



# Università degli studi di Trieste

**LAUREA MAGISTRALE IN GEOSCIENZE**  
**Classe Scienze e Tecnologie Geologiche**

**Curriculum: Esplorazione Geologica**

**Anno accademico 2024 - 2025**

**Analisi di Bacino e**  
**Stratigrafia Sequenziale (426SM)**

**Docente: Michele Rebesco**

# **Modulo 4.3**

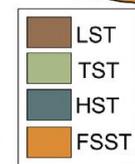
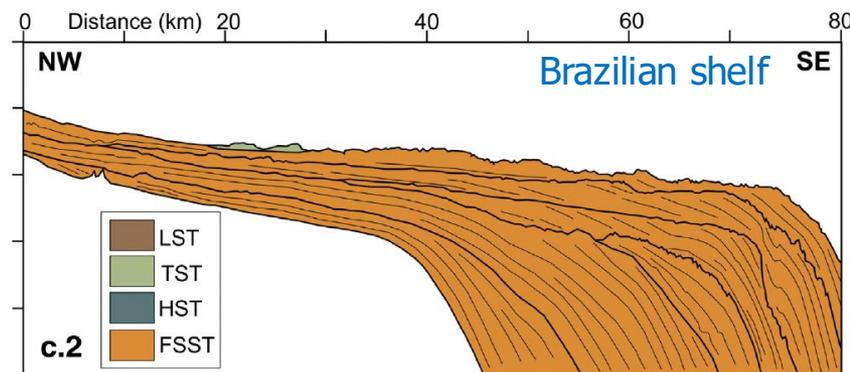
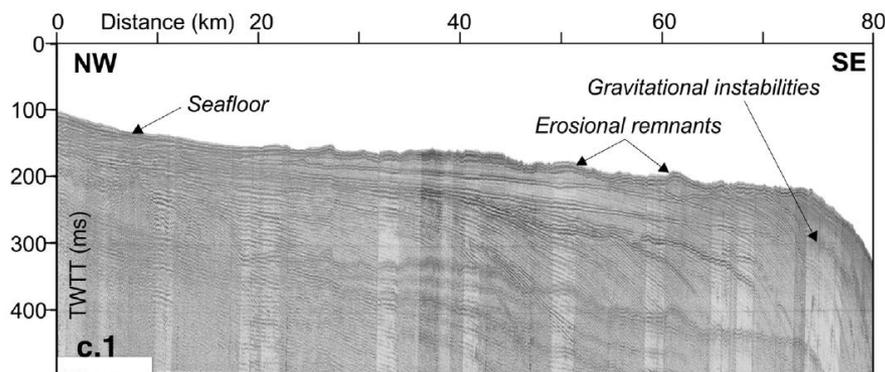
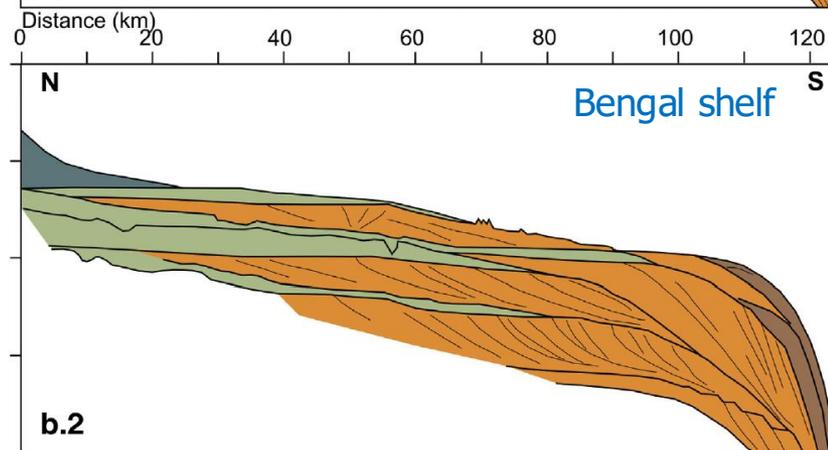
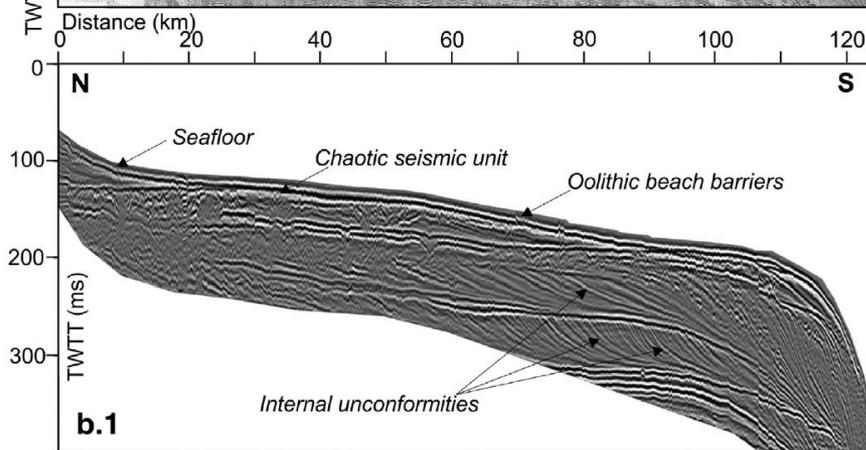
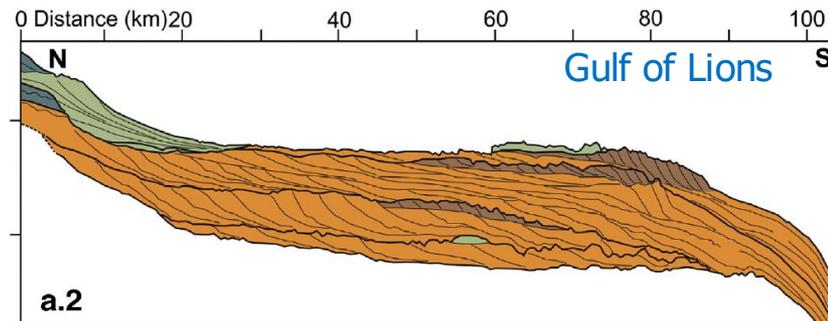
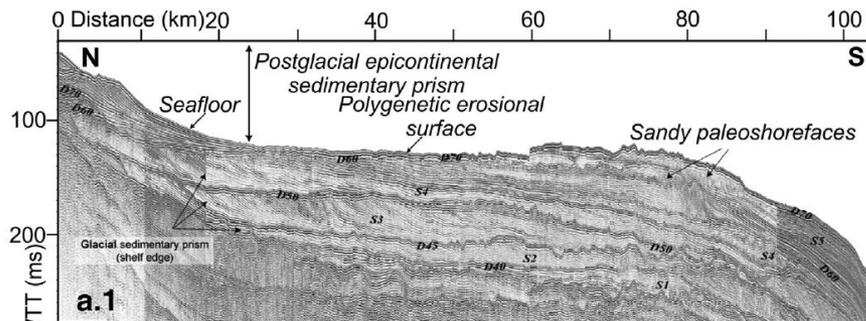
## **Sequence stratigraphy: applications (e.g. hydrocarbon reservoirs)**

### Outline:

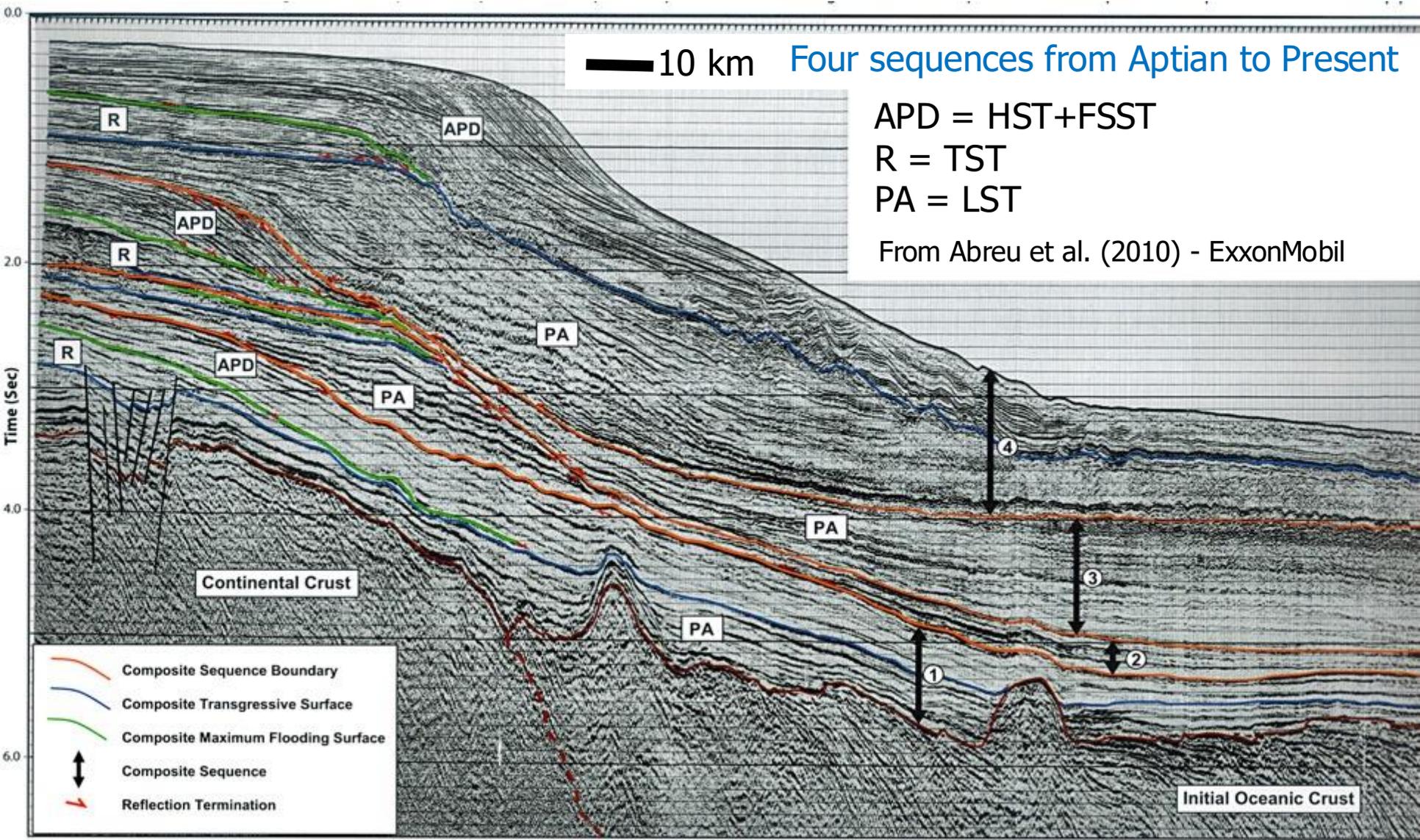
- Examples
- Sequence stratigraphic models
- Application to reservoir geology
- Exercise

