The Indus Delta – what can we learn from it?

Ali Jaffri, Ph.D.

The Indus Delta

What can we learn?

1. Do rapid facies changes only occur along depositional dip? Or are they just as rapid along depositional strike?

2. What exactly happens to abandoned lobes in this particular setting?

3. What lessons can we import from the Indus?

4 What are the implications for correlation in compound clinoforms on deltaic reservoirs such as the Frontier and Parkman in the Powder River Basin and the Gallup in the San Juan Basin?

Margins of the trunk distributary channel – 2 km across, 12 m deep

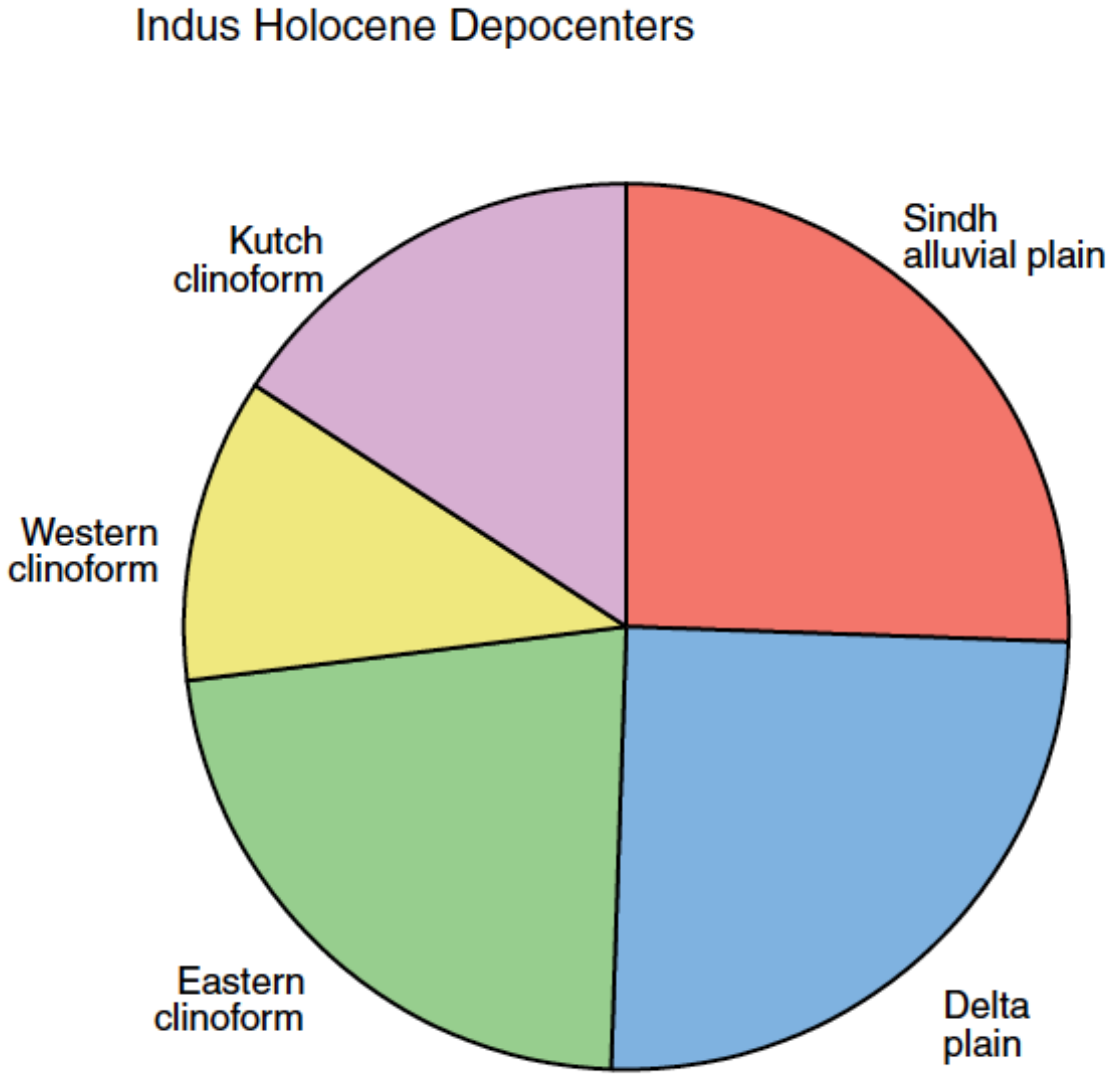
Indus River

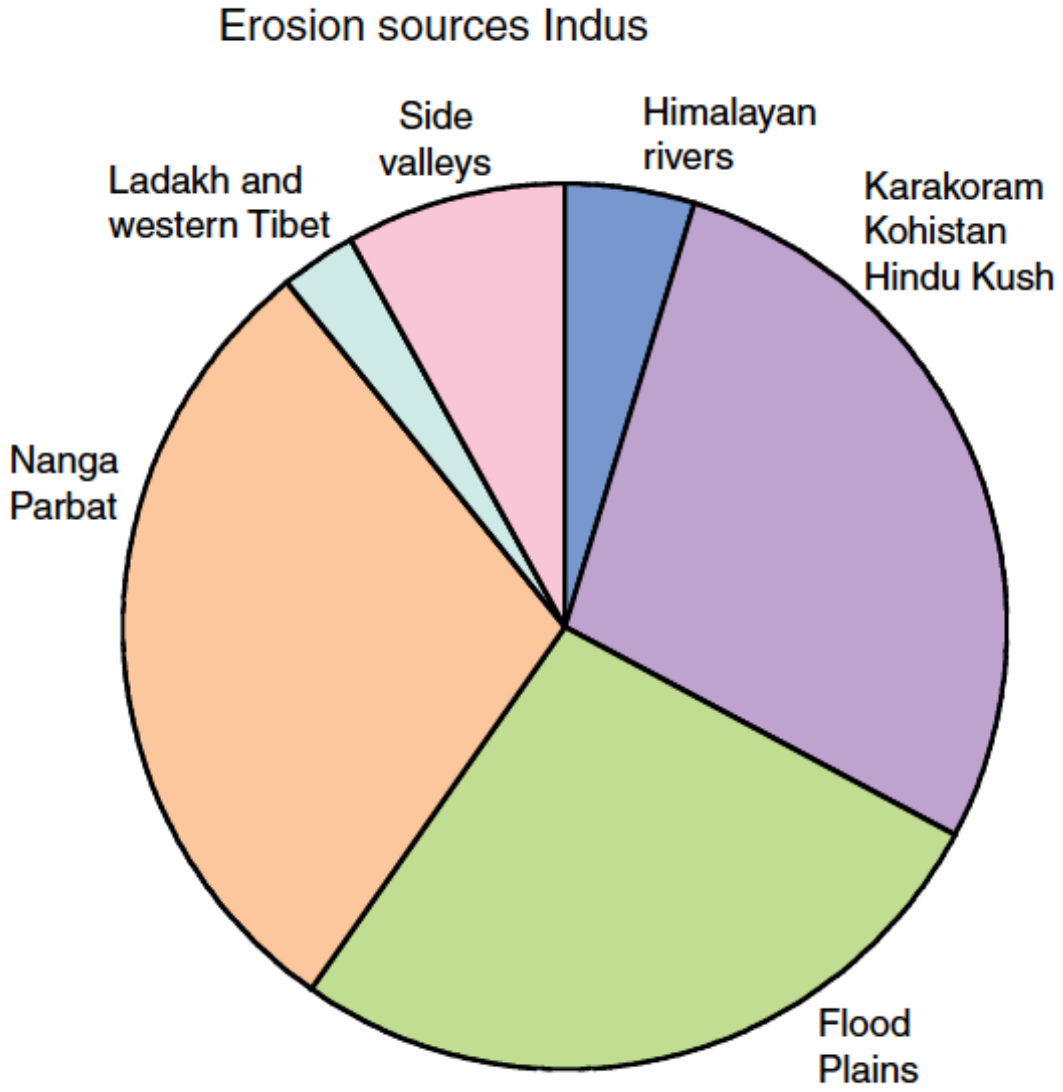
Nanga Parbat – Western Himalayan Syntaxis

