Paralic Successions

- **Reference:**

Walker & James: Ch. 9-12

Contents

- **Definitions**
- **Shorefaces**
- **Deltas**
- **Estuaries**
- **Sequence Stratigraphy**

Introduction

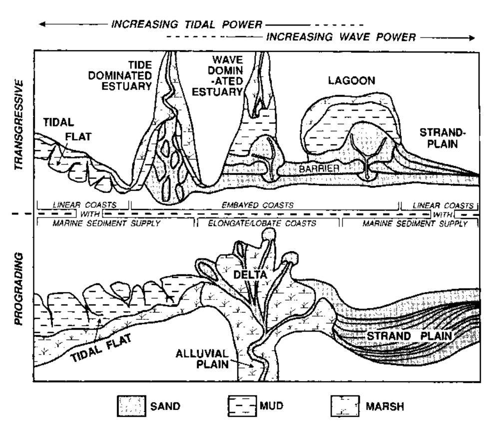
- **Paralic successions include a range of environments, each deposited at or near sea level**
- **Very sensitive to changes in relative sea level**
  - **Suitable to high-resolution sequence stratigraphic analyses**

Introduction

- **Main Environments:**
  - **Shoreface-shelf systems (strandplains)**
  - **Deltas**
  - **Estuaries**

Introduction

- **Sub-Environments:**
  - **Distributary channels and mouth bars**
  - **Crevasse splays and channels**
  - **Levees**
  - **Lagoons, lakes**
  - **Beaches**
  - **Tidal channels, tidal deltas, tidal flats**
  - **Bay-head deltas**
  - **Etc.**



Shoreface/Shelf

- Definitions (zones)
- Waves, wave-induced currents
- Sedimentary structures
- Vertical successions

Definitions

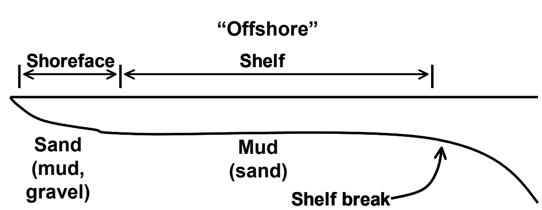
- Linear strandplains
  - Wave-dominated coastal zones
  - Multiple sediment sources
  - No deltaic "protuberance"
  - Not common now
  - Common at other times in the geologic record (e.g., Cretaceous Western Interior Seaway)

Definitions

- Shoreface
  - Always below low tide
  - Sand always in motion (fairweather waves); mud generally not deposited (some exceptions)
  - Concave-up profile
  - Gradient ~ 0.3°, decreases seaward
  - Width – 10s of m to 100s of m
  - Depth – 5 – 10 m (*not* 15 like your text says)
  - Transitional to shelf offshore

Definitions

- Shelf
  - "Offshore" zone
  - Dominated by deposition of mud (fairweather)
  - Sand eroded from shoreface and transported seaward during storms ("event beds")
  - May be non-depositional (modern shelves); reworked by tides, ocean currents
  - Very low slopes ~ 0.03°

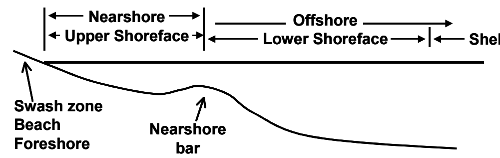


Definitions

- Upper Shoreface
  - Zone of breaking waves
  - "Surf zone"/nearshore zone of coastal geomorphologists
- Lower Shoreface
  - Waves start to shoal
  - Wave action keeps seabed constantly agitated
- Transition between upper & lower shoreface may be marked by nearshore bar system

Definitions

- Beach(face)/foreshore/swash zone
  - Acted upon by swash/backwash of waves
  - Above low tide line; tides may inundate/expose more/less of beach
- No agreement on shoreface/coastal zone terminology
  - Geologists/engineers/geomorphologists/ oceanographers
  - Between geologists



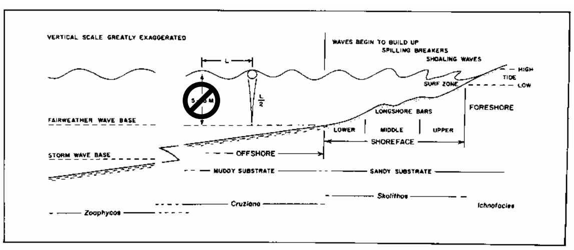


Figure 1 Shoreline to shallow marine profile locating foreshore, shoreface and offshore areas, as well as fairweather wave base and approximate ichnofacies occurrences. Note that fairweather waves of wavelength L cannot agitate the bed at depths greater than approximately L/2. Fairweather wave base lies at depths of about 5–[illegible]5 m.

Base of lower shoreface "probably" not lower than ~10m
Depends on wave climate

Waves, wave-induced currents

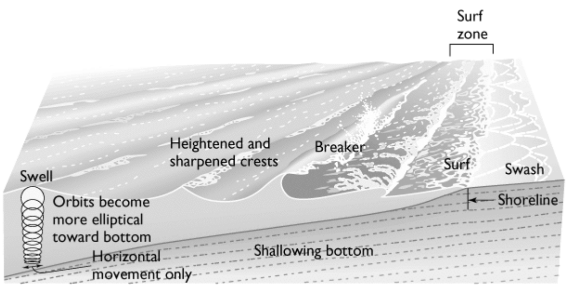
- Waves
  - Formed by wind blowing over "sea" surface
  - Parameters: height, wavelength, period
  - Controlled by:
    - *Duration* over which wind blows (time)
    - *Fetch* – distance over which wind blows
    - *Velocity* – of wind
    - Water depth

Waves, wave-induced currents

- Storm waves larger than "fairweather" waves
- Waves start interacting with the bottom when they move into "shallow" water (1/2 wavelength)
    - Start eroding/putting sediment into suspension
    - Generate currents that transport sediment

Waves, wave-induced currents

- Waves start to deform as they move into shallow water
  - Tend to refract – crestlines tend to become parallel to shoreline
  - Waves become steeper
  - Waves become asymmetric
  - Waves may eventually break/spill

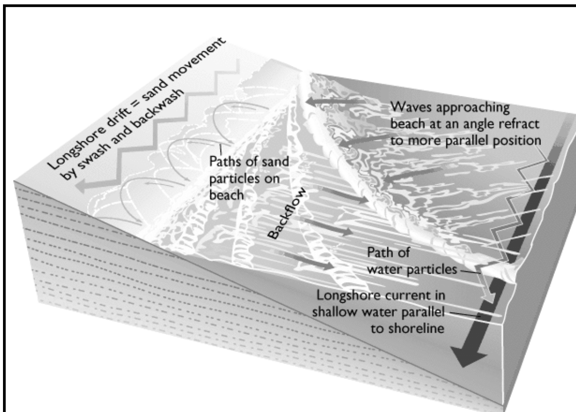


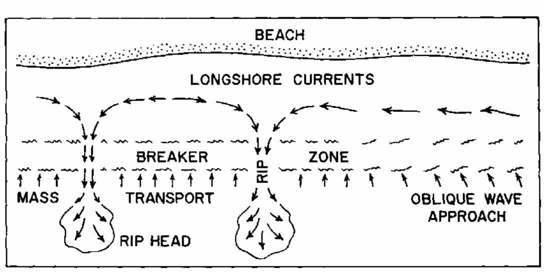
Waves, wave-induced currents

- Waves induce various types of currents:
  - Longshore currents
    - Generated by alongshore component of breaking waves
    - Shore parallel – surf zone
  - Rip currents
    - Shoaling waves push water toward shore – builds up
    - Built-up water moves suddenly seaward as a discrete (relatively narrow) shore-normal current – move out beyond surf zone

