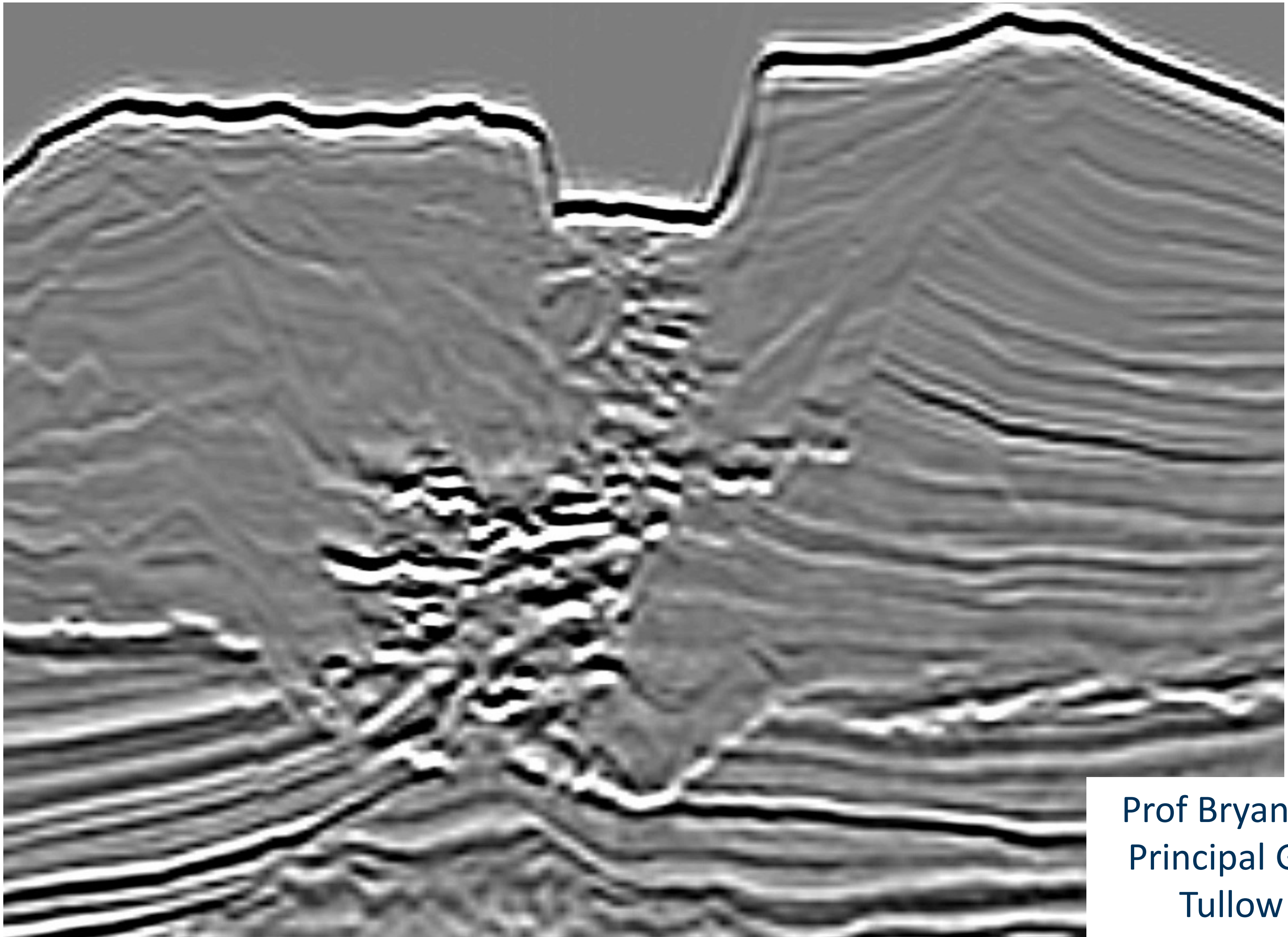
Entrenched slope channel complex systems:

Reservoir opportunities through understanding architectural element distribution and application to West Africa E&P



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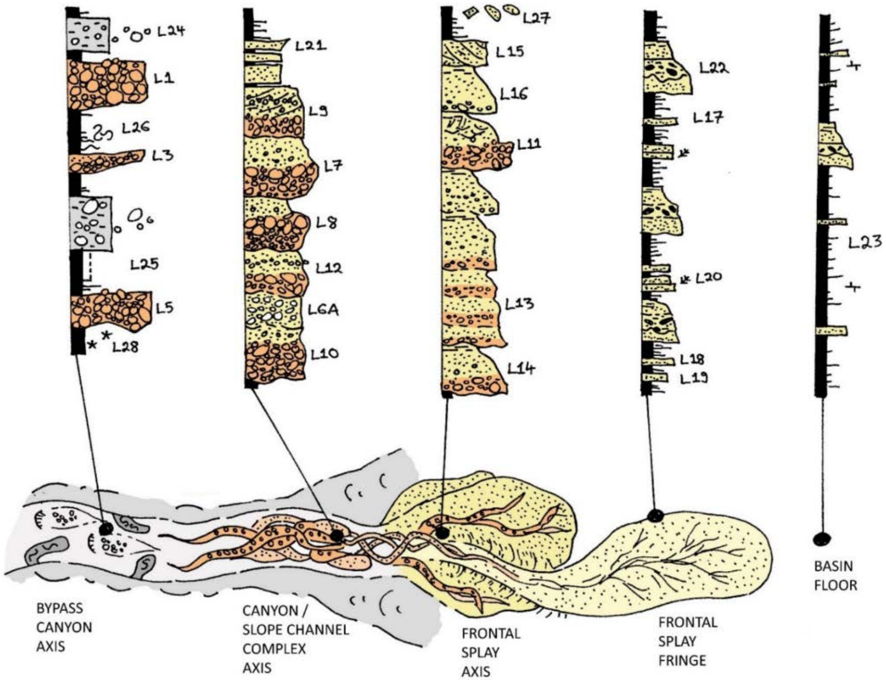
Some data from the TEN Fields are presented, along with conceptual figures by the author, with permission from Tullow Ghana Ltd, and its partners in the TEN Fields: Anadarko Petroleum Corporation, Kosmos Energy Ltd, Ghana National Petroleum Corporation (GNPC) and PetroSA

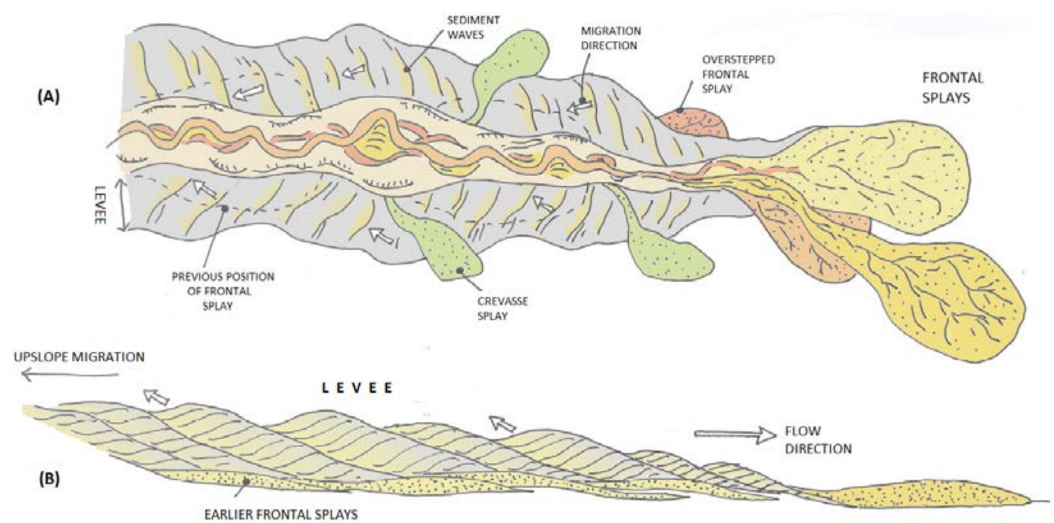
Talk Structure and Objectives

1. Review of confined slope channel complexes
2. Morphology: lateral gravitational foundering plus (*not versus*) inside levees
3. Morphology: Channel stacking – signatures and connectivity
4. Morphology: Late stage meandering skinny channels
5. Morphology: Levee complexes, outbuild and prograde
6. Existing and Unified Models
7. Recommendations for modeling

Where do confined slope channel complexes sit?…

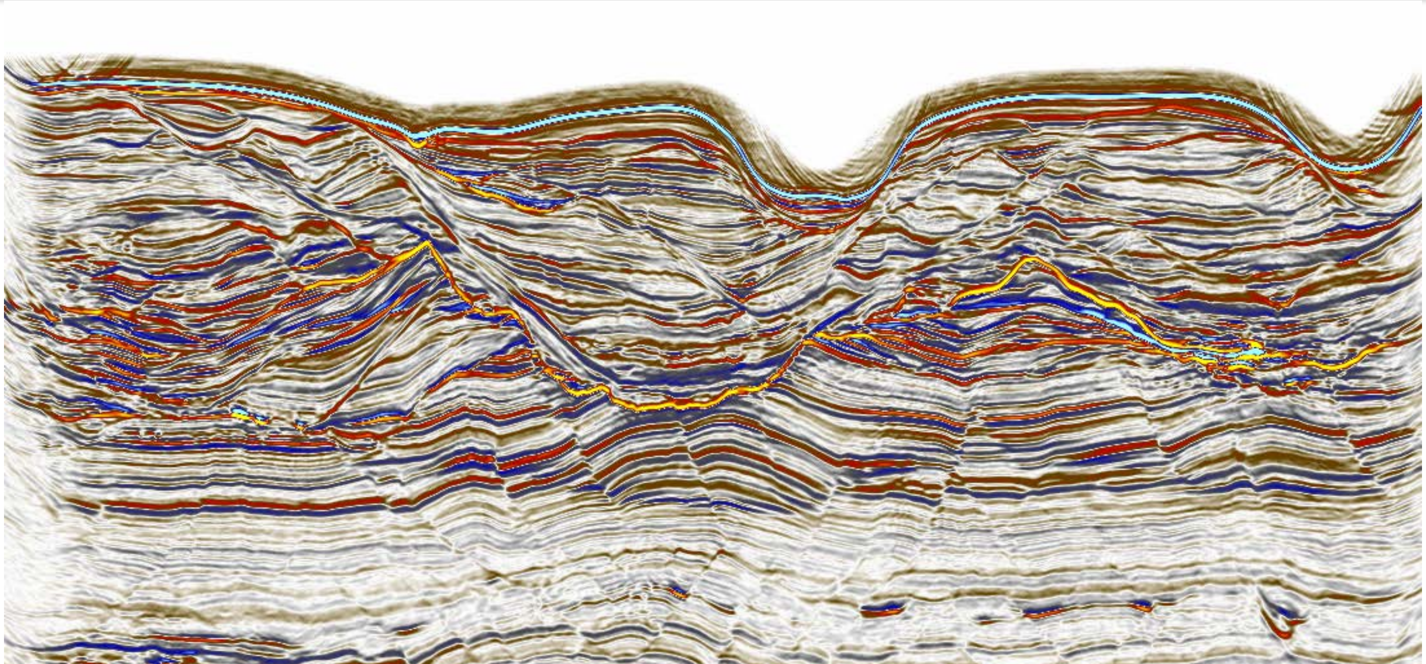
General Facies and FA Distribution in Slope Systems

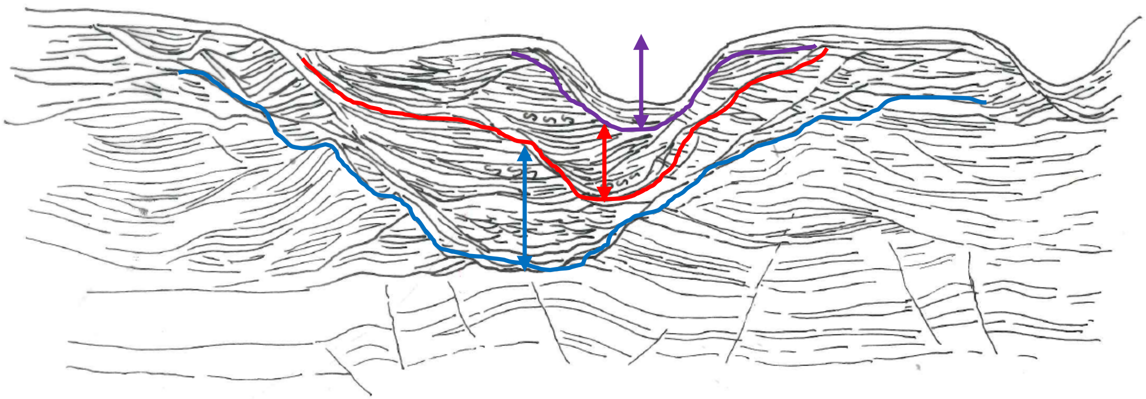




Cronin, AAPG Brae Play Memoir 115 (in press 2018)

What do confined slope channel complexes look like?



