Basin filling and stratigraphy

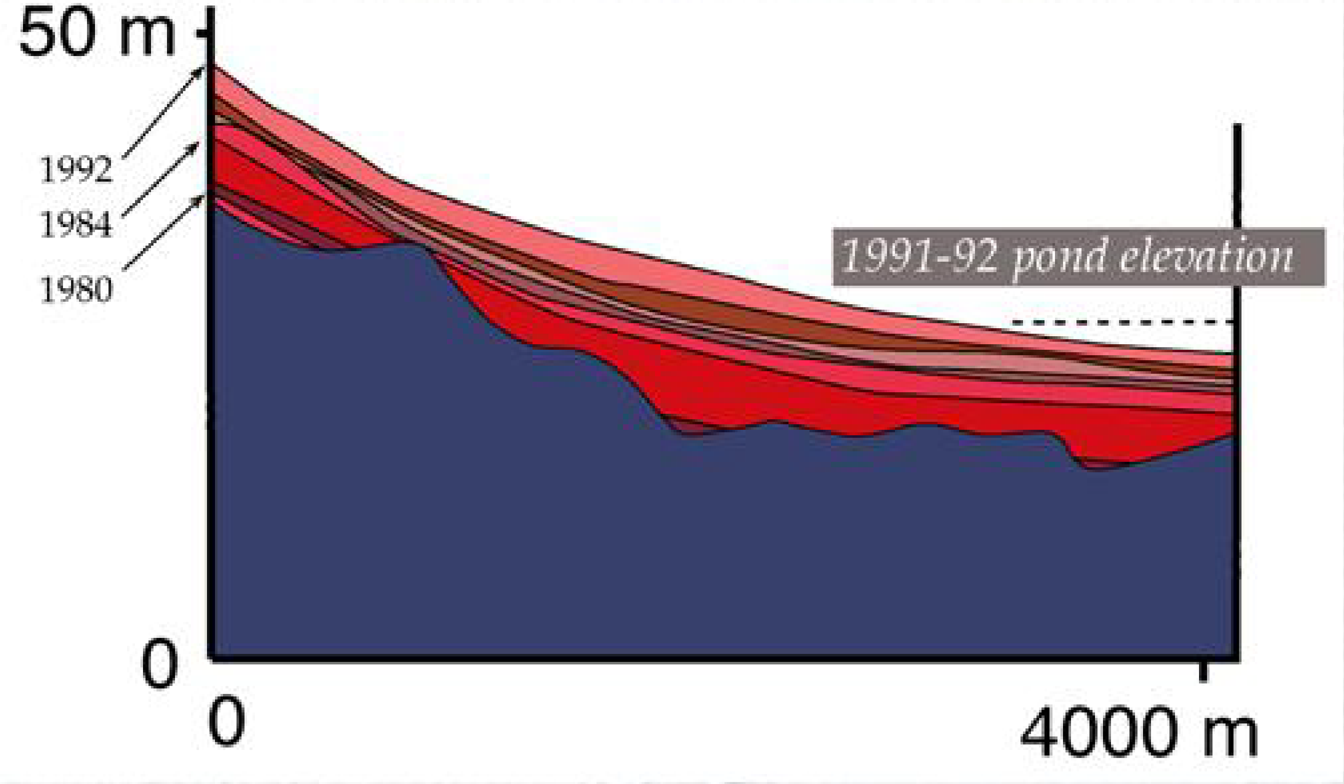
The basin filling problem

- Long-term behavior of transport systems ≠ sum of short-term events
- Interplay of sedimentation and subsidence
- Strong bio and chemical influences
- System evolution over time

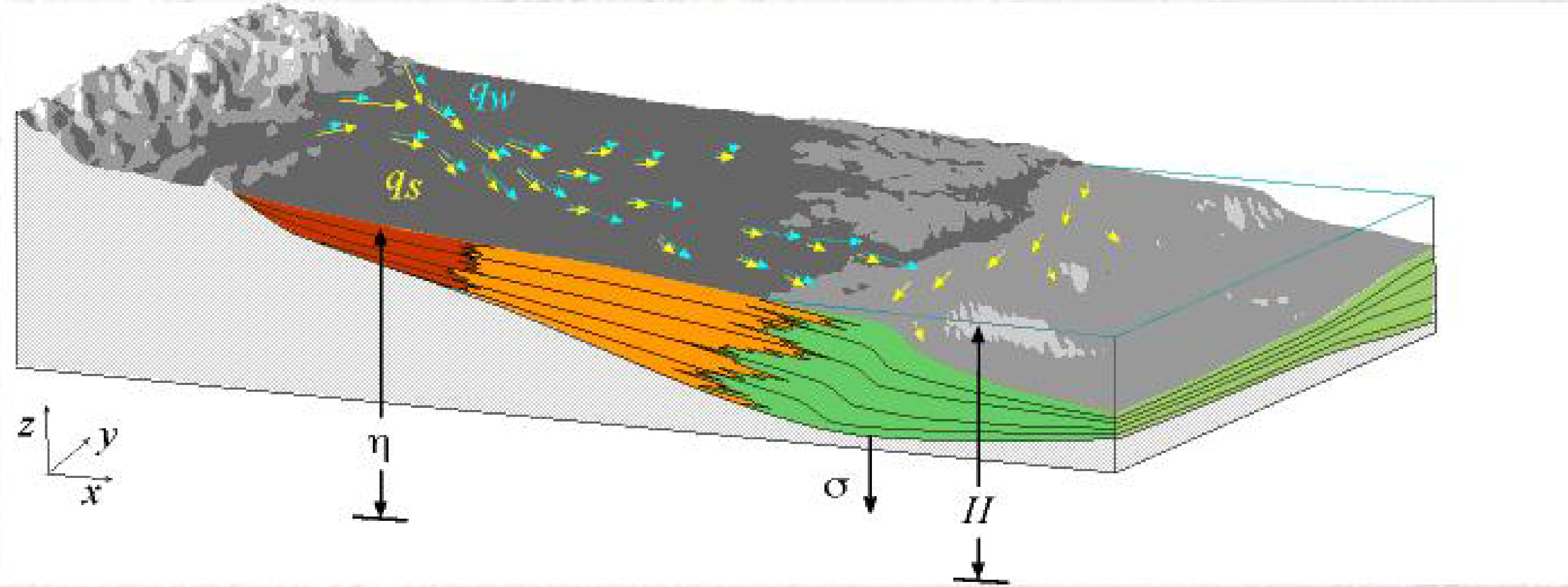
Long-term vs. short-term

- Short-term: changes in flow ⇒ changes in sediment flux ⇒ changes in morphology
- Long-term: tectonics ⇒ changes in sediment flux ⇒ changes in flow

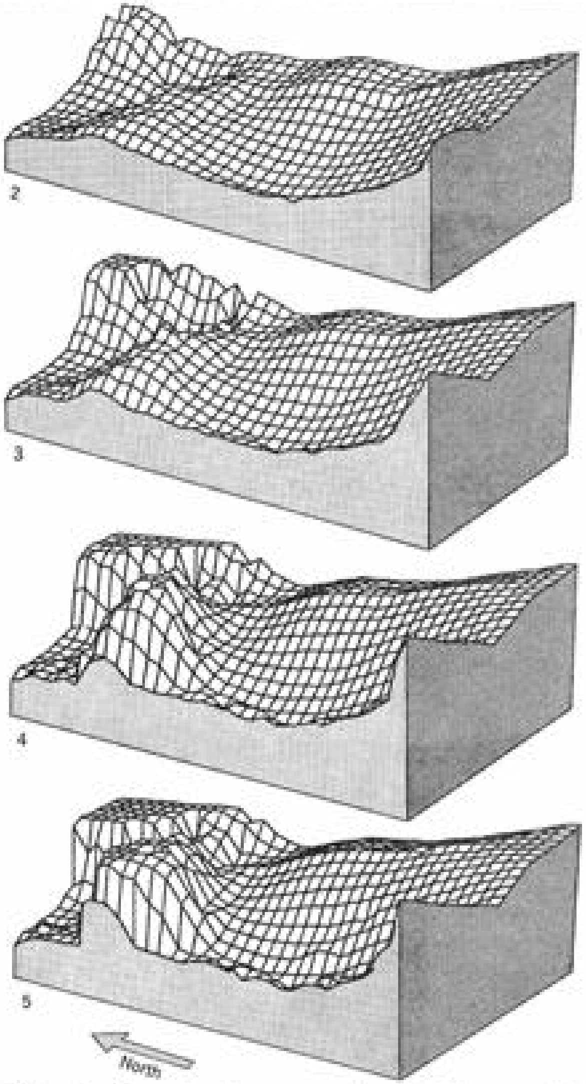
Depositional equilibrium



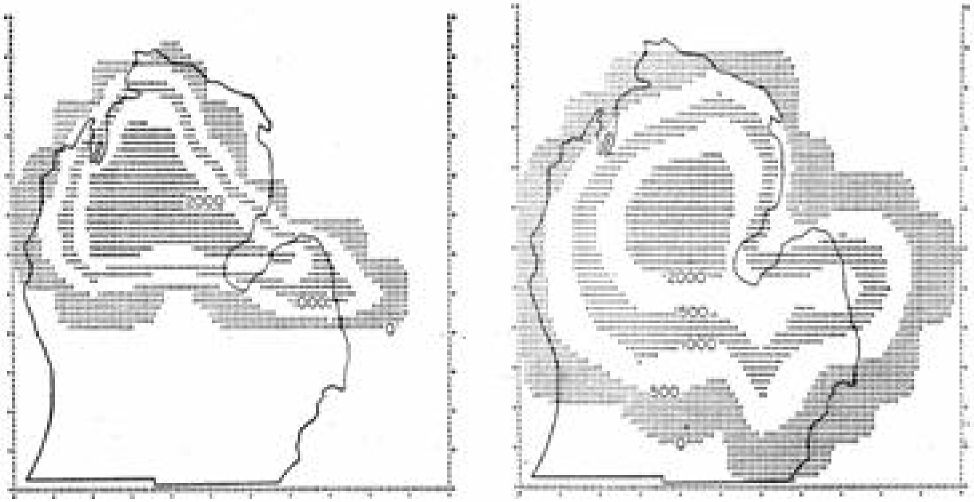
Subsidence + morphodynamics = stratigraphy



Early modeling



gure 9-44 Series of computer-drawn perspective block diagrams showing topog-



Briggs and Pollack (1967)

Harbaugh and Bonham-Carter (1970)

Approaches to modeling

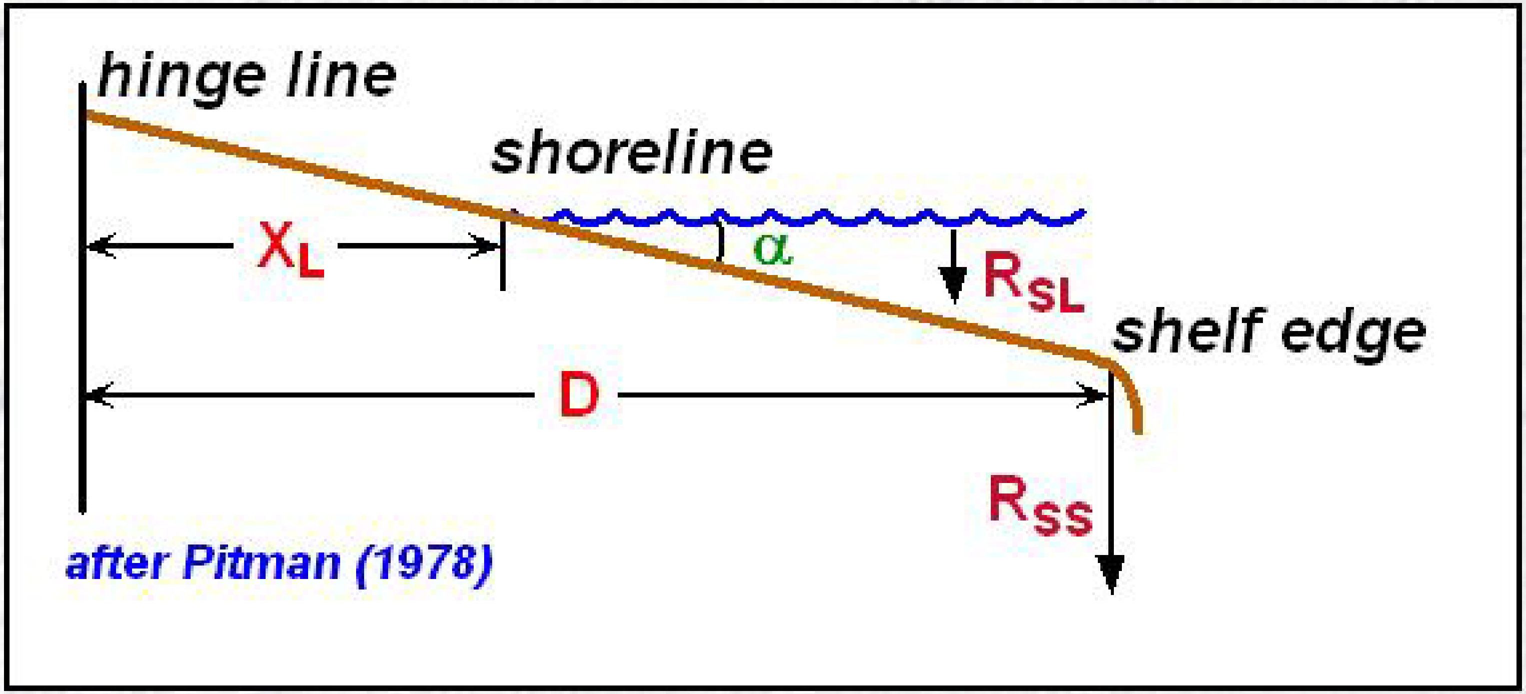
Geometric models

- Assume fixed depositional geometry
- Conserve mass
- Computationally simpler though generally nonlinear