The 15,600 foot Rupal Face of Nanga Parbat

Indus River

Source-To-Sink

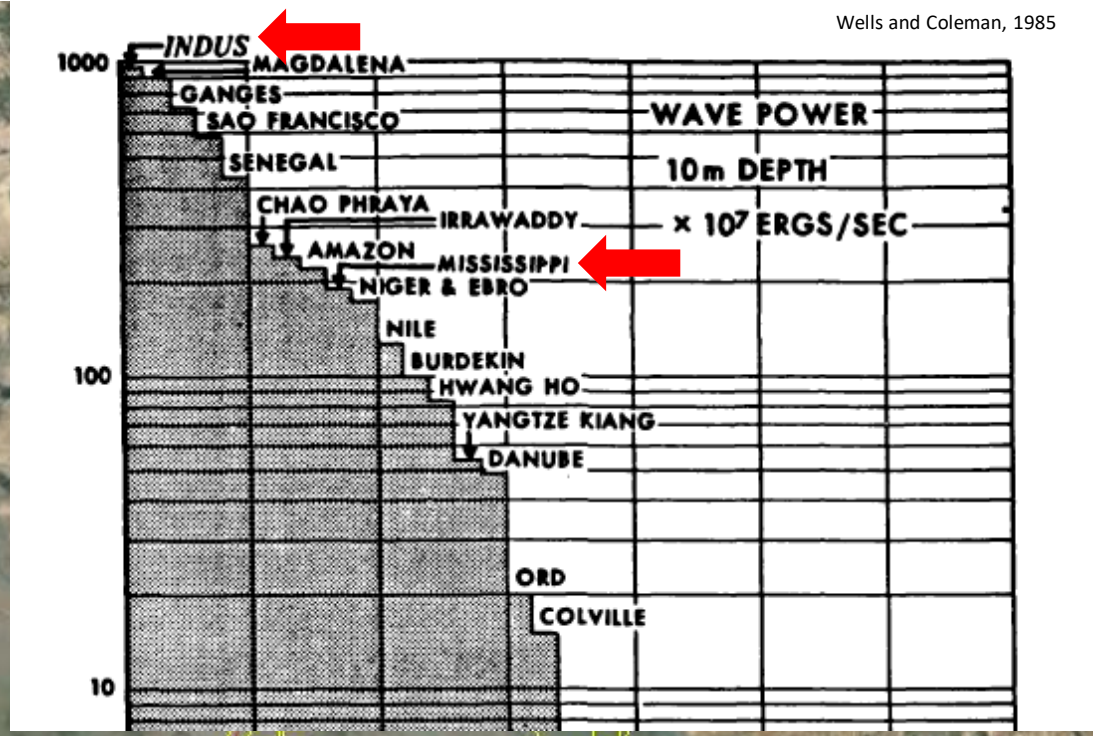




Clift and Giosan, 2013

The Indus Delta

Receives more wave energy than any other delta in the world



Makli

Upper Delta Plain

M-9

M10

AH2

N5

N110

N25

Karachi

Delta Front

Longshore drift

Prodelta

Lower Delta Plain

Sindh

Delta Front

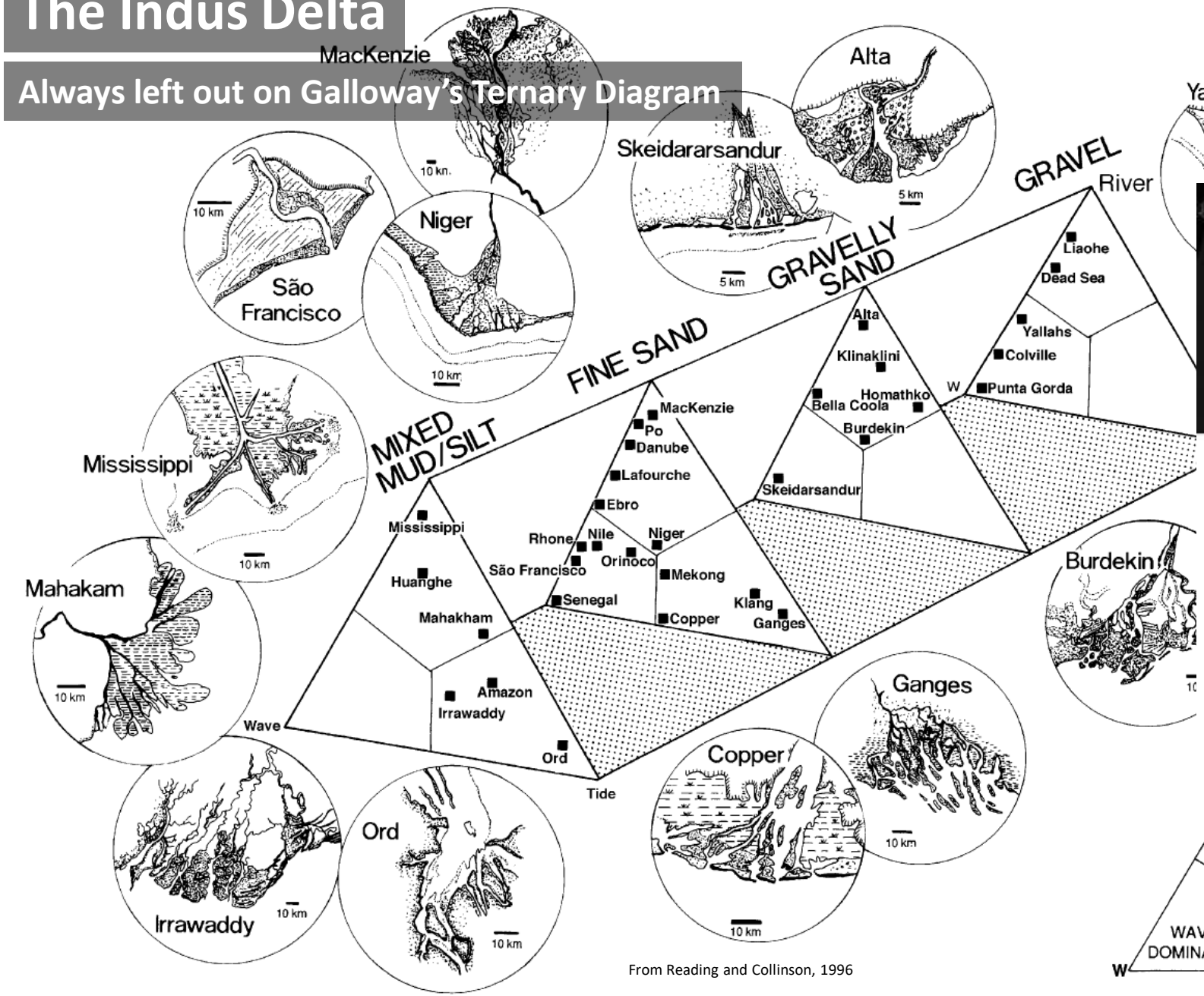
Prodelta

49

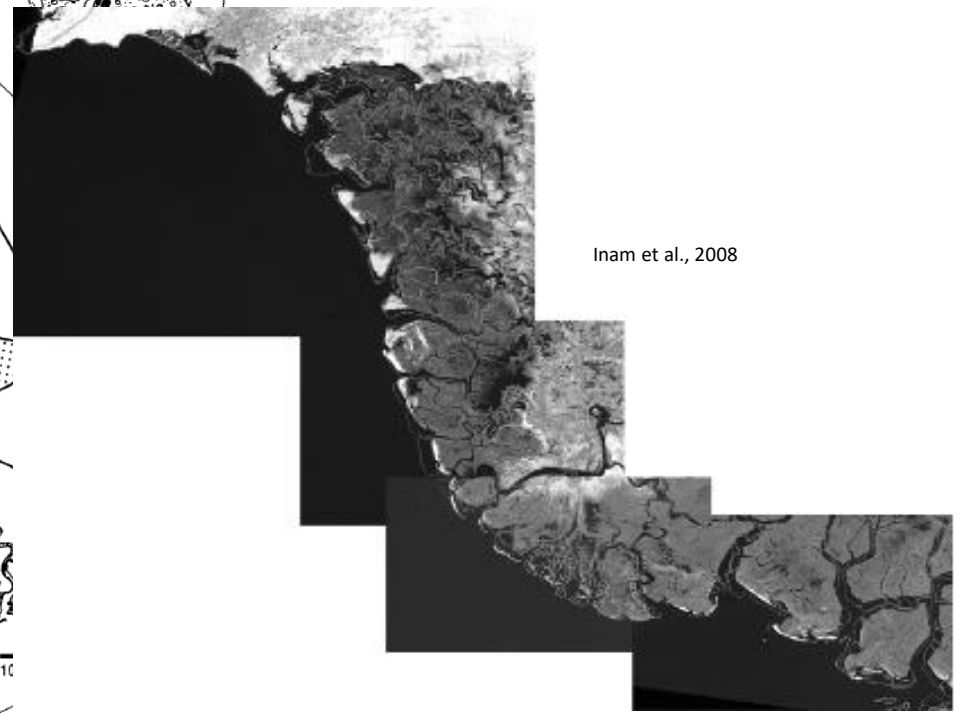
50 km

The Indus Delta

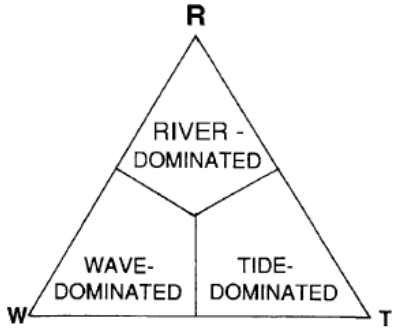
Always left out on Galloway's Ternary Diagram



From Reading and Collinson, 1996

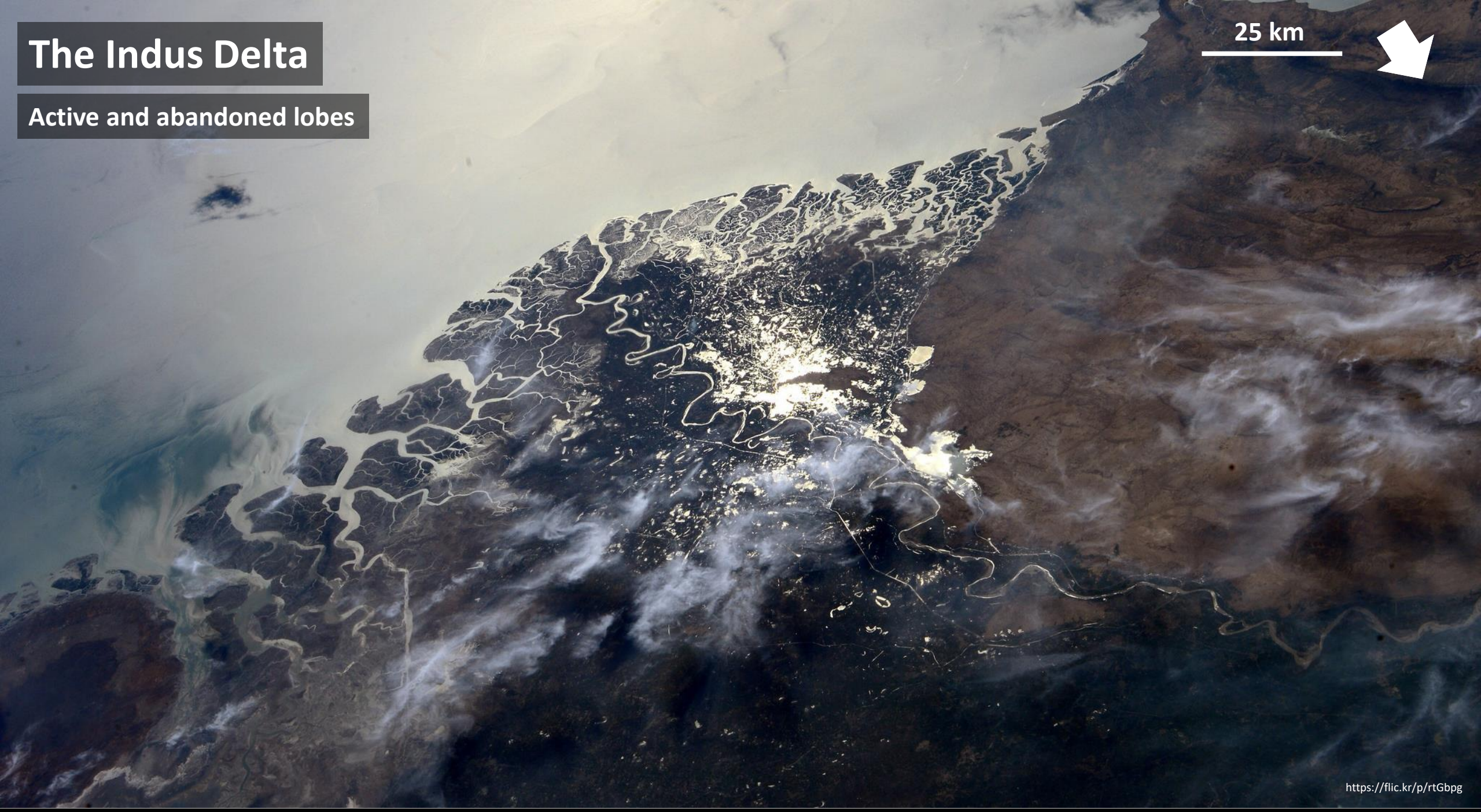


Inam et al., 2008



The Indus Delta

Active and abandoned lobes



https://flic.kr/p/rtGbpg

The Indus Delta

Active and abandoned lobes

25 km

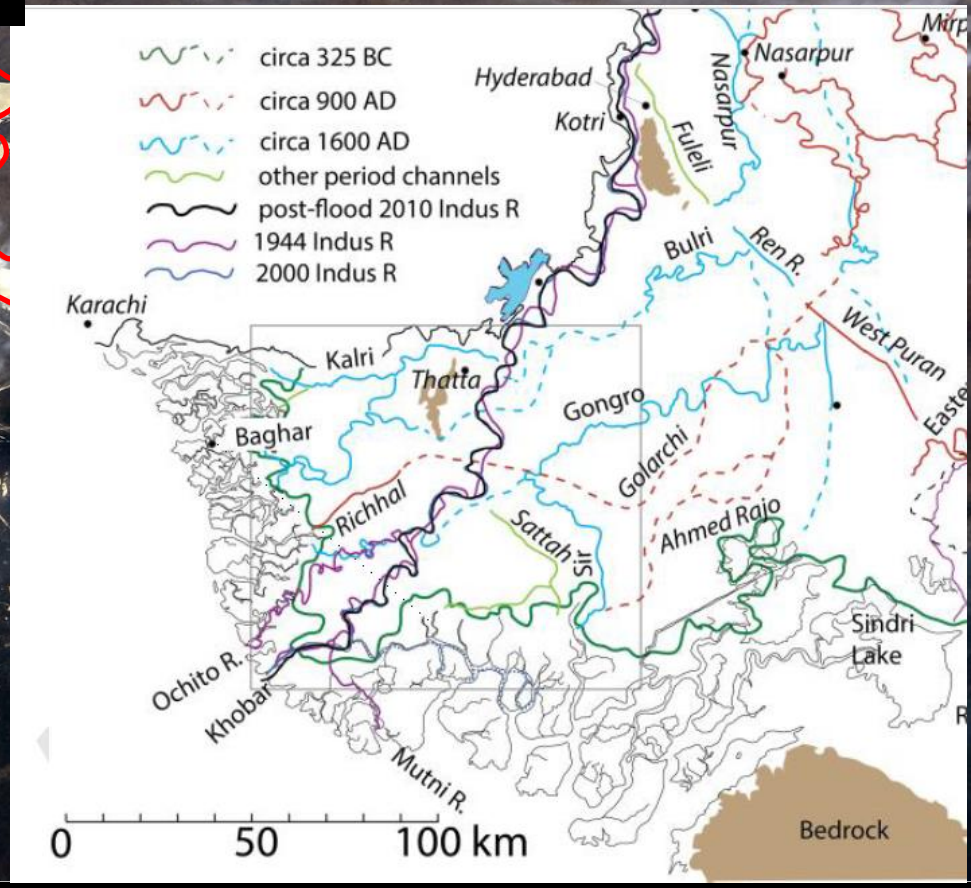
Abandoned Lobe
"Western Clinoform"

Abandoned Lobe
"Eastern Clinoform"

