Climatically Forced Progradation During Transgression? Supercritical-Flow Signature of an Extreme Fluvio-Deltaic Flood in the Late Carboniferous Pennine Basin (UK)*

Dario Ventra[1], Jochem F. Bijkerk[2], Matthieu Cartigny[3], and Sanem Açikalin[4]

Search and Discovery Article #10770 (2015)**
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Abstract

Modern sequence-stratigraphic models increasingly need to expand consideration of allogenic forcing to various factors interfering with the well-established role of base level at basin scale. Climate remains a particularly difficult variable to isolate in very ancient successions, for which accurate chronological correlation and proxy-based quantification of paleoenvironmental conditions are seriously limited. However, sedimentary facies analysis still represents a fundamental conceptual tool to recognize process-patterns typical of specific climatic contexts. Recent developments show that fluvial systems in monsoonal settings are subject to prolonged hydrological inactivity alternating with brief (inter)annual phases of possibly extreme discharges, recognizable by sedimentological attributes such as great volumes of supercritical-flow deposits, vegetation-induced structures within channel fills and coarse overbank facies. Distally linked, flood-prone deltas, with higher preservation potential, should also present distinctive traits. Late Carboniferous (Bashkirian) sandstones of the Lower Kinderscout Grit (Millstone Grit Group, UK) were deposited at subequatorial latitudes in fluvio-deltaic and shallow-marine settings of the Pennine Basin, north of the Variscan Orogen, during early assemblage of the Pangean megacontinent. Outcrops frequently feature large, wavy geometries and unusual architectures traditionally difficult to interpret. The unique stratal configuration of deltaic deposits at Derby Delph Quarry (West Yorkshire) comprises thick sets of giant, rhythmically undulating sedimentary structures in massive, poorly sorted sandstones, with fully aggradational architecture. Recent insights on sediment beds under supercritical currents

allow to interpret these deposits as geologically instantaneous progradation of a proximal delta front from a long-lived hyperpycnal current which accreted cyclic steps, bedforms identified only recently under high-energy flow conditions. The paleogeographic, paleoclimatic and sequence-stratigraphic context indicate that the region was subject to a tropical seasonal climate that enhanced megamonsoonal circulation on the eastern margin of the early Pangean landmass. Exceptional fluvial floods were able to transfer large volumes of sediment basinward, especially during interglacial phases of marked seasonality and base-level rise, forcing a high progradational efficiency for clastic systems locally also during transgressions.

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CLIMATICALLY FORCED PROGRADATION DURING TRANSGRESSION?

SUPERCRITICAL-FLOW SIGNATURE OF AN EXTREME FLUVIO-DELTAIC FLOOD IN THE LATE CARBONIFEROUS PENNINE BASIN (UK)

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Jochem Bijkerk
School of Earth and Environment, Leeds University, UK

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National Oceanography Centre, Southampton, UK

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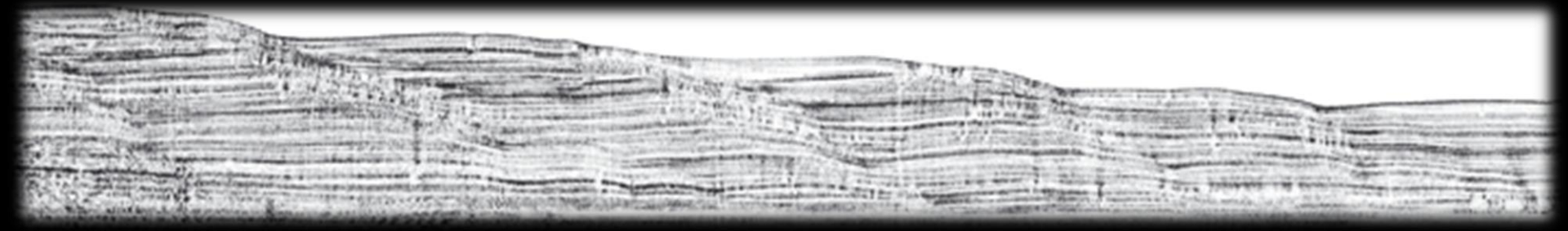
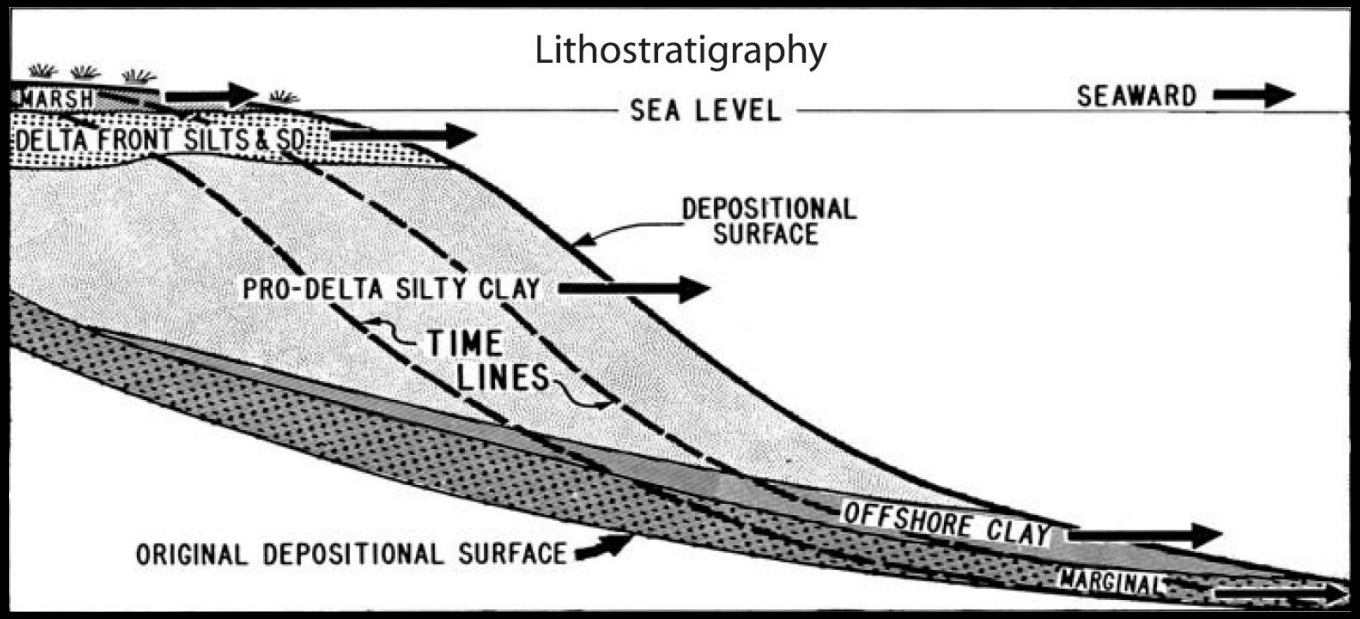
AAPG



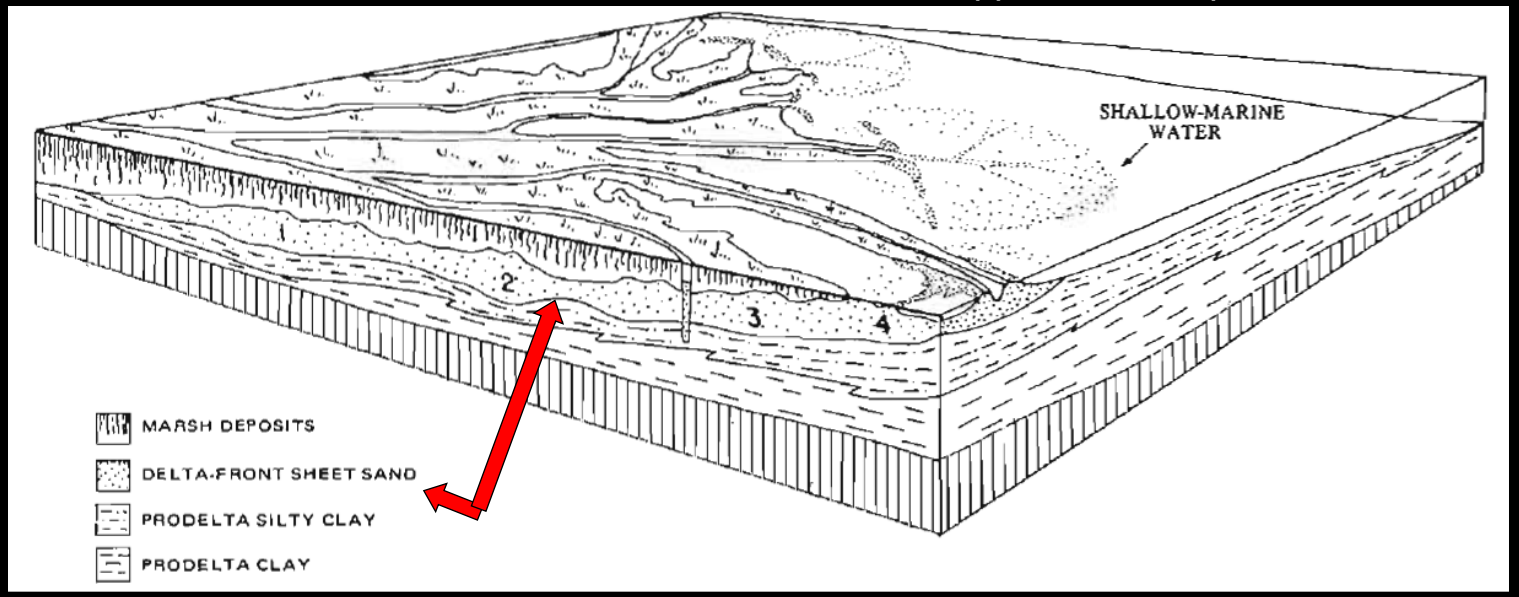
DELTAIC STRATIGRAPHY: CLASSICAL VS. RECENT MODELS



from Scruton, 1960, AAPG

Classical models of deltaic stratigraphy theorize over proximal sandstone 'belts' of high lateral and downdip continuity, but recent studies show this not to be the case for most deltaic systems.