# Upper Pleistocene shelf

From Lobo & Ridente (2013)

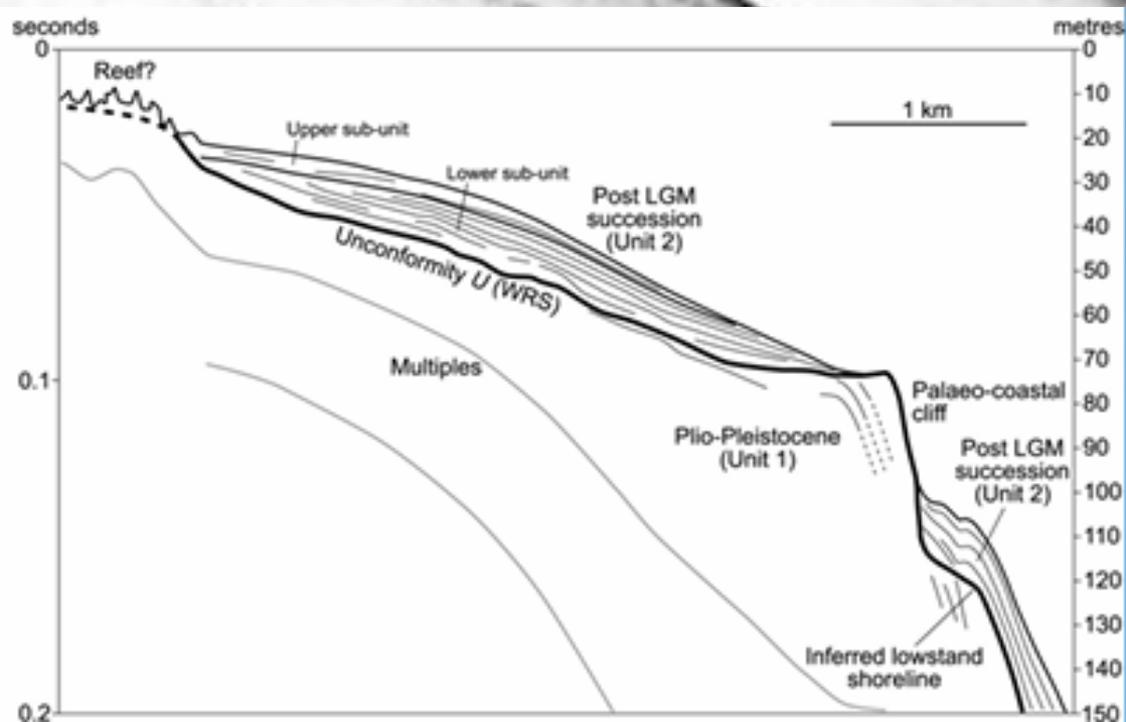
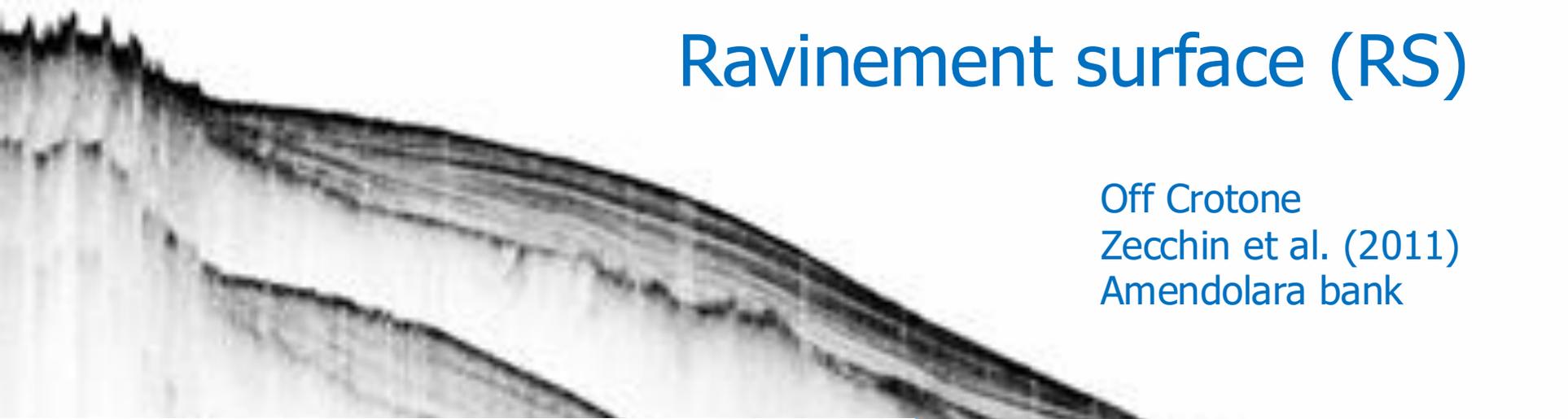


# Pelotas Basin (southern Brazil)



# Ravinement surface (RS)

Off Crotona  
Zecchin et al. (2011)  
Amendolara bank



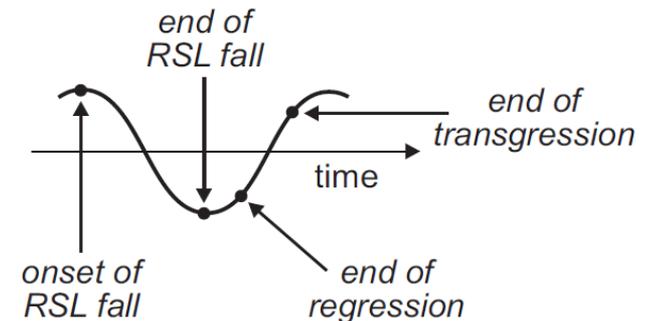
# Models

Sequence model Events and stages	Mitchum et al. (1977)	Posamentier et al. (1988)	Van Wagoner et al. (1988)	Hunt & Tucker (1992)	Galloway (1989)	Johnson & Murphy (1984)
	Depositional Sequence I	Depositional Sequence II	Depositional Sequence III	Depositional Sequence IV	Genetic Sequence	T-R Sequence
HNR <i>end of T</i>		HST	early HST	HST	HST	RST
T <i>end of R</i>	Sequence	TST	TST	TST	TST	TST
LNR <i>end of RSL fall</i>		late LST (wedge)	LST	LST	late LST (wedge)	
FR <i>onset of RSL fall</i>		early LST (fan)	late HST	FSST	early LST (fan)	RST
HNR		HST	early HST	HST	HST	

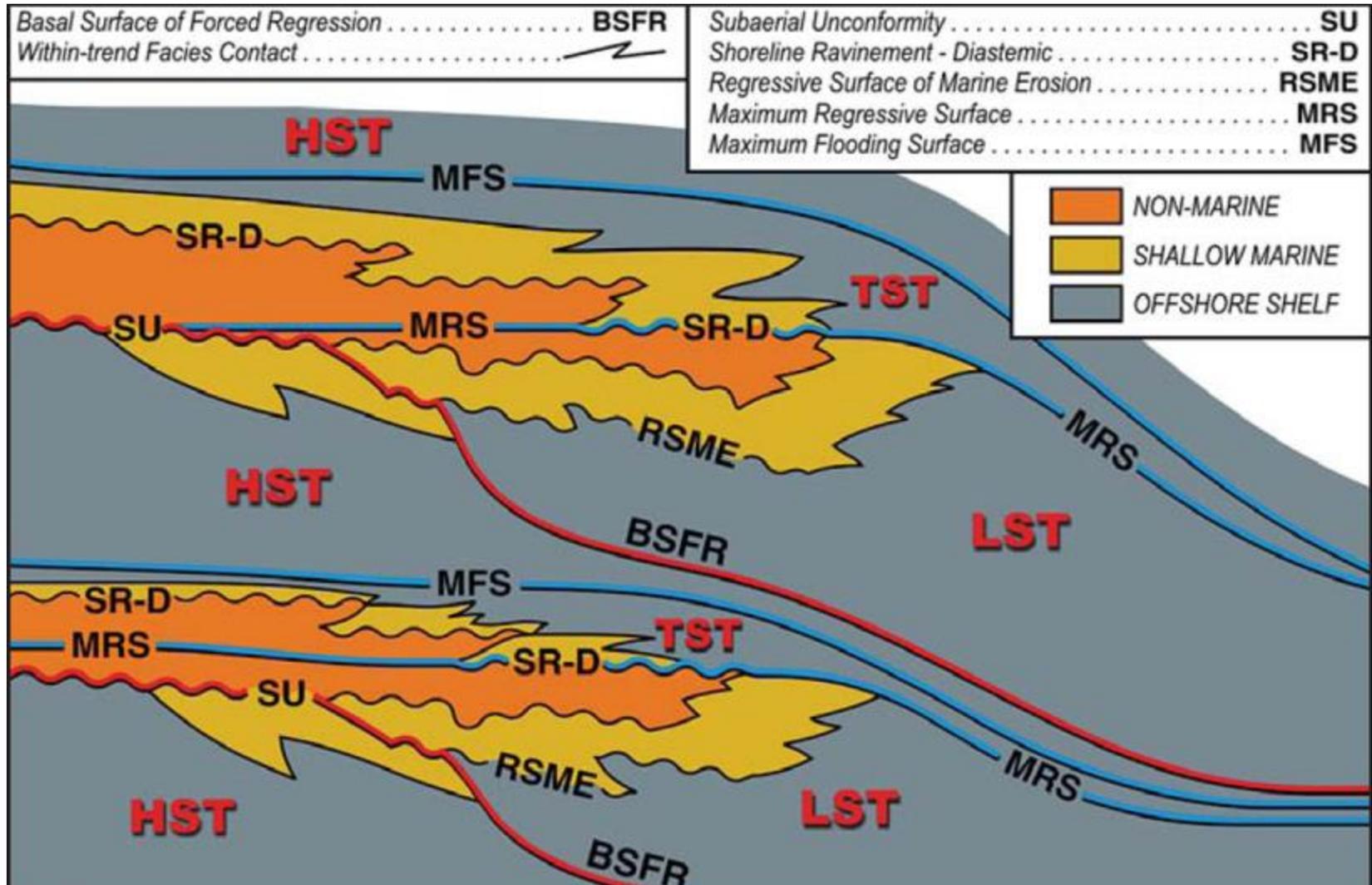
time ↑

CC\* (at onset of RSL fall), CC\*\* (at end of RSL fall), MFS (at end of T), MRS (at end of R)

