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The architecture and evolution of shallow water delta mouth bars: examples from the Lower Cretaceous of Spain

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The Architecture and evolution of shallow water delta mouth bars:

examples from the Lower Cretaceous of Spain

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Stratigraphic Architecture of Jorcas Deltas

Facies and architectural analysis

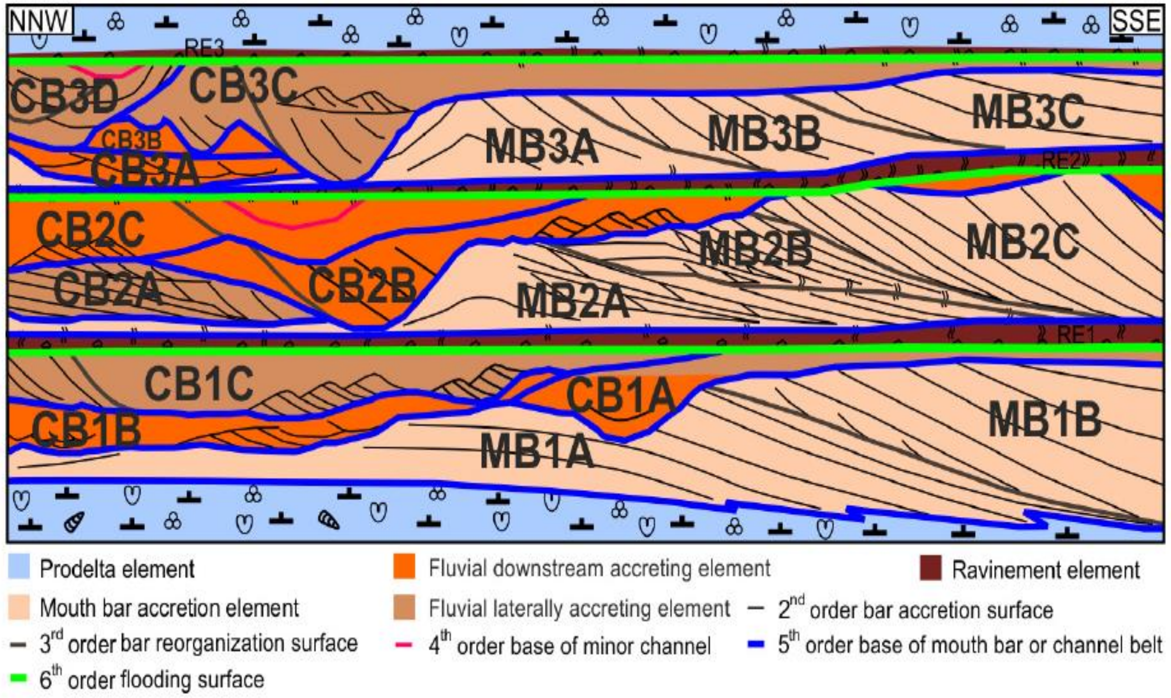

Fig. 5. Summary cartoon of the architectural elements of the Jorcas Section.

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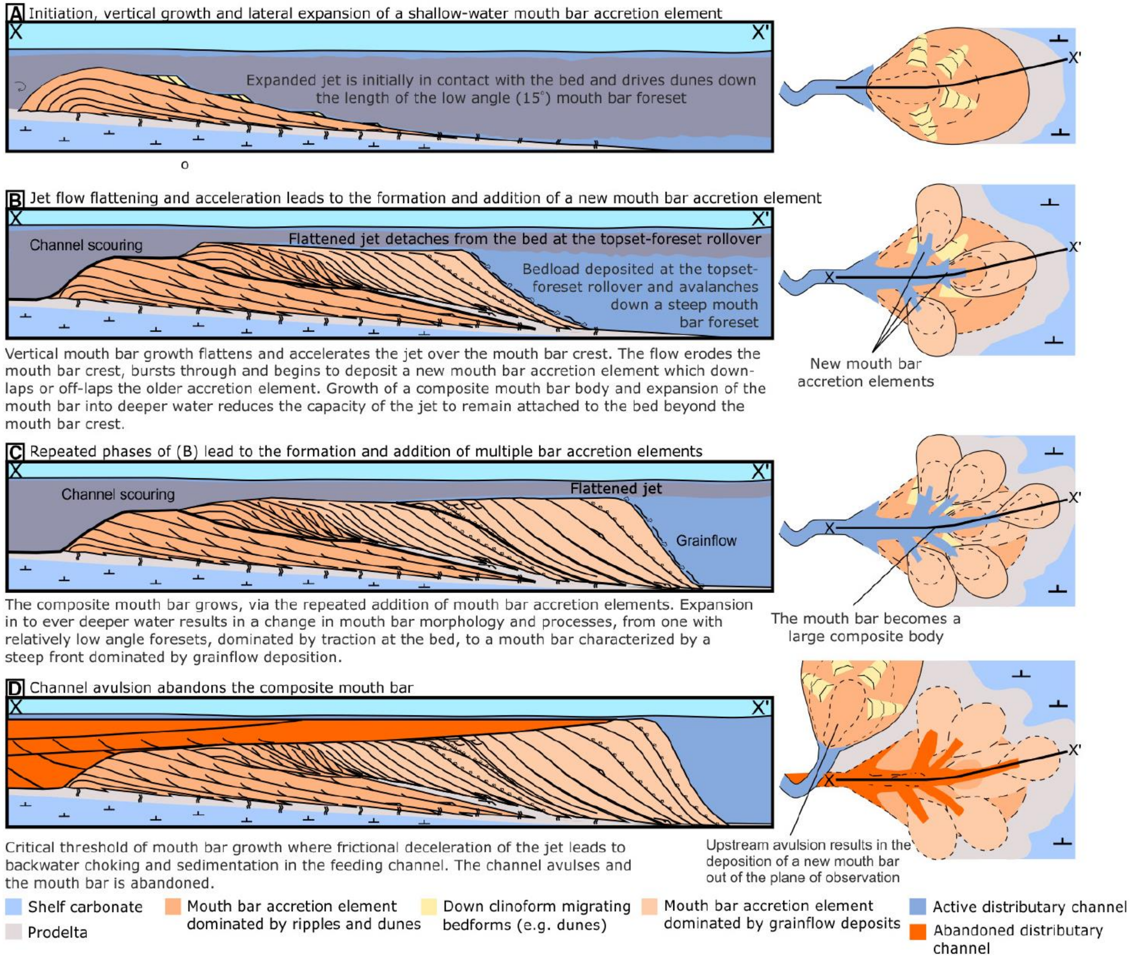
Mouth Bar Evolution and Abandonment