Dynamic models

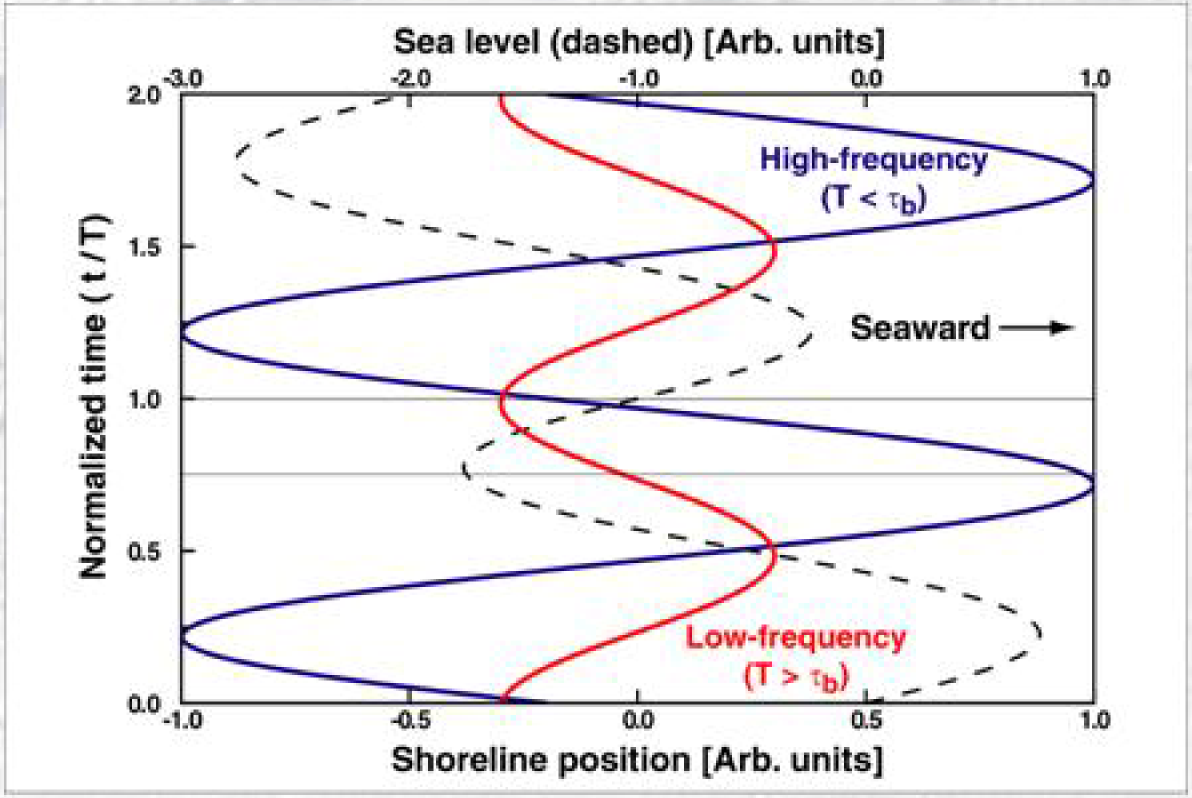
- Model variation in depositional geometry
- Include effects related to change in surface slope (e.g. change in discharge)
- Computationally more complex

Pitman (1978) shoreline model



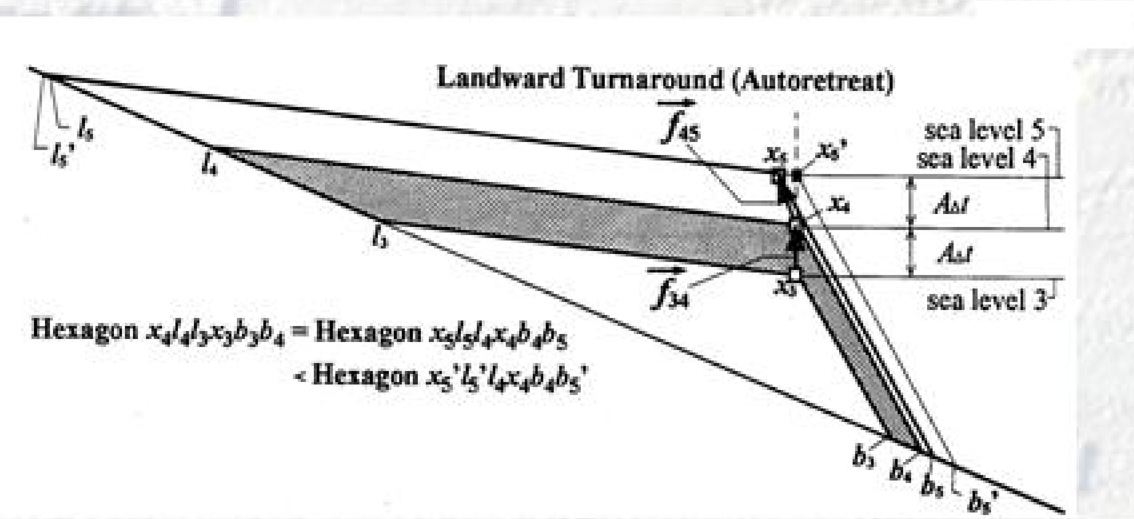
after Pitman (1978)

Pitman-Angevine shoreline response



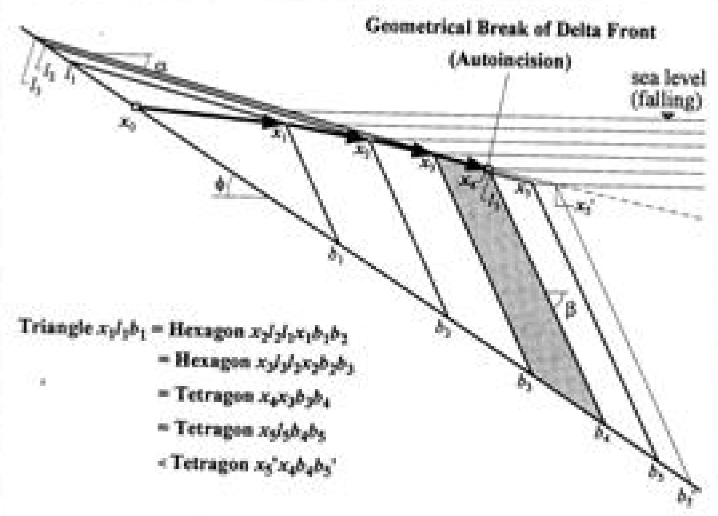
- **Amplitude** of shoreline response **decreases** with decreasing frequency of eustatic forcing
- **Phase shift increases** with decreasing frequency

Geometric model results



Autoretreat

Autoincision



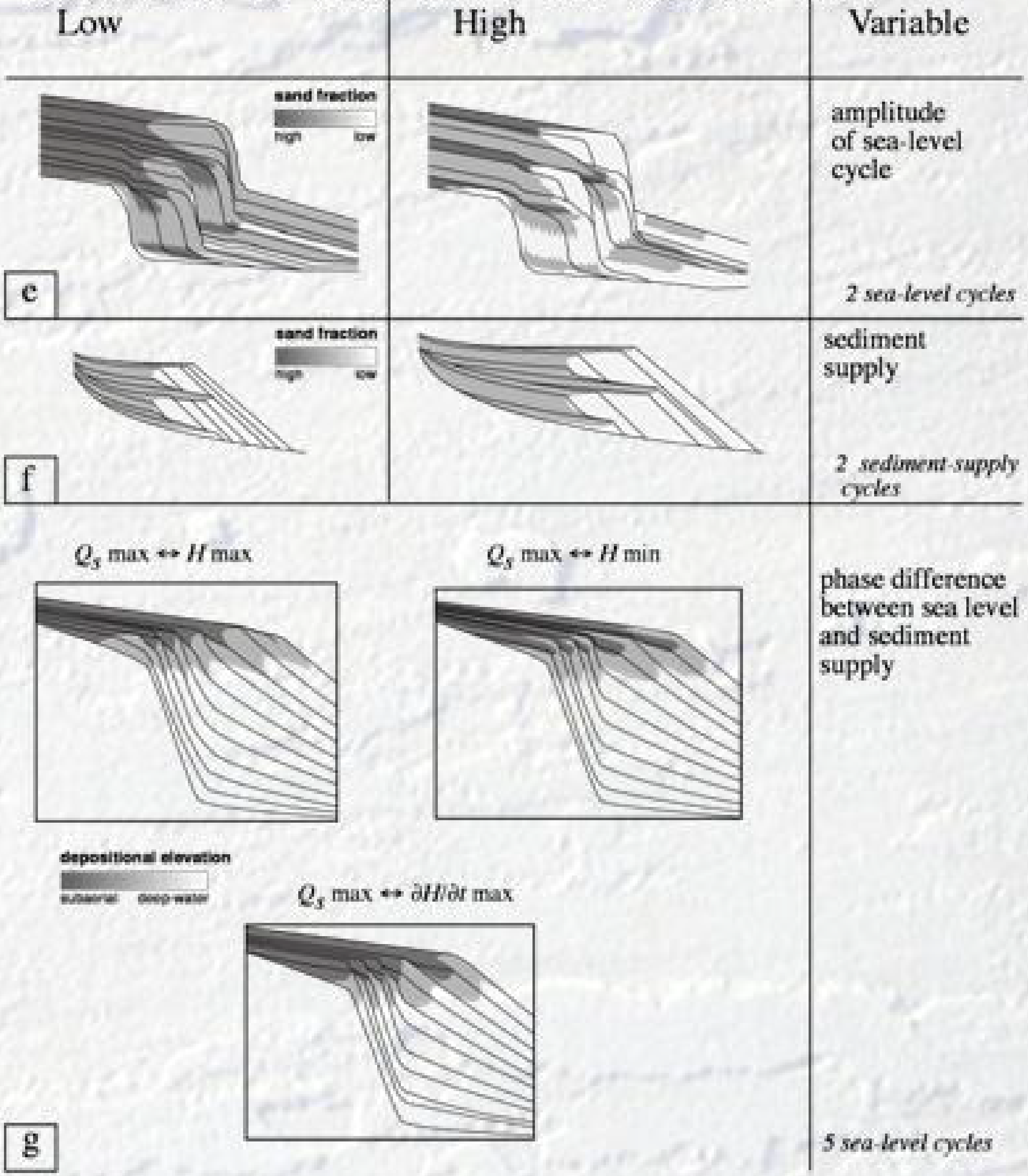
Muto and Steel, 1992 *ff*.

