



LECTURE 3 – SHOREFACE SETTINGS

Facies Models 4: Chapter 8



Outline

- What is a Shoreface? Definition, hydrodynamic processes, shoreface zonation
- Sedimentology and Ichnology
 - Lower & Upper Offshore
 - Lower Shoreface
 - Middle Shoreface
 - Upper Shoreface
 - Foreshore/Beach
- Tempestites
- Shoreface Variability: Storms & Tides
- Sequence Stratigraphic Framework: Incised Shorefaces: Forced Regressive, Lowstand or Transgressively Incised?

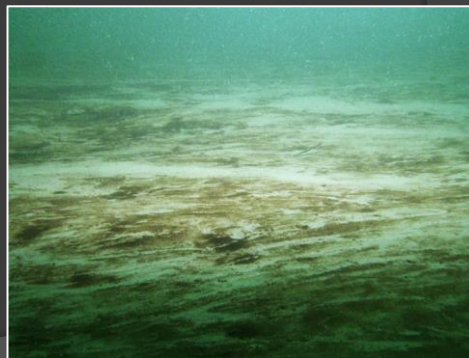
Beach-Shoreface

Beach: zone of sediment accumulation at the transition between land and water (*intertidal zone*). Dominated by *swash-backwash*.

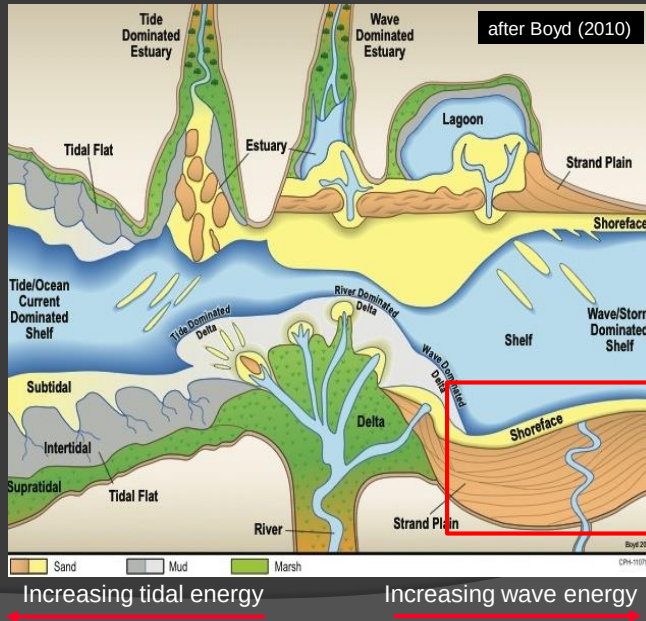


Beach-Shoreface

Shoreface: *Permanently subaqueous*, seaward sloping seafloor composed of sediment and *within the influence of fairweather wave agitation*.



Beach-Shorefaces

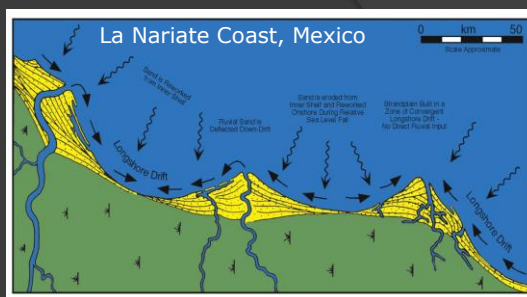


Best developed on **wave-dominated coasts** of low to moderate tidal range.

Wholly **dominated** by marine processes: mainly waves and wave-forced currents.

Shorefaces may occur on both regressive and transgressive coasts.

Strandplain Shorefaces



Stacked, narrow bodies of sandy sediment (shorefaces), oriented parallel to depositional strike.

Stacked packages: 10-100s m's broad, up to hundreds of kilometers long, and 10-20m thick: tabular bodies.

May be **interrupted along strike by deltas or estuaries.**

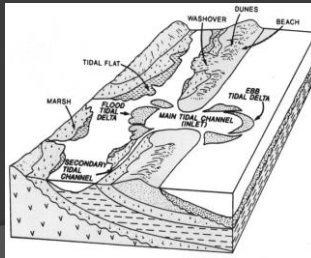
Typically developed on regressive coasts

Barrier Island Shorefaces

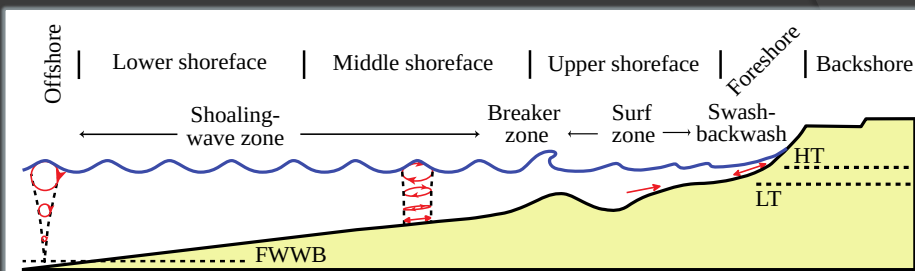
Barrier island deposits: similar to strandplain shorefaces in a seaward direction, but **pass landward into back-barrier lagoonal deposits, with washover fans, and tidal delta sands**

Barrier islands typically truncated along strike by tidal inlet complexes.

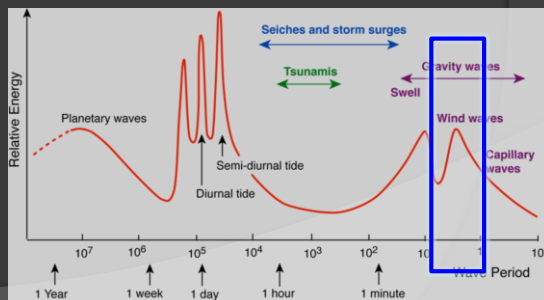
Typically developed on transgressive coasts



Beach-Shorefaces

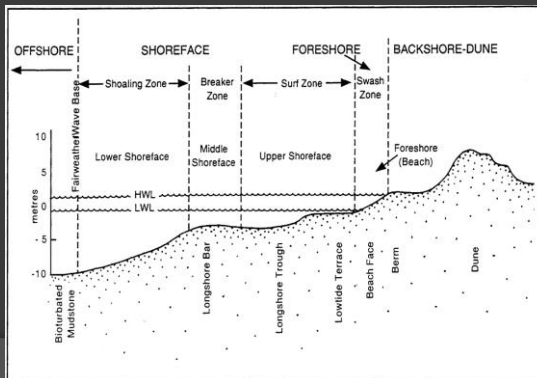


All shorefaces (strandplain and barrier island) exhibit a predictable onshore-offshore morphology reflecting sediment transport via shoaling (fair weather) oscillatory waves



Beach-Shorefaces

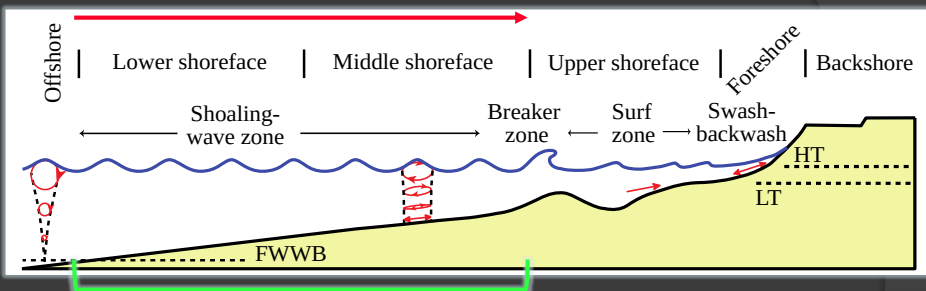
Fairweather wave base varies depending on slope of shoreface and wave conditions, but is **generally 10-15 m deep**. Storm weather wave base is typically much deeper than fairweather wave base.



There are **3 main zones in the shoreface** (upper, middle, and lower), passing into the foreshore in a landward direction, and the offshore/shelf in a seaward direction.

Shoreface Processes

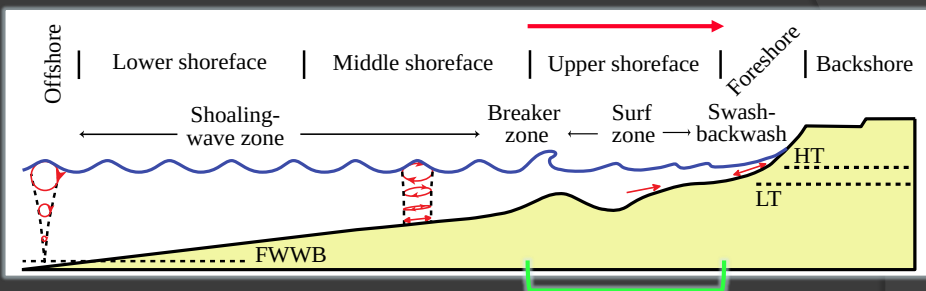
Shorefaces - Processes



As deep-water waves propagate into shallower water, their **orbital motions are impeded by the bed**. This motion is capable of moving sediment at the bed (entrainment), but with little transport.

Waves pass through a **shoaling zone**, where wave-lengths decrease and wave heights increase.

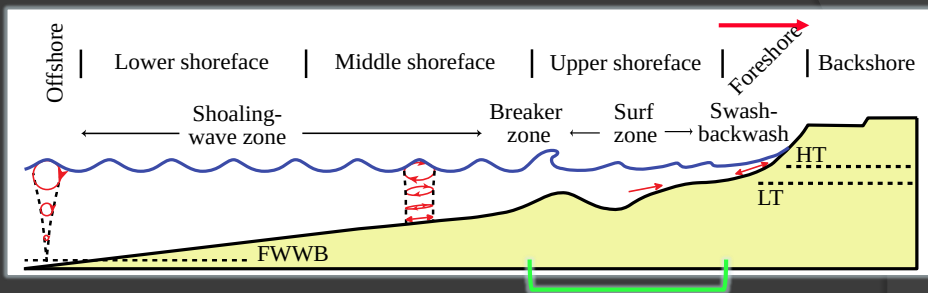
Shorefaces - Processes



When wave heights reach $1/7$ of the wavelength, the wave breaks producing the **surf zone**. The breaking of the wave forms a "translatory wave" – a wave that changes to a current by breaking.

In the surf zone (upper shoreface), **wave-forced currents** form *trough cross-stratification* and current-ripple lamination.

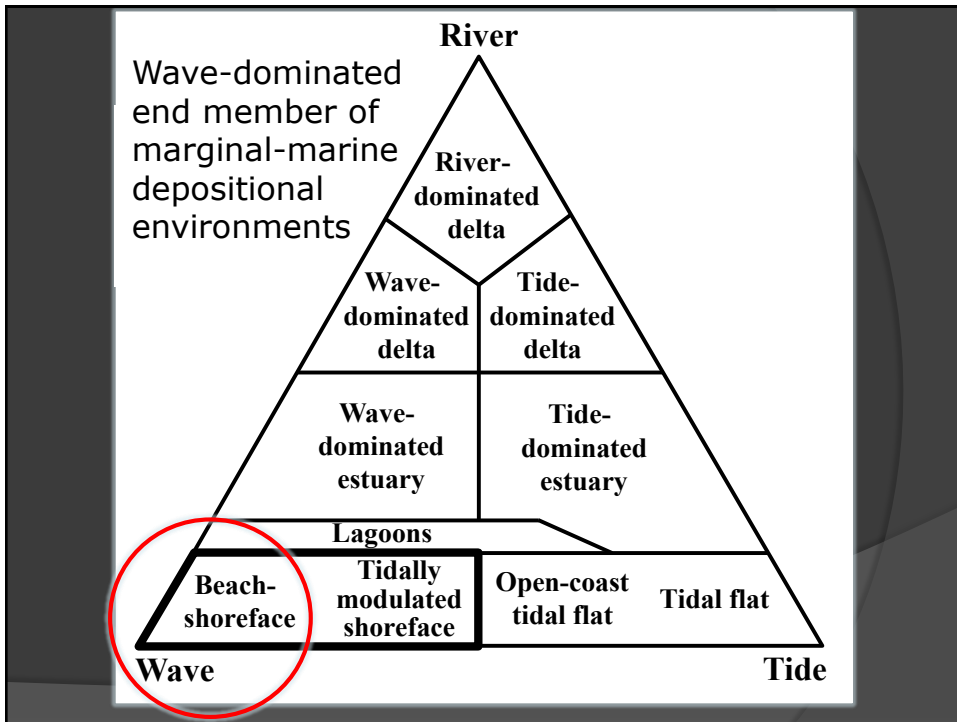
Shorefaces - Processes



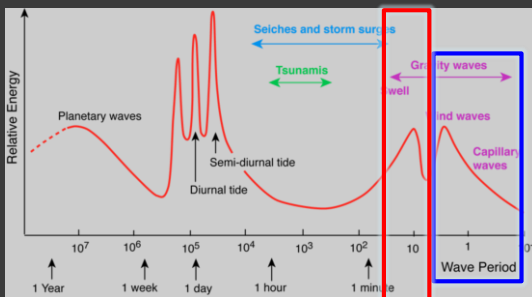
The surf zone gives way to the **swash zone** of the foreshore, in which very rapid, shallow swash flow moves up the beach, followed by backwash flow down the beachface.

