Geological Modeling: Modeling Long-term Basin Fills

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Course outline 1

- Lectures by Irina Overeem:
  - Introduction and overview
  - Deterministic and geometric models
  - Sedimentary process models I
  - Sedimentary process models II
  - Uncertainty in modeling
- Lecture by Overeem & Teyukhina:
  - Synthetic migrated data

Motivation

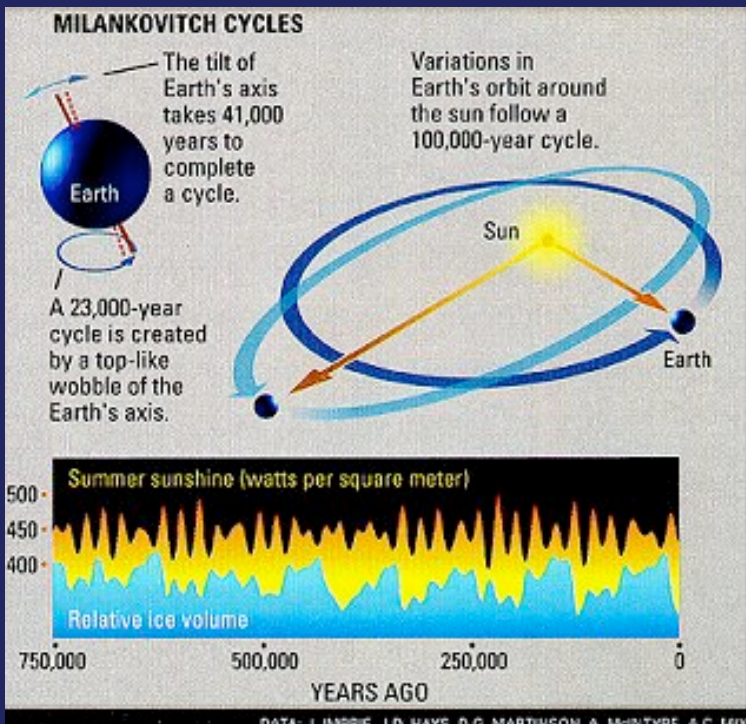
- Prediction of source rocks, reservoir, seals and traps requires an understanding of large-scale structural and stratigraphic evolution of the depositional sequences within a basin (i.e. in the exploration phase).
- Stratigraphic evolution determines the large-scale geometry of the depositional sequence, as well as the smaller-scale sedimentary facies and thus the potential reservoir properties.

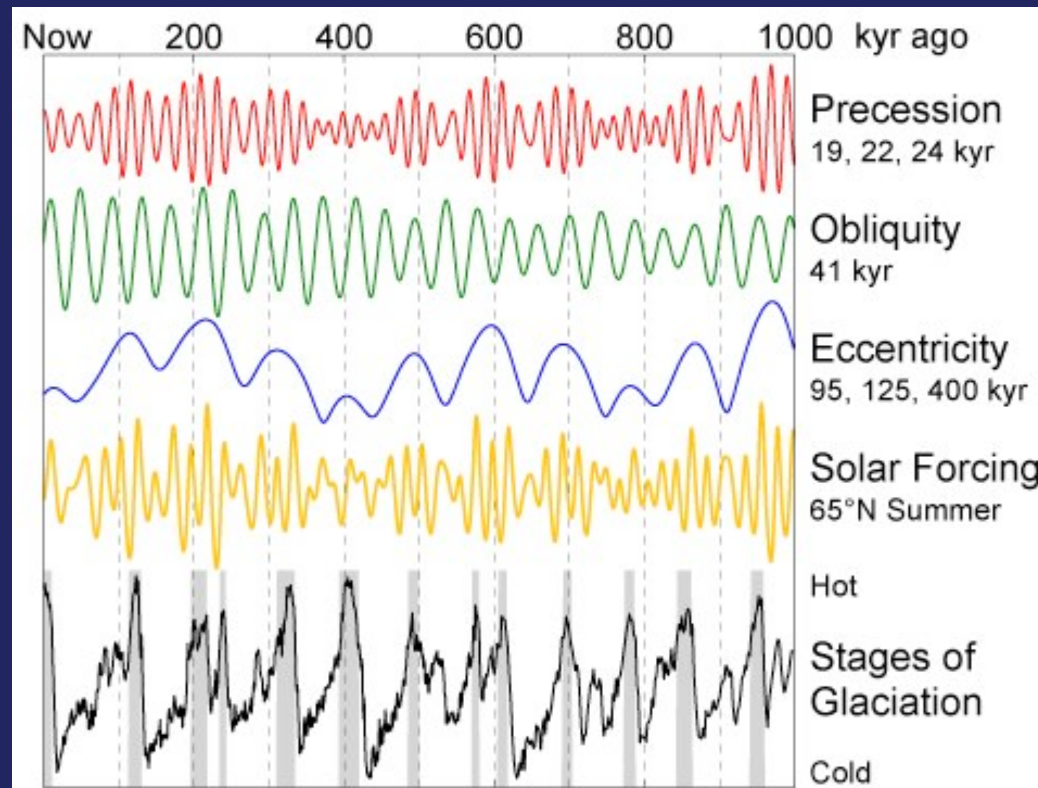
The interplay of sediment supply, sea level and subsidence

- A/S ratio (Jervey, 1988)

- A = accommodation = the space made available for potential sediment accumulation by tectonics and sea level change.
- S = supply = amount of sediment being delivered to a basin.