Geometric model results

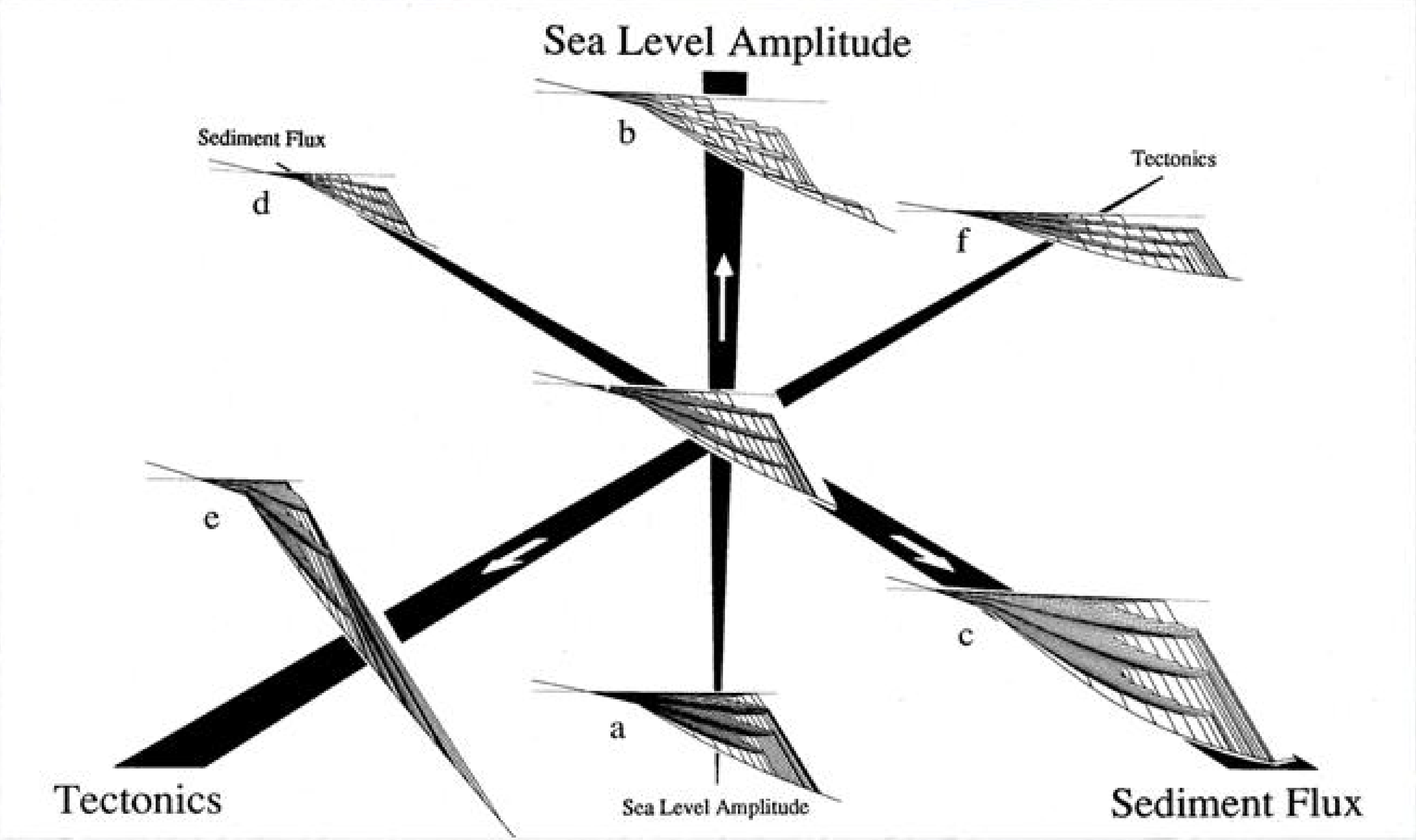
Ross et al., 1995

Jervey, 1988

Perlmutter et al., 1998

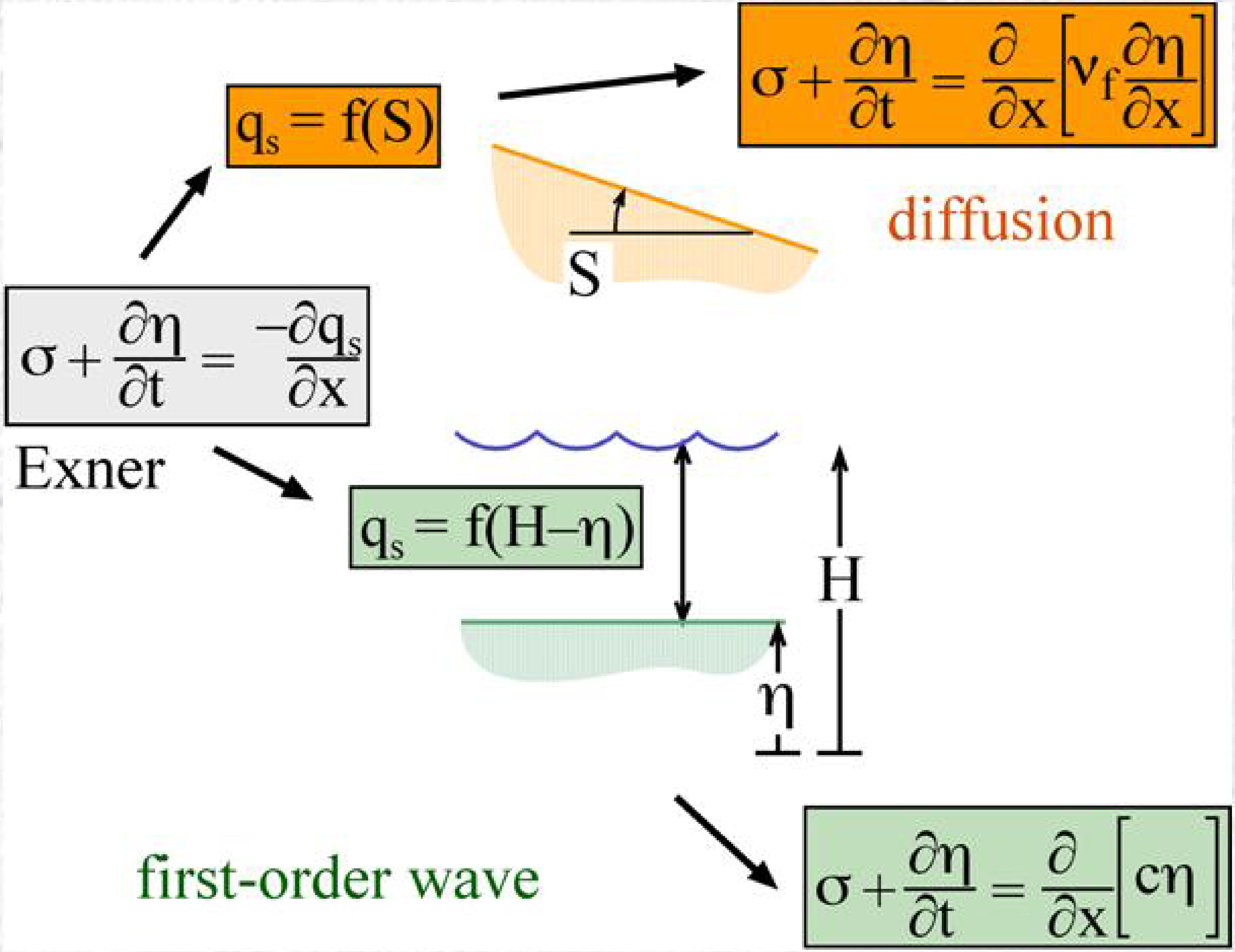


Geometric model results



Steckler et al., 1993

‘Single-equation’ morphodynamics



$$\sigma + \frac{\partial \eta}{\partial t} = \frac{-\partial q_s}{\partial x}$$

Exner

$$q_s = f(S)$$

$$\sigma + \frac{\partial \eta}{\partial t} = \frac{\partial}{\partial x}\left[\nu_f \frac{\partial \eta}{\partial x}\right]$$

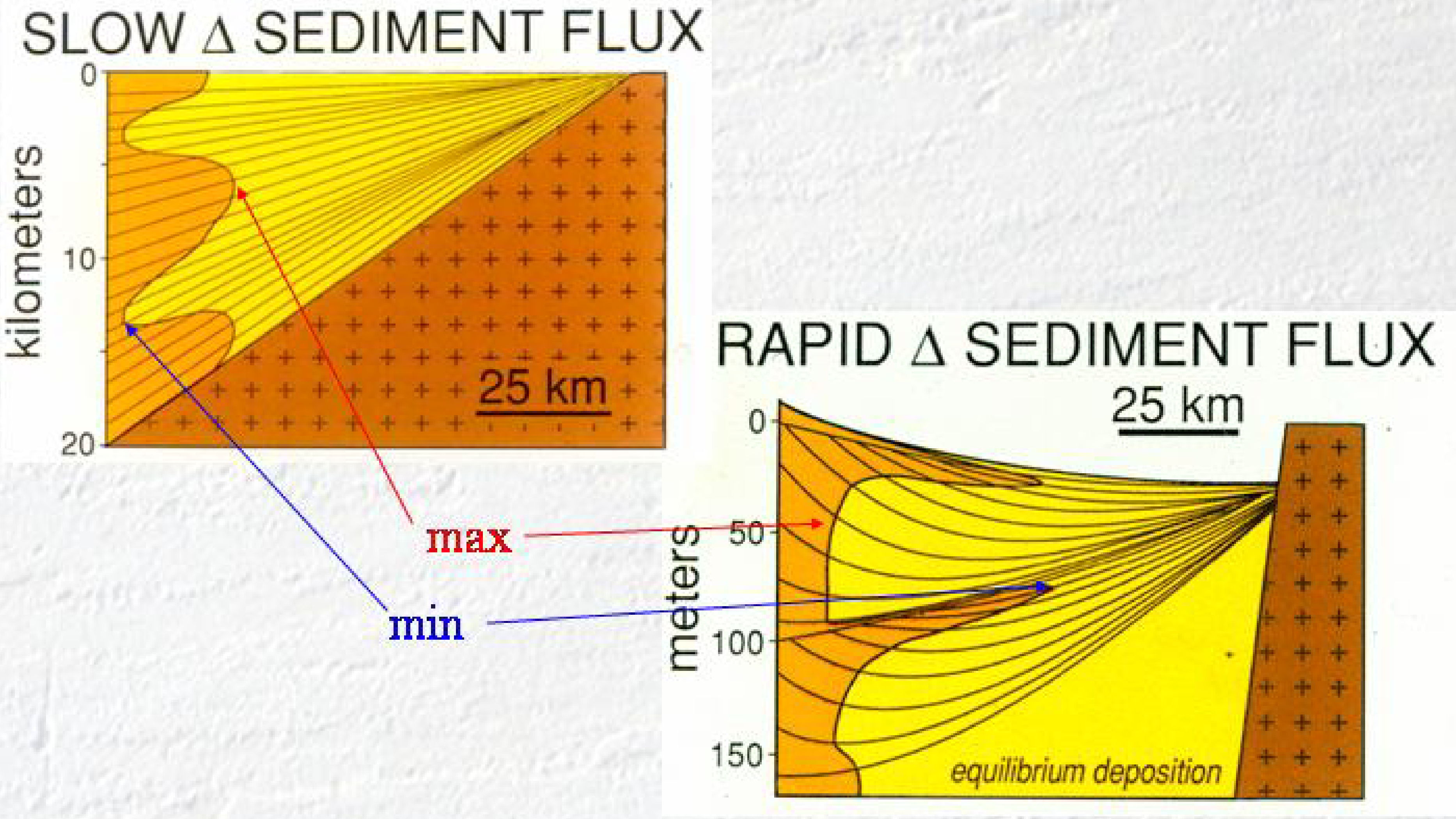
diffusion

$$q_s = f(H-\eta)$$

$$\sigma + \frac{\partial \eta}{\partial t} = \frac{\partial}{\partial x}\left[c\eta\right]$$

first-order wave

Sediment supply



SLOW Δ SEDIMENT FLUX

RAPID Δ SEDIMENT FLUX

max

min

Swenson's "unconformity number"

equilibrium time

change in water supply

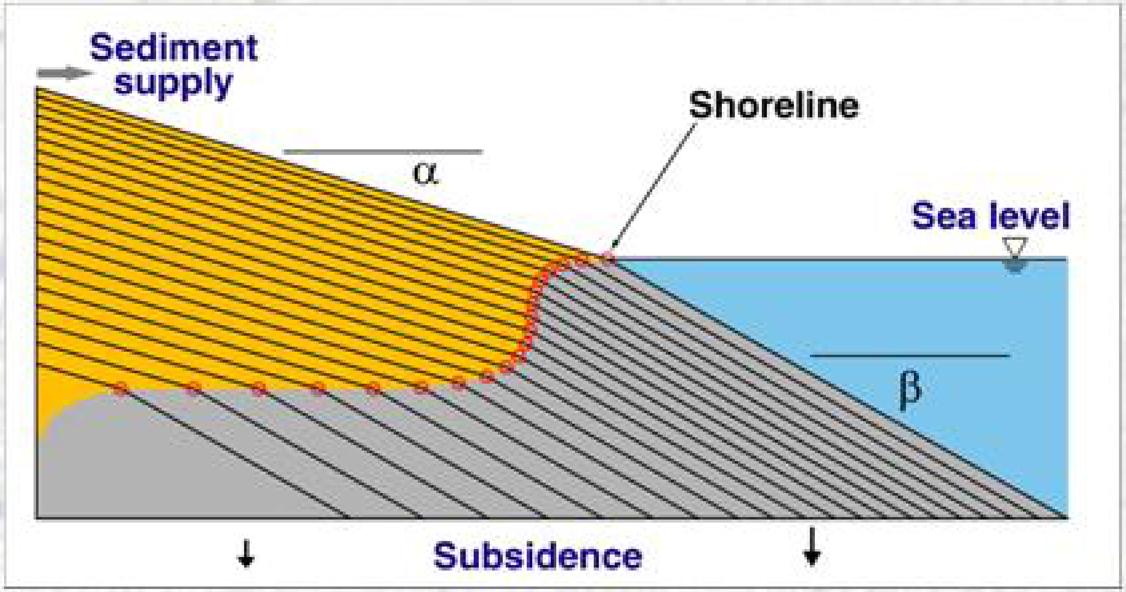
$$U_p = \sqrt{\frac{1}{4\pi}\frac{T_{eq}}{T}}\left(\frac{\Delta q_w}{q_{wo}} - \frac{\Delta q_s}{q_{so}}\right)$$

period of imposed change

change in sediment supply

Measures the potential of an upstream imposed change to induce unconformities in a diffusional model

Shoreline as a moving boundary: a geometric example



Known:

- Geometry (α,β)
- Forcing

Unknown:

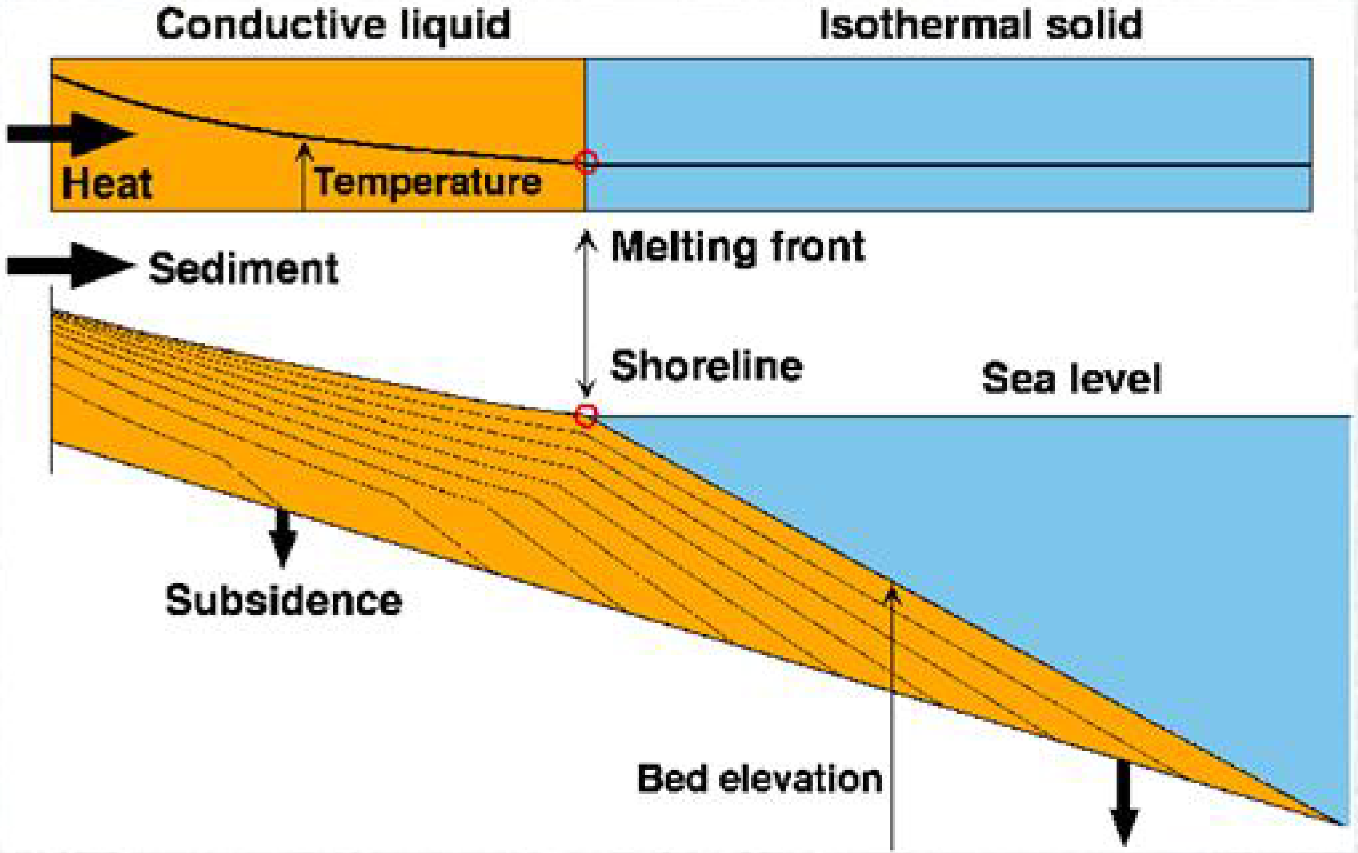
- Shoreline position

Closure scheme:

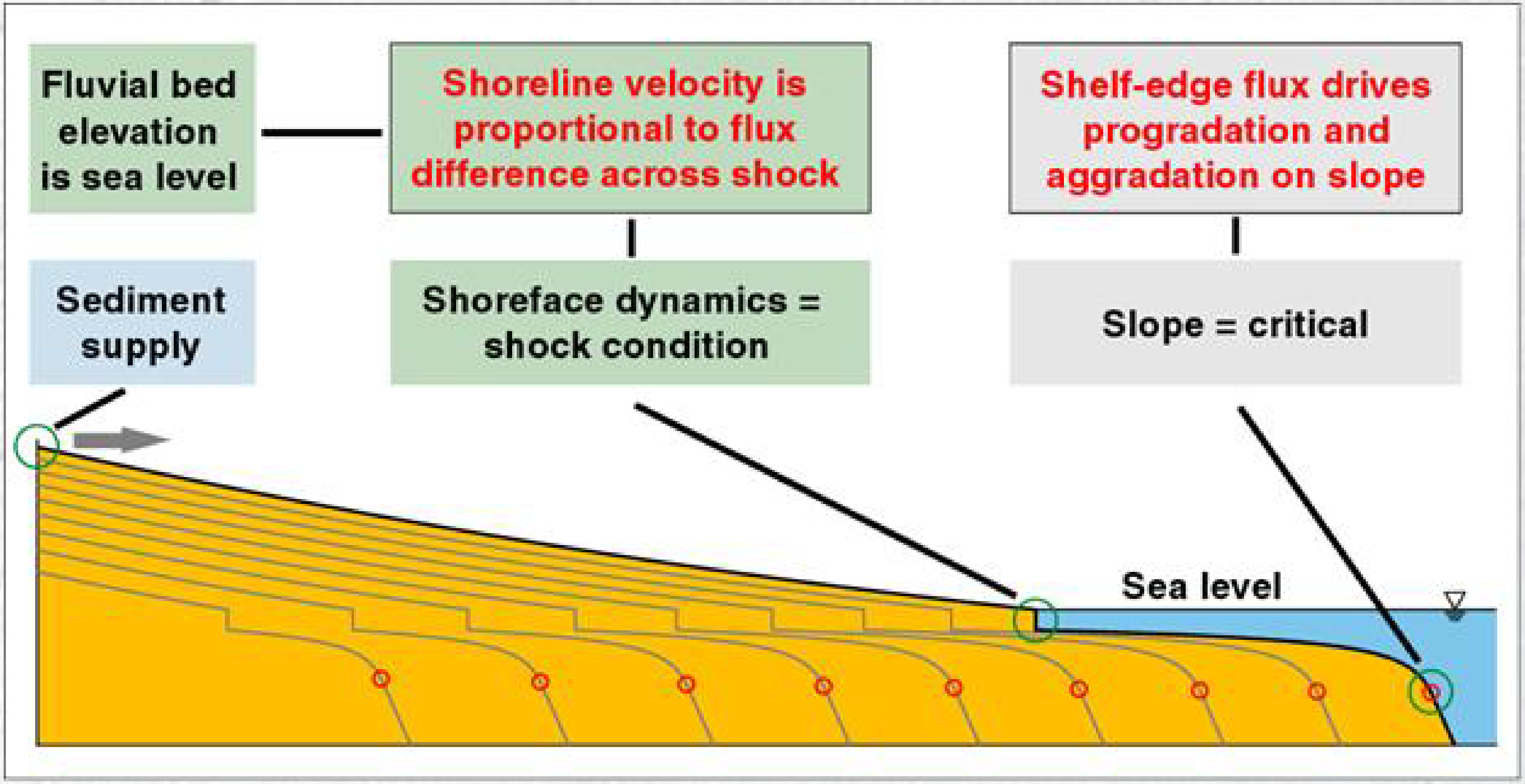
Specify shoreline sedimentation rate

(Pitman, 1978; Angevine, 1989)

The "melt metaphor"



Simple clinoform progradation: Boundary and matching conditions



Fluvial bed elevation is sea level

Shoreline velocity is proportional to flux difference across shock

Shelf-edge flux drives progradation and aggradation on slope

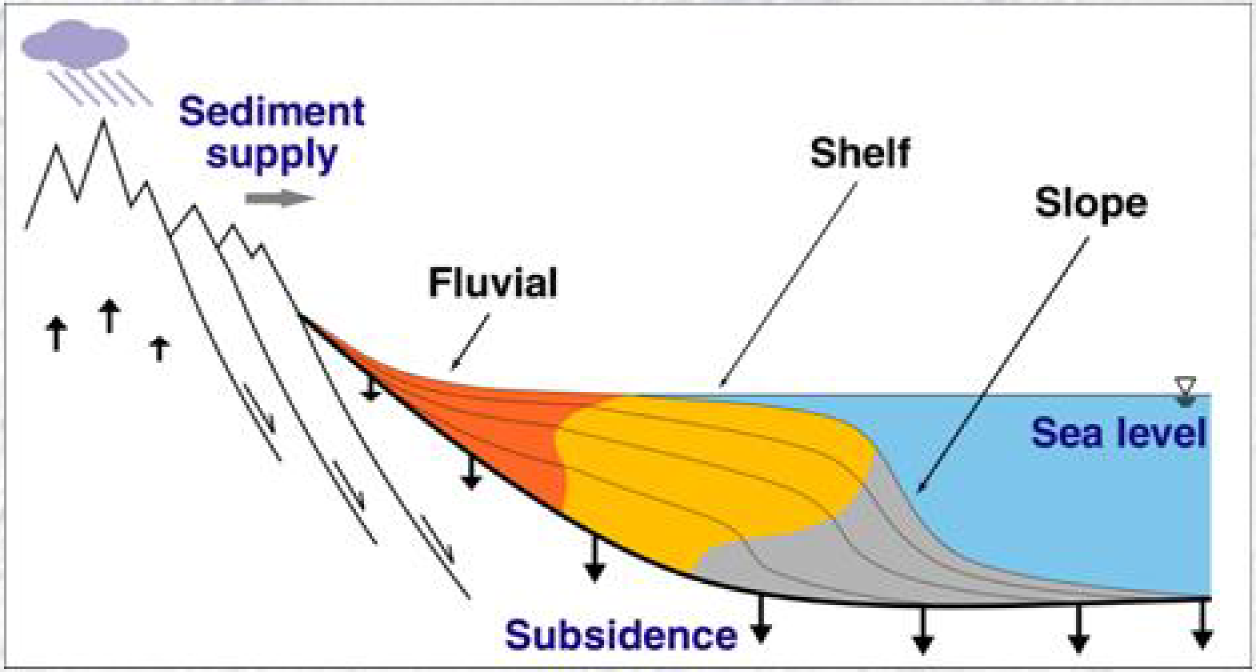
Sediment supply

Shoreface dynamics = shock condition

Slope = critical

Goal: Quantify sediment partitioning and shelf morphology

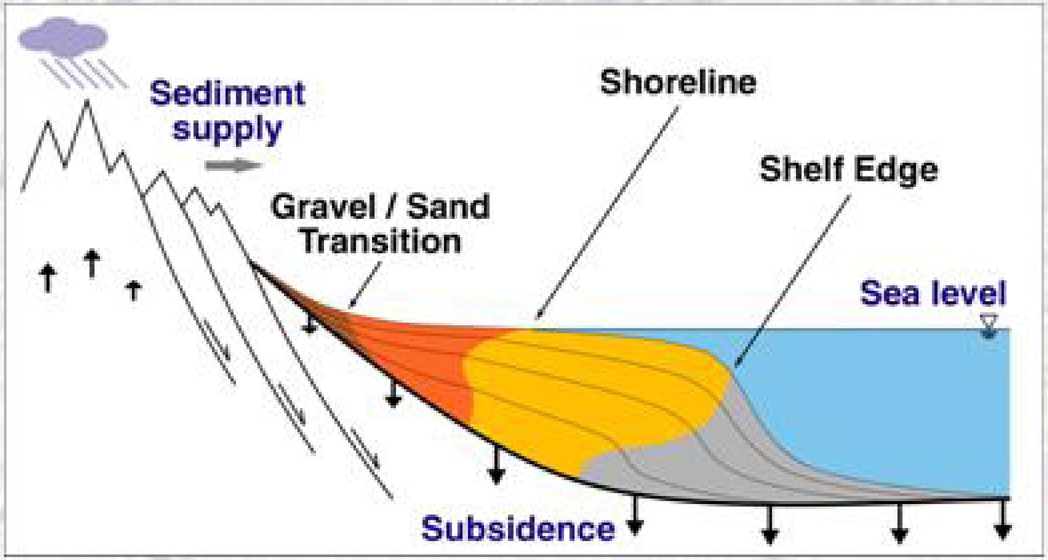
The whole-margin concept



Continental margins consist of coupled transport regimes, each with distinct sediment dynamics

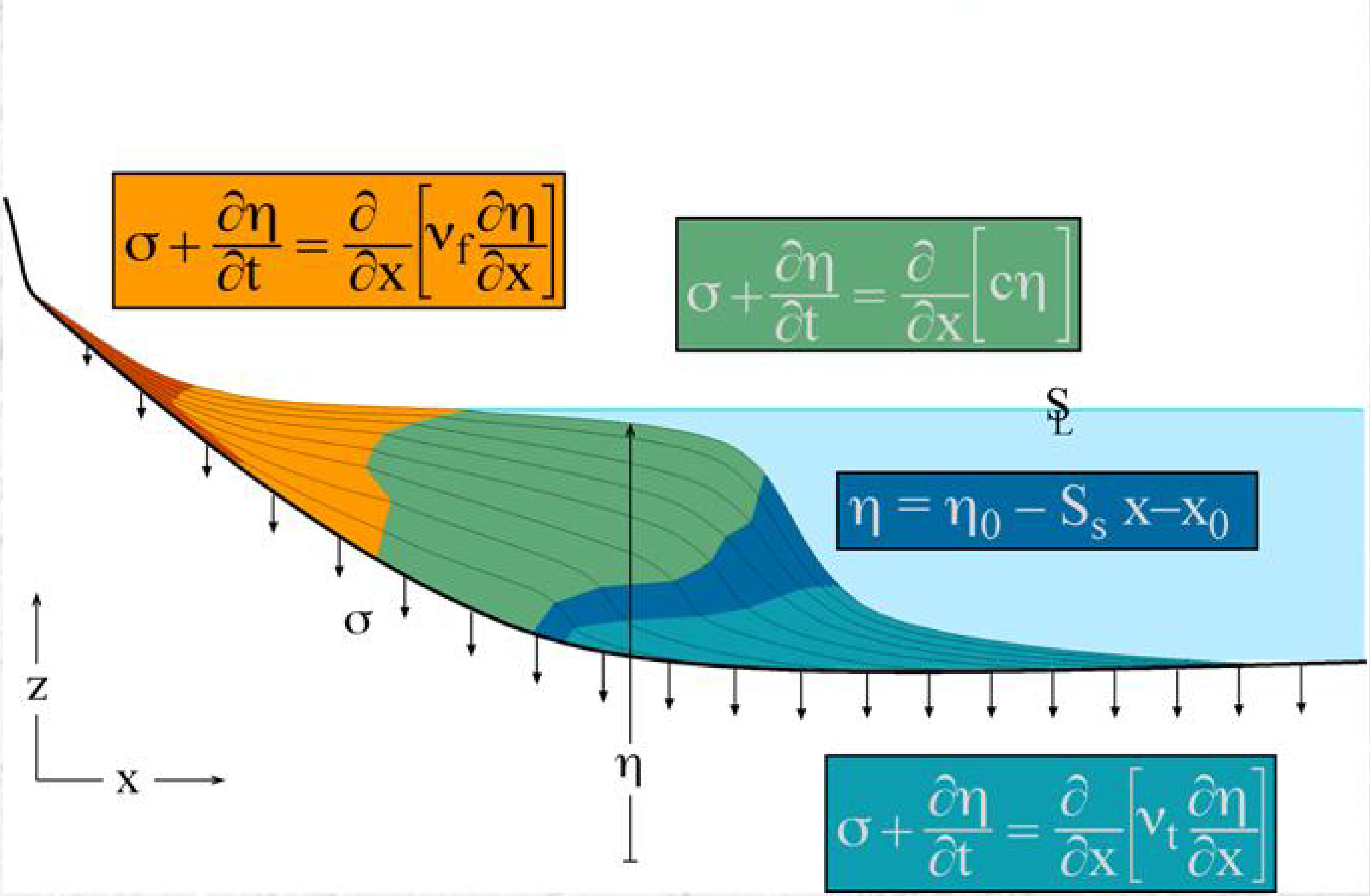
Transport regimes ⇔ sedimentary facies

Dynamic moving boundaries



- Transport regimes communicate across dynamic, **moving boundaries**, e.g. the shoreline
- Boundaries respond sensitively to **external forcing**
- On geologic time scales, boundary positions are **dependent variables** (function of transport physics)
- "Moving-boundary" problem

Component equations



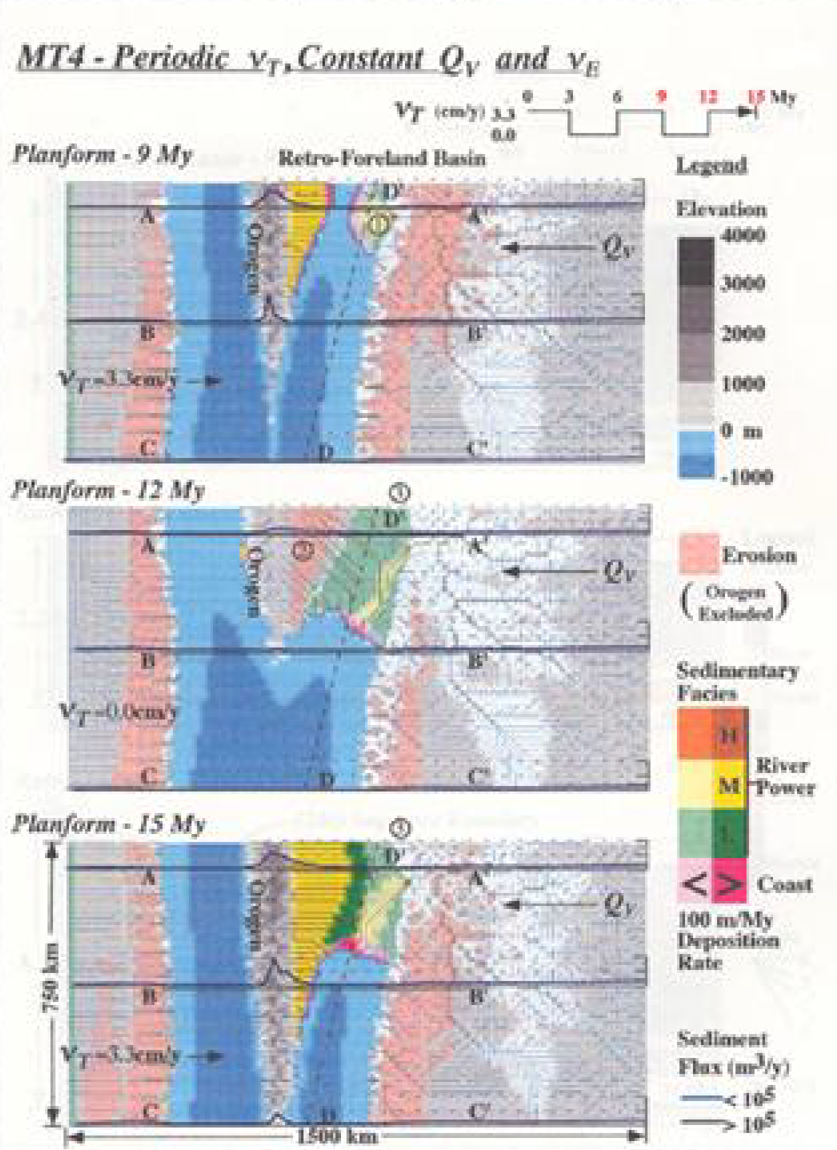
$$\sigma + \frac{\partial \eta}{\partial t} = \frac{\partial}{\partial x}\left[\nu_f \frac{\partial \eta}{\partial x}\right]$$

