Monsoonal and Ephemeral River Systems: Facies Model and Controls (A Review)*

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Abstract

This paper is a synthesis of 52 modern and ancient examples of monsoonal and subtropical river systems, including four original field datasets. Monsoon rain is the main surface water supply to many of the world's rivers. Some such rivers occur completely within the tropical monsoon climate zone, whereas others have parts of their drainages in temperate climate zones or on high elevations and receive some of their water discharge from snowmelt. Yet others have their upstream drainages in the tropical monsoon climates, but flow through subtropical dry lands. Some rivers in sub-humid to arid subtropics are ephemeral, receive monsoon rain, and transmit discharge only during abnormal or strengthened monsoon seasons and the associated cyclonic flow. Common to all these rivers is that they frequently experience high-magnitude floods that last from just hours to months, with a yearly (seasonal) to decadal (ephemeral) recurrence frequency. The high-magnitude floods are caused by intense monsoonal rainfall events that may contain most of the annual precipitation. Rivers may transmit lower magnitude flood or non-flood discharges during the rest of the year or the rest of the monsoon season, or the riverbeds may remain dry for the most of the year, or even for a decade. These rivers distinctly contrast with perennial rivers, where the annual discharge range (highest-lowest discharge) is relatively small compared to its annual discharge mean. Some monsoonal rivers have discharges 40–50 times greater during the summer monsoon. It is this highly seasonal discharge with a characteristically rapid rise, sharp peak and rapid decline of the flood hydrographs that define the monsoonal and sub-tropical river form and function, as well as the facies and facies successions, as up to 85–95% of their annual sediment transport and deposition occurs during these events. The paper presents specific recognition criteria that differentiate the highly seasonal river deposits from perennial river facies models. The internal variability within the highly seasonal rivers is presented as a continuum with end members. The monsoon regions and the bordering subtropical regions reside on each side of the equatorial perennial rainfall regions, approximately between ca 10–

35° N and S. However, multiple greenhouse world examples occur at considerably higher latitudes, suggesting hydrological cycle, pole ward moisture transport and climate zones different from the current icehouse world.

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Monsoonal and Ephemeral River Systems: Facies Model and Controls (a review)

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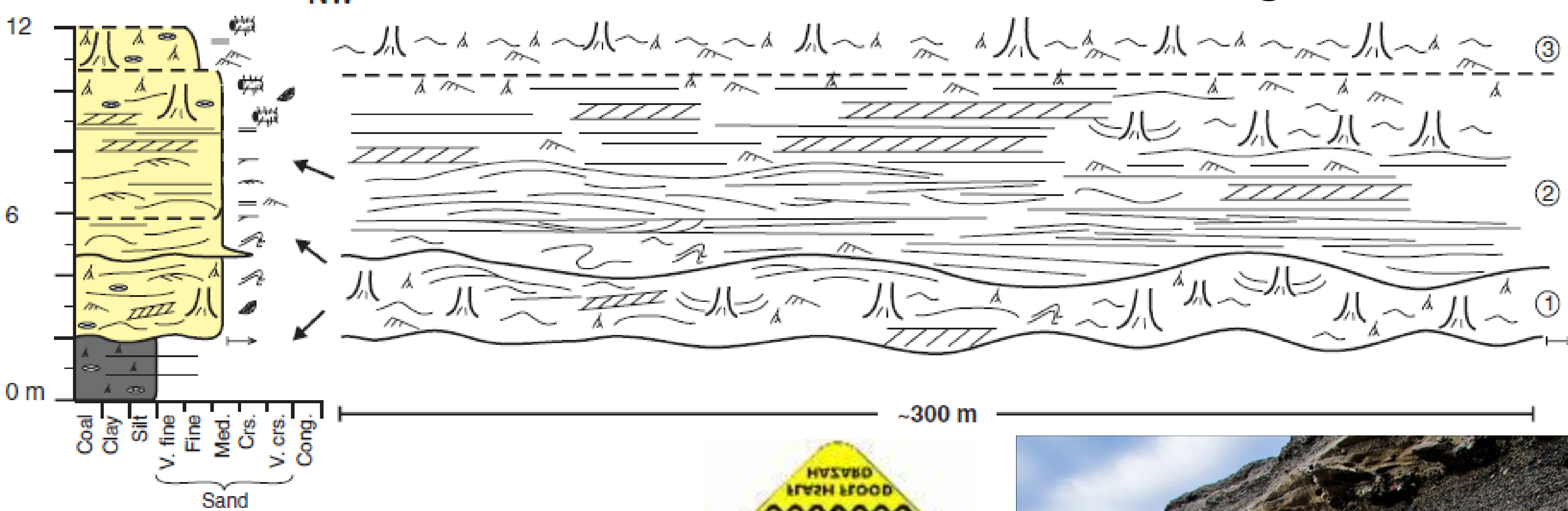
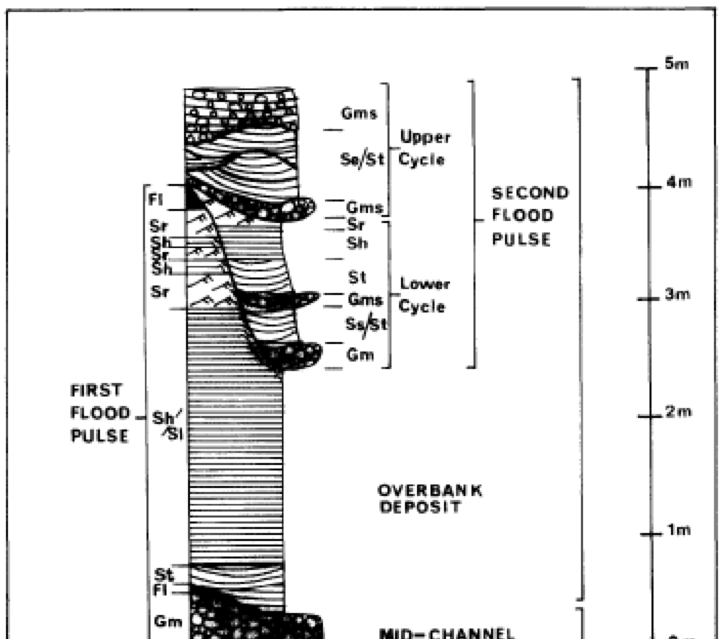
Notes by Presenter: Monsoon rain is the main surface water supply to many worlds' rivers. Commonly the monsoonal rivers are dealt with as tropical rivers, i.e. defined by temperatures > 18°. This study explores other aspects of the monsoonal domain, namely the characteristically high precipitation range or yearly variability (summer-winter precipitation).

Motivation:

What is wrong with these rivers?

Fielding et al. 2009





Stear 1985

Flashy rivers = Subtropical rivers??

Lake Missoula flood

Review:

52 ancient and modern monsoonal and subtropical rivers and 4 field datasets

(Plink-Bjorklund, 2015, review paper in Sedimentary Geology)

Questions asked:

1. What is the distinction of seasonal or flashy rivers from perennial precipitation zone rivers what concerns their morphodynamics, facies, and architecture?

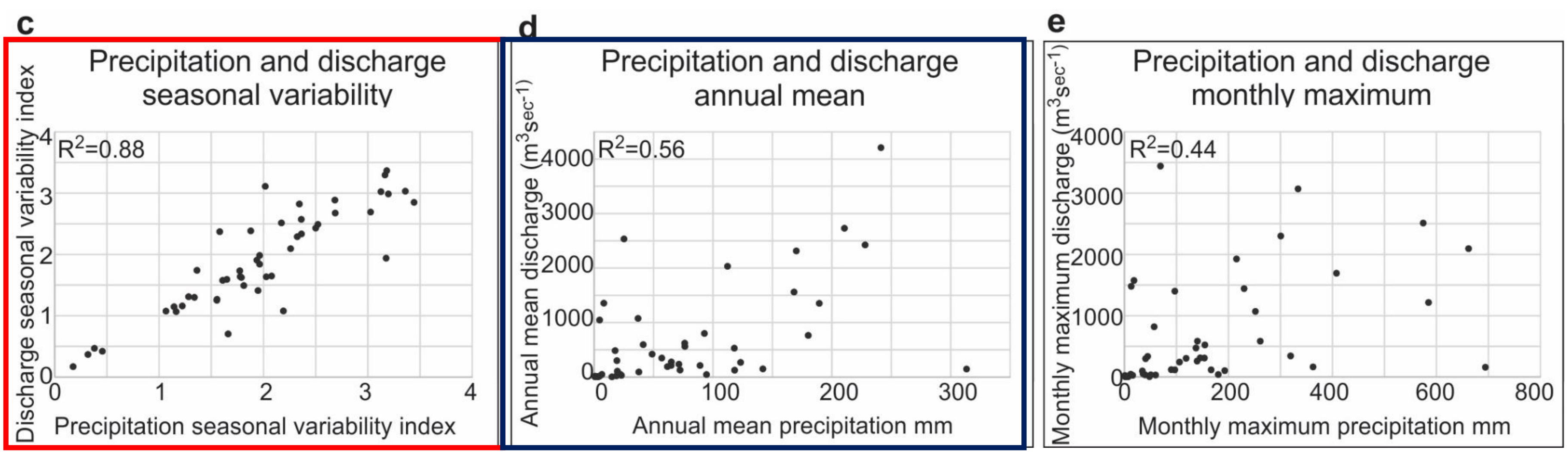
2. Why are they different?

Surface water supply to rivers in subtropics controlled by monsoon

Monsoon index (Wang & Ding 2008): $\frac{\text{summer – winter precipitation}}{\text{mean annual precipitation}}$

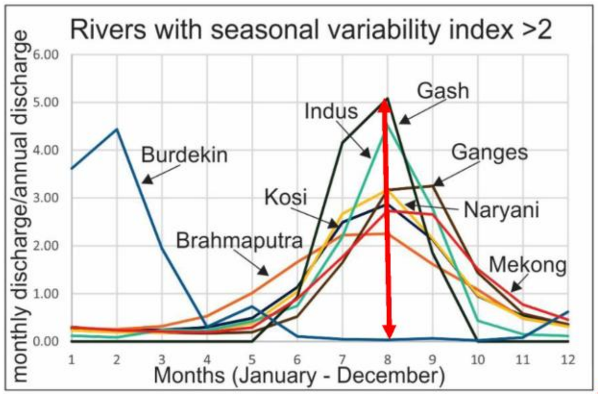
Precipitation seasonality index: $\frac{\text{wettest month – driest month precipitation}}{\text{mean annual precipitation}}$

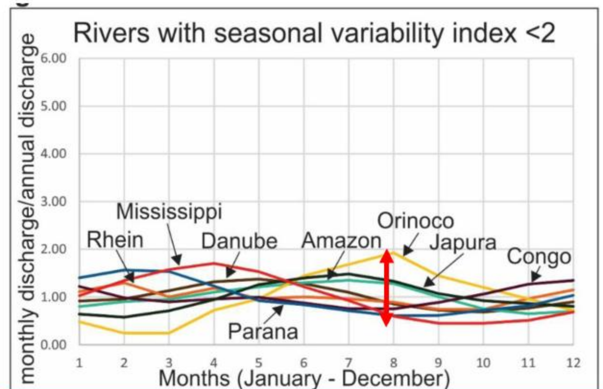
Discharge seasonality index: $\frac{\text{wettest month – driest month discharge}}{\text{mean annual discharge}}$

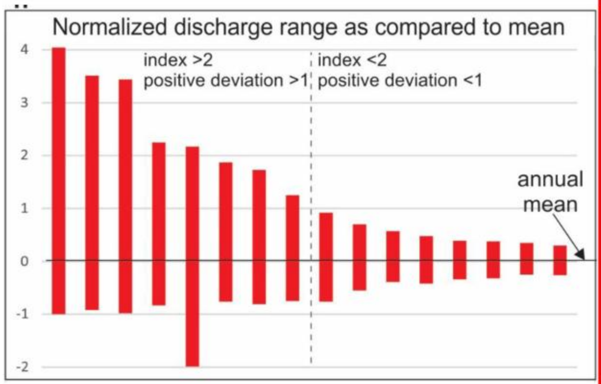


Link between monsoonal precipitation pattern and river discharge

Discharge seasonality index: $\frac{\text{highest – lowest monthly discharge}}{\text{mean annual discharge}}$