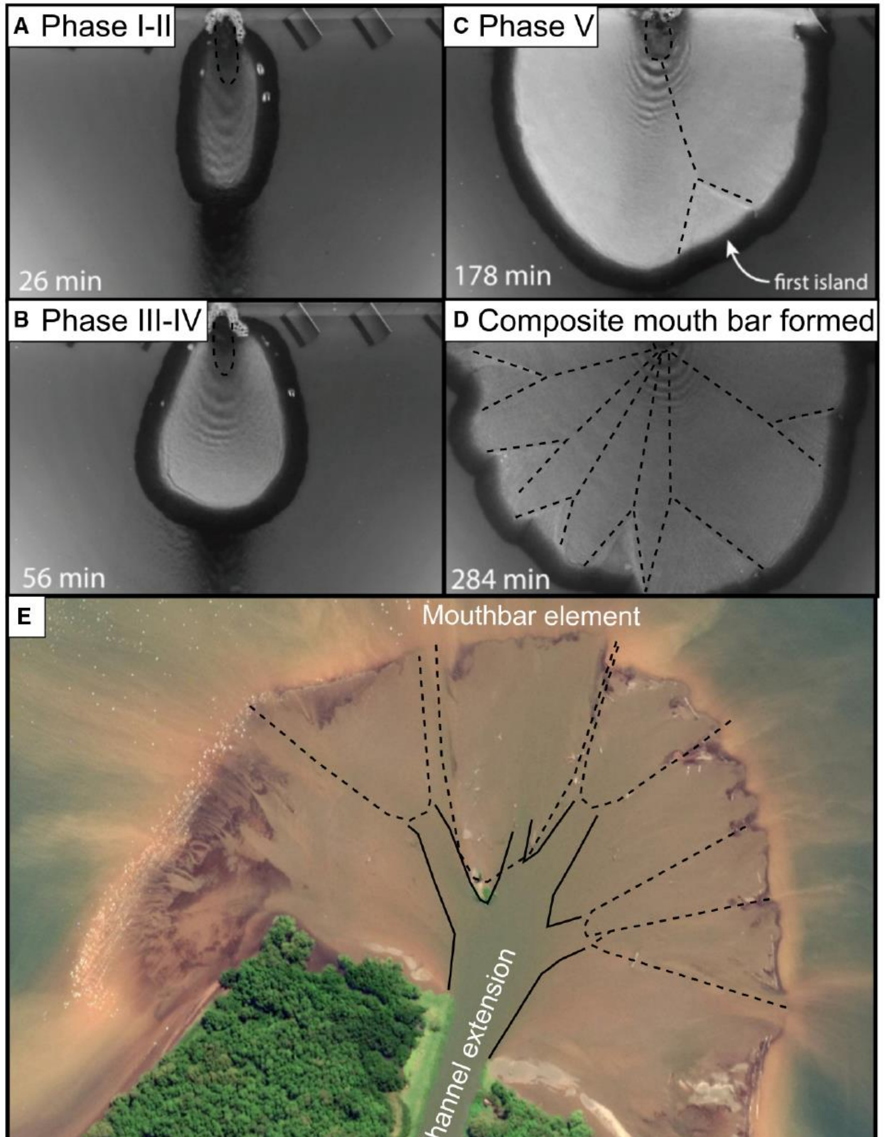


Abstract

- Improved understanding of delta mouth bar morphodynamics, and the resulting stratigraphic architectures, is important for predicting the loci of deposition of different sediment fractions, coastal geomorphic change and heterogeneity in mouth bar reservoirs.
- Facies and architectural analysis of exceptionally well-exposed shallow water (ca. 5 m depth) mouth bars and associated distributaries, from the Xert Formation (Lower Cretaceous), of the Maestrat Basin (east-central Spain), reveal that they grew via a succession of repeated autogenic cycles.
- The formation is part of a mixed clastic-carbonate succession deposited during a time of active faulting and incipient salt tectonism, but in an area away from their direct influence and where wave and tidal reworking were minimal.
- An initial mouth bar accretion element forms after avulsion of a distributary into shallow standing water.
- Turbulent expansion of the fluvial jet and high bed friction results in rapid flow deceleration, and deposition of sediment in an aggradational to expansional bar-form.
- Vertical bar growth causes flattening and acceleration of the jet.
- The accelerated flow scours channels on the bar top, which focuses further expansion of the mouth bar at individual loci where the channels break through the front of the mouth bar.
- Here, new mouth bar accretion elements form, downlapping and onlapping against a readily recognizable surface of mouth bar reorganization.
- Vertical growth of the new mouth bar accretion elements causes flattening and re-acceleration of the jet, leading to channelization, and initiation of the next generation of mouth bar accretion elements.
- Thus the mouth bar grows, until bed-friction effects cause backwater deceleration and superelevation of flow in the feeding distributary.
- Within-channel sedimentation, choking and upstream avulsion of the feeding channel, results in mouth bar abandonment.
- In this study, mouth bars are formed of at least two to three accretion elements, before abandonment happened.
- The results of this study contrast with the notion that mouth bars form by simple vertical aggradation and radial expansion.
- However, the architecture and facies distributions of shallow water mouth bars are a predictable product of intrinsic processes that operate to deposit them.

Comparison to experiments and modern deltas

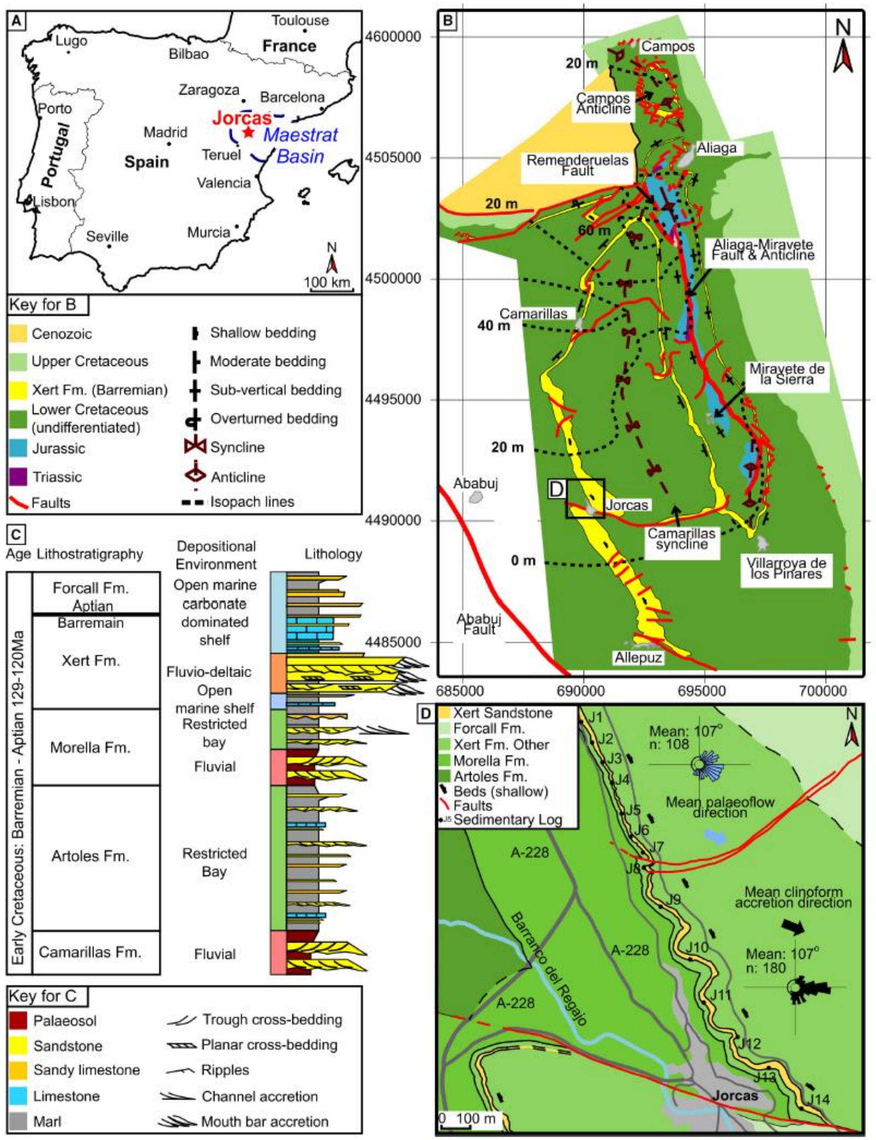
Fig. 12. Flume tank experiment from Shaw *et al.* (2018) (A) to (D) and a modern day example (E) showing mouth bar growth via mouth bar elements. (A) Initiation of the mouth bar via vertical aggradation and basinward extension. (B) Horizontal expansion of the mouth bar. (C) First instance of channelization of flow on the mouth bar top and focusing of sedimentation at a single locus – the formation of a new mouth bar accretion element. (D) A mature mouth bar, composed of multiple mouth bar accretion elements, and a dendritic plan view. Run times and phases of the experiment of Shaw *et al.* (2018) are shown. (E) A similar morphology to (D) is expressed at the mouth of the Rio Garumo River, Panama (9°00′21″N, 82°10′46″W). This river is depositing a mouth bar into the Laguna de Chiriqui, which is protected from open ocean processes by a reef system, and is no deeper than 4 m (Herdendorf, 1982).



Shaw *et al.*, 2018 flume experiments

Modern 'back reef lagoon' shallow water moth bar, Rio Garumo, Panama.