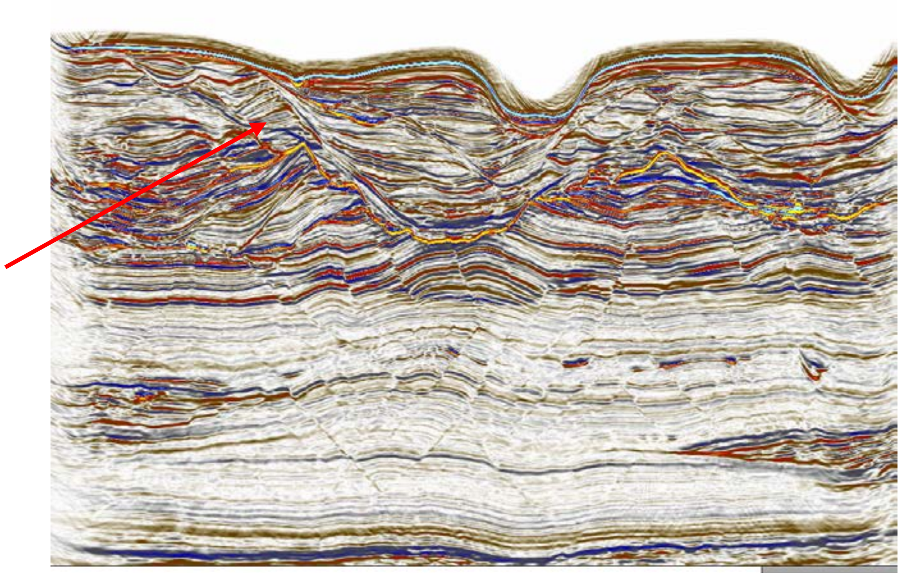


This was never a single channel or valley, it is a composite channel complex (i.e. no 'master' erosional surface);
Channels erode, stack and embed into each other;
Levees stack and aggrade on top of each other

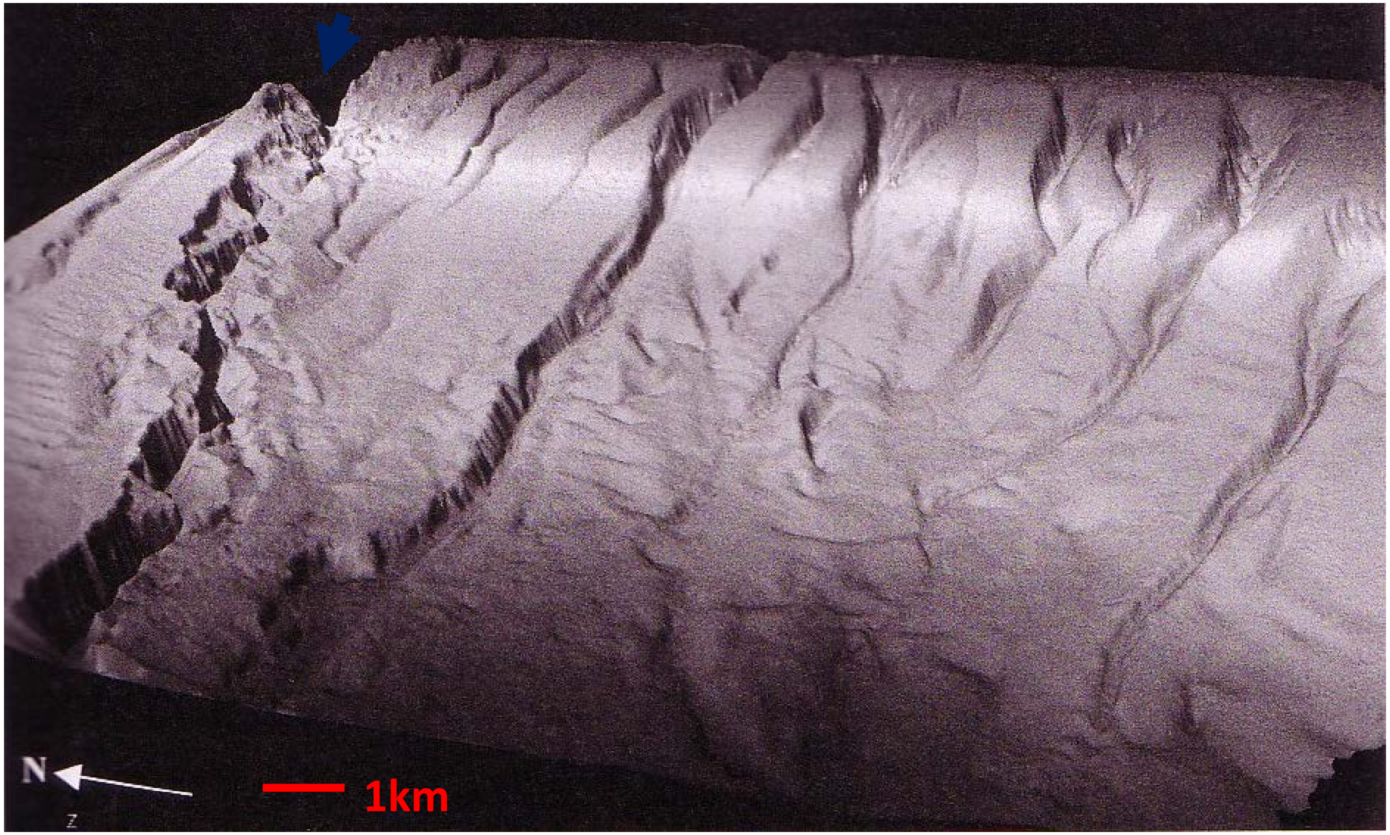
Gross Slope Channel Complex Morphology

1. Steer head Cross-sectional Profile

- Lateral Rotational failure/ foundering
- Deeper structural control



Multi-phase occupancy complexes have distinct geometries…



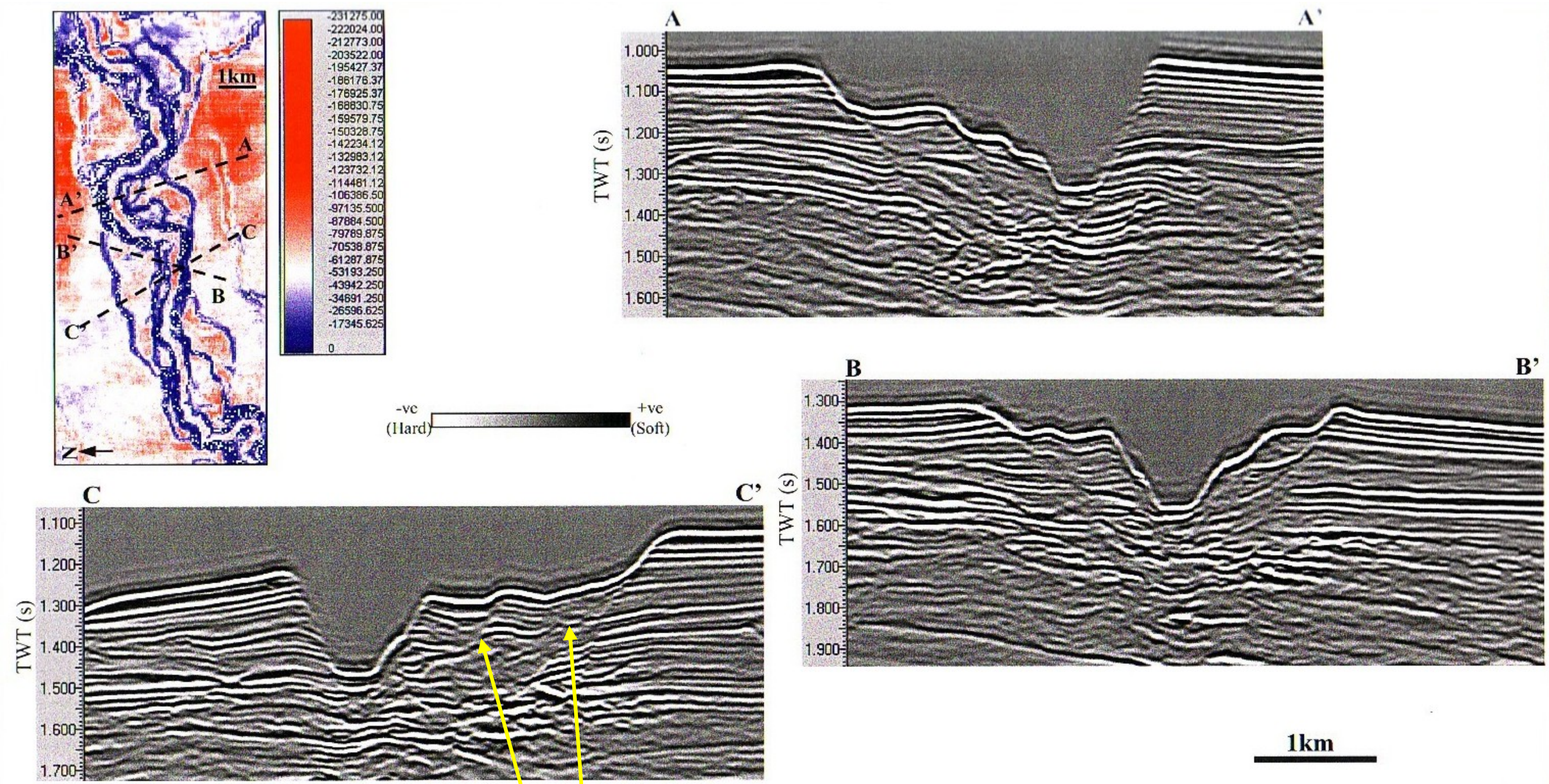
Entrenched deep-water slope channel complex: offshore southern Mauritania (roots in the Oligocene)

- Entrenchment of thalweg channels only seen in slope channel complexes with deeper structural control?
- Sediment waves seen on most levee shoulders
- Terraces formed by entrenchment and modified by later rotational failure

Gravitational foundering / Rotational slumping in entrenched slope channel complexes…

…with smaller scale inside levee development

Distinguishing rotational failure from inside levees…..

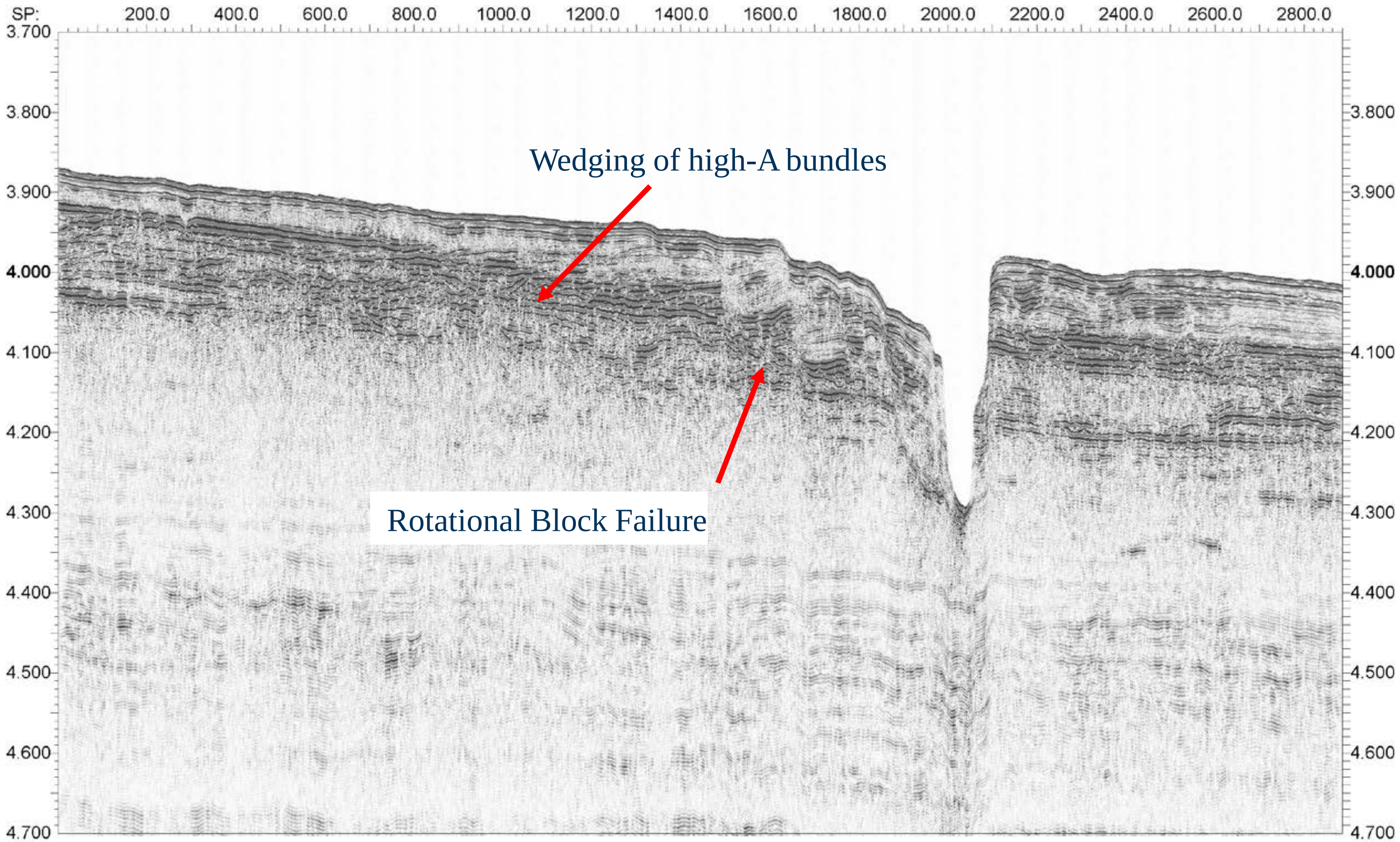


How easy is it to distinguish rotational failure from inside levee onlap?