Waves, wave-induced currents

- Waves induce various types of currents:
  - Swash/backwash
    - Breaking waves move up beachface - "swash"
    - Return flow of waves down beachface – "backwash"
    - May have a component alongshore if waves approach beach at an angle



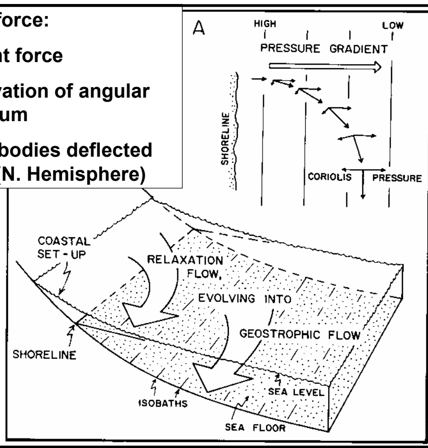


Waves, wave-induced currents

- Large storms may push water landward
  - "Storm surge", coastal setup
  - Different, much larger scale than processes forming rip currents
- Water ponded up against shore eventually moves seaward along seafloor
  - "Relaxation flow", coastal downwelling

Coriolis force:

- **Apparent force**
- **Conservation of angular momentum**
- **Moving bodies deflected to right (N. Hemisphere)**

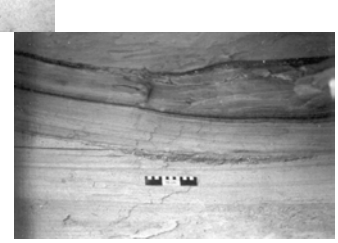


Sedimentary Structures

- **Shoreface/shelf characterized by interaction of different types of currents/water motions:**
- **Foreshore**
  - **Swash/backwash**
- **Upper shoreface**
  - **Rip currents, longshore currents, breaking waves**
- **Lower shoreface**
  - **Return flows, rip currents, shoaling waves, coastal currents**

Sedimentary Structures

- **Beachface/swash zone**
  - **Thin, fast water motion**
  - **Upper flow regime flat bed**
  - **Planar lamination**
  - **Antidunes – preserved?**
  - **Bioturbation: *Macaronichnus* (sometimes…)**



Macaronichnus

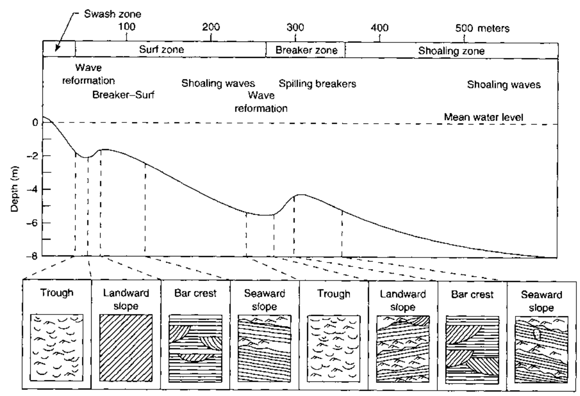
Cretaceous, Alberta

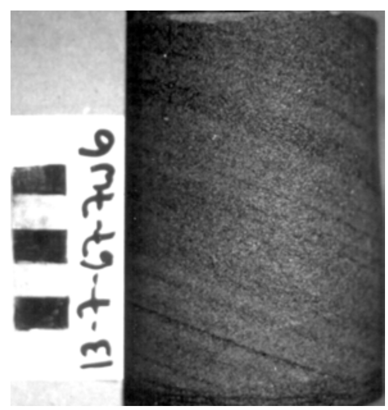
Sedimentary Structures

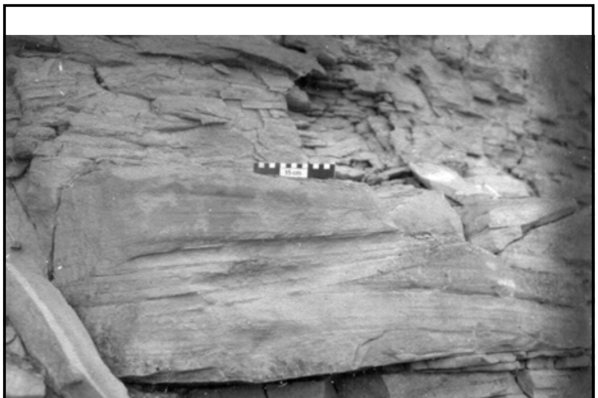
- **Shoreface**
  - **Structures depend on grain size, morphology (nearshore bars, etc.), currents, wave climate**
  - **Trough cross-beds (longshore currents)**
    - **Medium sand or coarser**
  - **Hummocky (“swaley”) cross-stratification (“combined flows”)**
    - **Very fine- to medium(?) sand**
  - **Planar lamination**

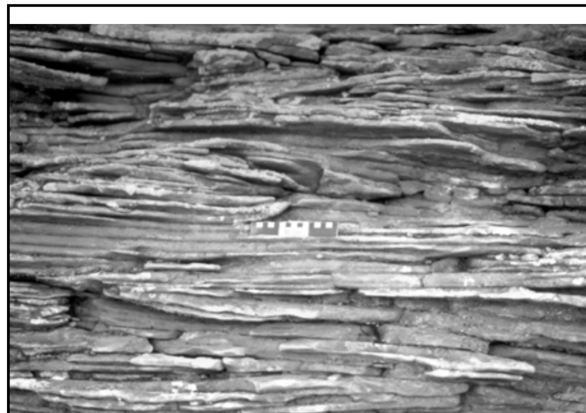
Sedimentary Structures

- **Shoreface**
  - ***Skolithos* ichnofacies**
    - ***Skolithos, Ophiomorpha, Arenicolites***
  - **Seafloor constantly agitated by waves, even during "fairweather" conditions**
  - **No mud deposited**









