Large Fluvial Fans (LFF) - Attributes or Are Large Fans Significant?*

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Abstract

In arguing for a strict definition of the alluvial fan (coarse-grained with radii <10 km, in mountain-front settings), Blair and McPherson (1994) proposed that there is no meaningful difference between the largest fans (large fluvial fans—LFF) and floodplains, as the building blocks of both are the channel-levee-overbank suite of deposits. Sediment bodies at the LFF scale (>100 km long, fan-shaped in planform), of which >160 are now identified globally, are relatively unstudied. The following perspectives suggest that their significance needs to be reconsidered. (1) LFF-formed land surfaces and sediment bodies: Large areas covered by single (up to 200,000 km^2) and nested LFF (750,000 km^2 contiguous LFF surfaces in South America alone) show that such surfaces are significant at continental scales—though often unrecognized, especially when located far from mountain fronts. Since LFF are a major component of modern Distributive Fluvial Systems (DFS—fanlike forms >30 km), their role in the evolution of buried fluvial strata holds specific interest. (2) Drainage patterns: a—Diverging channel patterns over distances >102 km characterize not only coastal deltas, but also LFF situated hundreds of km from coastlines. b—Rivers in marginal depressions between neighboring LFF tend to be the best developed sectors of lowland, non-axial river systems due to significantly higher episodic drainage discharge. (3) LFF cascade: First-tier LFF (apexed at the upland margin) can give rise in large enough basins to a second tier of downstream derived LFF, the first-tier with distinct conicality, the derived being flatter with alluvial ridges as the most prominent topography. (4) Stratigraphic record: The sheer size of LFF surfaces reduces the rate of surface reworking accomplished by the avulsing river. Combined with relatively higher infiltration capacities LFF are likely to hold more complete sedimentary and pedologic records than those held by the more frequently reworked floodplain surfaces confined between valley walls. (5) Applied aspects: Recognition of a relict LFF in Namibia allowed reinterpretation of the dimensions of two aquifers—as orders of magnitude larger than those implied by the floodplain model. Such reinterpretations can be expected elsewhere. Hydrocarbon exploration can benefit from understanding the architectures and more realistic paleogeographic reconstructions implied in 2 and 1 above. LFF thus warrant classification as a discrete type of fluvial sediment body.

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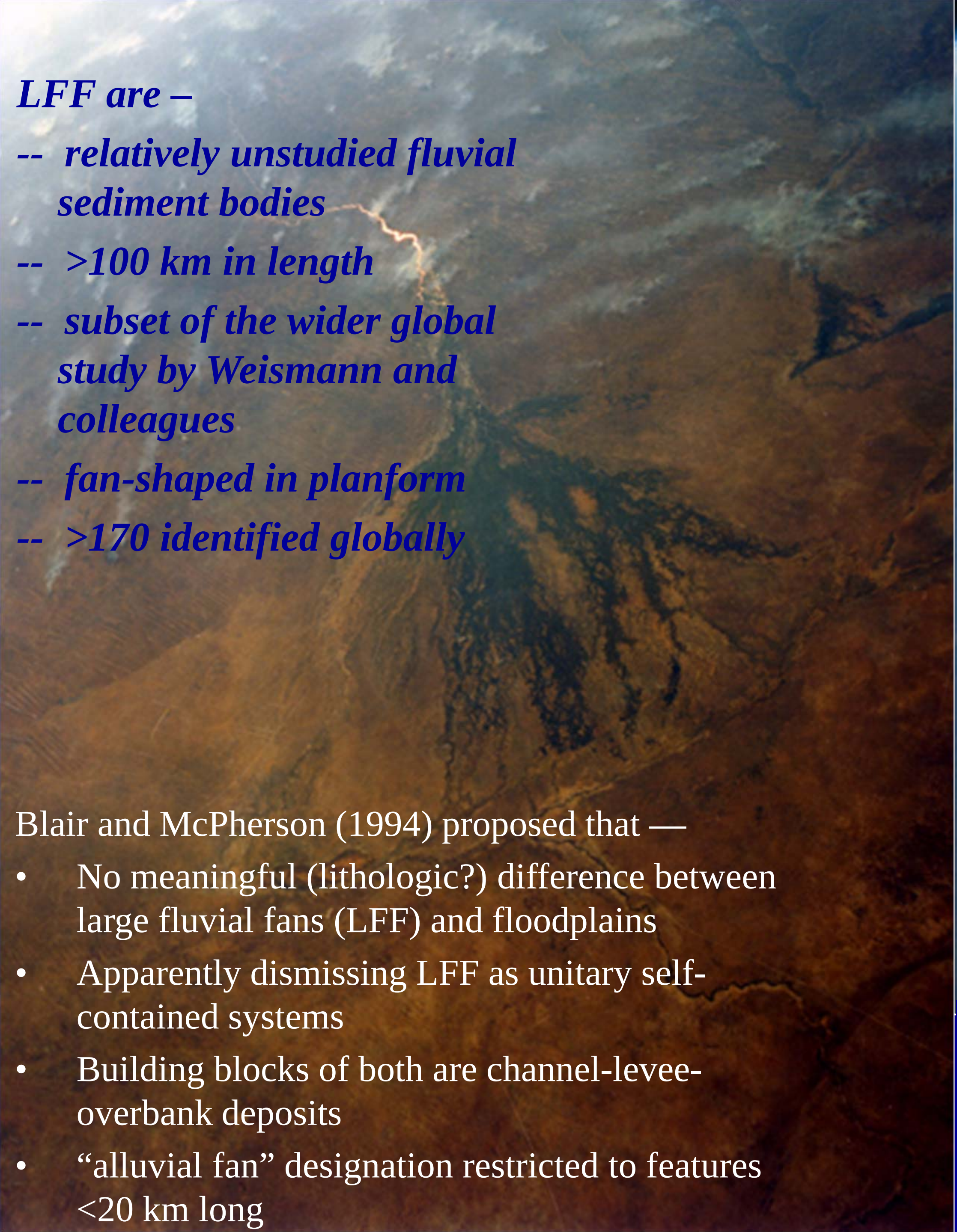
ISS040E008209, June 2014, 42 mm lens

Okavango megafan — Handheld images from Shuttle and the Space Station

STS43-151-32, Sep 1991, 90 mm lens



LFF are –

-- ***relatively unstudied fluvial sediment bodies***

-- ***>100 km in length***

-- ***subset of the wider global study by Weismann and colleagues***

-- ***fan-shaped in planform***

-- ***>170 identified globally***

Blair and McPherson (1994) proposed that —

- No meaningful (lithologic?) difference between large fluvial fans (LFF) and floodplains
- Apparently dismissing LFF as unitary self-contained systems
- Building blocks of both are channel-levee-overbank deposits
- "alluvial fan" designation restricted to features <20 km long

LFF-formed land surfaces —

- single LFF -- up to 200,000 km^2
- contiguous LFF in S America 0.75 m km^2

Planform and channel pattern —

- Triangle and diamond — Kosi, Tista
- Proximal-distal channel patterns, apex vs. distal, subapexes
- *Unconfined flow*

Nesting patterns / Tessellation —

- Tributary vs. axial drainages in forelands
- *Primary* vs. *derived* LFF
- Distributary vs. (con)tributary patterns

Accommodation —

- Slope control in LFF landscapes
- Sediment cascade — *"unfilled accommodation"*

Sedimentary record —

Applications —

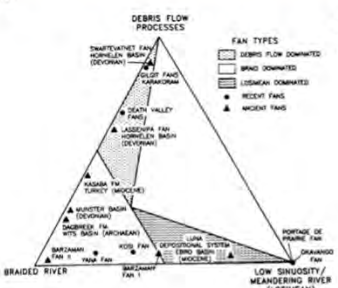


Fig. 8.69. A triangular classification of alluvial fans, showing the subdivision into the three main depositional styles. (Stanistreet and McCarthy 1993)

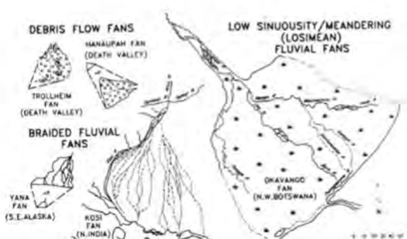
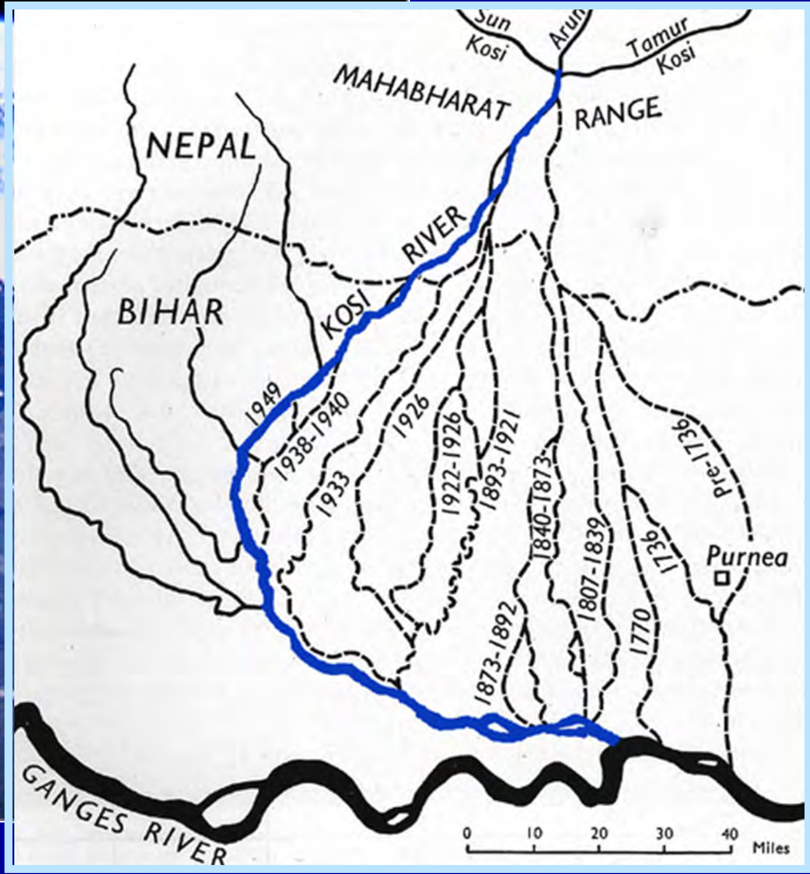


Fig. 8.70. A comparison of the sizes of modern alluvial fan systems. (Stanistreet and McCarthy 1993)

Kosi River avulsions —

- cross entire surface of fan
- average rate ~19 yr between switching events



Kosi R. avulsions

Global study — Criteria for recognition of LFF – *as bodies of sediment* — by remote sensing means —

A	**Setting — feasible water and sediment source —**
1	topographic margin: juxtaposed upland and lowland
2	river: upland river flowing into neighboring lowland
B	Morphological characteristics —
1	dimensions: > ~80 km long (width >40 km)
2	surface morphology: smooth surface (low roughness signatures)
3	___ : partial cone (at least proximally)
4	___ : cone apex (or remnant) near river exit-point from upland
5	___ : low declivity (<1 degree)
6	___ : continuous slope away from upland
7	drainage patterns : radiating from the apex

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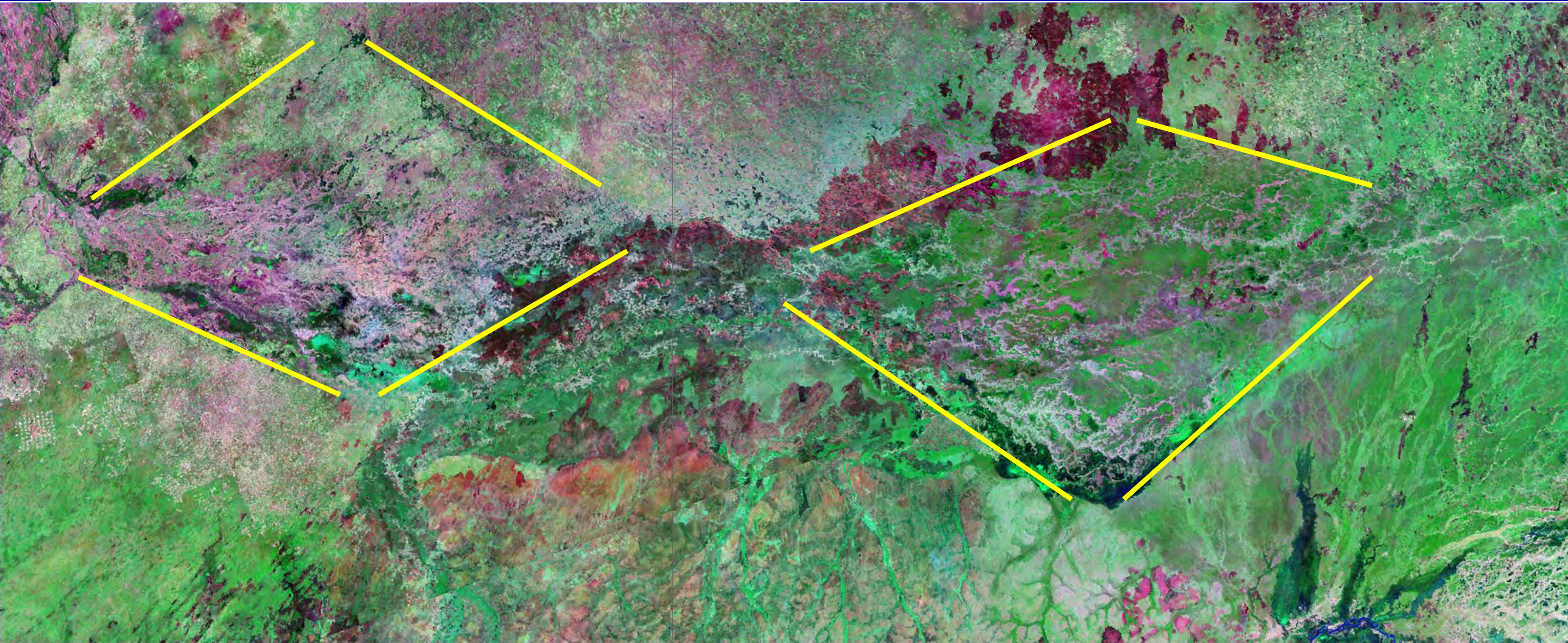
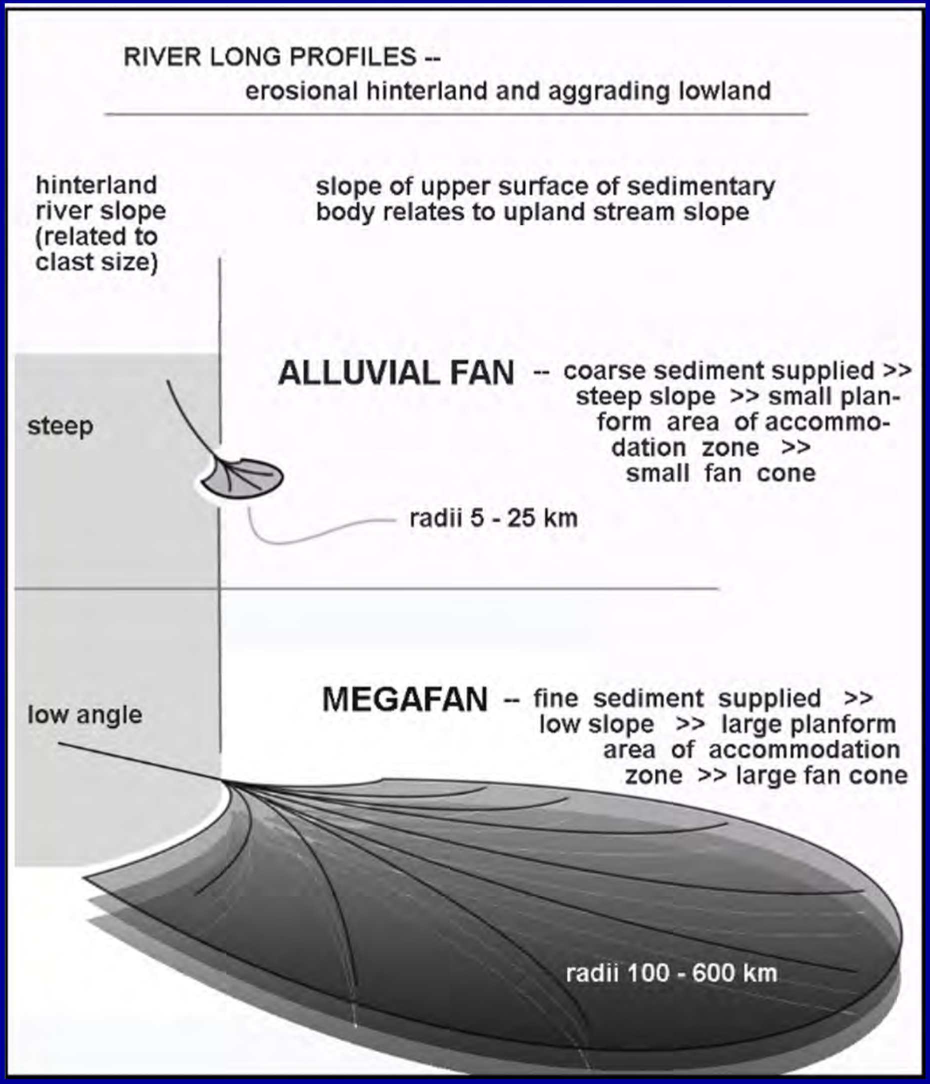
7	drainage patterns : radiating from the apex

we included upper radial *plus* contributary drainage patterns in our criteria



LFF length — river slope is a critical control



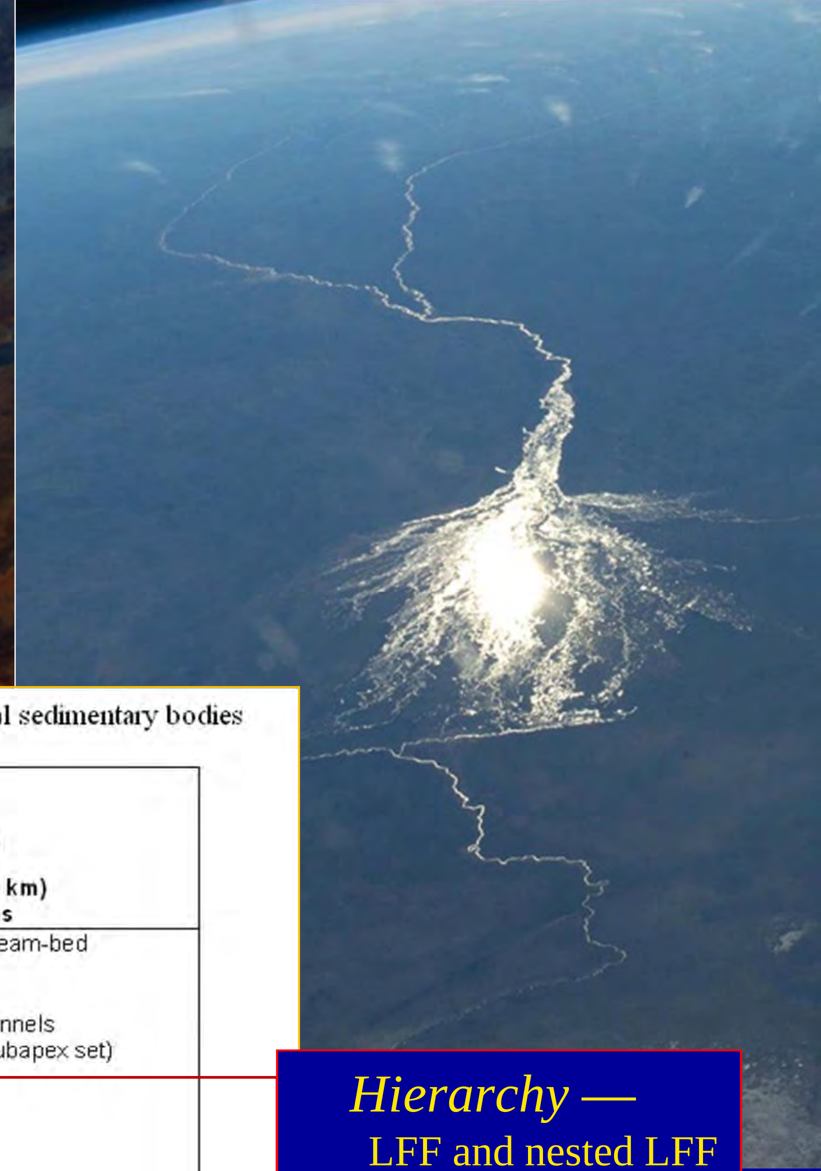


Table 1. Megafans and sets of megafans within Miall's (1996) hierarchical schema of fluvial sedimentary bodies (architectural elements). The mesoscale is italicised.

