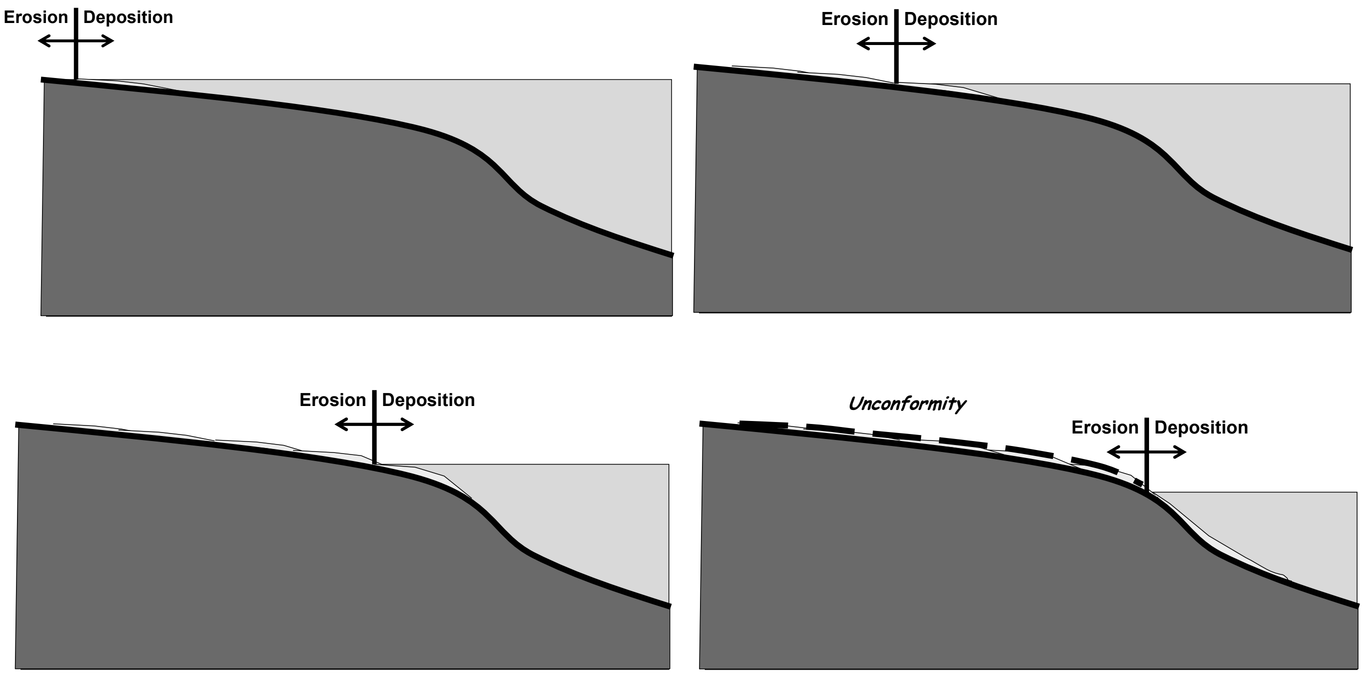
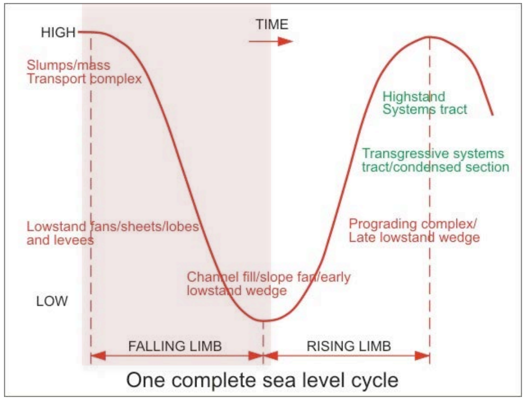
Sea-level cycle

Sea-level fall





- Sediment accumulation ceases along basin margin
- subaerial erosion surface expands basinward
- Sea-floor erosion on inner shelf in advance of prograding shoreline
- Unconformity, expandind basinward as sea-level falls
- Unconformity recognized by truncation of strata below and onlap of strata above

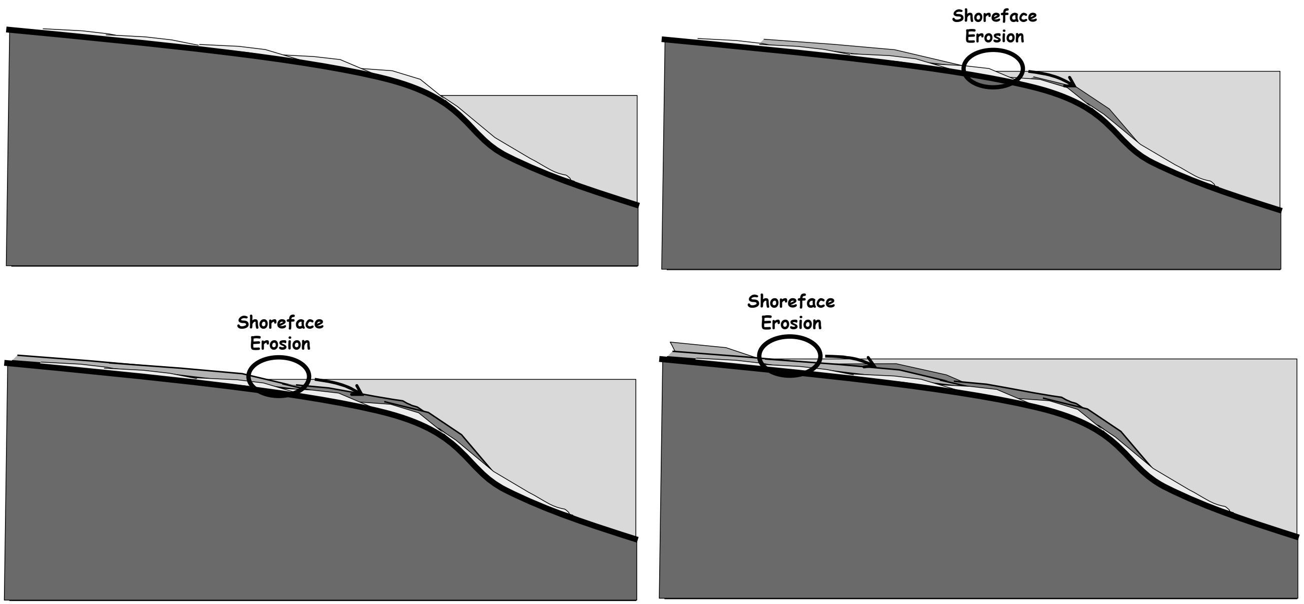
Typical features:

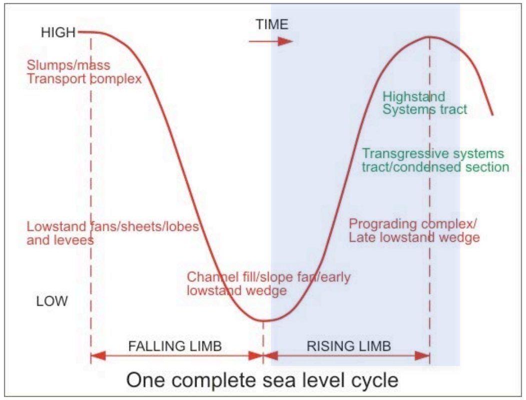
incised valleys
channels

soil development

Sea-level cycle

Sea-level rise



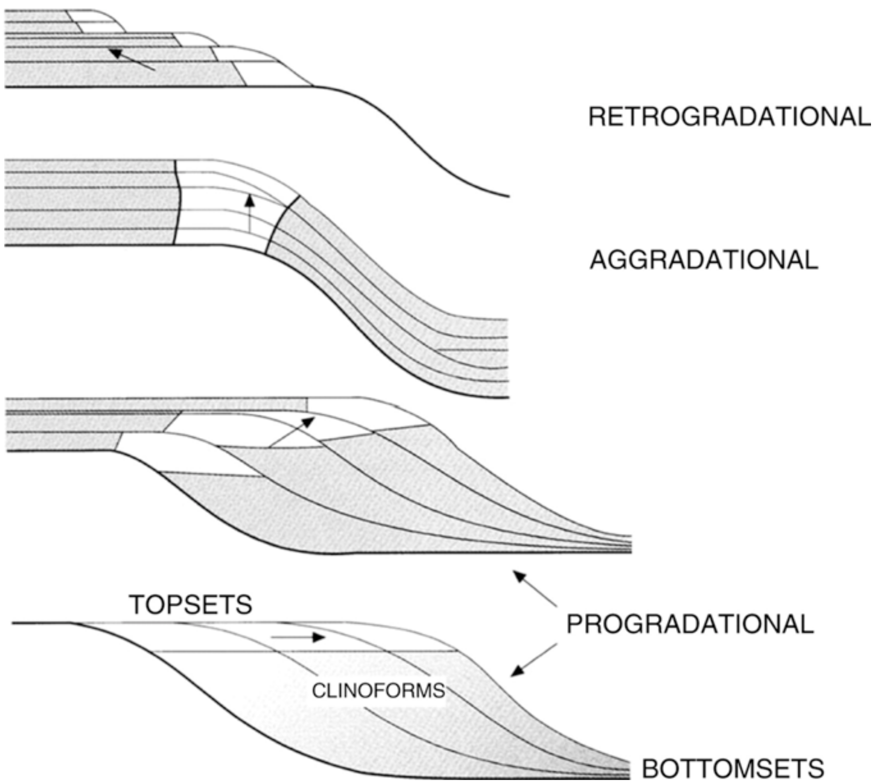


- Change from regressive trend to a transgressive trend in marine deposits
- Flooding surface: Surface across which there is evidence of an abrupt deepening
- Shoreface erosion, Erosion may cut down through underlying unconformity
- End of transgression, start of regression - **Maximum flooding surface**
- May be a surface of non-deposition or marine erosion
- May be an interval of very slow deposition – "Condensed section" – not really a surface

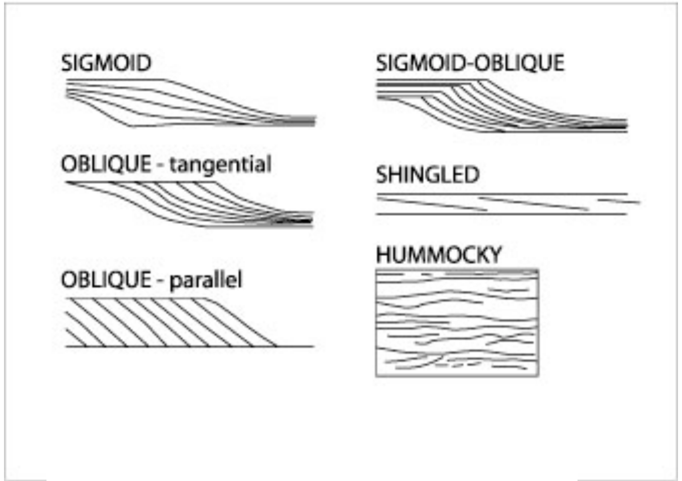
Clinoforms & Terminations

sea level changes lead to lateral changes of depositional system:

retrogradation, aggradation, progradation



clinoforms – internal geometries



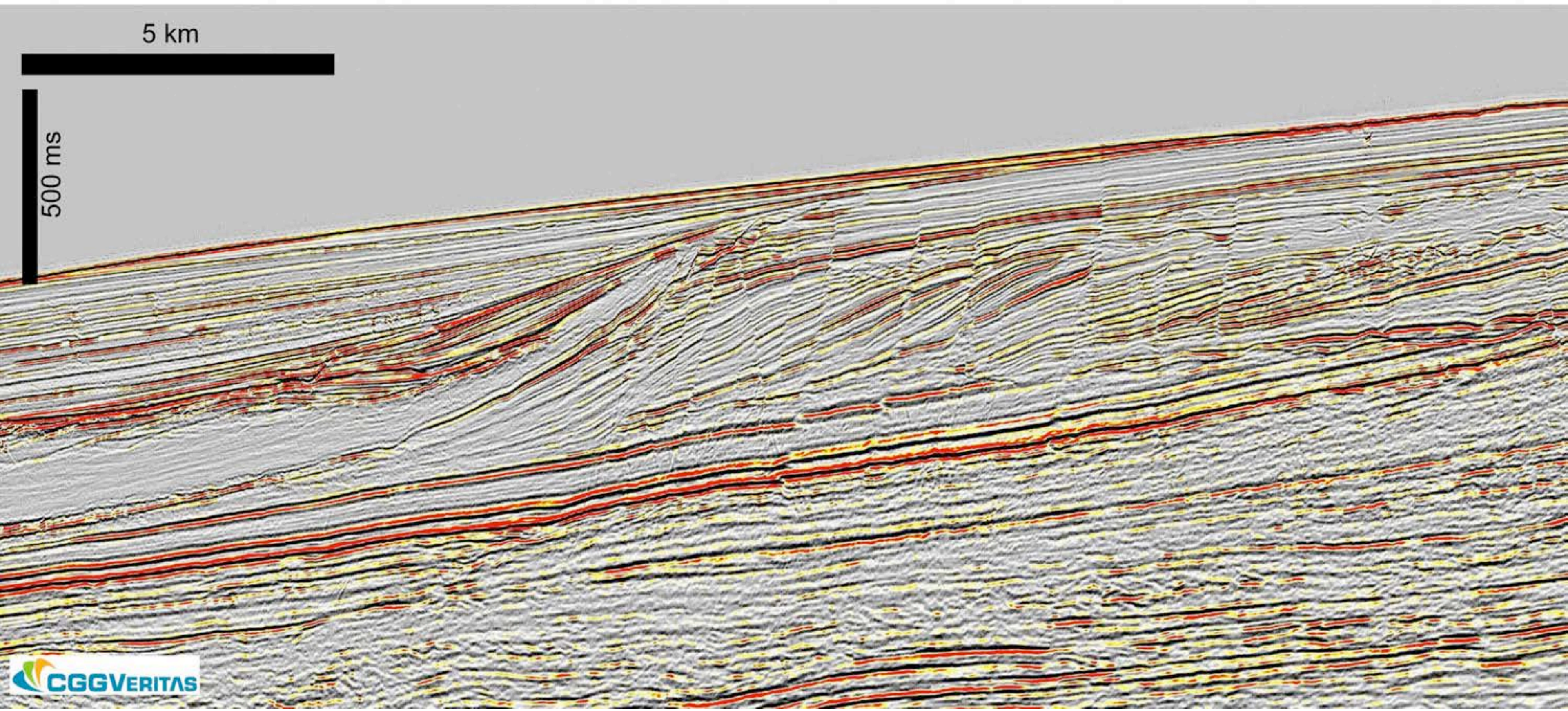
shape of a depositional surface at large scale (entire continental margin)

