Universiteit Utrecht
Faculty of Geosciences
River and delta morphodynamics

# Sorting out estuaries:
## similar effects of bed armouring and inherited cohesive layers on nonalluviated behaviour of rivers and estuaries

Maarten G. Kleinhans
& Harm Jan Pierik

NWO Applied and Engineering Sciences
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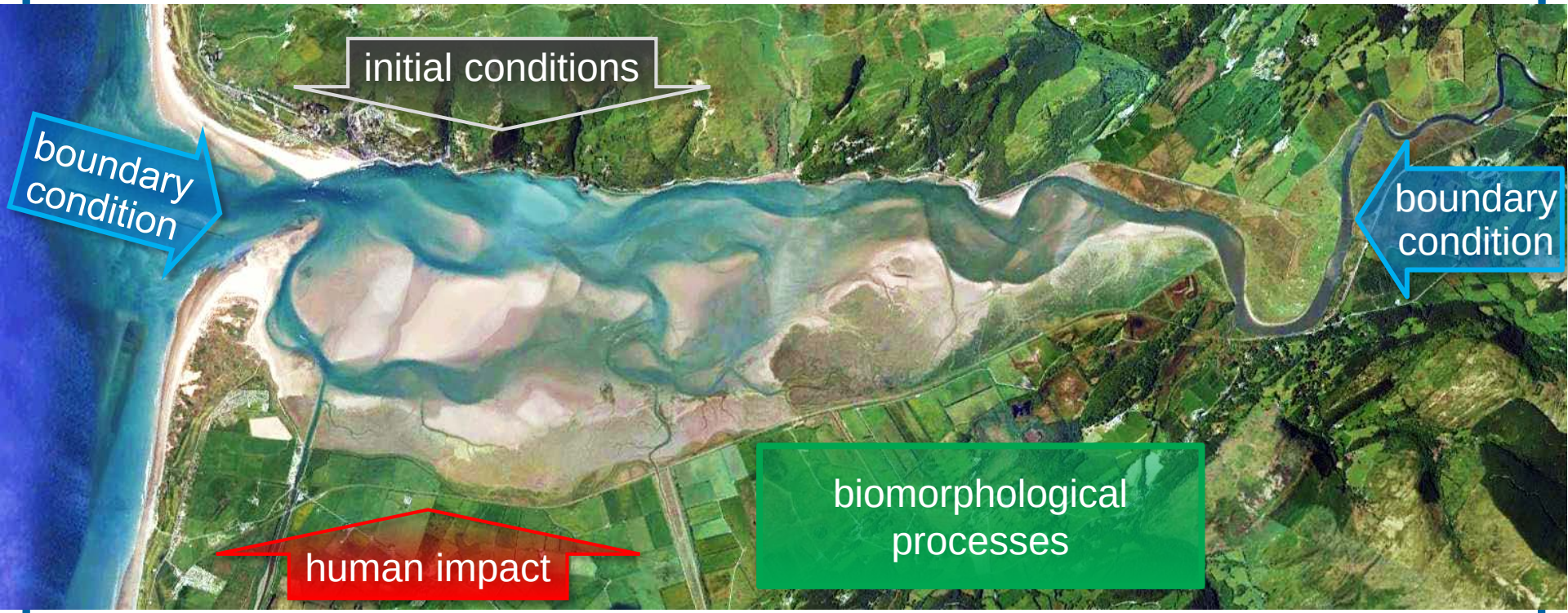
# This talk

- context: research program estuaries
- armouring in noncohesive sediment
  - sorting processes
  - effects
- cohesive and rocky substrate
  - small-scale effects
  - system-scale effects

# Dovey estuary (Wales)



# No model for past and future evolution

external

internal

fluvial+coastal drivers

?

biomorphological processes

human interference

**past & future** shape, patterns, stratigraphy

1. numerical model
2. Metronome experiments
3. test on geology

?

initial conditions

# Crash (-course) in disciplinarity

## Geology

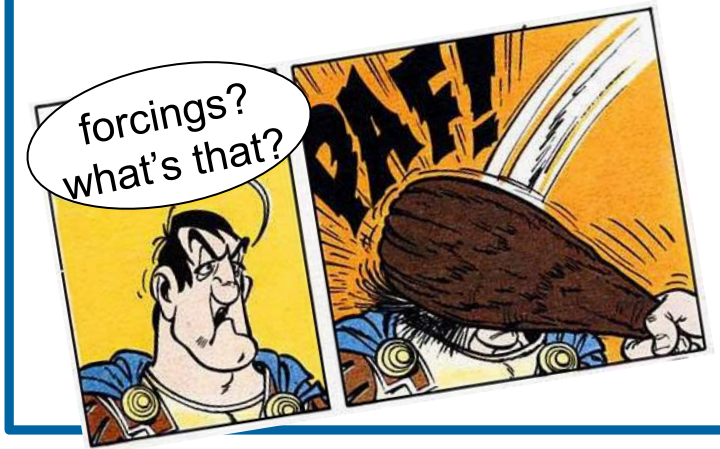
- filling up
- preservation
- forcings
- facies+dead stuff

## Geomorphology

- Sed. transport
- equilibrium
- bound. condit.
- broomstick veg.

## Ecology

- environm.+substr.
- food chains
- competition
- birth & mortality



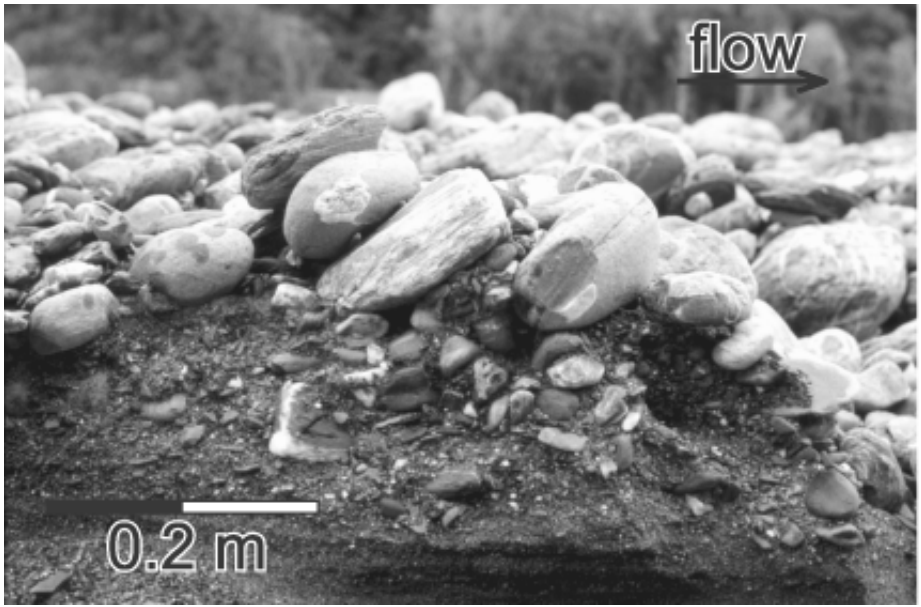

Ontology of animals:

- things to run away from
- things to eat
- things to mate with
- rocks

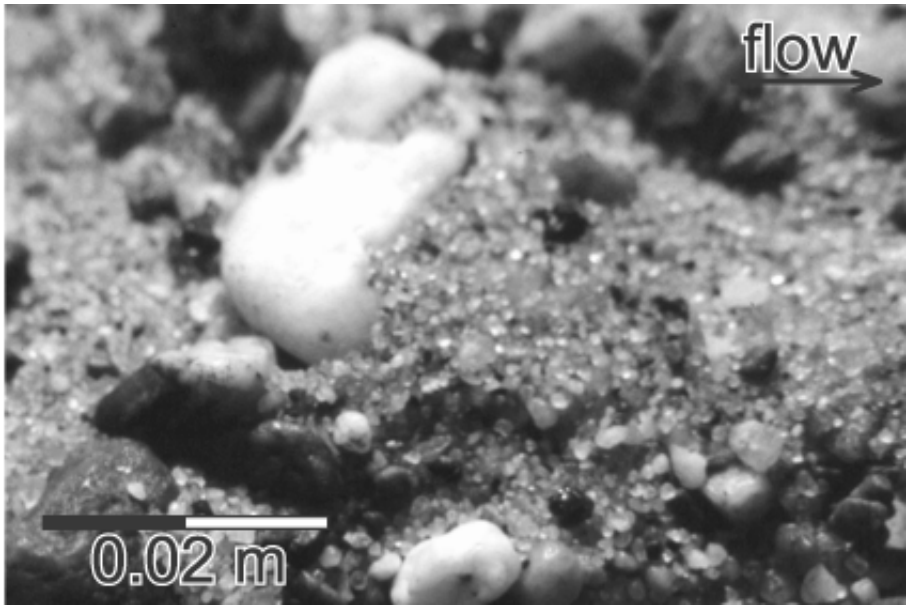
*Terry Pratchett*

# Sorting out sand and gravel

armouring

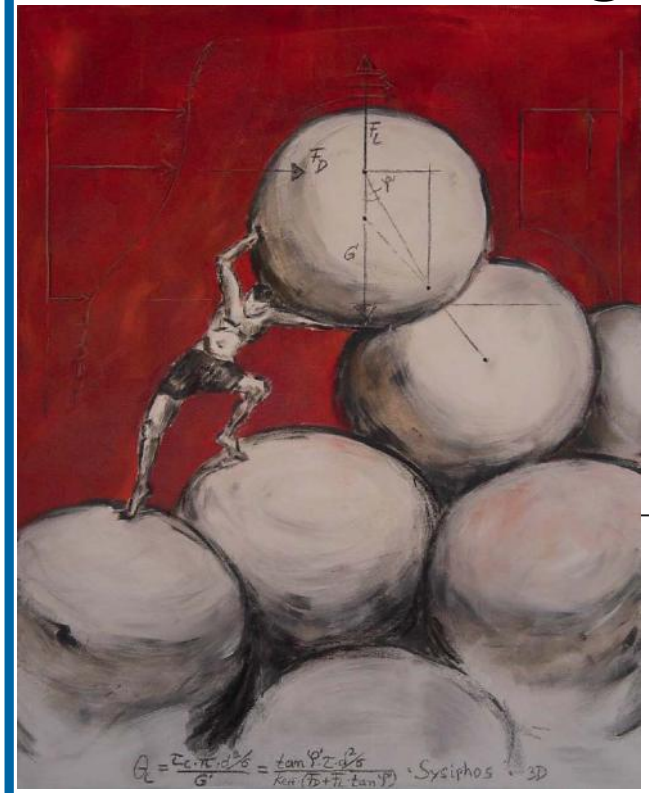


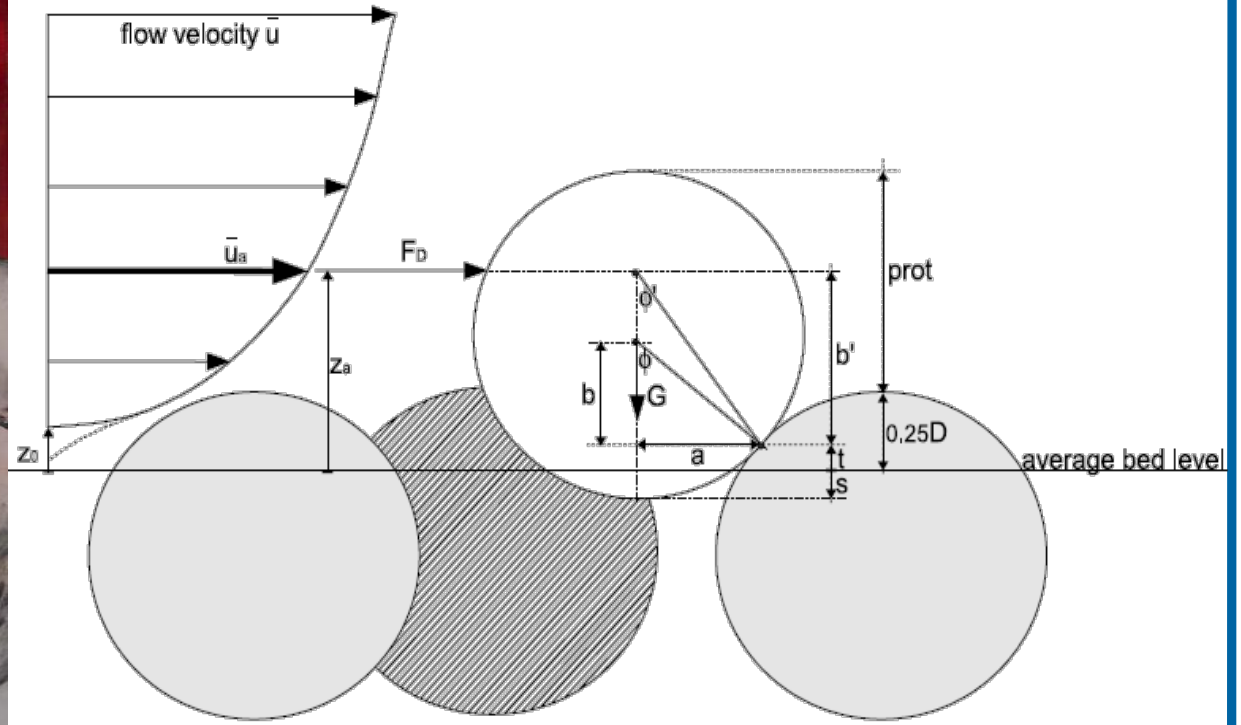

hiding



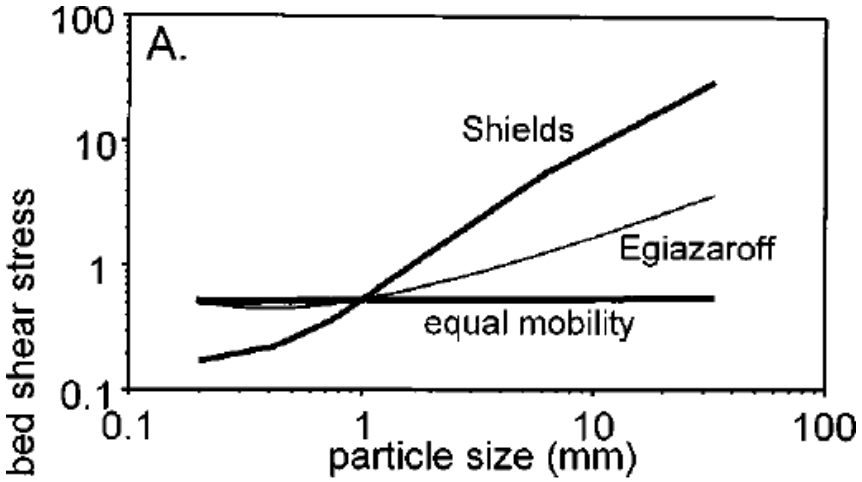

Kleinhans 2002 PhD thesis

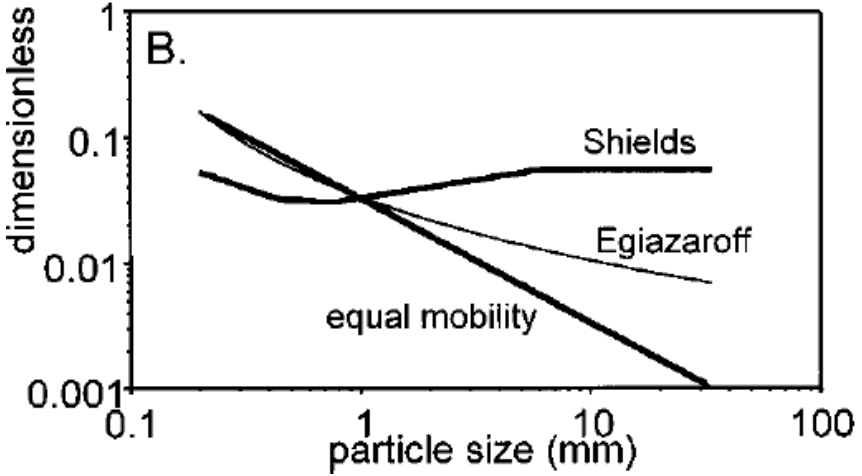
# Begin at the beginning

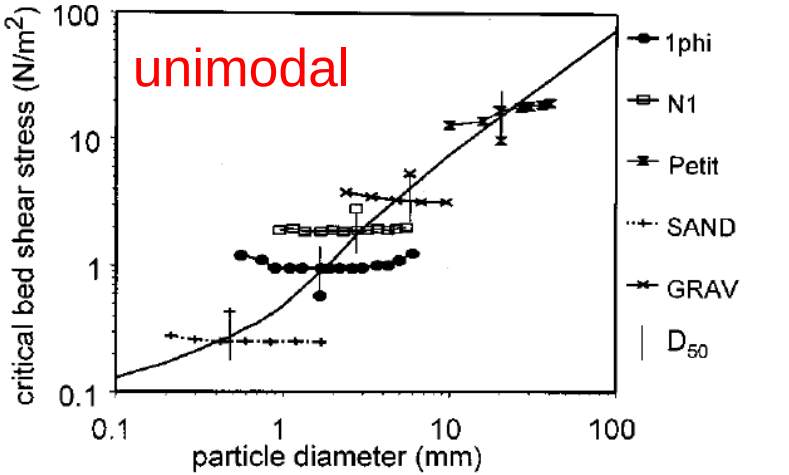


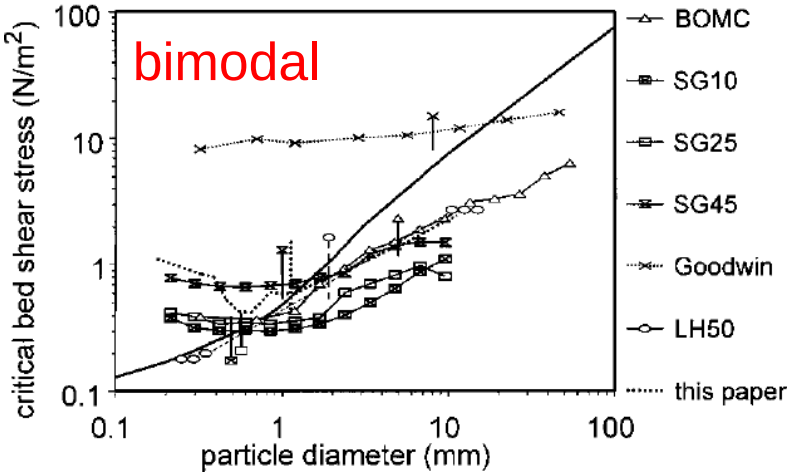



Vollmer & Kleinhans 2007 WRR



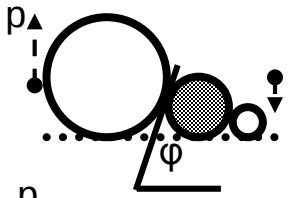




Kleinhans & van Rijn 2002 JHE

# Mixture → exposure and pivot angle

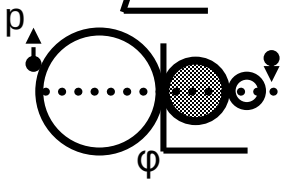
same floor




$\cos\varphi = (D_i - D_m)/(D_i + D_m)$

$p = D_i - D_m \quad (E = p/D_m)$

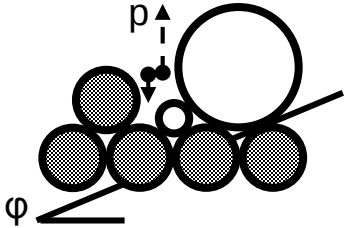
same centre




$\cos\varphi = \pi/2$

$p = (D_i - D_m)/2$

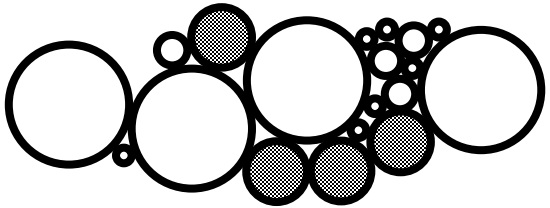
on Dm




$\sin\varphi = 2D_m/(D_i + D_m)$

$p = (D_m/\tan\varphi + D_i - D_m)/2$

Buffington, Kirchner

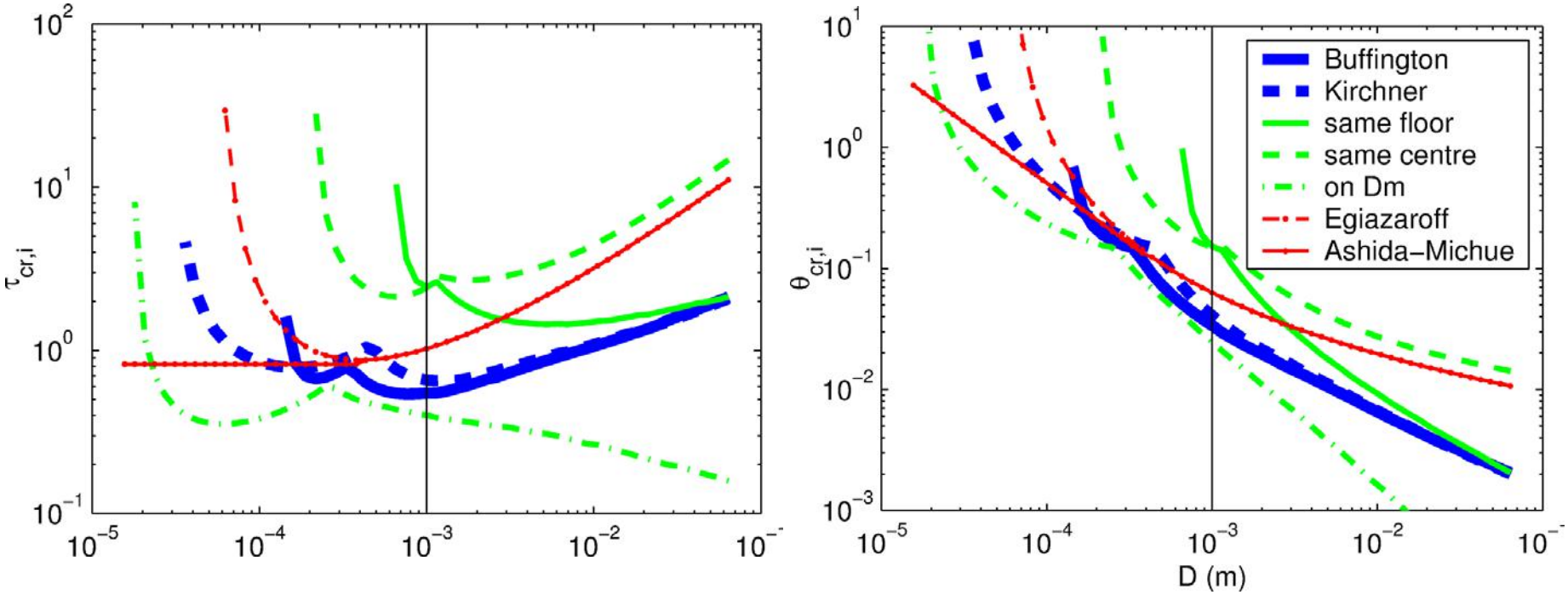


$\varphi = f(D_i, p_i)$

$E = f(D_i, p_i)$

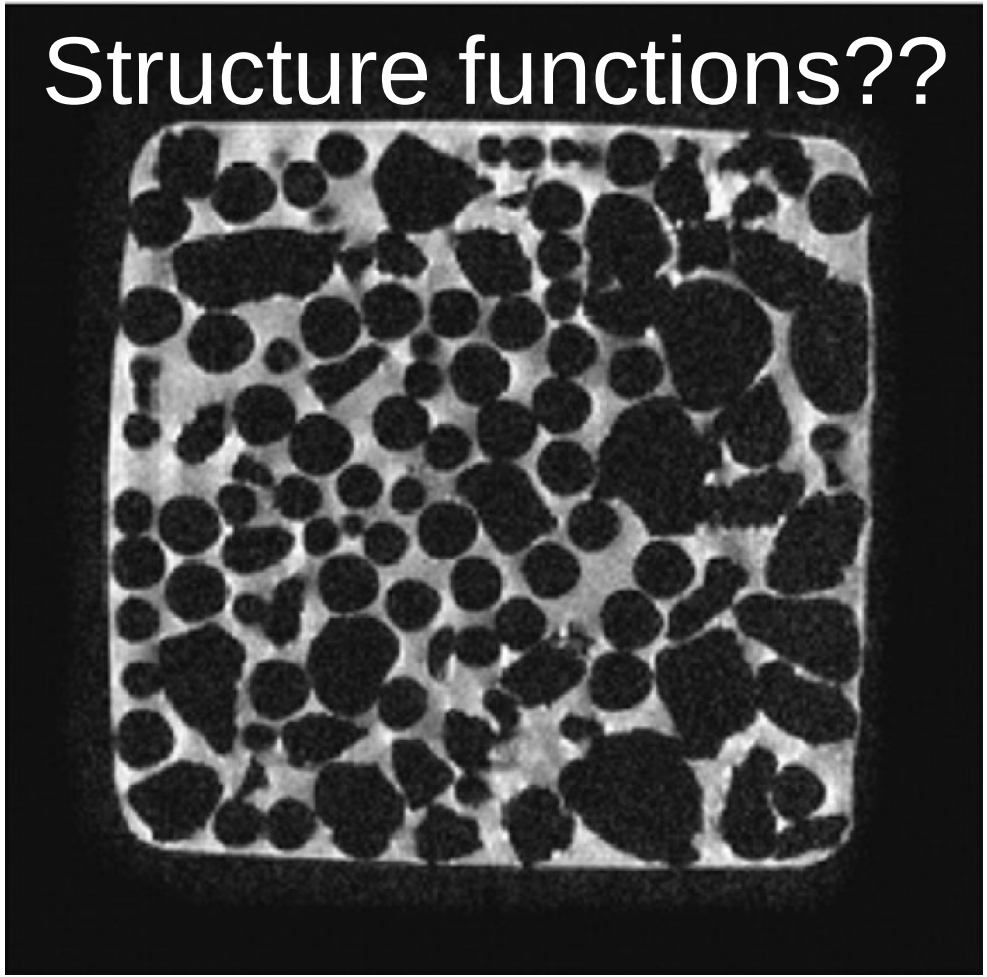