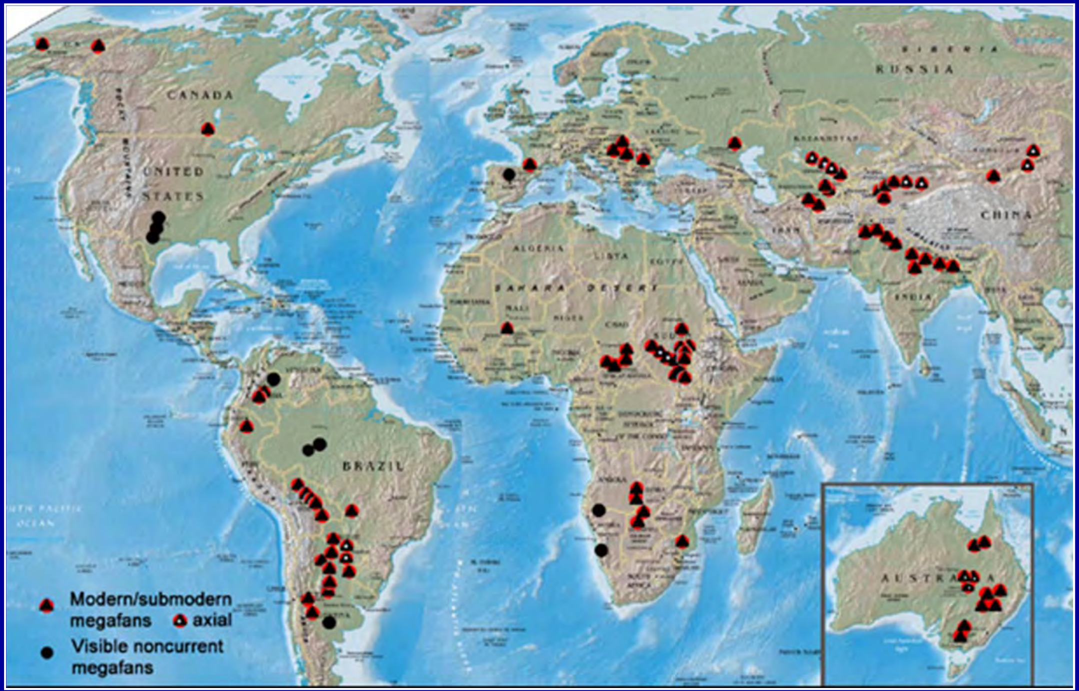
Group	Time scale (yr)	Abbreviated hierarchy of fluvial sedimentary bodies (architectural elements): **rivers and alluvial fans***	**megafan (radius > 100 km) distributary systems**
6	10^2-10^3	shallow channels, large stream-bed macroforms	shallow channels, large stream-bed macroforms
7	10^3-10^4	fan trench backfill, channels	channels
8	10^4-10^5	alluvial fan, channel belt	channel belt; packet of channels (sector set or megafan subapex set)
9	$\boldsymbol{10^5}$**-**$\boldsymbol{10^6}$	***delta, alluvial fan tract, major depositional system axis (Gulf of Mexico coast depositional axes)***	***megafan***
10	10^{6-7}	smaller basin-fill complexes (Tertiary fms., Gulf of Mexico coast)	set of nested megafans
11	10^{7-8}	larger basin-fill complexes (Triassic Molteno Fm., Karoo basin)	

* adapted from Miall (1996) and DeCelles et al. (1991).

Hierarchy —
LFF and nested LFF are mesoscale features, each integrated systems

Distribution —

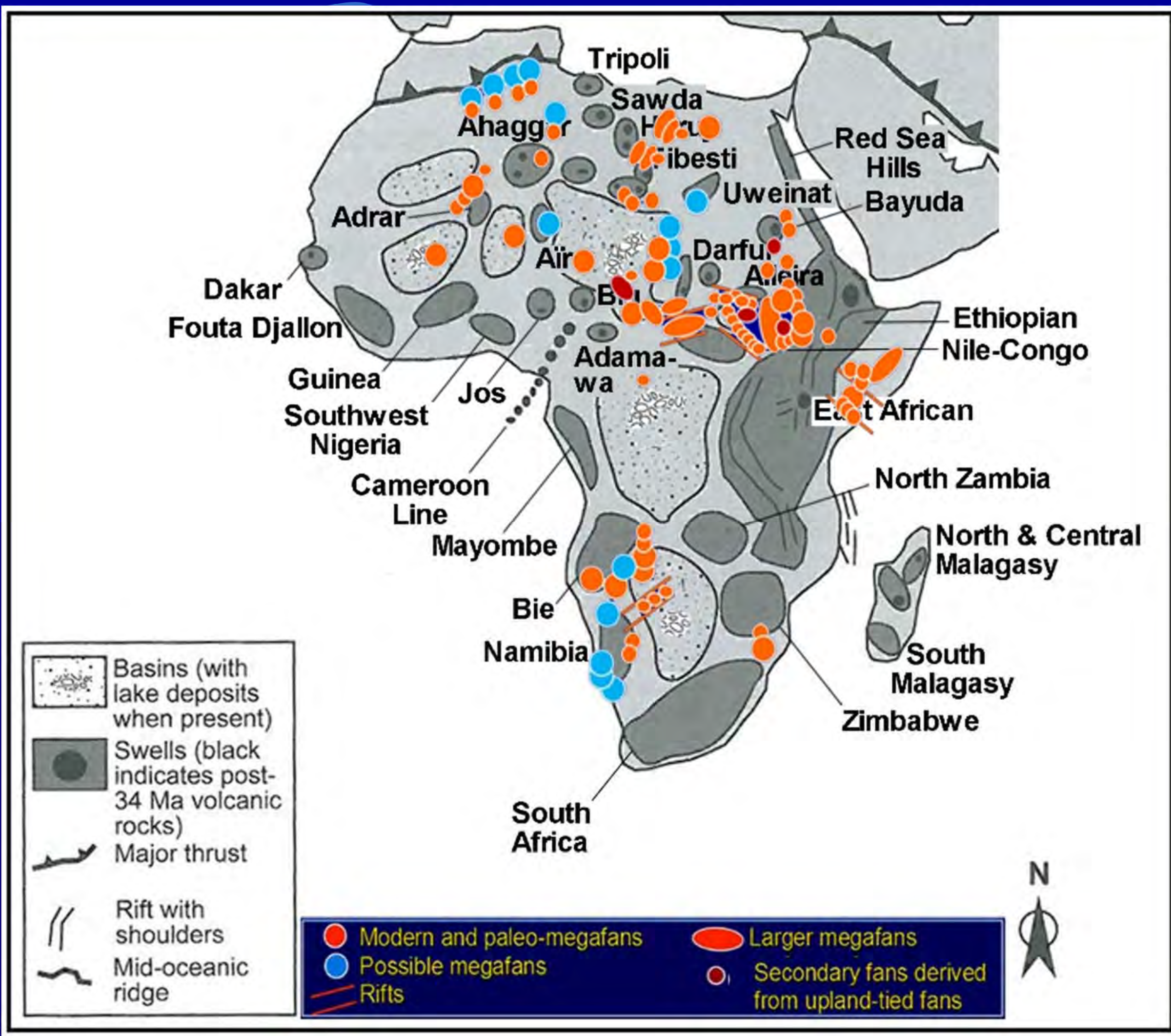
- >170 probable large fans identified worldwide, thus far
- basin type —
  - foreland basins — 49%
  - peri- and intracratonic basins — 43%
  - rift basins — 6%
  - interorogenic basins — 2%
- occur in all climates



mapped from Space Shuttle photographs, other space-based imagery, maps (especially 1:1m ONC charts), various reports

Distribution —

Megafan distribution in Africa's basin-swell context.
Rifts shown as parallel lines



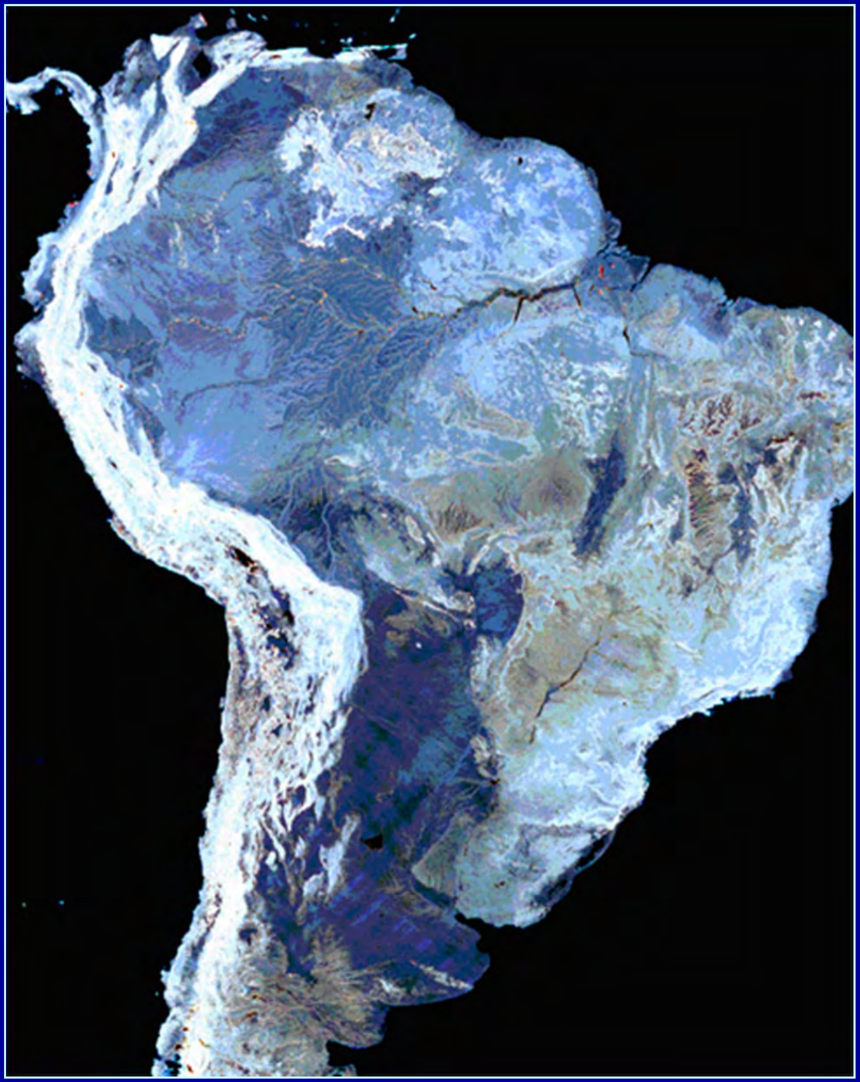
Swell margins: single-margin
(i.e. larger) basins —

- fan distribution along basin circumferences
- large fans at variable altitudes
  - on swell flanks mainly
  - sometimes on basin floors
- *diamond-shaped fans* more frequent
- clusters of fans in the T/T pattern

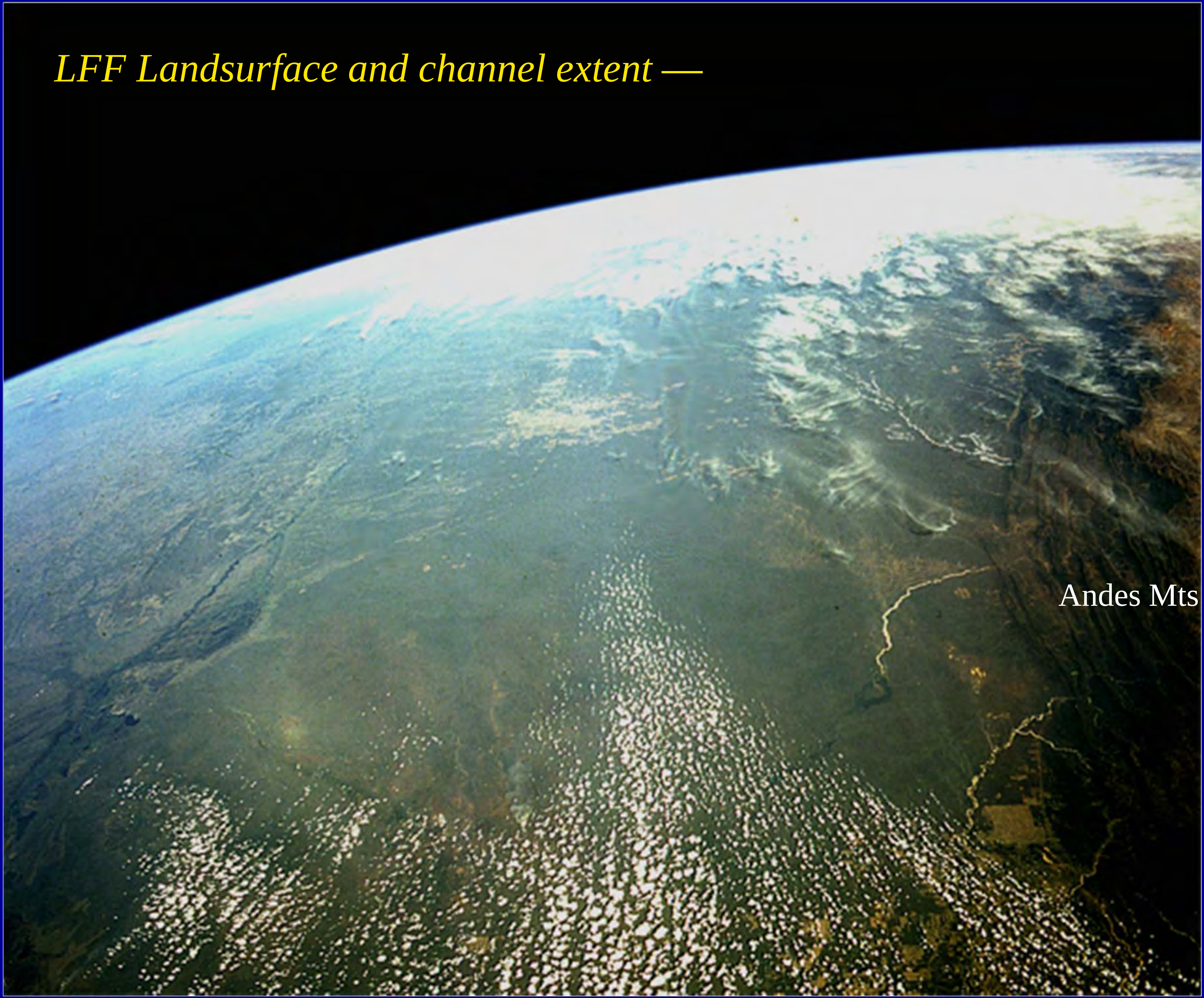
Rifts: smaller double-margin basins —

- most fans and fan clusters within rifted lowlands
- occasionally on swell crests — Salamat fan (Central African Rep.)
- *triangle-shaped fans* more frequent

LFF coincide well with terrain roughness in most parts of the world —



LFF Landsurface and channel extent —



Megafans of northern Argentina and Paraguay

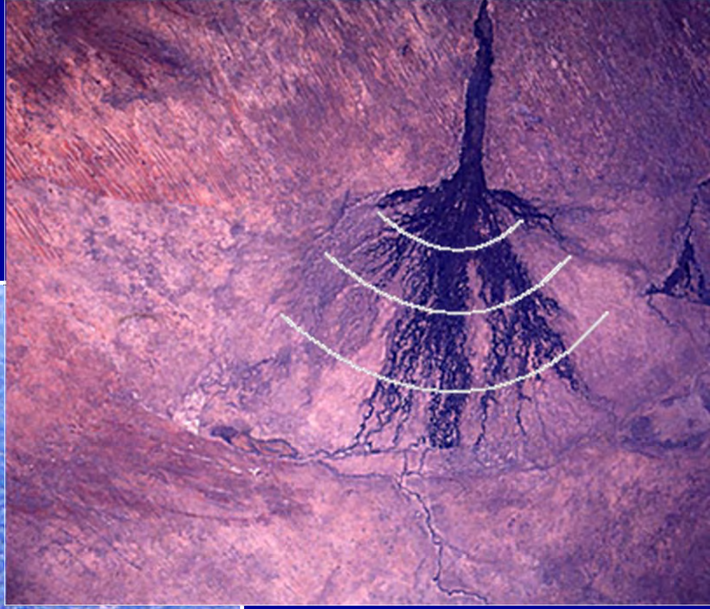
LFF Landsurface and channel extent —

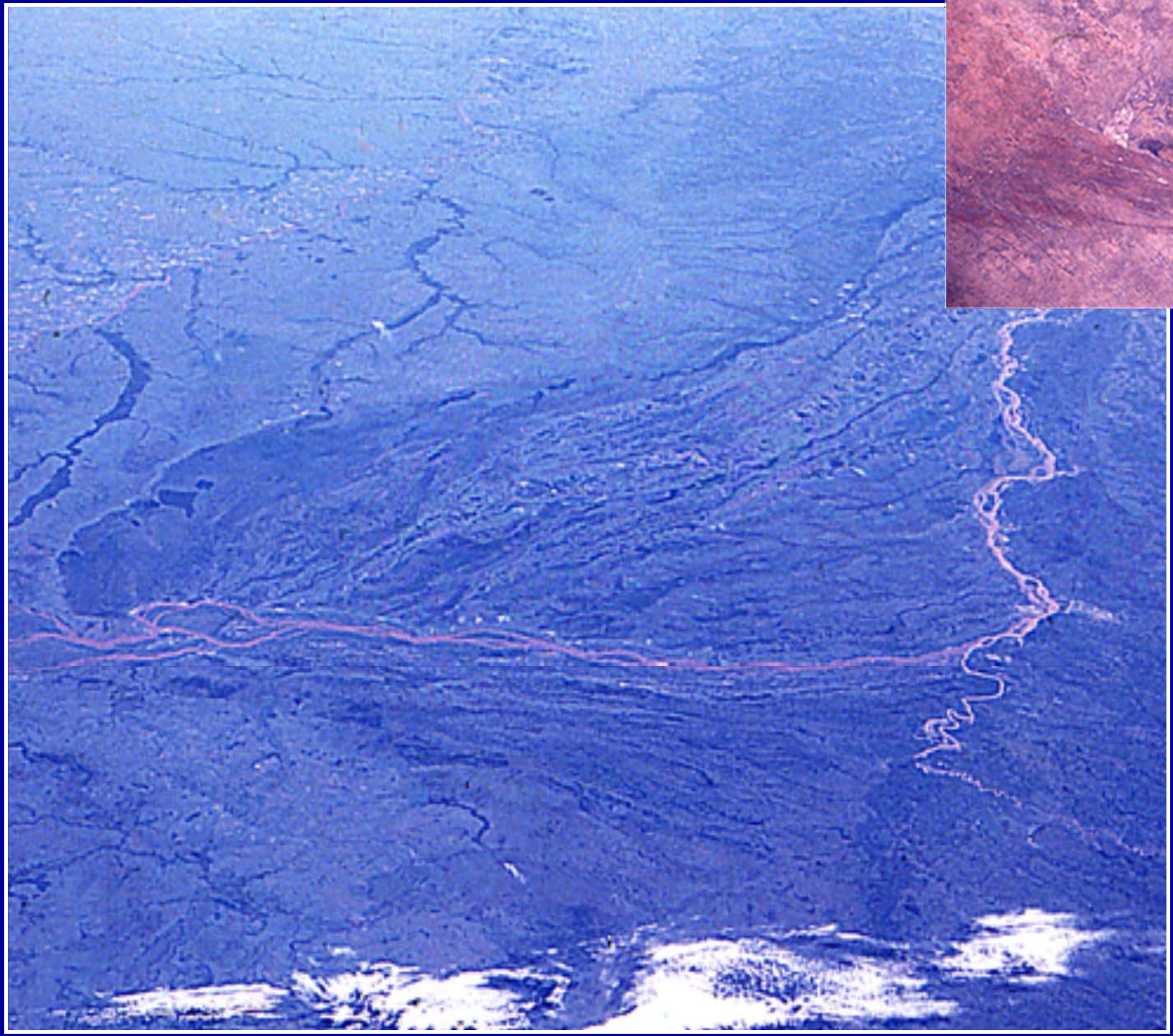
Megafans of northern Argentina and Paraguay