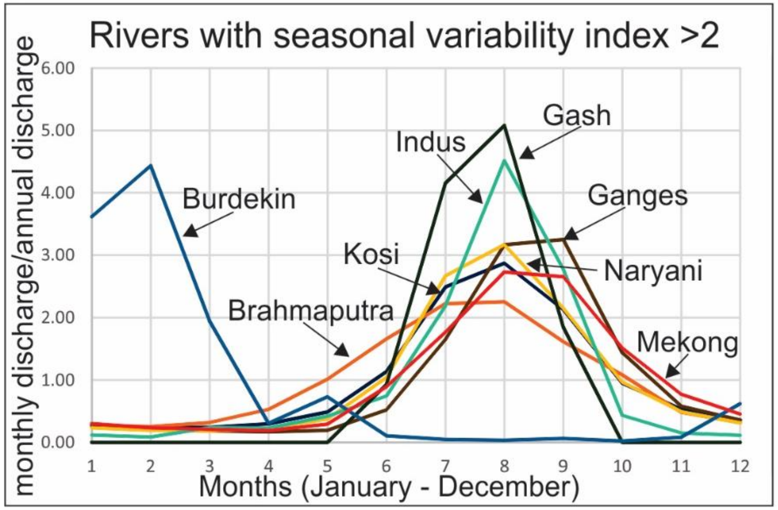


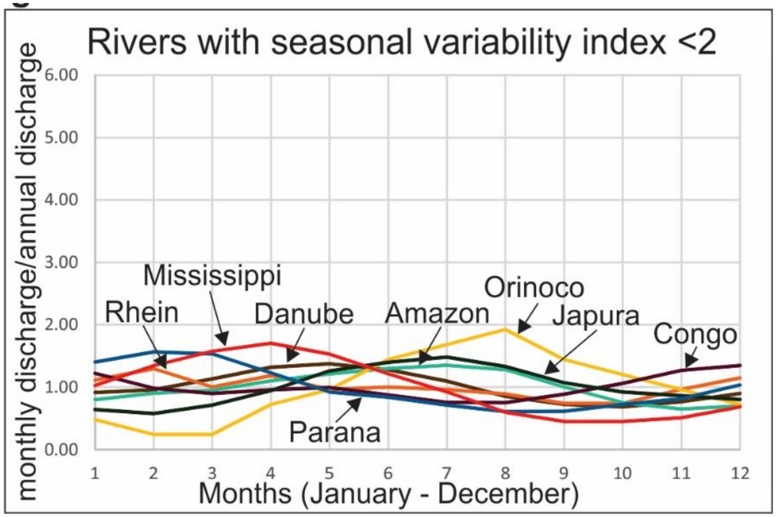
Rivers that receive most of their surface water supply from monsoon precipitation have a high seasonality index and are distinct from the rainforest and temporal perennial precipitation zone rivers. Subtropical rivers have a higher inter-annual variability as compared to monsoonal rivers

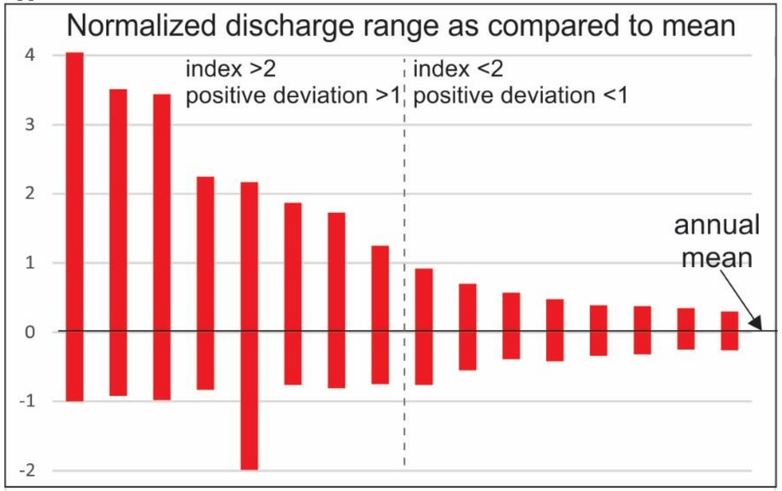
Notes by Presenter: The difference is quite notable. Mississippi has floods of catastrophic proportions, but that flood discharge as compared to the annual mean is small compared to the subtropical rivers.

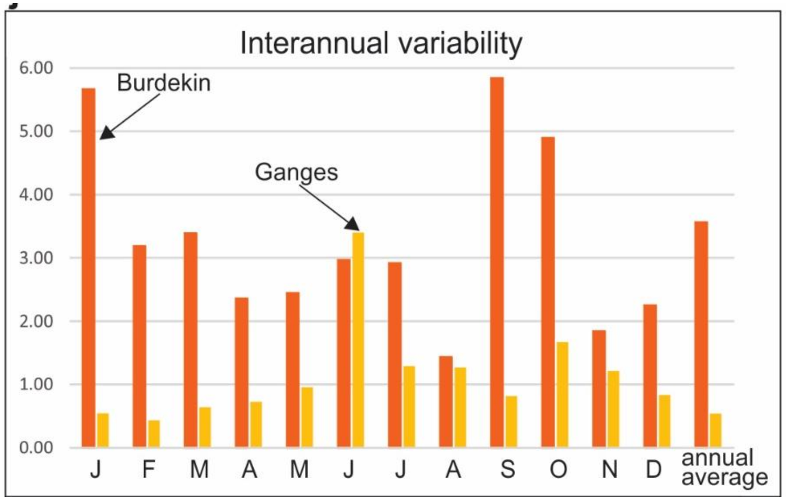
Link between monsoonal precipitation pattern and river discharge

Discharge seasonality index: $\frac{\text{highest – lowest monthly discharge}}{\text{mean annual discharge}}$

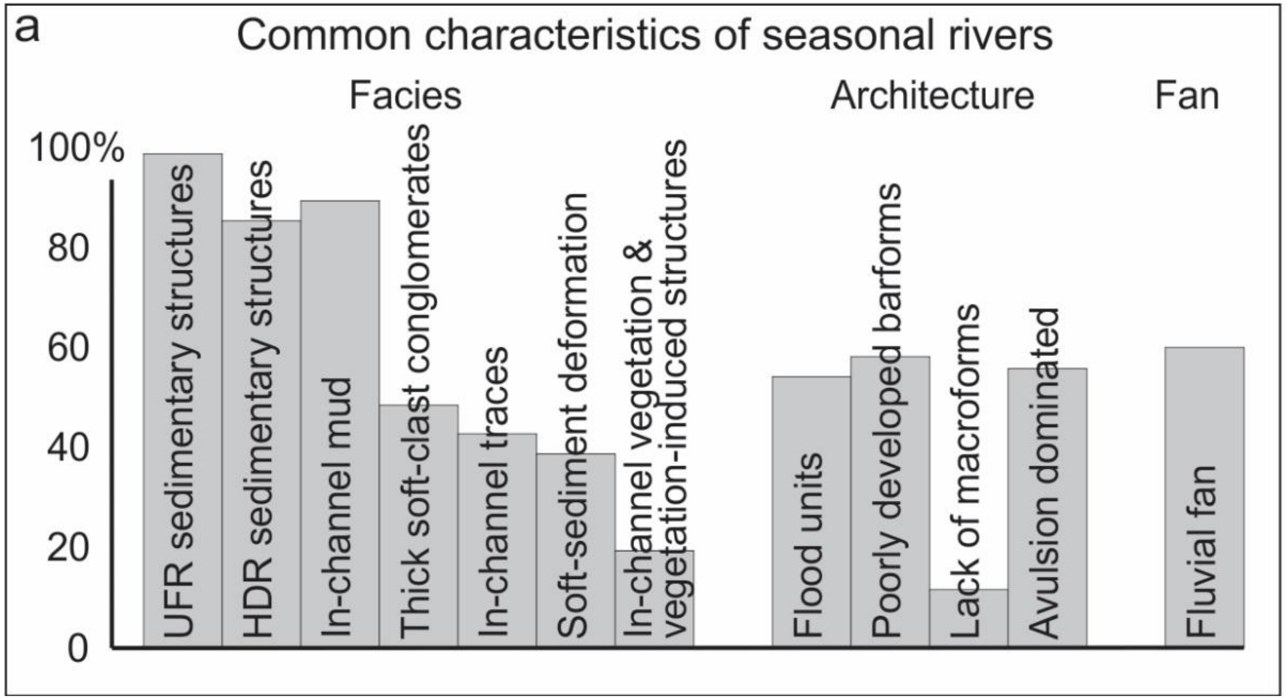


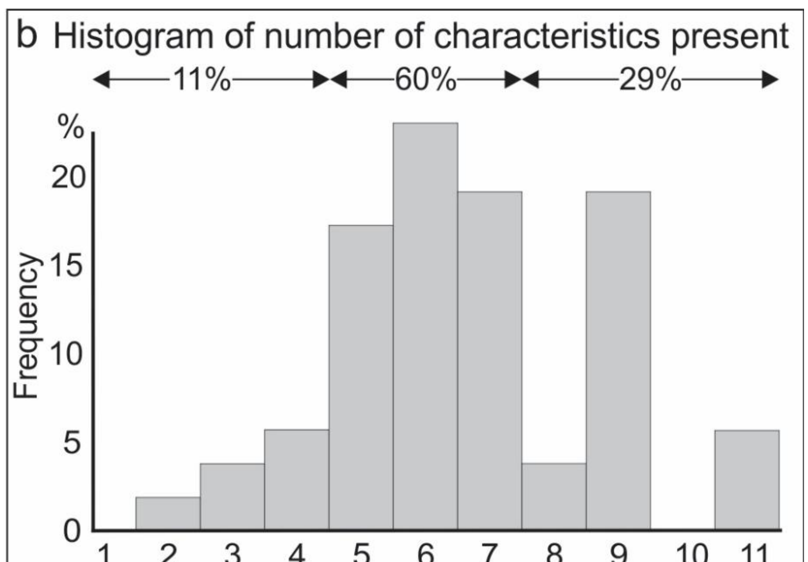




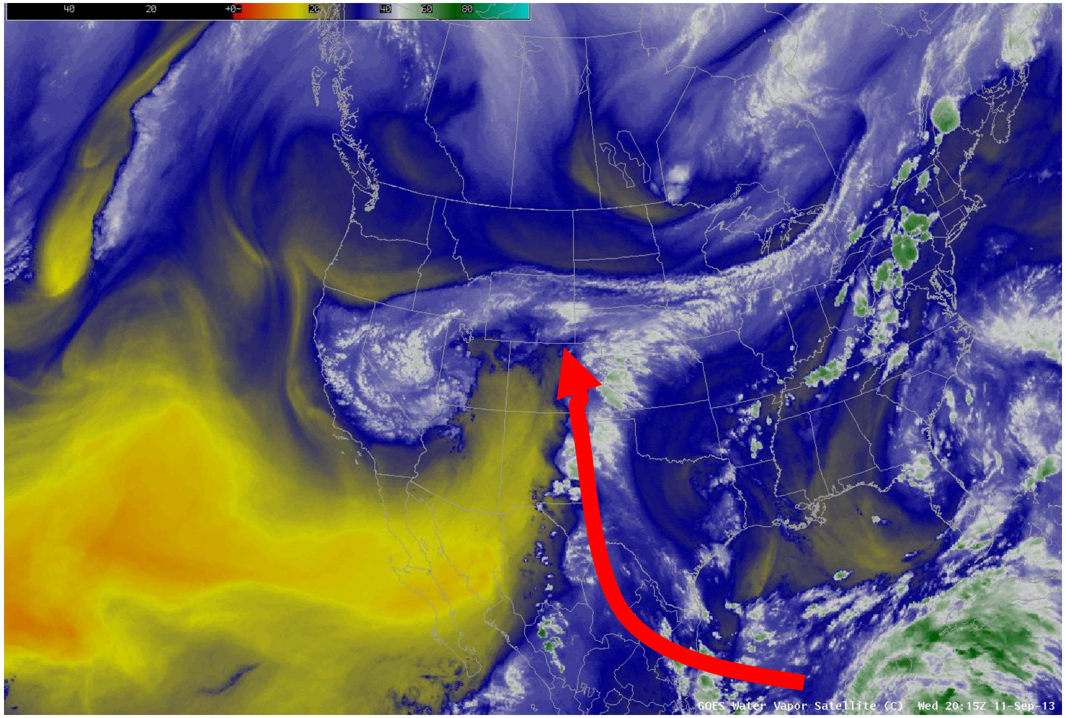


Review results: 11 common criteria





What difference does this make?



The 2013 September Colorado extreme precipitation event dropped the average annual precipitation of 450mm (17 inches) in 8 days

What difference does it make, compared to the same amount of rain distributed over a year?

What happened to small streams during September 2013 extreme precipitation event?

- Discharge?

- Flow velocities?

- Water level?

- Sediment concentration?

- Erosion rate?

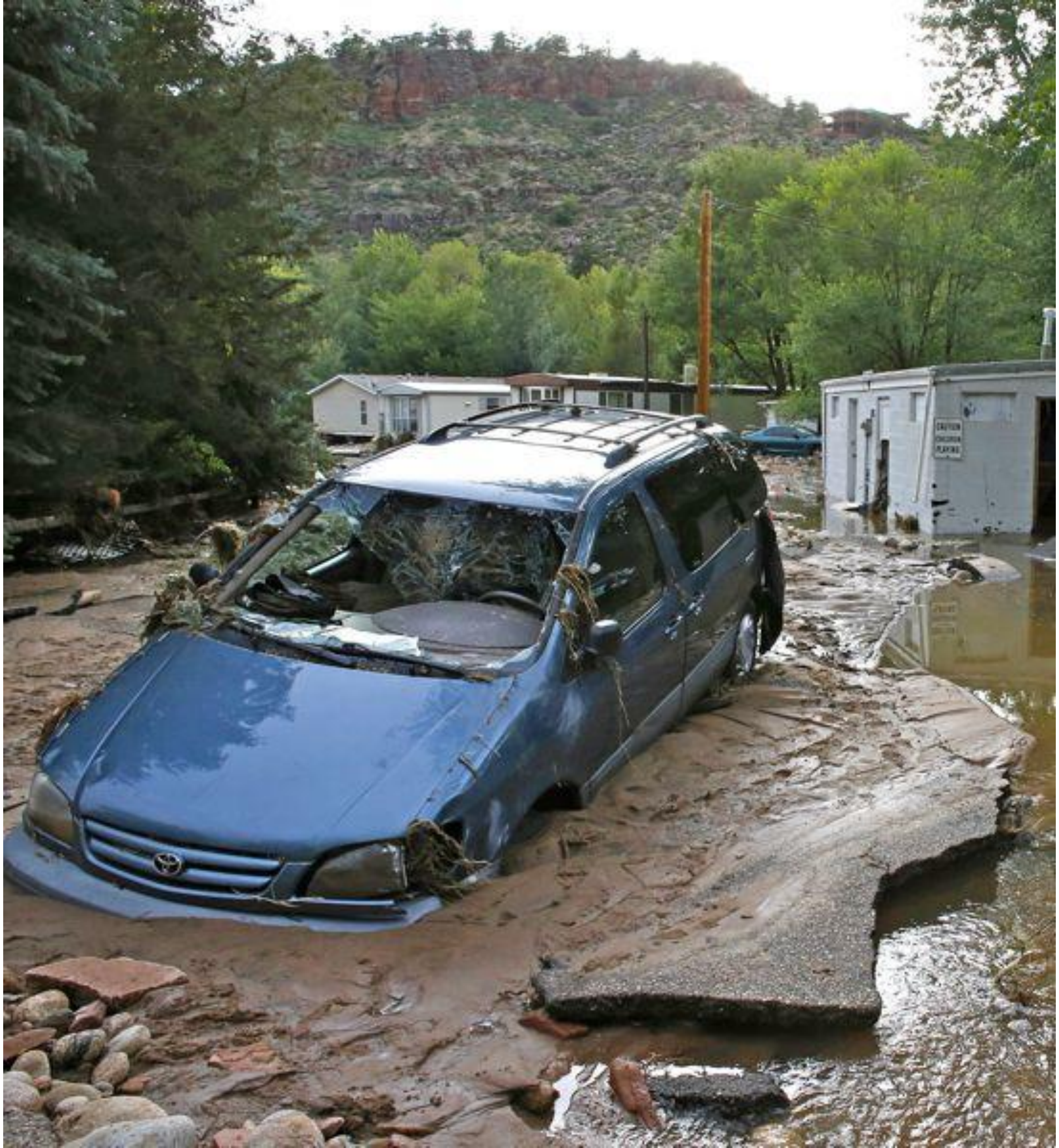
- Deposition rate?