Vollmer & Kleinhans 2007 RCEM

# Hiding depends on particle configuration




Vollmer & Kleinhans 2007 RCEM

# Structure functions??

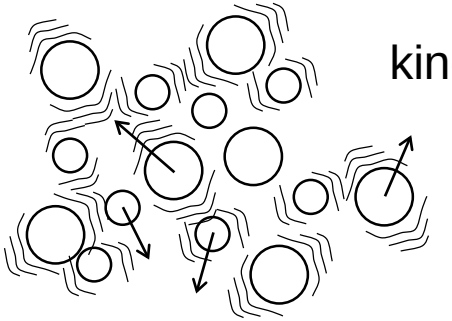


Kleinhans et al. 2008 SedGeo

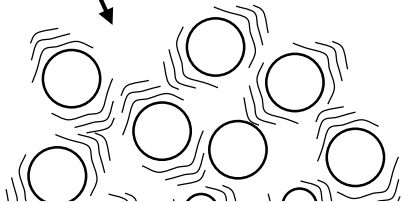
# Brazil nut effect

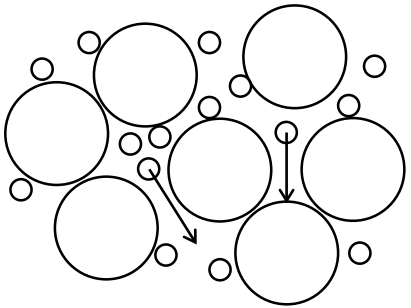
- Sorting in motion

# Sorting mechanisms

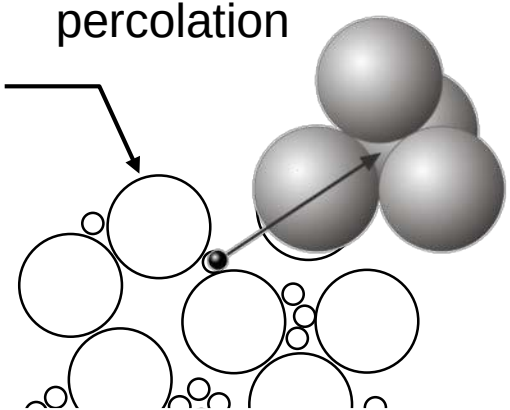


kinematic sorting

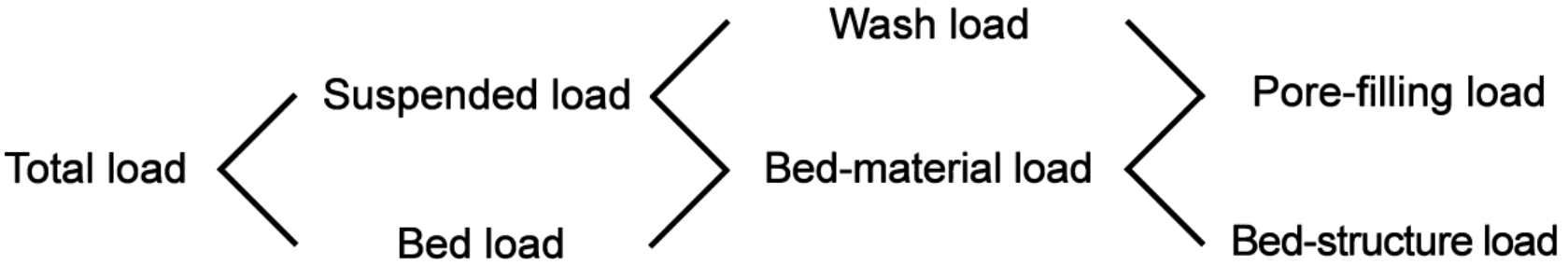




percolation



Tetrahedral packing
$D_{small}/D_{large}$=0.155

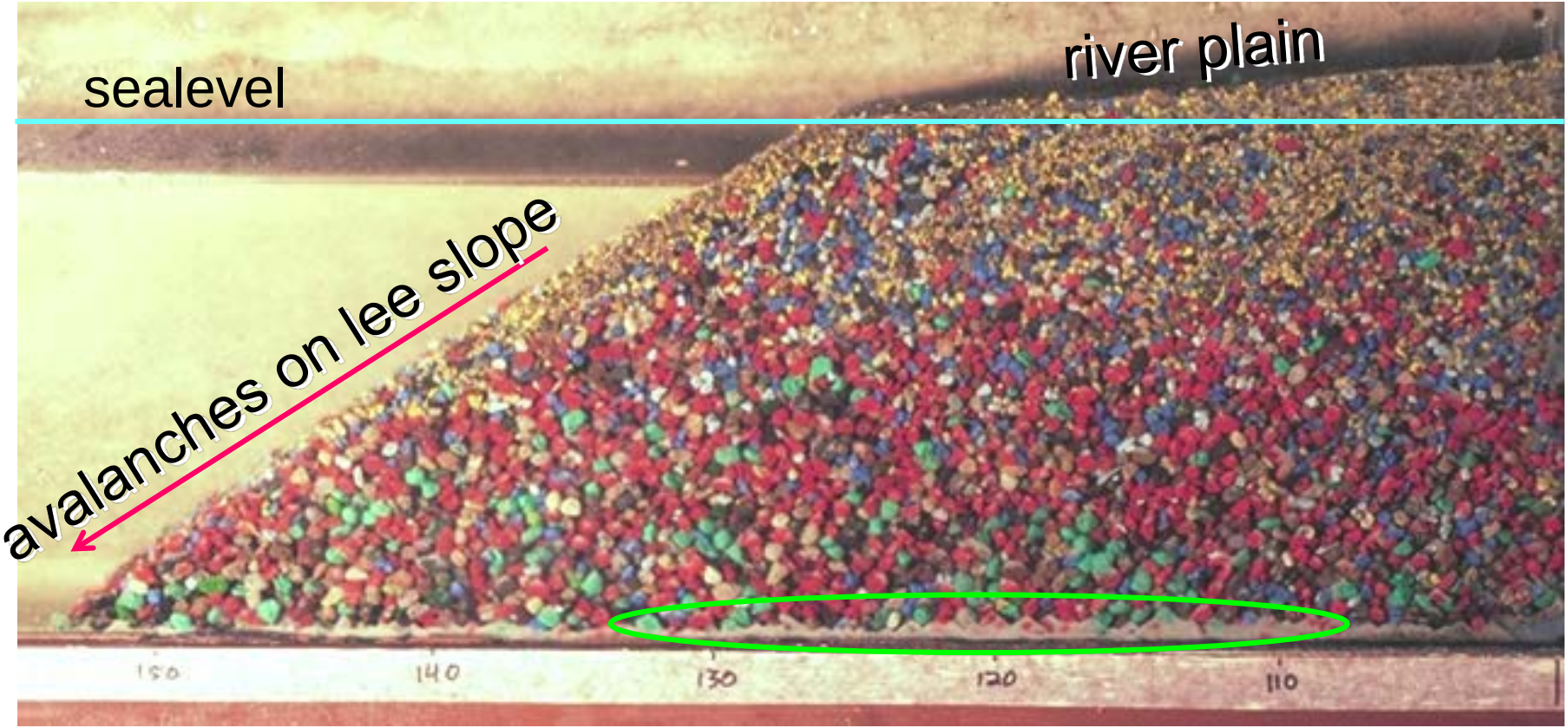



Kleinhans 2004 ESR, Frings et al. 2008 Sed

# Sorting at dune scale


Kleinhans 2005 SANDPIT

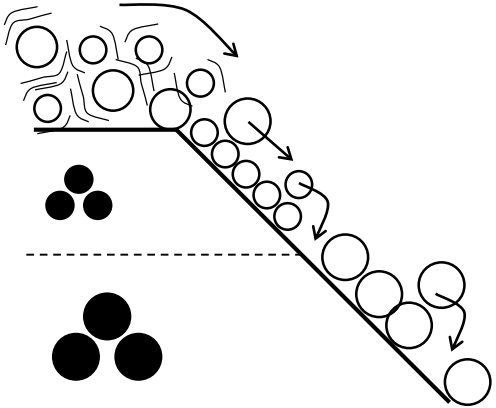
# Sorting in avalanches



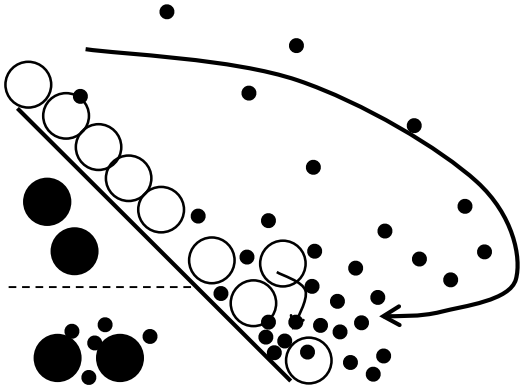

Kleinhans 2005 Sedimentology

# Sorting mechanisms in dunes

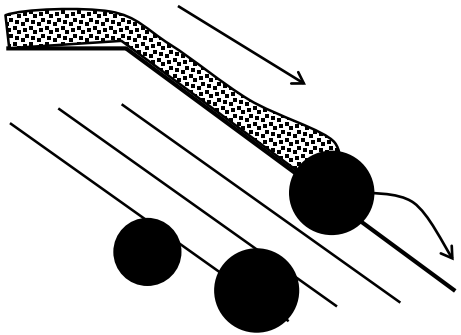
sorting in avalanche



suspension

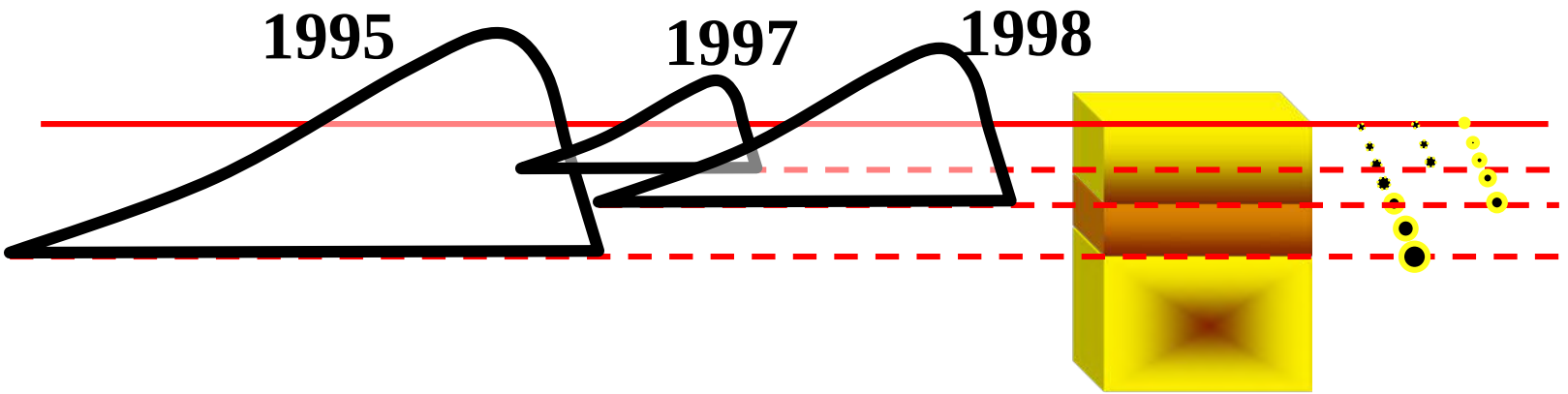


drag

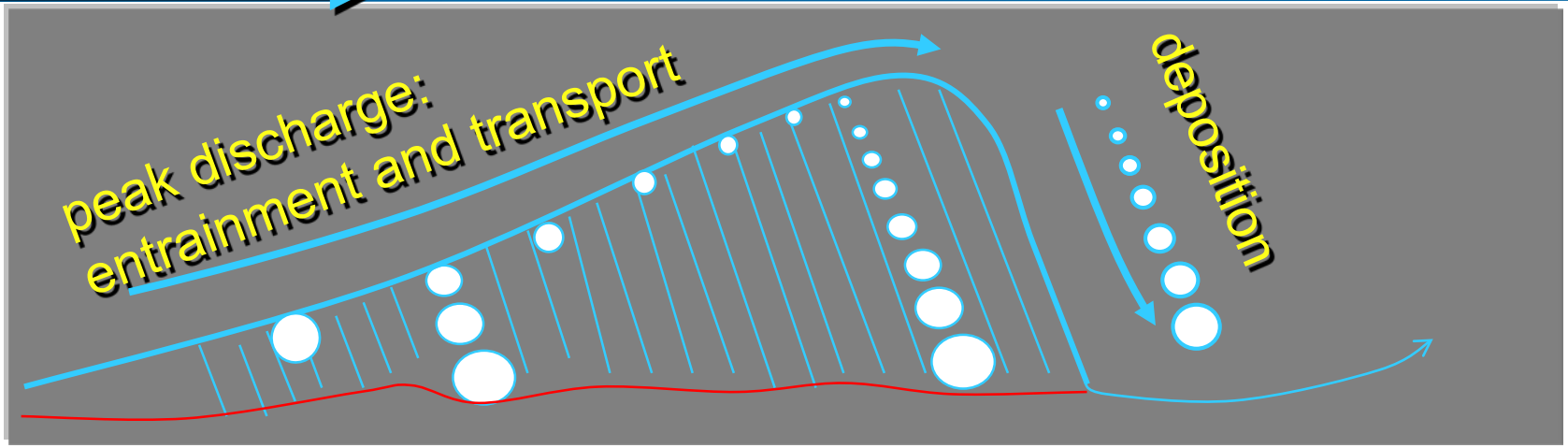


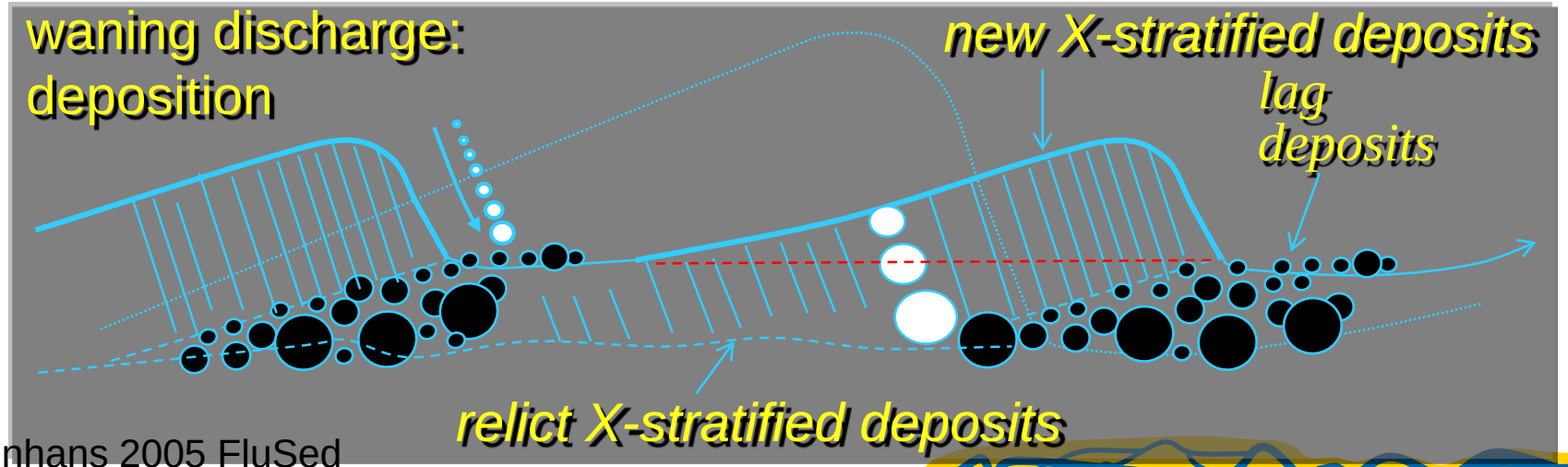
Kleinhans 2004 ESR

# Effects of sorting on transport

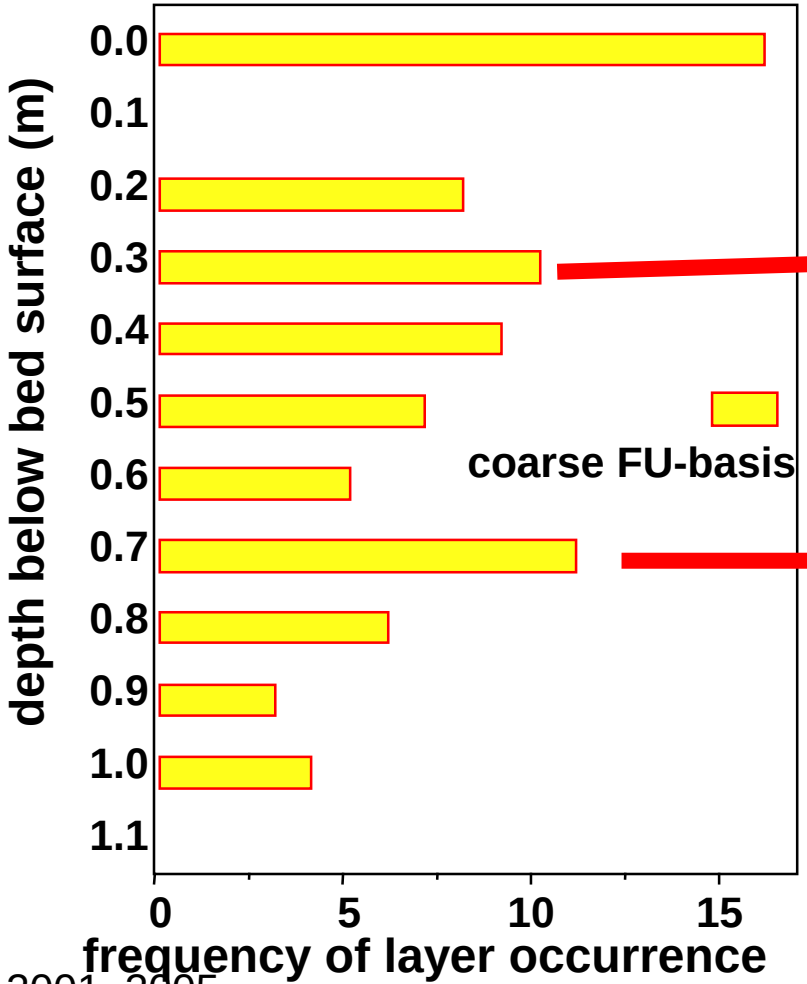