LFF planform and channel pattern —

- triangle and diamond —
- structural controls

Okavango R.
“inland delta”
Botswana

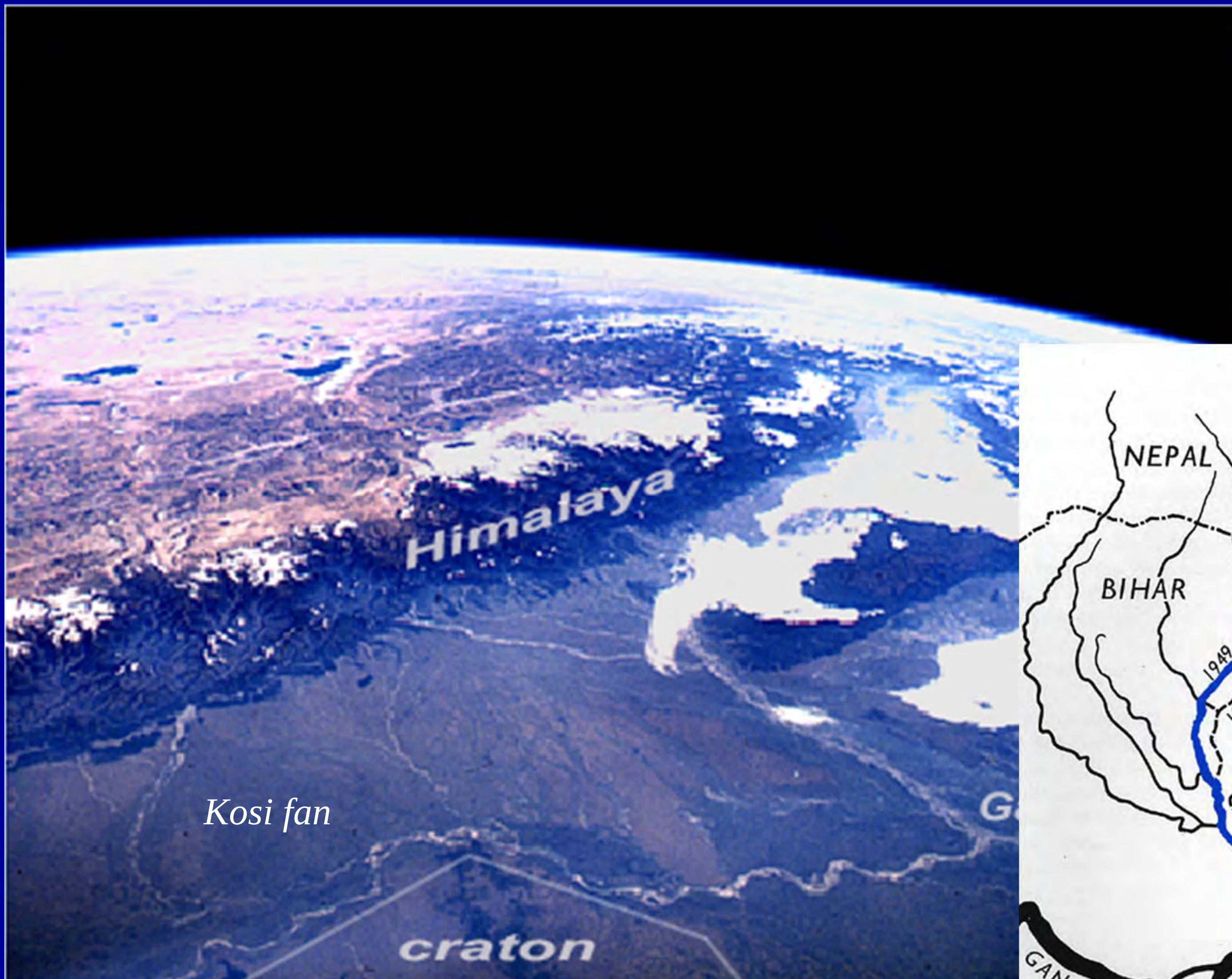


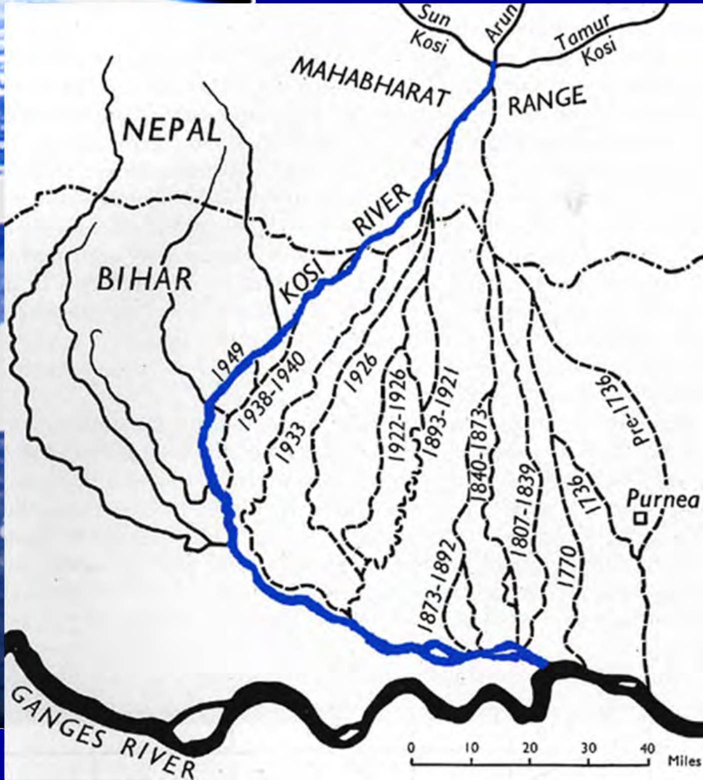


Paraná megafan –
420 km (long radius)

LFF planform and channel pattern —

- triangle and diamond —
- structural controls





LFF planform and channel pattern —

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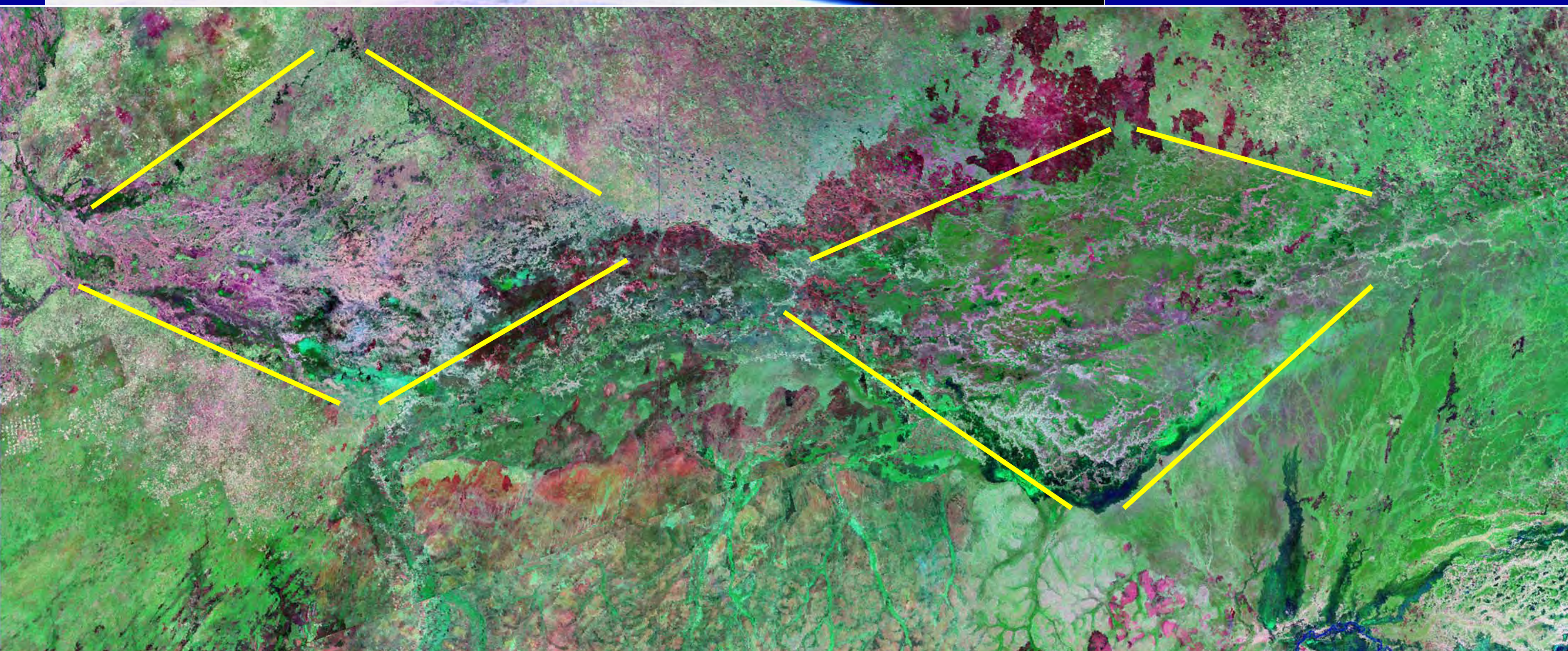
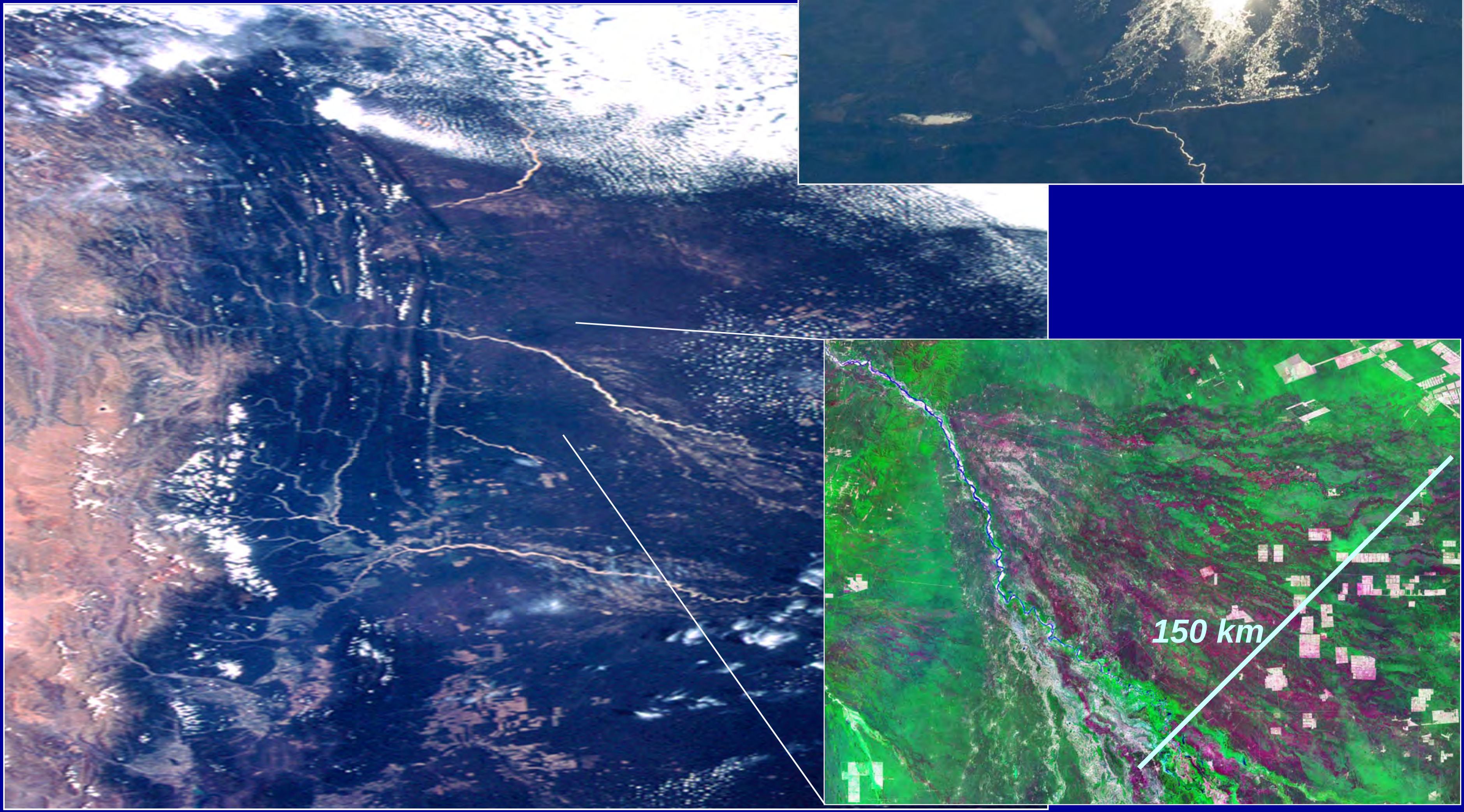


"unconfined" flow —

- *classic sheetflood at one scale, covering wide areas*
- *regional lack of confinement at the LFF scale*



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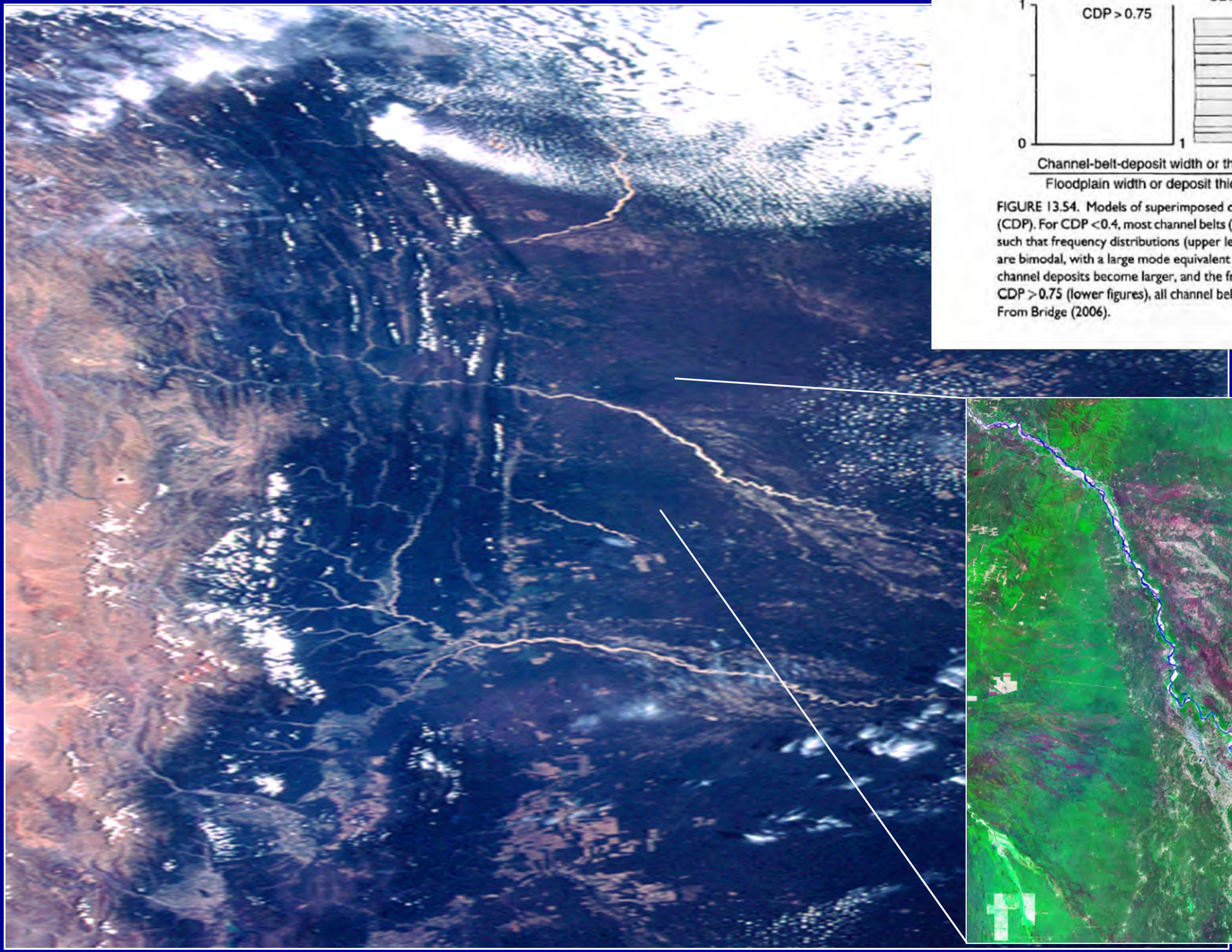


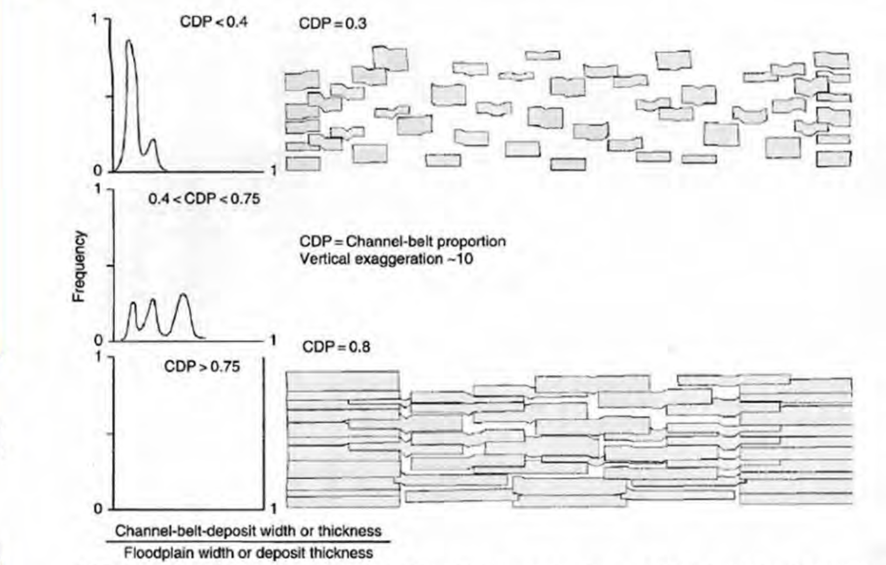
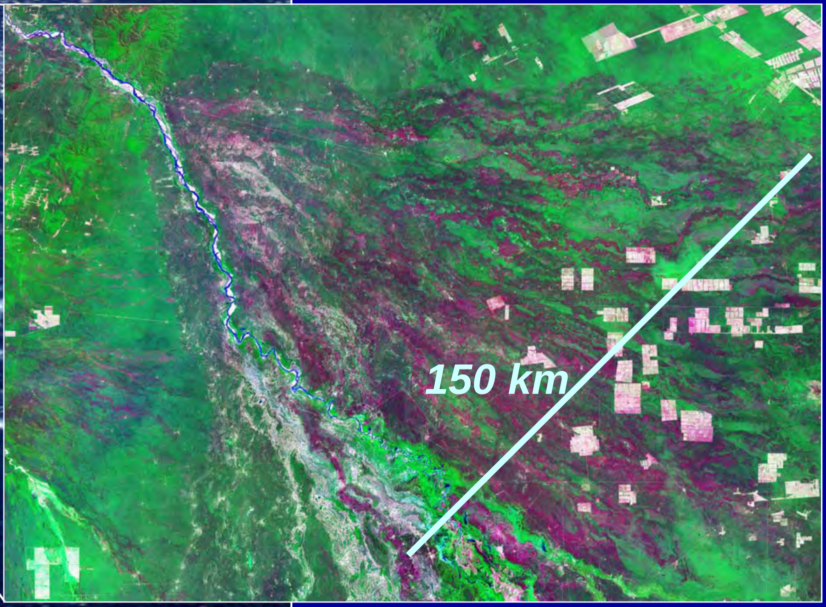
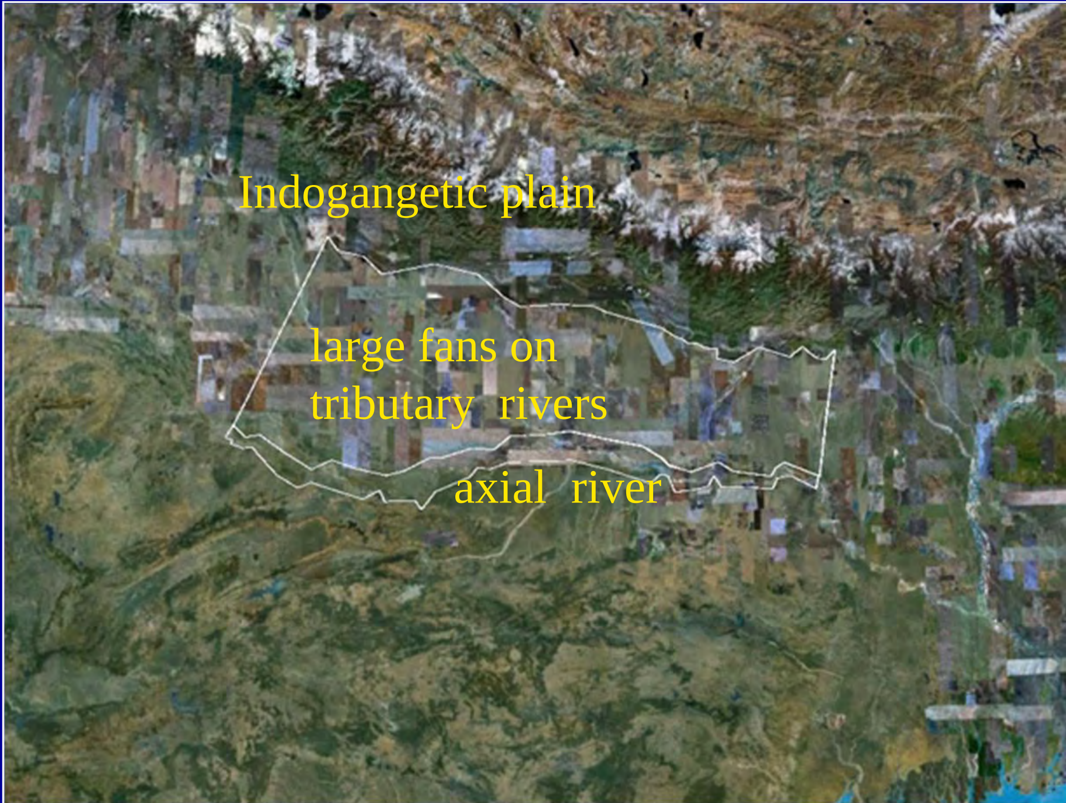


FIGURE 13.54. Models of superimposed channel belts. Channel-belt connectedness increases with the channel-deposit proportion (CDP). For CDP < 0.4, most channel belts (shown as stippled boxes in the cross-floodplain section on the upper right) are unconnected, such that frequency distributions (upper left) of the channel-deposit width or thickness (relative to the floodplain width or thickness) are bimodal, with a large mode equivalent to unconnected channel belts. As the CDP increases, more channel belts are connected, channel deposits become larger, and the frequency distribution of channel-deposit width or thickness becomes polymodal. For CDP > 0.75 (lower figures), all channel belts are connected and the single-channel deposit is as wide and thick as the floodplain. From Bridge (2006).