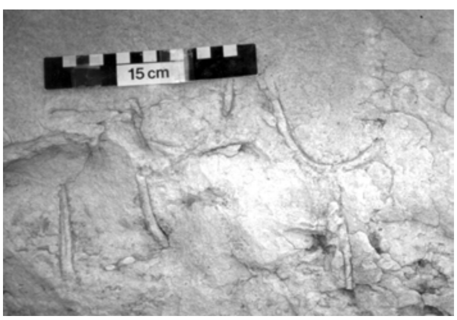
Skolithos

Cretaceous, Alberta

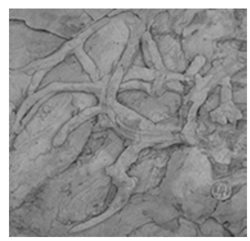
Holocene, San Salvador

Arenicolites

Cretaceous, New Mexico



Ophiomorpha



Cretaceous, Utah

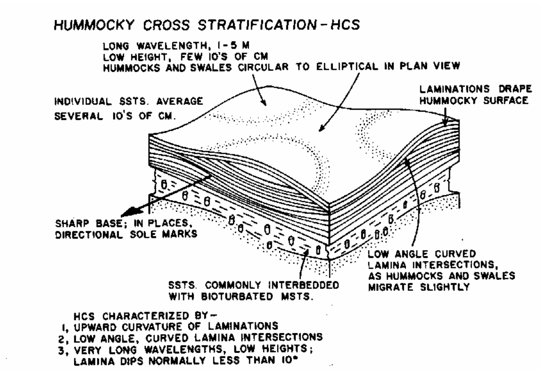
Pleistocene, Barbados

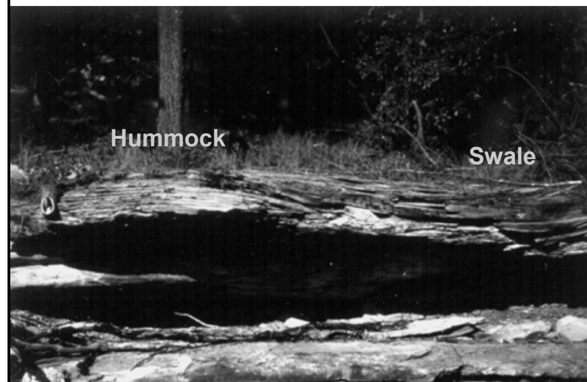
Sedimentary Structures

- Shelf
  - Below fairweather wave base
  - Deposition of mud during normal conditions
  - Sand transported onto shelf from shoreface by return flows
    - Rip currents, coastal downwelling
  - Erosion of mud, followed by deposition of sand
  - Sedimentary structures show wave influence

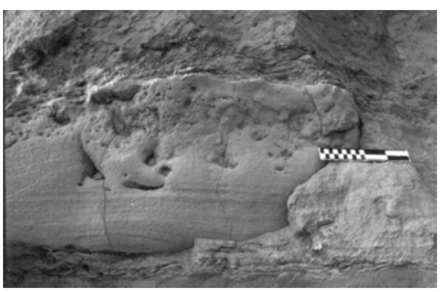
Sedimentary Structures

- Shelf
  - *Cruziana* ichnofacies – inner shelf
    - *Teichichnus, Rhizocoralium, Cruziana* (Paleozoic rocks – trilobites)
  - Laminated-to-burrowed beds (storm beds)





Laminated-to-burrowed bed



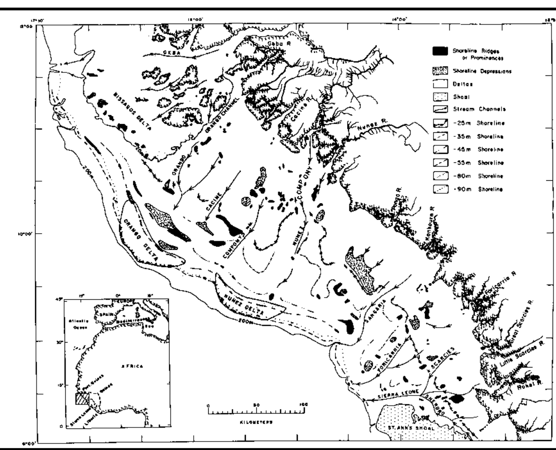
"Event sedimentation" (storm deposits)

Sedimentary Structures

- Shelf
  - Sandstones get finer-grained, thinner in seaward direction
  - Lose hummocky cross-stratification
    - Ripple cross-laminated (wave ripples)
  - *Zoophycus* ichnofacies – outer shelf

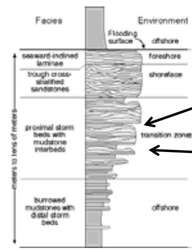
Sedimentary Structures

- Not all shelves are prograding
- Holocene transgression cuts off sediment supply
  - Trapped in estuaries, doesn't make it onto shelf
- Shelf exposes "relict" sediments, deposited under other conditions ("Palimpsest")
  - Fluvial, deltaic, shoreface, etc.
  - Lower sea level
- Reworked by shelf currents, etc.



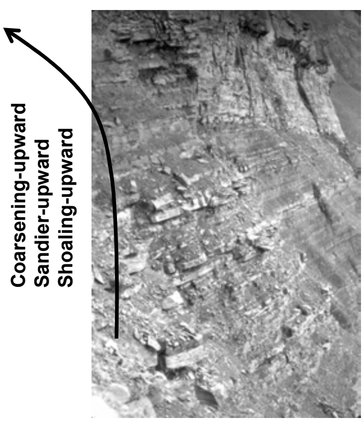
Vertical Succession

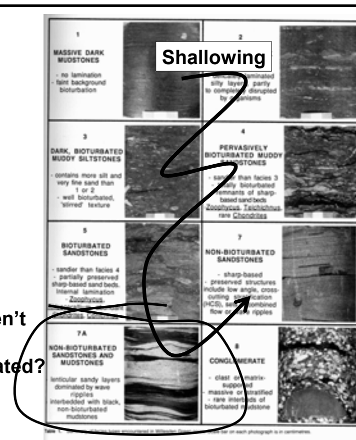
- **Prograding shoreline**
  - **Deepest water deposits at base of the section**
  - **Overlain by progressively shallower water deposits**
  - **“Coarsening upward” successions**

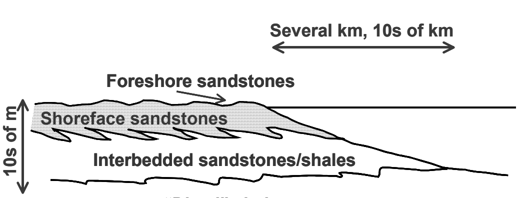


Lower shoreface (Exxon and others)

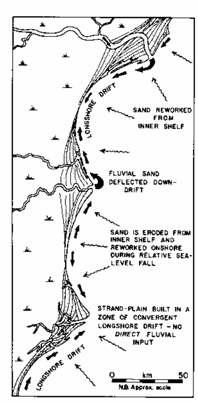
Inner Shelf (Walker and others)

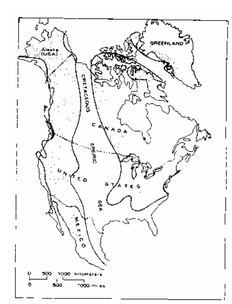


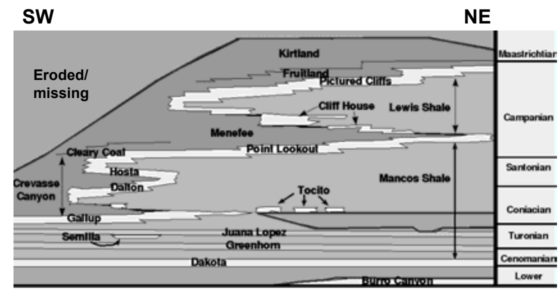




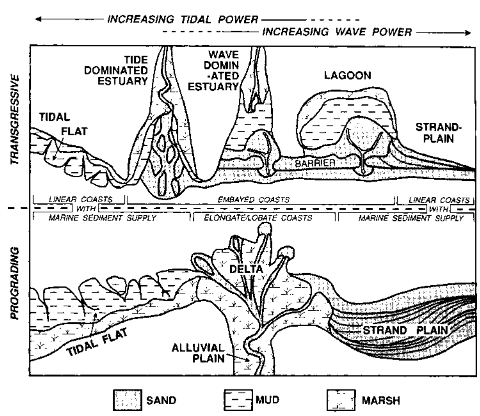
Walker & Plint (Facies Models)