strata packages with oblique internal layering, 3 geometric elements:
topset - most shallow / low-angle area

foreset - central & steepest area
bottomset - flat area basinwards

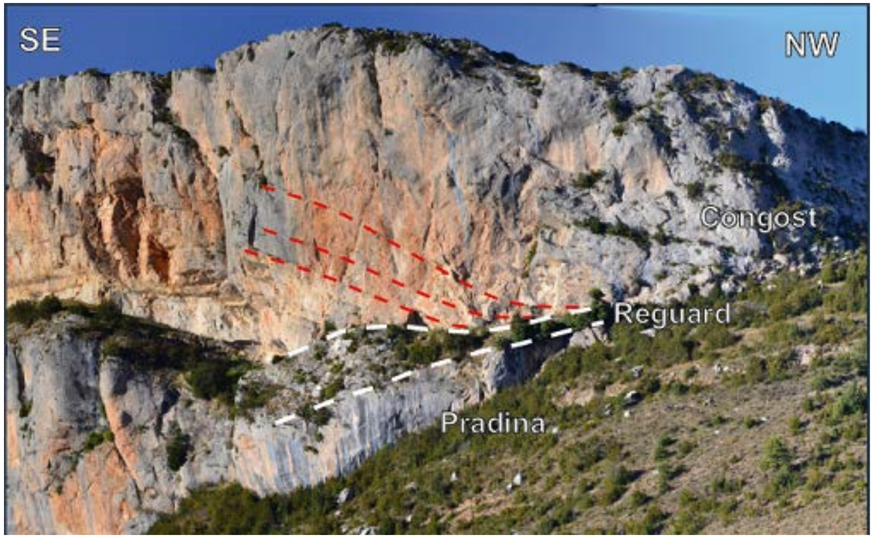
Clinoforms & Terminations

clinoforms –visible in seismic section

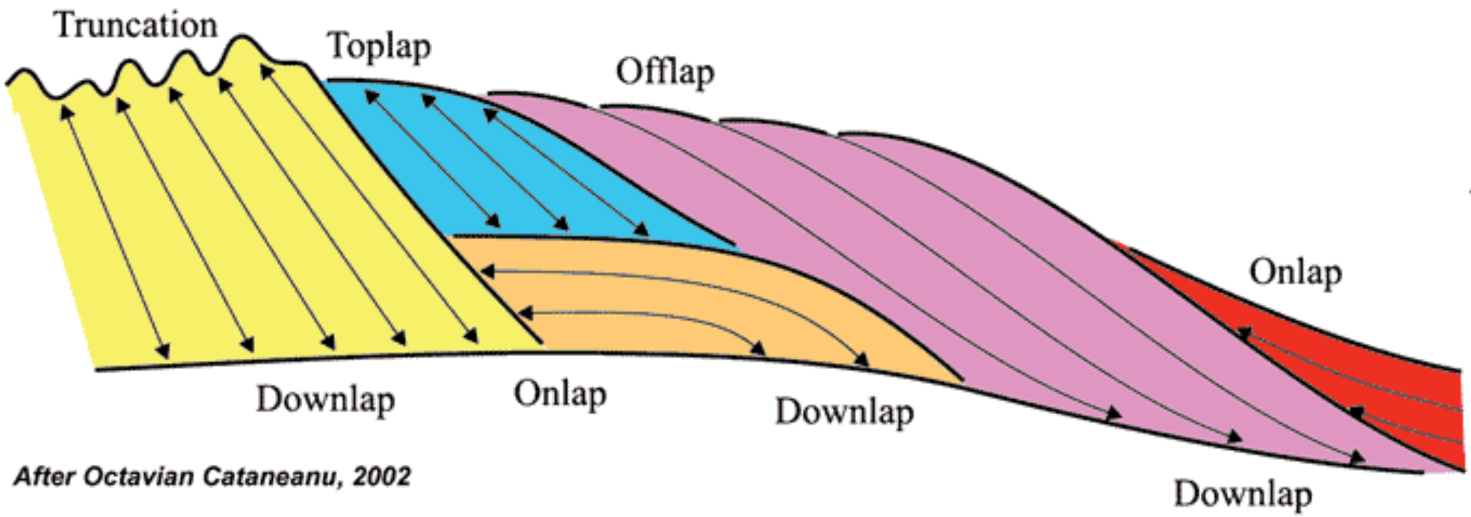


Clinoforms & Terminations

clinoforms –visible in large outcrops



Stratal / reflection terminations



Describe geometric relationships between a reflection/marker and the surface against which it terminates (originally developed in seismic stratigraphy)

Lapout - lateral termination of a reflection ("bedding plane") at its depositional limit, based on geometry alone: ***toplap, downlap, onlap, offlap*** (original surface)

Truncation, implies surface originally extended further, but was cut: ***erosional truncation, fault (tectonic) truncation***

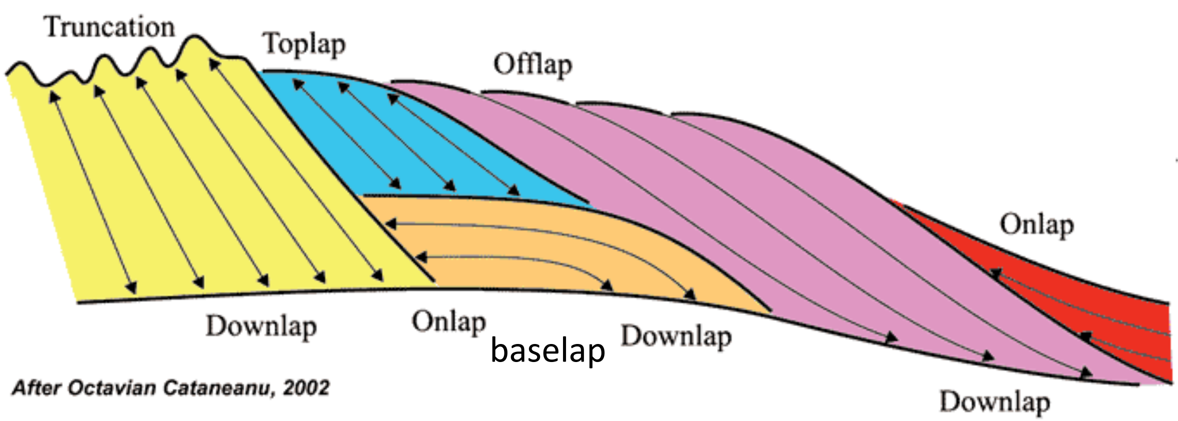
Different types of stratal terminations could be used to define depositional history

Clinoforms & Terminations

Toplap: termination of inclined reflections against an overlying, lower angle surface, assumes termination is original depositional limit

Erosional truncation: termination of reflections against an overlying erosion surface – may be marine (e.g. submarine channel) or non-marine (fluvial channel)

Distinction between toplap and erosional truncation sometimes involves interpretation



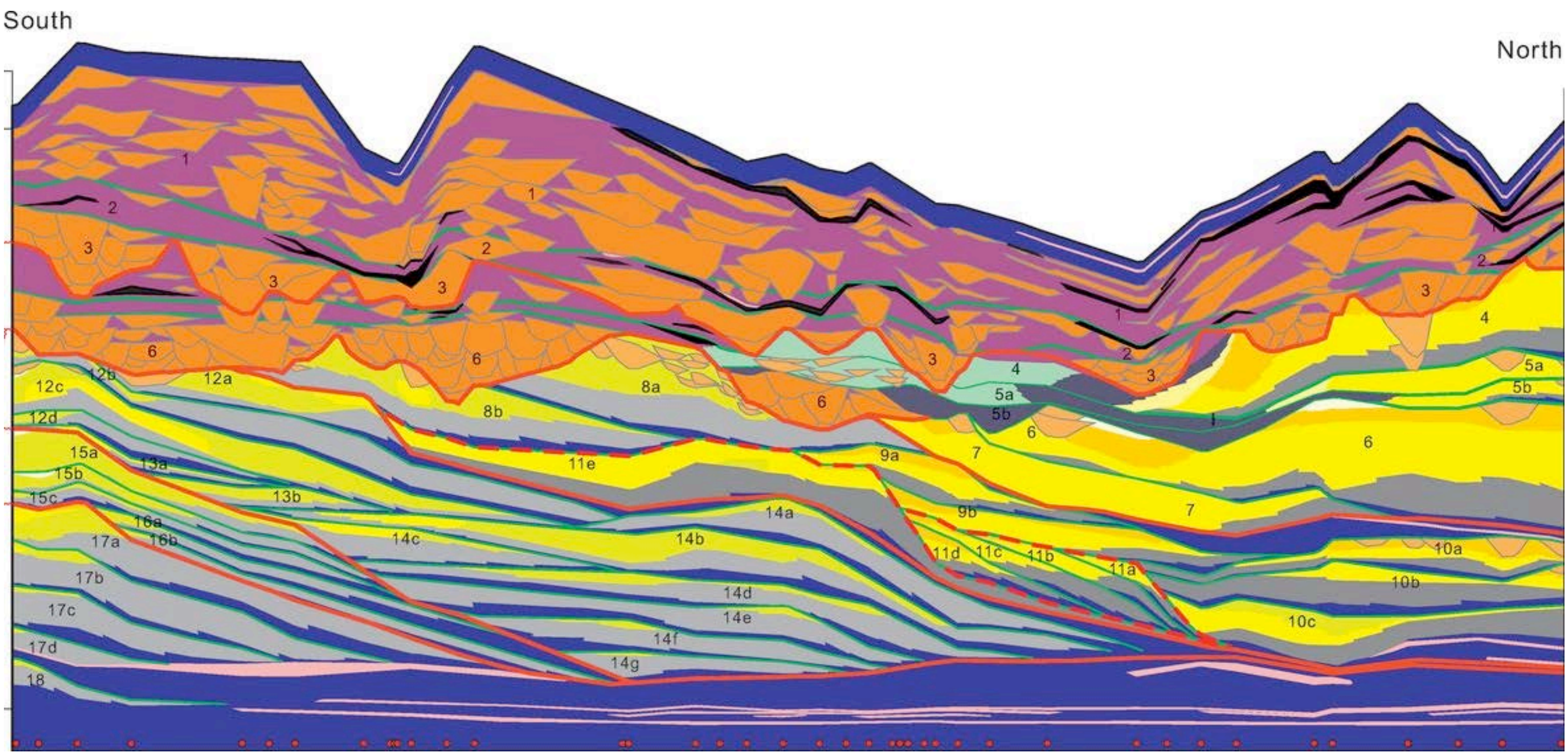
After Octavian Cataneanu, 2002

Baselap: lapout of reflections against an underlying seismic horizon - downlap and onlap

Downlap: dip of the underlying horizon is less than that of the terminating reflections (almost always indicates a marine setting)

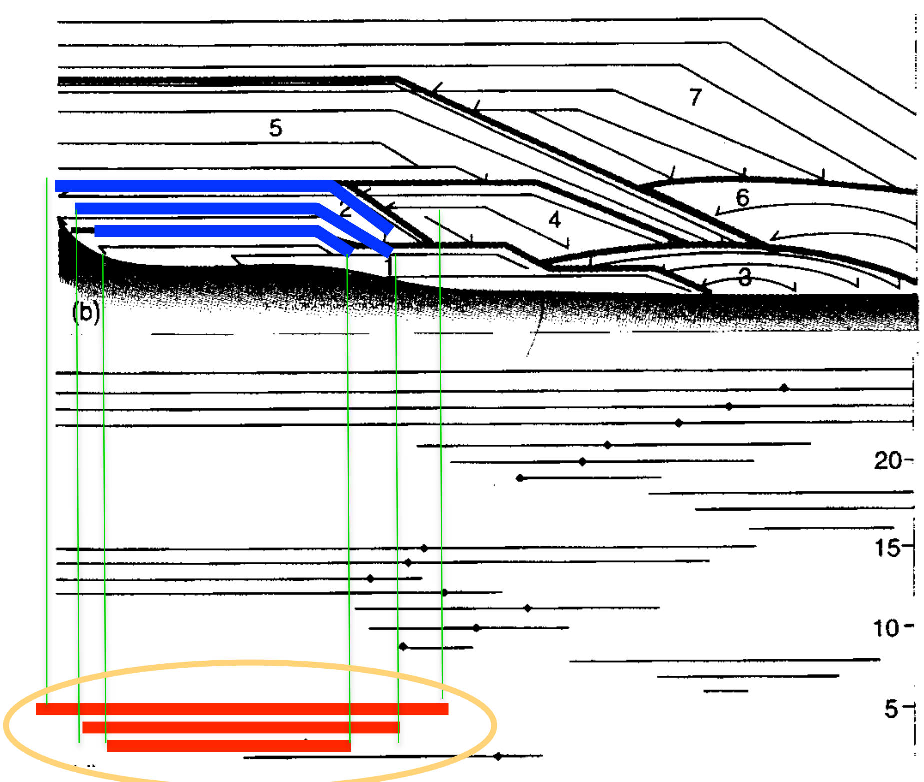
Onlap: dip of the underlying horizon is greater than that of the terminating reflections (maybe marine or non-marine)

Chronostratigraphic interpretation



How can we identify depositional history and internal organisation of deposition in highly complex sedimentary systems?