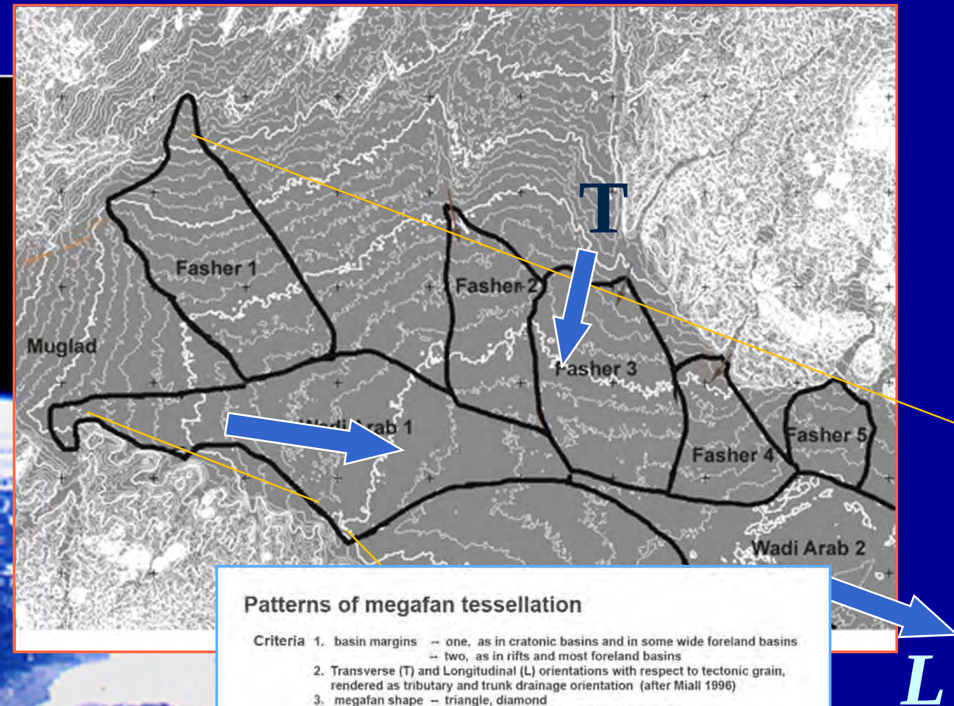
LFF planform and channel pattern —

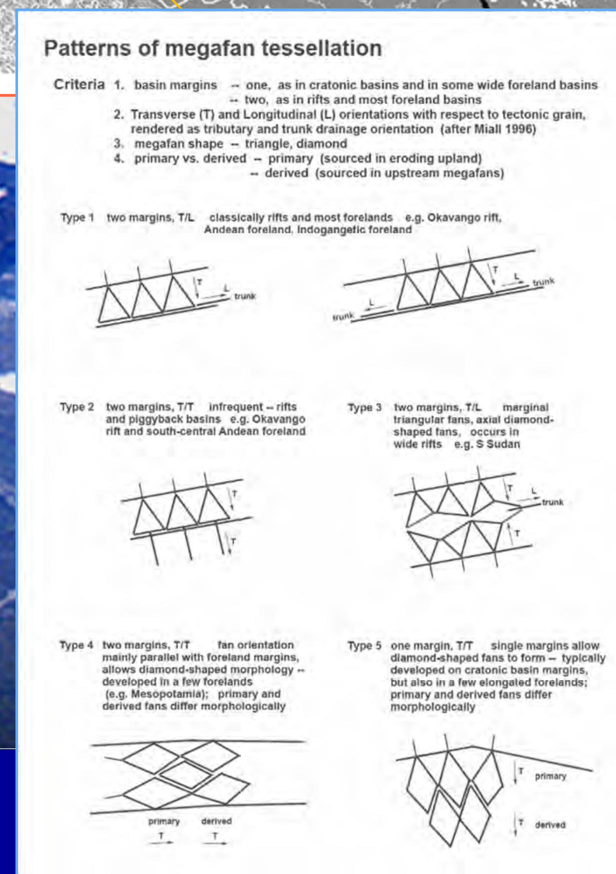
- LFF typically act as tributary drainages, at least in forelands
- few axial LFF known



Nesting patterns — six empirically derived

- Transverse (*T*)
- Longitudinal (*L*)





Patterns of megafan tessellation

Criteria
1. basin margins -- one, as in cratonic basins and in some wide foreland basins
   -- two, as in rifts and most foreland basins
2. Transverse (T) and Longitudinal (L) orientations with respect to tectonic grain, rendered as tributary and trunk drainage orientation (after Miall 1996)
3. megafan shape -- triangle, diamond
4. primary vs. derived -- primary (sourced in eroding upland)
   -- derived (sourced in upstream megafans)

Type 1 two margins, T/L classically rifts and most forelands e.g. Okavango rift, Andean foreland, Indogangetic foreland

Type 2 two margins, T/T infrequent -- rifts and piggyback basins e.g. Okavango rift and south-central Andean foreland

Type 3 two margins, T/L marginal triangular fans, axial diamond-shaped fans, occurs in wide rifts e.g. S Sudan

Type 4 two margins, T/T fan orientation mainly parallel with foreland margins, allows diamond-shaped morphology -- developed in a few forelands (e.g. Mesopotamia); primary and derived fans differ morphologically

Type 5 one margin, T/T single margins allow diamond-shaped fans to form -- typically developed on cratonic basin margins, but also in a few elongated forelands; primary and derived fans differ morphologically

Nesting patterns —

- Transverse (*T*)
- Longitudinal (*L*)

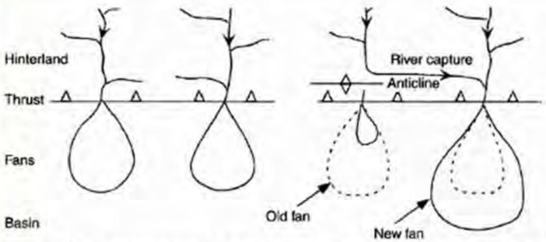
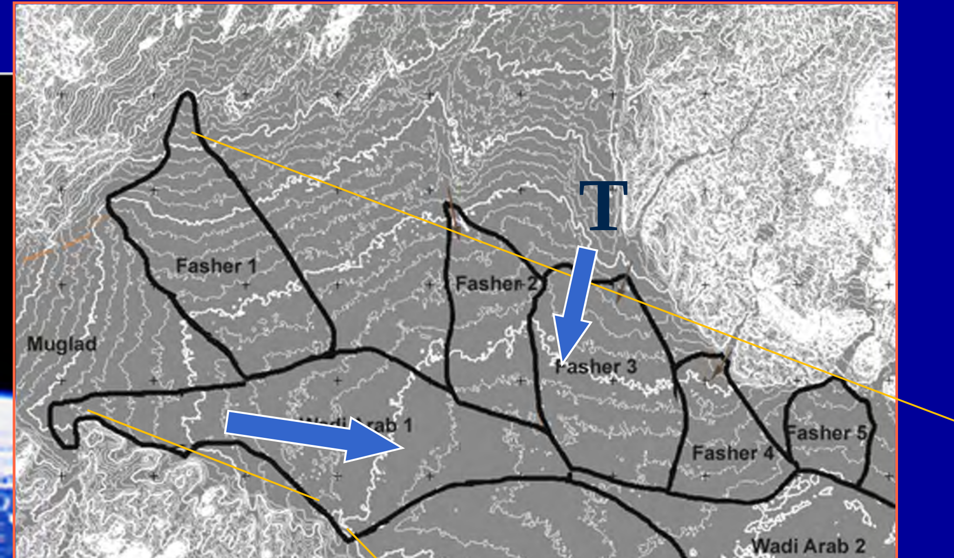
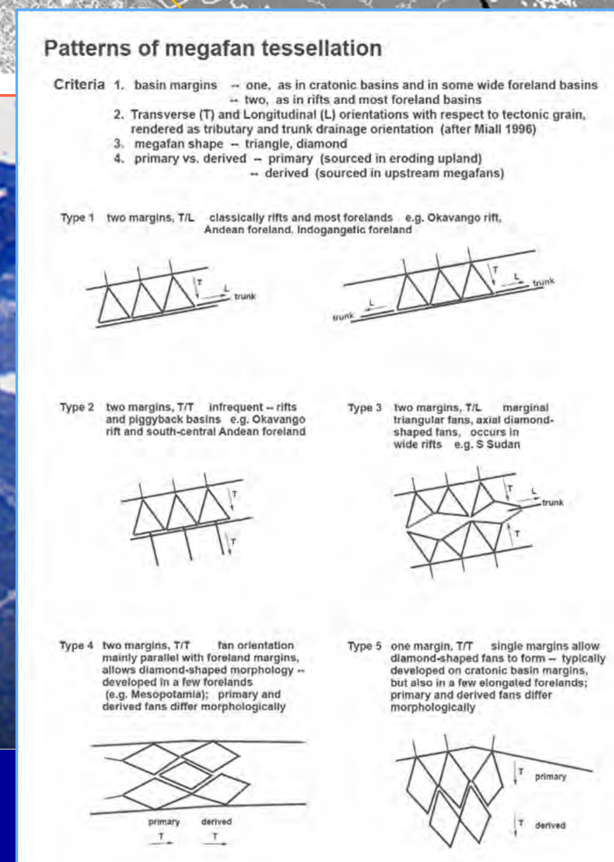


FIGURE 20.12. Hypothetical changes in alluvial-fan size in a foreland (compressional) basin due to hinterland tectonics and river capture. From Bridge (2003). An increase in water and sediment supply to the growing fan should result in an increase in channel size and frequent avulsion, hence increasing the channel-deposit proportion.





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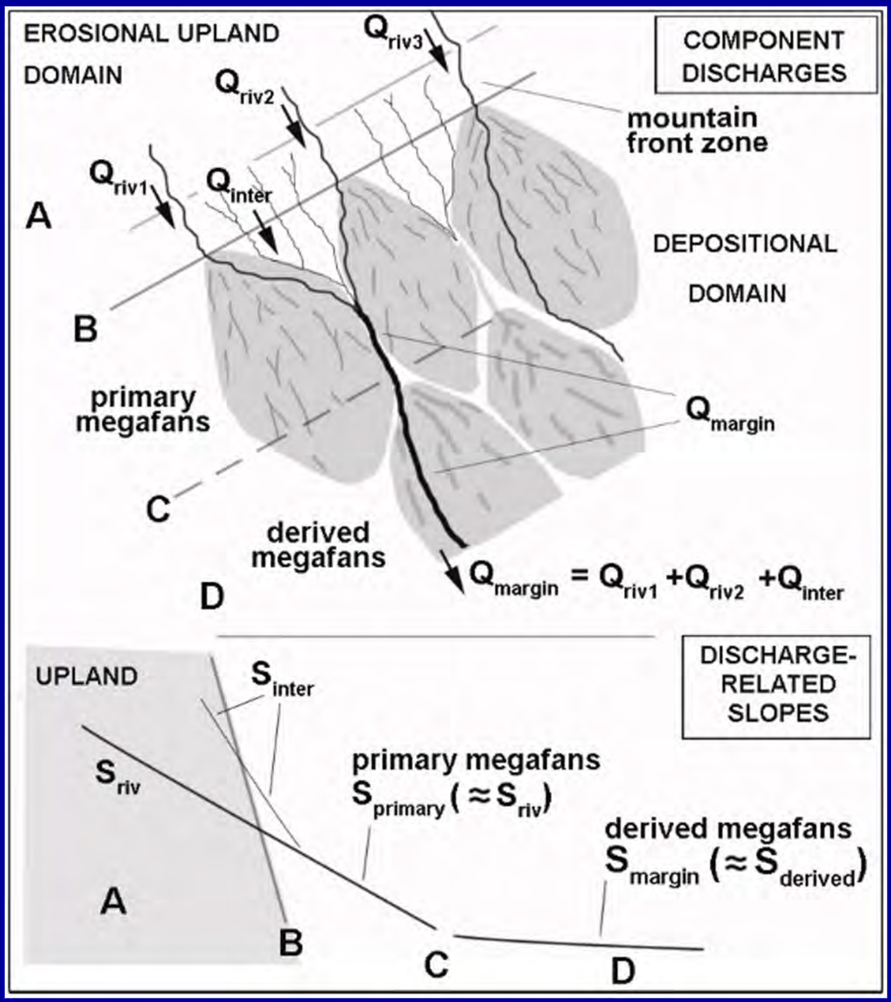
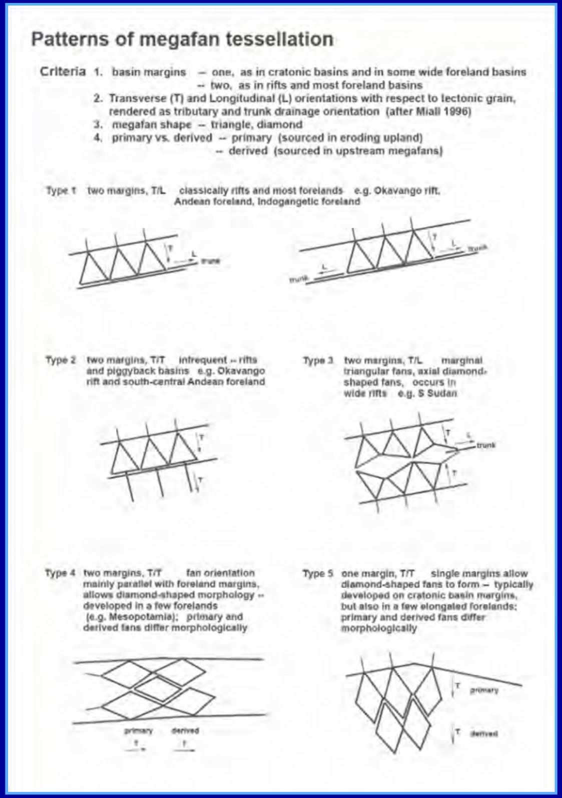
Nesting patterns in single-margin basins —

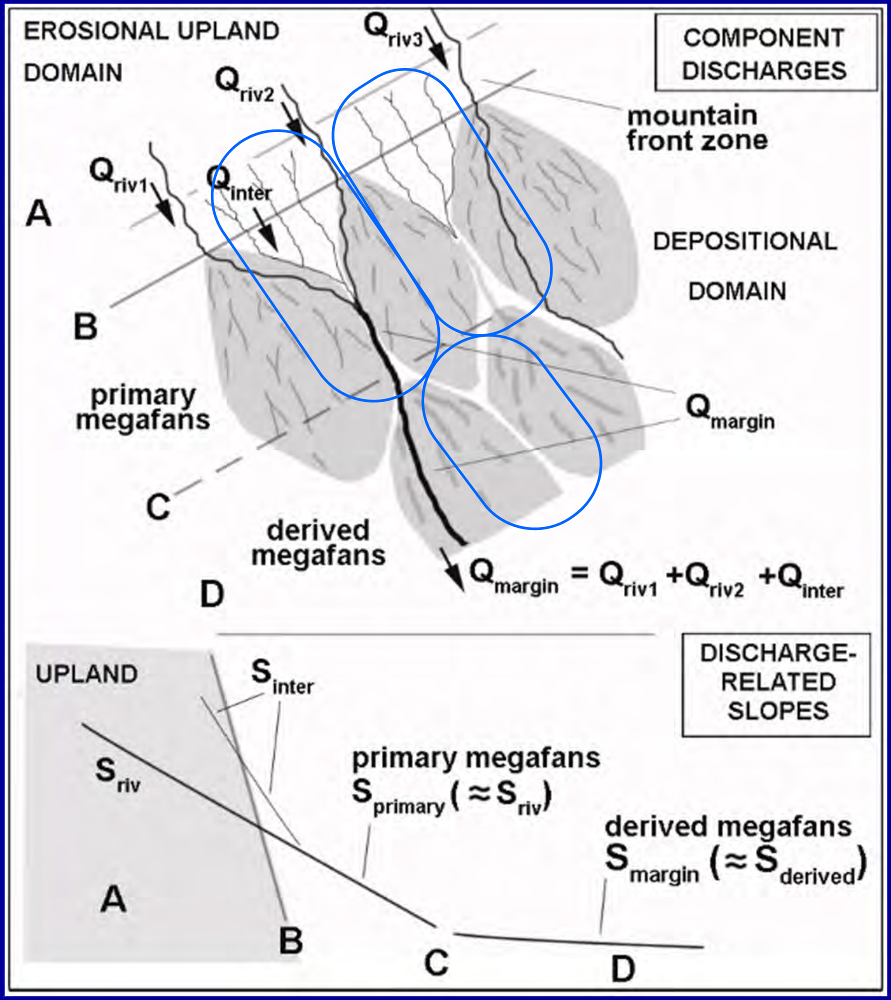
- "primary" LFF
- fan-margin rivers
- "derived" LFF

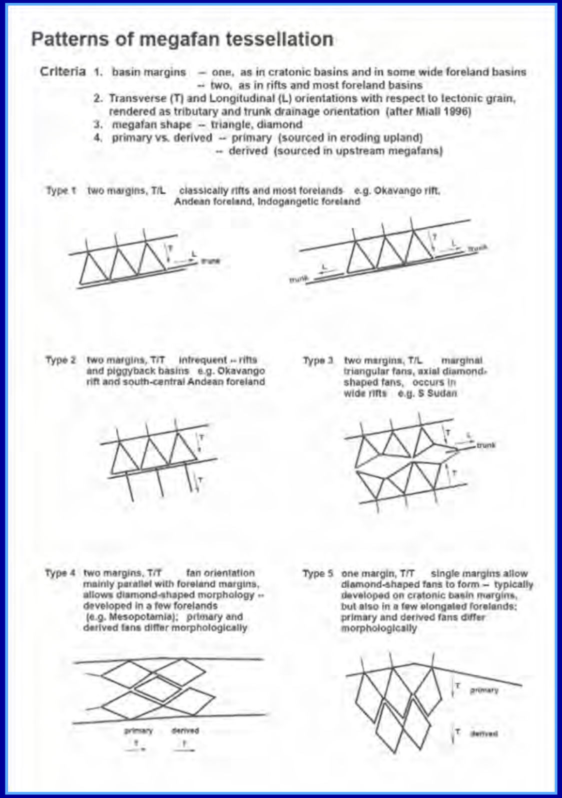




Nesting patterns in single-margin basins —

- “primary” LFF
- fan-margin rivers
- “derived” LFF
- distributary vs. contributary in the same landscape