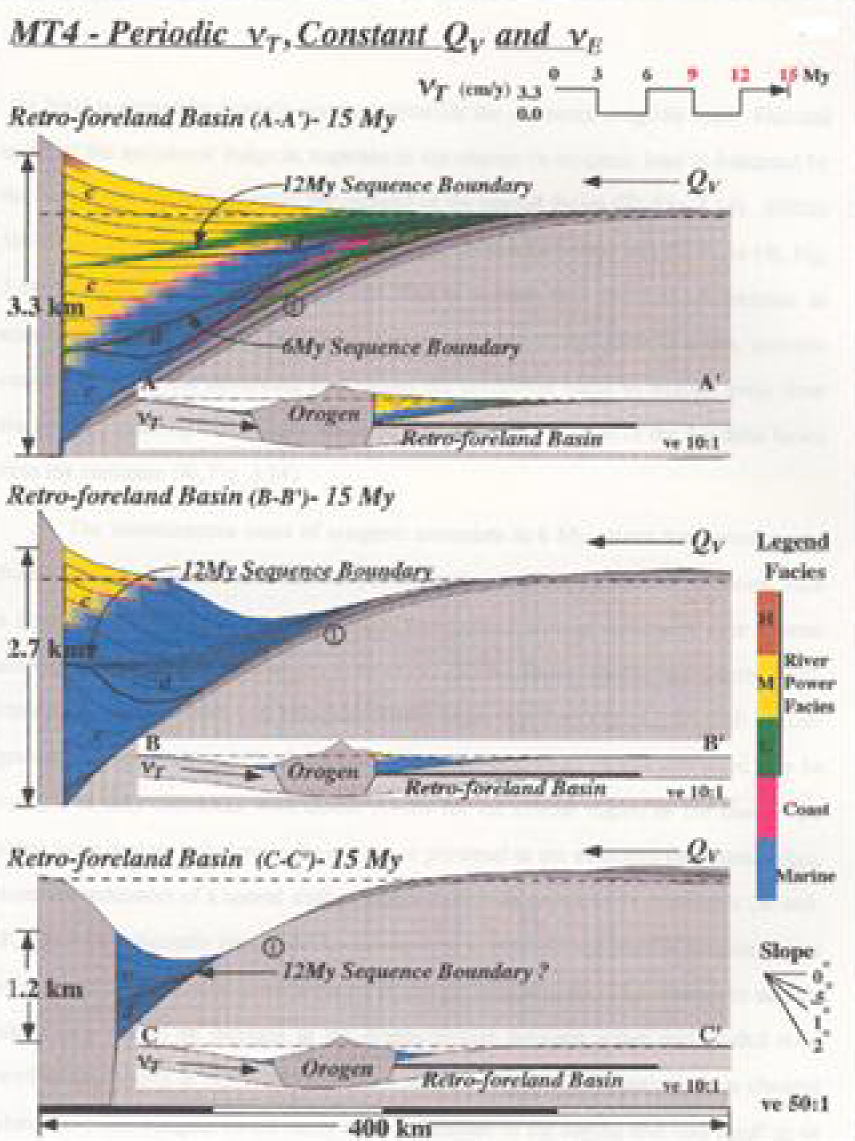
$$\sigma + \frac{\partial \eta}{\partial t} = \frac{\partial}{\partial x}\left[c\eta\right]$$

$$\eta = \eta_0 - S_s\ x - x_0$$

$$\sigma + \frac{\partial \eta}{\partial t} = \frac{\partial}{\partial x}\left[\nu_t \frac{\partial \eta}{\partial x}\right]$$

Coupling morphodynamics and tectonics



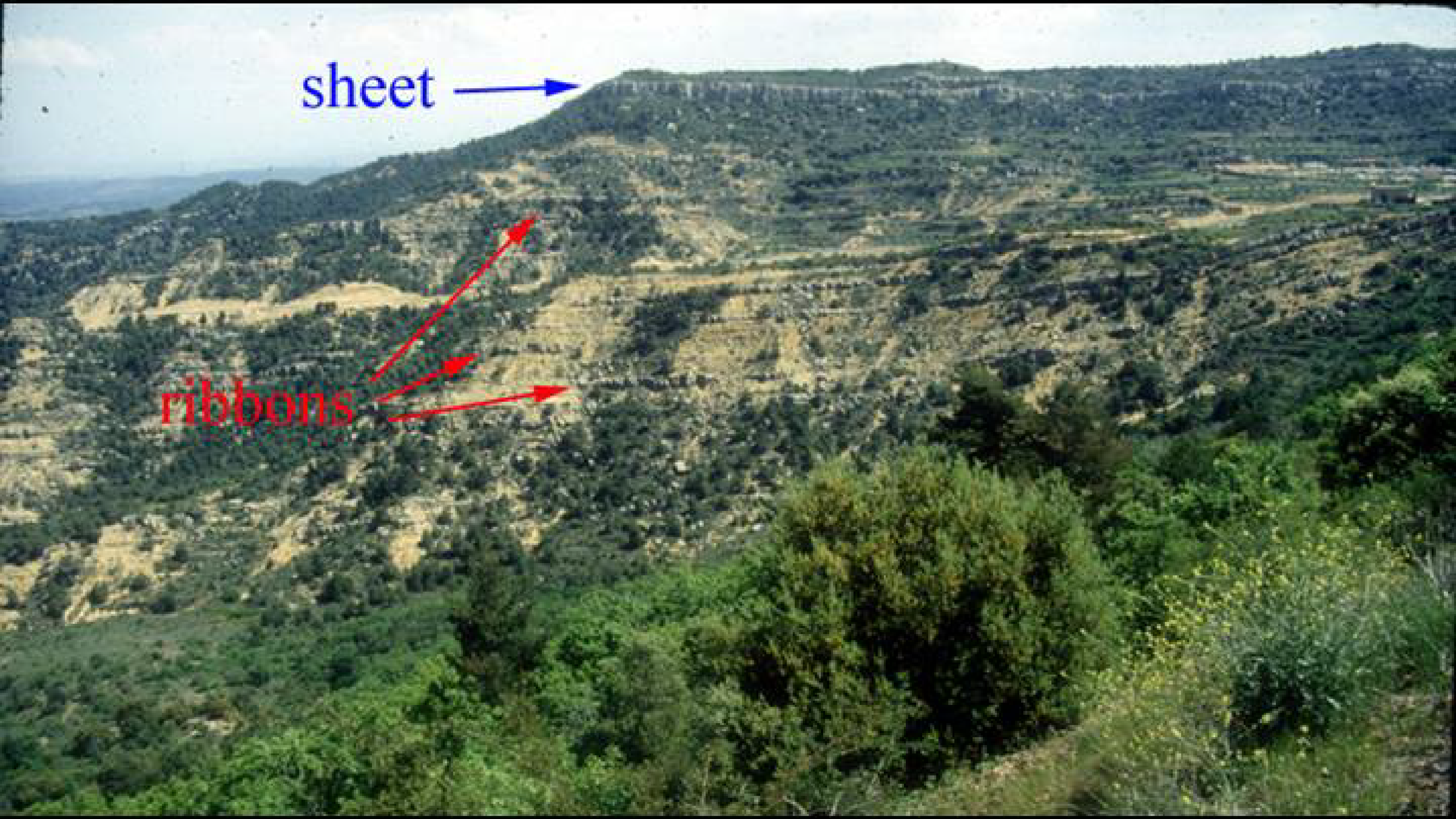


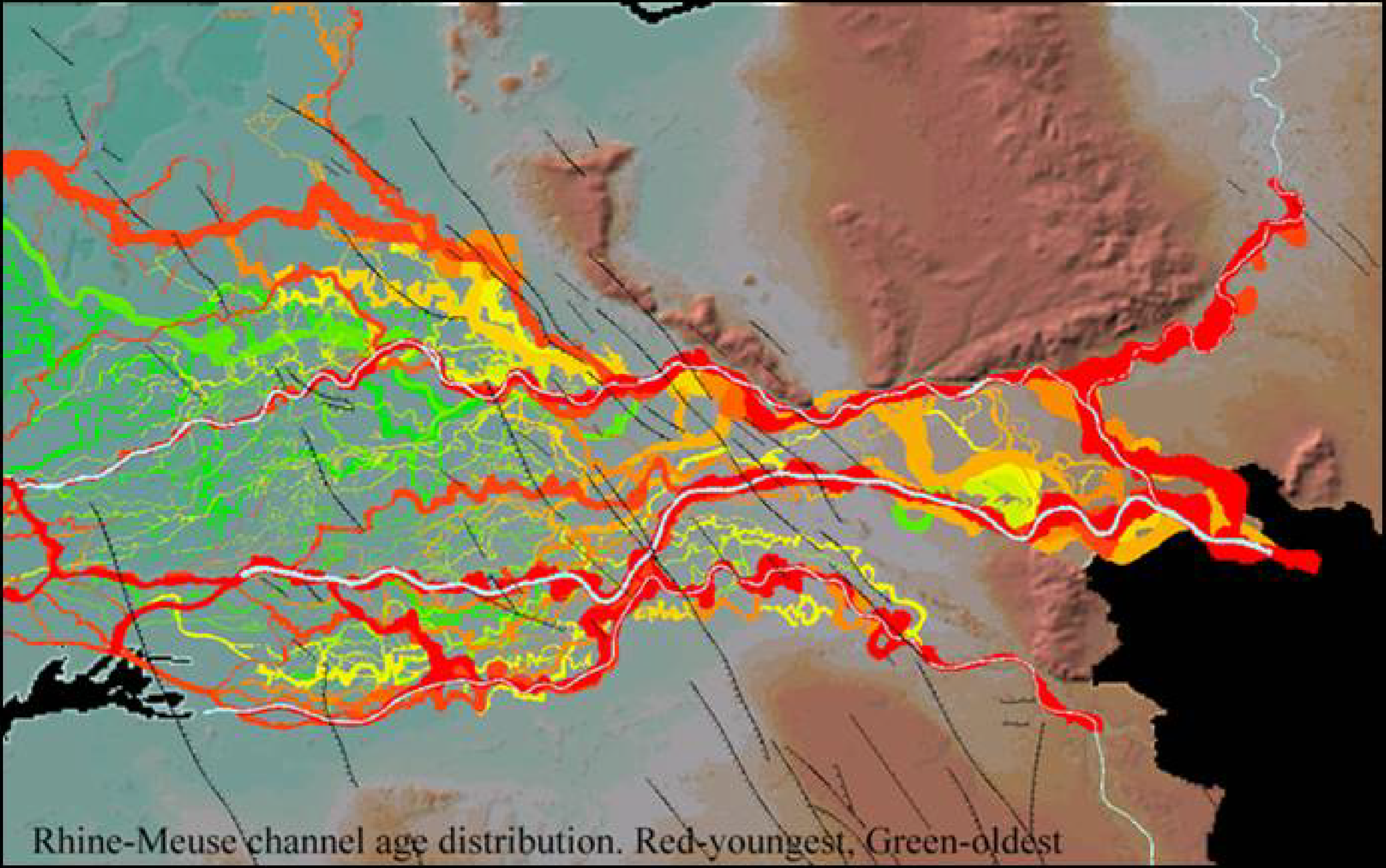
Johnson & Beaumont, 1995

Three-part hierarchy of channelized sedimentary systems

Deterministic short term	**Chaotic mid-term**	**Deterministic long term**
•Within-channel changes •Classical fluid-sediment models	•Flow switching among channels •Cellular models	•Averages out chaotic behavior •Integrated, parameterized models

(probably applies to most natural chaotic systems)

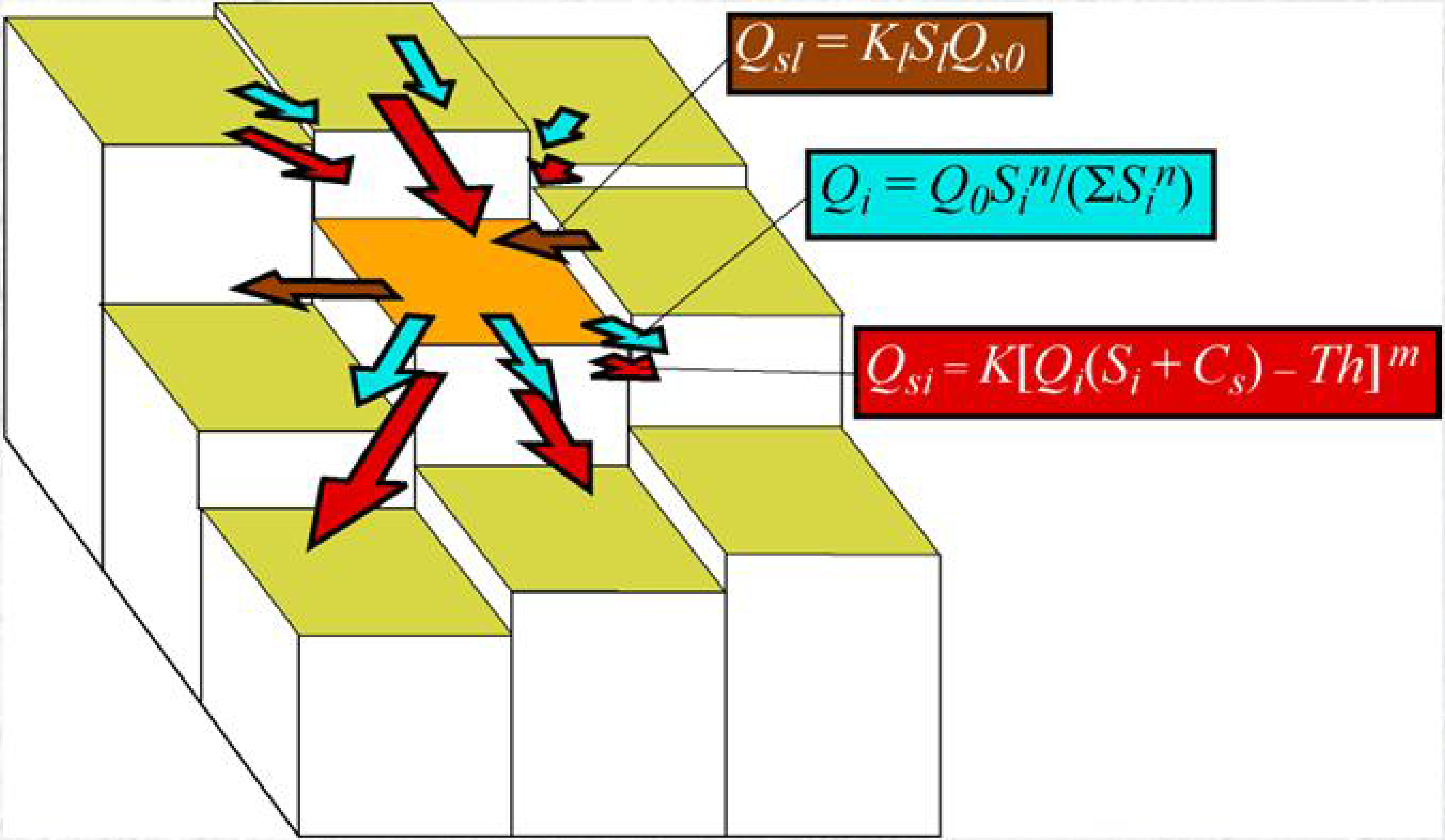

sheet
ribbons



Rhine-Meuse channel age distribution. Red-youngest, Green-oldest

Berendsen and Stouthamer (2001)