from Gould, 1970, 'The Mississippi Delta Complex', SEPM



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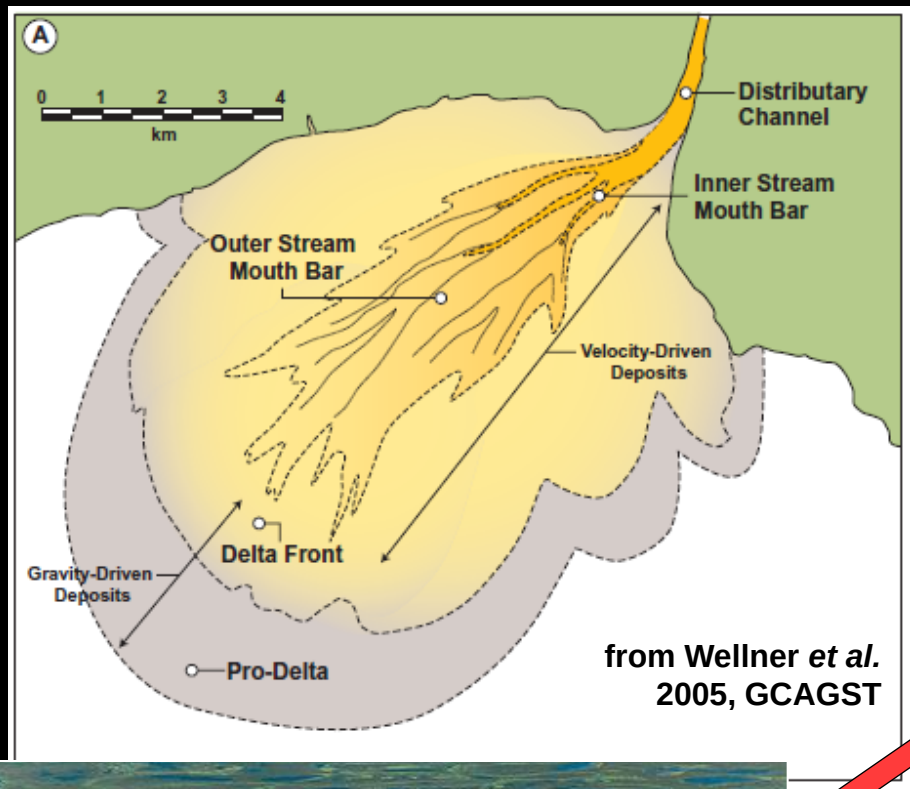
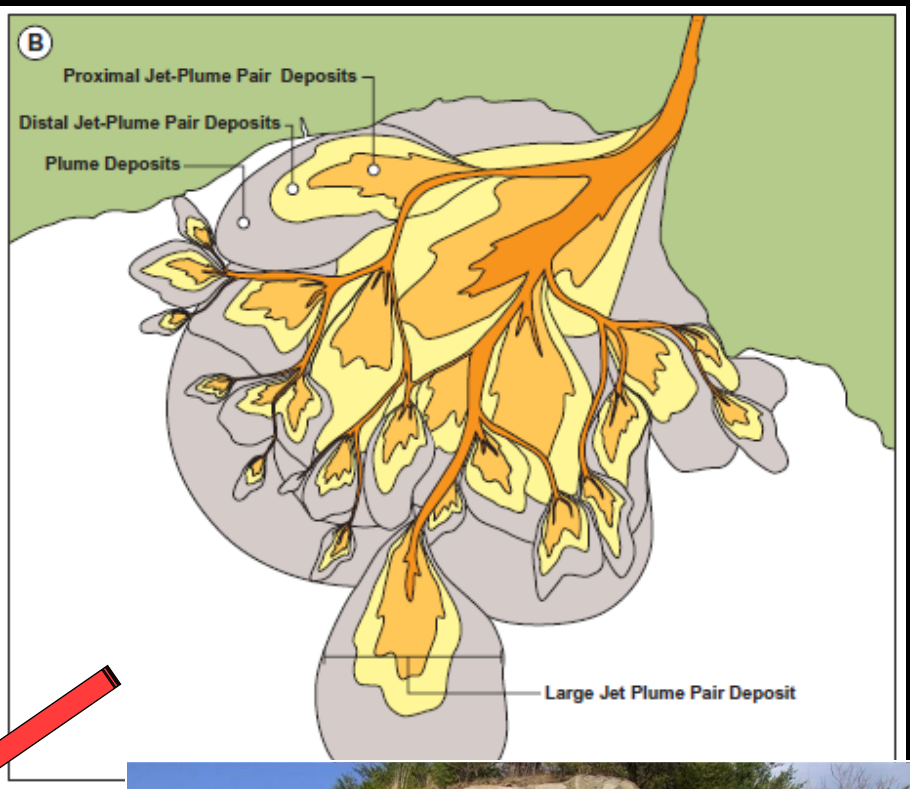
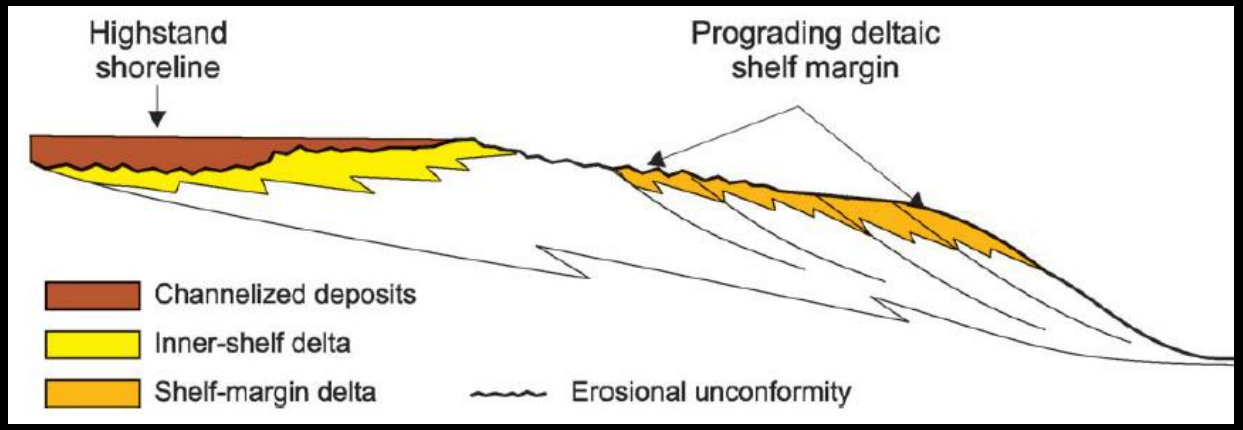


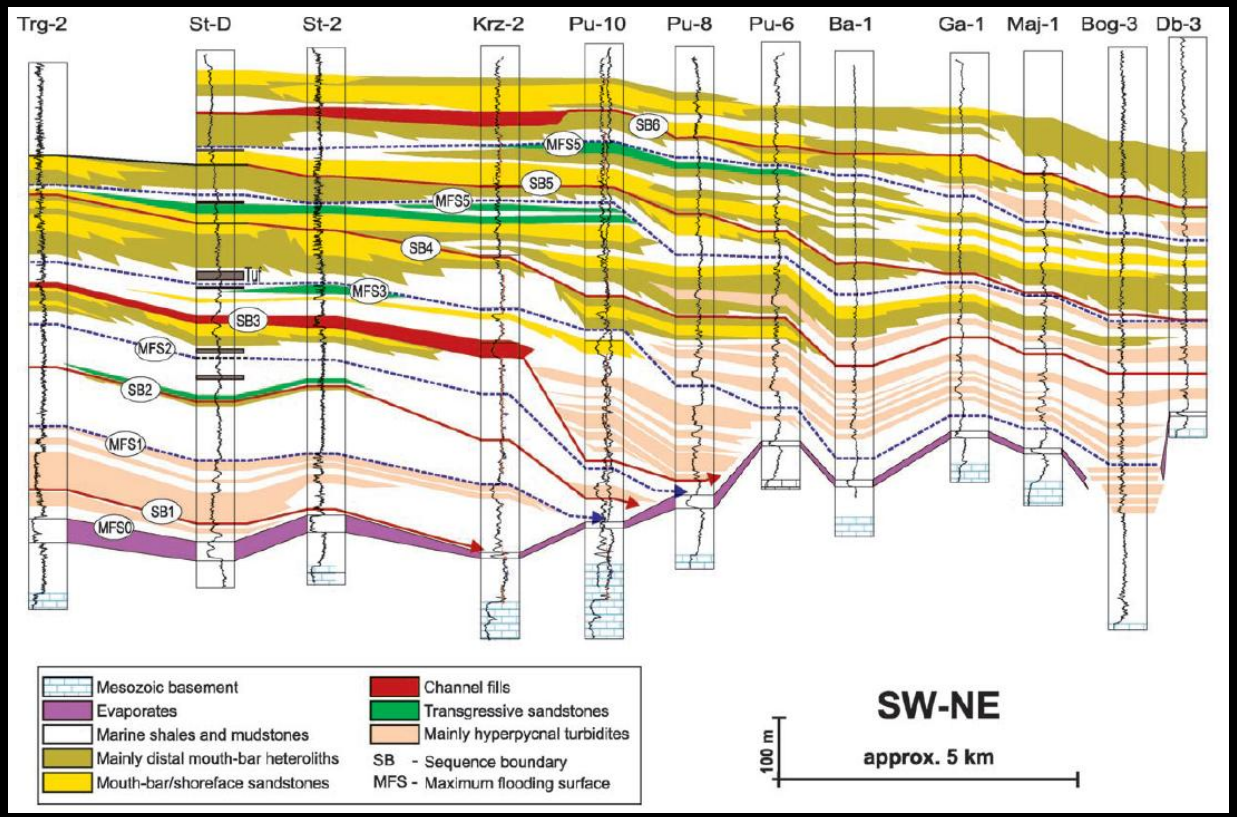


from Wellner *et al.* 2005, GCAGST

DELTAIC STRATIGRAPHY: CLASSICAL VS. RECENT MODELS



from Porebski & Steel, 2003, Earth Science Reviews

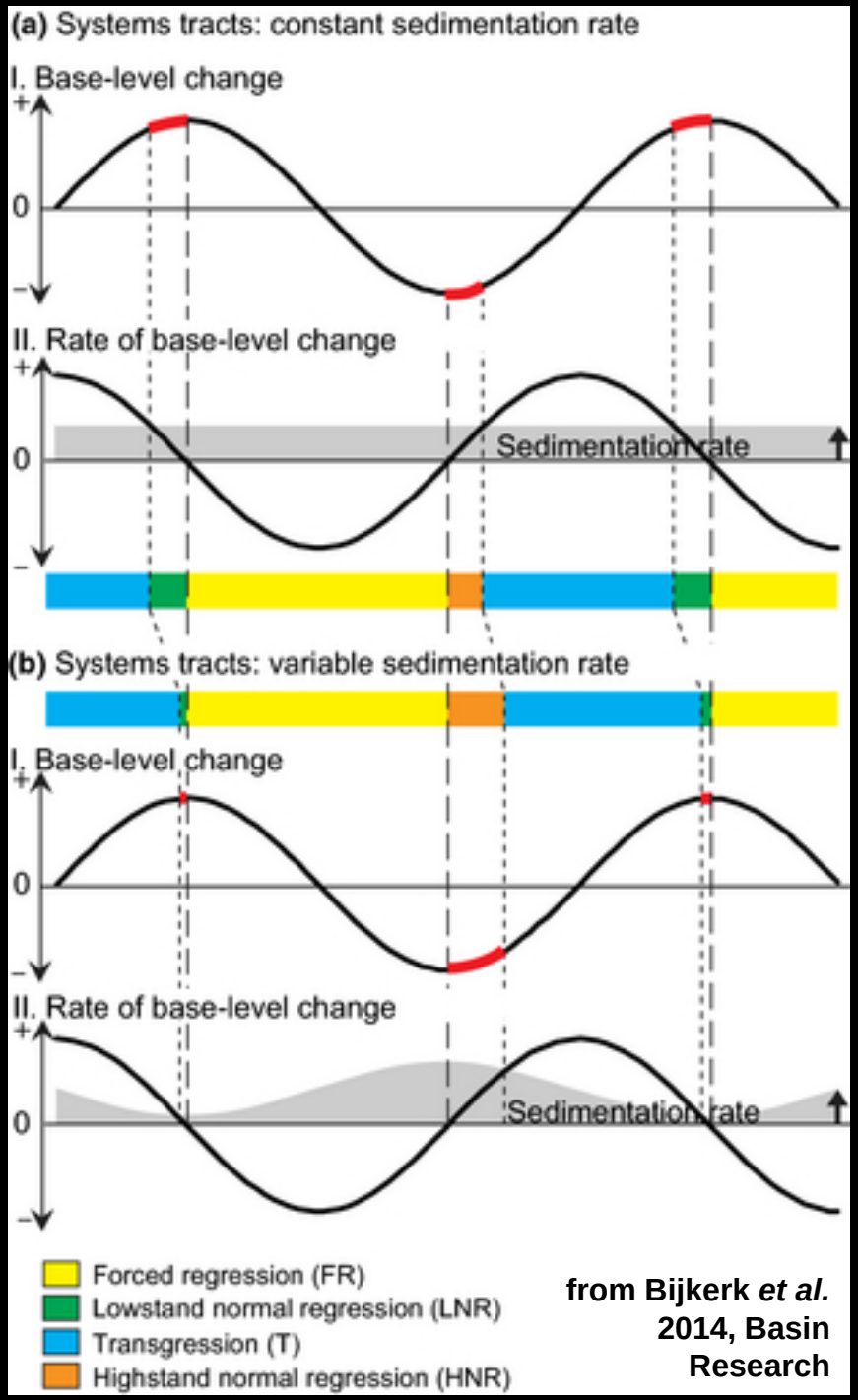


SHELF-EDGE DELTAS

High-accommodation bathymetric settings provide a possible context for aggradation of large volumes of sand(stones) with good vertical and lateral connectivity in proximal deltaic domains.

Are there any other settings and/or controls which might favour this kind of architectural development??

