

Oceanic Flood Deposits in the Cretaceous Western Interior of North America*

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Abstract

The apparent paucity of storm, wave-induced underflow deposits in ancient shelf settings is puzzling given the ubiquity of storm deposits in many shallow marine sections worldwide. The western margin of the Cretaceous Western Interior Seaway was characterized by small-to-moderate-sized rivers and was storm-dominated, which are near perfect conditions for the generation of storm, wave-induced underflows or oceanic floods. In these settings, storm waves are coupled with an increased delivery of river-derived fresh water and fine-grained sediments, creating high density underflows which transport sediments from the shoreface to the shelf. Even though oceanic floods occur over a shorter time period (i.e., days) compared to sustained river flood-induced underflows (i.e., weeks), they have the capacity to transfer a much greater volume of fine-grained sediments onto the shelf.

Early results from the Upper Cretaceous strata of the Book Cliffs region, eastern Utah and western Colorado have revealed the presence of oceanic flood deposits in a variety of stratigraphic intervals. The oceanic flood deposits occur as channelized or lobate, isolated shelf bodies that are dominated by organic-rich siltstones and mudstones; very fine- to fine-grained Bouma-like sandstone beds, including wave-modified turbidites, hyperpycnites and classical turbidites; and hummocky-cross-stratified sandstones. Paleocurrent data reveal a dominant across-shelf, offshore-directed transport trend. Wave-modification is prevalent and includes combined flow ripples, quasi-planar laminations, and low-amplitude HCS, indicating deposition above storm wave base. Storm wave-induced underflows or oceanic flood deposits require further investigation before a genetic facies model for hyperpycnites can be constructed.



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Fundamental Questions

How are Sediments Delivered onto the Shelf?

Is the Transport Direction Across- or Along-Shelf?

Role of Hyperpycnal Flows/River Flood Events?

Role of Storms/Wave-Modified Underflows/Oceanic Flood Events?

Focus of Research

Ancient Examples of Across-Shelf Underflows

Isolated Shelf Channels and Lobes - Book Cliffs UT-CO

Depositional Model

Implications for Petroleum Exploration/Development
(e.g. Tight Gas Sandstones and Gas Shales)

The background image shows a large, layered sedimentary cliff face under a blue sky with light clouds. A person is standing on the sandy shore at the base of the cliff, providing a sense of scale. The cliff face exhibits distinct horizontal sedimentary layers and some vertical erosion patterns.

Outline

Introduction

Stratigraphy

Depositional Environments - Shelf

Wave-Modified Turbidites

Hyperpycnal Flows

Isolated Shelf Channels and Lobes: Book Cliffs

Paleogeography

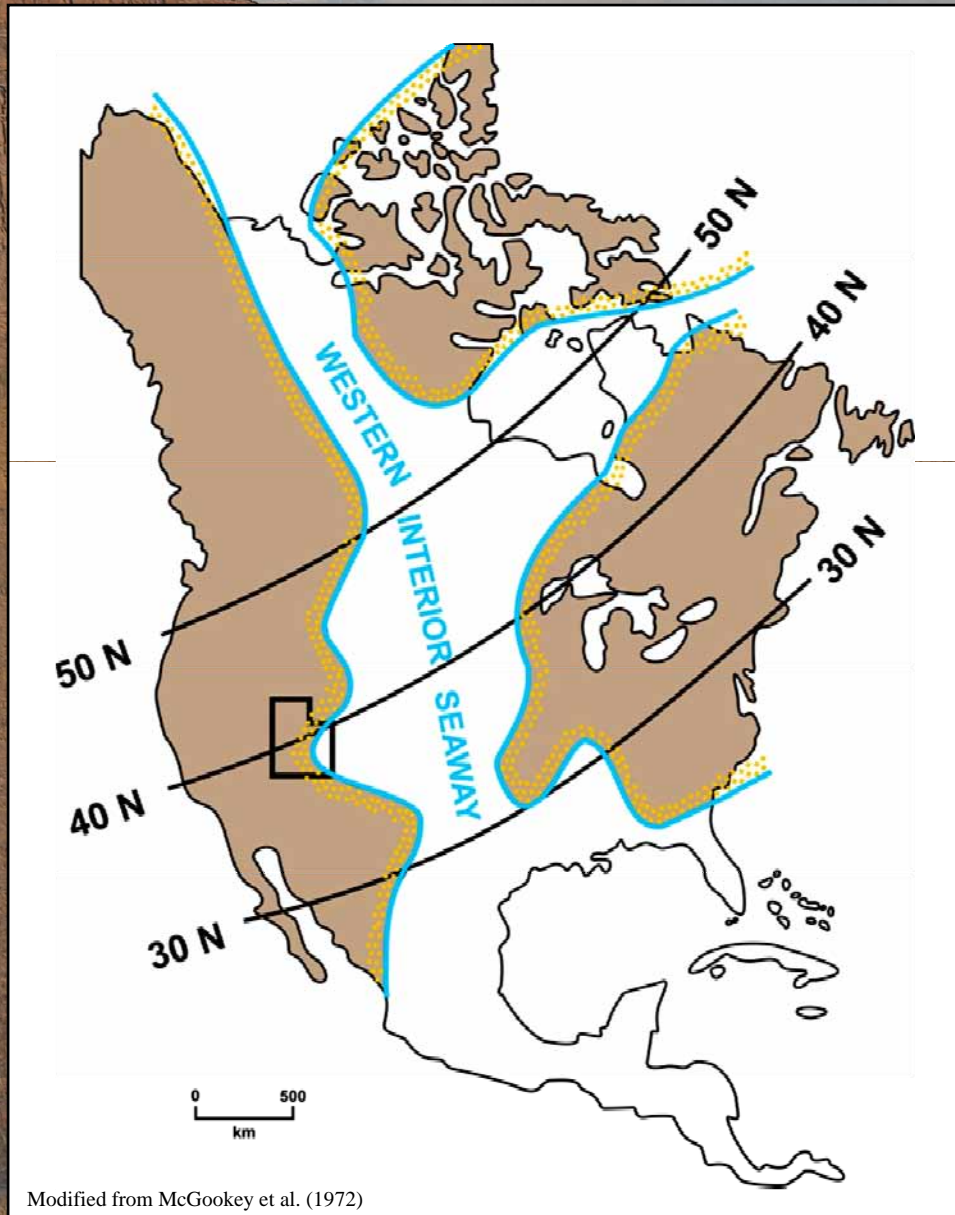
Sedimentary Architecture

Facies/Sedimentology

Depositional Model

Conclusions

Introduction - North America in the Cretaceous Period



Modified from McGookey et al. (1972)

Cretaceous Western Interior Seaway was 1000+ km wide.

Arctic Ocean connected with the Gulf of Mexico. Maximum water depths a few hundred meters.

Paleoshoreline trends oriented approximately north to south.

Sediments eroded from the Rocky Mountains (Sevier thrust front) to the west and deposited along the western margin of the seaway.

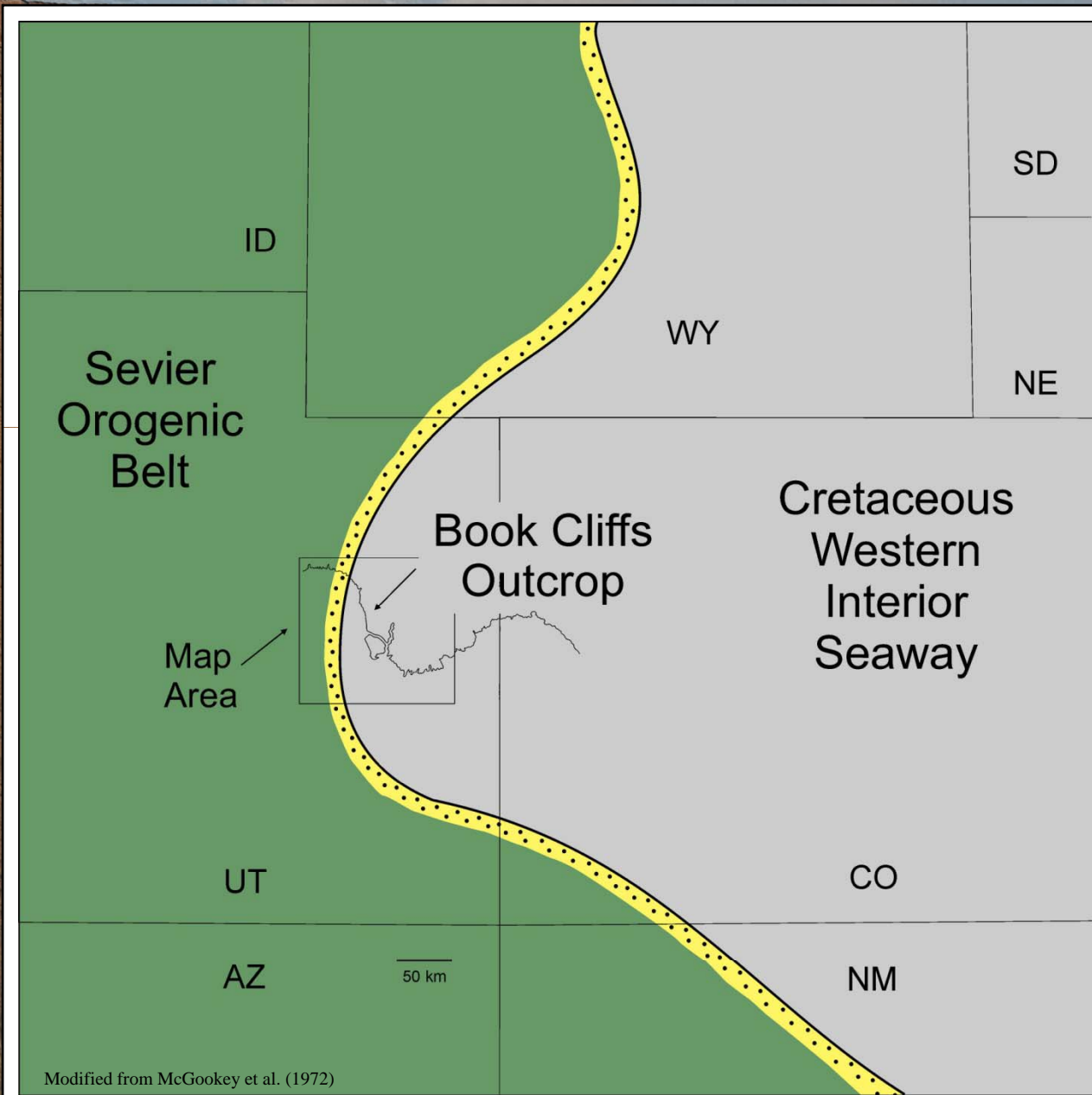
Shoreline passes through eastern Utah in the area of the Utah Bight.

Cretaceous of Utah

Paleoshoreline trends are well established and were oriented north to south through the Utah Bight region of east-central Utah.

Book Cliffs outcrop covers the coastal plain-fluvial (green), shallow marine-shoreface (yellow) and offshore-shelf (grey) environments.

Time equivalent units can be physically “walked-out” into the basin.