Geological Setting



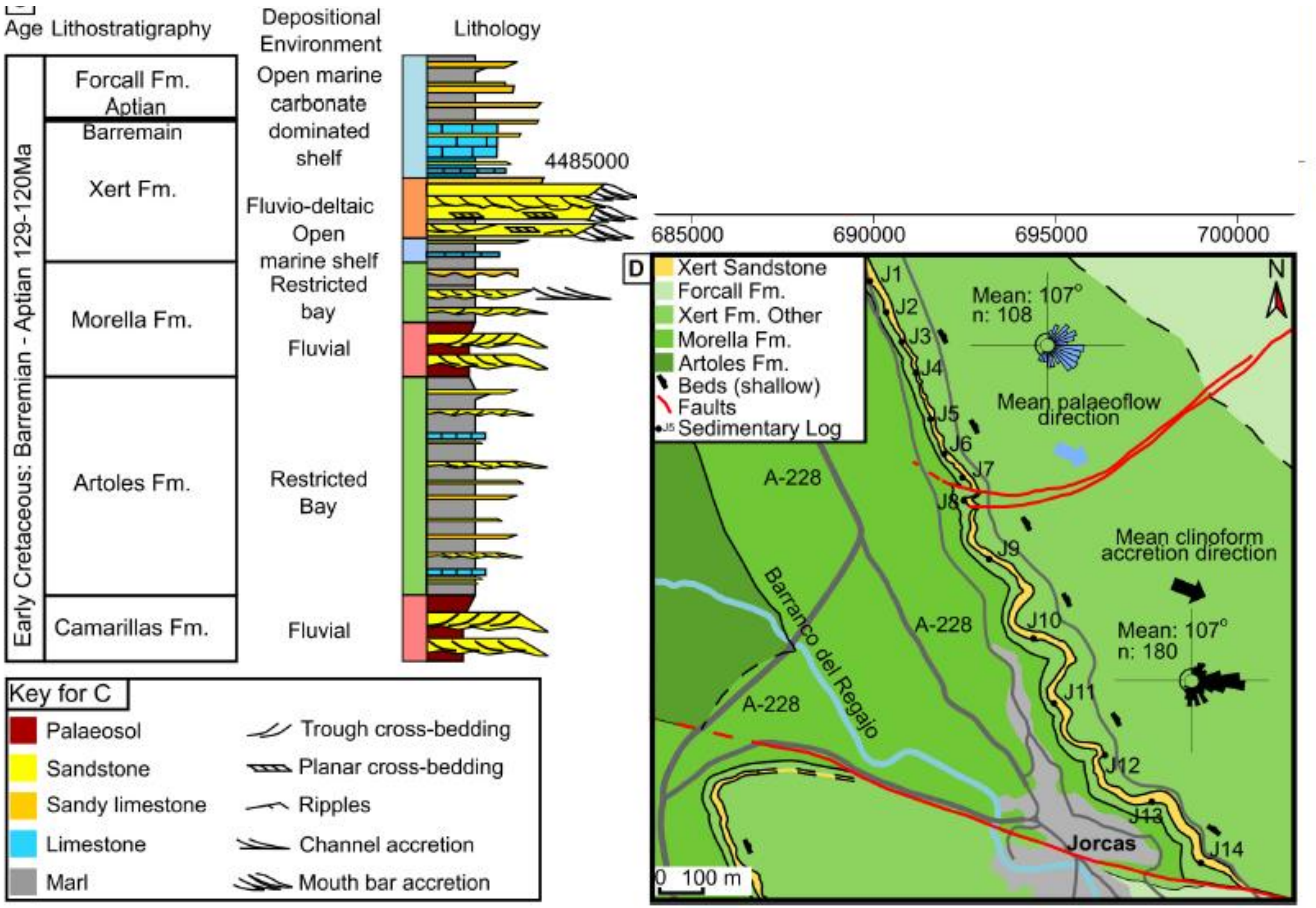
- Deltaic sandbodies part of transgressive succession in transition from coastal fluvial clastics to marine carbonate 'shelf' facies.
- Deposition during period of 'mild' salt tectonics with associated faulting.
- Deltas built into low energy carbonate 'shelf'. (very) limited wave or tide generated currents.
- Jorcas section is 45 degrees to accretion direction (ESE) and depositional strike

Excellent exposures of shallow marine delta mouth-bar sandbodies

- 1.7km long, 12-14m thick amalgamated delta front sandstones consisting of four main architectural elements: Terminal Distributary Channel, Mouth bar, Granular transgressive lag & Massive bioturbated sands.
- Mean dominant palaeoflow and mouth bar progradation directions are into the outcrop (towards the east) meaning that the outcrop is orientated (NNW-SSE) slightly oblique to it and combined with the outcrop weathering pattern (Figure 2) both lateral (perpendicular to flow) and spatial (parallel to flow) change are being observed.
- Mouth bar clinoform angle (from palaeohorizontal) shows three distinct sets <5^{o} (upper succession, log 5-4), 5-10^{o} (lower succession mouth bar & middle succession mouth bar, log 3-1) & 18-25^{o} (Upper succession mouth bar, log 3-2 & middle mouth bar succession log 1-4) with the angle generally decreasing with increasing distance.
- Maximum measured clinoform height indicates a palaeo-water depth of no more than 4.5m with some as low as 2.5m indicating a very shallow water column (seas surface to sea floor).
- The sandstones are split into three successions separated by regionally (at least outcrop length) correlatable granular, sometimes pebbly, massive sandstones.
- Internally, these successions show a predominance of terminal distributary channel architectural elements in the north that transition in the centre of the outcrop to dominantly mouth bar's in the south.
- Architectural elements are stacked vertically in relatively the same spatial position for each succession with slight internal variations.