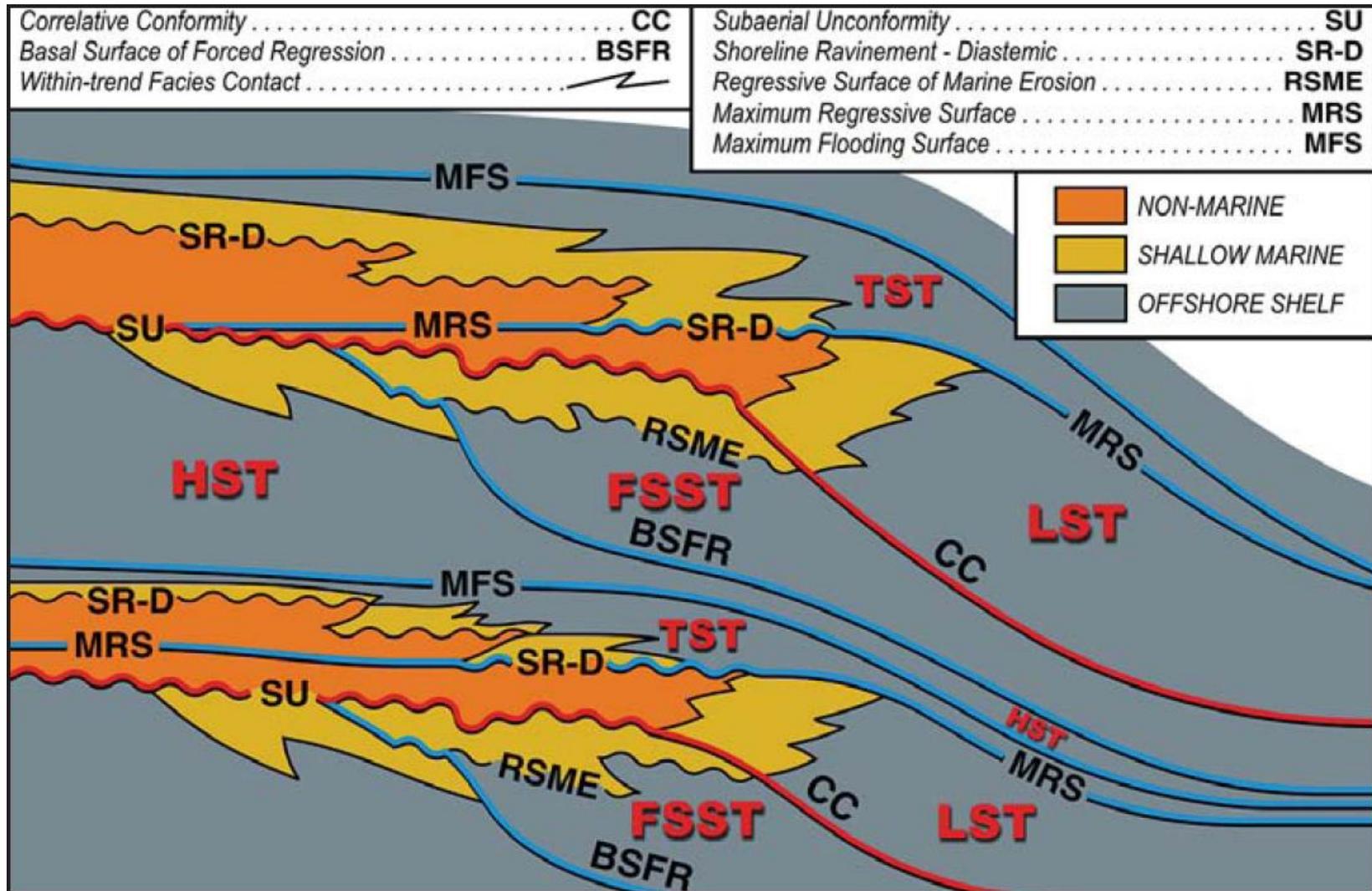
- sequence boundary
- systems tract boundary
- - - within-sequence surface
- · · within-systems tract surface



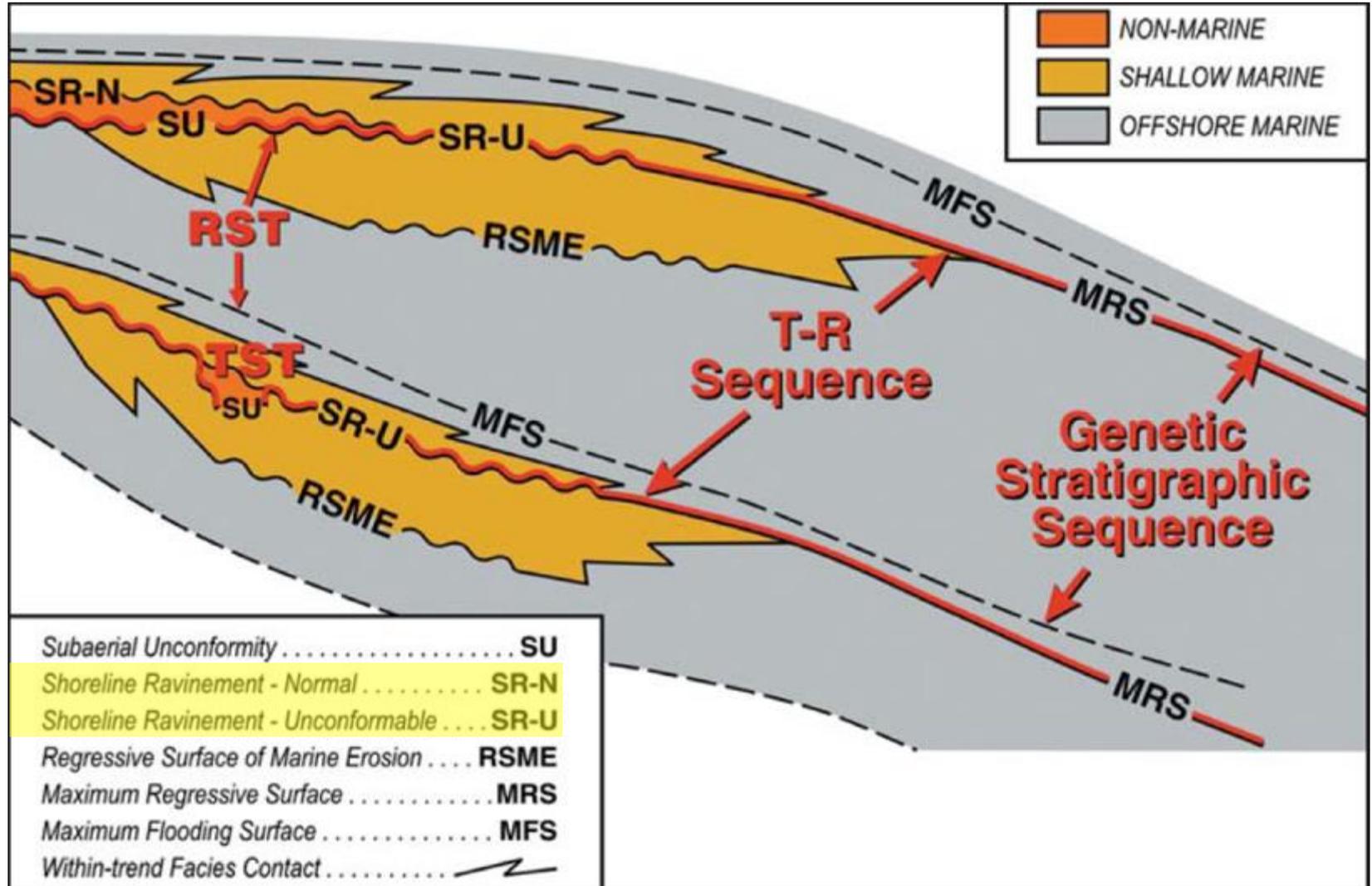
# Depositional sequence of Posamentier & Allen, 1999



