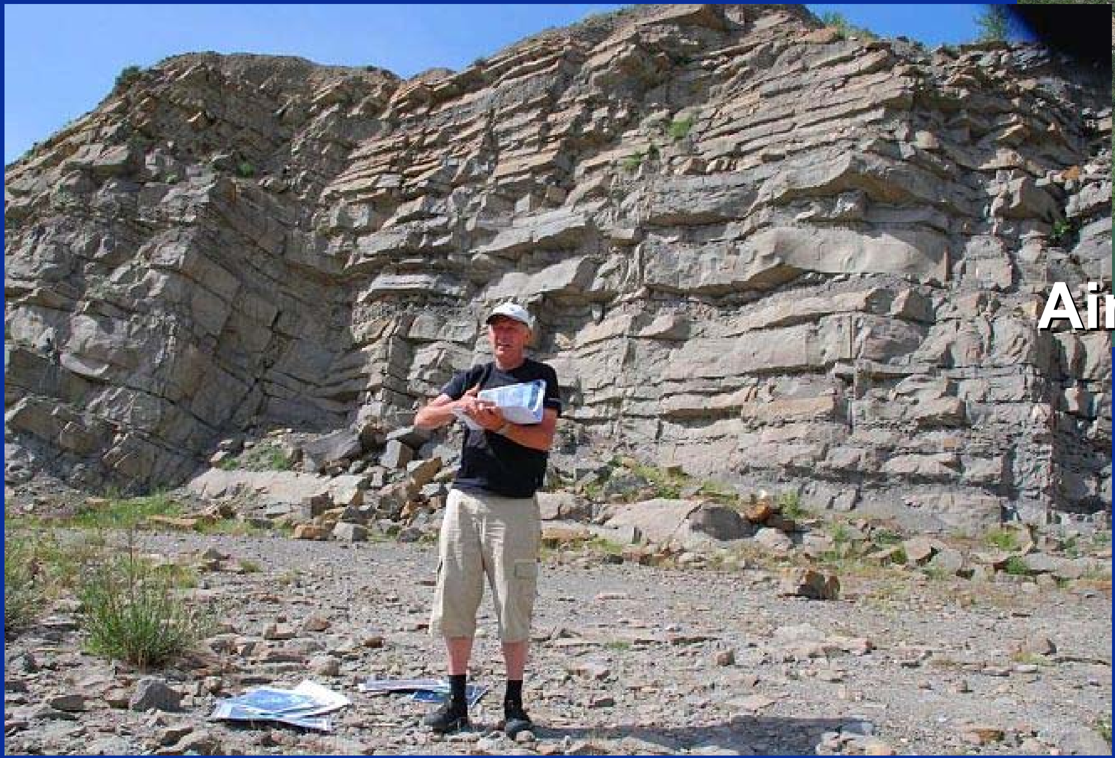
Image courtesy of the Open University

The Monterey Channel



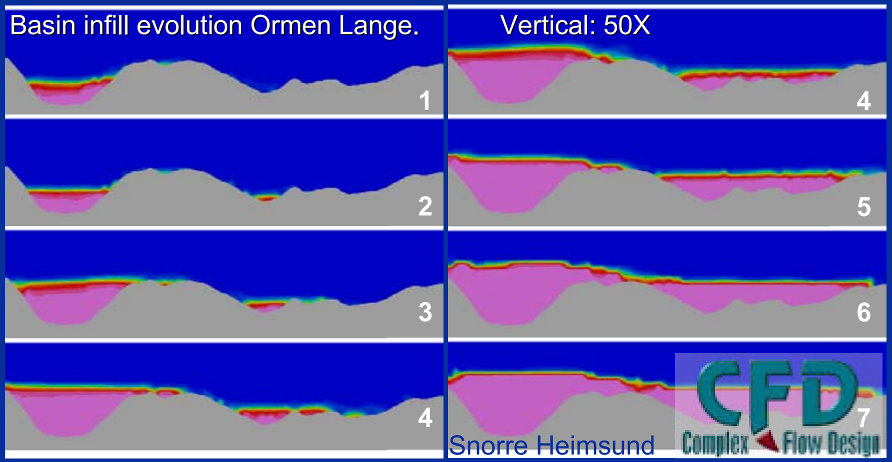
So what is a deep marine deposit?

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

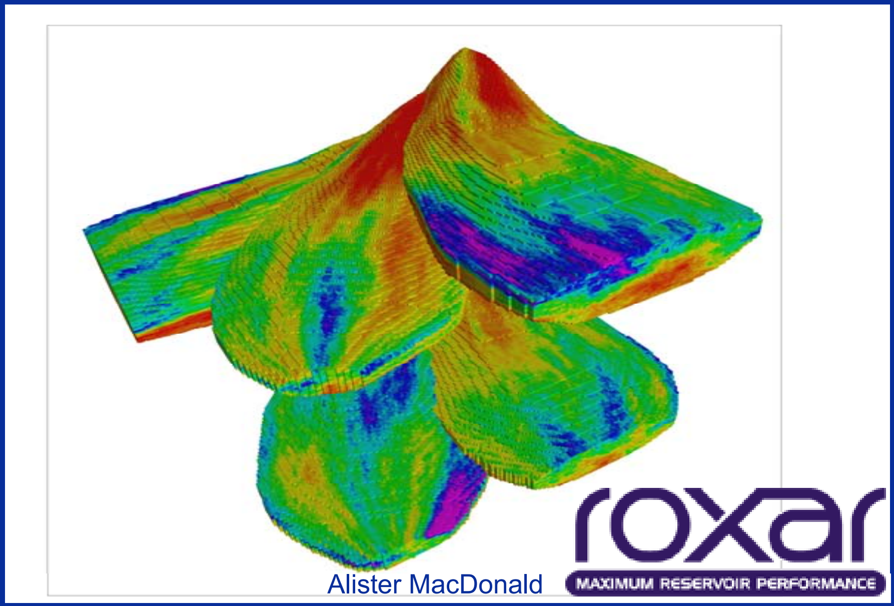


Why new approach?

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

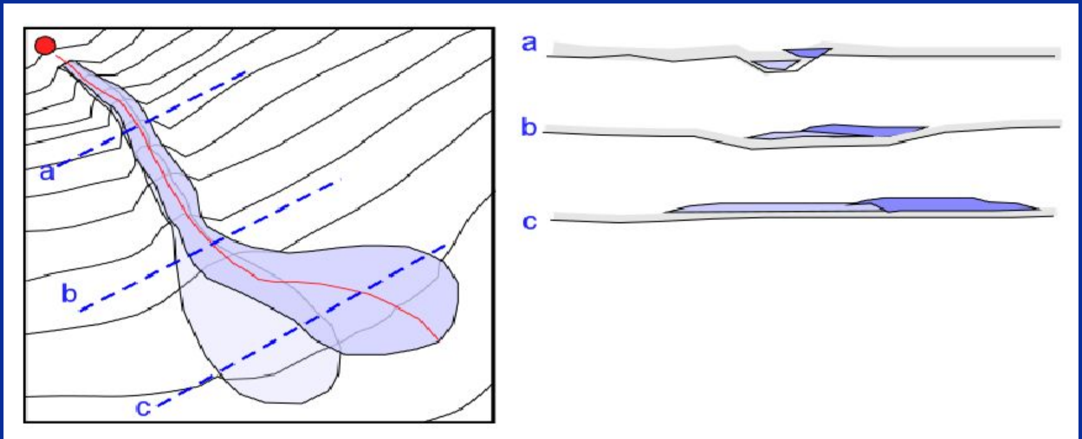


- Object models:
  - Simplistic geometry.
  - Wrong interaction between turbidite events.
  - Can condition on data.



Basic ideas in TuMod

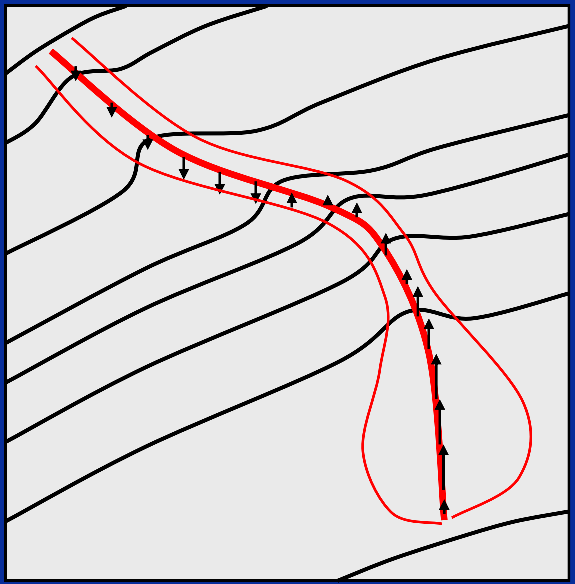
- Combine process model with stochastic elements
- Mimic the sequence of deposition.
- Use simplified physical flow process to generate channel/lobe shapes fast.



- 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

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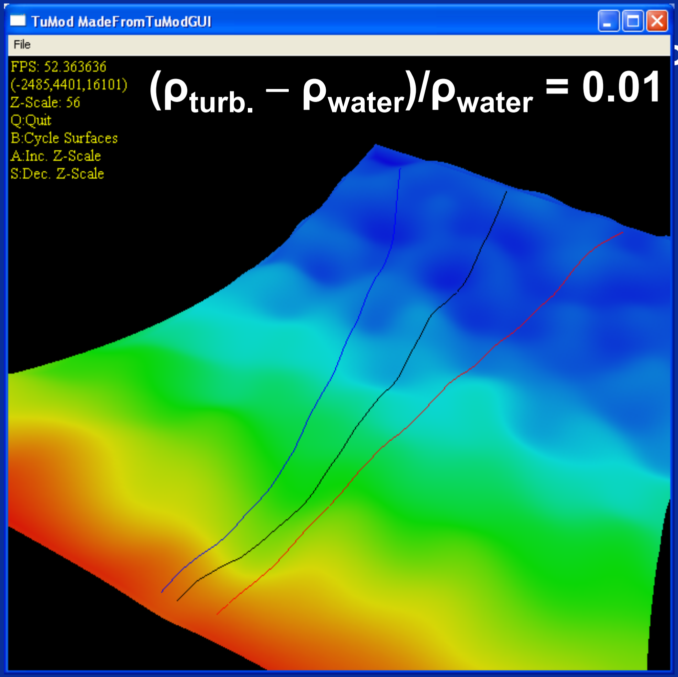
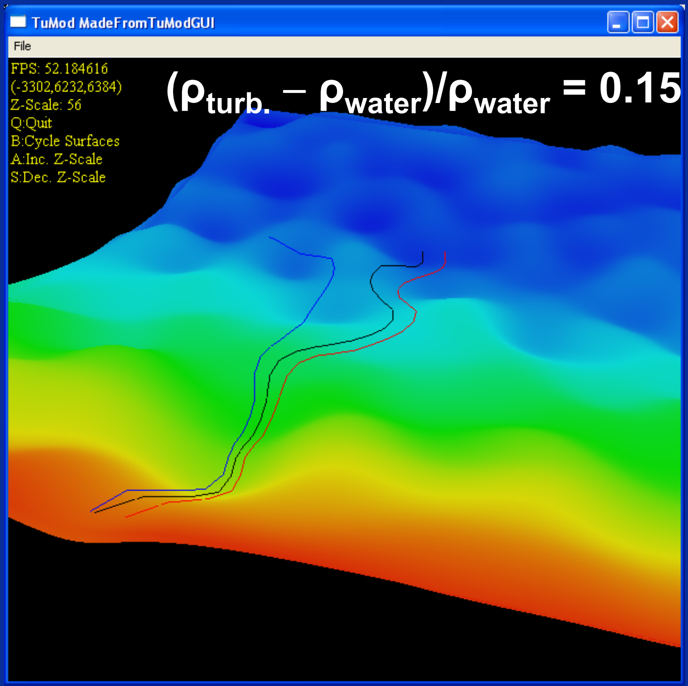
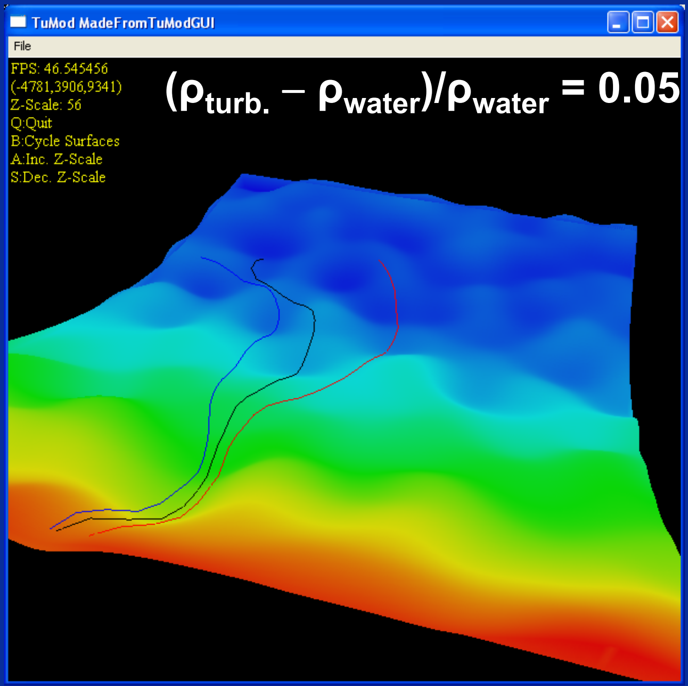
Density and velocity determines sensitivity to topography







2. Height: Deposition and erosion

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

$$\partial h_2/\partial s = [1/(\gamma_2(1-c_2))][\gamma_1(1-c_2) - (1-c_2)(\tau_i+\tau_b) - 2\rho_2 u_2(W_i+W_b) - \gamma_3 \partial c_2/\partial s]$$

with:

$$\gamma_1=(\rho_s-\rho_w)h_2 c_2\, g \sin\beta$$

$$\gamma_2=(\rho_s-\rho_w)h_2 c_2\, g \cos\beta - \rho_2(u_2)^2=(\rho_s-\rho_w)h_2 c_2\, g \cos\beta\, [1-(h_{2,cr}/h_2)^3]$$

$$\gamma_3=2\rho_2 h_2(u_2)^2 + (\rho_s-\rho_w)(1-c_2)h_2(u_2)^2 + 0.5(\rho_s-\rho_w)(1-c_2)(h_2)^2\, g \cos\beta$$

mass balance for fluid in lower layer 2

$$\partial(u_2 h_2(1-c_2))/\partial s - W_i - W_b = 0$$

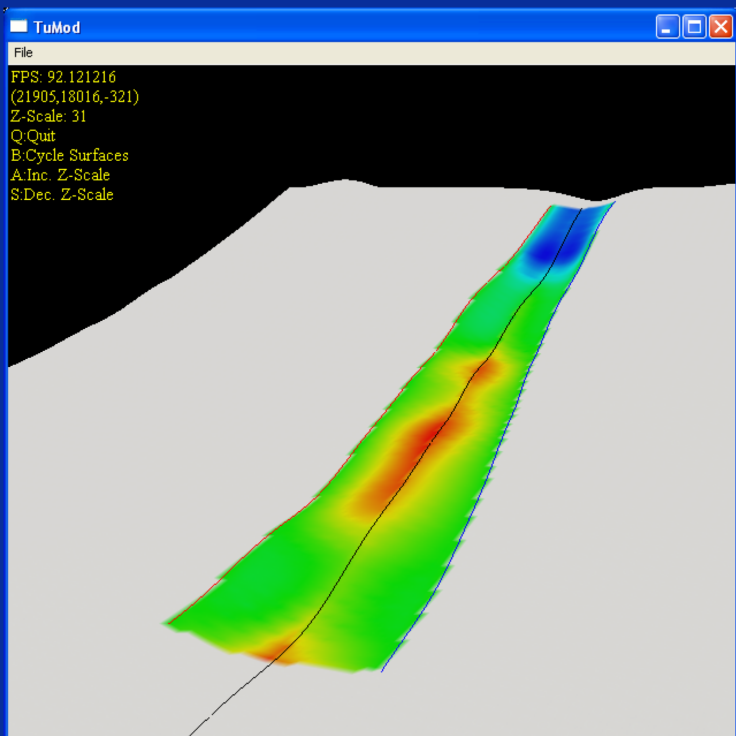
mass balance for sediment in lower layer 2

$$\partial(u_2 c_2 h_2)/\partial s - S_i - S_b = 0$$

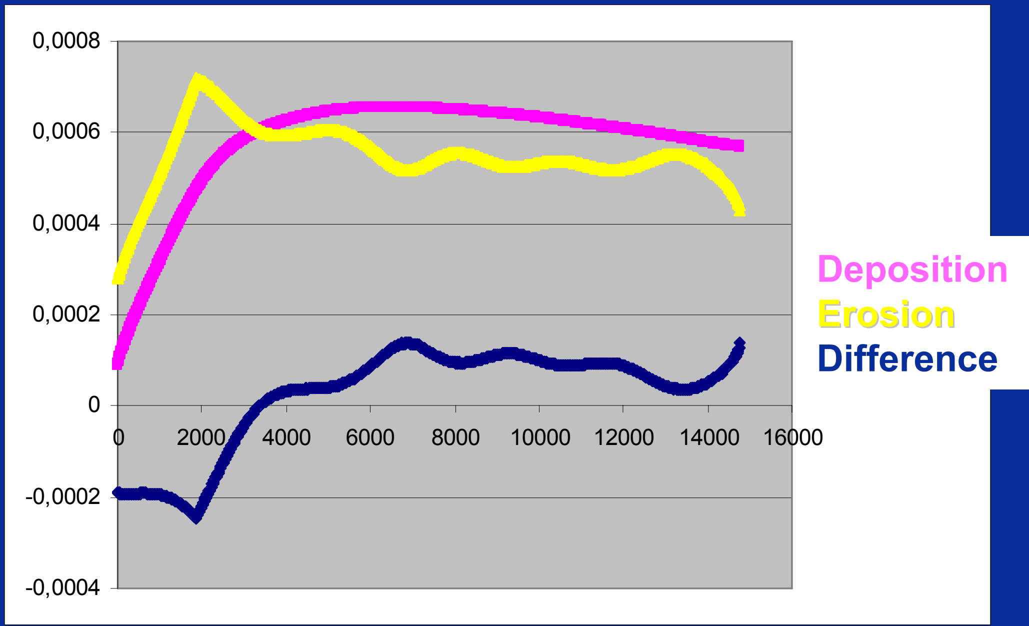
with :
h_1, h_2 = thickness of upper and lower layer ($h_1+h_2=h$=flow depth),
c_1, c_2 = depth-averaged volumetric suspended sediment concentration in upper layer 1and lower layer 2,
$u_1=q_1/h_1$, $u_2=q_2/h_2$ = velocity in upper layer 1 and lower layer 2,
W_i= exchange of fluid at the interface,
W_b = exchange of fluid at the bed,
S_i = exchange of sediment at the interface,
S_b = exchange of sediment at the bed,
ρ_2 = mixture density of lower layer,
ρ_w = fluid density (clear water in upper layer 1),
ρ_s = sediment density,
τ_i = shear stress at interface ($= \rho C_{di} u_2^2$),
τ_b = bed shear stress ($= \rho C_d u_2^2$),
C_d = bottom friction coefficient ($= g/C^2$), C = Chézy coefficient,
C_{di} = interface friction coeffcient,
β = angle of bed slope in s-direction,
s = coordinate along bed slope.