Nesting patterns —

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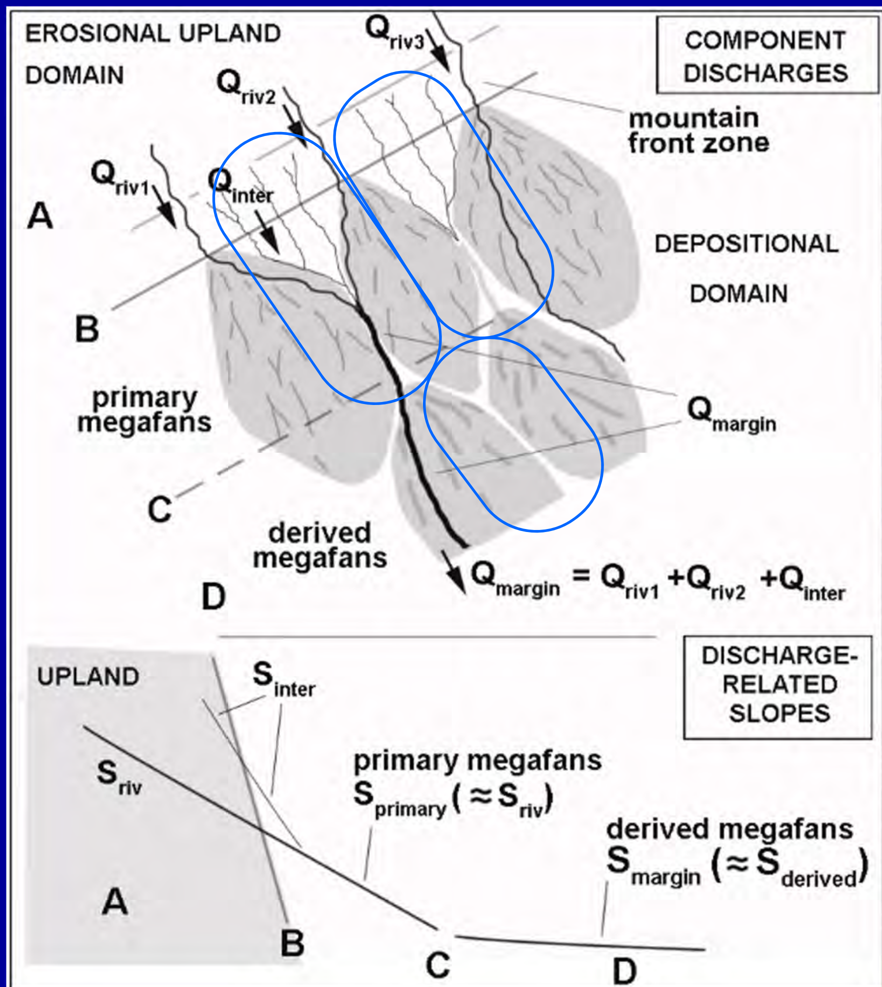
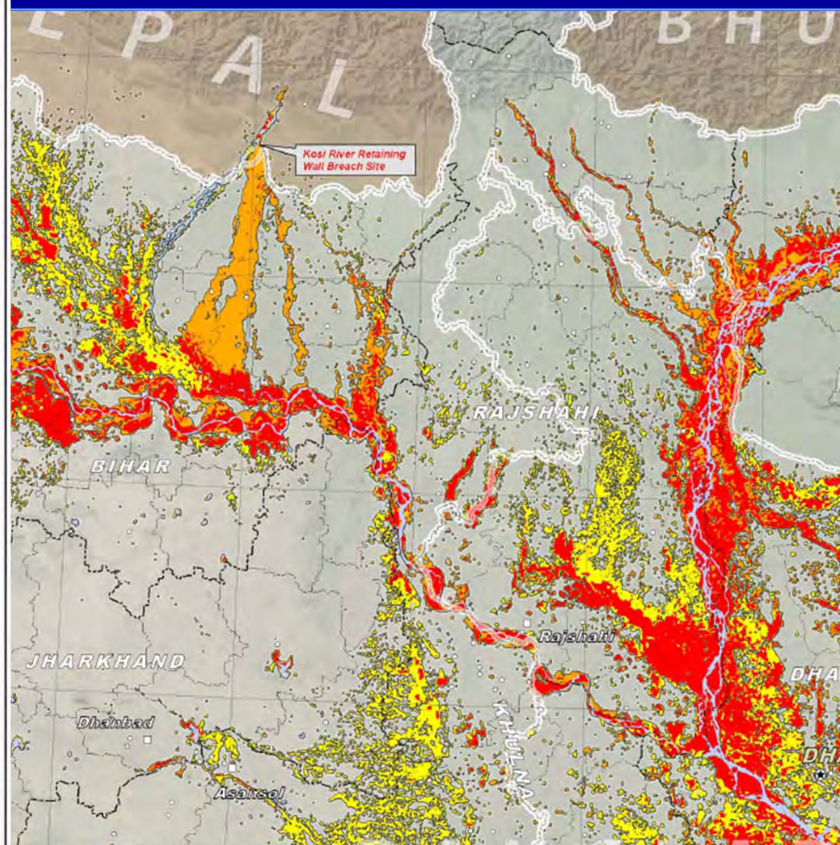
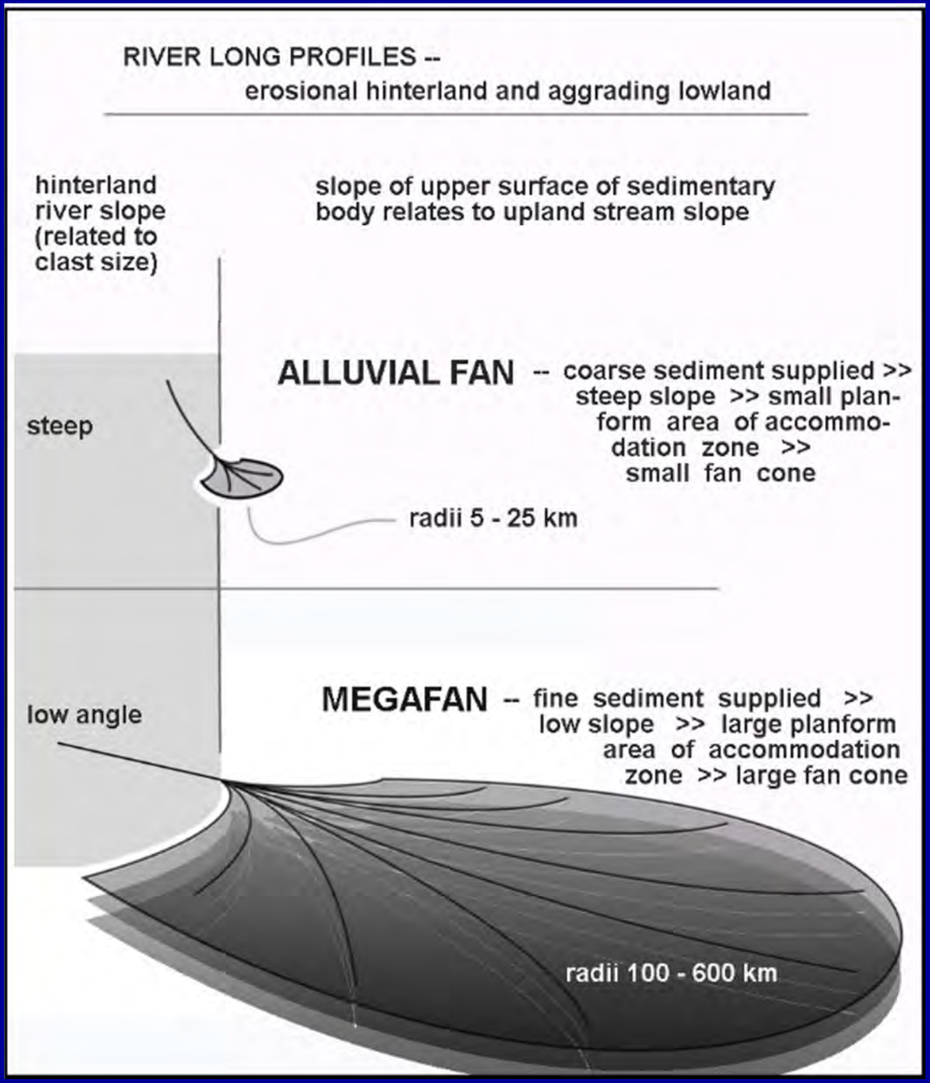




Accommodation — major changes may result from slight changes in slope



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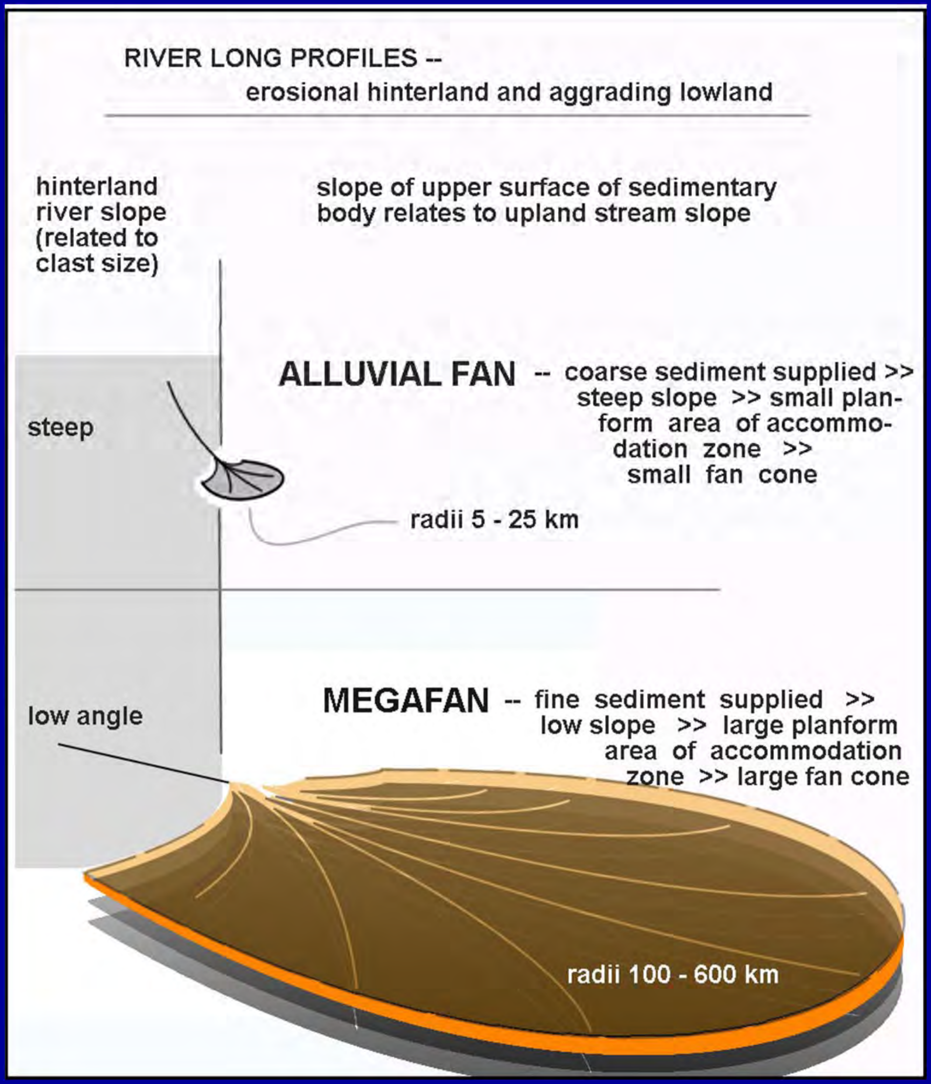
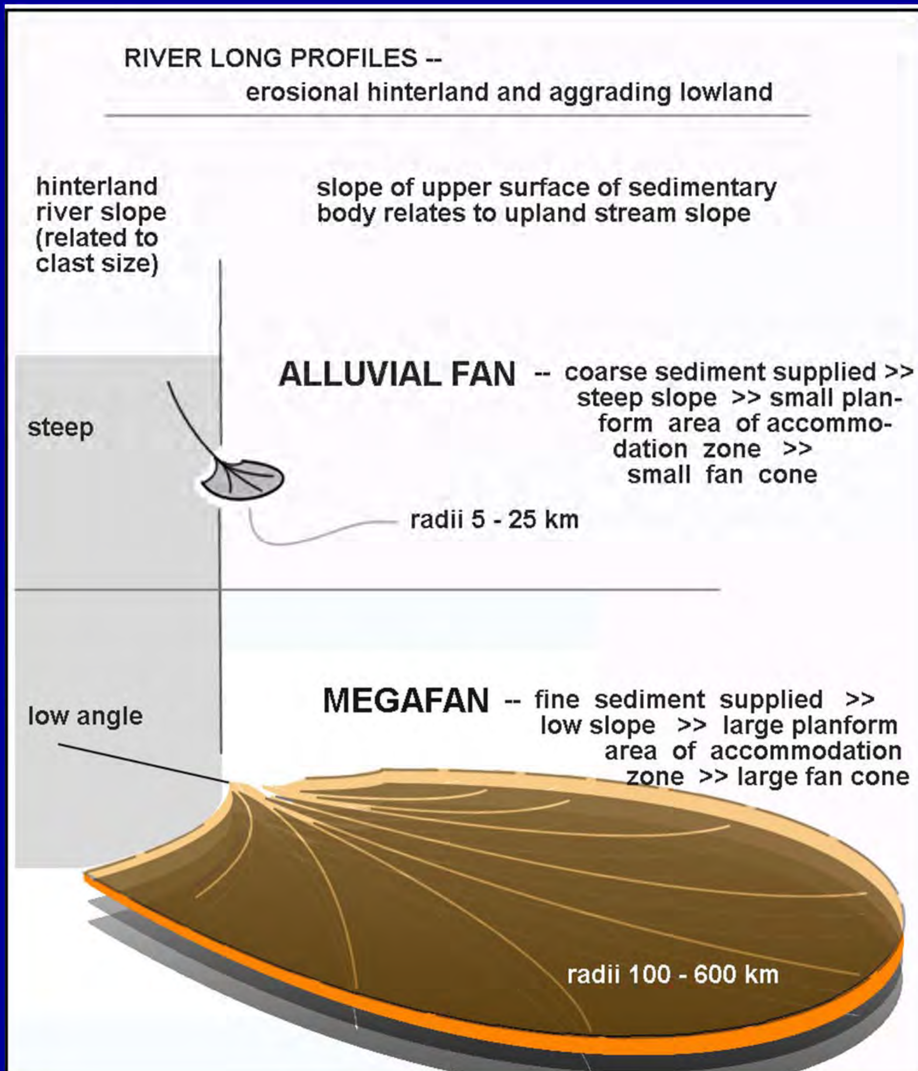


potential accommodation surface

Accommodation — major changes may res



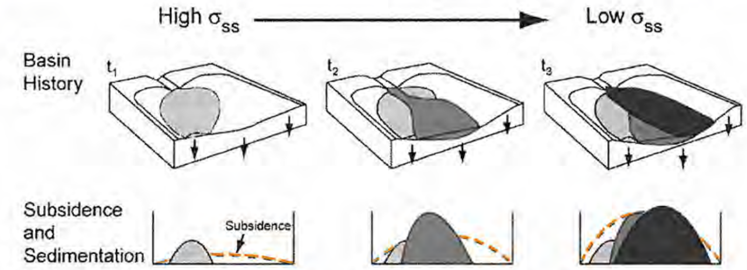
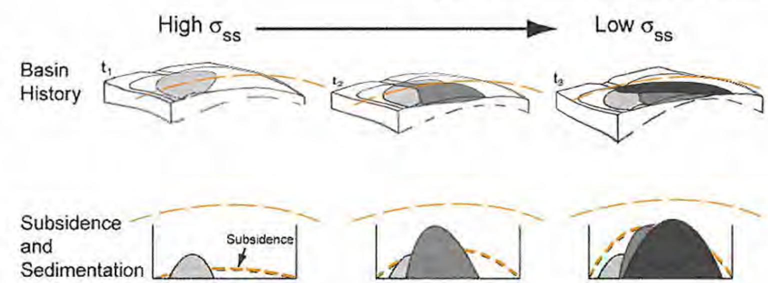


Fig. 3.32 The process by which deposition is gradually distributed across an entire distributive basin, such as an alluvial fan, delta or submarine fan. In deltas the lateral displacement is typically driven by slope advantages, triggered by an avulsion event. In fluvial systems this process is recognizable by the clustering of channels and the rapid displacement of clusters to different

potential accommodation surfaces

Autogenic Processes: Avulsion and Architecture

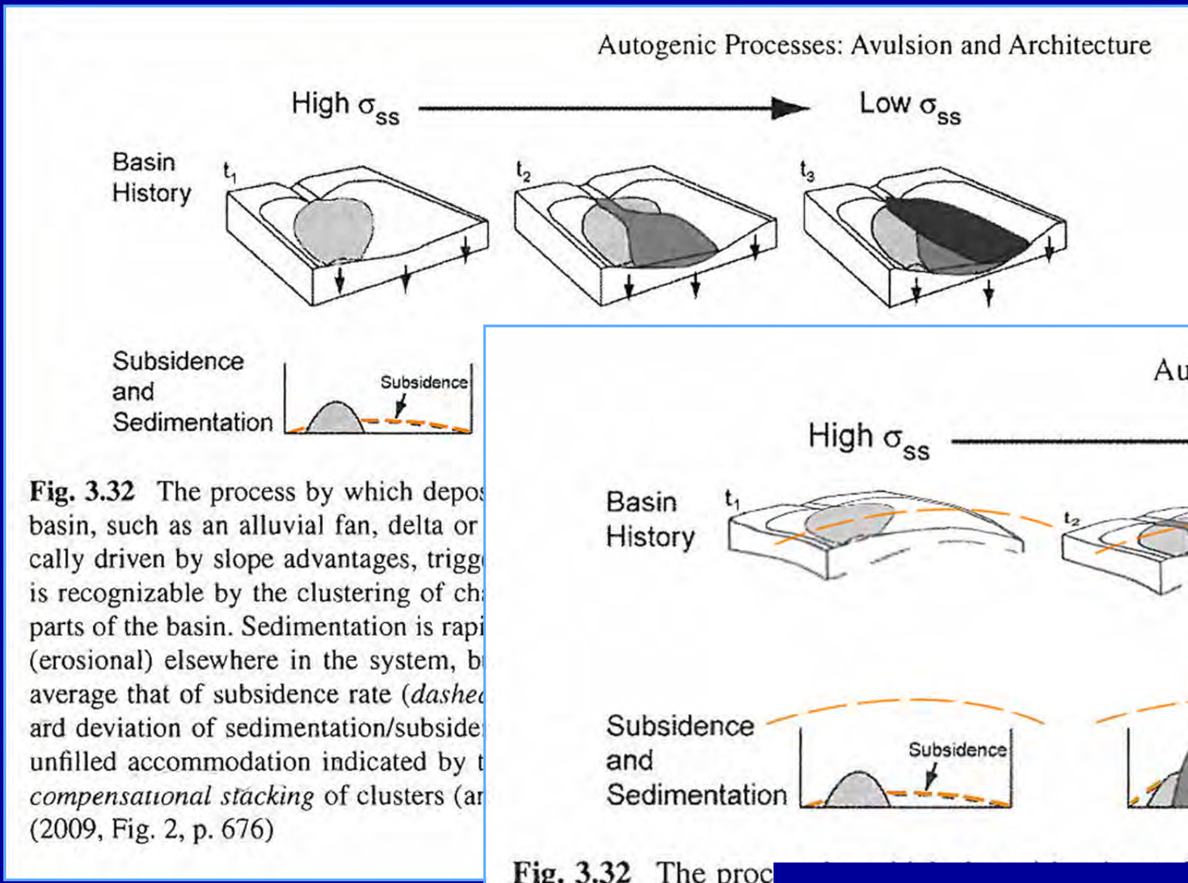


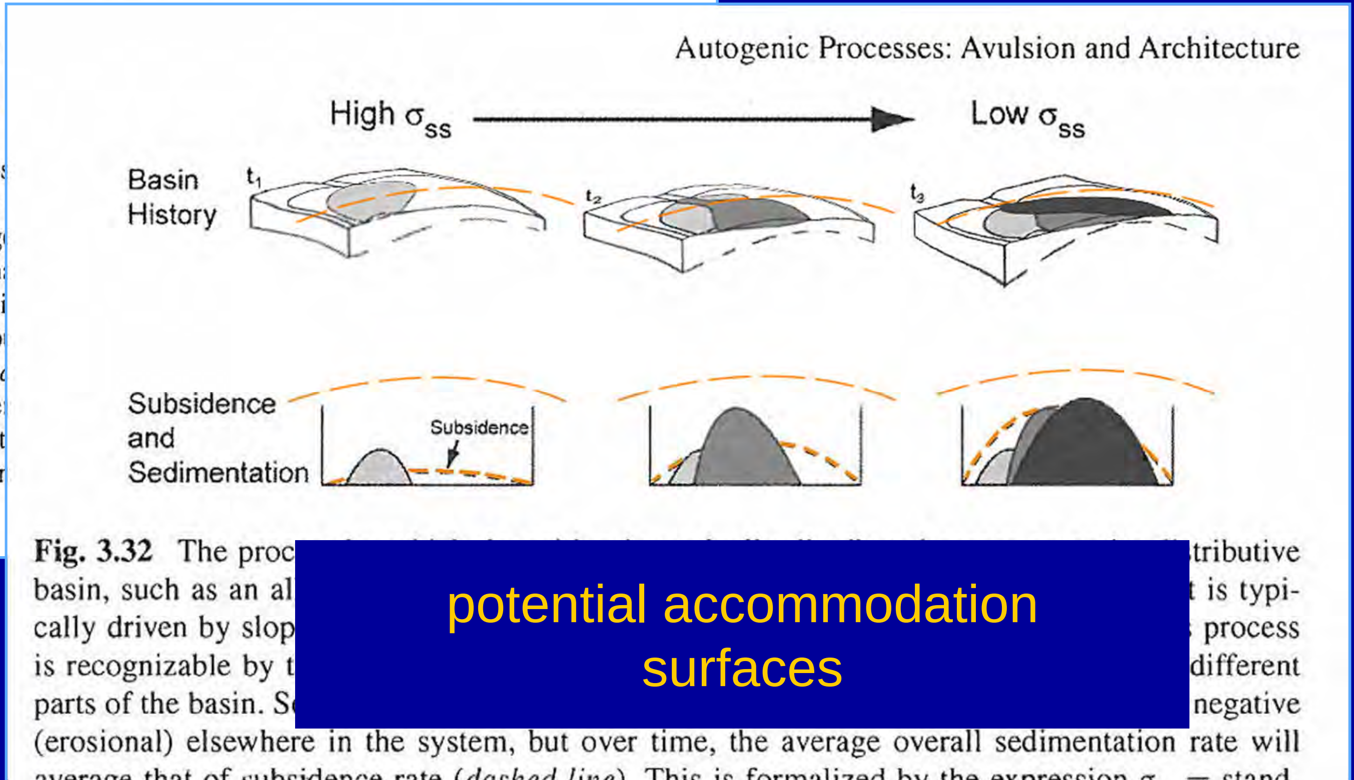
potential accommodation surfaces

ard deviation of sedimentation/subsidence. Successive clusters form following avulsion into the unfilled accommodation indicated by the *white spaces* below the *dashed line*. This can lead to *compensational stacking* of clusters (and delta/submarine fan) lobes. Diagram from Straub et al. (2009, Fig. 2, p. 676)