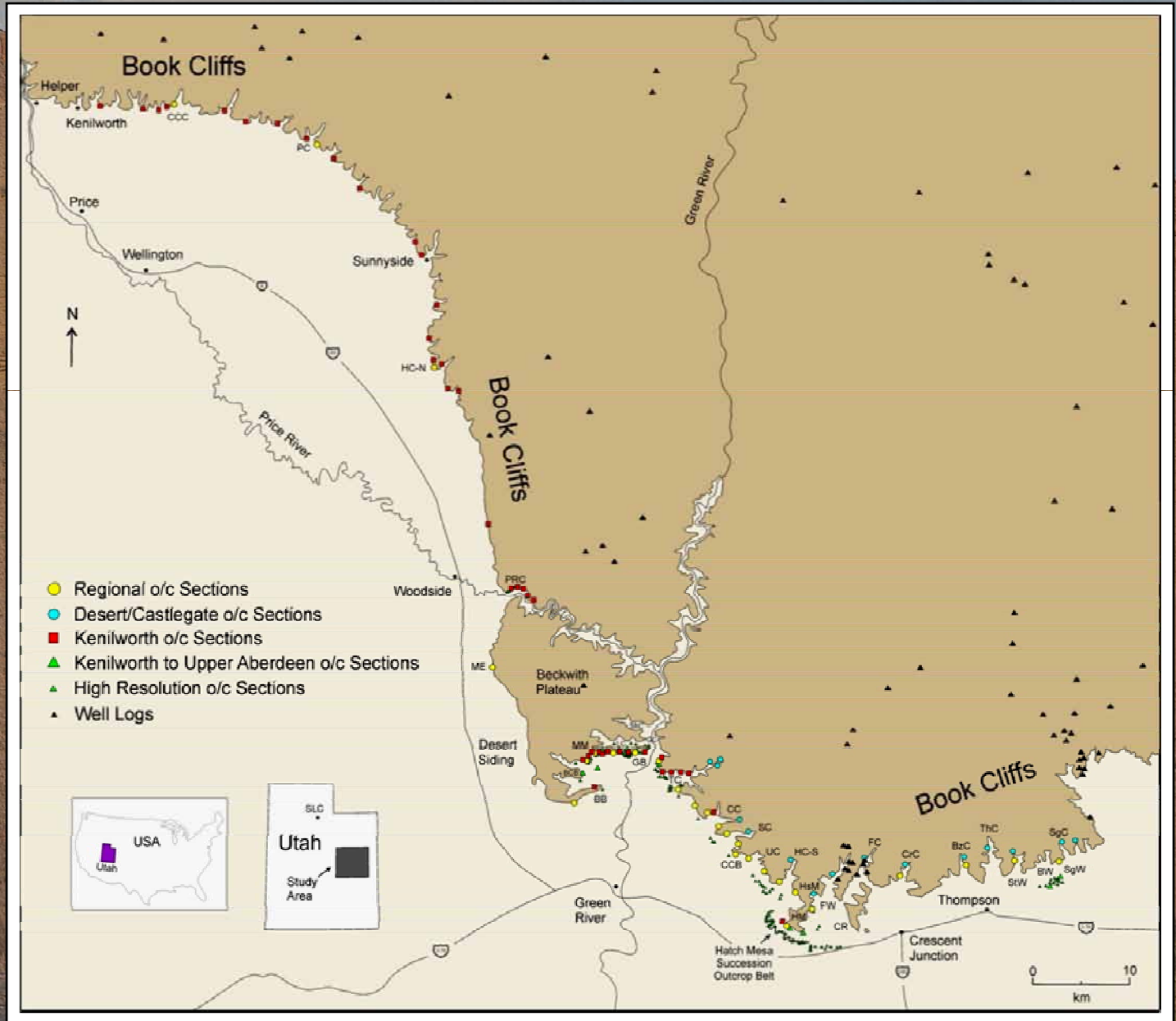
Study Area: Book Cliffs UT-CO

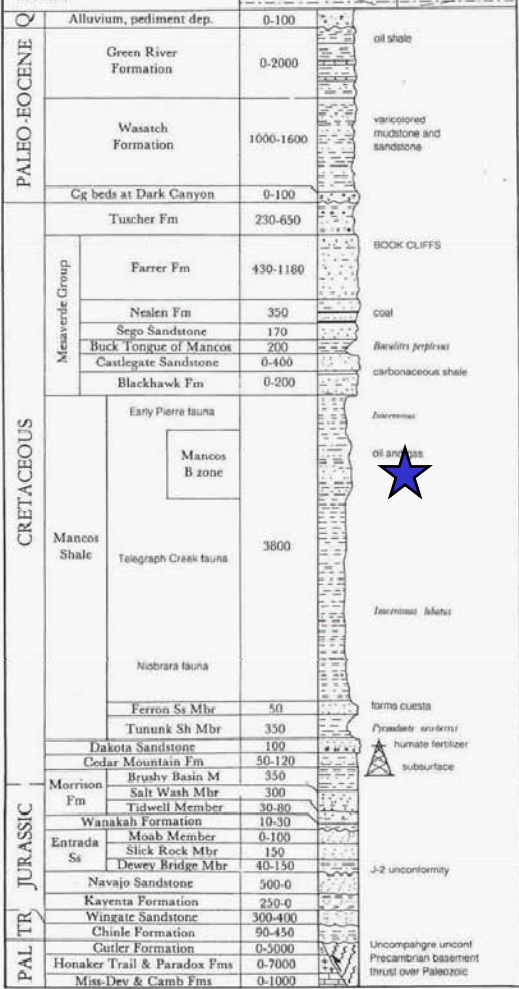
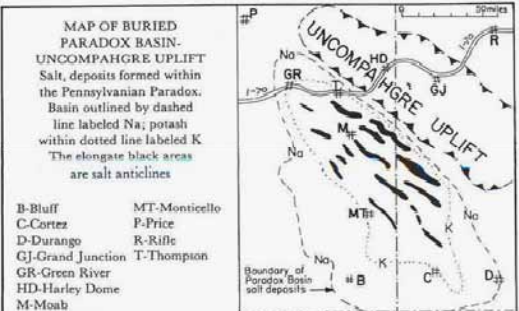
250+ measured outcrop sections.

100+ well logs suites.

200+ thin sections of ss and mst for petrographic analysis.

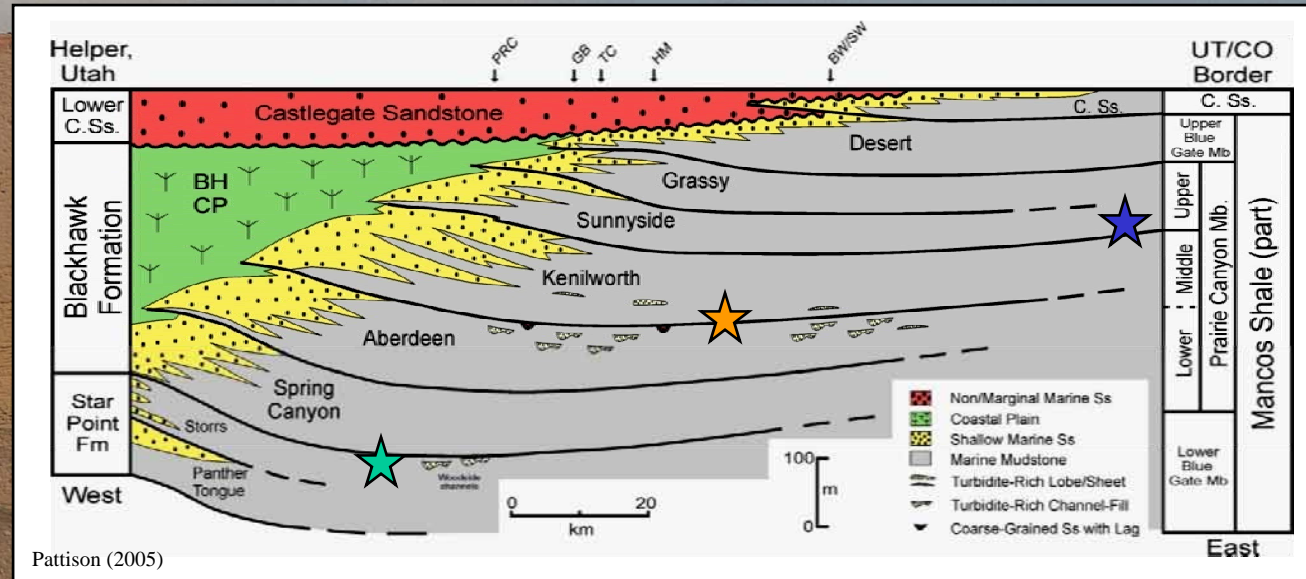
Continuous photo-panoramas









MAP WITH TEXT - Cashin, 1973; Williams, 1964; Willis, 1985; Szklar, 1992; GREEN RIVER - Cashin, 1967b; WASATCH - Fauch et al, 1982; CRETACEOUS - Young, 1955, 1966; Willis, 1985; Fisher et al, 1960; Craig, 1981; Dooling & Graham, 1972b; Gil & Hall, 1975; Kottg, 1977; Jackson, 1983; JURASSIC - O'Sullivan, 1981b, 1984; TRIASSIC - Stewart et al, 1972a; PRECAMBRIAN - Twiss, 1977; UNCOMPAGRE FAULT - White & Jacobson, 1983; Heyman, 1983; Fraker & Vasek, 1983.

Stratigraphy

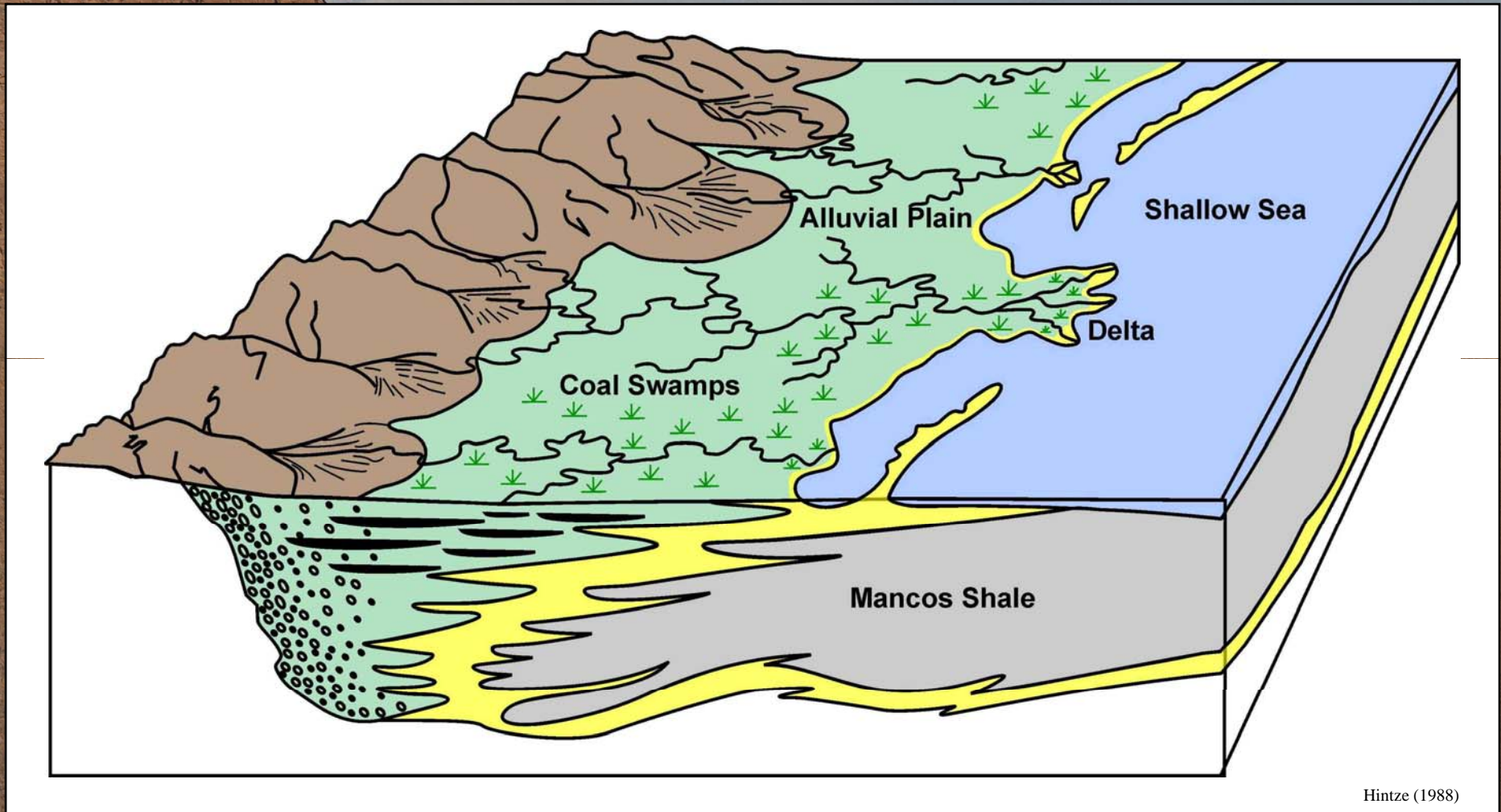


Pattison (2005)

Channelized and lobate isolated shelf sandstone bodies are concentrated along at least four horizons:

- (i)  Turonian Lower Ferron Sandstone/Juana Lopez Member (Mancos Shale),
- (ii)  Campanian Storrs Member (Star Point Formation),
- (iii)  Campanian upper Aberdeen to lower Kenilworth members (Blackhawk Formation), and
- (iv)  Campanian Prairie Canyon Member or Mancos B.