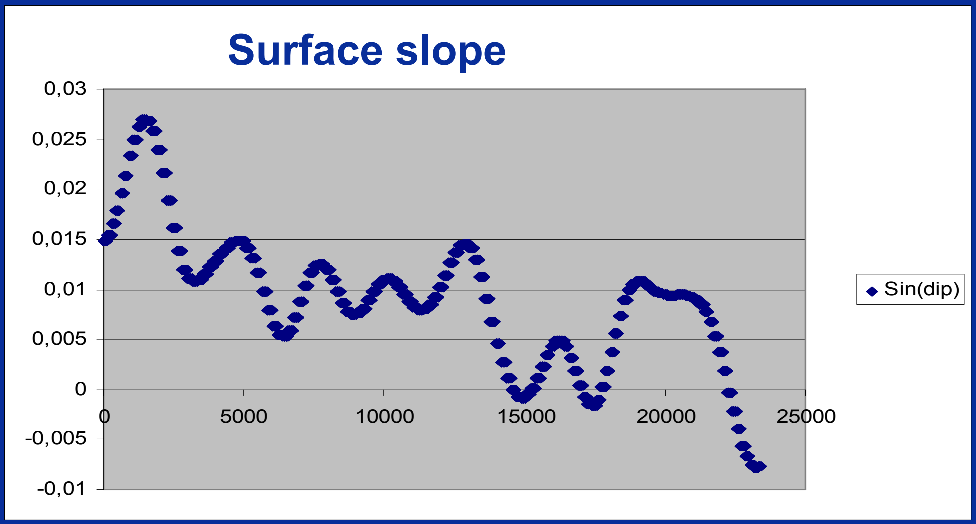
- Detects *hydraulic jump.*
  - Caused by dilution of sediment and reduced speed at basin floor.

Example

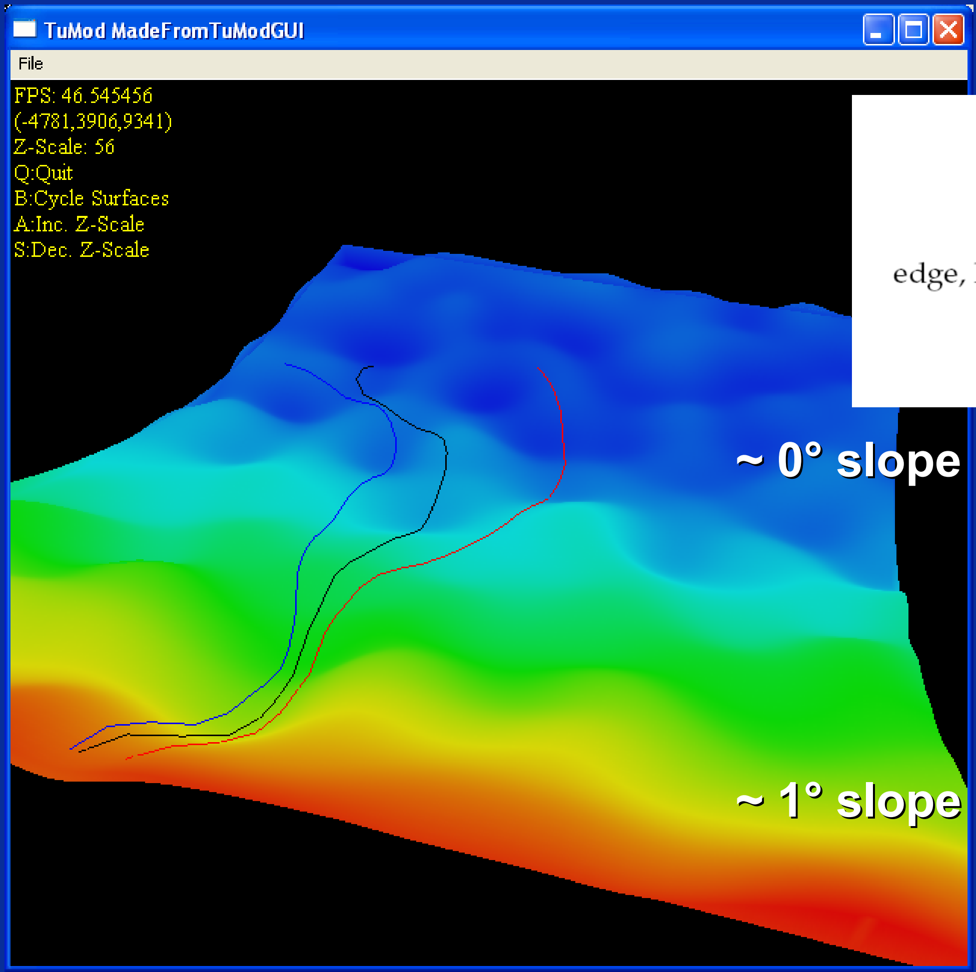


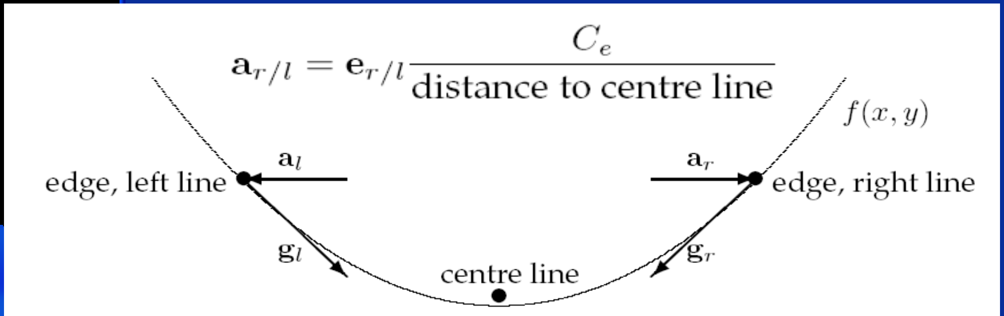
Blue is erosion
Red is deposition





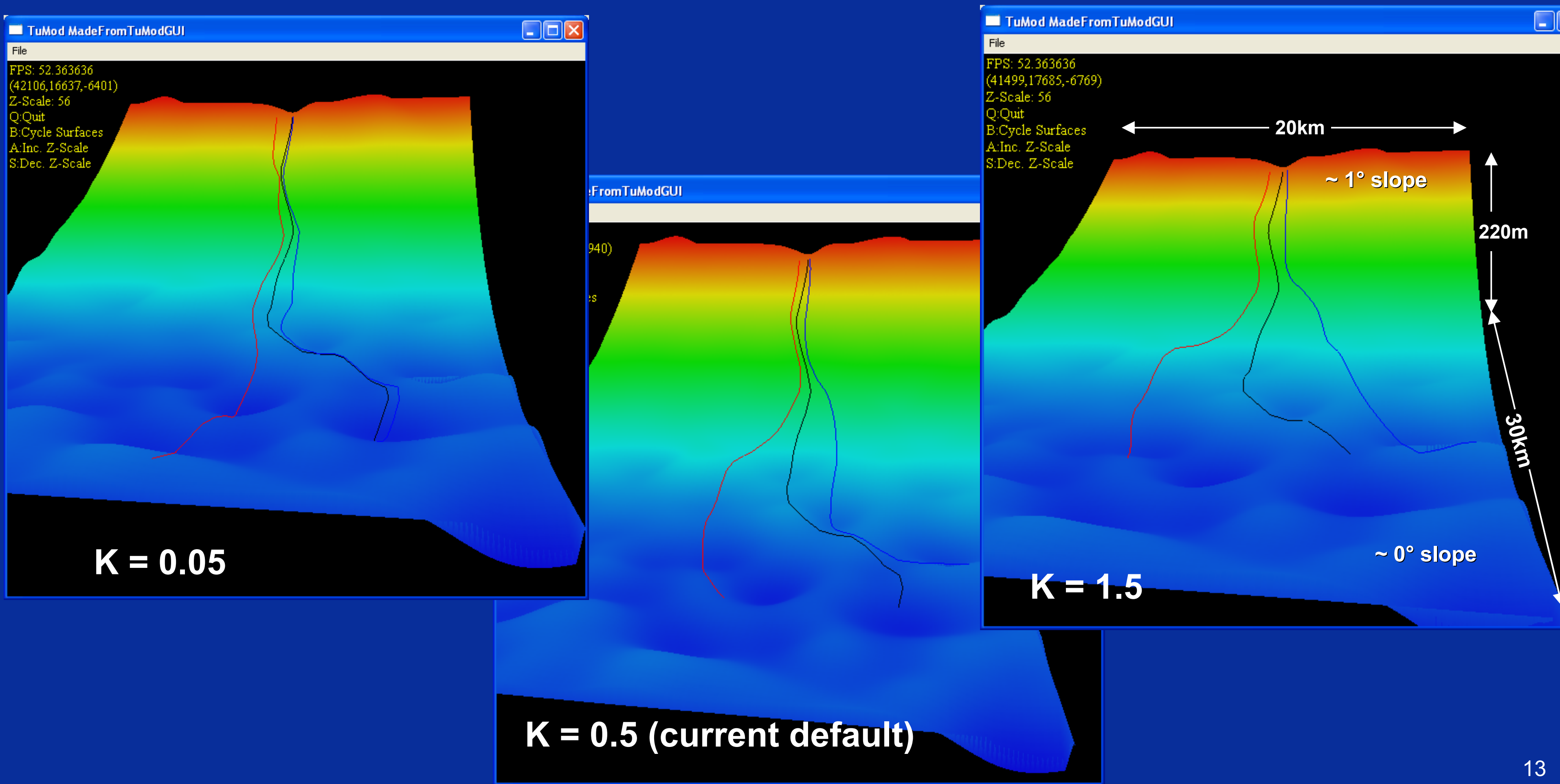
3. Width


TuMod MadeFromTuModGUI
File
FPS: 46.545456
(-4781,3906,9341)
Z-Scale: 56
Q:Quit
B:Cycle Surfaces
A:Inc. Z-Scale
S:Dec. Z-Scale
~ 0° slope
~ 1° slope


$\mathbf{a}_{r/l} = \mathbf{e}_{r/l} \frac{C_e}{\text{distance to centre line}}$
$f(x,y)$
edge, left line
$\mathbf{a}_l$
$\mathbf{a}_r$
edge, right line
$\mathbf{g}_l$
$\mathbf{g}_r$
centre line

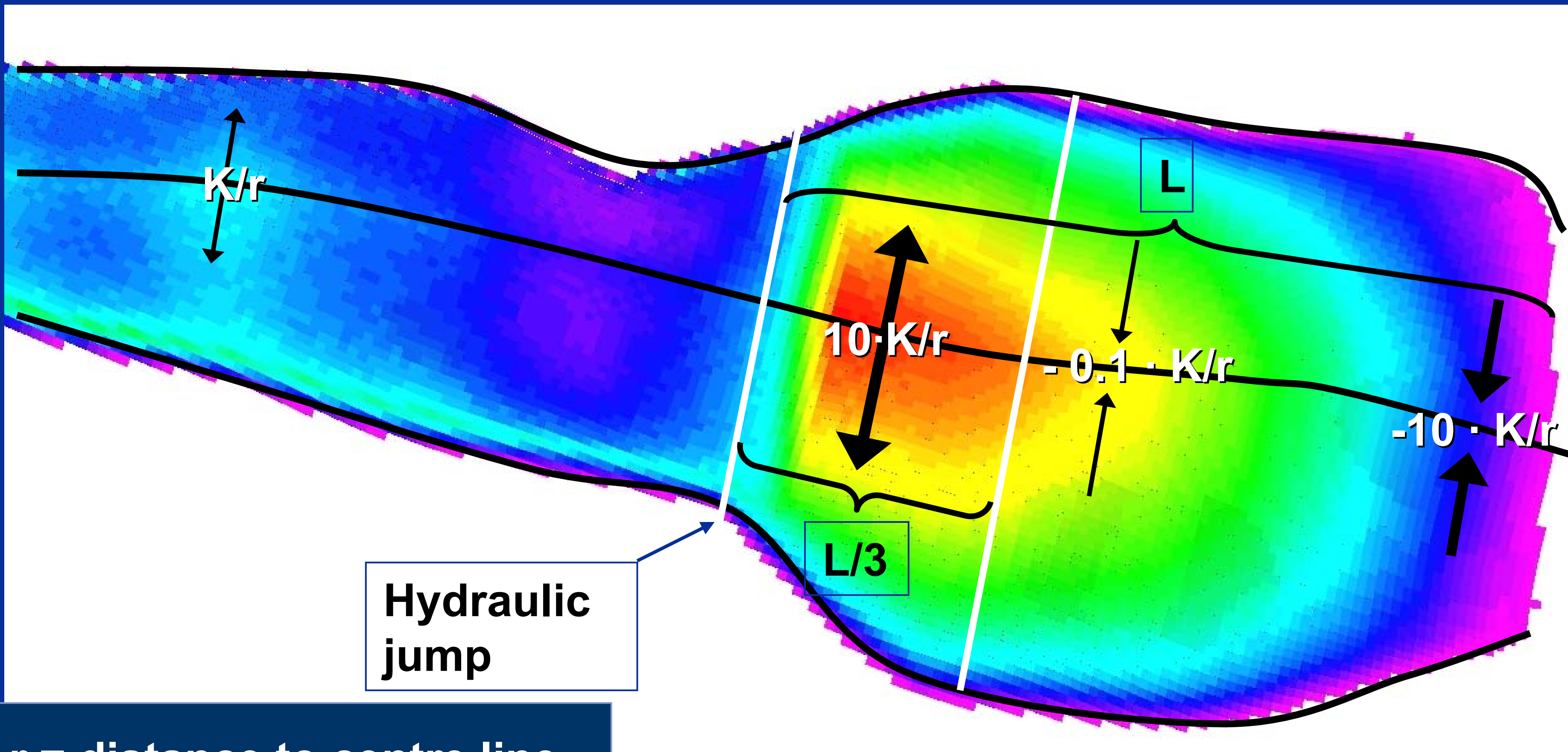
Repulsion

- Force ∝ K / (distance to centre line)