Active Lobe

Syvitski et al., 2014

https://flic.kr/p/rtGbpg



The Indus Delta

Stop 1 – Overview of the abandoned lobe

Upper Delta Plain of the abandoned lobe

Lower Delta Plain of the abandoned lobe

The Indus Delta

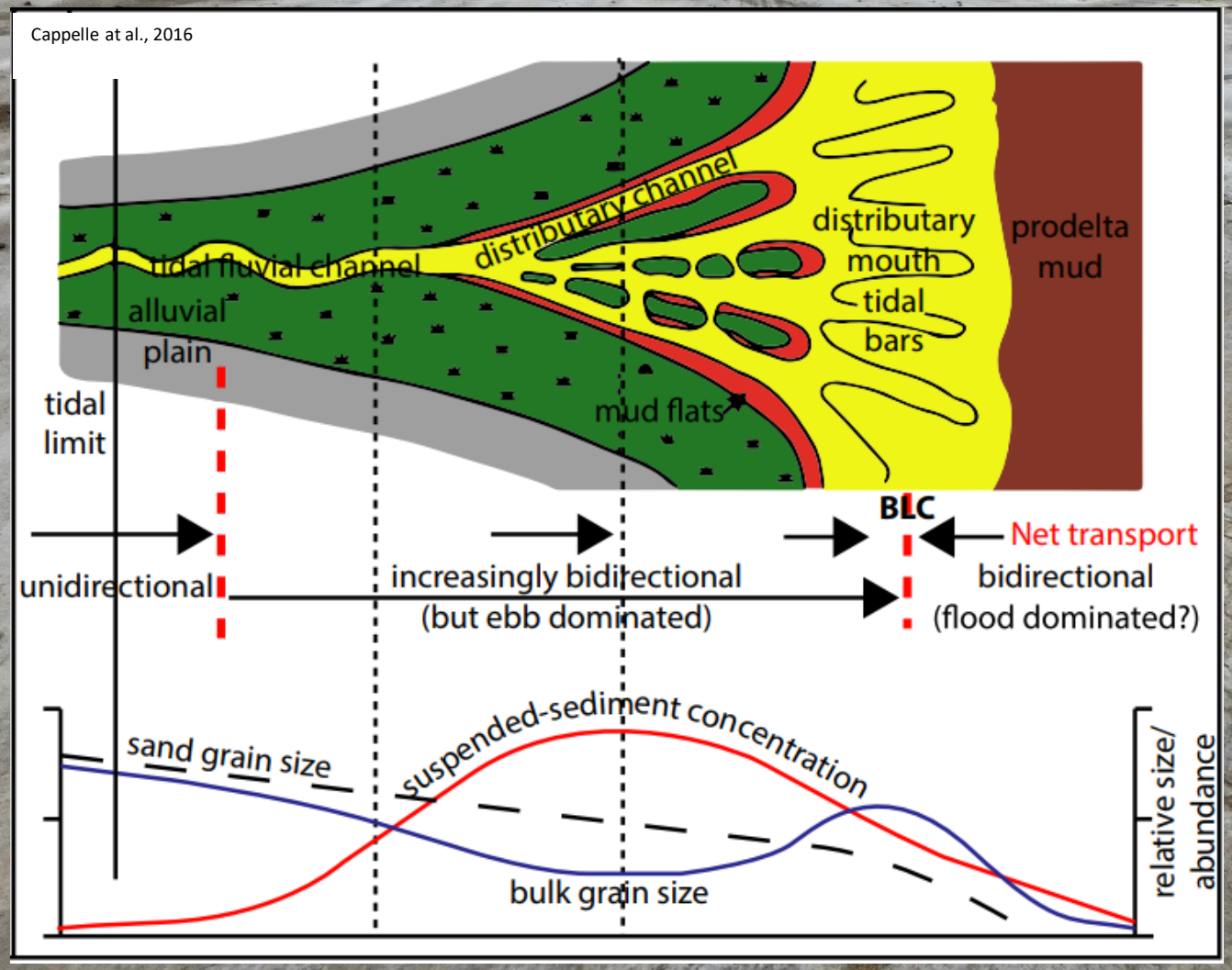
Stop 2 – Turbidity Maximum Zone, Lower Delta Plain of the abandoned lobe, 23 miles (37 km) from the sea

Semidiurnal – diurnal inequality
Flood tide = 154 cm/s
Ebb tide = 257 cm/s
Mesotidal = 2.7 m

National Geospatial Intelligence Agency, 2005

The Indus Delta

Stop 2 – Turbidity Maximum Zone, Lower Delta Plain of the abandoned lobe, 23 miles (37 km) from the sea



The Indus Delta

Lower Delta Plain of the abandoned lobe

Stop 3 – Lower Delta Plain, abandoned lobe, bank-attached bar, 17 miles (27 km) from the sea

The Indus Delta

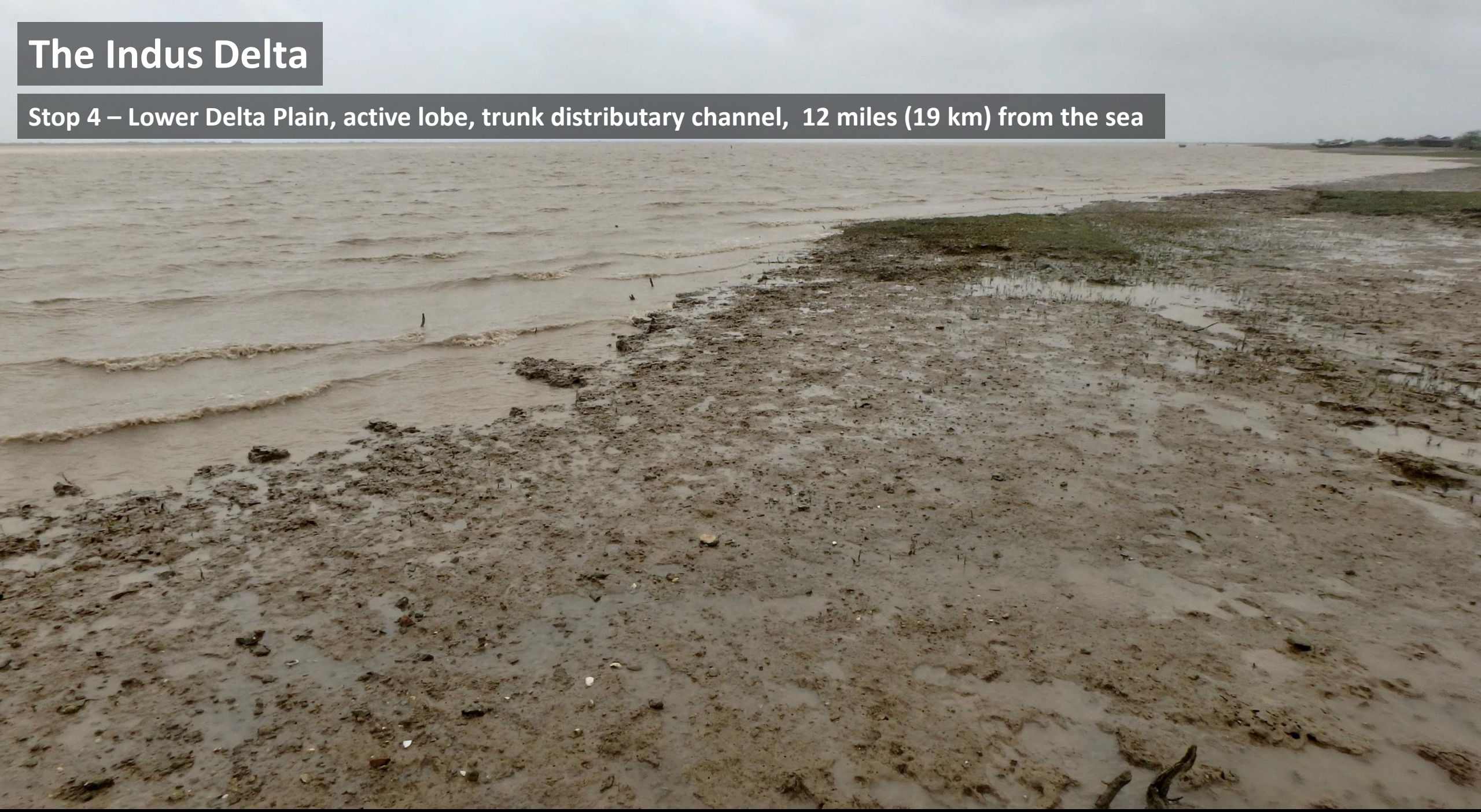
Stop 3 – Lower Delta Plain, abandoned lobe, bank-attached bar, 17 miles (27 km) from the sea

The Indus Delta

Stop 4 – Upper Delta Plain, oxbow lake, 18 miles (29 km) from sea

The Indus Delta

Stop 4 – Lower Delta Plain, active lobe, trunk distributary channel, 12 miles (19 km) from the sea



The Indus Delta

Stop 4 – Lower Delta Plain, active lobe, trunk distributary channel, 12 miles (19 km) from the sea

The Indus Delta

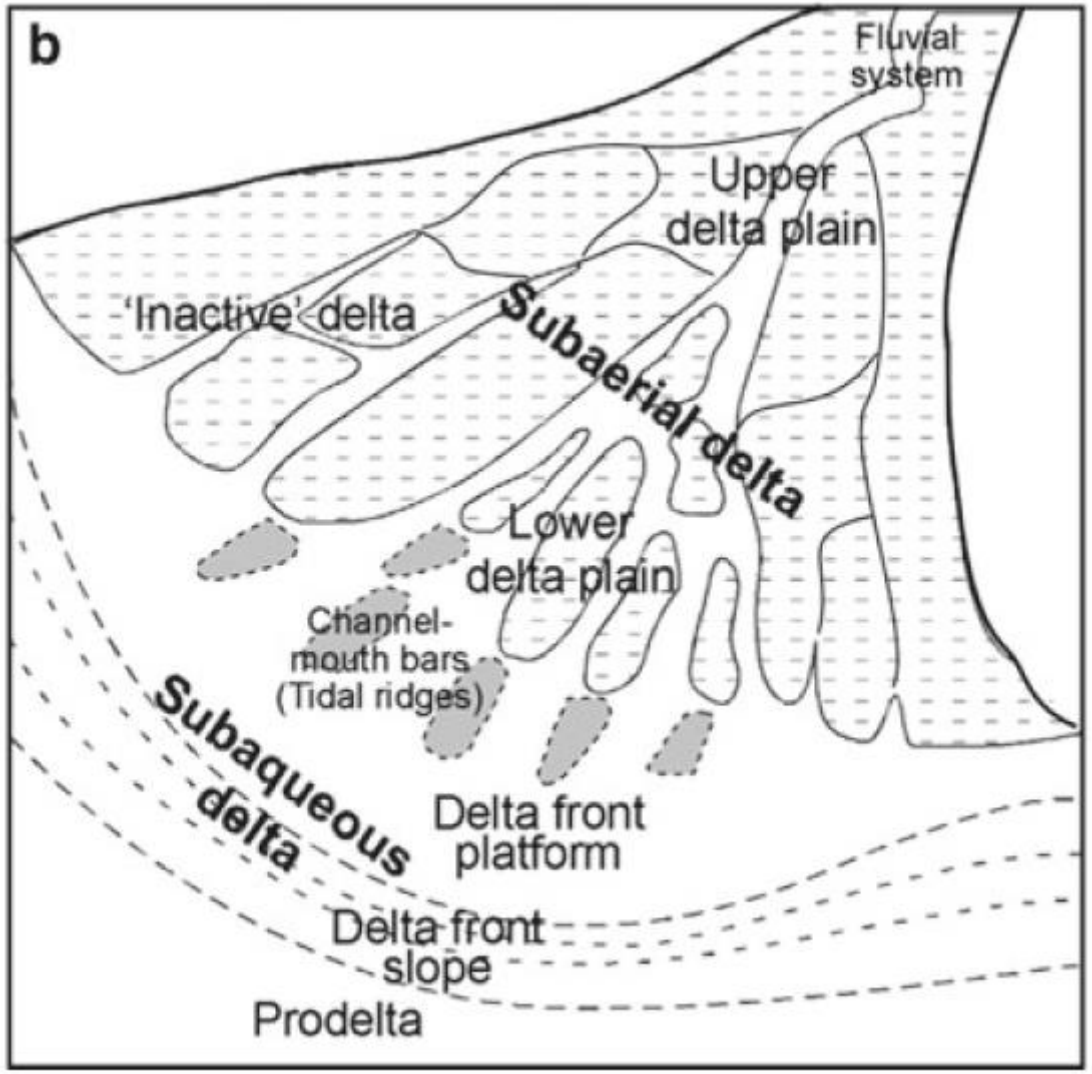
Stop 5 – Delta Front, terminal mouthbar, 0 miles (0 km) from the sea