- Stability of channels?

- Floodplain?

Pre-flood conditions = not much happened in Colorado streams


RDC




BRENNAN LINSLEY/AP

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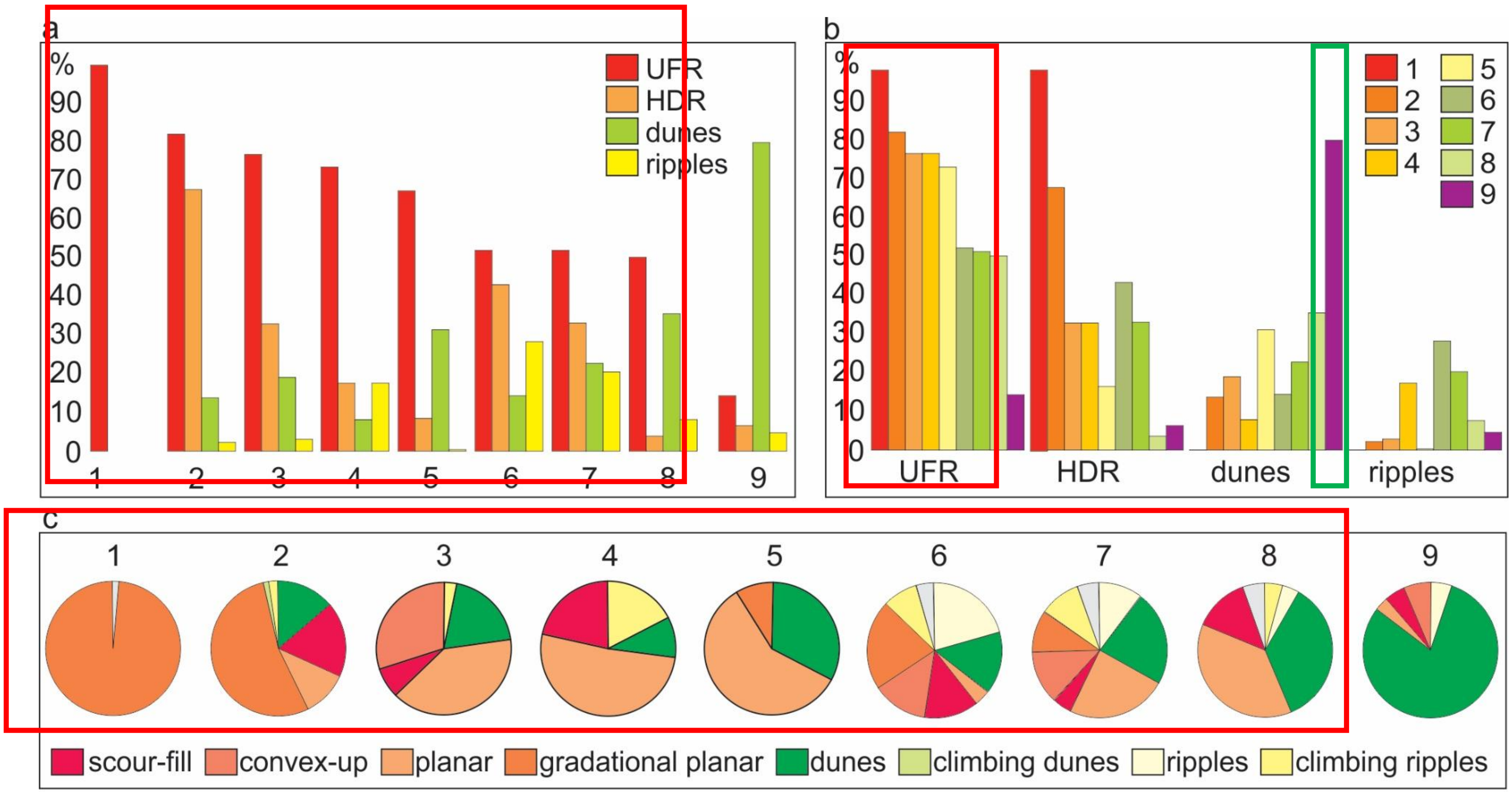
CRESTVIEW


JOHN WARK/AP

Consequence of extreme precipitation on river form and function?

- Extremely large discharge
- Extremely high flow velocities
- Bankfull discharge
- Extremely large sediment load
- Canyons flushed clean
- Channel avulsion and erosion
- Rapid sediment accumulation
- Flooding and floodplain deposition

1-2 Abundant Froude supercritical (98%) and high deposition rate (85%) sedimentary structures



High flow velocities & the characteristically rapid rise, sharp peak and rapid decline of the flood hydrograph + flushing + suspension transport

Planar laminations

Eocene Wasatch Fm, Uinta Basin

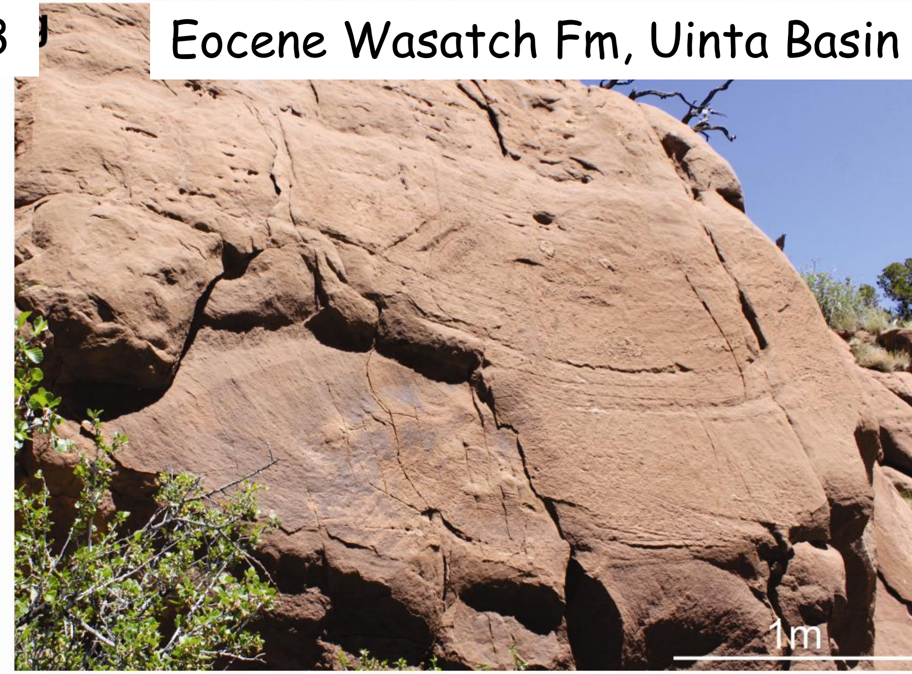
1981 flood in Laingsburg (Stear 1985)

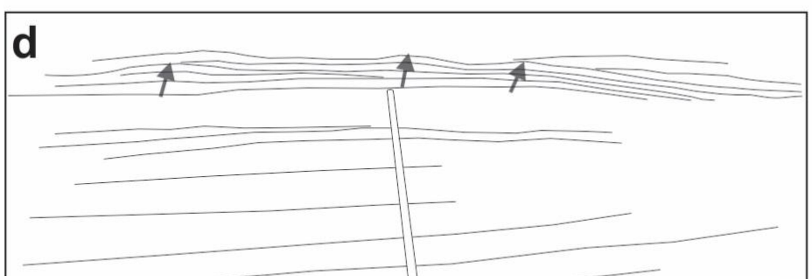
Permian Beaufort Fm. (Stear 1985)

Convex-up low-angle & scour-and-fill bedforms

Mississippian-Permian (Allen et al, 2013

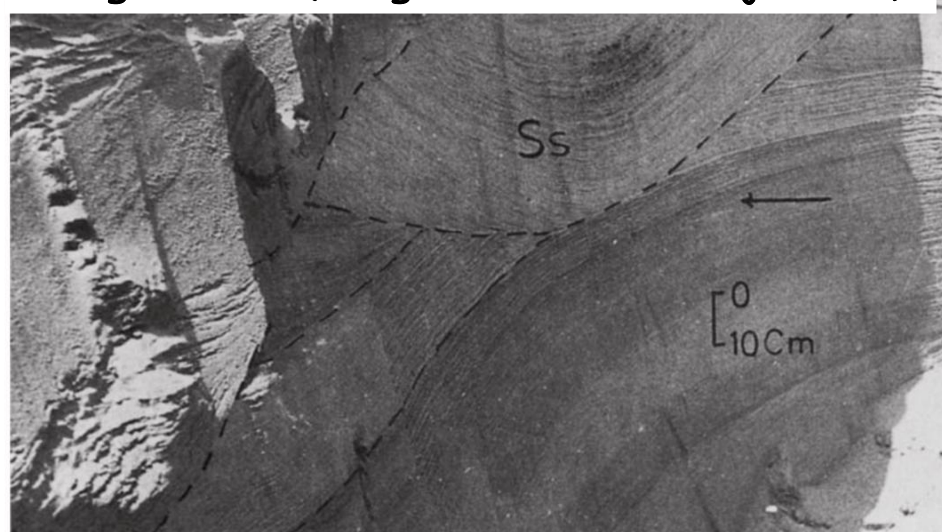
Eocene Wasatch Fm, Uinta Basin





Eocene Wasatch Fm, Uinta Basin

Ganga River (Singh and Bhardwaj, 1991)



Humpback or sigmoidal cross strata

Wasatch Fm., Uinta Basin

Devonian Chloritic sandstone
Ireland (Kelly and Olsen 1993)

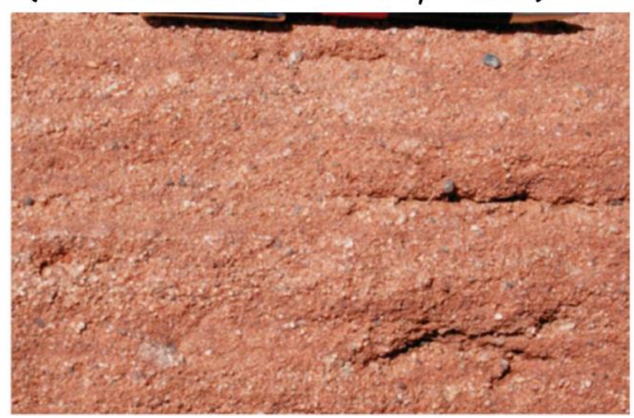
Permian, Antarctica (Fielding 2006)

Climbing ripples & dunes; gradational planar laminations

Eocene Wasatch Fm., Uinta Basin

Eocene Wasatch Fm, Uinta Basin

Triassic Moenkopi Fm.
(Banham and Mountney 2014)

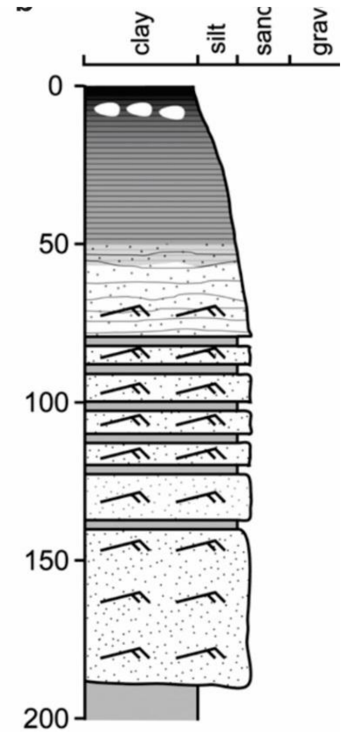


Notes by Presenter: Increases coarse sediment transport rates and suppresses dune formation and migration.

