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

Justin Wilkinson

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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 km²) and nested LFF (750,000 km² 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.

References Cited


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 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

**LFF-formed land surfaces —**
- single LFF — up to 200,000 km²
- contiguous LFF in S America 0.75 m km²

**Planform and channel pattern —**
- Triangle and diamond — Kosi, Tista
- Proximal-distal channel patterns, apex vs. distal, subapaxes
- *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 —**
Blair and McPherson (1994) proposed that:

- There is no meaningful (lithologic?) difference between large fluvial fans (LFF) and floodplains.
- The building blocks of both are channel-levee-overbank deposits.
- Restricted "alluvial fan" designation to features <20 km long.

LFF are:
- Relatively unstudied.
- Fluvial sediment bodies.
- >100 km in length.
- Fan-shaped in planform.
- >170 identified globally.
Kosi River avulsions —
- cross entire surface of fan
- average rate ~19 yr between switching events
Global study — Criteria for recognition of LFF — as bodies of sediment — by remote sensing means —

<table>
<thead>
<tr>
<th>A</th>
<th>Setting — feasible water and sediment source —</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>topographic margin: juxtaposed upland and lowland</td>
</tr>
<tr>
<td>2</td>
<td>river: upland river flowing into neighboring lowland</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th>Morphological characteristics —</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dimensions: &gt; ~80 km long (width &gt;40 km)</td>
</tr>
<tr>
<td>2</td>
<td>surface morphology: smooth surface (low roughness signatures)</td>
</tr>
<tr>
<td>3</td>
<td>: partial cone (at least proximally)</td>
</tr>
<tr>
<td>4</td>
<td>: cone apex (or remnant) near river exit-point from upland</td>
</tr>
<tr>
<td>5</td>
<td>: low declivity (&lt;1 degree)</td>
</tr>
<tr>
<td>6</td>
<td>: continuous slope away from upland</td>
</tr>
<tr>
<td>7</td>
<td>drainage patterns: radiating from the apex</td>
</tr>
</tbody>
</table>
Global study — Criteria for recognition of LFF — as bodies of sediment — by remote sensing means

we included upper radial plus contributary drainage patterns in our criteria
LFF length — river slope is a critical control
Hierarchy —
LFF and nested LFF are mesoscale features, each integrated systems.

<table>
<thead>
<tr>
<th>Group</th>
<th>Time scale (yr)</th>
<th>Abbreviated hierarchy of fluvial sedimentary bodies (architectural elements)</th>
<th>megafan (radius &gt;100 km) distributary systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>$10^5-10^3$</td>
<td>shallow channels, large stream-bed macroforms</td>
<td>shallow channels, large stream-bed macroforms</td>
</tr>
<tr>
<td>7</td>
<td>$10^3-10^4$</td>
<td>fan trench backfill, channels</td>
<td>channels</td>
</tr>
<tr>
<td>8</td>
<td>$10^4-10^5$</td>
<td>alluvial fan, channel belt</td>
<td>channel belt, packet of channels</td>
</tr>
<tr>
<td>9</td>
<td>$10^6-10^6$</td>
<td>delta, alluvial fan tract, major depositional system axis (Gulf of Mexico coast depositional axes)</td>
<td>megafan</td>
</tr>
<tr>
<td>10</td>
<td>$10^6-10^7$</td>
<td>smaller basin-fill complexes (Tertiary fms., Gulf of Mexico coast)</td>
<td>set of nested megafans</td>
</tr>
<tr>
<td>11</td>
<td>$10^7-10^8$</td>
<td>larger basin-fill complexes (Triassic Molteno Fm., Karoo basin)</td>
<td></td>
</tr>
</tbody>
</table>

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

* adapted from Miall (1996) and DeCelles et al. (1991).
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 ©MJ Wilkinson
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 —
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 —

- triangle and diamond —
- structural controls
“unconfined” flow —
— classic sheetflood at one scale, covering wide areas
— regional lack of confinement at the LFF scale
“unconfined” flow —
— classic sheetflood at one scale, covering wide areas
— regional lack of confinement at the LFF scale
**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, Intergangetic 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, axially diamond-shaped fans, occurs in
   wide rifts e.g. S Sudan

Type 4: two margins, $T/T$ — fan orientation nearly 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
devolved on cratonic basin margins, but also in a few elongated forelands;
primary and derived fans differ morphologically
**Nesting patterns**

- Transverse (T)
- Longitudinal (L)

*Patterns of megafan tessellation*

Criteria:
1. Basin margins – one, as in cratonic basins and in some wide foreland basins.
2. Transverse (T) and Longitudinal (L) orientations with respect to tectonic grain, expressed as tributary and trunk drainage orientation (after Miall 1996).
3. Megafan shape – triangle, diamond, or fan-shaped.
4. Primary vs. derived – primary (sourced in eroding upland) vs. derived (sourced in upstream megafans).

Type 1: Two margins, TL; classically rifts and forelands, e.g., Okavango rift, Andean foreland, Inhomogeneous foreland.

