Are Relay Ramps Pathways for Turbidity Currents?

A study combining analog sandbox experiments and numerical flow calculations

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(http://www.fault-analysis-group.ucd.ie/gallery/relay.html)

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ISES (Dutch Research Centre for Integrated Solid Earth Science)

vrije Universiteit amsterdam

TU Delft
Delft University of Technology

Outline

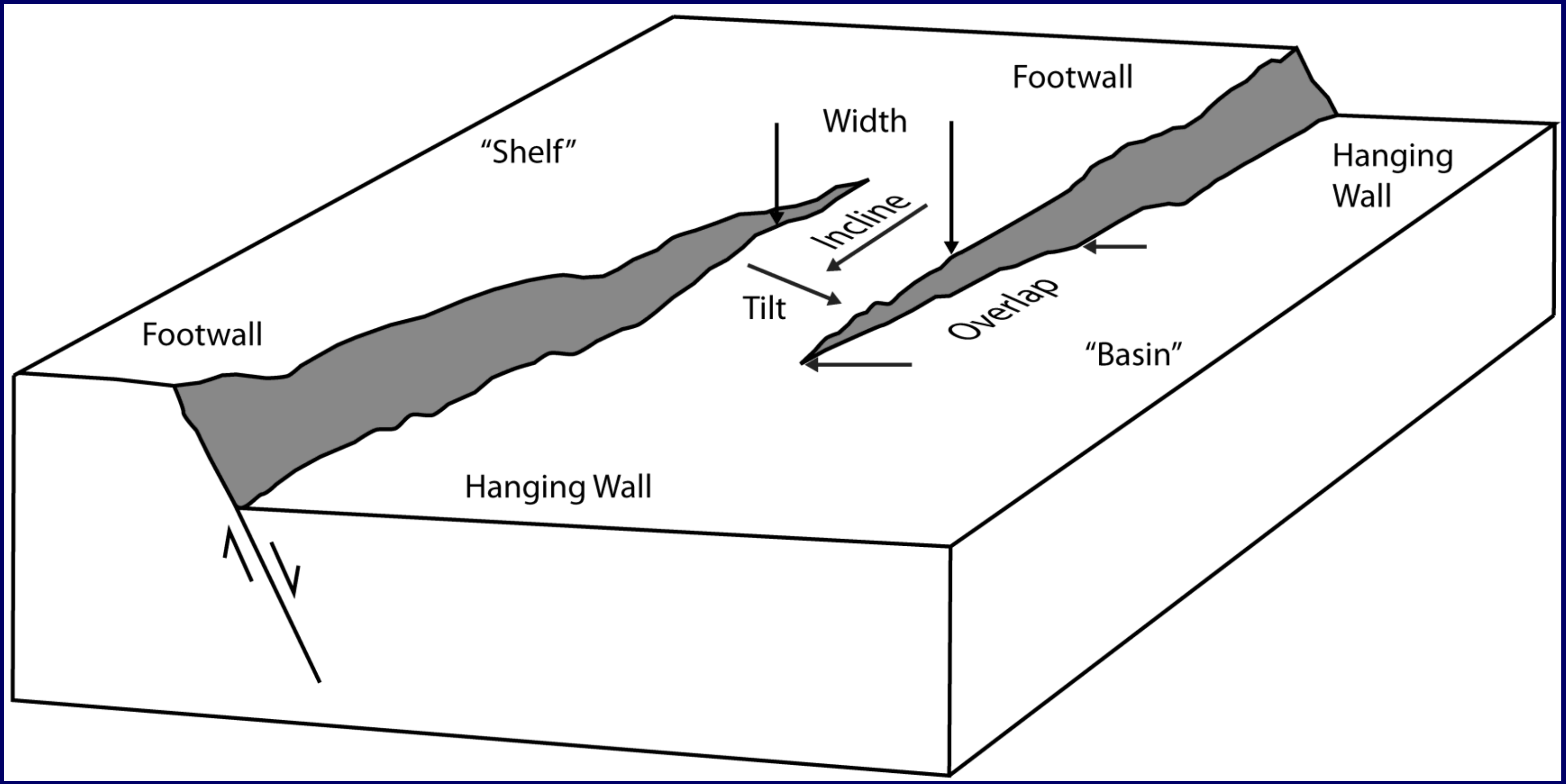
- background
  - relay ramps?
  - role in sediment routing?
- relevance/aim
- approach/method
  - sandbox modeling
  - numerical modeling
- results
- conclusions/wrap-up

Relay Ramps?

- common feature at continental margins, associated with extensional tectonics
- transfer zones consisting of reoriented bedding between two synthetic normal faults that overlap in map view
- develop in normal fault zones through propagation of en-echelon faults
- dimensions of up to tens of kilometers in width, length
- transient features!

