Present and Future Trends in Mudrocks

Joe Cartwright

Department of Earth Sciences
University of Oxford

Imperial College, London, September 24th 2013

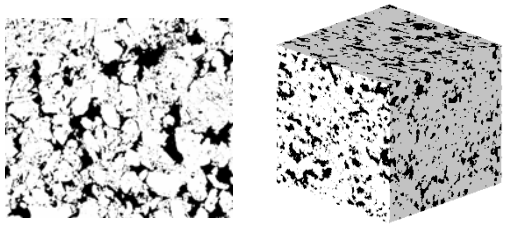
Thanks to: CAPROCKS sponsors, Schlumberger,
Andrew Aplin, Tom Praeger, Cristina Neagu, Bruce Levell

UNIVERSITY OF OXFORD

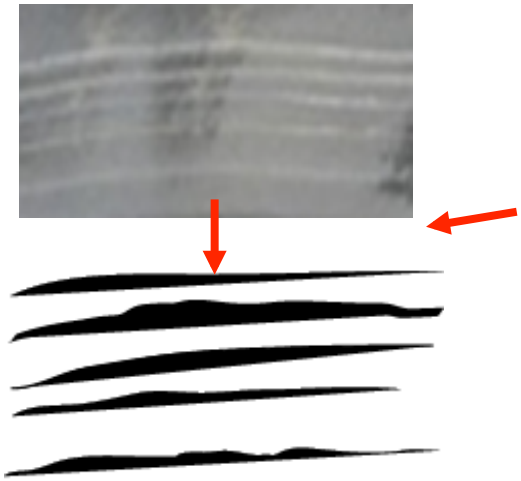
Outline

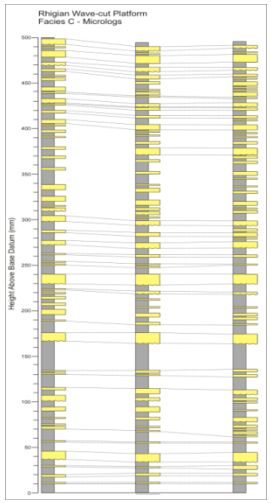
- General comments on some challenges ahead for research on mudrocks
- Compaction and diagenetic impact on physical properties
- Fluid migration through fine-grained sediments
- Natural fracture systems

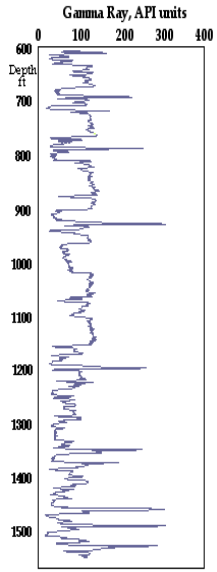
Mudrocks, the grand challenge: scales of heterogeneity



Pore scale

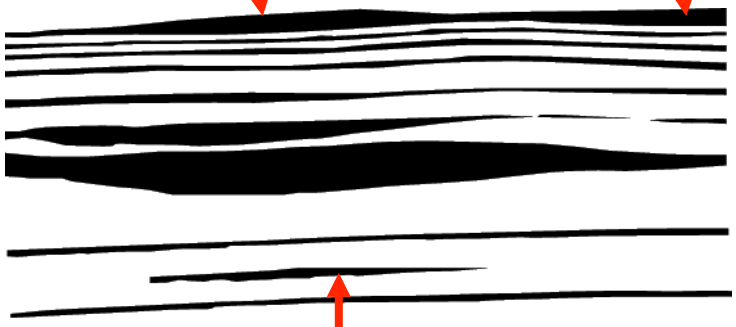


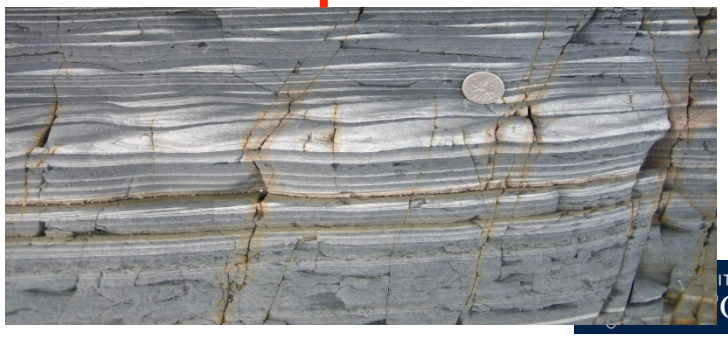




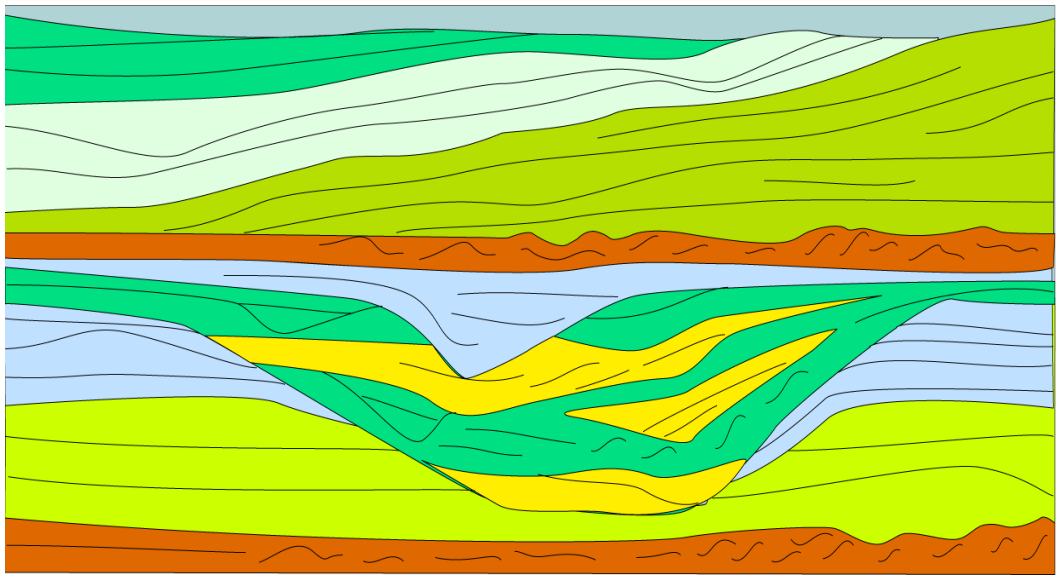
Core/lamina scale

Bed/bedset





Genetic unit



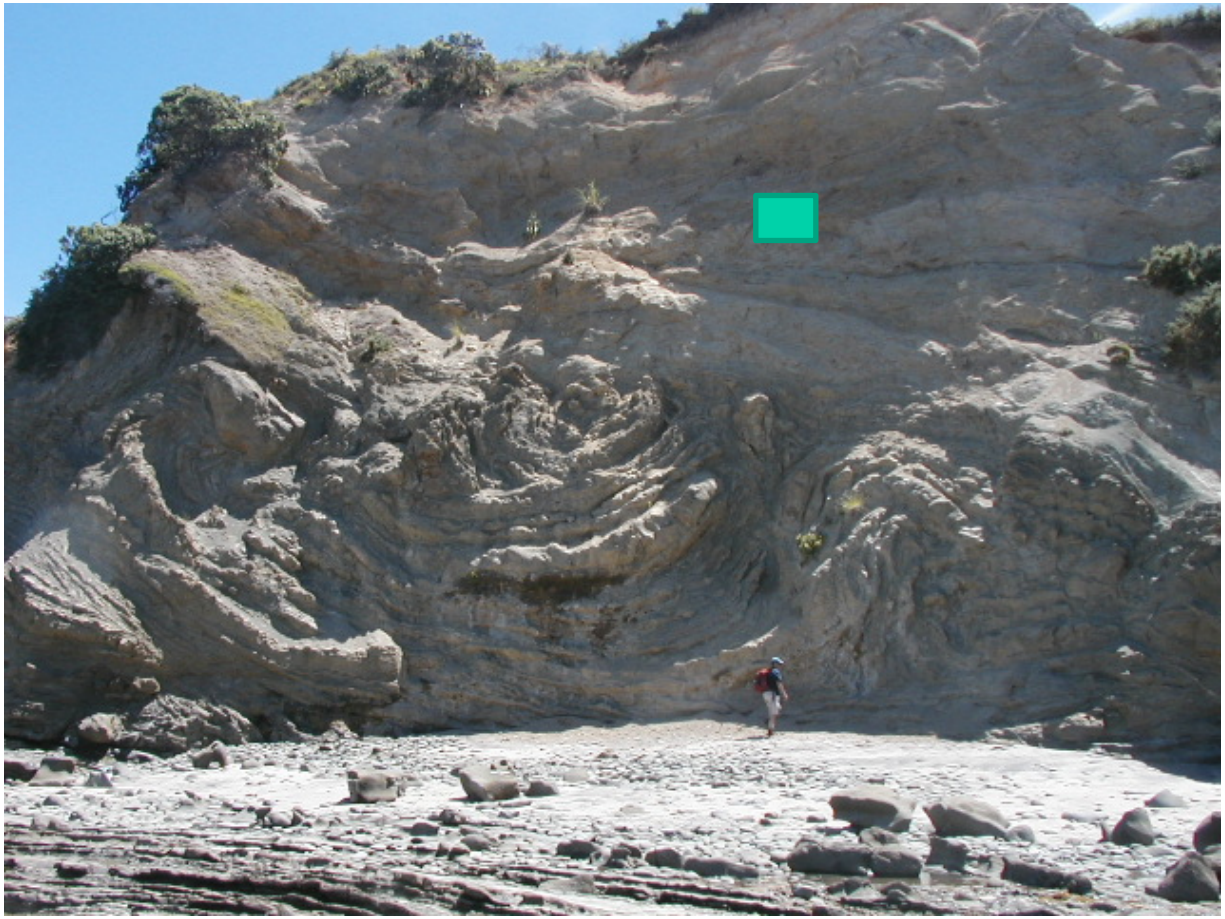
Depositional heterogeneity at all scales.....

