

# **PS Shale Mechanics within Fluvial Growth Faults of the Notom Ferron Sandstone, Utah\***

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## **Abstract**

Passive continental margins host regional-scale growth faults, which form hydrocarbon traps and locally thickened reservoir compartments. Self-similarity of scales suggests that analysis of growth faults in outcrops may be applied to regional-scale systems. This study used detailed sedimentological and stratigraphic data and a photo mosaic covering 100 m laterally, to analyze shale deformation mechanics within small-scale growth faults at the base of the Turonian Notom delta of the Ferron Sandstone in Central Utah. Five growth-fault blocks are exposed in strike and dip views and include sandy growth strata and pre-growth muddy facies. The highly curved faults sole out into bedding parallel decollement surfaces associated with deformed prodelta shales, which also form diapirs. Throw on individual faults averages 4 m and heave increases with depth from 2.5 to 5 m. Four sedimentological sections indicate deposition in a river-dominated, storm-influenced delta that prograded northeastward into a protected embayment. Three parasequences are represented in the pregrowth strata and comprise mixed heterolithic facies deposited in a prodelta and distal-delta front environment. Growth strata are primarily planar and quasi-planar fine sandstones deposited as upstream and downstream accreting mouth bars. Deposition of mouth bar sands formed a “critical wedge” that initiated growth faulting at the sand/mud interface. Low density mobile prodelta muds, guided by a pressure gradient, accommodate the fault strain and deform to produce diapirs that penetrate the sediment-water interface. Motion on the primary fault surface ceases when growth strata contact higher-strength, dewatered pre-growth strata. Sands at the fault contact in the growth strata lock onto higher-strength pre-growth muds. Further deformation of the growth strata are accommodated by synthetic microfaulting in the growth sands in the terminal phase of motion. Smaller-scale growth faulting may have different triggers than regional-scale faults, which are driven by critical-taper dynamics at the continental margin. This example emphasizes the importance of single point stress sources associated with sandy mouth bar deposits, which act as fault initiation points, versus the regional stress regime associated with regional-scale growth faults. This can lead to expanded, but localized, reservoir compartments within river-dominated deltaic parasequences, such as those found in Prudhoe Bay Field, Alaska.

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# Shale mechanics within fluvial growth faults of the Notom Ferron sandstone, Utah

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## Introduction

Passive continental margins host regional-scale growth faults which form hydrocarbon traps and locally thickened reservoir compartments. Due to similarity of scales, researching outcrop-scale growth faults may aid knowledge of regional-scale systems. Previous outcrop studies of growth faults lacked detailed pregrowth facies analysis due to outcrop inaccessibility or poorly exposed pregrowth strata. A set of accessible, well-exposed growth faults within the Notom Ferron Sandstone of central Utah provides an opportunity for further study of this subject.

## Research Questions

1. How was growth faulting initiated?
2. How was accommodation for growth strata created?
3. How were muds and sands partitioned between depositional environments?
4. How was growth faulting terminated?

The results are then used to answer larger questions:

1. Does growth faulting affect host delta progradation?
2. Are small-scale growth faulting processes similar to those of large, shelf-perched deltaic growth faults?

## Geological Setting

Ferron Sandstone is part of the upper Cretaceous Mancos Shale (fig 1). It is made of three clastic wedges which prograded northeastward into the Cretaceous Western Interior Seaway during the late Turonian.