Type 2: Two margins, T/L; infrequent, rifts and sigmoidal basins, e.g., Okavango rift and South-central Andean foreland.

Type 3: Two margins, T/L; marginal, triangular fans, axial diamond-shaped fans, as in wide rifts, e.g., S Sudan.

Type 4: Two margins, T/L; fan orientation of foreland parallel with foreland margins, allows diamond-shaped morphology, as in wide forelands, e.g., Mesopotamia; primary and derived fans differ morphologically.

Type 5: One margin, T/L; 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 in single-margin basins —
- “primary” LFF
- fan-margin rivers
- “derived” LFF

![Diagram of nesting patterns in single-margin basins]

**Patterns of megafan tessellation**

Criteria:
1. Basin margins — new, as in cratonic basins and some wide foreland basins
2. Transverse (T) and longitudinal (L) orientations with respect to basin grain, rendered as tributary and main drainage orientation (after Milia 1990)
3. Megafan shape — triangle, diamond
4. Primary vs. derived — primary (sourced in eroding upland)
   - derived (sourced in upstream megafans)

**Types of megafan tessellation**

- **Type 1**: Two margins, TS; clastic fans and retool forelands; e.g., Okavango-Rift, Andean fan, Indus-Pakistan fan
- **Type 2**: Two margins, TS; interfluvial fans and piggyback basins; e.g., Okavango rift and south-central Andean fan
- **Type 3**: Two margins, TS; triangular fans, axial diamond-shaped fans, sourced to wave fans; e.g., S Sudan
- **Type 4**: Two margins, TS; fan orientation nearly parallel with foreland margins; allows diamond-shaped morphology; developed in a few foreland basins; e.g., Paoay/Philippines; primary and derived fans differ morphologically
- **Type 5**: One margin allowing diamond-shaped fans to form; typically developed on cratonic basin margins, but also in a few elongated foreland; primary and derived fans differ morphologically
Nesting patterns in single-margin basins —
- “primary” LFF
- fan-margin rivers
- “derived” LFF
- distributary vs. contributary in the same landscape
Nesting patterns —
- “primary” LFF
- fan-margin rivers
- “derived” LFF
- distributary vs. contributary in the same landscape
Accommodation — major changes may result from slight changes in slope
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Accommodation — major changes may result from slight changes in slope potential accommodation surfaces

RIVER LONG PROFILES — erosional hinterland and aggrading lowland

hinterland river slope (related to clast size)

slope of upper surface of sedimentary body relates to upland stream slope

ALLUVIAL FAN — coarse sediment supplied >> steep slope >> small planform area of accommodation zone >> small fan cone

steep

radii 5 - 25 km

MEGAFAN — fine sediment supplied >> low slope >> large planform area of accommodation zone >> large fan cone

low angle

radii 100 - 600 km

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 levels. Alluvial fans are formed by the rapid influx of sediment into a broad, shallower basin.
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?

Fig. 3.32 The process by which deposition of a basin, such as an alluvial fan, delta or distributive basin, such as an alluvial fan, delta or distributary basin, is typically driven by slope advantages, triggering another part of the basin. Sedimentation is rapid (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 $\sigma_{ss} = \text{standard deviation of sedimentation/subsidence}$ and is recognizable by the clustering of channel parts of the basin. Subsidence and sedimentation are typically driven by the potential accommodation surfaces (and is compensational stacking of clusters) (2009, Fig. 2, p. 676)
Accommodation — sediment cascade and “unfilled accommodation” (Straub, 2009) —

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

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Accommodation — sediment cascade and “unfilled accommodation” (Straub, 2009) — question of autogenic avulsion vs. assumed filling of allogenically-induced tectonic subsidence.

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Accommodation — sediment cascade and “unfilled accommodation” (Straub, 2009) — question of autogenic avulsion vs. assumed filling of allogenically-induced tectonic subsidence

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Accommodation and channel-sand connectivity on a single LFF —

Megafans of northern Argentina and Paraguay
Megafans of northern Argentina and Paraguay

LFF and the sedimentary record —
LFF and the sedimentary record — pedogenic units —

RIVER LONG PROFILES --
erosional hinterland and aggrading lowland

hinterland river slope (related to clast size)
slope of upper surface of sedimentary body relates to upland stream slope

ALLUVIAL FAN -- coarse sediment supplied >> steep slope >> small planform area of accommodation zone >> small fan cone

radii 5 - 25 km

MEGAFAIN -- fine sediment supplied >> low slope >> large planform area of accommodation zone >> large fan cone

radii 100 - 600 km
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

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Sedimentary record —
- LFF drainage diversions
- pedogenic units
- relation to incised valleys?

Applications — numerous
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

Distribution plot gives an inaccurate sense of LFF significance

76% < 100 km long
Landform ages—that include megafan surfaces—coincide well with ages of some trumpeter bird species —
Middle Earth —
*Lord of the Rings*
Tolkein 1974