The Indus Delta

Stop 5 – Delta Front, terminal mouthbar, 0 miles (0 km) from the sea

The Indus Delta

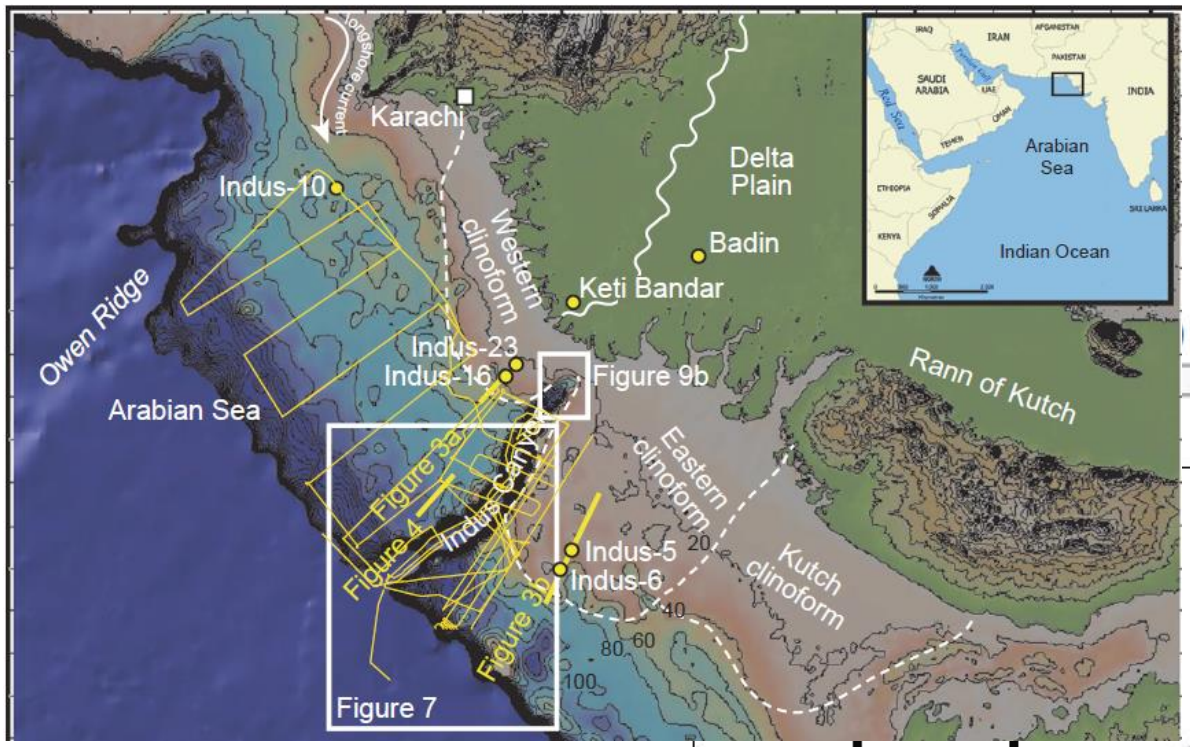
What can we learn?



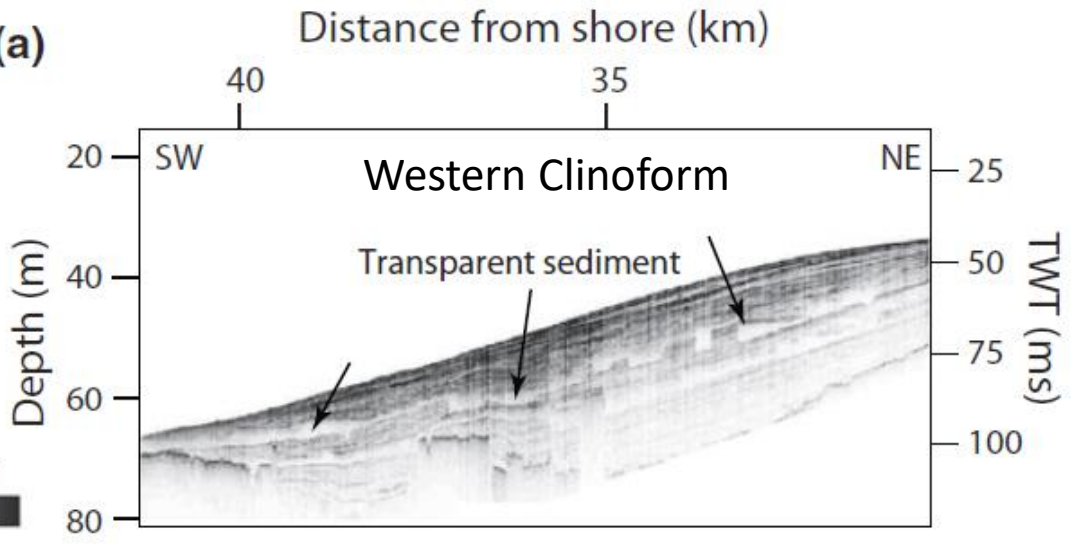
Goodbred et al., 2012

The Indus Delta

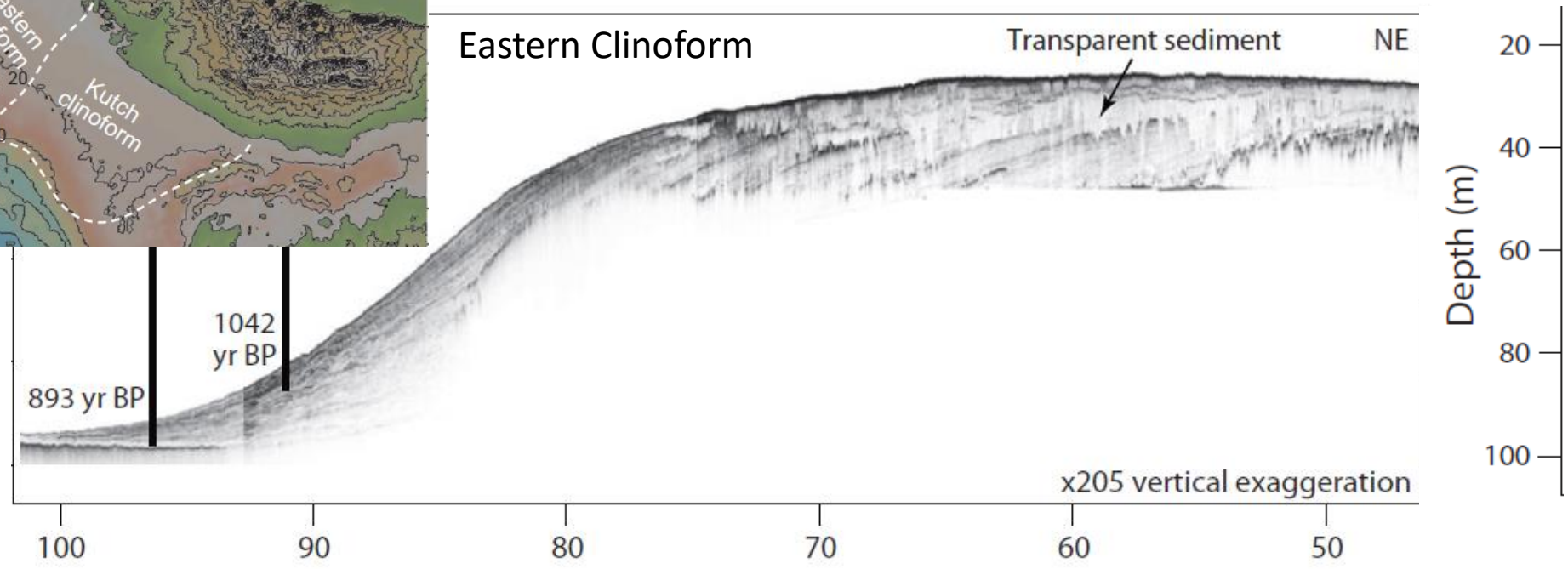
The Indus has a compound clinoform geometry