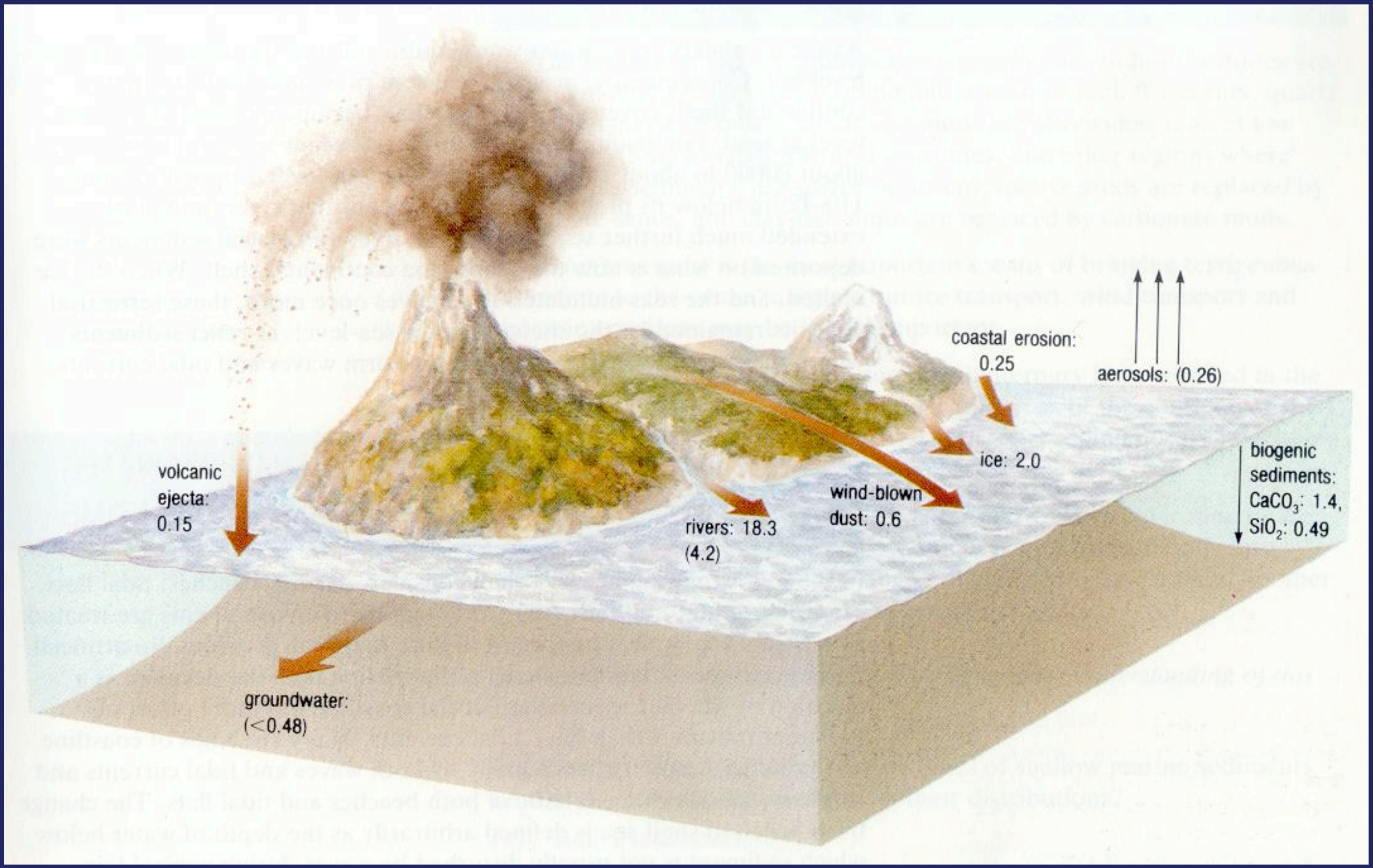
Sea level and Climate





Milankovitch cycles drive glaciations and consequently sea level fluctuations

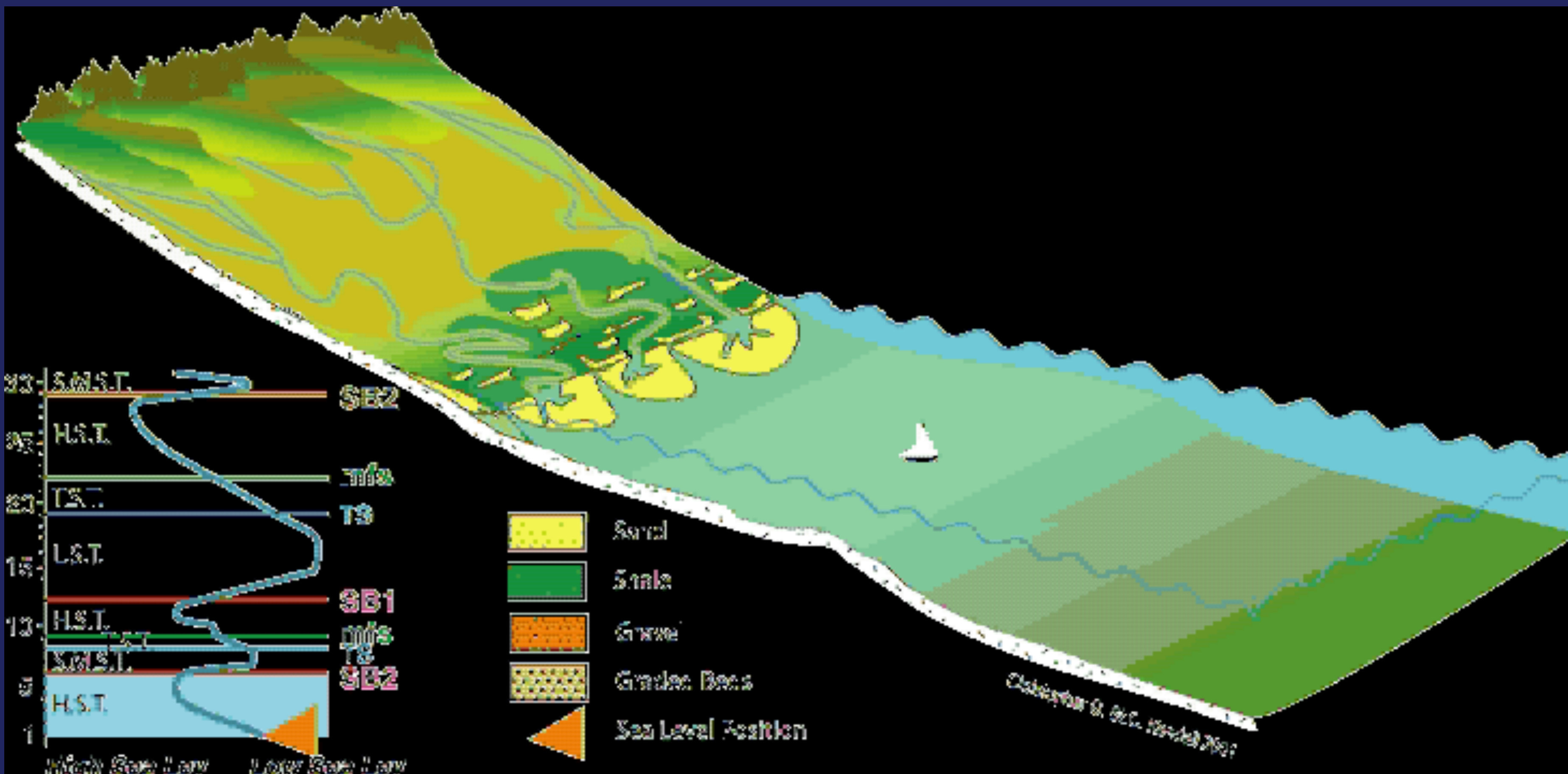
Sediment Supply



Which process would one need to capture to get first-order estimate of sediment supply?

The sedimentary material is derived from rivers (77%), wind-blown dust (2%), coastal erosion (1%), ice (9%), vulcanic ejecta (<1%) and biogenics (8%), aerosols and groundwater (Open University, 1989).

Conceptual longterm basin fill



Courtesy Christopher Kendall, University of South Carolina, USA

Numerical Modeling of long-term basin fills
A simple case: sediment supply into a stable basin

- Sediment supply (constant, 4 grainsize classes)
- Process: River channel switching
- Process: Delta Plume deposition

- Model Example: SedFlux-3D

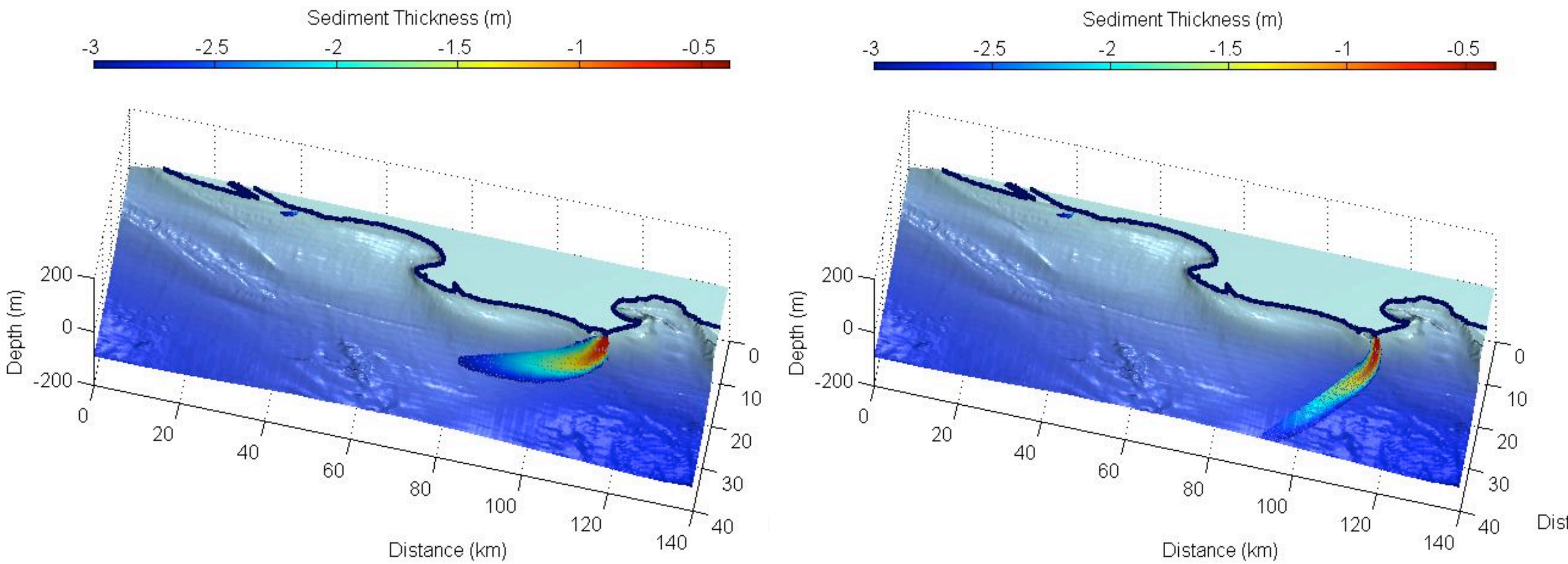
Hypopycnal Plume

- **Steady 2D advection-diffusion equation:**

$$\frac{\partial uI}{\partial x}+\frac{\partial vI}{\partial y}+\lambda I=\frac{\partial}{\partial y}\left(K\frac{\partial I}{\partial y}\right)+\frac{\partial}{\partial x}\left(K\frac{\partial I}{\partial x}\right)$$

where: **x, y are coordinate directions**
u, v are velocities
K is turbulent sediment diffusivity
I is sediment inventory
λ is the first-order removal rate constant