Cellular braiding

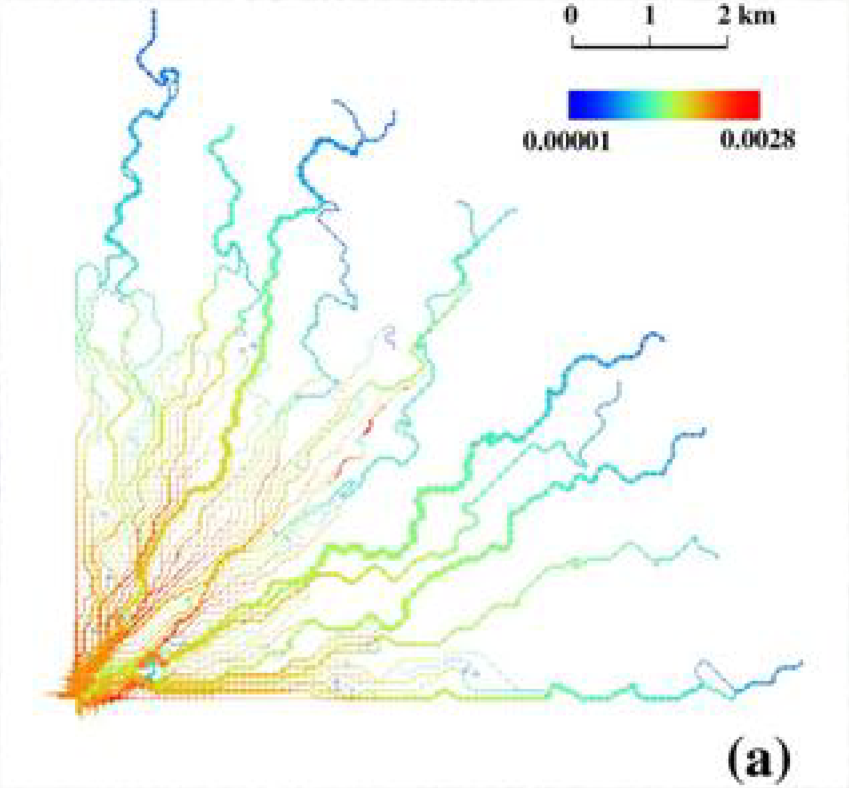


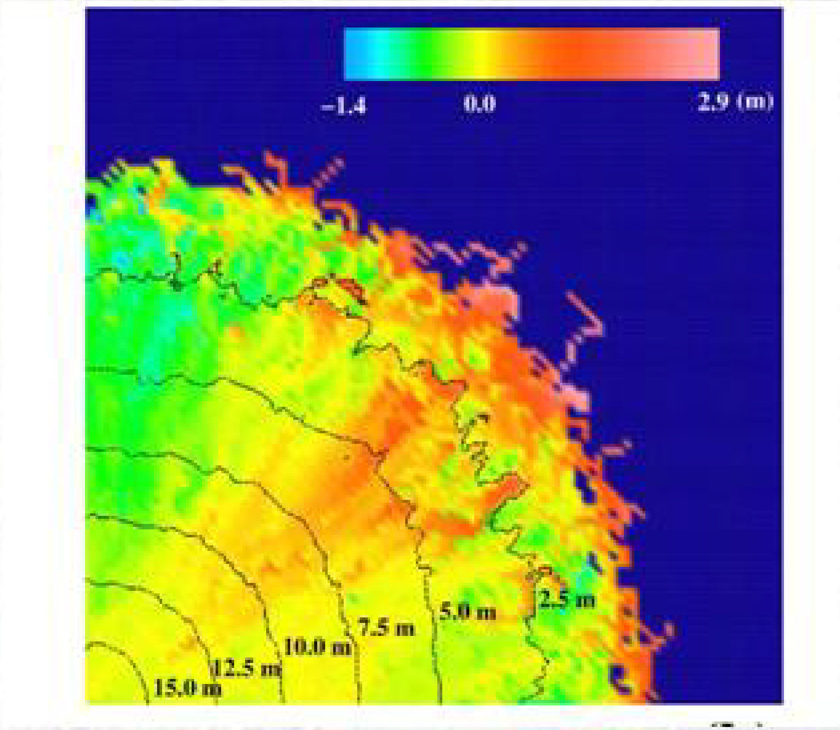
$Q_{sl} = K_l S_l Q_{s0}$

$Q_i = Q_0 S_i^n / (\Sigma S_i^n)$

$Q_{si} = K[Q_i(S_i + C_s) - Th]^m$

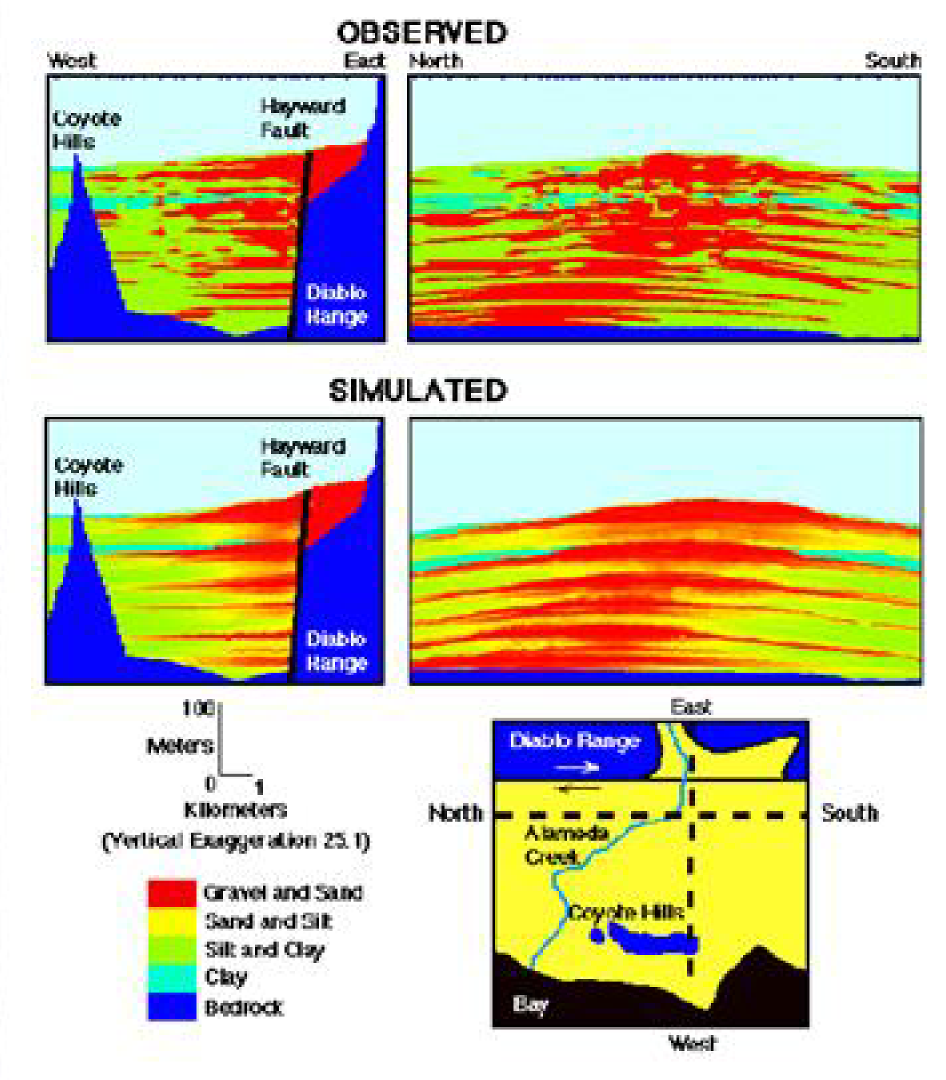
Murray & Paola (1994)





Sun et al., in press

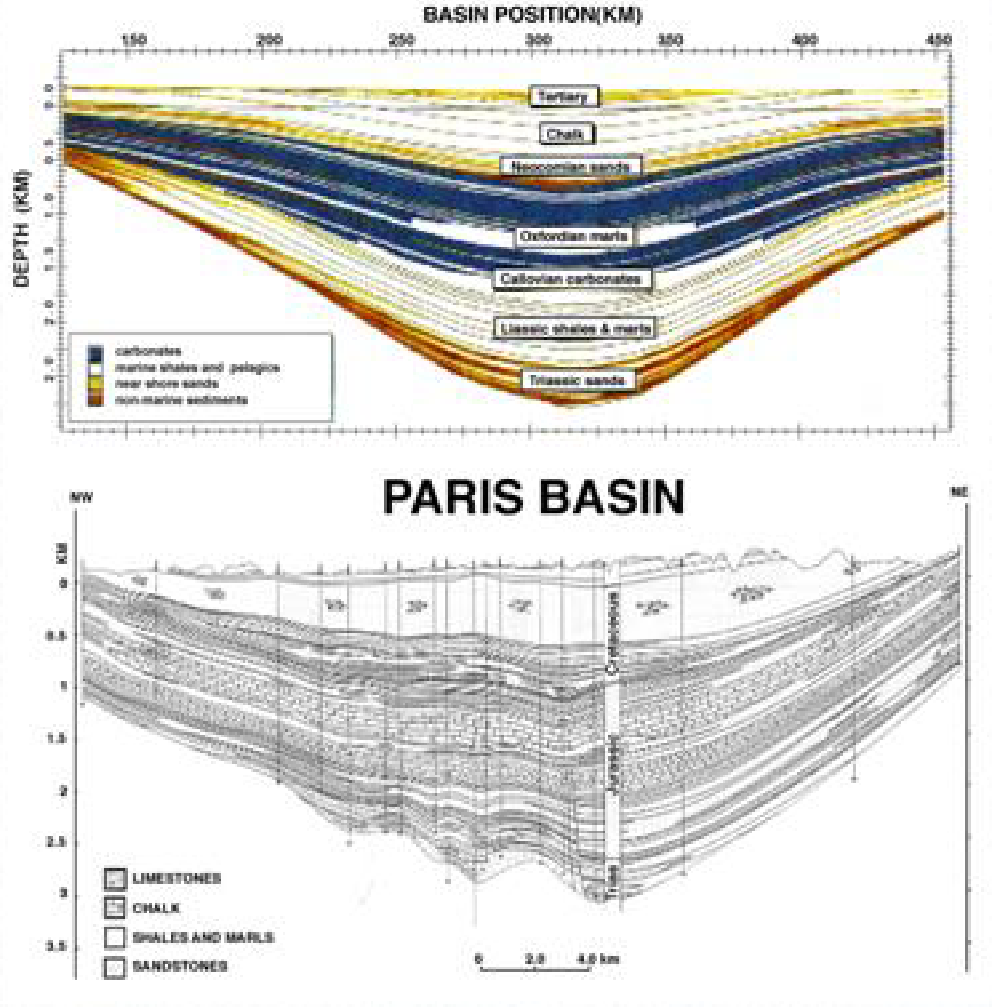
SEDSIM



- Led by John Harbaugh (Stanford)
- Uses 'marker-in-cell' method
- Mixed Eulerian-Lagrangian
- Development largely closed

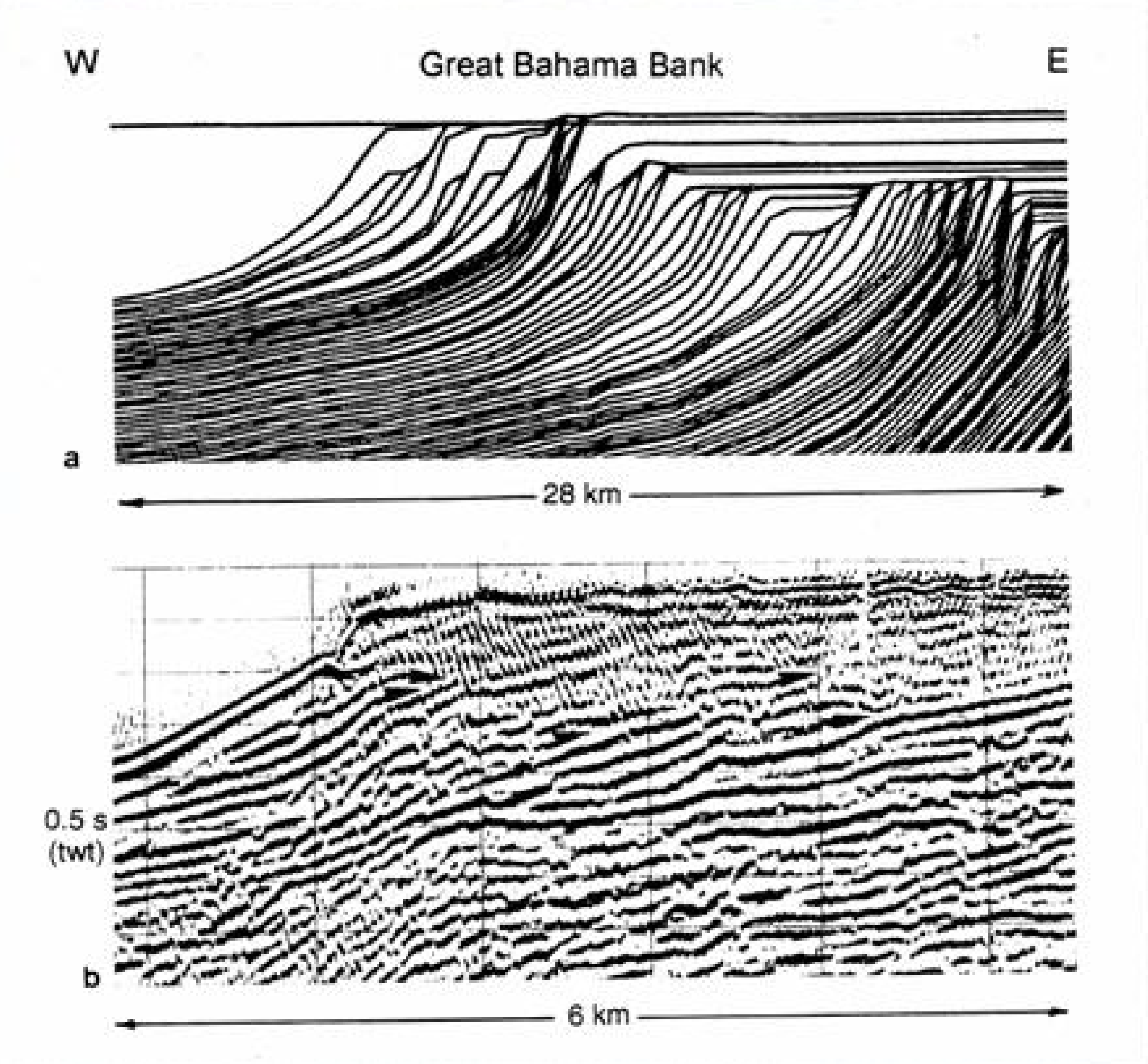
Kolterman & Gorelick (1992)