Excellent exposures of shallow marine delta mouth-bar sandbodies

Geological Setting



Architectural analysis

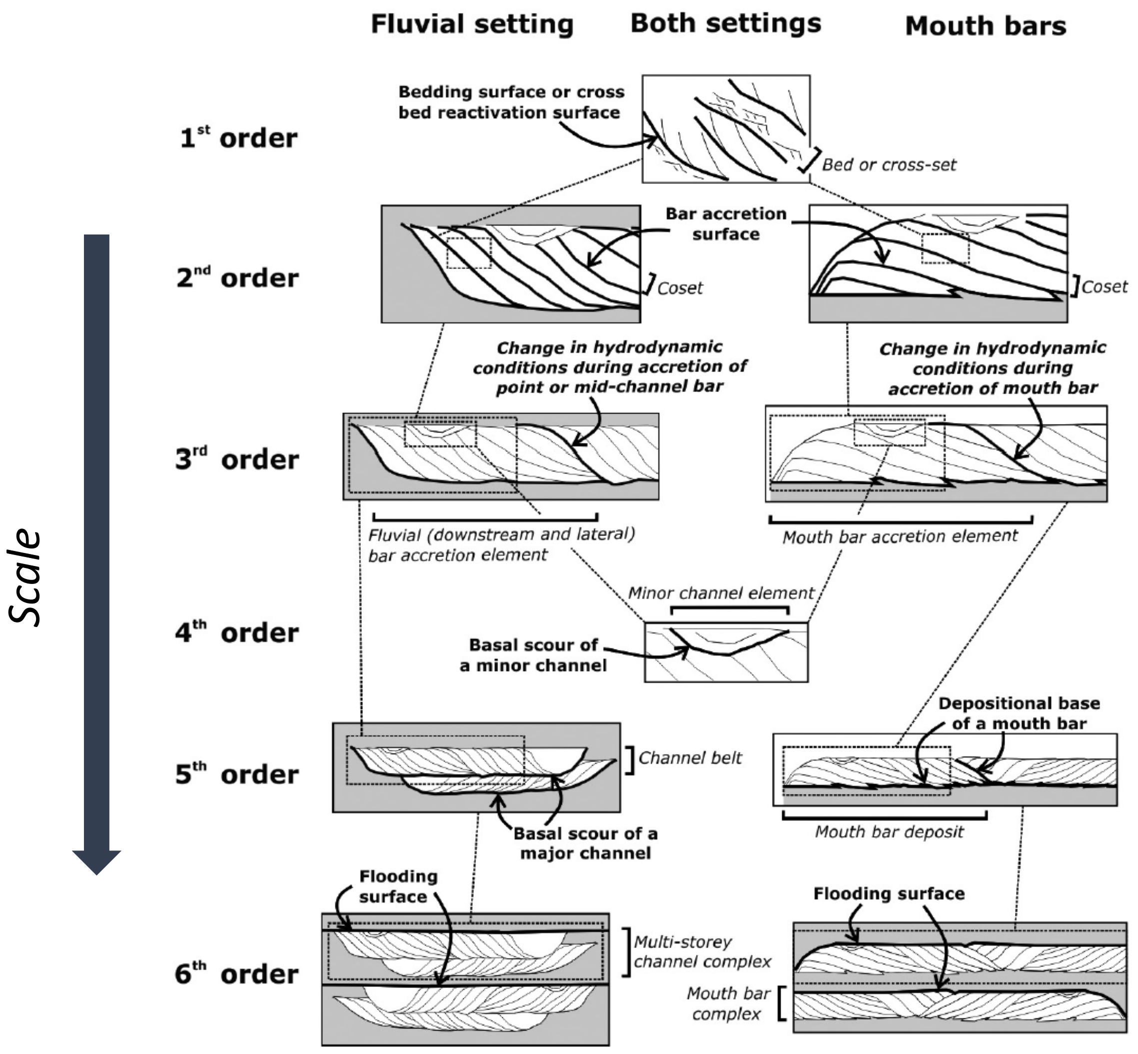


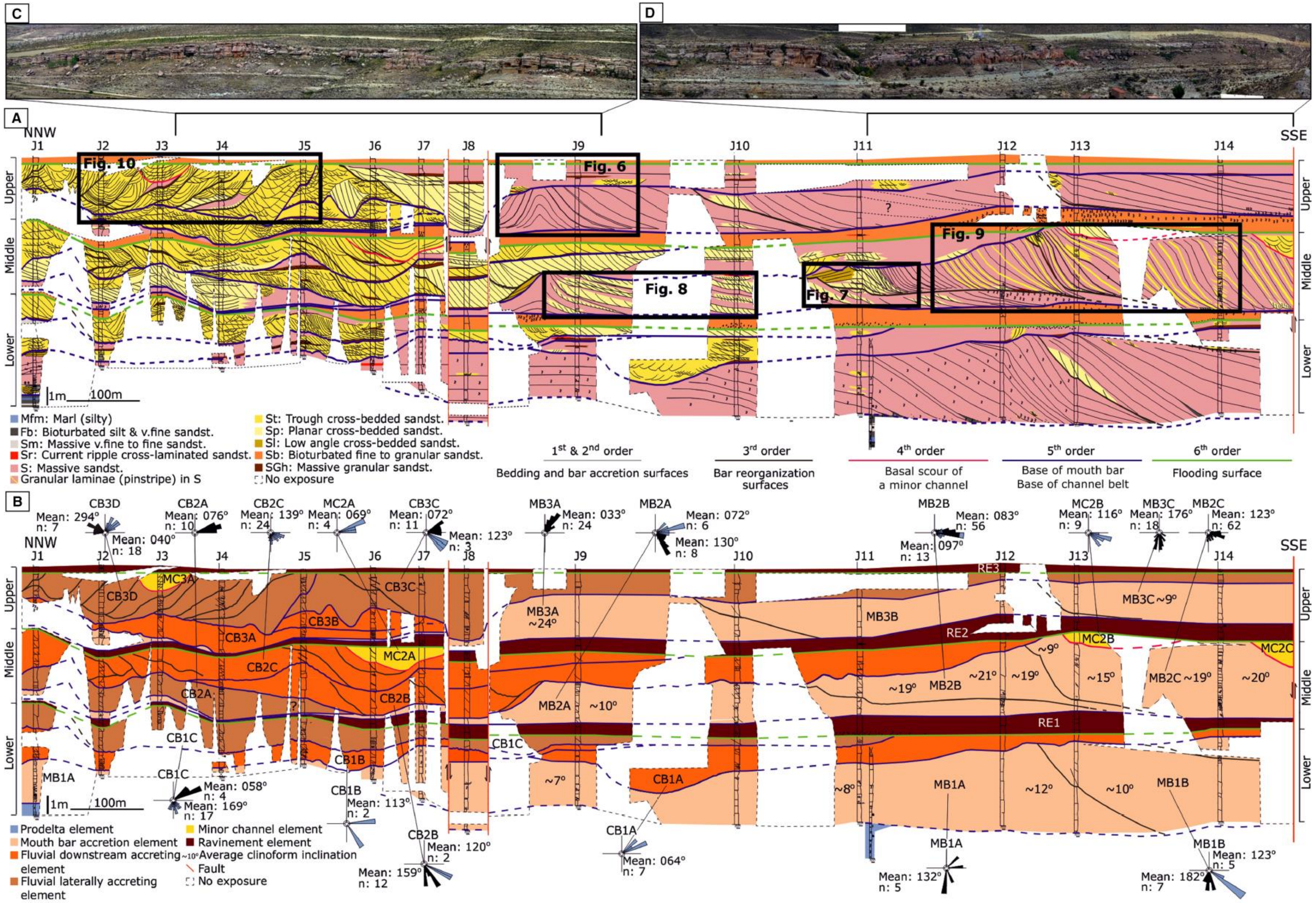
Fig. 2. Hierarchy of bounding surfaces and architectural elements developed in this study. Modified from Miall (1985, 1996) and adopted for a fluvio-deltaic setting. Surfaces are shown in bold and elements are shown in italic text. Scale and geometry are schematic and are not implied. See Figs 4 to 10 and text for specific details of scale and geometry of architectural elements and their bounding surfaces in the Jorcas case study.

- New methodology/terminology for shallow marine mouth bars modified from Miall (1985,1996)
- Key **bounding surfaces** and *architectural elements* defined