Plume examples

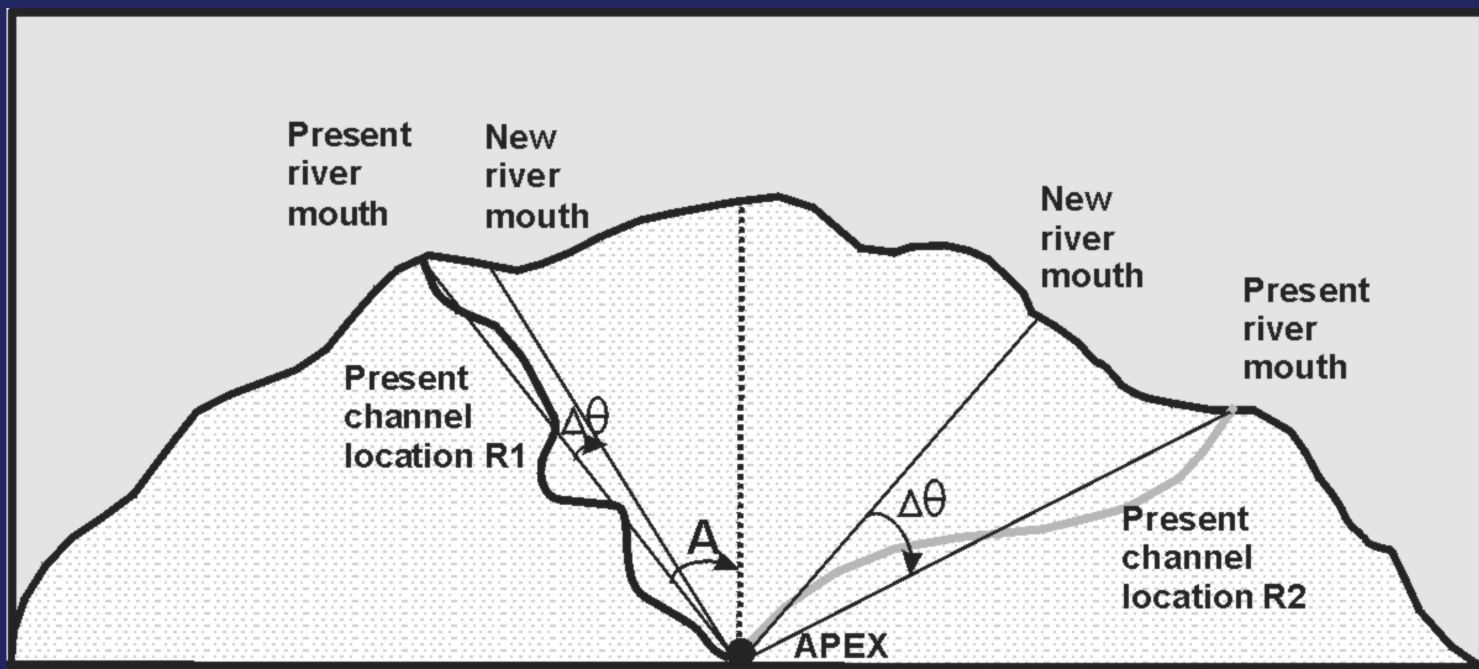


River Mouth Angle = 15 º

River Mouth Angle = 45 º

Data courtesy, Kettner and Hutton, CSDMS

Stochastic avulsion mechanism



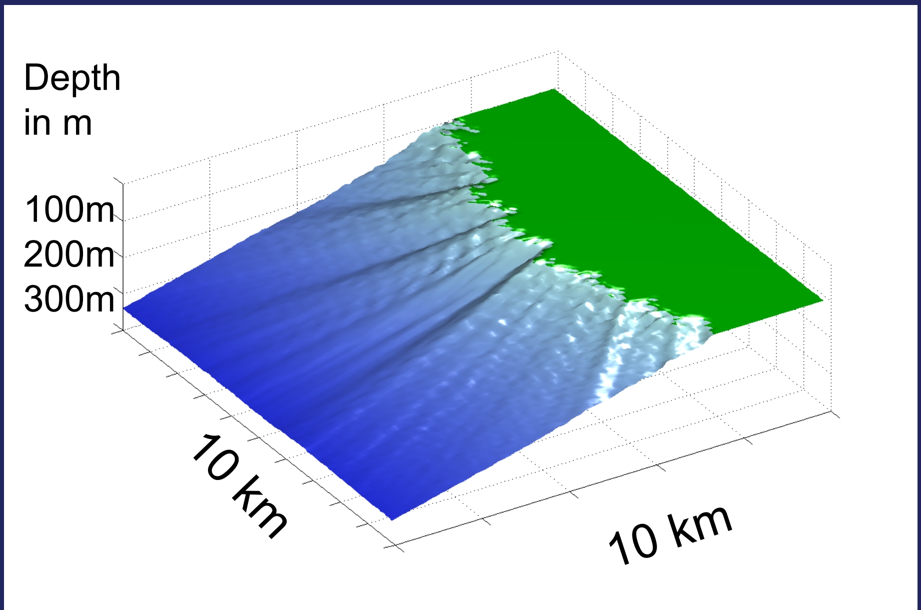
$$A_{t+\Delta t} = A_t + \Delta\theta \qquad \Delta\theta = \mu X$$

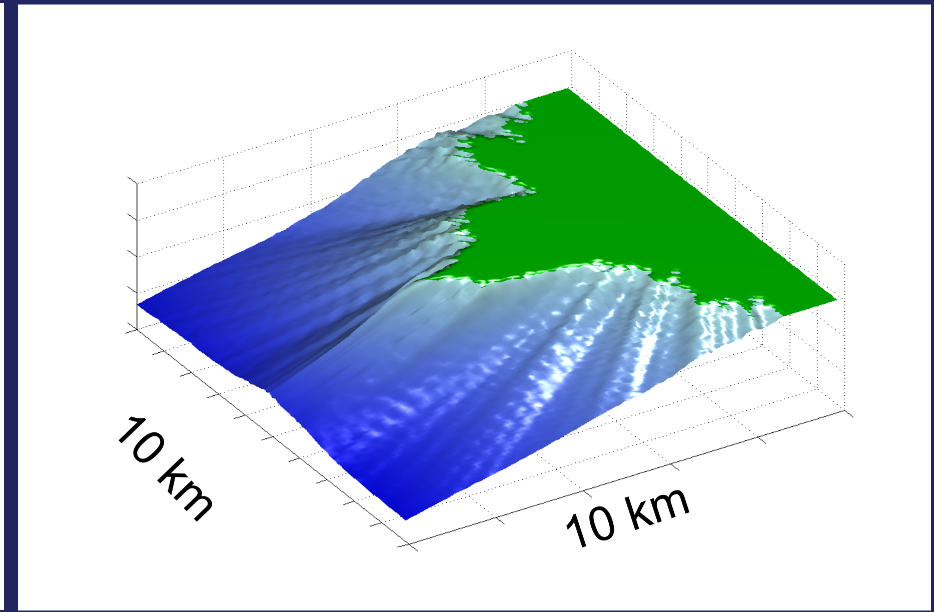
At specific time steps, *t + Δt*, the river mouth angle, *A*, changes by an amount drawn from a Gaussian distribution. The rate of switching is controlled by changing the scaling factor, *μ* of the Gaussian deviate, *X*.