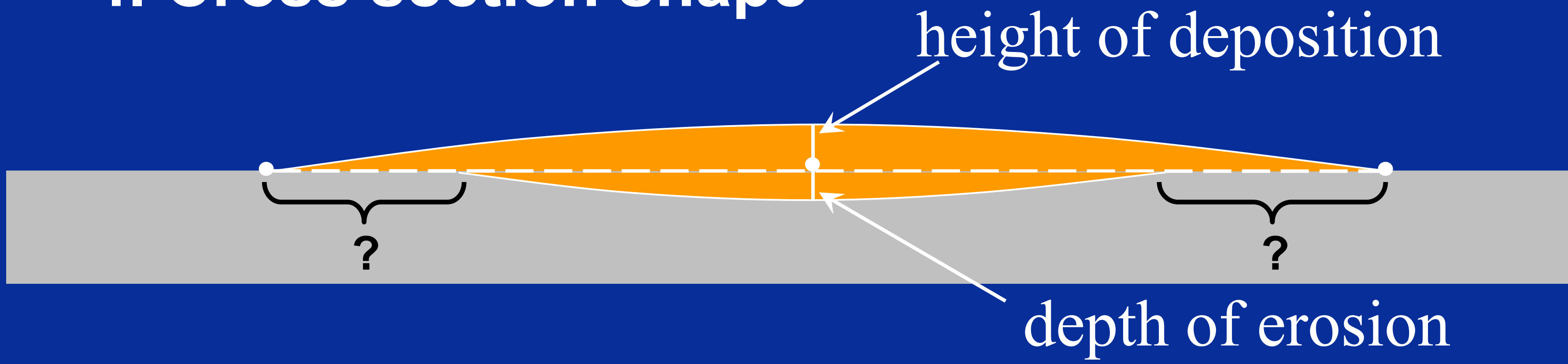
Closing the lobe

- Length, L, depend on mass at hydraulic jump

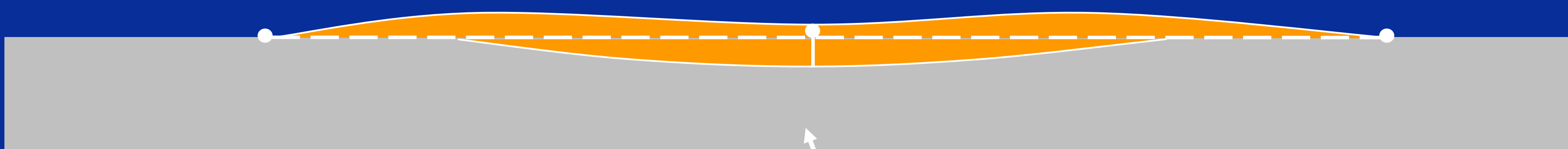


r = distance to centre line

4. Cross section shape

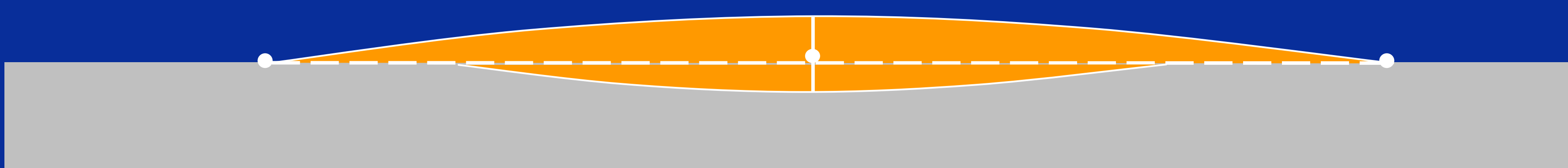


Draping deposit



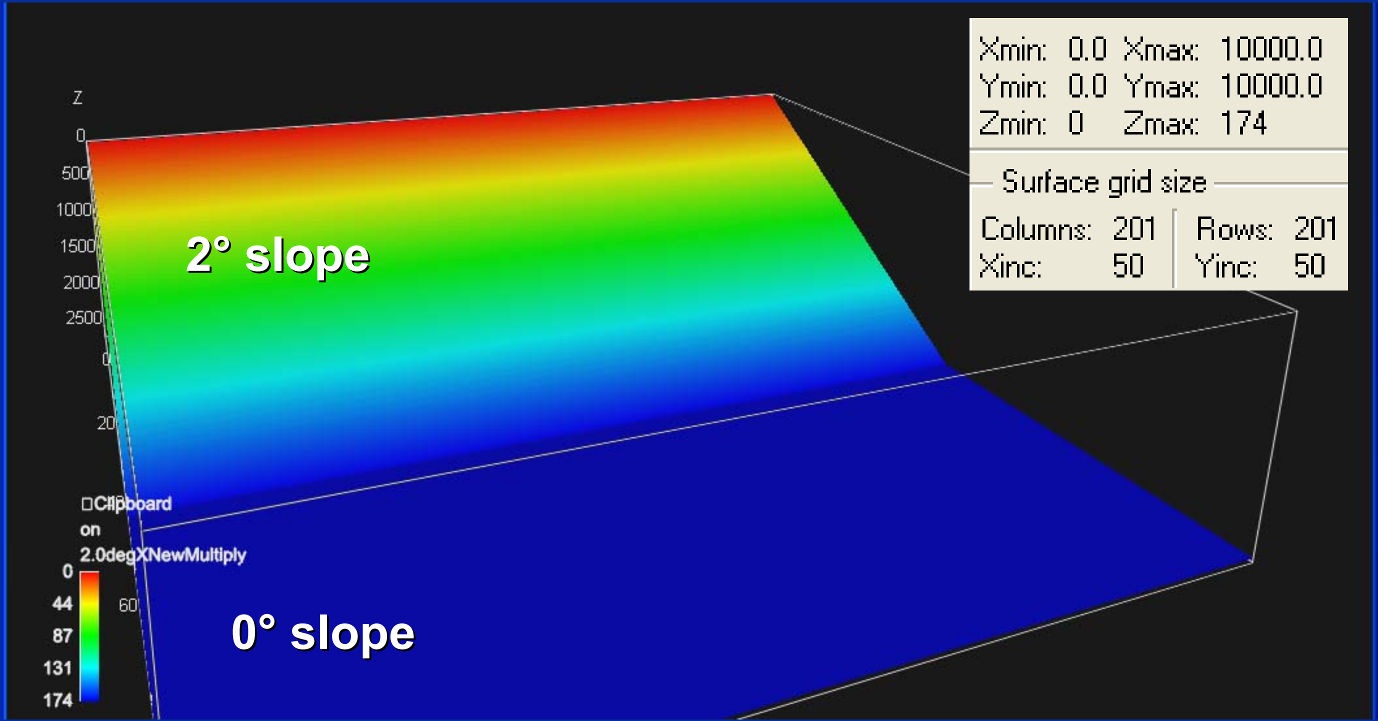
Filling deposit

Mixing these extremes



Physics is to stable!

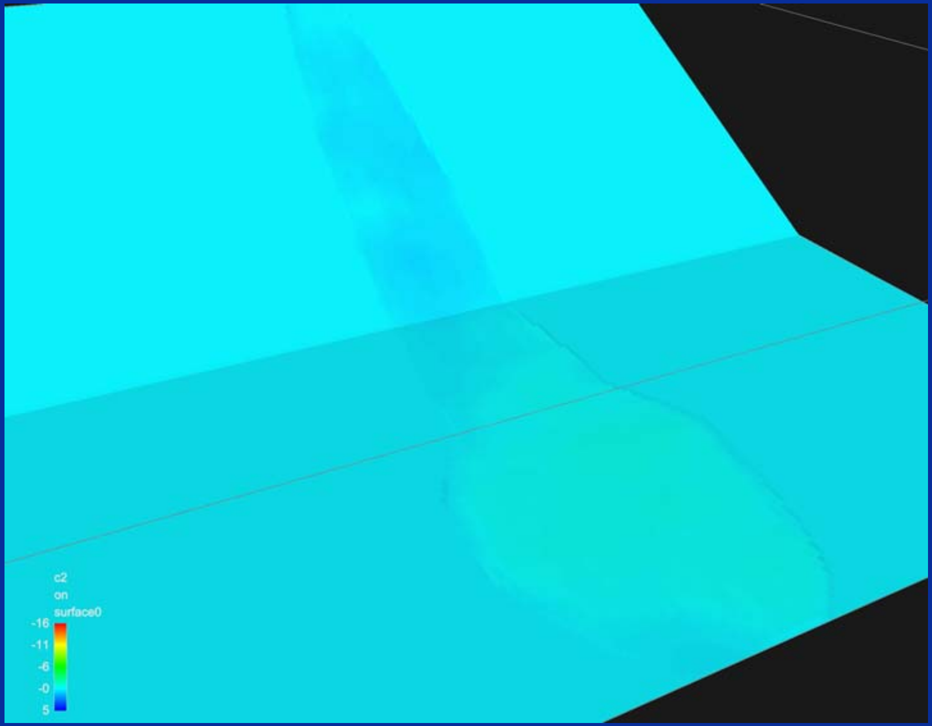
- 2° dipping plane
- Dips in X-direction
- 20 Events

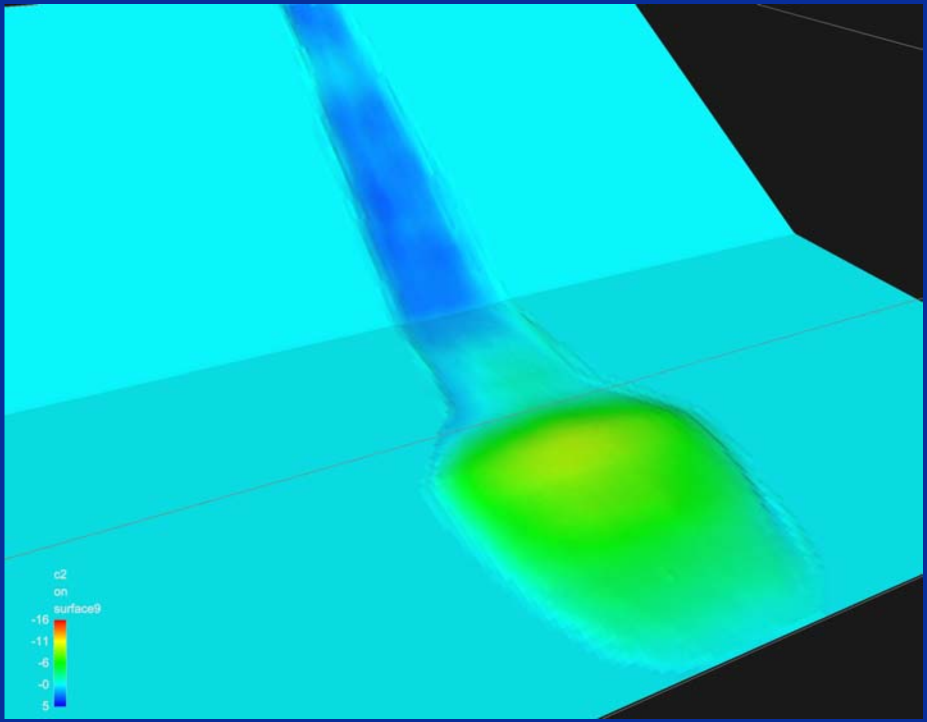


Results: Event: 1, 10

Red = net deposition

Blue = net erosion



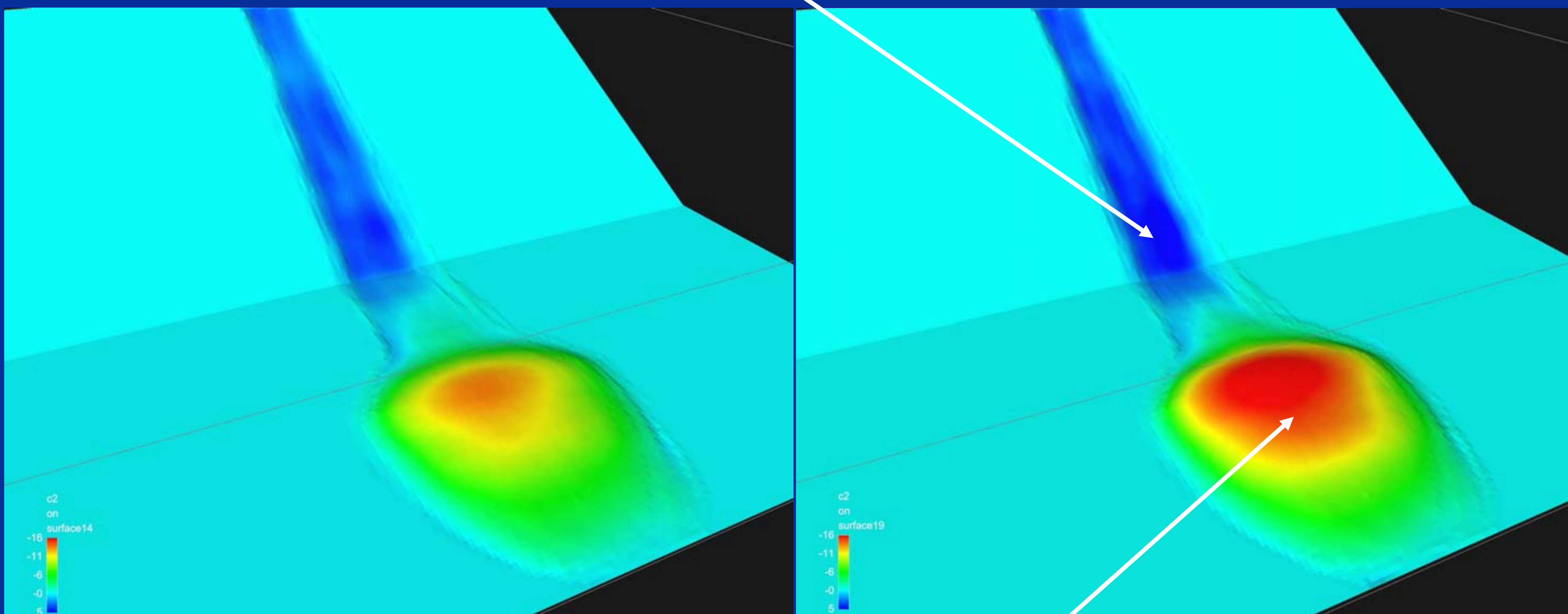


Results: Event: 15, 20

Red = net deposition

Blue = net erosion

Deep ditch



High pile

This pattern will continue for Event:21, 22, …

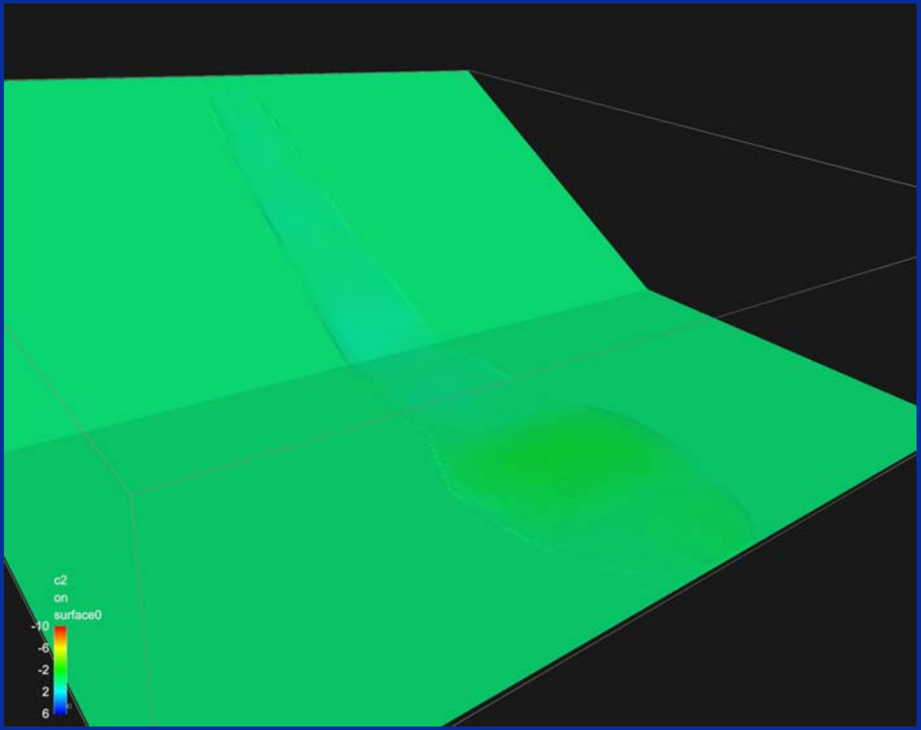
Problem and solution

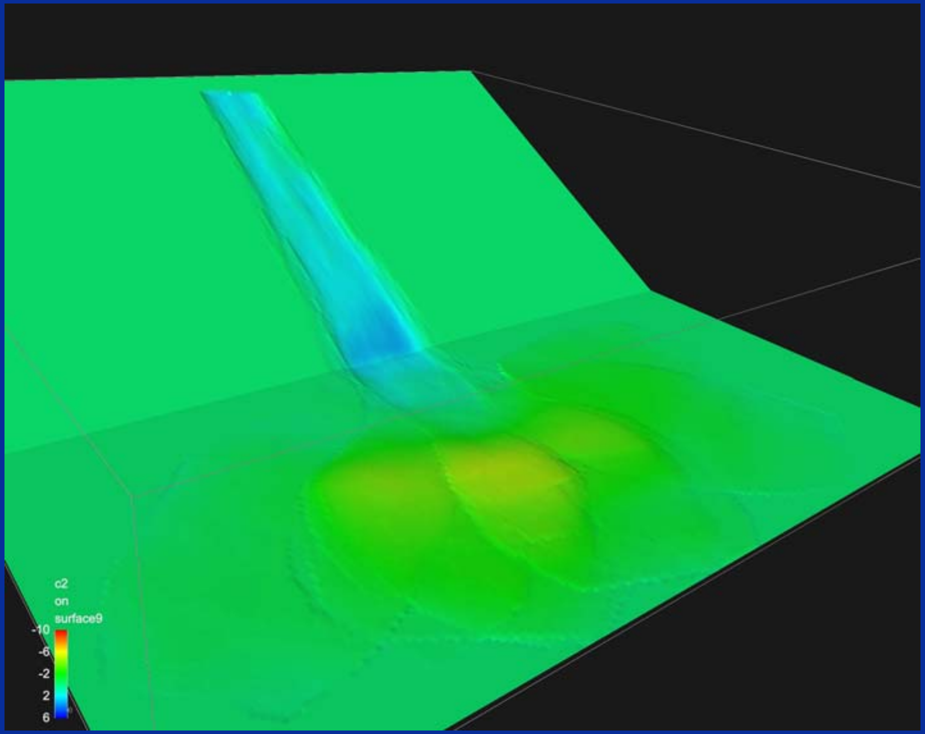
- Problem
  - All events stack on top of each other.
  - Sea floor is incredibly flat.
- Solution
  - Turbidity current sends shockwave forward to find easiest path.
  - Add antenna to turbidite flow.