# Depositional sequence of Hunt & Tucker, 1992 and Helland-Hansen & Gjelberg, 1994

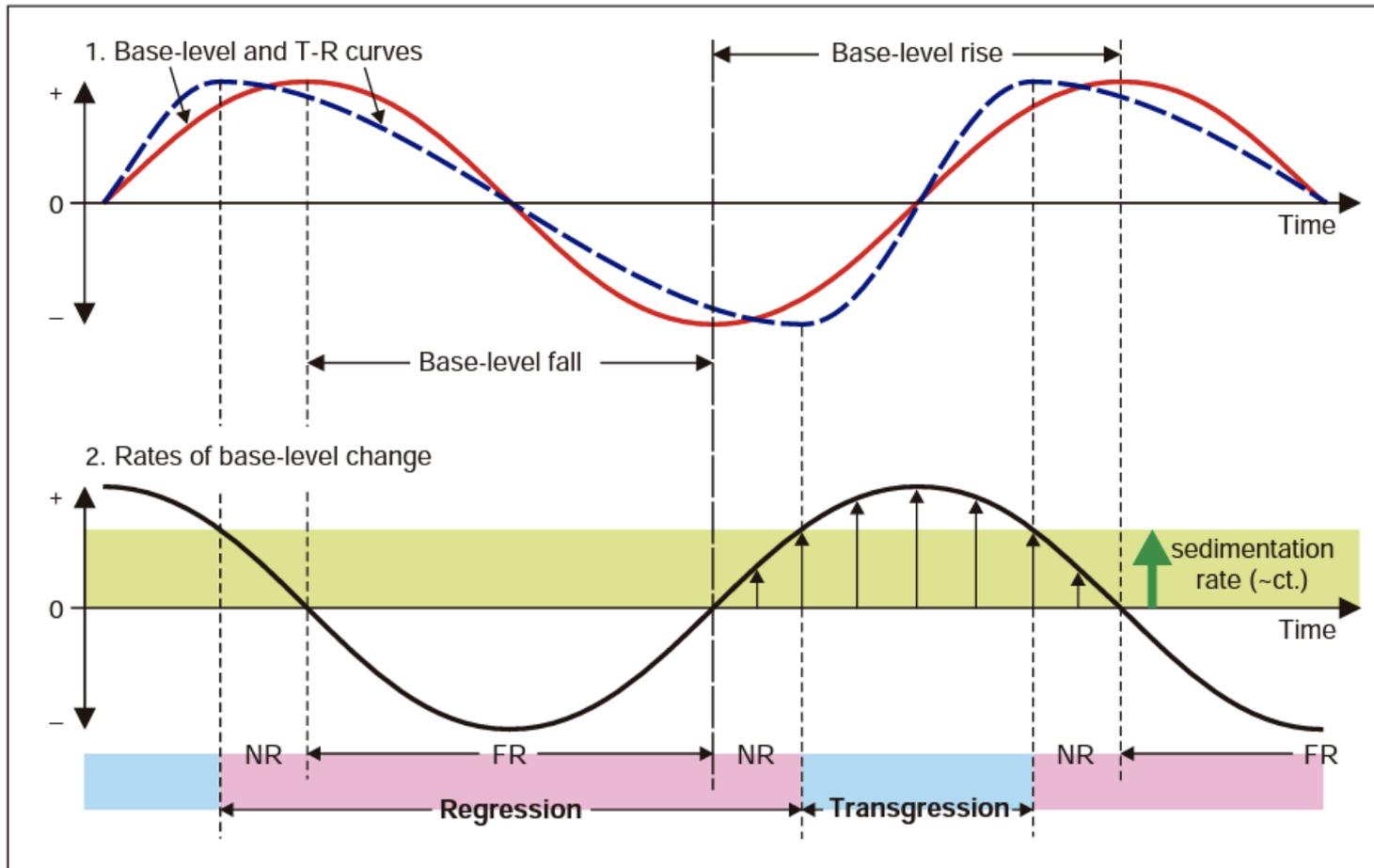


# T-R and genetic sequences



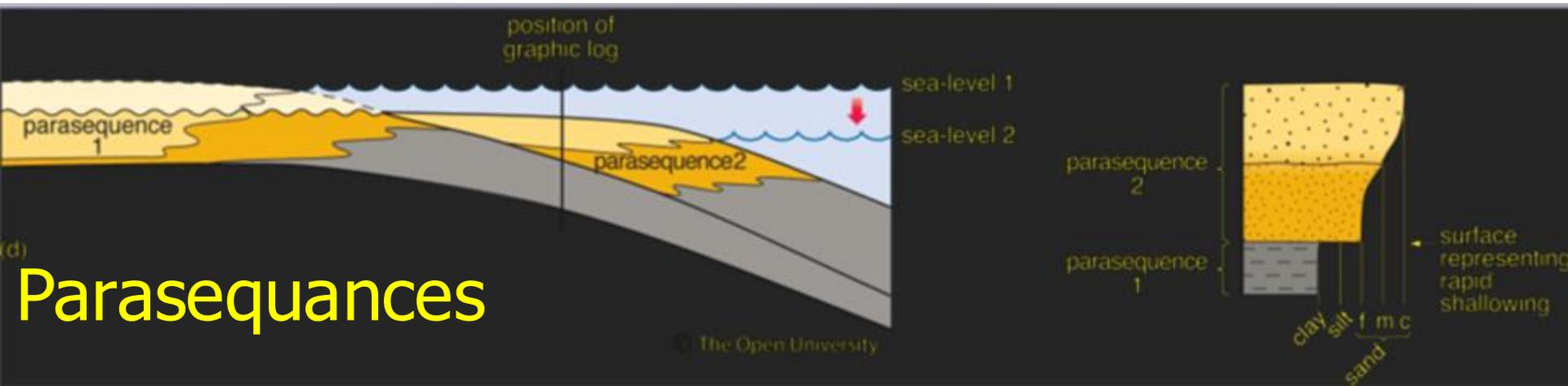
# Base-level and transgressive–regressive (T–R) curves.

Sequence stratigraphic surfaces, and systems tracts, are all defined relative to these curves. The T–R curve, describing the shoreline shifts, is the result of the interplay between sedimentation and base-level changes at the shoreline.



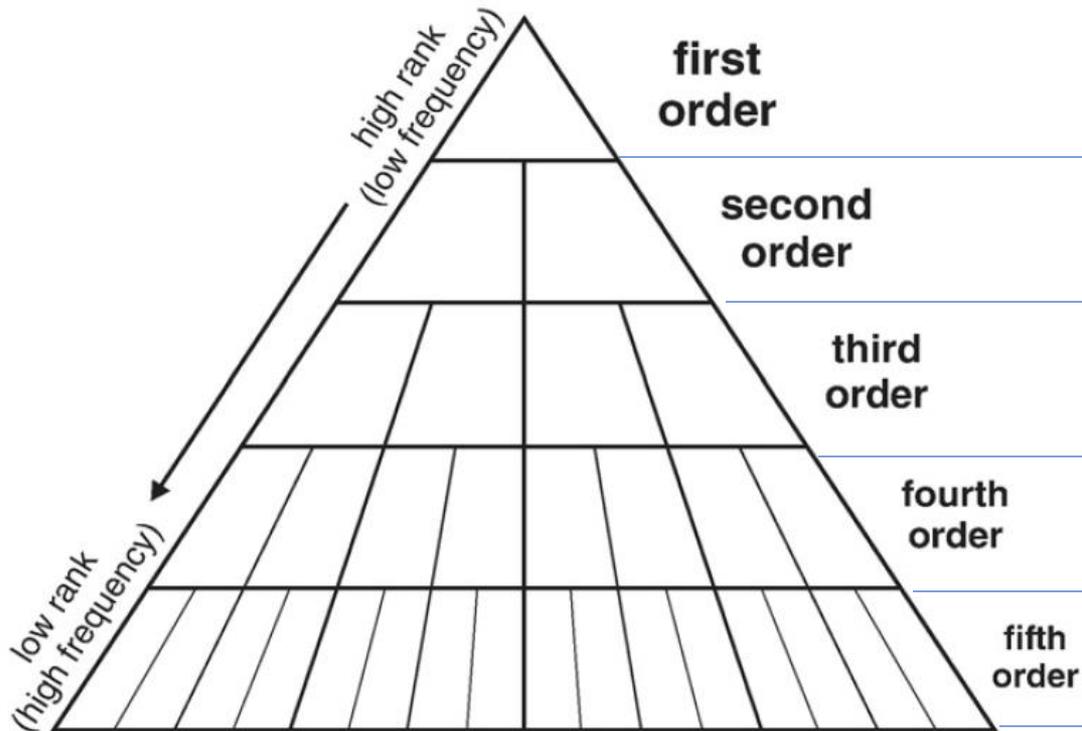
Sedimentation rates during a cycle of base-level change are considered constant and the reference baselevel curve is shown as a symmetrical sine curve, only for simplicity.

The 'parasequence' is a stratigraphic unit defined as 'a relatively conformable succession of genetically related beds or bedsets bounded by flooding surfaces'. Parasequences are commonly identified with the coarsening-upward prograding lobes in coastal to shallow-marine settings. Such parasequences are usually the higher frequency building blocks of successions associated with overall trends of coastal progradation or retrogradation, so they may be part of larger-scale systems tracts. Depending on the scale of observation, parasequences could be placed within the context of larger-scale systems tracts, or they could be studied in relation to discrete cycles of changing depositional trends. Overall, there has been more confusion than advantage associated with the usage of the parasequence concept.



# Parasequences

# Sequence hierarchy

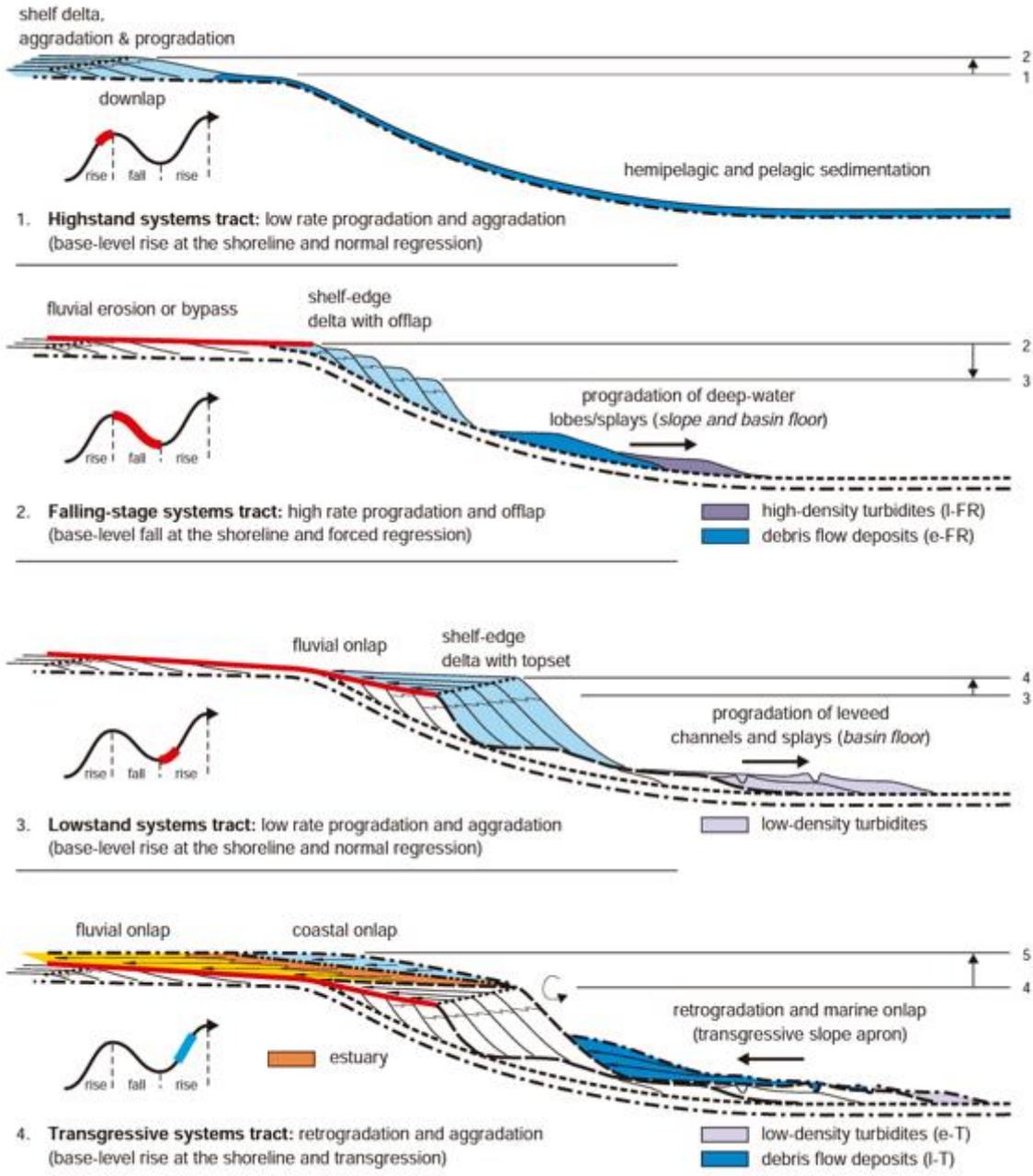


Order	Time (Ma)
First order	50+
Second order	3-50
Third order	0.5-3
Fourth order	0.08-0.5
Fifth order	0.03-0.08
Sixth order	0.01-0.03

From Vail et al. (1991)

# Regional architecture of depositional systems (modified from Catuneanu, 2002)

downlapping clinoforms are concave-up, whereas transgressive 'healing phase' strata associated with coastal and marine onlap tend to be convex-up



- subaerial unconformity
- correlative conformity
- basal surface of forced regression
- transgressive ravinement surface
- maximum regressive surface
- maximum flooding surface
- within-trend normal regressive surface
- lateral shifts of facies