Note: all seismic sections looking down-channel

Cap Timiris Channel Complex, offshore Mauritania

Rotational failure is often more clear in some places…



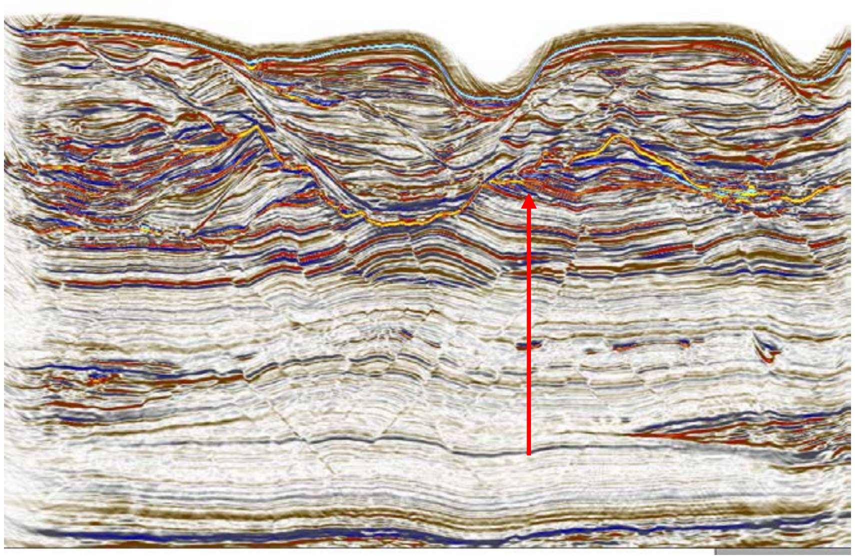
(seismic data courtesy of the University of Bremen)

… and is then subsequently draped

Gross Slope Channel Complex Morphology

2. Precursive Sand Sheets

- Earlier frontal or crevasse splays



Precursive sand sheets interpreted as frontal splays… could also be crevasse splays

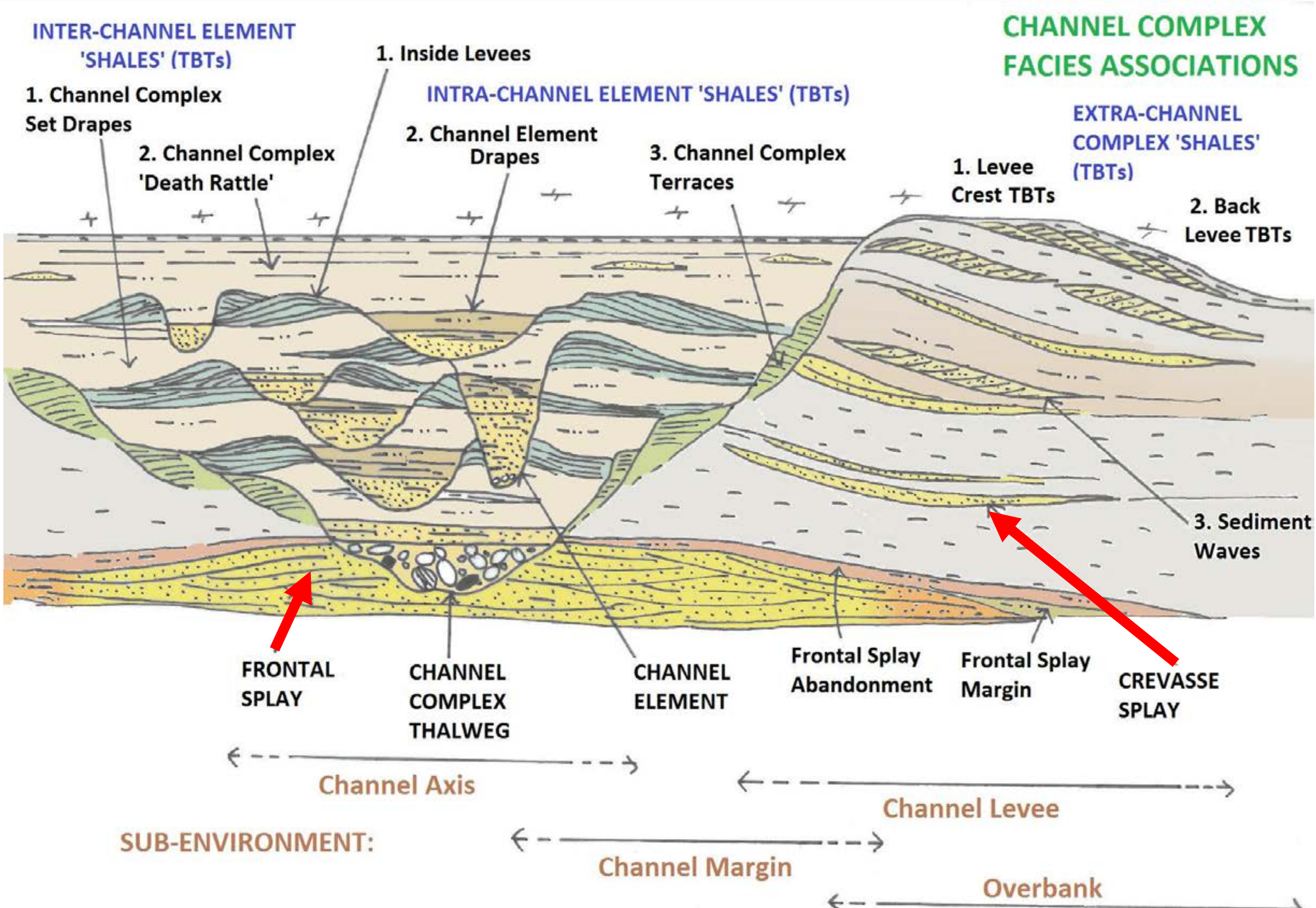
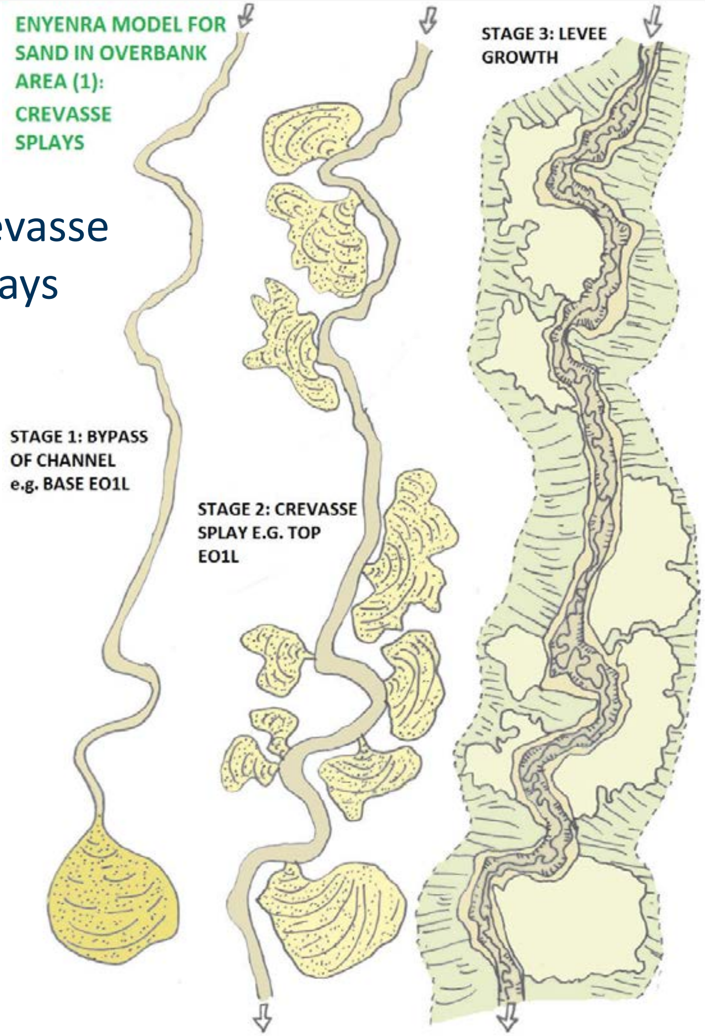


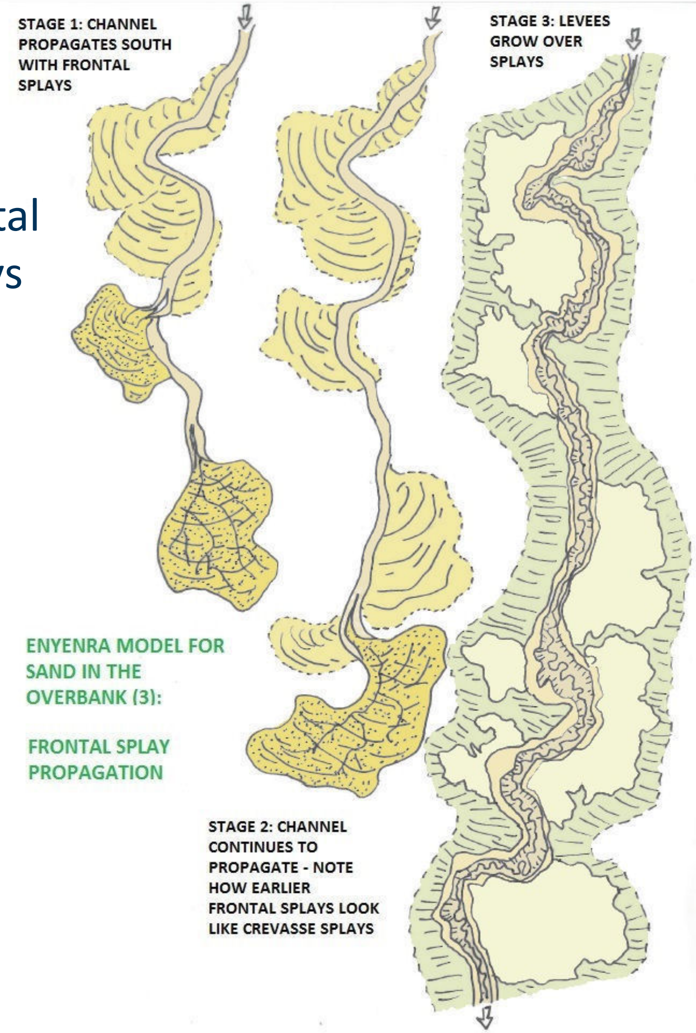
Figure showing thin-bedded turbidite distribution in channel complexes

Alternative models for precursive sand sheets…

Crevasse Splays



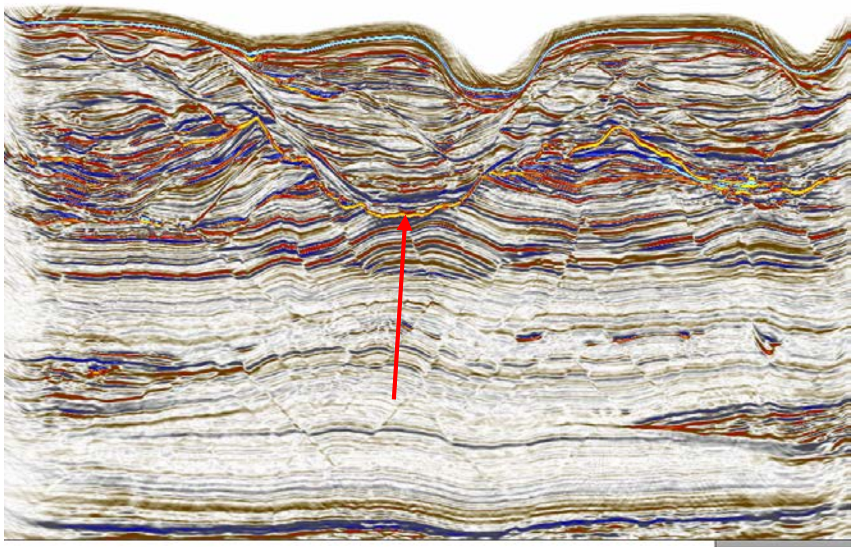
Frontal Splays



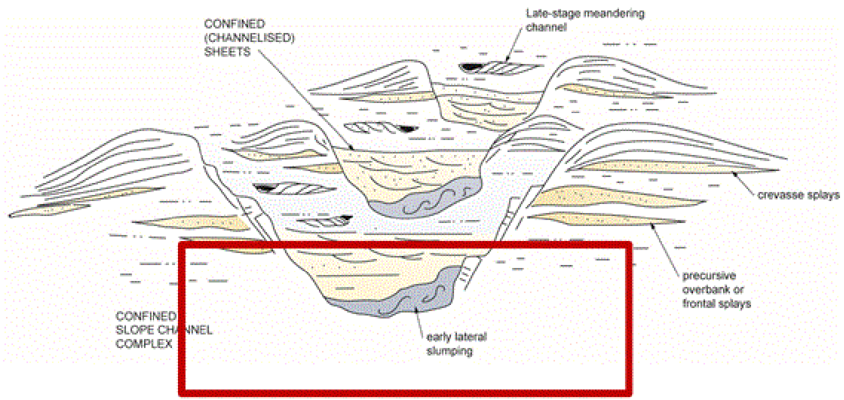
…Impacting on connectivity: <u>crevasse splays</u> are usually disconnected from the channel axis, <u>frontal splays</u> may even connect across the channel