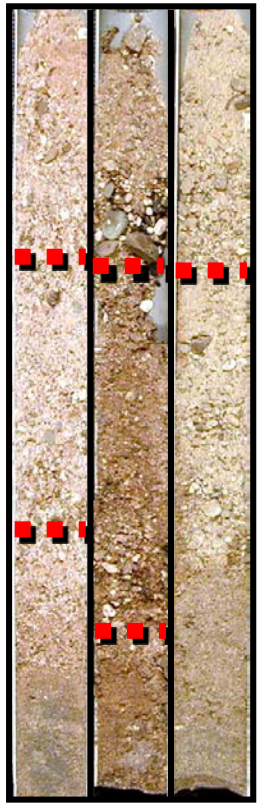

Kleinhans 2001, 2005




Kleinhans 2005 FluSed



observed trough level 1995

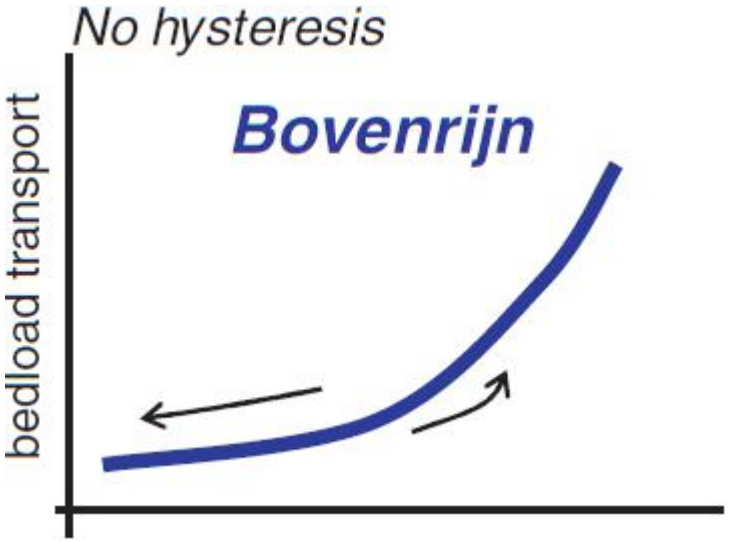
observed trough level 1998

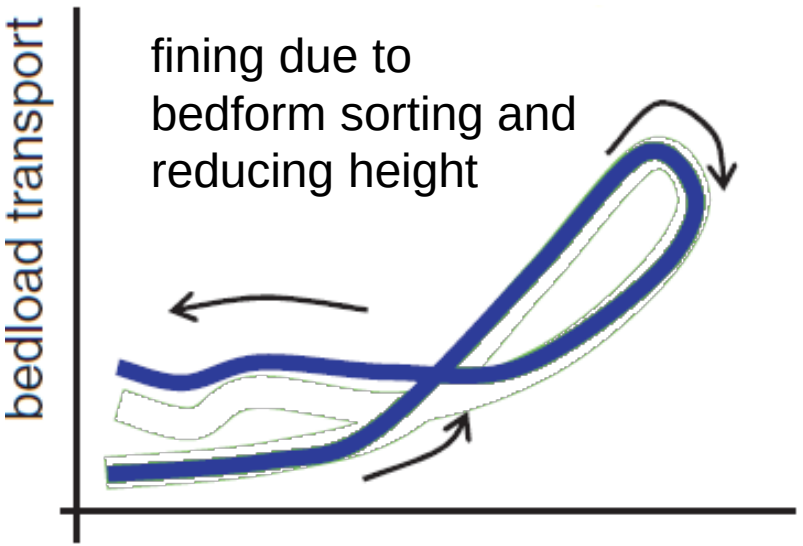
***coarse*** layer

***= 'armour' layer!***

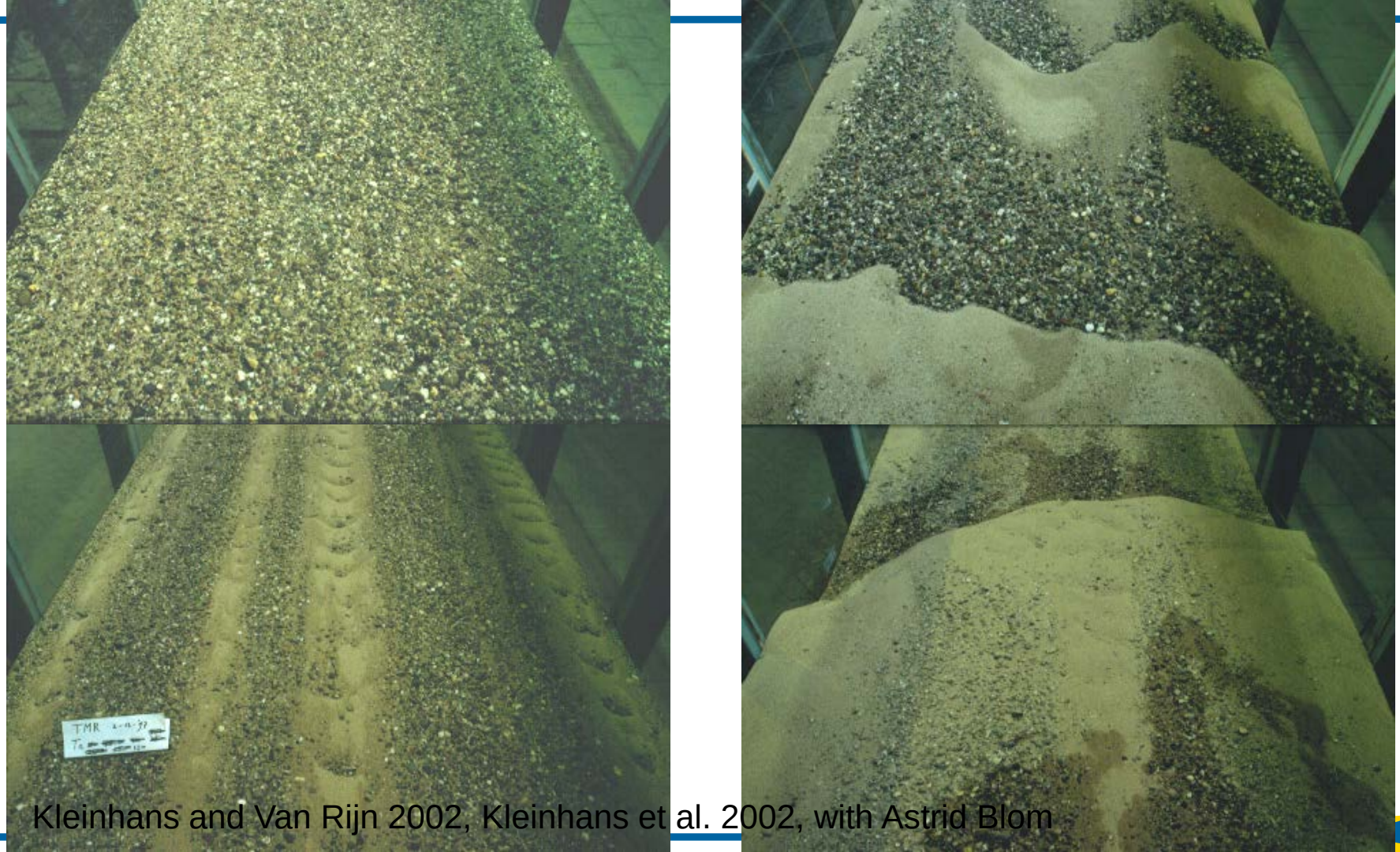
Kleinhans 2001, 2005

# Effect on transport



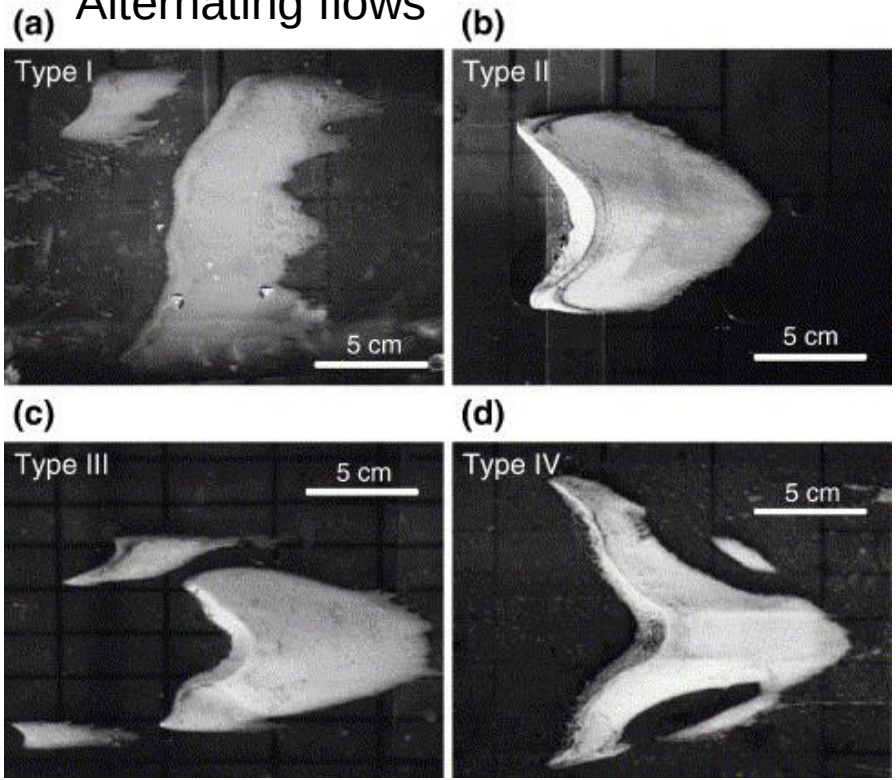

Kleinhans et al. 2007 NJG



Kleinhans and Van Rijn 2002, Kleinhans et al. 2002, with Astrid Blom

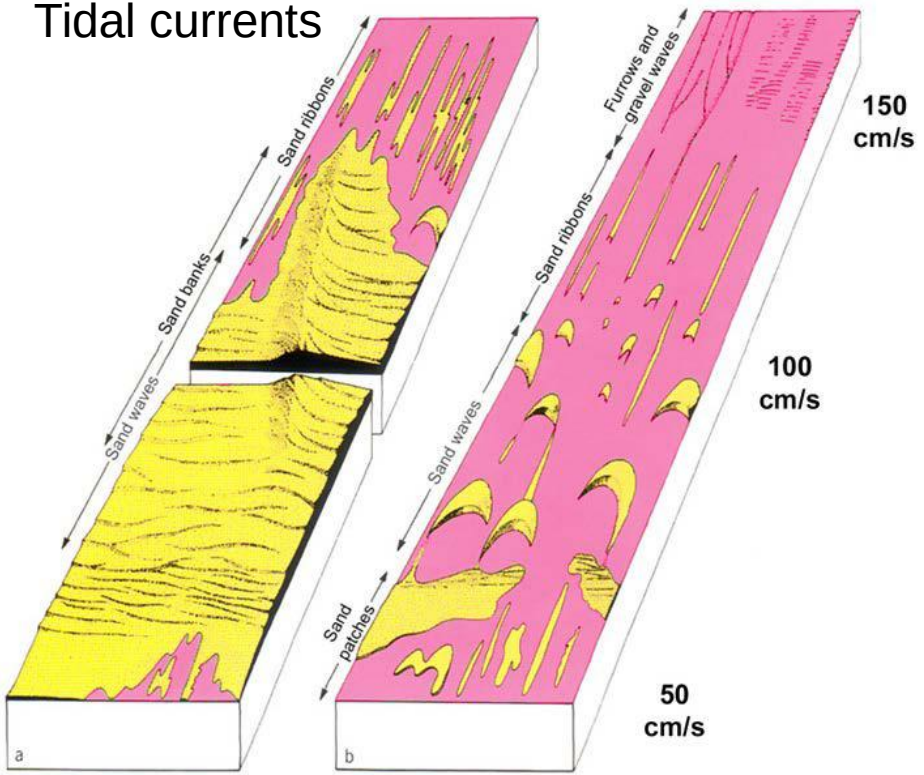
# Barchans in coastal waterscapes

Alternating flows




Taniguchi and Endo 2007 Geom

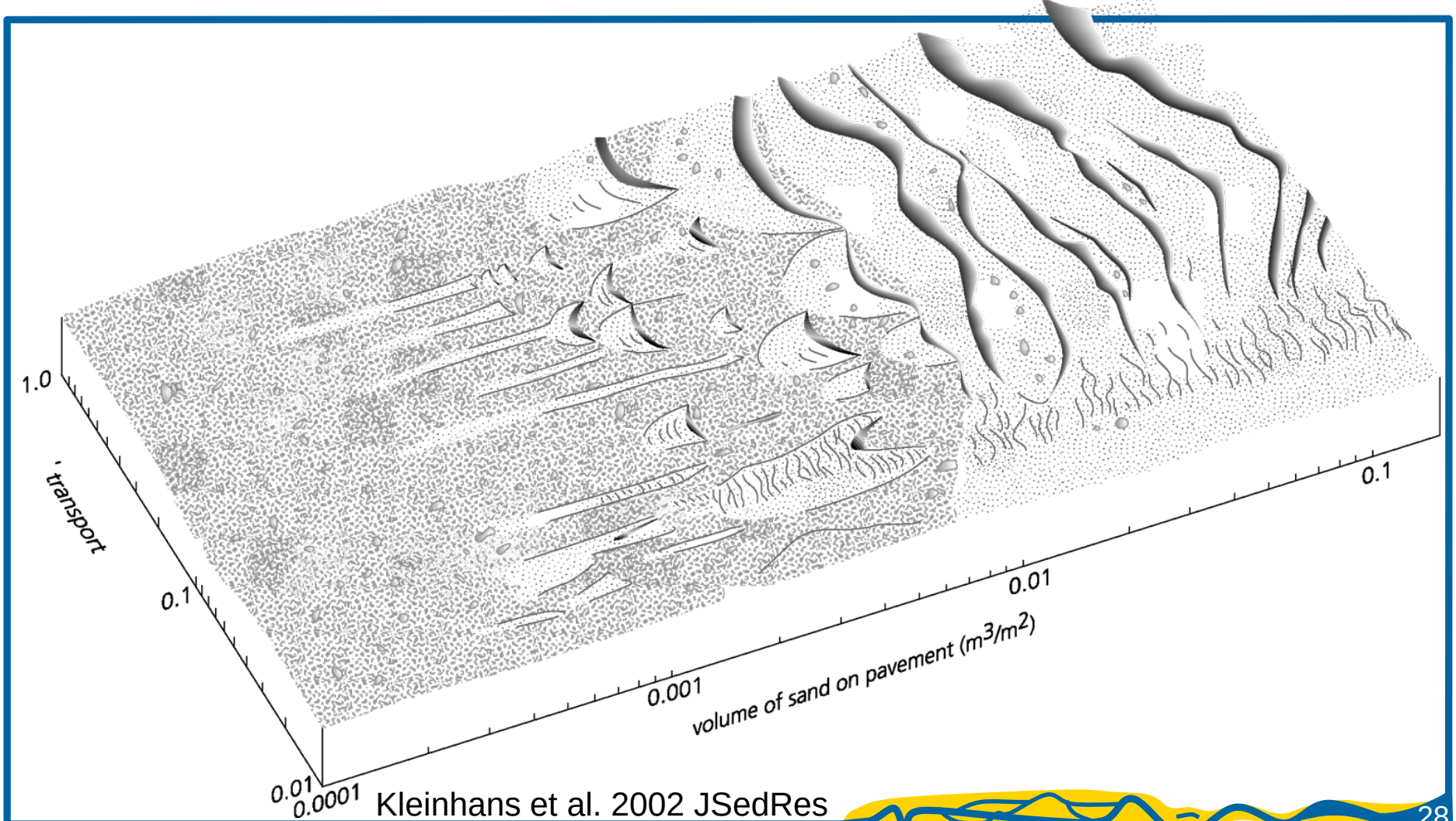
Tidal currents




Belderson et al. 1982

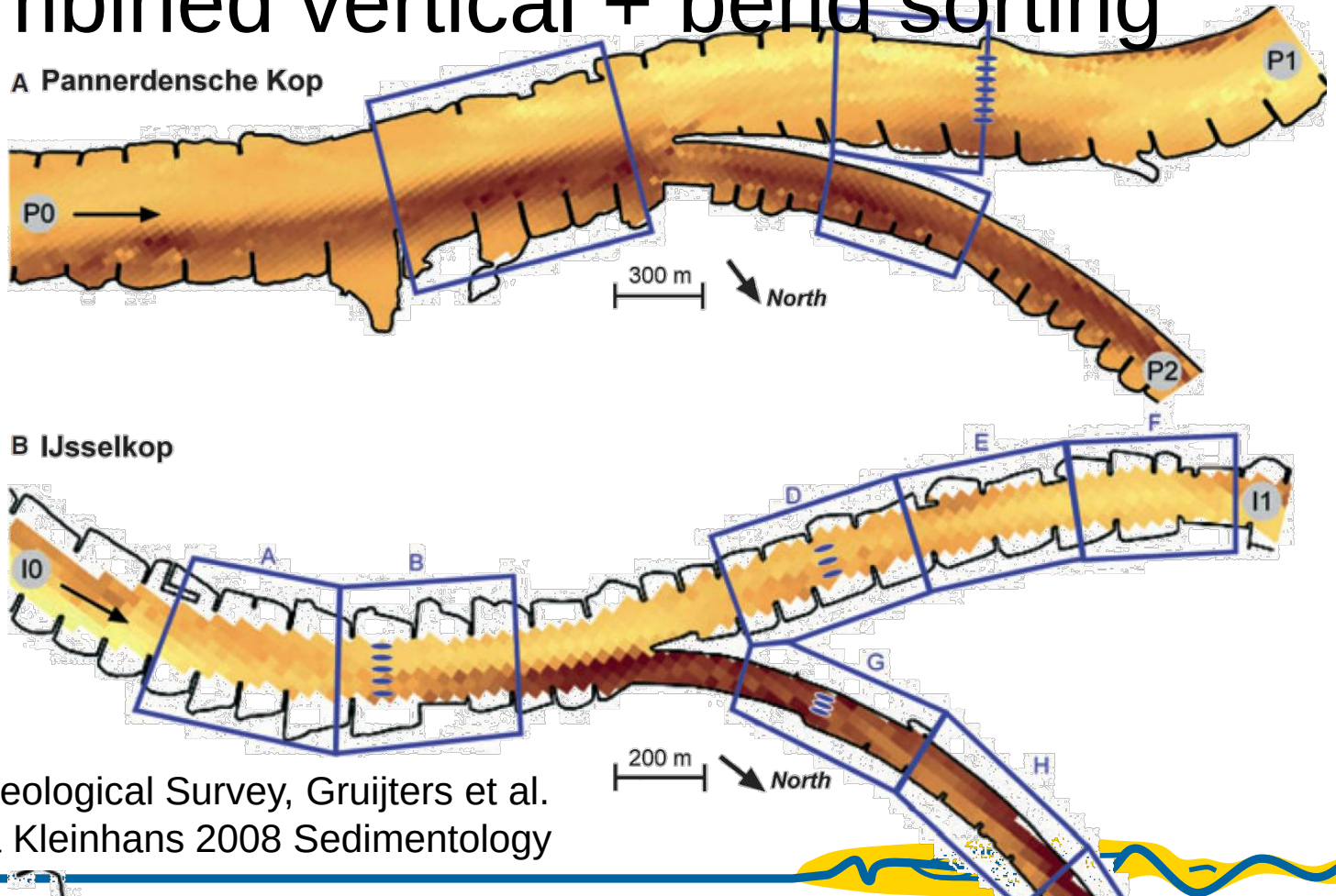
Belderson et al. 1982

# Winnowing in dune troughs $f(\theta)$



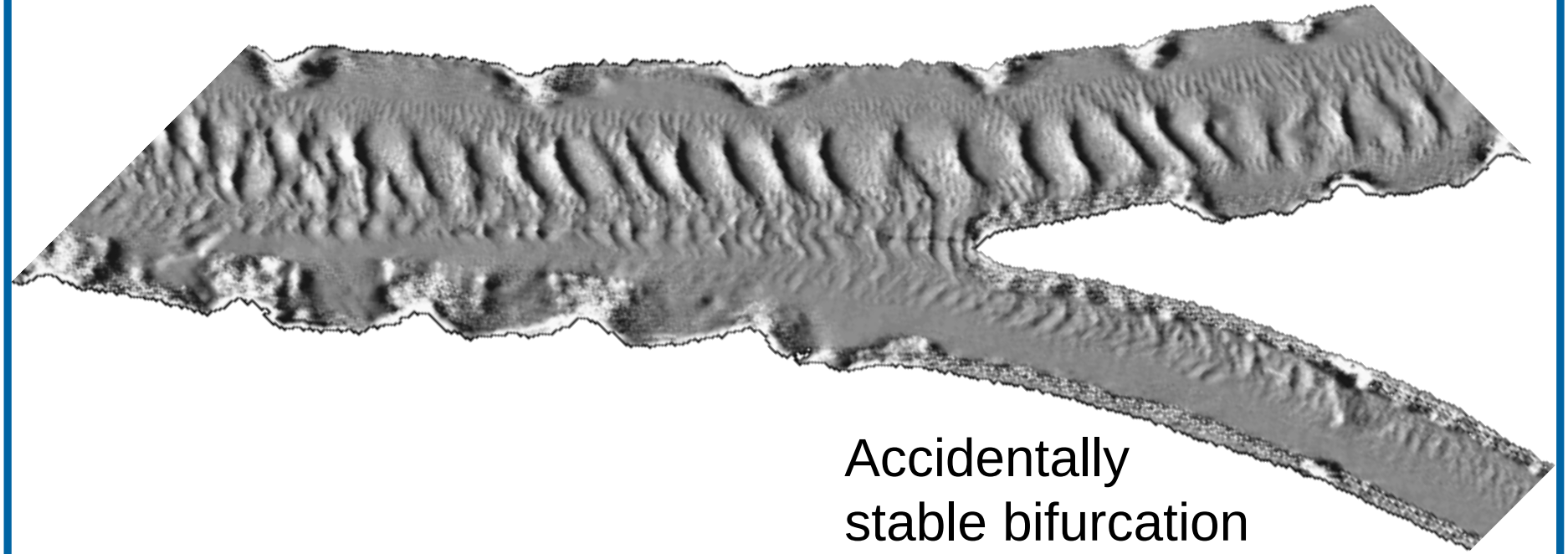

Kleinhans et al. 2002 JSedRes

# Combined vertical + bend sorting




Dutch Geological Survey, Gruijters et al.
Frings & Kleinhans 2008 Sedimentology

# Sediment-starved dunes in Pannerden

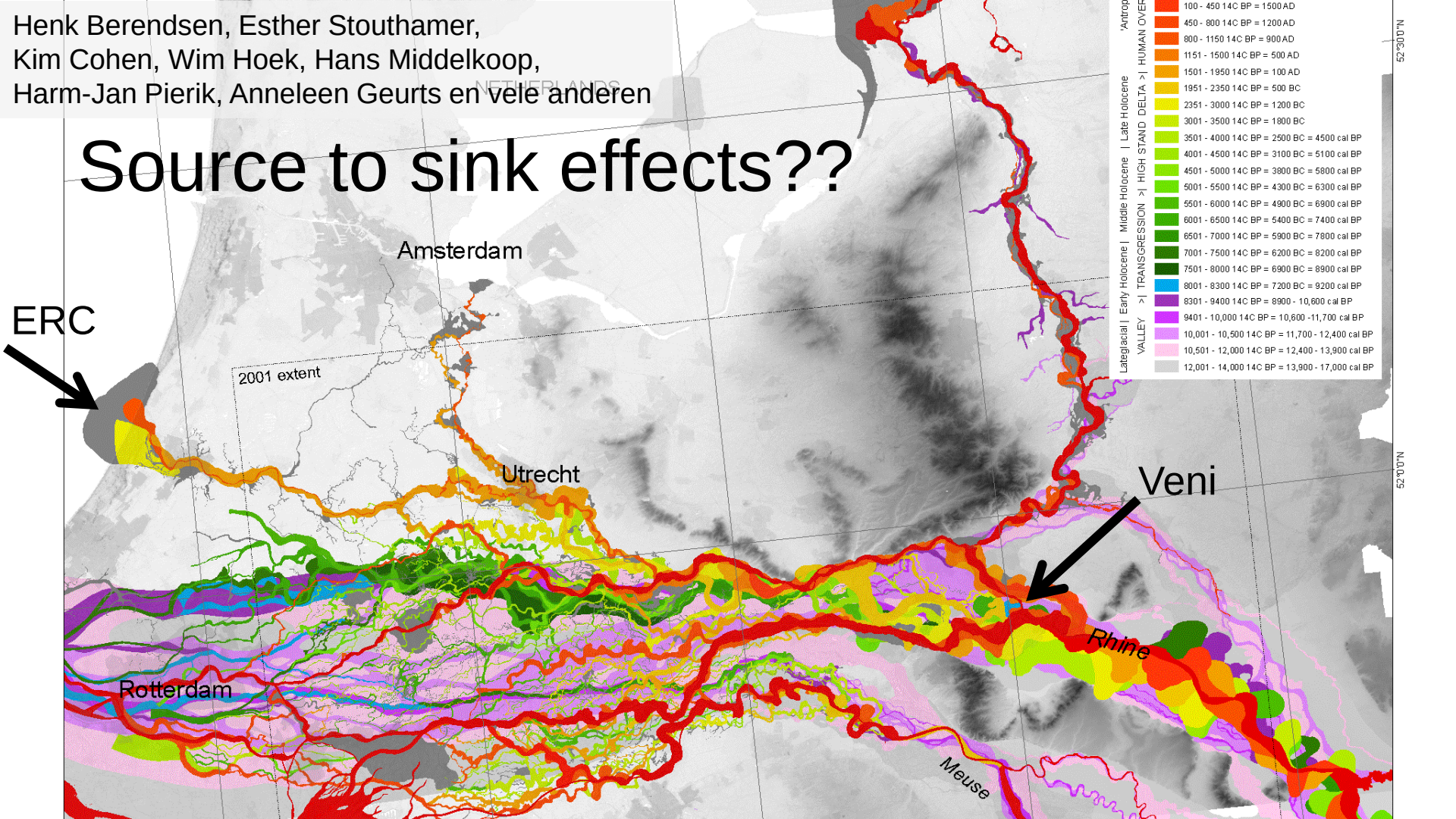