Clift et al., 2014

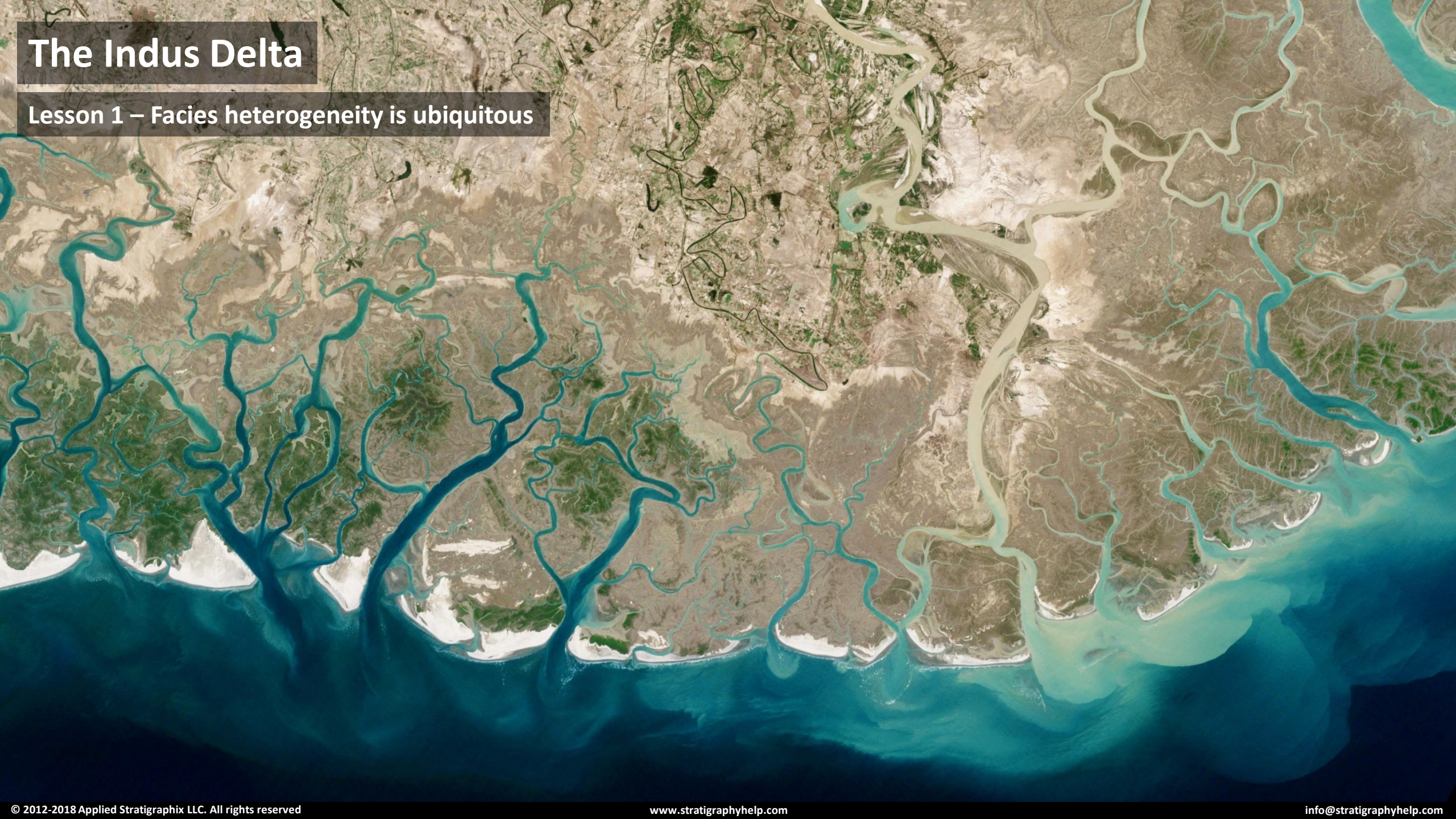


Amplitude+



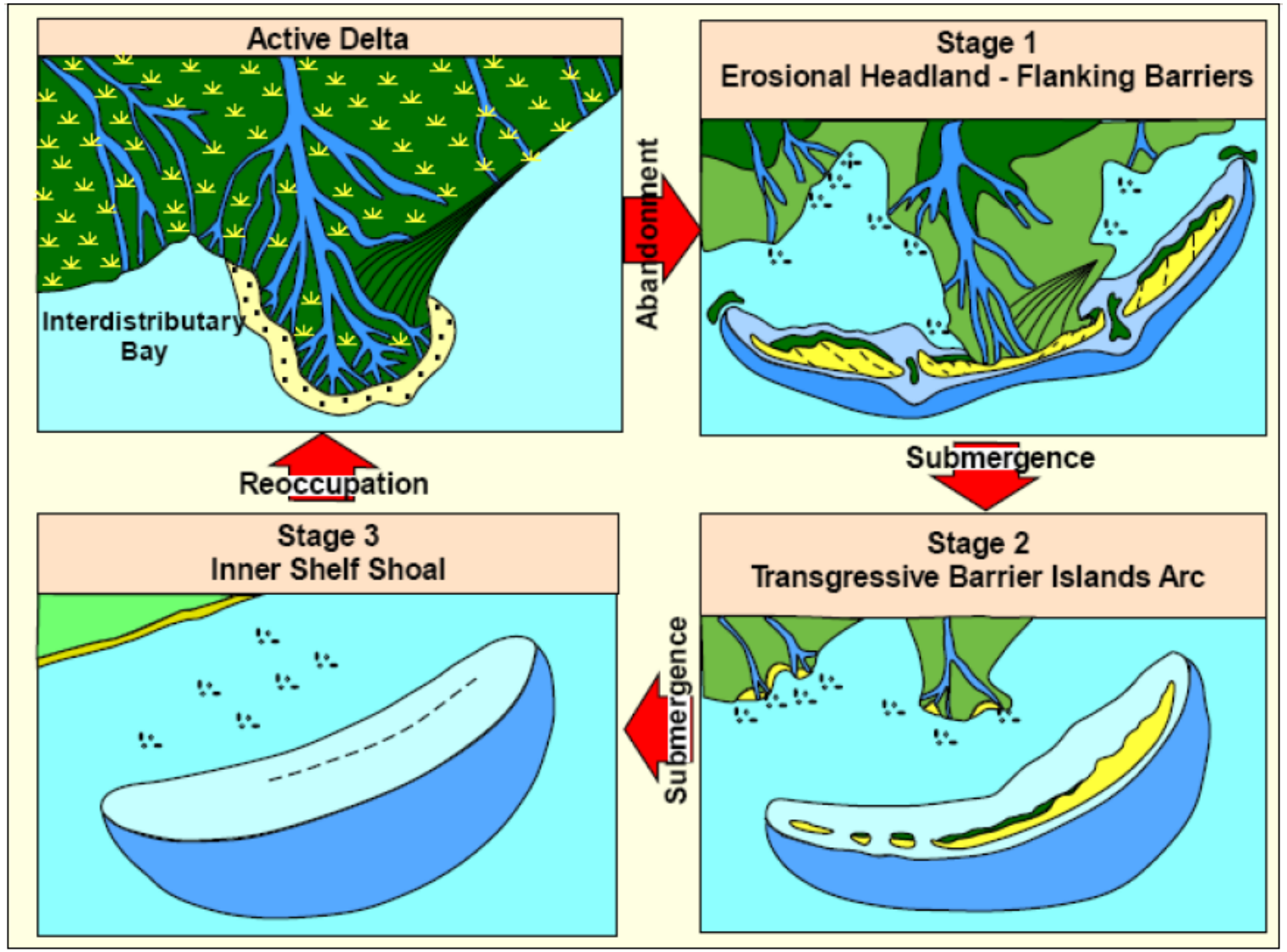
The Indus Delta

Lesson 1 – Facies heterogeneity is ubiquitous



The Indus Delta

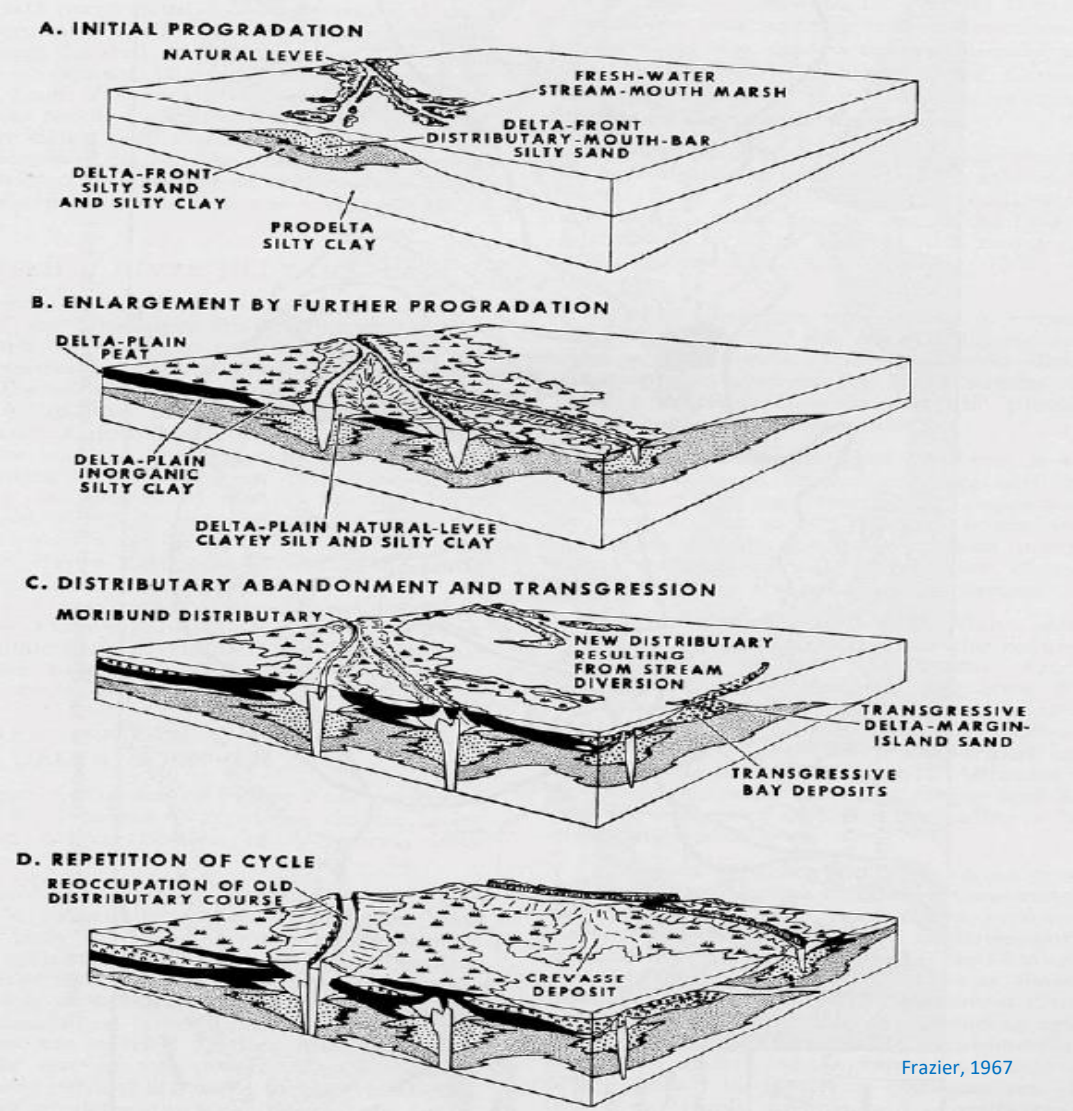
Lesson 2 – The Indus is a fantastic place to study processes on abandoned lobes



Suter, 2010

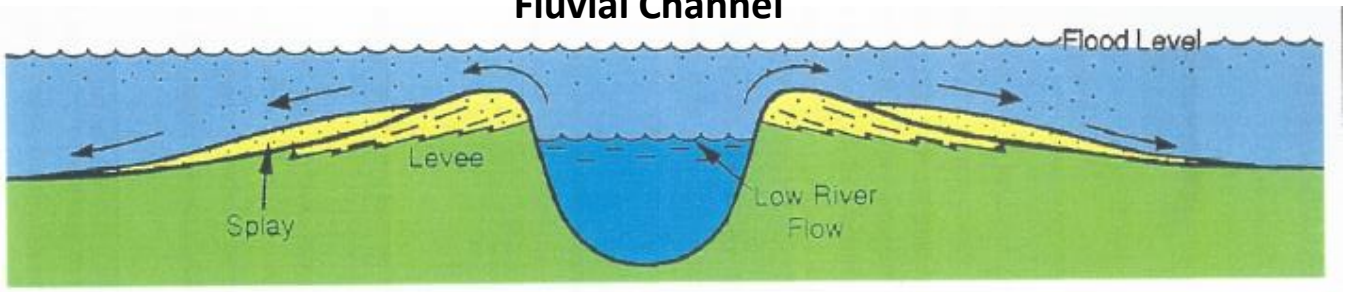
The Indus Delta

Lesson 2 – Our current models of delta abandonment are very “Mississippi-centric”