San Juan Basin – New Mexico



Deltas

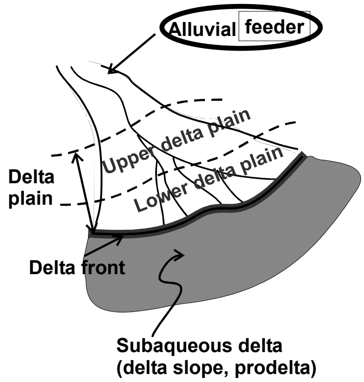
- Morphology, processes
- River-dominated deltas
- Wave-dominated deltas
- Tide-dominated deltas
- Controls on deltaic architecture

Morphology & Processes

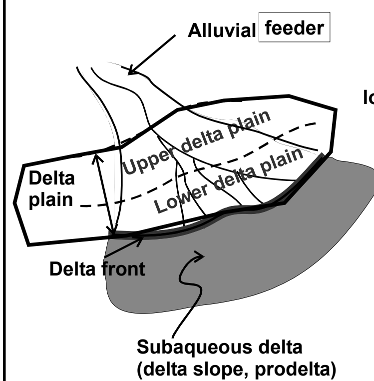
- Discrete shoreline protuberances formed where rivers enter oceans, seas, lakes or lagoons and supply sediment faster than it can be redistributed by basinal processes

Morphology & Processes

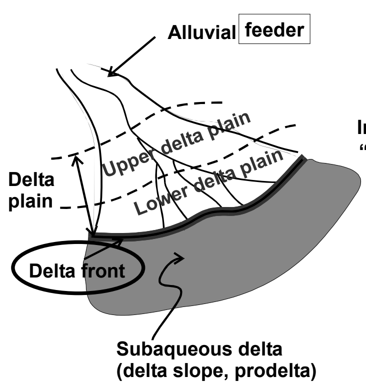
- Parts of a delta:
  - Alluvial feeder (river)
  - Delta plain
    - Upper – Above tidal influence
    - Lower – Inundated by tides/storm surges
  - Delta front – interaction of fluvial and “basinal” processes (waves, etc.)
  - Prodelta – deposition of fines from suspension
  - Delta slope – between delta front and prodelta on “deep water” deltas



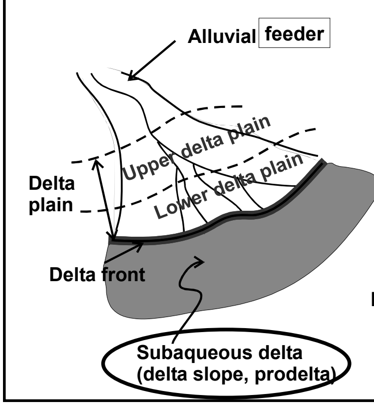
Alluvial feeder:
River



Delta plain:
Channels flanked by low-lying interchannel areas (forests, swamps, lakes, salt flats, etc.)
Upper: never inundated by marine waters ("older")
Lower: inundated by marine waters ("younger")



Delta front:
Interaction of river & "basinal" processes (waves)
-coarse sediment deposited
-beach ridges



Prodelta: fine-grained deposition from suspension, failure deposits

Morphology & Processes

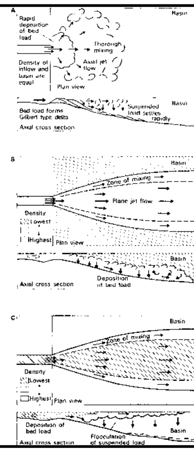
- Factors affecting morphology, sedimentary dynamics, stratigraphy
  - Fluvial discharge:
    - Water (volume, "flashiness")
    - Sediment (volume, grain size)
  - Wave climate
  - Tidal range

Morphology & Processes

- Factors affecting morphology, sedimentary dynamics, stratigraphy
  - Offshore slope
  - Density of river water, ambient basin water
  - Subsidence (compaction, tectonics)
  - Climate (vegetation)

Morphology & Processes

- **Interaction between river discharge and basinal waters:**
  - **Homopycnal – densities about the same (lacustrine deltas)**
  - **Hyperpycnal – river water denser than ambient water (glaciolacustrine deltas)**
  - **Hypopycnal – river water less dense than ambient water (almost all marine deltas)**



Homopycnal
- lacustrine deltas

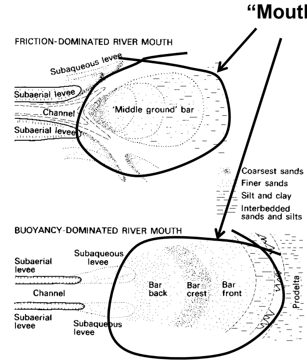
Hyperpycnal
- glaciolacustrine deltas

Hypopycnal
- marine deltas

Morphology & Processes

- **"Mouth bars" form where river enters sea/lake**
  - **Flow expands, slows down, loses competence -> deposition of coarse-grained sediments**
  - **Shape depends on delta front processes, interaction between ambient and river waters**

"Mouth bars"



"Shallow water"

"Deep water"

Morphology & Processes

- **Rapid sedimentation on deltas, especially near river mouths, leads to submarine slope instability**
  - **Oversteepening**
  - **High pore pressures**

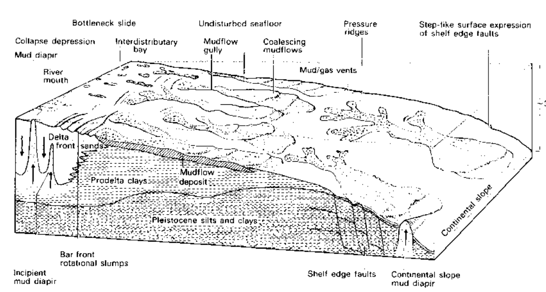
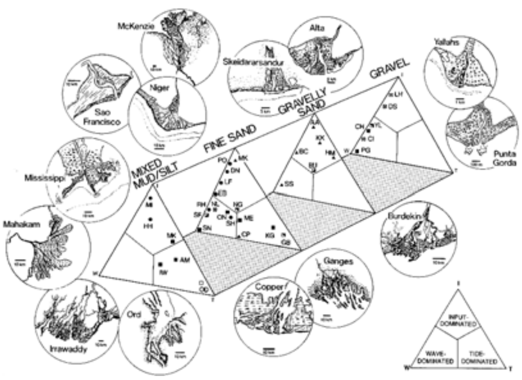


Fig. 6.42. Summary of the main types of sediment-induced deformational features arising from surface instability of sediments and deep-seated flowage of overpressured clays in the Mississippi delta (after Coleman, 1981).