Accidentally
stable bifurcation

Frings and Kleinhans 2008 Sedimentology
Kleinhans et al. 2012 ESPL

Henk Berendsen, Esther Stouthamer,
Kim Cohen, Wim Hoek, Hans Middelkoop,
Harm-Jan Pierik, Anneleen Geurts en vele anderen

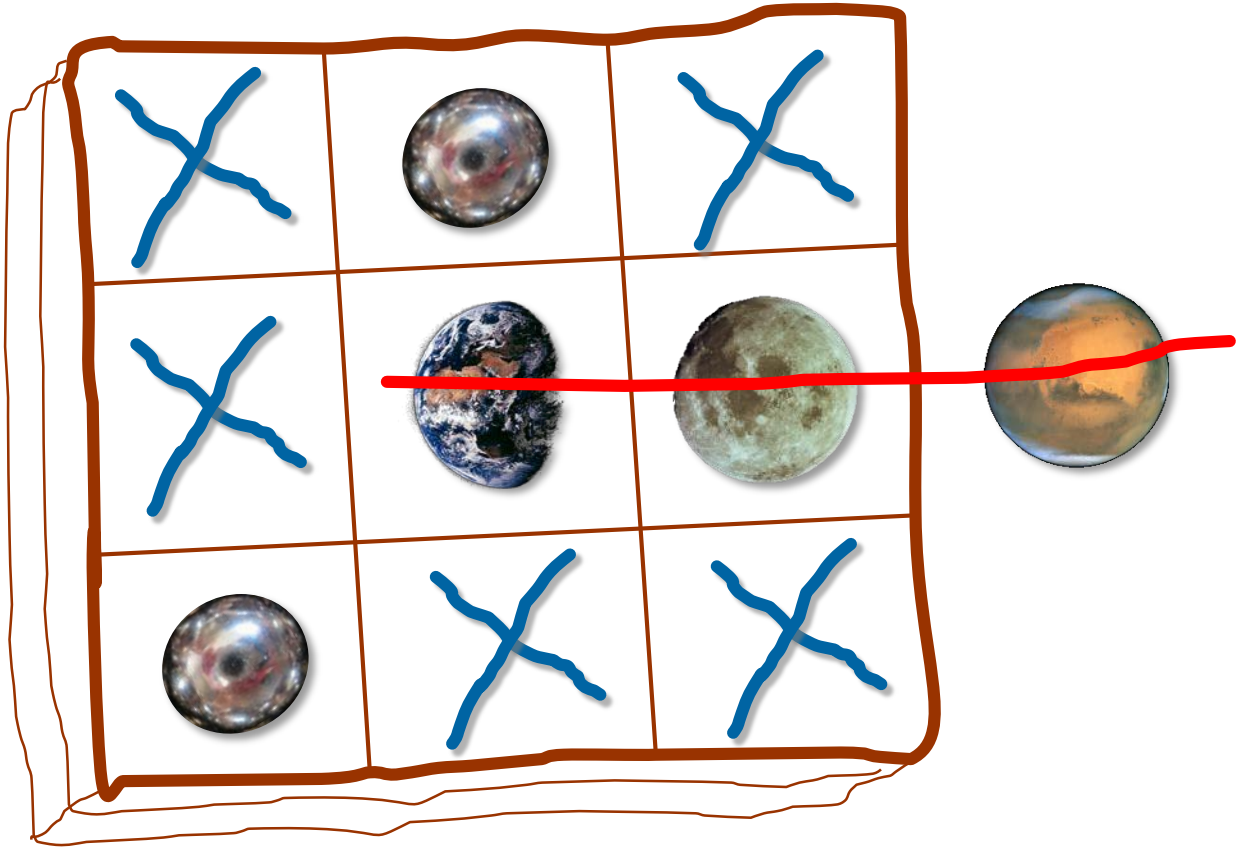
# Source to sink effects??



# Conclusions so far...


- Spatial scales of sorting ...
  - hiding, kinematic, winnowing, avalanching, dune lags, degradation
- ... affect sediment transport ...
  - magnitude, hysteresis
- ... bedforms ...
  - dimensions, sediment supply-limited forms
- ... channel and bifurcation development
  - reduced bed erosion→ *shallower!*, accidentally stable bifurcation
- ... and downstream delta development (?)

# Think out of the box

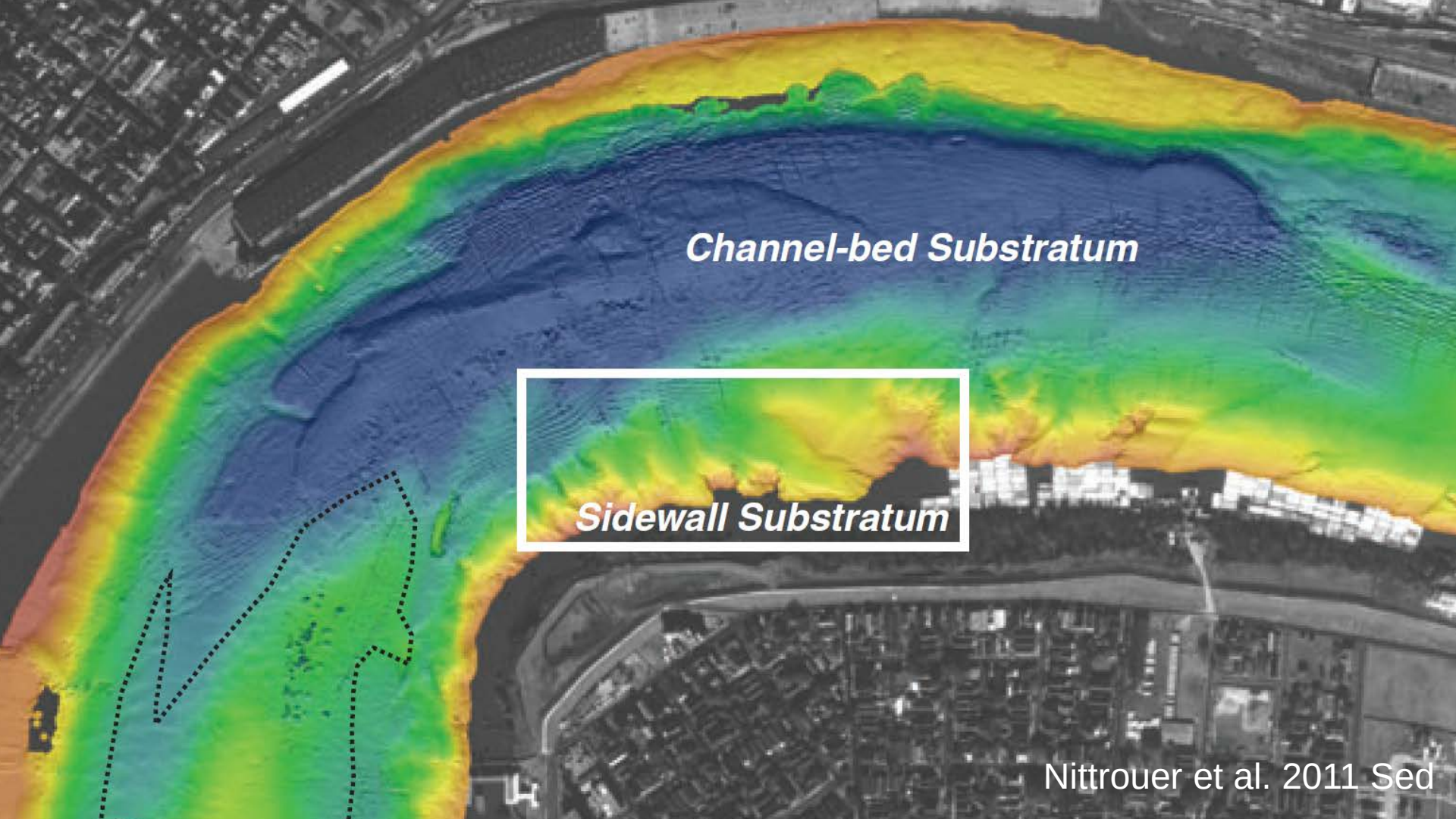


Kleinhans 2010: A tale of two planets... (ESPL)

# Cohesive / bedrock effects

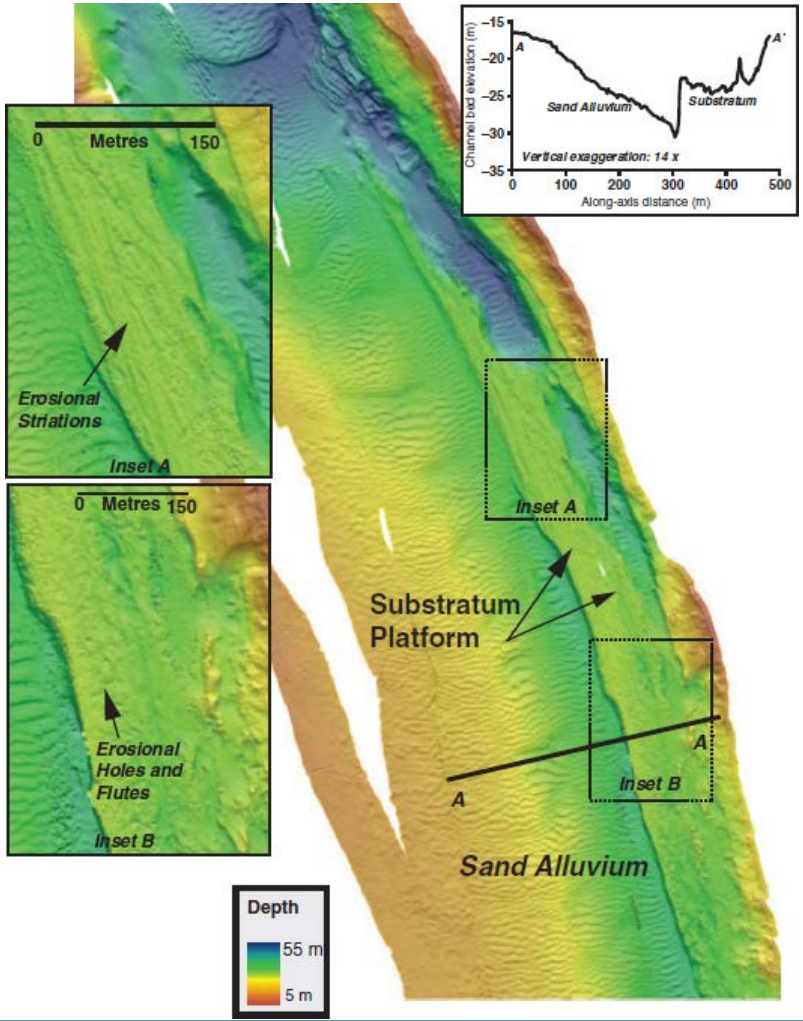
- sediment starvation =
  constraints on bars and channels
  - bedrock
  - self-formed mud and peat
  - → topographic forcing
- bedrock erosion?

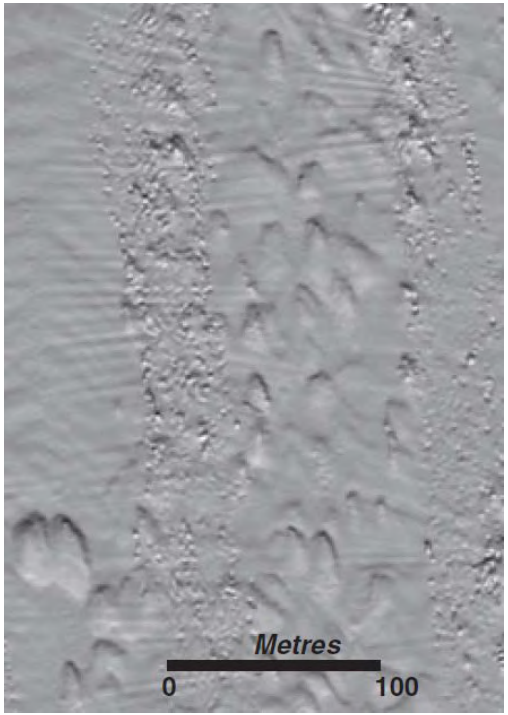

Data RWS, image Cleveringa Pers. Comm.