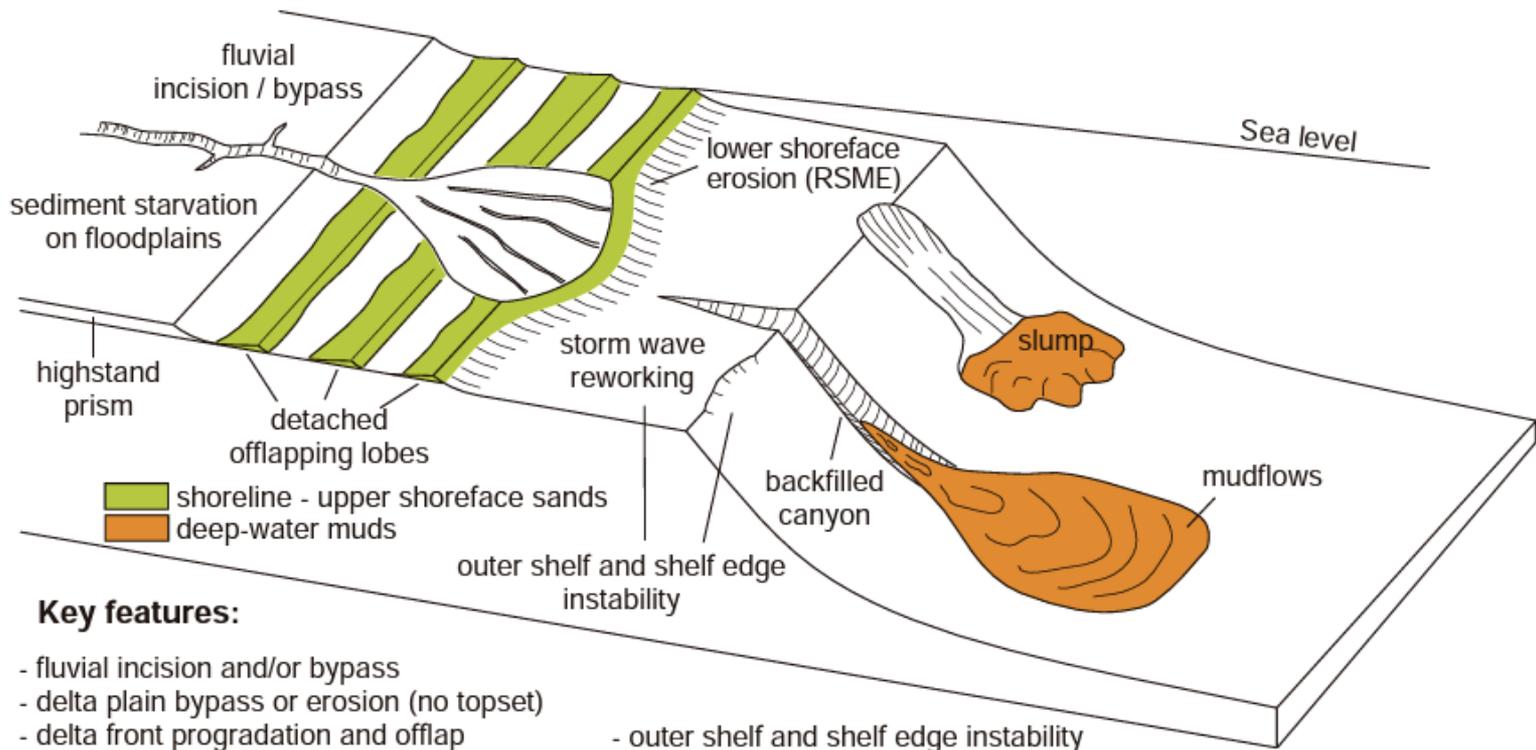
# Grading trends along vertical profiles through the fluvial, shallow- and deep-water parts of the various systems tracts.

Systems tract Environment	HST		FSST		LST		TST	
	maximum grain size	sand-mud ratio	maximum grain size	sand-mud ratio	maximum grain size	sand-mud ratio	maximum grain size	sand-mud ratio
<b>Fluvial</b>	Upward decrease <sup>(1)</sup>	Upward increase <sup>(2)</sup>	N/A <sup>(3)</sup>		Upward decrease <sup>(4)</sup>		Upward decrease <sup>(4)</sup>	
<b>Shallow water</b>	Upward increase <sup>(5)</sup>		Upward increase <sup>(5)</sup>		Upward increase <sup>(5)</sup>		Upward decrease <sup>(6)</sup>	
<b>Deep water</b>	N/A <sup>(7)</sup>		Upward increase <sup>(8)</sup>		Upward decrease <sup>(9)</sup>		Upward decrease <sup>(10)</sup>	

The trends of change in maximum grain size and sand/mud ratio correlate in general, with the exception of the highstand fluvial systems (shaded area).

# Depositional processes and products of the early falling-stage systems tract (modified from Catuneanu, 2003)

**Early forced regression:** depositional processes and products



**Key features:**

- fluvial incision and/or bypass
- delta plain bypass or erosion (no topset)
- delta front progradation and offlap
- erosion in the lower shoreface
- outer shelf and shelf edge instability
- dominant gravity flows: debris flows / mudflows

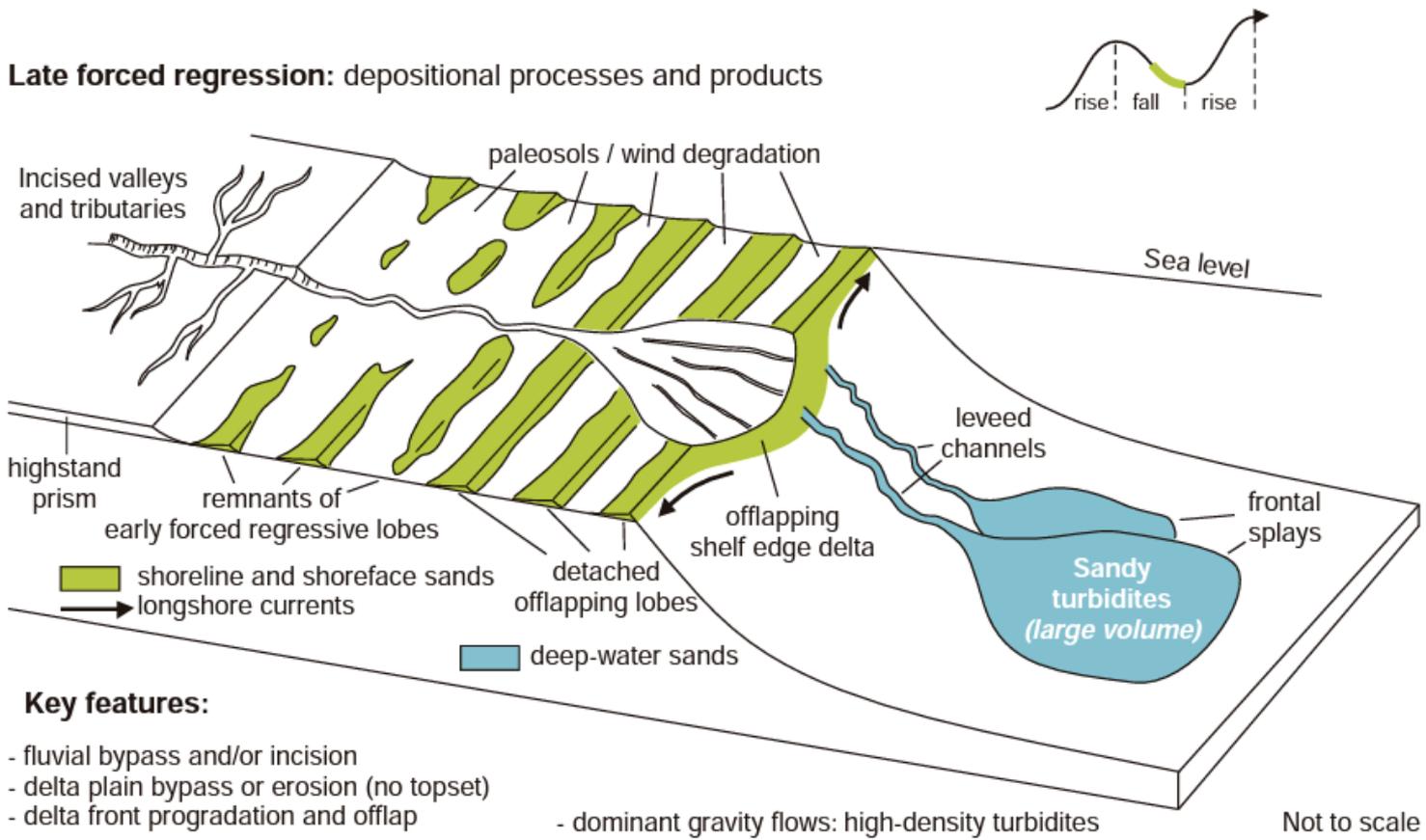
Not to scale

Most of the sand that accumulates during this stage is captured within detached and offlapping shoreline to upper shoreface systems. A significant amount of finer-grained sediment starts to accumulate in the deep-water environment as mudflow deposits.

# Depositional processes and products of the late falling-stage systems tract (modified from Catuneanu, 2003)

The sediment mass balance changes in the favor of the deep-sea submarine fans, which capture most of the sand. The subaerial unconformity keeps forming and expanding basinward until the end of base-level fall. Note that fluvial systems are likely to incise into the highstand prism but may only bypass the rest of the subaerially exposed shelf, unless the base level falls below the elevation of the shelf edge.