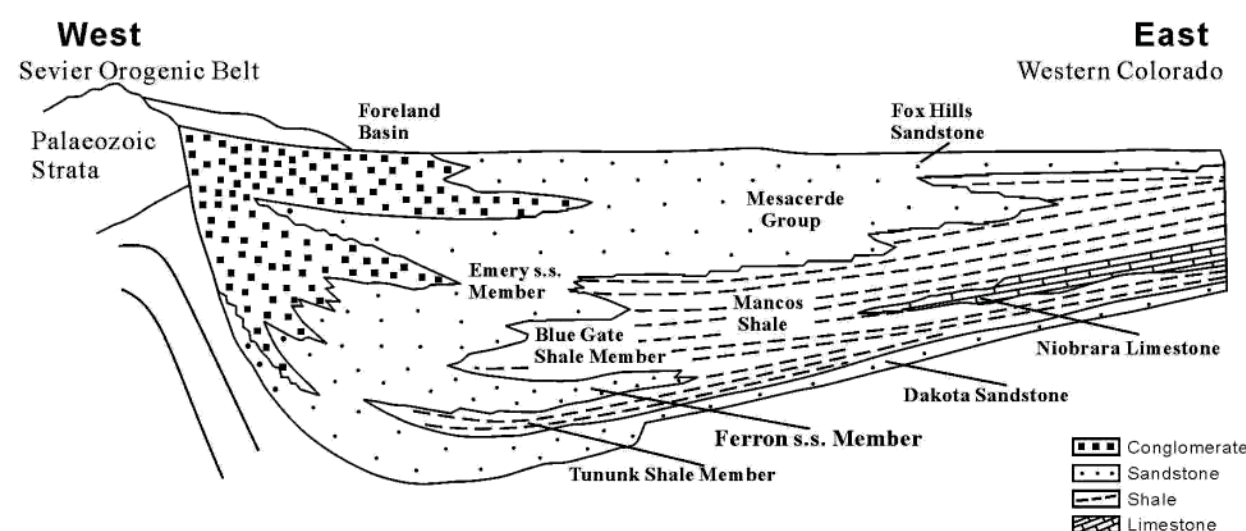


Figure 1 – The geological context of the Ferron Sandstone. [1]

Notom Ferron contains 43 parasequences. Of these, parasequence 6 is characterized by a regressive shoreline associated with a relative sea level fall. Two internal discontinuities divide it into 3 sections: Ps 6-1 to 6-3. The focus of this study, Ps 6-1 and 6-2, are part of an asymmetrical bay-head delta and display along-strike facies change. From north to southeast, shore face deposits pass into heterolithic river-dominated delta-front successions, and finally wave/storm-reworked delta-front deposits. Ps 6-3 predominantly consists of river-dominated delta-front deposits. [2]

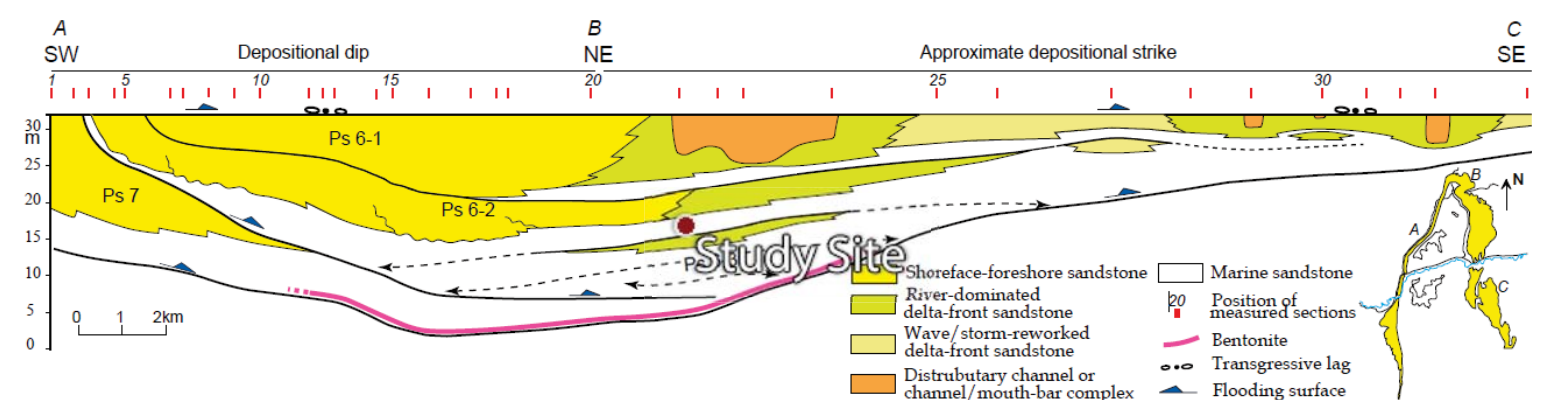


Figure 2 – A schematic cross section of Ps-6, which is interpreted to be a regional delta which prograded northwest. [2]