Chronostratigraphic interpretation – Wheeler diagram



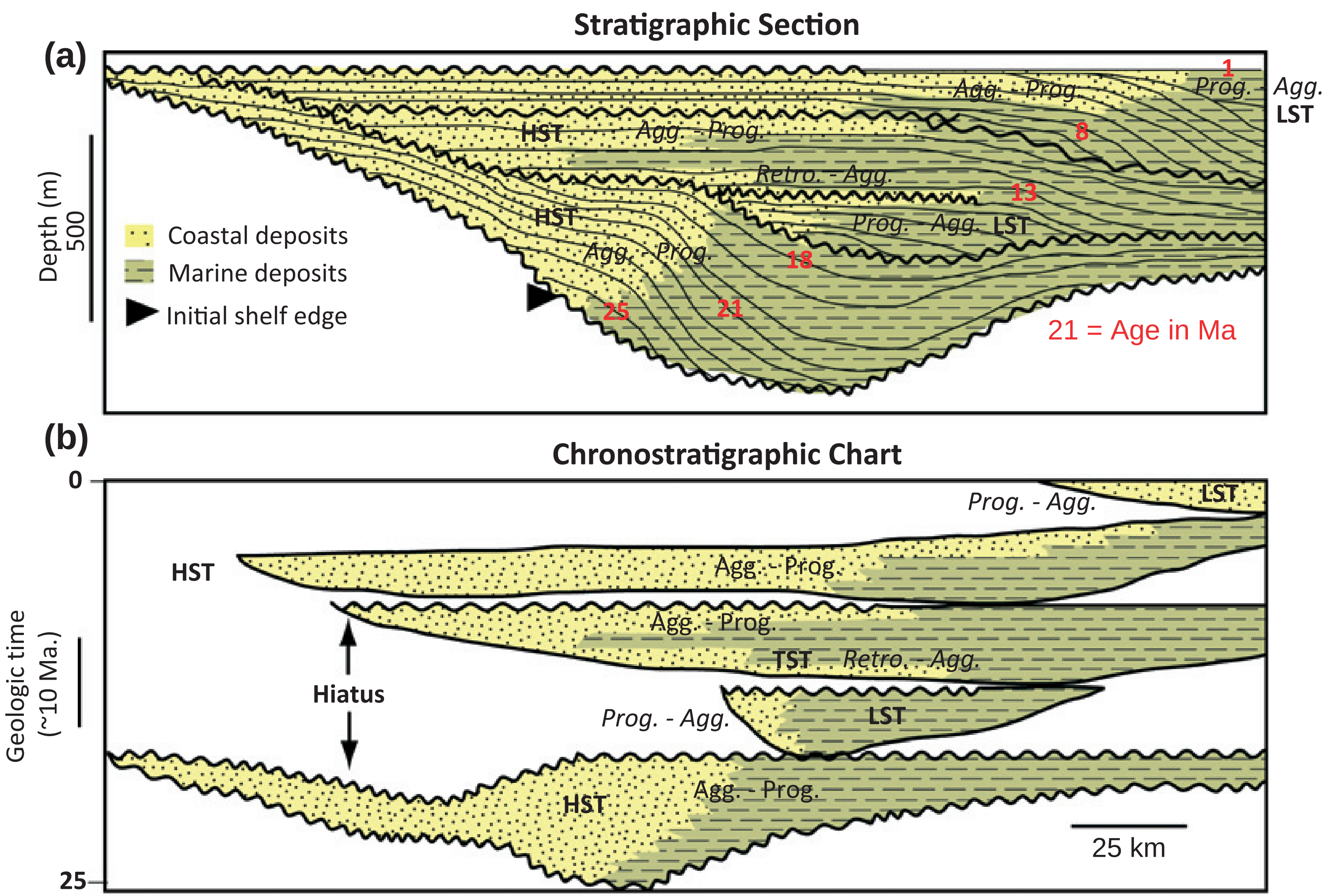
Measure the lateral extent of all terminations and transform it into your grid below

Start with the lowermost (oldest) termination and mark it in the lowermost time line of your chronostratigraphic chart.

Identification of deposutional packages and the time relation-ships between different depositional packages

Chronostratigraphic interpretation – Wheeler diagram

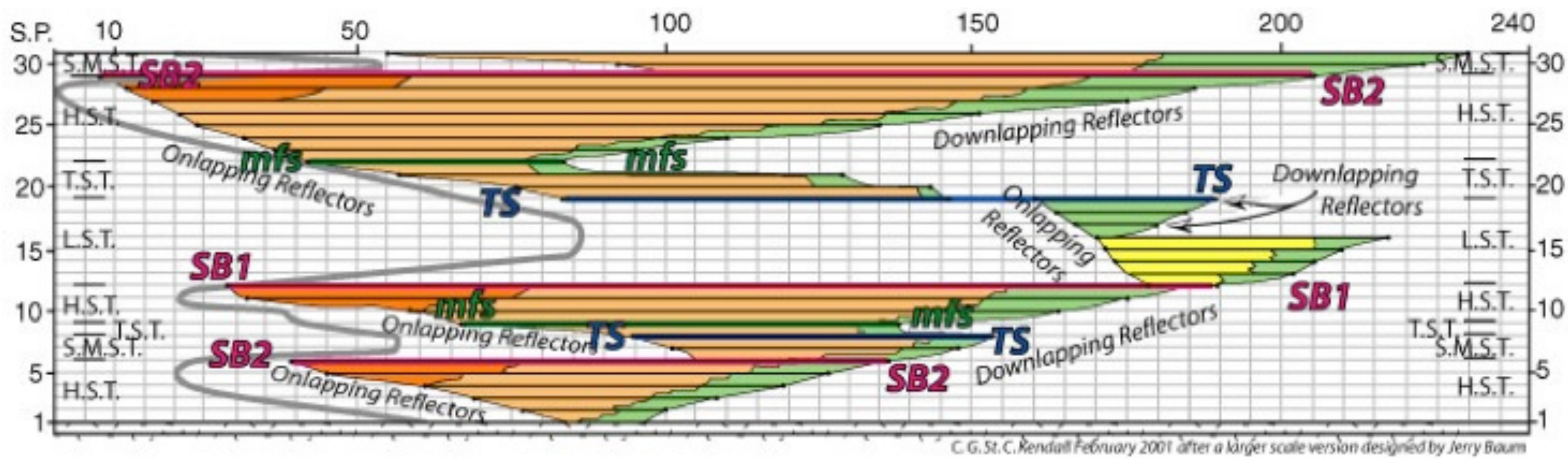
Wheeler diagram – chronostratigraphic interpretation of complex sedimentary systems



Chronostratigraphic interpretation – Wheeler diagram

Wheeler diagram

- chronostratigraphic chart to analysing the timing and geometric organization of the sedimentary fill of a basin
- identification of genetic packages of sedimentary cycles bounded by unconformities
- genetic packages = system tracts (basic units in sequence stratigraphy)



Chronostratigraphic interpretation – Wheeler diagram

Wheeler diagram

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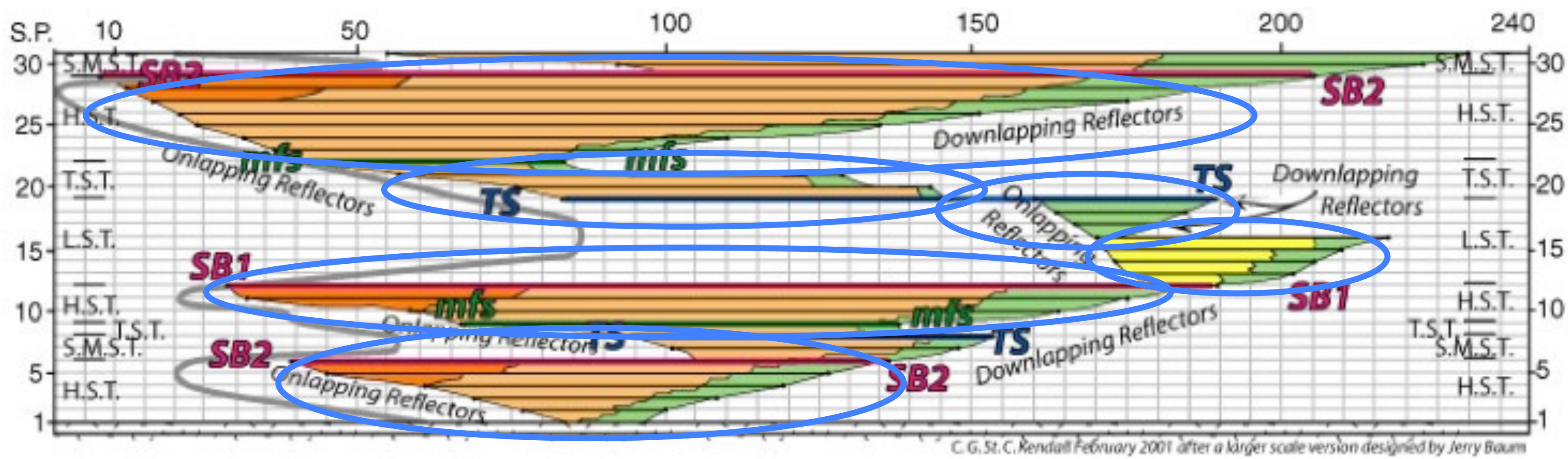
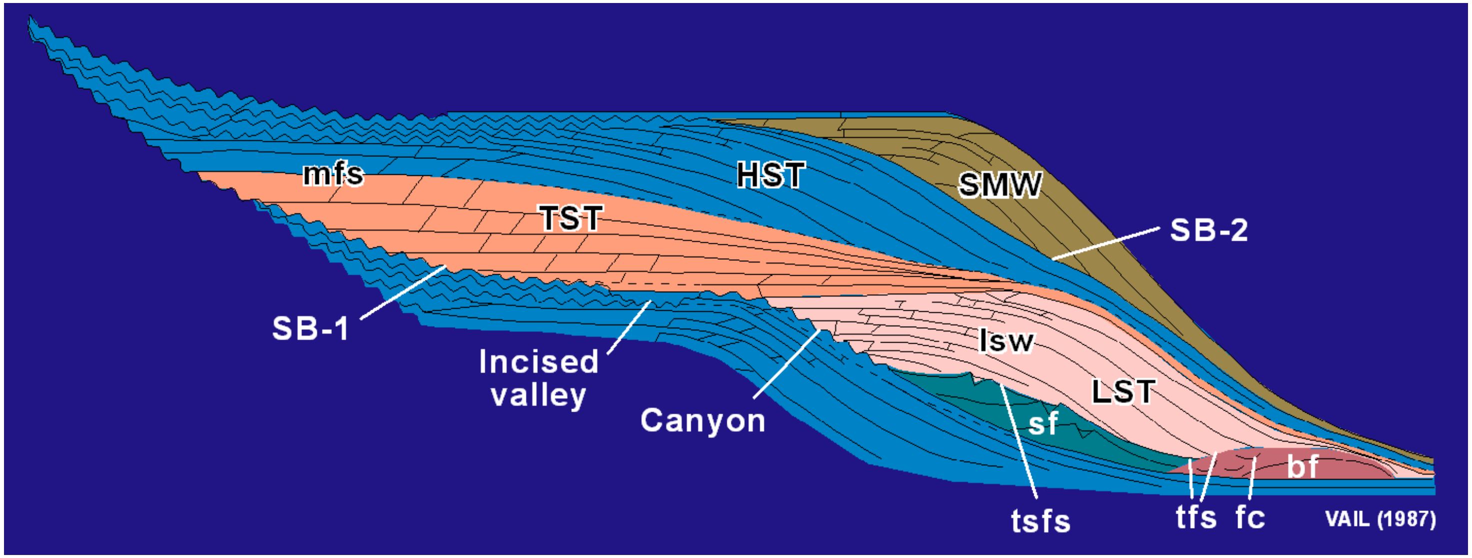


Sequence stratigraphy - Introduction

Sequence stratigraphy is "*the subdivision of sedimentary basin fills into genetic packages (= sequences) bounded by unconformities and their correlative conformities*"

Emery & Myers, 1996

Genetic package – sediments that are continuously (conformably) deposited



Sequence stratigraphy - Introduction

sequence:

"A chronologic succession of sedimentary rocks from older below to younger above, essentially without interruption, bounded by unconformities."

unconformity:

"A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession. It commonly implies ... erosion with loss of the previously formed record."