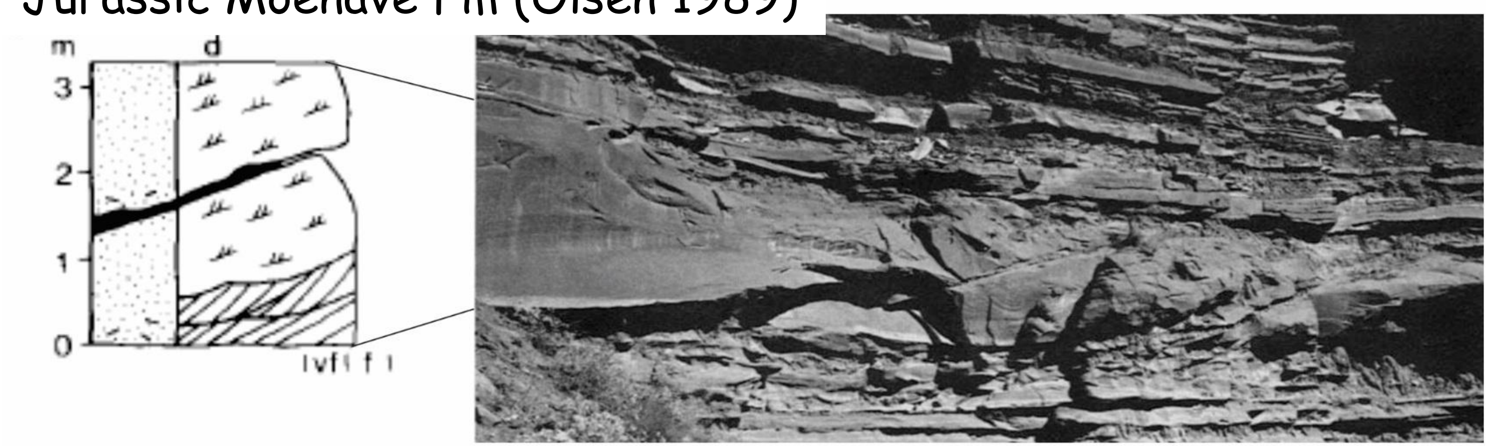
Climbing-ripple filled channels

Eocene Wasatch Fm, Uinta Basin

Rio Colorado, Altiplano (Donselaar et al., 2013)



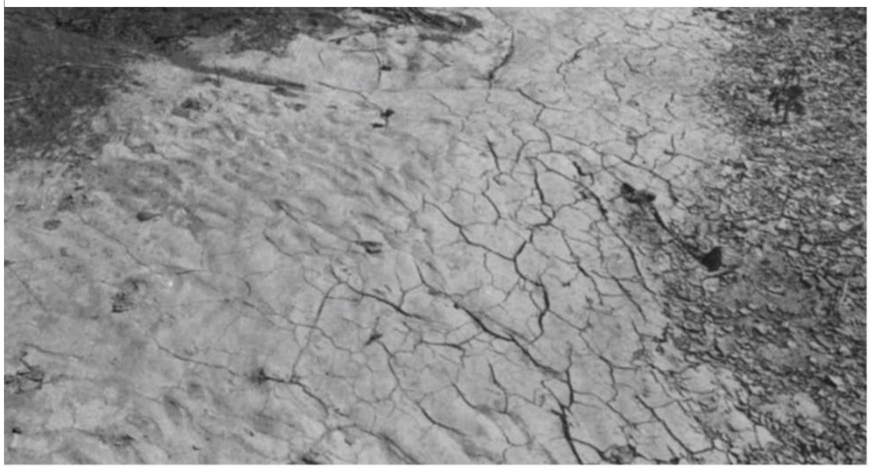
Jurassic Moenave Fm (Olsen 1989)



3: In-channel mud (89%)

Commonly cover UFR structures= extremely rapid waning of floods

1981 flood in Laingsburg (Stear 1985)

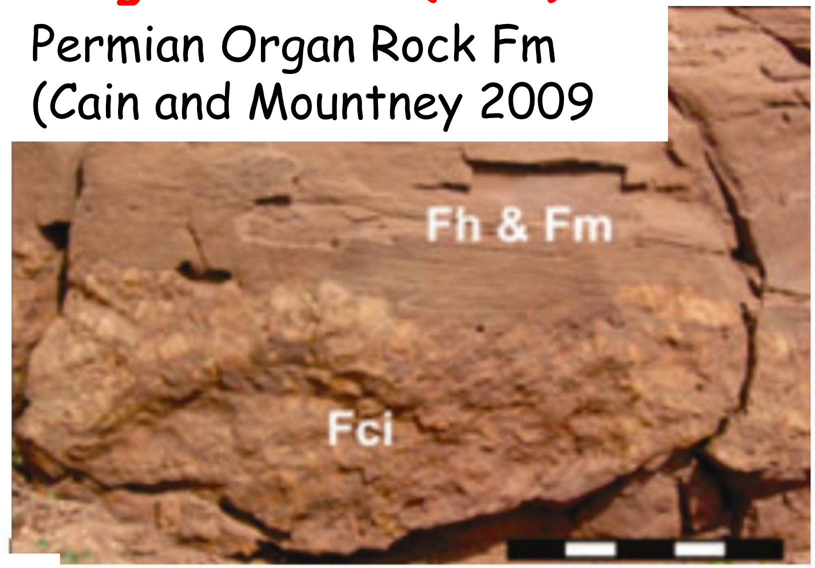


Permian Beaufort Fm. (Stear 1985)

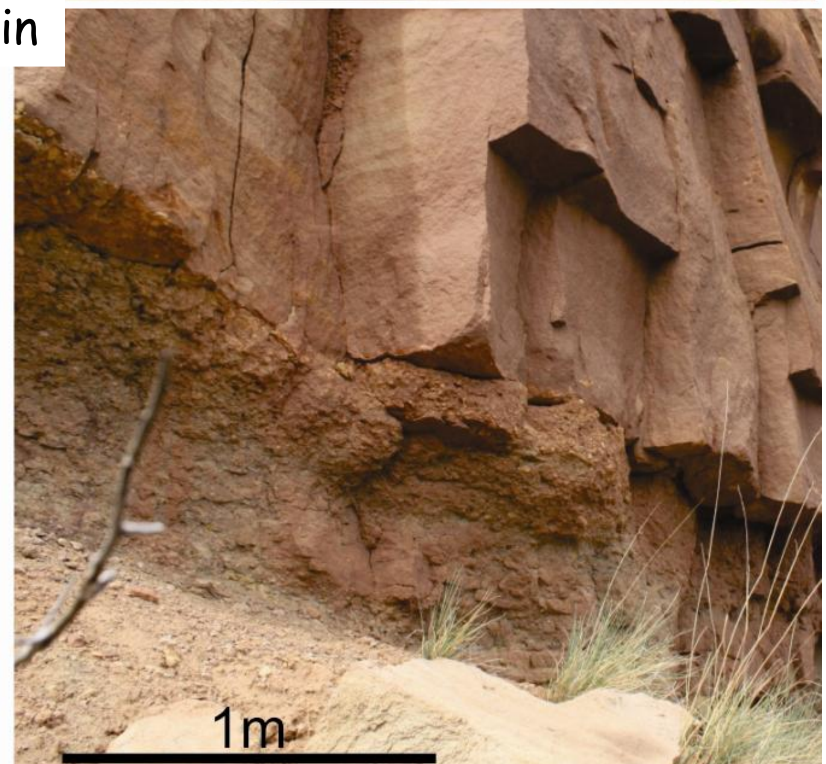
Eocene Green River Fm, Uinta Basin

4: Thick mud-clast conglomerates (48%)

Permian Organ Rock Fm
(Cain and Mountney 2009



Eocene Wasatch Fm, Uinta Basin



UFR erosion and undercutting + rapid water level lowering during falling stage of floods

Bank erosion and undercutting

Porewater overpressure and fluidization

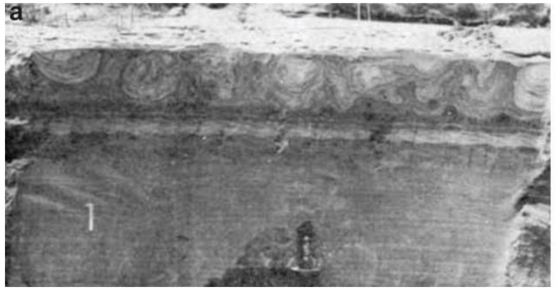
Rupen River India (Gibling and Tandon 1997)

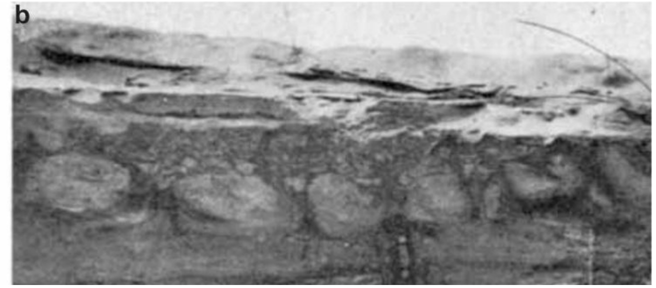
Big Thomson River, Colorado 2013

5: Soft-sediment deformation (39%)

Porewater expulsion during falling stage of floods

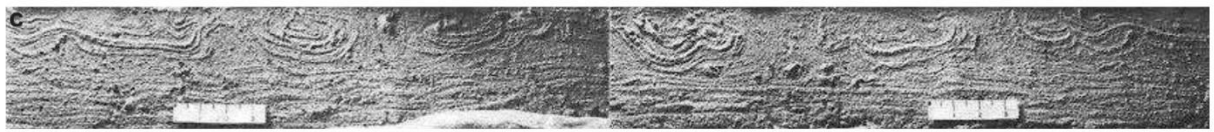
Lateral shearing under UFR, highly sediment ladden current



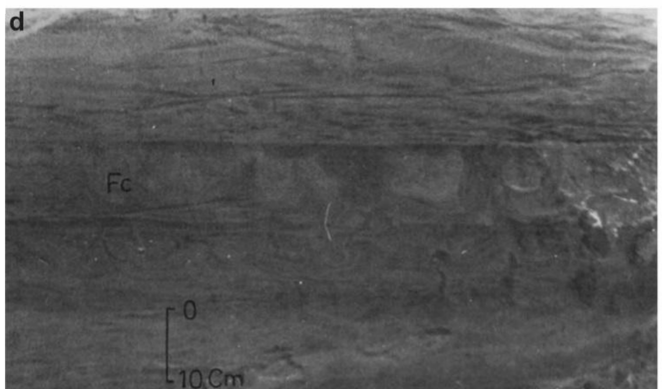


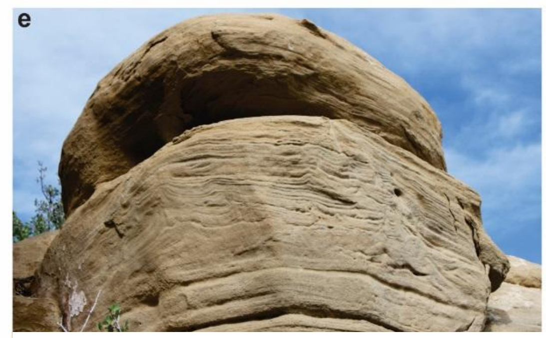
Brahmaputra River (Coleman 1969)

Bijou Creek 1965 flood (McKee et al 1965)



Ganga River (Singh and Bhardwaj 1991)

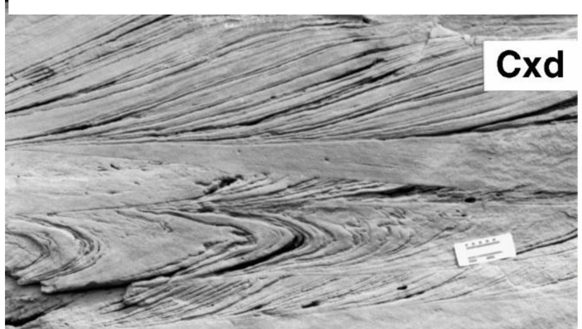


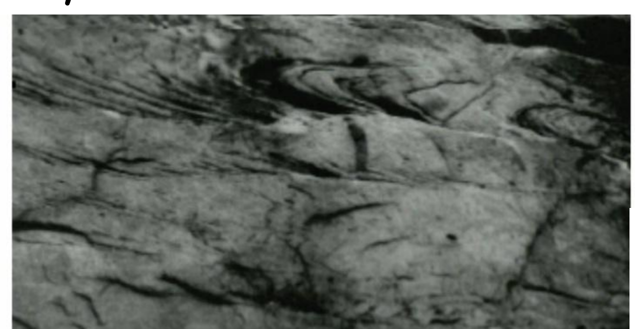


Eocene Uinta Basin

Jurassic Kayenta Fm

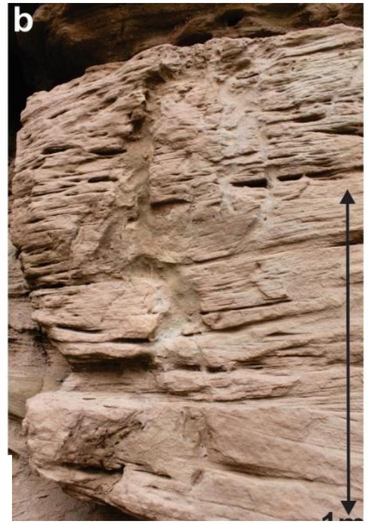
North and Taylor 1996





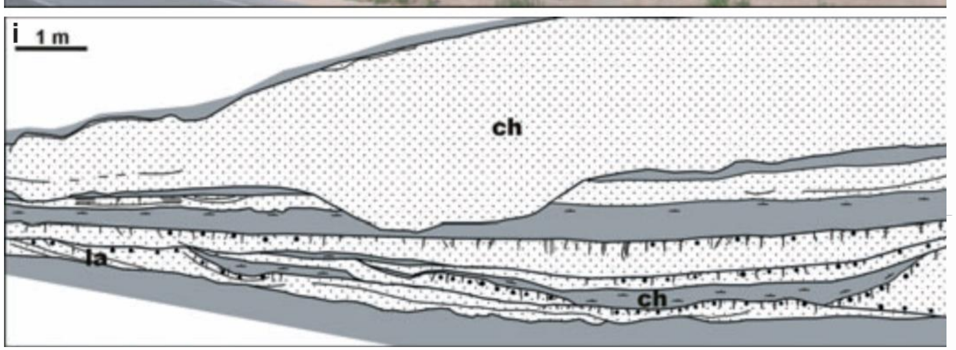
Bromley 1991

6: In-channel traces & pedogenic modification (42%)