Nittrouer et al. 2011 Sed

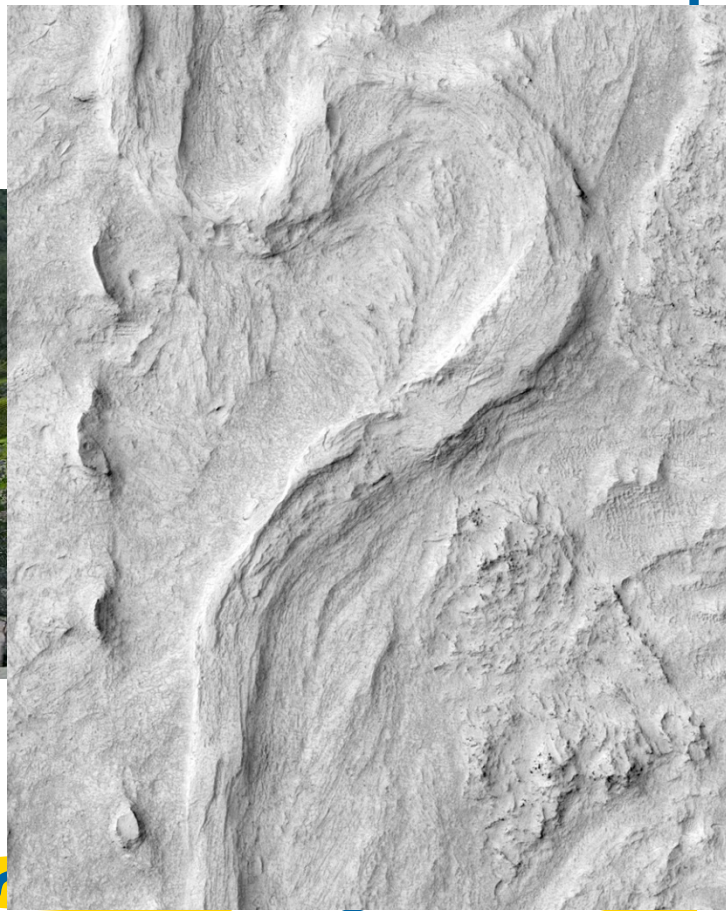
# Mississippi




Nittrouer et al. 2011 Sed

# Not this...



# Constraining geological constraints?

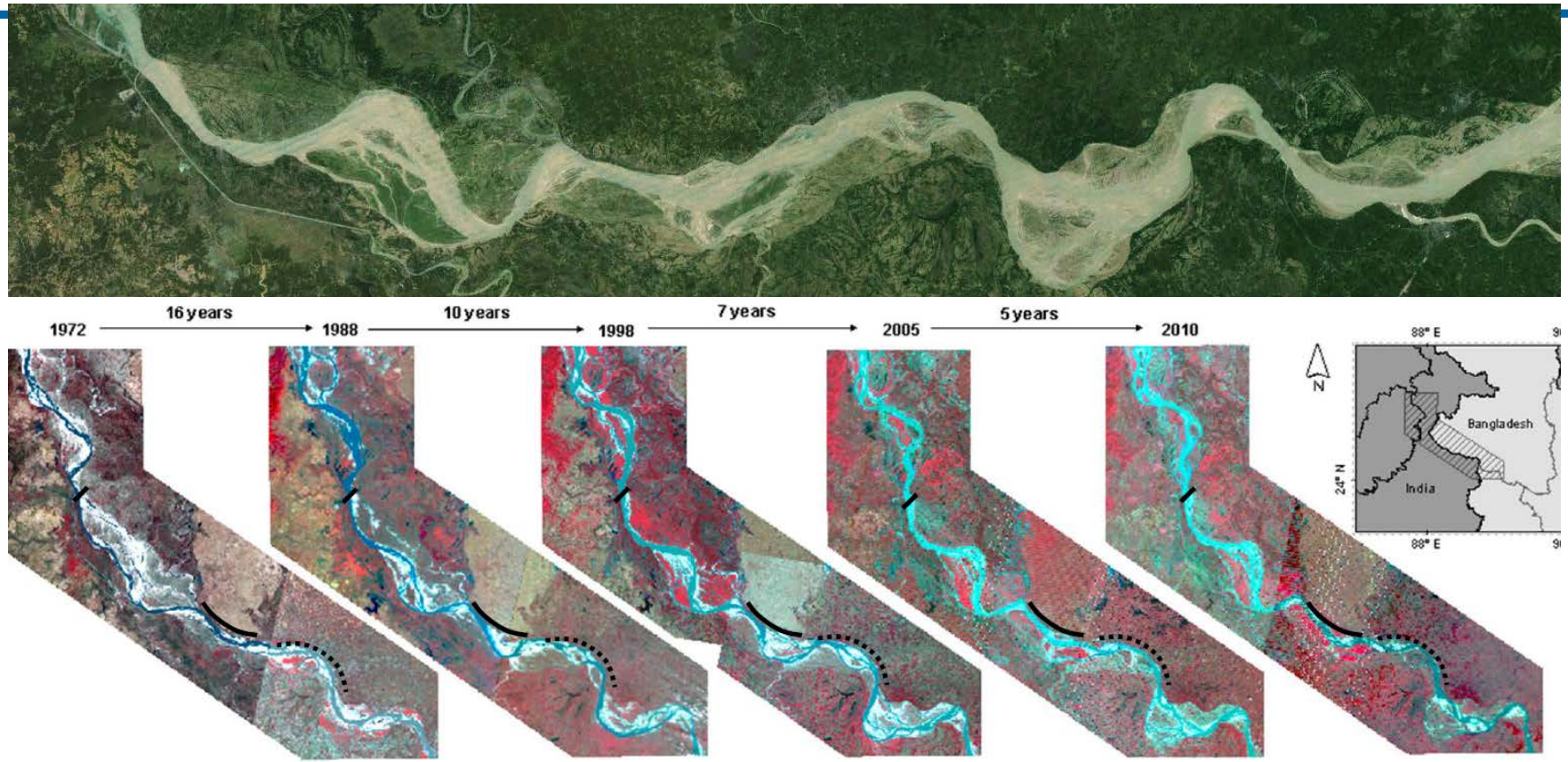
- consolidated mud & stronger stuff
  can be eroded *subaqueously* by moving sediment impact
  iff sediment supply-limited

  - subaqueously: not failure, not dissolution, not bank erosion
  - supply-limited: as in armoured beds → upstream supply...

- in deltaic *sedimentary accreting* settings??
- Yup.

# Did it matter here?

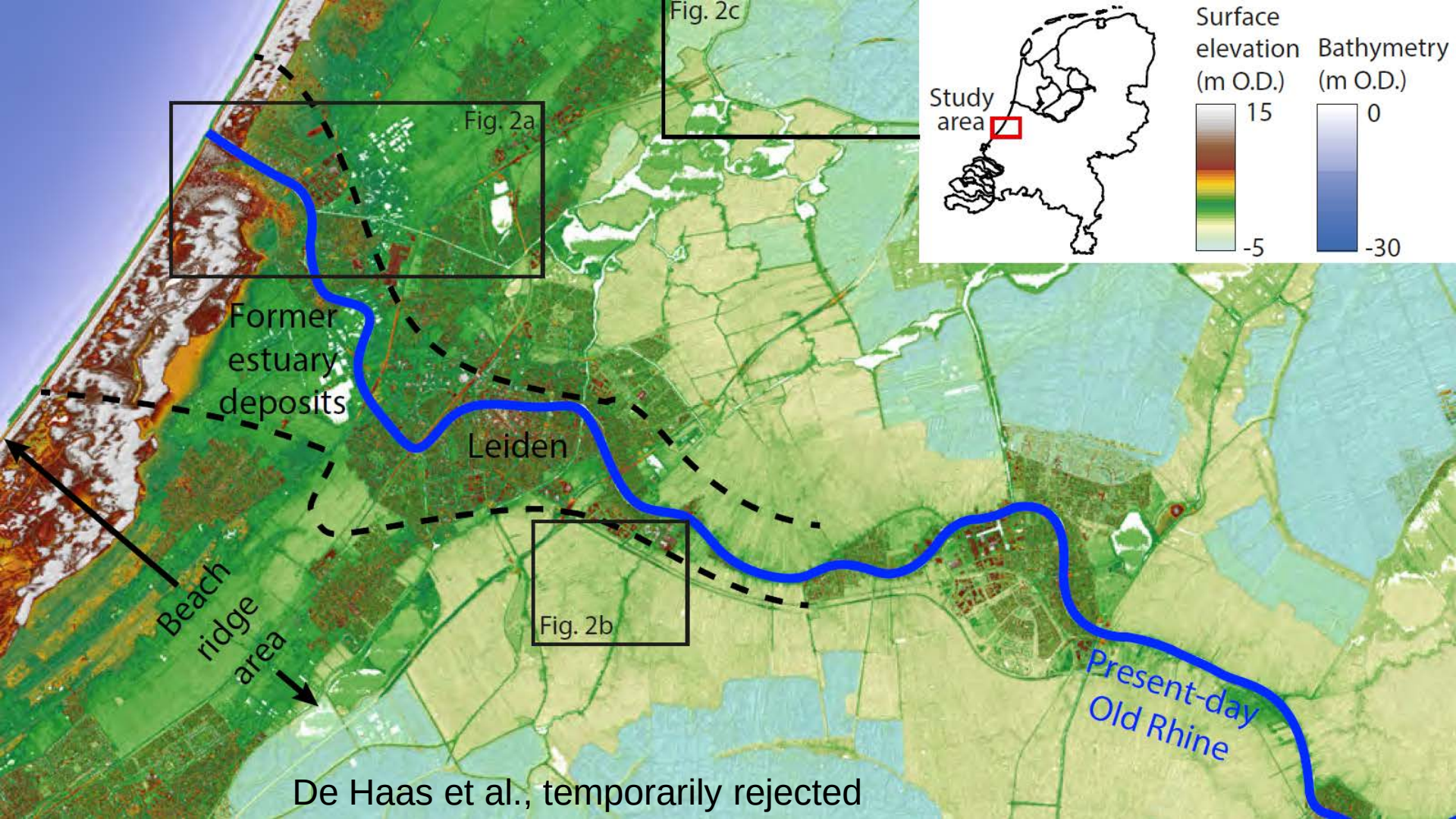
Kleinhans et al. 2010 Geom




# hard banks constrain rivers (= initial condition)

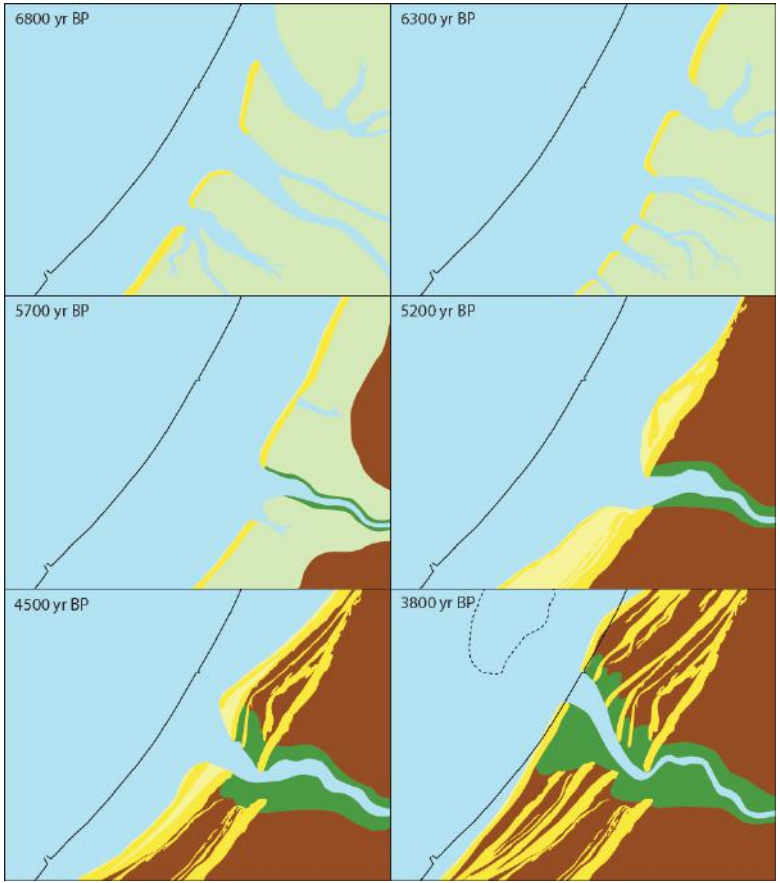
Gupta et al. 2013 Remote Sensing Letters

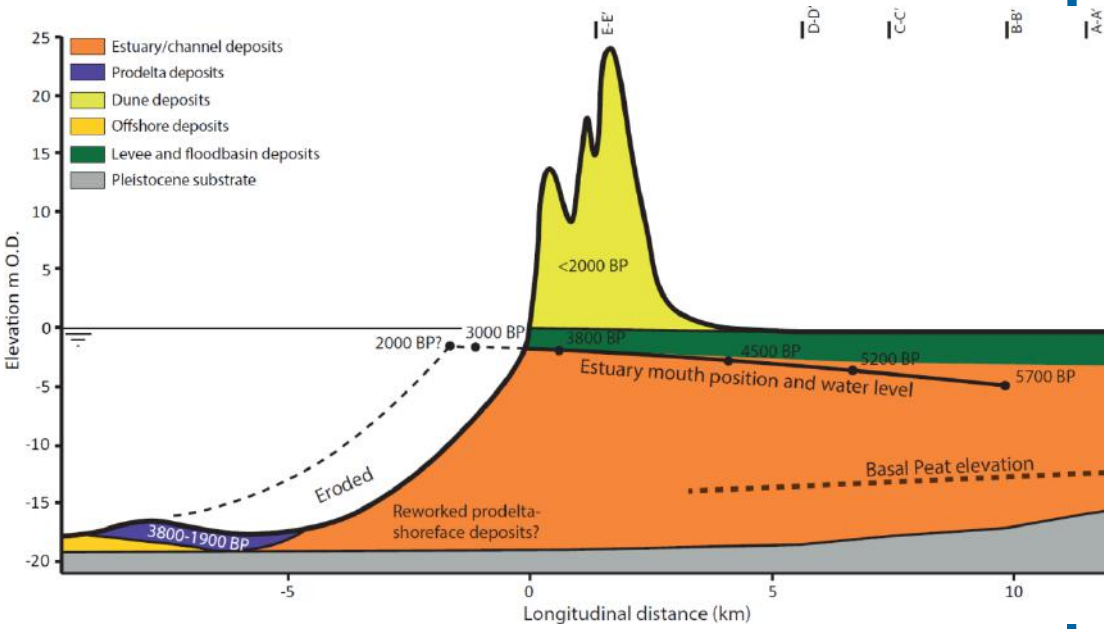
Figure 3-5[7] Sequential changes in the River Ganges over a 38 year period.