## Field Site

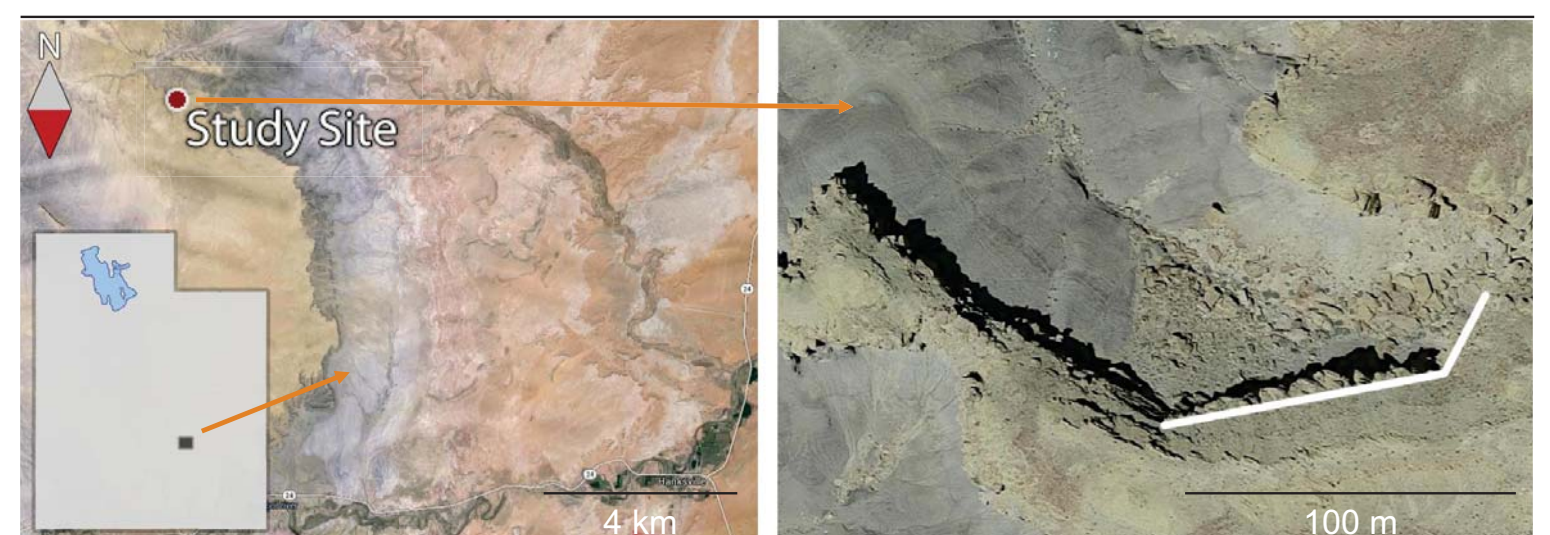


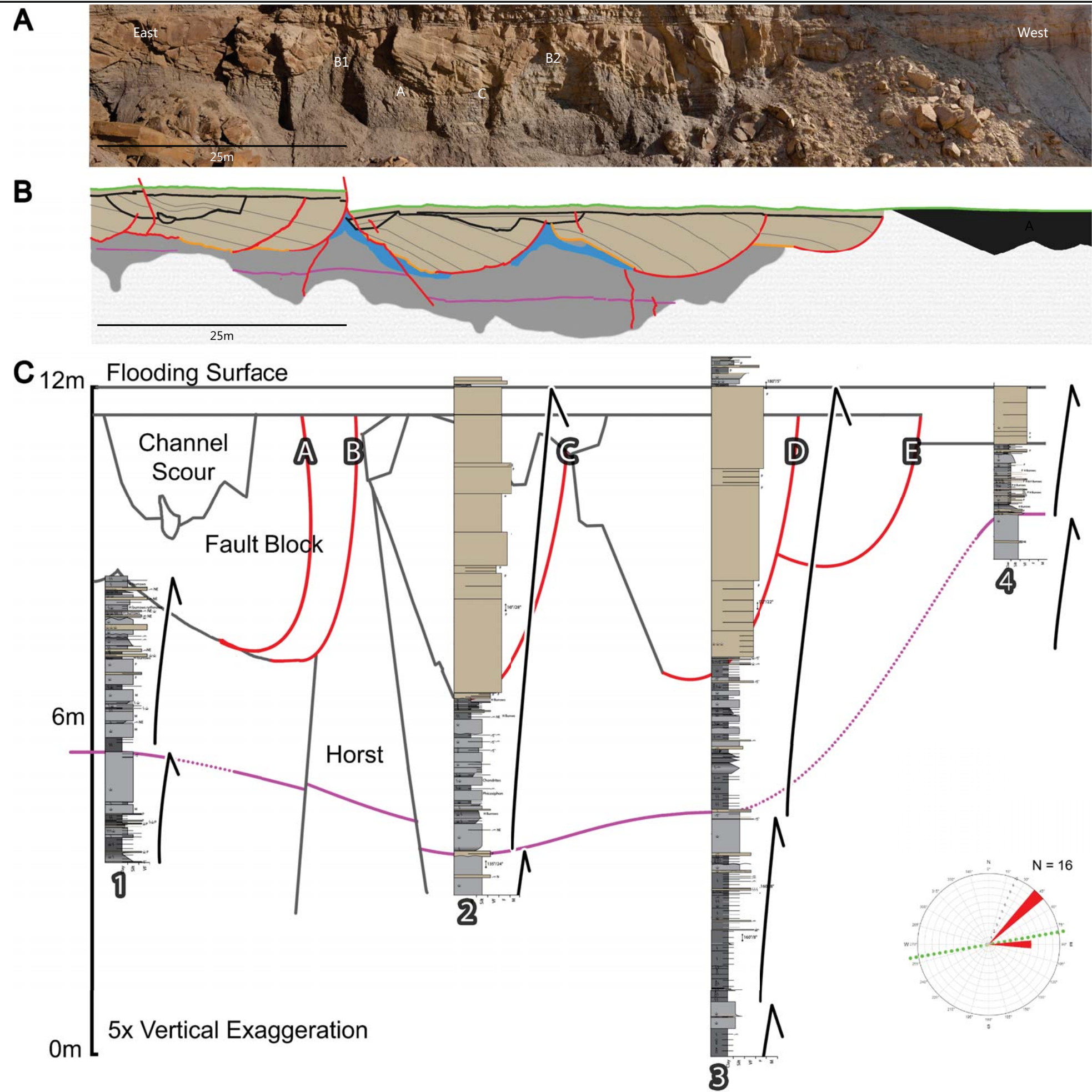
Figure 3 – Location of the field site in Utah. The study outcrop is traced in white.

## Methods

Four stratigraphic sections were taken, and a photomosaic of the outcrop was created. Specific pre-growth beds were tracked across the outcrop in order to generate a step-by-step kinematic restoration of one of the growth faults.