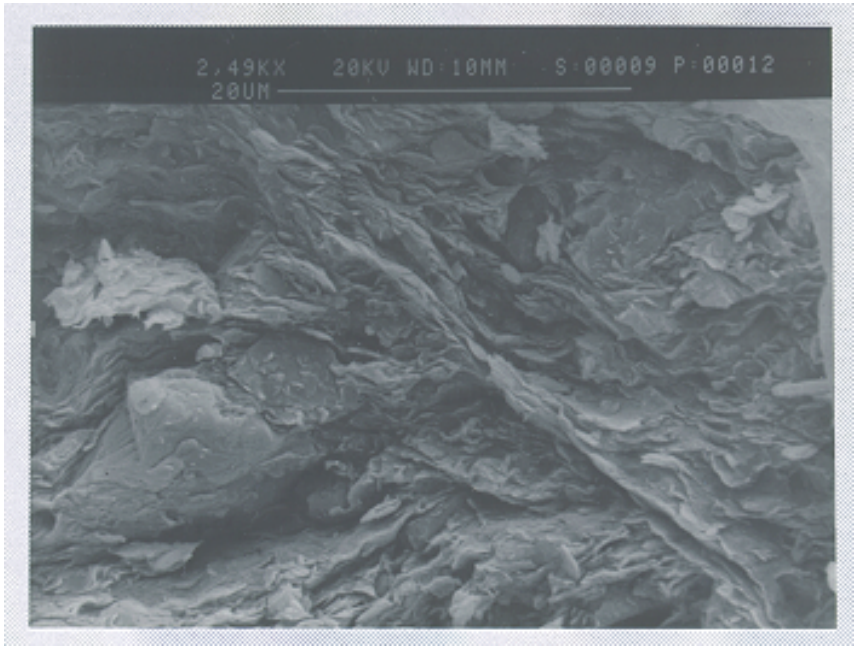
Late Ordovician, Llangranog

Mass transport deposits

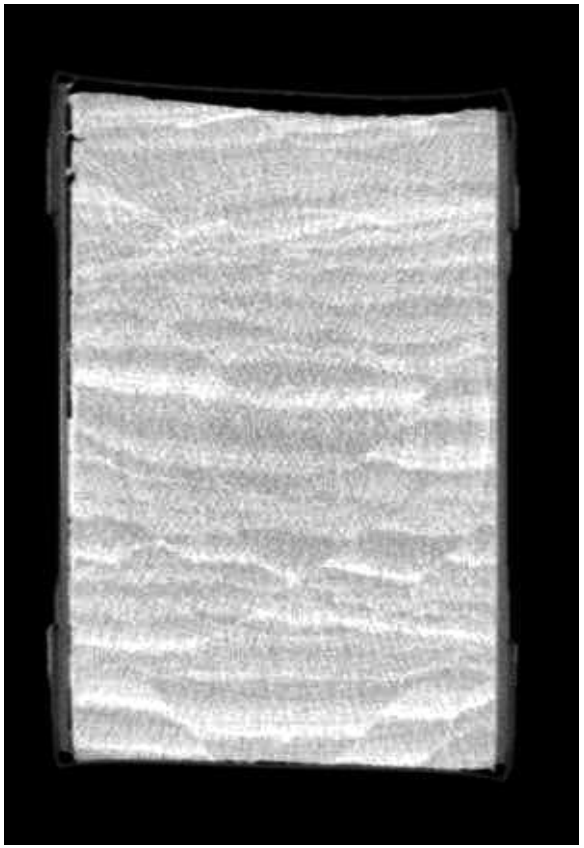
c/o Tuvie Omeru, Cardiff

Waitemata Group, Auckland, NZ





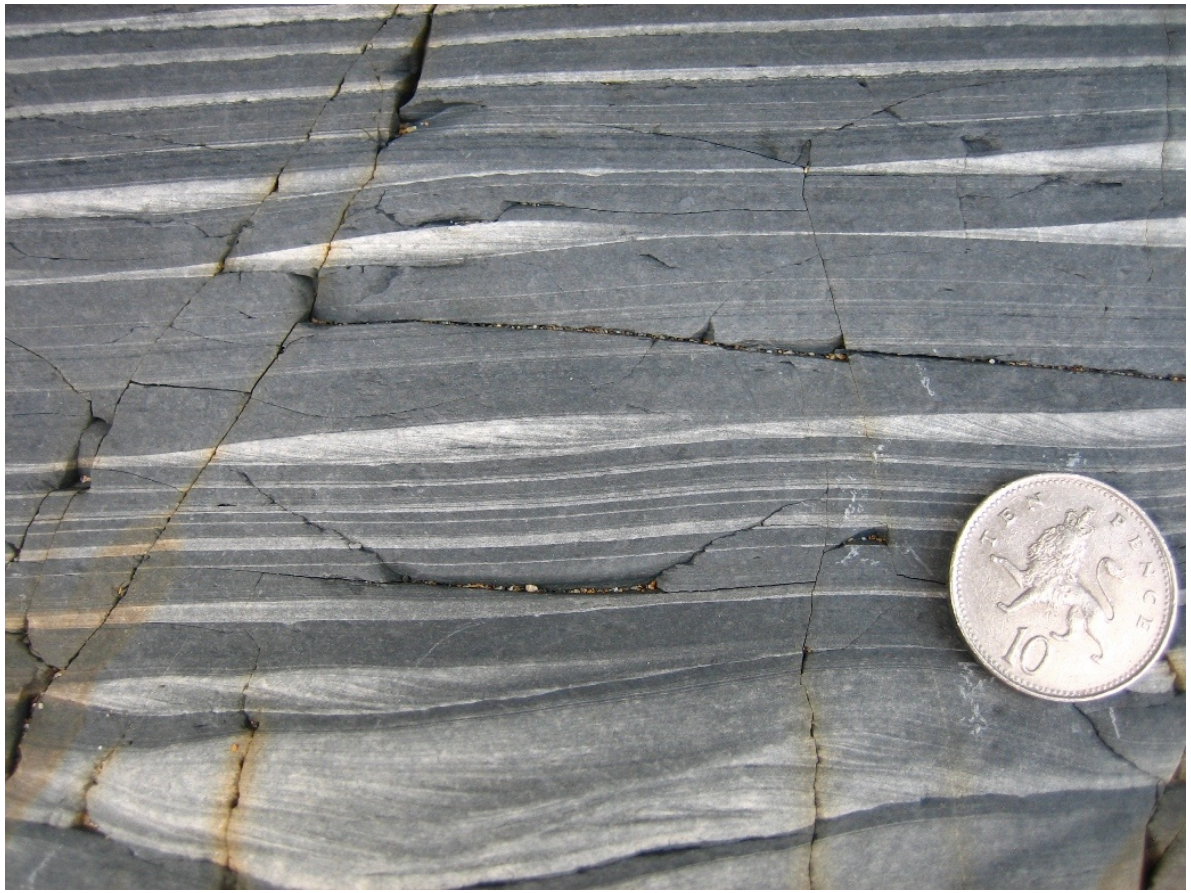
10microM



5cm

Depositional and structural heterogeneity at the micro scale:
Impact on transport of gas to induced fractures

Impact on flow? Below conventional log resolution.....



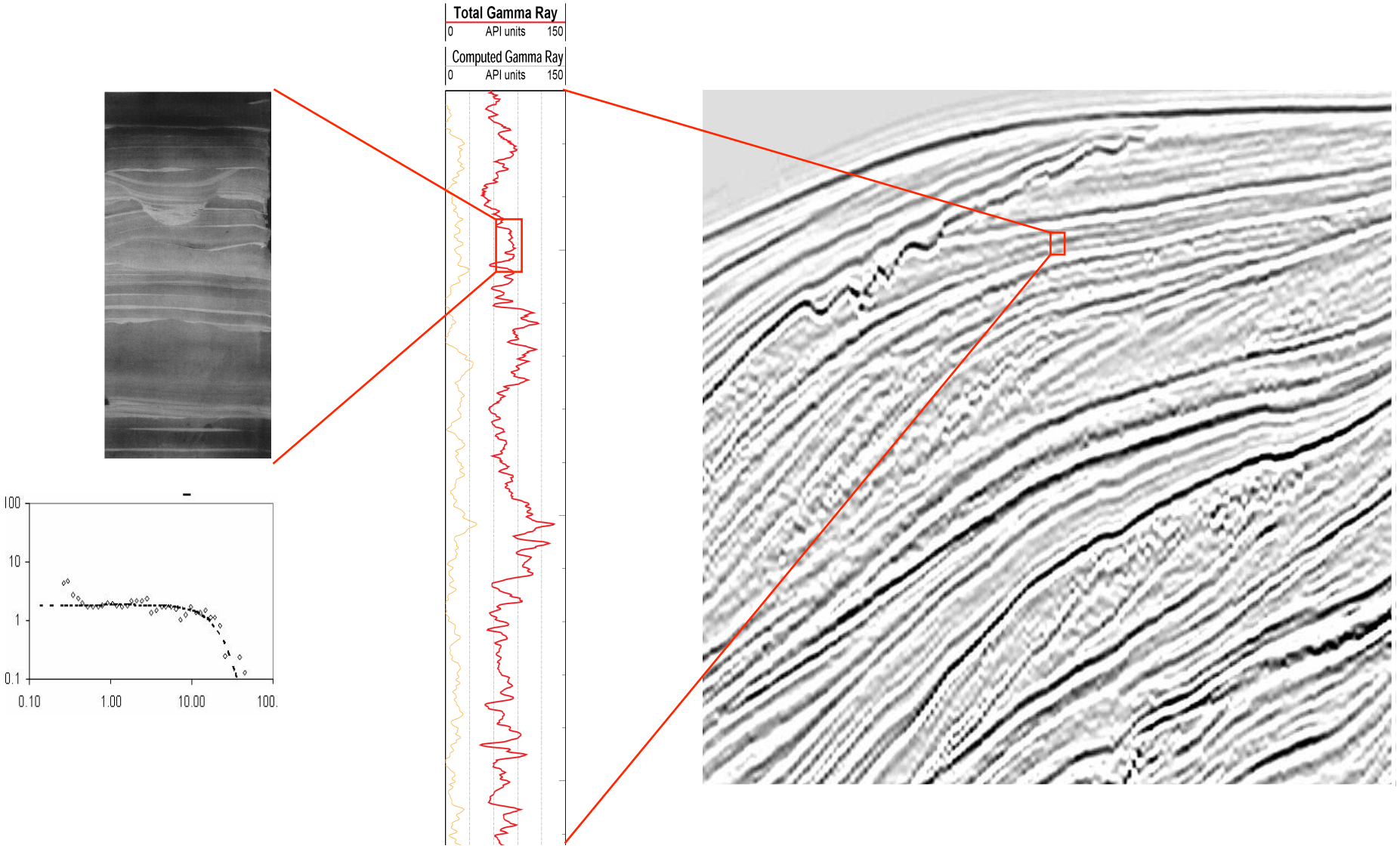
Ordovician slope, West Wales

Structural and diagenetic....

Hemipelagic silty clays, NZ

Layering anisotropy?
Vertical pathways?

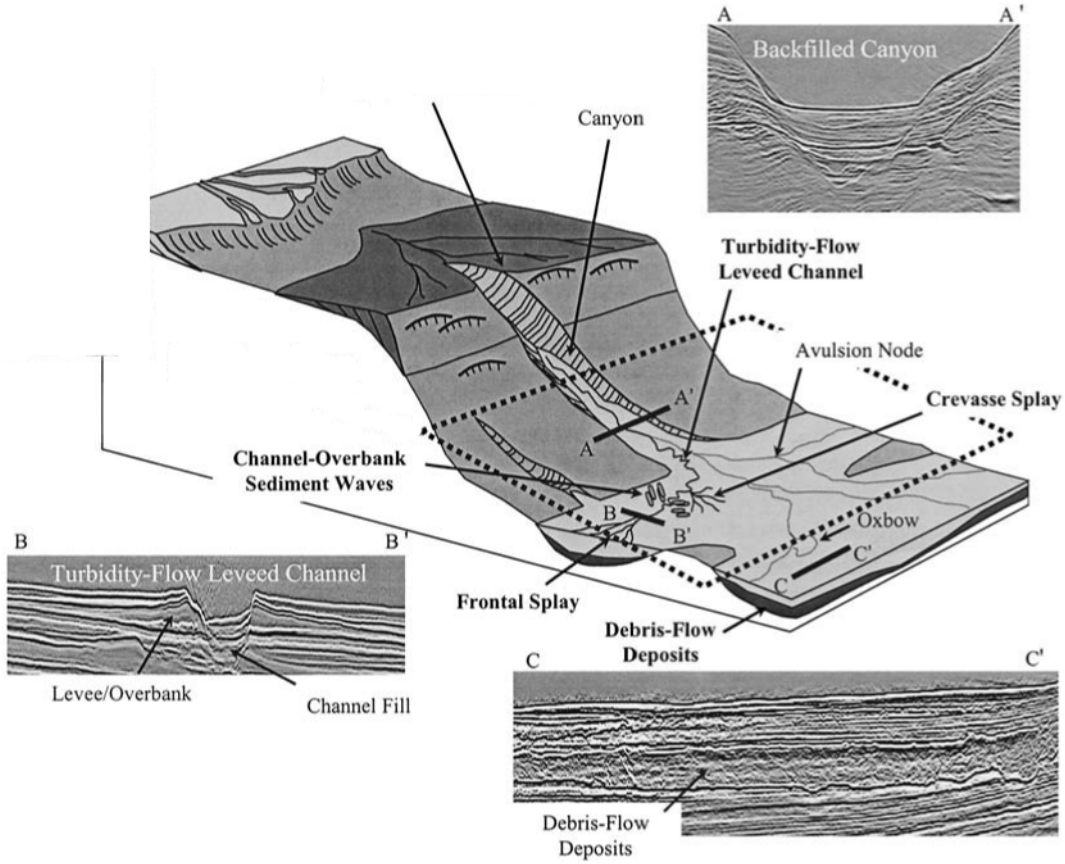
How do HC migrate across
1000s of metres
of hemipelagites?



What scale (s) is important to understand for what processes?
How to observe, and represent this in models?

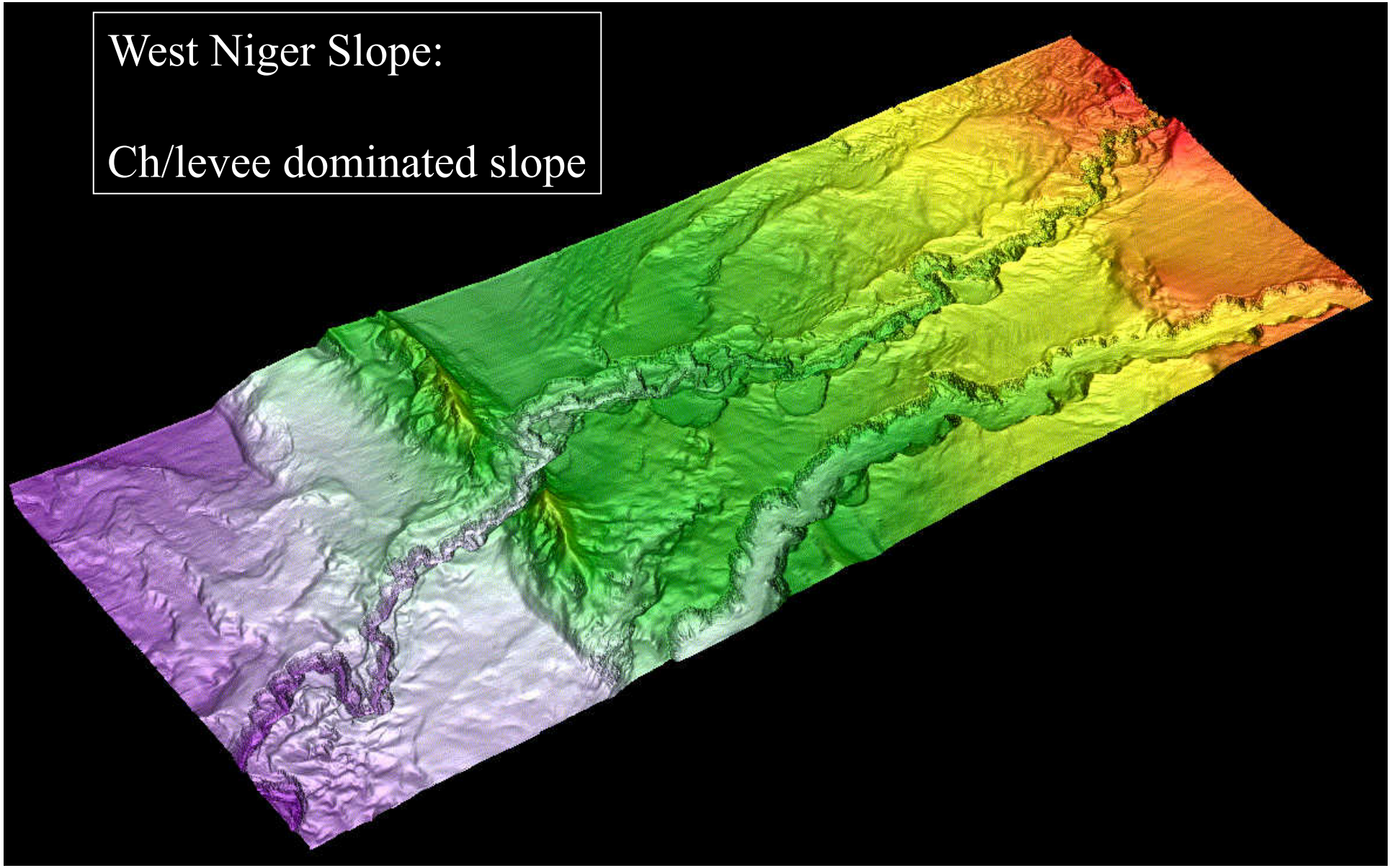
UNIVERSITY OF OXFORD

Point sourced models predominate…….(AAPG 26; SEPM 42)



Kolla and Posamentier, 2003

Heinio et al. 2004



But >80% of rock volume is hemipelagite/MTDs

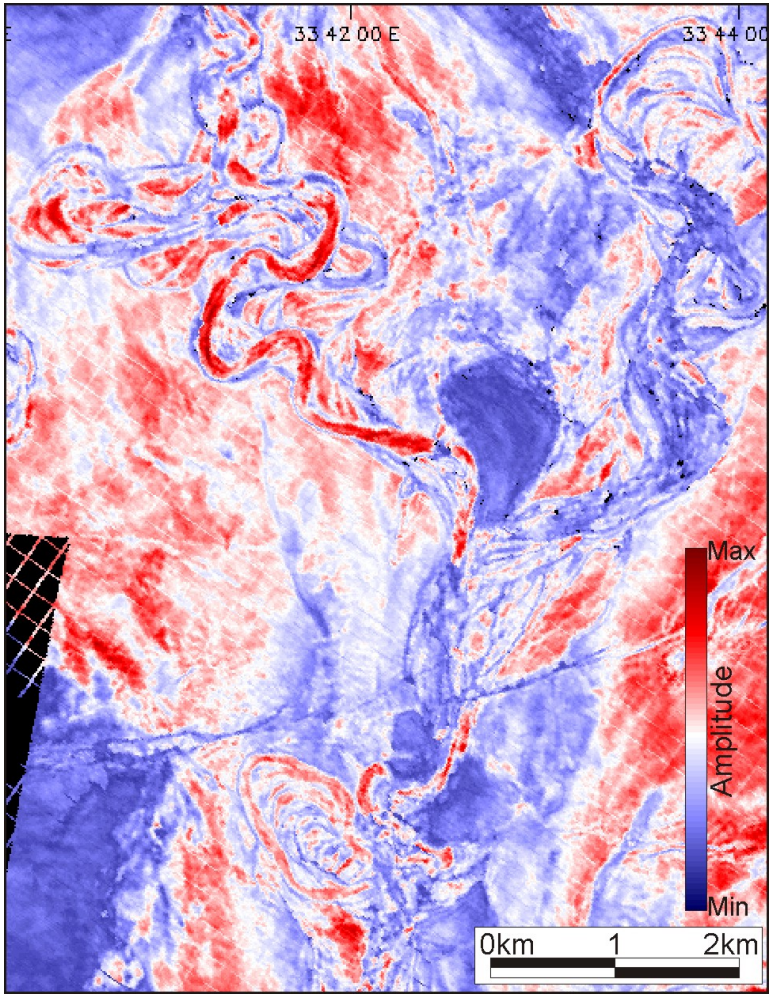
UNIVERSITY OF OXFORD

Depositional models....