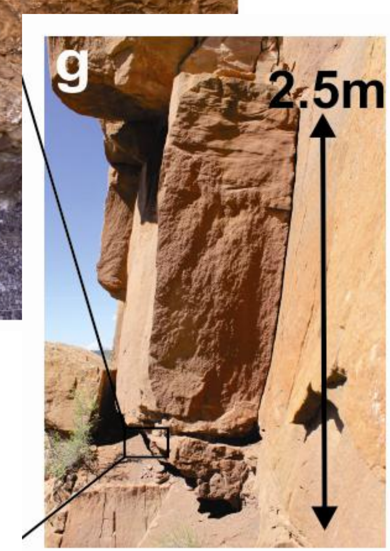


Eocene Uinta Basin

Channel bed exposure,
highly variable and sustainably low water table,
soil moisture conditions



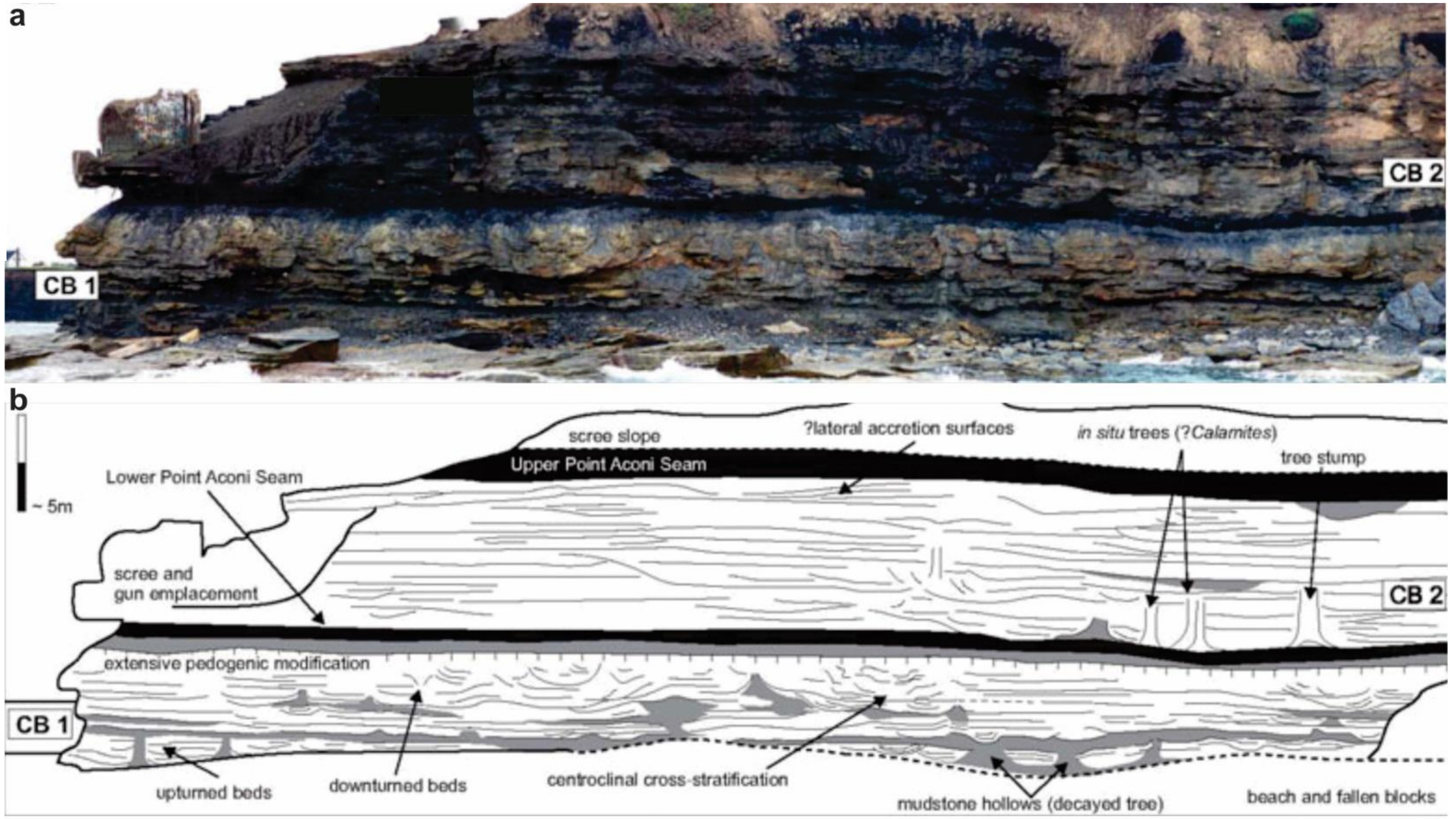
termite nests
other burrows



Paleogene Ebro Basin (Saez et al. 2007)

7: In-channel vegetation and vegetation induced sedimentary structures (20%)

Pennsylvanian -Permian Allen et al 2013



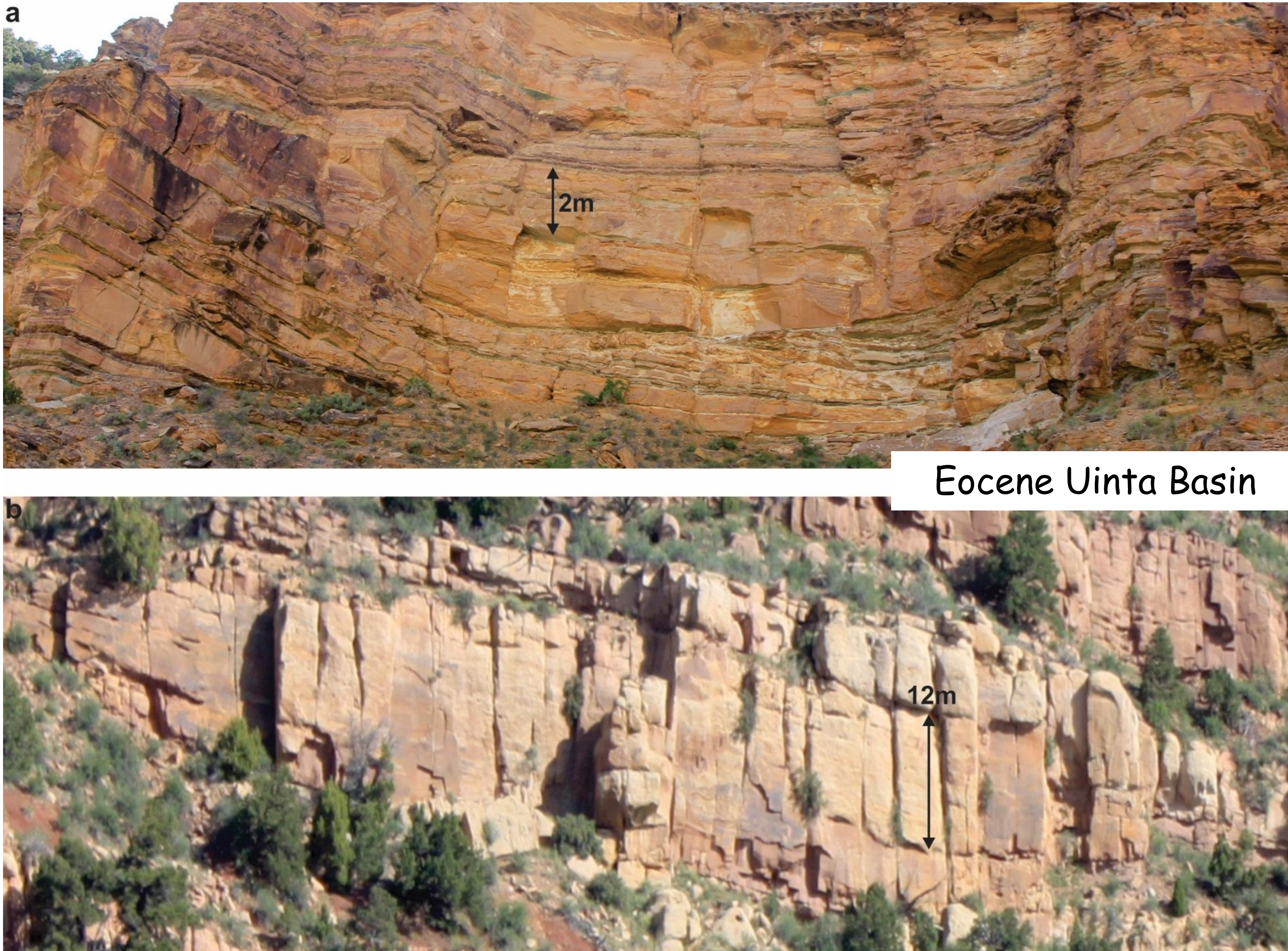
Burdekin River Australia Fielding et al 2009

8-9 Architecture: Flood units (54%) & poorly developed bars (58%)

Tista River, India (Chakraborty and Ghosh 2010)