## Data



## Stratigraphic Features

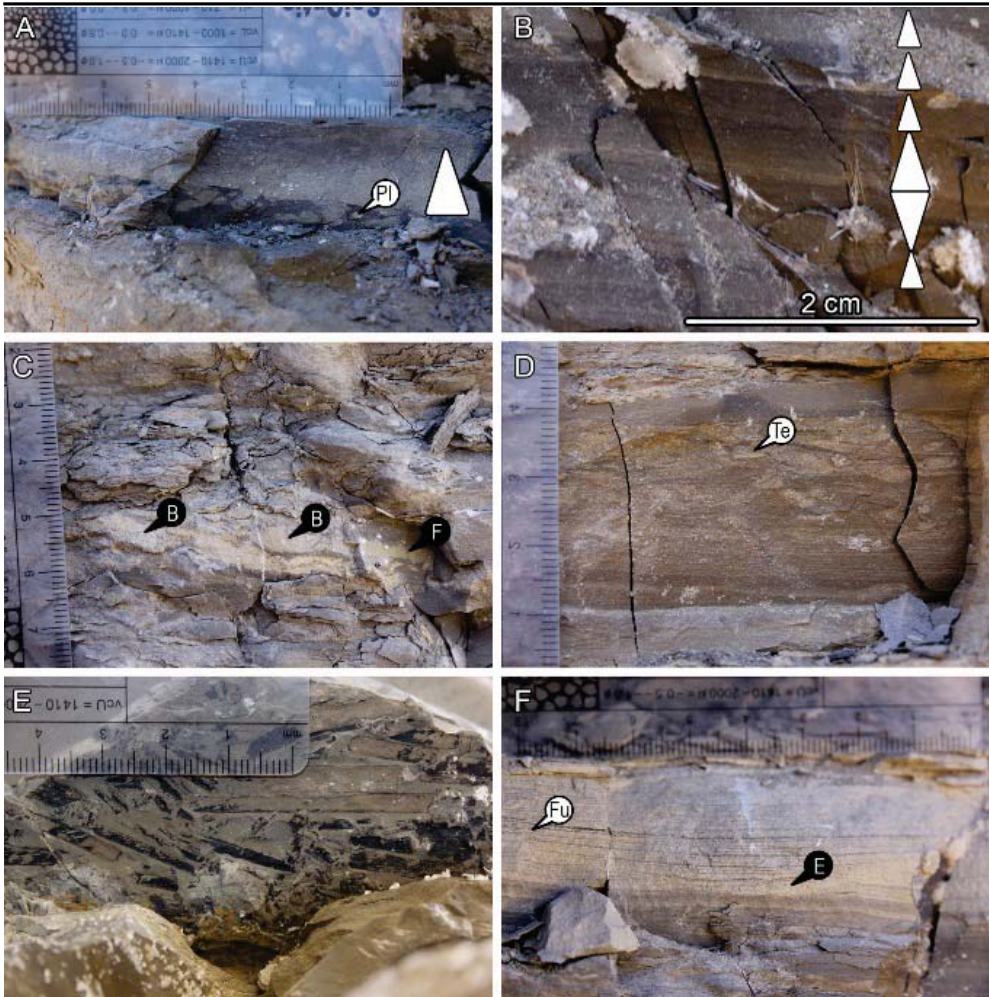


Figure 5 – Pregrowth facies. A) Turbidites. Pl. Planolites. B) Hyperpycnite and turbidites. C) Soft sediment deformation. F. microfault, B. boudinage. D) Stressed Cruziana ichnofacies. Te. Teichichnus. E) Coalified Plant material. F) Storm beds. Fu. Fugichnia, E. erosional surface.