Need better process-based work on fine-grained depositional systems

Better calibration of core-logs-seismic (high resolution)

Mine ODP archive

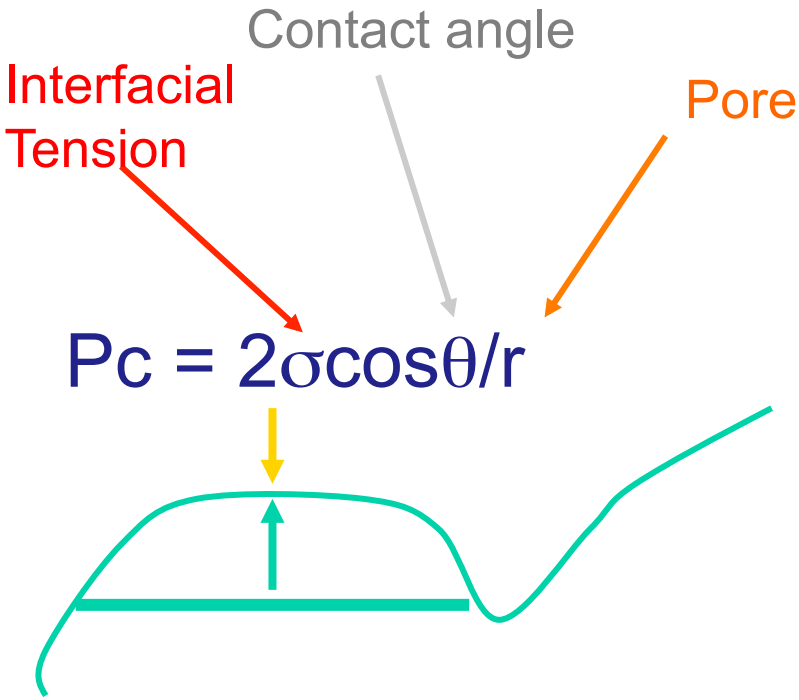


Clark et al. 2011

More time to think, not faster mapping per se

UNIVERSITY OF OXFORD

Simple Evaluation of Capillary Seal



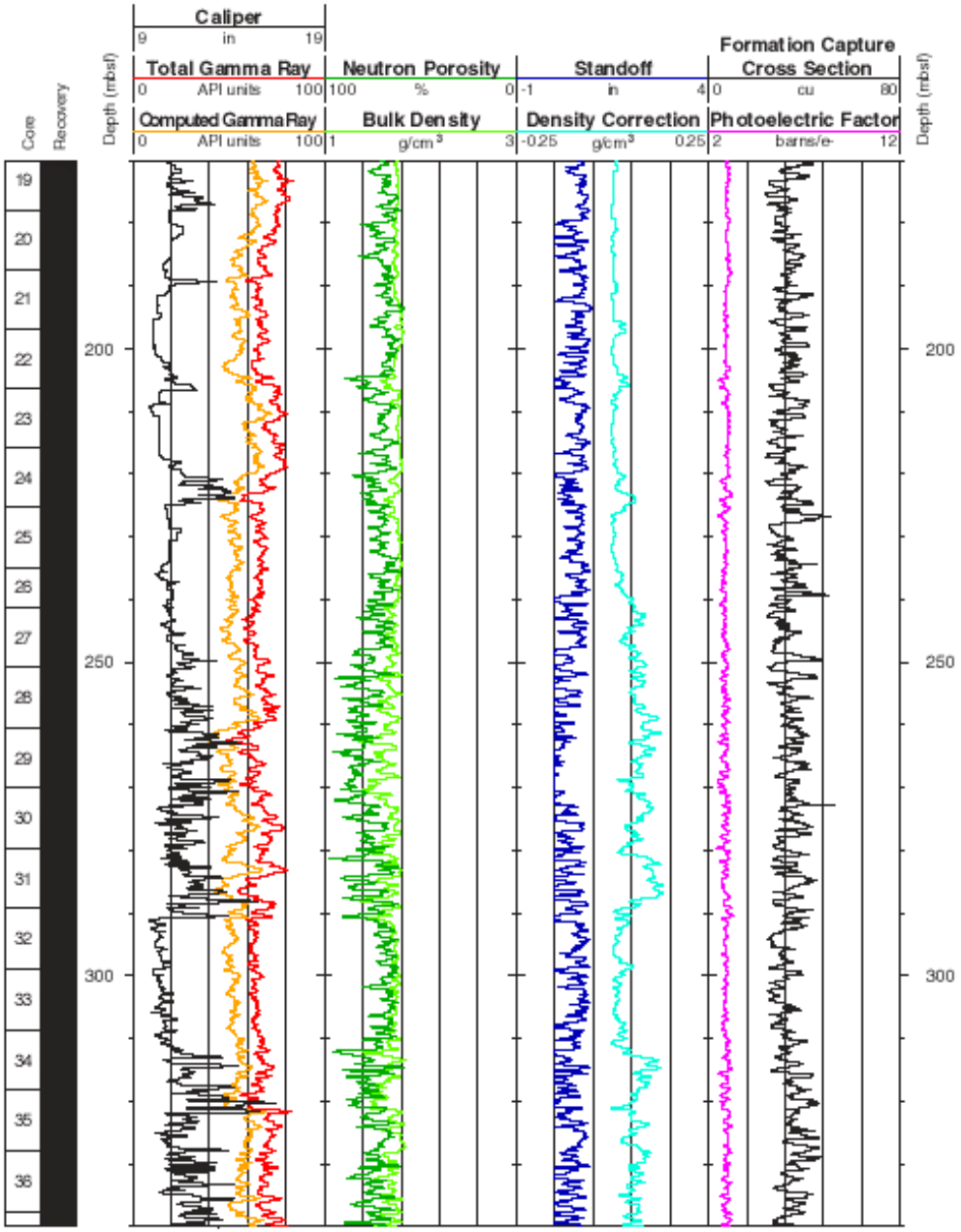
Can continuous and effective HC columns form in mudrocks?

Column height $h = Pc/(\rho_w-\rho_p)g$

Petrophysics of Mudrocks

- Basic Lithological Characterisation
- Physics of mineral/fluid interactions, fluid flow
- Fluid types and saturation, OM
- Mechanical properties
- Pushing resolution limits

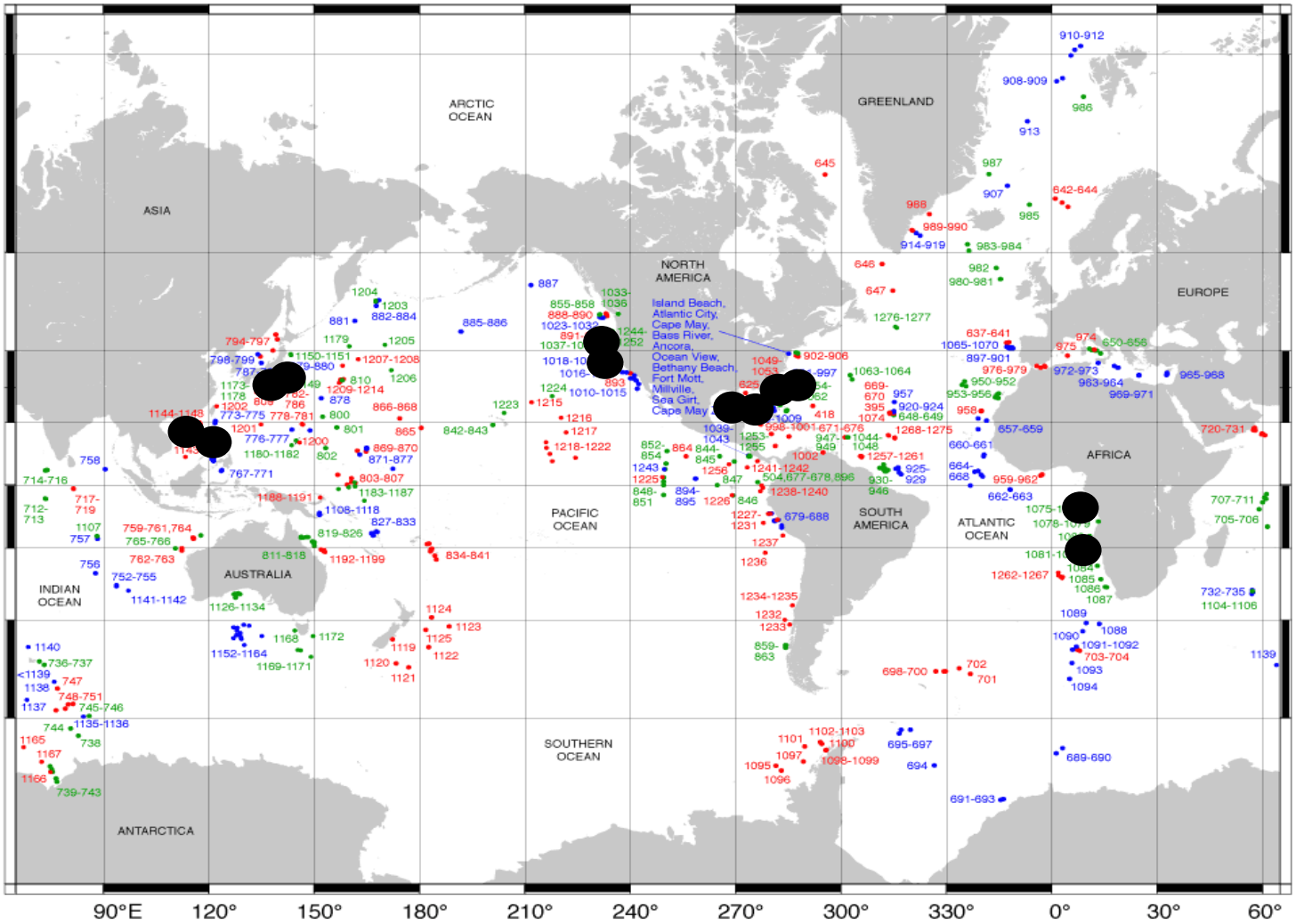
UNIVERSITY OF OXFORD



Logs are the key.....

UNIVERSITY OF OXFORD

Tom Praeger, PhD Thesis: Mining the ODP Archive



Studied Areas: 8000 m of Core Examined

UNIVERSITY OF OXFORD

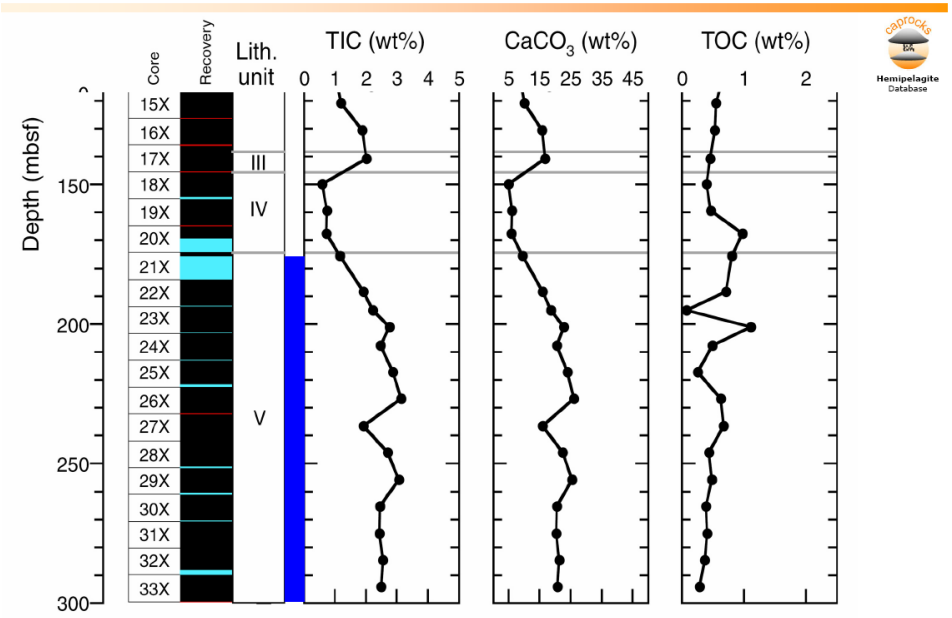


Figure 2. Total inorganic carbon (TIC), $CaCO_3$, and total organic carbon (TOC) from Site 1320. Blue bar denotes studied hemipelagic interval