Avulsions of main delta lobe

The scaling factor μ = 0.3

The scaling factor μ = 0.03

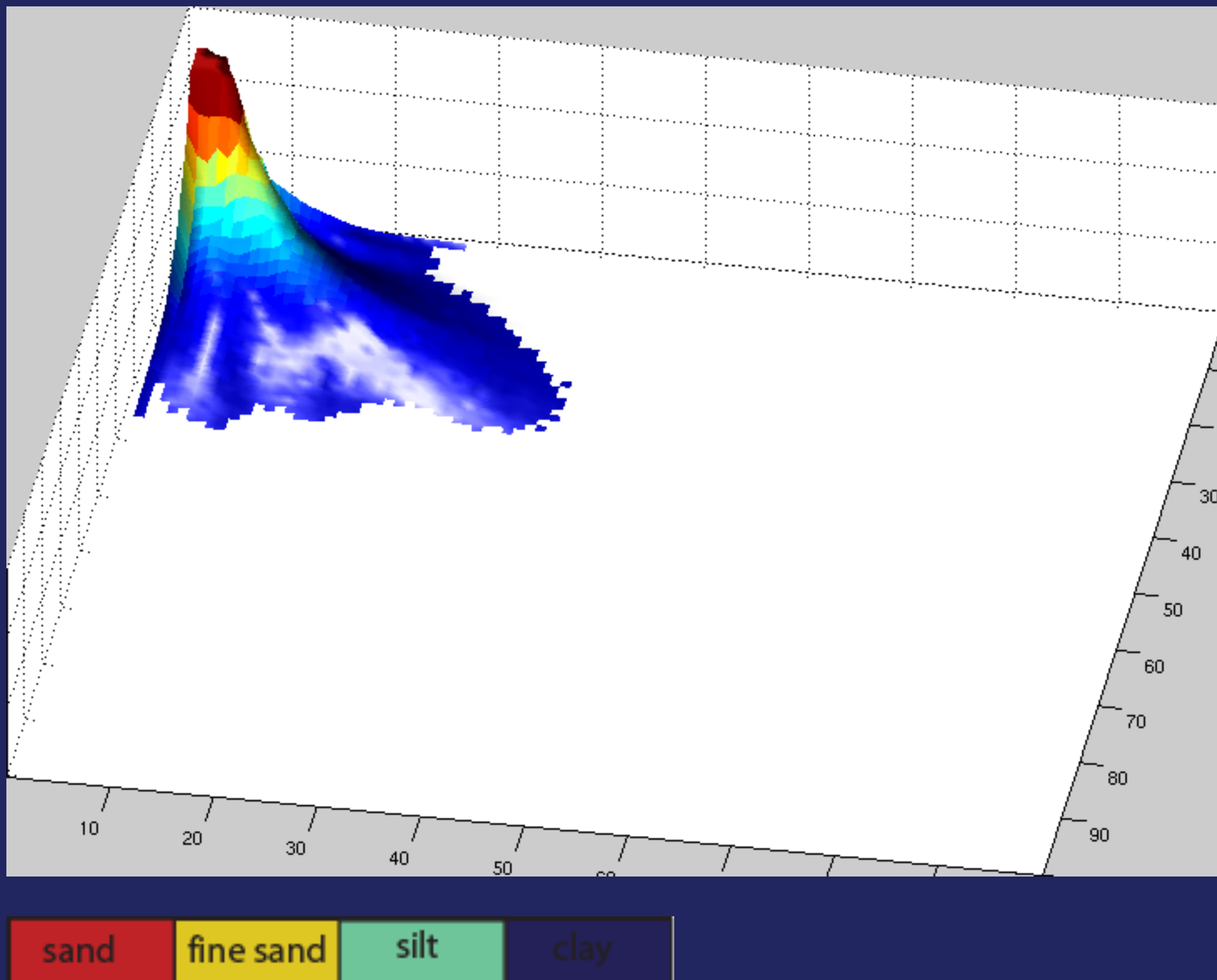




High avulsion frequency results in uniform progradation

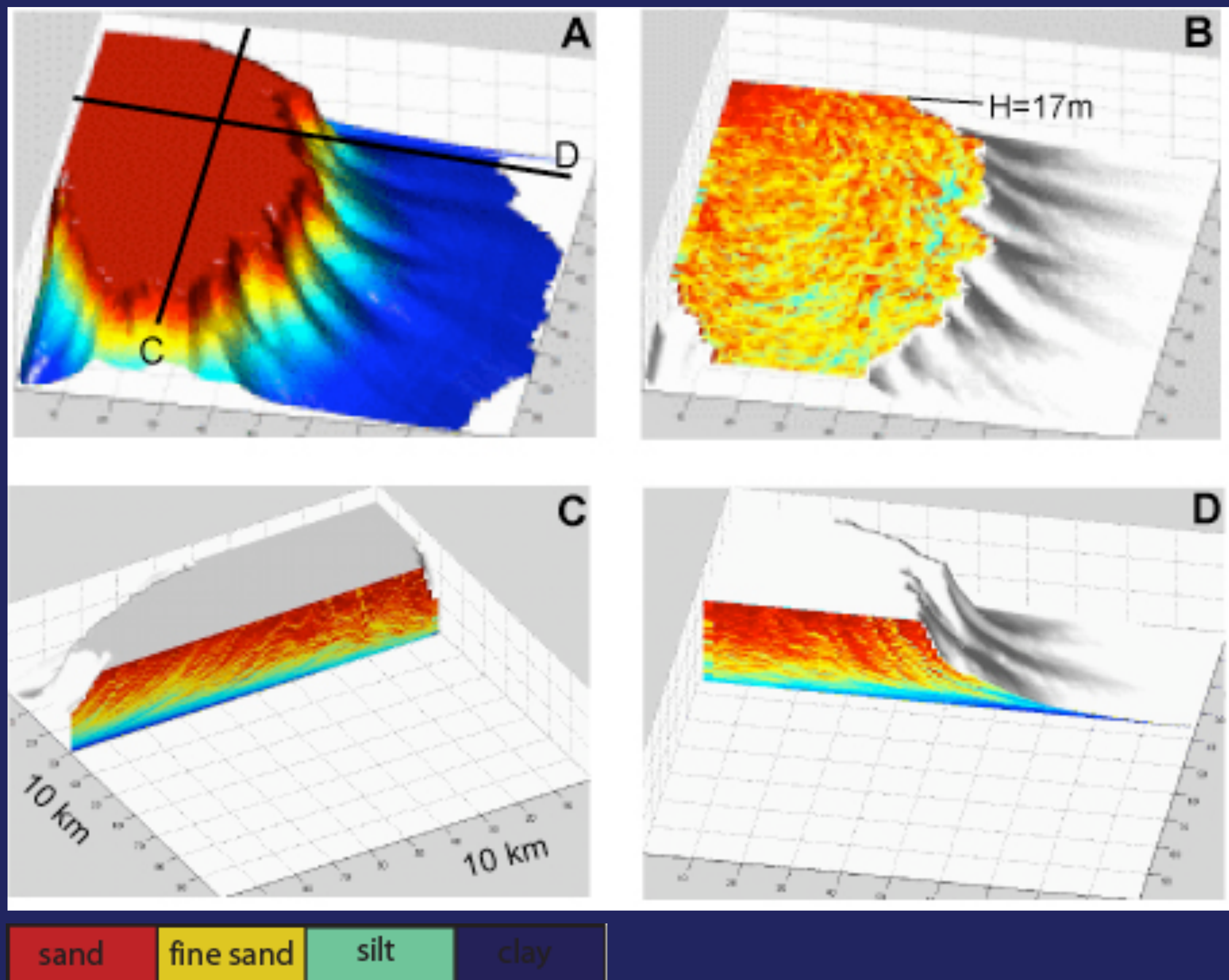
Low avulsion frequency results in distinct lobe formation and locally enhanced progradation

The simple case: sediment supply into a stable basin

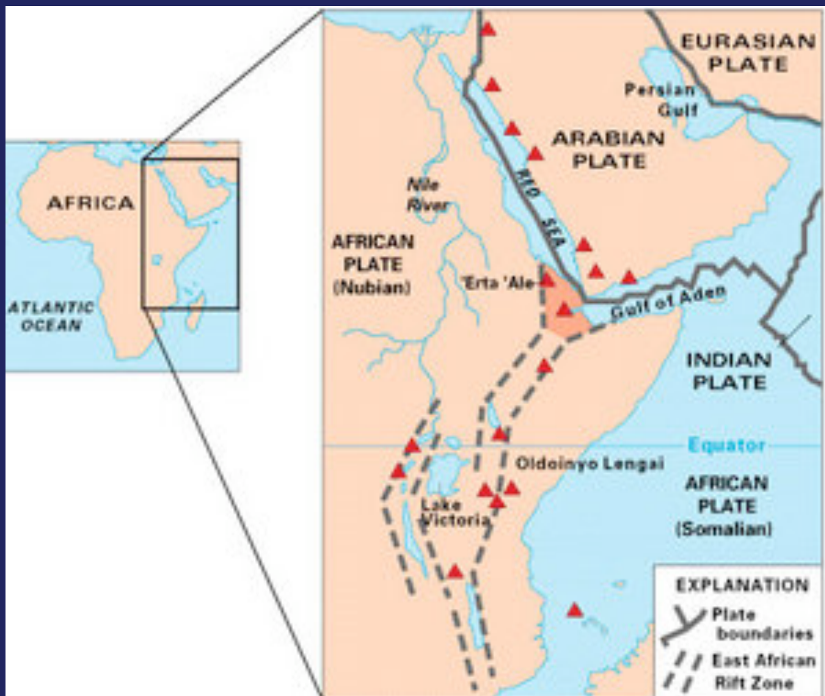


10 by 10 km basin, 40m water depth, single river, time-continuous supply

Visualize horizon slices, strike and dip sections



SedFlux-3D experiment of a Rift Basin



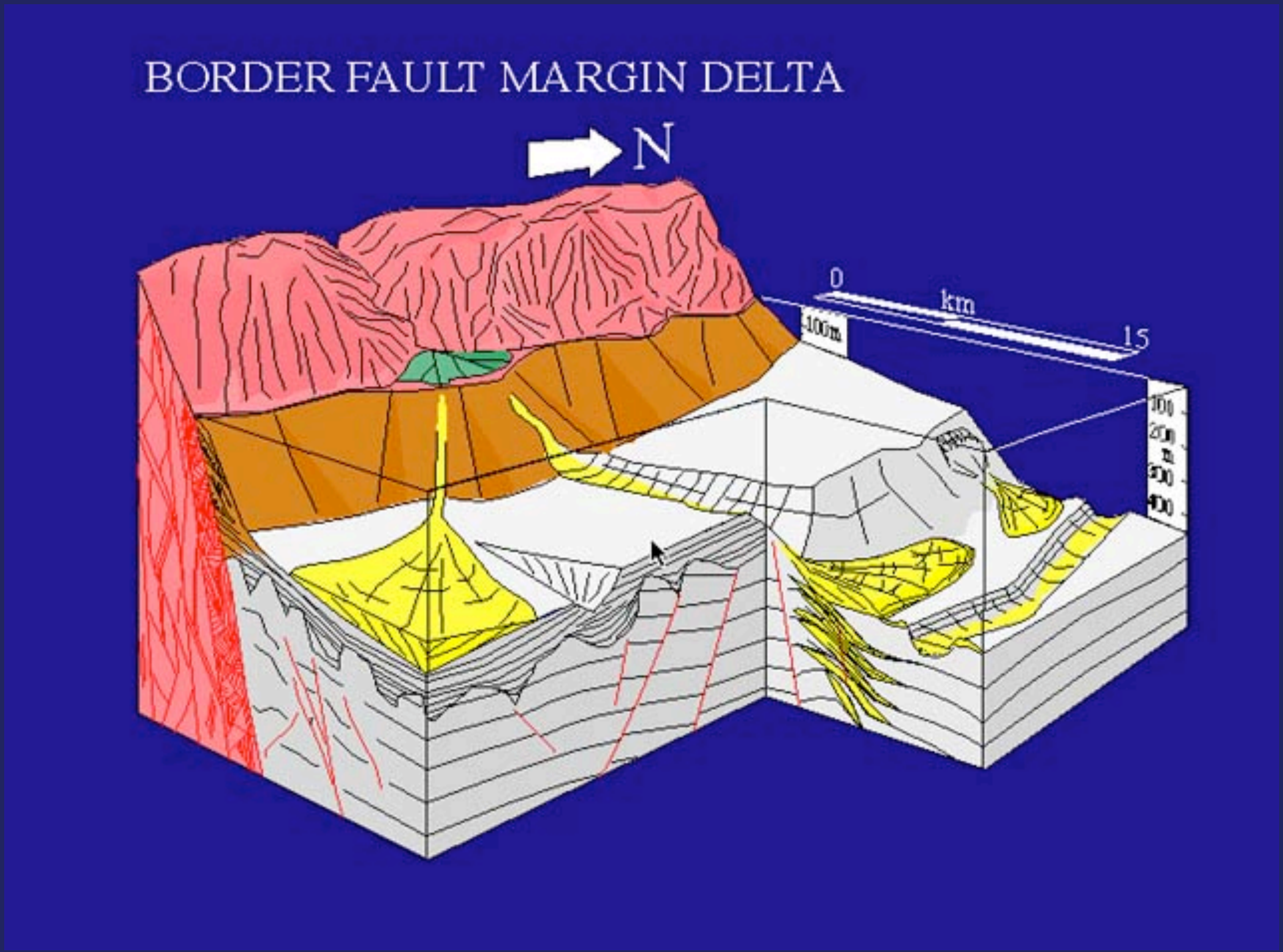
Example: Lake Malawi, Eastern Rift of the Great Rift Valley

Formed ~35 million years ago due to the rifting and separation of the African and Arabian plates. The lithosphere has stretched significantly and is as a result only 20 km thick as opposed to the normal 100 km.