Architectural analysis – Correlation Panels and Virtual Outcrop Jorcas

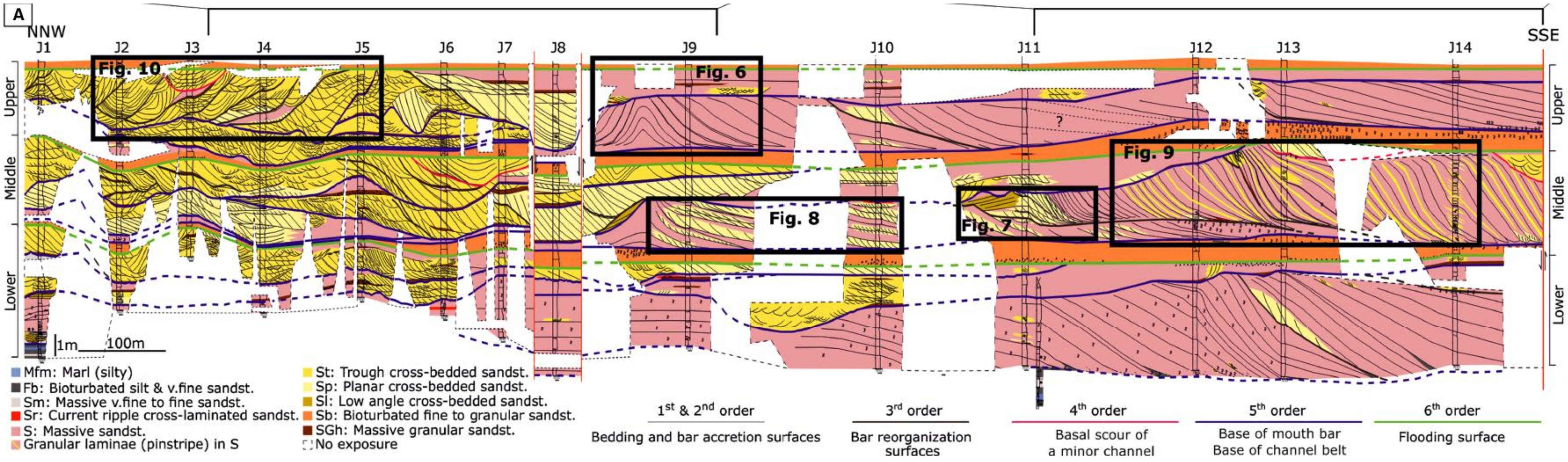
Vertical and spatial facies variations

Architectural elements and bounding surfaces

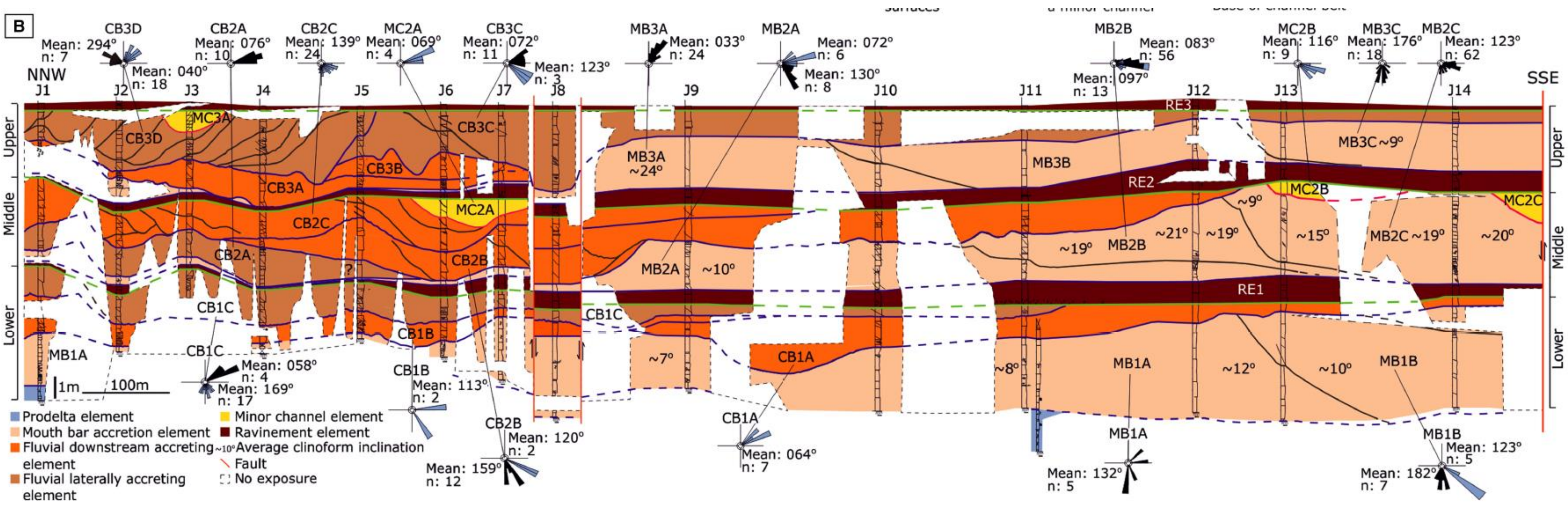


NB 45 degrees to ESE progradation direction

Facies Variations – Correlation Panels and Virtual Outcrop Jorcas



Architectural element correlation



Architectural analysis – Summary

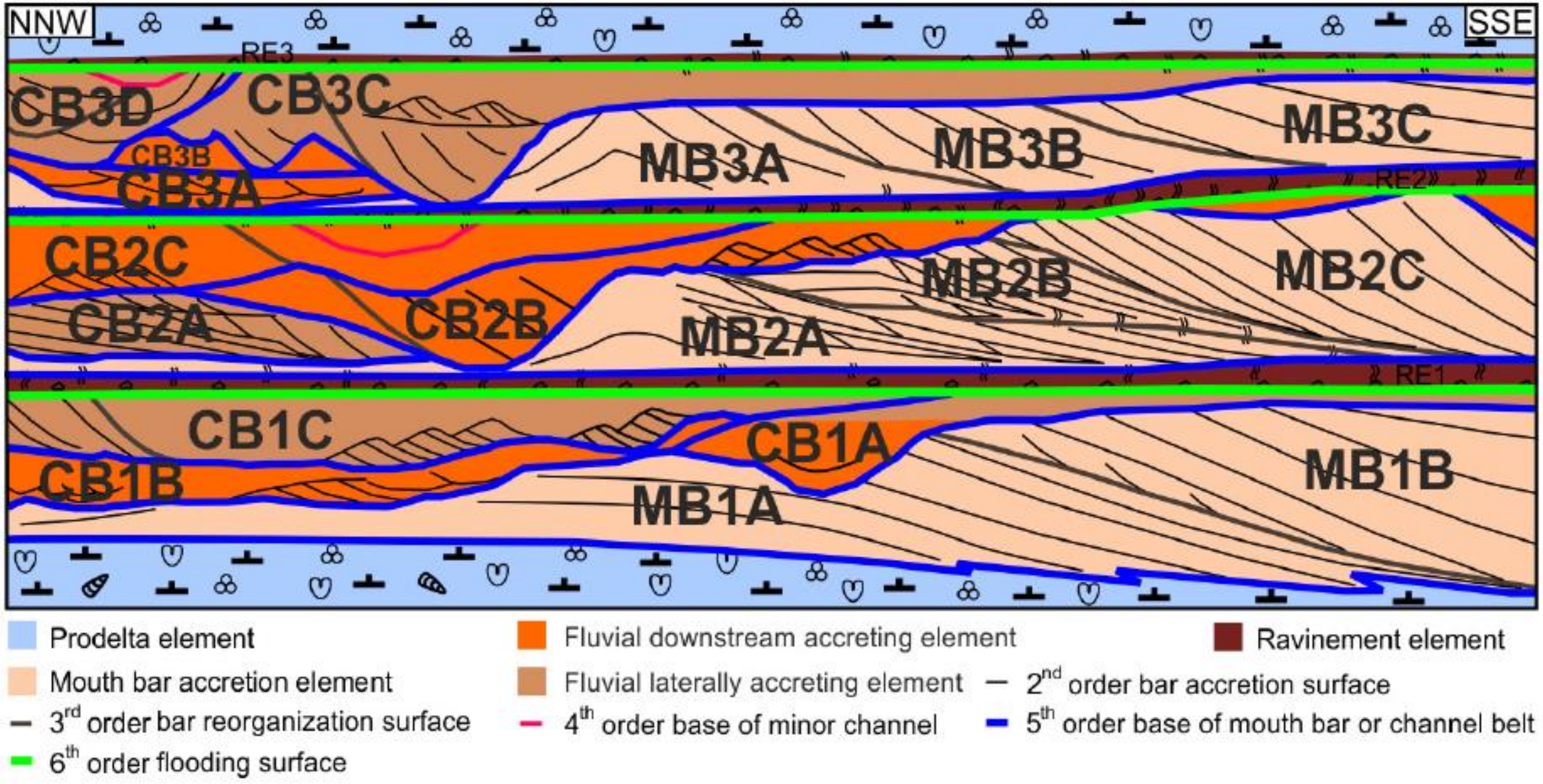


Fig. 5. Summary cartoon of the architectural elements of the Jorcas Section.

Mouth Bar Aggradation Sub-element

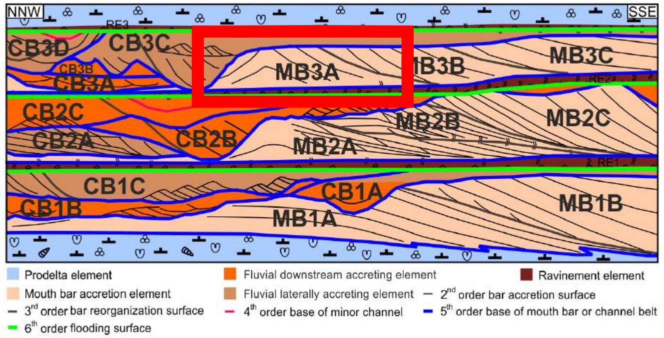


Fig. 5. Summary cartoon of the architectural elements of the Jorcas Section.

- An initial mouth bar accretion element forms after avulsion of a distributary into shallow standing water.

- Turbulent expansion of the fluvial jet and high bed friction results in rapid flow deceleration, and deposition of sediment in an aggradational to expansional bar-form.

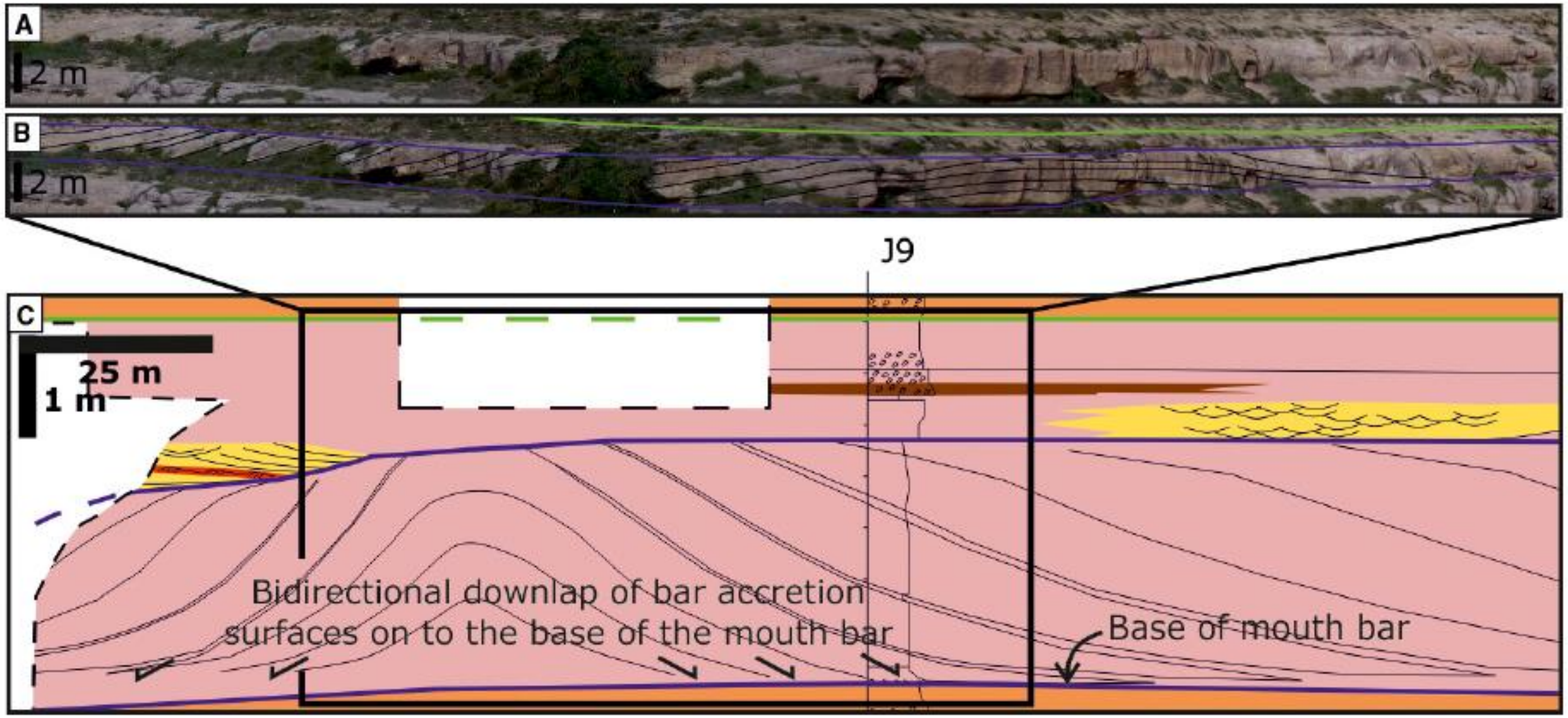
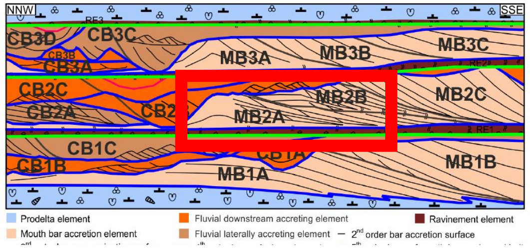