Shorefaces - Processes

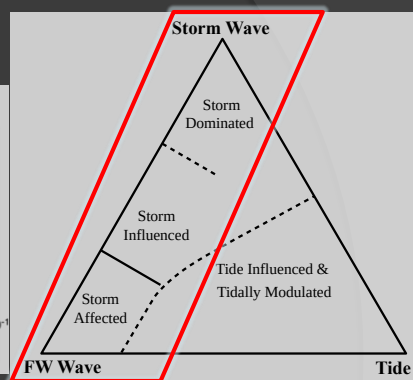




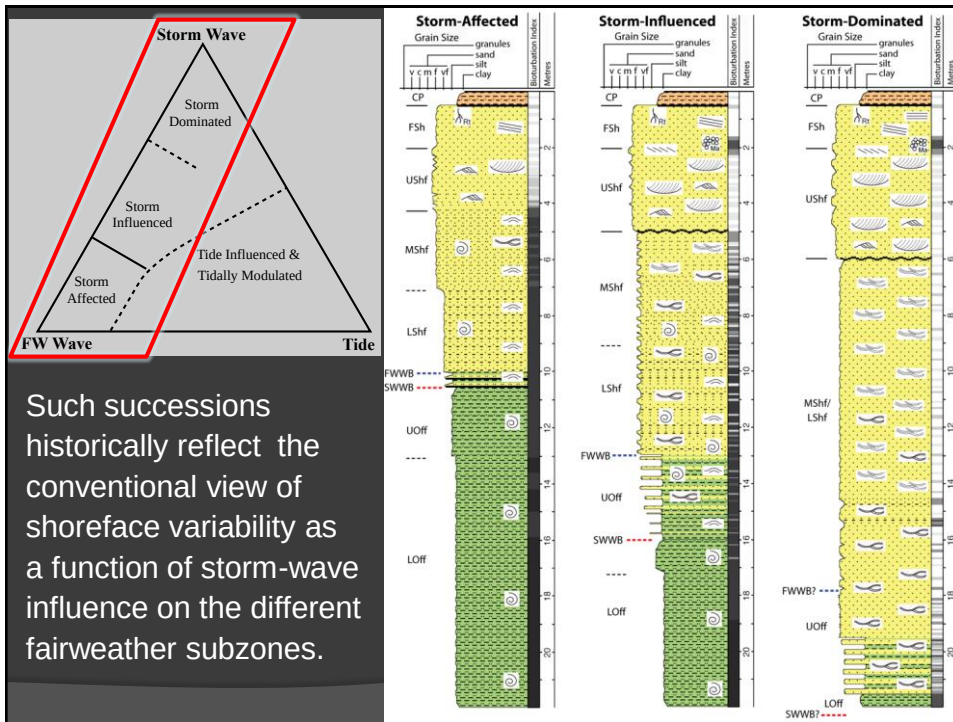
Beach-Shorefaces



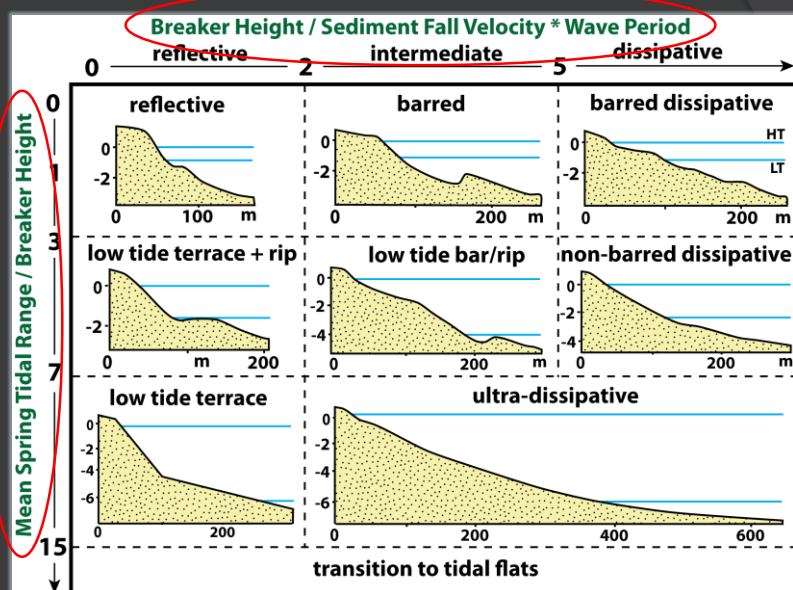
Modified after Allen (1997)



Preserved successions vary sedimentologically and ichnologically as a function of storm-wave influence and tidal influence



What about tidal influences?

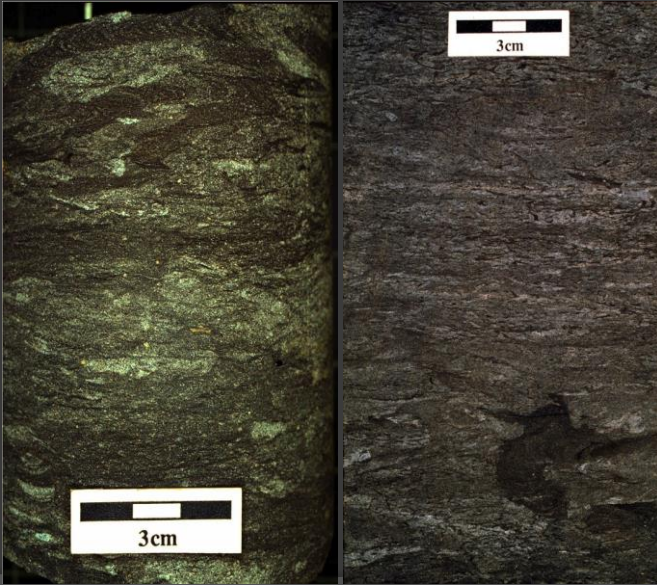


Shoreface Facies / Environments

Shoreface Facies

• Backshore	Terrestrial; storm-wave influenced	Supratidal
• Foreshore	Swash-backwash	Intertidal
• Upper Shoreface	Surf zone	
• Middle Shoreface		
• Lower Shoreface	Shoaling wave zone	
• Upper Offshore		FWWB
• Lower Offshore	Storm wave Influenced	SWB

Shoreface Facies – Lower Offshore



Facies:

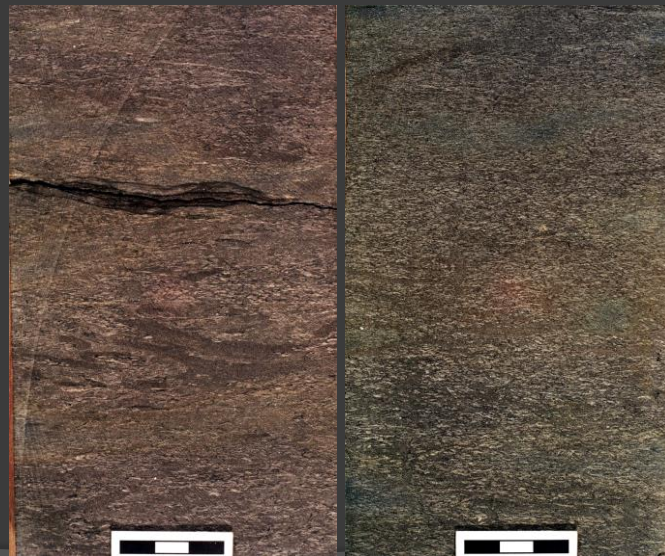
Mainly **silty mudstones**:

quiet water conditions

Thin, parallel laminated sandstones:

distal and low-energy tempestites.

Shoreface Facies – Lower Offshore



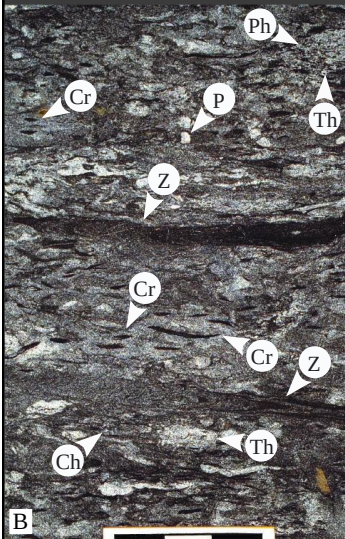
Bioturbation:

uniform and intense. Mostly horizontal forms

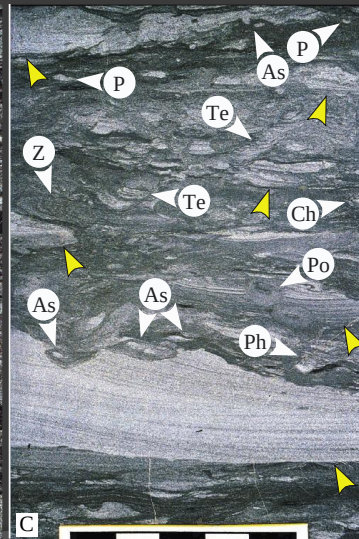
Distal expression of the **Cruziana** Ichnofacies and the **Zoophycos** Ichnofacies.

Shoreface Facies – Upper Offshore

Storm Influenced



Storm Dominated



Facies:

Sandy mudstones:
quiet water conditions

Parallel laminated sandstones:
Variable thicknesses. Remnants of tempestites (yellow arrows).

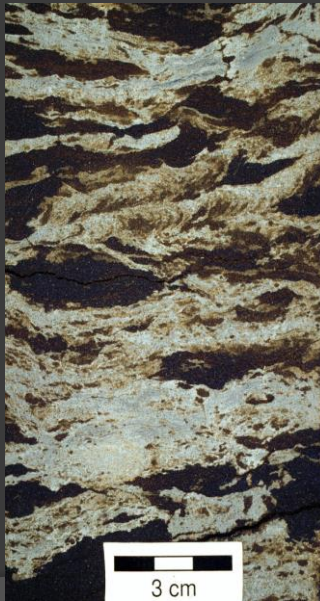
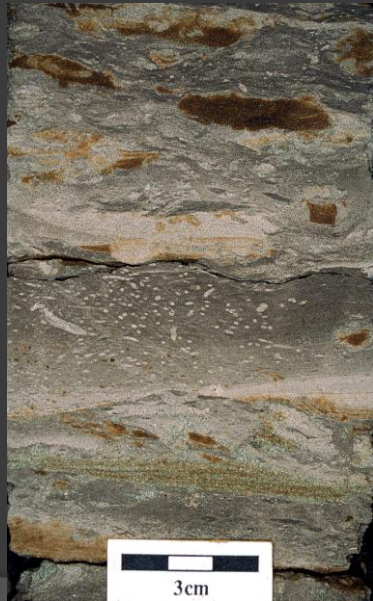
Shoreface Facies – Upper Offshore



Bioturbation:
uniform and intense. May be variable where tempestites are common. Mostly horizontal, some vertical forms

Reflects the **archetypal Cruziana Ichnofacies**.

Shoreface Facies – Upper Offshore



Tar sands
examples of upper
offshore: sand is
dark (oil saturated)
and mudstones
grey or white.

Bioturbation:
uniform and
intense. May be
variable where
tempestites are
common. Mostly
horizontal, some
vertical forms

Shoreface Facies - Lower Shoreface

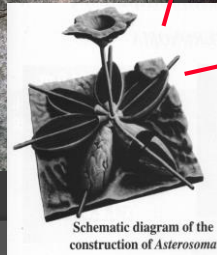
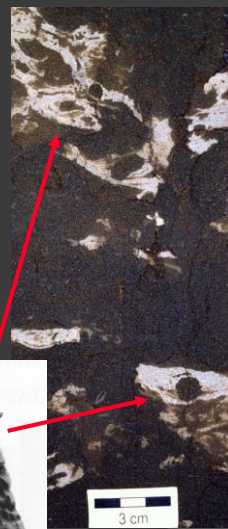
Facies:

Muddy sandstones:
weak but persistent wave
agitation at or above **fair-
weather wave base**.

**Parallel laminated
sandstones:** represent
remnants of tempestites.



Shoreface Facies - Lower Shoreface



Bioturbation:
either uniform and intense, or sporadic and of variable intensity. Mixed horizontal and vertical burrows.

Reflects the proximal expression of the *Cruziana* Ichnofacies.

Shoreface Facies - Lower Shoreface

Significant variability in sed-ichno character of lower shoreface sediments with increasing storm influence

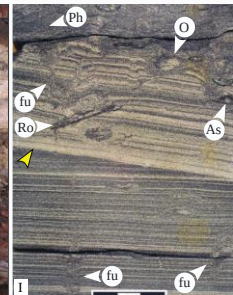
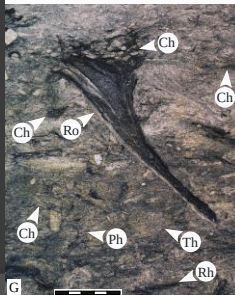
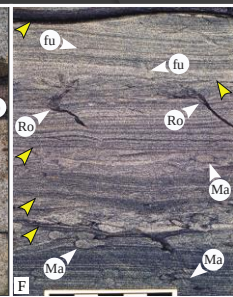
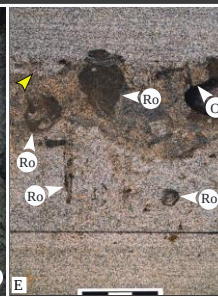
Proximal

Distal

Storm Affected

Storm Influenced

Storm Dominated



Facies - Middle Shoreface



Mainly **erosionally amalgamated, parallel laminated sandstones**: high-energy conditions and sandy shifting substrates. Record preservation of **tempestites**.

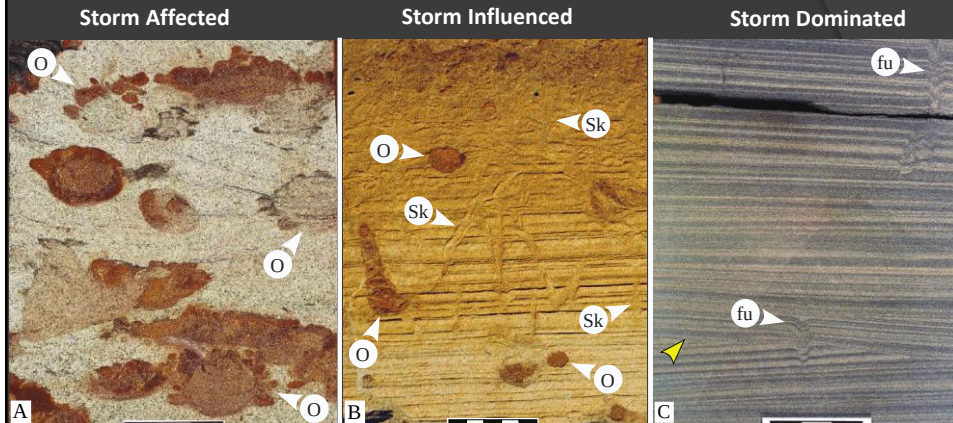
Facies - Middle Shoreface



Bioturbation: variable, typically sporadically distributed, and of low intensity.