Depositional Environments - Shelf



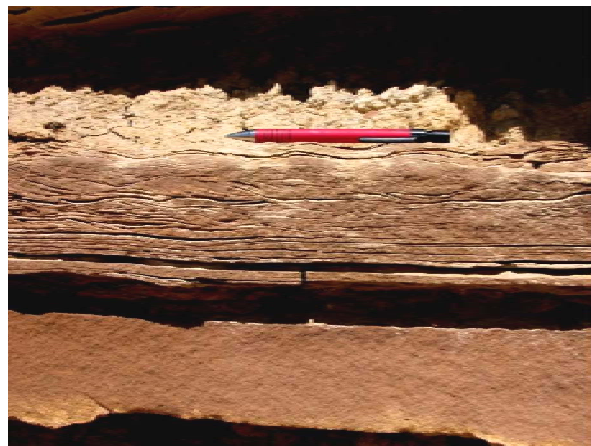
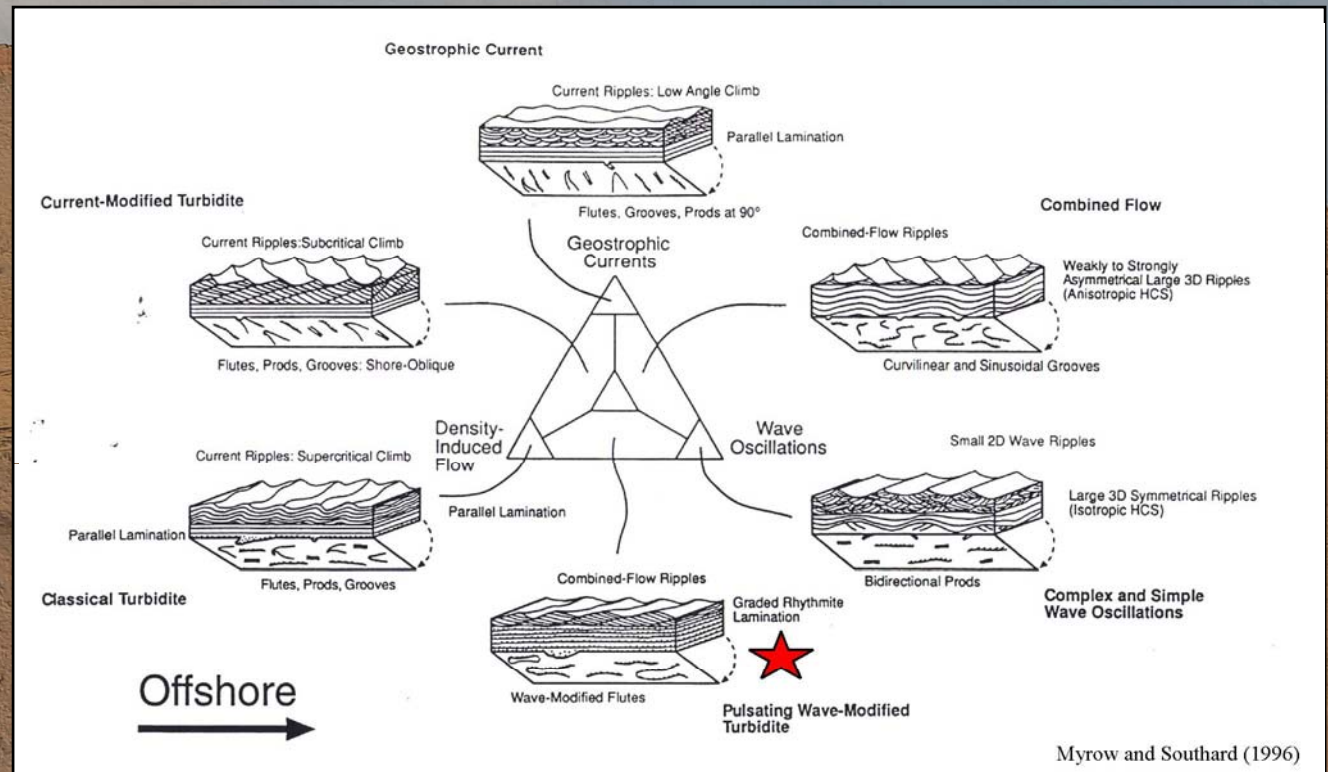
Late Cretaceous depositional environments. CWIS was storm-dominated.

Focus on the variety of **shelf deposits**: HCS sandstones, classical turbidites, wave-modified turbidites, and hyperpycnites (oceanic flood events).

Wave-Modified Turbidites

Wave-modified turbidites are deposited above SWB. Genetically linked to HCS ss: **combined flow**.

Excellent examples are observed in the lower Kenilworth Member, Book Cliffs, Utah.

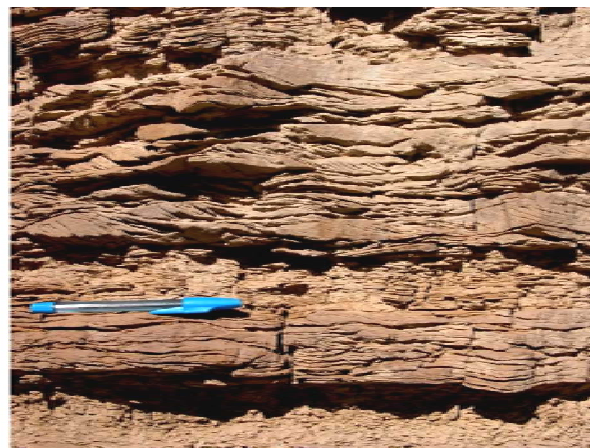
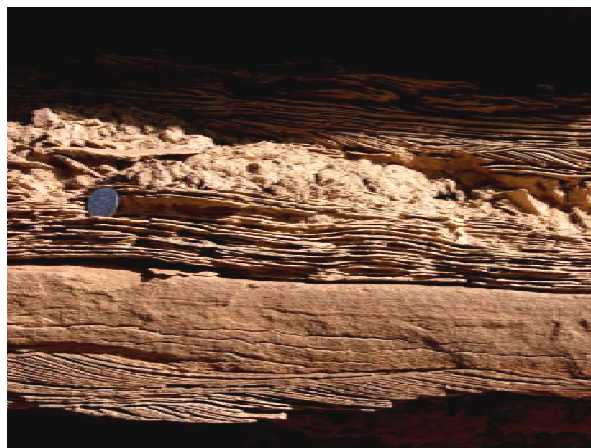
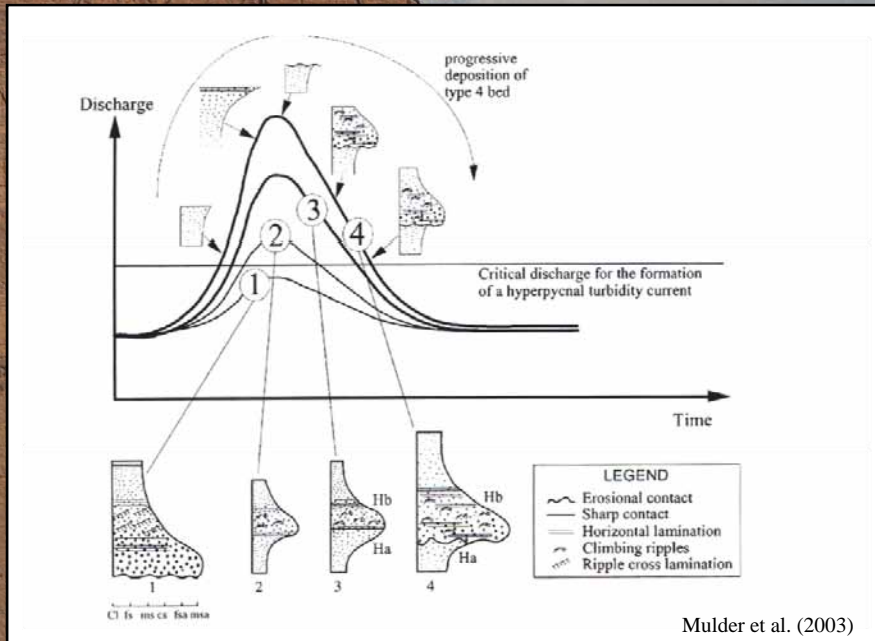


Hyperpycnal Flows

Marine hyperpycnal plume is a particular kind of turbidity current occurring at a river mouth. Concentration of suspended sediment is so large that the density of river water is greater than the density of sea water. Plume can plunge and possibly erode the sea floor. Can be self-maintained for weeks: river-flood events. Shorter duration, higher energy events occur when storm waves are coupled with river floods: **oceanic flood events**.

Stacked Bouma-like beds are deposited.

Underflows are more typical of small- to medium-sized rivers.