Athmer et al., 2008

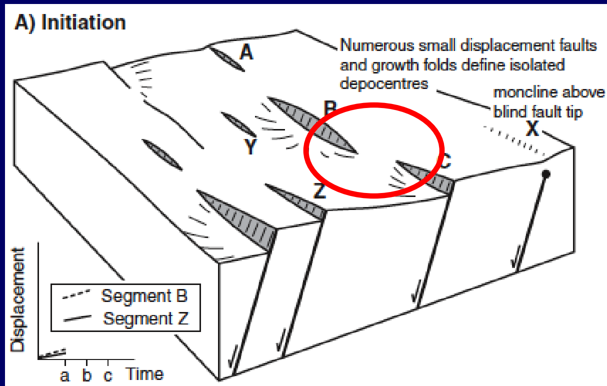
Anatomy of a Relay Ramp



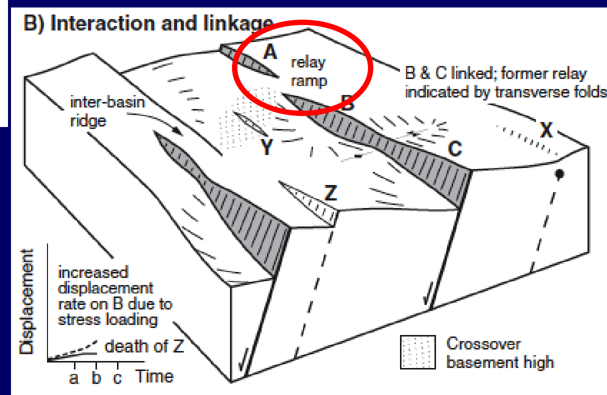
Athmer et al., submitted

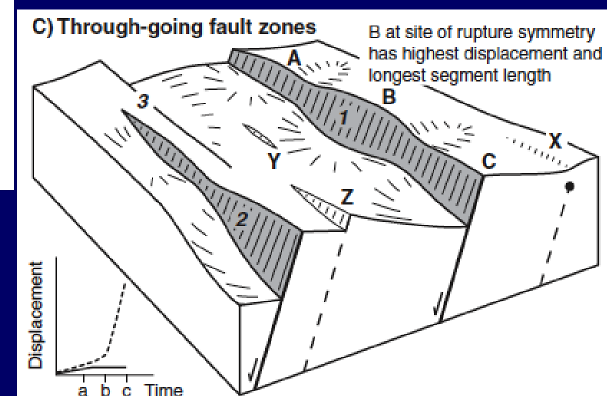
Formation stages

formation: different stages, with different morphology



stages A, B:
relay ramps unfaulted
continuous path upthrown to downthrown block





stage C:
continued extension, overlapping fault link, ramp becomes breached

Gawthorpe and Collela, 2000

Field-Scale Examples

Canyonlands Grabens, Utah

image by Bruce Trudgill:
http://geology.mines.edu/faculty/btrudgil/trudgill25.jpg

Arches NP, Utah

image by Michael Strugale: http://www.flickr.com/photos/strugale/2933812701

Role in Sediment Routing

large-scale relay-ramps:

- influence transport of sediments towards basins
- large-scale: several kilometers width, 10s of kilometers length

- documented examples **from subaerial settings**

  - East African Rift (Soreghan et al., 1999)

  - Suez Rift (Gupta et al., 1999; Young et al., 2002)

  - Gulf of Corinth, Greece (Gawthorpe and Hurst, 1993)

(http://www.fault-analysis-group.ucd.ie/gallery/relay.html)

Submarine Setting?...

relay-ramps in **submarine setting** (lakes, oceans):

- role in sediment routing less clear
- no convincing evidence yet published

- current status: **speculative**

  - "RRs may act as conduits for river-sourced submarine gravity flows in the Danish North Sea" (Bruhn and Vagle, 2005)
  - "flow constraining by channelization and tilting of RRs might help direct flows down the ramp" (Soreghan et al., 1999)

Relevance/Aim

deep-marine turbidite systems:

major exploration targets on many passive continental margins (e.g. offshore Norway, West Africa, Brazil)

role of RRs in sediment routing of great relevance to predict location of reservoirs

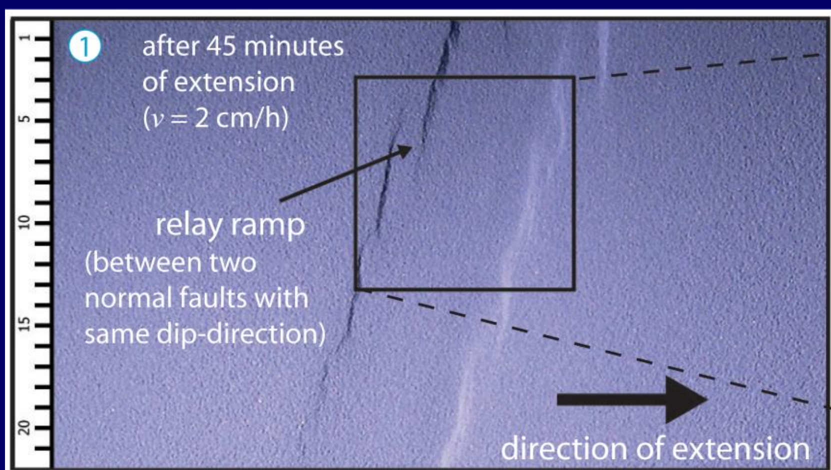
AIM: investigate the influence of relay ramps on

1. pathways of turbidity currents from shelf to basin
2. distribution of deep-marine sediments in/around rifted-basin margins

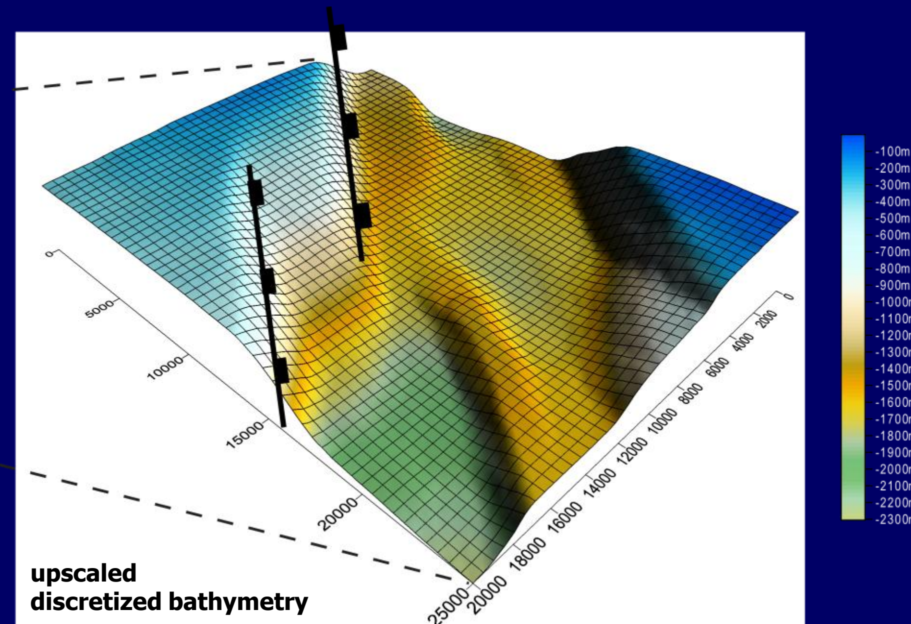
Approach

combination of **A**nalog and **N**umerical modeling:

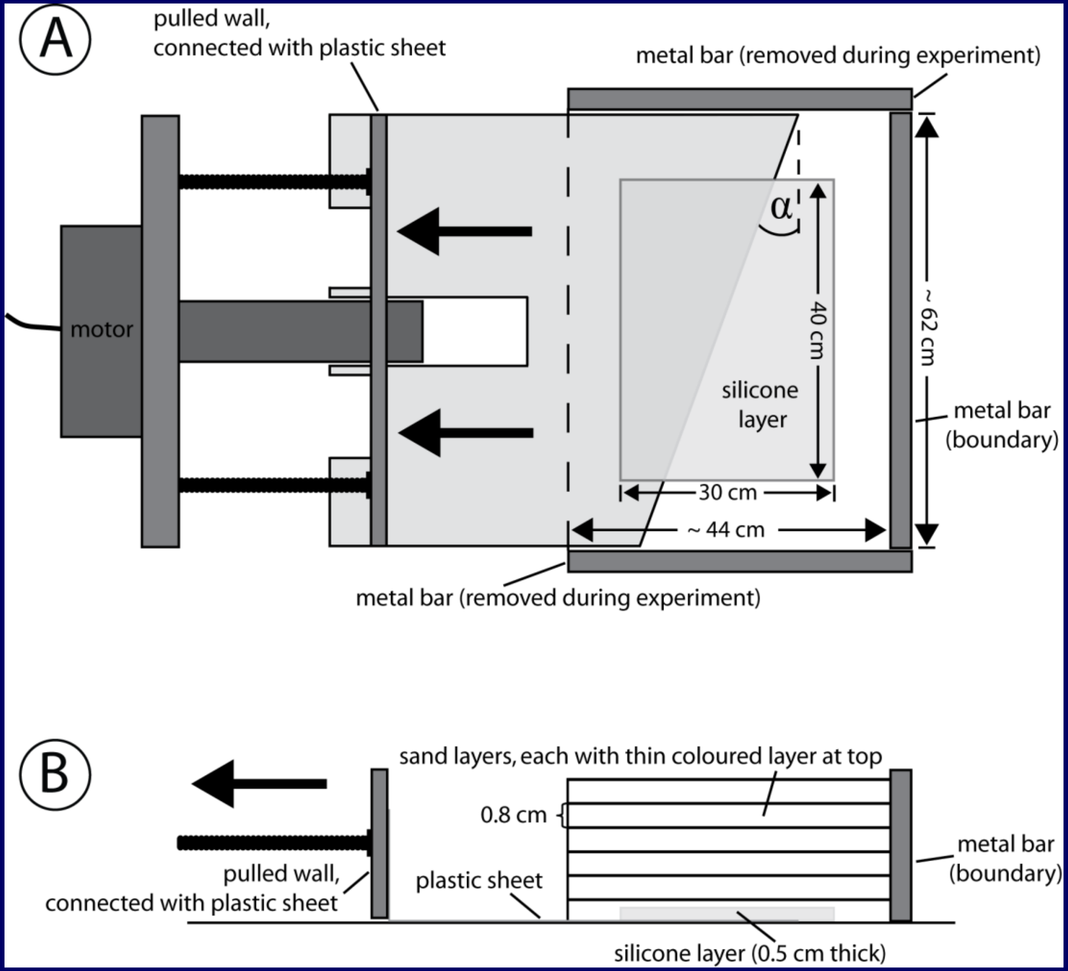
A. sandbox modeling : realistic rift basin bathymetries (incl. RR)
N. process-based model : turbidity-current flow & sedimentation

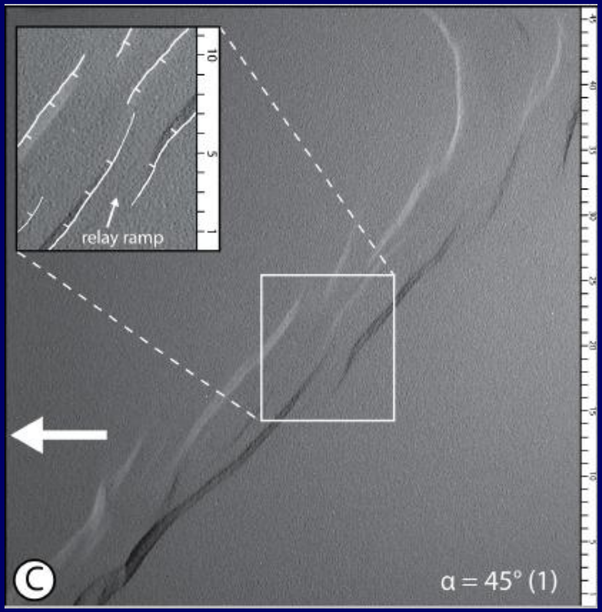


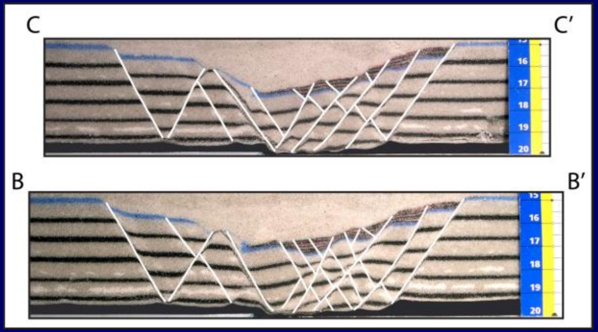
analog model (Athmer et al., 2008)



Sandbox Modeling







Athmer et al., submitted

Numerical Model

FanBuilder : simulates evolution of fan stratigraphy in 3D
: each flow & sedimentation modeled separately