Case-study comparisons



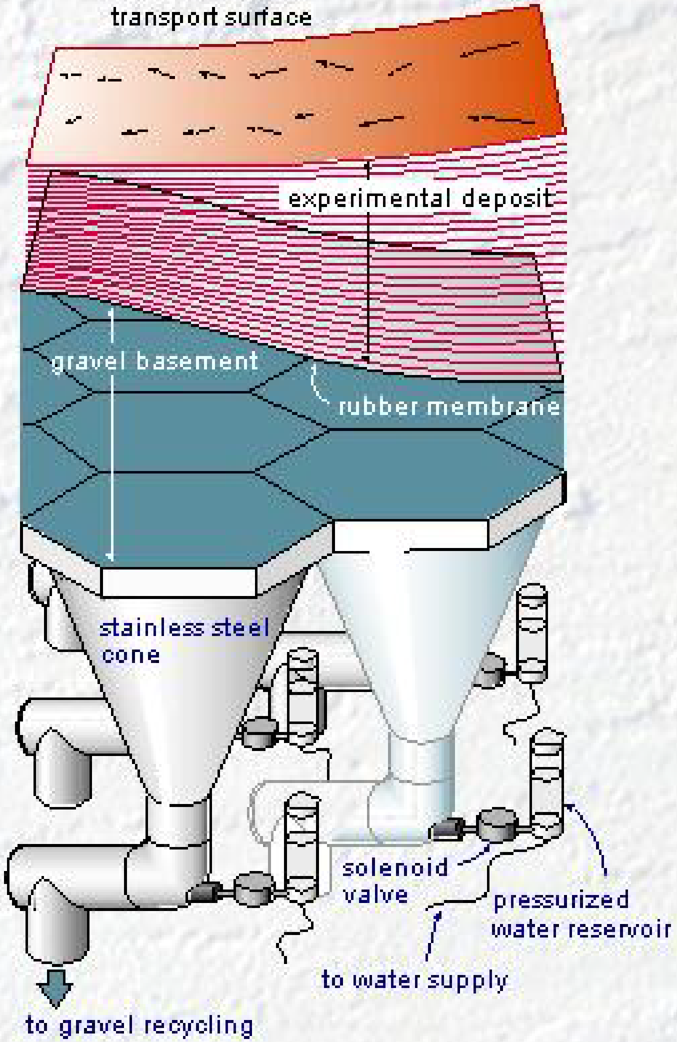
Aigner et al., 1989

Case-study comparisons

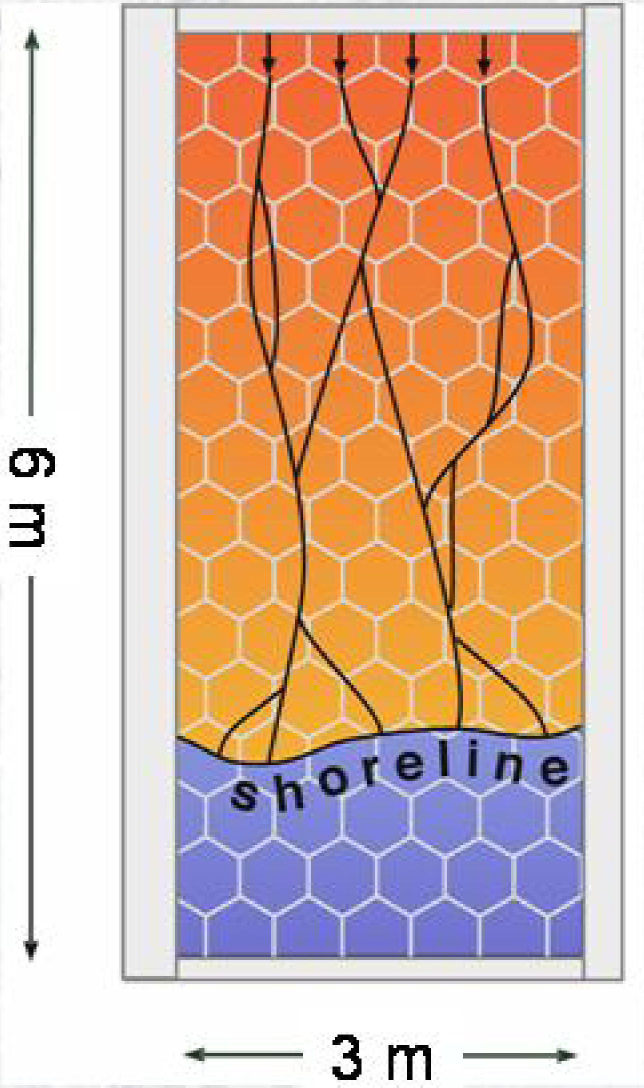


Eberli et al., 1994

"Jurassic Tank" mechanics

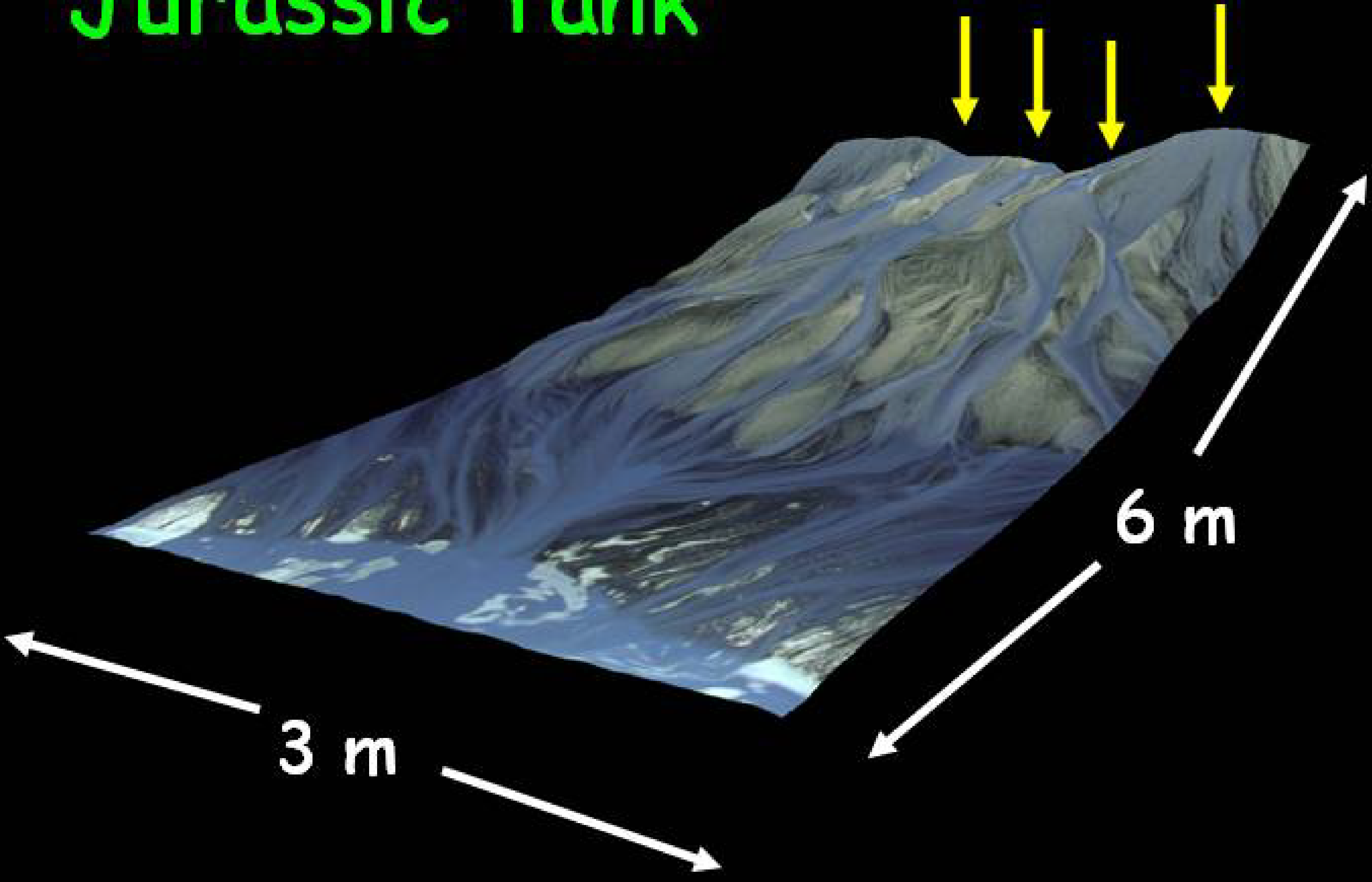


X-sectional view



Plan view

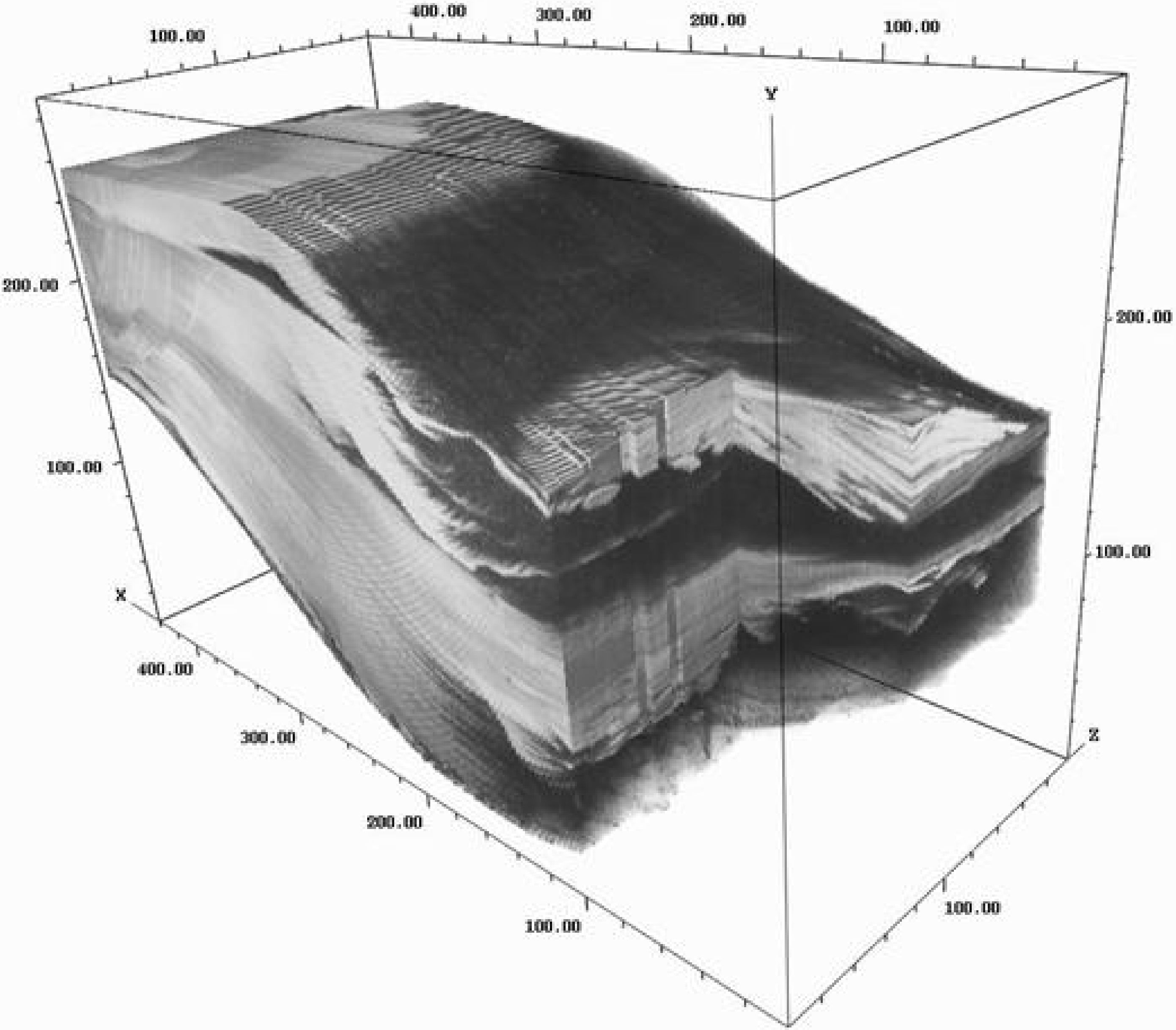
“Jurassic Tank”