Fig. 6. (A) Segment of the virtual outcrop model showing a mouth bar aggradation sub-element. (B) The same part of the virtual outcrop model with annotations. (A) and (B) show perspective. (C) Architectural sketch based on the virtual outcrop model, showing bed and coset boundaries (second-order bar accretion surfaces) bidirectionally downlapping a relatively flat depositional surface, and defining a bell-shape architecture. The underlying surface represents the (fifth-order) base of the mouth bar. (C) is corrected for perspective. See Fig. 4 for a key. The position of the architecture shown in this figure is shown on Fig. 4.

Mouth Bar Aggradation Sub-element



- Vertical bar growth causes flattening and acceleration of the jet.
- The accelerated flow scours channels on the bar top, which focuses further expansion of the mouth bar at individual loci where the channels break through the front of the mouth bar.
- Here, new mouth bar accretion elements form, downlapping and onlapping against a readily recognizable surface of mouth bar reorganization.

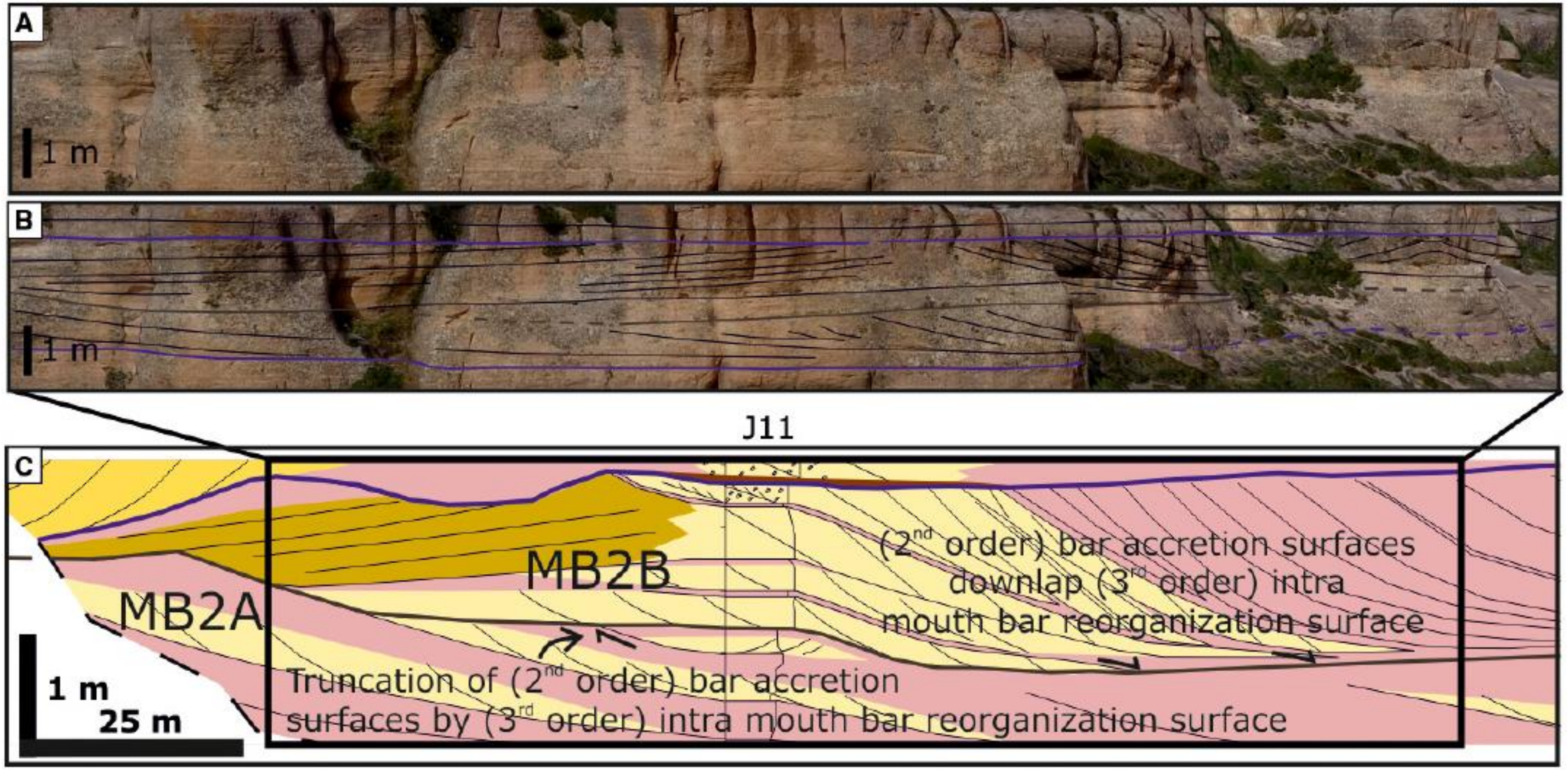


Fig. 7. (A) Segment of the virtual outcrop model showing mouth bar aggradation, and mouth bar expansion sub-elements within a single mouth bar accretion element. (B) The same part of the virtual outcrop model with annotations. (A) and (B) show perspective. (C) Sketch based on the virtual outcrop model showing facies distribution and architecture of mouth bar aggradation and expansion sub-elements within a single mouth bar accretion element. Bed and coset boundaries (second-order bar accretion surfaces) in the middle upper part of the sketch downlap bidirectionally onto an erosional surface which truncates underlying beds and cosets. This is a mouth bar aggradation sub-element. To the right of the mouth bar aggradation sub-element, beds and cosets systematically offlap one another towards the right, defining classic clinothems, and represent a mouth expansion sub-element. This erosive, underlying (third-order) surface marks an intra-mouth bar episode of hydrodynamic reorganization. (C) is corrected for perspective. See Fig. 4 for a key. The position of the architecture shown in this figure is shown on Fig. 4.