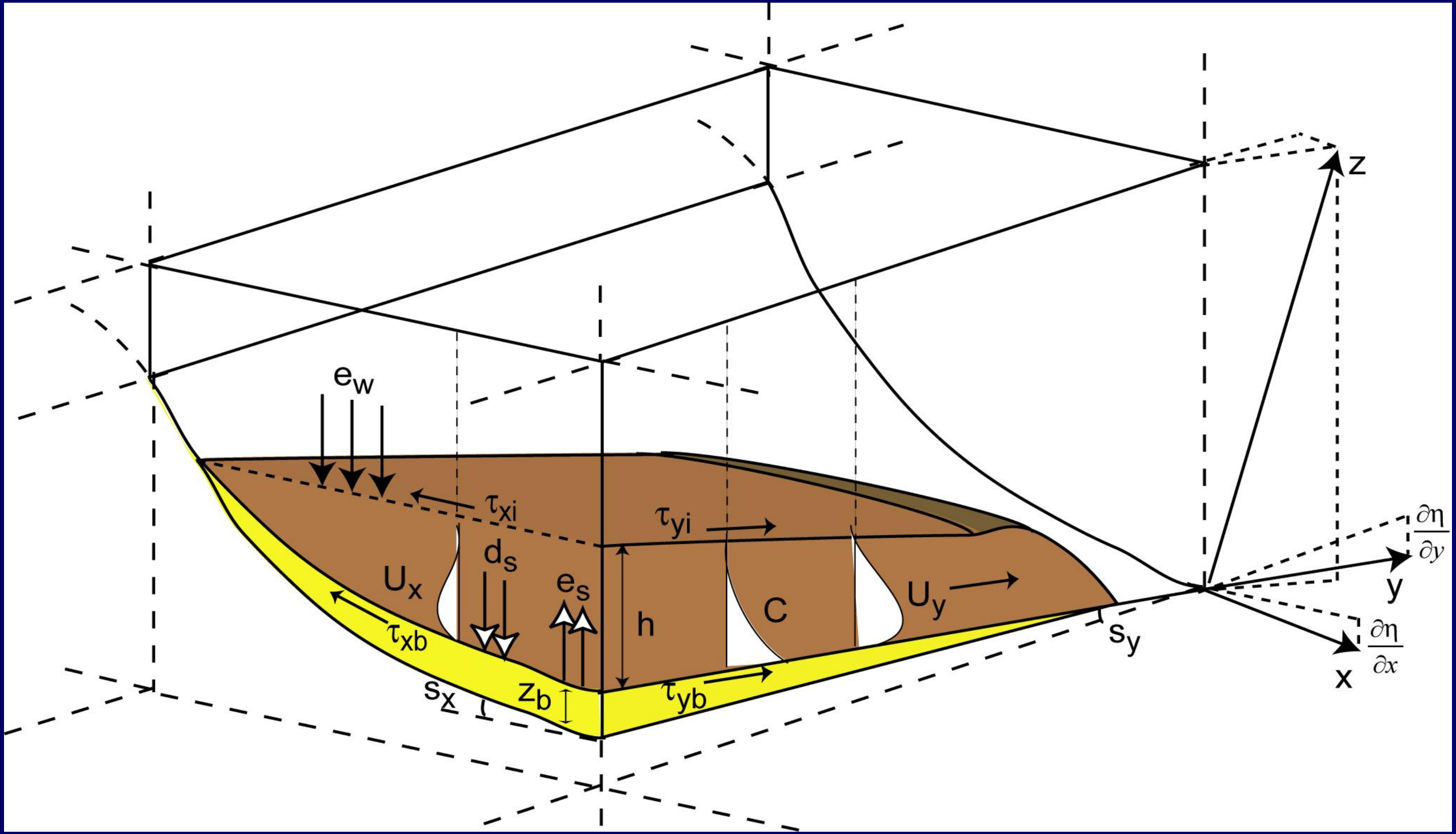
classification : **process-based** (2-DH model Parker and co-workers)
: hydrodynamics, sediment transport
: erosion, deposition, water entrainment

input : flow velocity, concentration & height, sediment volume, recurrence interval, **bathymetry**

output : **thickness**, **grain size**
: geometry of deposits (shape, size)
: erosive contacts

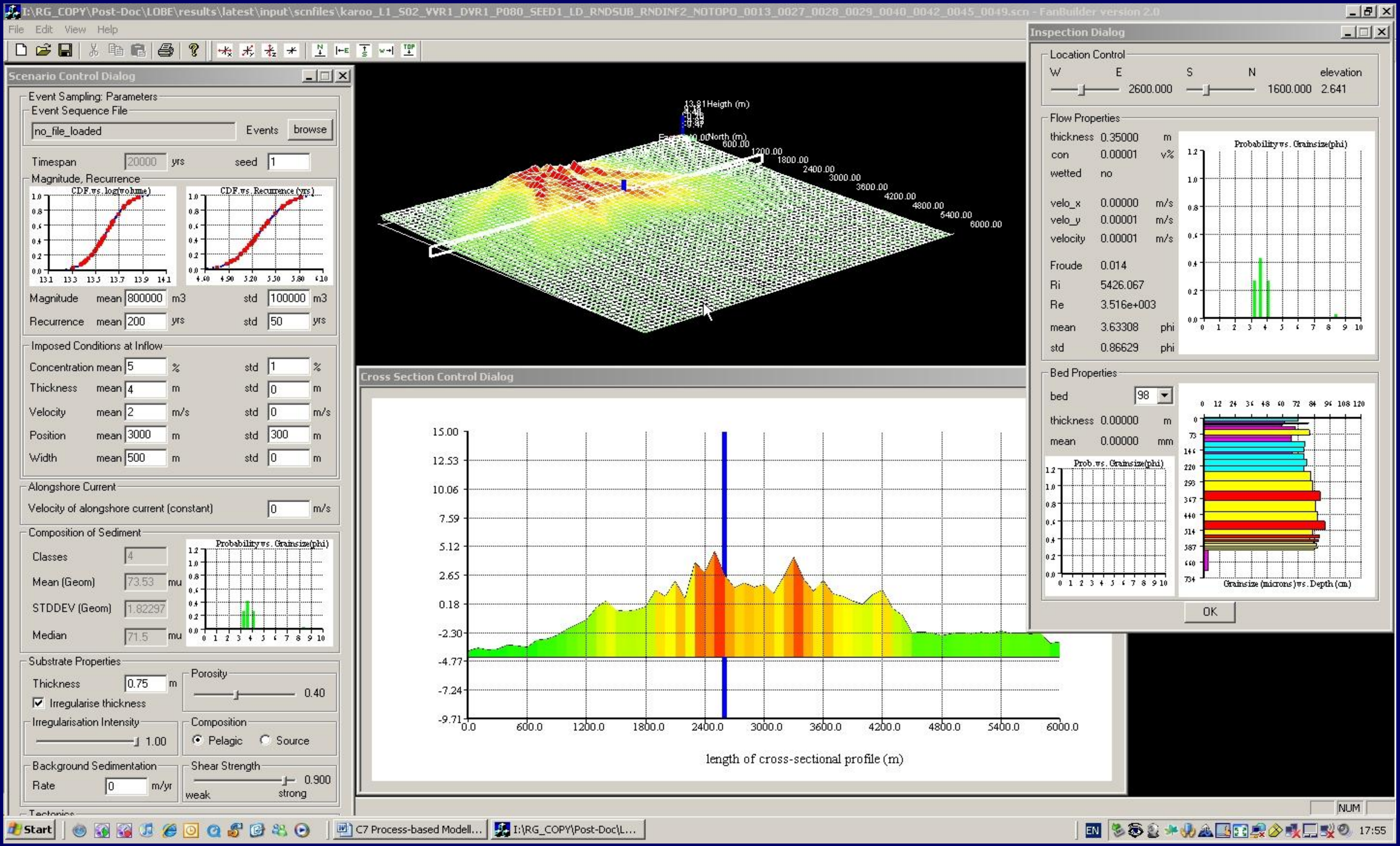
validation : laboratory data (Groenenberg et al., 2007, 2009)