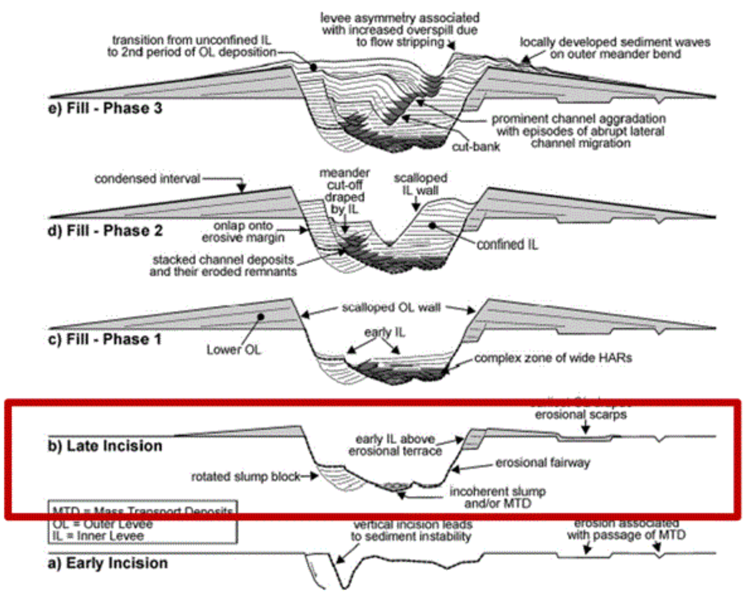
Gross Slope Channel Complex Morphology

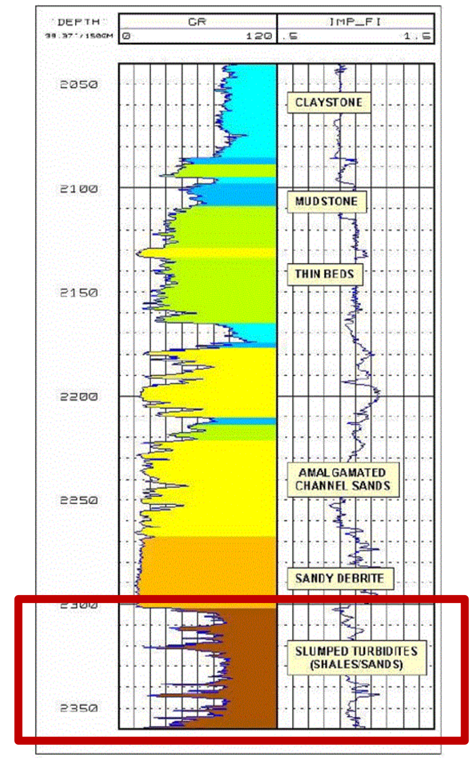
3. Basal MTDs

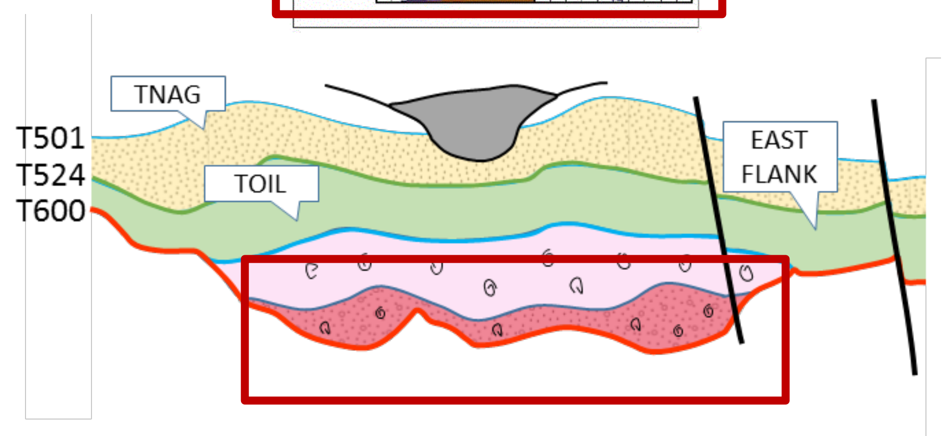


Basal MTDs: in all slope channel complexes







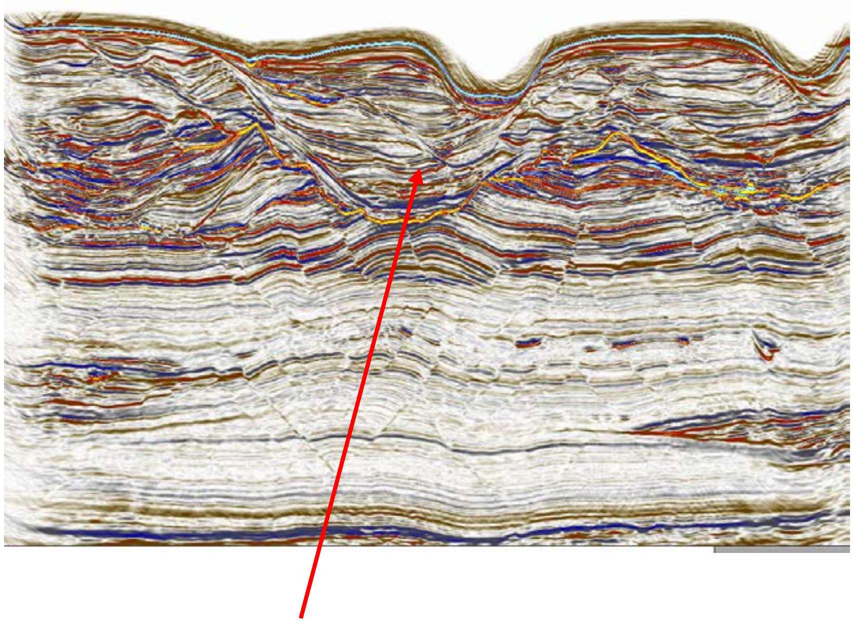


What commonalities do we see.....

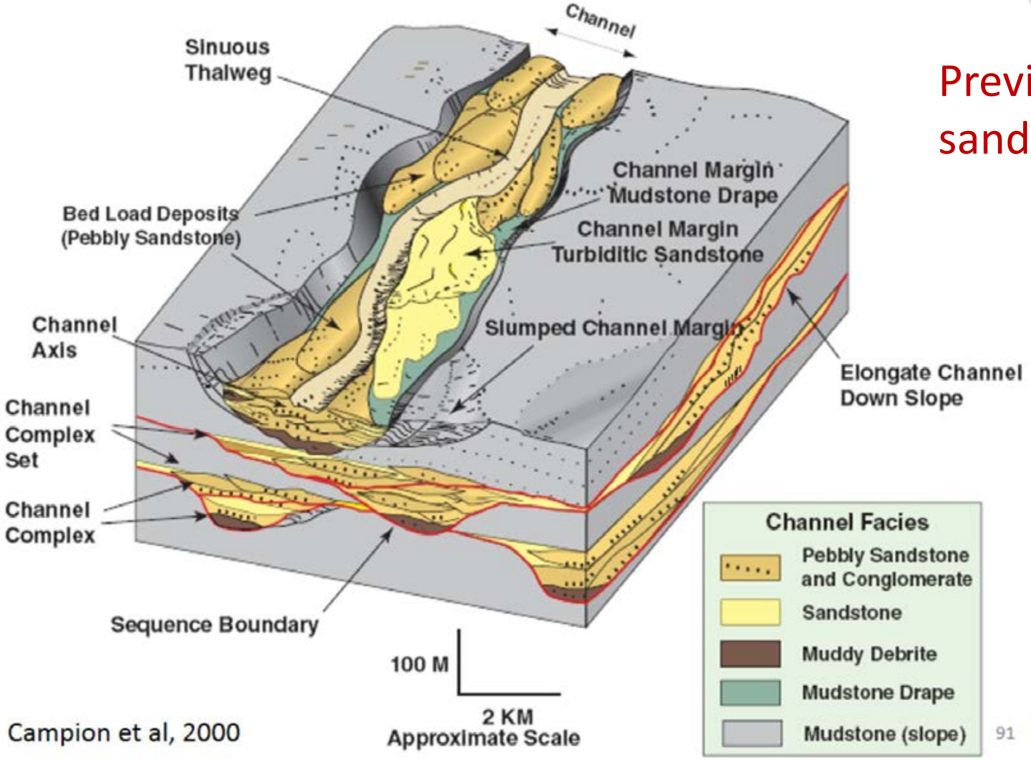
Gross Slope Channel Complex Morphology

4. Lower Channel Complex channels/ confined sheets

- MTDs, then
- Lateral offset stack, amalgamated channels

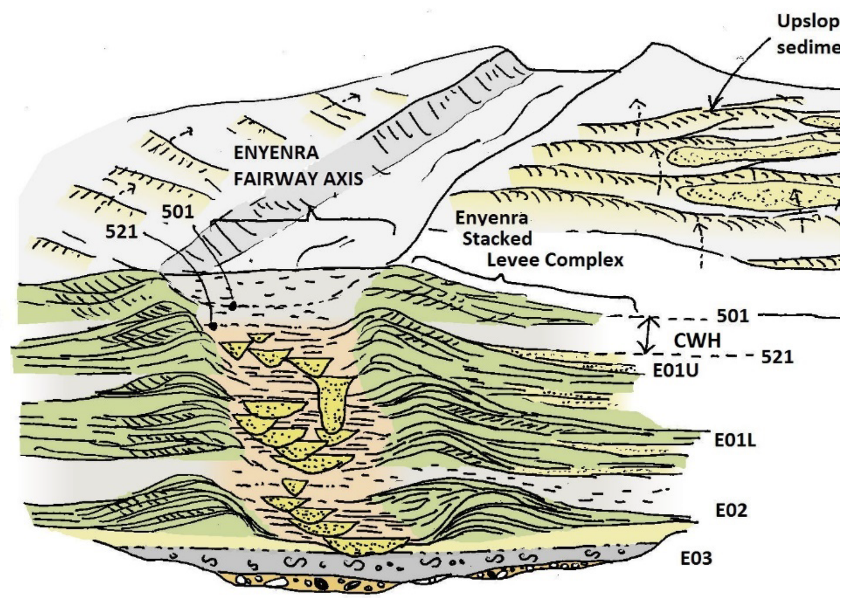


Confined Slope Channel Complex models



Campion et al, 2000

Previous models often show sand-prone axial fairways…

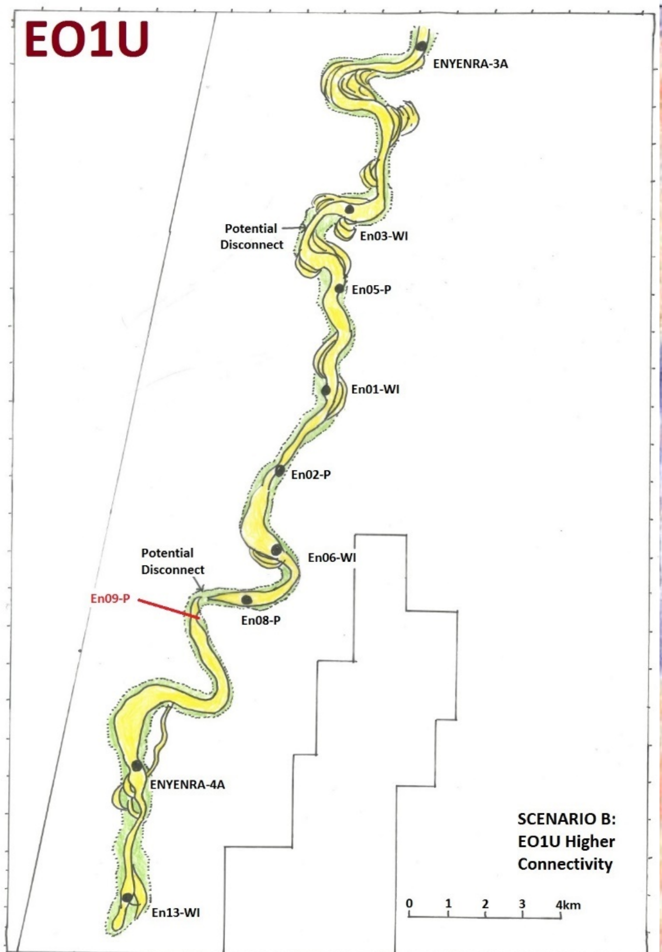


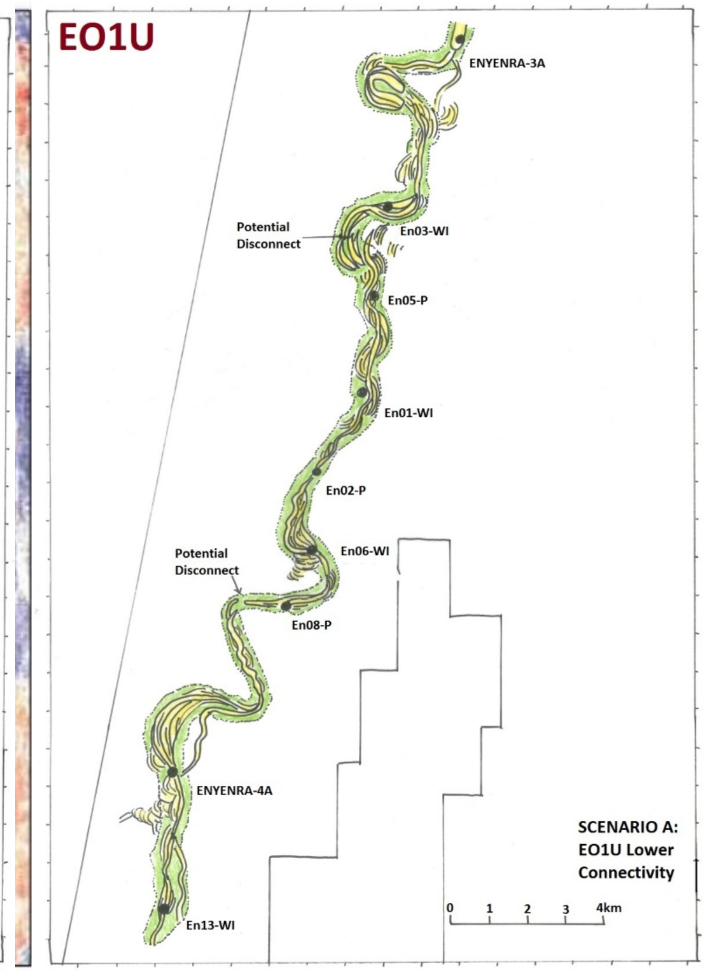
CWH:
Channel Wane Heterolithics
(fining-upwards termination of
the Enyenra Slope Channel Complex)

But this doesn't capture the architecture of fields like Enyenra…

Lower parts of Slope Channel Complexes generally sandier, later stages generally confined meander belts

... that are then followed by skinny meandering channels ...