THE CLIMATE FACTOR….

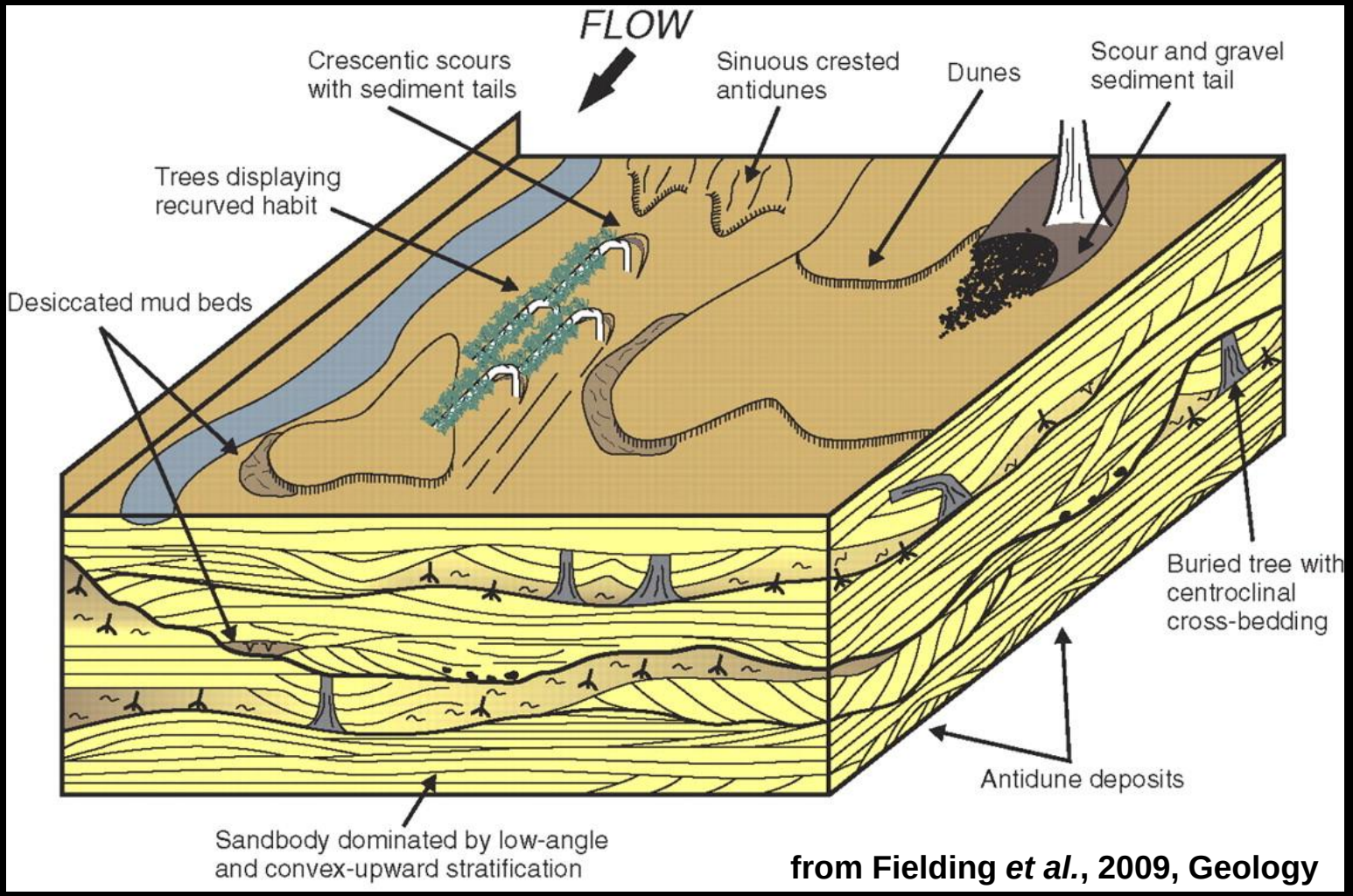


from Bijkerk *et al.* 2014, Basin Research

Chao Phraya Delta, Thailand

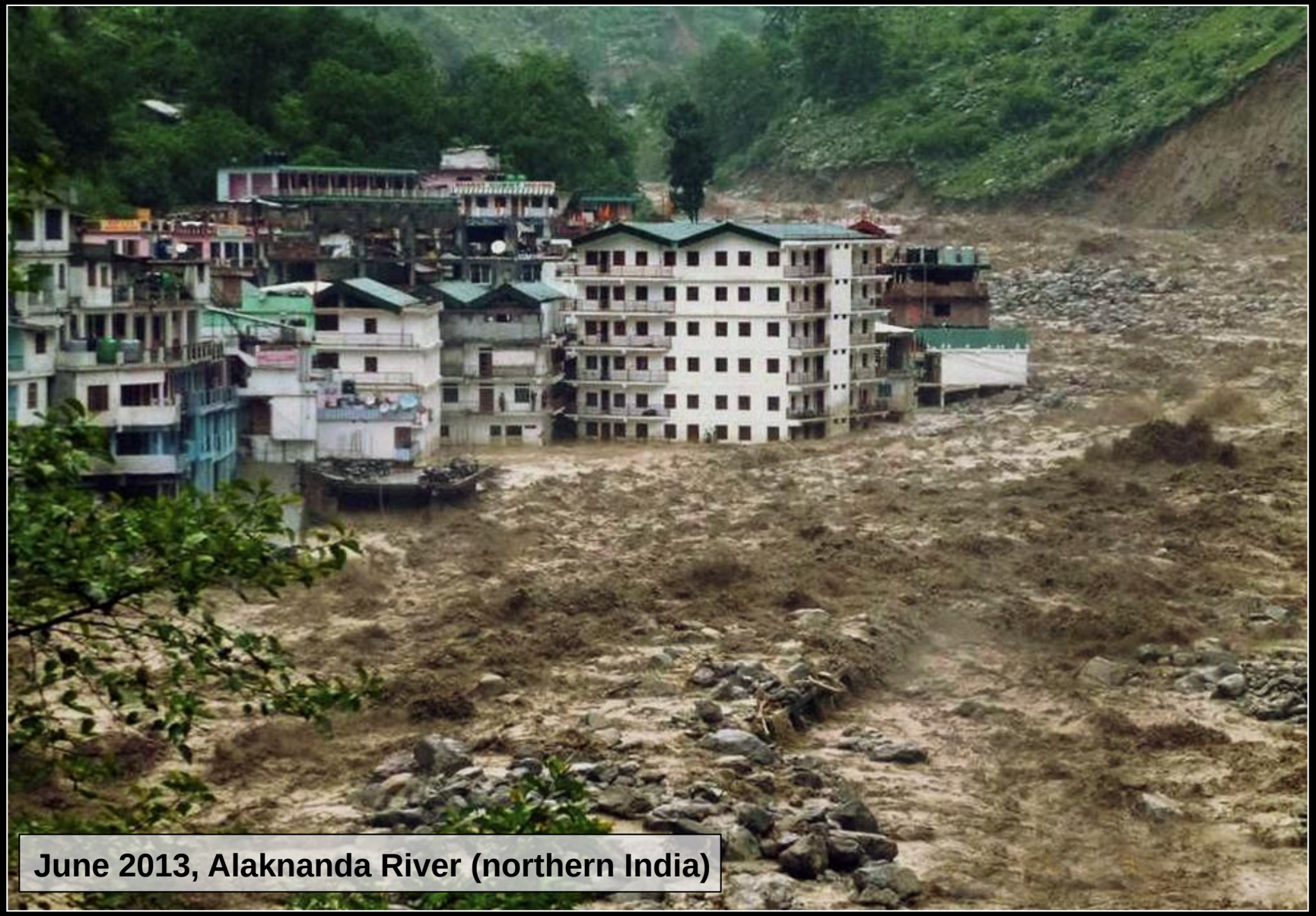
2009-2011: based on modern systems and stratigraphic evidence, Fielding *et al.* define a new facies model for deposits of rivers active in highly seasonal / monsoonal, flood-dominated (sub)tropical latitudes.

Facies and architectures controlled by extreme seasonal to interannual discharge variability and prolonged flood events.



from Fielding *et al.*, 2009, Geology

Unfortunately, a very actualistic facies model: extreme hydrological events in alluvial settings occur with almost annual frequency in subhumid to semiarid (sub)tropics around the world…

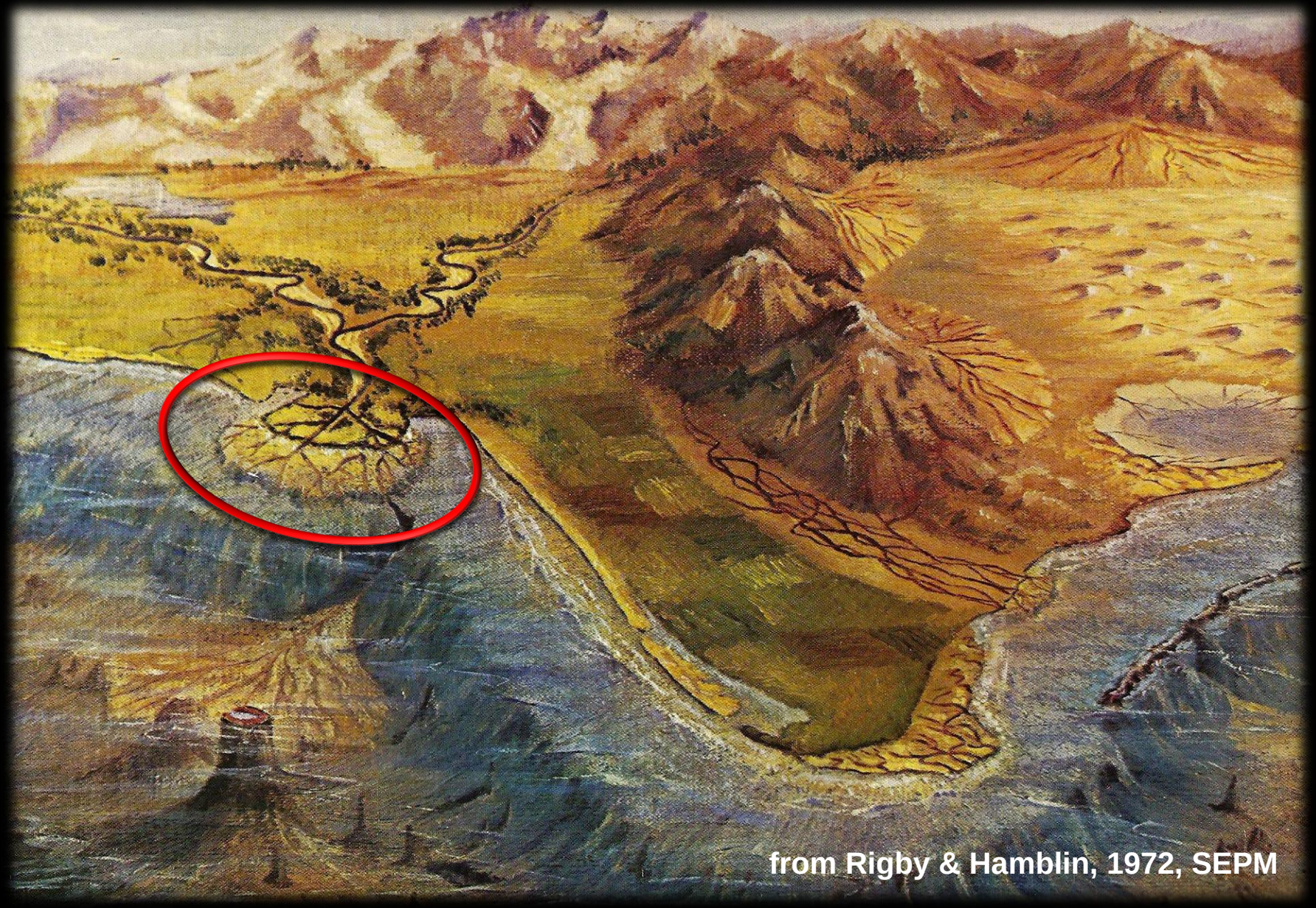


June 2013, Alaknanda River (northern India)