Glossary of Geology (Bates & Jackson 1987)

Sequence stratigraphy - Introduction

„A relatively conformable succession of genetically related strata bound at its top and base by unconformities and their correlative conformities *(Vail, et al., 1977)*. It is composed of a succession of genetically linked deposition systems (systems tracts) and is interpreted to be deposited between eustatic-fall inflection points.“

(Posamentier et al. 1988)

Benefits of sequence stratigraphy

- Understanding and prediction of discontinuities in the sedimentary succession
- Subdivision of the succession in chronological (time dependent) units, useful for stratigraphic correlation and facies prediction
- Understanding of the sedimentary succession in time and space
- Understanding of past sea-level changes (amplitude and rate)
- Identification and classification of complex hierarchies of sedimentary cycles (from 10 ka to >50 Ma)

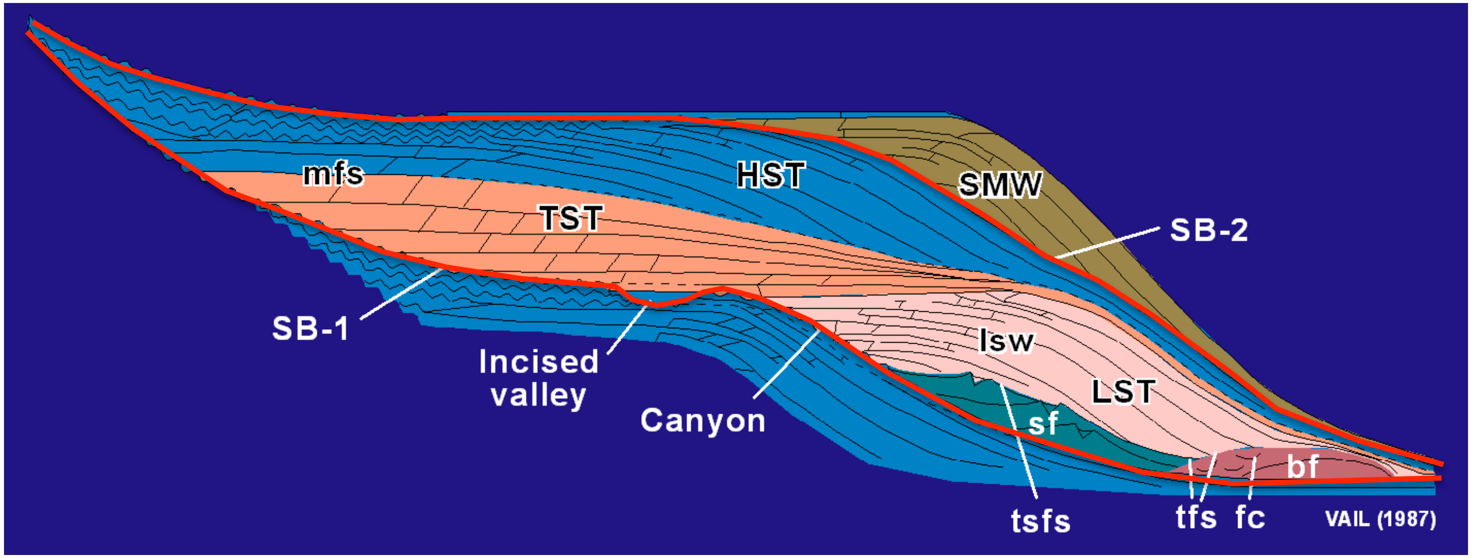
lunch break

Sequence stratigraphy – System tracts

Sequence is made of individual subunits representing different episodes of the sedimtary cyle of the sequence = **System Tracts**

System Tracts

- genetically associated stratigraphic units that were deposited during specific phases of the relative sea-level cycle (Posamentier, et al, 1988)
- defined on the basis of bounding surfaces, position within a sequence, and parasequence stacking pattern (Van Wagoner et al., 1988).



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Sequence stratigraphy – System tracts

Two main Concepts

3 System Tracts (Exxon Model)

lowstand systems tract – LST

transgressive systems tract – TST

highstand systems tract – HST

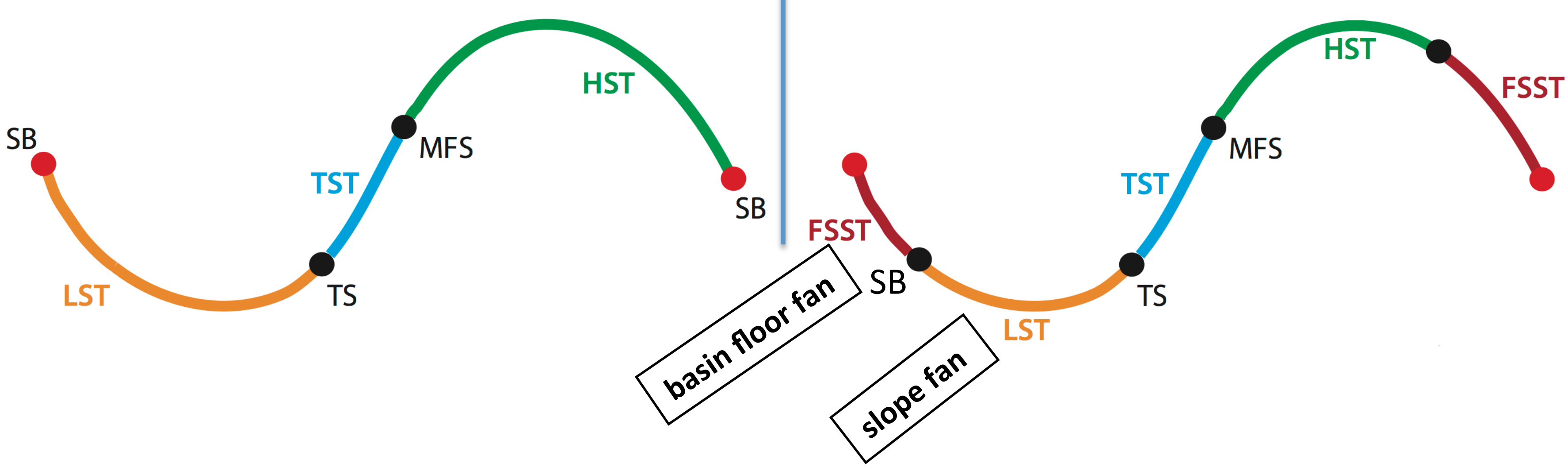
4 System tracts

Highstand Systems Tract – HST

Falling Stage Systems Tract -FSST

Lowstand Systems Tract – LST

Transgressive Systems Tract – TST



Position of surfaces and boundaries varies according to different concepts

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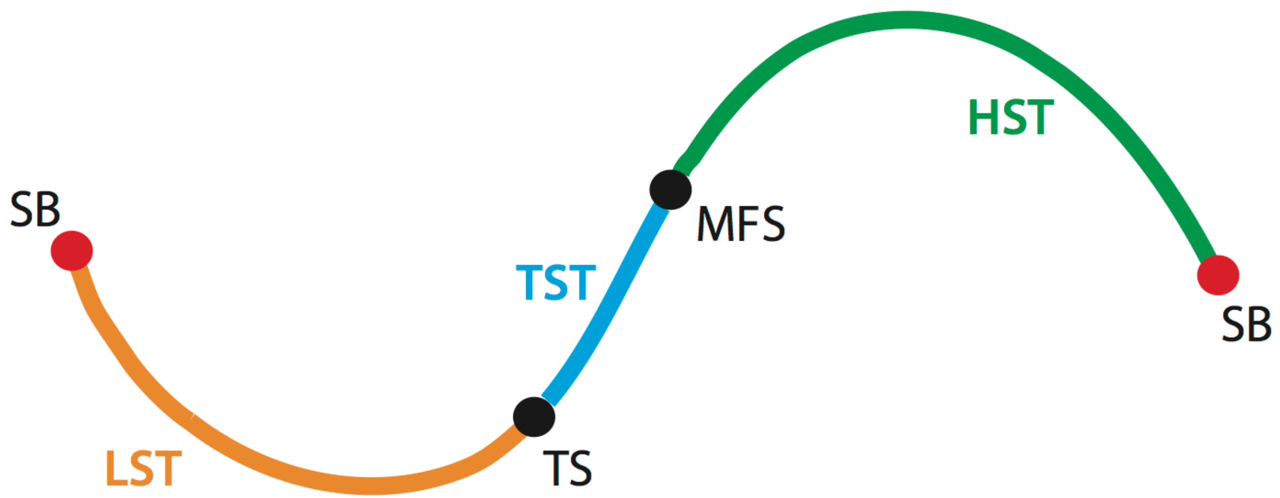
3 System tracts (EXXON) Model

3 System tracts

classical Model in sequence stratigraphy (Exxon Model)