New results: Event: 1, 10

Red = net deposition

Blue = net erosion

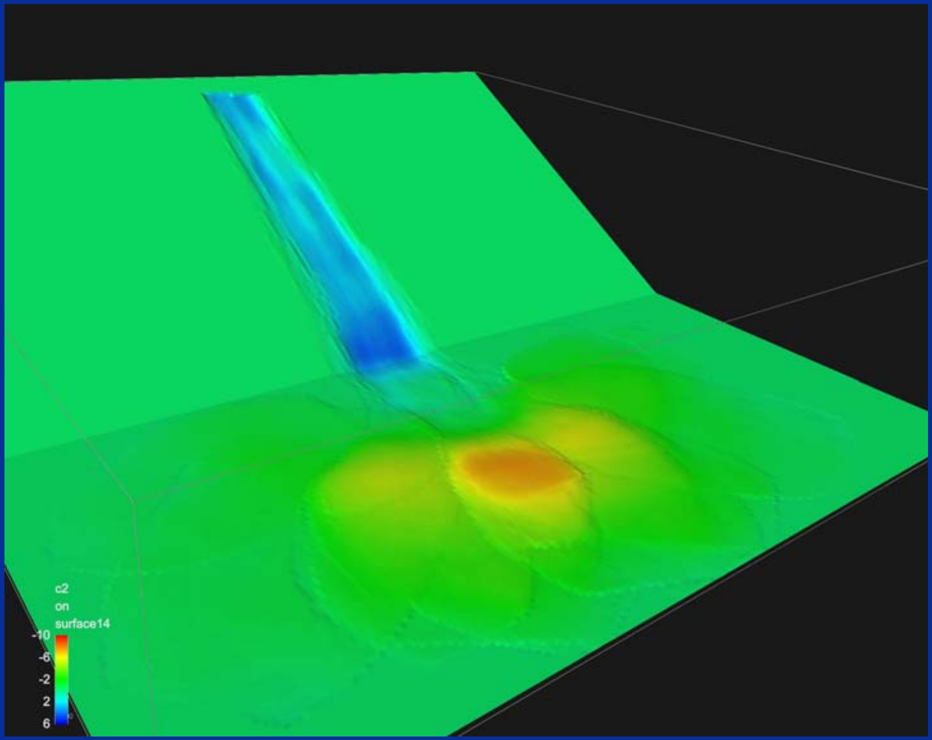


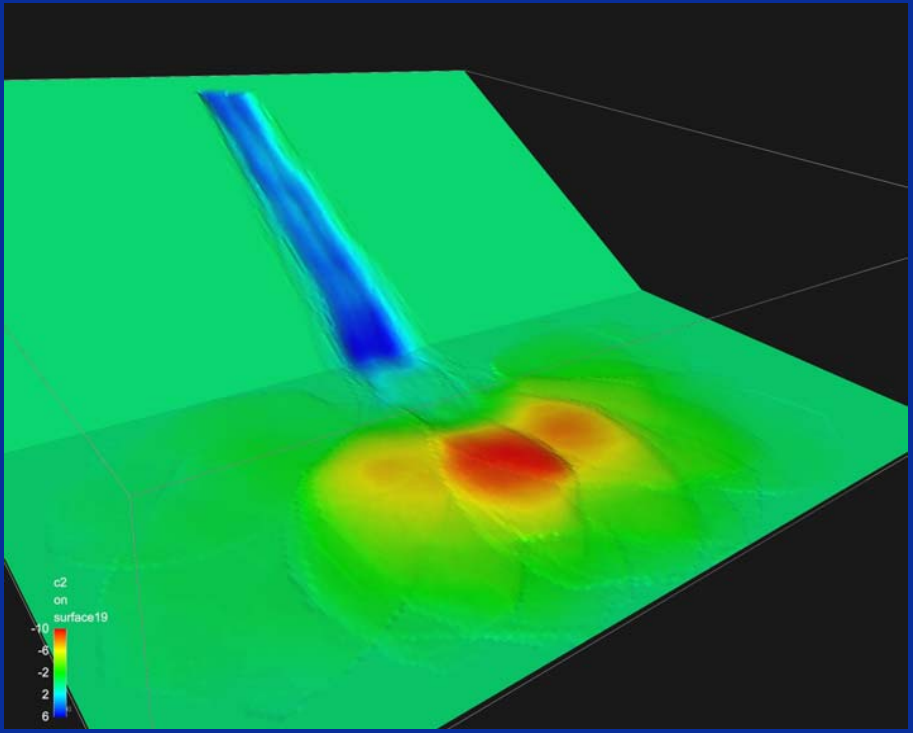


New results: Event: 15, 20

Red = net deposition

Blue = net erosion

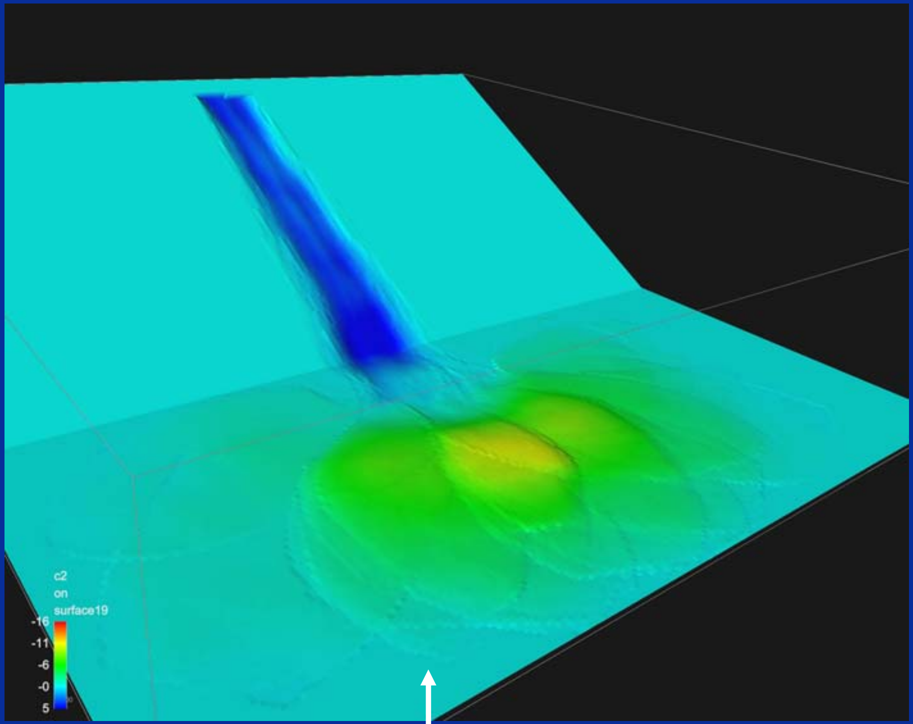


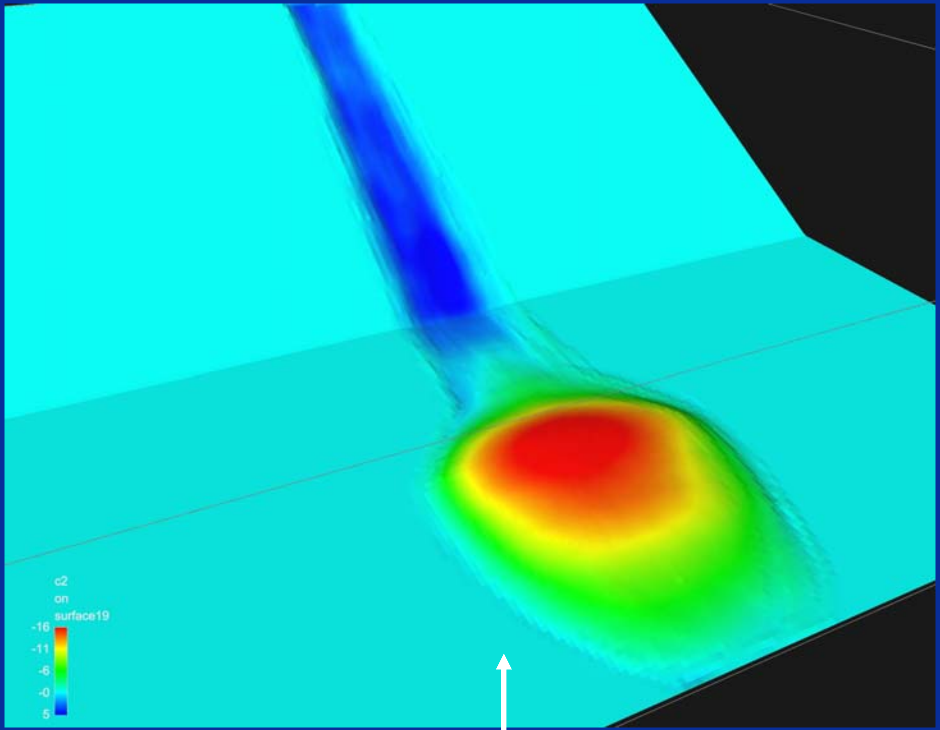


Comparing end results

Red = net deposition

Blue = net erosion

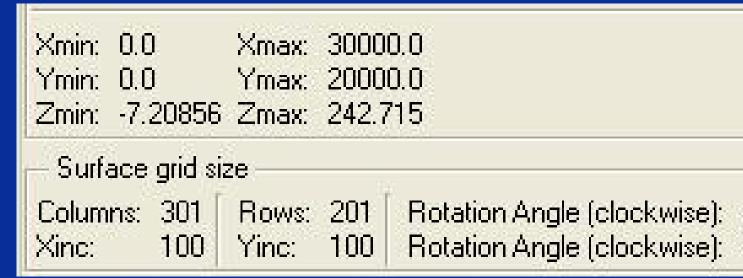


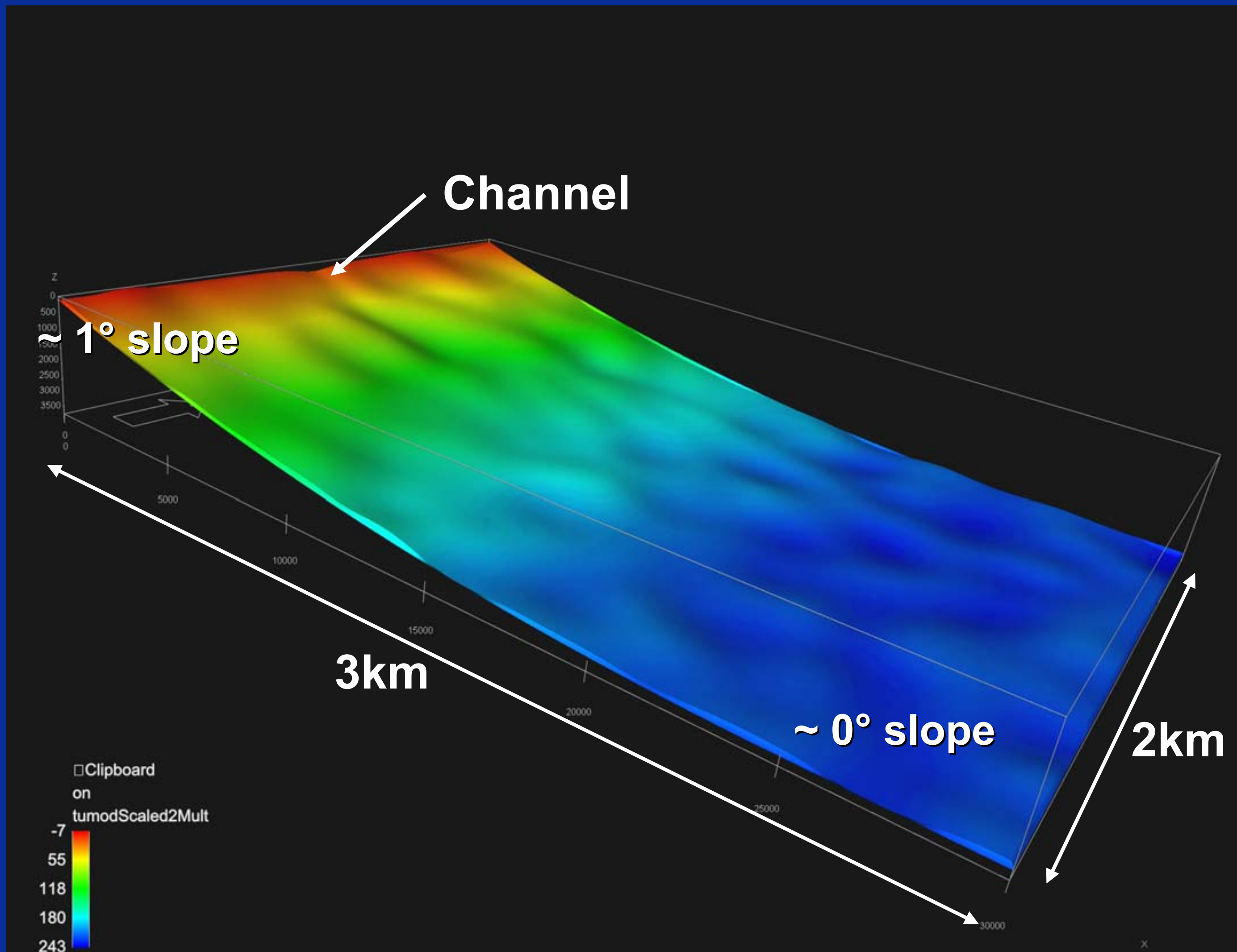


Looking forward: On

Looking forward: Off