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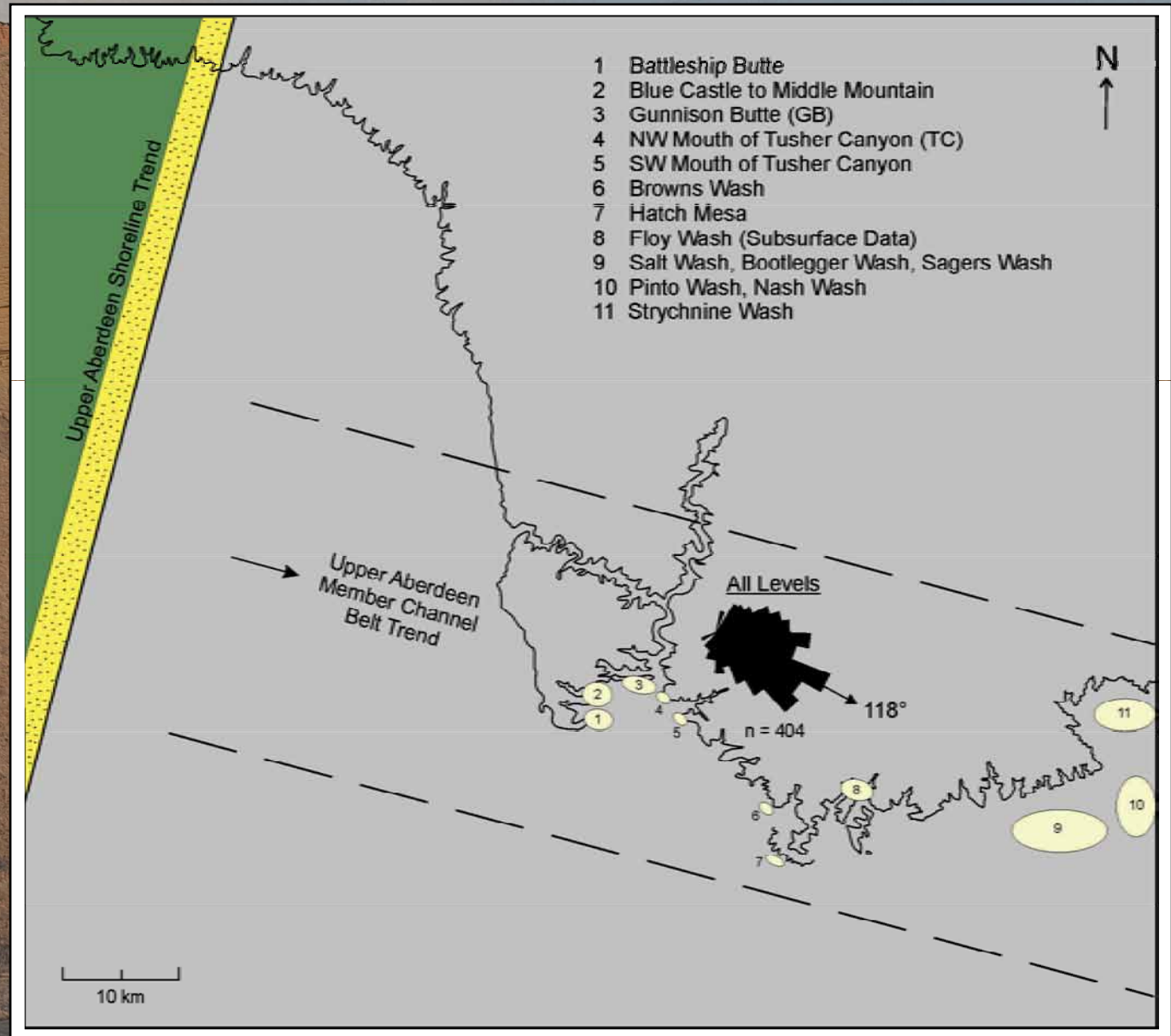
Isolated Shelf Channels: Book Cliffs, Utah

Mean offshore transport direction N118°E (n = 404).

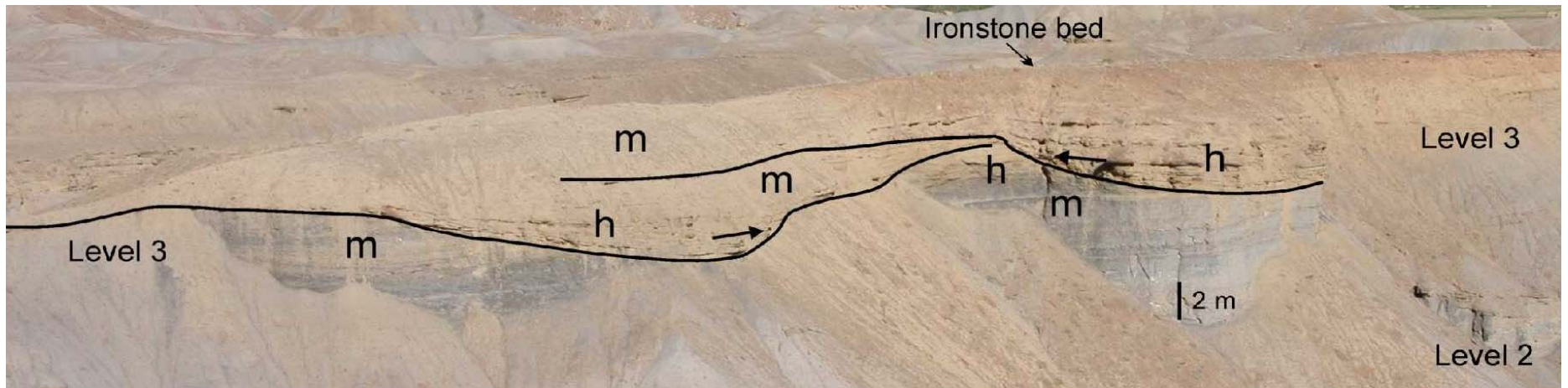
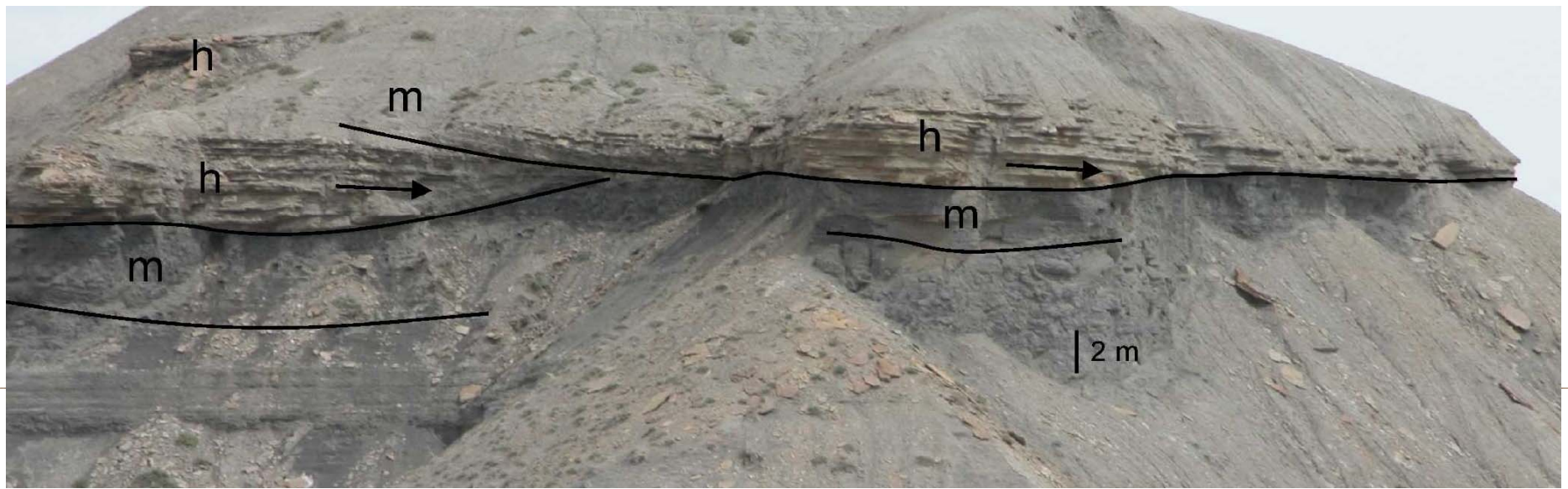
Offshore transport of FG sediments.

Channel-fill deposits occur at four distinct levels, but are mostly concentrated along Levels 2 and 3.

Channels are sharp-based, 2 to 12 m thick, and a few tens of meters wide.

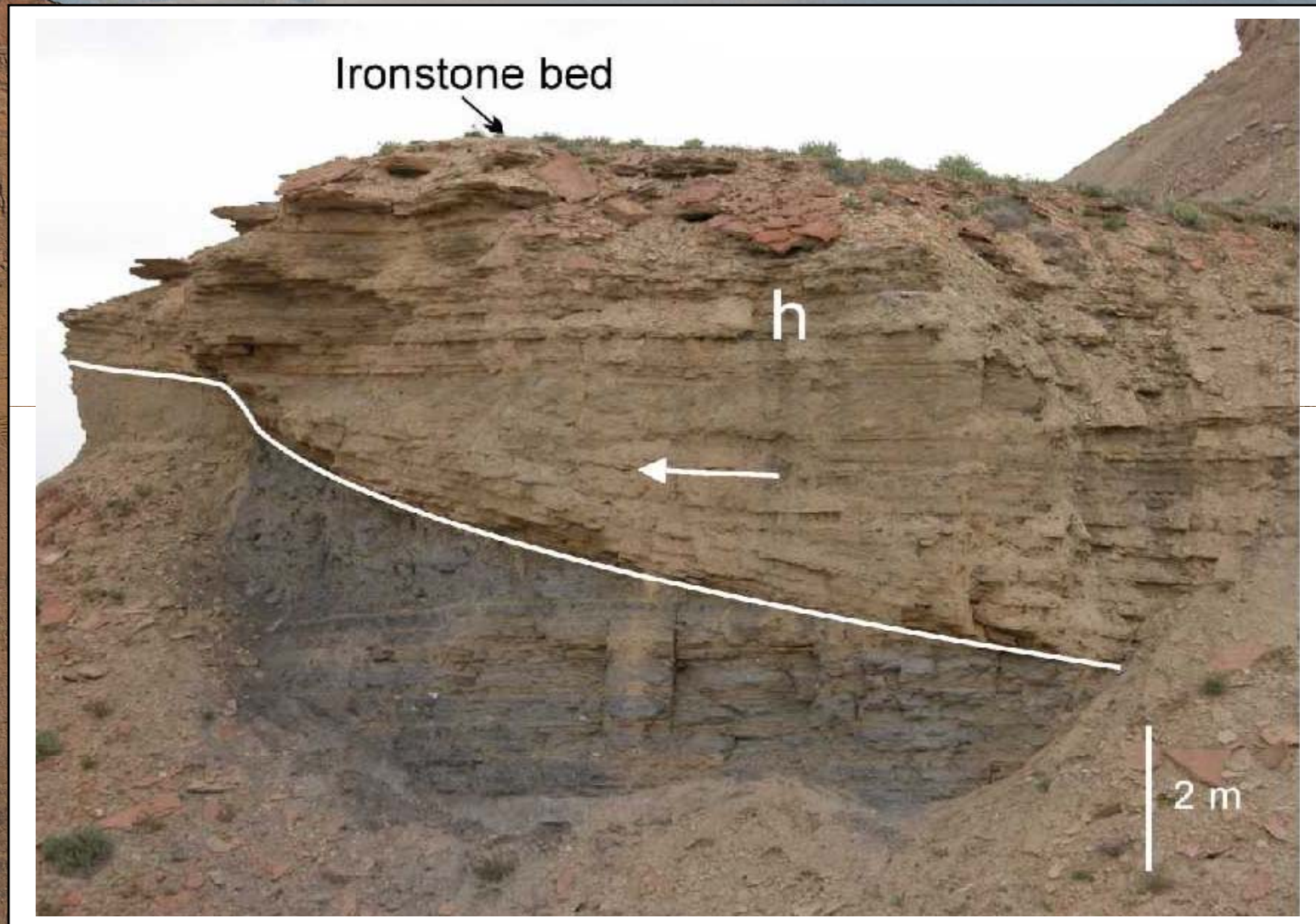


Shelf Channels: Sedimentary Architecture



Multistory package of nested mst-, heterolithic- or ss-rich channel-fill units. Sharp and erosional contacts between each channel fill. Pinch and swell sand body geometries, onlap and downlap. Concave-up beds drape channel margins. Accretion surfaces dip 2-11°.

Shelf Channels: Sedimentary Architecture



Multistory package of nested mst-, heterolithic- or ss-rich channel-fill units. Sharp and erosional contacts between each channel fill. Pinch and swell sand body geometries, onlap and downlap. Concave-up beds drape channel margins. Accretion surfaces dip 2-11°.