3 System Tracts: LST – TST – HST

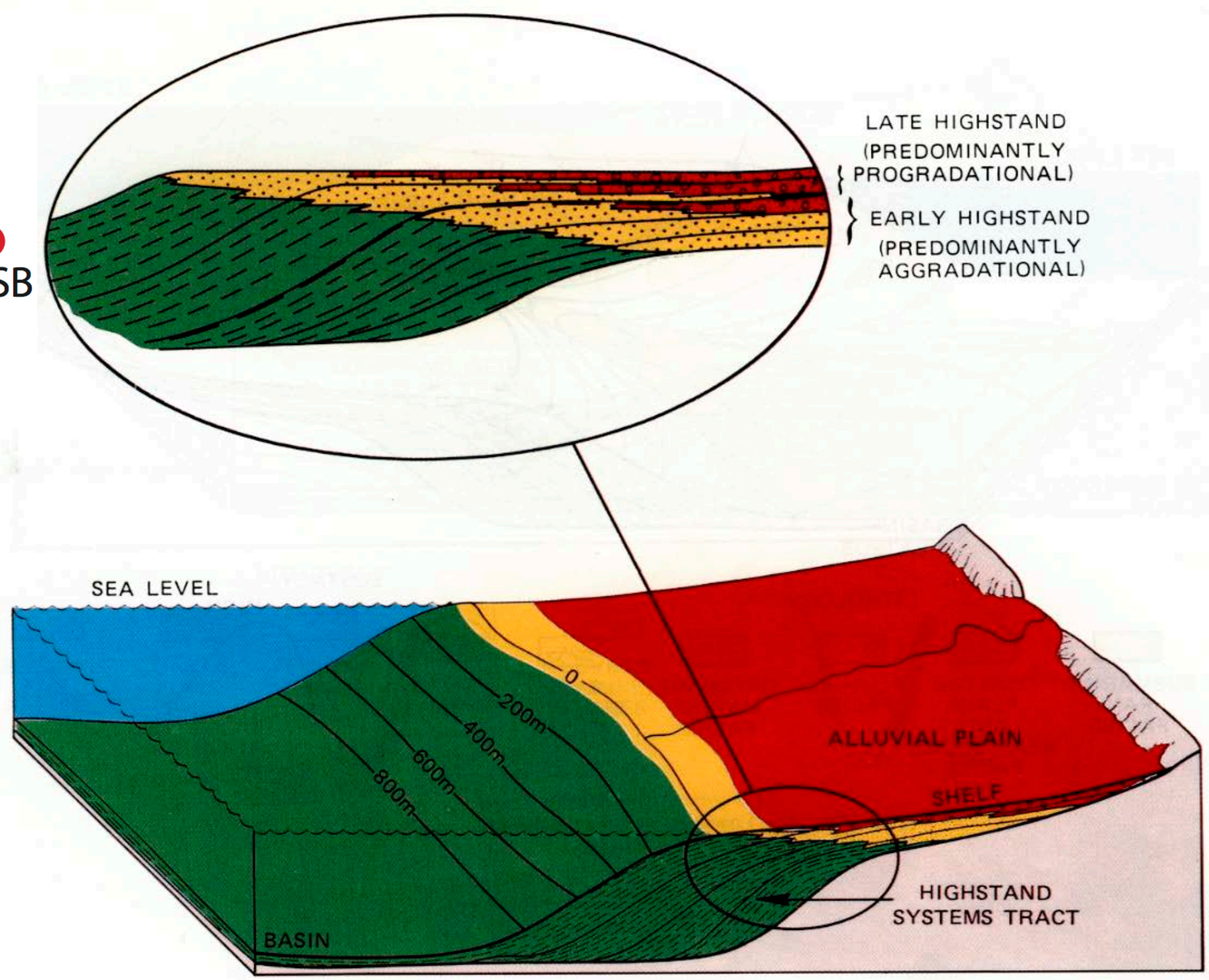
3 surfaces: SB – TS – MFS

Sequence Boundary between HST & LST

Two types of sequence boundaries: SB type 1, SB type 2

3 System tracts – Exxon Model

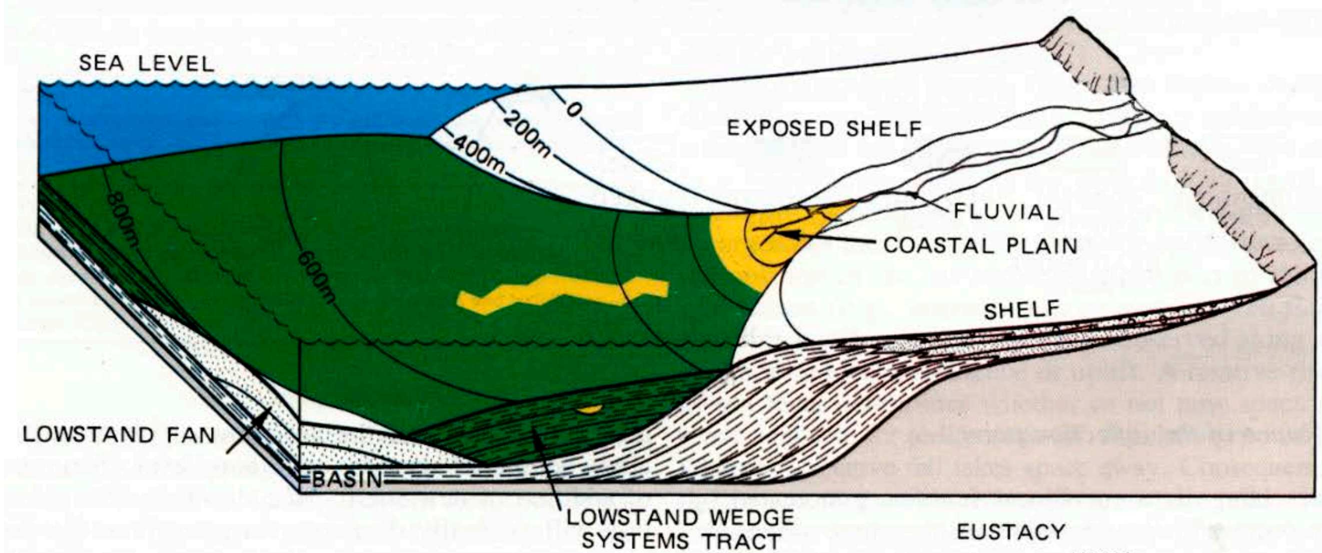
Highstand **S**ystem **T**ract - HST

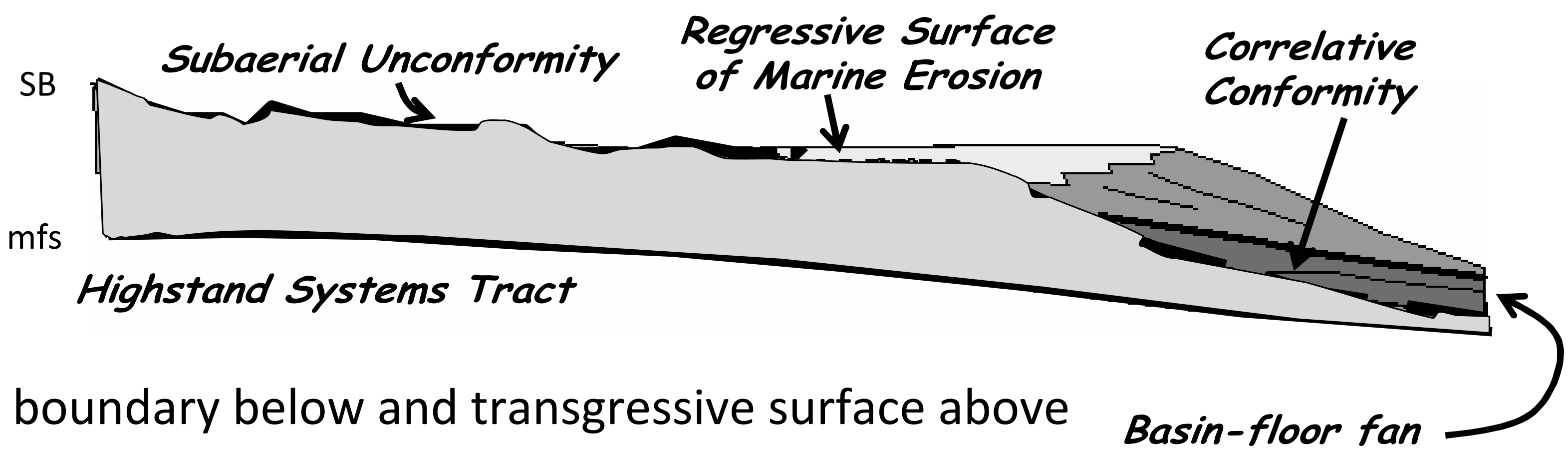


- maximum flooding surface at the base and sequence boundary at the top
- generally shingled or off-lapping (clinoformal) geometries
- Progradation on shelf
- Sets of high-frequency cycles show upward thinning and upward shallowing trends

3 System tracts – Exxon Model

Lowstand System Tract - LST

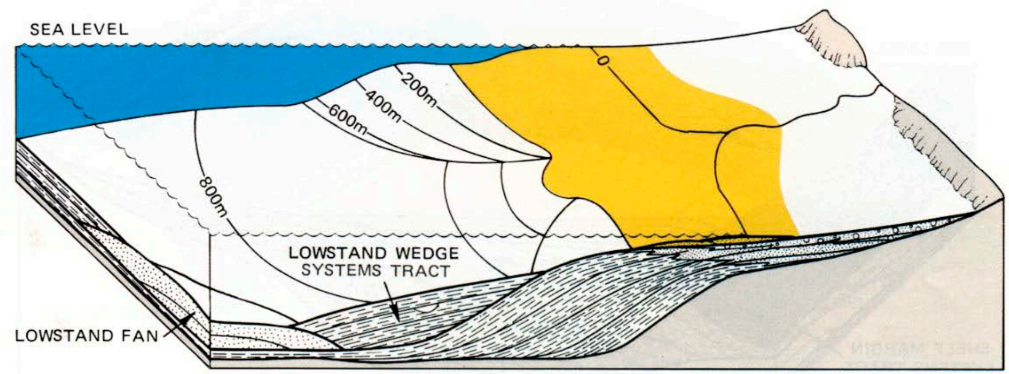


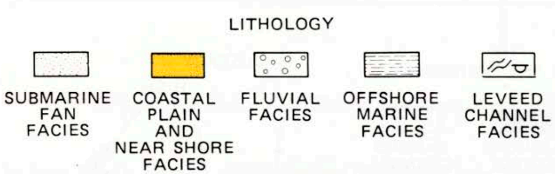


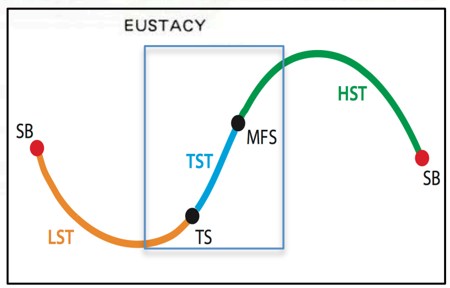
- Sequence boundary below and transgressive surface above
- deposition in prograding wedges, submarine fans
- erosion on shelf, incised valleys, sediment bypass across shelf

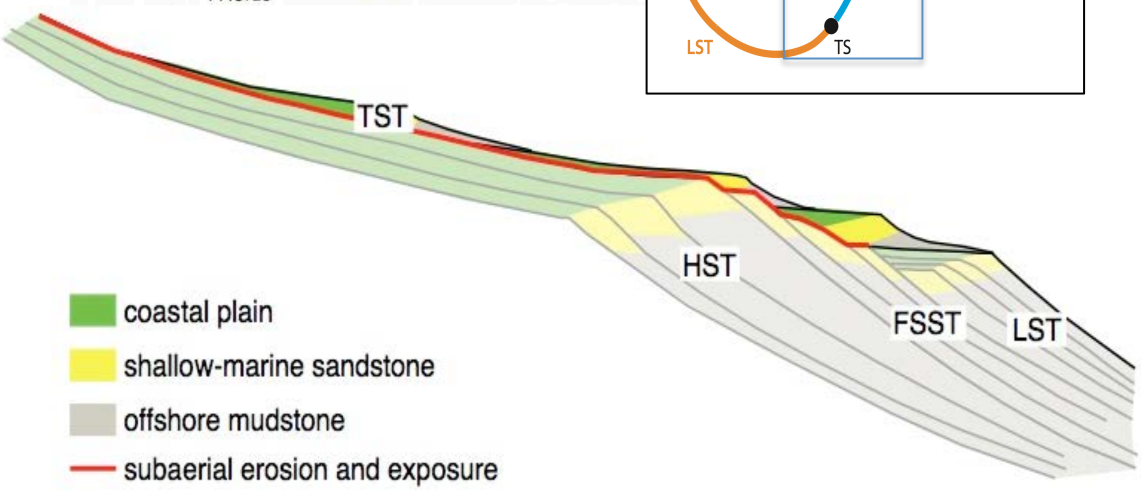
3 System tracts – Exxon Model

Transgressive System Tract - TST



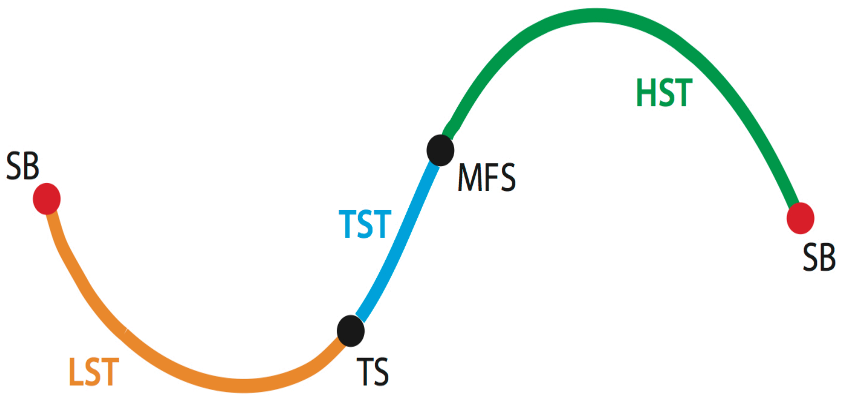






- Transgressive surface (TS) below, maximum flooding surface (MFS) above
- retrogradational stacking pattern
- flooding of erosive structures on the shelf (incised valleys)
- estuaries well developed, trapping sediment from the shelf
- coastal plain aggradation
- marine shales across the shelf, low thickness (partially non-deposition)

3 System tracts – Exxon Model



Sequence boundary

- laterally most extensive unconformity and its correlative conformity
- truncation + toplap below, onlap + downlap above
- abrupt basinward shift of facies above

Transgressive surface (TS)

- Top of the LST
- first major flooding surface across the shelf
- progradational/aggradational stacking pattern below and retrogradational stacking pattern above

Maximum flooding surface (MFS)

- Top of the TST
- shows the maximum landward extent of basinal facies (flooding)
- retrogradational stacking pattern below and progradational/aggradational stacking pattern above

3 System tracts – Exxon Model

Sequence type 1

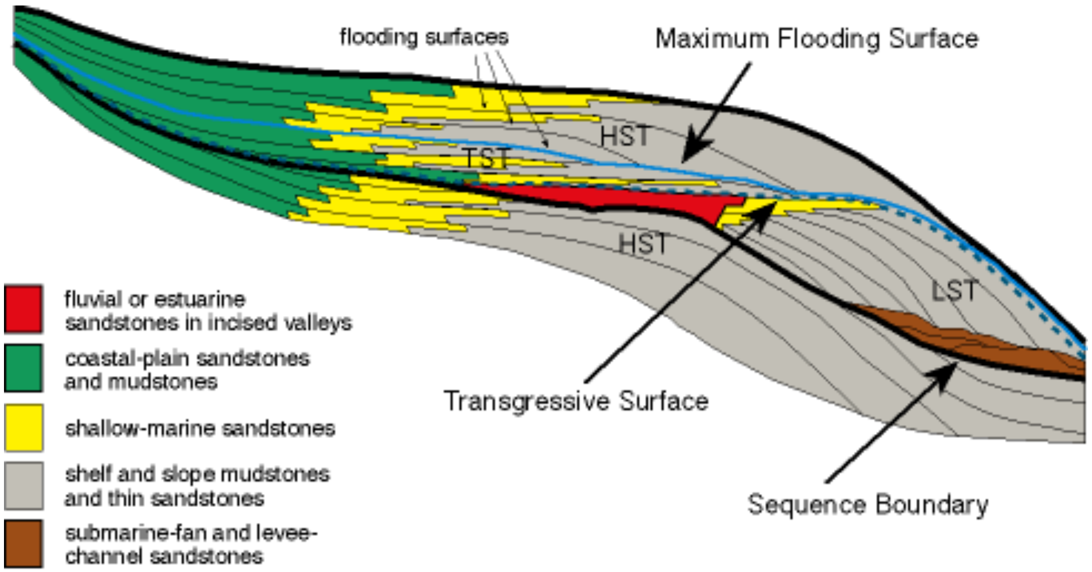


figure adapted from Van Wagoner et al. (1990)

- strong sea level fall - truncation by river systems (erosional surface, incised valleys)
- deposition of sediment towards the clinoforms and the shelf break.
- high sediment load causes instabilities in the slope and the formation of lowstand fans
- lowest relative sea level characterised coastal onlap below the clinoforms.