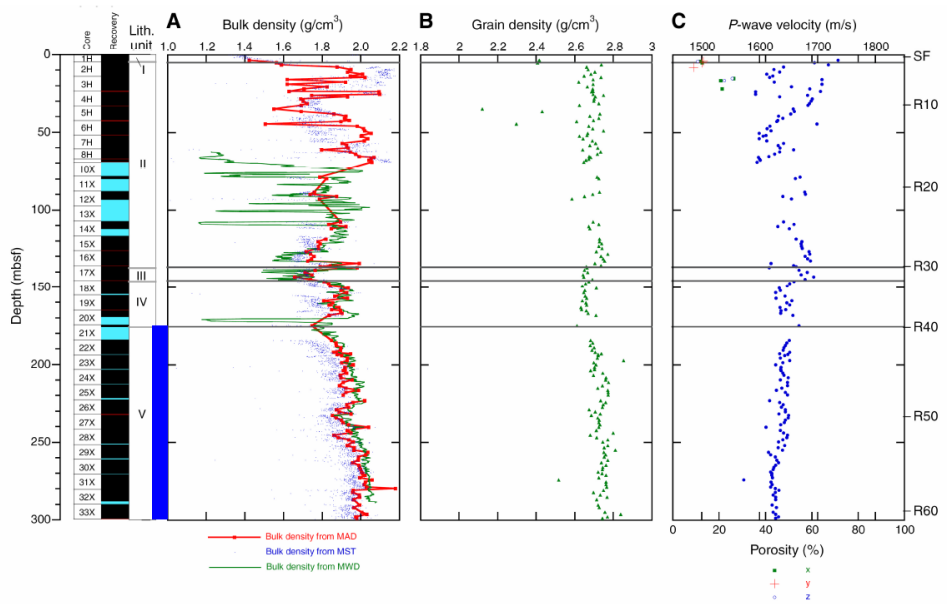


Figure 3. Physical properties for Site 1320. Blue bar denoted studied hemipelagic interval