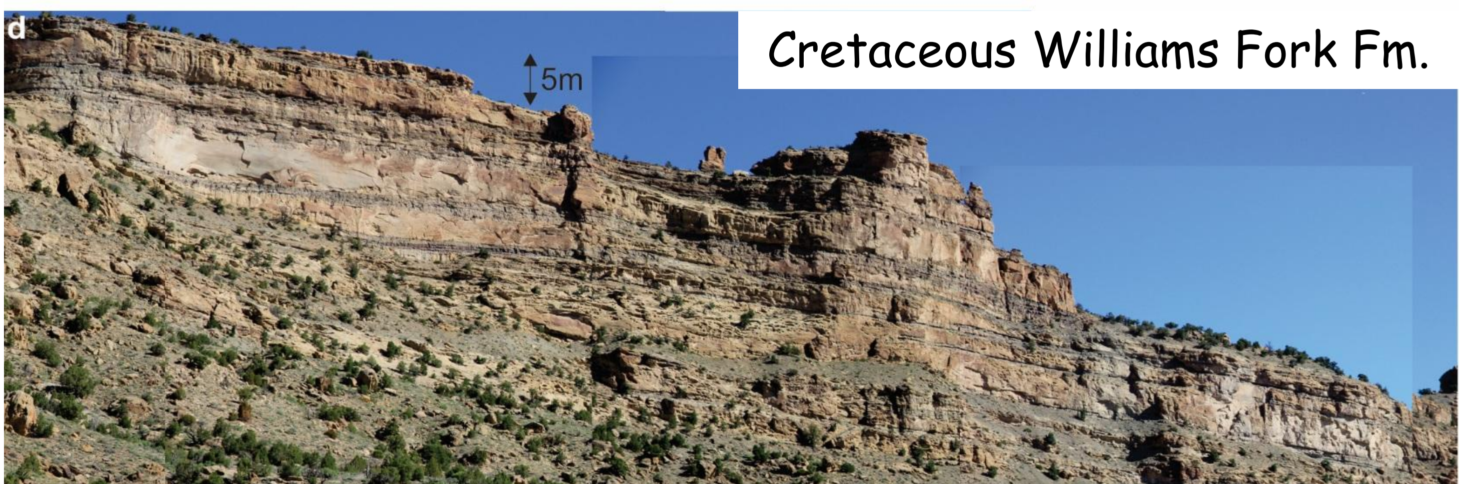
Eocene Uinta Basin

Stacked flood units

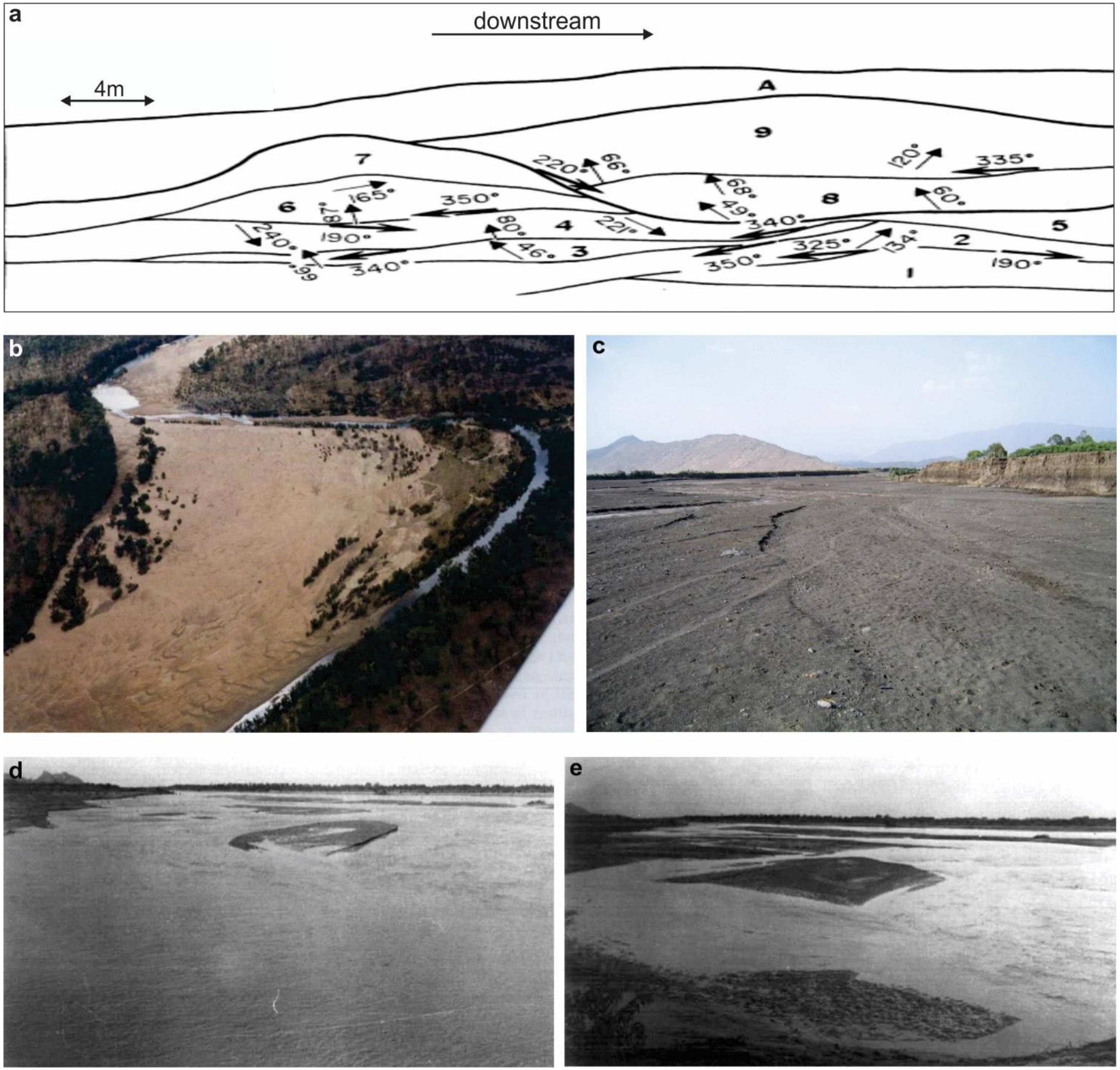


Eocene Uinta Basin

Stacked flood units

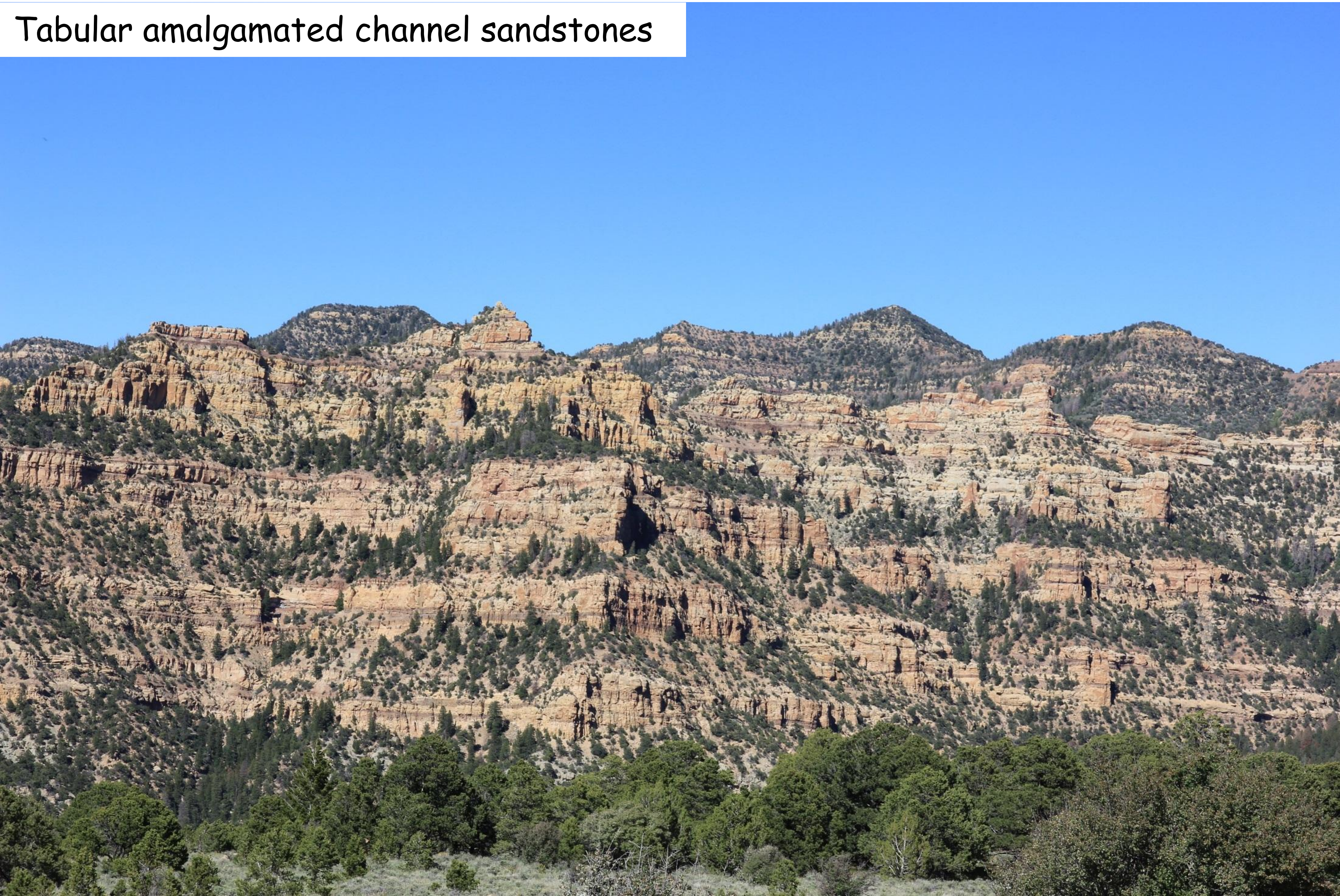


Poorly developed bars



10 Architecture: Avulsion dominated (56%)

Tabular amalgamated channel sandstones



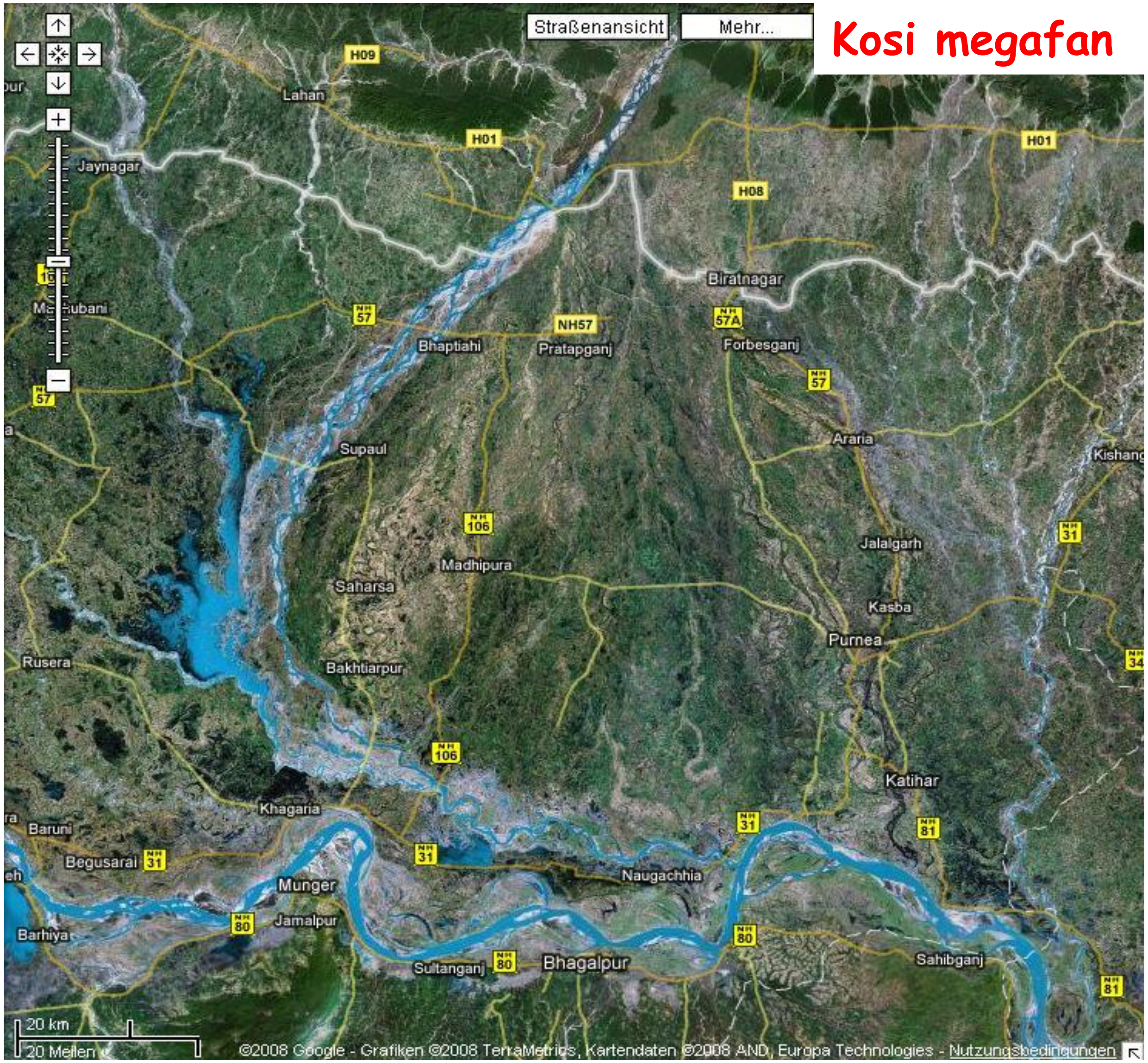
Architecture: Avulsion dominated (56%)

Splay-rich floodplain, avulsion units

11 Architecture: Fluvial fans (60%)

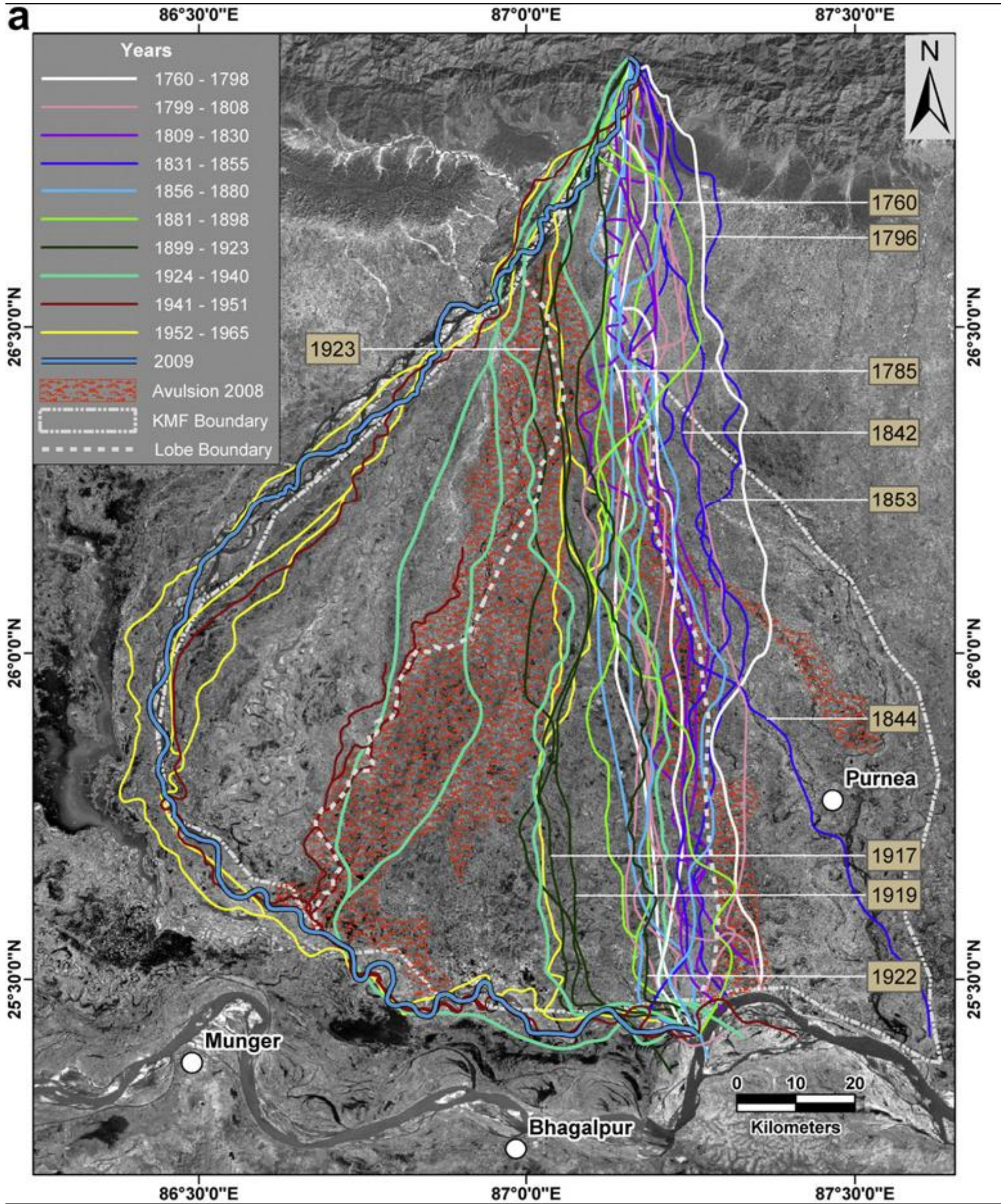
Mountainous hinterland, large drainage, seasonal discharge, most common in foreland basins (Leier et al. 2005)