Configuration sketch



Groenenberg, 2007

FanBuilder



File Edit View Help
Scenario Control Dialog
Event Sampling: Parameters
Event Sequence File
no_file_loaded
Events browse
Timespan 20000 yrs
seed 1
Magnitude, Recurrence
CDF vs. log(volume)
CDF vs. Recurrence (yrs)
Magnitude mean 800000 m3 std 100000 m3
Recurrence mean 200 yrs std 50 yrs
Imposed Conditions at Inflow
Concentration mean 5 % std 1 %
Thickness mean 4 m std 0 m
Velocity mean 2 m/s std 0 m/s
Position mean 3000 m std 300 m
Width mean 500 m std 0 m
Alongshore Current
Velocity of alongshore current (constant) 0 m/s
Composition of Sediment
Classes 4
Mean (Geom) 73.53 mu
STDDEV (Geom) 1.82297
Median 71.5 mu
Probability vs. Grainsize(phi)
Substrate Properties
Thickness 0.75 m
Porosity 0.40
Irregularise thickness
Irregularisation Intensity 1.00
Composition
Pelagic Source
Background Sedimentation
Rate 0 m/yr
Shear Strength 0.900
weak strong
Tectonics
Heigth (m)
North (m)
Cross Section Control Dialog
length of cross-sectional profile (m)
Inspection Dialog
Location Control
W E S N elevation
2600.000 1600.000 2.641
Flow Properties
thickness 0.35000 m
con 0.00001 v%
wetted no
velo_x 0.00000 m/s
velo_y 0.00001 m/s
velocity 0.00001 m/s
Froude 0.014
Ri 5426.067
Re 3.516e+003
mean 3.63308 phi
std 0.86629 phi
Probability vs. Grainsize(phi)
Bed Properties
bed 98
thickness 0.00000 m
mean 0.00000 mm
Prob. vs. Grainsize(phi)
Grainsize (microns) vs. Depth (cm)
OK
Start
C7 Process-based Modell...
NUM
17:55

Numerical Experiments

variables: - ramp geometry
- inflow angle
- on-ramp confinement

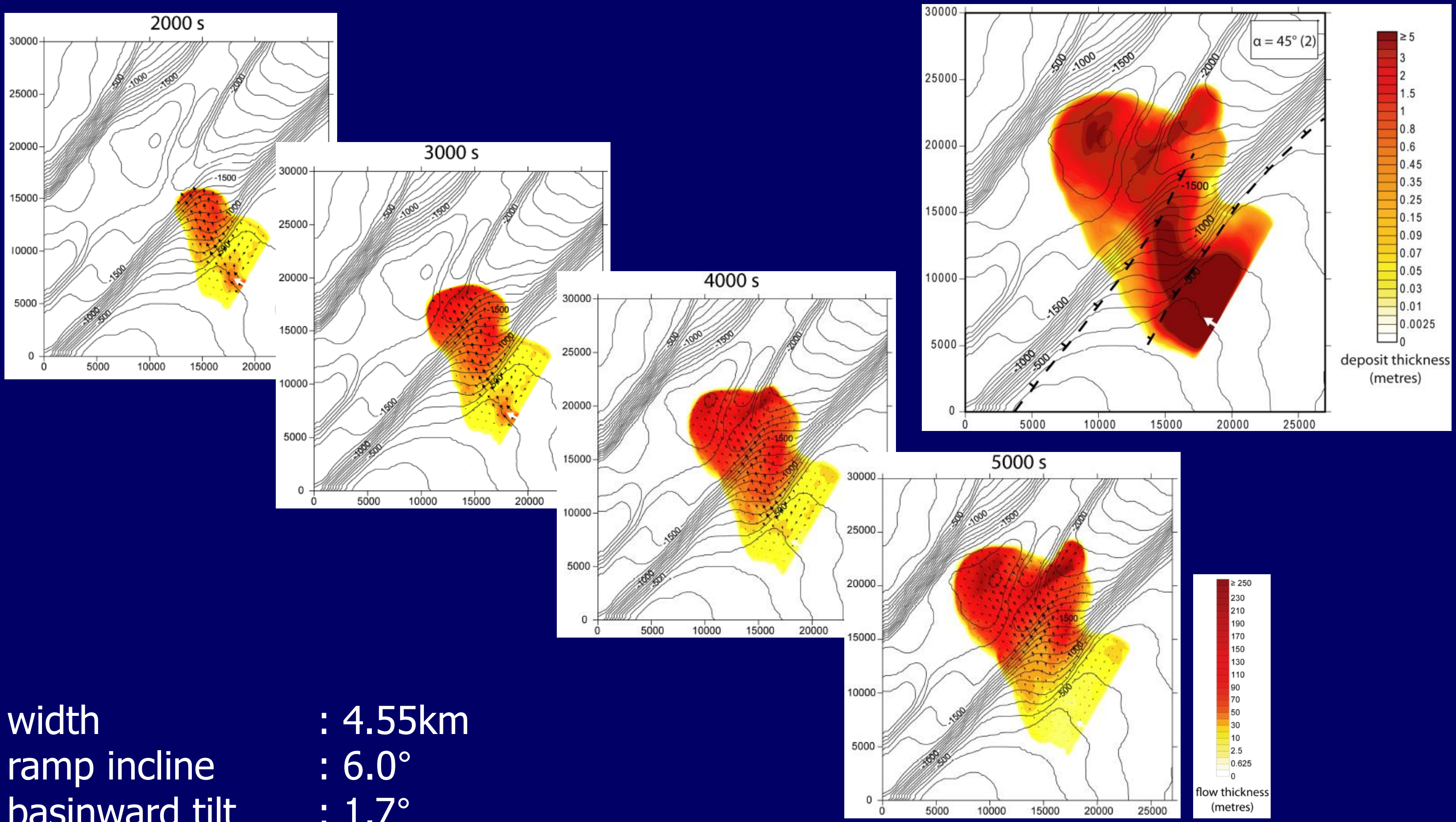
Experiment (Figure 3)	Obliquity α (°)	Relay ramp geometry			
		Overlap (cm)	Width (cm)	Incline (°)	Tilt (°)
A	20	3.95	1.33	2.9	2.6
B	30	2.05	0.71	5.2	4.4
C	45 (1)	4.52	1.67	3.5	1.4
D	45 (2)	5.47	1.82	6.0	1.7
D (modified)	45 (3)	5.47	1.82	5.1	-1.5

ramp geometry : width, incline, tilt
inflow angle : angle of incidence between streamwise flow direction at entrance and ramp incline
confinement : no confinement vs. channel-like