(a) Sandy Debris flow (amalgamated sheets) in lower part of an Oligocene complex and (b) thinner bedded section with meander forms in the upper part of the channel complex (Sikkema and Wojcik, 2000)

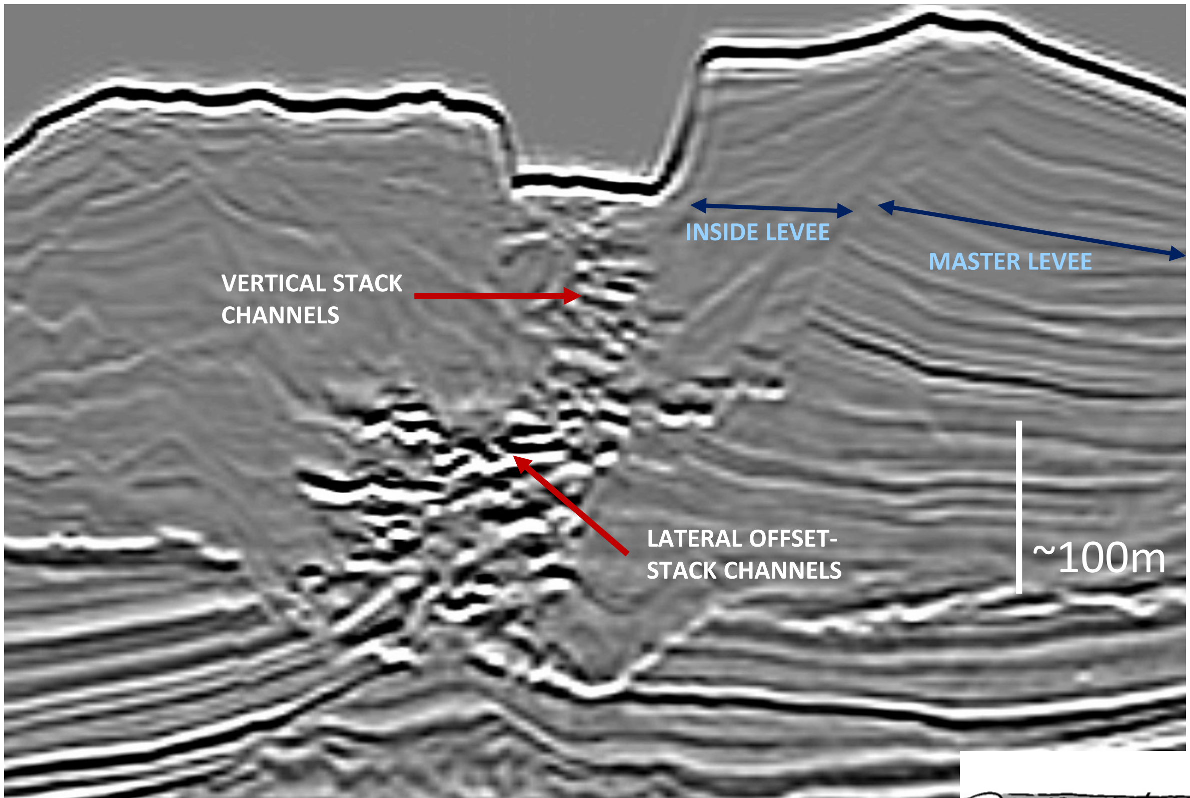
Gross Slope Channel Complex Morphology

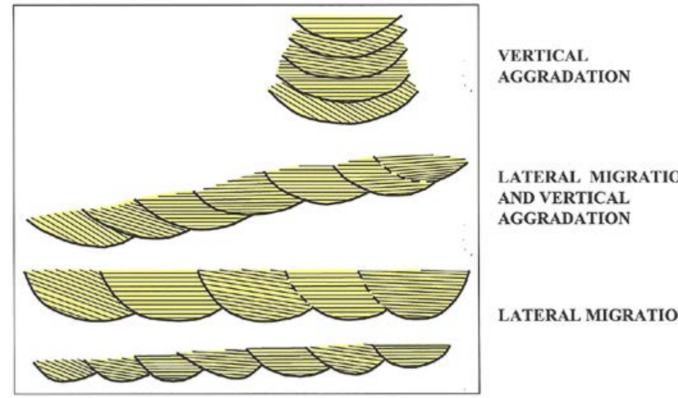
5. Stacking patterns in channel elements

- Lateral stacking versus high angle offset-stack and vertical stacking
- Inside/ internal levees

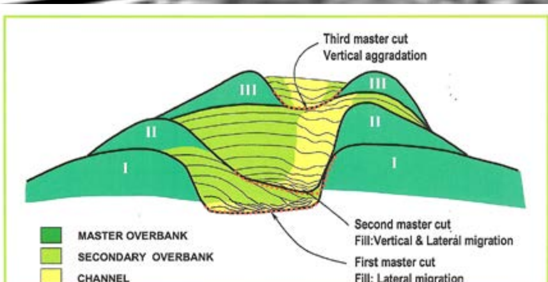
Channels stack depending on confinement and rate of aggradation…

… the more vertical the aggradation the more silt and clay in the system

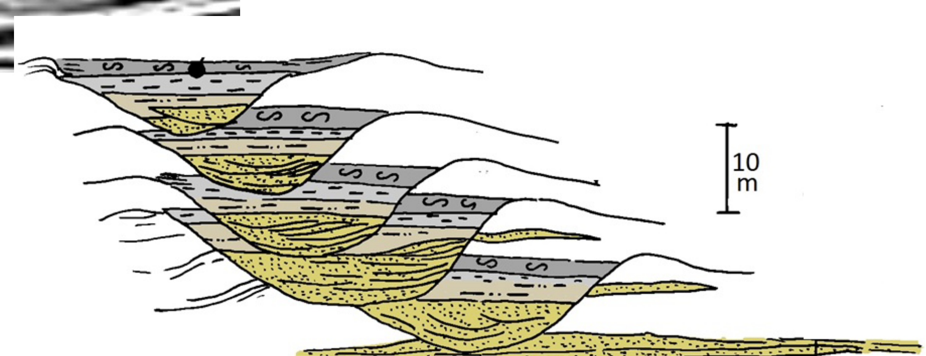




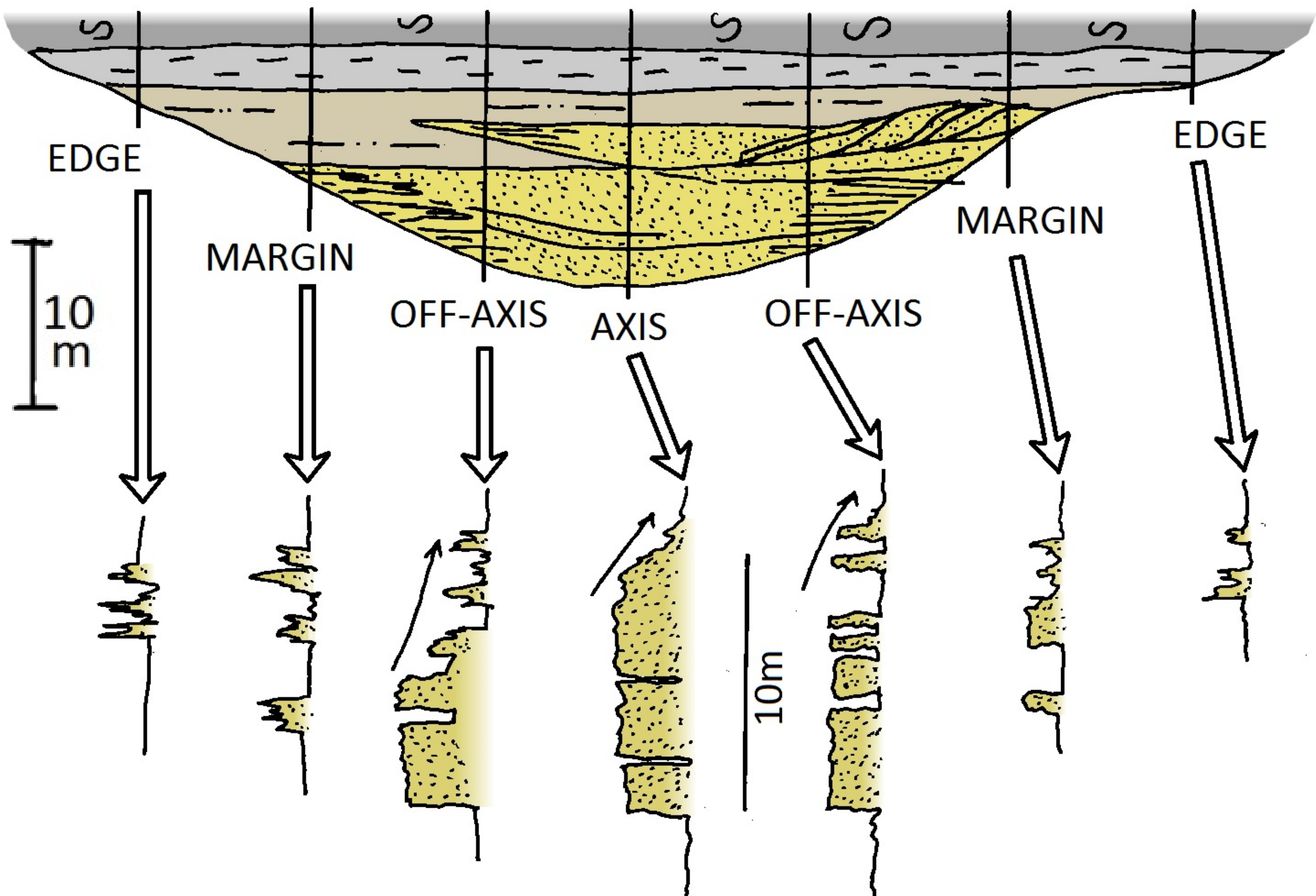
Kolla (2007, MPG)



Kolla (2007, MPG)



Channel architecture varies but can be benchmarked by log pattern…

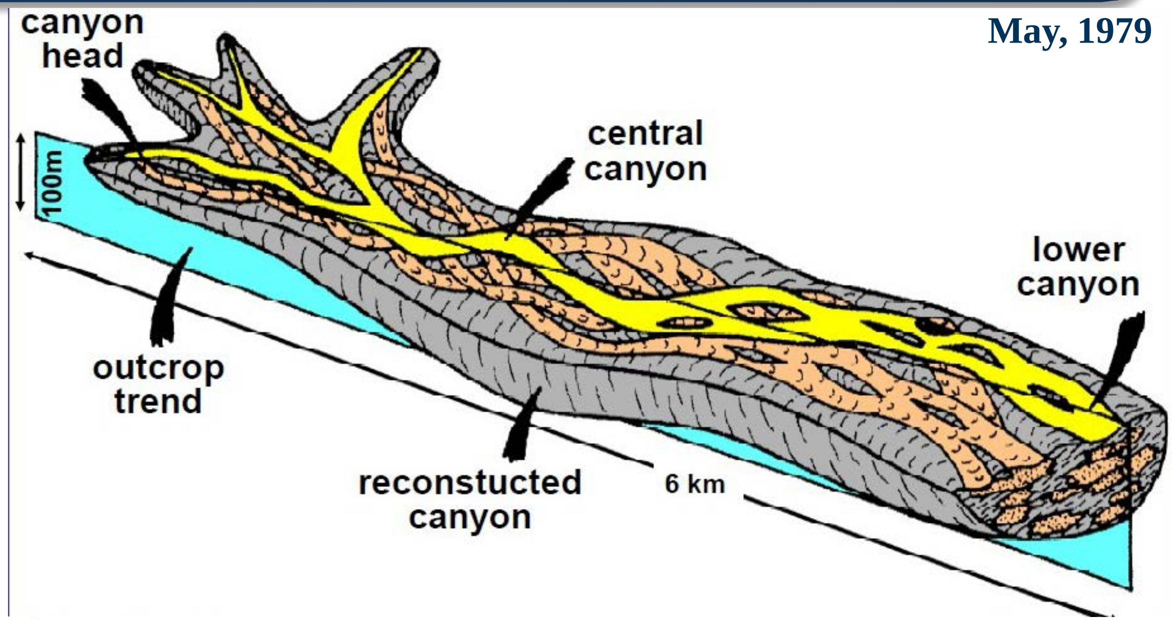


Gross Slope Channel Complex Morphology

6. Late-stage channel elements

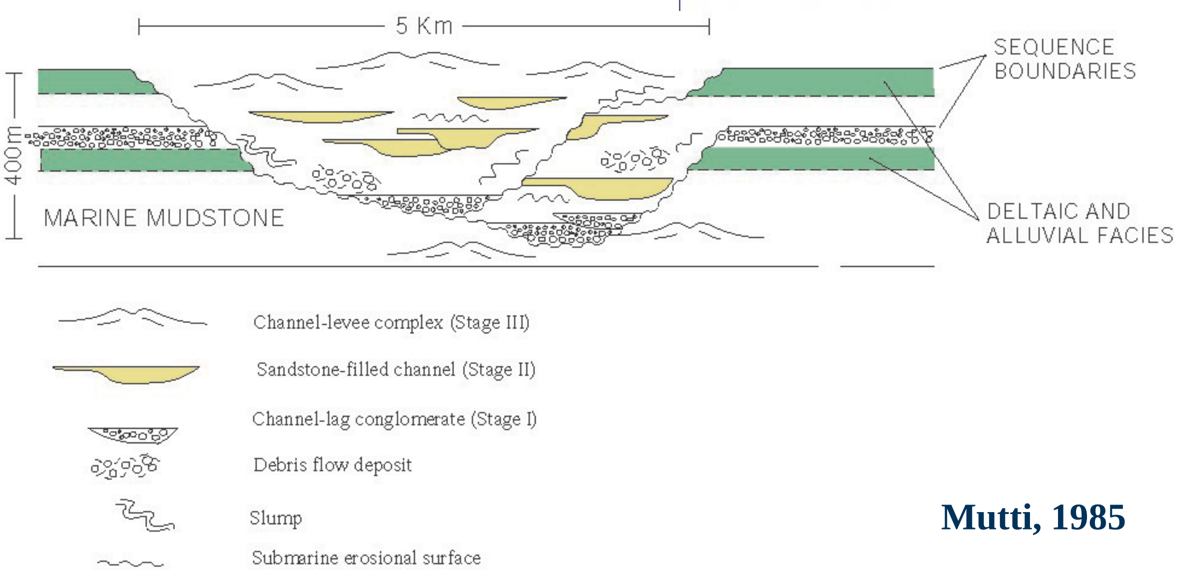
- Only late stage in fining-upwards Slope Channel Complex systems!
- Sometimes found throughout finer-grained Slope Channel Complexes