Accommodation — "unfilled accommodation" (Straub, 2009) —

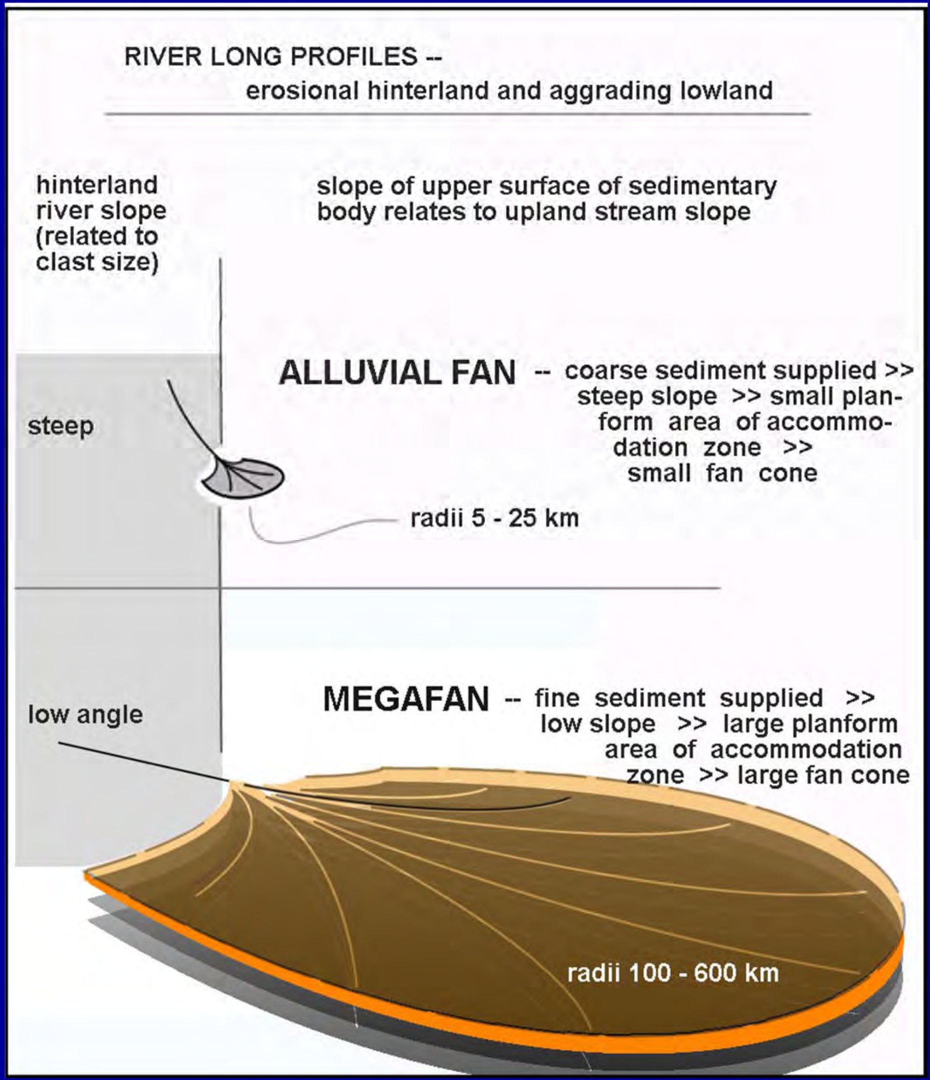
- *a permanent condition on (some) very large LFF surfaces?*
- *what are the controls on lobe development on convex surfaces?*
  - *regional slope ?*
  - *alluvial ridge development (Wang's "roughness") ?*
  - *neighboring fans ?*





potential accommodation surfaces

Accommodation — sediment cascade and "unfilled accommodation" (Straub, 2009) —



question of autogenic avulsion
vs.
assumed filling of allogenically-induced tectonic subsidence

Autogenic Processes: Avulsion and Architecture

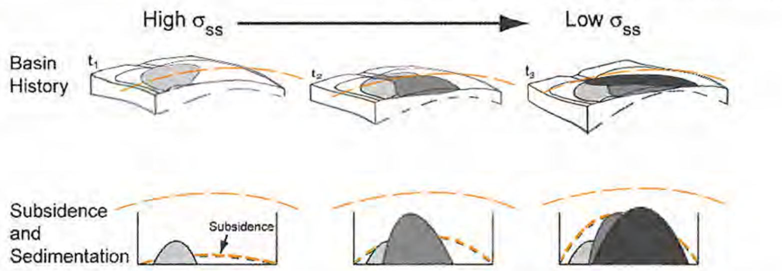


Fig. 3.32 The process by which deposition is gradually distributed across an entire distributive basin, such as an alluvial fan, delta or submarine fan. In deltas the lateral displacement is typically driven by slope advantages, triggered by an avulsion event. In fluvial systems this process is recognizable by the clustering of channels and the rapid displacement of clusters to different parts of the basin. Sedimentation is rapid where clusters are forming, but is slow, zero or negative (erosional) elsewhere in the system, but over time, the average overall sedimentation rate will average that of subsidence rate (*dashed line*). This is formalized by the expression σ_{ss} = standard deviation of sedimentation/subsidence. Successive clusters form following avulsion into the unfilled accommodation indicated by the *white spaces* below the *dashed line*. This can lead to *compensational stacking* of clusters (and delta/submarine fan) lobes. Diagram from Straub et al. (2009, Fig. 2, p. 676)

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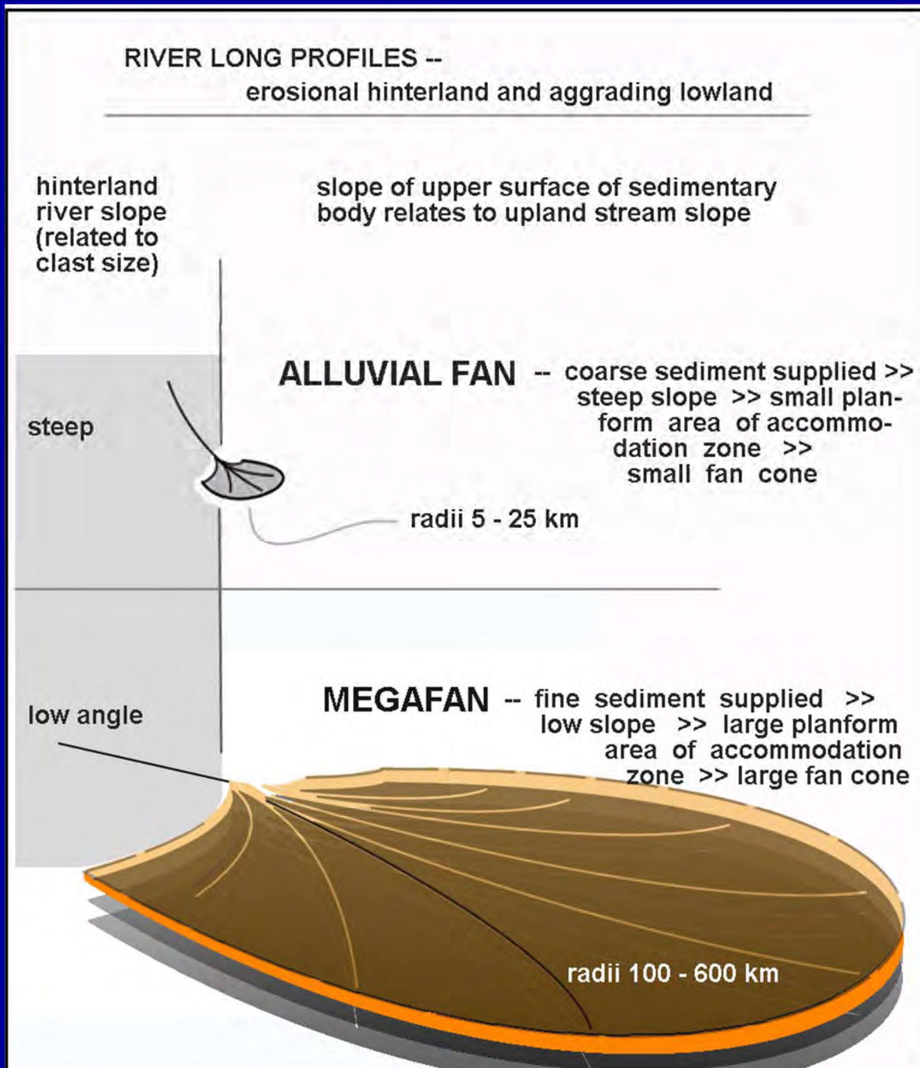

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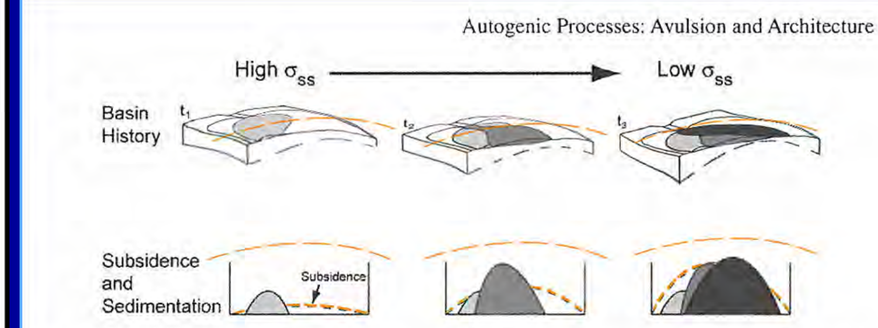

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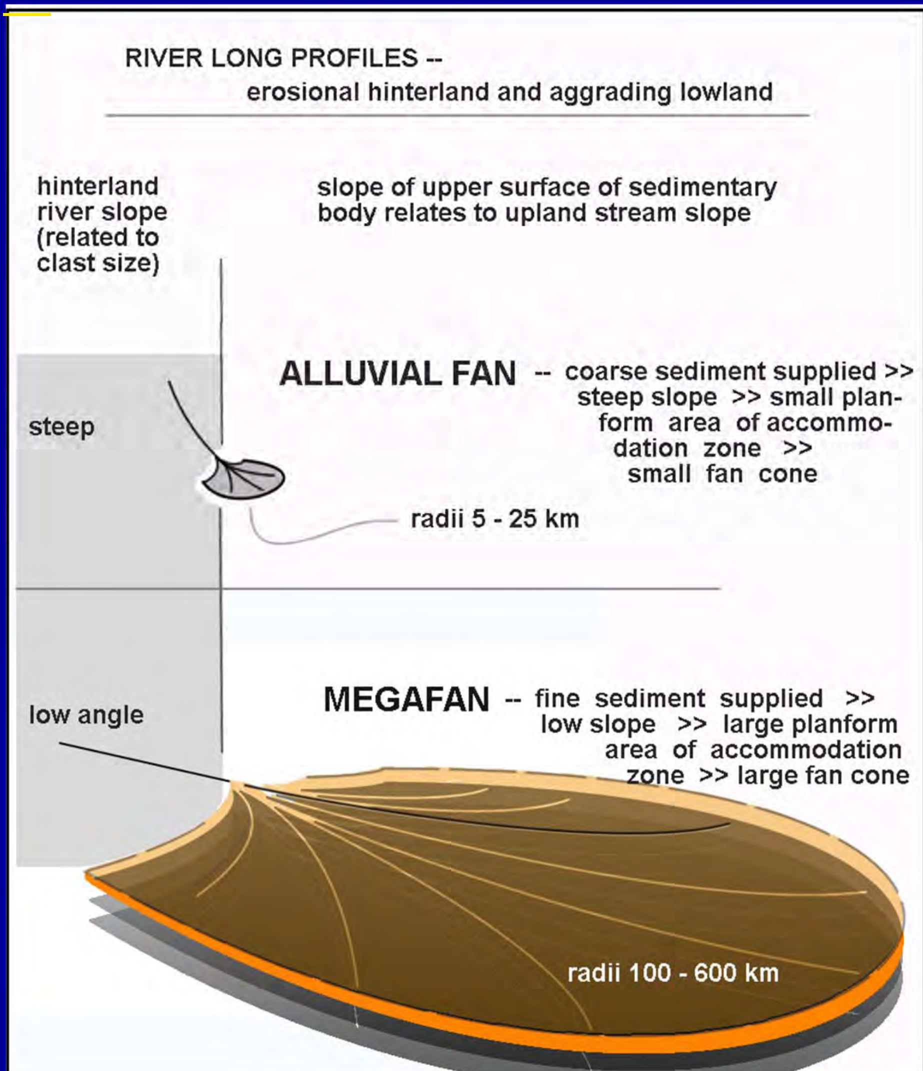

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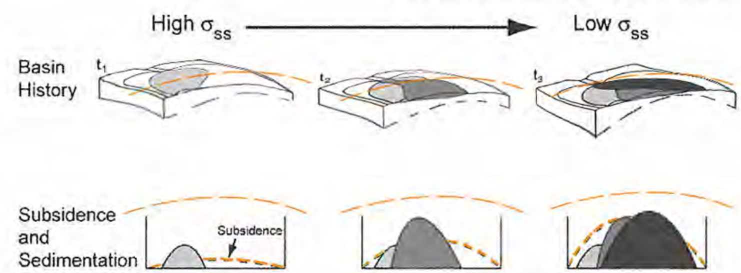

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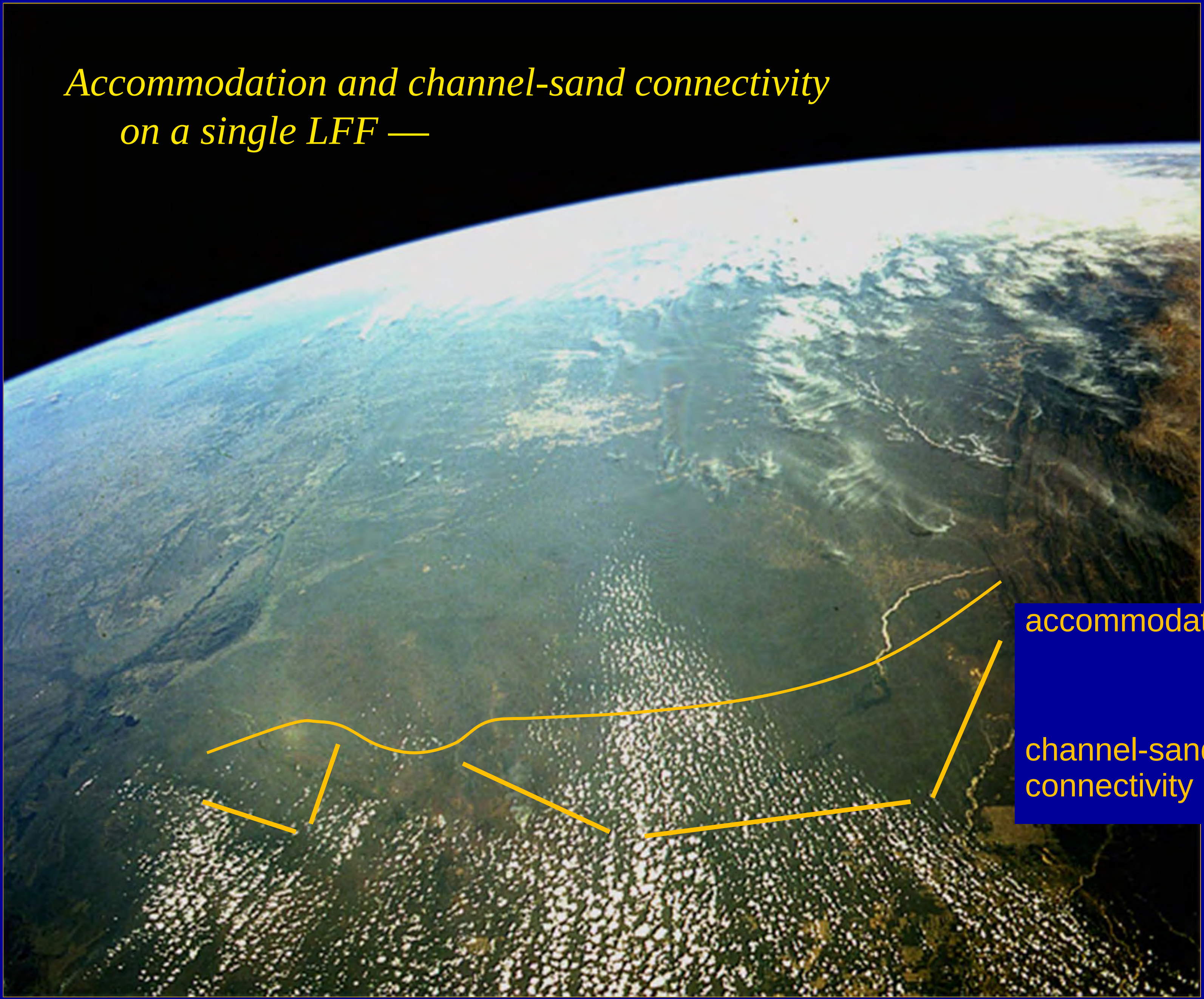
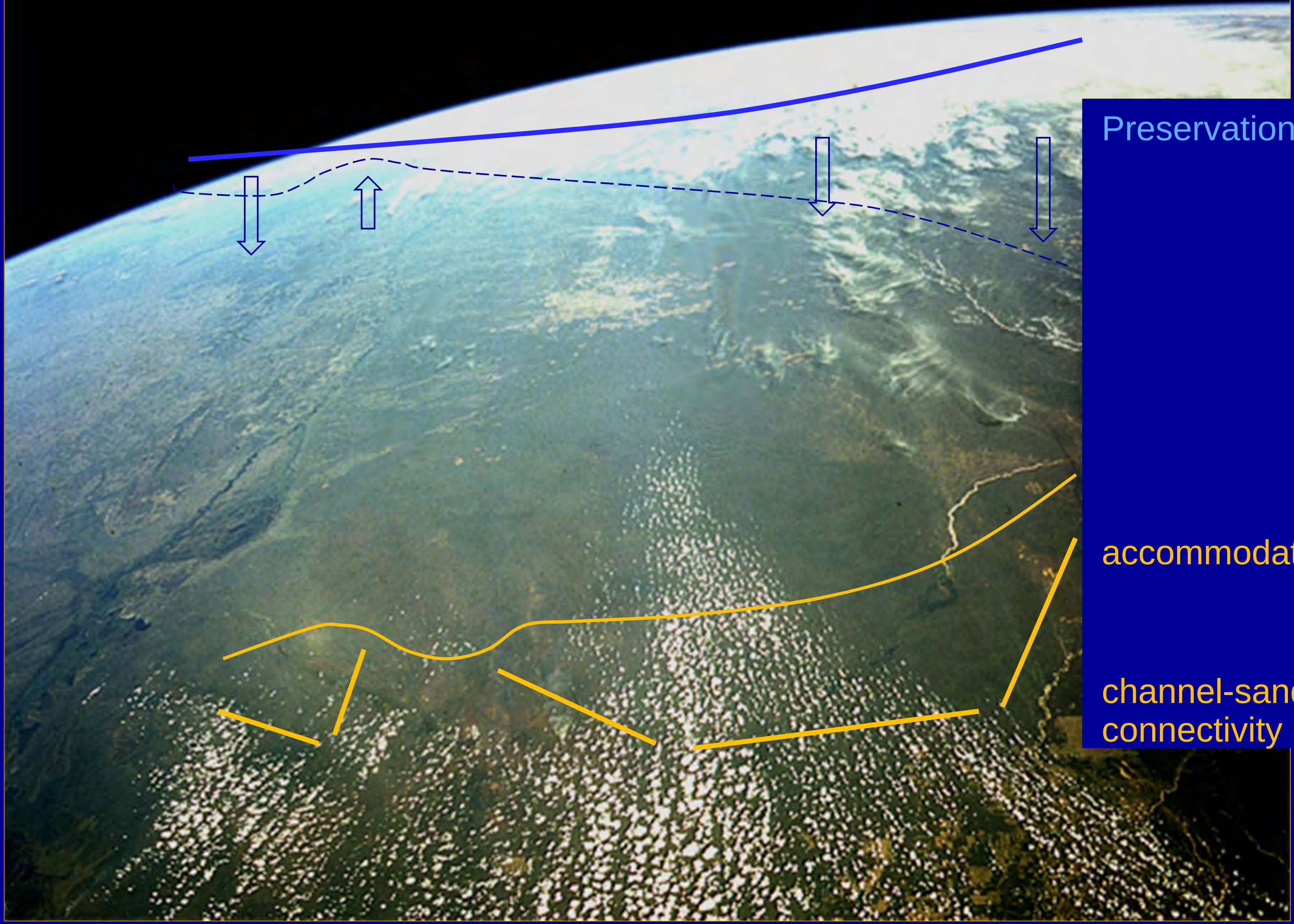
Accommodation and channel-sand connectivity on a single LFF —