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3 System tracts – Exxon Model

Sequence type 2

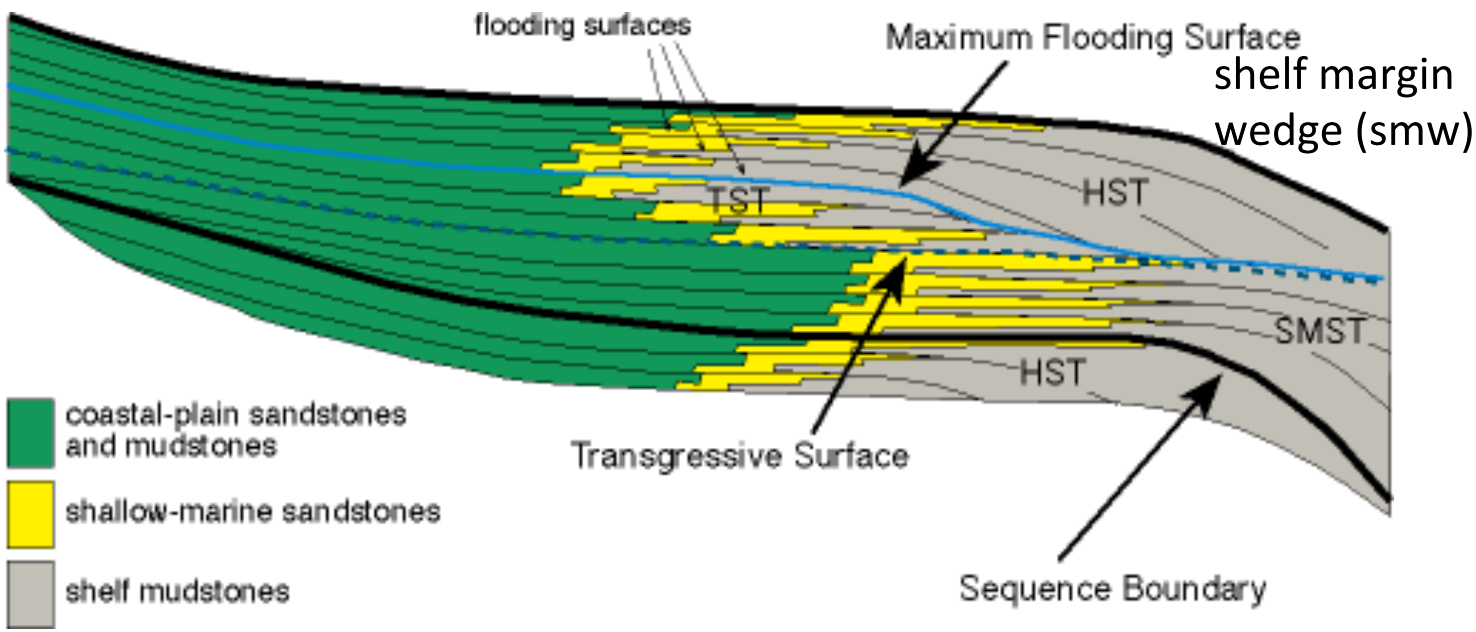
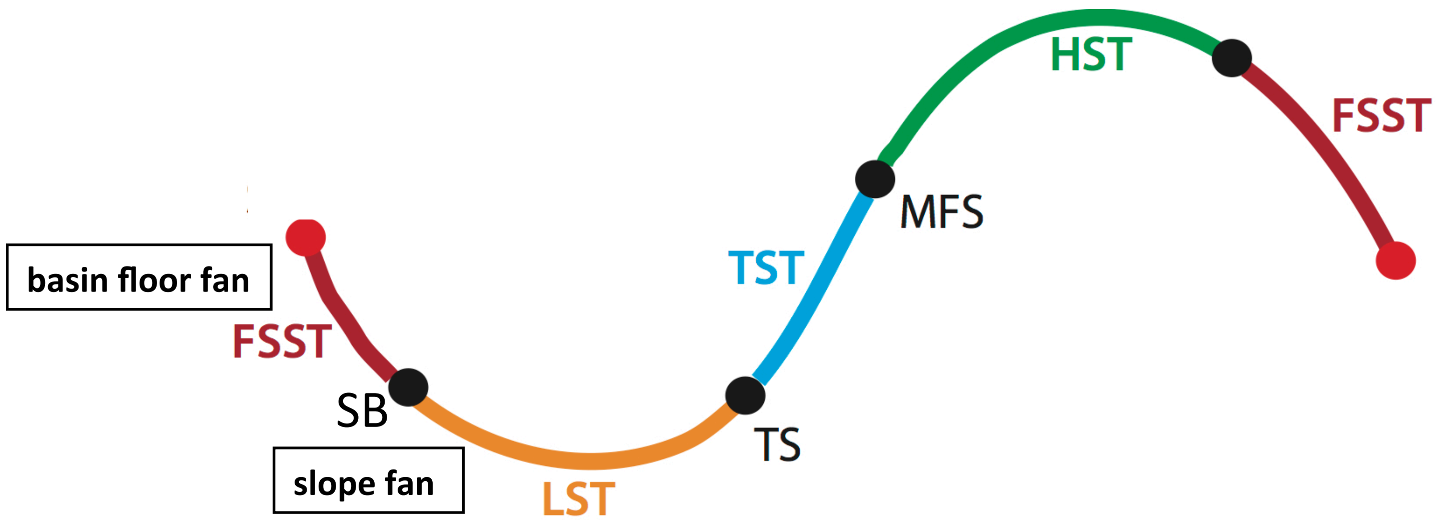


figure adapted from Van Wagoner et al. (1990)

- low sea level fall - no fluvial truncations (erosional surfaces, incised valleys) within the LST (= **no** submarine fans)
- sediments above type 2 SB are called *Shelf Margin Wedge* (SMW), the system tracts = *Shelf Margin Systems Tract* (SMST)
- Depending on the change in relative sea level, the ST is aggradational at its top and progradational at the foot

4 system tracts



4 System tracts Highstand Systems Tract - HST

Falling Stage Systems Tract -FSST

Lowstand Systems Tract - LST

Transgressive Systems Tract – TST

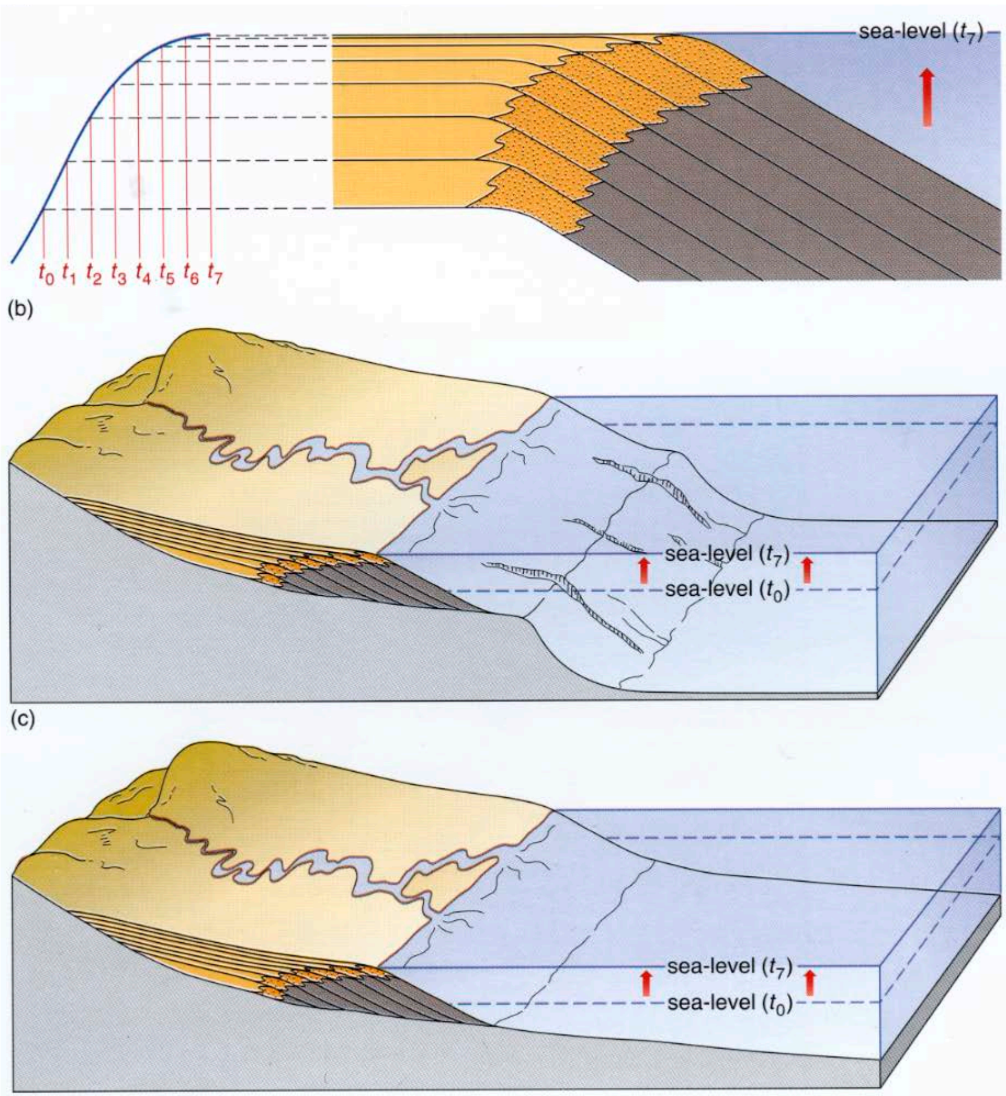
3 Surfaces Transgressive surface - ts

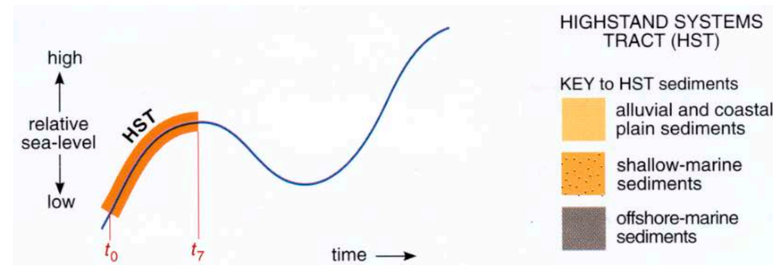
Maximum Flooding surface – mfs

Sequence Boundary – SB

4 system tracts

Highstand **S**ystem **T**ract - HST





Sediments between maximum rate of sea level rise and maximum relative sea level

Base: maximum flooding surface
Top: sequence boundary

Generally off-lapping (clinoformal) stratal geometry

Sets of high-frequency cycles show upward thinning and upward shallowing trends (parasequences)