De Haas et al., temporarily rejected

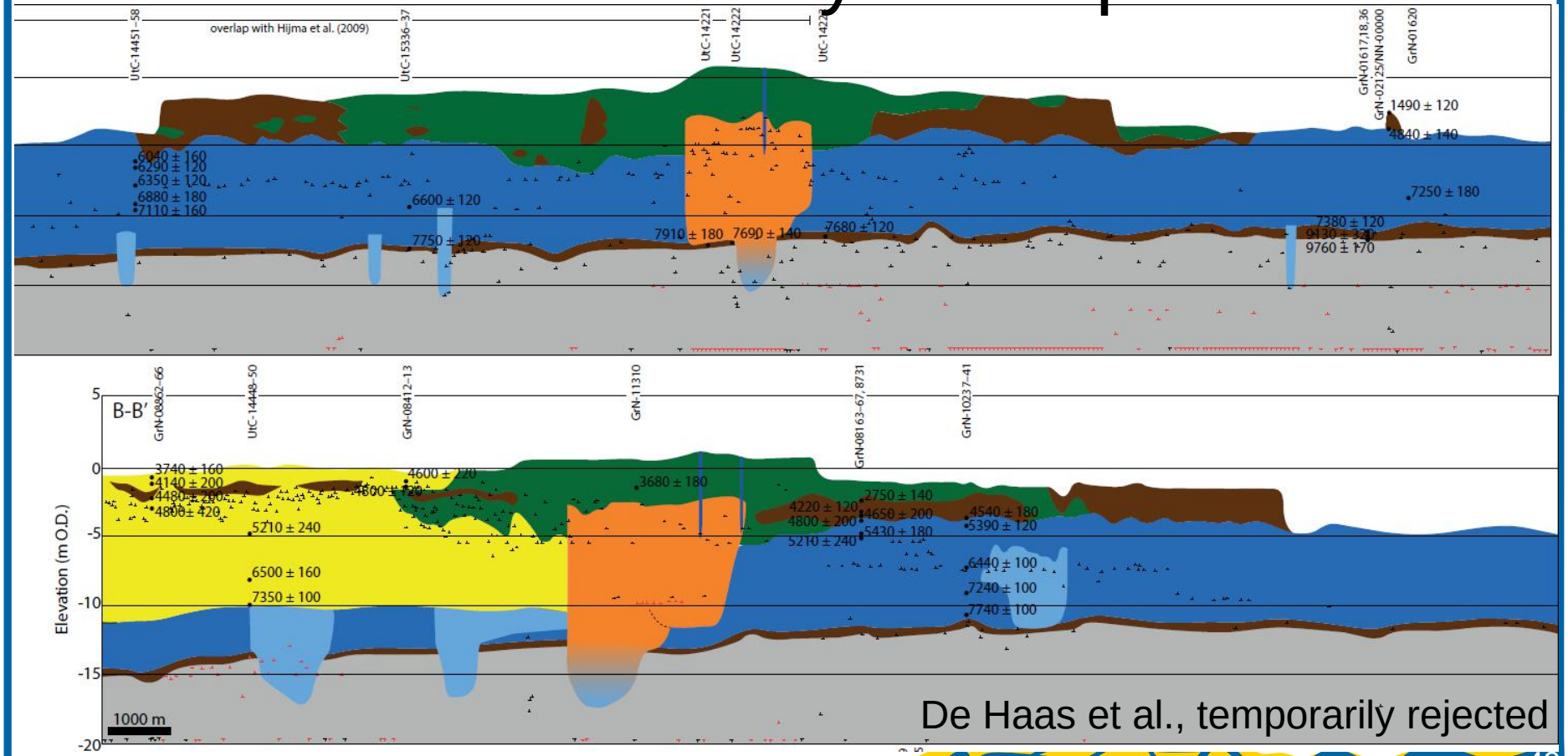
# Leiden estuary




de Haas et al. temporarily rejected, Sedimentology

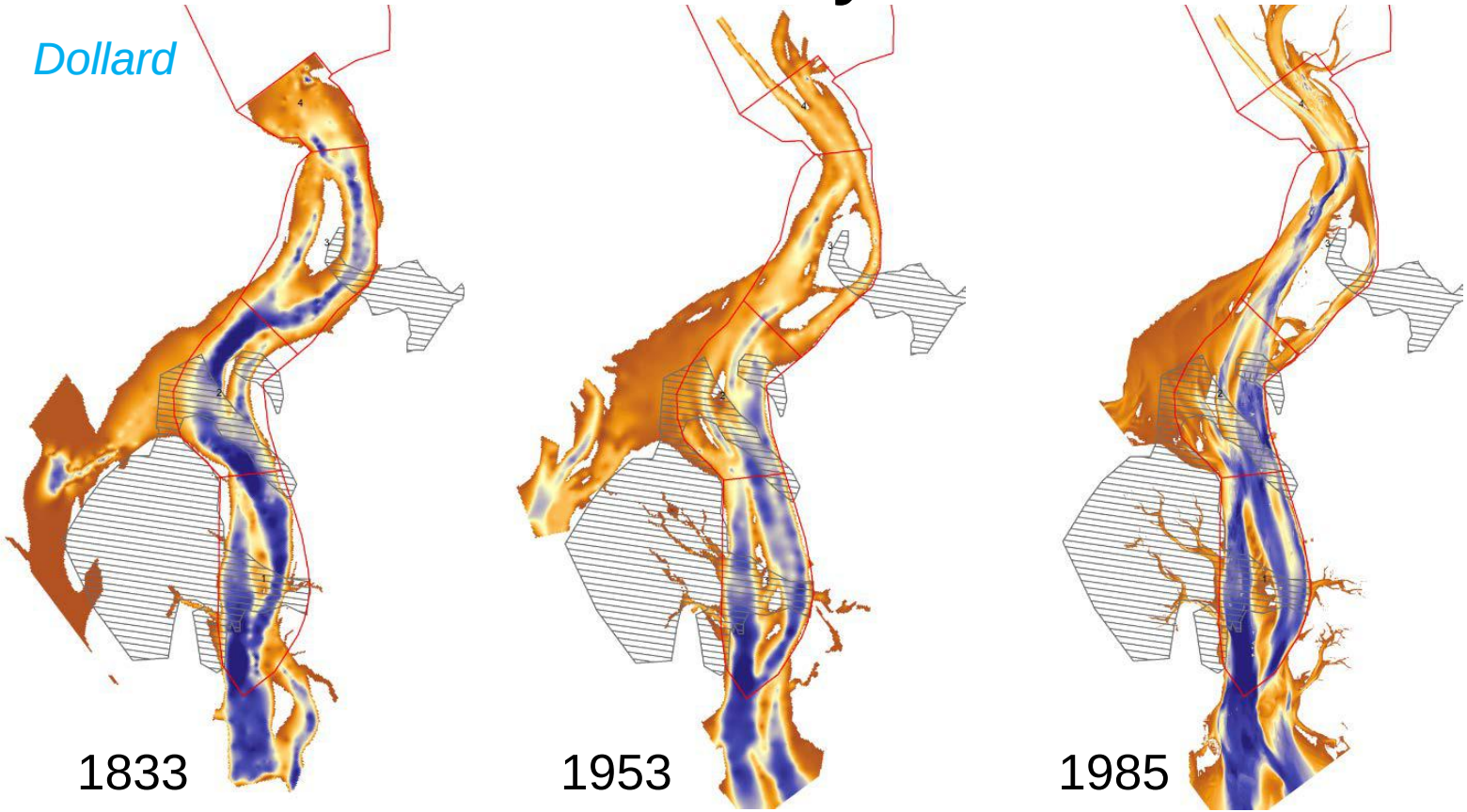
# Constrained by basal peat




De Haas et al., temporarily rejected


Harke Douma, Elisabeth Addink

# Historical bathymetries



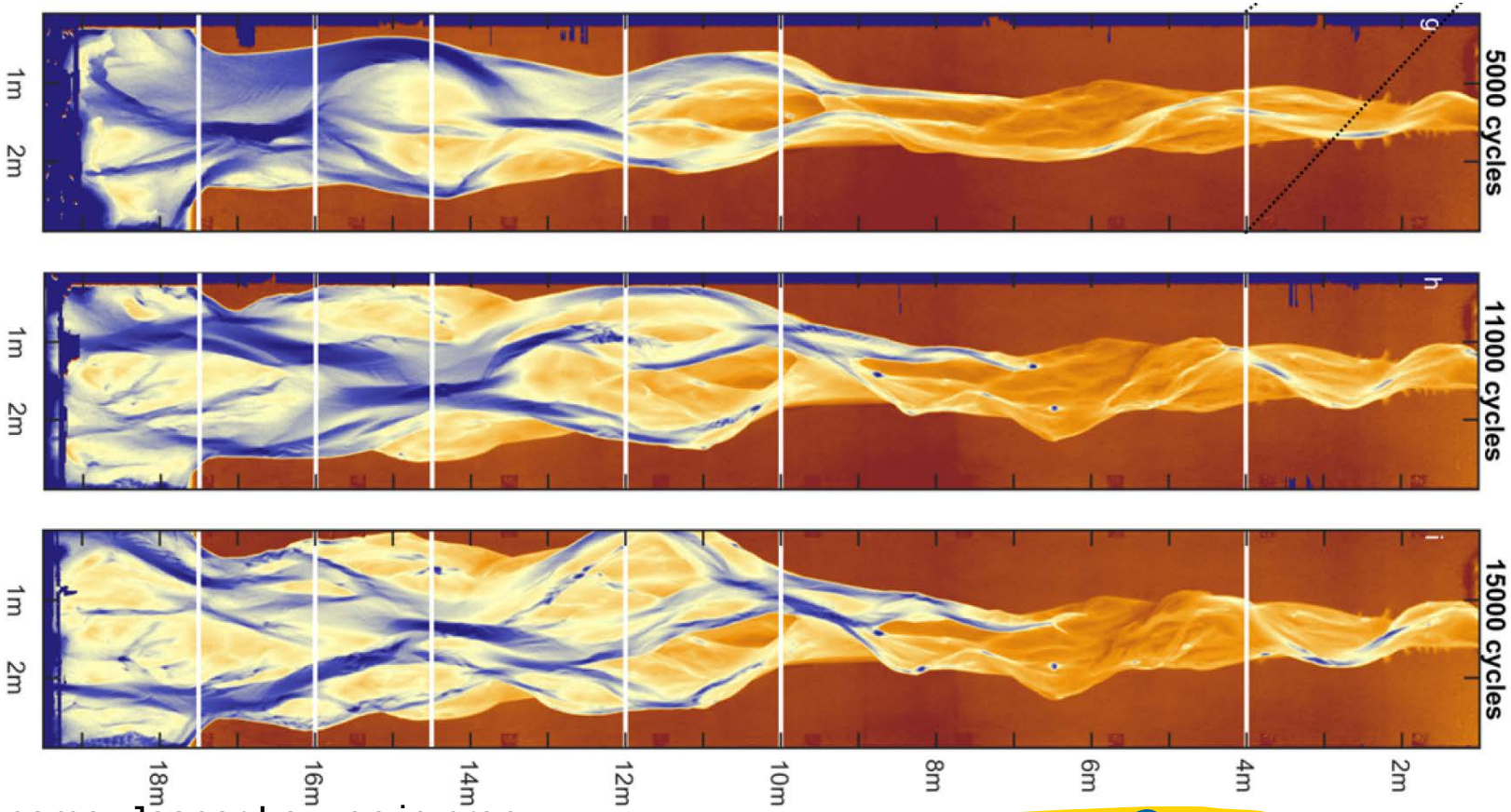
# To trust is good, to control better

experiments in Utrecht

Nature

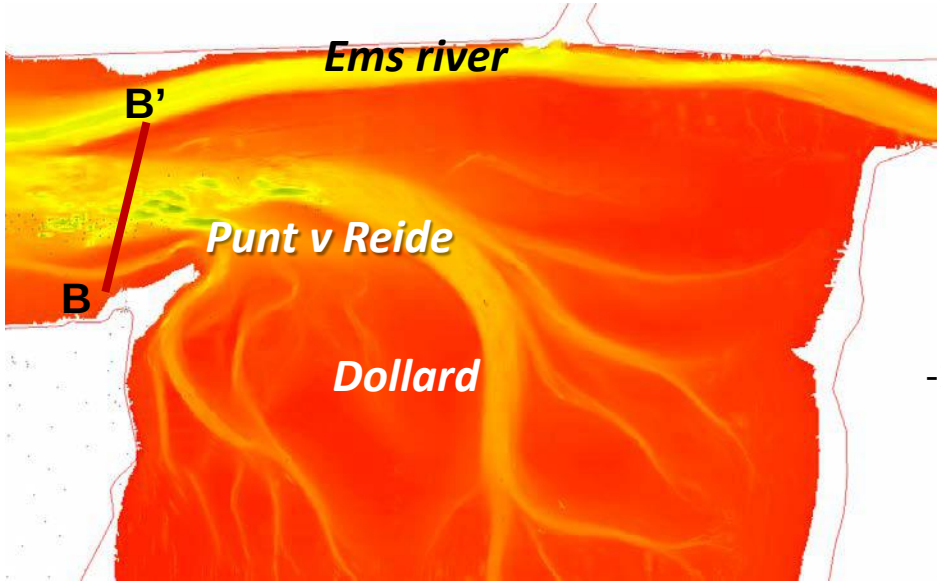
geology
ecology

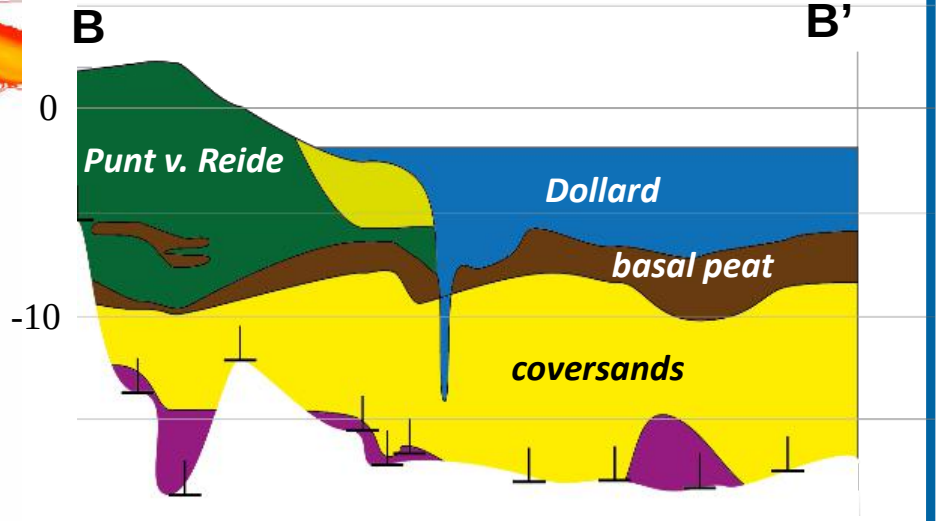
# Self-formed nodes?



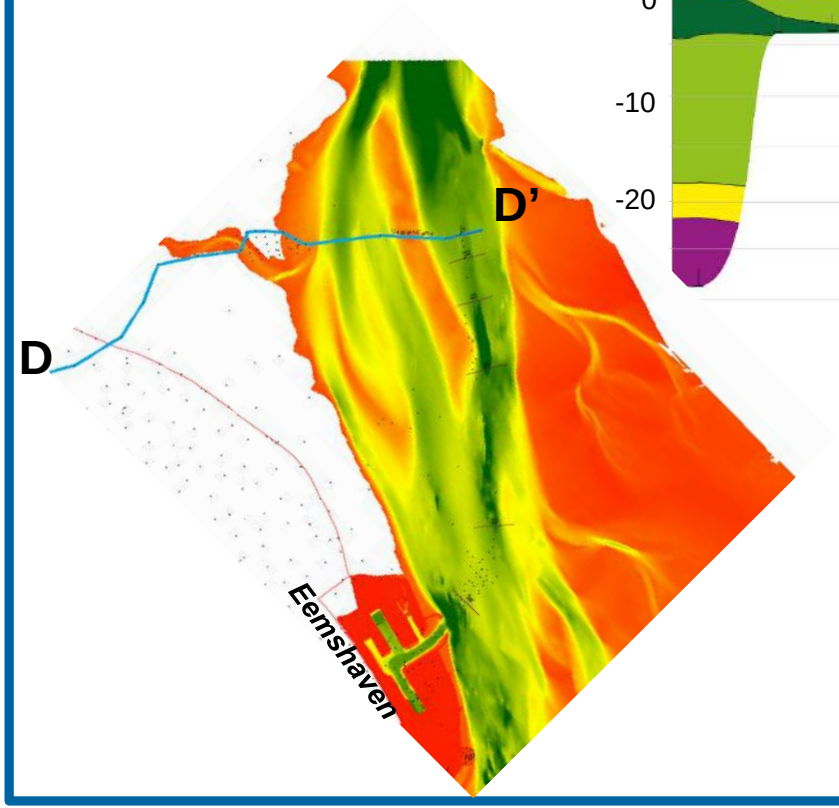

Metronome, Jasper Leuven in prep.

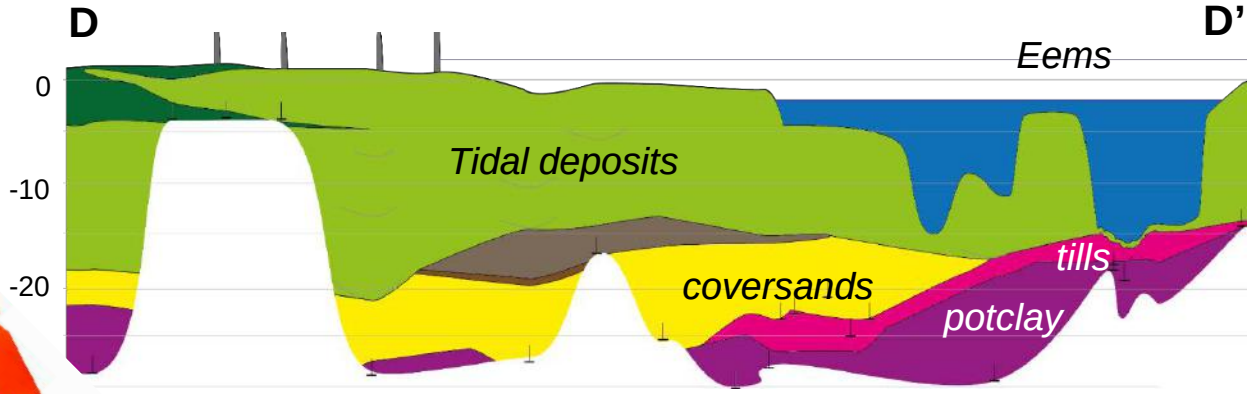
# Eems-Dollard



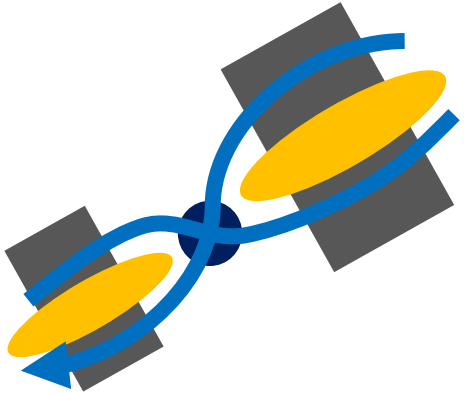
# Eems-Dollard

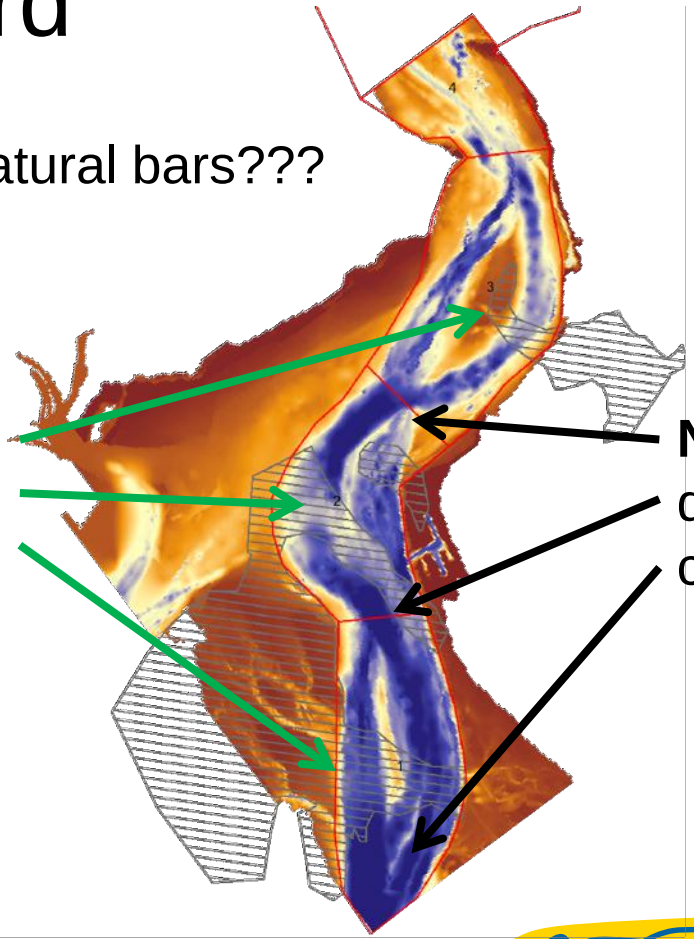


# Eems-Dollard

Interaction geology / natural bars???