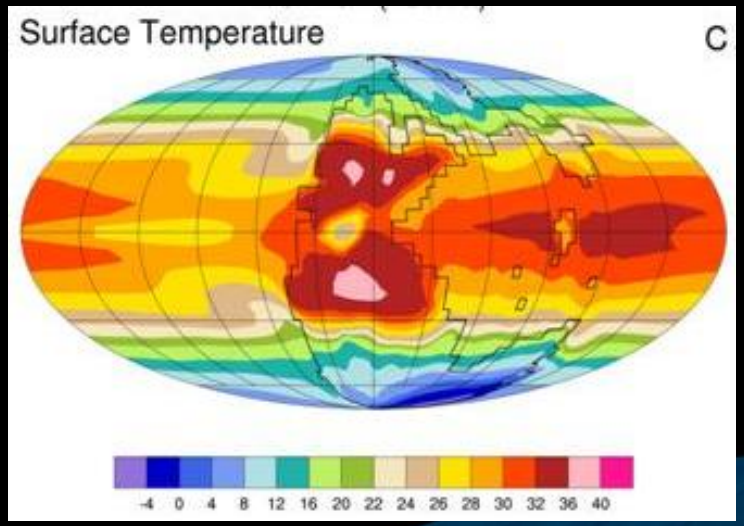

June 2013, Alaknanda River (northern India)

Toowoomba Floods, 2010-2011 (Queensland, Australia)

PRESERVING THE SIGNATURE OF EXCEPTIONAL EVENTS IN FLOOD-DOMINATED FLUVIODELTAIC SYSTEMS: PROXIMAL VS. DISTAL SIGNATURES



from Rigby & Hamblin, 1972, SEPM



LATE CARBONIFEROUS EARLY PANGEA (~310 Ma)

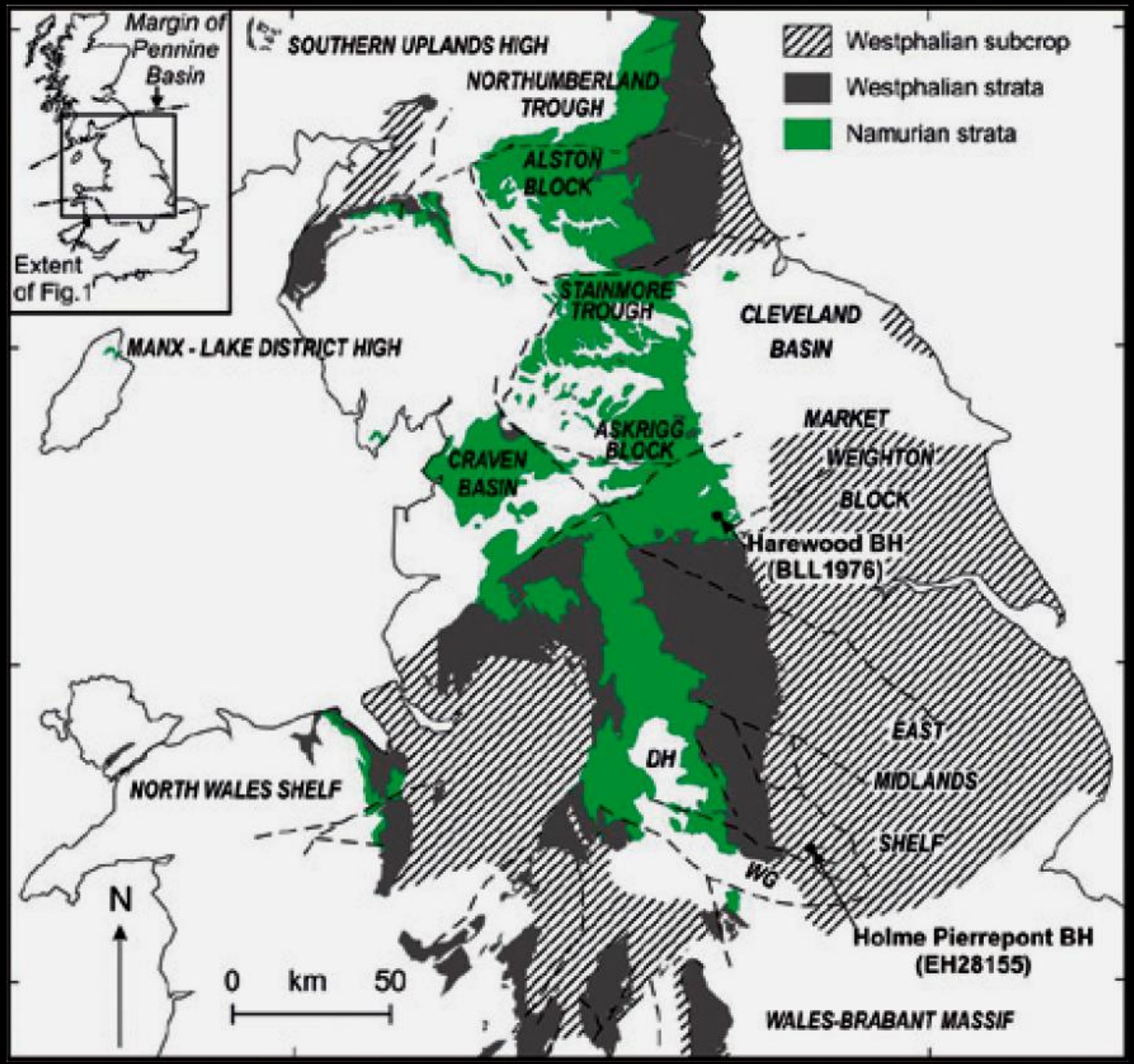
Partially merged continental configuration, with high and increasing climate seasonality in most regions of the northern hemisphere, due to the early onset of Pangean ‘megamonsoons’.

Laurussia

reconstruction by
Ron Blakey

LATE CARBONIFEROUS PALEOGEOGRAPHY NORTHEASTERN LAURUSSIA (NORTHERN EUROPE)

EARLY LATE CARBONIFEROUS PENNINE BASIN (NORTHERN ENGLAND)



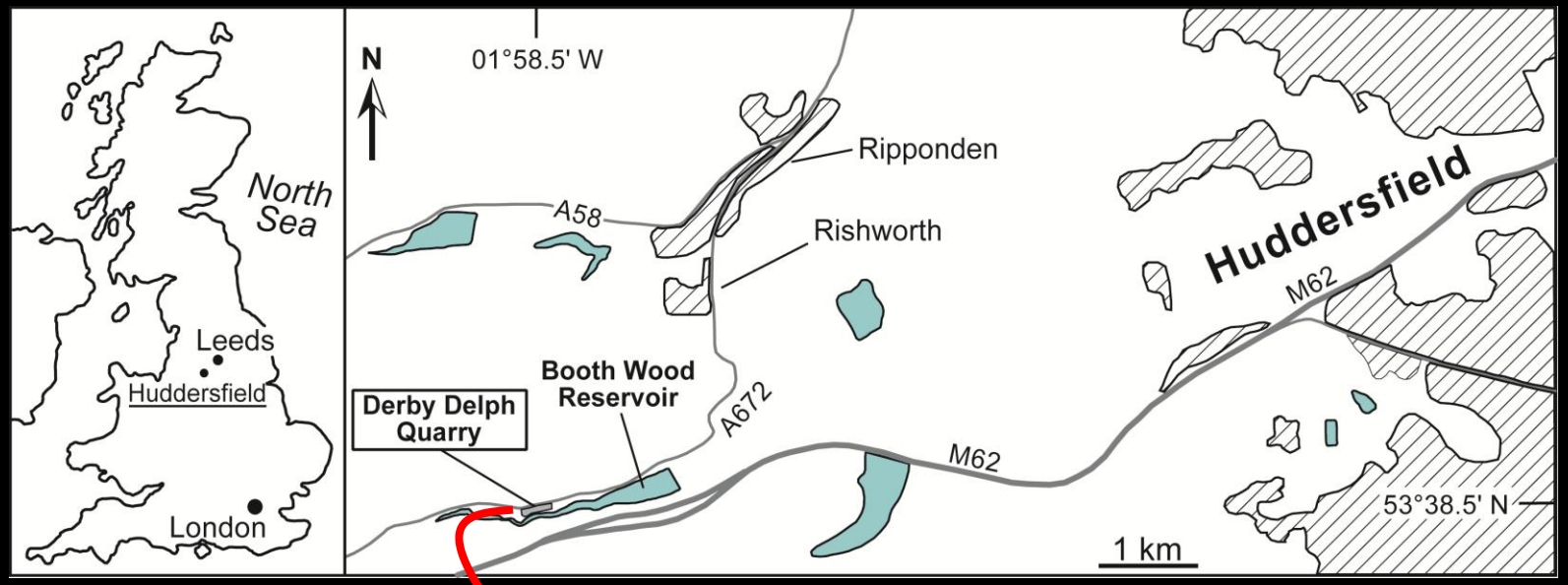
from Waters *et al*., 2011, GSL Special Report

- Series of deep, interconnected sub-basins formed after back-arc extension and regional subsidence north of the Variscan Orogen;

- fed mostly by northern and western highland sources with progressive development of fluvio-deltaic and distally linked turbidite systems;

- affected by glacioeustatic and glacioclimatic oscillations (late Paleozoic Gondwanan glaciation).

NOT QUITE THE IDEAL LANDSCAPE FOR OUTCROP GEOLOGY….