- Physical properties

Porosity

Bulk density

P-wave velocity

Shear strength

Gamma-ray

Resistivity

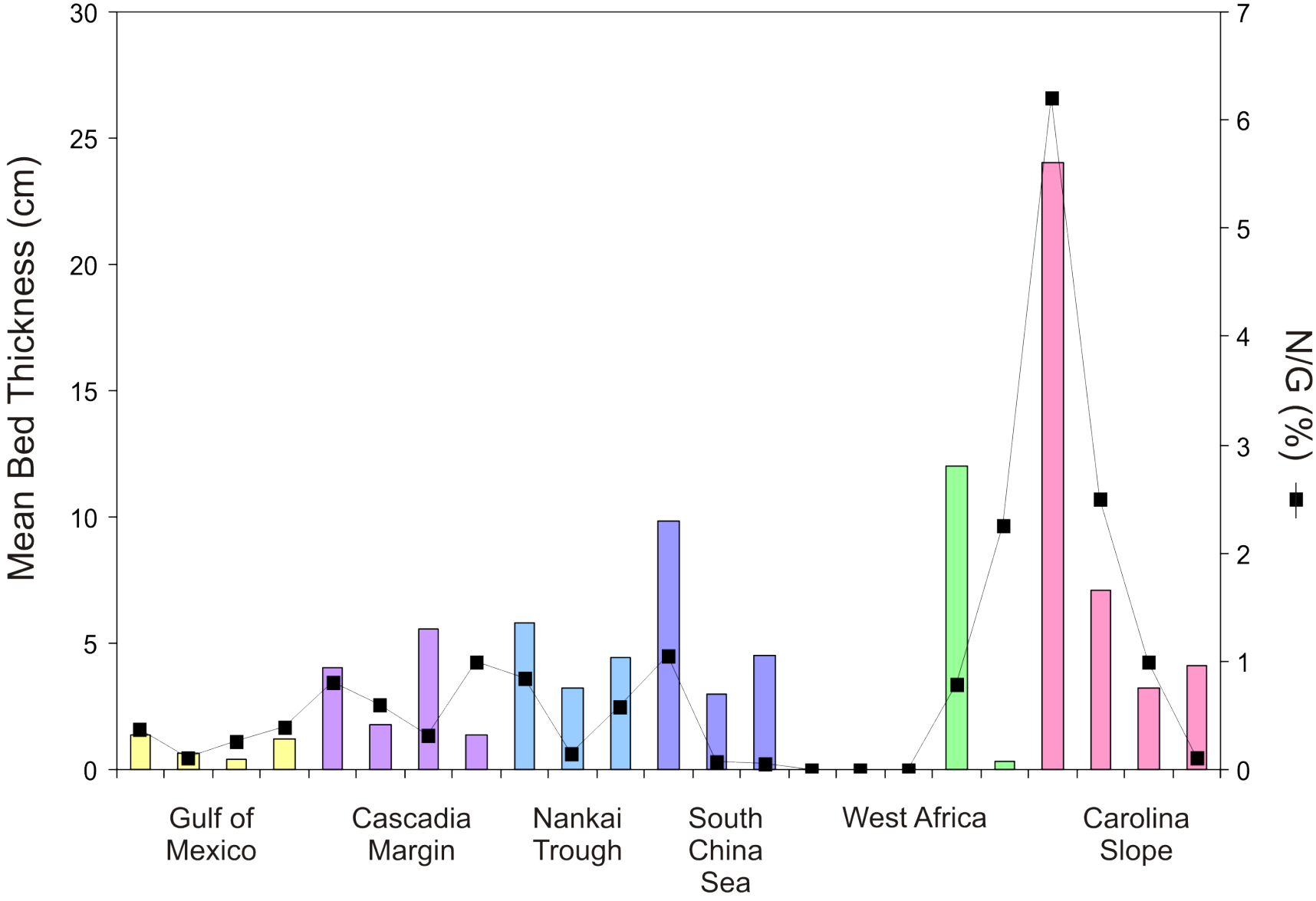
Bulk mineralogy

Clay mineralogy

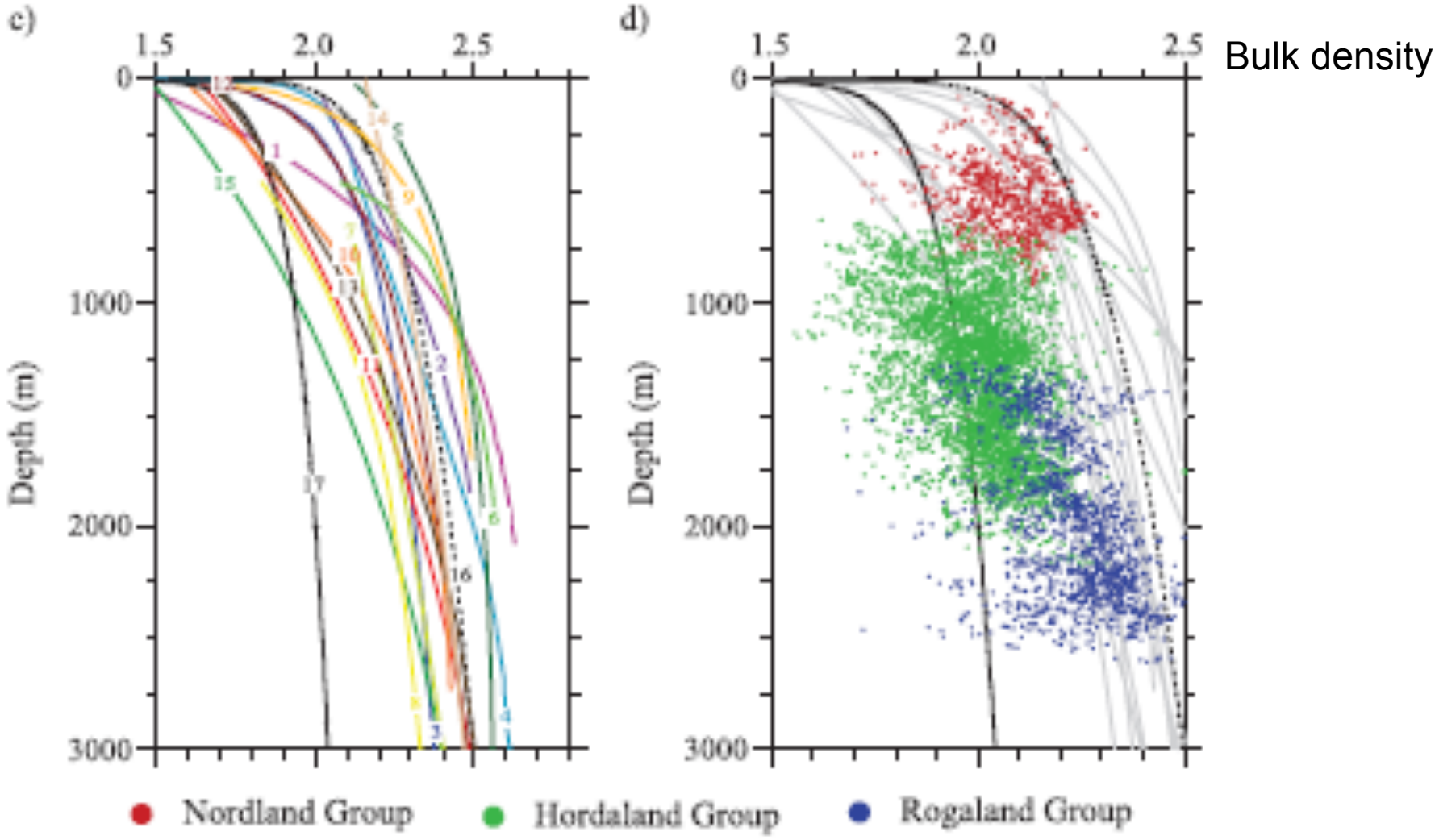
TOC

UNIVERSITY OF OXFORD

Mean Bed Thickness / N/G



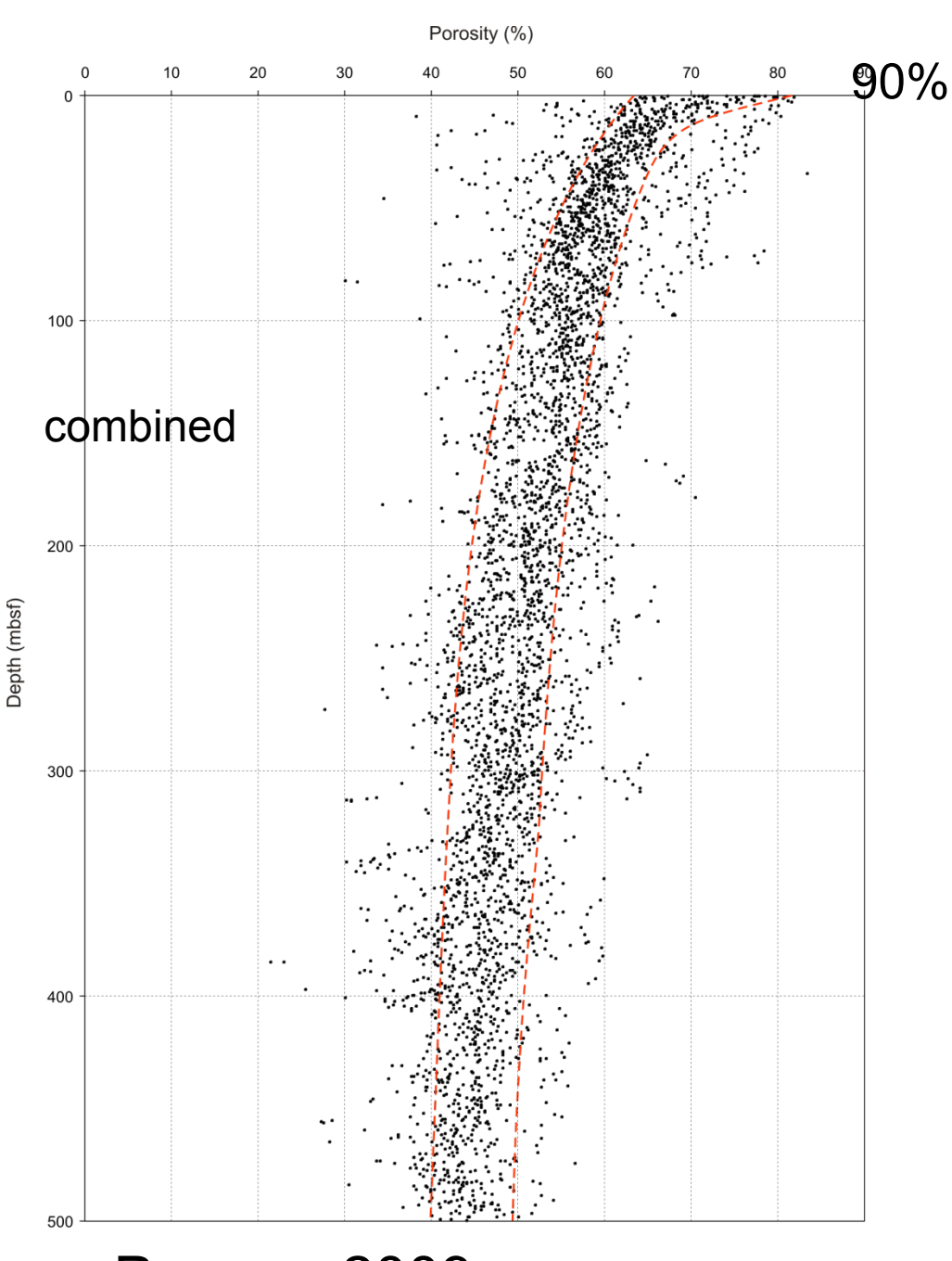
‘Compaction’ curves and porosity data

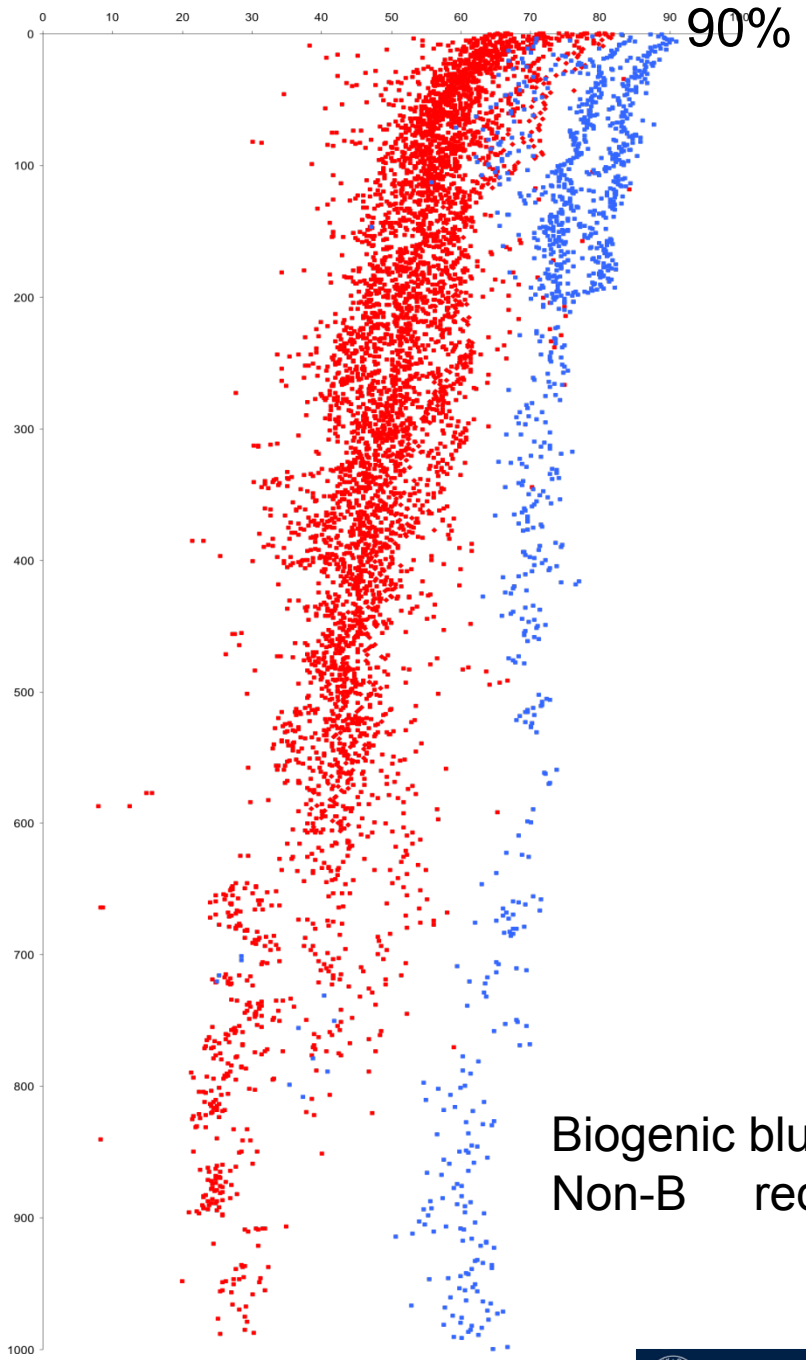


Bulk density

Marcussen et al, AAPG; 2009

UNIVERSITY OF OXFORD



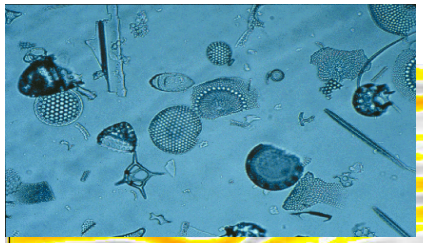


Praeger 2009

UNIVERSITY OF OXFORD

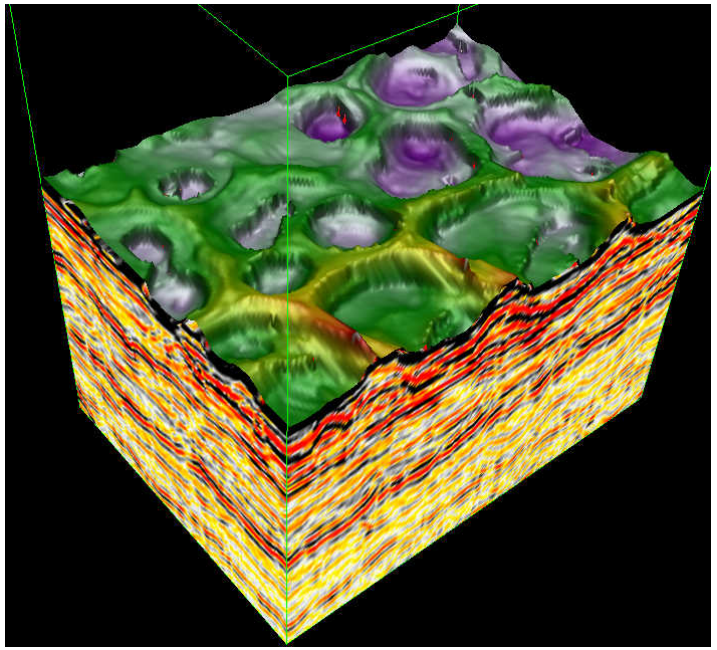
How does diagenesis impact physical properties?

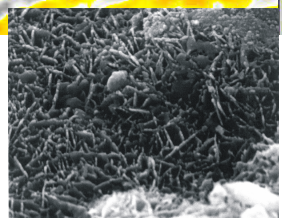
Opal A



1 km

Davies, 2005 GSABull.

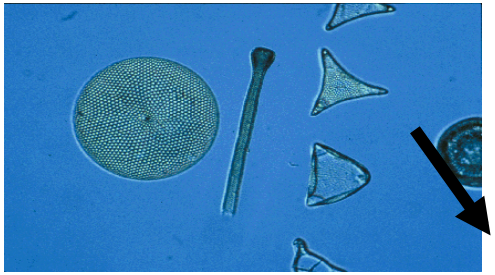


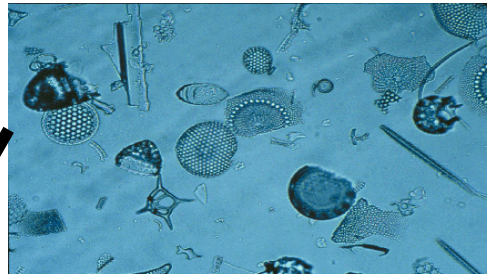


Opal CT

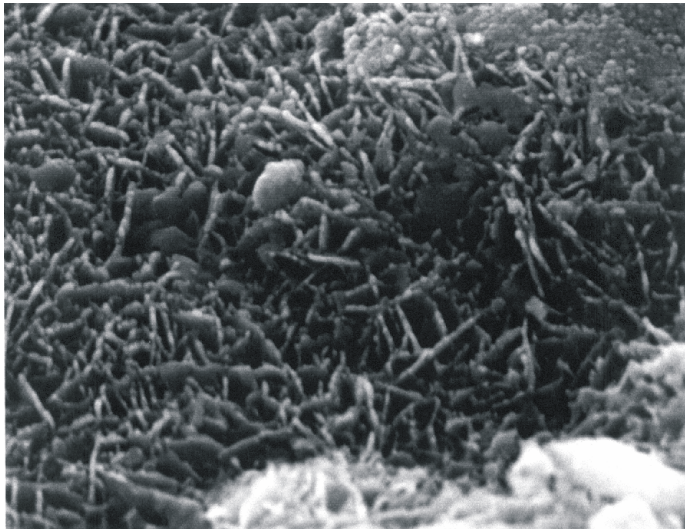
0.01 mm

Dissolution of opal A….precipation of opal CT





Opaline silica

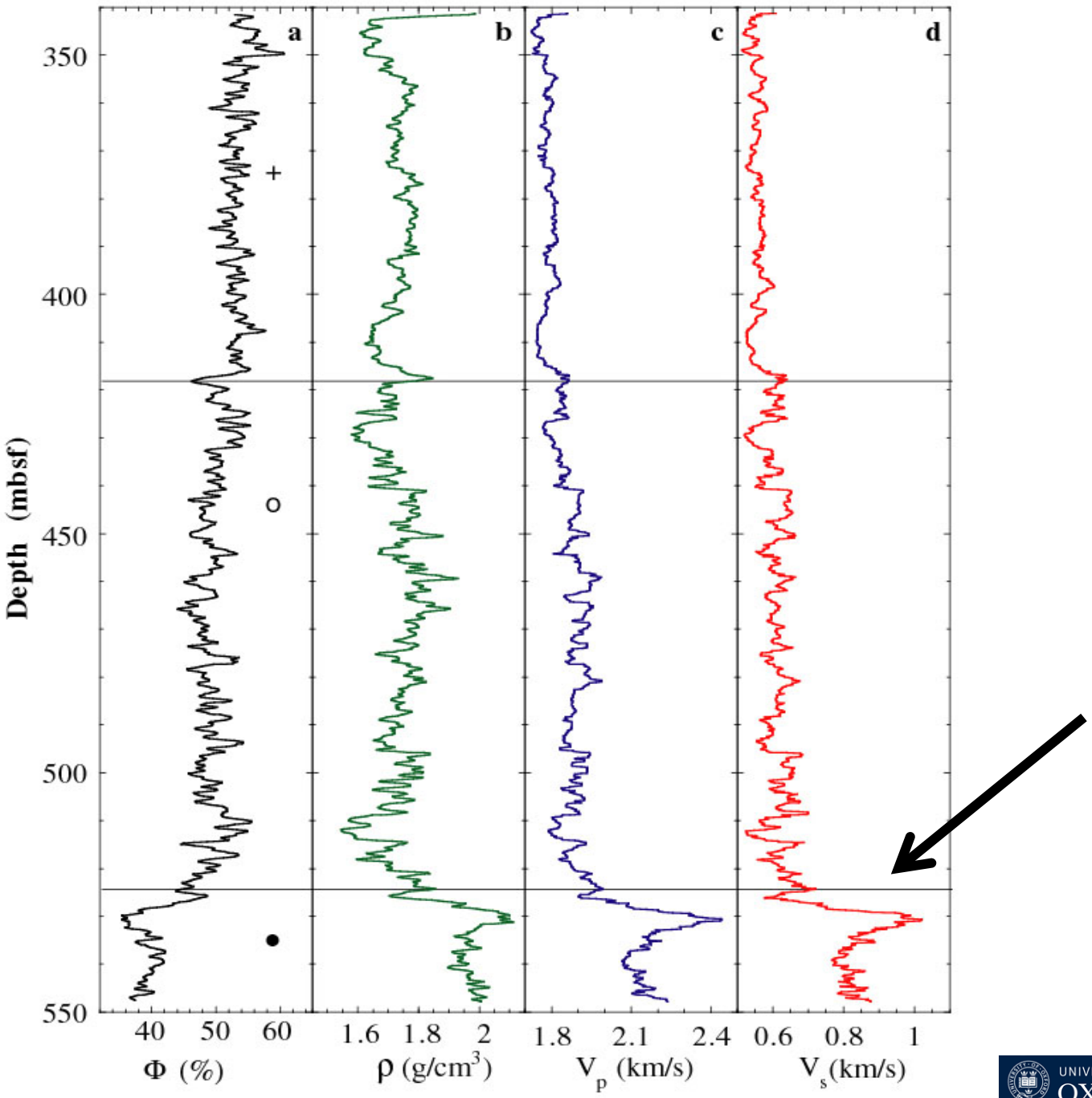


Opal CT

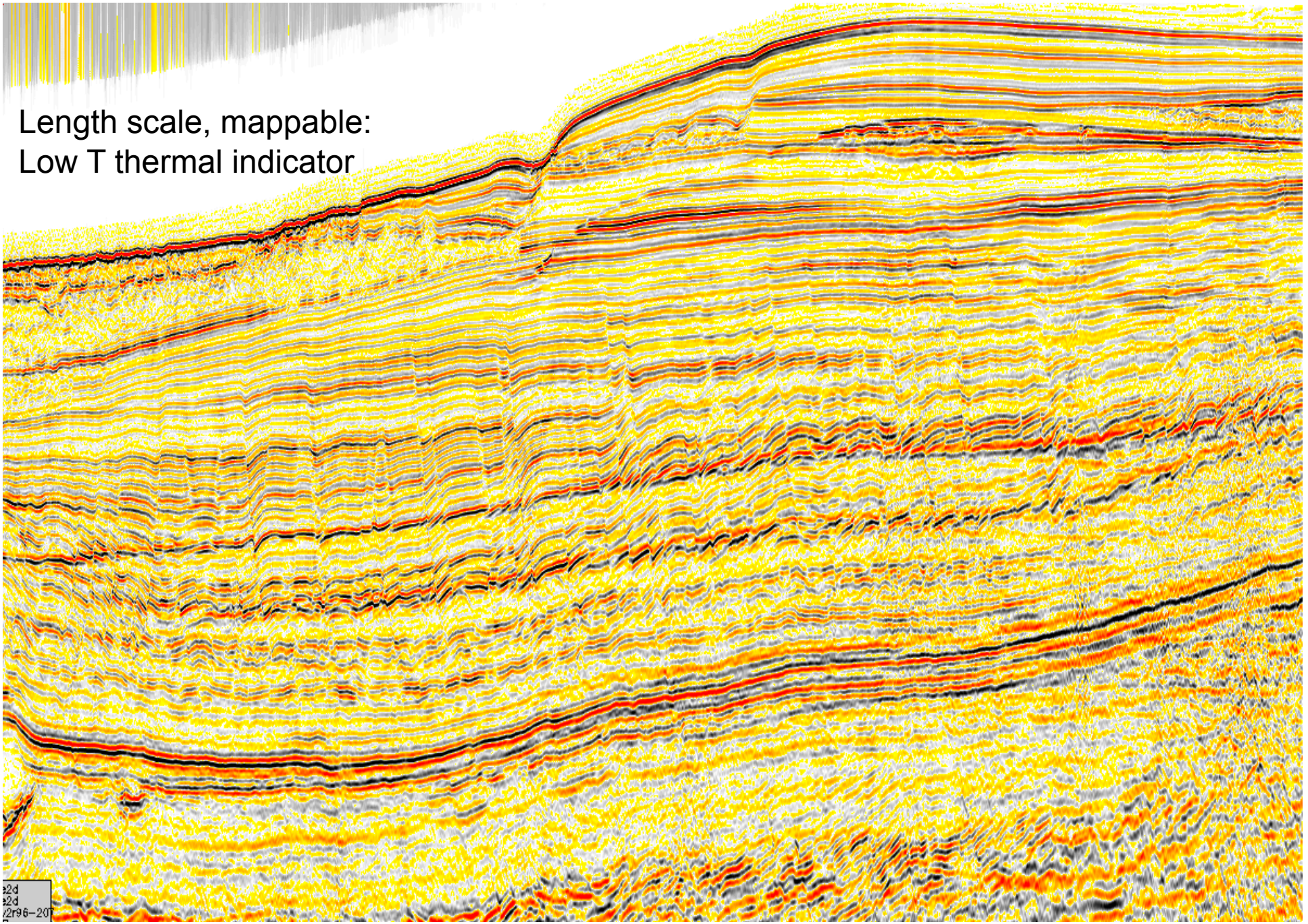
Usually at 15-45°C (first 700 m of burial)