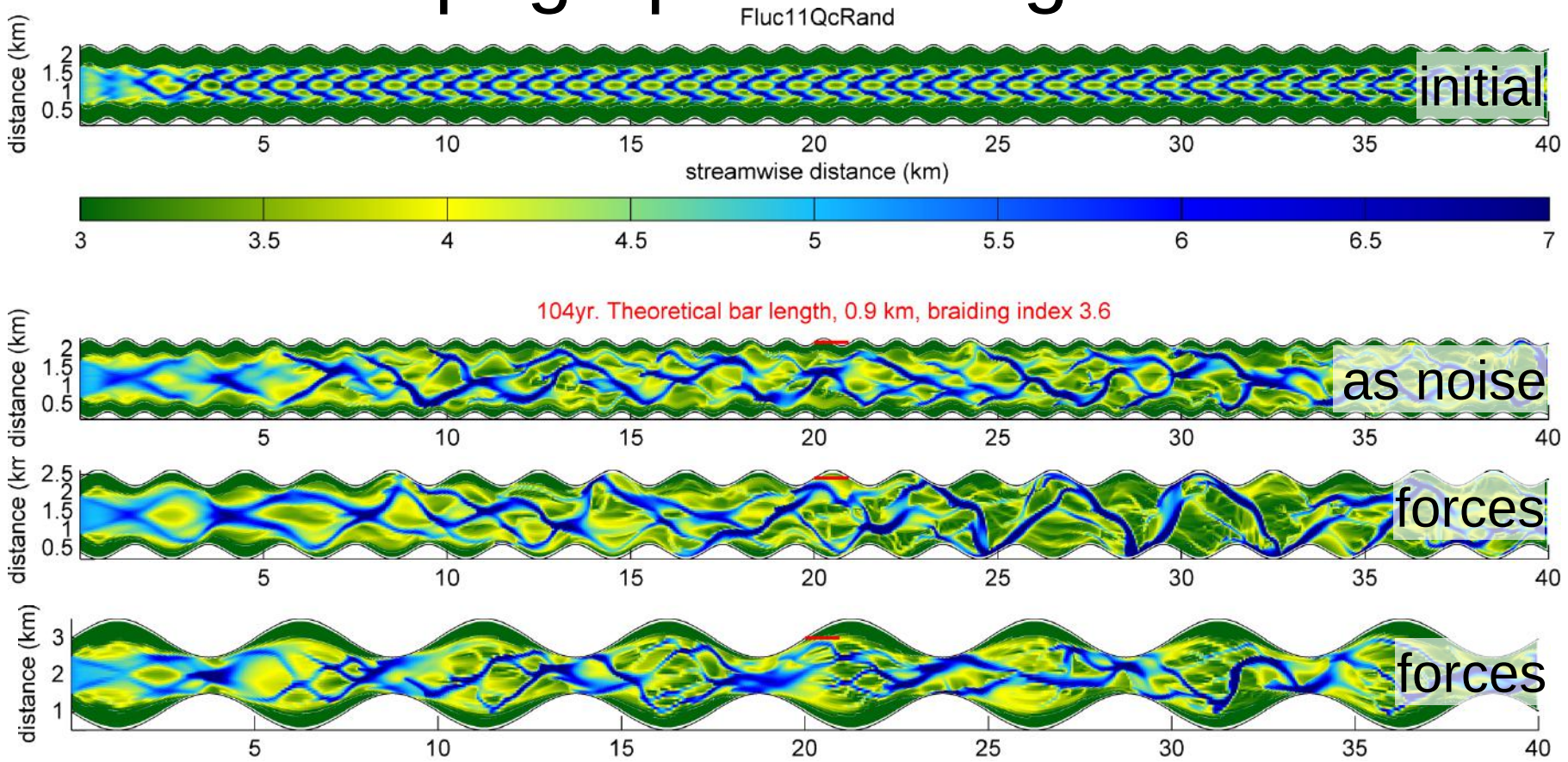




**Resistant layer:**
shallow wide channel bars

**No resistant layer:**
deep narrow channel confluence

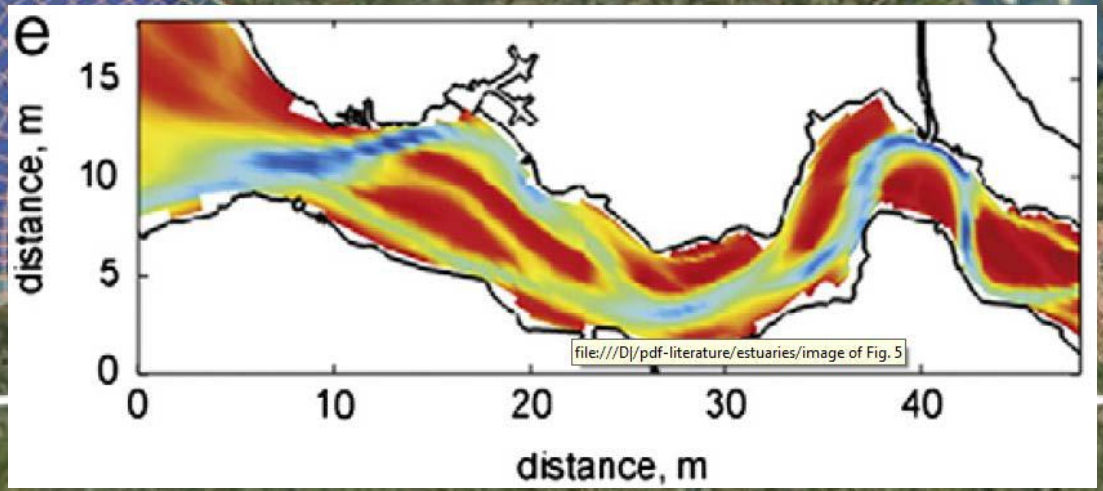
# When topographic forcing effective?




Kleinhans 2010 FluSed

# Banks = topographic forcing

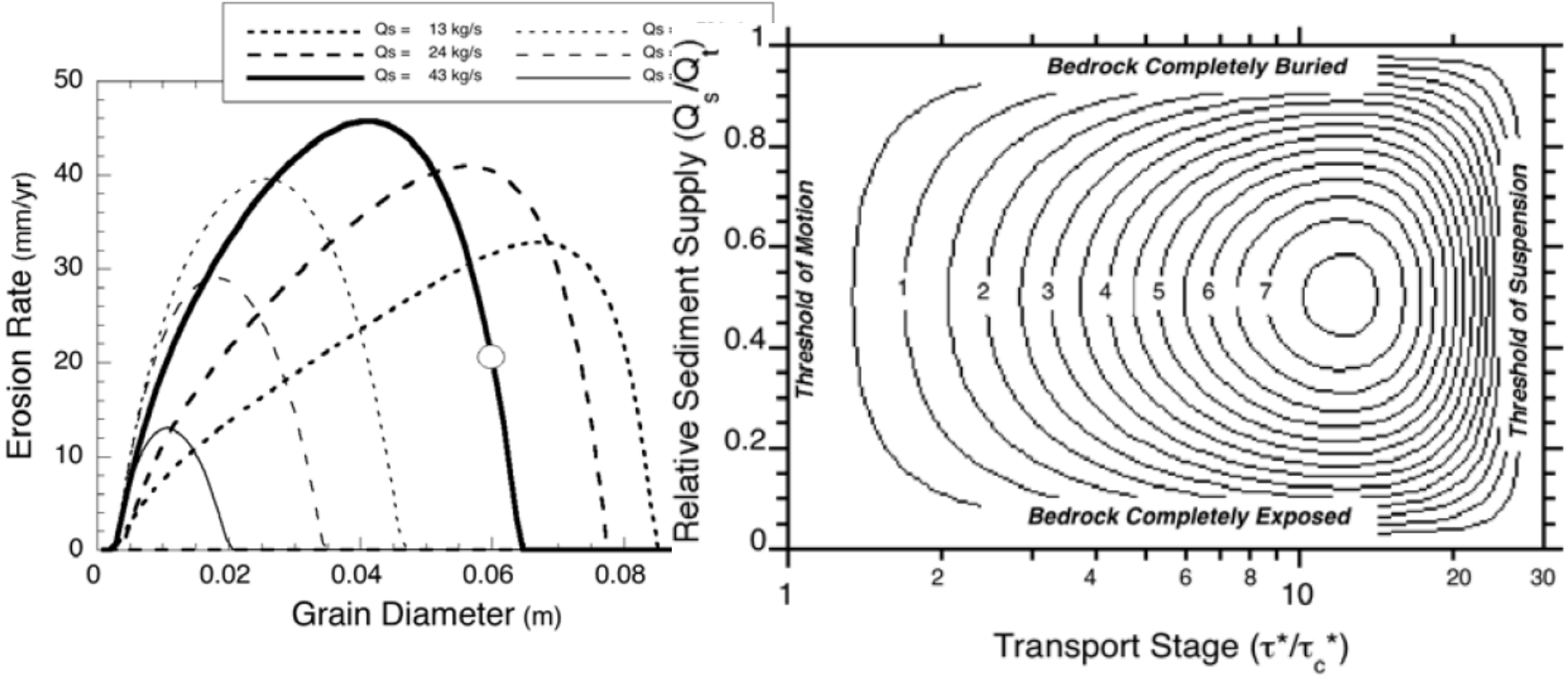
file:///D|/pdf-literature/estuaries/image of Fig. 2




Antwerp

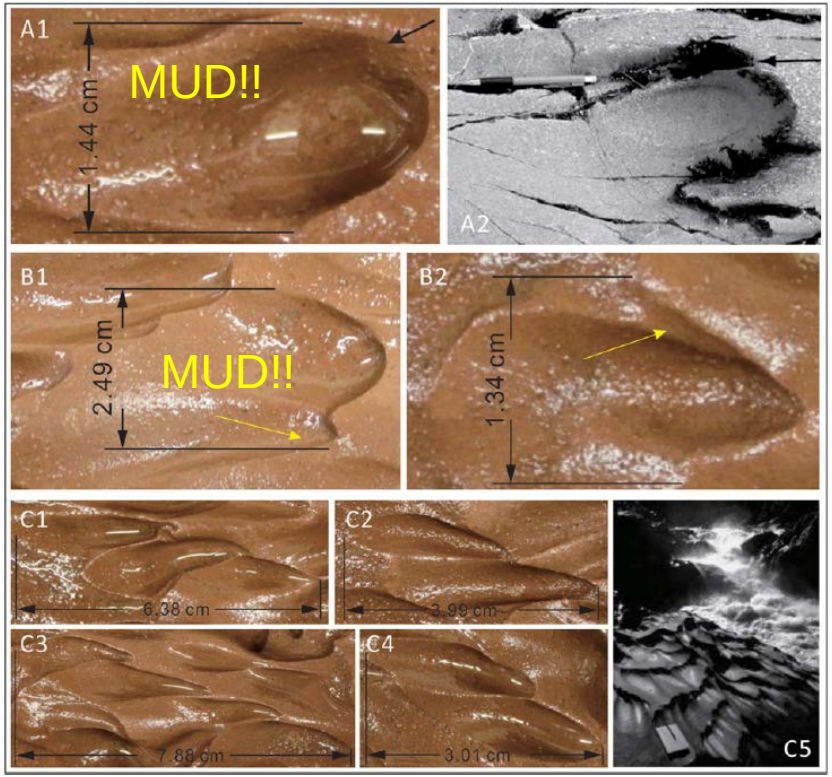
van der Wegen and Roelvink 2012

# Bedrock erosion rate by saltation

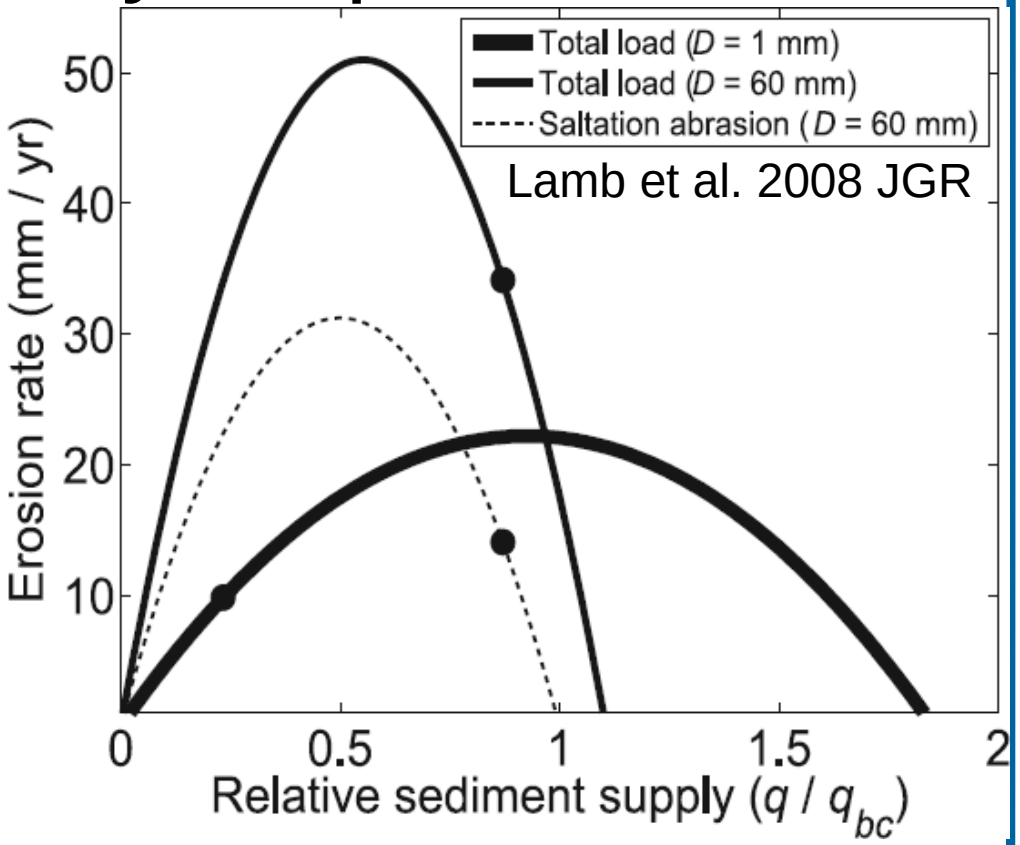



Sklar and Dietrich 2004

# Also abrasion by suspension!




Yin et al. 2016 Geom



# Conclusions... effects of something hard:

- partially alluviated conditions:
  - less sediment transport
  - flat dune troughs? barchans? sand ribbons?
- Low / no erodibility:
  - lateral constraints → narrowing
  - vertical constraints → widening

topographic forcing

- **continuum**:
  - self-formed in the waterscape
    - coarse-grained layers
    - mud flats
    - vegetated / peat layers
  - inherited / imposed
    - rock
    - hard clay
    - hard peat

induration

how fast ‘bedrock’ erosion?