## Late forced regression: depositional processes and products



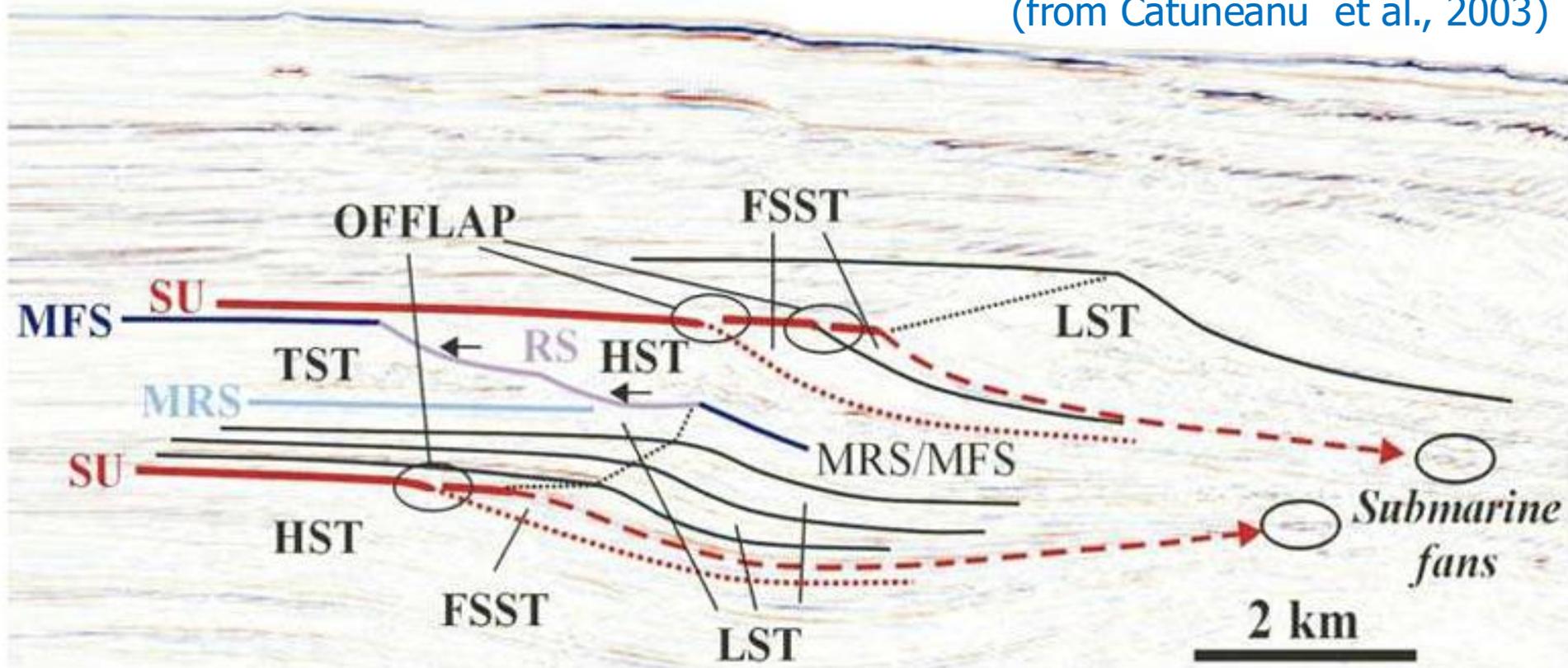
### Key features:

- fluvial bypass and/or incision
- delta plain bypass or erosion (no topset)
- delta front progradation and offlap
- dominant gravity flows: high-density turbidites

The turbidity currents of the deep basin are dominantly of high-density type, due to the massive amount of sediment supply, and hence they tend to be overloaded and aggradational (sediment load > energy of the flow)

# Interpreted seismic line showing the location of the best deep-water reservoirs in a sequence stratigraphic framework

(from Catuneanu et al., 2003)



The offlap type of stratal termination is highly significant for deep-water exploration because the youngest clinoform associated with offlap leads to the top of the coarsest deep-water facies.

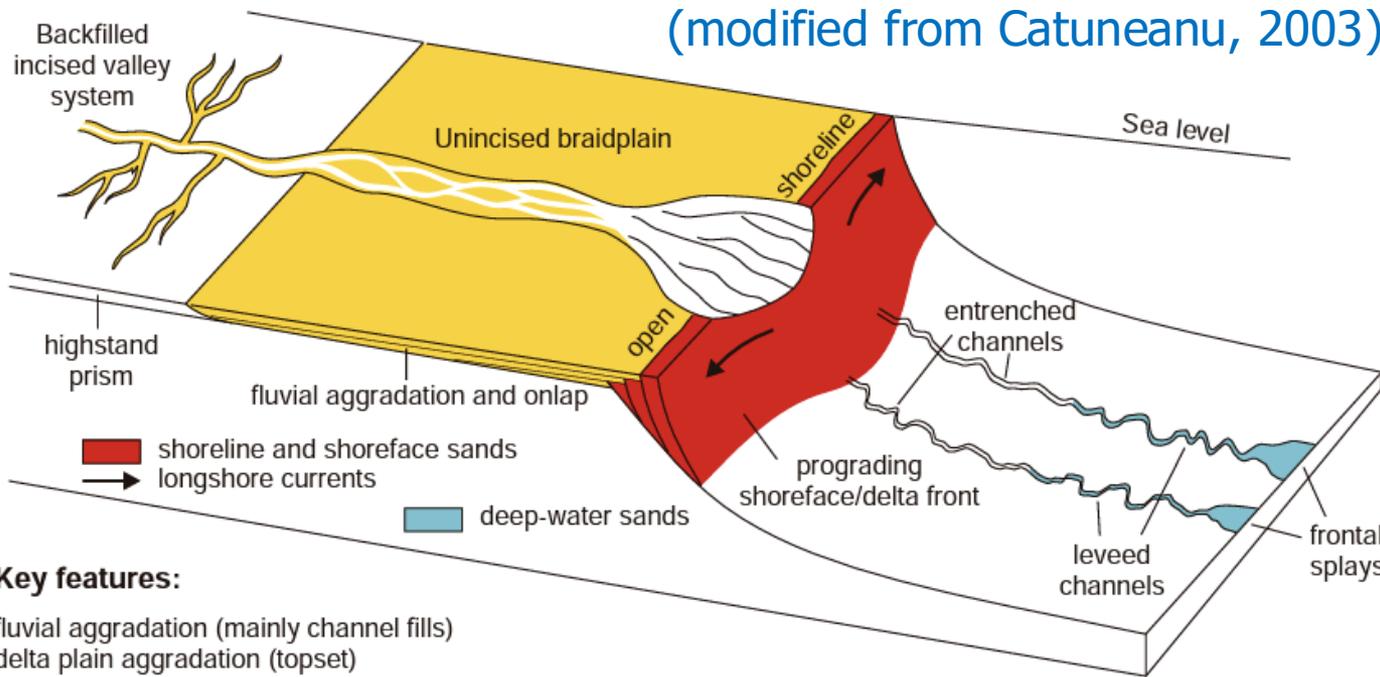
# Depositional processes and products of the lowstand systems tract

In contrast to the FSST, the sediment of this stage of early-rise normal regression is more evenly distributed. Sand is present in amalgamated fluvial channel fills, beach, and delta front systems, as well as in submarine fans. The 'lowstand prism' gradually expands landward via fluvial aggradation and onlap.

**Lowstand normal regression:** depositional processes and products



(modified from Catuneanu, 2003)



**Key features:**

- fluvial aggradation (mainly channel fills)
- delta plain aggradation (topset)
- delta front progradation
- dominant gravity flows: low-density turbidites

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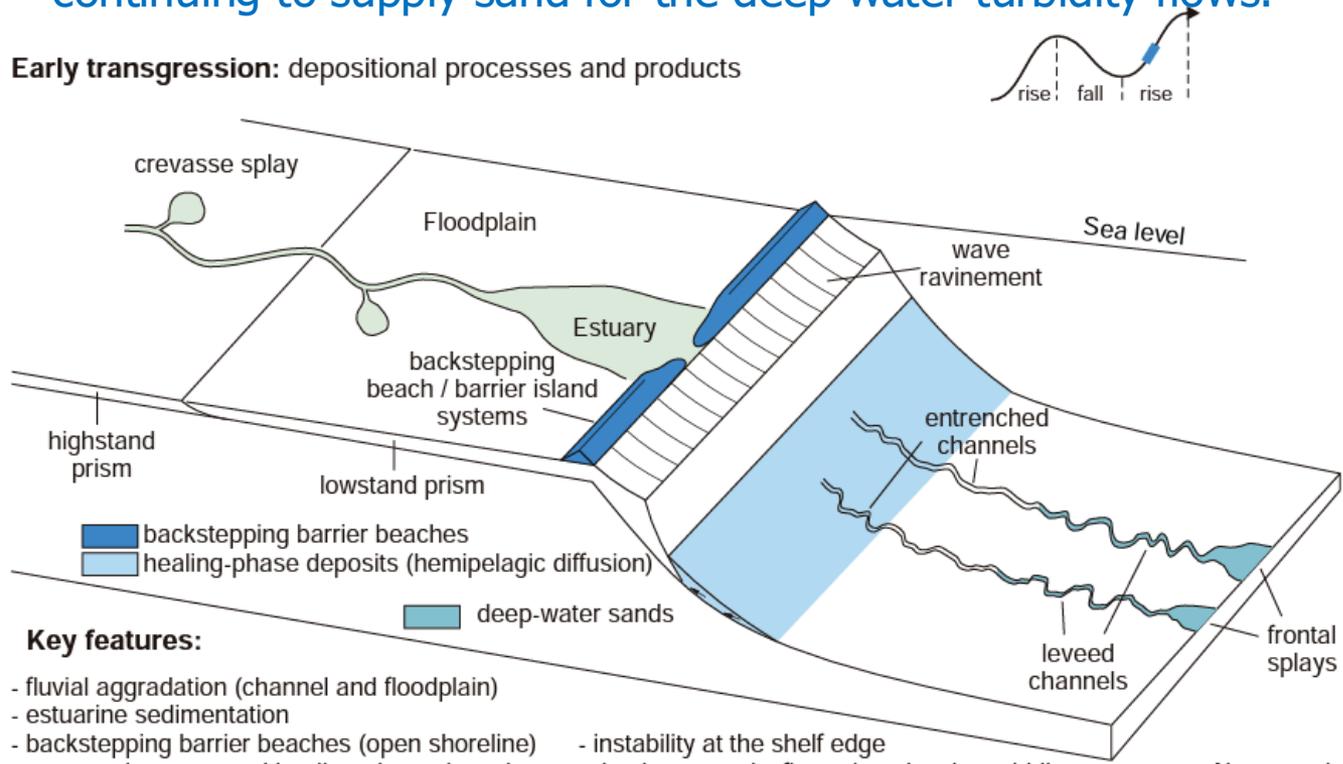
Aggradation on the continental shelf in fluvial to shallow-marine environments reduces the amount of sediment supply to the deep basin, and hence the turbidity currents of this stage are dominantly of low-density type, being underloaded (entrenched) on the continental slope and aggradational only on the low-gradient basin floor where the energy of the flow drops below the threshold of balance with the sediment load.

# Depositional processes and products of the early TST (modified from Catuneanu, 2003)

Rapid rates of base-level rise trigger a retrogradational shift of facies on the continental shelf, where most of the riverborn sediment is now trapped in fluvial, coastal and shallow-marine systems. Wave-ravinement processes erode the underlying normal regressive shelf-edge deltas and open shoreline systems, continuing to supply sand for the deep-water turbidity flows.

Similarly to the lowstand systems tract, the turbidity flows tend to be of low-density type, underloaded on the steep continental slope (flow energy > sediment load, which causes entrenchment), but become overloaded/aggradational on the low-gradient basin floor (sediment load > flow energy). They travel farther into the basin relative to the high-density late falling-stage flows because the higher proportion of mud sustains the construction of levees over larger distances.