Meandering channel elements have been known and described before



May, 1979

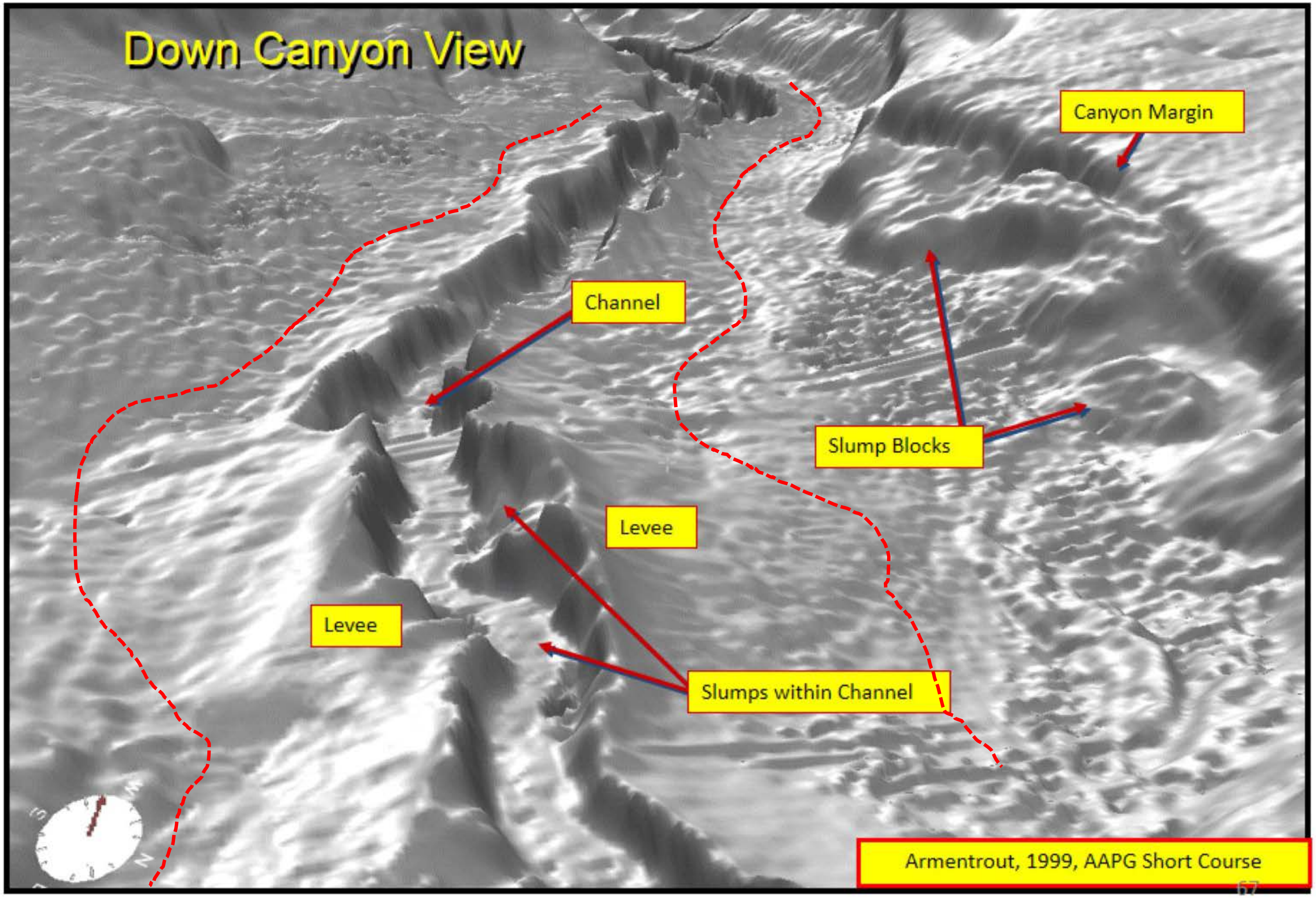
But as so often with turbidites if you read back a little further than what is in vogue now….



Mutti, 1985

Inside Levees within Nigerian Slope Channel Complex

Inside levees often have limited lateral extent….



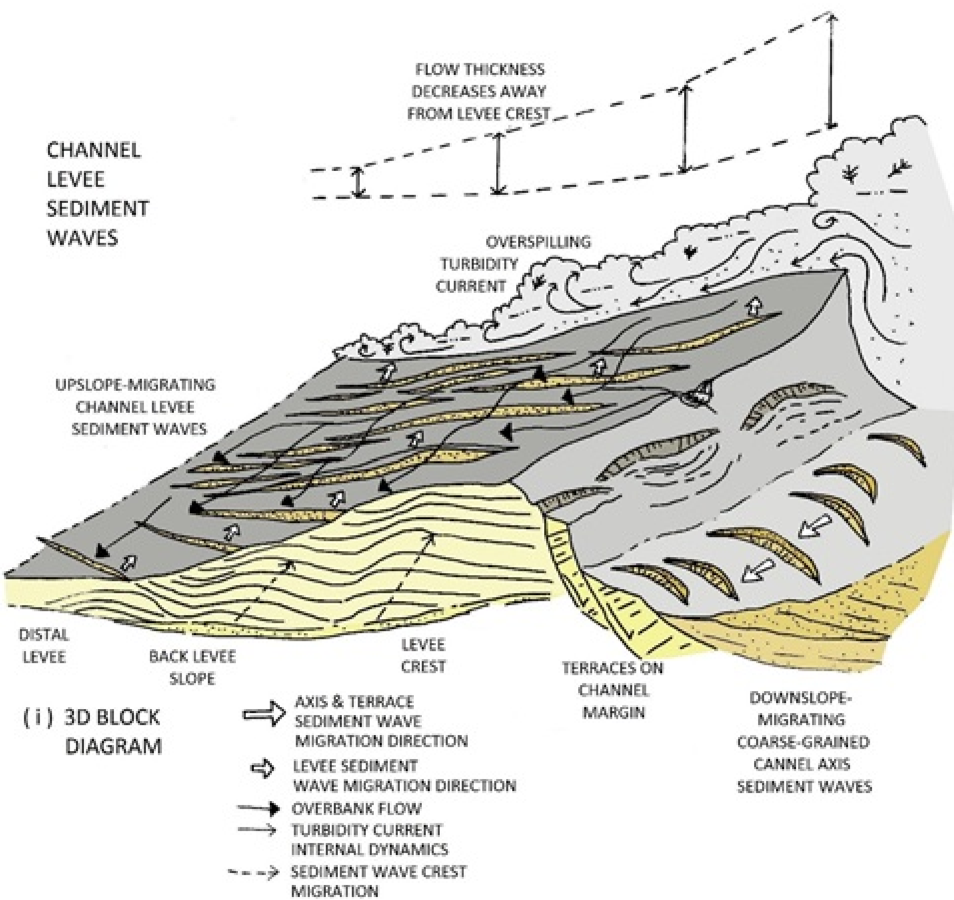
Gross Slope Channel Complex Morphology

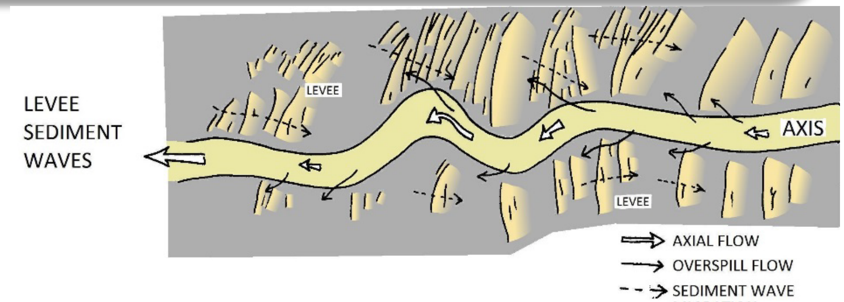
7. Levee Growth

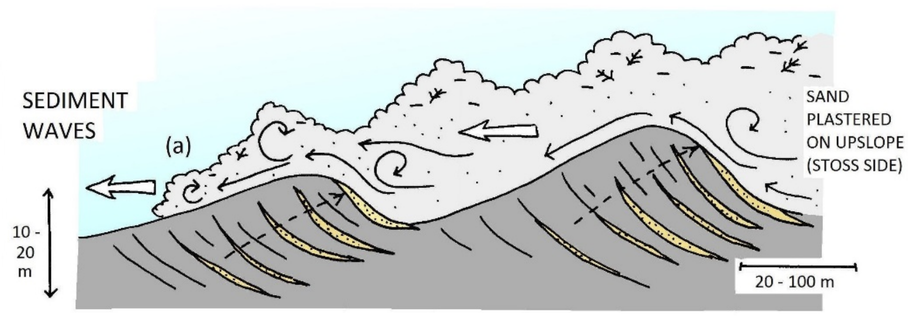
- Most models have levee complexes growing early, related to ‘master erosional surfaces’
- Levees often degrade in sand % away from the levee crest, but distal levee locations are often the sites for crevasse splay, sediment wave and other intra-channel elements

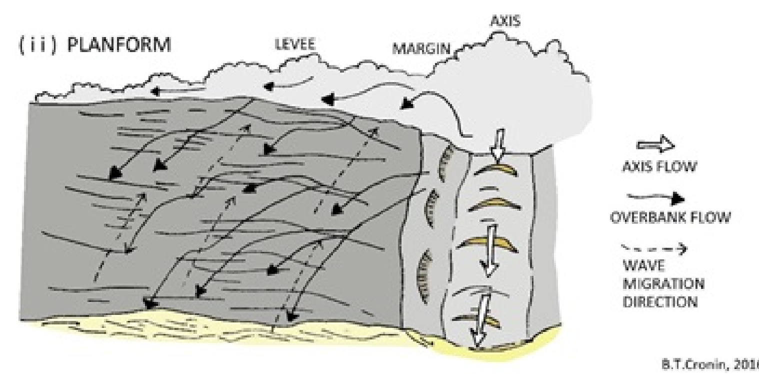
Sediment wave model based on modern and subsurface examples

Sediment wave formation from levee overspillng of turbidity currents….





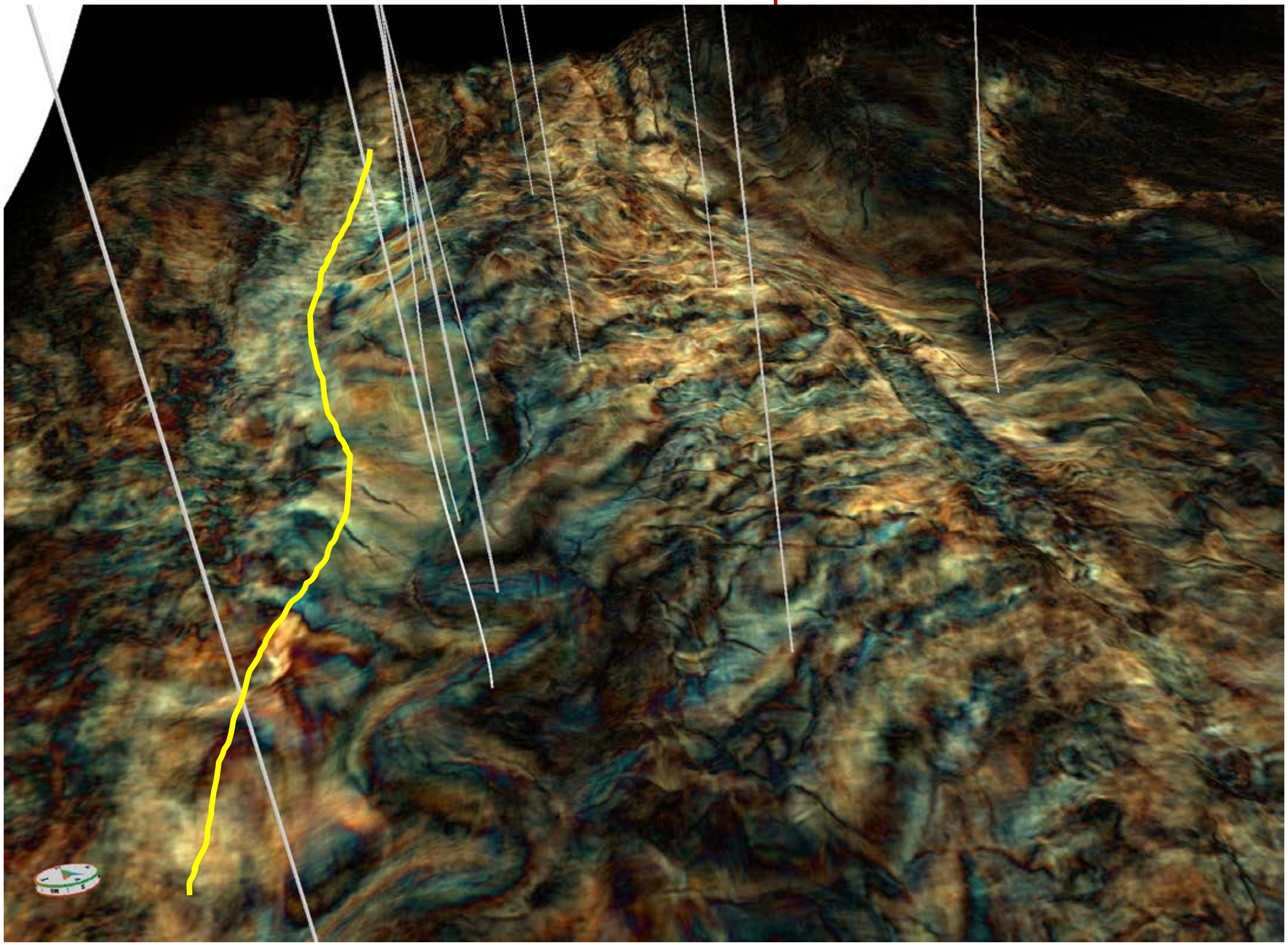




… perhaps the entire levee is made of sediment waves??