Mouth Bar expansion sub-elements

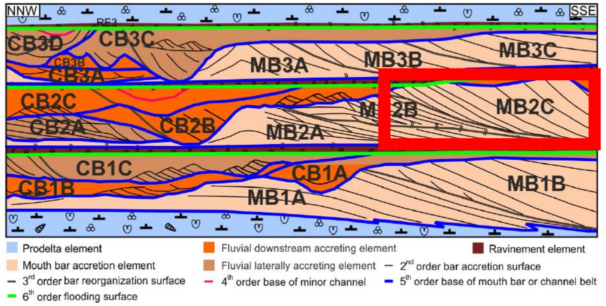
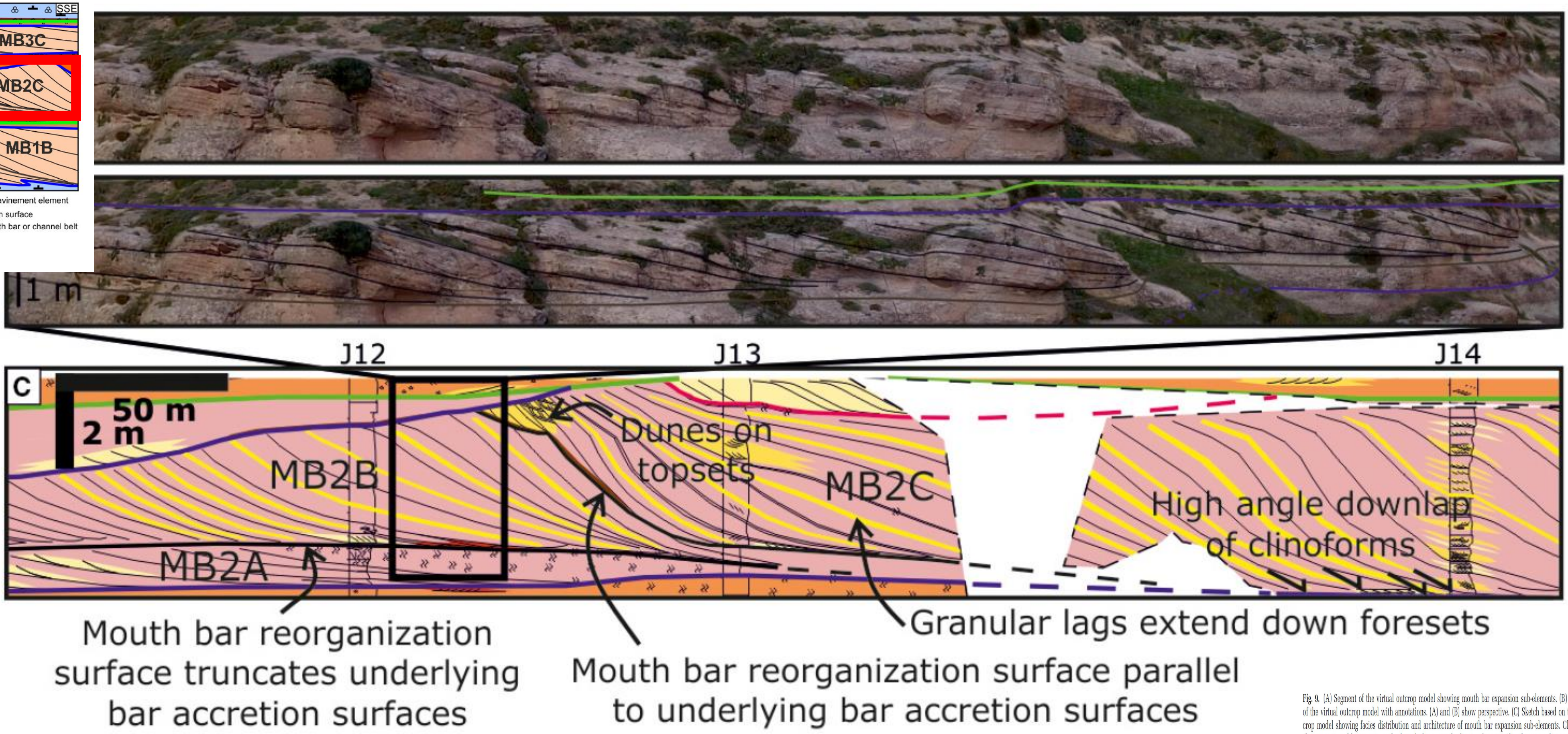


Fig. 5. Summary cartoon of the architectural elements of the Jorcas Section.



- Vertical growth of the new mouth bar accretion elements causes flattening and re-acceleration of the jet, leading to channelization, and initiation of the next generation of mouth bar accretion elements.

Fig. 9. (A) Segment of the virtual outcrop model showing mouth bar expansion sub-elements. (B) The same part of the virtual outcrop model with annotations. (A) and (B) show perspective. (C) Sketch based on the virtual outcrop model showing facies distribution and architecture of mouth bar expansion sub-elements. Clinothems have short topsets and bottomsets, and relatively long, steeply dipping foresets. Clinothems are dominated by massive sandstone containing abundant granular laminae that represent grainflow avalanches down the mouth bar foresets. Three mouth bar accretion elements (MB2A to MB2C), from the same mouth bar, are shown. In the oldest, MB2A (second-order) bar accretion surfaces downlap onto a relatively flat, depositional surface that represents the base of the mouth bar. Topsets and foresets of MB2A bar accretion surfaces are truncated by a (third-order) mouth bar reorganization surface. The latter is downlapped by bar accretion surfaces of the later mouth bar accretion element, MB2B. Bar accretion surfaces of the youngest mouth bar accretion element, MB2C, downlap and climb down a mouth bar reorganization surface, that is largely parallel bar accretion surfaces in MB2B. Note the increase in inclination of mouth bar accretion foresets from MB2A to MB2C: (C) is corrected for perspective. See Fig. 4 for a key. The position of the architecture shown in this figure is shown on Fig. 4.

Fluvial Lateral Accretion Elements

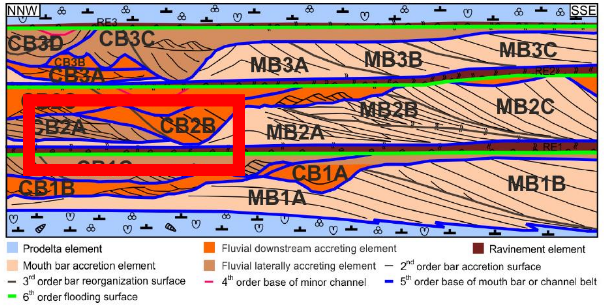


Fig. 5. Summary cartoon of the architectural elements of the Jorcas Section.

- Thus the mouth bar grows, until bed-friction effects cause backwater deceleration and superelevation of flow in the feeding distributary.

- Within-channel sedimentation, choking and upstream avulsion of the feeding channel, results in mouth bar abandonment.