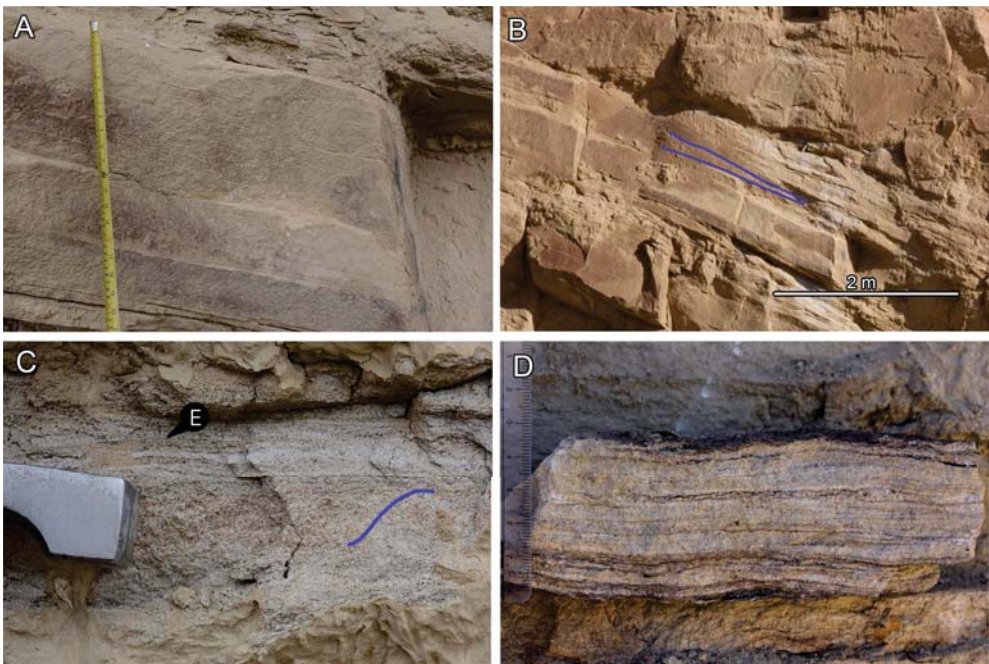


Figure 6 – Growth facies. A) Planar-laminated fine-grained sandstones. B) Quasi-planar sandstones. C) Cross beds, erosionally truncated by combined-flow ripple-laminations. D) Laminated sandstone with macerated coaly plant material. Some gentle undulation is displayed.