Lake dimensions: 560 km long, 75 km wide

Bordered by the Livingston Mountains (1500m above lake level), short, steep drainage basins.

Conceptual Model



Courtesy Lacustrine Rift Basin Research Program, University of Miami, USA

SedFlux-3D experiment of a Rift Basin

(scenario funded by EXXON-Mobil TX, USA)

- user-specified rapid subsidence
- 5 alluvial fans and their deltas fill the basin
- eustatic sea level change

- duration of experiment = 180,000 yrs

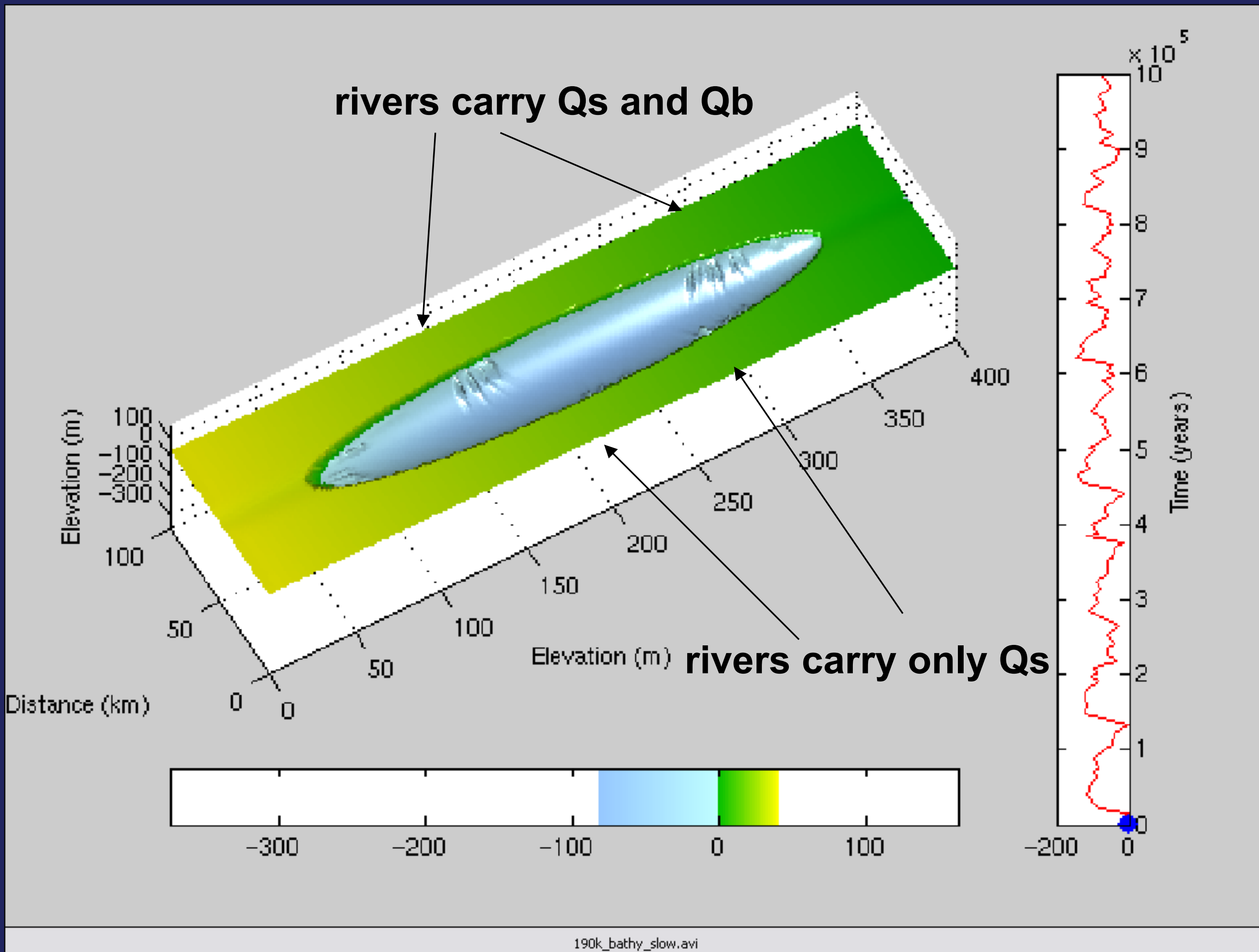
User-defined subsidence

- Stack of Matlab grids → subsidence rate S = f(x,y,t) [L/T]

- S(t0) = subsidence rate at start of simulation
- S(ti) = subsidence rate at specified time I

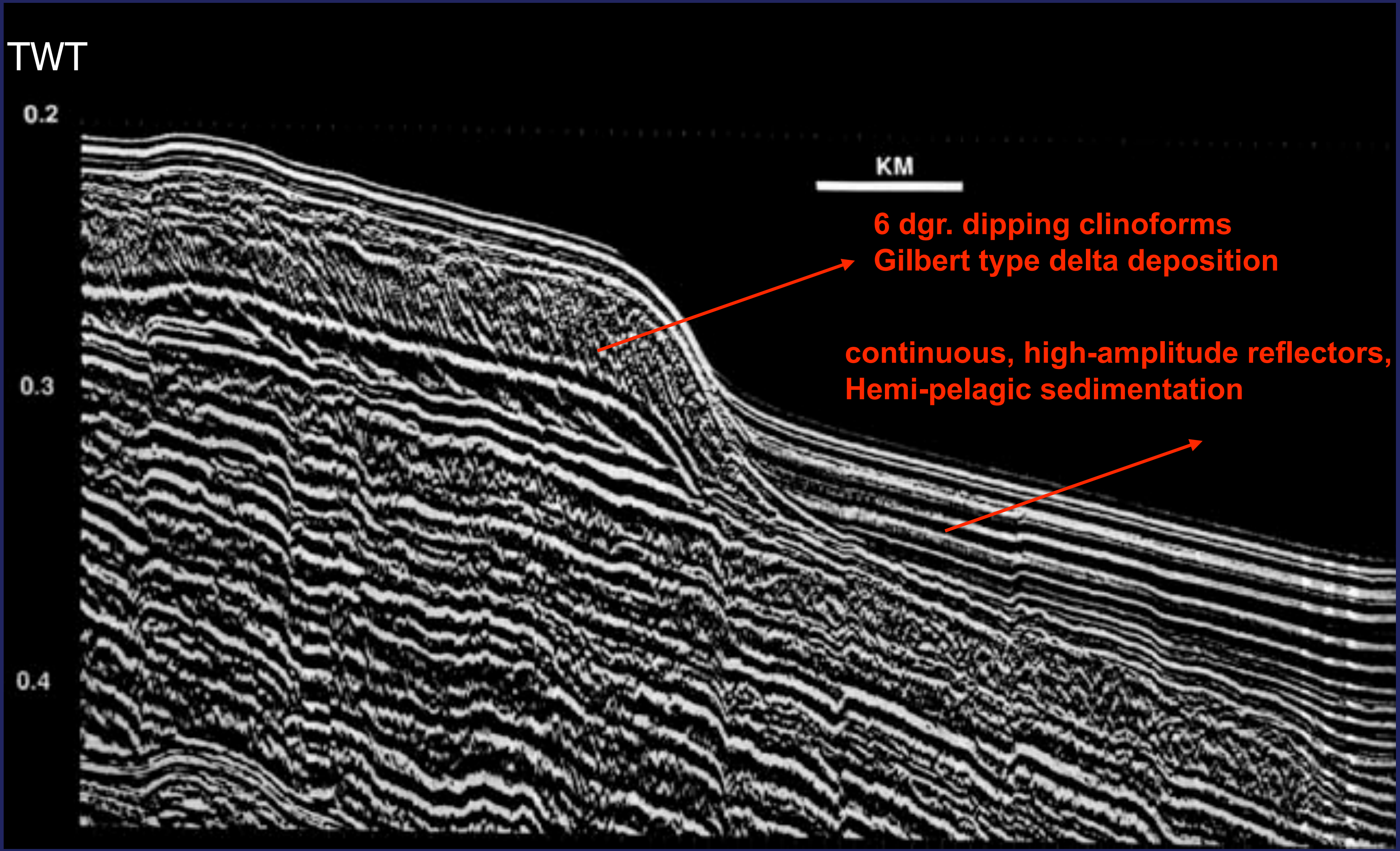
- Linear interpolation of subsidence rates in intermediate time steps