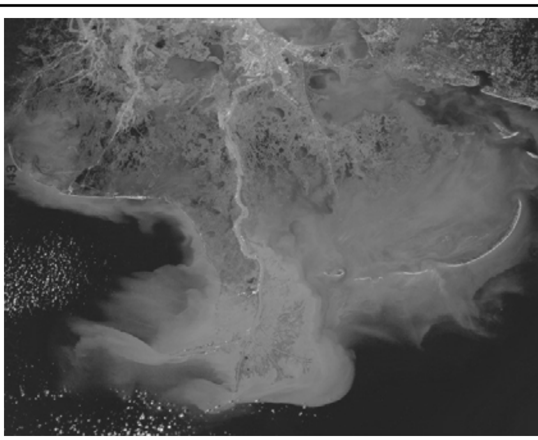
Morphology & Processes

- Relative role of waves, tides and fluvial processes important
- Need to also consider grain size
- Also depth of water into which delta forms
  - May depend on sea level – sequence stratigraphy



River-Dominated Deltas

- Supply > redistribution/reworking
- Progradation around river mouths
- "Birdfoot"
- Complex facies distributions
- Mississippi is "classic"
  - But humanity's influence: fixing channel position, dredging, etc.



River-Dominated Deltas

- Classic progradational deltaic succession:
  - Coarsening-upward succession
  - Progradation of mouth bar
- Also:
  - Distributary channels ("fluvial")
  - Interdistributary deposits – salt water marshes, levees, crevasse splays, etc.

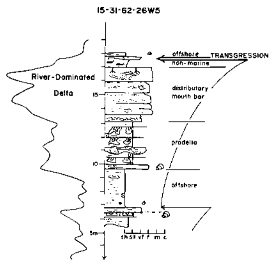


Fig. 4. 15-31-62-26W5. Core through the upper portion of Member E, suggesting progradation of a river-dominated delta front (distributary mouth bar). Gamma-ray log on left. Legend - Figure 6; location - Figures 1 and 2.

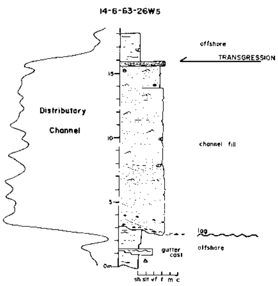
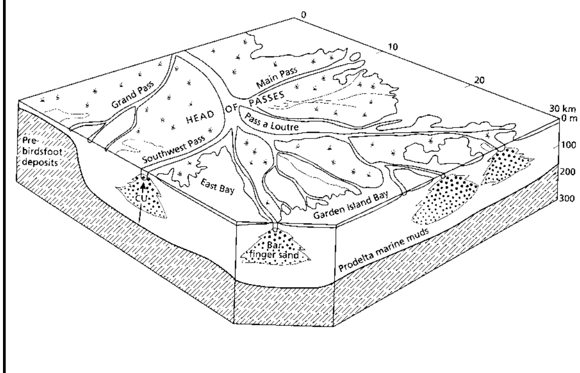
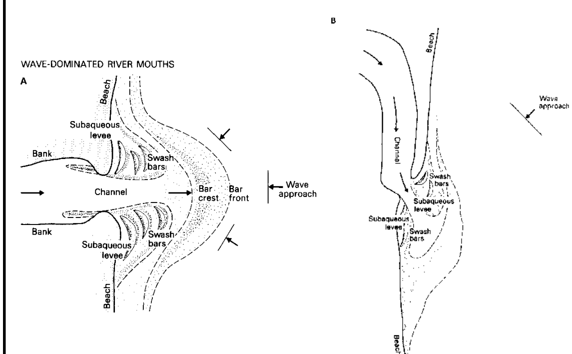


Fig. 5. 14-6-62-26W5. Core through the Simonette channel, Member E. Gamma-ray log on left. Legend - Figure 6; location - Figures 1 and 2.



Wave-Dominated Deltas

- Waves redistribute most sediment supplied by river mouths
- "Regular" (smooth) shoreline
- Progradation of entire delta front
- Shore-parallel, sheet-like delta front sand
- Sao Francisco



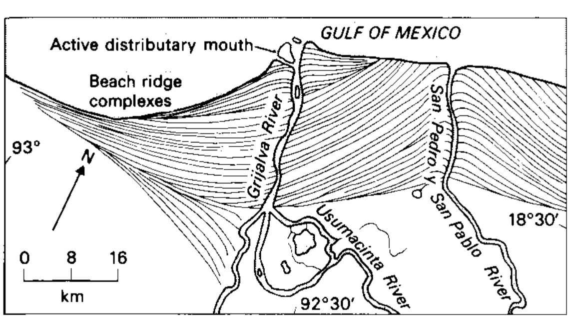


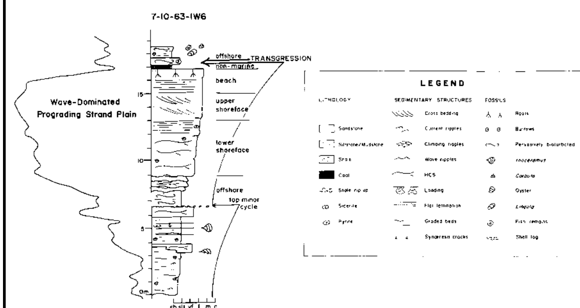
Fig. 6.22. Wave-dominated Grijalva delta (after Psuty, 1967).

Wave-Dominated Deltas

- Laterally continuous sandstones
  - Delta front deposits – spread onshore/alongshore by waves
- Shape depends on direction of wave approach with respect to progradation direction

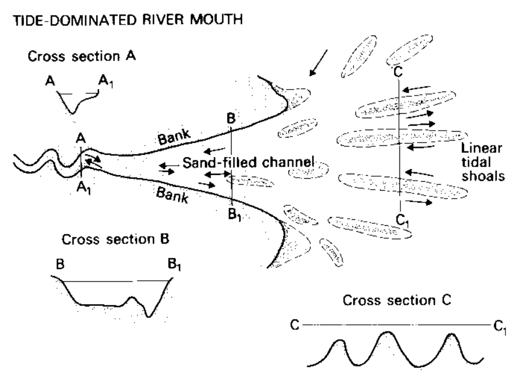
Morphology & Processes

- **Vertical succession:**
  - **Coarsening-upward**
  - **Sedimentary structures show evidence of waves (see "Shoreface" section)**
    - **Trough cross-bedding**
    - **Hummocky cross-stratification**
    - **Swaley cross-stratification**
    - **Wave ripples**
- **Lobate outline indicates delta rather than strandplain**
  - **Need to be able to map it**



Tide-Dominated Deltas

- Tides redistribute most sediment supplied by river mouths
- Tidal ridges on delta front, tidal channels on delta plain
- Sandbodies perpendicular to shoreline
- Complex progradation pattern
- Ord River delta



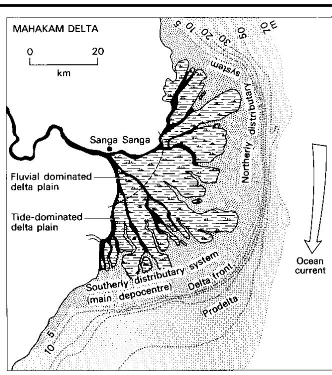


Fig. 6.8. Mahakam delta, Indonesia; a fine-grained, tide-dominated delta with an extensive area of tidal flats, estuarine channels, tidal channels and creeks dominating the delta plain (after Allen, Laurier and Thouvenin, 1979).