## Structural Features

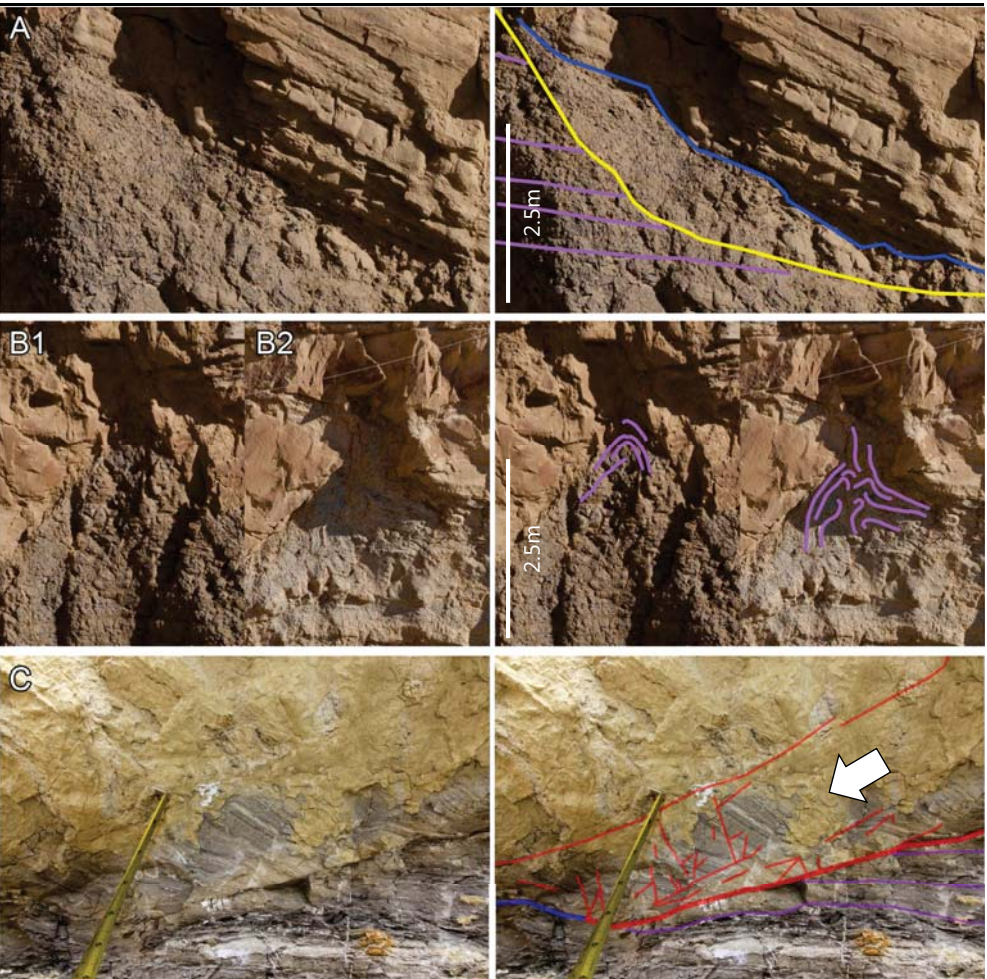


Figure 7 – Structural features. A) Distorted shales are separated from fault blocks by stratigraphic contacts (blue) and from intact pregrowth (purple) by erosional contacts (yellow). B) Distorted shales terminate in shale diapirs (purple) on proximal (B2) and distal (B1) ends of the fault blocks. C) Synthetic microfaulting (red) in sands at fault block bases; pregrowth (purple) is intact, in contrast to higher areas where pregrowth is smeared and sands are intact. Arrow shows direction of fault block movement.

## Interpretation

Upward coarsening heterolithics suggest deposition in a river-dominated, storm-influenced delta. Combined flow, graded structures, and soft sediment deformation suggest rapid progradation supplied by high-volume storm-triggered flood events. Fast outbuilding prevents passive compaction; the pregrowth is highly saturated by growth faulting onset. Growth faulting begins at the sand-mud interface by deposition of a critical wedge. Sinking growth strata mobilizes adjacent muds, which follow a pressure gradient upwards, creating deformed zones and diapirs. Growth faulting ceases as growth strata contacts dewatered, high strength pregrowth. Sands at the fault surface lock into the pregrowth, and synthetic microfaulting briefly supports movement.