Rift Basin

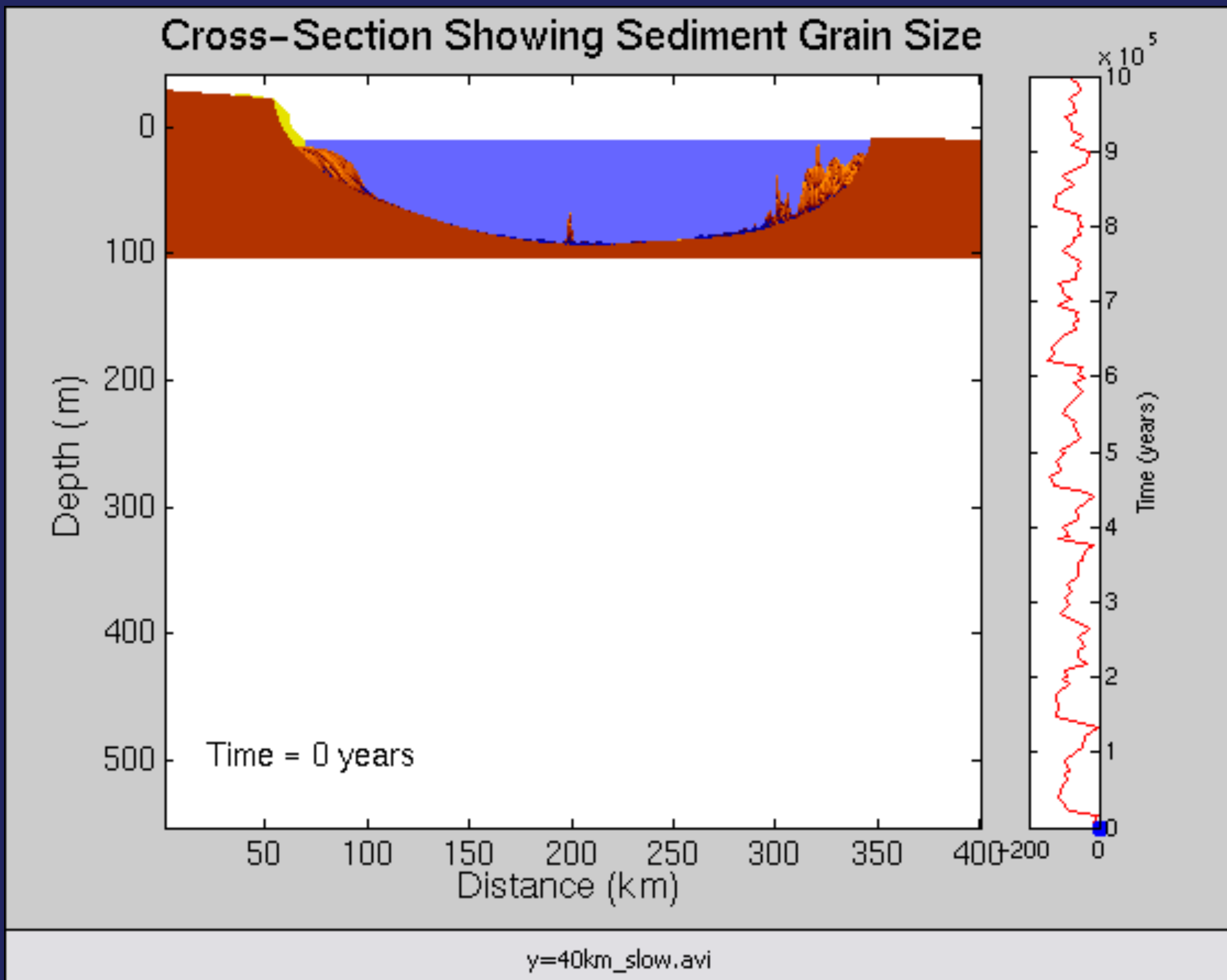


rivers carry Qs and Qb
rivers carry only Qs
Elevation (m)
100
0
−100
−200
−300
100
50
0
Distance (km)
0
50
100
150
200
250
300
350
400
Elevation (m)
−300
−200
−100
0
100
× 10^5
10
9
8
7
6
5
4
3
2
1
0
Time (years)
−200
0
190k_bathy_slow.avi

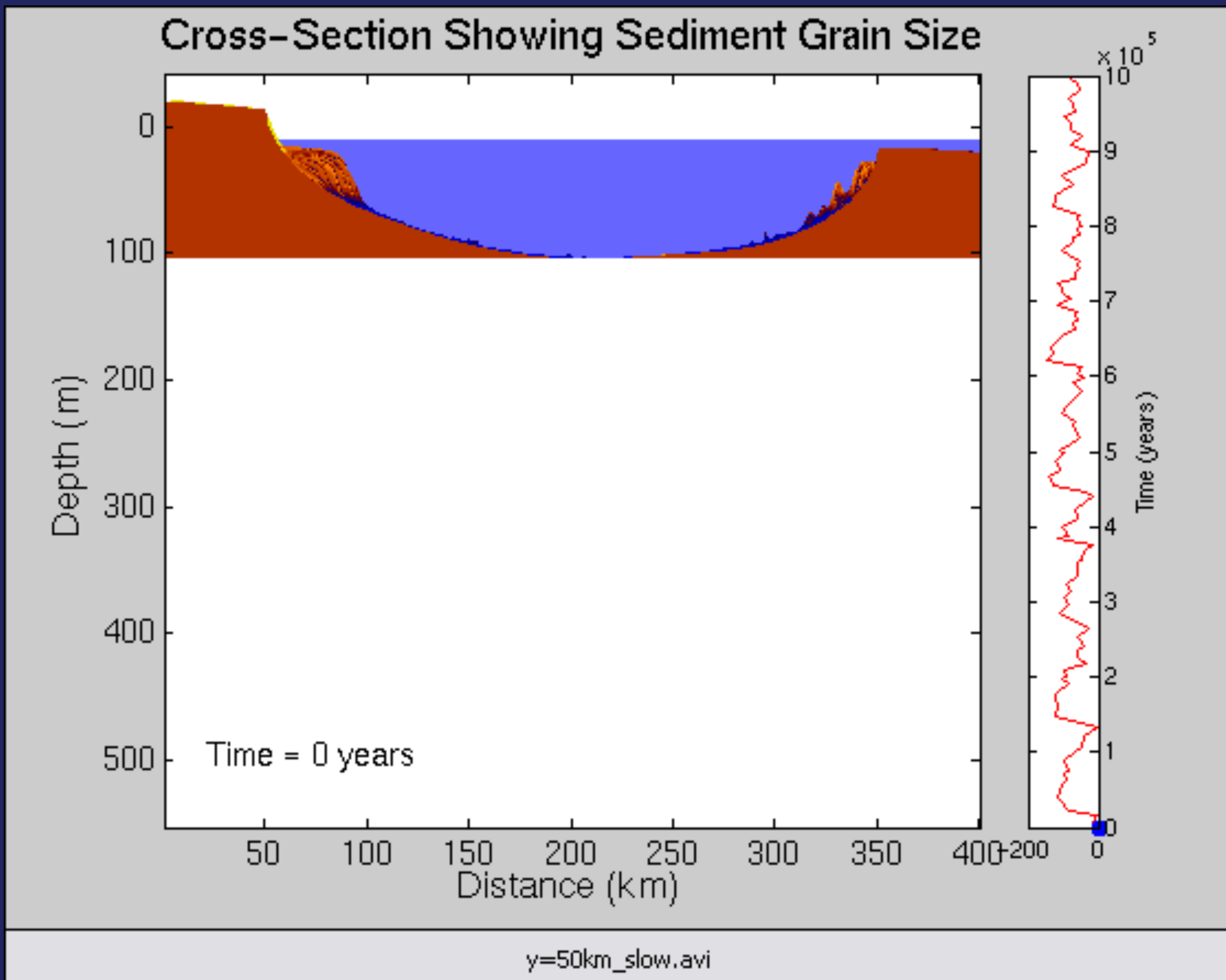
Airgun seismic profile in N-Lake Malawi



Courtesy Lacustrine Rift Basin Research Program, University of Miami, USA longitudinal section at 40 km