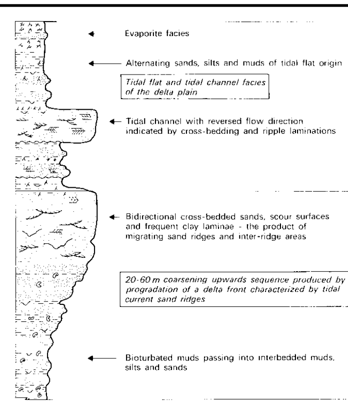


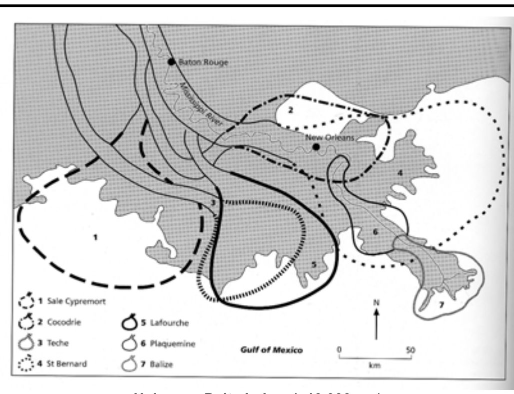
Fig. 6.25. Composite, idealized sequence through the tide-dominated Ord delta (after Coleman and Wright, 1975).

Controls on Deltaic Architecture

- Interplay of river, wave and tidal influences, grain size affects morphology/stratigraphy of any delta
- Through time (1000s, 10000s of years or more) delta growth affected by factors such as basin subsidence (tectonic, compaction), changes in sea level, river avulsion, changes in sediment supply, etc.

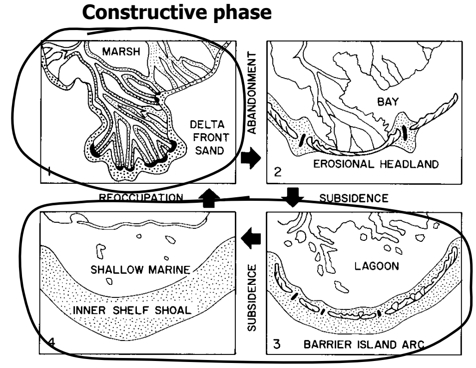
Morphology & Processes

- Delta grows in proximity to river mouth
  - Sediment supplied by river
- Away from river mouth, delta reworked by waves, tidal currents
- “Constructive” and “Destructive” phases – both may be depositional

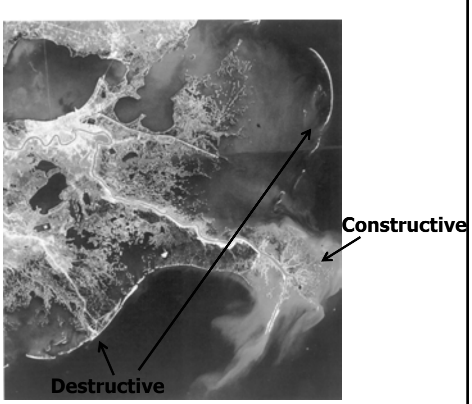


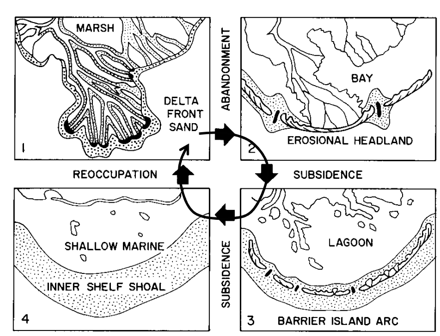
Holocene Delta Lobes (<10,000 yrs)
Each 10 – 50 m thick

Constructive phase



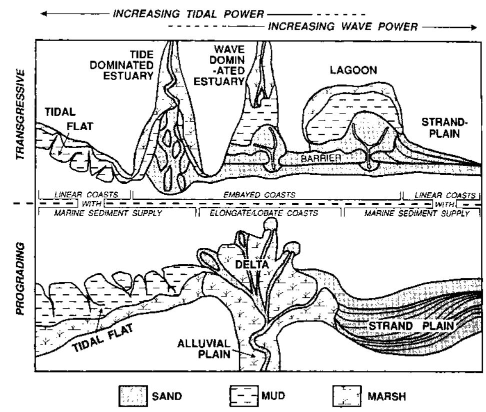
Destructive phase





Controls on Deltaic Architecture

- **Autocyclic**
  - **Determined by the system itself**
  - **Lobe switching, compaction-induced subsidence**
- **Allocyclic**
  - **Determined by external forcing**
  - **Sea-level change, climate, tectonic subsidence, etc.**

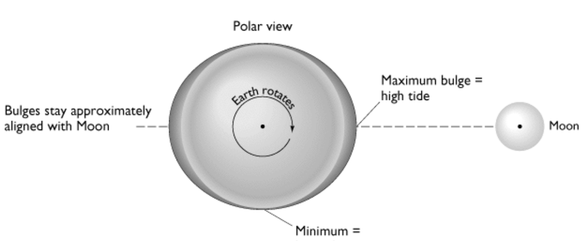


Estuaries

- **Tides**
- **Processes and Facies**
- **Controls on Estuary Development**

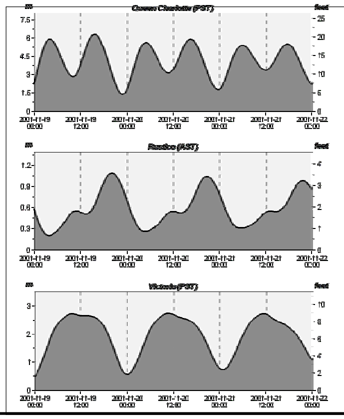
Tides

- **Gravitational attraction of moon/sun on Earth deform oceanic water surface**
- **"Bulges" pulled toward moon (and sun)**
- **Earth rotates through bulges - tides**
  - **"High" and "low**



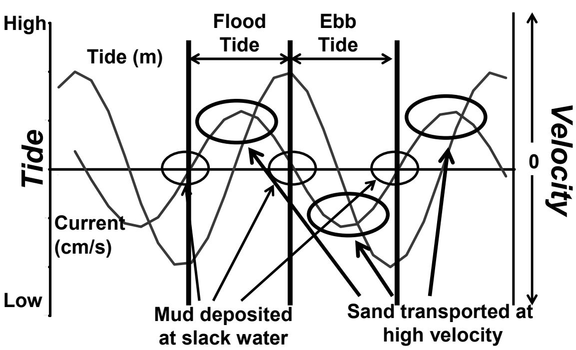
Tides

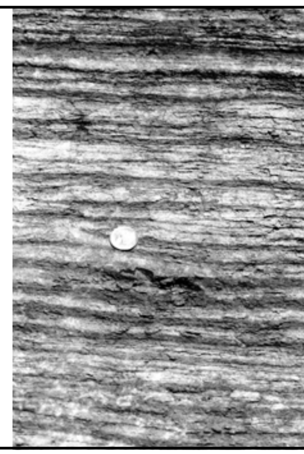
- **Generally two low/high tides per day**
  - **Some places: one low/high tide per day**
- **Tidal range variable from place to place**
  - **0 m in lakes (not large enough)**
  - **<< 1 m in some seas (e.g., Mediterranean)**
  - **Microtidal coasts: 0-2 m (e.g., Hawaii)**
  - **Mesotidal coasts: 2-4 m (e.g., Gulf of St. Lawrence)**
  - **Macrotidal coasts: > 4 m (e.g., Bay of Fundy: up to 16 m)**