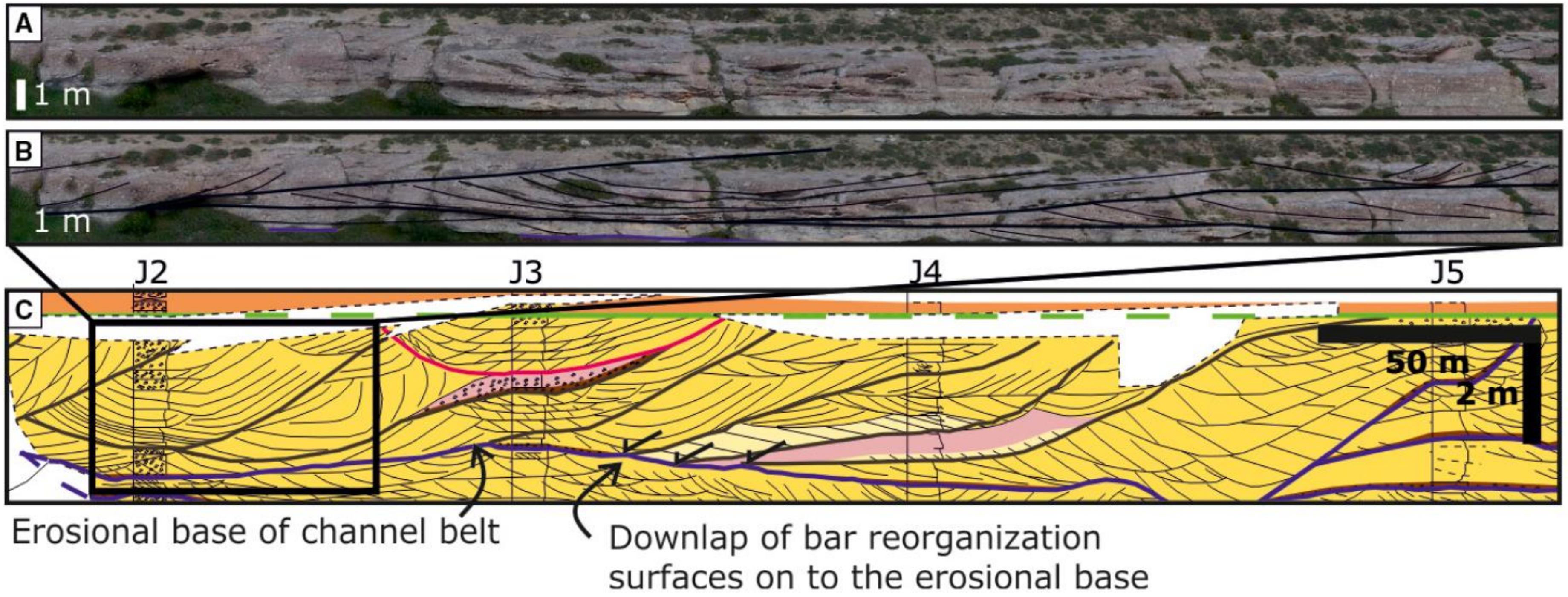


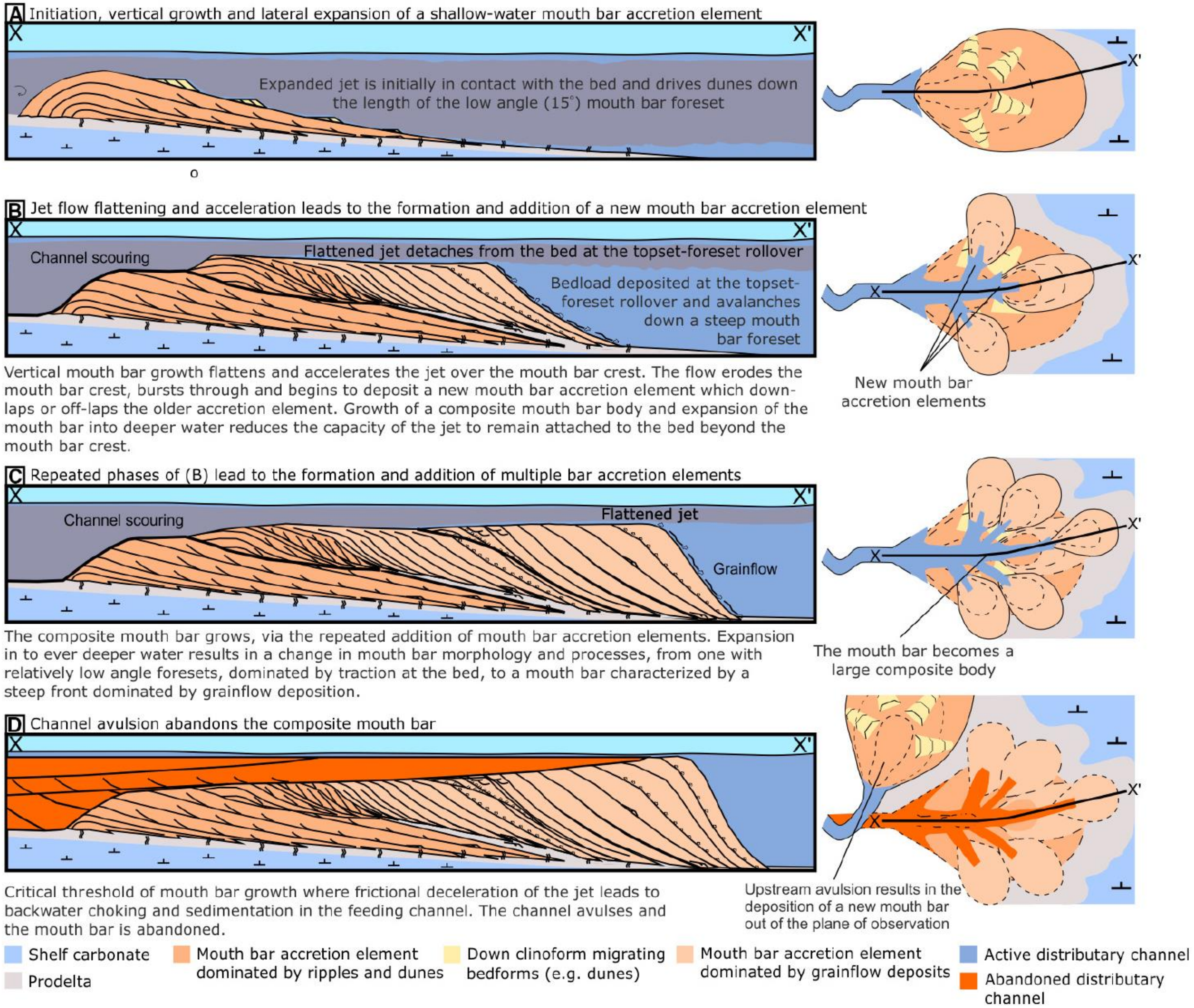
Fig. 10. (A) Segment of the virtual outcrop model showing fluvial laterally accreting bar elements. (B) The same part of the virtual outcrop model with annotations. (A) and (B) show perspective. (C) Architectural sketch based on the virtual outcrop model, showing complex internal structure of cross-cutting bed and coset contacts (second-order bar accretion surfaces), but systematic downlap of (third-order) surfaces representing reorganization of the bar onto the basal (fifth-order) erosion surface that marks the basal scour of a major channel: (C) is corrected for perspective. See Fig. 4 for a key. The position of the architecture shown in this figure is shown on Fig. 4.

Evolution of shallow water mouth bars

- In this study, mouth bars are formed of at least two to three accretion elements, before abandonment happened.

- These mouth bars did not form by simple vertical aggradation and radial expansion.

- The architecture and facies distributions of shallow water mouth bars are a predictable product of intrinsic processes that operate to deposit them.



Initiation

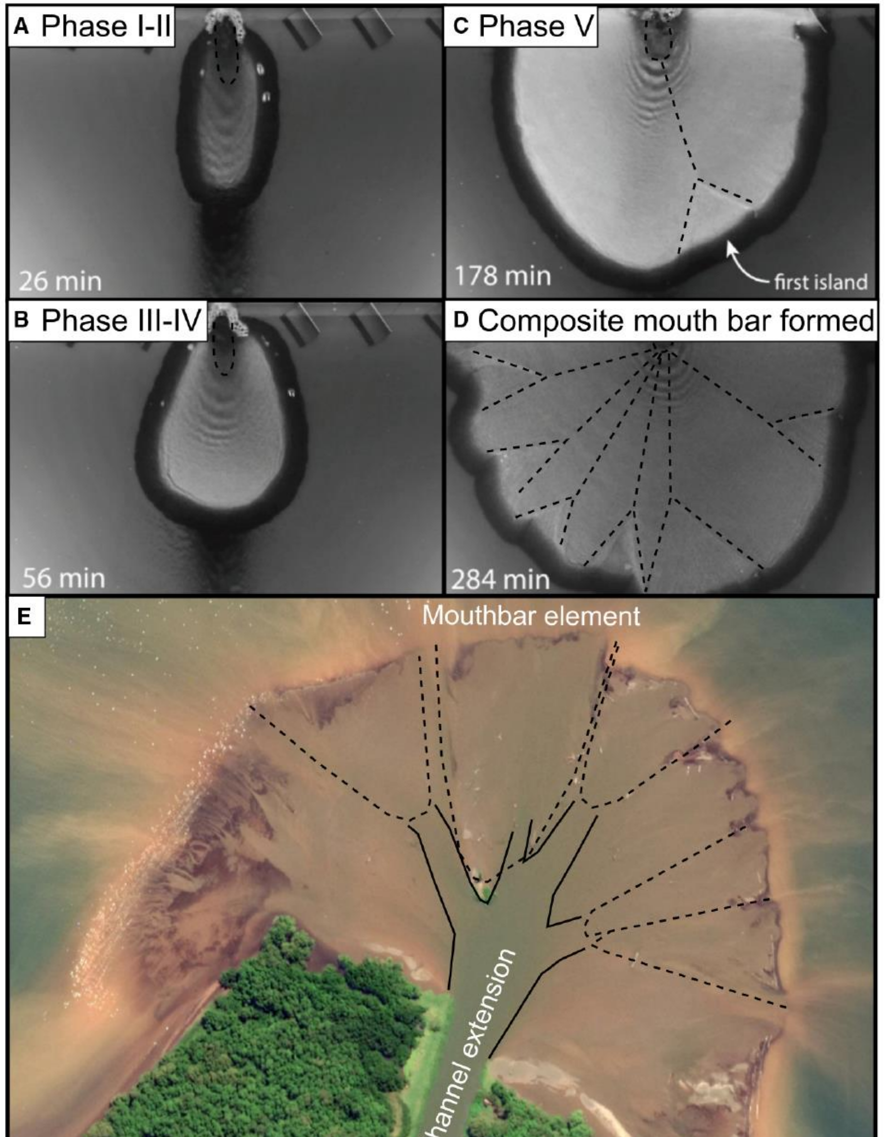
Expansion/ progradation

Repeated formation of accretion elements and abandonment

Avulsion and abandonment

Comparison to experiments and modern deltas

Fig. 12. Flume tank experiment from Shaw *et al.* (2018) (A) to (D) and a modern day example (E) showing mouth bar growth via mouth bar elements. (A) Initiation of the mouth bar via vertical aggradation and basinward extension. (B) Horizontal expansion of the mouth bar. (C) First instance of channelization of flow on the mouth bar top and focusing of sedimentation at a single locus – the formation of a new mouth bar accretion element. (D) A mature mouth bar, composed of multiple mouth bar accretion elements, and a dendritic plan view. Run times and phases of the experiment of Shaw *et al.* (2018) are shown. (E) A similar morphology to (D) is expressed at the mouth of the Rio Garumo River, Panama (9°00′21″N, 82°10′46″W). This river is depositing a mouth bar into the Laguna de Chiriqui, which is protected from open ocean processes by a reef system, and is no deeper than 4 m (Herdendorf, 1982)



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