Longitudinal section at 50 km



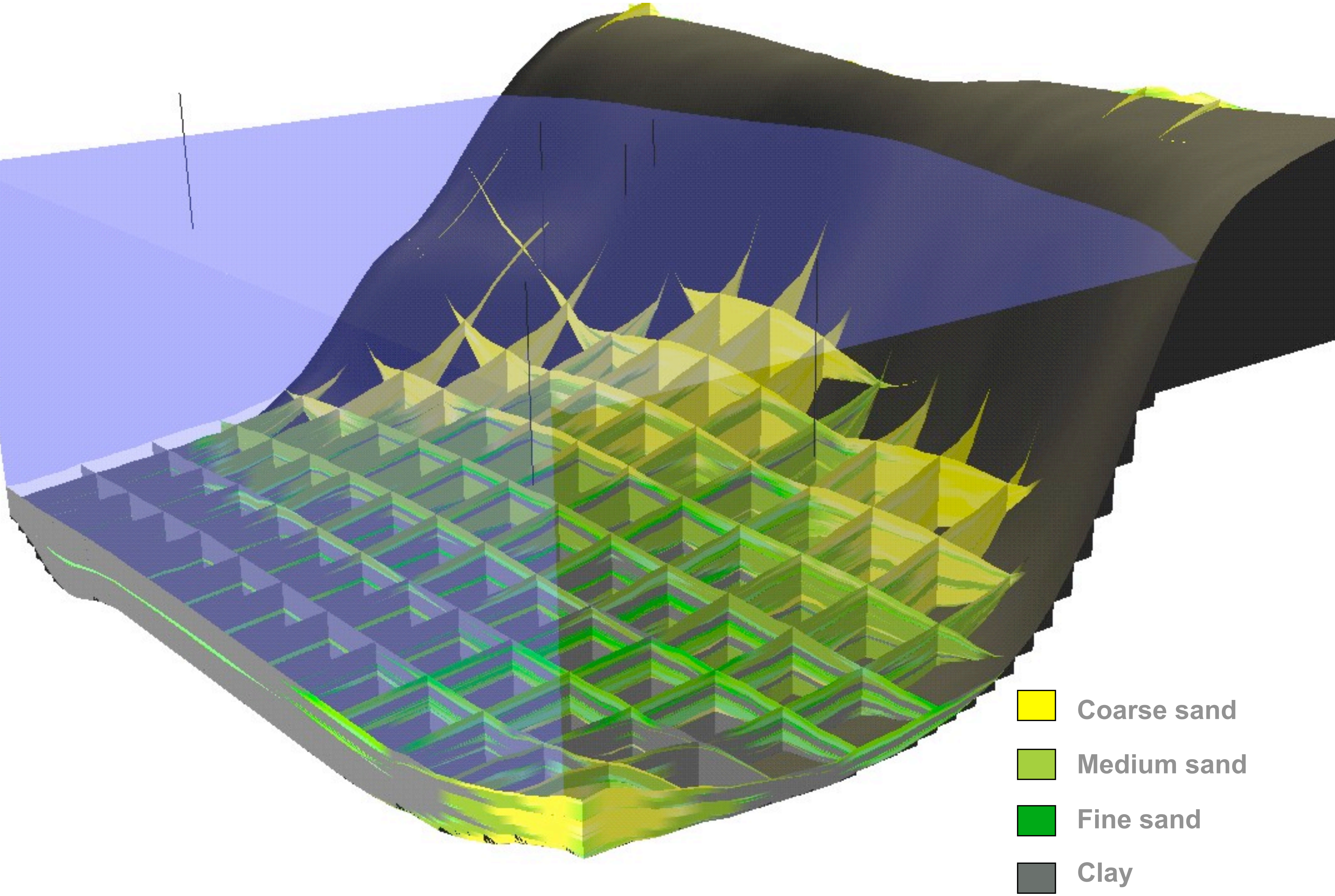
A couple of other basinfill models

- MAJOR ONES: SEDSIM, DIONYSUS

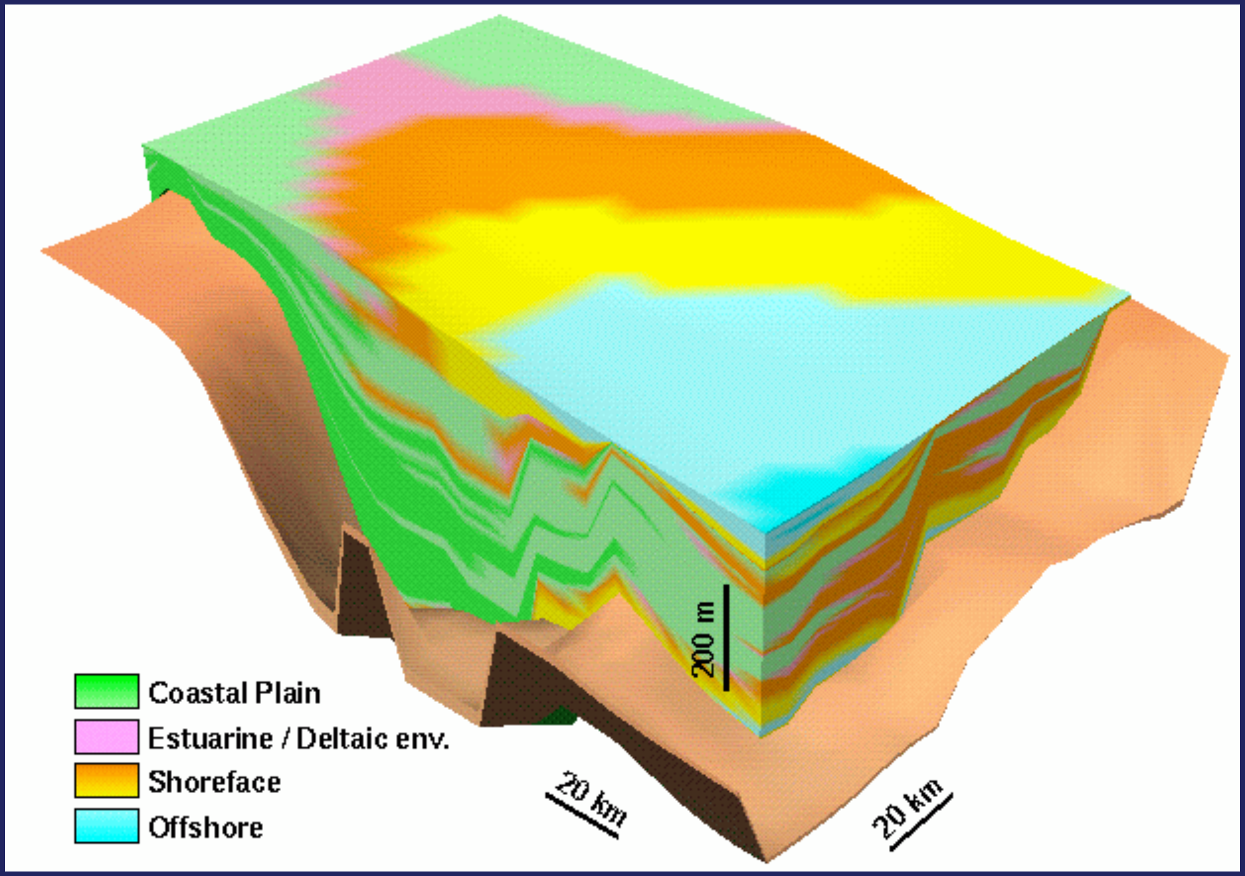
- QDSSM (Meijer, 2002)
- Integrated tectono-sedimentary model (Clevis, 2003)

SEDSIM: sediment transport based on fluid dynamics (Navier-Stokes equation)

- First version developed at Stanford University, USA (Tetzlaff & Harbaugh)
- Further developed at University of Adelaide and CSIRO, Australia (Dyt & Griffiths)
- SEDSIM example: 16 Ma of basin evolution simulated for exploration purposes (Courtesy of CSIRO, Perth, Australia)
- Input variables:
  - Initial topography
  - Sea-level history
  - Sediment supply
  - Ocean currents and wind field