Discharge, grain size,
sediment flux decrease;
Floodplain sediment incresae
Most splays in anastomosing zone



Shukla et al. 2001

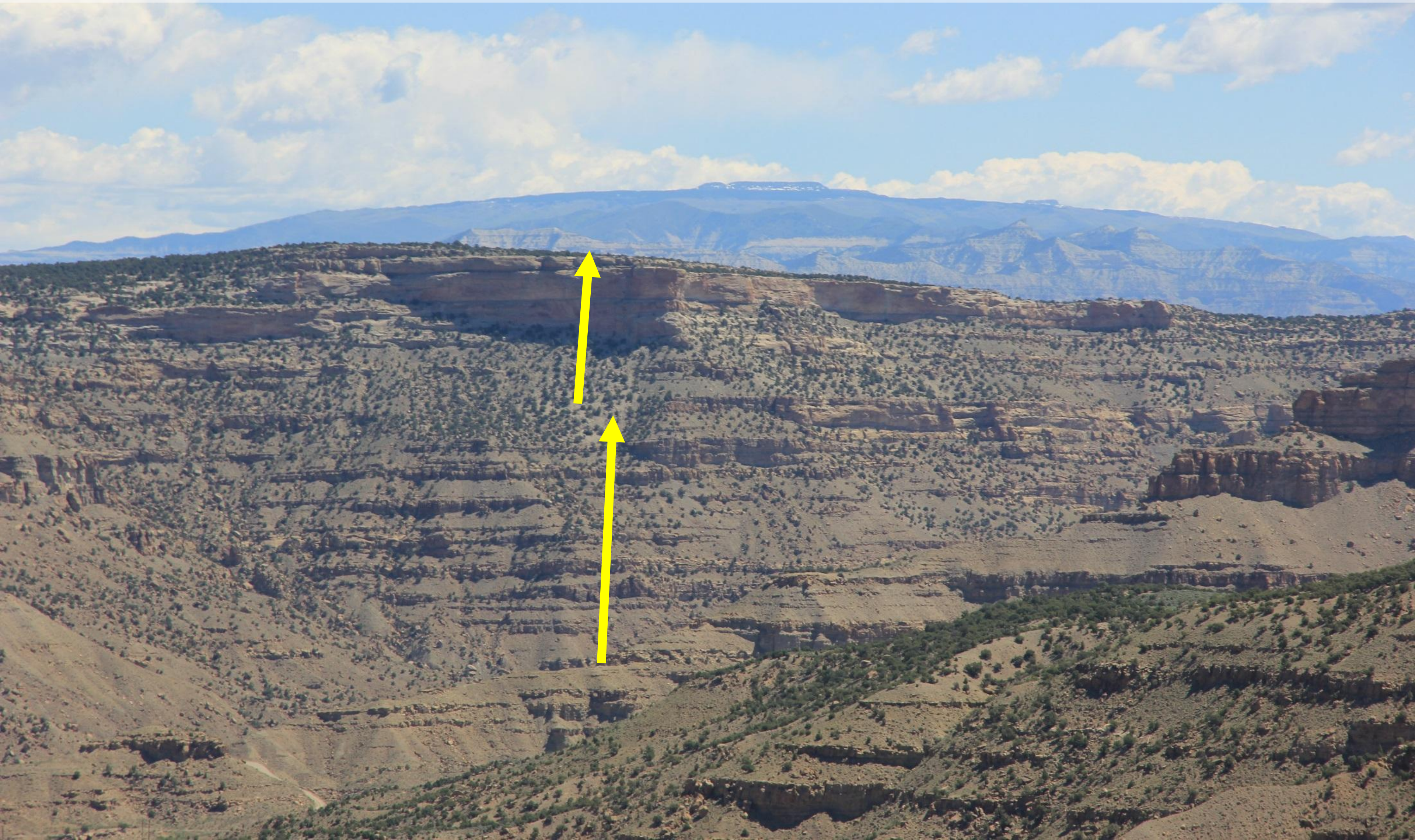
Architecture: Fluvial fans (60%)



Chakraborty et al. 2010

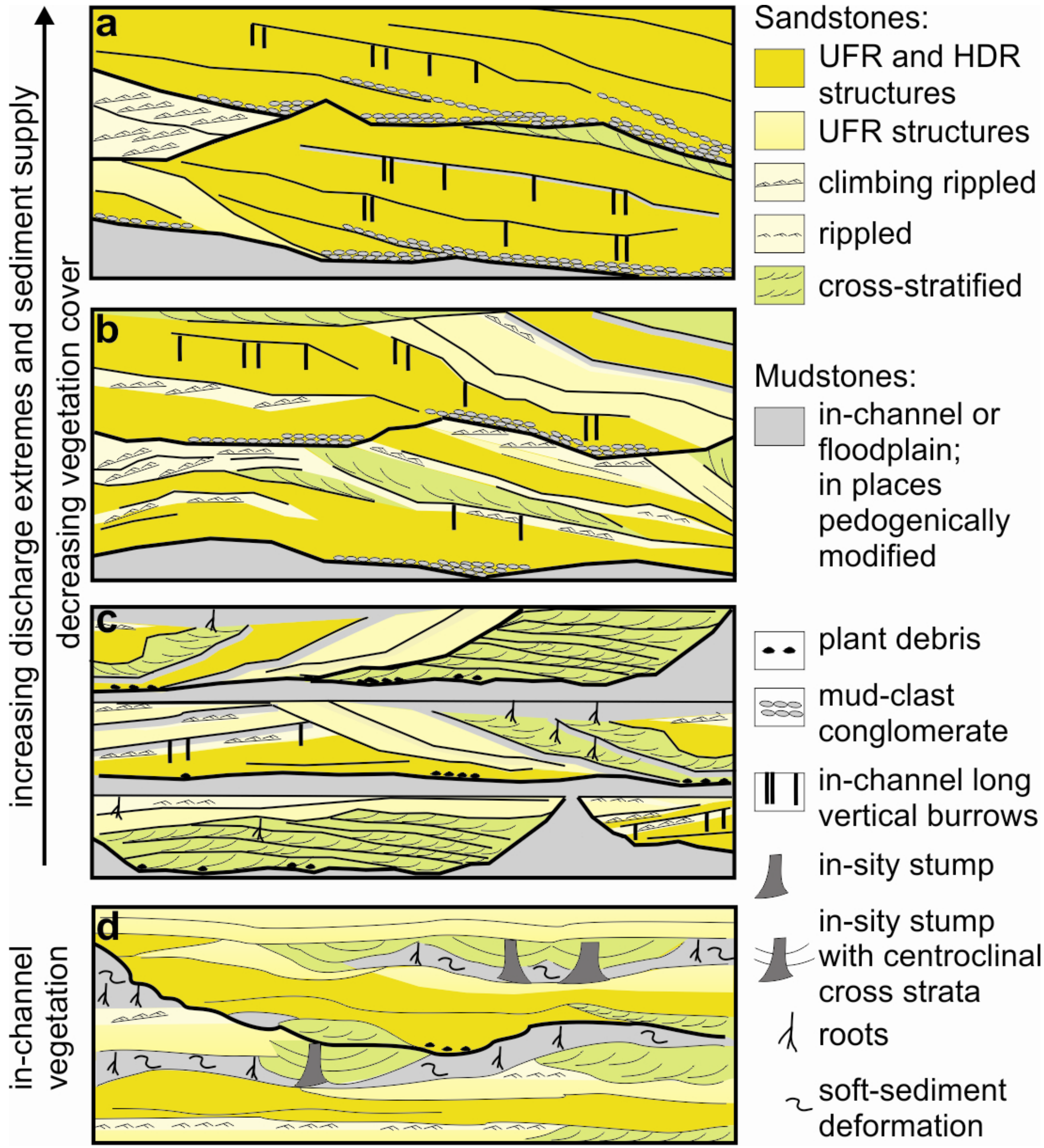
Architecture: Fluvial fans (60%)

Williams Fork Fm., Piceance basin:
Predictable upward coarsening packages

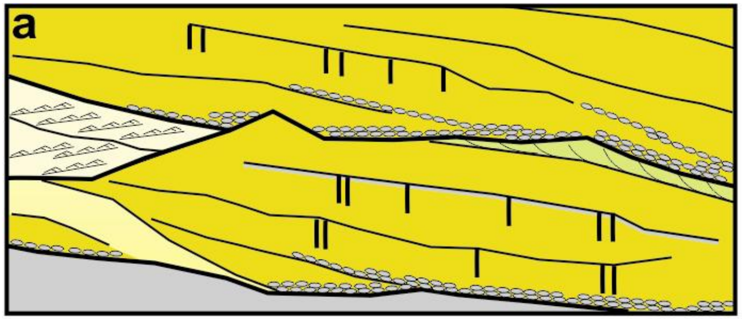


End-member facies models

100% high magnitude flood deposition



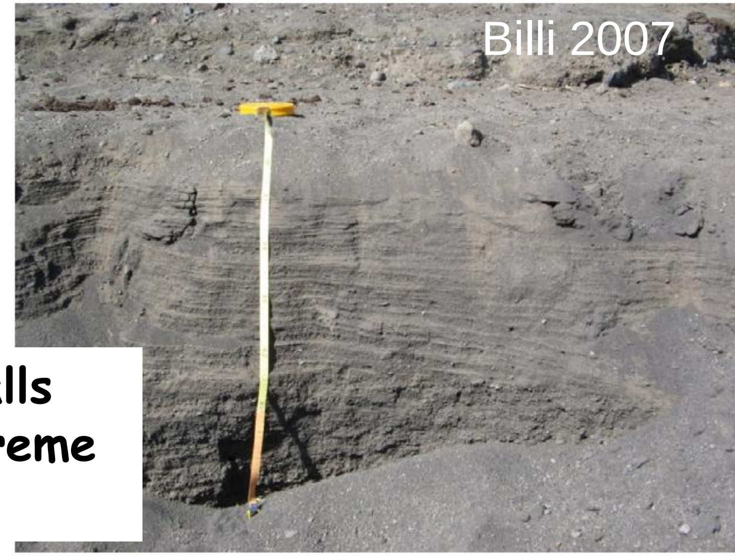
More similar to flashflood or megaflood deposits than facies models for river systems…



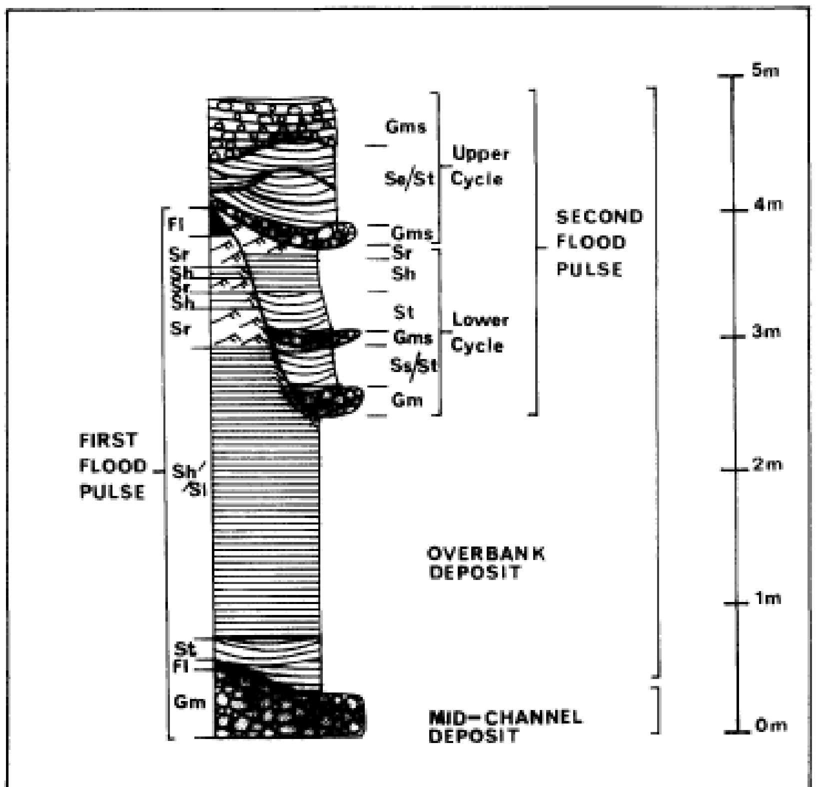
Flashy rivers where all deposition happens during high-magnitude floods

Modern analogues:
Kobo Basin, Ethiopia

Semi-arid subtropics, annual rainfall of **750 mm/yr (30 inches)**, occurs in a few intense downpours during the monsoon season, channels are dry for rest of the year