Another example

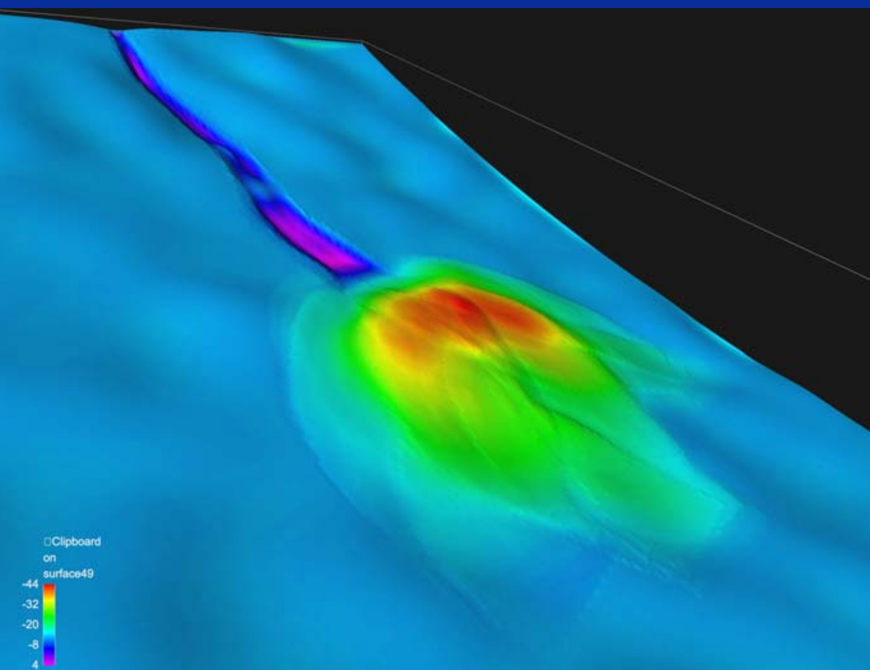


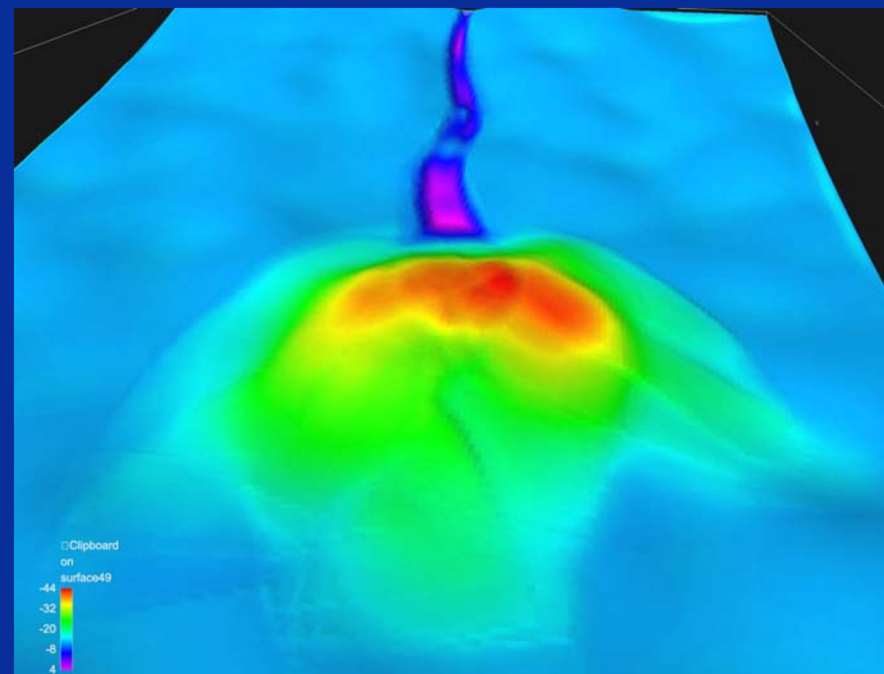


50 Events

Red = net deposition

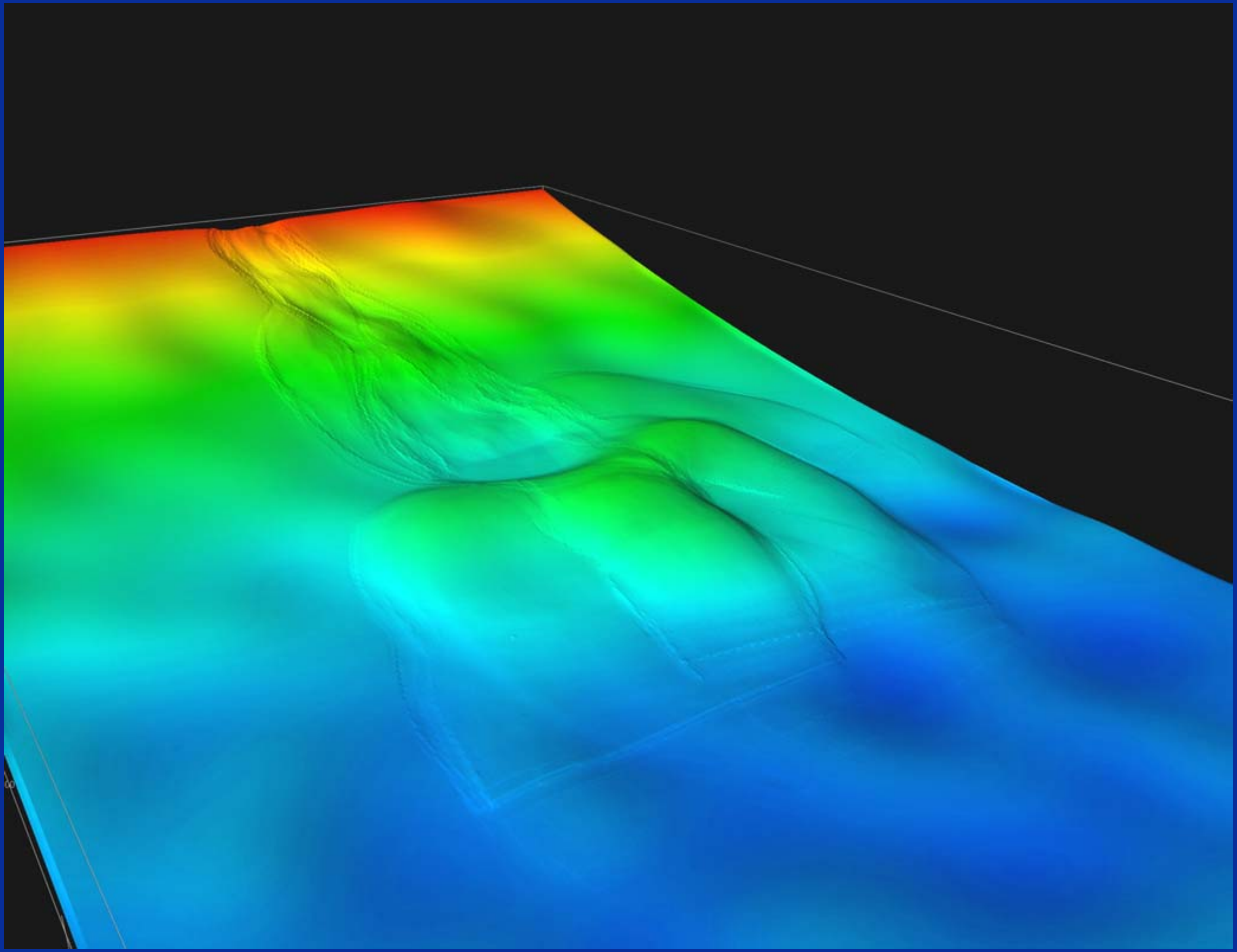
Blue = net erosion





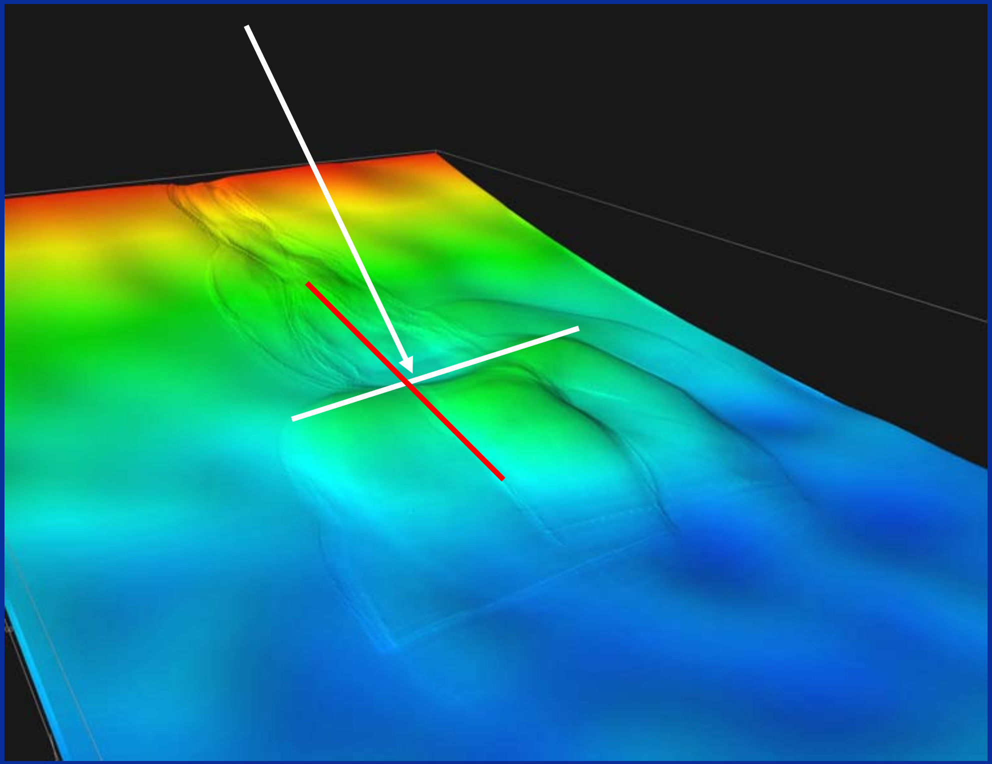
Final realization

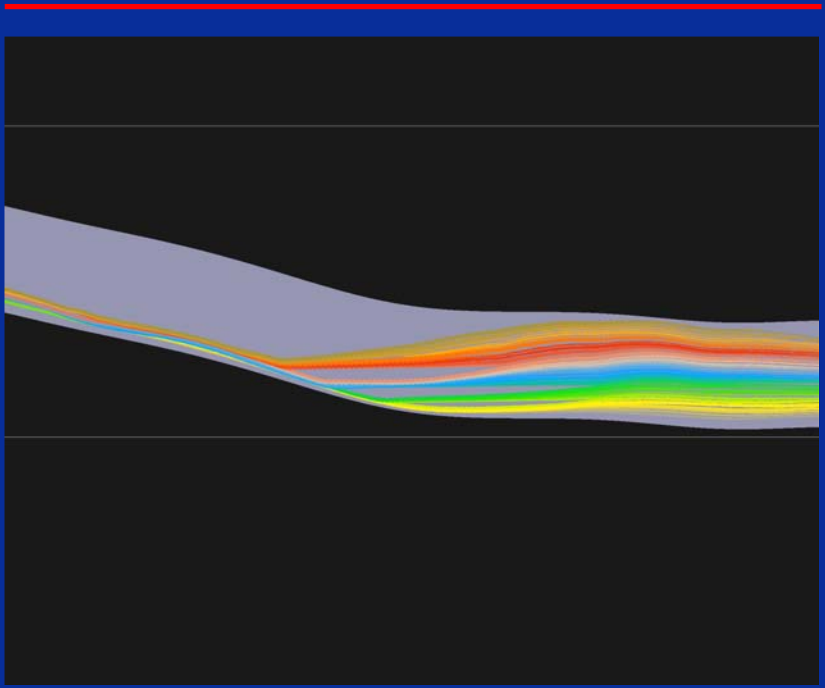
Similar example: 70 Events

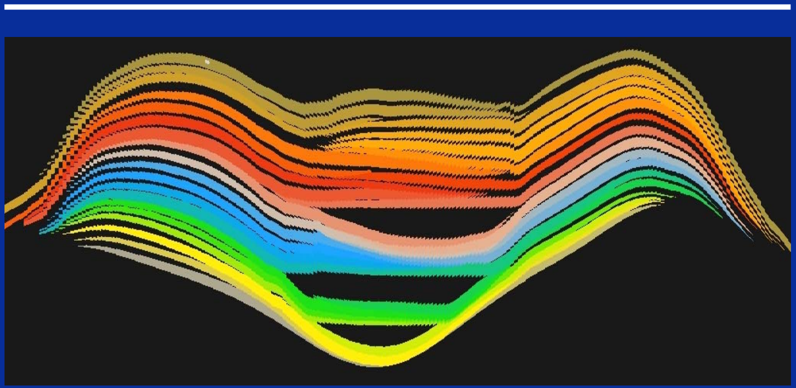


Filling

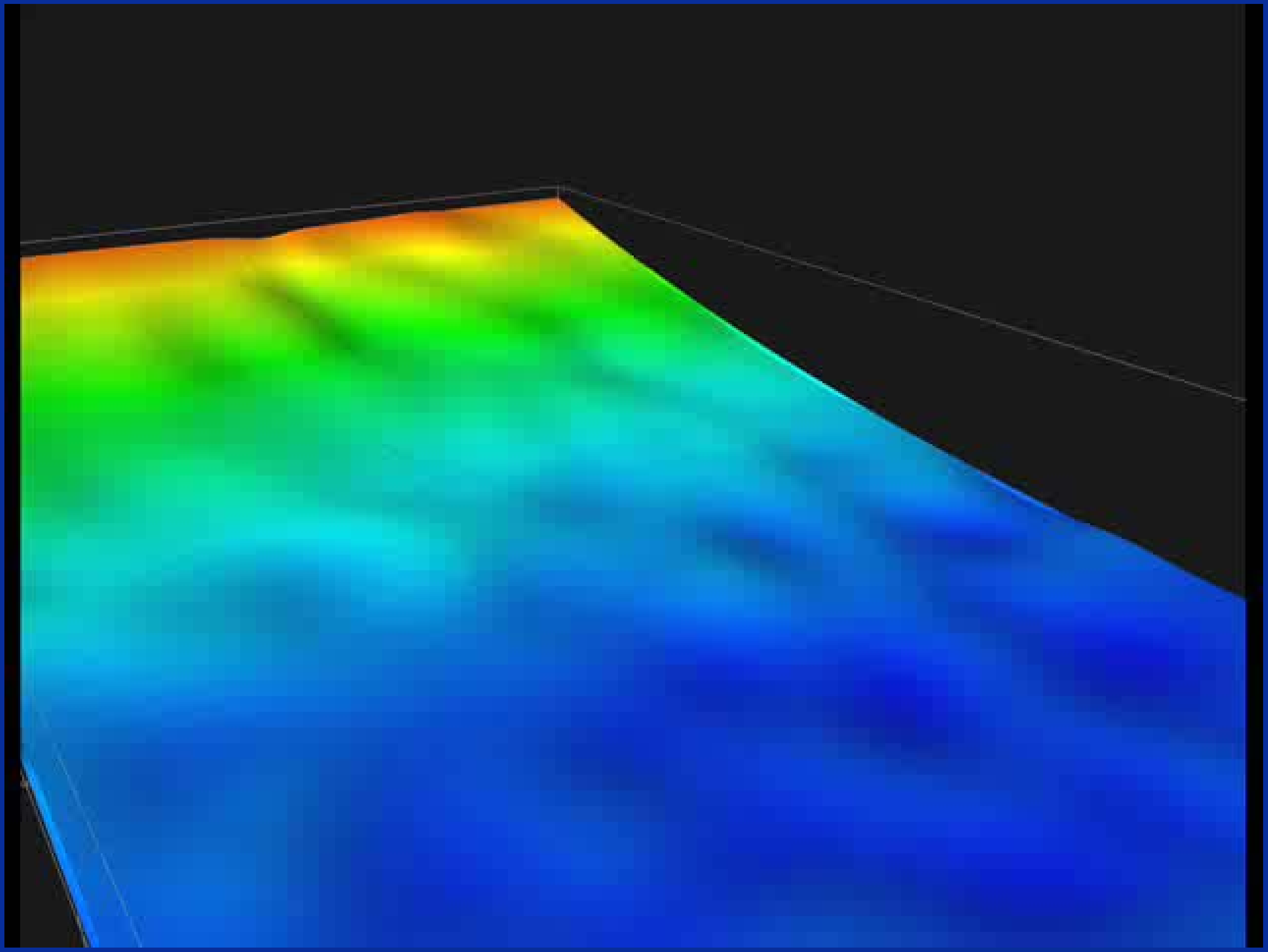
Filling accommodation space with shale between events using spill-point algorithm.