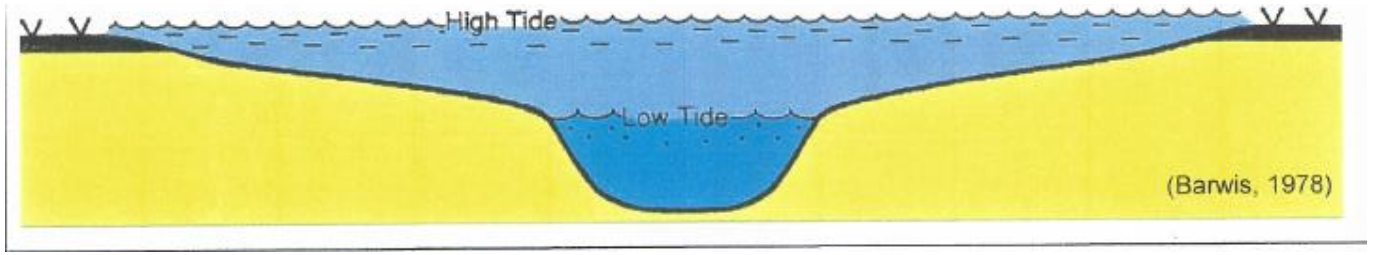
Frazier, 1967

Fluvial Channel



Flood-stage = max energy

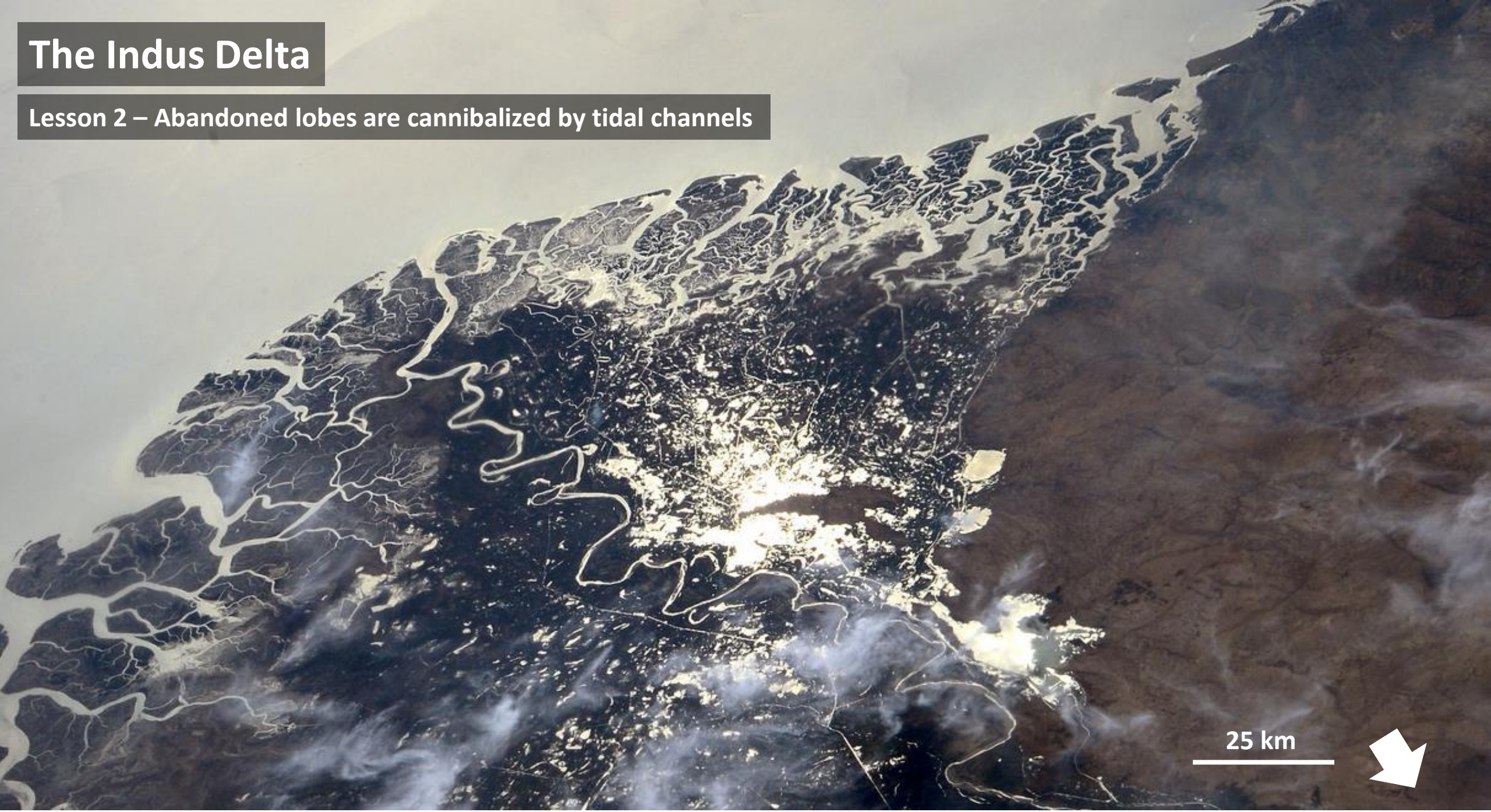
Tidal Channel



High Tide = min energy

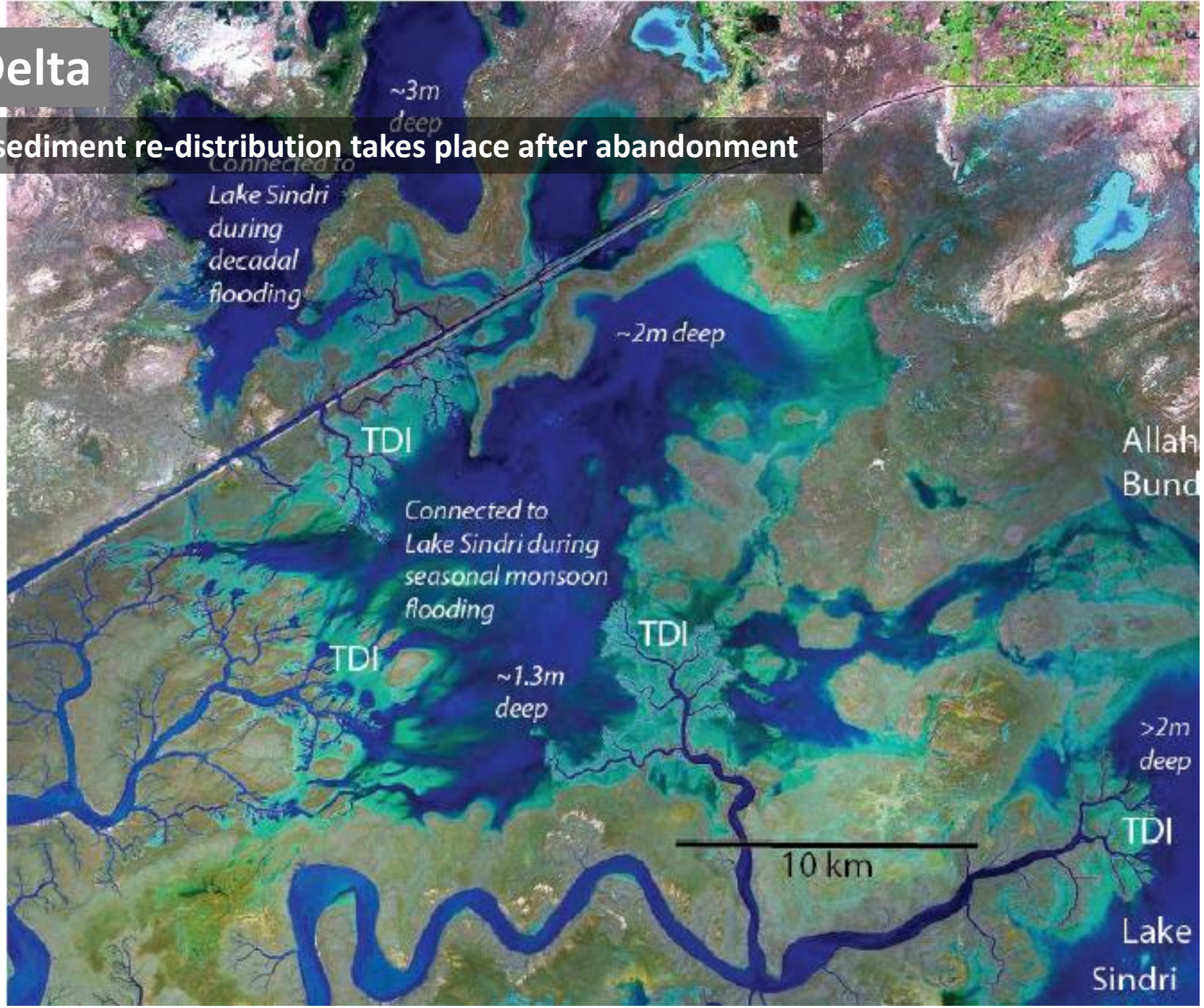
The Indus Delta

Lesson 2 – Abandoned lobes are cannibalized by tidal channels



The Indus Delta

Lesson 3 – Major sediment re-distribution takes place after abandonment



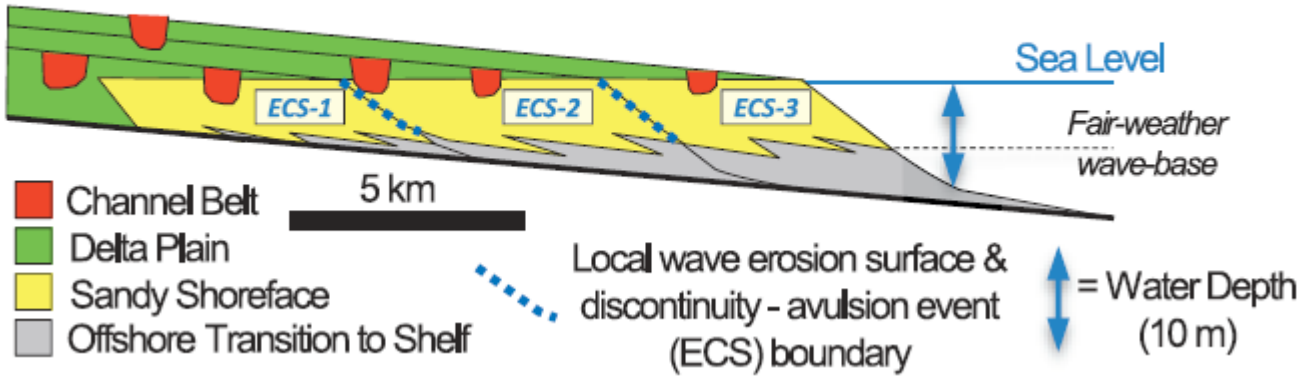
Syvitski et al., 2014

The Indus Delta

How much of that complexity is actually preserved in the rock record?

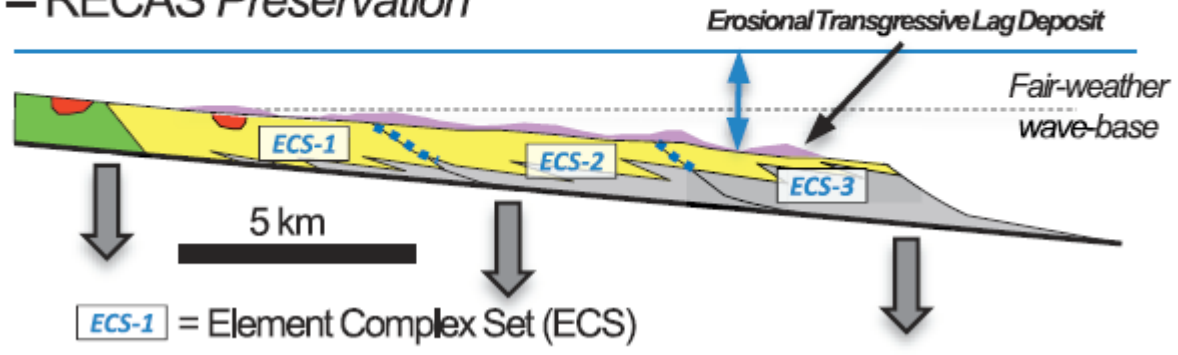
1a) Low-Accommodation Avulsion-Driven System

Flat Regressive Shoreline Trajectory (A<S) - RECAS *Progradation*



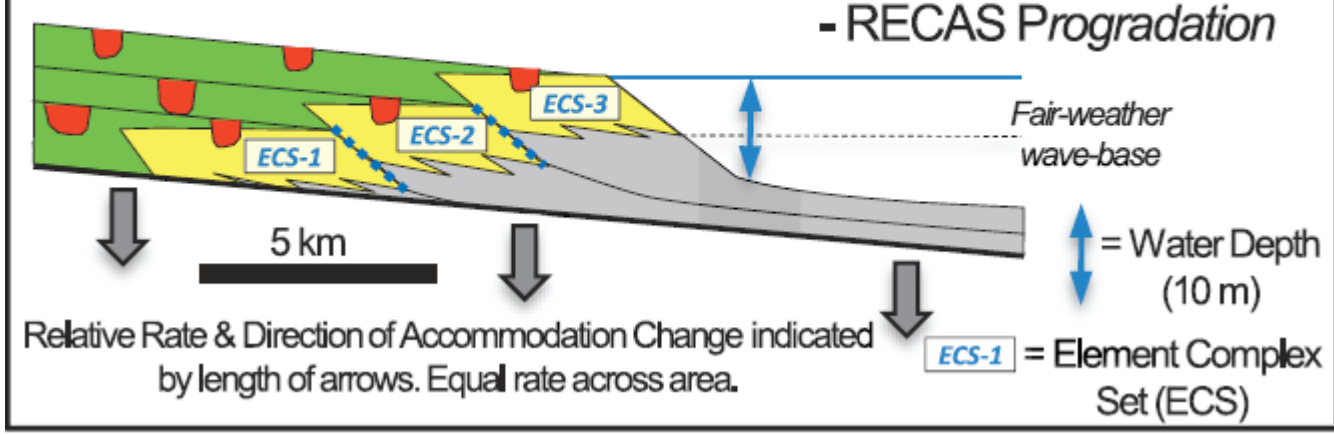
1b) Low-Accommodation Avulsion-Driven System

Ascending Transgressive, low angle Shoreline Trajectory (A>S) – RECAS *Preservation*



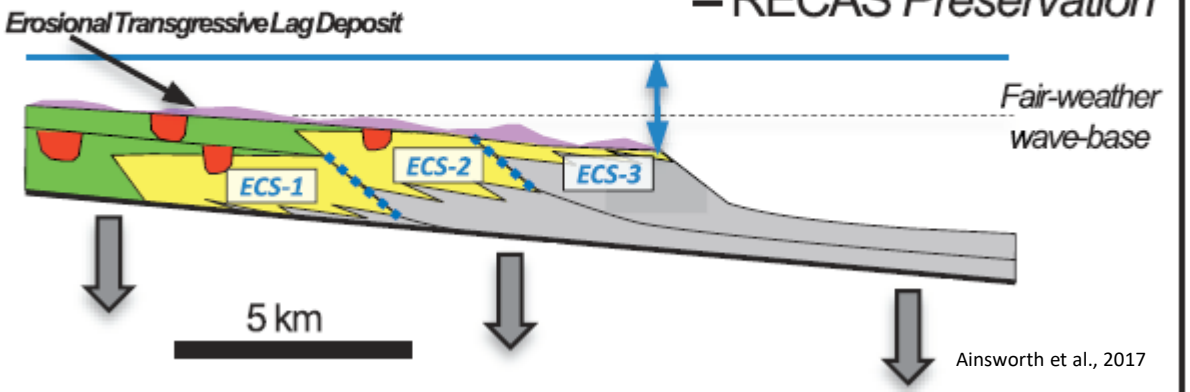
2a) High-Accommodation Avulsion-Driven System

Ascending Regressive, high angle Shoreline Trajectory (A<S) - RECAS *Progradation*