4 system tracts

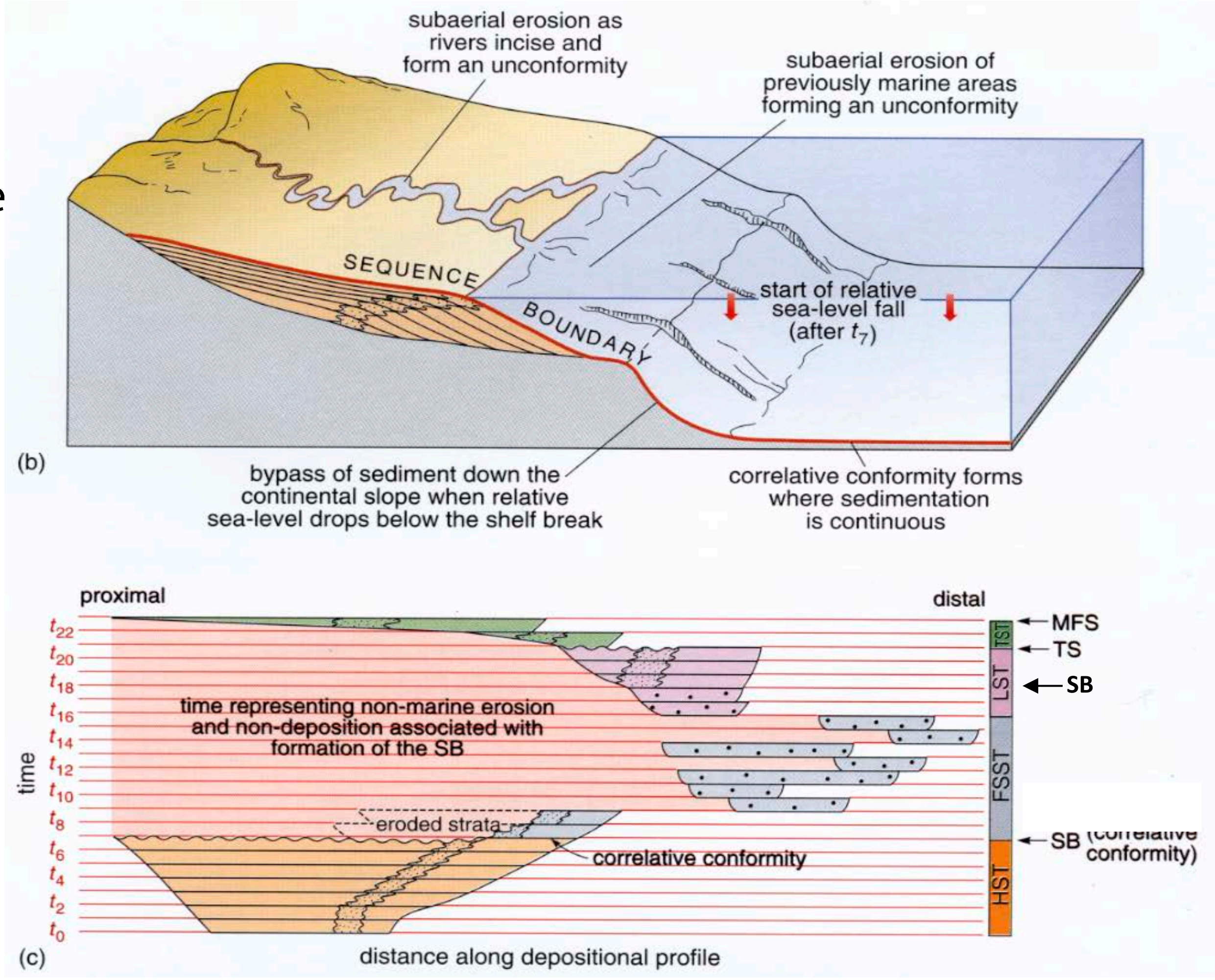
Sequence **B**oundary (SB)

Laterally most extensive unconformity and its correlative conformity

The unconformity or correlative conformity, that bounds a sequence

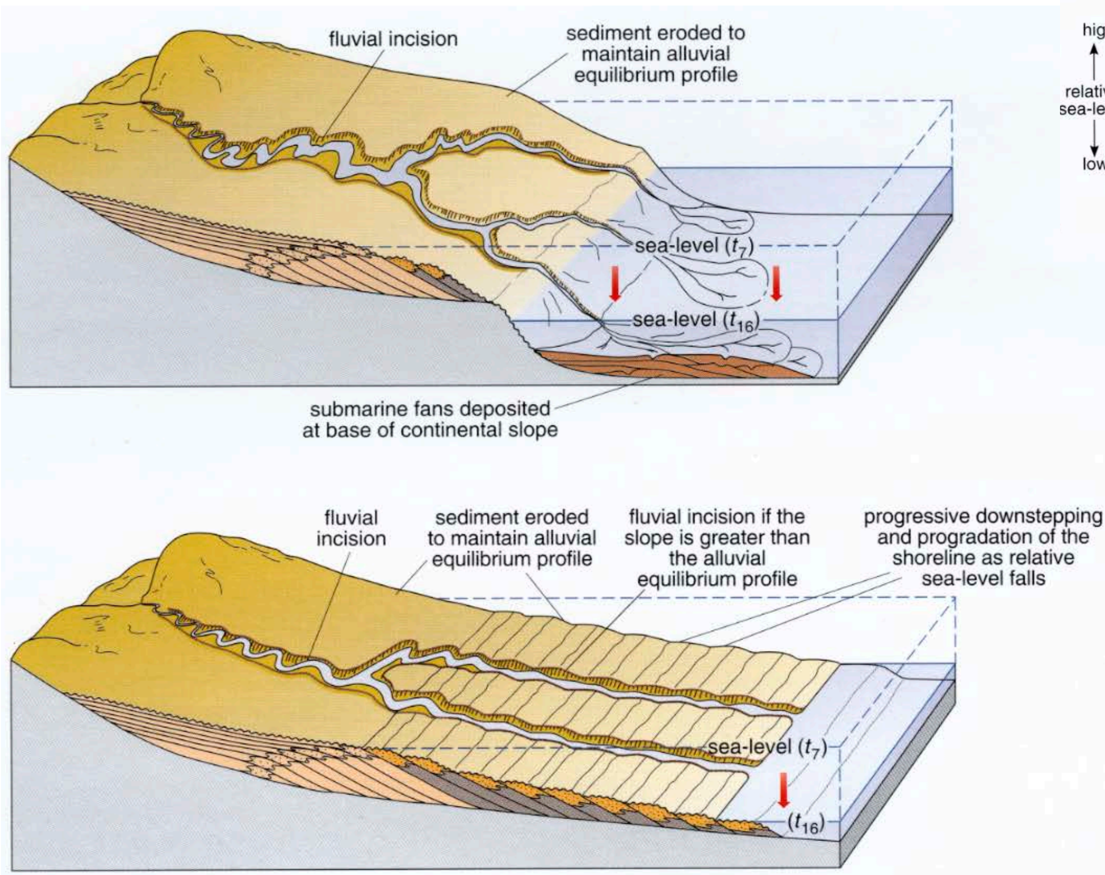
Commonly (but not always) represents a significant change in stratal arrangements

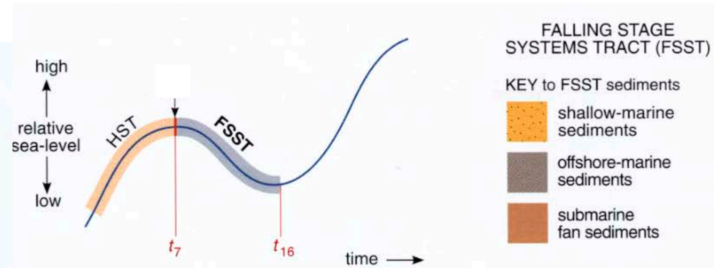
Mostly a major physical feature



4 system tracts

Falling **S**tage **S**ystems **T**ract - FSST





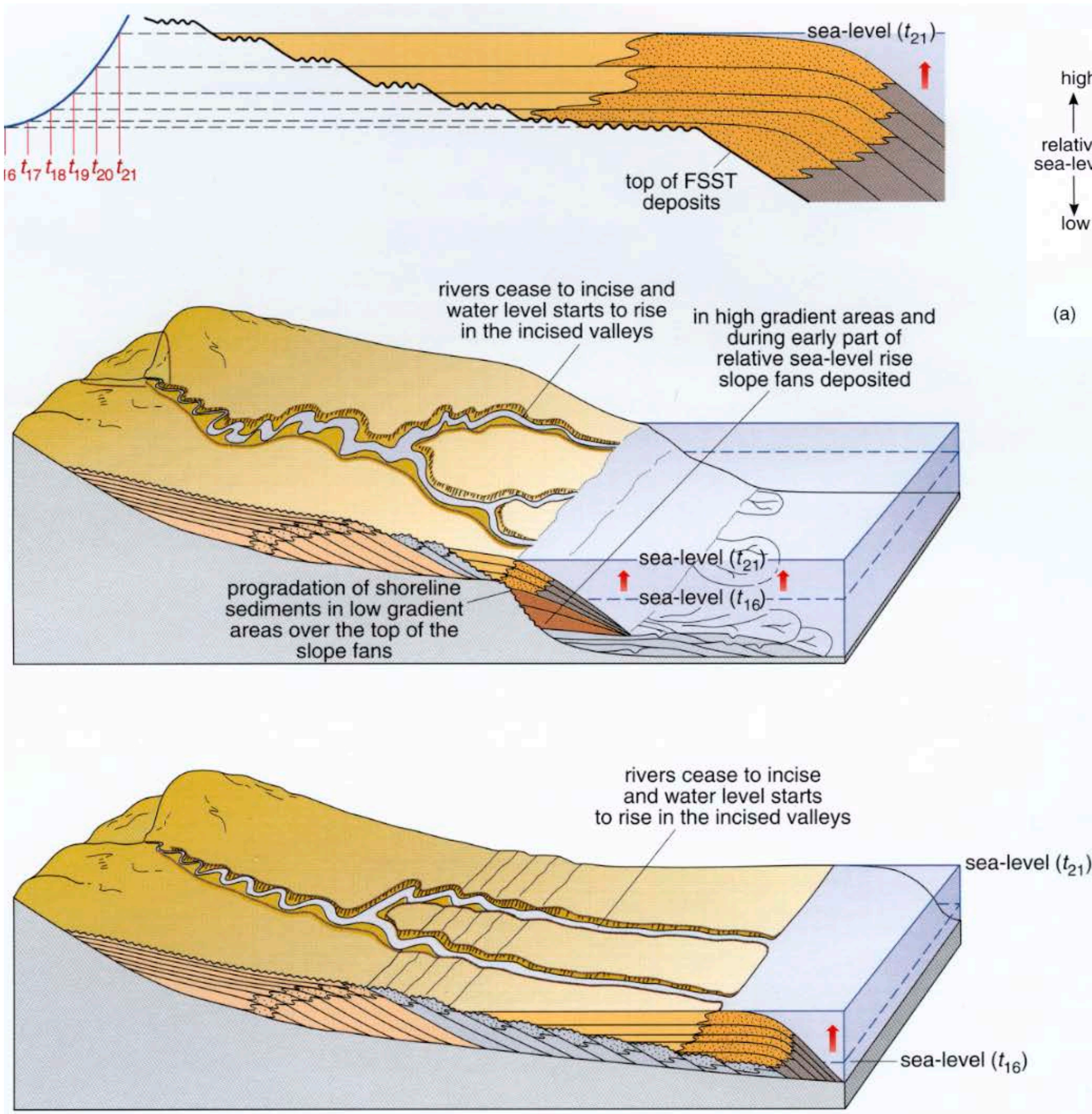
Combination of increasing sea-level fall and increase of erosion

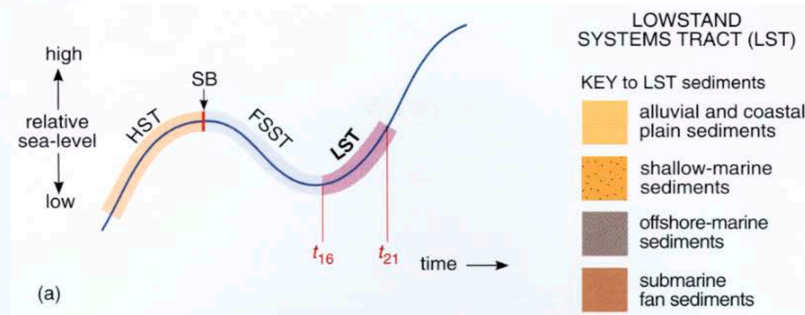
Facies shift towards distal (progradation).

Deposition in lower levels (height) due to sea level fall.