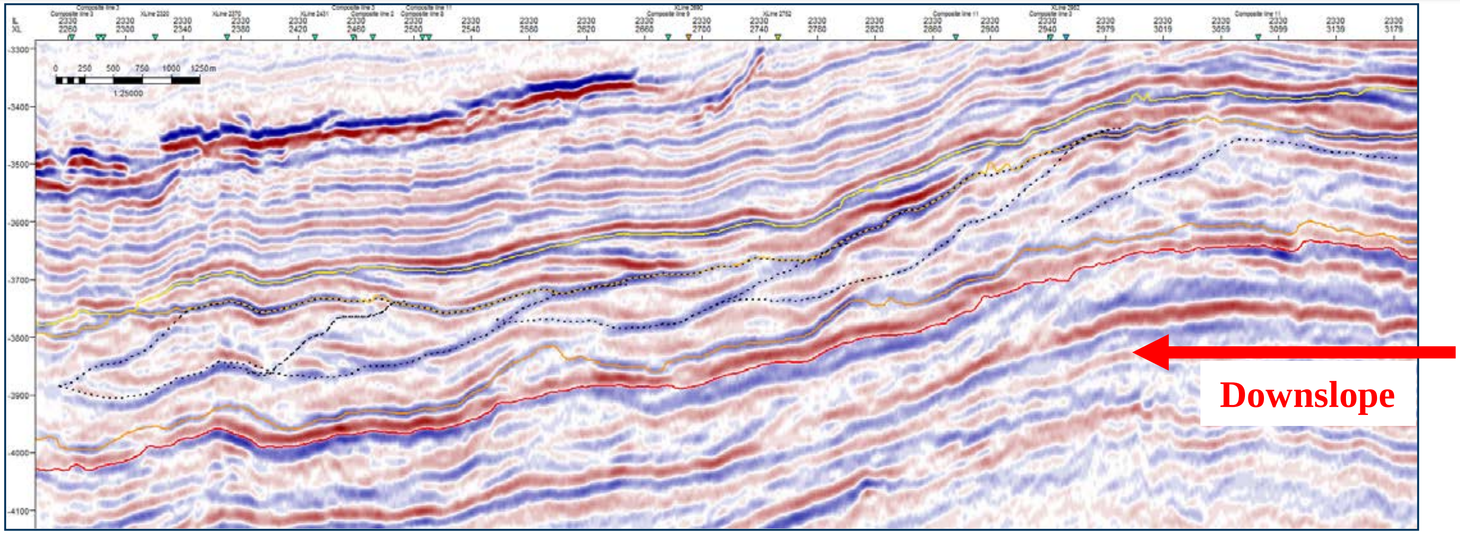
Sediment wave ridges found in large aggradational channel-levee complex, offshore west Africa

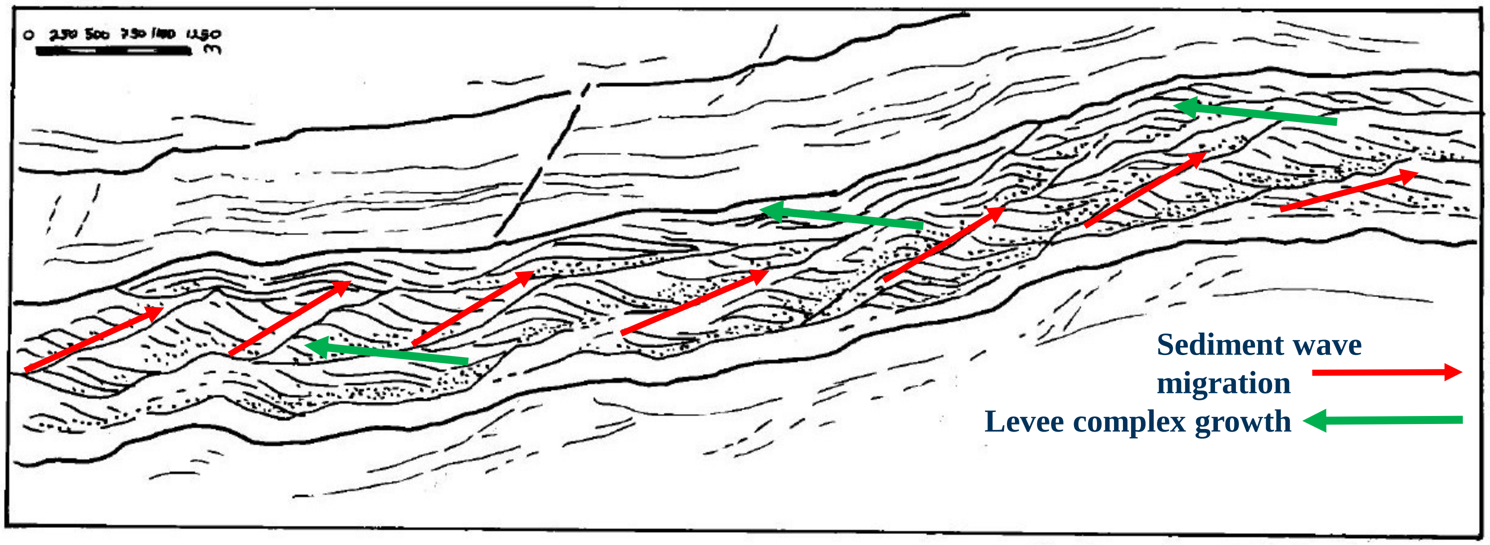
Sediment wave formation seen in subsurface examples….



… perhaps the entire levee is made of sediment waves??

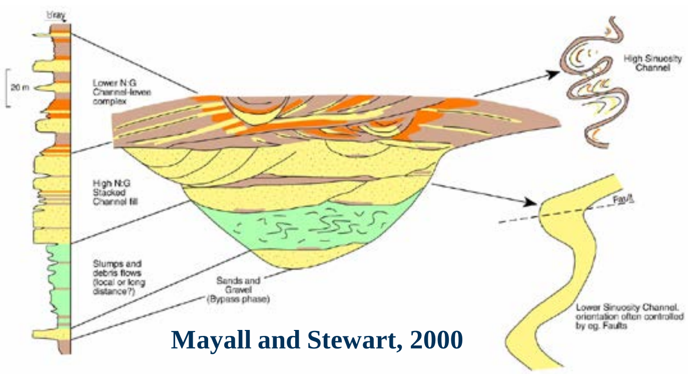
Dip section through multi-phase levee complex



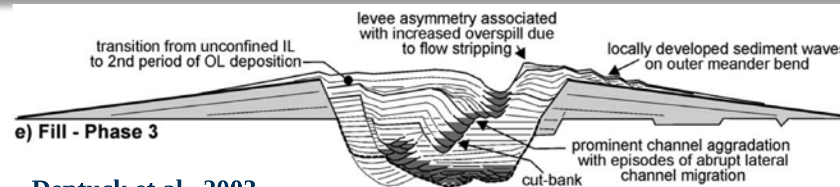


… shows sediment waves migrating upslope/levee, but the levee ITSELF builds downstream as cosets of sediment waves

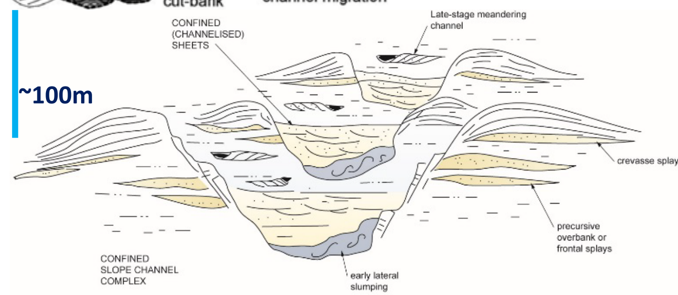
Existing models: sometimes show multi-phase occupancy with multiphase levees….



Mayall and Stewart, 2000

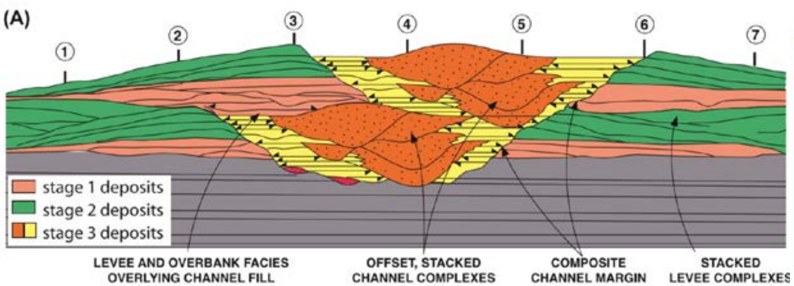


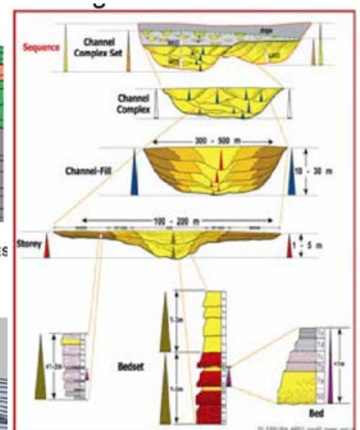
Deptuck et al., 2003



Cronin et al., 2007

Beauboeuf, 2004





Deep Water Hierarchy - Confined Setting

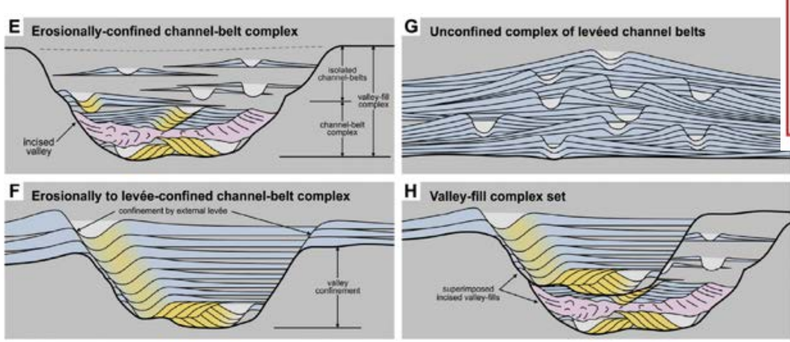
Sprague et al., 2002

- Channel Complex Set
- Channel Complex
- Channel-Fill
- Storey

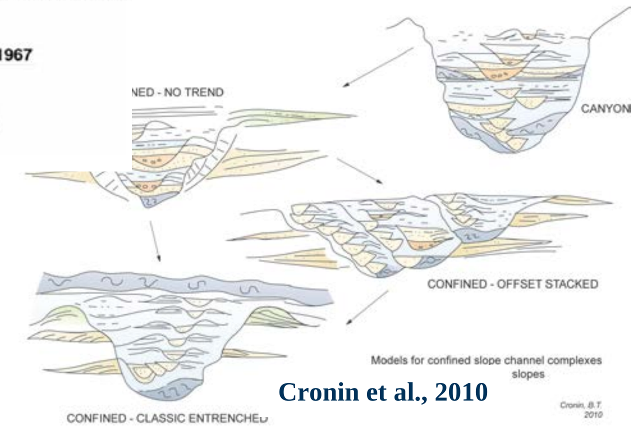
Modified from: Beaubouef et al., 1999, 2000