North Sea
Leeds
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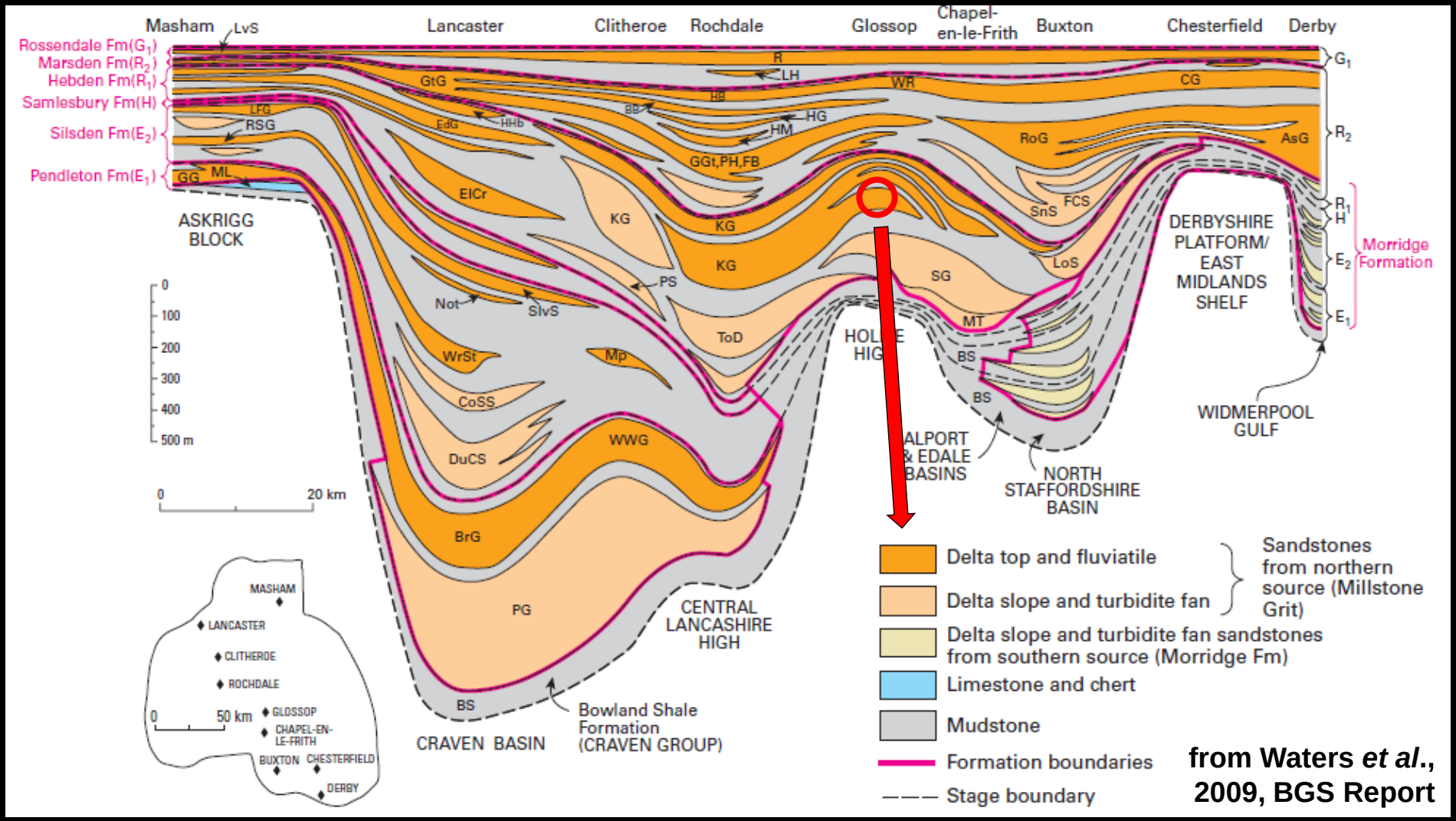
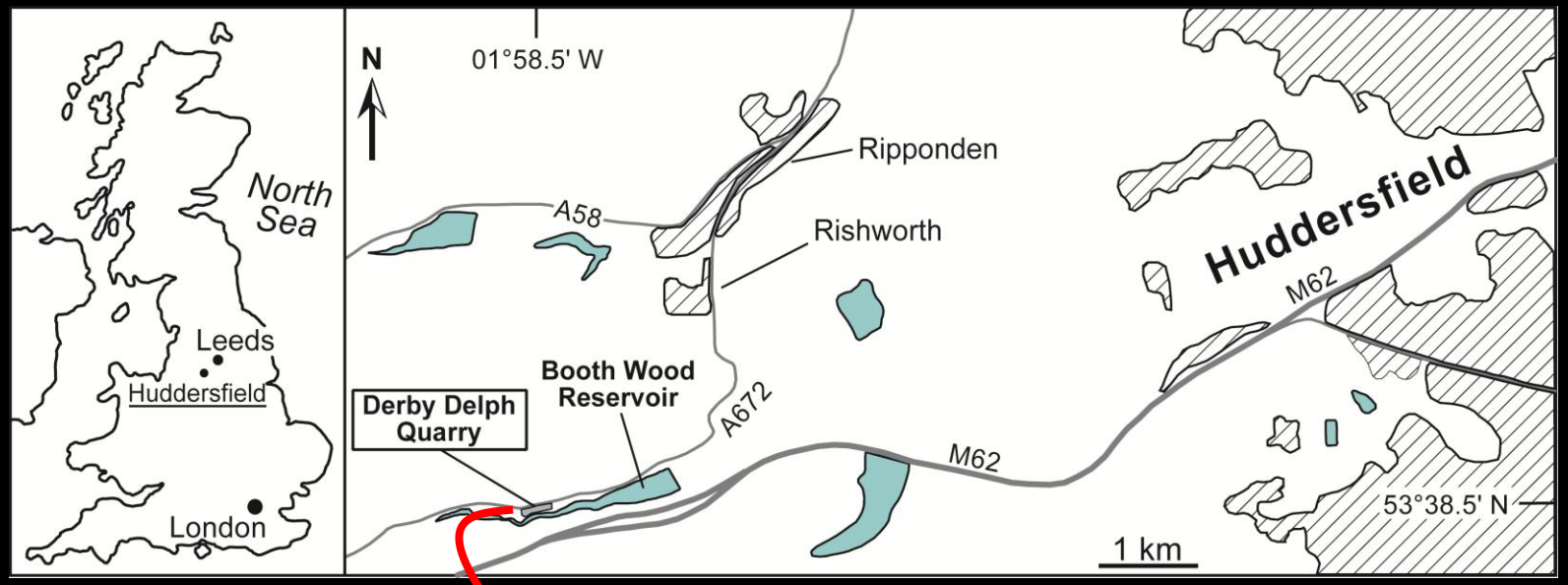
London
N
01°58.5' W
Ripponden
A58
Rishworth
Huddersfield
M62
Booth Wood Reservoir
Derby Delph Quarry
A672
M62
53°38.5' N
1 km


200 m

KINDERSCOUT GRIT (Hebden Formation, Millstone Grit Group)
BASHKIRIAN (~320 Ma, MIDDLE 'NAMURIAN')



from Waters *et al.*, 2009, BGS Report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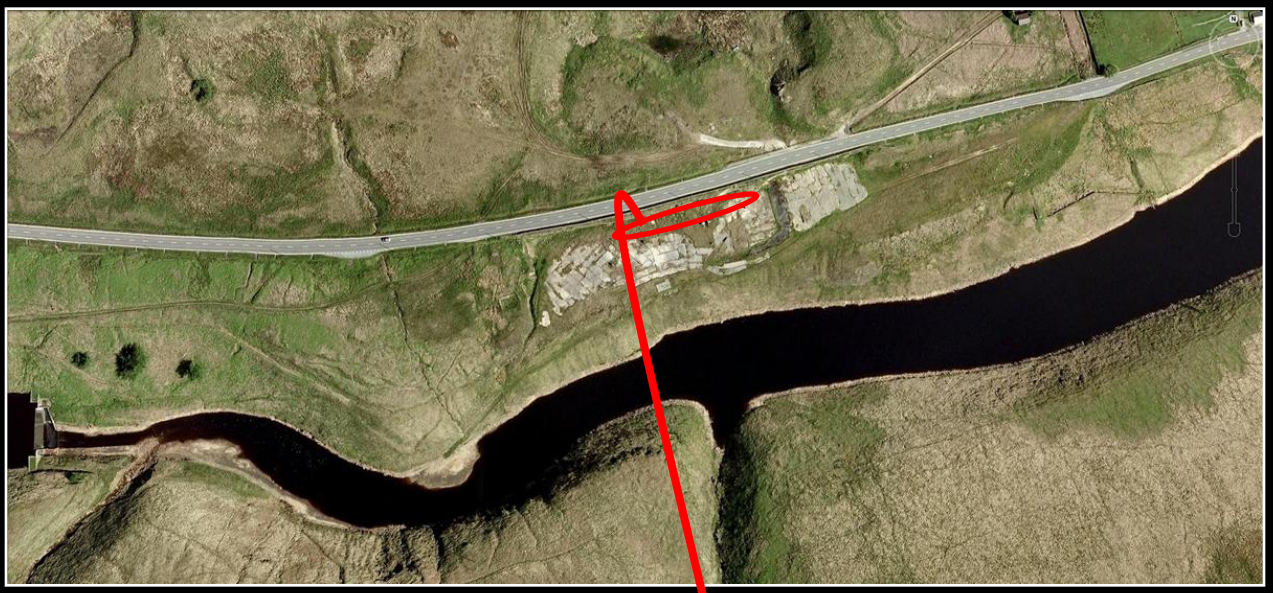

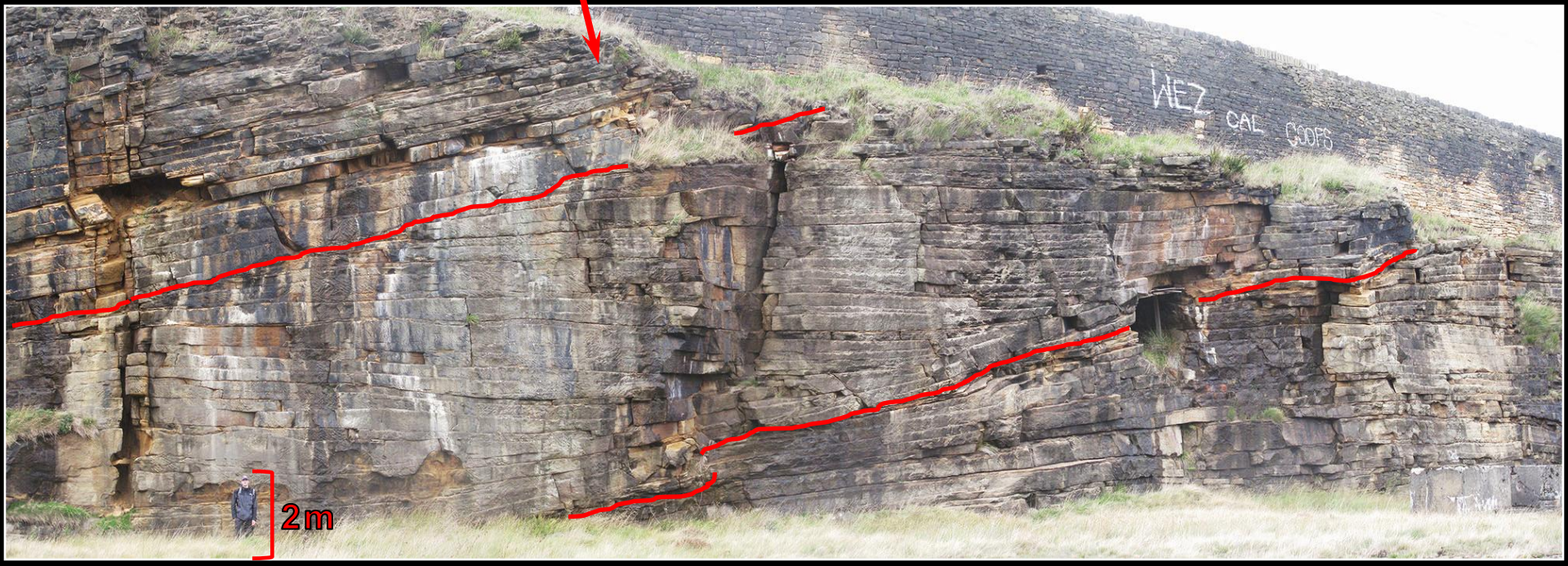
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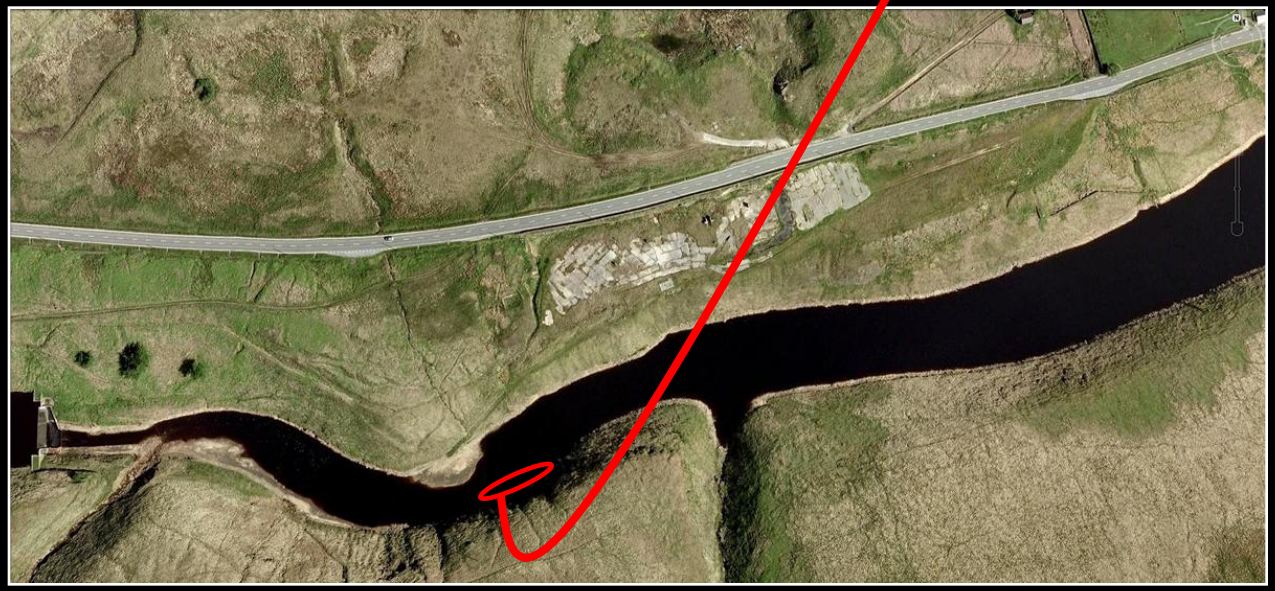
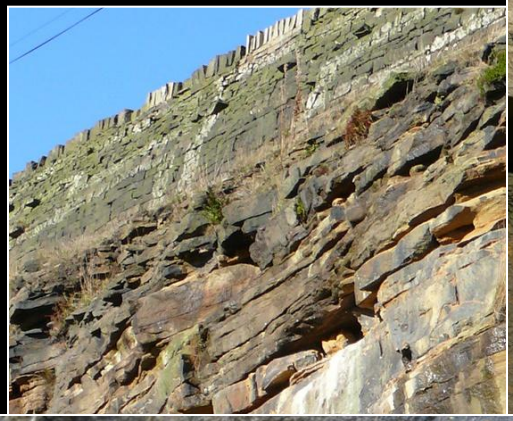




UNUSUAL ARCHITECTURE AND SCALE OF THESE STRATA PREVIOUSLY RECOGNIZED BY VARIOUS AUTHORS

Sedimentology (1977) **24,** 271–290

Deep distributary channels and giant bedforms in the Upper Carboniferous of the Central Pennines, northern England

PETER J. McCABE*

Department of Geology, The University, Keele, Staffordshire ST5 5BG

Giant "undulatory beds" deposited by wash-out and remoulding of dunes at peak-flood stage in delta-plain distributary channels.