***Skolithos* Ichnofacies.**

Facies - Middle Shoreface



Significant variability as a function of storm-influence: not a clearly defined sub-environment in storm-dominated settings

Some suggest **elimination of this subenvironment!**



Facies - Upper Shoreface

Facies:

Mainly **well-sorted trough cross-stratified sandstones**: high-energy conditions.

Reflects wave-forced currents produced by breaking waves.

Lesser low-angle planar stratified and current rippled sandstones.

Facies - Upper Shoreface

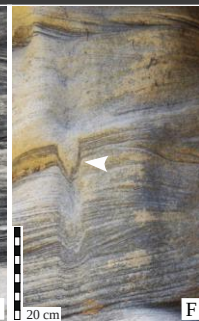


Mainly **well-sorted trough cross-stratified sandstones**: high-energy conditions.

Lesser low-angle planar stratified and current rippled sandstones.



Facies - Upper Shoreface



Bioturbation: rare and sporadically distributed (BI 0-2).

Reflects **Skolithos Ichnofacies**.

Facies - Upper Shoreface



Bioturbation:
rare and
sporadically
distributed (BI
0-2).
Reflects
Skolithos
Ichnofacies.

Facies - Upper Shoreface

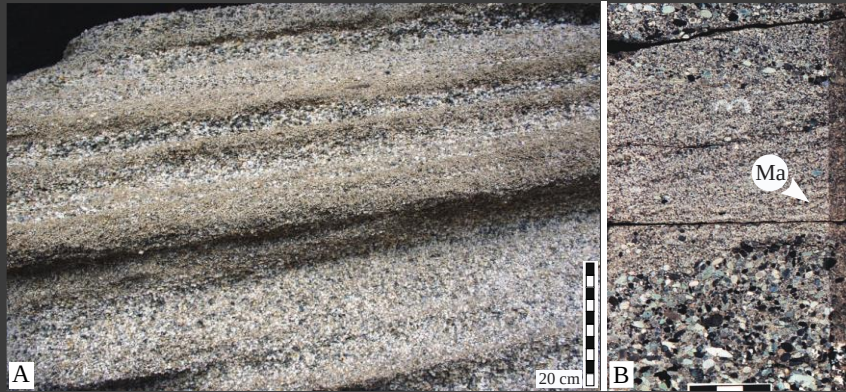


Bioturbation: rare and
sporadically distributed.
Reflects *Skolithos*
ichnofacies.

May contain, instead, a
Macaronichnus
segregatis suite instead
near the top of the UShf



Facies - Foreshore (Beach)

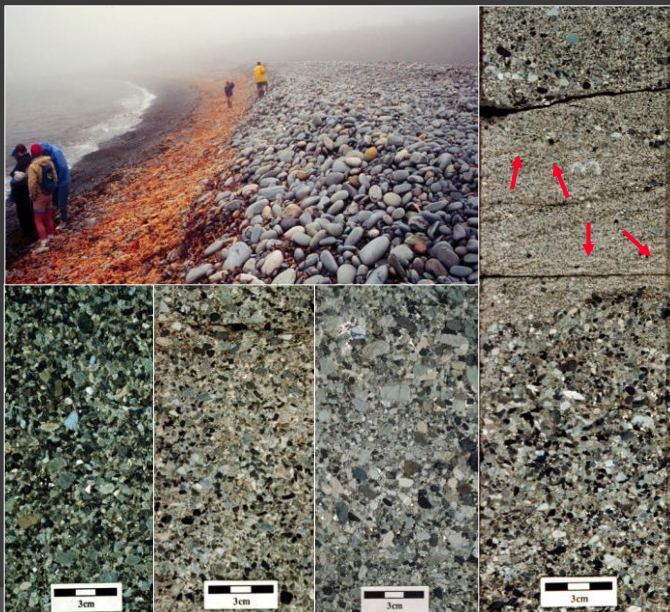


Facies:

Mainly **well-sorted, low-angle planar parallel laminated sandstones**: very high energy conditions (sheet flow)

Upper contact, if preserved, may show roots and/or pedogenic modification.

Facies - Gravelly Foreshore (Beach)



Facies:

Well-sorted and well-segregated, clast-supported granule to pebble conglomerates: massive to low-angle planar stratified.

Facies - Foreshore (Beach)



Bioturbation: rare and sporadically distributed.

Impoverished (low diversity) *Skolithos* Ichnofacies; may be dominated by *Macaronichnus segregatis* suites.

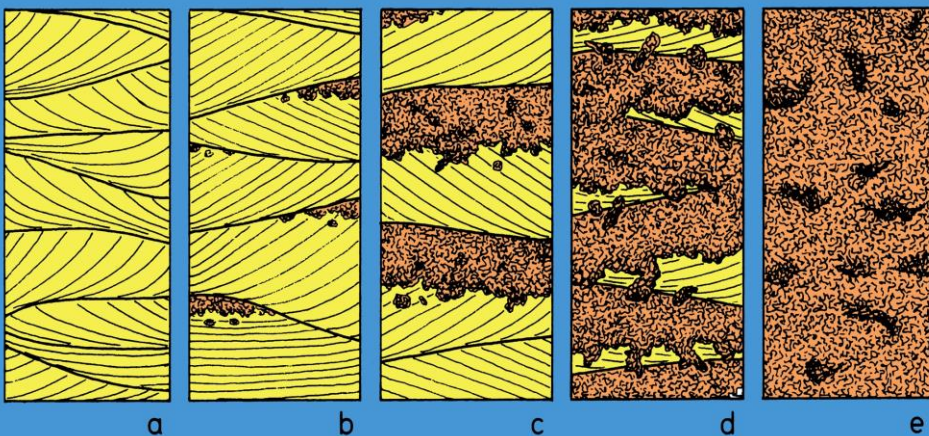
May show roots and/or pedogenic modification at contact with foreshore.

Facies - Foreshore to Backshore



Recognition of Tempestites – Storm Indicators

Animal-Sediment Interactions: Deposition vs. Erosion



C represents a **well-balanced** rhythm between **deposition and erosion**: sporadic bioturbation.

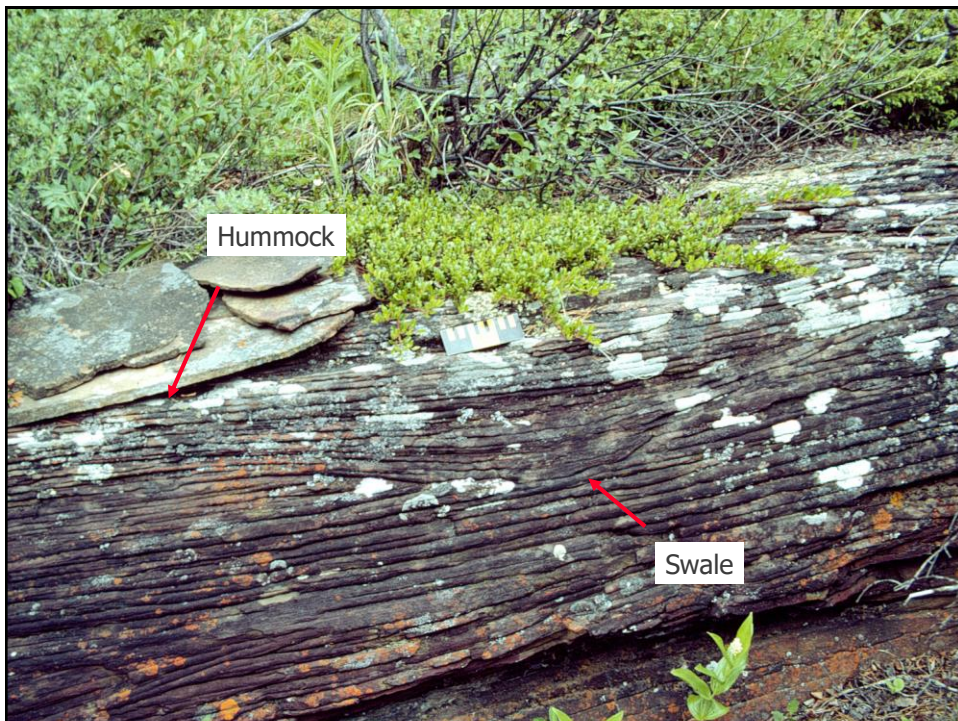
B to A: **progressively greater erosion** with little bioturbation preserved.

D to E: progressively **less erosion** and **longer periods of bioturbation** and slower depositional rates (modified after Bromley, 1996).

Recognition of Tempestites

Tempestite: the deposit of a storm.

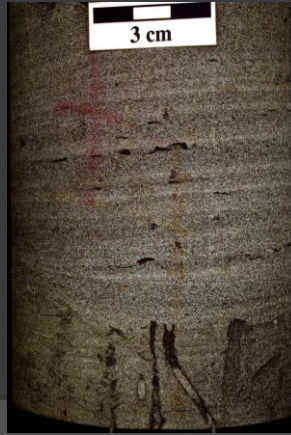
Beds dominated by oscillatory structures: mostly hummocky cross-stratification (**HCS**) and swaley cross-stratification (**SCS**).



Recognition of Tempestites

In shallow marine settings, tempestites are recognized by:

Erosional bases, locally with **lags** of intervening material and/or biogenic debris.



Recognition of Tempestites

In shallow marine settings, tempestites are recognized by:

Beds dominated by oscillatory structures, mostly hummocky cross-stratification (**HCS**) and swaley cross-stratification (**SCS**).



Recognition of Tempestites

In the shallow marine realm, tempestites are recognized by:

Waning energy oscillation ripples and rarer combined flow ripples.



Recognition of Tempestites

In the shallow marine realm, tempestites are recognized by:

Fugichnia (escape structures) of fauna entrained in the flow or buried beneath the bed.

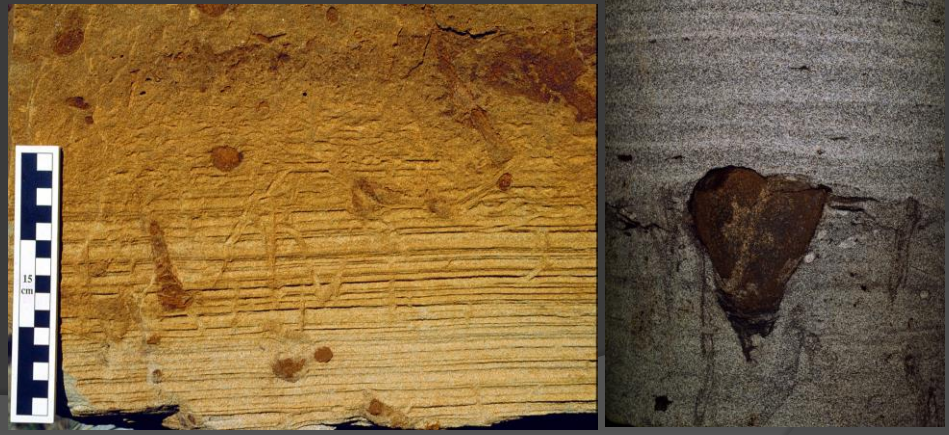


Recognition of Tempestites

Recolonization of substrate by opportunists.

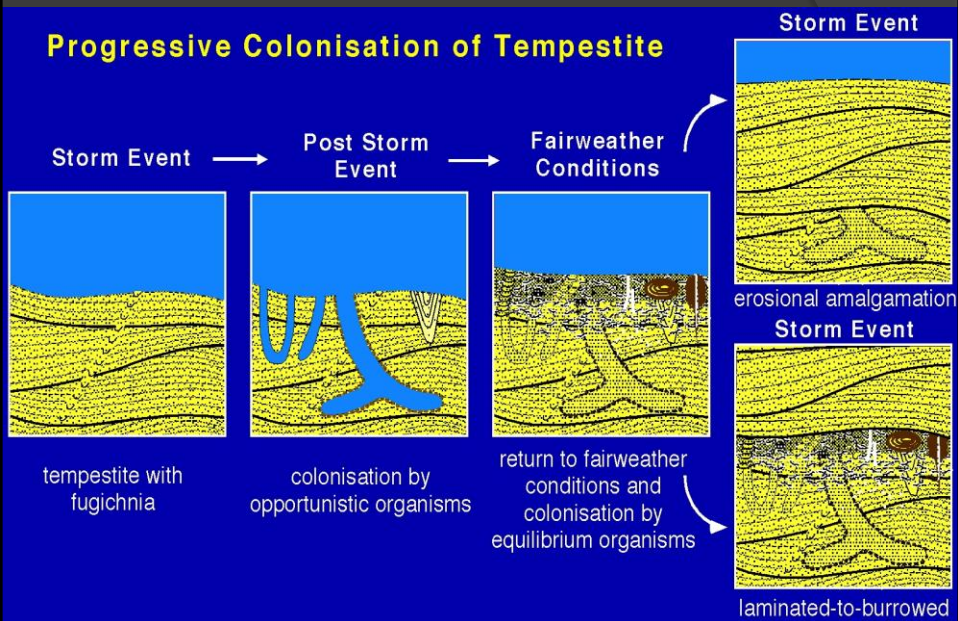
Return to fair-weather conditions and **return of resident community**. **Top down colonization**

A **truncated top** marks an ensuing storm event.