flow properties : defined at entrance

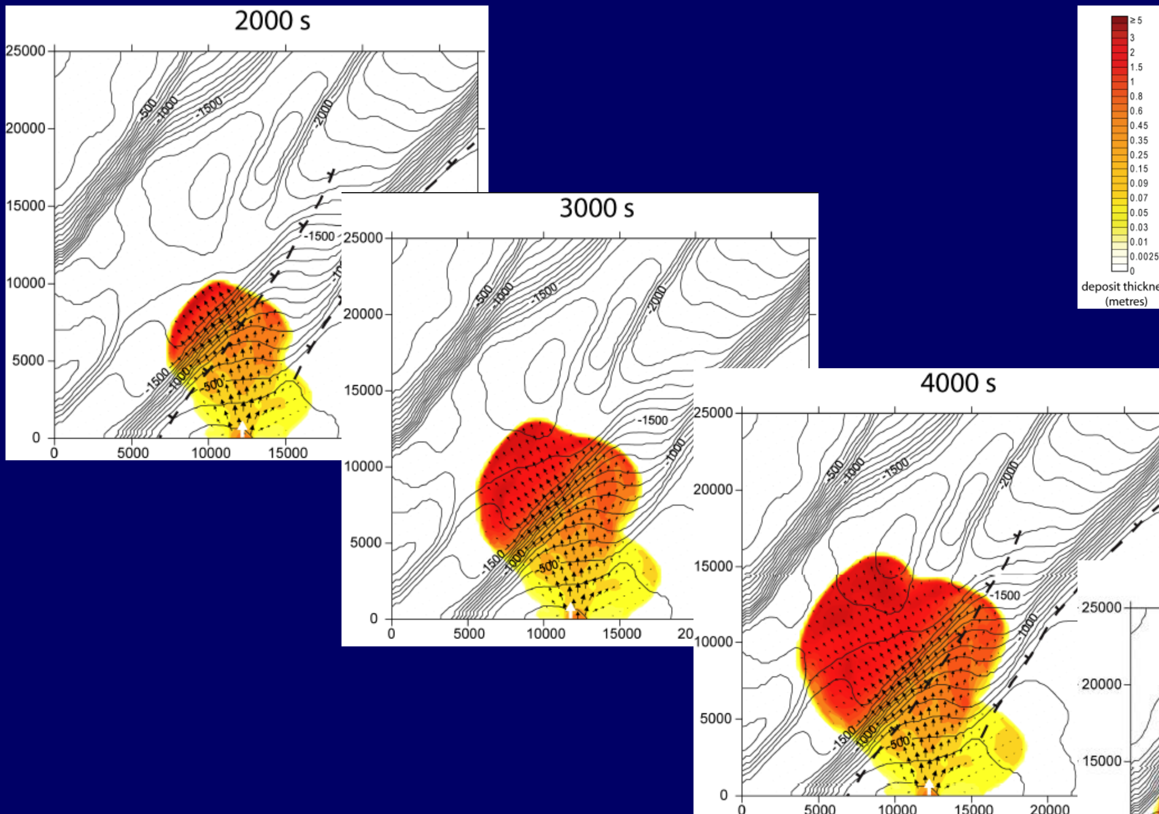
flow depth : 40m
velocity : 5 ms^{-1}
density : 1092 kgm^{-3} (4%)
grain size : 125 μm (fs)

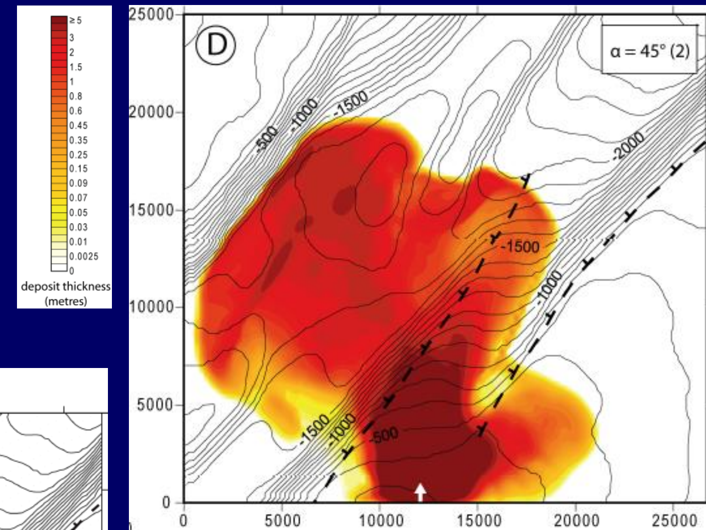
Results: Perpendicular Inflow

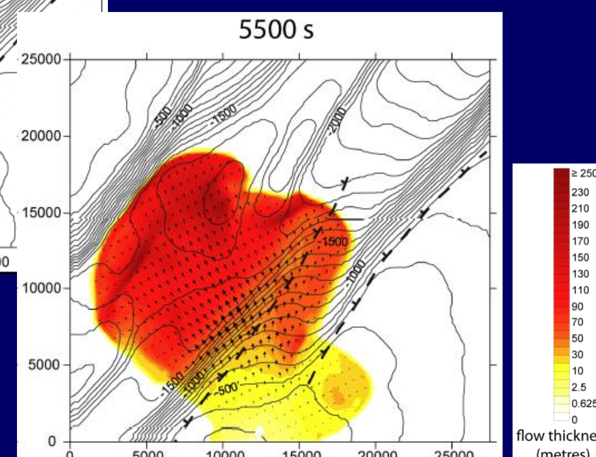


width : 4.55km
ramp incline : 6.0°
basinward tilt : 1.7°

Results Oblique Inflow (1)