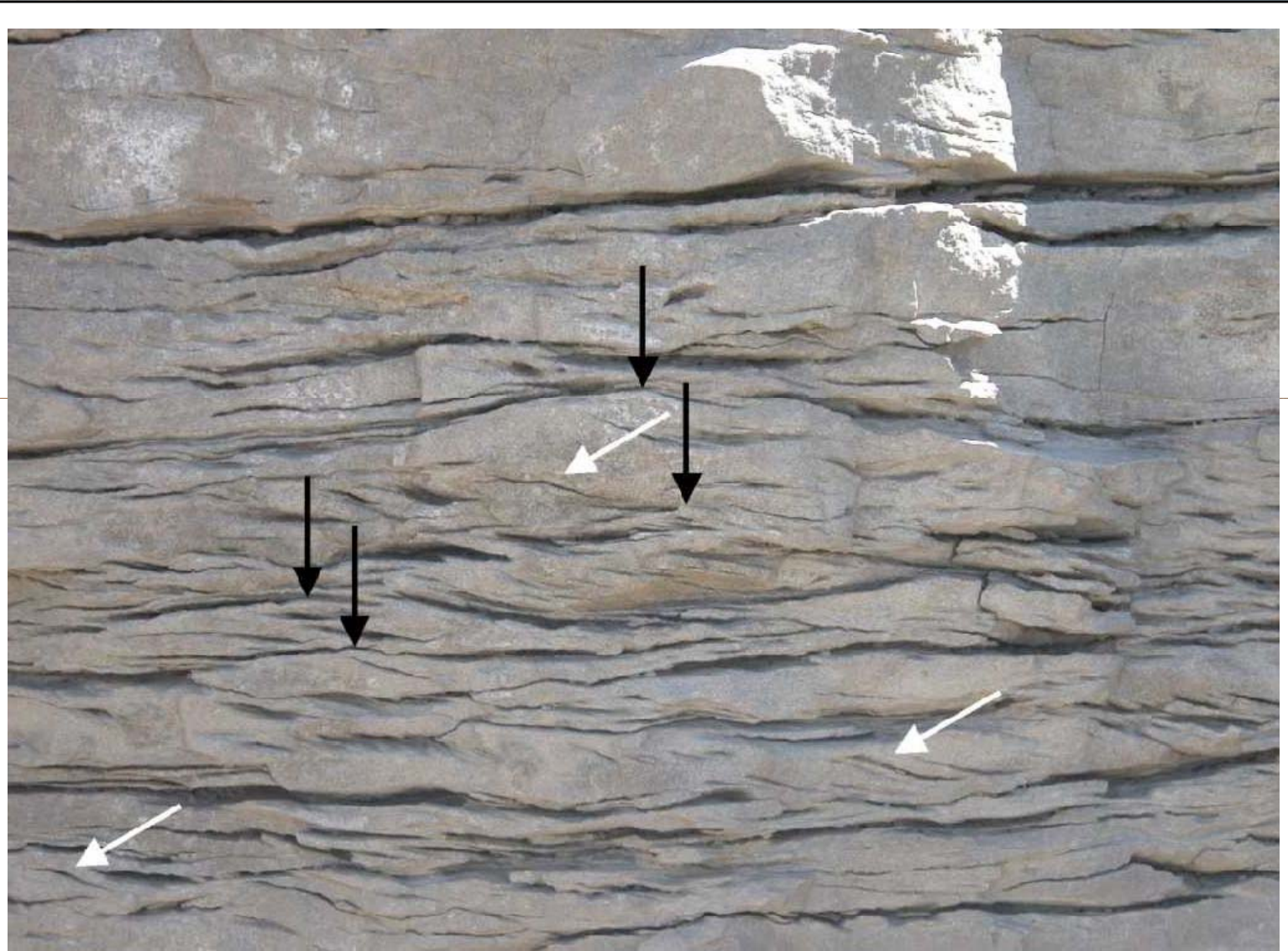
Shelf Channels: Facies

Current, combined flow (CF) and wave **ripples**.

Starved current ripples and climbing ripples.

Abundance of plant material: lofting rhythmities.

Sharp-based beds with normal grading.



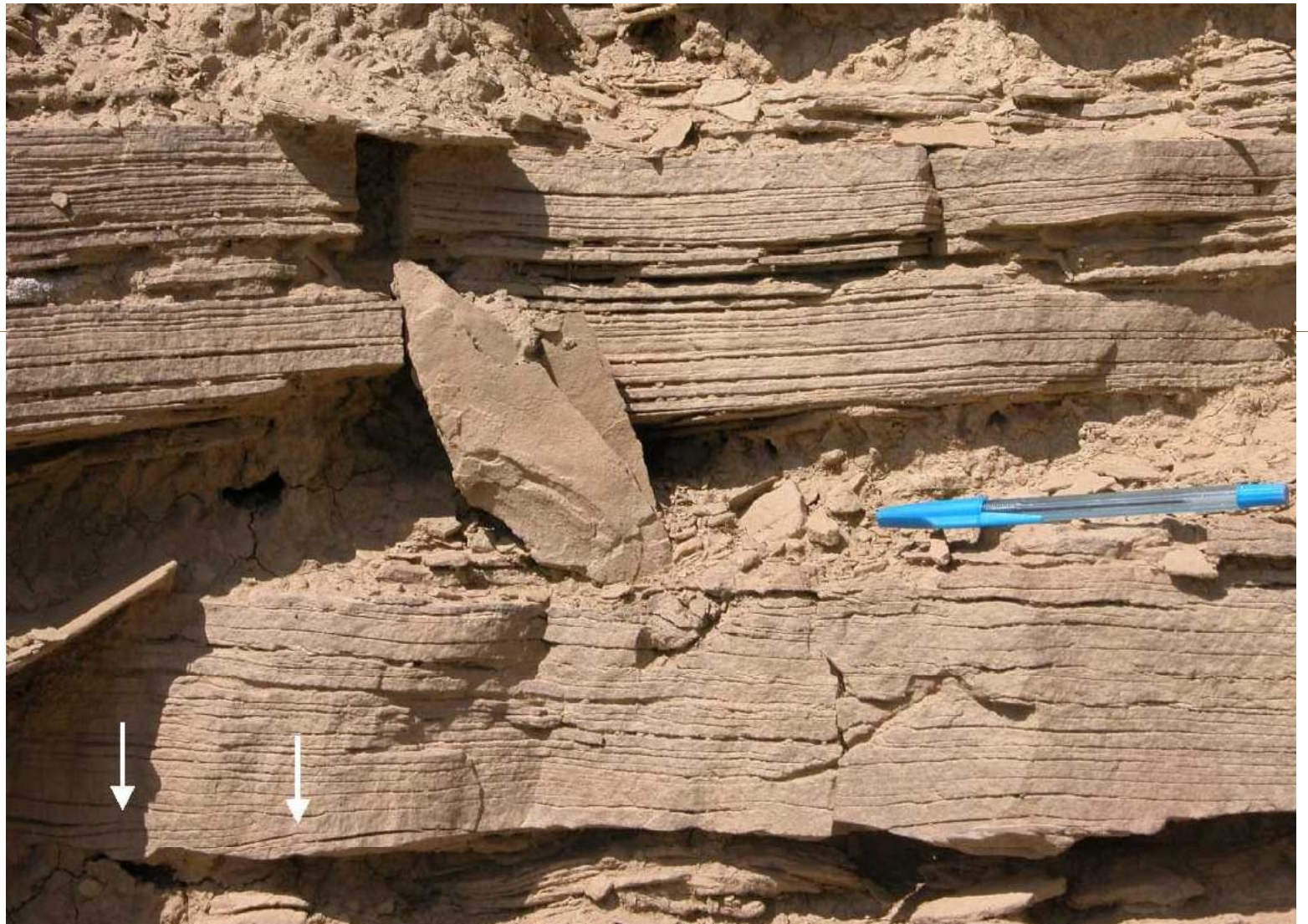
Convex-up sigmoidal profiles (white arrows) and weakly asymmetrical to symmetrical ripple crests (black arrows) are two criteria used to identify CF ripples (Myrow et al. 2002; Dumas et al. 2005).

Shelf Channels: Facies

Low Bl.

Horizontal grazing or crawling traces confined to the uppermost bedding plane: *Gyrochorte* and chevron-like tracks.

Gently curving planar-laminated sandstones: m-wavelength, cm-amplitude, low angle truncation surfaces (arrows).



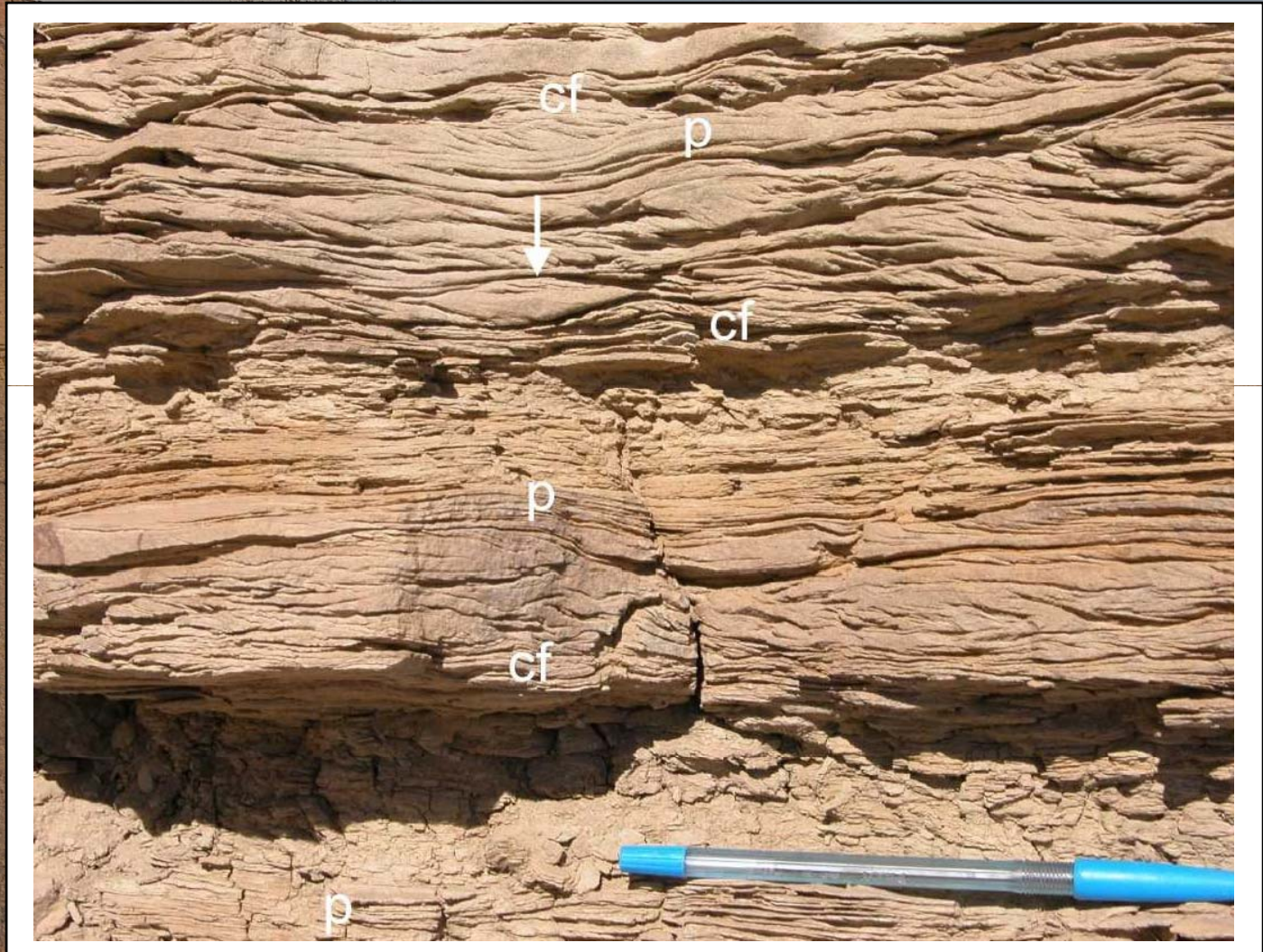
Shelf Channels: Facies

Very fine-grained ss,
slst and mst.

Stacked Bouma-like
event beds.