Coarse sand
Medium sand
Fine sand
Clay

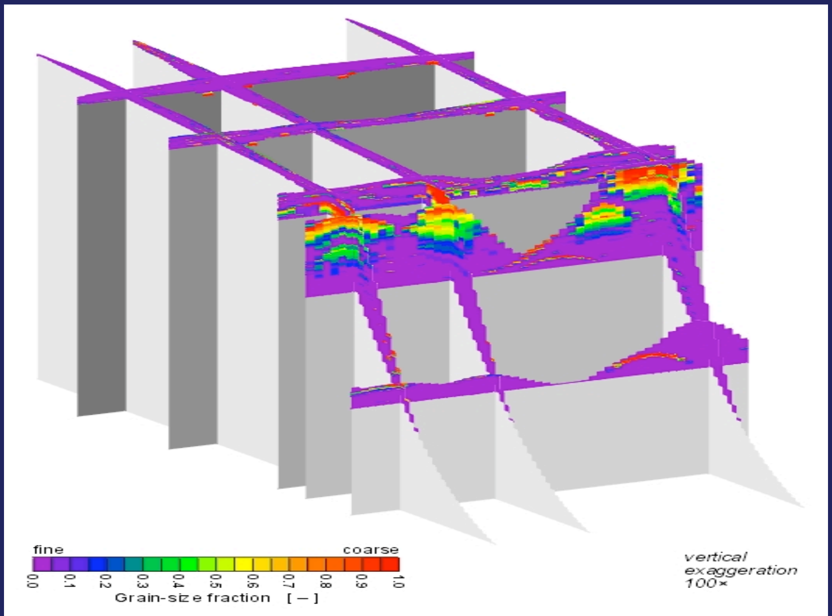
DIONISOS

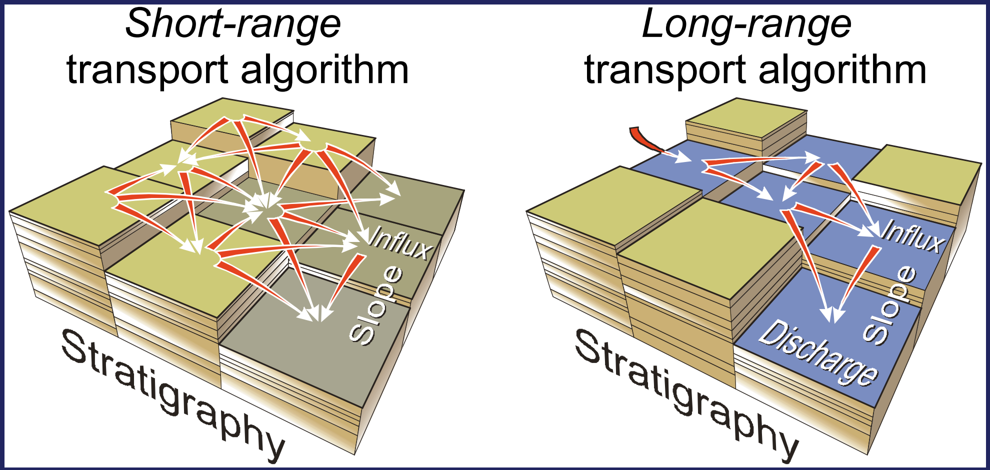


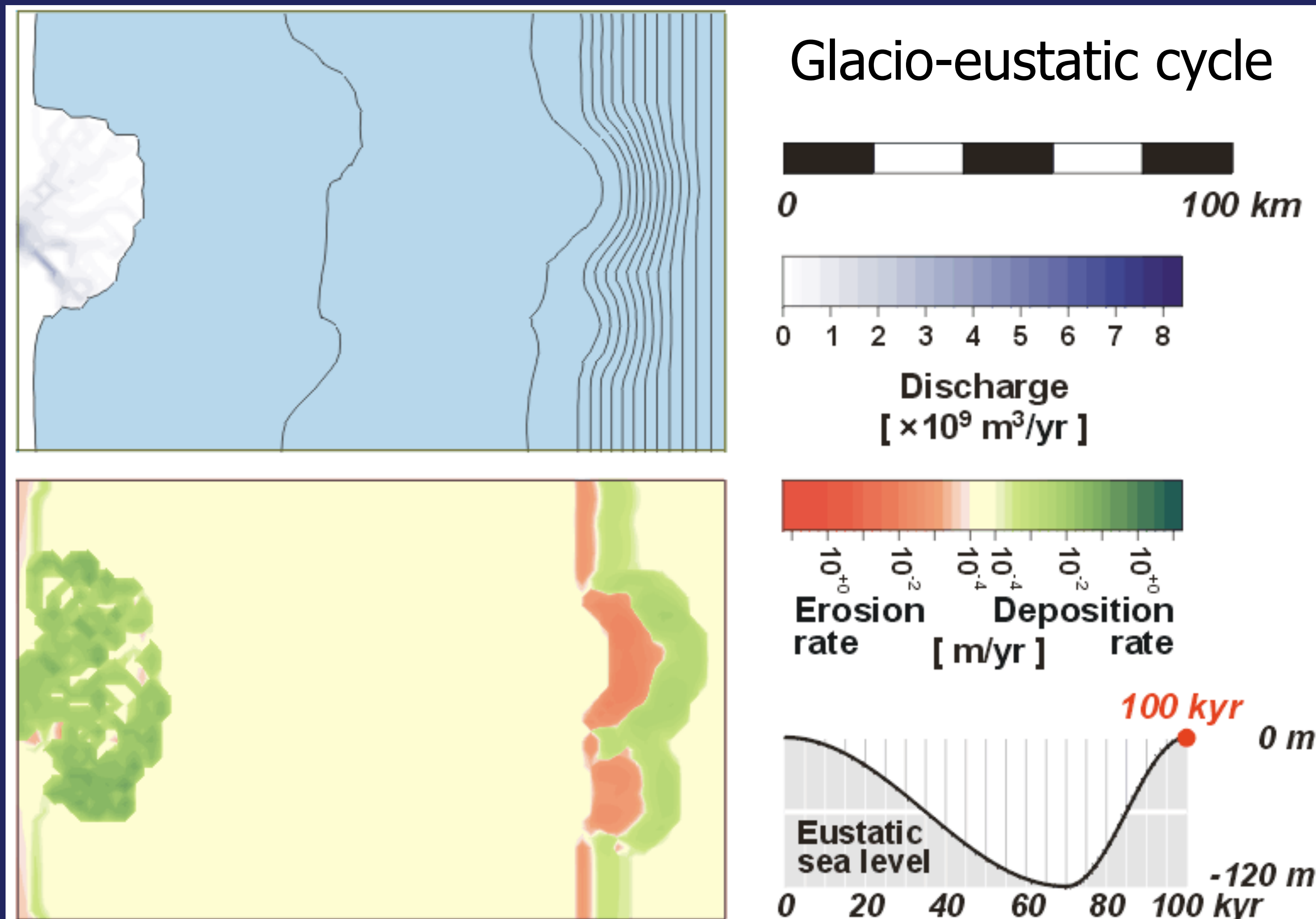
- Developed at IFP (Granjeon & Joseph, 1999)
- Based on diffusion equation (dynamic-slope model)
- Used in exploration

QDSSM (Meijer, 2002)

- Diffusion-advection
- Delta model

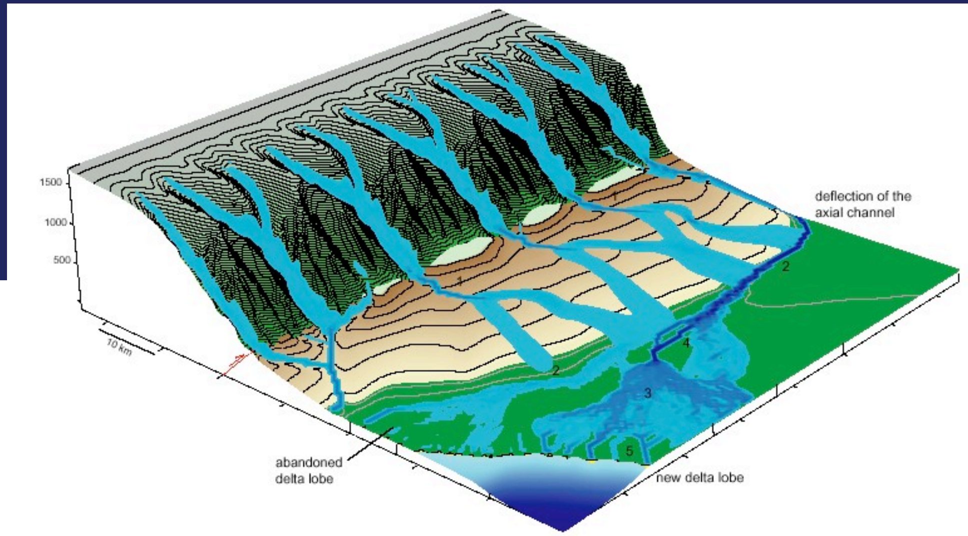


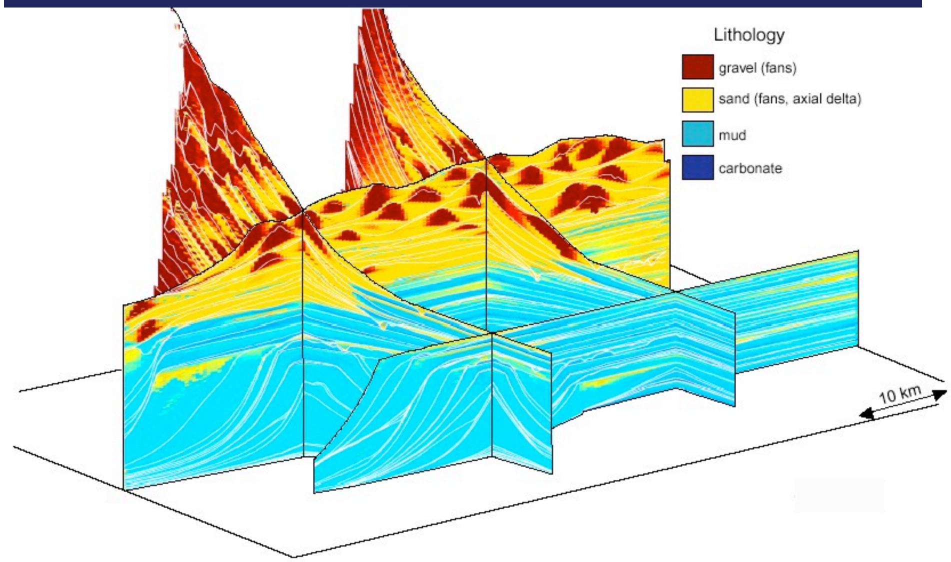



Glacio-eustatic cycle
0
100 km
0 1 2 3 4 5 6 7 8
Discharge
[×10^9 m^3/yr]
Erosion rate
Deposition rate
[m/yr]
100 kyr
0 m
-120 m
Eustatic sea level
0 20 40 60 80 100 kyr

Integrated tectono-sedimentary model (Clevis, 2003)

- Diffusion-advection eqn
- Foreland-basin setting





Summary

- Modeling long-term basin fills is commonly approached by using sequence stratigraphic insights and analysing the A/S ratio

- Numerical models that simulate subsidence, sea level change and bulk sedimentary processes are a tool to experiment with the different factors controlling the large-scale geometry.