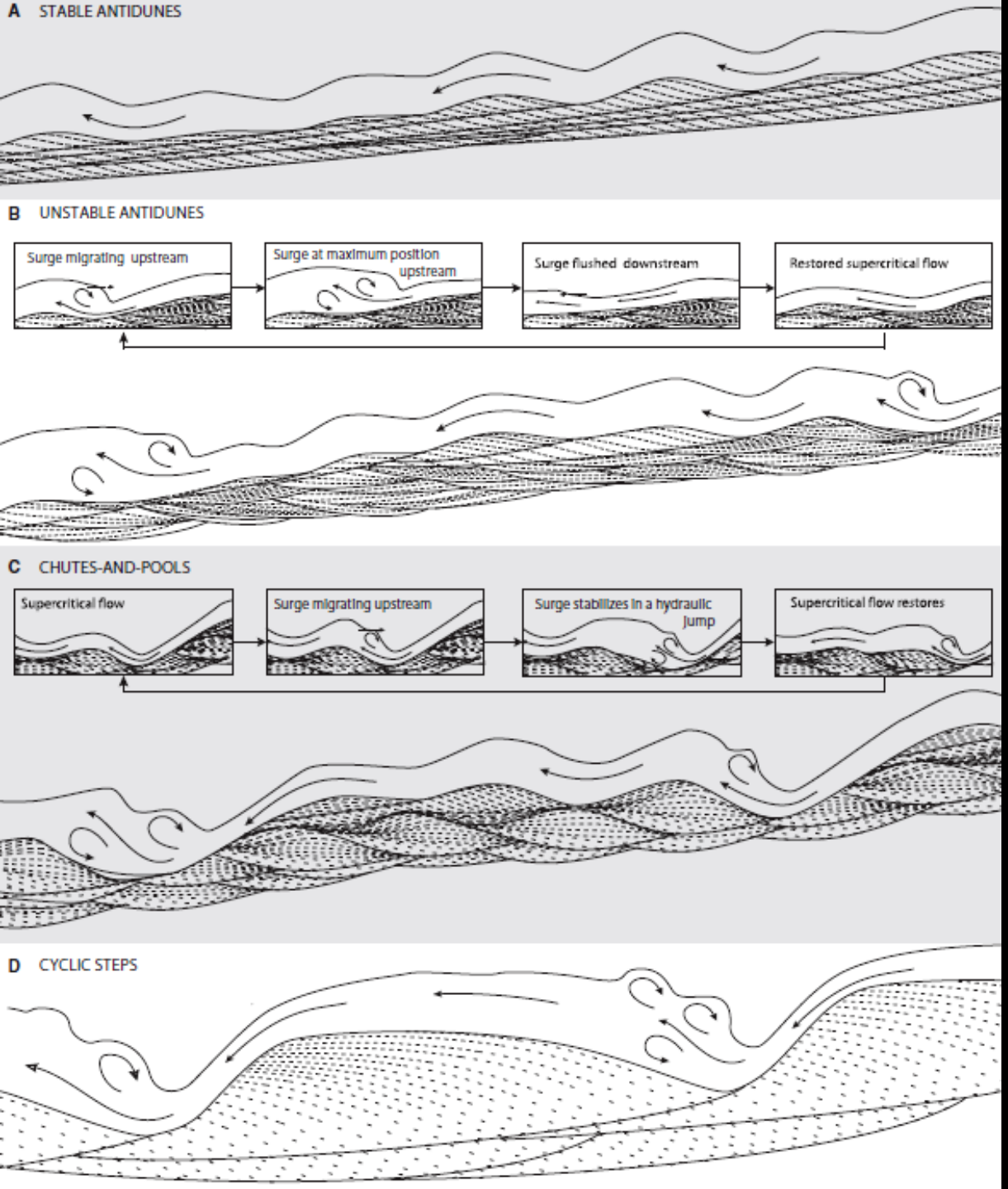
PROCEEDINGS OF THE YORKSHIRE GEOLOGICAL SOCIETY, VOL. 51, PART 4, PP. 273–296, 1997

A sequence stratigraphic model for deposition of the Lower Kinderscout Delta, an Upper Carboniferous turbidite-fronted delta

GARY J. HAMPSON

Department of Geology, Royal School of Mines, Imperial College, London SW7 2BP, UK

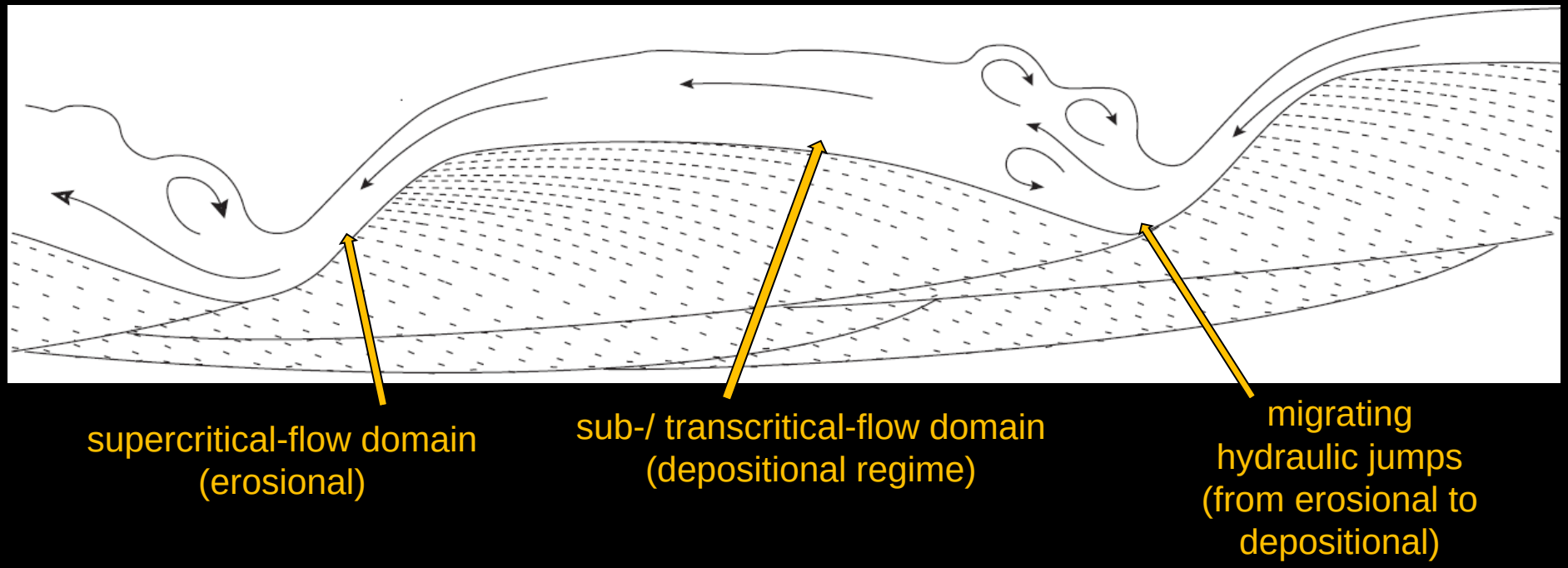
"Complex, giant cross beds" from scour infill at migrating channel confluences over distal alluvial / delta plains.



from Cartigny *et al*., 2014, Sedimentology

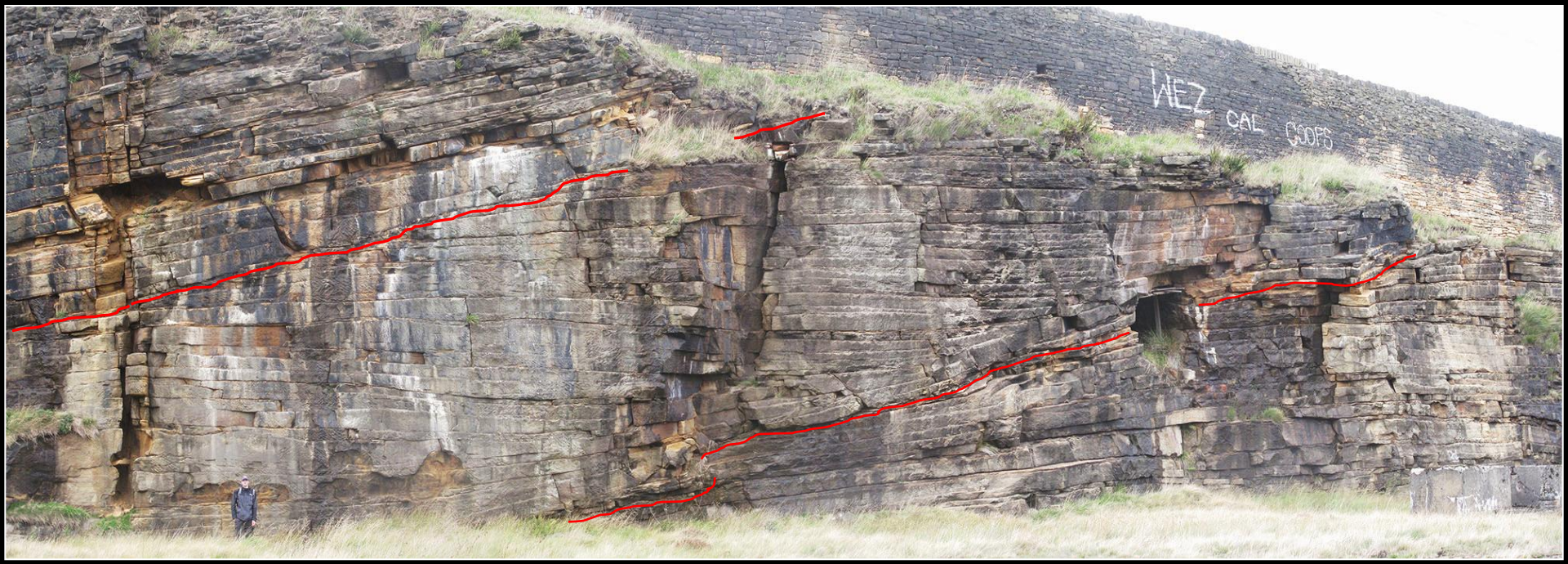
OUR HYPOTHESIS:

Large-scale bedforms developing at high Froude numbers (~ 1.5; cyclic steps) probably with associated superposed antidunes or chutes-and-pools.