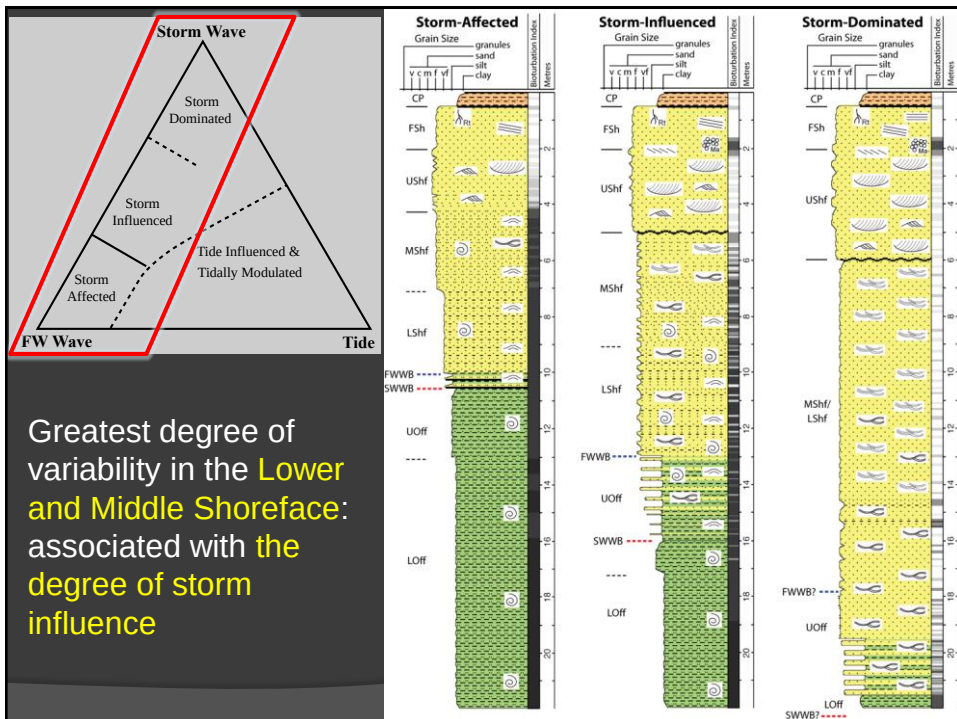


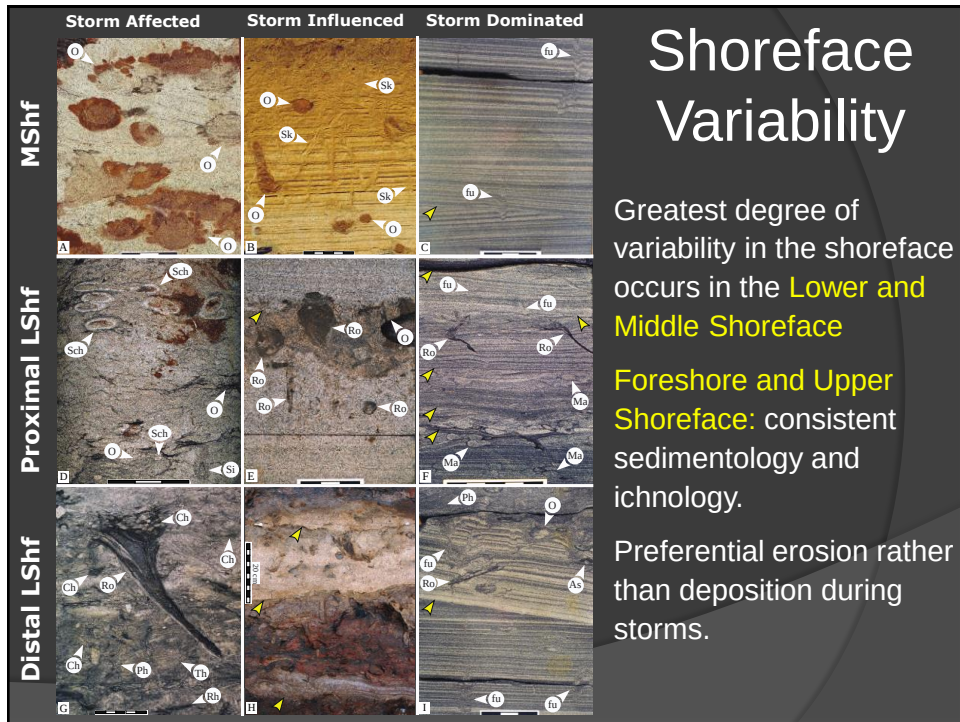
Recognition of Tempestites – Ichnology

Progressive Colonisation of Tempeste

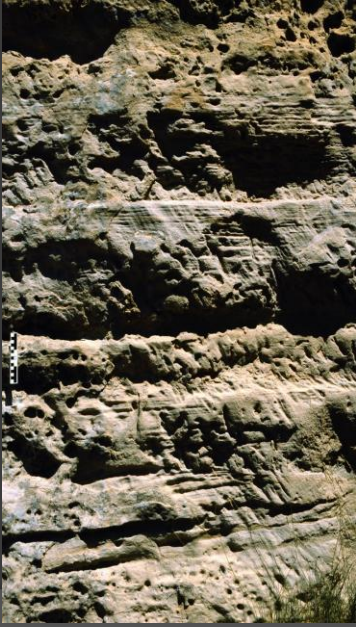


Shoreface Variability: Storm Influence



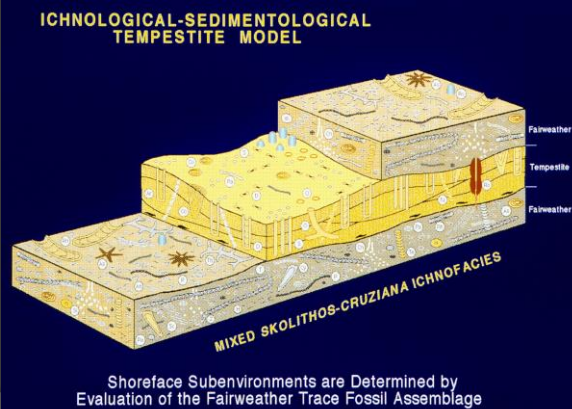


Storm-Influenced Shorefaces



L/M S: **Stacked tempestites with burrowed tops** and/or fair-weather beds.

Facies show **"laminated-to-burrowed"** appearance



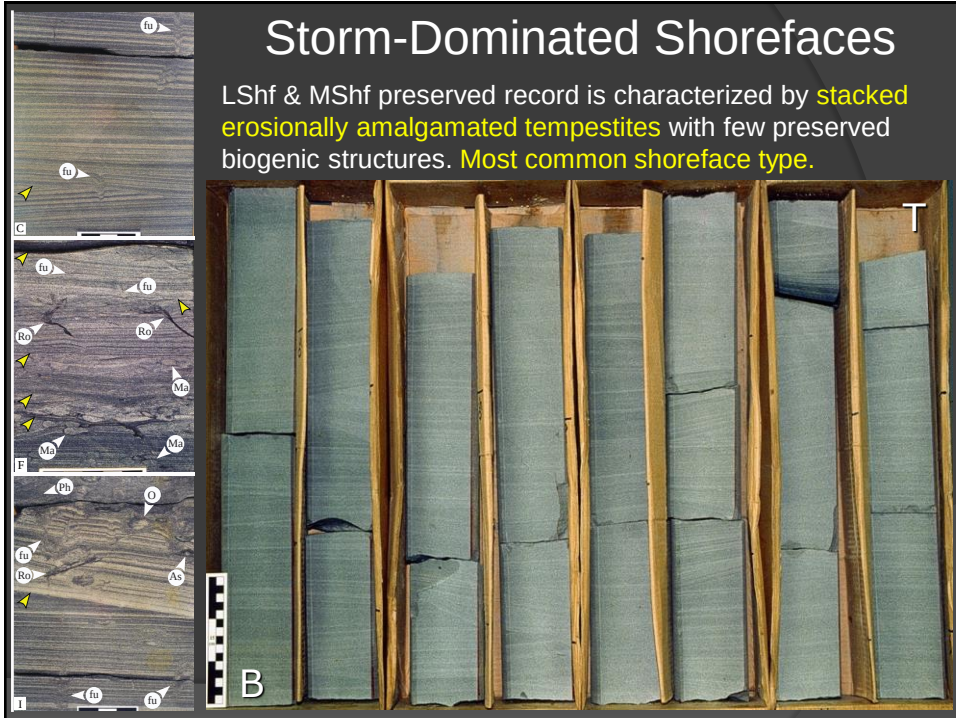
Storm-Influenced Shorefaces

L/M S: **Stacked tempestites with burrowed tops** and/or fair-weather beds.

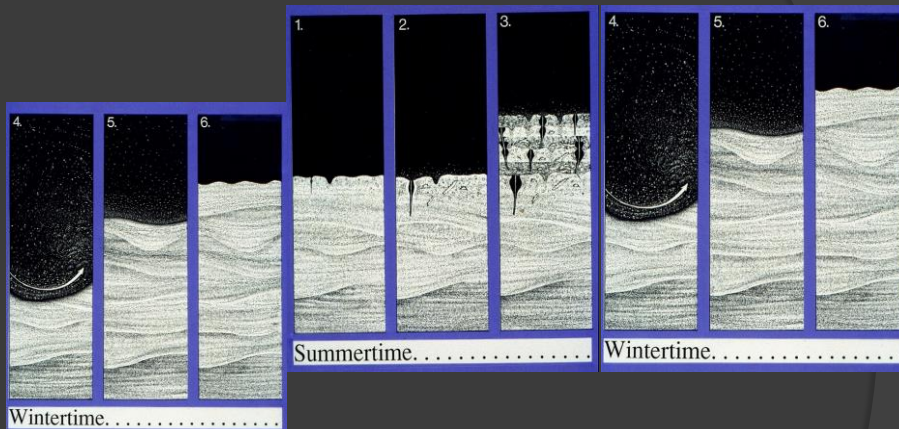
Facies show **"laminated-to-burrowed"** appearance.

Storm-Dominated Shorefaces

LShf & MShf preserved record is characterized by **stacked erosional amalgamated tempestites** with few preserved biogenic structures. **Most common shoreface type.**



Storm-Dominated Shorefaces

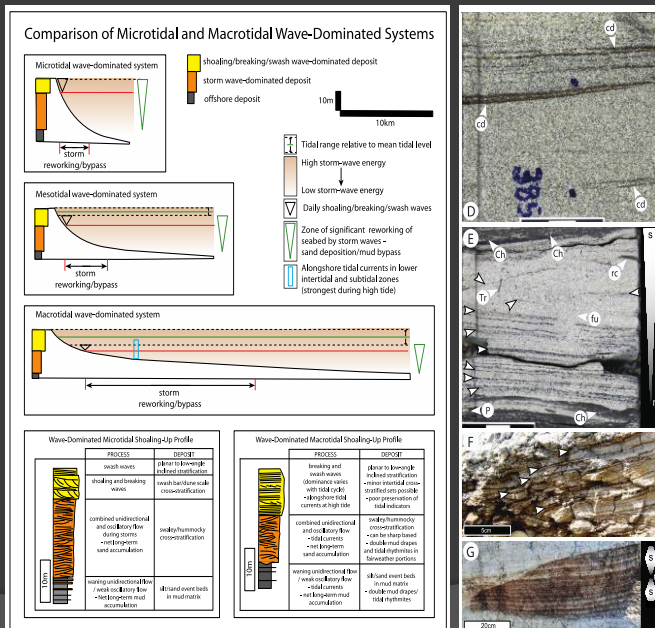


Storm-dominated shorefaces are subject to periodic high intensity and high frequency storms: **limit preservation of fairweather beds**

Most of the time, the shoreface is not swept by storms! Bioturbation is possible between storm events, despite the **geological perception of "storm-domination"!**

Shoreface Variability: Tidal Influence

Tidal Effects on Shorefaces



Vakarelov *et al.* (2011) focused on the tidal effects on otherwise wave-dominated shorefaces.

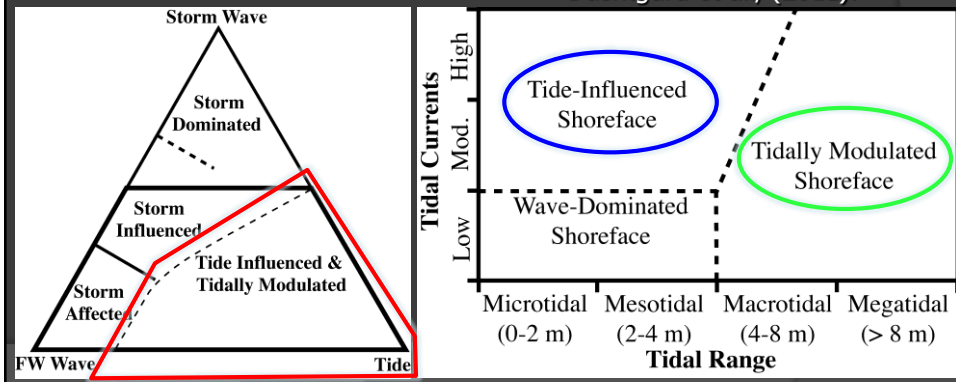
They summarize such settings in the context of the products of **two end-member extremes in a continuum**, based on tidal range.

Shoreface Variability – Tidal Influences

Dashtgard *et al.* (2011) argued that this was too simplistic. They suggested an alternate model.

Tidally Modulated Shoreface (TMS): weak to strong tidal currents, large tidal range

Tide-Influenced Shoreface (TIS): strong tidal currents, small tidal range
Dashtgard *et al.*, (2011).