Tides

- **Tidal currents**
  - **Unidirectional**
  - **Generally not simple onshore/offshore**
    - **Flood (rising) and ebb (falling) tides commonly take mutually evasive paths**
  - **Strength of currents generally proportional to tidal range**
    - **Also depends on shape of coastal area**
  - **"Slack water" (currents stop) at end of flood and ebb tides (before currents reverse)**





Alternating shale (dark)/sandstone (light) laminations

Shale is mud deposited at slack water

Cretaceous Horseshoe Canyon Fm., Drumheller

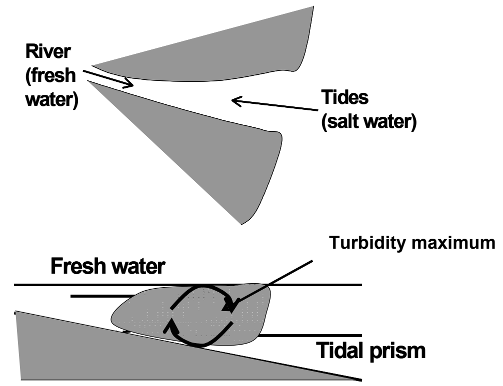
Processes and Facies

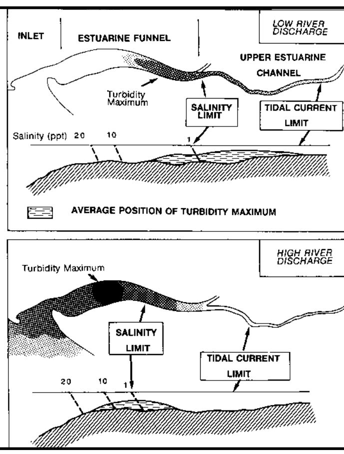
- **Coastal plain features, characterized by the interaction of a tidal prism and freshwater discharge**
- **Characteristic circulation types and sedimentary response patterns**
- **Drowned river valleys**
- **"Geologist's Definition"**

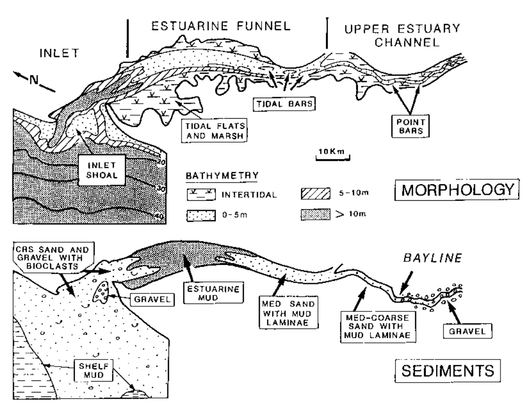
East Coast Estuaries

Processes and Facies

- **Estuarine circulation:**
  - **Salt water tends to flow in under fresh water (denser)**
  - **Landward flow of marine water along floor of estuary**
  - **Seaward flow of fresh water at surface**







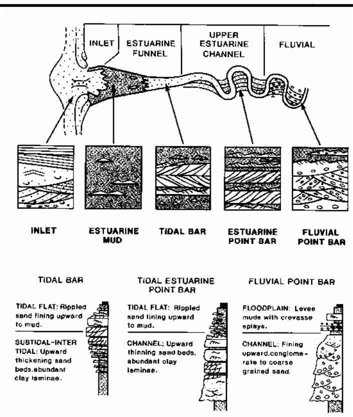
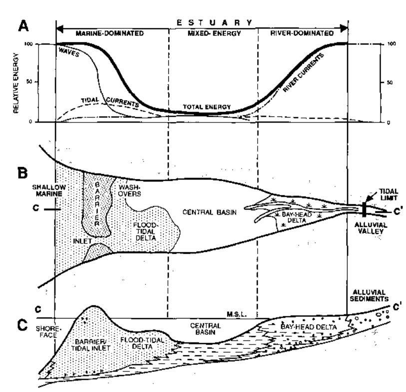
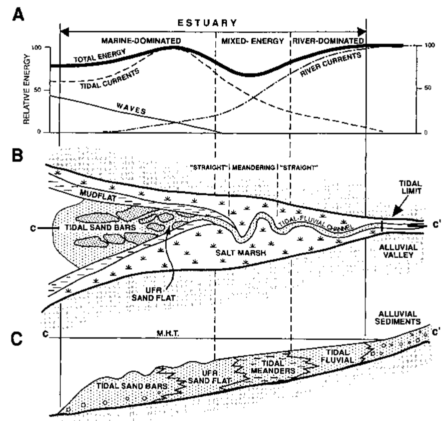
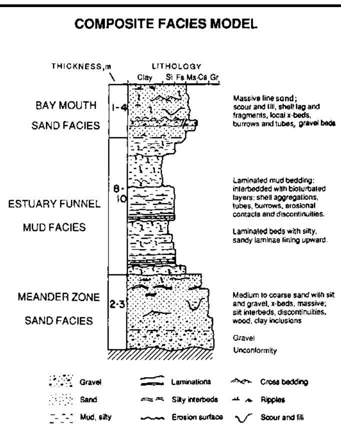


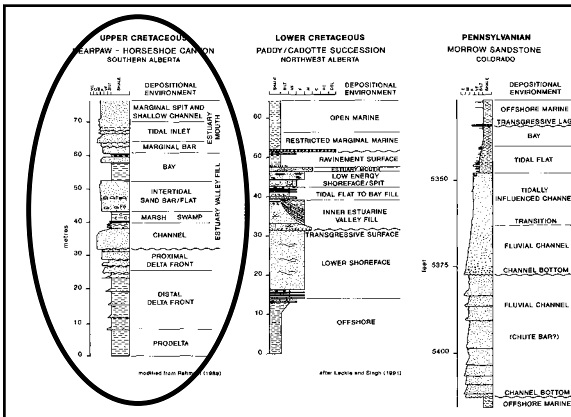
Figure 8 Schematic illustration of the variable facies successions occurring along a longitudinal profile within a Gironde-type macrotidal, or open-ended, estuary. Modified from Allen

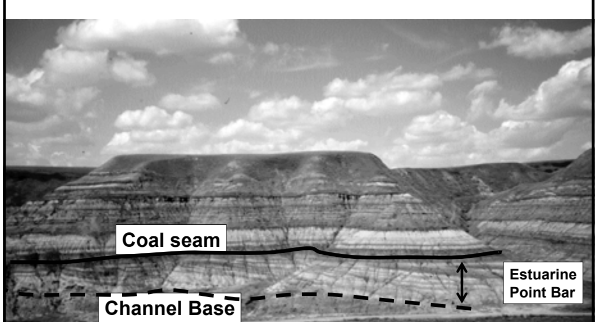


Kromme Estuary – S. Africa









Lateral Accretion Surfaces
Incised valley fill ("estuary")
Horseshoe Canyon Formation - Drumheller