Megafans of northern Argentina and Paraguay

LFF and the sedimentary record —



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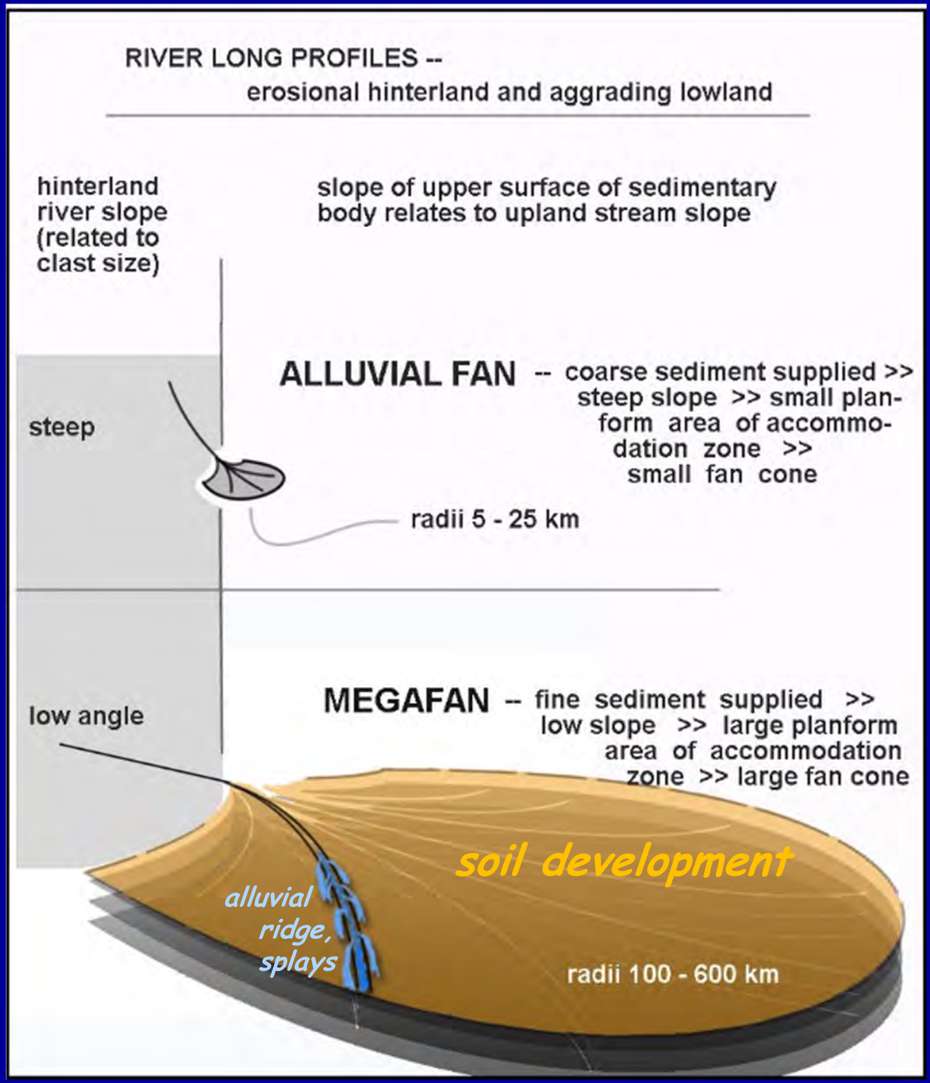
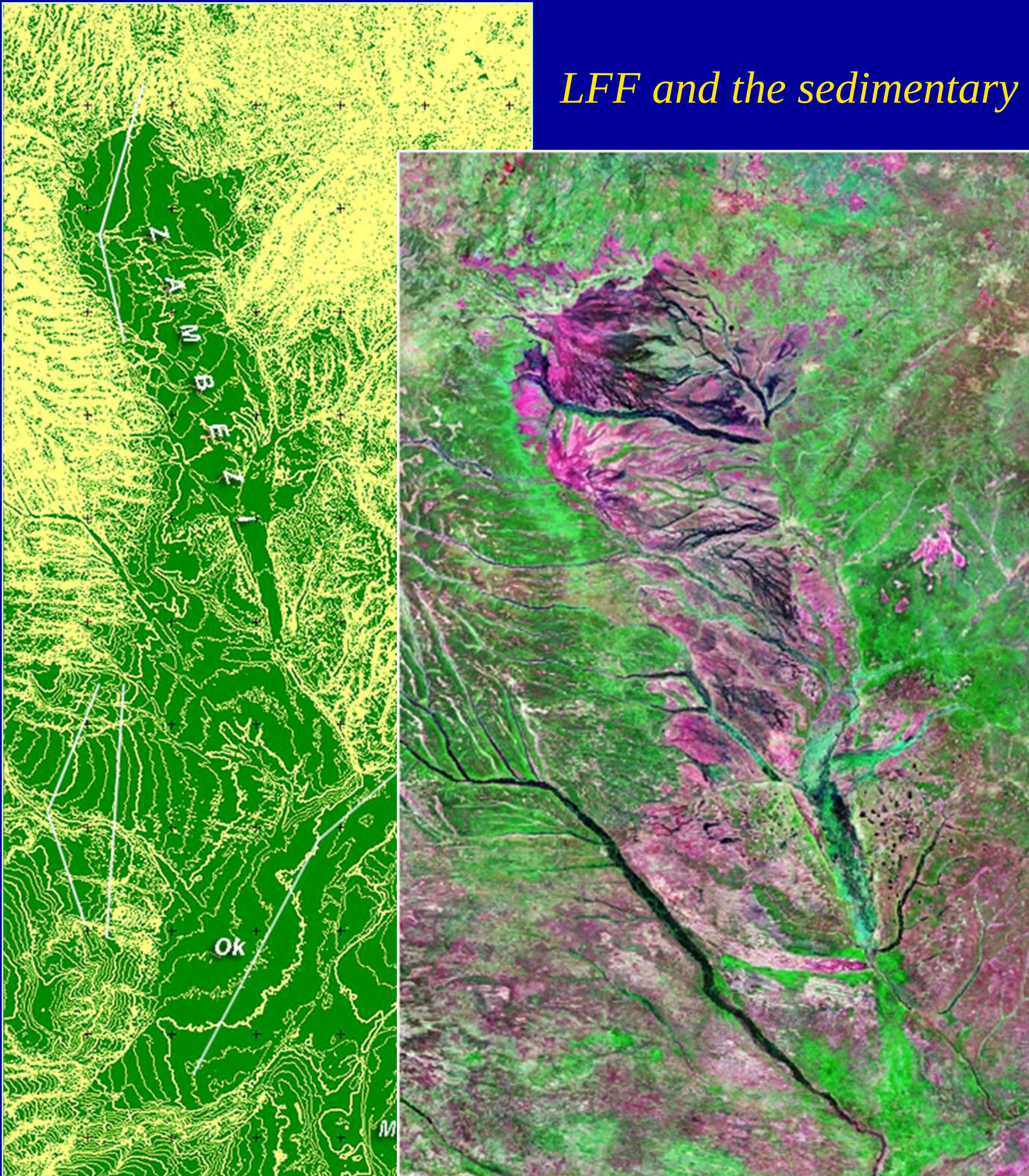
LFF and the sedimentary record — pedogenic units —



LFF and the sedimentary record — pedogenic units —



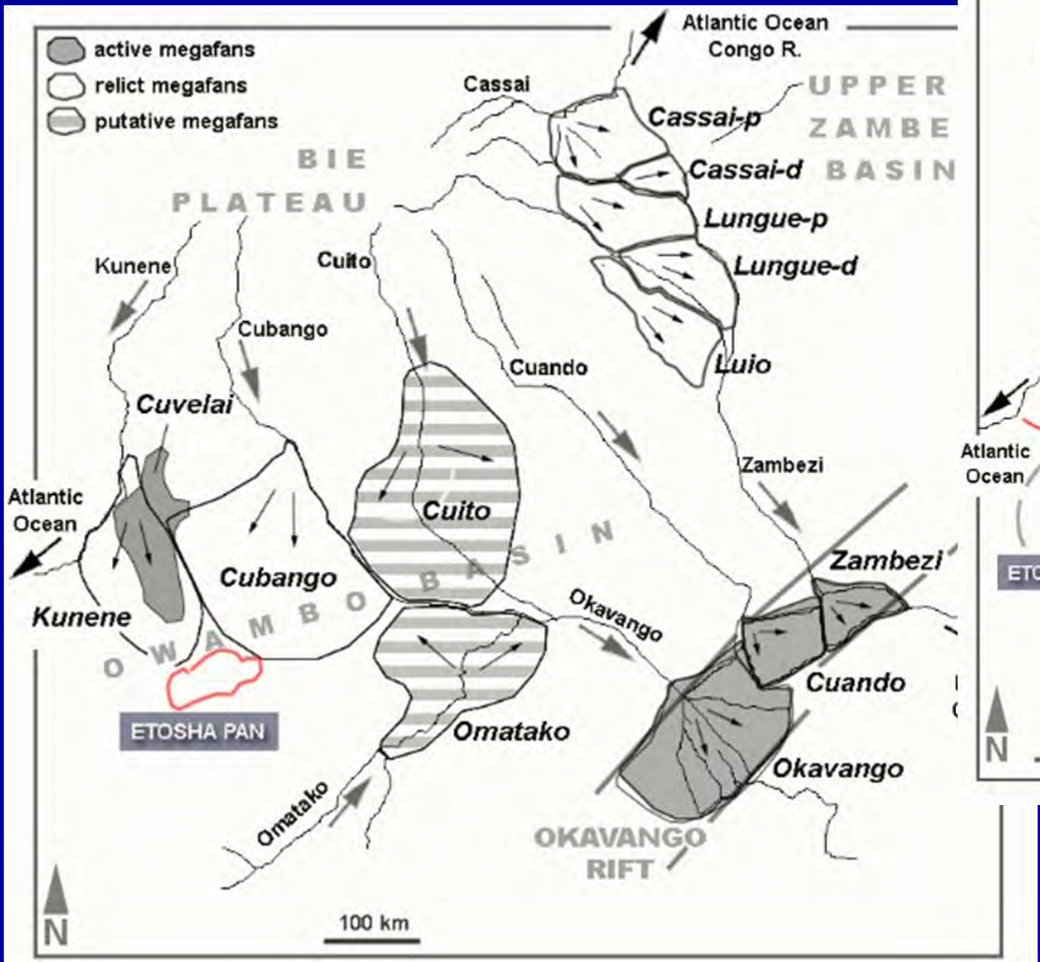
LFF on basin divides

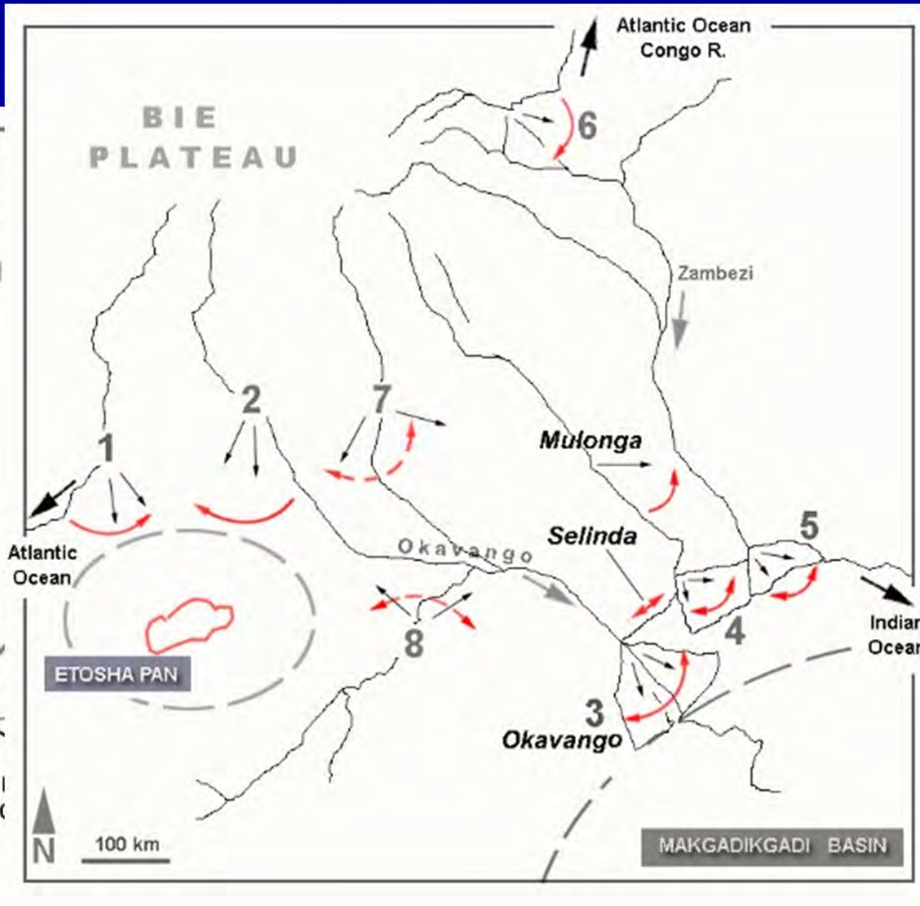
and the sedimentary record—

Bié Swell and Kalahari basin —

LFF on basin divides —

and the sedimentary record —

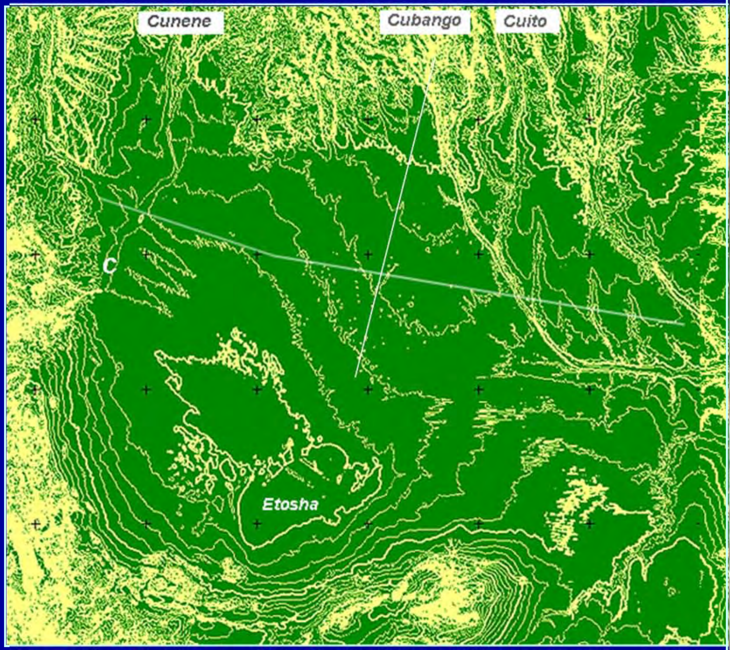


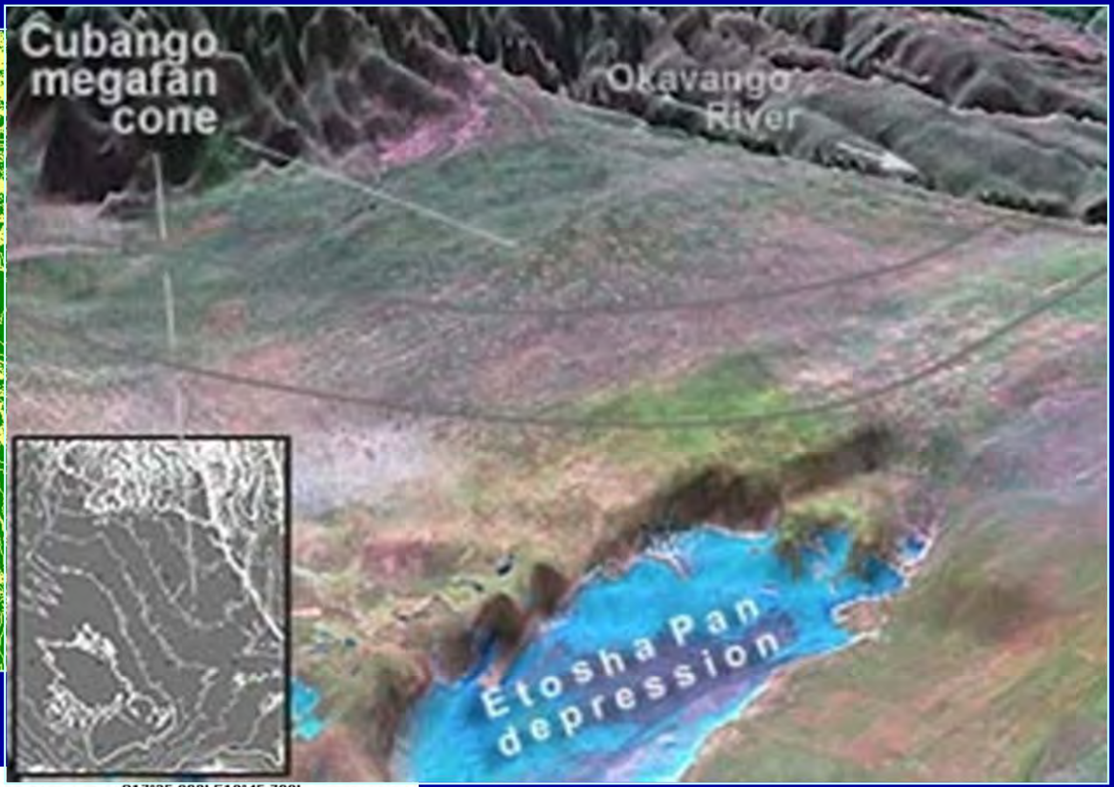


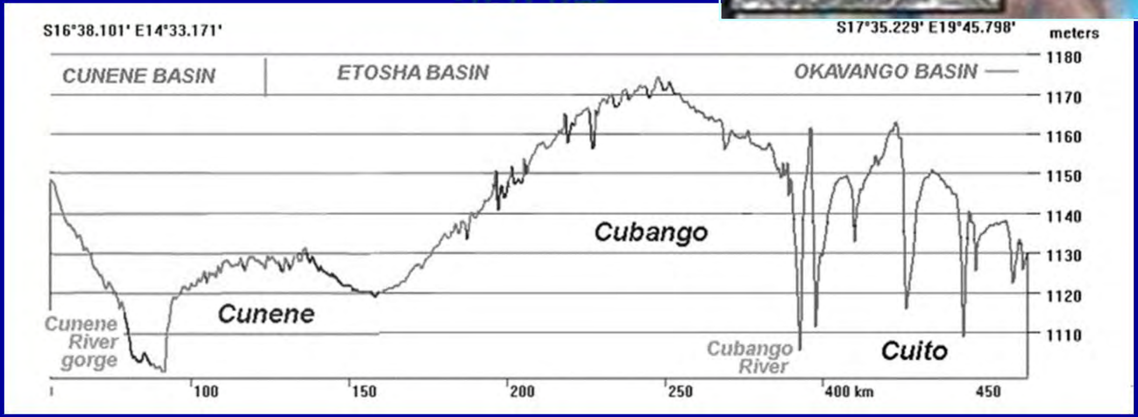
An aside: well-known fan-feeder basin relationship — $A_f = c\, A_d^{\,n}$ —

does not hold in the Okavango rift

Cubango LFF — two superimposed aquifers recently discovered —







LFF landsurfaces —

- *LFF and nested LFF landsurfaces lie firmly in the mesoscale landscape/sediment body category*

LFF planform and drainage patterns —

- *triangles, diamonds*
- *associated radial and tributary patterns*
- *contributary vs. distributary flow overlap — not straightforward at the fluvial mesoscale*

Nesting patterns / Tessellation —

- *Six types*

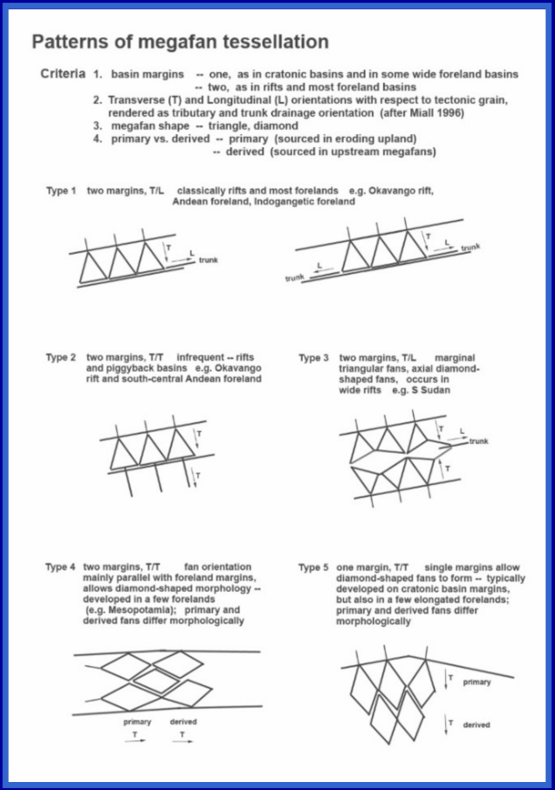
Accommodation —

- *Issues significantly different from individual rivers, even axial rivers*

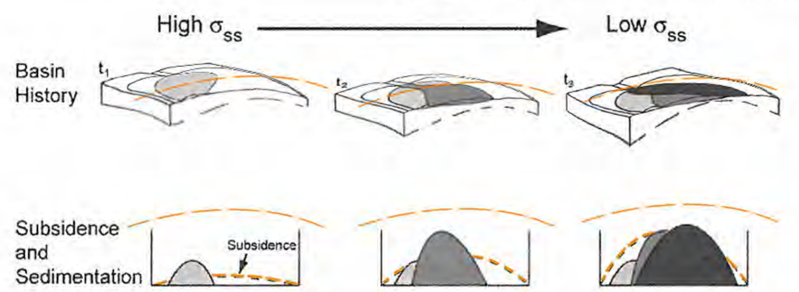
Sedimentary record —

- *LFF drainage diversions*
- *pedogenic units*
- *relation to incised valleys ?*