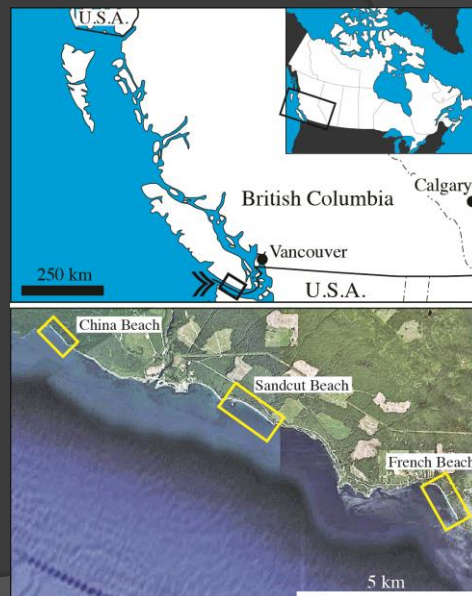


Tide-Influenced Shoreface

Settings with strong tidal currents and suppressed wave activity (*e.g.*, straits, bays)

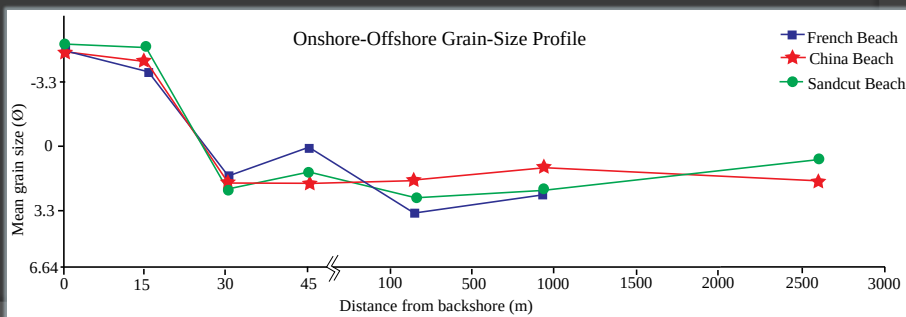
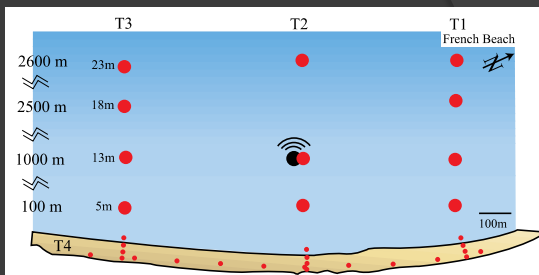
Model based on Juan de Fuca Strait beach-shorefaces

(Frey and Dashtgard, 2011)



Tide-Influenced Shoreface

Grain size is uniform from the lower foreshore to the offshore for all 3 beaches



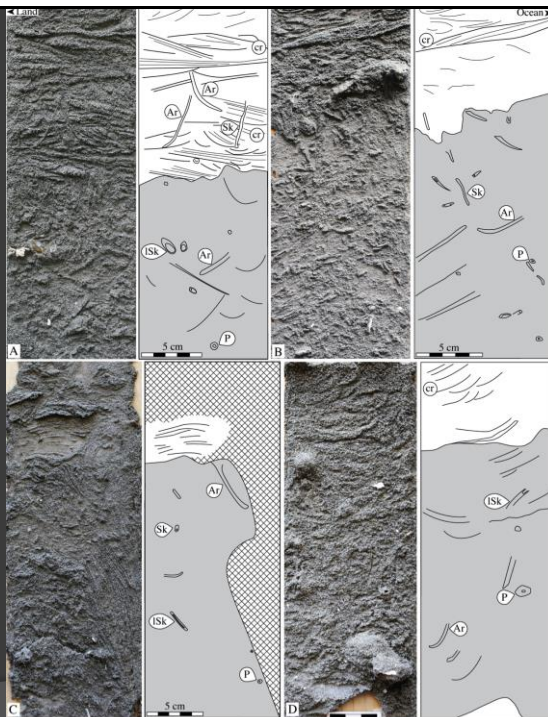
Tide-Influenced Shoreface

Offshore-Lower Shoreface:

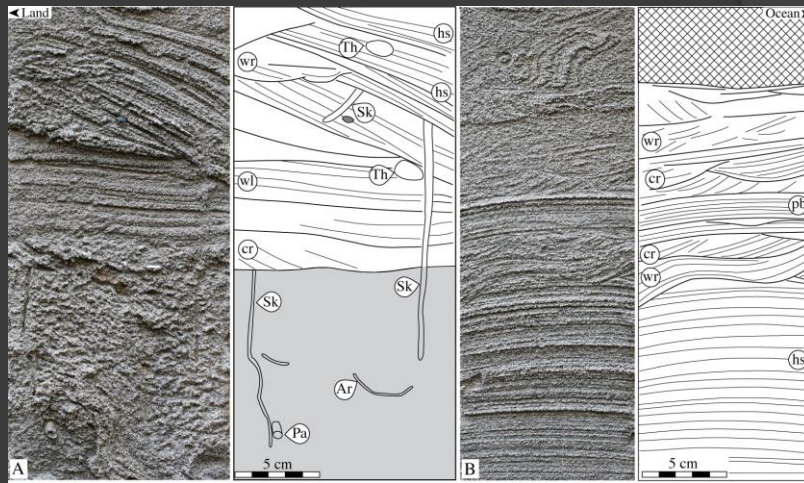
Sand-dominated

Rarely preserved sed. structures – mainly current-generated structures

Intensely bioturbated (BI 4-6): mainly simple forms - *Skolithos* Ichnofacies

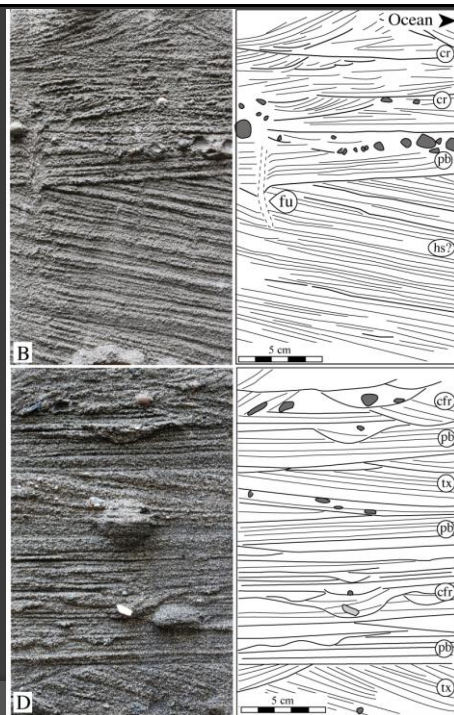


Tide-Influenced Shoreface



Middle – Upper Shoreface:

Preservation of mainly wave-generated sed. structures (HCS, WR)
Skolithos Ichnofacies – reduced burrowing (BI 0-5) relative to LShf



Tide-Influenced Shoreface

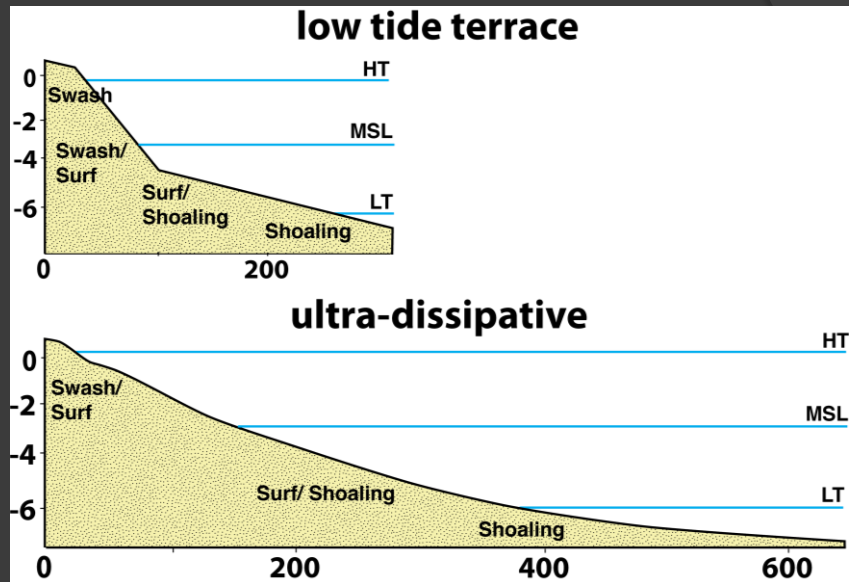
Upper Shoreface – Foreshore:

Interbedded sedimentary structures (tidal modulation)

Preservation of trough cross-beds (storm-deposits)

Very rare burrowing (BI 0-1)

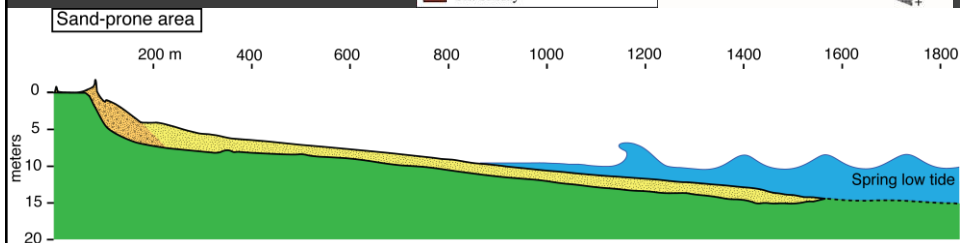
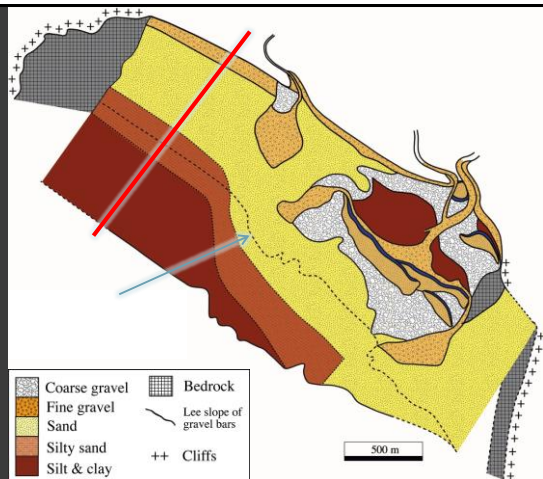
Tidally Modulated Shorefaces



Masselink and Hegge, 1995

Tidally Modulated Shoreface

Sediments deposited at high tide (under 12 m water depth) successively exposed to shoaling waves, breakers and surf, and swash-backwash with falling tide



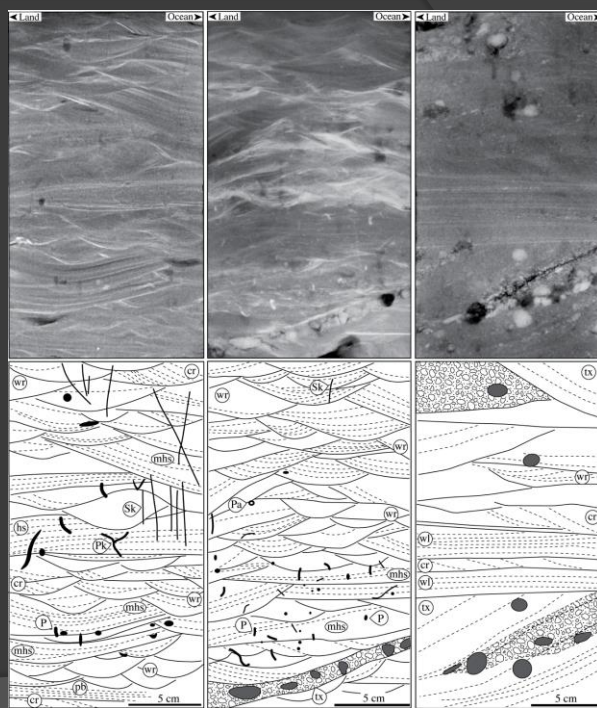
Tidally Modulated Shorefaces

Proximal Lower Shoreface:

Dom. by oscillatory-generated sed. structures

Interbedding of sed. structures evident

Low bioturbation intensity (BI 1-3): *Skolithos* Ichnofacies



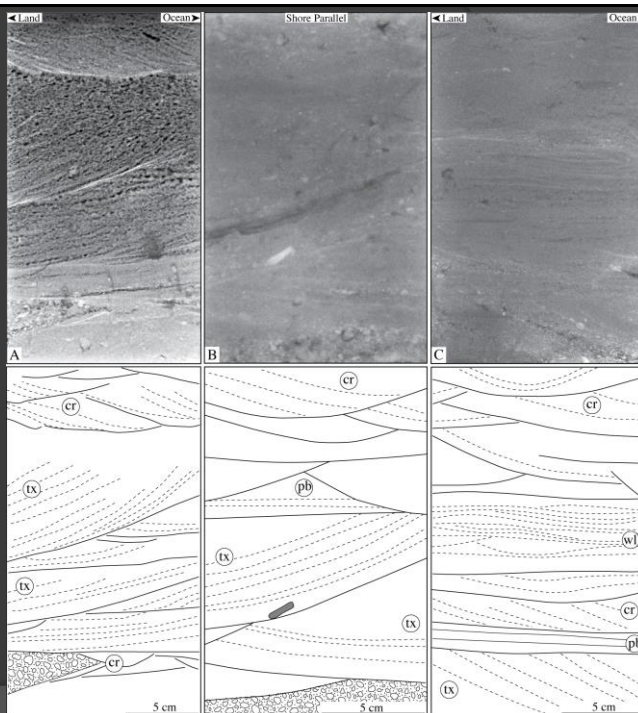
Tidally Modulated Shorefaces

Upper Shoreface:

Dom. by current-generated (surf) sed. structures: TXB

Interbedding of sed. structures evident

Very rare bioturbation (BI 0-1), incr. seaward (BI 0-2)