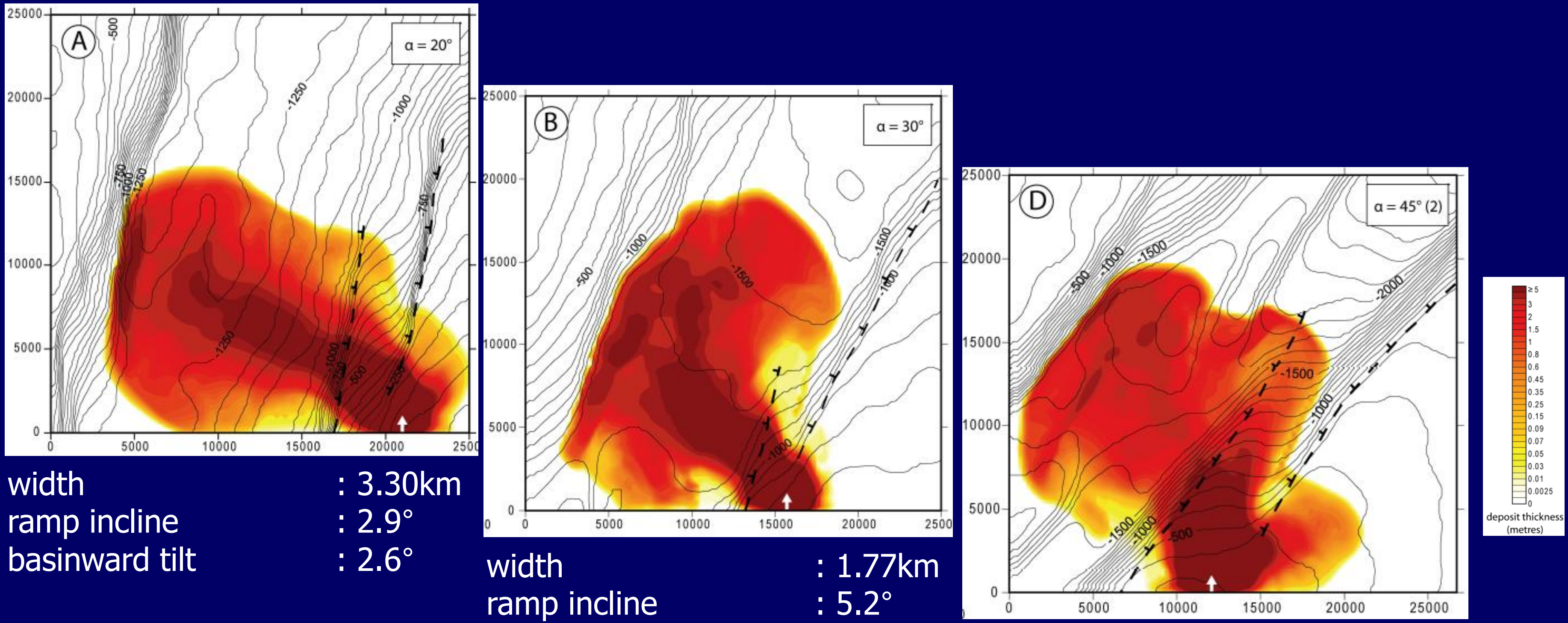






width : 4.55km
ramp incline : 6.0°
basinward tilt : 1.7°

Results: Ramp Geometry



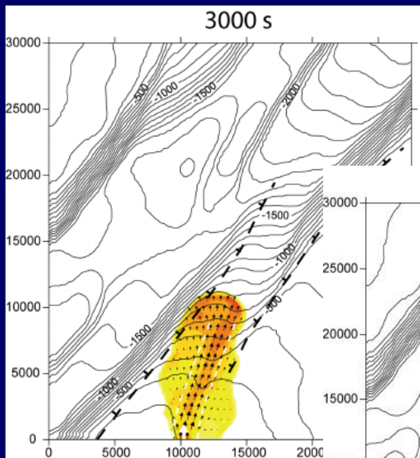
width	: 3.30km
ramp incline	: 2.9°
basinward tilt	: 2.6°

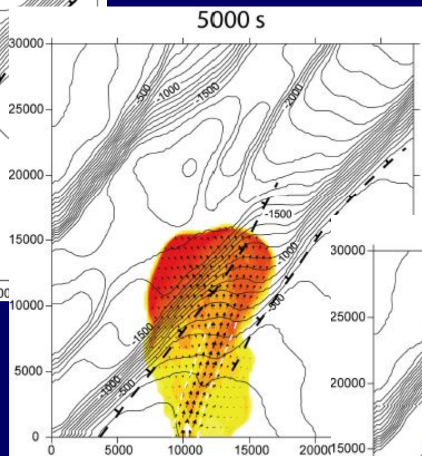
width	: 1.77km
ramp incline	: 5.2°
basinward tilt	: 4.4°

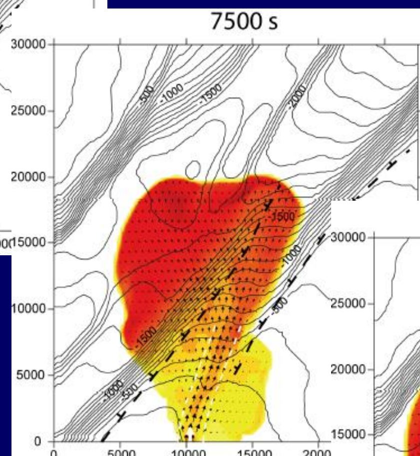
width	: 4.55km
ramp incline	: 6.0°
basinward tilt	: 1.7°

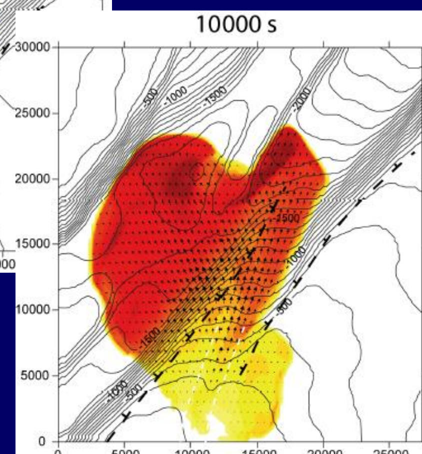
*larger width, incline, smaller tilt "facilitate" down-ramp flow