# Reconstruction

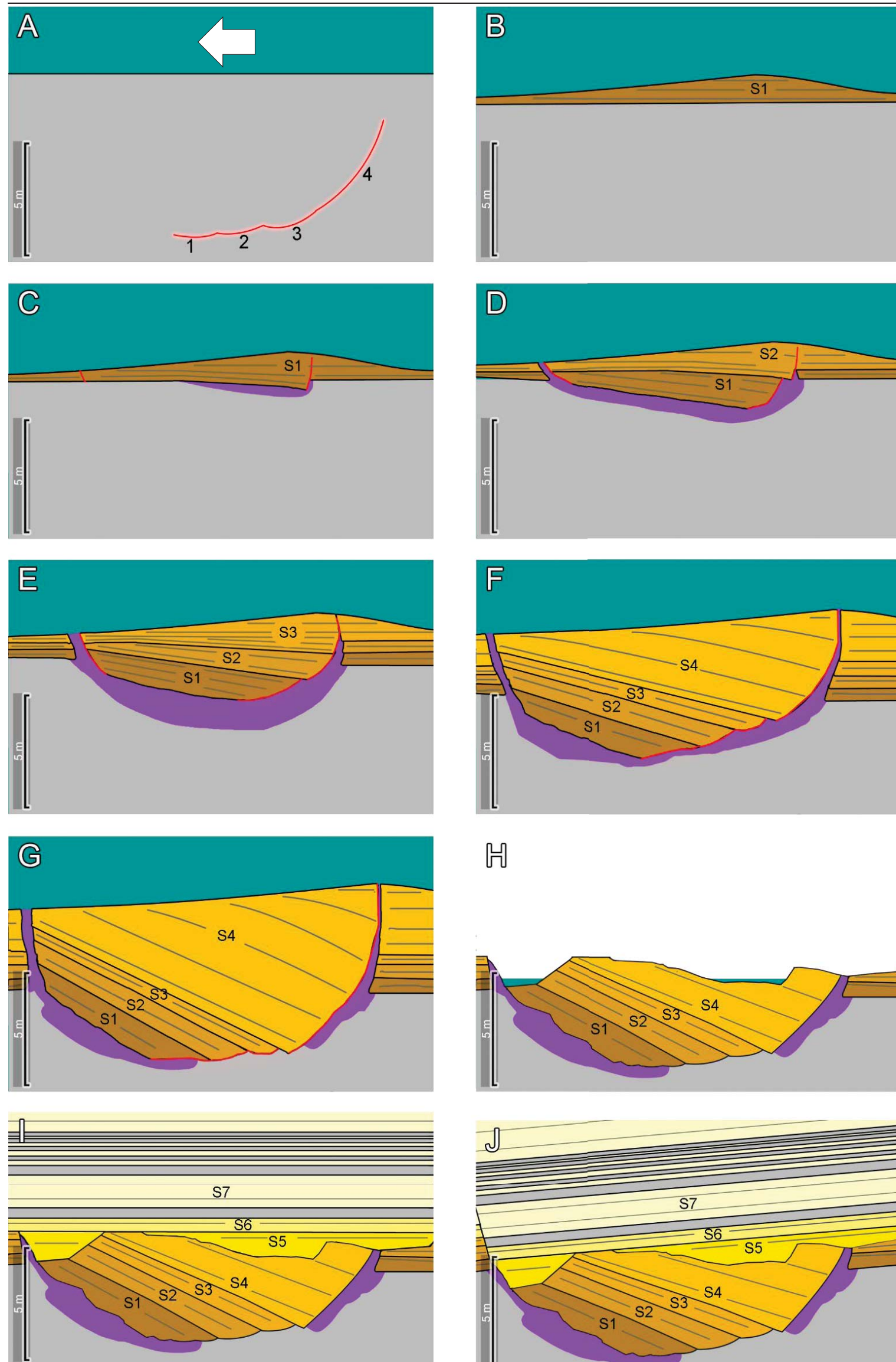


Figure 9 – Reconstruction of growth fault C

1. The pregrowth is deposited as a wedge of prodelta and distal delta front muds, silts, and sands (A).
2. Deposition of mouth bar sands (B) forms a “critical wedge” which initiates growth faulting at the sand/mud interface (C).
3. Accommodation is created by reactive diapirism (D,E,F); as the growth fault develops, pregrowth strata follow a pressure gradient to the sediment-water interface.
4. The primary fault surface deactivates when growth strata contacts and locks into stable, dewatered pre-growth strata (G). Further deformation of growth strata is briefly supported by synthetic microfaulting of growth sands. When the weight of overlying sands can no longer induce microfaulting, the growth fault becomes inactive.

# Discussion

## Comparison to regional-scale growth faults

Contrasting local-scale growth faults, regional-scale growth faults are driven by gravitational slumping and sliding on the continental slope. The “critical wedge” is the entire shelf margin delta instead of a mouth bar; stress is regional instead of local. Such growth faults also form on different bases (far thicker muds, shales, or salt) and access stable sediment supplies. Despite this, some similarities exist. For instance, shale diapirism on overpressured shales [3] is analogous to mud diapirism in this study, which occurred in response to localized shortening from the intrusion of fault blocks.

## Reservoir Mechanics

Major oil fields such as Prudhoe Bay and Athabasca are based in shallow fluvial-deltaic formations. Such fields are generally heterogeneous, and outcrop analogs may explain inconsistent production across the same unit. For instance, growth faulting may locally thicken sandstones to provide expanded, but localized reservoir compartments. These may be charged through the growth fault surface, as a shale smear is absent and growth sands contact the pregrowth. As the growth strata are joined to a regional proximal delta front sandstone bed, these growth faults may concentrate reserves from isolated heterolithic pregrowth beds into a single sandstone unit. Compartmentalization occurs where fault sandstones and regional sandstone beds contact overlying marine shales, and where fault blocks contact distorted shales, and are thus sealing.

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