ODP 904A

150 other calibrations



UNIVERSITY OF OXFORD



30 km by 2000m

UNIVERSITY OF OXFORD

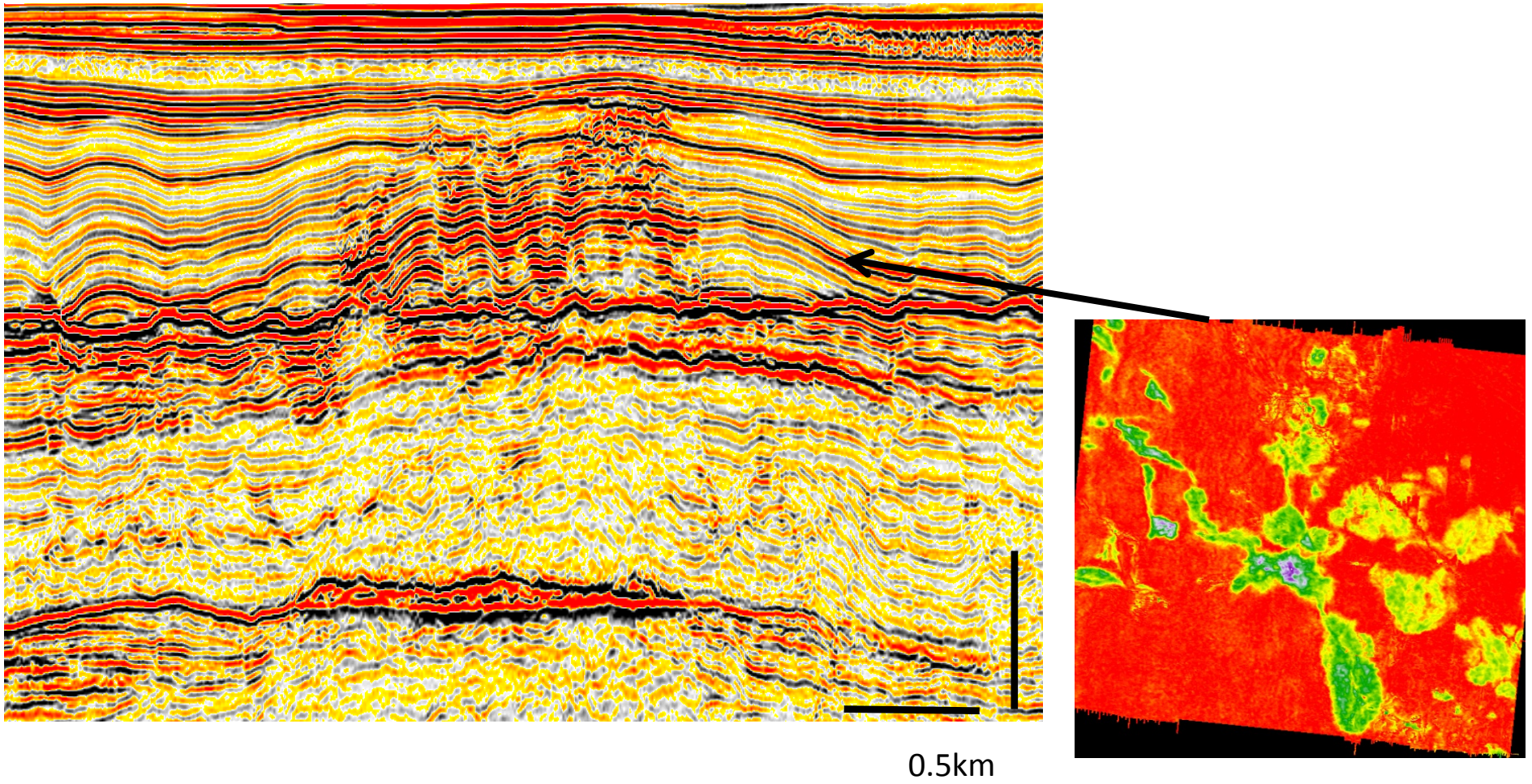
Hydrocarbon migration and fluid flow

Focused fluid flow across thick mudrock sequences

Evidence in stacked DHIs

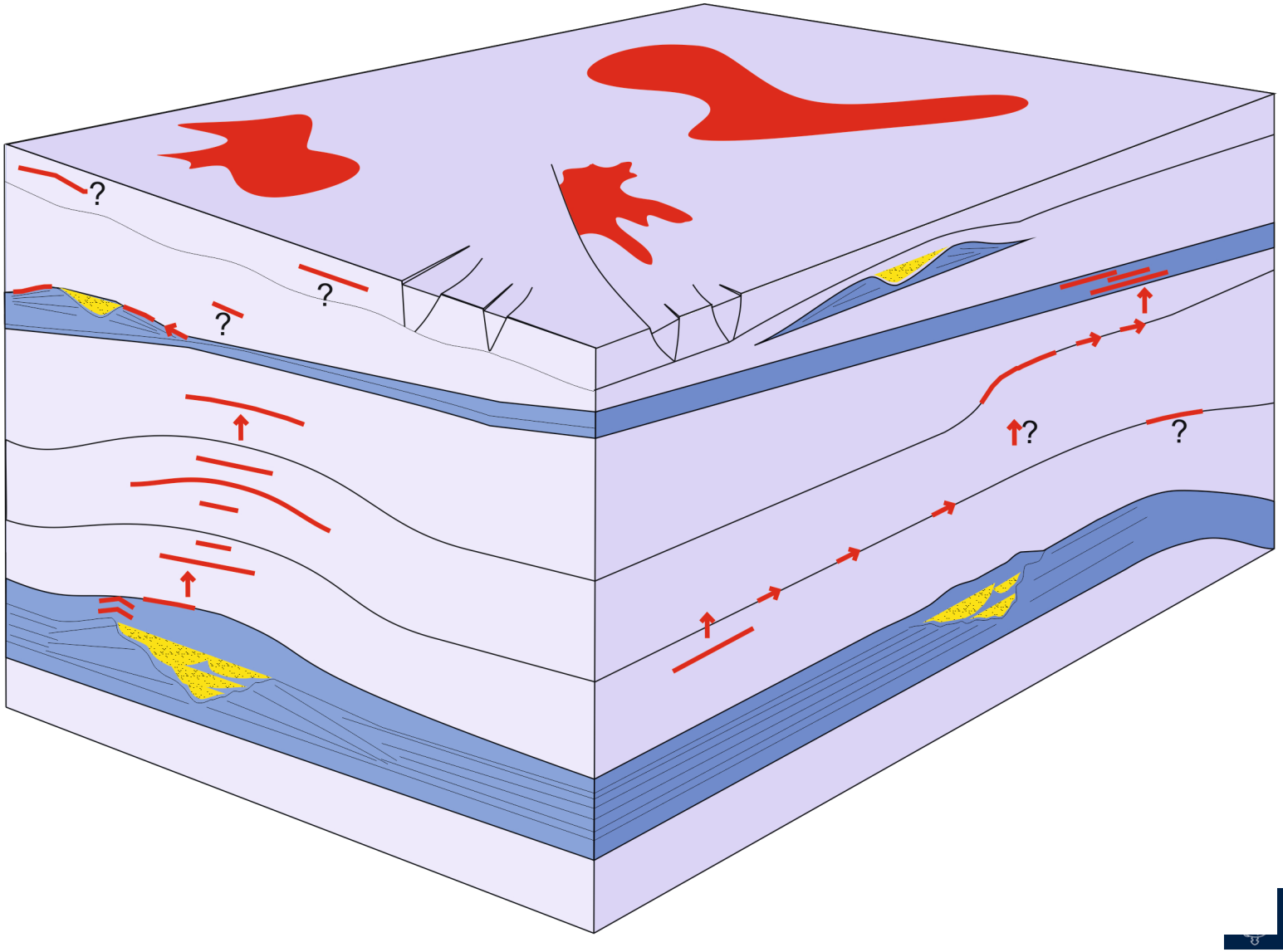
Shallow accumulations with no stratal flow path

High resolution attribute mapping of gas migration pathways

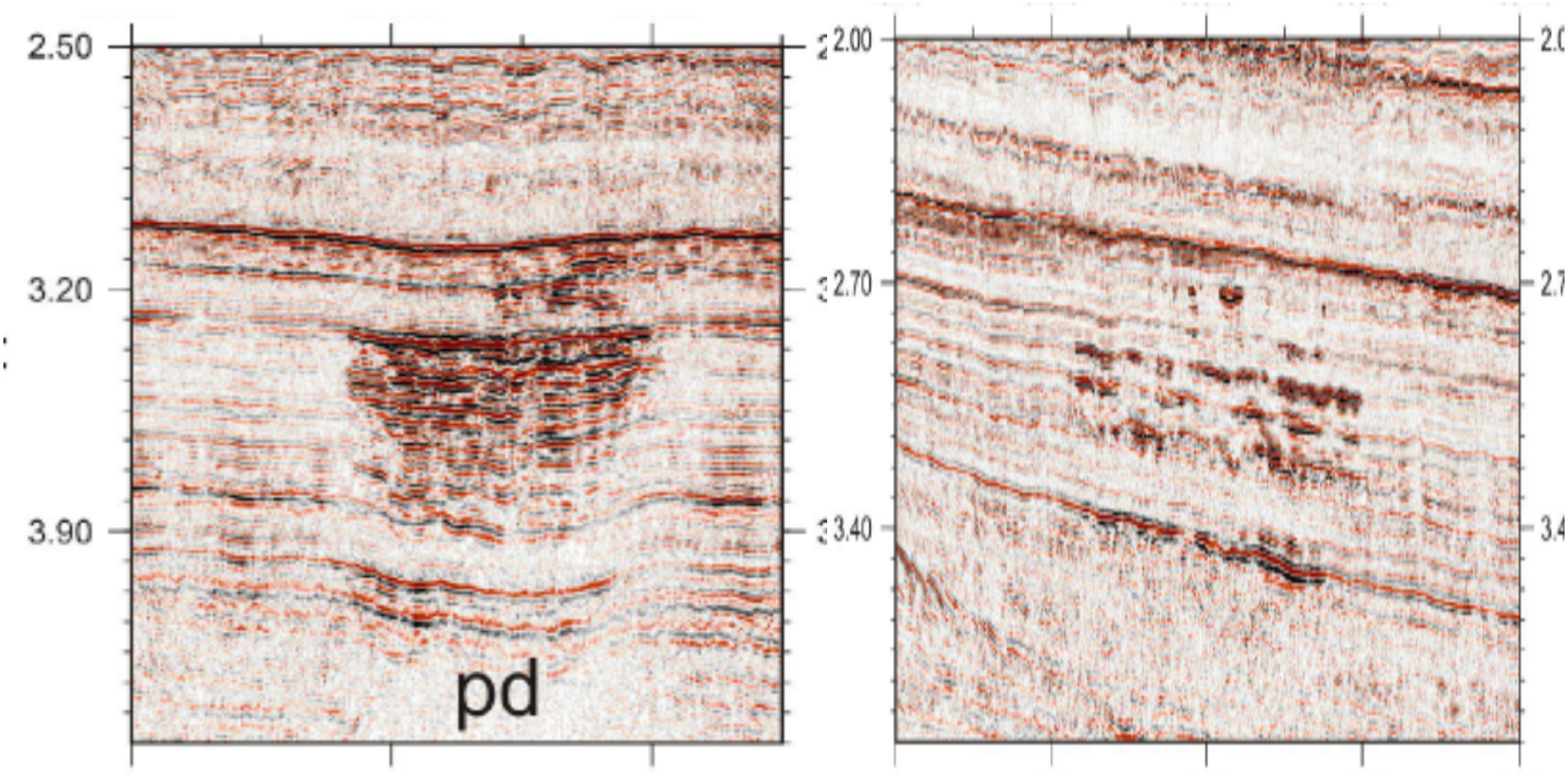


Amplitude map of arrowed horizon showing the pattern of amplitude anomalies resulting from gas migration into this stratigraphic level

Spatial associations.....