CYCLIC-STEP DYNAMICS

Supercritical-flow bedforms that accrete and shift upcurrent through dominantly erosive migration of hydraulic jumps at the base of the lee side (flow deceleration), dominant deposition over the stoss side (subcritical to critical flow), and erosion over the lee side (flow acceleration into a hydraulic jump).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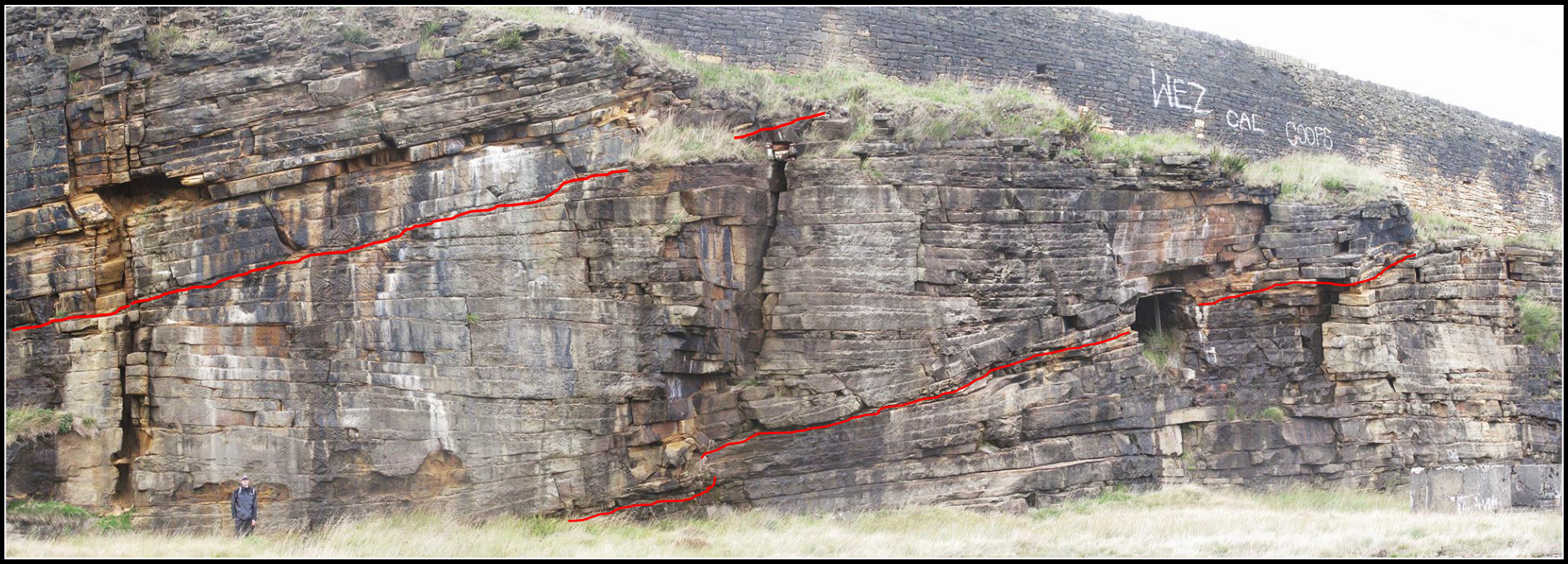
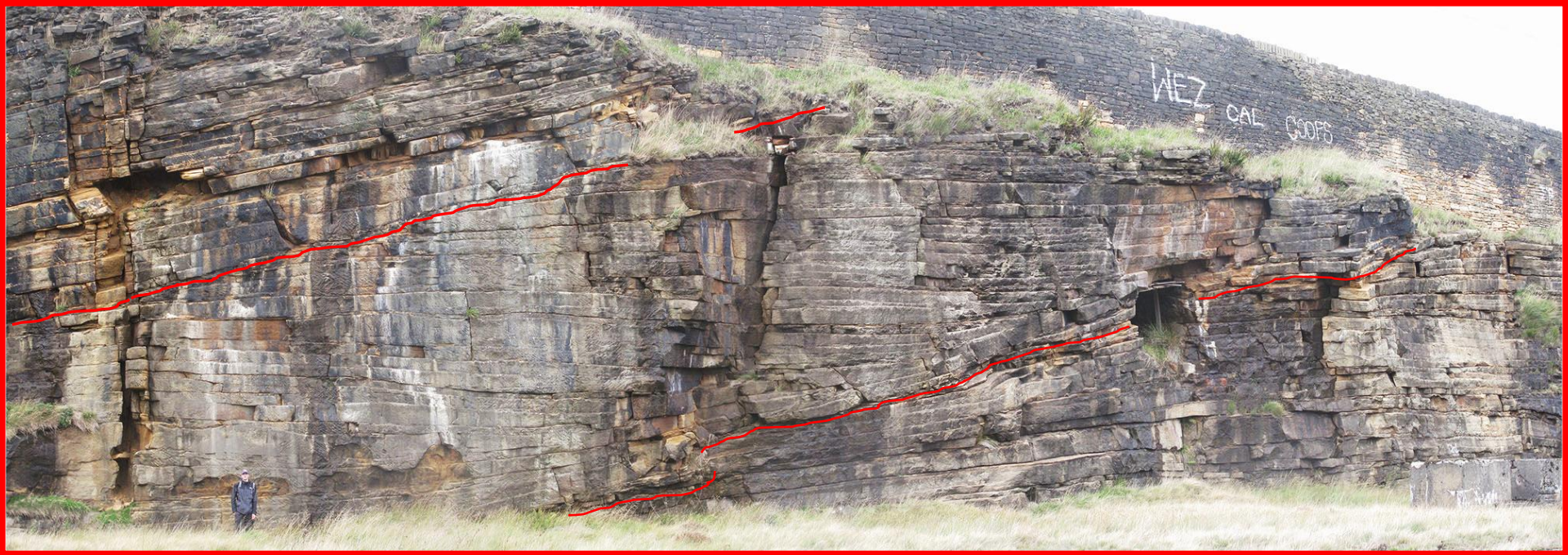


‘Sediment waves’ along the Slims River delta front
(Kluane Lake, Yukon)

from Gilbert & Crookshanks, 2009, Sedimentology



‘Sediment waves’ along the Slims River delta front (Kluane Lake, Yukon)

from Gilbert & Crookshanks, 2009, Sedimentology

A SINGLE DEPOSITIONAL EVENT…

…is the most likely interpretation due to a combination of (missing!) sedimentological attributes:

- lack of associated subcritical-flow structures;

- lack of unconformable erosional surfaces;

- lack of tidal and/or wave reworking;

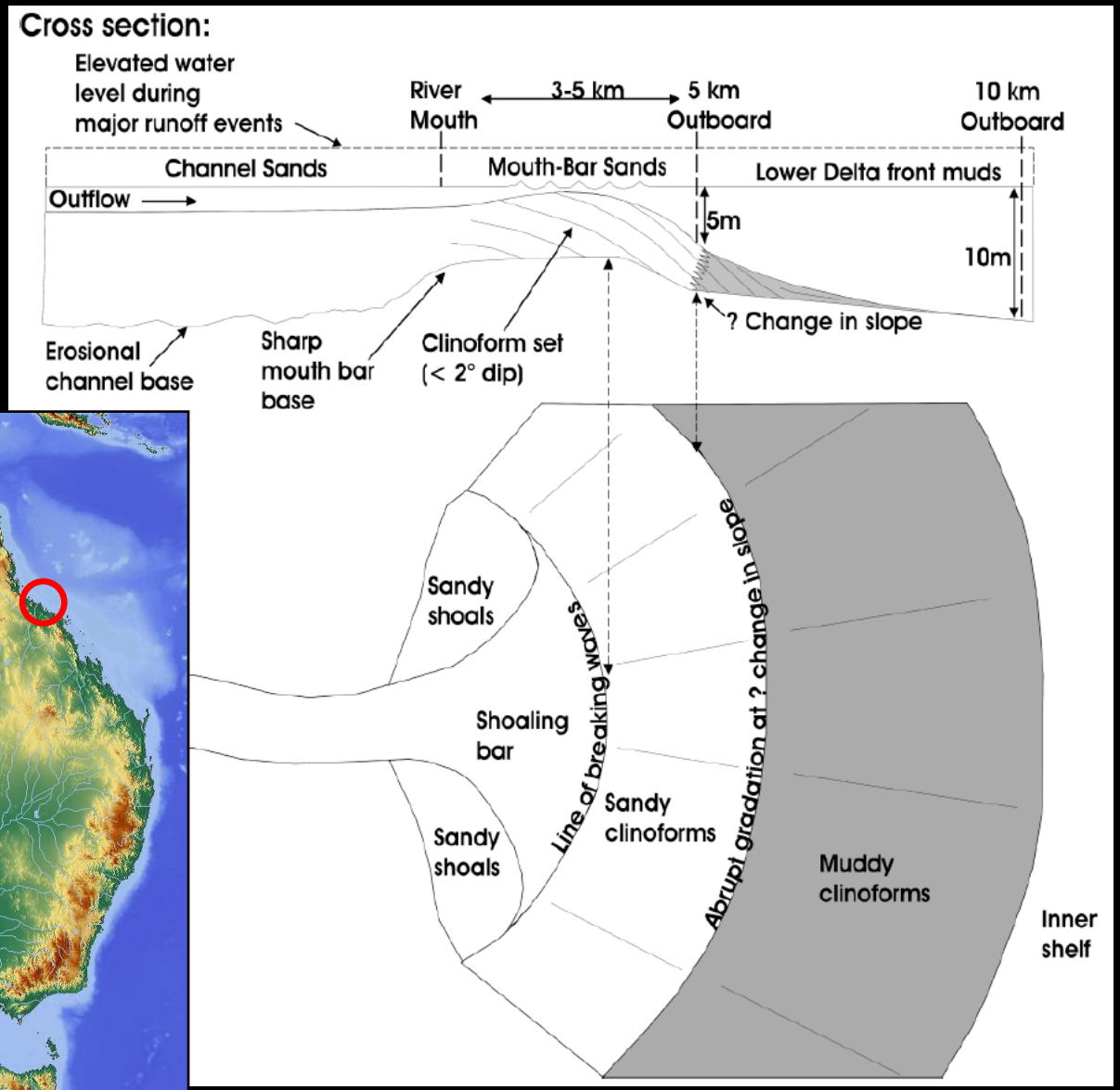
- lack of interbedded fines (changes in depositional/supply) regime;

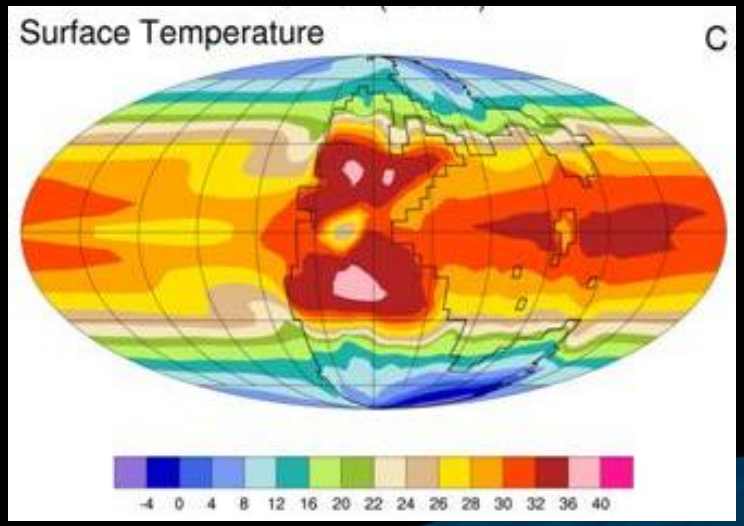
- lack of bioturbation;

- lack of large-scale deformation related to subaqueous instability of steeply sloping stratal surfaces.

MODERN ANALOGUE? BURDEKIN RIVER DELTA (NE AUSTRALIA)

from Fielding *et al.*, 2005, J. Sed. Res.





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Partially merged continental configuration, with high and increasing climate seasonality in most regions of the northern hemisphere, due to the early onset of Pangean ‘megamonsoons’.