**Stacked sets of
planar- to ripple-
laminated** ss, with
diffuse contacts.

Up to twelve
divisions occur in a
single bed. Some
beds begin with a
ripple-laminated
division at the base,
while others have
planar laminations at
the base.



Weakly- to strongly-asymmetrical combined flow ripples are dominant, with lesser amounts of current ripples. Most planar-laminated sandstone divisions have gently curving laminations with or without small-scale truncation surfaces. Wave-modified hyperpycnal-flow or hyperpycnites.

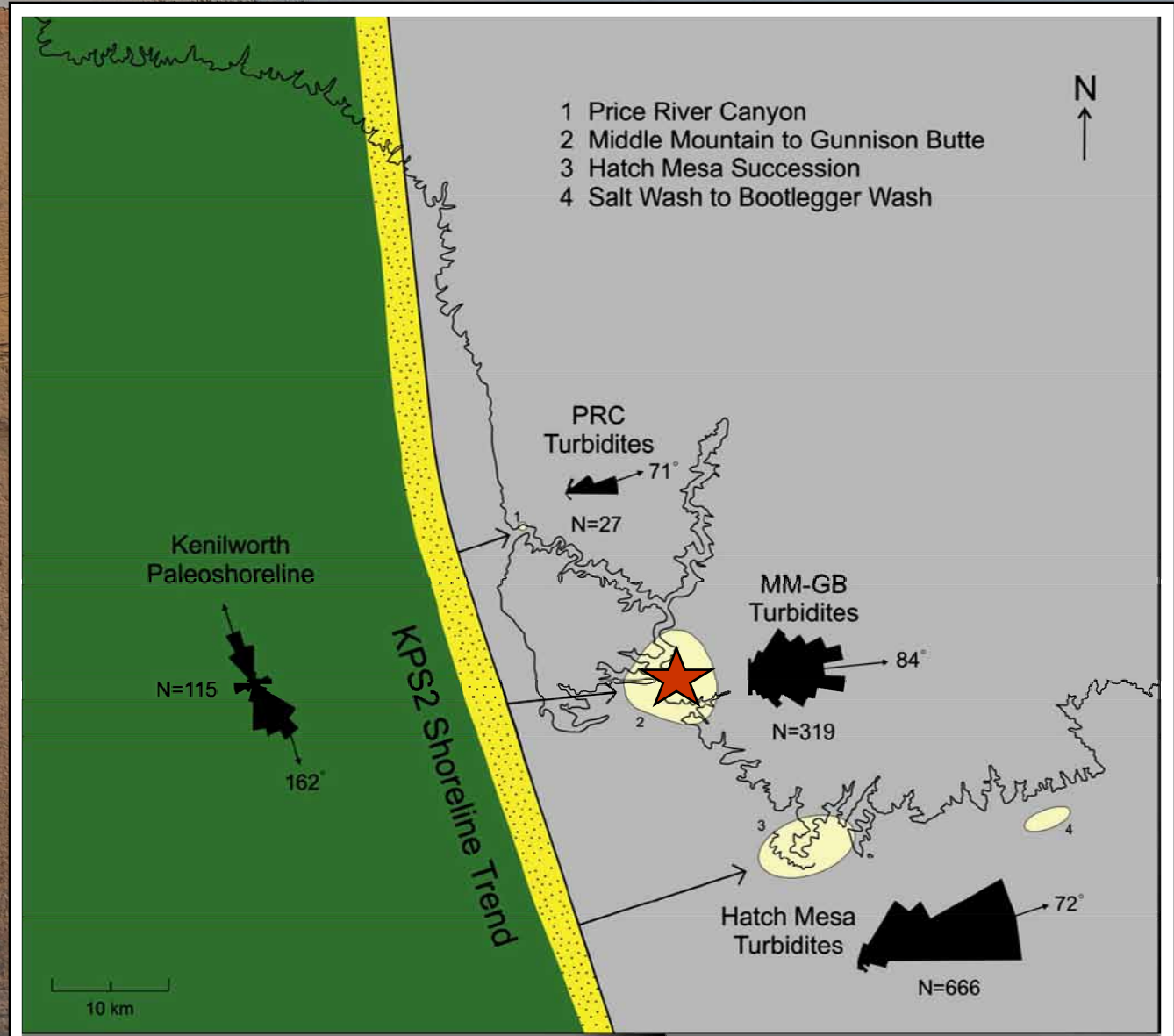
Isolated Shelf Lobes: Book Cliffs, Utah

Lower Kenilworth paleoshoreline trend N18°W.

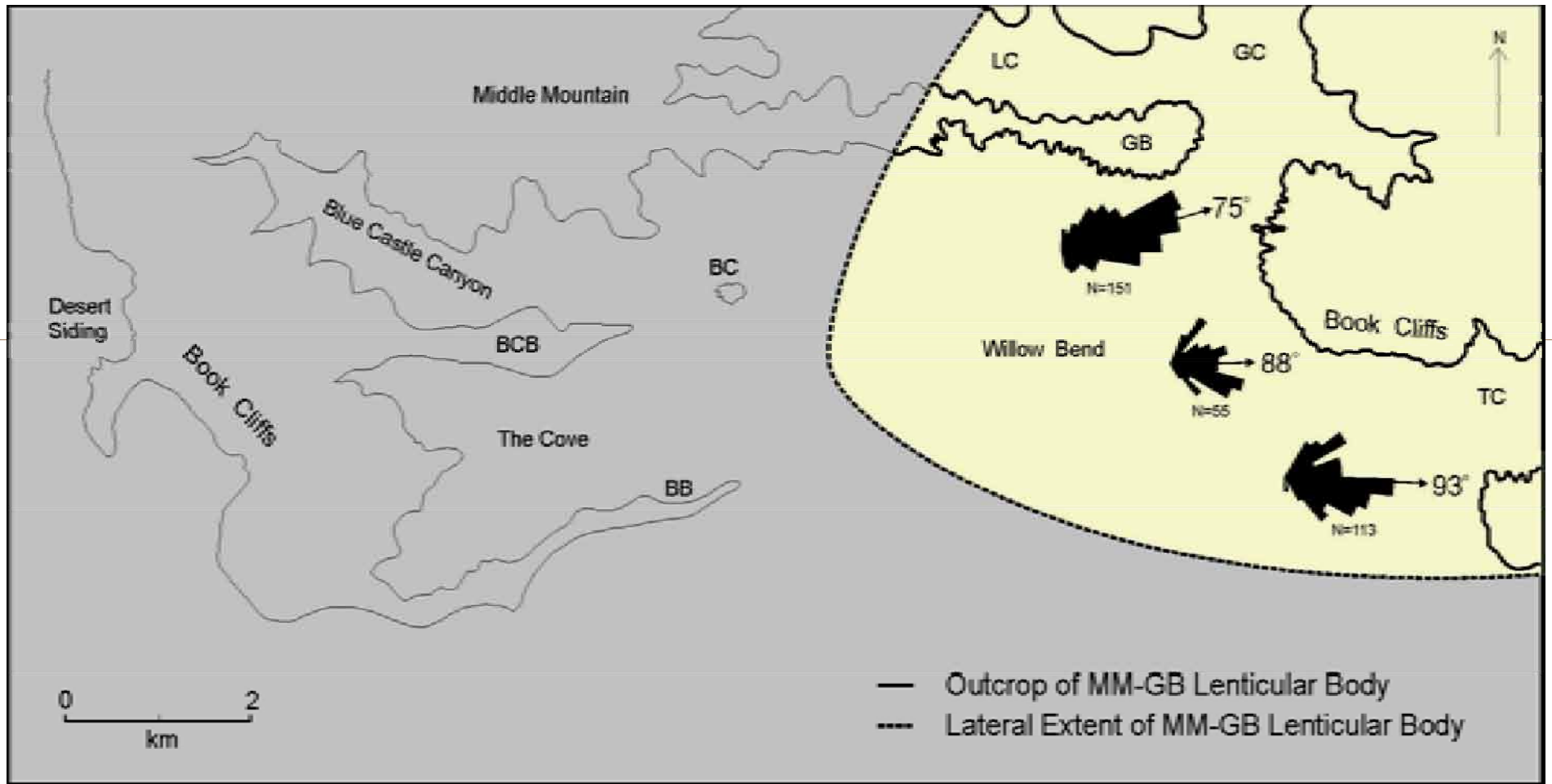
Inner shelf turbidites at four localities.

Kenilworth and Hatch Mesa turbidites were transported N71°E to N84°E (mean = N76°E; n = 1012), approximately orthogonal to the Kenilworth paleoshoreline.

Offshore transport of FG sediments.

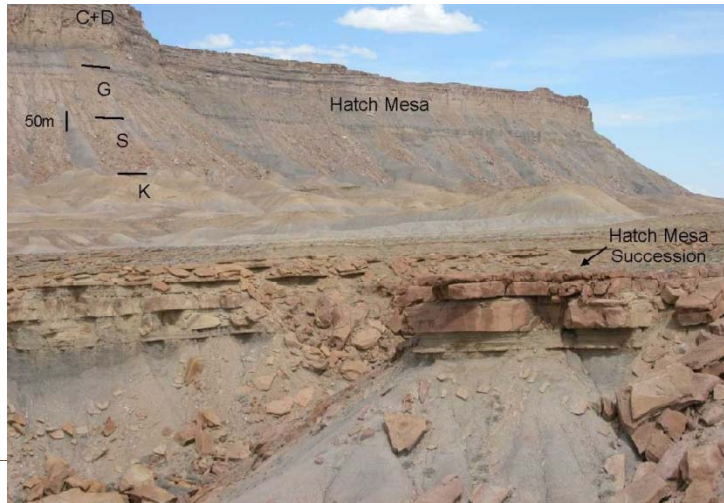


Shelf Lobes: Paleogeography of MM-GB Body

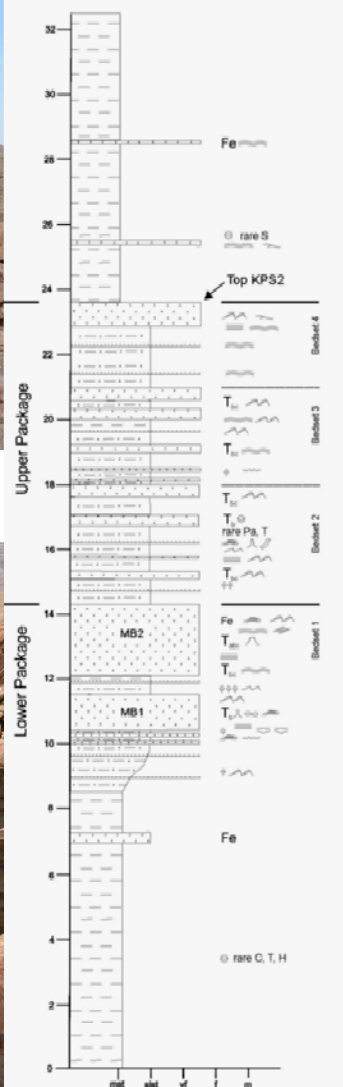
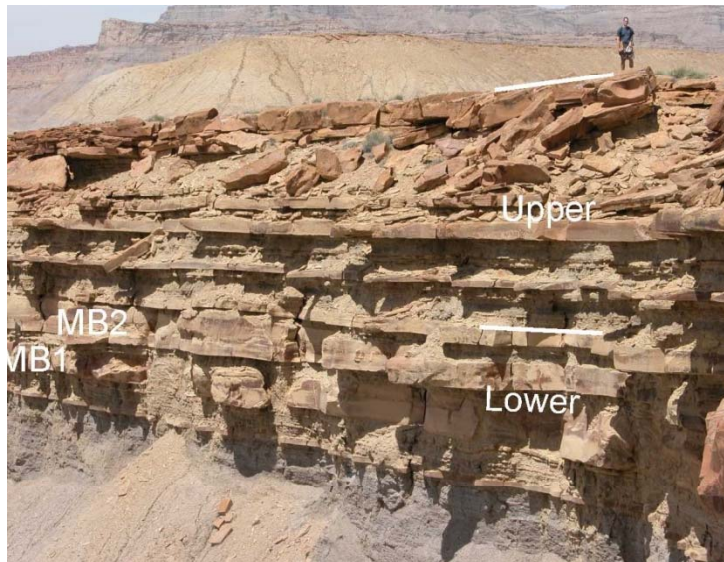


Up-dip terminus of MM-GB lobate shelf body is very well constrained. Excellent 3D outcrop control in the Green River embayment. MM-GB body is clearly detached from its time equivalent shoreface. Isolated, marine mudstone-encased, turbidite-rich body.