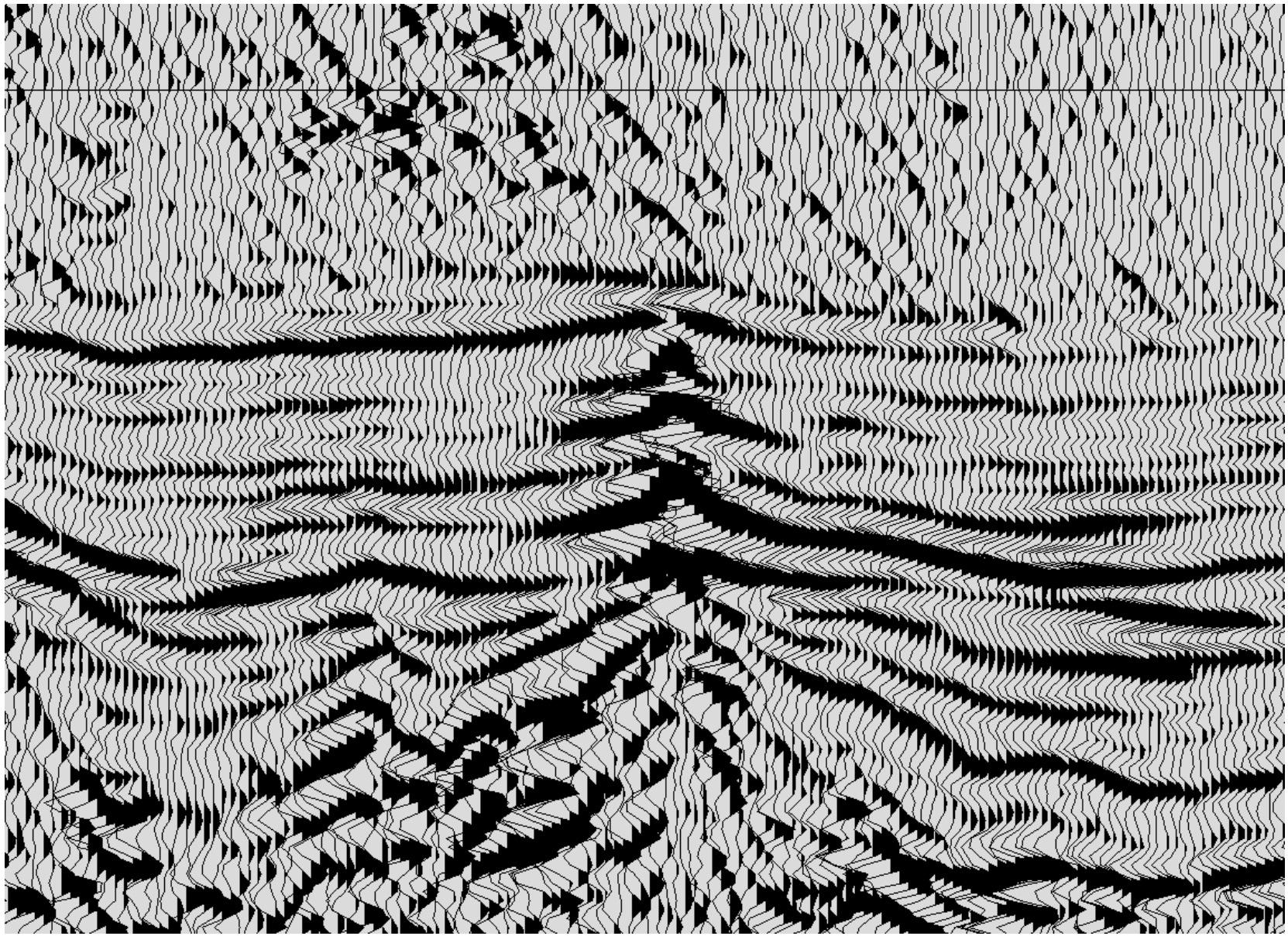


Gas migration across hemipelagites

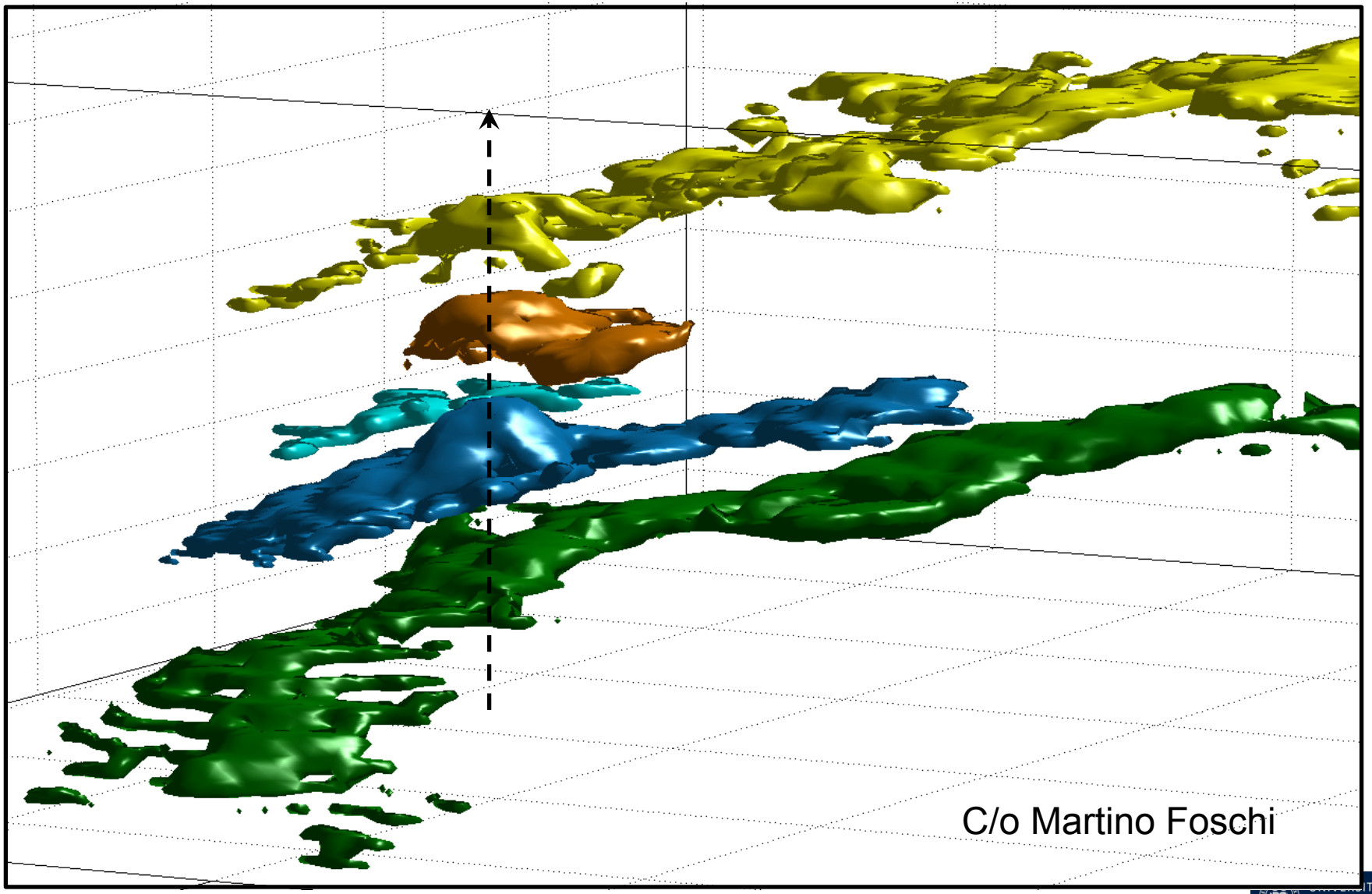


Foschi et al. AAPG submitted

10km wide panels



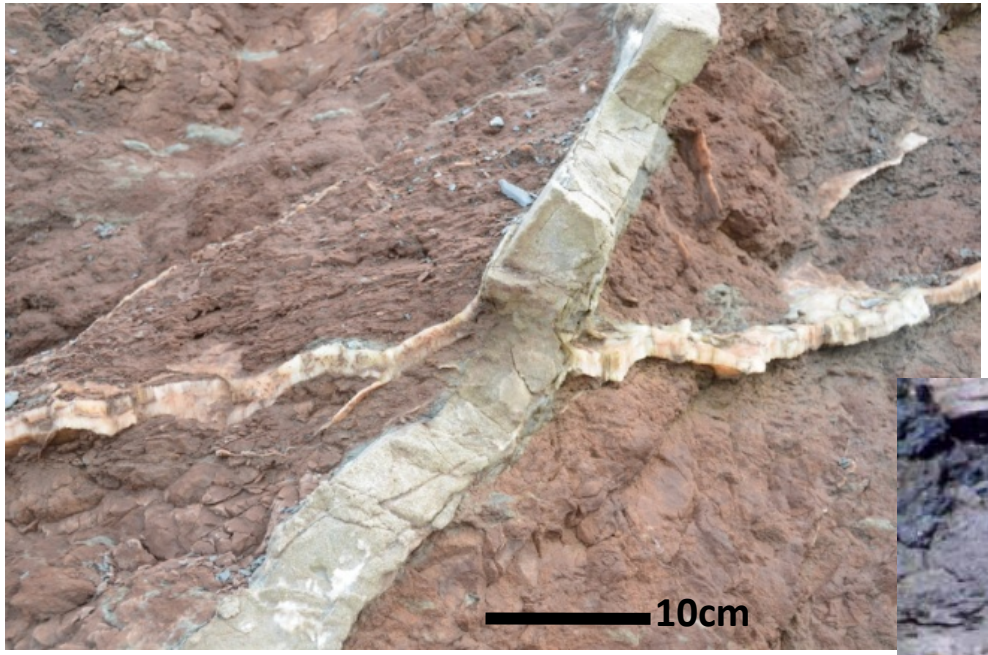
Close-up of the vertical axial conduit



Fracture Systems in Mudrocks

- Tectonic versus diagenetic mechanisms
- Burial versus Uplift phase: timing
- Mineralisation- what can it tell us?