Laurussia

reconstruction by
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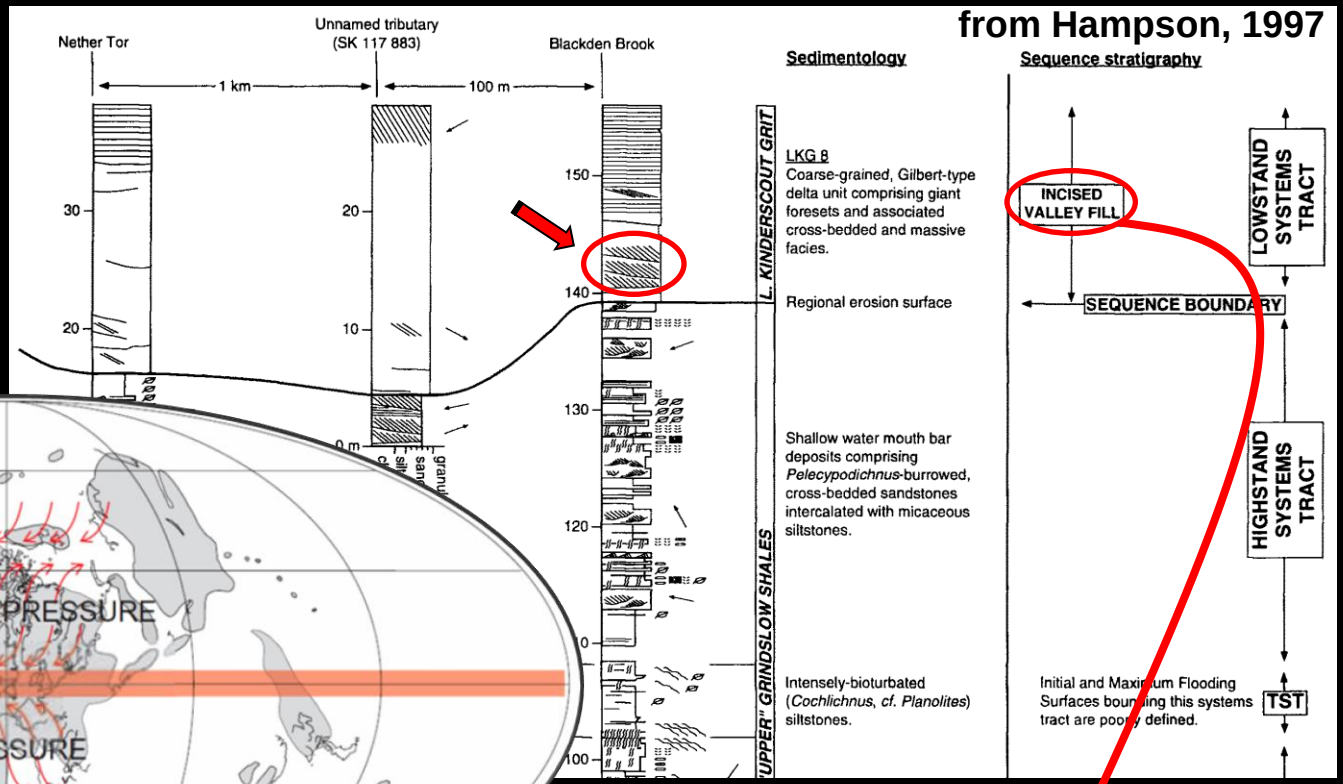
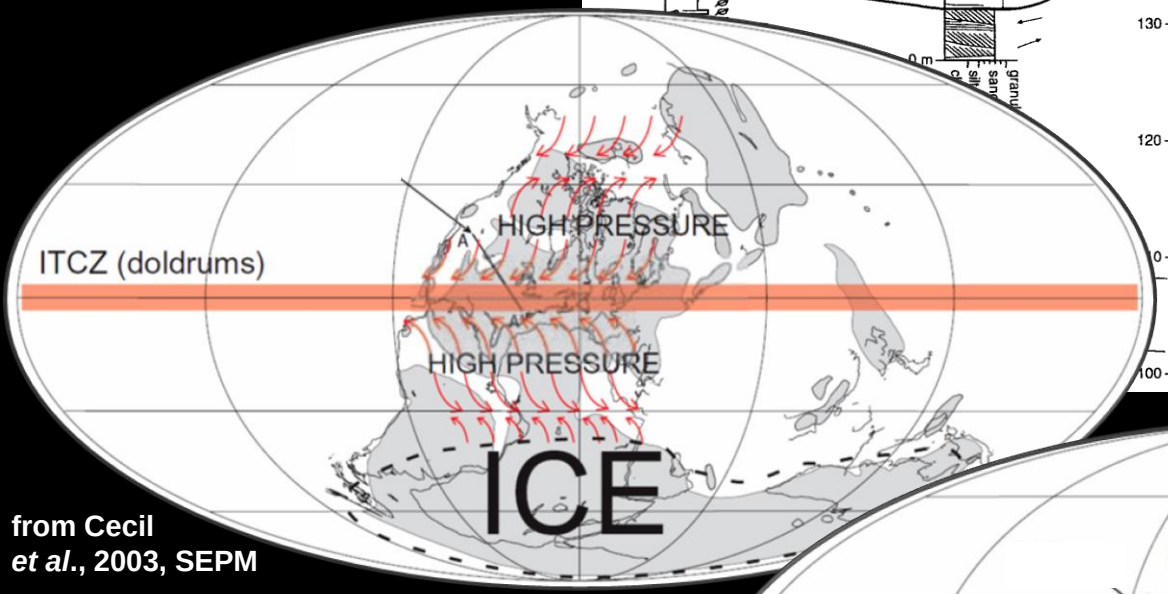
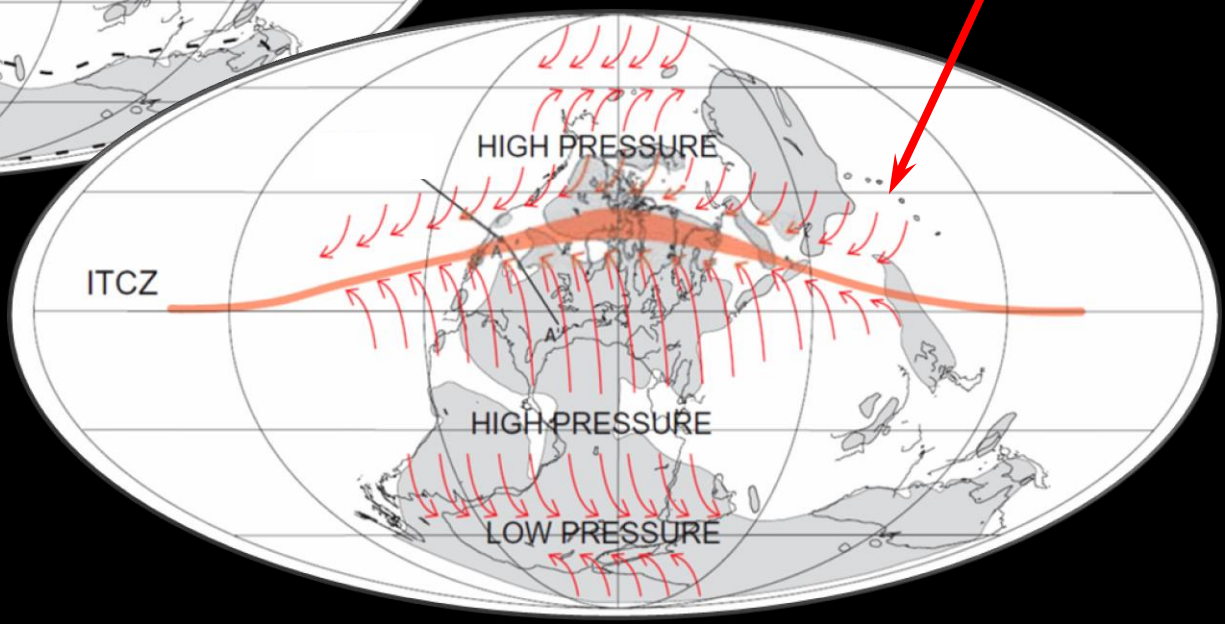
FROM SEQUENCE-STRATIGRAPHIC TO CLIMATIC PHASE…

from Hampson, 1997





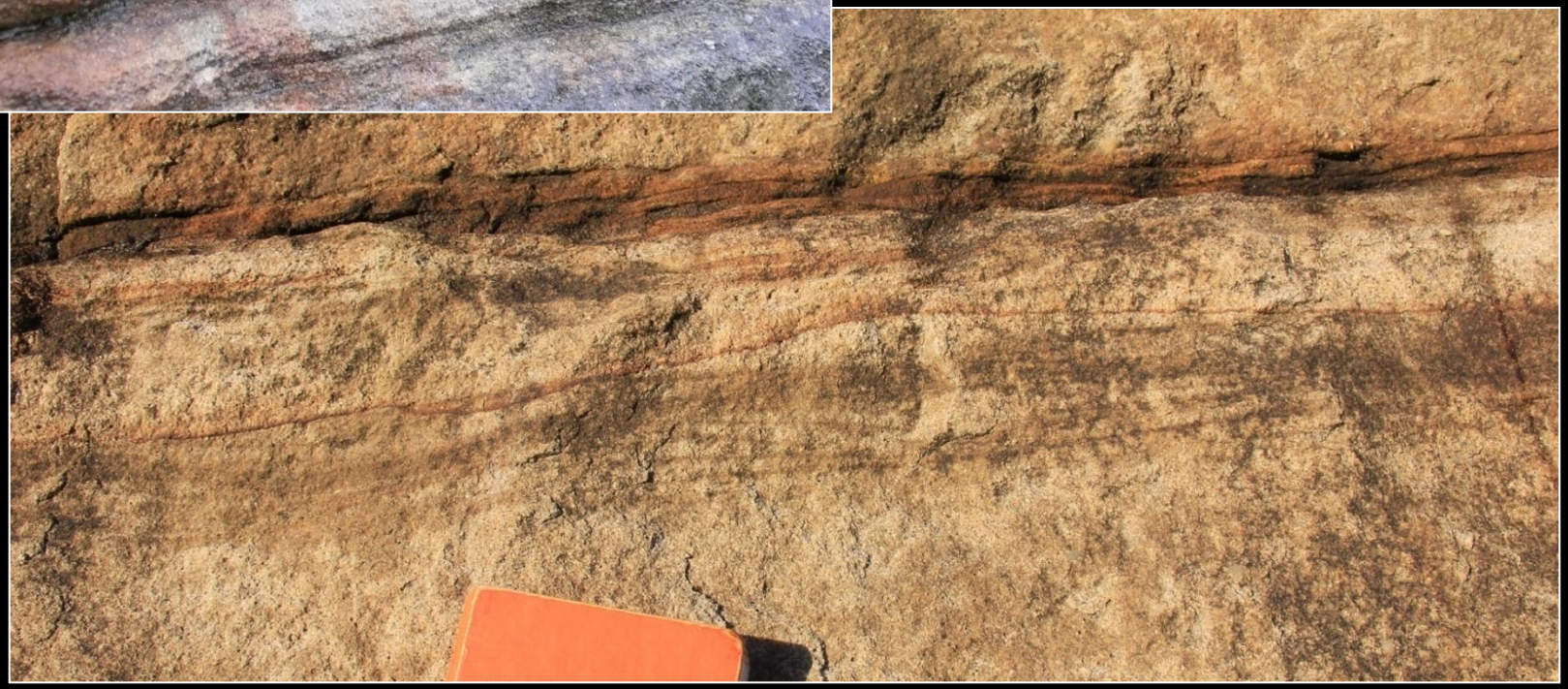
from Cecil *et al*., 2003, SEPM



Gondwanan interglacial phases characterized by increased seasonal / latitudinal excursions of the ITCZ and thus enhanced monsoonal circulation in the tropics.

WORK IN PROGRESS…

- Detailed facies analysis to characterize depositional processes (traction carpets, gradual aggradation) and dynamics at sub-bedform scale;
- microfacies analysis to pinpoint textural heterogeneities and for application to reservoir analysis in deeper marine settings.



…AND THANKS TO Colin Waters (British Geological Survey) and Ian Kane (Statoil) for feedback on regional geology.

Sedimentology Utrecht University

AAPG

ACE 2015