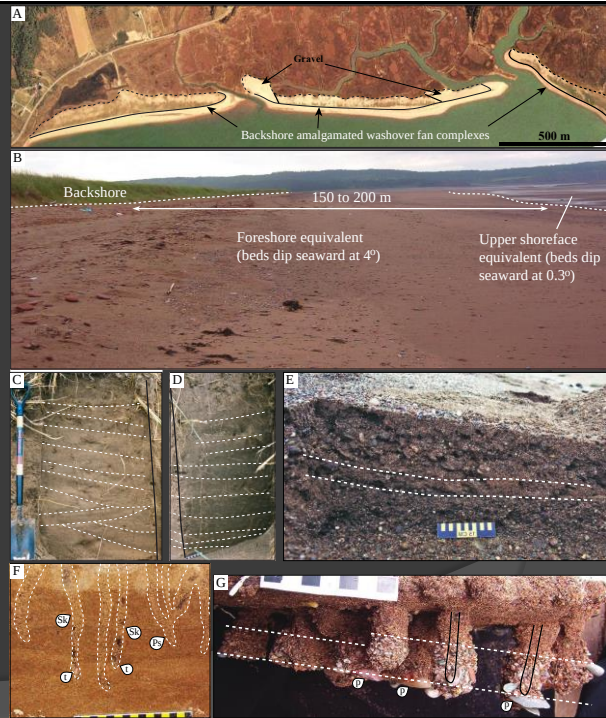
Tidally Modulated Shorefaces

Foreshore:

Dom. by seaward-dipping plane beds

4 to 5 m thick
(proportional to tidal range)

No burrowing except in upper foreshore:
Pseudonichnus Ichnofacies



Tidally Modulated Shorefaces

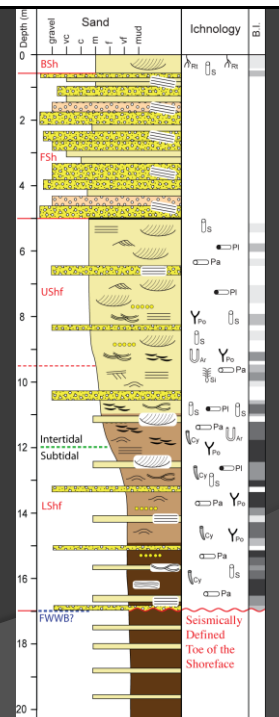
Positive ID of Tidally Modulated Shorefaces possible from **Upper and Lower Shoreface Deposits**:

Interbedding of sedimentary structures from shoaling waves, breakers and surf, and swash-backwash

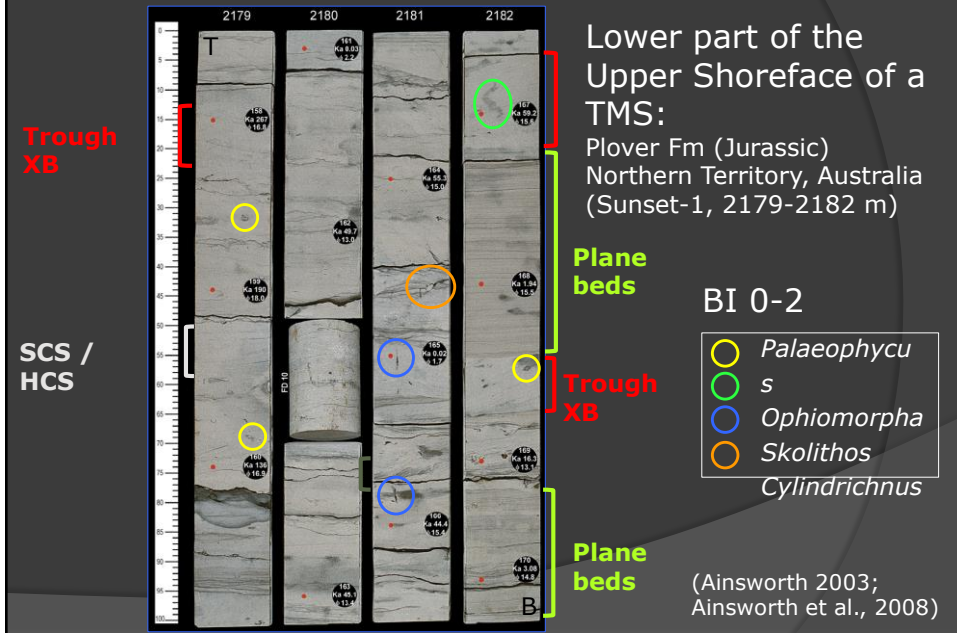
Dominance of the *Skolithos* Ichnofacies across the shoreface

Possible reduced burrowing in LShf and increased in UShf

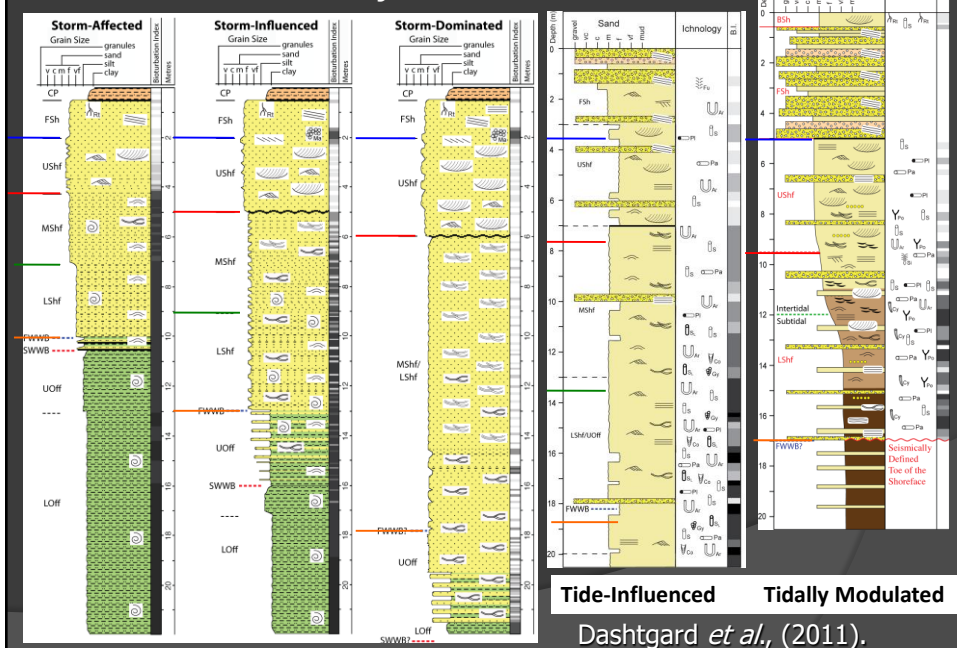
Anomalously thick foreshore (if preserved)



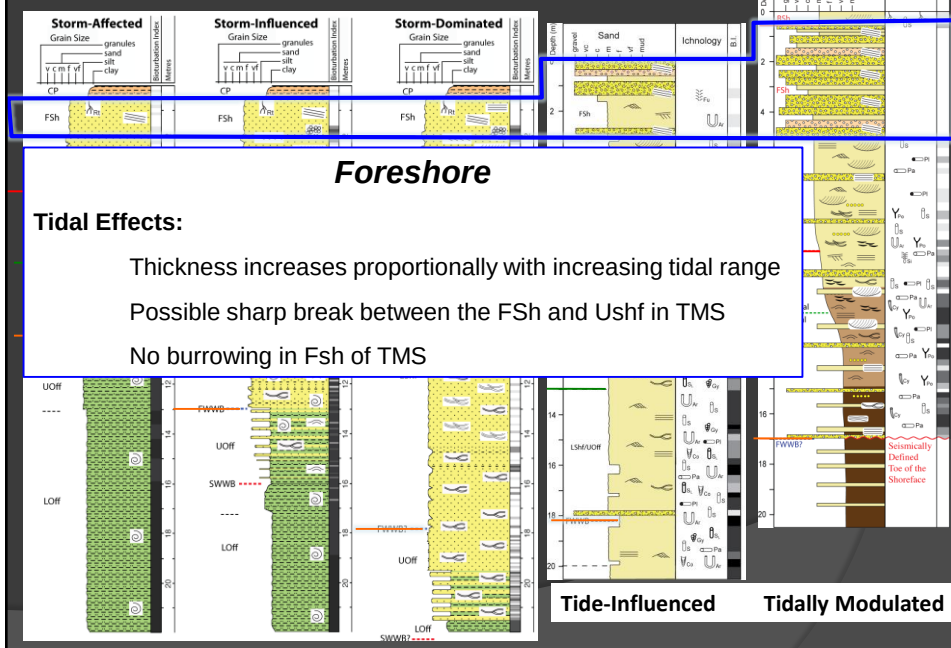
Tidally Modulated Shorefaces



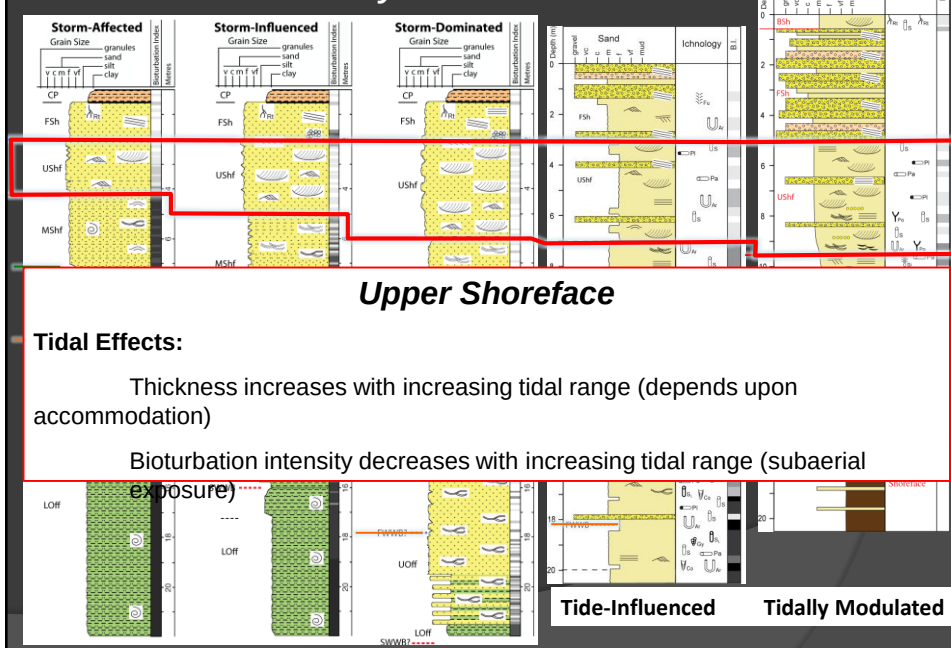
Shoreface Variability – Storms vs Tides



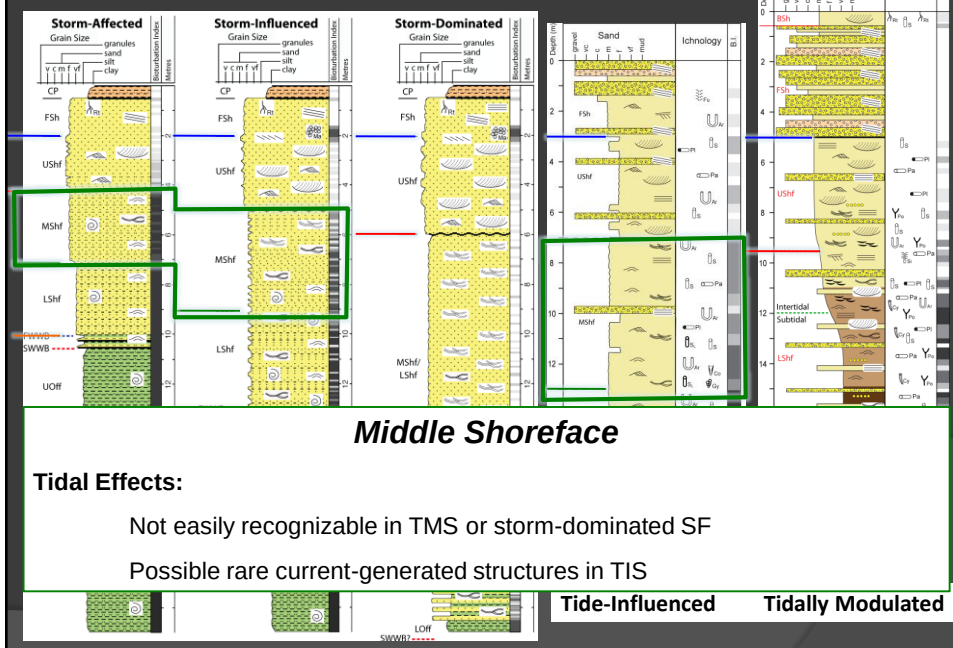
Shoreface Variability – Storms vs Tides



Shoreface Variability – Storms vs Tides



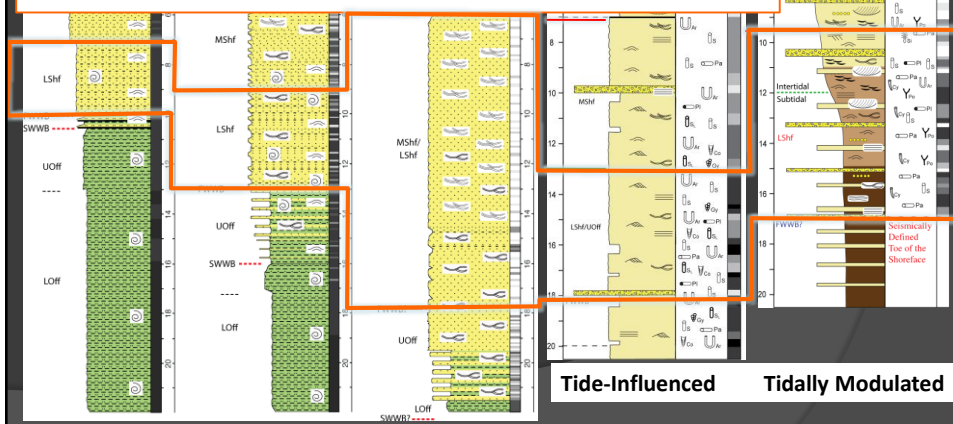
Shoreface Variability – Storms vs Tides



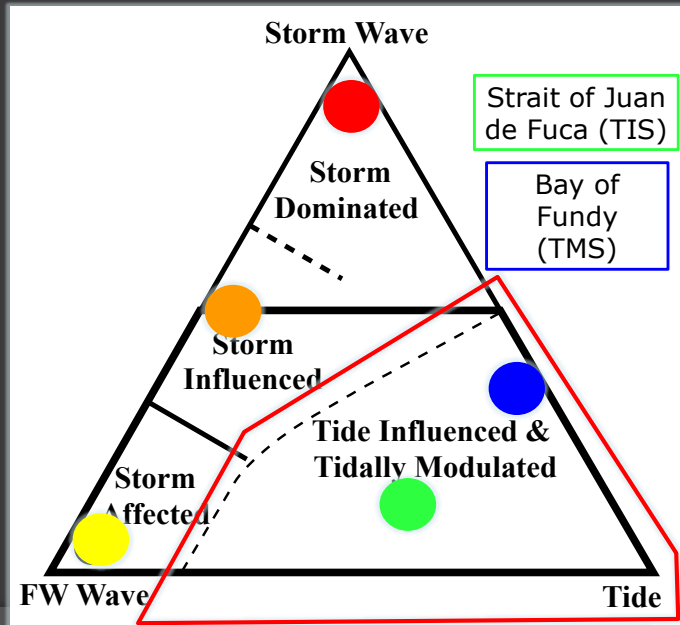
Lower Shoreface

Tidal Effects:

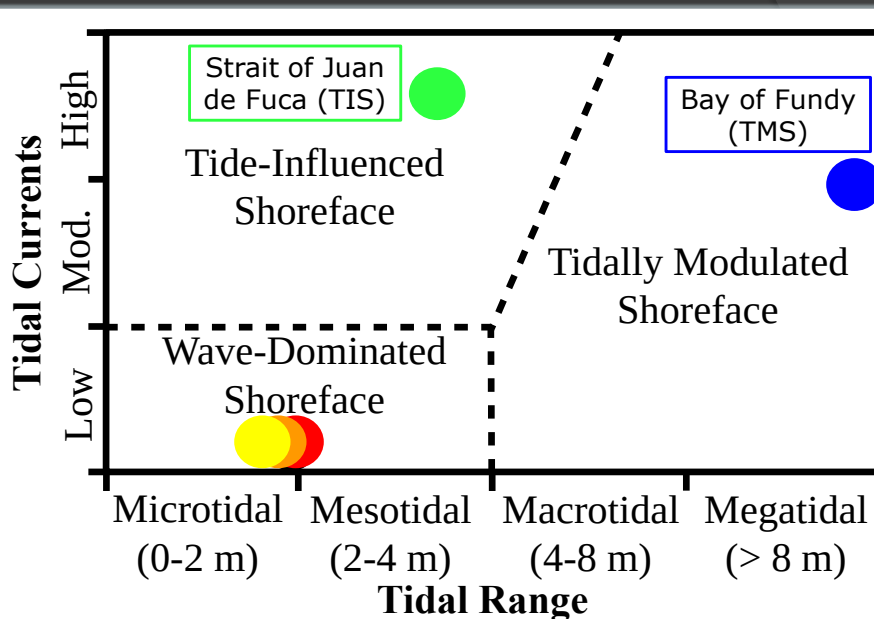
- Amalgamated middle and lower SF in TMS & storm-dom SF
- Thickness increases with increasing tidal influence
- Current-generated structures in TIS and possibly TMS
- Bioturbation intensity decreases with increasing tidal range
- Skolithos* Ichnofacies in TIS and TMS



Shoreface Variability – Storms vs Tides



Shoreface Variability – Storms vs Tides



Stratigraphic Expressions of Shorefaces

Stratigraphic Expressions of Shorefaces

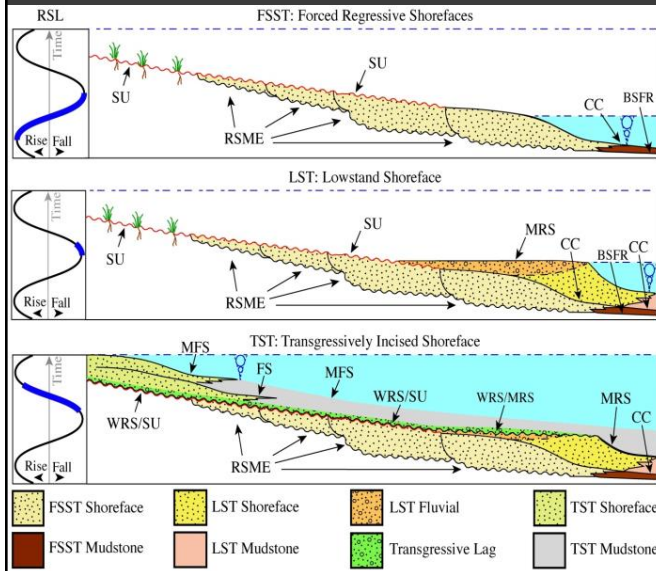
All previously described shorefaces are typical of **normal regressive shorelines**, wherein all subenvironments are preserved.

Variability in shoreface character of normal regressive systems is linked to the **degree of storm and tidal influence** only.

However, preserved expressions of shorefaces can also **vary significantly as a function of base level rise and fall**

Incised shorefaces are developed under forced regressive / lowstand and transgressive conditions, but vary significantly from a stratigraphic architecture perspective.

Incised Shorefaces

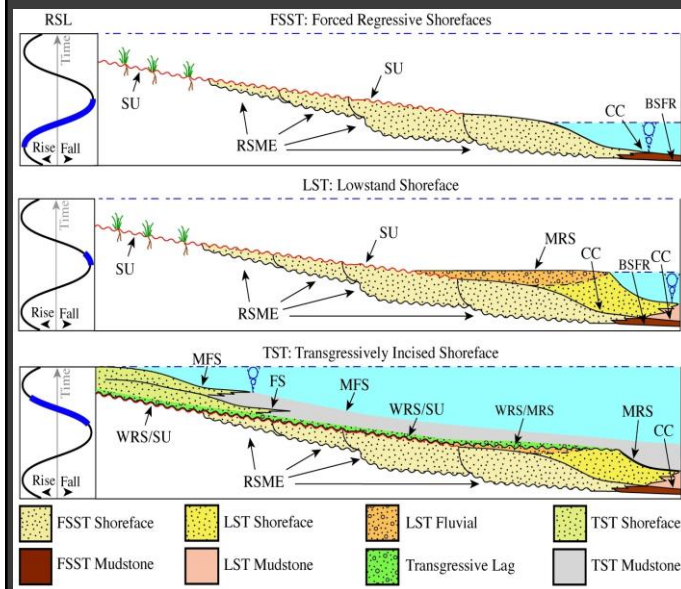


Incised shorefaces: form in response to **allogenicly induced relative sea level changes**

May occur in response to base level fall or to relative sea level rise across a *previously* subaerially exposed substrate.

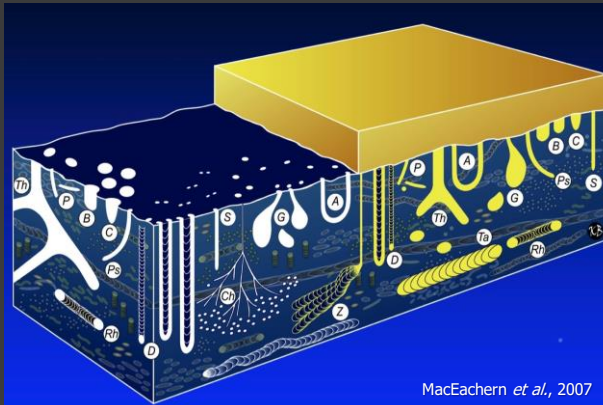
May pass alongstrike into deltas.

Incised Shorefaces



Changes in relative sea level shifts the **position of fair-weather wave base and storm wave base**, allowing waves to cut the erosional discontinuities subaqueously.

Glossifungites Ichnofacies



Firmground substrates demarcated by the **Glossifungites Ichnofacies** characterize many of the basal discontinuities associated with incised shorefaces.

Firmgrounds:
dewatered or stiff substrates, typically mudstones.

Siliciclastic firmgrounds: **erosional exhumation and/or subaerial exposure** of a substrate prior to colonization.

Carbonate firmgrounds: may include **autogenic submarine cementation** due to reduced sediment accumulation.

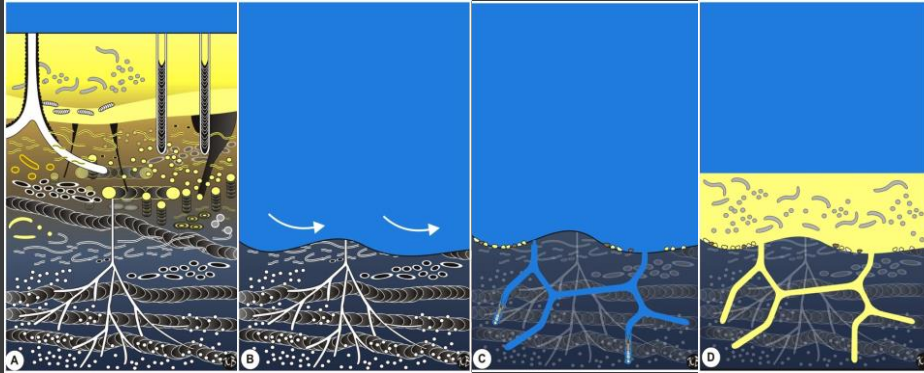
Glossifungites Ichnofacies



Ichnogenera are typically:

- **Robust** (large diameter)
- **Sharp-walled**
- **Unlined**
- **Vertical to subvertical domiciles** (some horizontal and/or branched)
- **Passively infilled**

Glossifungites Ichnofacies



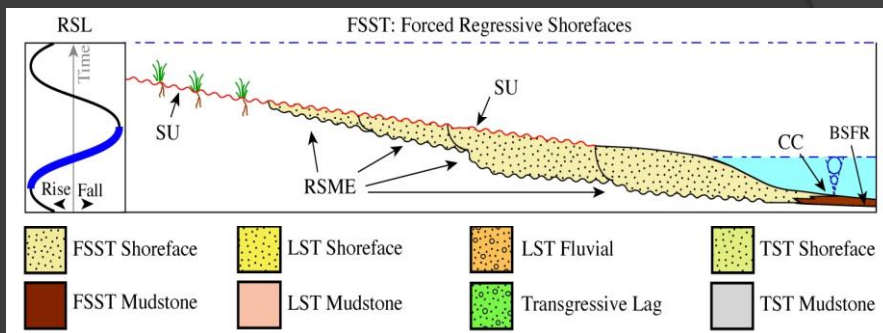
MacEachern *et al.*, 2007

Predominantly demarcate **erosional discontinuities**.

Colonization corresponds to a **hiatus between the erosional event and subsequent depositional event**.

These substrate-controlled suites are **overwhelmingly marine or marginal-marine** in origin.

Forced Regressive Shorefaces: The Falling Stage Systems Tract (FSST)

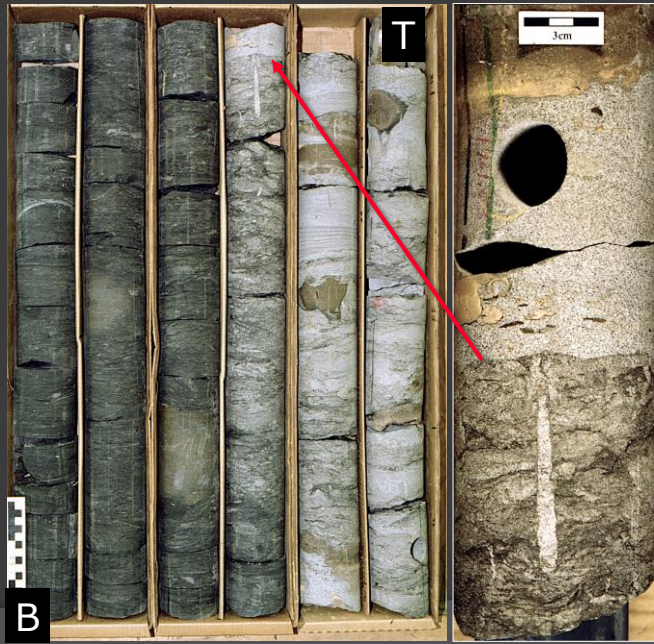


During relative sea level fall: deeper water deposits are brought into a zone of wave attack (below FWWB to above FWWB).

Erosion along subaqueous **regressive surface of marine erosion (RSME)** extends as far seaward as **fairweather wave base**.

Basinward, the RSME passes into the non-erosional **basal surface of forced regression (BSFR)**.

Forced Regressive Shorefaces of the FSST

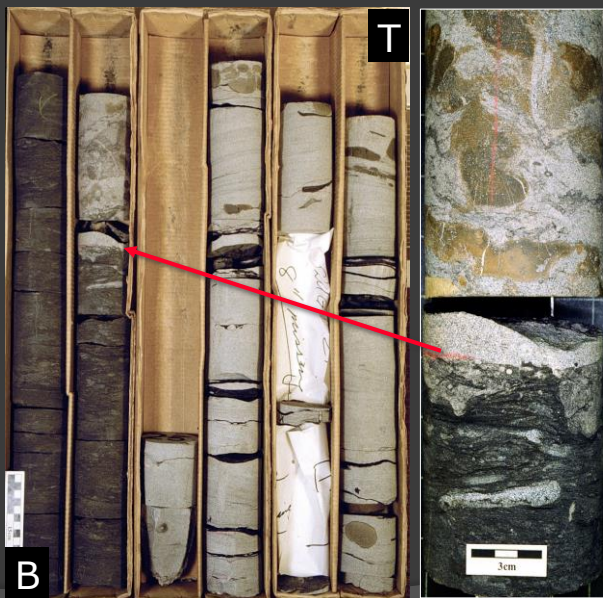


Viking Fm, Kaybob Field is interpreted as a **Forced Regressive Shoreface**.

