

New Mesoscale Fluvial Landscapes – Seismic Geomorphology and Exploration

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Summary

Megafans (100-600 km radius) are very large alluvial fans that cover significant areas on most continents, the surprising finding of recent global surveys. The number of such fans and patterns of sedimentation on them provides new mesoscale architectures that can now be applied on continental fluvial depositional systems, and therefore on . Megafan-scale reconstructions underground as yet have not been attempted. Seismic surveys offer new possibilities in identifying the following prospective situations at potentially unsuspected locations: (i) sand concentrations points, (ii) sand-mud continuums at the mesoscale, (iii) paleo-valley forms in these generally unvalleyed landscapes, (iv) stratigraphic traps, and (v) structural traps.

Introduction—Discovery of the widespread distribution of megafans

A megafan is a low-angle, partial cone of river-laid sediments that can reach hundreds of km in length (100 km minimum length used in our global survey), with areas varying from 7000 to 200,000 km² [1, 2]. As such, megafans are mesoscale landforms (Fig. 1) — features that have received surprisingly little attention in modern landscape studies. We know of almost none in subsurface “paleogeography” reconstructions.

Inaccurately termed “inland deltas,” megafans need to be distinguished specifically from coastal deltas since they require no distal water body for their development. In our global study we examined inland megafans only.

Megafans form most typically at mountain fronts. The Kosi River megafan, located at the foot of the Himalaya Mts. in northern India, is one of the few well known examples. The discovery of the global distribution of megafans shows that they are at least as important as a global landform as deltas, due to their great size and far greater number (i.e., large fans vs. comparably large deltas).

Based originally on astronaut images that revealed their worldwide occurrence, more than 160 modern large fans have now been documented on all continents in our mapping campaign [3] — proving that these features are not merely a freakish end-member of the alluvial fan continuum.

Our global study also revealed that megafans are often clustered (the Himalayan foreland plains are a prime example), so that flat landscapes they develop can

dominate extensive continental surfaces — 1.2 million km² in South America, another classic example [1]).

The sample is now large enough that controls of megafan location are well understood. Thus, the presence of megafans has been successfully predicted in modern landscapes even where diagnostic patterns were not obvious remotely or on the ground (radial stream patterns removed by erosion and overprinted by dunes and younger vegetation patterns). The world survey has consequently increased our confidence in locating these features subsurface.

Present literature tends to lump together fans of all sizes [e.g., 4]. World surveys have now demonstrated con-



Figure 1: The Okavango River megafan is a classic feature seen from space since the dark vegetation contrasts with the surrounding dun-colored Kalahari Desert of NW Botswana. Flow is toward the camera. The megafan measures 150 km from apex to toe. Smoke plumes from numerous fires burn in southeast Angola (middle ground and top). Unique NASA frame no. STS43-151-32, 08/08/1991.

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clusively that the great size of megafans ordains that processes of formation (primarily sequences of overlaid alluvial ridge complexes) are different compared with processes on the classic, smaller alluvial fan (Table 1, Fig. 2).

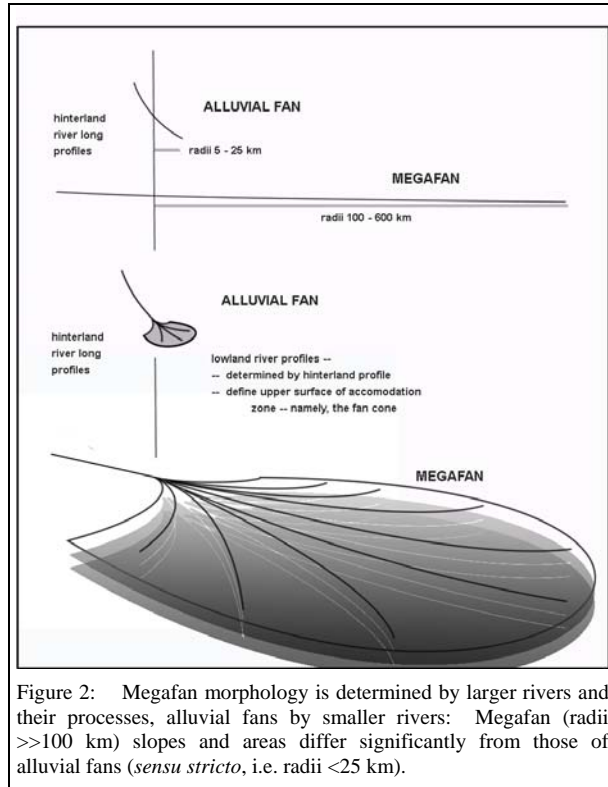


Figure 2: Megafan morphology is determined by larger rivers and their processes, alluvial fans by smaller rivers: Megafan (radii >>100 km) slopes and areas differ significantly from those of alluvial fans (*sensu stricto*, i.e. radii <25 km).