2b) High-Accommodation Avulsion-Driven System

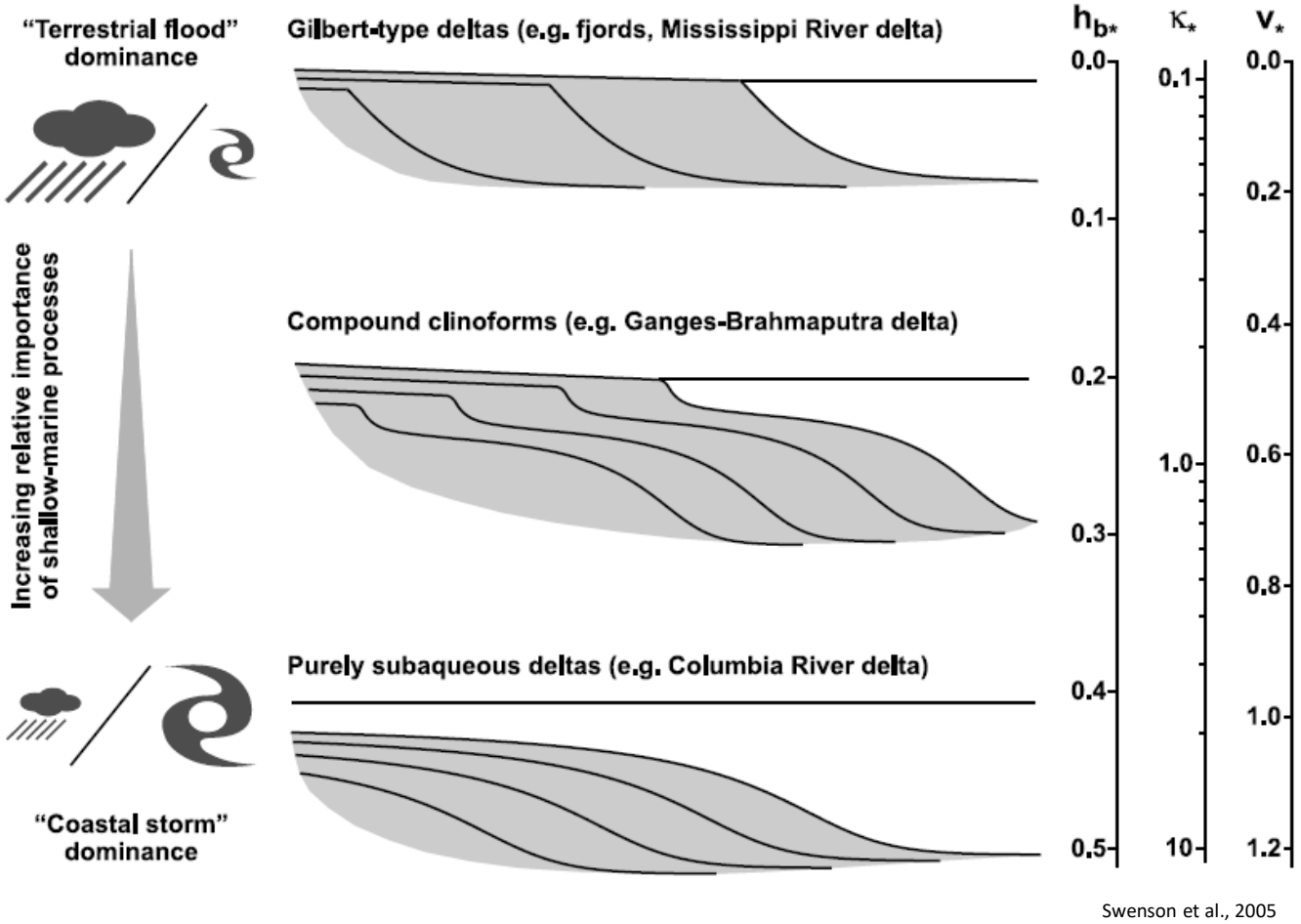
Ascending Transgressive, low angle Shoreline Trajectory (A>S) – RECAS *Preservation*



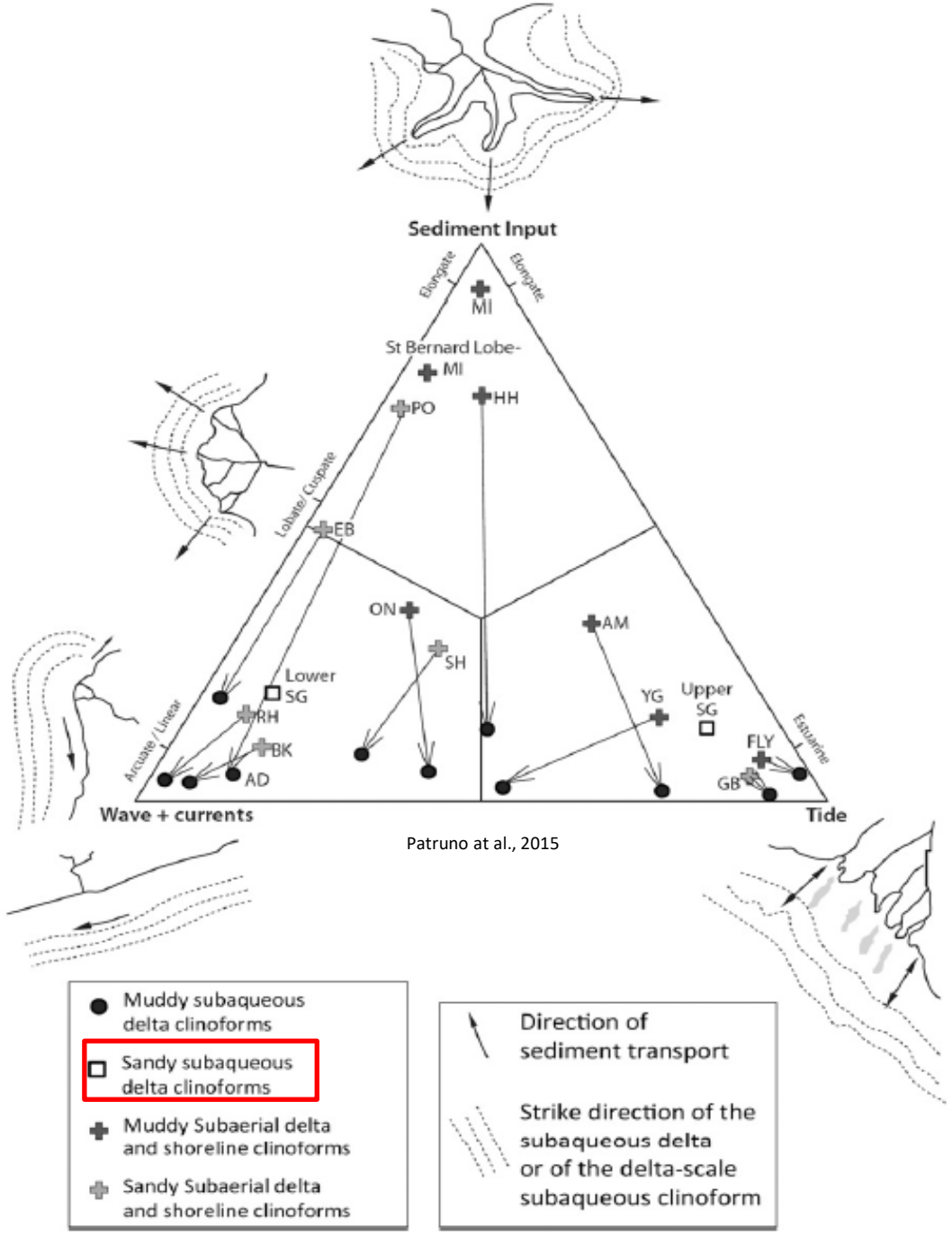
Ainsworth et al., 2017

The Indus Delta

How common are subaqueous clinoforms?



Swenson et al., 2005

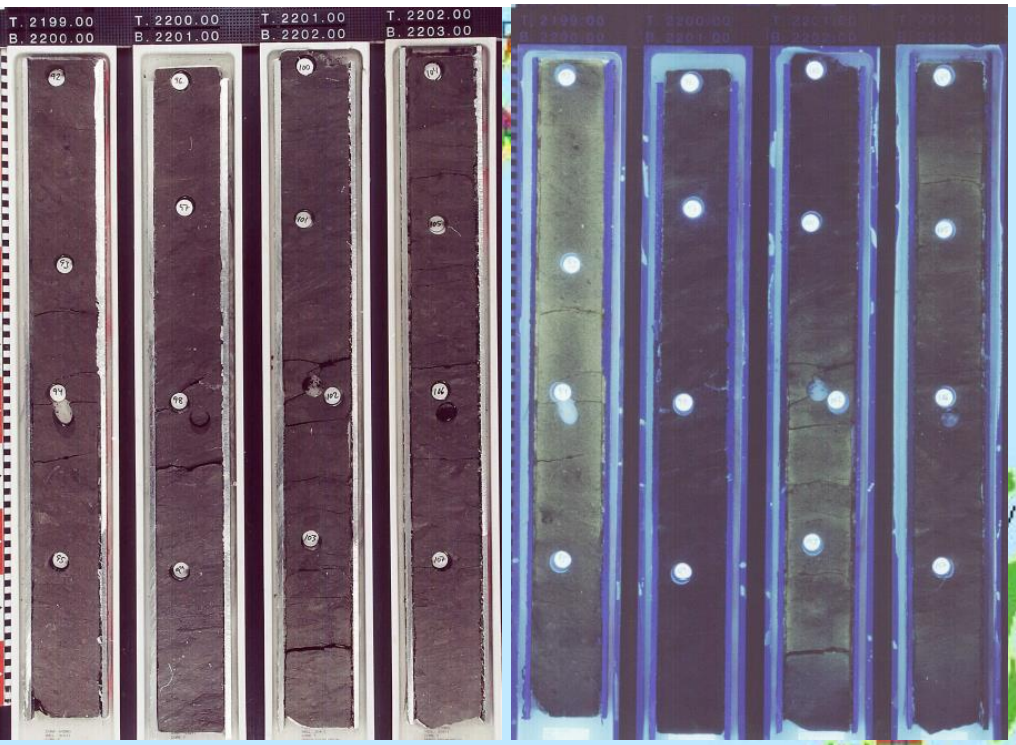


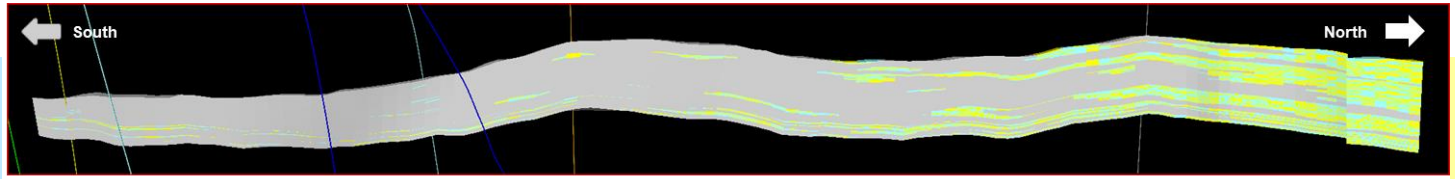
Patruno at al., 2015

Amazon, Ganges-Brahmaputra, Yangtze, Yellow River and many more

The Indus Delta

Subaqueous clinoforms are important!



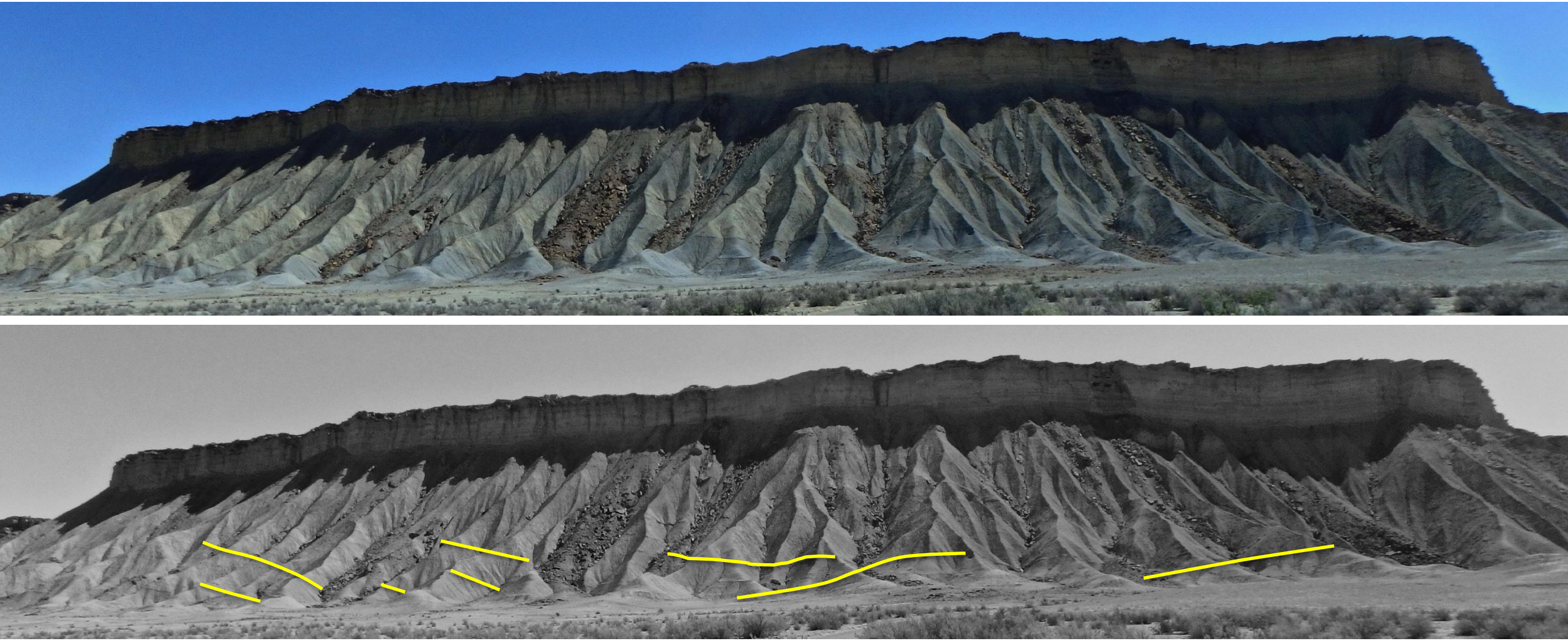


Lithofacies Sandstone Siltstone Calcite cementation

Model length is 15 km
Max thickness is 118 meters

The Indus Delta

Documented examples of Cretaceous subaqueous clinoforms from Rocky Mountain Basins