A subtle expression of the ***Glossifungites* Ichnofacies** occurs in this proximal position.

The juxtaposition of facies is not an obvious indicator of a stratigraphic break!

Forced Regressive Shorefaces of the FSST

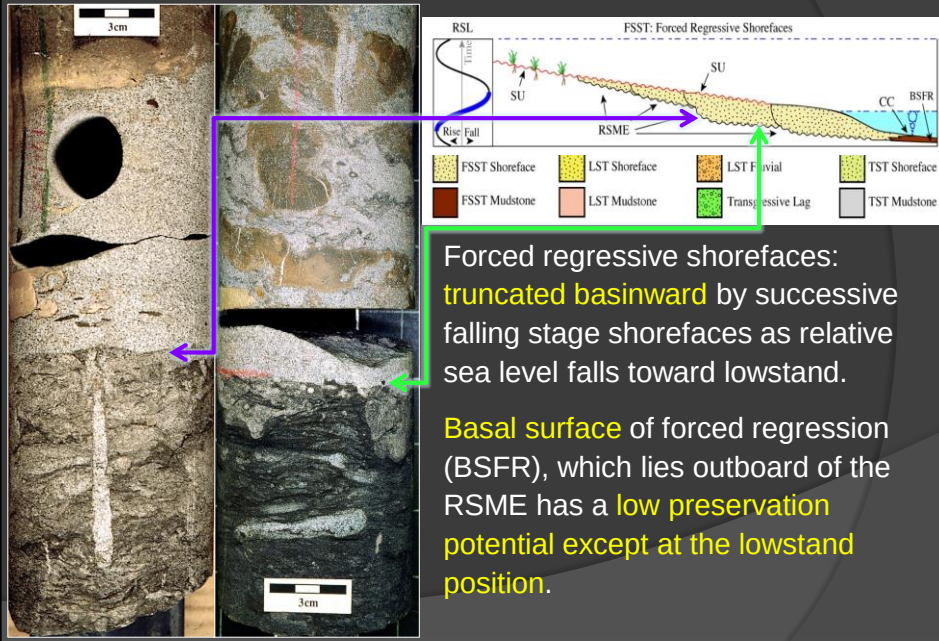


In a more distal position (Kaybob Field): **juxtaposition of facies is more apparent.**

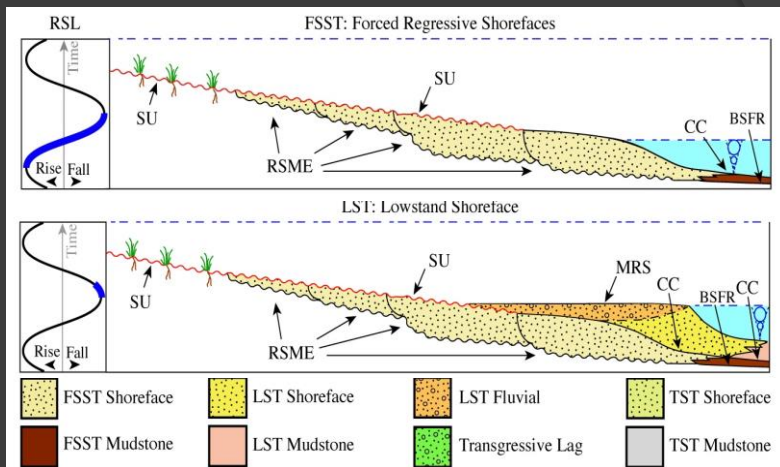
Here, **lower shoreface sandstones** erosionally overlie lower offshore mudstones.

Firmground *Thalassinoides* (*Glossifungites* Ichnofacies) mark the stratigraphic break, **interpreted as a RSME.**

Forced Regressive Shorefaces of the FSST

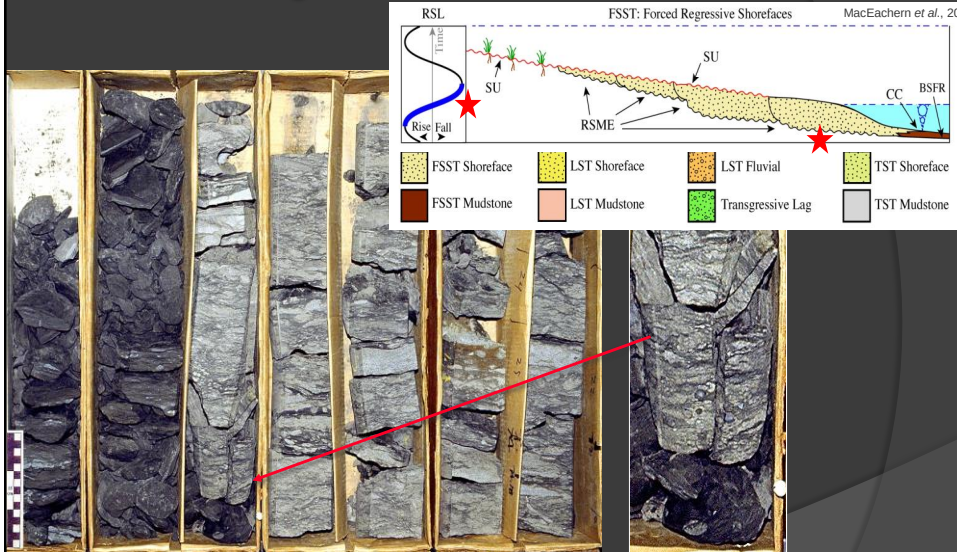


Lowstand Shorefaces of the LST



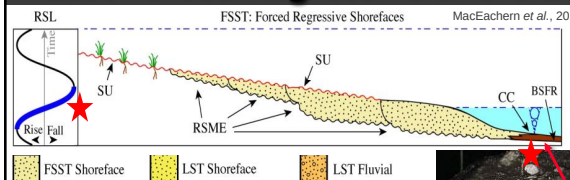
The lowstand shoreface progrades while base level is stable but low, and coarse detritus starts to accumulate in fluvial valleys. The contact between the FSST and LST constitutes the **Correlative Conformity (CC)**, and the shoreface of the LST is typically finer-grained than the FSST.

Last Forced Regressive Shoreface of the FSST



In proximity to the lowstand positions, forced regressive shorefaces show both the **RSME** and the **Basal Surface of Forced Regression (BSFR)** (Catuneanu et al., 2011).

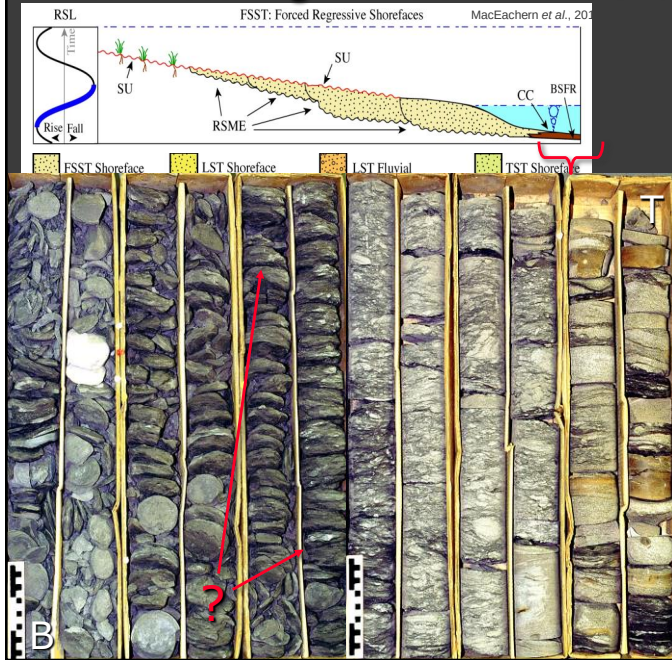
Last Forced Regressive Shoreface of the FSST



Lowstand shorefaces occur while sea level is low but not rapidly falling, or slowly rising but prior to transgression.

The **basal surface of forced regression (BSFR)** outboard of the RSME of the late FSST has a high preservation potential. Its preservation is favoured by progradation and aggradation of the Lowstand Shoreface, which buries the surface.

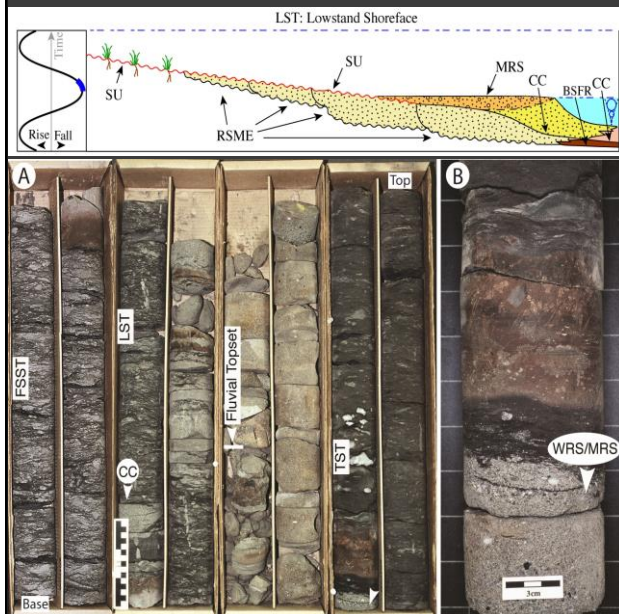
Last Forced Regressive Shoreface of the FSST



Further basinward, identification of the BSFR as a discrete surface is exceedingly difficult.

A normal progradational expression is generated and recognition of an incised relationship can be determined only in more landward positions.

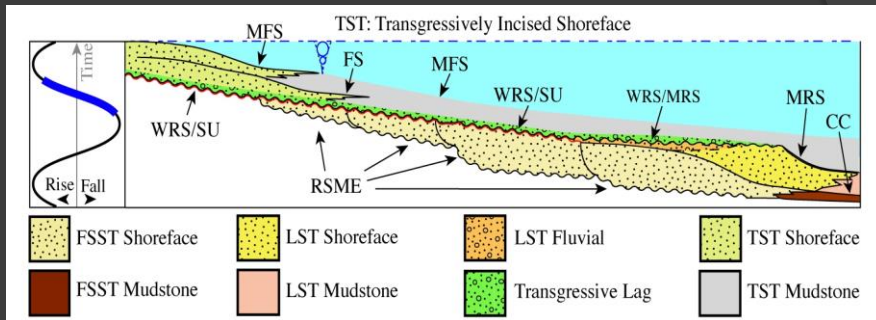
Lowstand Shorefaces of the LST



The **Correlative Conformity (CC)**: marked by a finer-grained, coarsening-upward succession of the LST shoreface.

Normal progradational regression persists until relative sea level rise exceeds sediment influx. This is the **Maximum Regressive Surface (MRS)**. The surface may be modified by wave ravinement (WRS).

Transgressively Incised Shorefaces of the TST

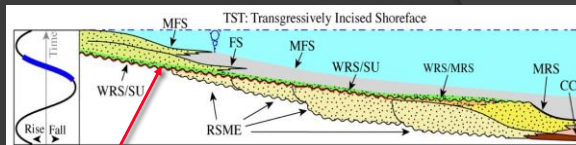


Relative sea level had **previously fallen** past the position of later transgressive shoreface development, **excavating a subaerial unconformity (SU)**.

Subsequent **relative rise of sea level cuts a wave ravinement surface (WRS)**, which **modifies the subaerial unconformity** (generating a WRS/SU).

The **WRS/SU is erosional**, and **passes progressively basinward through a wave ravinement surface** and into a non-erosional, low-energy flooding surface.

Transgressively Incised Shorefaces



Transgressively incised systems: delineated by an **erosional discontinuity (WRS/SU)**.

Proximal expression of the discontinuity is **broadly similar** to that of the RSME.

All are excavated by **wave erosion** in a **subaqueous marine setting**.

Transgressively Incised Shorefaces

Distal expression of WRS/SU is unique (and distinct).

There, the **erosional expression** extends well seaward of fairweather wave base for the overlying shoreface complex.

This is because the **surface was cut while sea level was at a lower position**, and was subsequently deepened during ensuing transgression.

Transgressively Incised Shorefaces vs. Forced Regressive Shorefaces

Main difference lies in the **extent of the erosional discontinuity**

In **proximal positions**, where sandstone overlies the discontinuity, **differentiating** the two systems is difficult.

In **distal positions**, differentiation based on by recognition of a continuing **erosional expression of the discontinuity** rather than development of the **non-erosional BSFR**.

Incised Shorefaces: Summary

Recognition of allogenicly controlled shoreline successions can be critical. **Ichnological relationships are commonly essential** to the identification and interpretation of such successions.

Recognition of **RSME-bound falling stage systems tract (FSST) shoreline deposits** indicates that potential shoreline reservoirs *lie further basinward*, and therefore constitute a viable hydrocarbon play.

Forced Regressive shorefaces and deltas, themselves, **may be inferior reservoirs**, owing to their eventual subaerial exposure during continued seal level fall.

Incised Shorefaces: Summary

SU- and CC-bound lowstand shorefaces mark the last shoreline position for a given sequence. No additional shoreline successions will lie further seaward of the lowstand complex.

Any potential **reservoirs lying further seaward** will be **associated with sediment bypass** during cutting of the unconformity, the most significant of which might be **submarine fans**.

Lowstand shorefaces and deltas **may be good reservoirs**, as they tend to be coarser grained and thicker than falling stage shorefaces.

Incised Shorefaces: Summary

WRS/SU-bound, transgressively incised shorefaces demonstrate incremental progradation during the transgressive systems tract; these systems form sharp-based parasequences, typically in retrogradational parasequence sets.

They indicate the presence of lowstand shoreface/delta deposits lying further basinward. They commonly erosively overlie the remnants of forced regressive shoreface/delta deposits.

Transgressively incised shorefaces may be good reservoirs. They tend to be coarser grained, owing to cannibalization of units deposited on the unconformity. Thicknesses vary significantly, depending upon shoreline trajectory and rate of subsequent sea level rise.