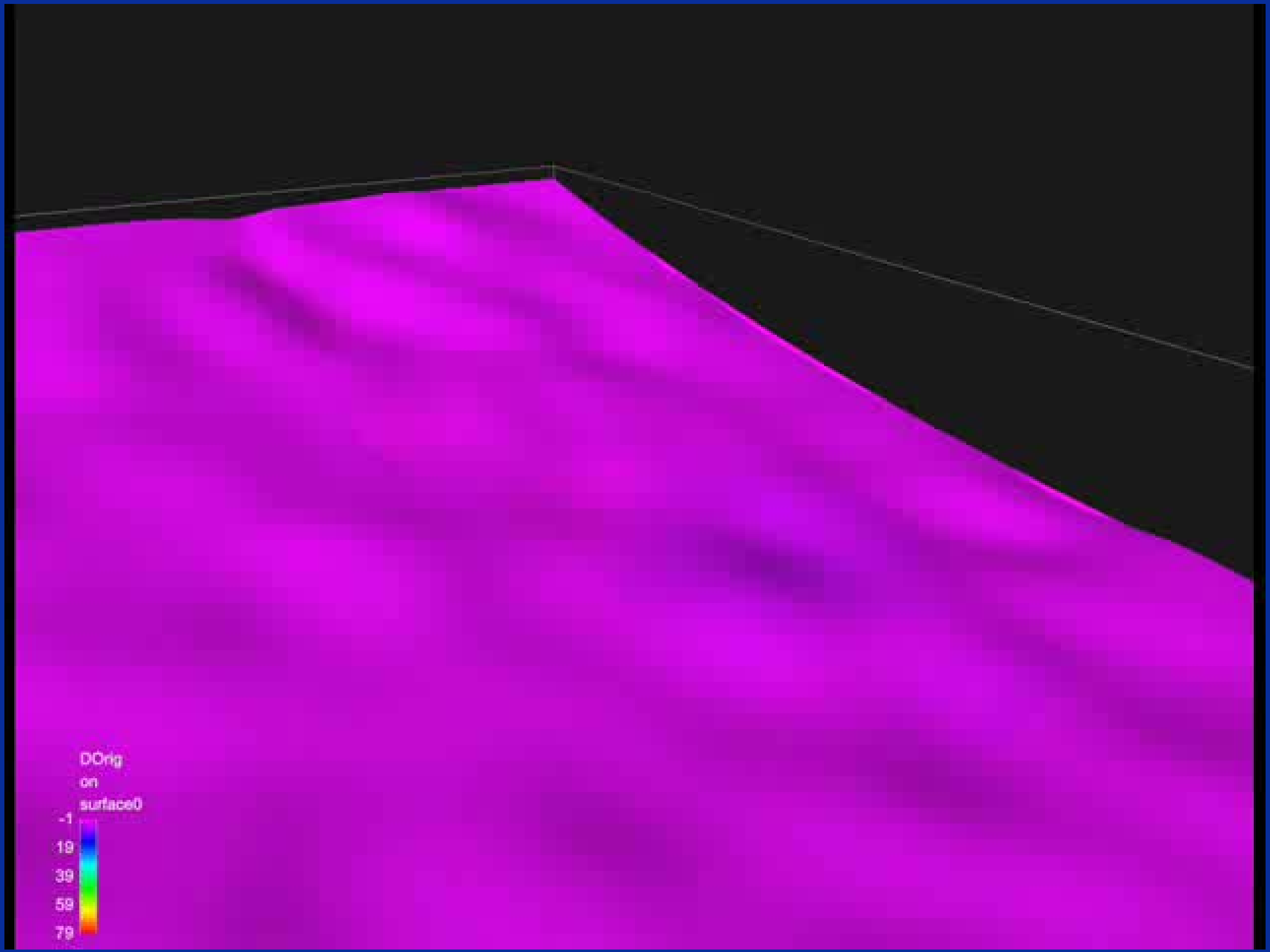




70 Events cont.

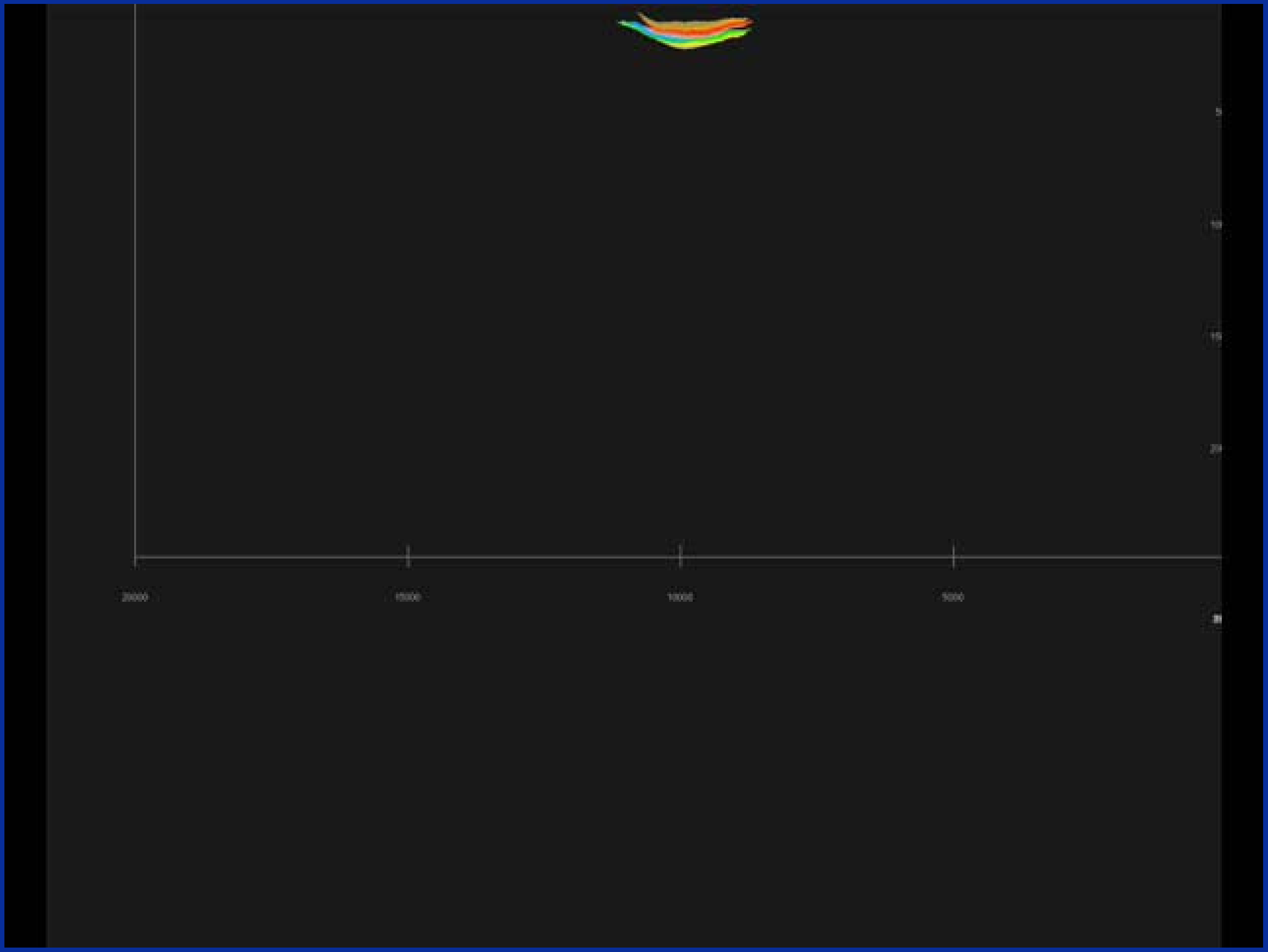


70 Events cont.



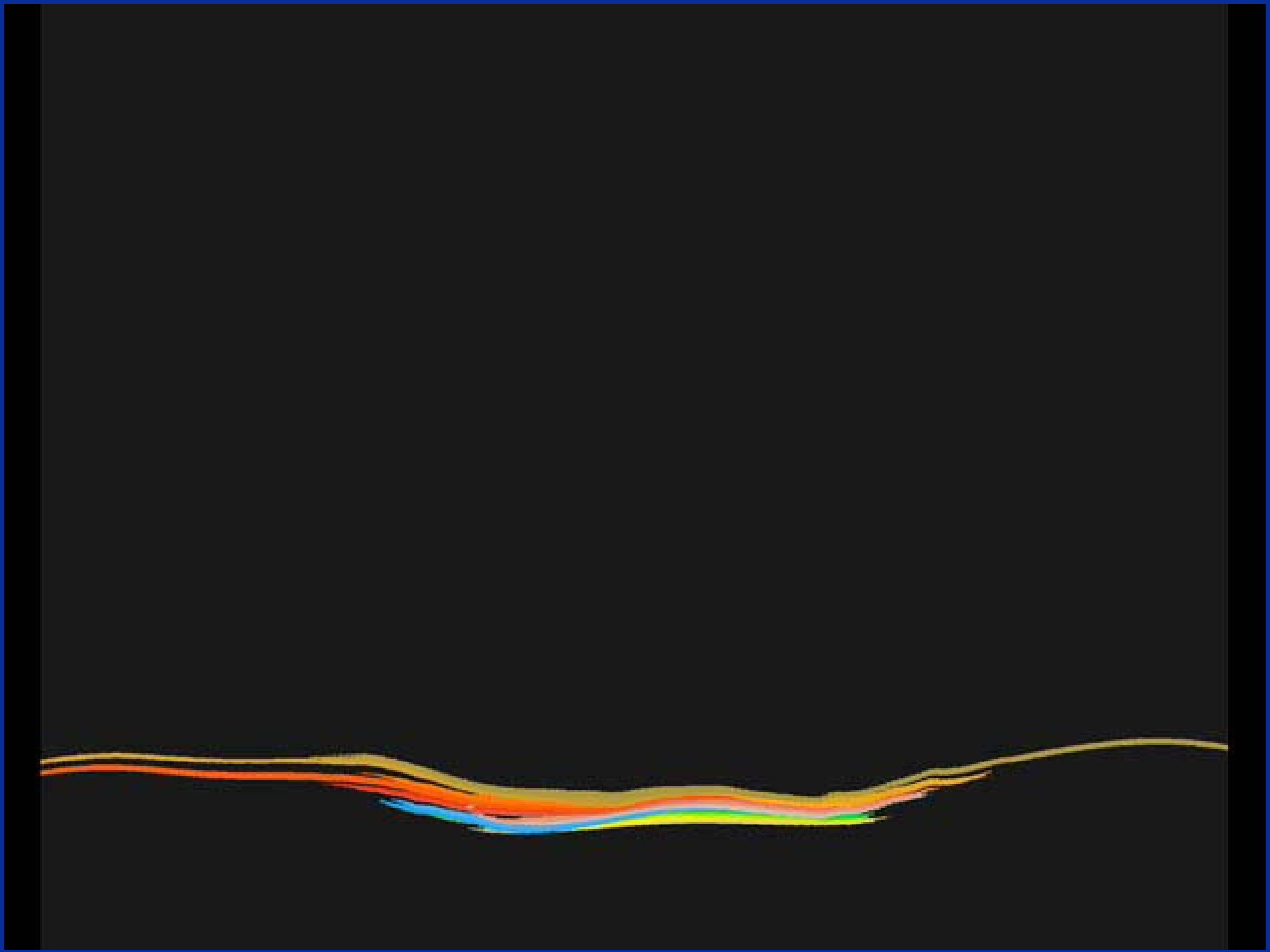
35 Events: Cross sections

From channel to abyssal plane

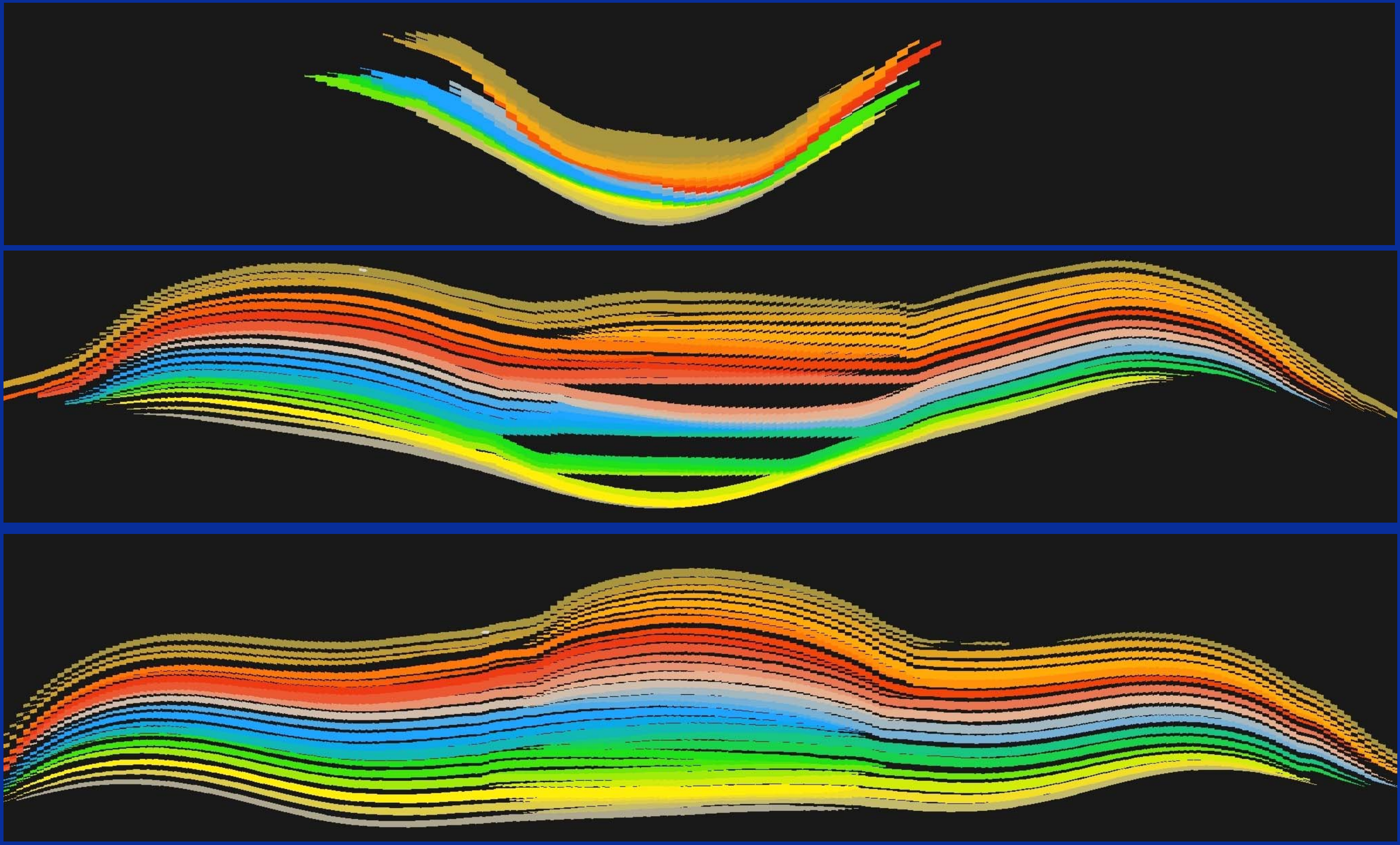


35 Events: Cross sections

Around hydraulic jump.



35 Events: Cross sections

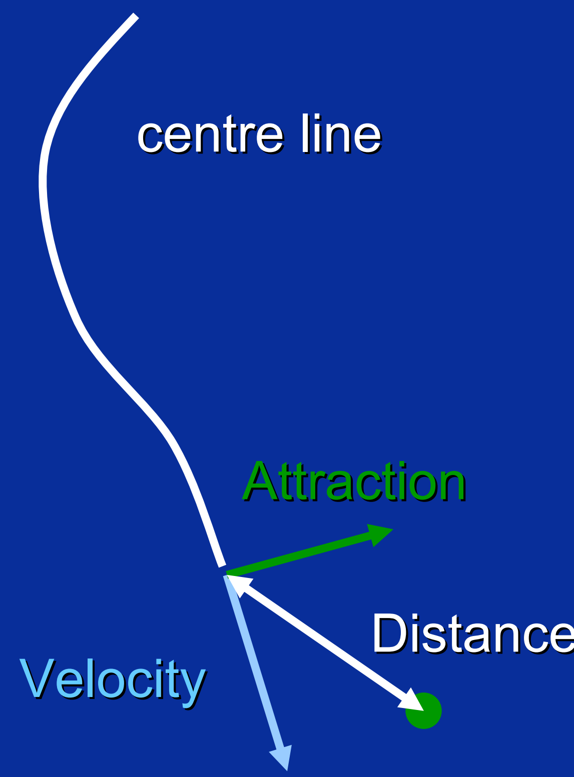


Well conditioning

- 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.