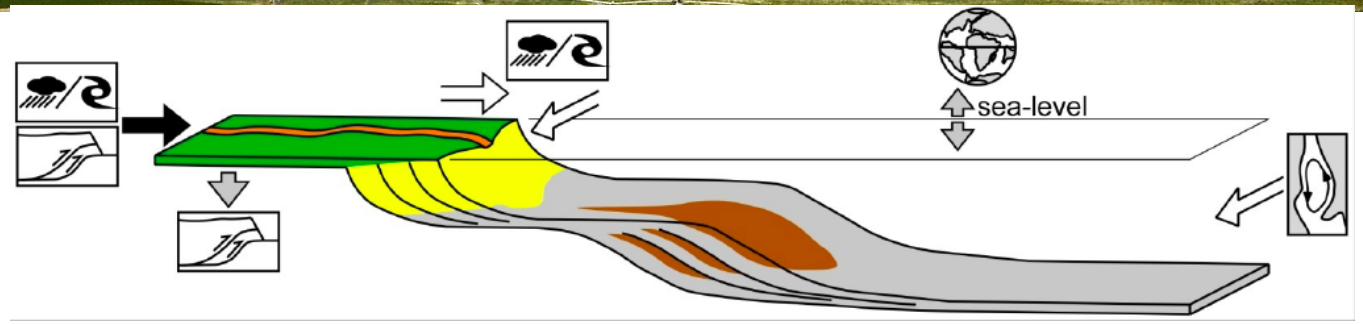


Mud-rich subaqueous clinoforms from the Turonian Ferron Sandstone in Utah

The Indus Delta

Documented examples of Cretaceous subaqueous clinoforms from Rocky Mountain Basins

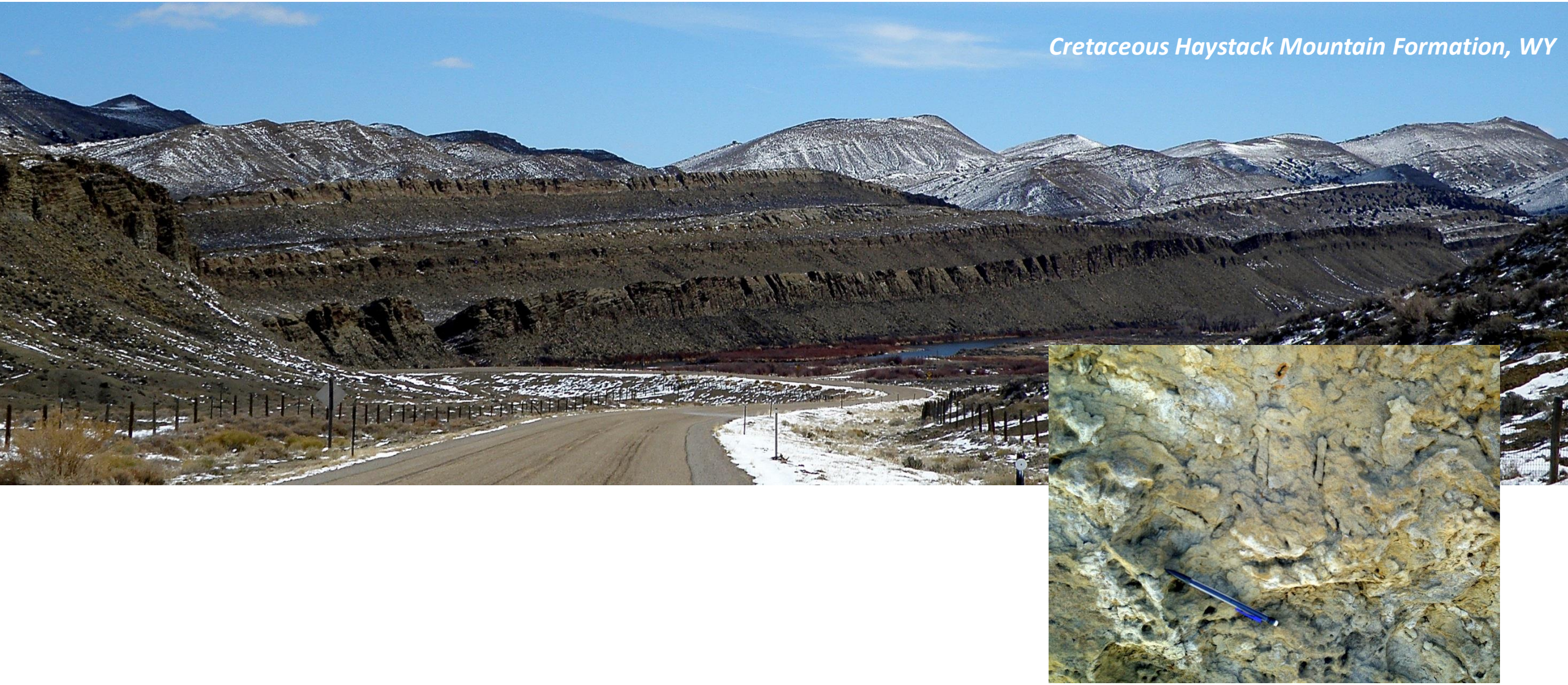
Cretaceous Blackhawk Formation, Book Cliffs, UT



Hampson, 2010

The Indus Delta

Documented examples of Cretaceous subaqueous clinoforms from Rocky Mountain Basins



Cretaceous Haystack Mountain Formation, WY

The Indus Delta

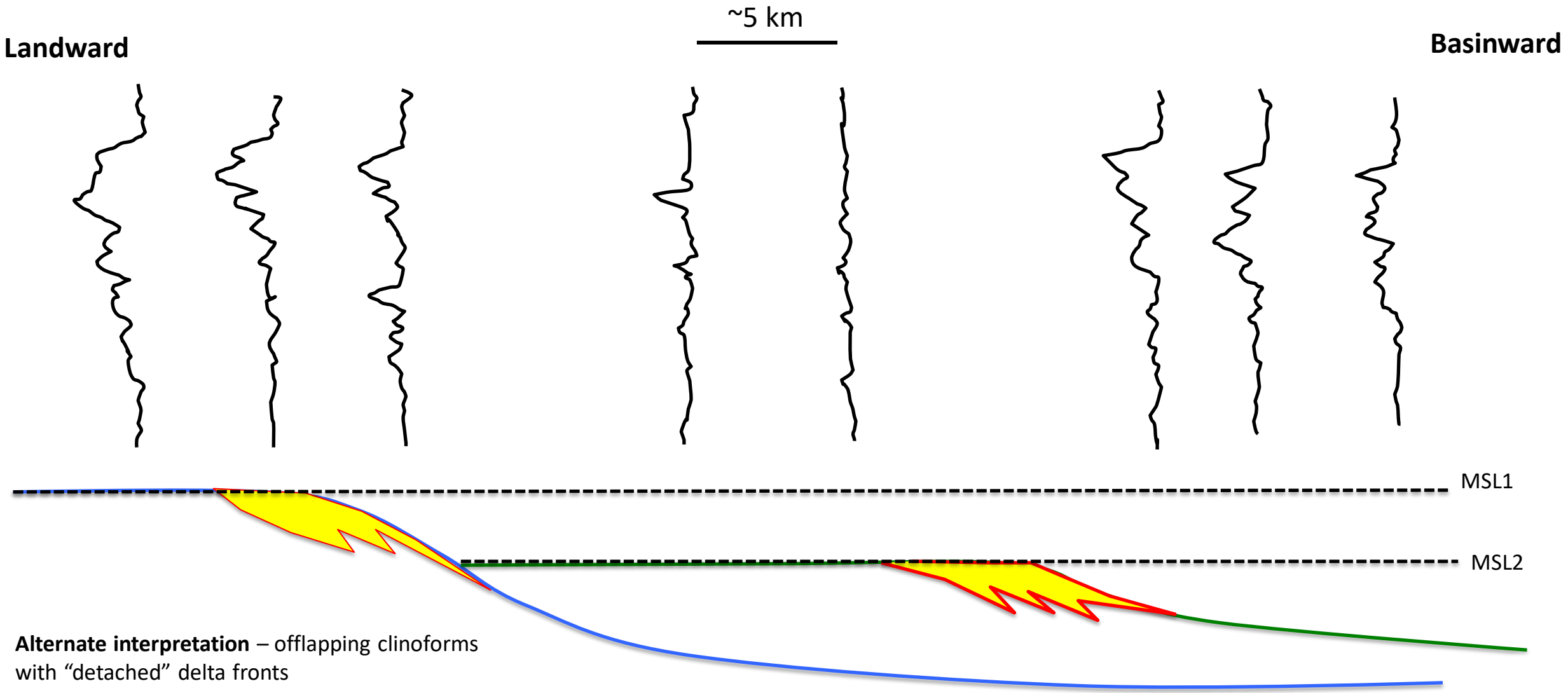
Can we look for subaqueous clinoforms closer to home?

Tide-influenced Frewens Allomember of the Frontier Formation, Powder River Basin. Photo has been vertically exaggerated to accentuate clinoform geometries.

Where is the subaqueous set associated with these subaerial clinoforms?

The Indus Delta

How would this impact log correlation

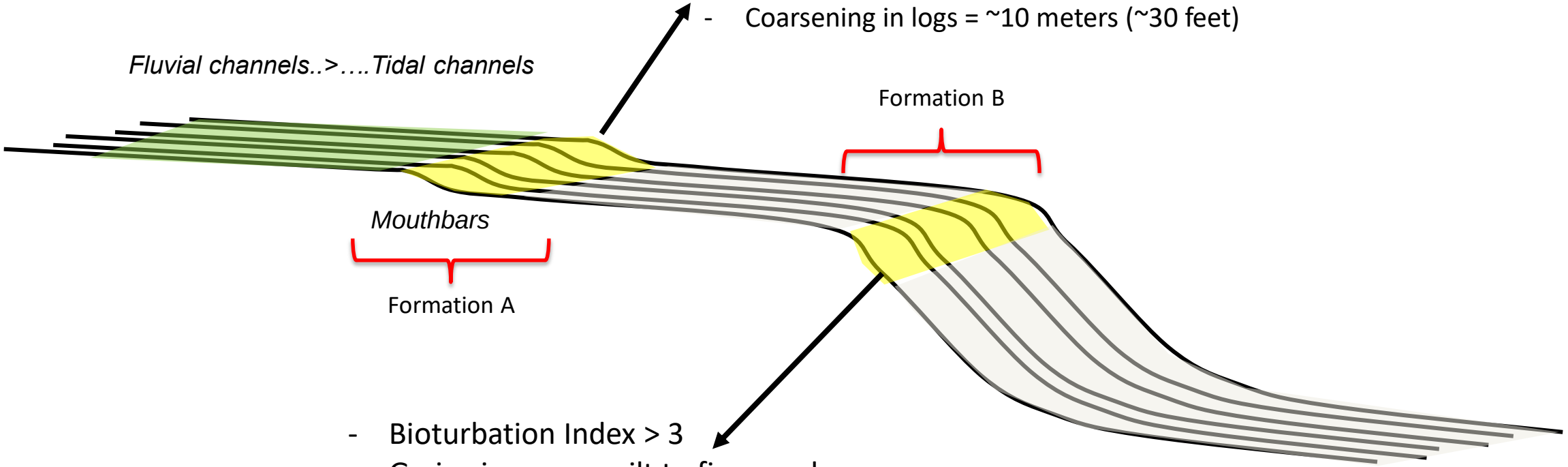


Alternate interpretation – offlapping clinoforms with "detached" delta fronts

The Indus Delta

How would you know if you drilled a sand-rich subaqueous clinoform?

- Bioturbation Index < 2
- Grain size range: coarse to fine sand
- Stressed *Skolithos* ichnofacies
- Coarsening in logs = ~10 meters (~30 feet)



- Bioturbation Index > 3
- Grain size range: silt to fine sand
- Archetypal *Cruziana* ichnofacies
- Coarsening in logs > 20 meters (~60 feet)

The Indus Delta

Key Lessons from the Indus

1. Mixed-process deltas are best classified at the lobe-level, this allows better predictability for reservoirs
2. Lobe abandonment is very complex and can involve tidal channel cannibalization and sediment redistribution
3. The Indus has well developed compound clinoforms – like the majority of large modern rivers today
4. Compound clinoforms can have sand-rich roll-overs in which case they can be potential reservoirs

Cretaceous Mancos Shale – San Juan Basin, NM