Estuaries

- Complex facies distributions
- Sand at mouth and upper fluvial reaches ("bay head delta"), mud in middle locations
- Stratigraphic succession: "upward deepening"
- Channel-fill geometry
  - Marine influence

Sequence Stratigraphy of Paralic Successions

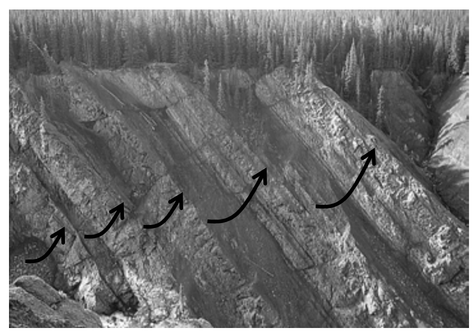
- **In a simple world, progradation of shoreface/shelf systems and deltas occurs during highstand**
  - **Highstand systems tract (HST)**
  - **Between Maximum Flooding Surface and Sequence Boundary**

Sequence Stratigraphy of Paralic Successions

- **In reality, progradation/transgression can occur at any point on relative sea level curve – depends on interplay between sediment supply and accomodation (relative sea level)**
  - **But "usually" (?) during highstand**

Sequence Stratigraphy of Paralic Successions

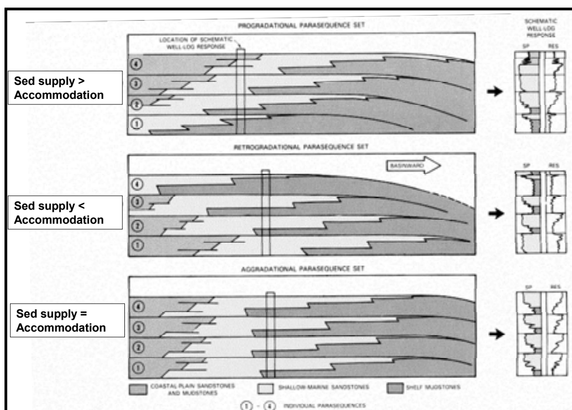
- **Parasequences develop in response to "episodic" (non-uniform) progradation**
- **Relatively short-lived changes in:**
  - **Sediment supply (Climate? Tectonism?)**
  - **Relative sea level (Subsidence? Eustacy?)**
  - **Autocyclic processes (e.g., deltaic lobe switching)**
- **Ultimately, causes of parasequence development may be an intractable problem**



Parasequences - Cretaceous Clastics, Alberta

Sequence Stratigraphy of Paralic Successions

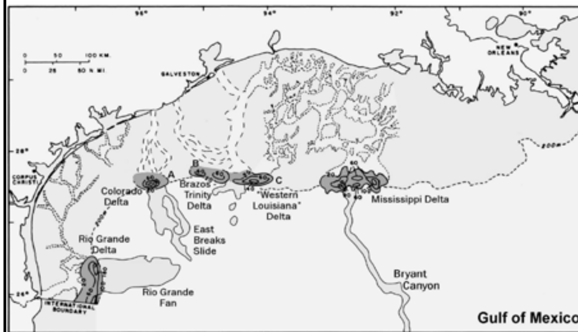
- **Parasequence stacking patterns reflect longer-term interplay between sediment supply and accomodation**



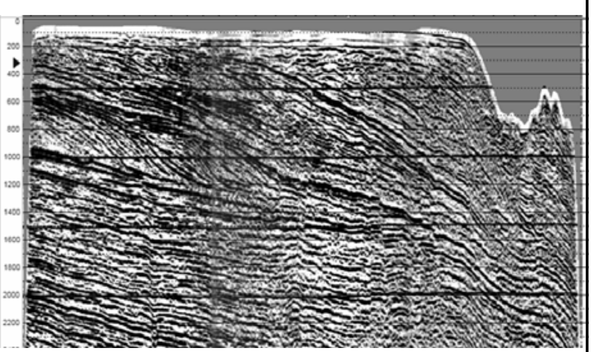
Van Wagoner et al., 1988

Sequence Stratigraphy of Paralic Successions

- **Shelf-margin deltas – form at shelf margin**
  - **Commonly, but not always, at relative sea level lowstand**
  - **Feed lowstand fans/aprons**
- **Shelf-perched deltas – system did not prograde all the way to shelf margin**
  - **Do not feed lowstand fans/aprons**



Suter, 2003



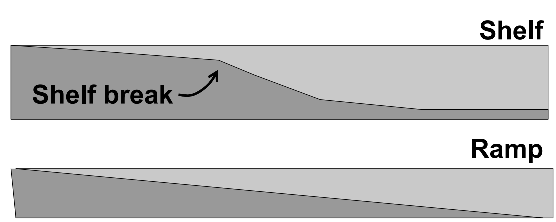
Shelf-perched delta, Scotian Shelf

Sequence Stratigraphy of Paralic Successions

- **As relative sea level begins to rise:**
  - **Rising base level – sediment trapped in coastal plain**
  - **Drowning of river valleys – sediment trapped in estuaries**
  - **Shorelines get cut off from clastic sediment supply -> transgression**
  - **Development of flooding surfaces**

Sequence Stratigraphy of Paralic Successions

- **Other influences**
  - **Morphology of basin**
    - **Shelf – has a distinct shelf break**
    - **Ramp – no distinct shelf break**
  - **Patterns of subsidence**
    - **Passive margin – subsidence greatest towards center of basin**
    - **Foreland basin – subsidence greatest towards basin margin**
    - **Other types of basins**



Sequence Stratigraphy of Paralic Successions

- Interplay of eustatic sea level change, sediment supply, subsidence (rates, patterns), basin morphology, etc. cause changes in systems tract development from basin to basin, and over time within a single basin
  - Don't always see all systems tracts (fully) developed

Summary

- Paralic successions influenced by changes in relative sea level, sediment supply (type, rate), basin morphology (ramp, shelf), "basinal processes" (waves, tides)

Summary

- Wave-dominated shoreface/shelf systems
  - Also known as strandplains
  - Waves and wave-generated currents transport sediment
  - Different zones identifiable based on lithology, sedimentary structures
    - Foreshore, shoreface, shelf
  - Strandplains not common now
    - End of Holocene transgression
  - Shoaling upward succession

Summary

- Deltas – shoreline protuberances at river mouths
  - Morphology, stratigraphic succession record interaction between fluvial and basinal processes
  - Typical stratigraphic expression: shoaling upward succession

Summary

- Estuaries – drowned river valleys
  - Generally developed during transgression/relative sea level rise
  - Stratigraphic succession records "upward deepening"

Summary

- Systems tract/surface development depends on a variety of factors
  - Eustatic sea level
  - Sediment supply
  - Subsidence
  - Basin morphology
  - Etc.
- Will vary from basin to basin, and over time within a given basin