Applications — numerous



Autogenic Processes: Avulsion and Architecture



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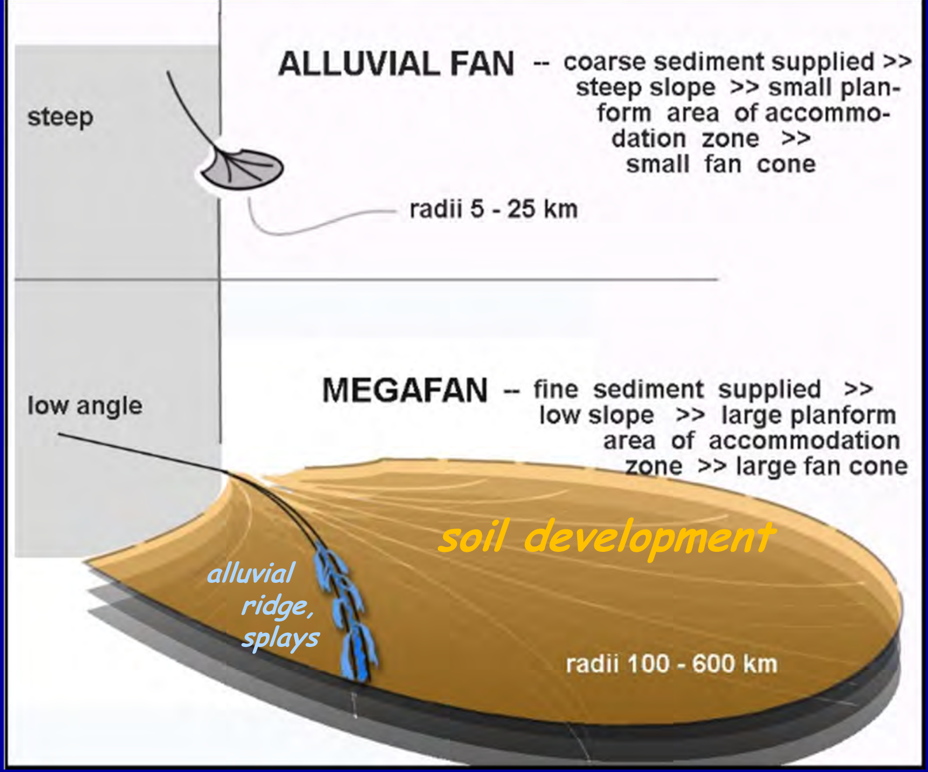
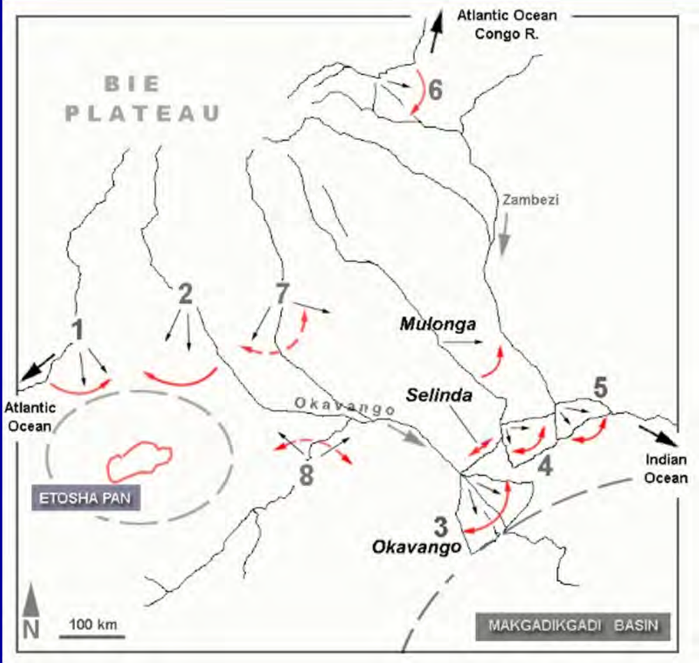
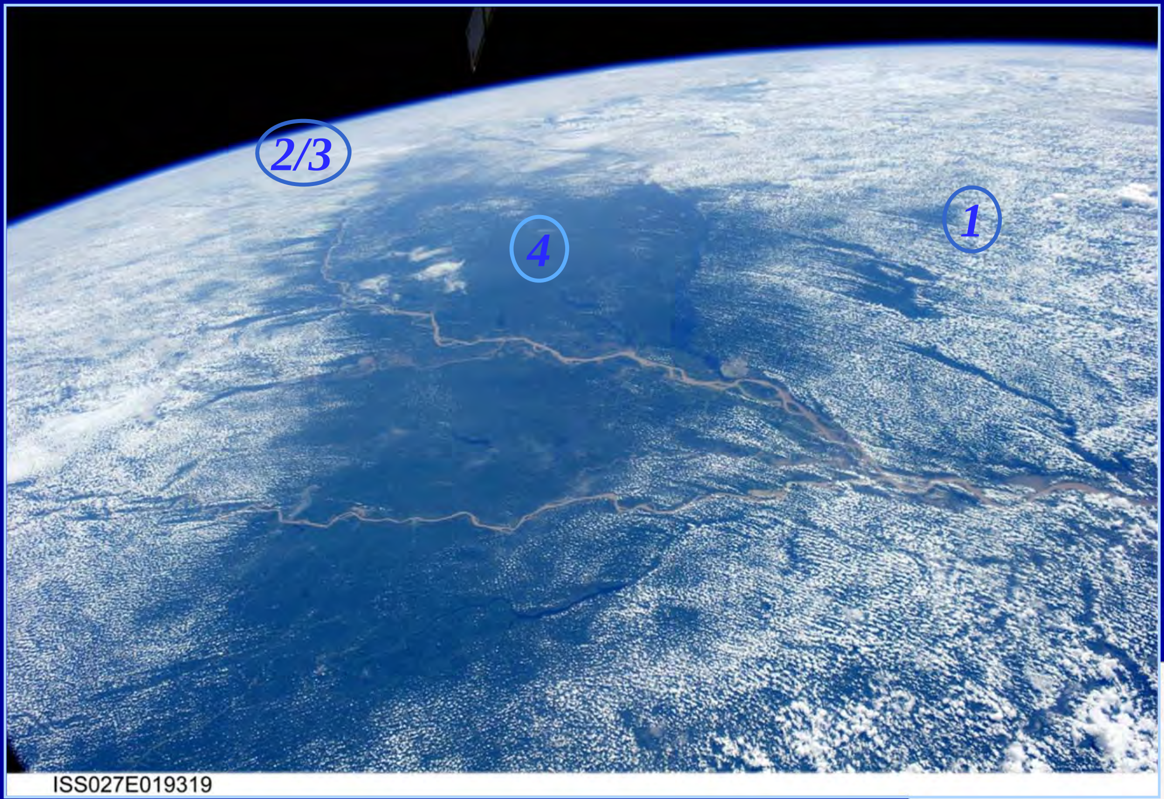
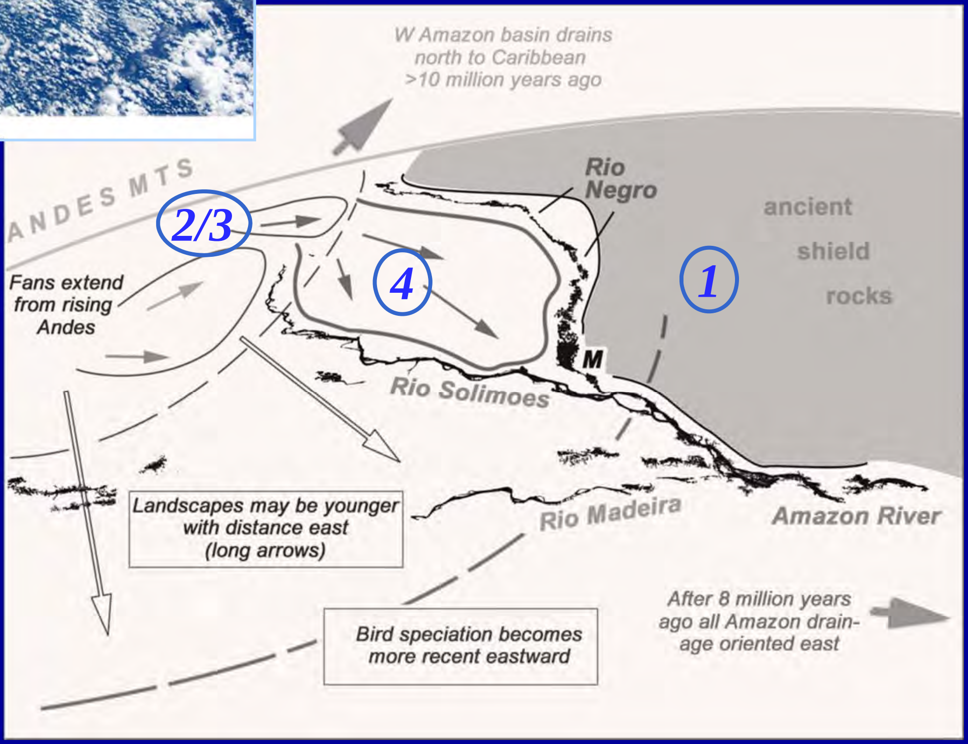


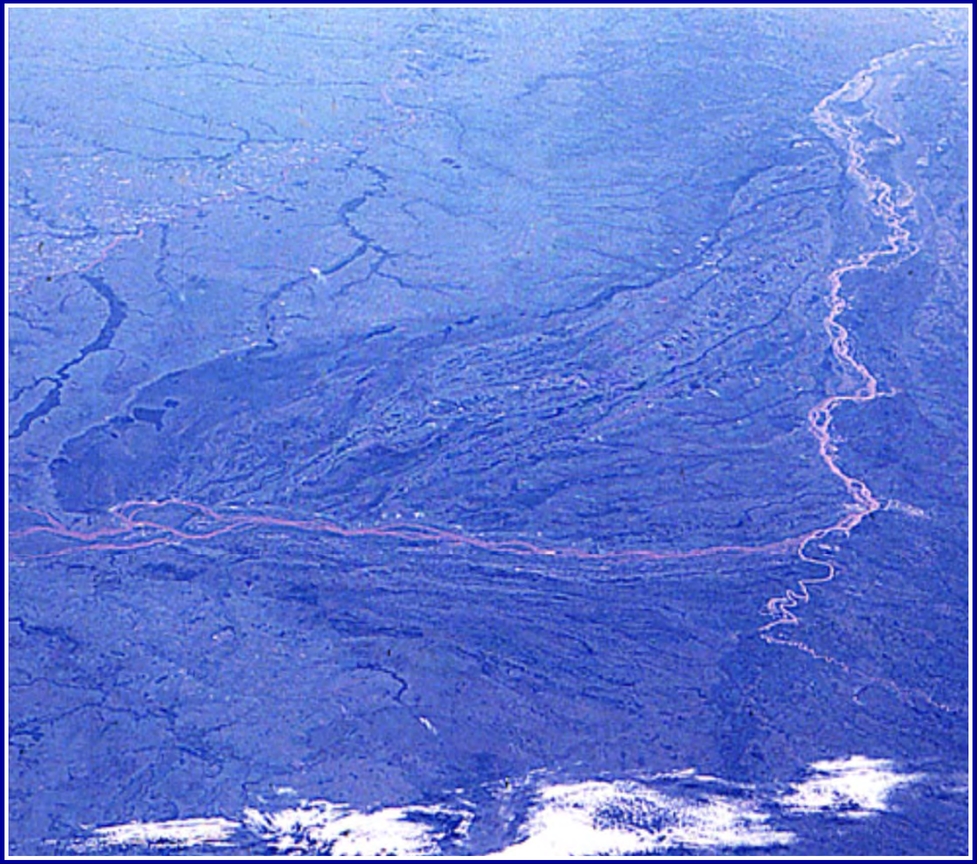




Landform ages—that include megafan surfaces—coincide well with ages of some trumpeter bird species —

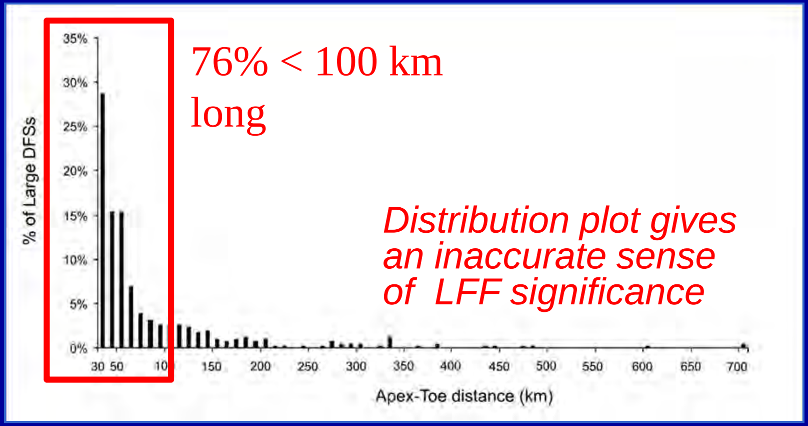


Floodplains at one scale, but LFF at another —



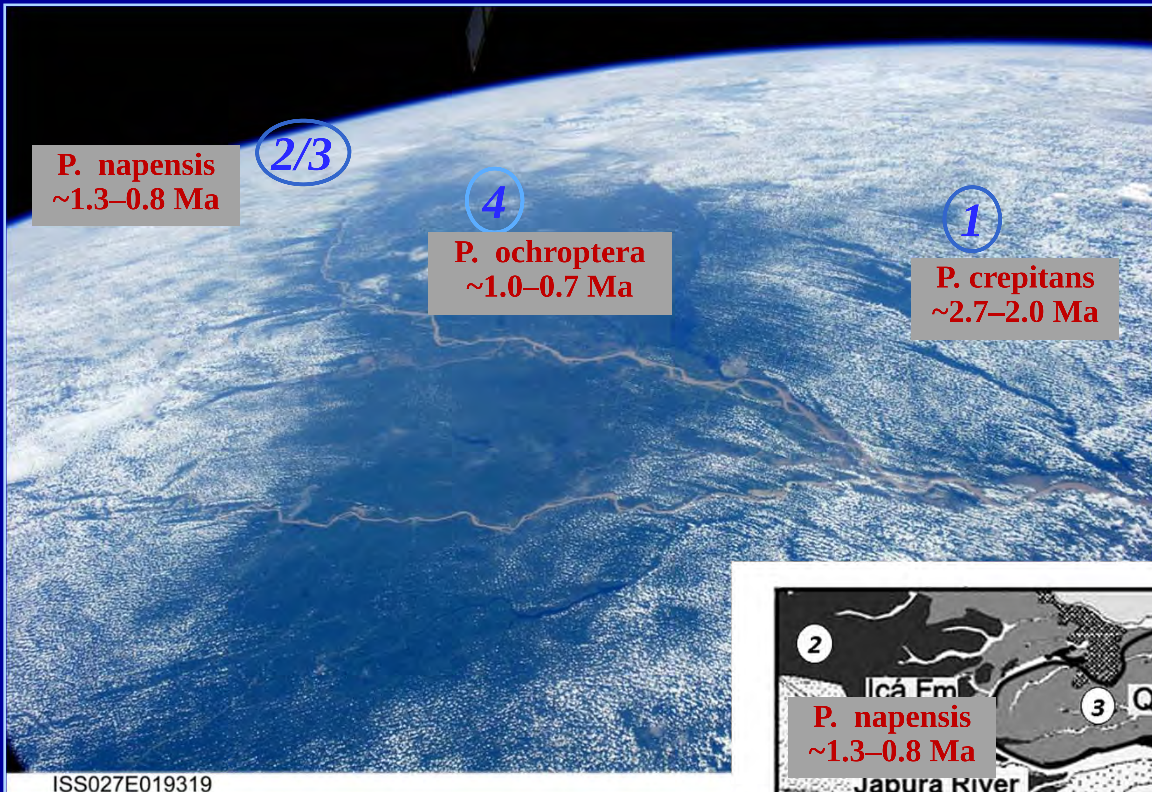
Accommodation — Contiguous LFF amount to vast areas —

cultural aspects of geology?



- low LFF frequency gives a false sense of LFF significance
- paleogeographic reconstructions in geology generally fail completely to recognize such landscapes —
  - landscapes without —
    - floodplains in the normal sense
    - hillsides/valley walls
  - landscapes WITH —
    - floodplain features very extensively developed

roughness map



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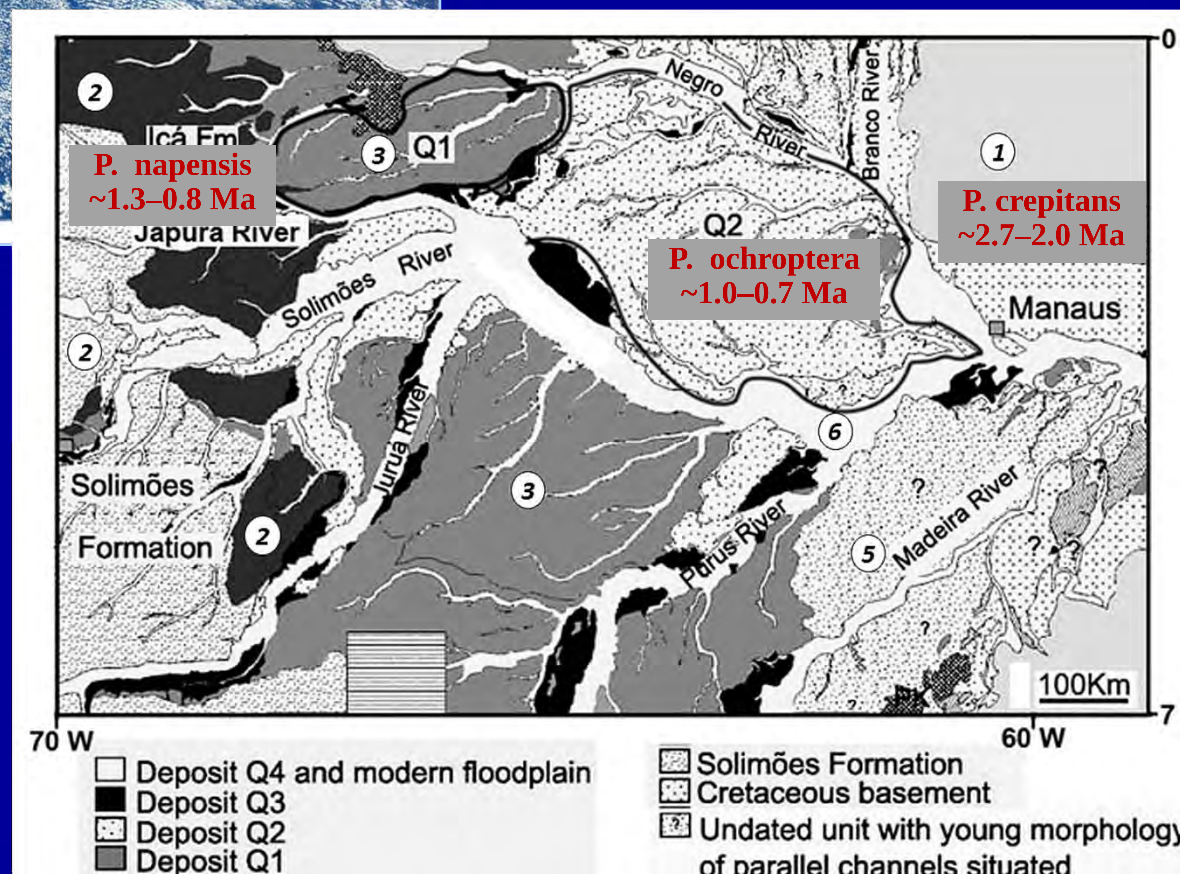

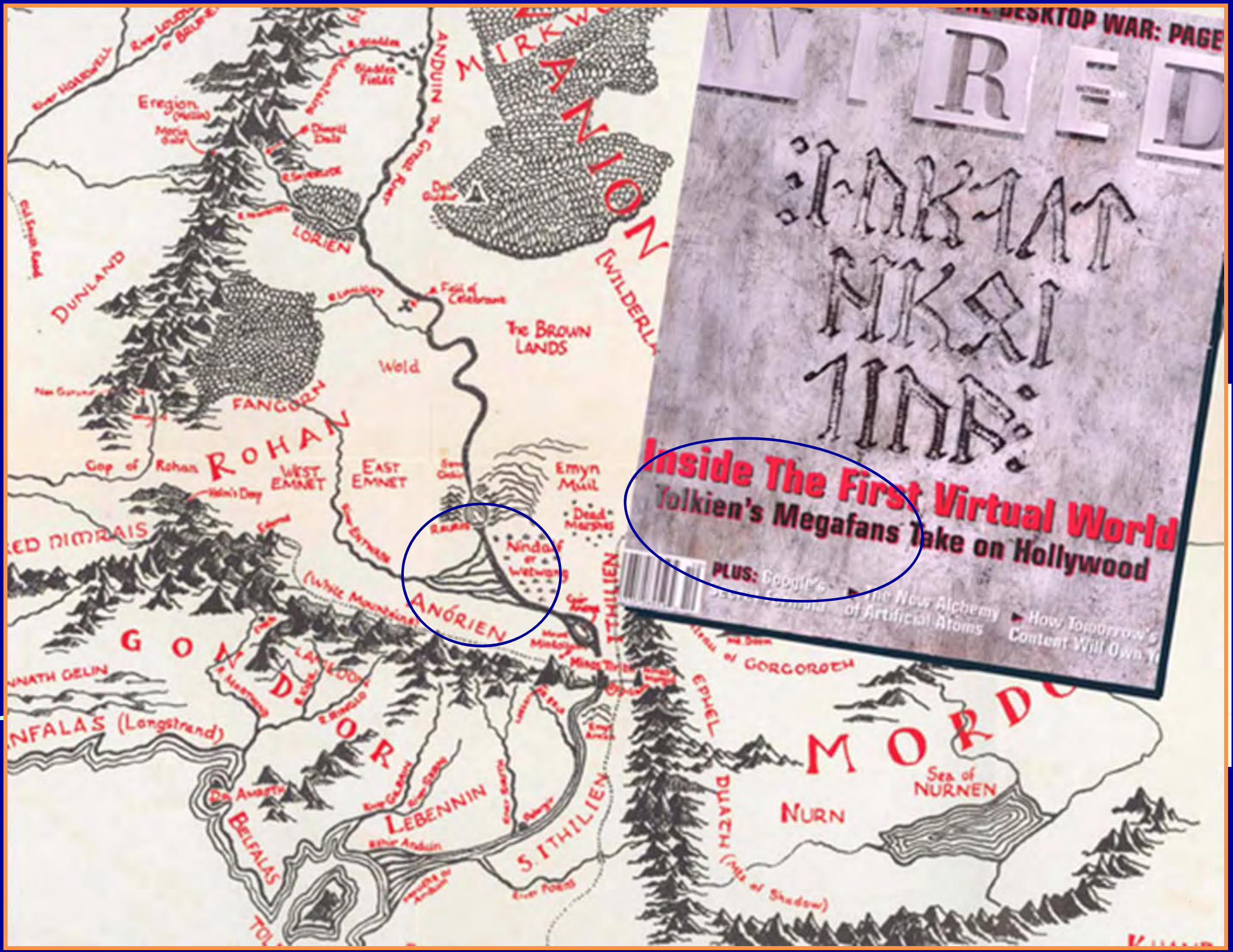

Middle Earth —
Lord of the Rings
Tolkein 1974