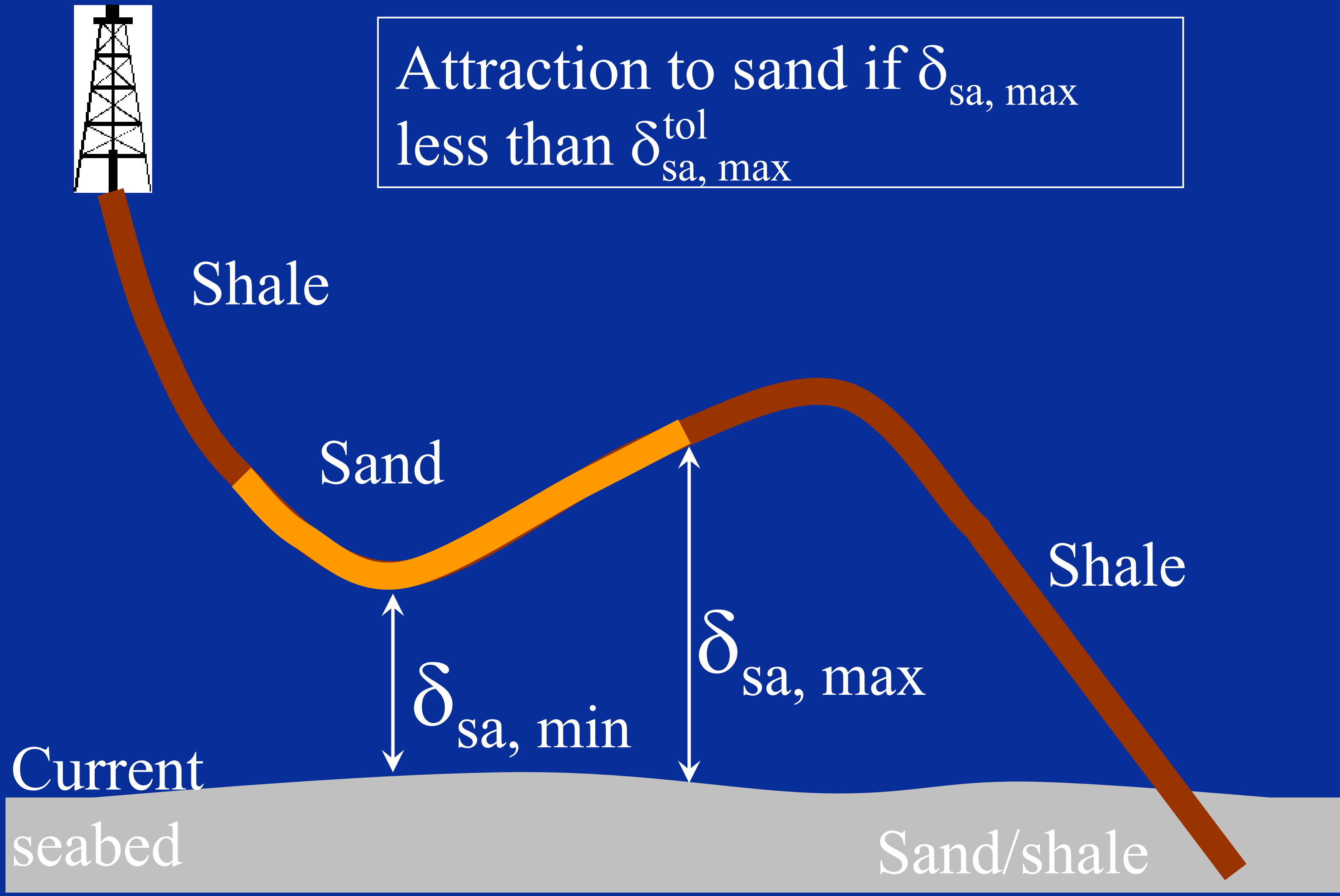
Physics conditioning – centre line

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



Active sand observations

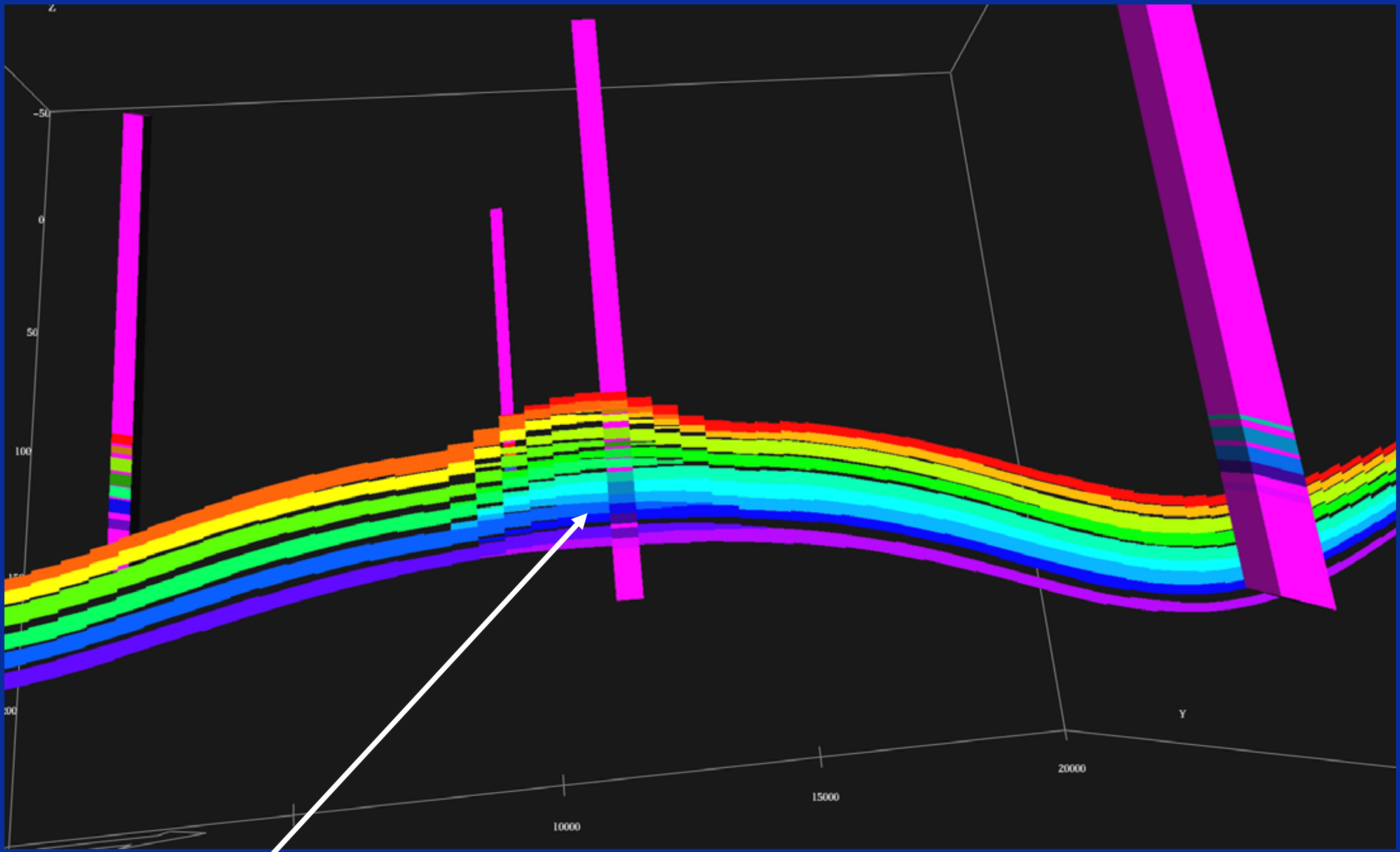
Attraction to sand if $\delta_{sa,\ max}$ less than $\delta^{tol}_{sa,\ max}$



15 Events with wells

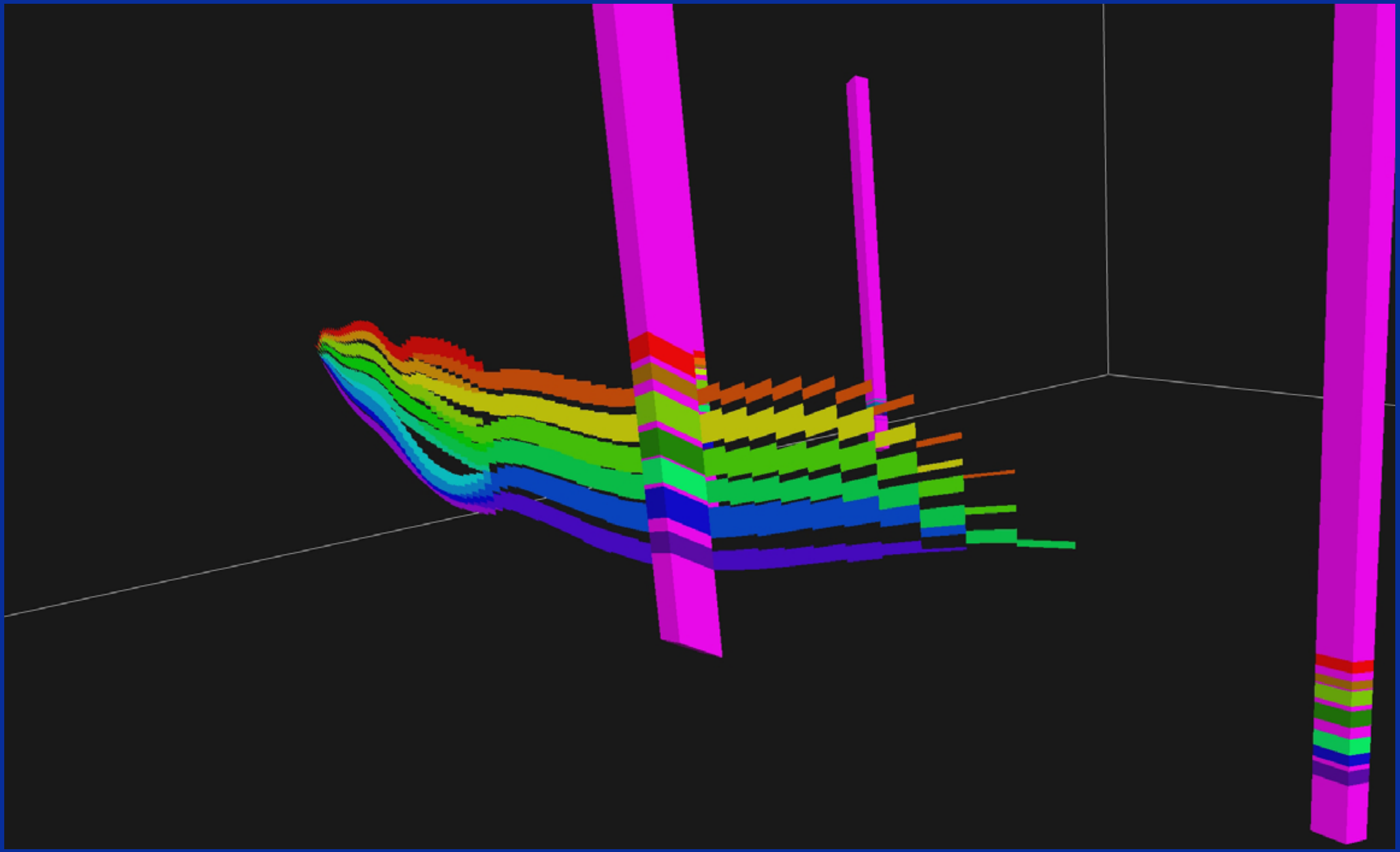
Well logs:

- Facies
  - Sand
  - Shale
- Body



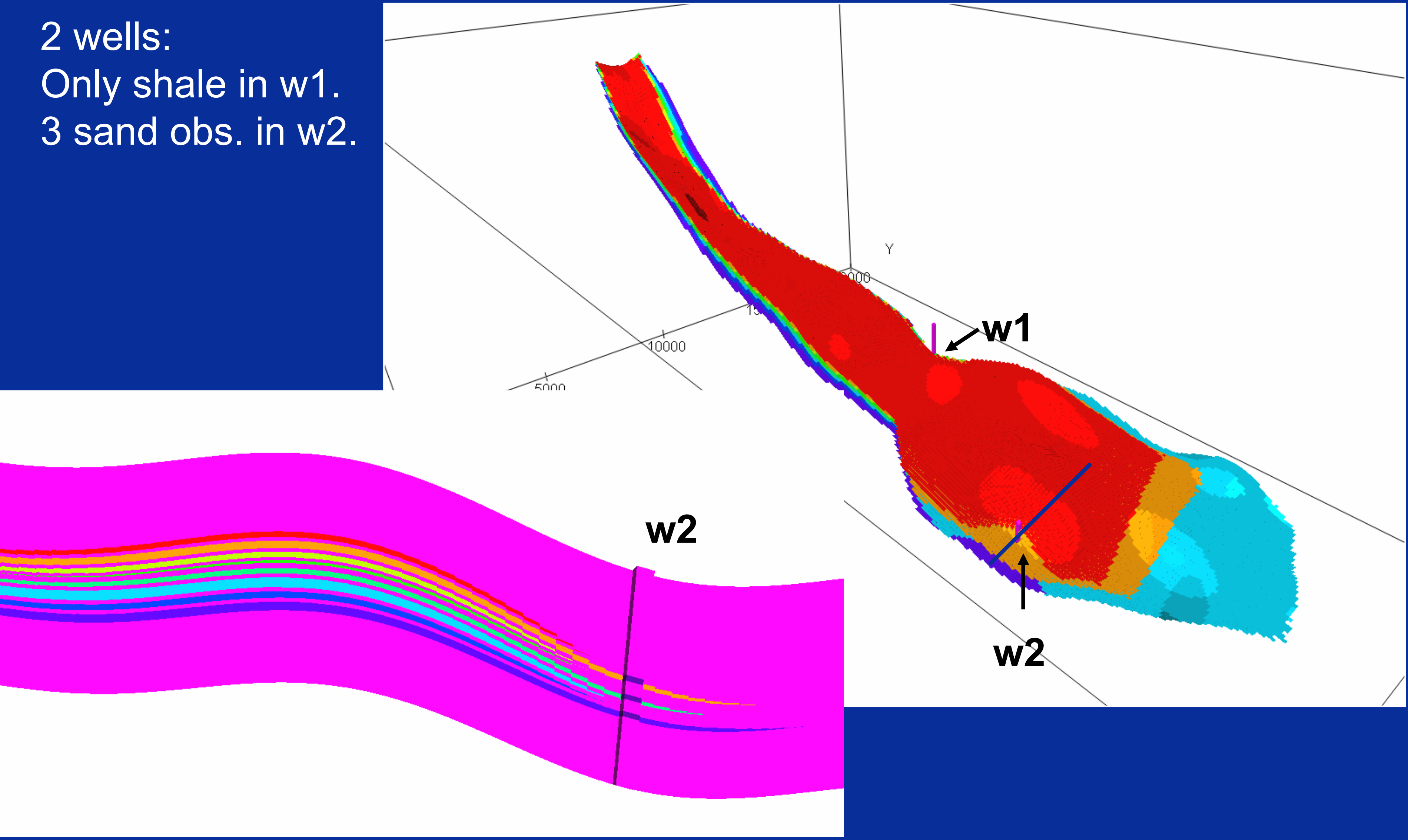
Note stacking

15 Events with wells cont.

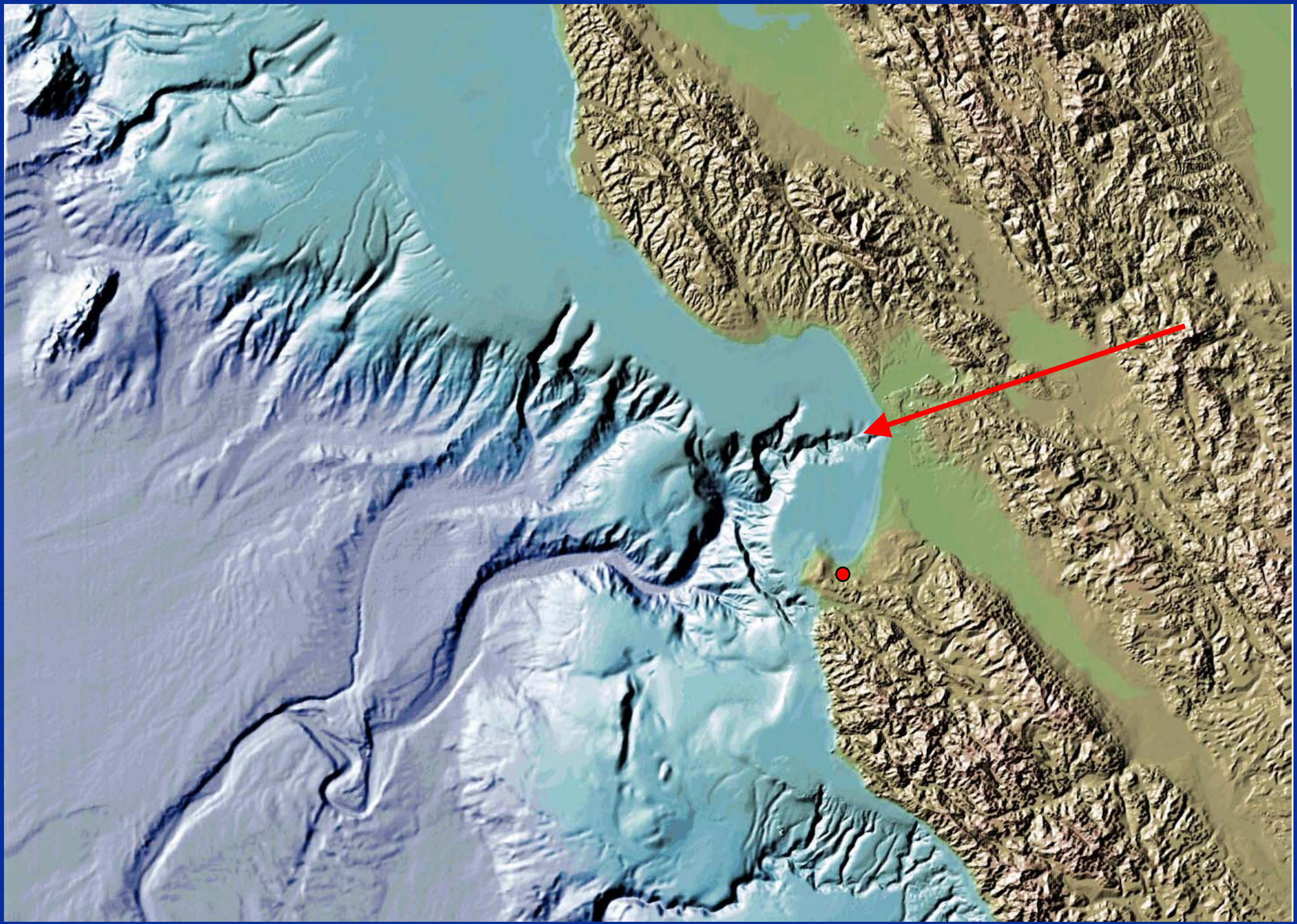


Well conditioning: 8 Events

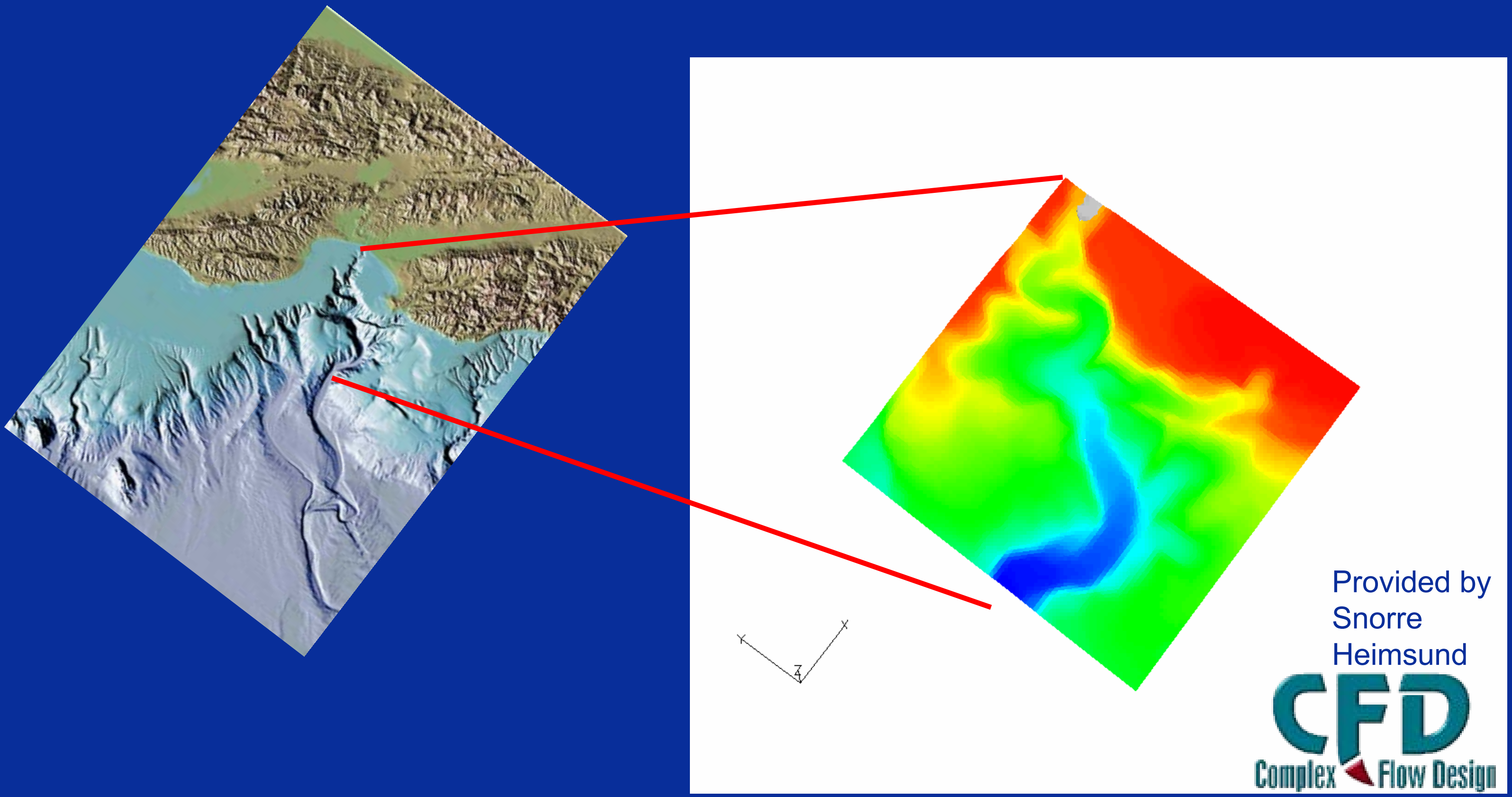
2 wells:
Only shale in w1.
3 sand obs. in w2.



The Monterey Channel

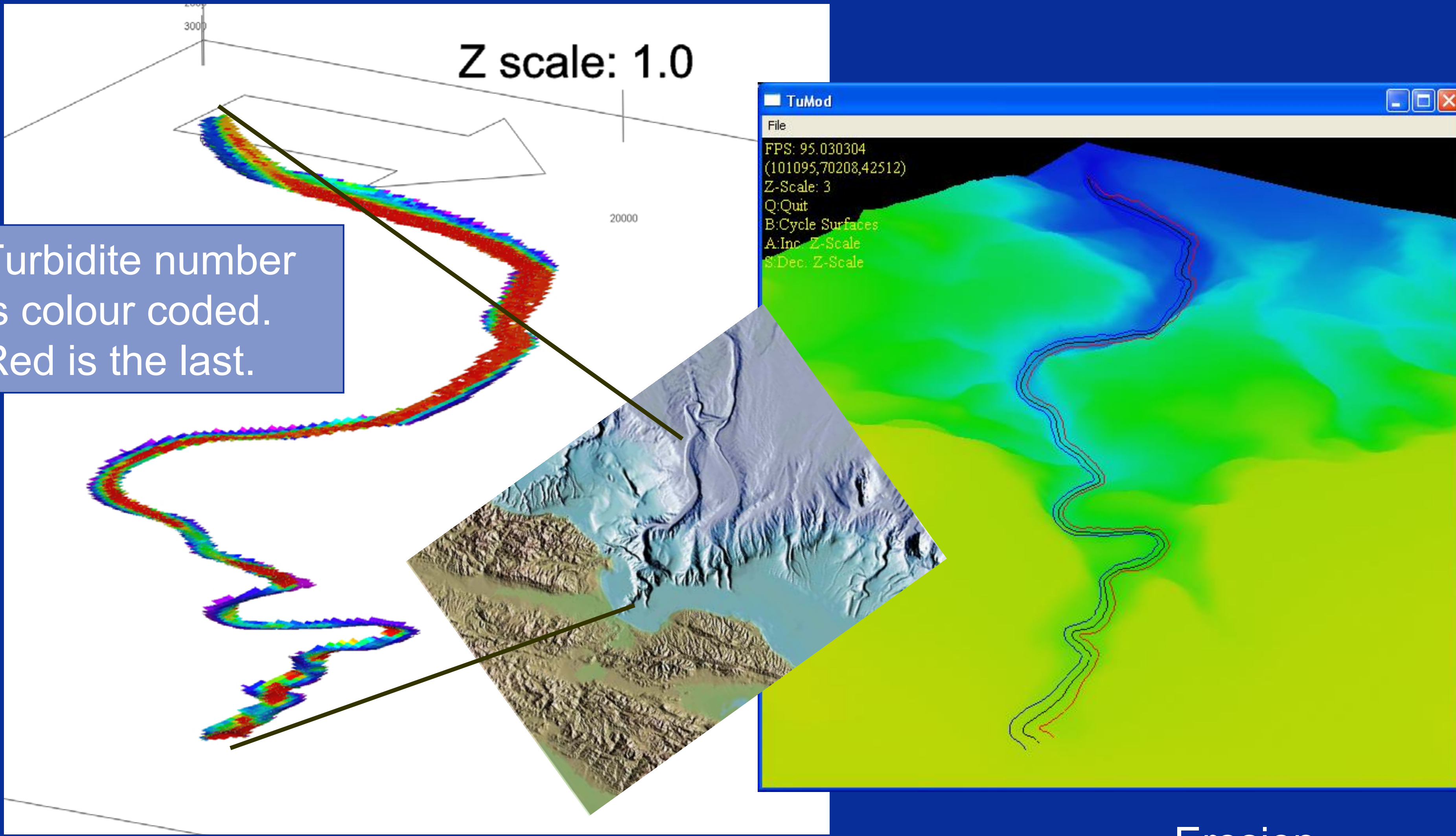


Monterey, detailed simulation



Erosion
dominates,
no deposition

Monterey, TuMod simulation

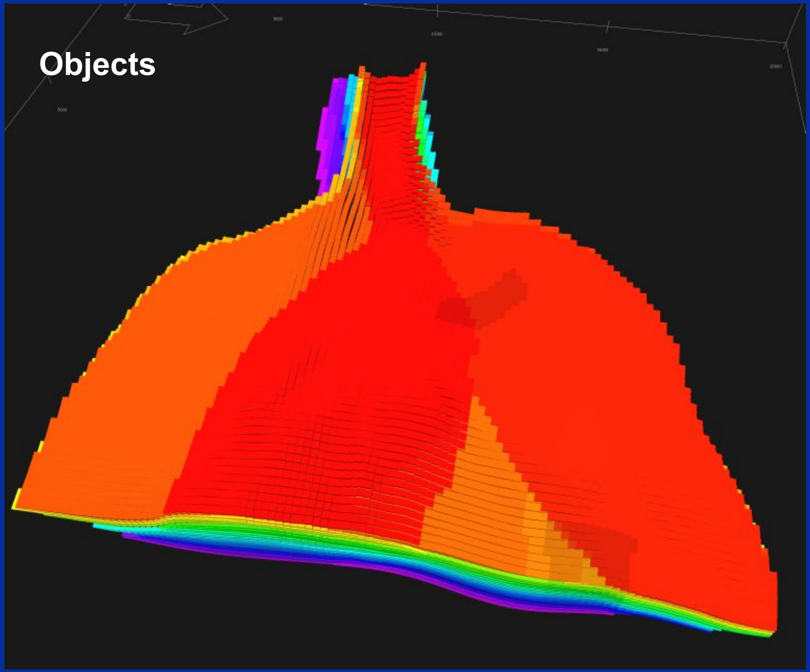


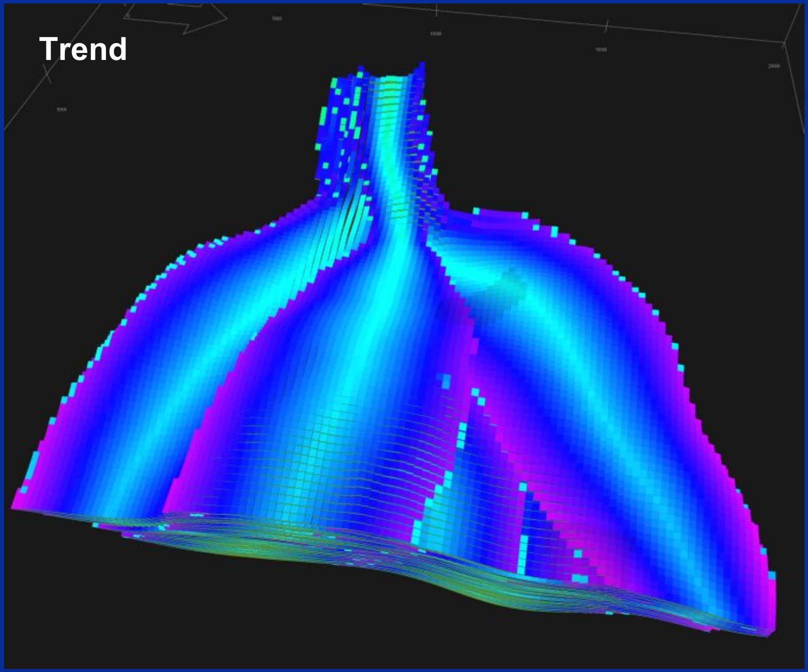
Turbidite number is colour coded. Red is the last.

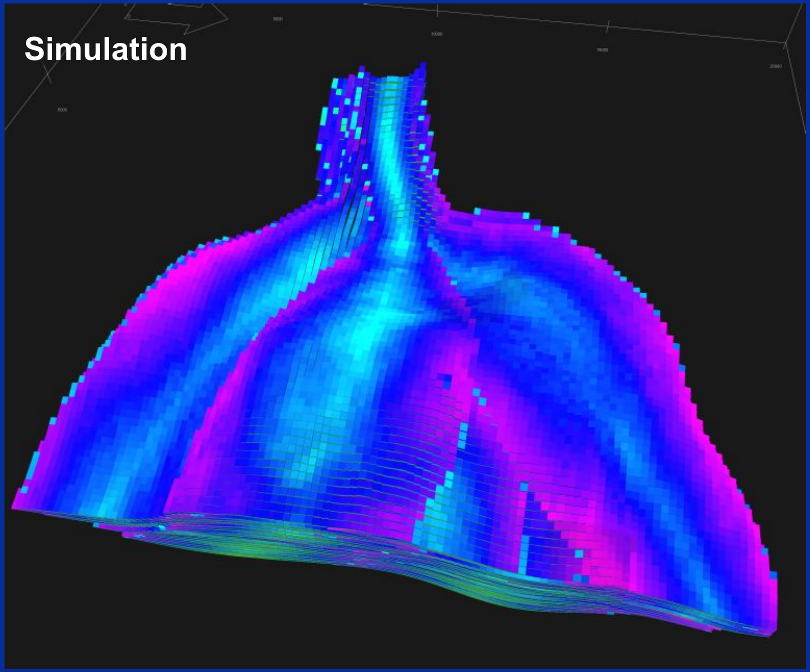
Erosion dominates

Petrophysics

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

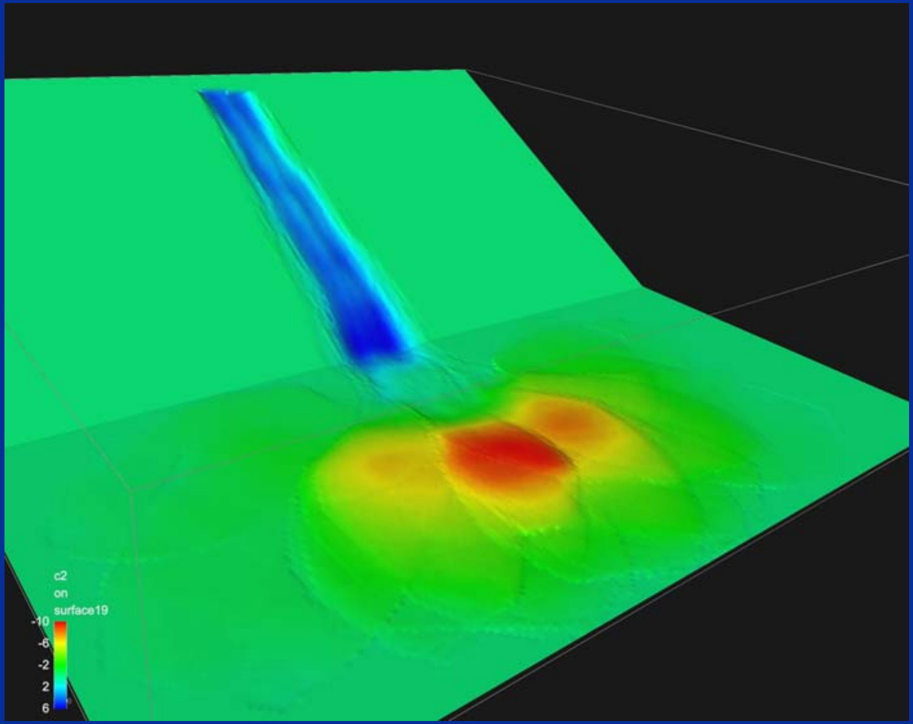


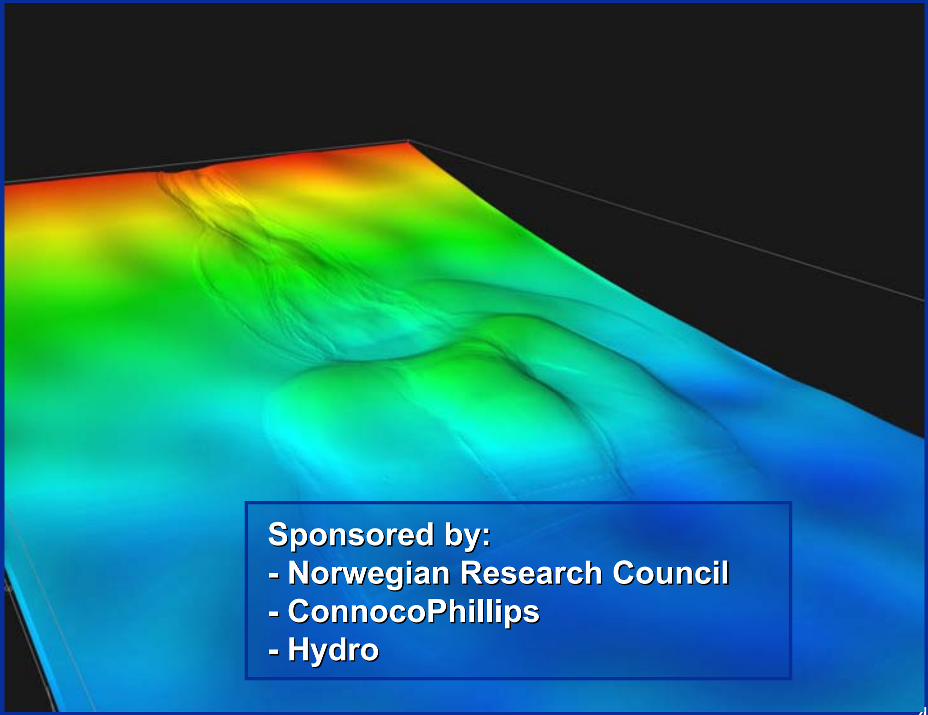




Summary

- 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