Early transgression: depositional processes and products



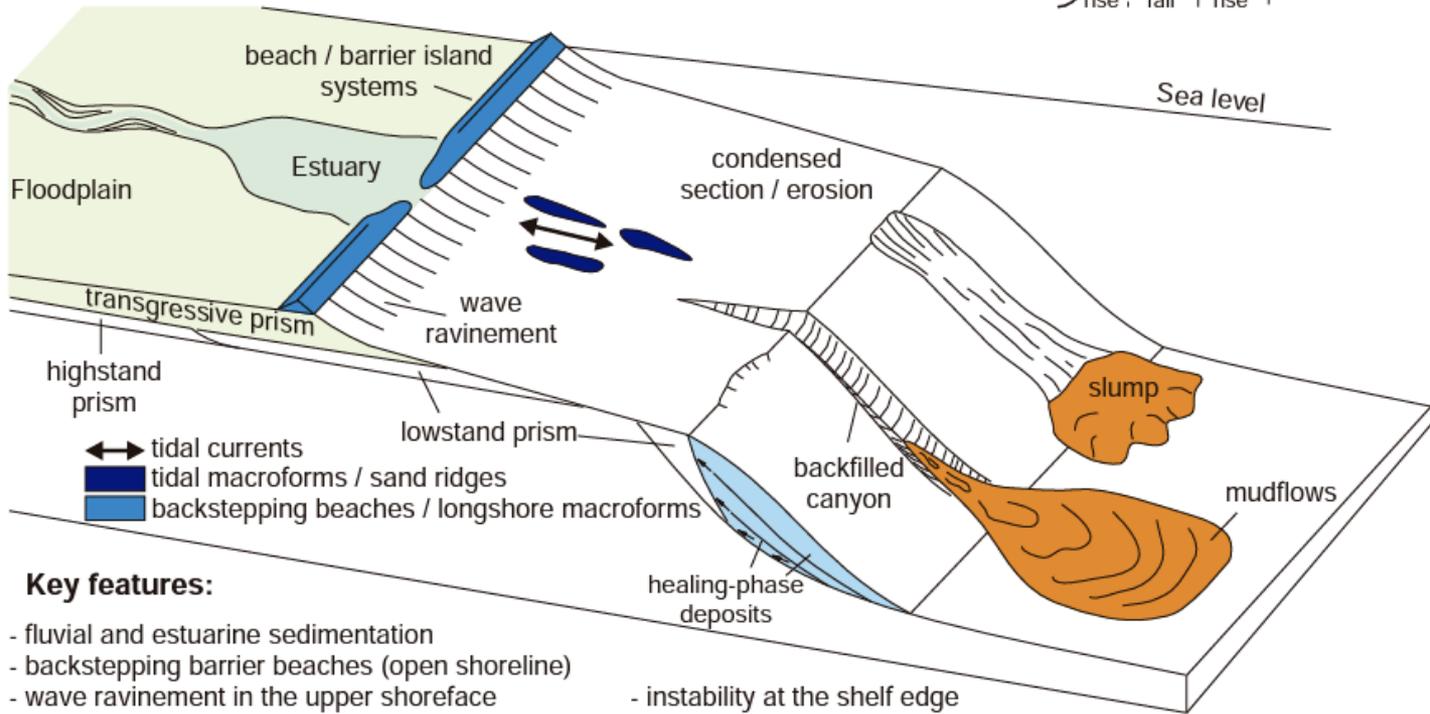
# Depositional processes and products of the late TST (modified from Catuneanu, 2003)

Most of the terrigenous sediment is trapped in the fluvial to shallow-marine transgressive prism, which includes fluvial, estuarine, deltaic, open shoreline, and lower shoreface deposits. Additional sand is incorporated within shelf macroforms (sheets, ridges, ribbons) generated by storm surges and tidal currents.

Such shelf-sand deposits are generally associated with the transgressive systems tract, as the best conditions to accumulate and the highest preservation potential are offered to shelf macroforms that form during shoreline transgression. As base level rises rapidly during transgression, hydraulic instability at the shelf edge generates mudflows in the deep-water environment.



Late transgression: depositional processes and products



**Key features:**

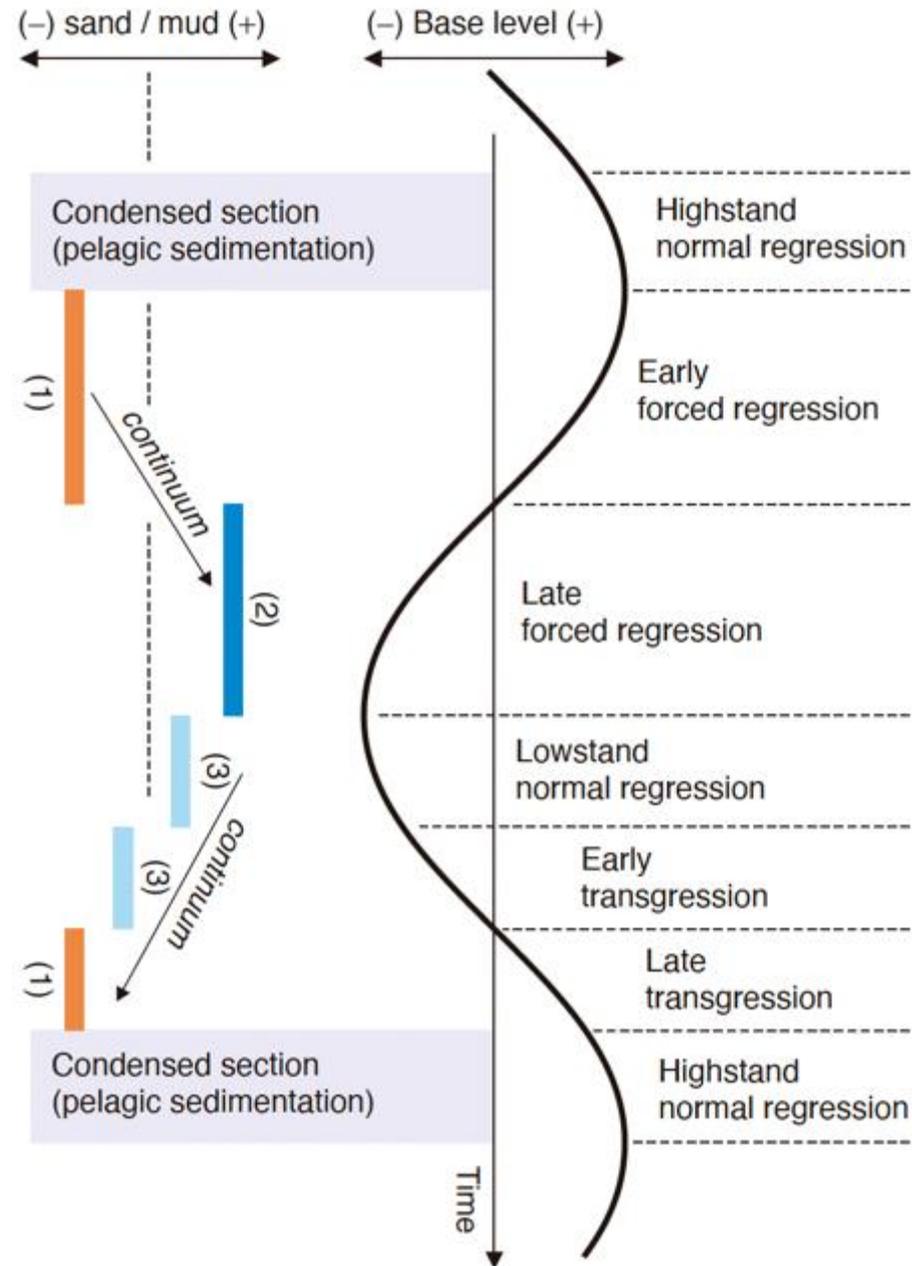
- fluvial and estuarine sedimentation
- backstepping barrier beaches (open shoreline)
- wave ravinement in the upper shoreface
- longshore and tidal macroforms
- instability at the shelf edge
- dominant gravity flows: mudflows

Not to scale

# Dominant types of gravity flows that supply sediment to the deep-water environment, in relation to specific stages of shoreline shift

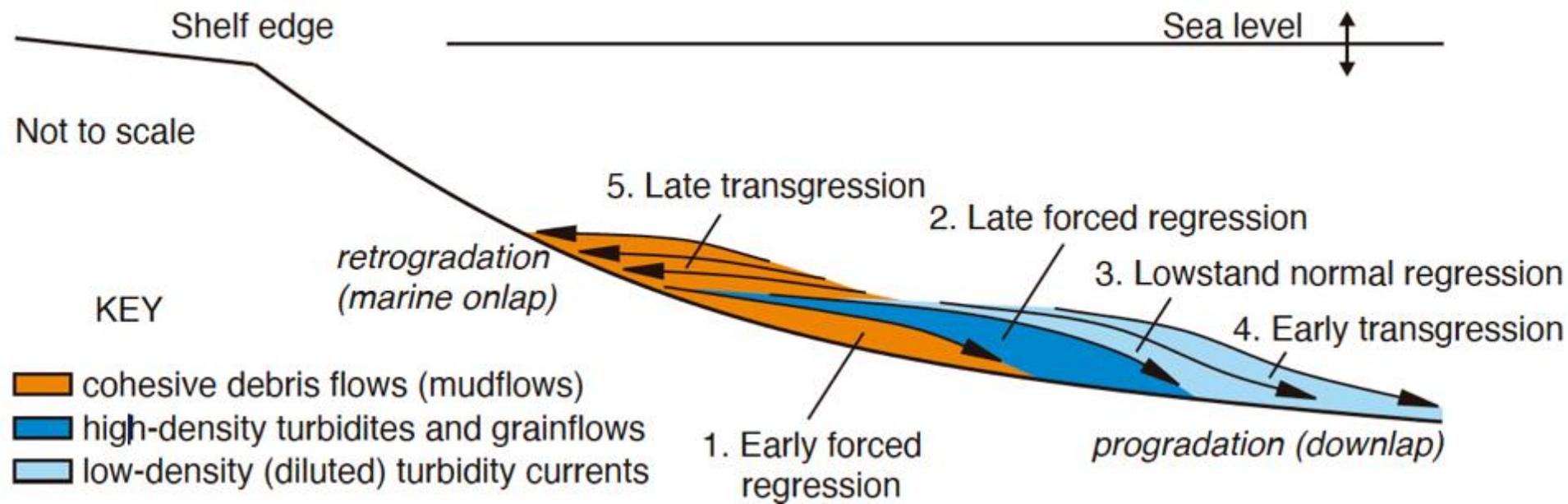
Note that there is a continuum between the end-member types of gravity flows as changes in sediment supply are gradational through time.

Key: (1) cohesive debris flows (mudflows); (2) high-density turbidity currents and grainflows, forming proximal frontal splays; (3) lower-density turbidity currents, forming leveed channels and distal frontal splays.