Campbell, 1967

- Bedset
- Bed
- Laminaset
- Lamina

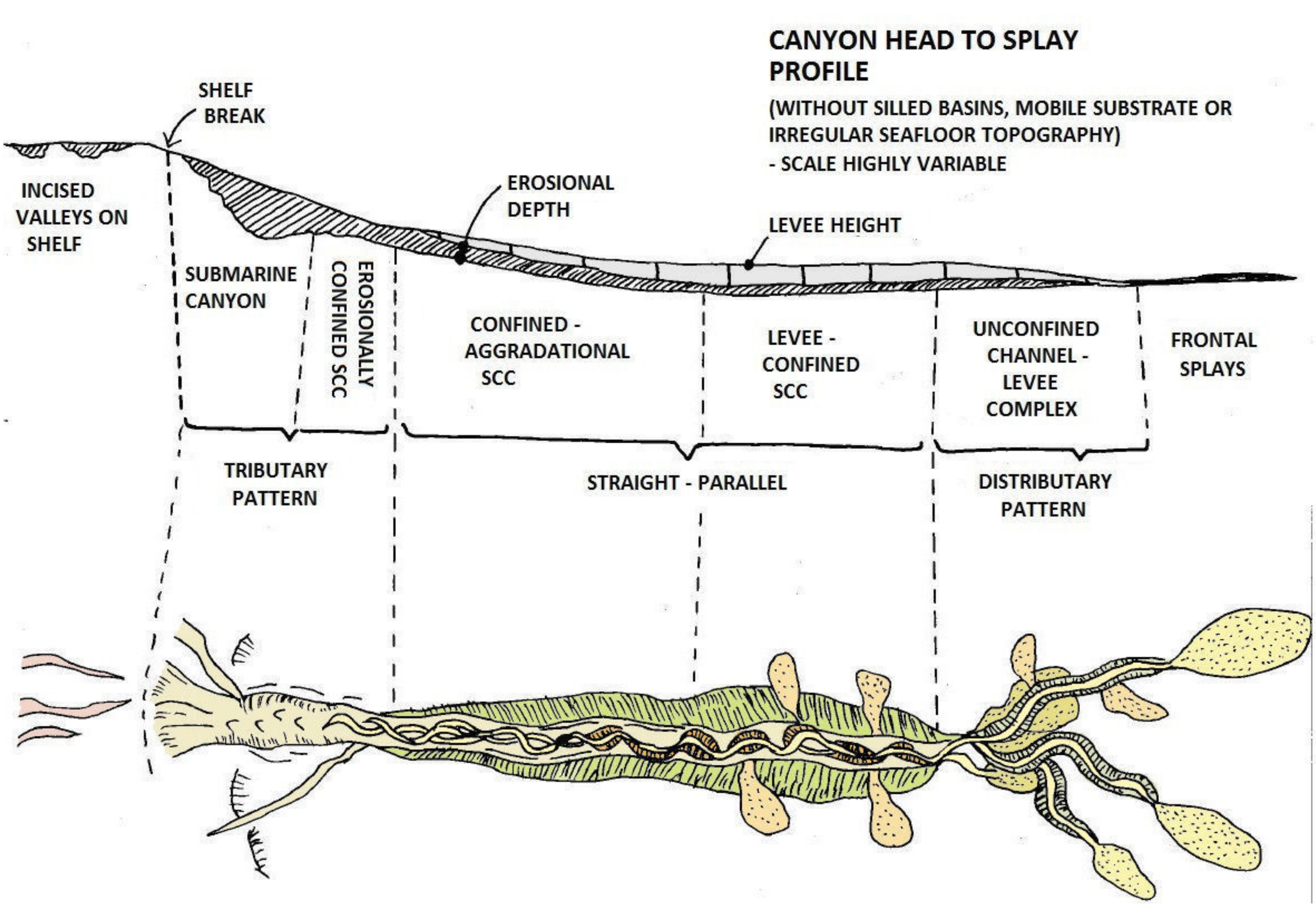


Janoko et al., 2013



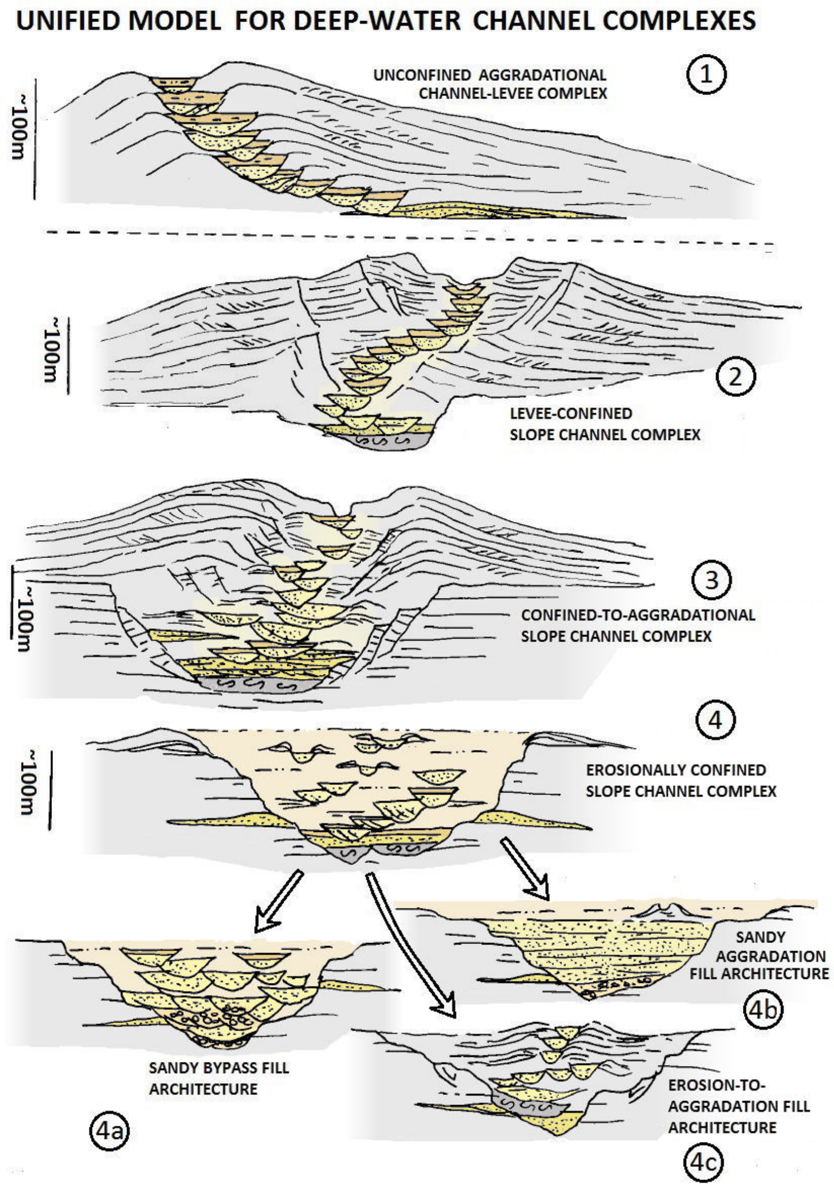
Cronin et al., 2010

New Unified Models: Proximal-Distal Model



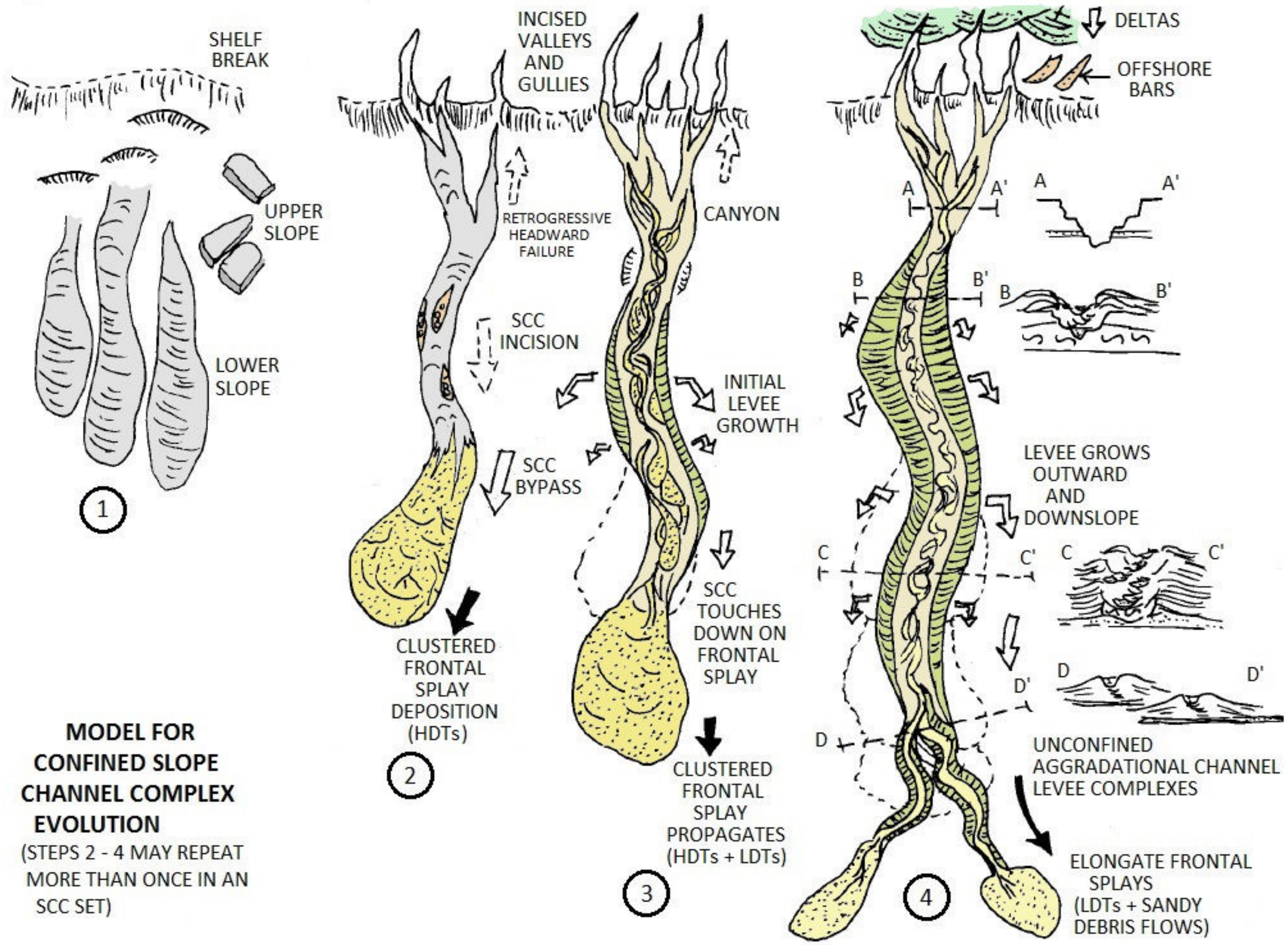
We recognise updip-downdip changes in channel complex architecture

New Unified Models: Variable Architecture Model



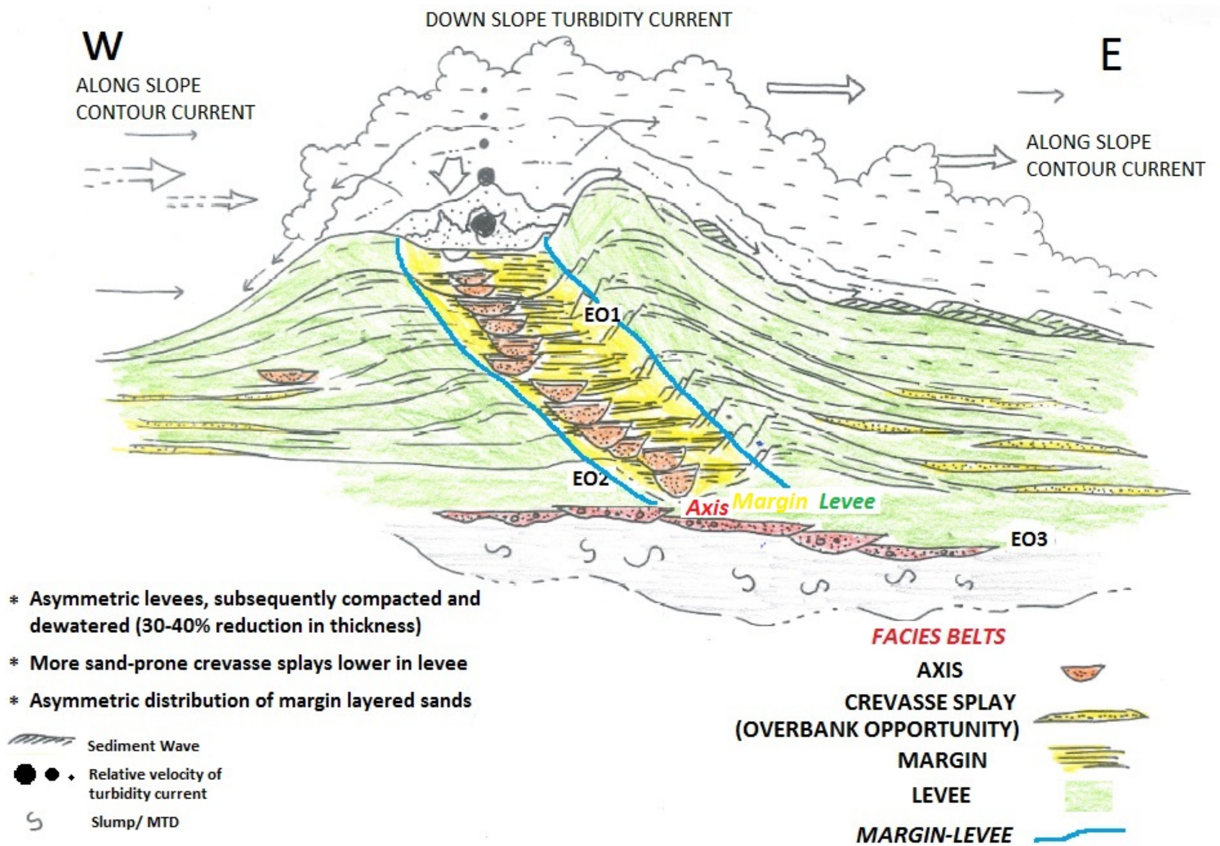
We recognise variation in the main slope channel complex systems: and have a unified model for architectural change

New Unified Models: Sequence Stratigraphy Model



We understand better the evolution of the systems, which allows us to predict distribution of infill opportunities outside the main channel complex system belt

New Unified Models: Facies Belts Model



We are now modelling facies belt delineation within the slope channel complexes to differentiate:

(1) axis (the confined belt of variably connected reservoir);

(2) margin (connected thinner beds and erosional remnants) and

(3) **levee/overbank**, which are separate infill opportunities

Conclusions

1. Most current conceptual models for slope channel complexes are based on narrow ranges of character: there is more variation in nature and unified conceptual models need to be used to capture this
2. Scenarios for net sand presence and connectivity need to be considered when building models for channel complex reservoirs
3. Lateral gravitational foundering and inside levees both exist
4. Channel stacking: trajectories indicate N:G and connectivity
5. Late stage meandering skinny channels are the most obvious feature but not the best reservoir
6. Levee complexes, outbuild and prograde and there are significant reservoir opportunities there

Coming soon… November 2018