4 system tracts

Lowstand **S**ystems **T**ract (LST)





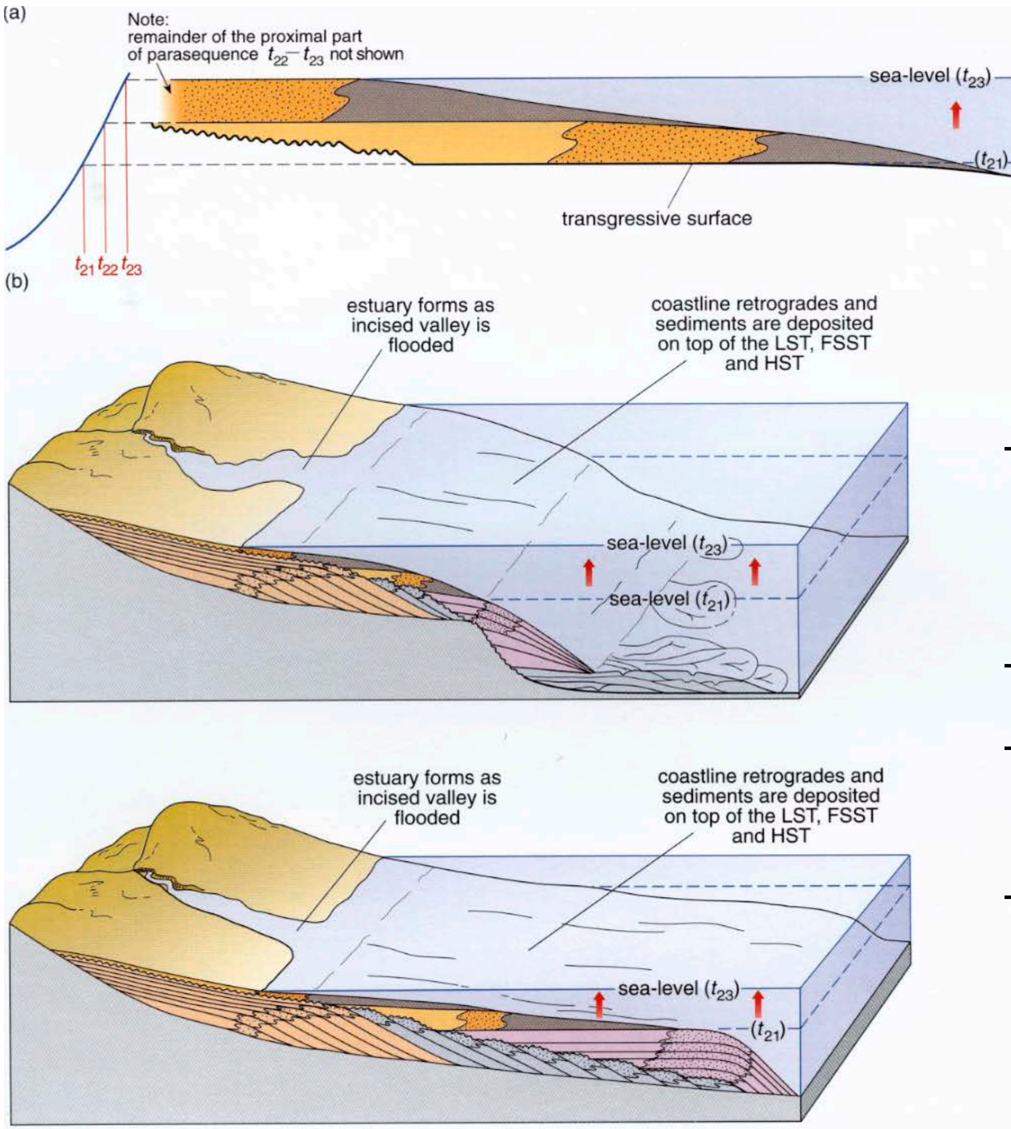
- Package between minimum relative sea level and increase in accommodation space
- Shoreline starts building upwards from its lowest position
- Progradational to aggradational sediments

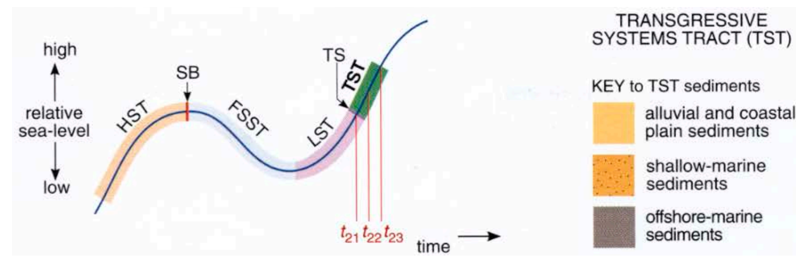
Transgressive **S**urface - TS

- First landward shift of sedimentation, sea level rises significantly and exceeds sedimentation
- The base of the first retrogradational parasequence is defined as the transgressive surface

4 system tracts

Transgressive **S**ystems **T**ract - TST

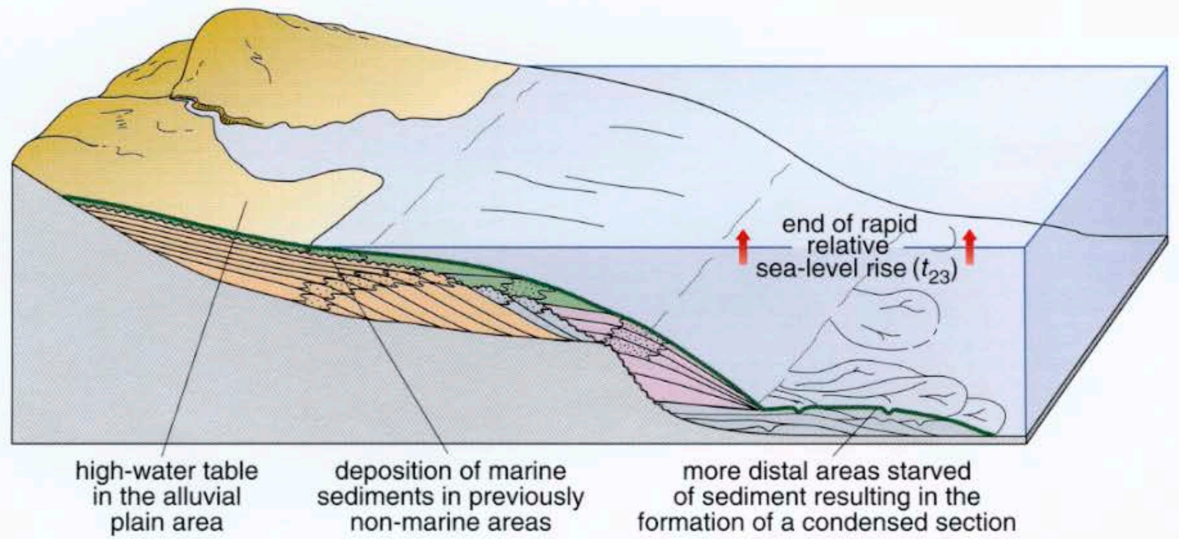


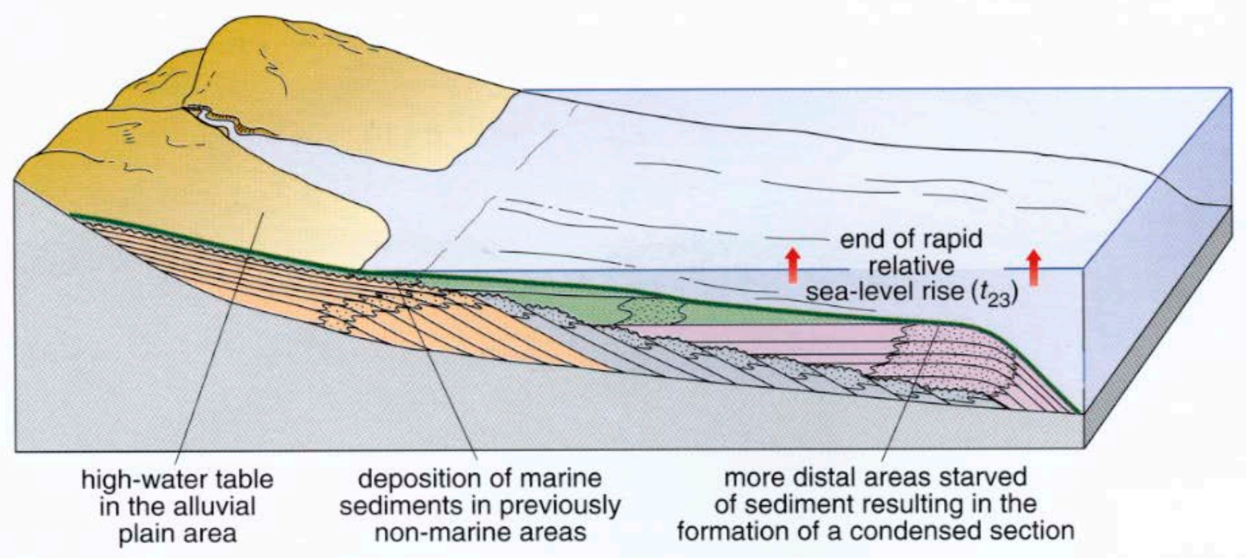


- first landward shift of deposition at the base and maximum flooding surface at the top
- retrogradational stacking pattern
- sediment deposition tends to be proximal (estuaries, sediment traps)
- sets of high-frequency cycles show upward thickening and upward deepening trends

4 system tracts

Maximum Flooding Surface - MFS



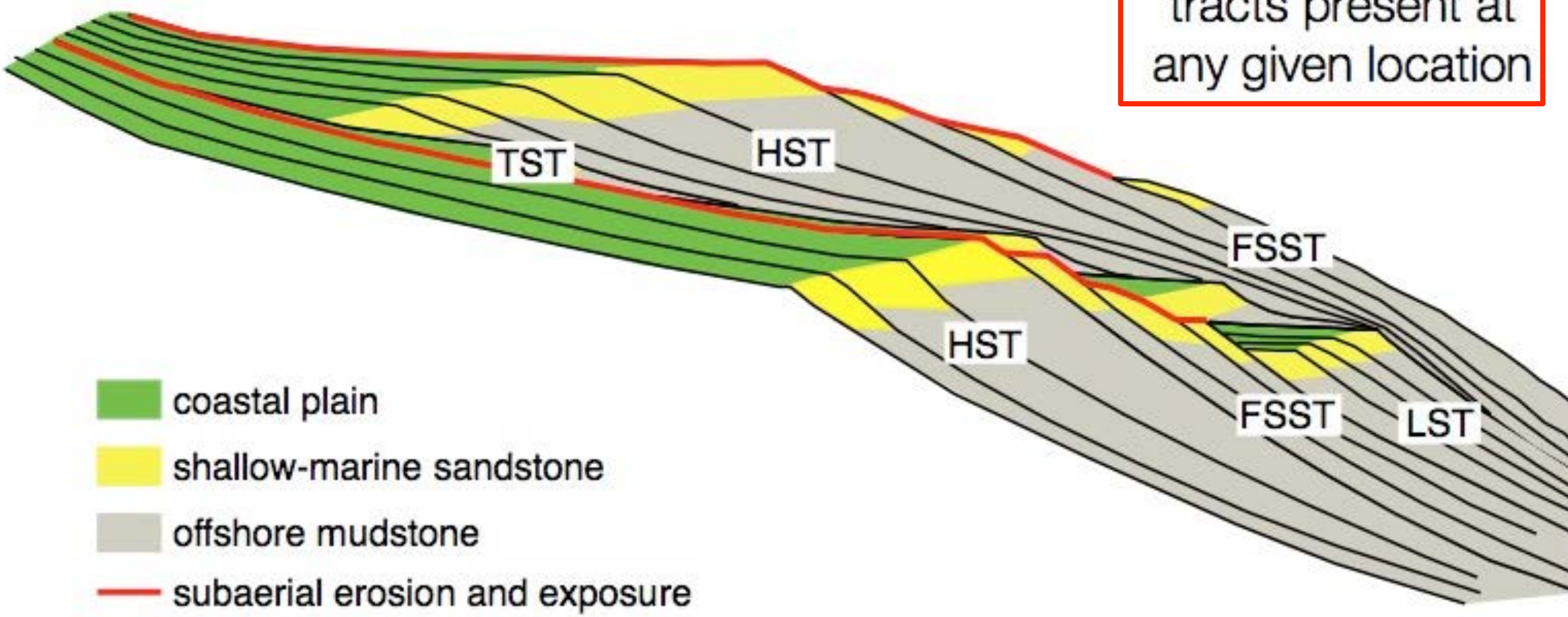


- Surface marks turn-around from landward-stepping to seaward stepping strata
- Further out on platform coincides with the downlap surface (depending on the level of condensation of clinoform toes)
- Recognition of the MFS is important for separating TST and HST

4 system tracts

Complete depositional sequence

Not all systems tracts present at any given location

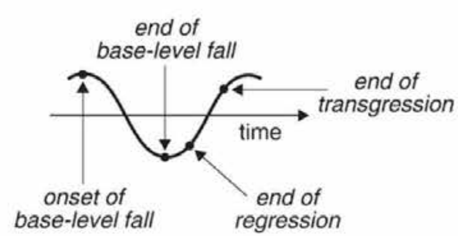


Sequence stratigraphic concepts

Nomenclature of systems tracts and timing of sequence boundaries for the existing sequence stratigraphic models

Events \ Sequence model	3 ST	3 ST modified	4 ST	Genetic Sequence	T-R Sequence
	HST	early HST	HST	HST	RST
end of transgression				MFS	
	TST	TST	TST	TST	TST
end of regression					MRS
	late LST (wedge)	LST	LST	late LST (wedge)	
end of base-level fall			CC**		
	early LST (fan)	late HST	FSST	early LST (fan)	RST
onset of base-level fall	CC*				
	HST	early HST	HST	HST	

sequence boundary
systems tract boundary
within systems tract surface



Catuneanu et al, (2009)

Abbreviations: LST — lowstand systems tract; TST — transgressive systems tract; HST — highstand systems tract; FSST — falling-stage systems tract; RST — regressive systems tract; T–R — transgressive–regressive; CC*—correlative conformity sensu Posamentier and Allen (1999); CC** — correlative conformity sensu Hunt and Tucker (1992); MFS — maximum flooding surface; MRS — maximum regressive surface.