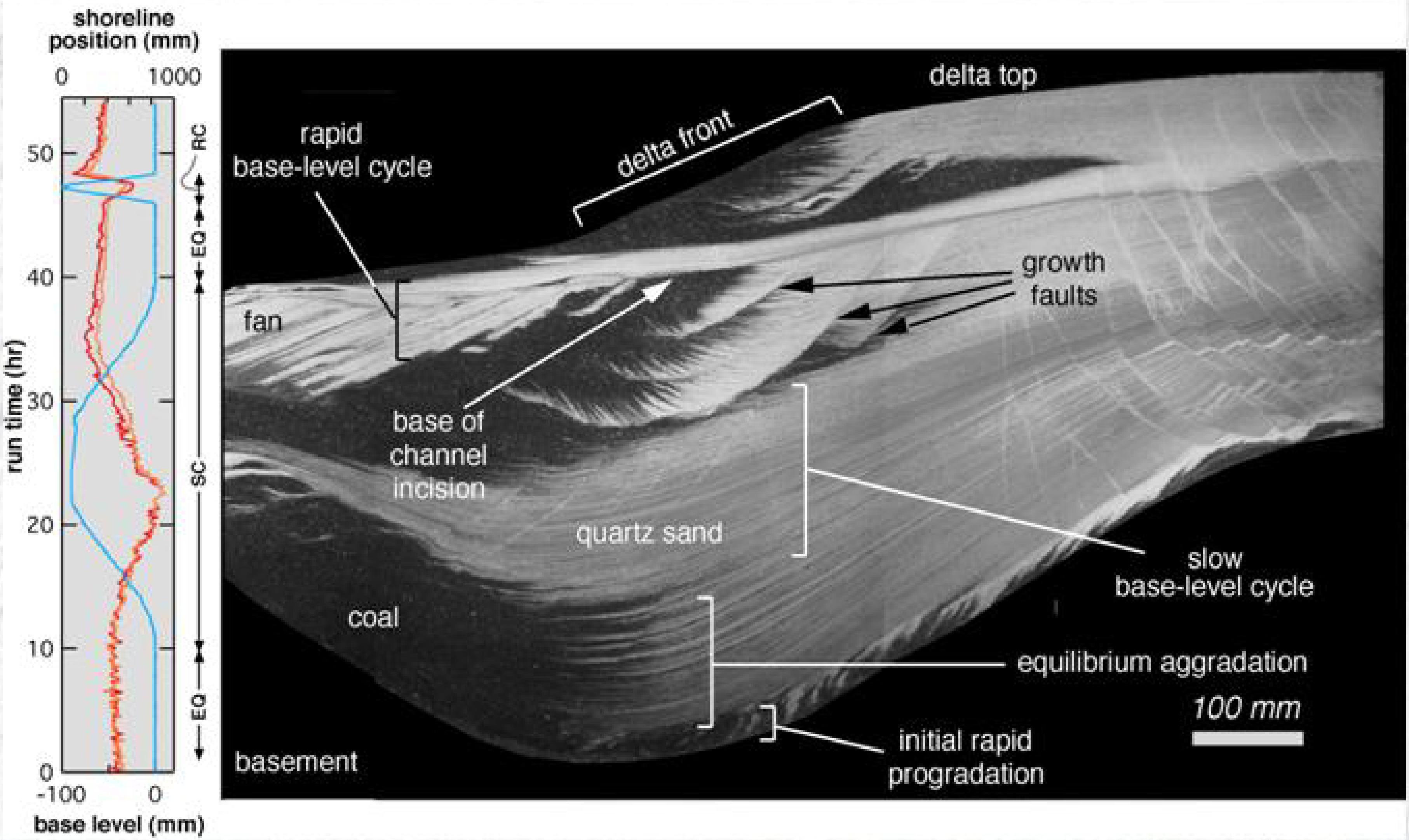
BRAIDED STREAM

Provided by: Chris Paola
St. Anthony Falls Laboratory
University of Minnesota

Experimental basin (XES) is 3 m wide, 6 m long. Water and sediment supply is continuous. Basin floor subsides continuously during experiment. Total elapsed time is 45 minutes.



100.00
400.00
300.00
200.00
100.00
Y
200.00
200.00
100.00
100.00
X
400.00
300.00
200.00
100.00
Z
100.00


shoreline position (mm)
0
1000
50
40
30
20
10
0
-100
0
base level (mm)
run time (hr)
RC
EQ
SC
EQ
rapid base-level cycle
delta front
delta top
growth faults
fan
base of channel incision
quartz sand
slow base-level cycle
coal
equilibrium aggradation
100 mm
initial rapid progradation
basement

Coarse-grained channel fills

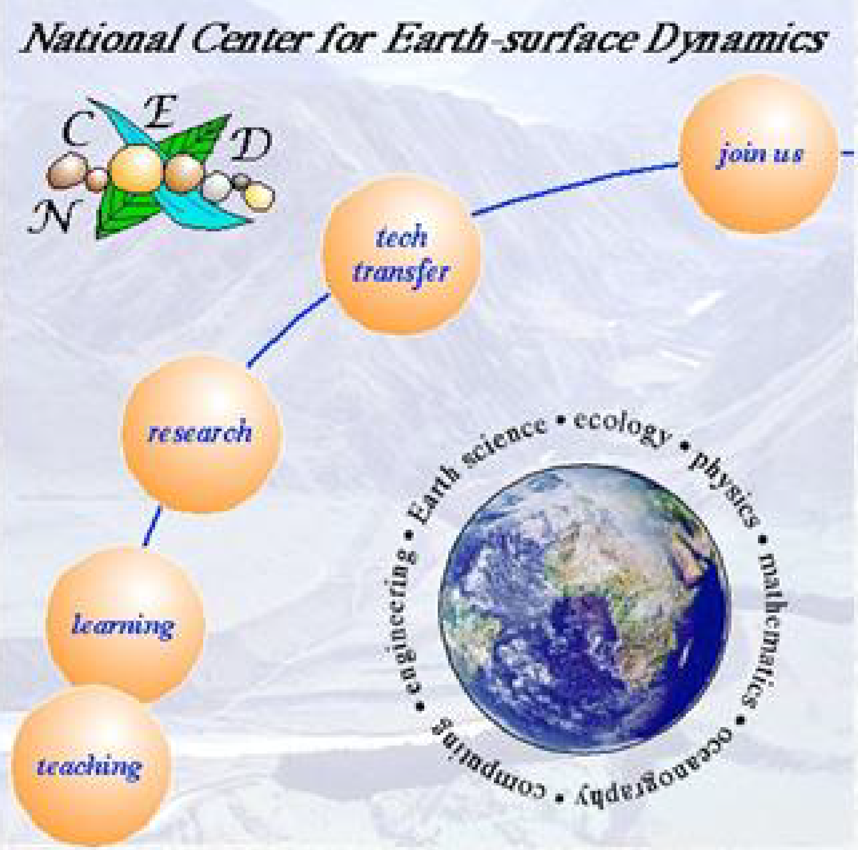
Gravel channel fill, Canterbury gravels, NZ

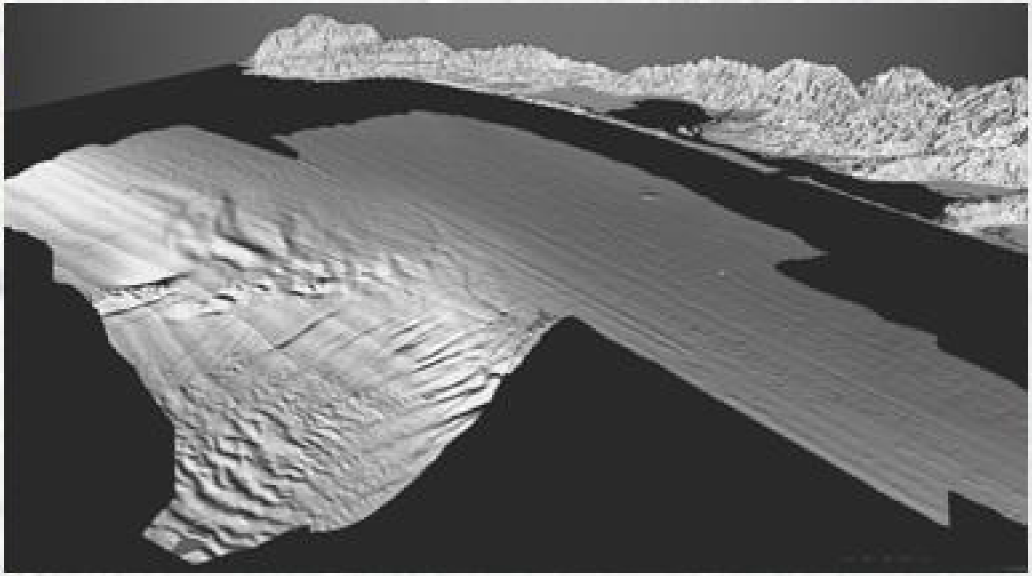
Sand channel fill, Jurassic Tank

Major CSM issues in stratigaphy

- Time averaging
- Coupling to tectonics
- Dynamic moving boundaries
- Sediment markers & mixing
- Invertibility
- Testability/constrainable parameters
- Hierarchy of complexity

Rationales and Goals





Landscape + seascape

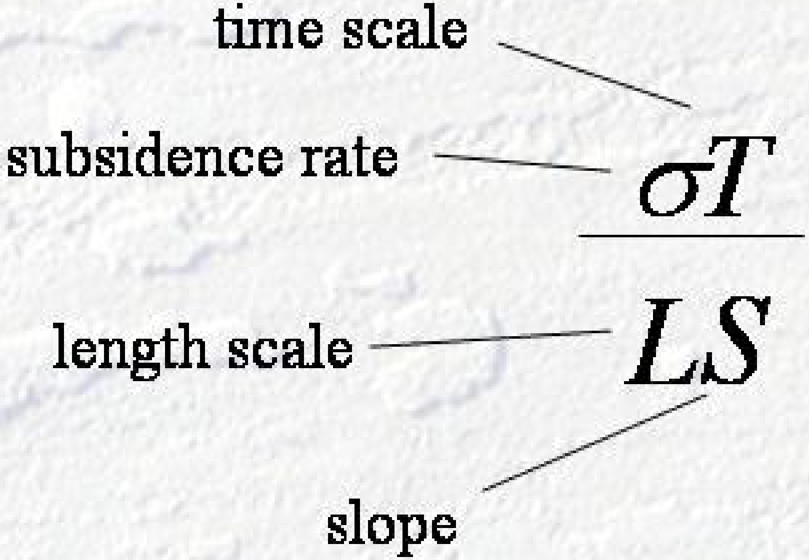
OUR CORE RESEARCH TEAM

Synergy, Analogy, Cross-Fertilization

Jill Banfield	Geomicrobiology
Bill Dietrich	Terrestrial geomorphology
Efi Foufoula	Geomorphic scaling
Miki Hondzo	Environmental fluid dynamics
David Mohrig	Submarine morphodynamics
Chris Paola	Stratigraphic modeling
Gary Parker	Engineering sediment transport
Lesley Perg	Field geomorphology
Fernando Porté-Agel	Environmental turbulence
Mary Power	Stream ecology
Ignacio Rodríguez-Iturbe	Drainage basin modeling
Vaughan Voller	Moving-boundary dynamics

Theory, Experiment, Numerical Modeling, Field

A simple scaling ratio



time scale

subsidence rate

$$\frac{\sigma T}{LS}$$

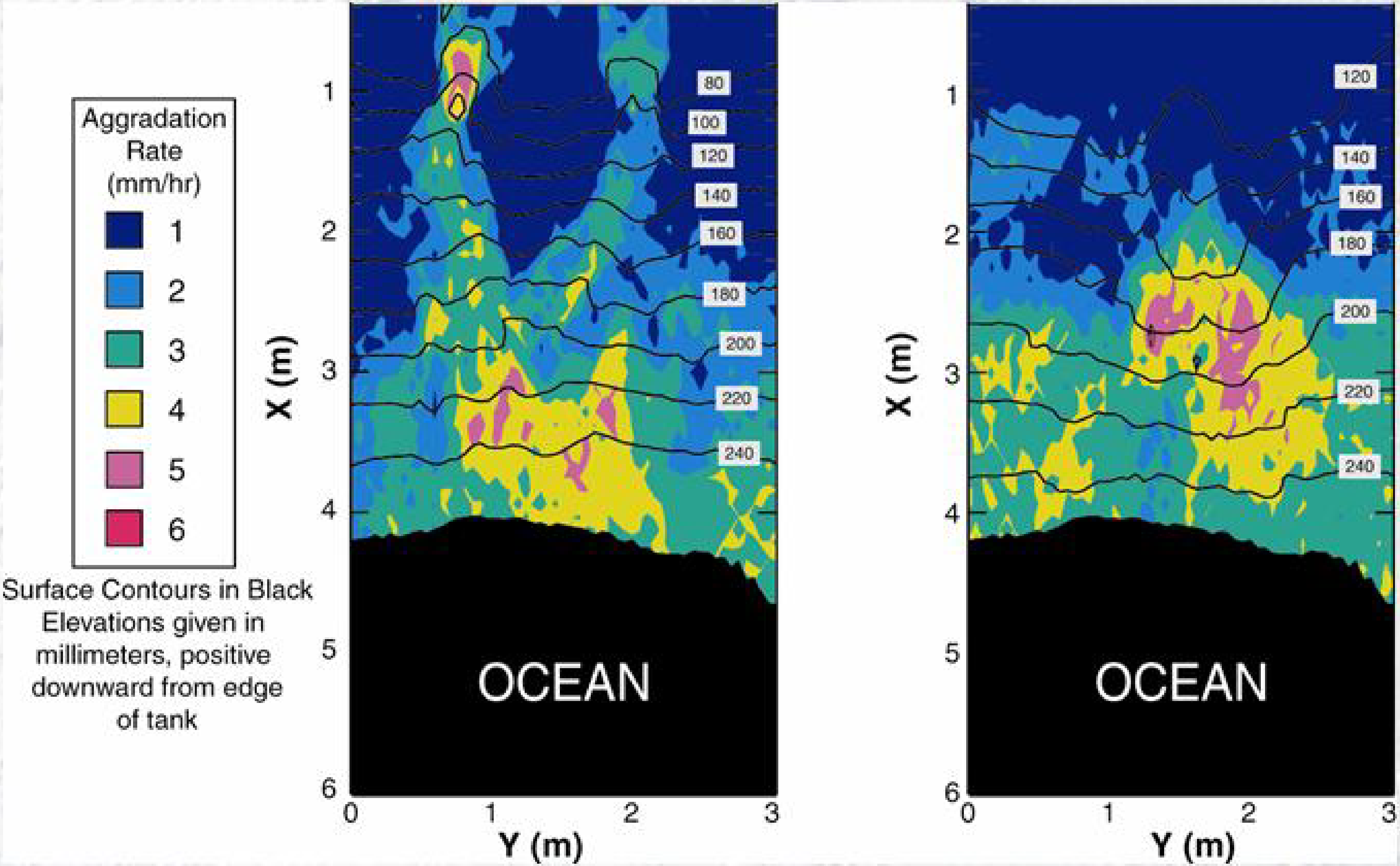
length scale

slope

$$\frac{\text{Vertical scale for sedimentation}}{\text{Vertical scale for slope changes}}$$

Geometric models are best applied to problems for which this ratio is large

Depositional Patterns



Surface Contours in Black
Elevations given in millimeters, positive downward from edge of tank

173 hours

194 hours