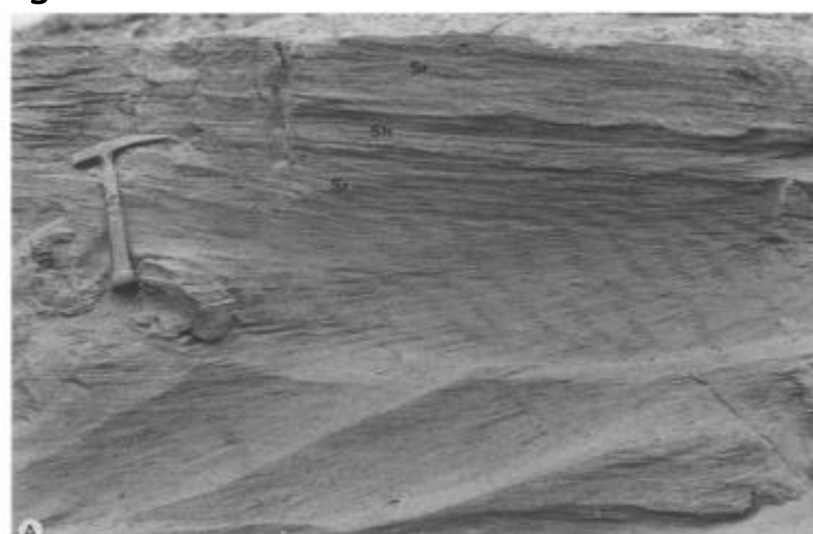


annual precipitation falls during very short extreme precipitation events



Karoo, South Africa:

Arid, annual rainfall of **100-200 mm/yr (4-8 inches)**, fell in 1981 in couple of hours; sparse vegetation

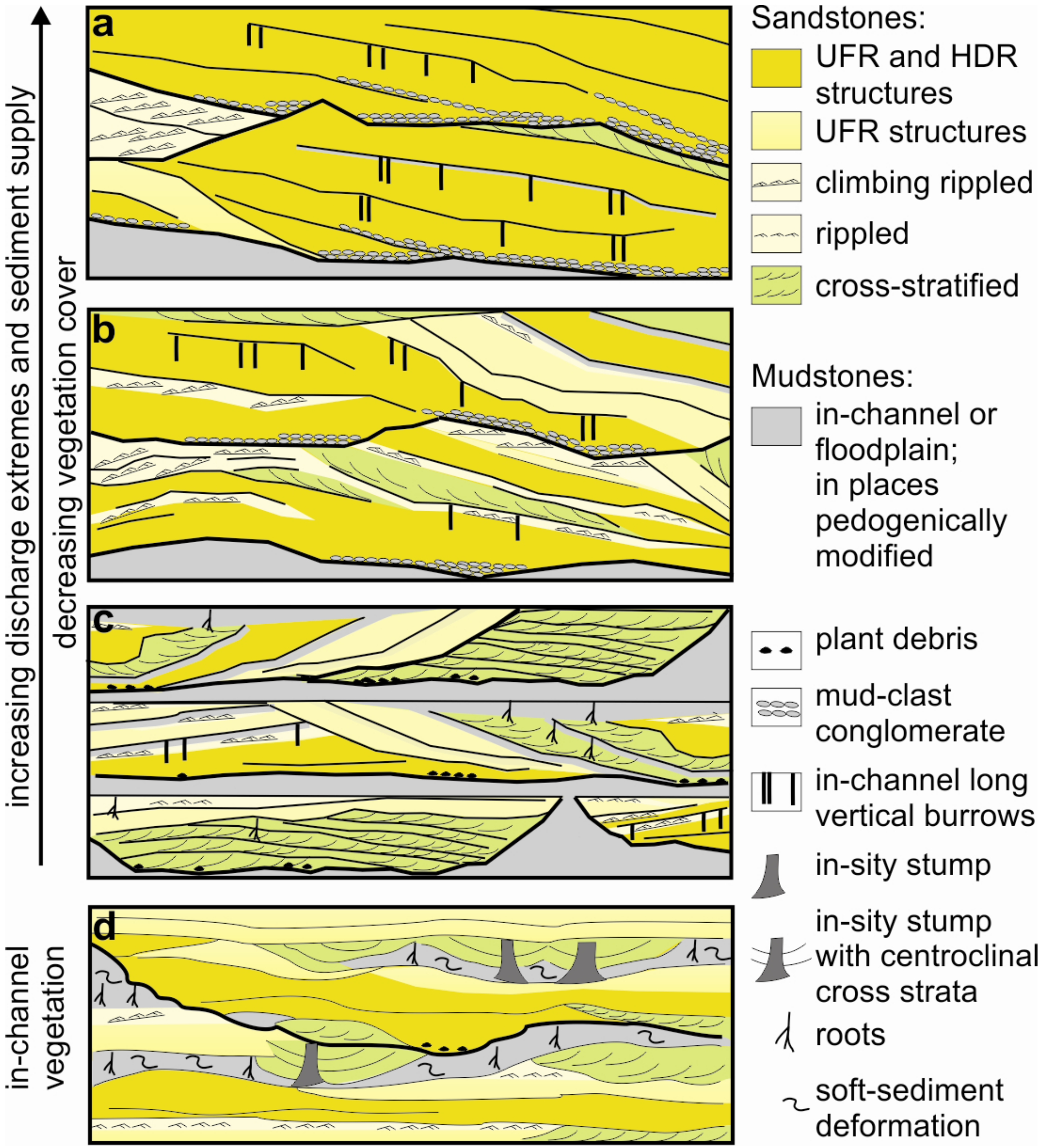


Stear 1985

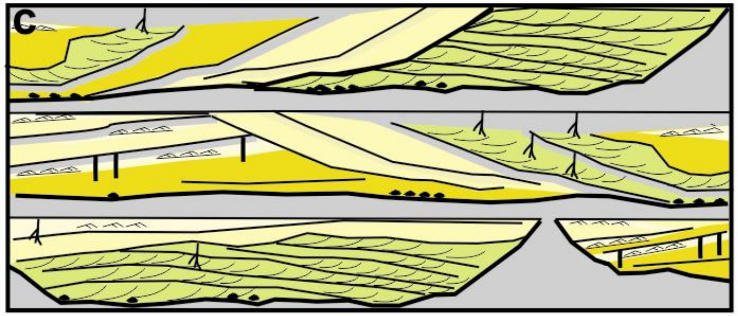
End-member facies models

100% high magnitude flood deposition, where the annual rain comes during very short extreme precipitation events

50% high magnitude flood deposition + sustained bedorfm migration



Mixed flashy supercritical flow and sustained bedload migration



Modern analogues:

annual precipitation falls over the monsoon season of 3-4 months

Himalayan monsoonal domain rivers: >1000-1200 mm (39-47 inches) of rain per year (e.g., Shukla et al., 2001; Singh et al., 2007), over the monsoon season of 3-4 months;

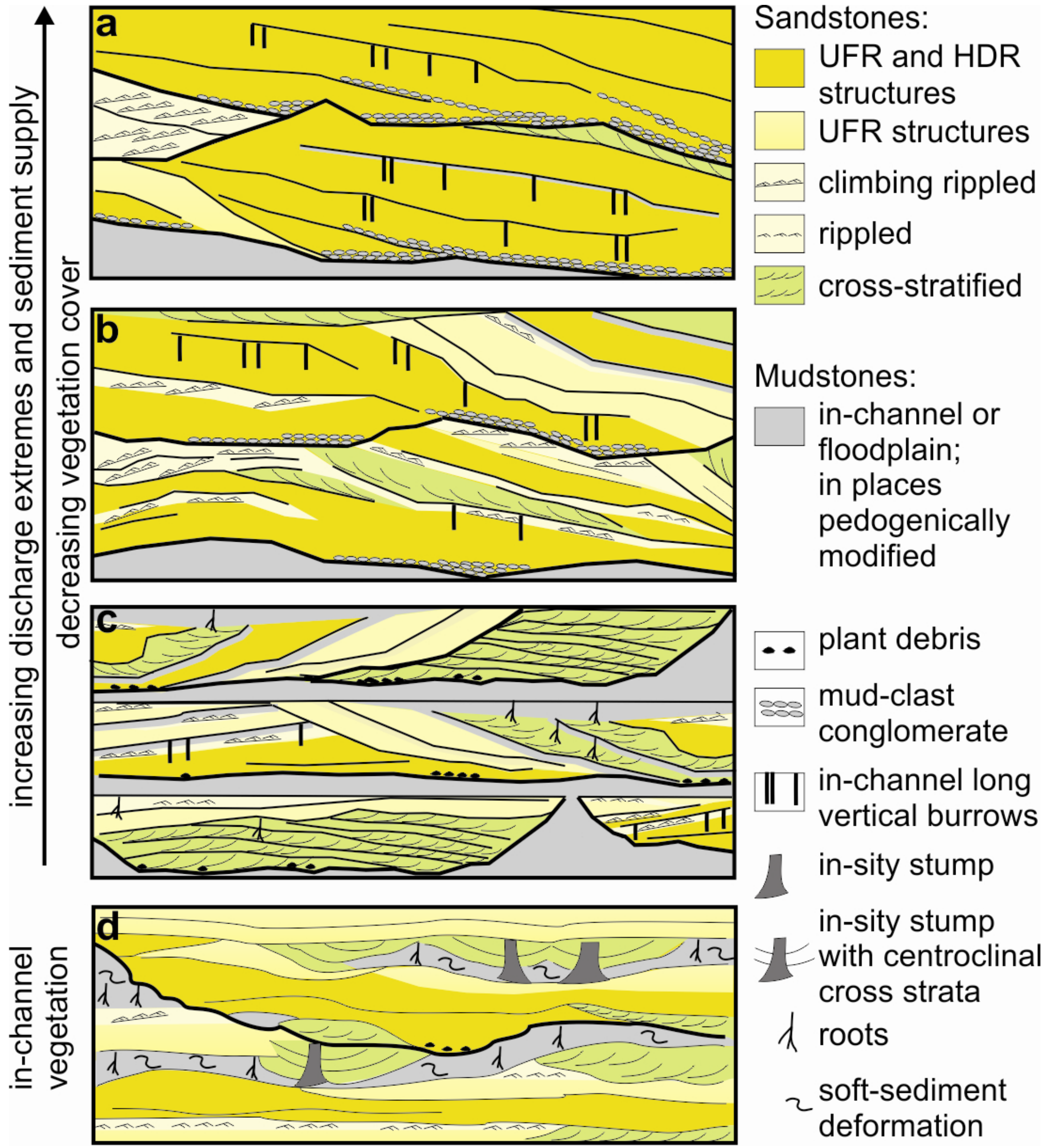
Semi-arid subtropics with **100-200 mm (4-8 inches)** of rain (e.g. Abdullatif, 1989)

End-member facies models

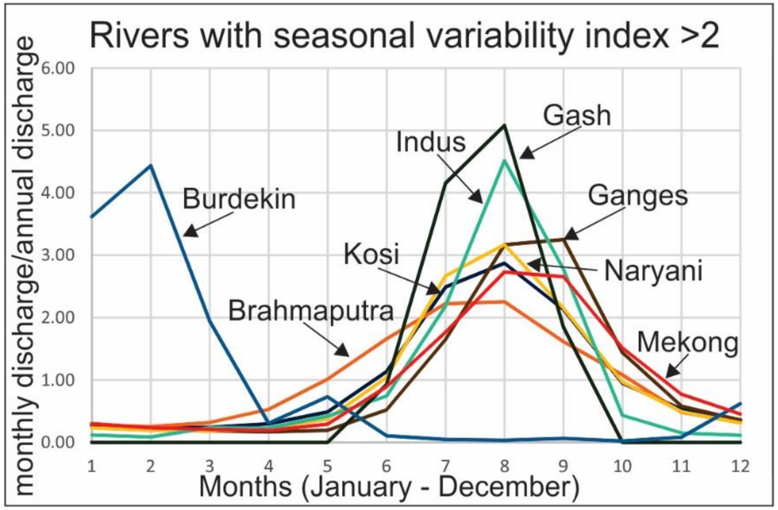
100% high magnitude flood deposition, where the annual rain comes during very short extreme precipitation events

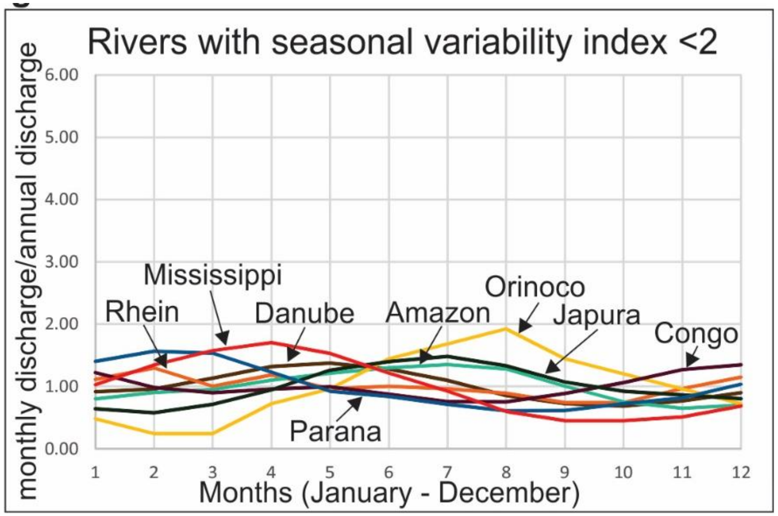
50% high magnitude flood deposition, where rain falls throughout the monsoon season over 3-4 months

Rivers with in-channel vegetation (Fielding et al., 2009)



Conclusions:





- Large discharge range as compared to the annual average discharge is what sets apart rivers that receive most of their surface water supply from monsoon precipitation

- The key difference in morphodynamics is supercritical flow and suspension transport/deposition

- Provide a paleoclimate proxy, but for precipitation pattern rather than latitude; as e.g., in early Eocene they also occurred in mid-latitudes, although in current climate conditions restricted to either side of rainforest zone within ca 35°

MINES

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Petroleum Corporation

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EOG Resources

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