Shelf Lobes: Sedimentary Architecture



Proximal



The Hatch Mesa lobe is at least 10 km long and 8 km wide, while the MM-GB body is 8 km long by 8 km wide. These shelf lobes are 6 to 20 m thick.



Distal

Laterally Continuous, Onlap, Pinch and Swell Sand Body Geometry, No Clinofolds, Compensatory Geometries, 3-4 CU Successions, Erosional Scours (Proximal), Load and Flame Structures

Detached from their time equivalent shoreface deposits.

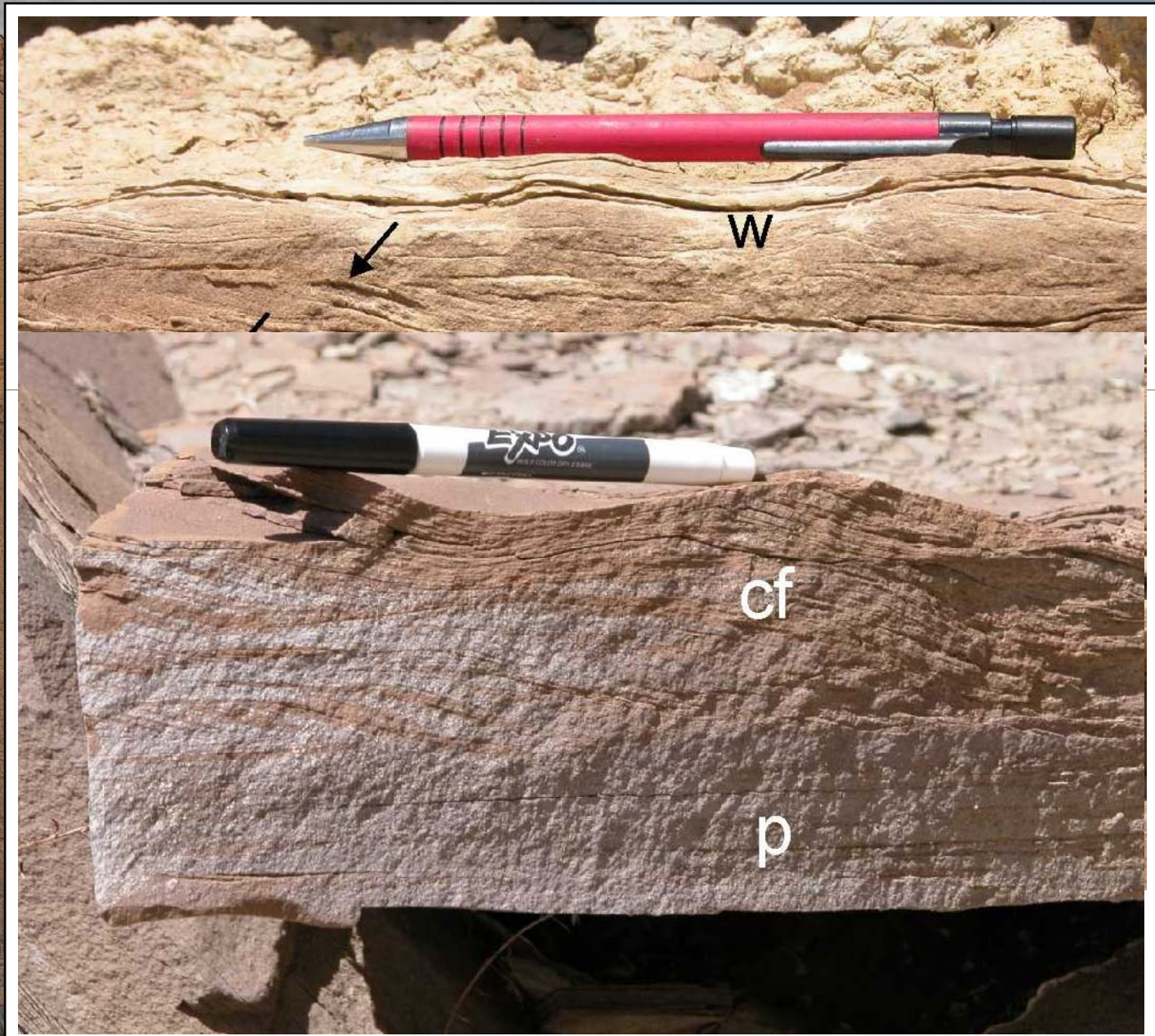
Shelf Lobes: Facies

Bouma T_{bc} beds capped by current, combined-flow and/or wave ripples.

Turbidite or turbidite-like event beds were likely generated by storms (i.e. oceanic floods), river flooding, high rates of sedimentation, and/or earthquakes.

Sharp-based with well defined sole marks.

Abundant finely comminuted plant material. Low bioturbation index.



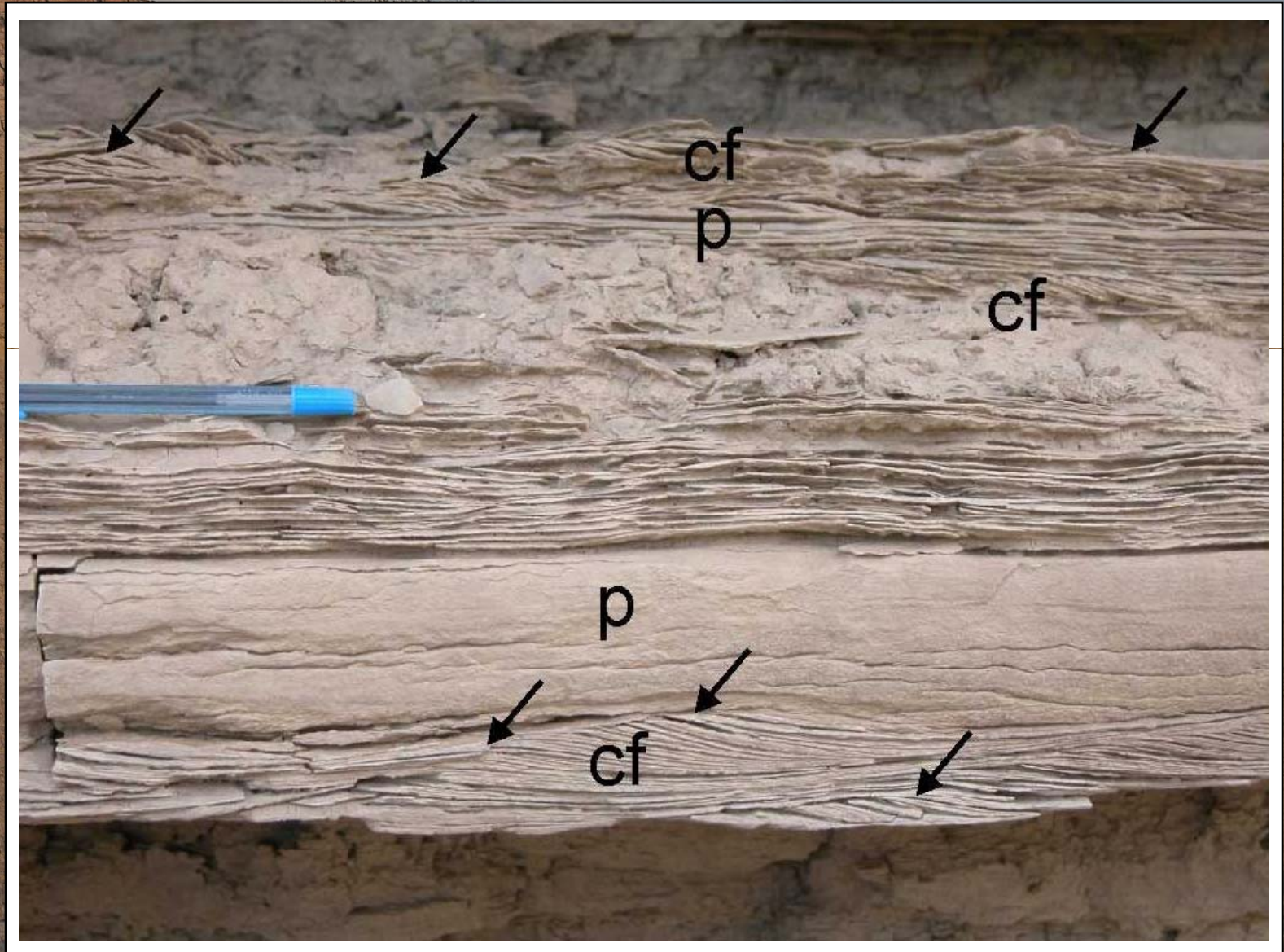
Shelf Lobes: Facies

Mixture of current, combined-flow and wave ripples.

Planar-laminations are gently-curved with low angle truncation.

Stacked Bouma-like beds with relatively diffuse contacts.

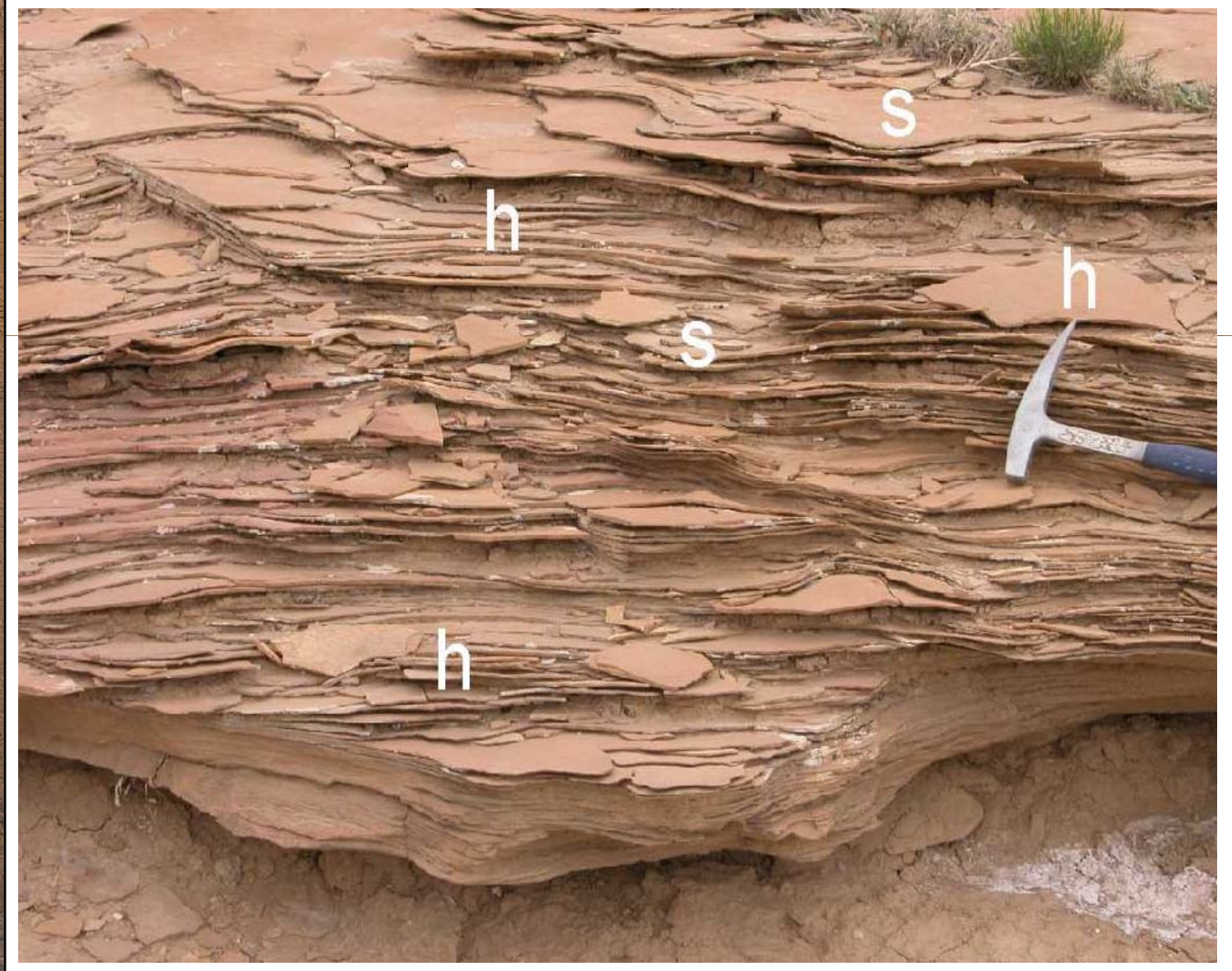
Deposition from wave-modified hyperpycnal flows.