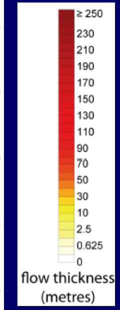
Results: Oblique Inflow & Confinement

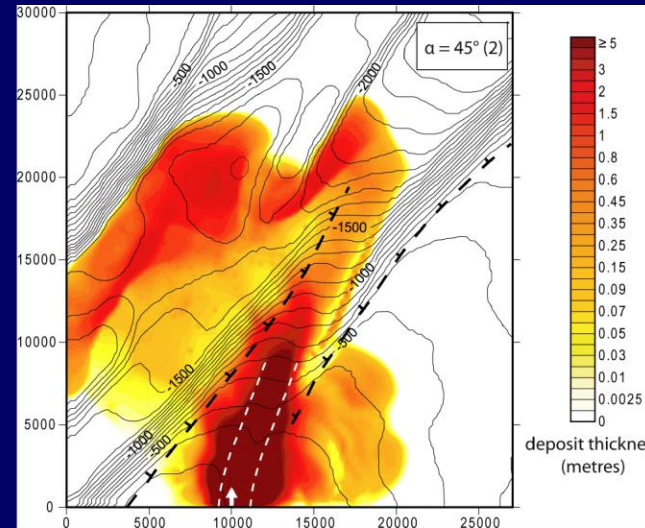






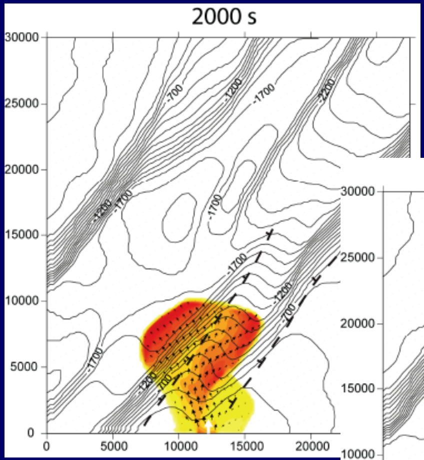


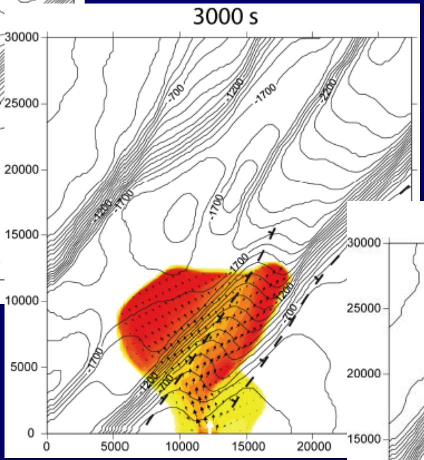


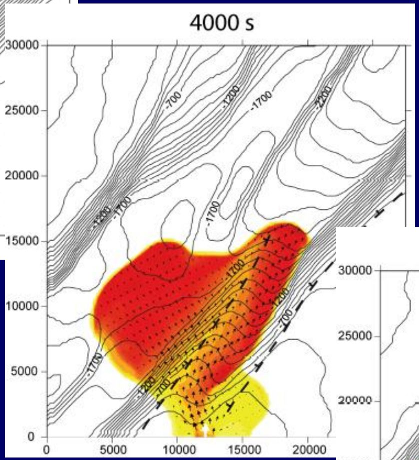


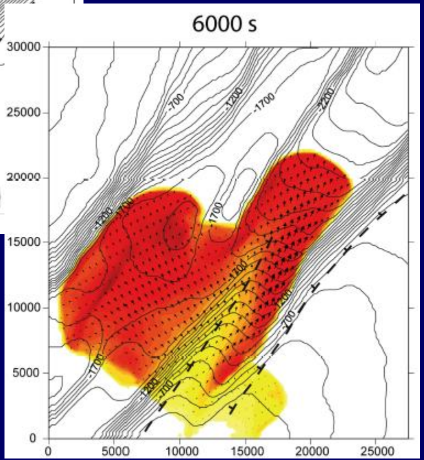
width : 4.55km
ramp incline : 6.0°
basinward tilt : 1.7°
channel depth : 45m, decreasing monotonically

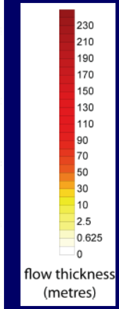
Results: Oblique Inflow & Landward-Tilt

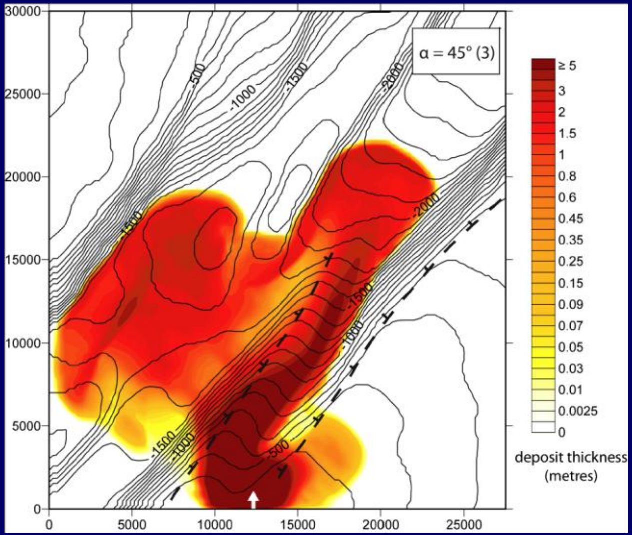








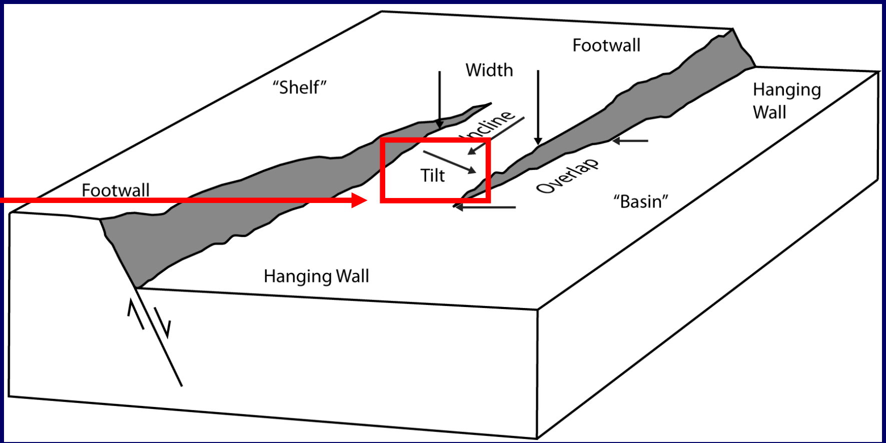




width : 4.55km
ramp incline : 5.2°
basinward tilt : -1.5°

*** modified: experimentally obtained relay ramps all slightly tilted basinward**.

Conclusions



Athmer et al., submitted

most influential factor : **ramp tilt**

observations:

- massive spill-over down the fault directly into basin for all **basinward-tilted** ramp experiments
  *basinward tilt common feature of all but largest-scale RRs

- on-ramp confinement results in funneling down the ramp

- flow has great difficulty in turning in the direction of ramp incline reacts "sluggish" to gradient change in upper reaches of ramp

Wrap-up

other important considerations:

- location of sediment source (shelf edge, delta) morphology of RR such that their incline is perpendicular to shelf-edge
- RRs transient features, open-stage morphology is transient, requires that timing of sediment supply is synchronous with open-stage phase

Are relay ramps pathways for turbidity currents?

Answer: Questionable...