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

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
- 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 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

- 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

- 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...)

**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

*Macaronichnus*
Cretaceous, Alberta
Sedimentary Structures

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

**Skolithos**  
Cretaceous, Alberta

**Holocene, San Salvador**

**Arenicolites**  
Cretaceous, New Mexico

**Ophiomorpha**  
Cretaceous, Utah

**Pleistocene, Barbados**
HUMMOCKY CROSS STRATIFICATION - HCS
- Low wavelength, 1-5 m
- Low height, few cm of mud
- Hummocks and swales circular to elliptical in plan view
- Individual sets average several 10s of cm
- Sharp base, w/ planar, directional sole marks
- Laminations draping hummocky surface
- Sets commonly interbedded w/ burrowed units
- HCS characterized by:
  - Lumpy curvature of laminations
  - Low angle, curved lamina intersections
  - Sets tend to be curved
  - Laminations normally less than 10 cm

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

Why aren't these bioturbated?

Walk & Plint (Facies Models)
Stacked Prograding shelf/shoreface systems
Cretaceous – NW New Mexico

Eroded/missing
SW NE

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
Morphology & Processes

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

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”)

Prodelta: fine-grained deposition from suspension, failure deposits
**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)

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**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

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**Morphology & Processes**

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

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
**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
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"

- 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)

**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"
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
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

- In reality, progradation/transgression can occur at any point on relative sea level curve – depends on interplay between sediment supply and accommodation (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 accommodation

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

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

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

Other influences
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  - 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