Shelf Lobes: Facies

Hummocky cross stratified event beds. Some HCS ss beds have well defined hummocks (h), swales (s) and truncation surfaces (arrows).

Large weakly asymmetrical ripple-laminated sandstones are interpreted as **low angle HCS ss** (quasi-planar laminations). Low angle HCS has m-scale wavelength, cm- to dm-scale amplitude, gently curved, and with small-scale truncations.



The background image shows a large, layered sedimentary cliff face under a blue sky with light clouds. A person is standing on the base of the cliff on the right side, providing a sense of scale. The cliff face exhibits various sedimentary structures, including horizontal bedding and some vertical erosion patterns. The foreground shows some sparse vegetation and a small body of water.

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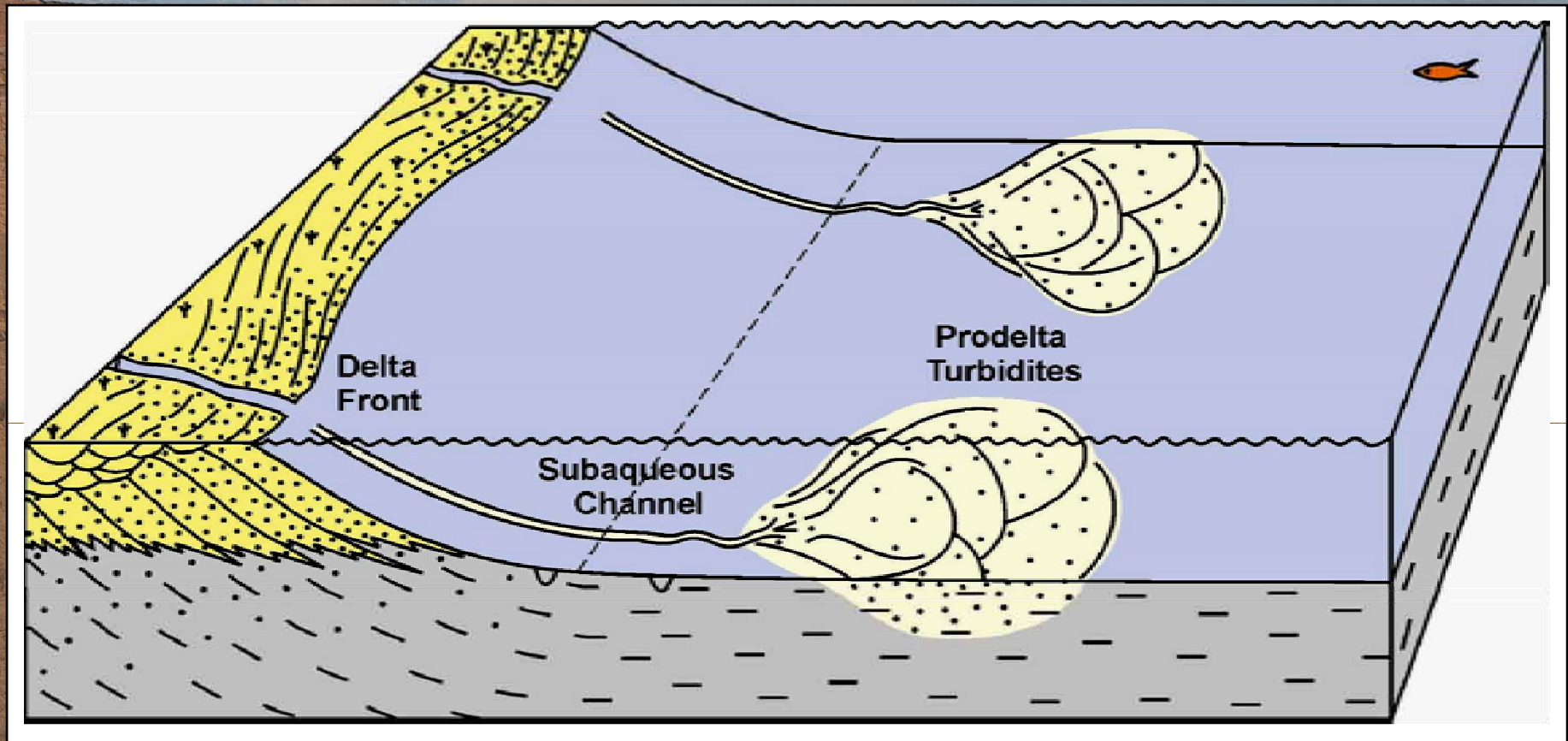
Sedimentary Architecture

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Depositional Model

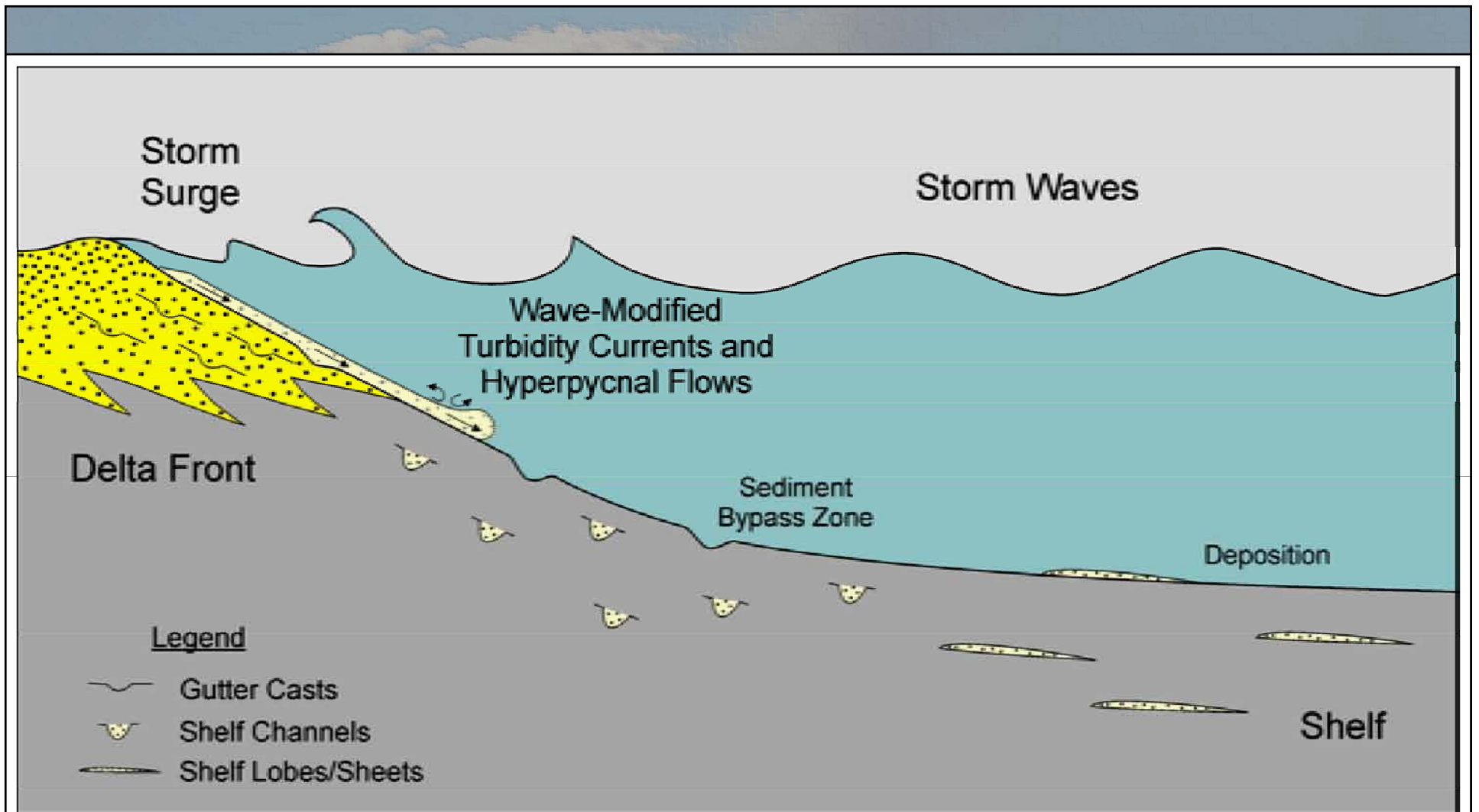
Conclusions

Depositional Model



Three component depositional model: (1) delta front, (2) subaqueous channels, and (3) an isolated prodelta turbidite complex.

Channels cut by turbid underflows generated by oceanic (i.e. high density, shorter-lived, storm-induced hyperpycnal flows) or river (i.e. longer-lived, sustained hyperpycnal flows) flood events. High-energy flows: channels incised, sediments transported basinwards (i.e. bypass). Low-energy flows: channels filled.



Storm-induced underflows, sediment bypass and deposition on the inner shelf. Gutter-casted shoreface deposits located up-depositional-dip of the isolated bodies.

Subaqueous channels cut and filled on the inner shelf by density underflows.
Storm activity and/or river flooding events

Conclusions

The western margin of the Cretaceous Western Interior Seaway was characterized by small-to-moderate-sized rivers and was storm-dominated, which are near perfect conditions for the generation of storm wave-induced underflows or oceanic floods.

Oceanic flood deposits are concentrated along a variety of stratigraphic intervals in the Upper Cretaceous strata of the Book Cliffs, eastern Utah and western Colorado.

They occur as channelized or lobate, isolated shelf bodies that are dominated by organic-rich siltstones and mudstones, and very fine- to fine-grained sandstones (wave-modified turbidites, hyperpycnites, classical turbidites, HCS).

Wave-modification is prevalent and includes combined flow ripples, quasi-planar laminations, and low-amplitude HCS, indicating deposition above storm wave base.

Paleocurrent data reveals a dominant across-shelf, offshore-directed transport trend.

The Mancos Shale mud belt is still going strong 70+ km into the basin with no sign of diminishment, nor any sign of clinoforms, nor any large excursions of the shoreface.

Clearly demonstrates that the offshore transport of FG sediments does occur.

Storm wave-induced underflows are a type of hyperpycnal flow that delivers orders of magnitude more sediment to the shelf than conventional river flood-generated hyperpycnal flows. Need to be included in a genetic facies model for hyperpycnites.

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Questions?