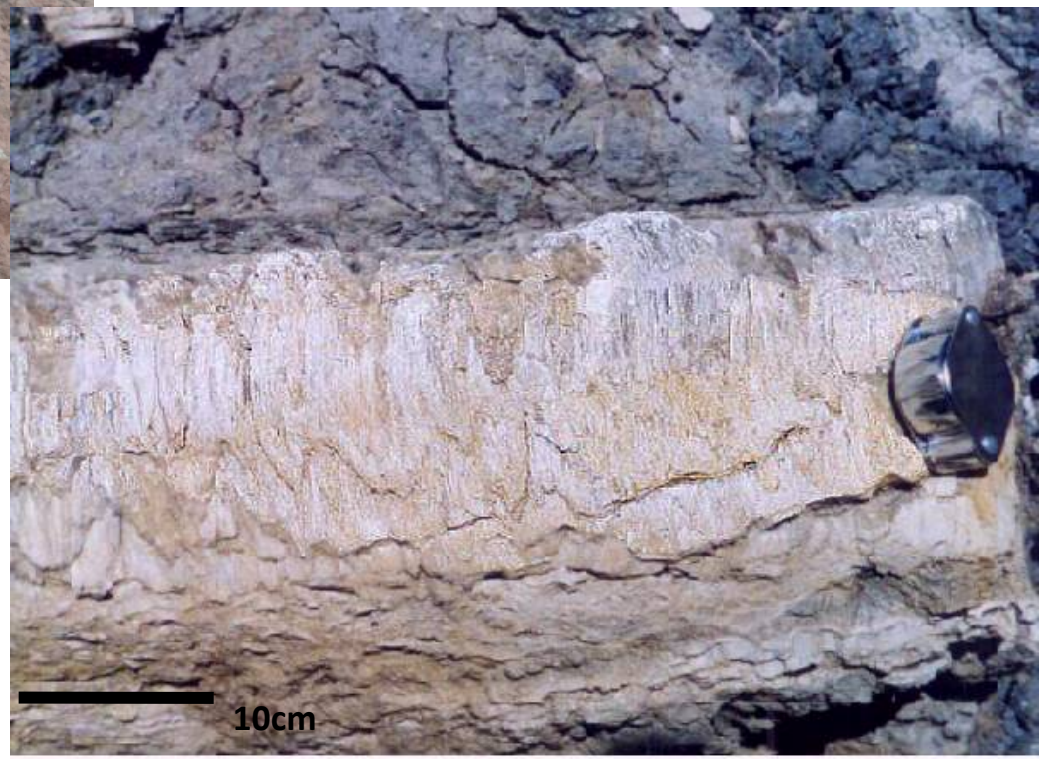
Mode I Fractures in Fine Grained Rocks



Hydraulic Fractures :Mercia Mudstone, Triassic, Bristol Channel Basin, UK

Fibrous veins widely seen in shale gas cores

Shales-with-Beef: Jurassic, Wessex Basin, UK



Shearman, 1972; Stoneley and Selley, 1980s

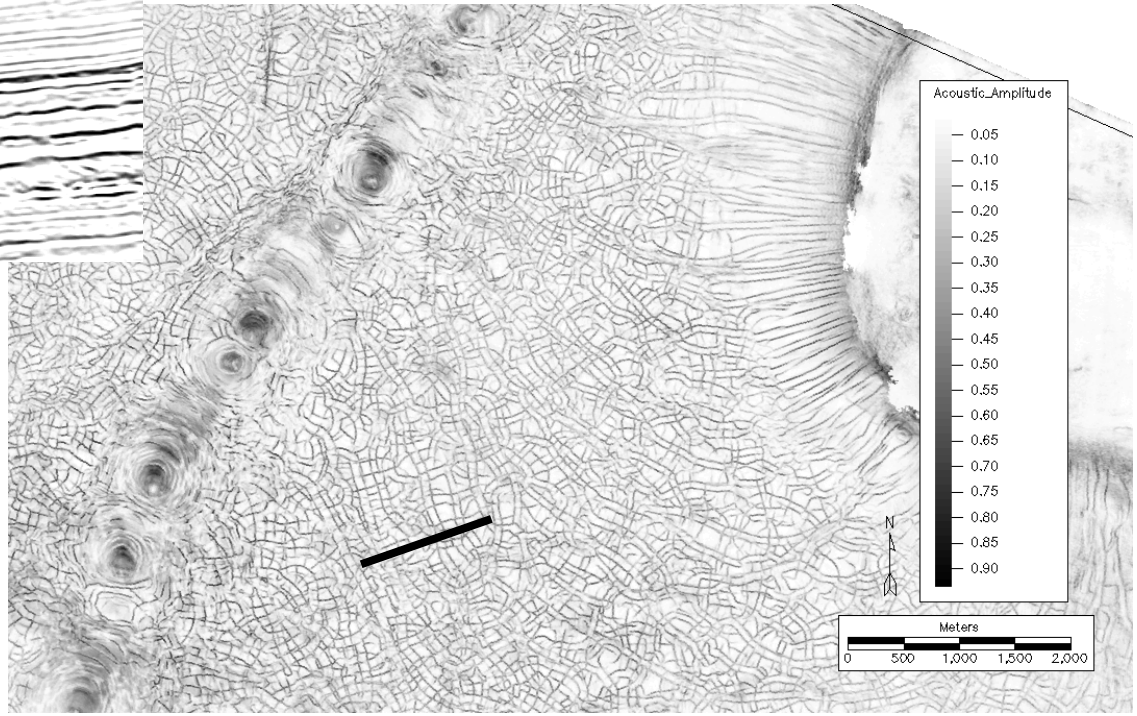
UNIVERSITY OF OXFORD

Joints: still an enigma

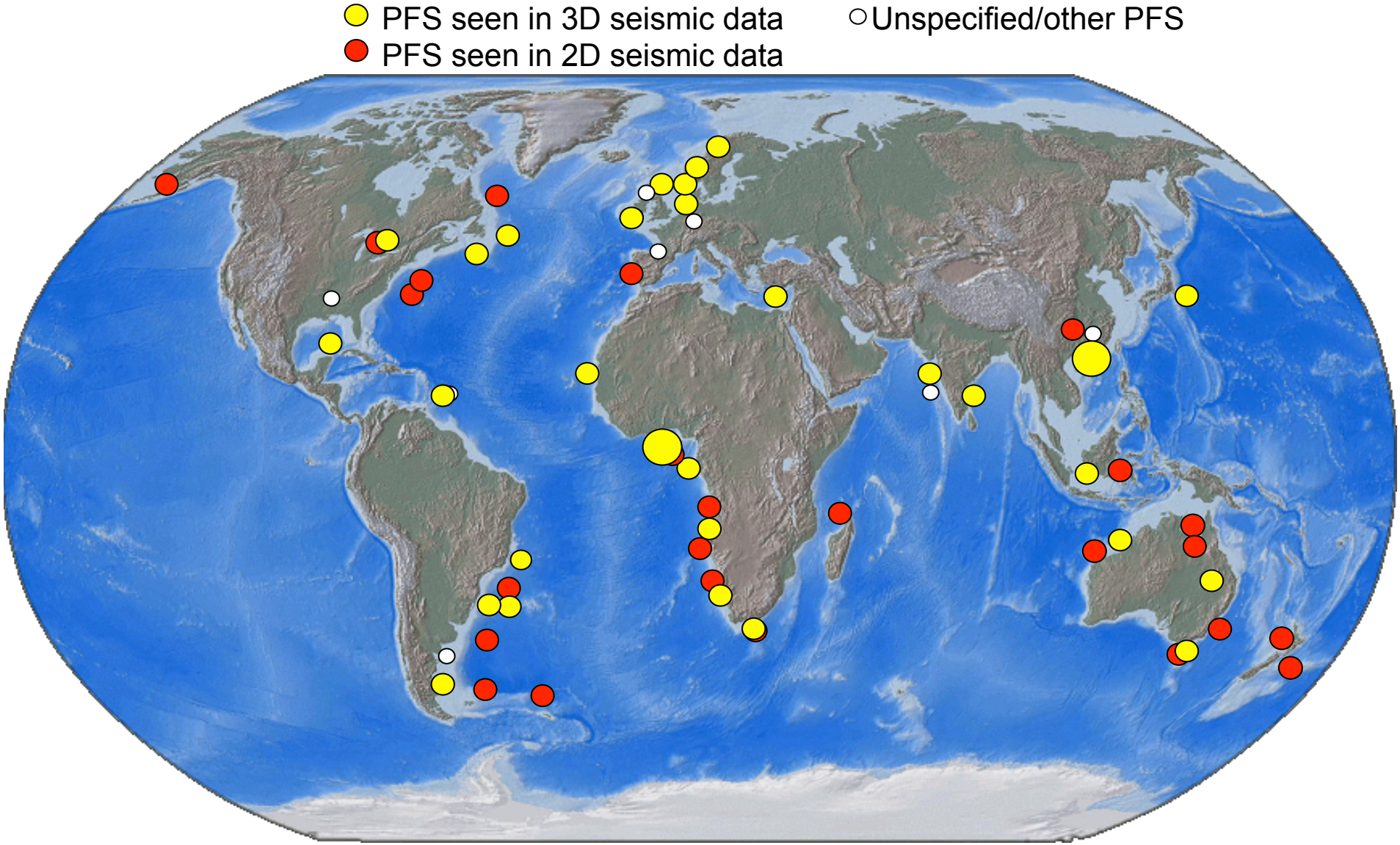
Hydraulic fractures?Elastic unloading? Late uplift, near surface? Present in subsurface?

UNIVERSITY OF OXFORD

Polygonal Fault Systems: A link between diagenesis and fracture development in fine-grained sediments?



Polygonal faults, pockmarks and a salt diapir imaged with a stratal coherence slice from a 3D survey


PFS seen in 3D seismic data
PFS seen in 2D seismic data
Unspecified/other PFS

Polygonal faults: shear failure in mudrocks due to diagenesis

- Not predicted by soil mechanics theory- layer bound, non-tectonic type of faulting process
- Only hosted in fine-grained facies-

  clays, marls, chalks, siliceous oozes
- Experimental work shows that shear failure occurs during diagenesis due to change in interparticle forces

Impact on:

Unconventionals – key contribution to natural fracture development

Hydrates, Slope Stability, CO2 storage

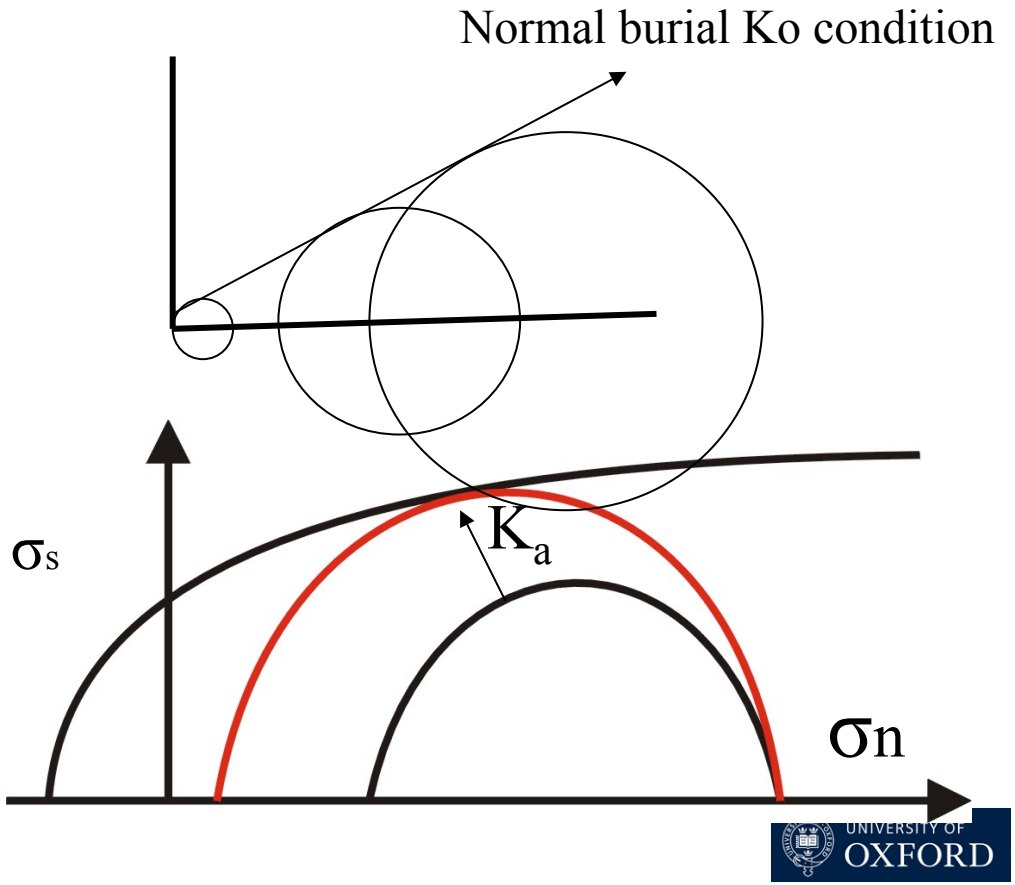
Hydrocarbon seal integrity

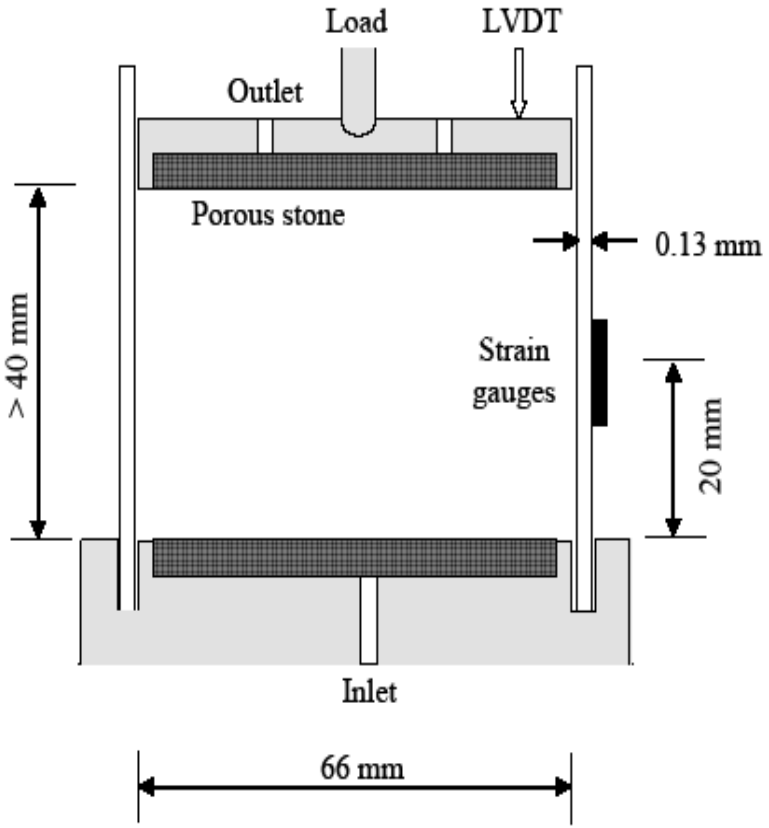
Shear failure observed……..

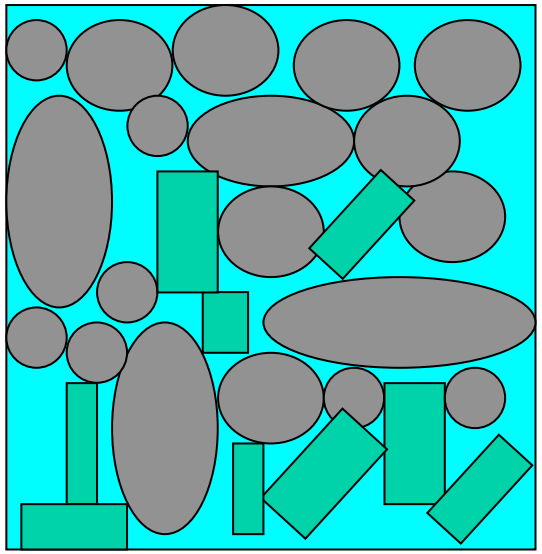
How does failure occur under the Ko condition?

No tectonic extension: so no tensile component to stress state

Failure in shear:
By a reduction in
Horizontal effective stress



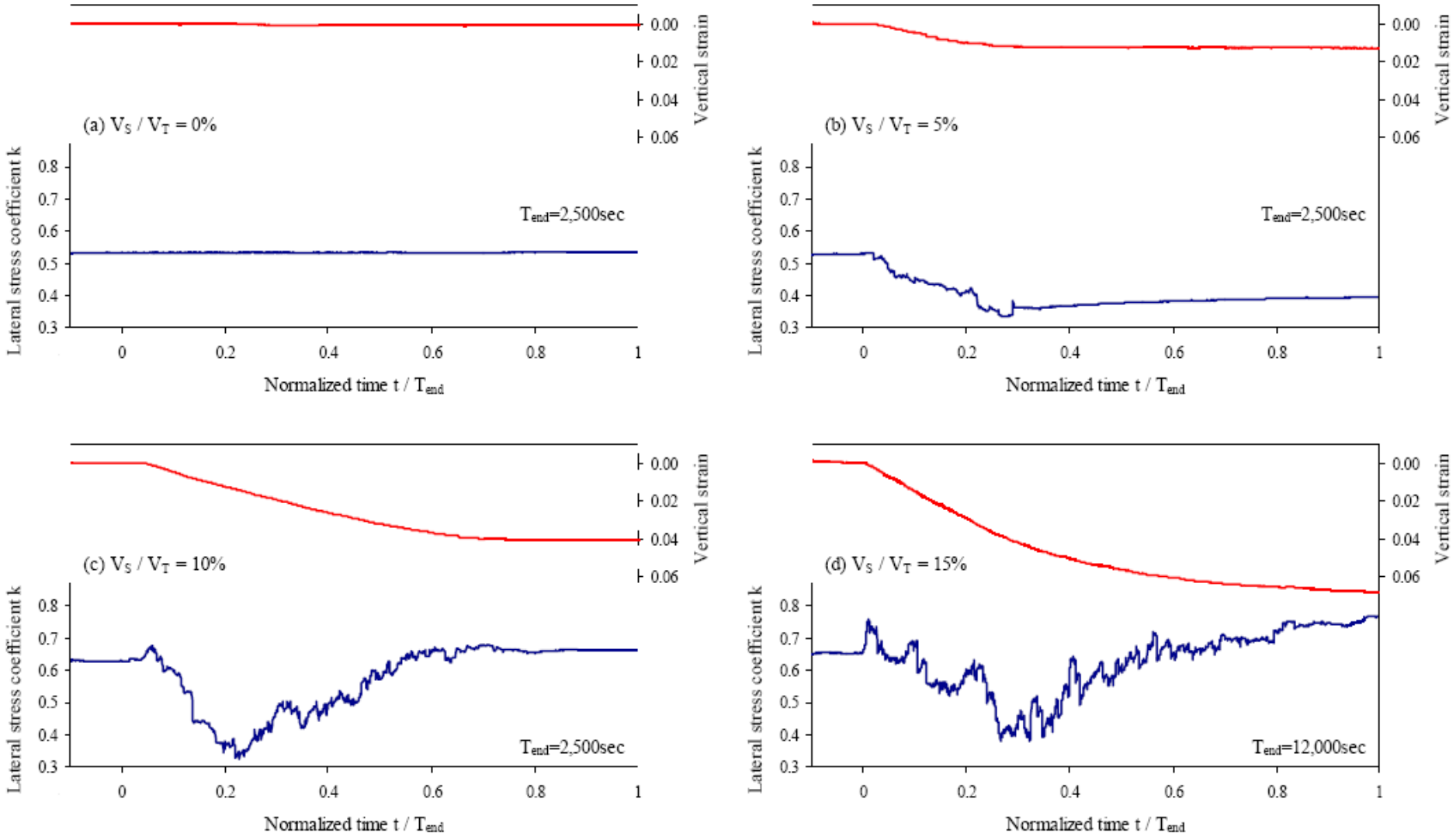




Contraction-driven shear failure in compacting uncemented sediments

Hosung Shin[1], J. Carlos Santamarina[1], Joseph A. Cartwright[2]
[1]Georgia Institute of Technology, Civil and Environmental Engineering, 790 Atlantic Drive N.W., Atlanta, Georgia 30332-0355, USA
[2]3D Lab, School of Earth, Ocean and Planetary Sciences, Cardiff University, Cardiff, Wales CF10 3XQ, UK

UNIVERSITY OF OXFORD



Blue is K stress path with time: 0.4 is shear failure, Red is vertical strain (compaction)

UNIVERSITY OF OXFORD

New shear failure mechanism

- Diagenesis leads to shear failure
- Strain softening materials (clays etc)
- No tectonic stress component implied
- Dissolution, change in mineral surface properties, volume change with phase, pore fluid chemistry changes

Concluding remarks

- Mudrocks have been intensively studied for over 50 yrs, we owe much to the pioneers: Illing, Hedberg, Hubbert, Downey.

- Much more to come in: facies analysis, petrophysics, across-scale integration, geophysics-geochemistry, QI.