Relevance of megafans to exploration

Megafans may be very important. As relatively large features, their discovery provides a new component feature of the fluvial mesoscale — that will undoubtedly allow more realistic reconstructions of subsurface patterns, and arguably help detection of larger plays.

Three specific megafan geometries are probably important in exploration, in all of which 3D seismic capability can be a primary method in identifying critical lithologies and structures —

- *Sand-rich host rocks – Concentration points*
 - Channel sands are concentrated at megafan apexes.
 - Subapexes also exist at various locales downfan from the apex, including downstream of forebulge zones.

- Some megafans are diamond-shaped so that channels meet at a distal point.
- *Stratigraphic traps*
 - Distal and even medial megafan environments are overwhelmingly fine grained (seals) because channels are more widely spaced downfan, and infiltration reduces channel size (on some fans) downfan.
 - Channel sands lead directly toward such downfan trapping seals, especially in foreland settings where deeper units are back tilted so fluids migrate up dip toward the clay-rich seals.
- *Convex vs. concave (valleyed) surfaces*

Megafans by definition are convex surfaces. However —

- Empirical studies show that fan-margin channels are larger than on-fan channels since they combine the discharge of rivers from *two* neighboring fans. Fan-margin channels occupy the relatively narrow concave depression between the slopes of neighboring megafans. Fan-margin rivers are often incised.
- Concave zones such as these depressions are known to generate different internal architectures compared with the convex depositional zones of the megafan surface, implying different exploration strategies in each.

Contribution of seismic surveys

Localized 3D seismic surveys can provide critical data and visualization for the reconstruction of buried landsurfaces that were built by megafans —

- *Sand-rich host rocks – Concentration points*

Seismic surveys can discriminate sand-rich zones versus surrounding clay-rich overbank facies. These points are localized, confined to the search for megafan apex zones.

Apexes can be located with less precision from analysis of modern landscapes and/or regional geology studies. Seismic surveys are appropriate to pinpoint such locations.

- *Stratigraphic traps in megafan landscapes*

Regional seismic surveys provide, with well control, the stratigraphic context in any basin. Ideally, this regional information is complemented by local 3D seismic surveys

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that provide a more detailed image of the subsurface landscape and allow for quantification of key reservoir and seal properties.

This in turn allows appreciation of grain-size gradation (from sand to mud) within single narrow stratigraphic units over long distances, allowing reconstruction of the stratigraphic trap environment.

- *Structural traps in megafan landscapes*

Tectonic models indicate that the forebulge in foreland basins migrates into the backbulge basin. Sand-rich apexes of megafans in backbulge basins can thus coincide with the new forebulge—thereby providing prospective localities by the overlapping effects of both host and seal. Seismic surveys should be able to detect such subtle stratigraphies and overprinted structures.

- *Fan-margin channels*

High fidelity 3D seismic time slices have revealed with a good degree of confidence the morphological differences between unincised river plains and incised valleys [e.g., 5]. Depending on the specific fills of the concave, valleyed zones, targets of interest could lie within either the megafan sediments (above), or they could lie in the interfan depression (valleyed) zone.

This distinction is important because valleyed zones are known to generate different internal architectures compared with the *unconfined* depositional zones of the megafan surface. Each zone in turn requires a different exploration strategy. Seismic surveys are probably the best method of distinguishing one from the other.

Table 1: Hierarchy of fluvial forms (“groups”). **Left column:** well-known components of the hierarchy, after Miall (1991). **Right column:** megafans and sets of megafans occupy the less well defined “fluvial mesoscale” (bold, outlined). Columns show that the hierarchy of forms os different in confined “valleyed” settings (left column) *versus* unconfined fluvial settings (megafans), the source of new debates in sedimentology. (Adapted from [1]; based on [4]).

Group	time scale (yr)	Hierarchy of fluvial sedimentary bodies (architectural elements)	
		rivers and alluvial fans	megafan distributary systems (radii >100 km)
6	10 ² -10 ³	shallow channel, large stream-bed macroform	shallow channel, large stream-bed macroform
7	10 ³ -10 ⁴	channel, fan trench backfill	channel
8	10 ⁴ -10 ⁵	channel belt, alluvial fan	channel belt
9	10⁵-10⁶	floodplain, alluvial fan tract (bajada), delta, major depositional system axis (Gulf of Mexico coast depositional axes)	megafan
10	10⁶-7	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)	

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Conclusions

- Observations from space have identified numerous megafan systems that had not been obvious from prospecting on the ground.
- Application of fundamental geomorphic building blocks explains / constrains the internal architecture of megafans.
- Smart combination of those geologic concepts with both regional 2D seismic & well control, combined with local high resolution 3D seismic data, can provide a fertile framework for HC explorers — and may help the industry to identify presently overlooked plays, at the smaller fluvial scale (subfan scale) and at the mesoscale (megafan) scale.

REFERENCE CHANGE: Reference lists **will not** be included at the end of the expanded abstract, but should be prepared separately and entered during the submission process in the online form.