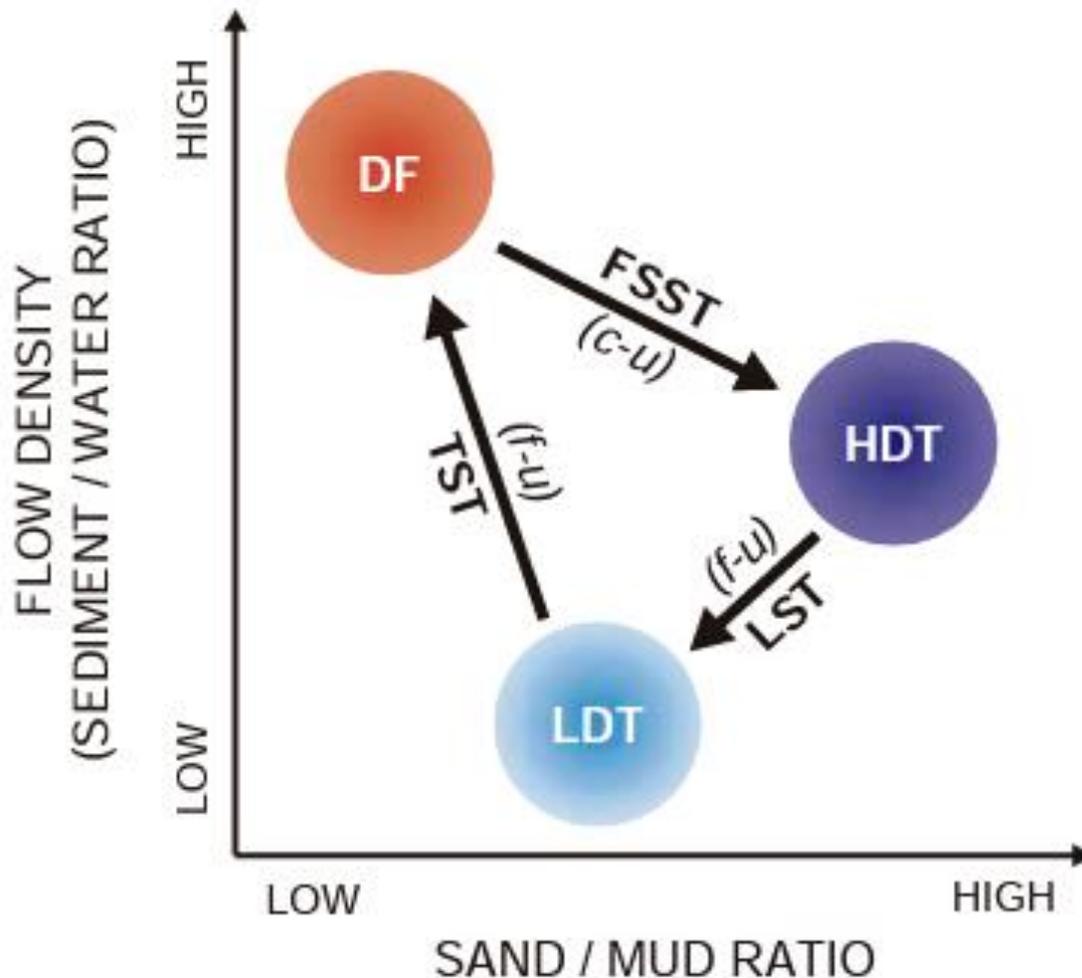


# Idealized architecture of a submarine fan complex that may form during the base-level cycle

The fan progrades during the first four time in response to the change in the type of gravity flow, based on the assumption that the travel distance of the flow depends on its rheological behavior: mudflows travel the shortest distance, due to their discrete shear strength; turbidites travel farther, due to their fluidal behavior, to a distance that is inversely proportional to the flow density. The fan retrogrades during transgression, as a result of the gradual change from fluidal to plastic behavior (turbidites to mudflows, respectively) which accompanies the decrease with time in the sand/mud ratio. According to this general scenario, submarine fans are more likely to onlap the continental slope during transgressions.



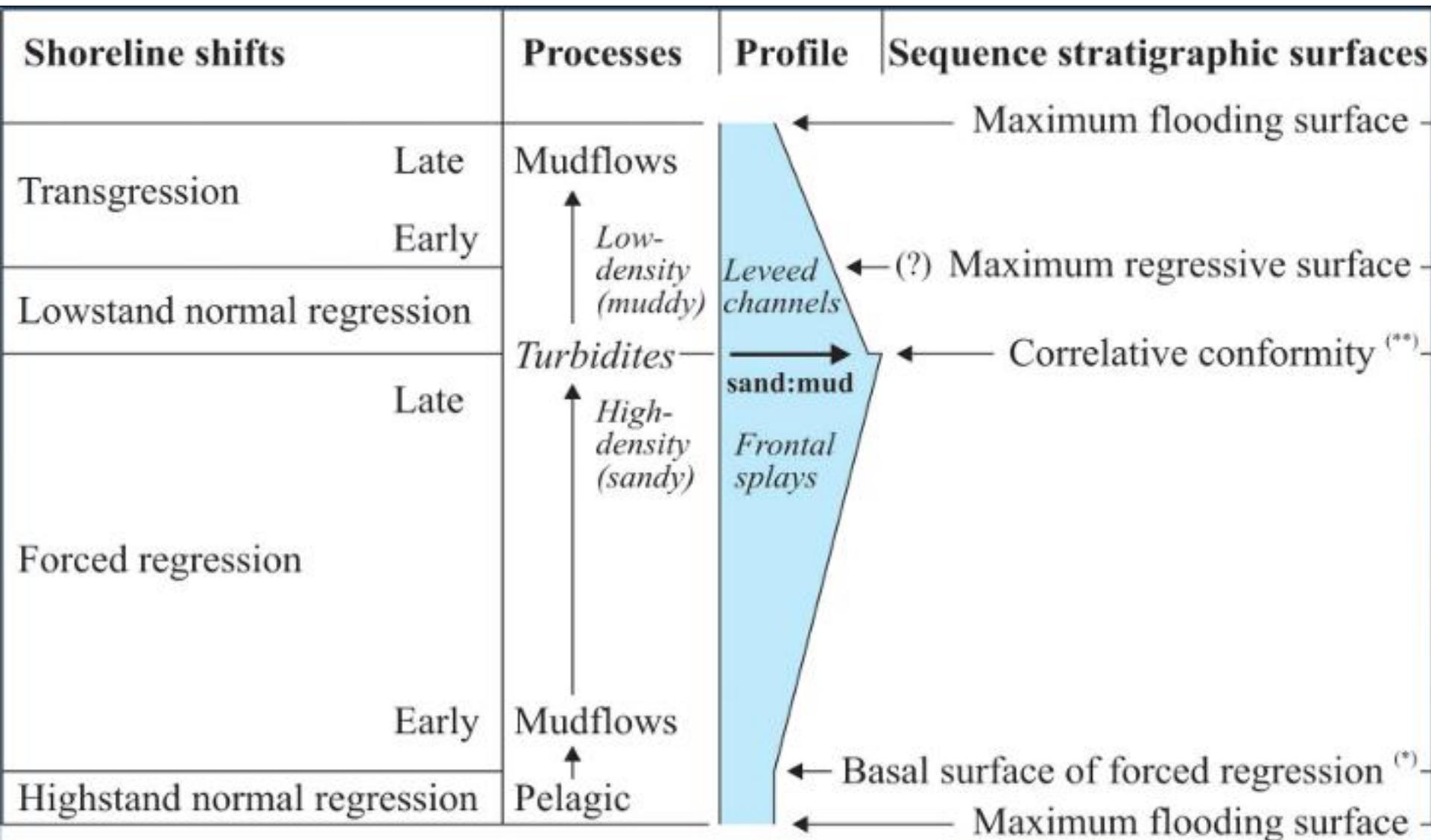
# Trends of change in the main types of gravity flows that operate in the deep-water environment during the formation of systems tracts



## Abbreviations:

- DF—cohesive debris flows (mudflows);
- HDT—high-density turbidites;
- LDT—low-density turbidites;
- FSST— falling-stage systems tract;
- LST—lowstand systems tract;
- TST—transgressive systems tract;
- c-u—coarsening-upward;
- f-u—fining-upward.

# Deep-water sequence



# Sediment budget and the petroleum play significance of systems tracts.

Systems tract	Significance	Fluvial	Coastal	Shallow-water	Deep-water
Highstand Systems Tract	Sediment budget	Good: <i>aggrading systems</i>	Good: <i>deltas and strandplains (coastal prisms)</i>	Good: <i>gradationally based shoreface and shelf facies</i>	Poor
	Reservoir	Fair: <i>channel fills, crevasse splays</i>	Good: <i>shoreline sands</i>	Good: <i>shoreface sands</i>	Poor
	Source and Seal	Poor source, fair seal: <i>overbank facies</i>	Poor	Fair: <i>shelf fines</i>	Good: <i>pelagic facies</i>
Transgressive Systems Tract	Sediment budget	Good: <i>rapidly aggrading systems, incised and unincised</i>	Good: <i>estuaries, deltas, backstepping beaches</i>	Fair: <i>onlapping shoreface and shelf facies</i>	Fair: <i>low-density turbidity flows and debris flows</i>
	Reservoir	Fair: <i>channel fills, crevasse splays</i>	Good: <i>estuarine, deltaic, and beach sands</i>	Fair: <i>shelf-sand deposits, basal healing-phase wedges</i>	Fair: <i>turbidites (basin floor)</i>
	Source and Seal	Poor source, fair seal: <i>overbank fines</i>	Poor source, fair seal: <i>central estuary facies</i>	Good: <i>shelf fines (shelf facies may be missing distally)</i>	Good: <i>pelagic facies</i>
Lowstand Systems Tract	Sediment budget	Good: <i>amalgamated channel fills, incised and unincised</i>	Good: <i>shelf/shelf-edge deltas, strandplains</i>	Good: <i>gradationally based shoreface and shelf facies</i>	Fair: <i>low-density turbidity flows</i>
	Reservoir	Good: <i>channel fills</i>	Good: <i>shoreline sands</i>	Good: <i>shoreface sands</i>	Good: <i>turbidites (basin floor)</i>
	Source and Seal	Poor	Poor	Fair: <i>shelf fines</i>	Fair: <i>"overbank" pelagics</i>
Falling-stage Systems Tract	Sediment budget	Poor	Fair: <i>offlapping deltas, downstepping beaches</i>	Fair: <i>sharp-based shoreface, and shelf facies</i>	Good: <i>debris flows and high-density turbidity flows</i>
	Reservoir	Poor	Fair: <i>detached shoreline sands</i>	Fair: <i>shoreface sands</i>	Good: <i>turbidites (slope and basin floor)</i>
	Source and Seal	Poor	Poor	Fair: <i>shelf fines</i>	Fair: <i>"overbank" pelagics</i>

# Application to reservoir geology: HST

## Fluvial

Sediment budget: good (aggrading systems)  
Reservoir: fair (channel fill, crevasse splays)  
Poor source, fair seal (overbank fines)

## Coastal

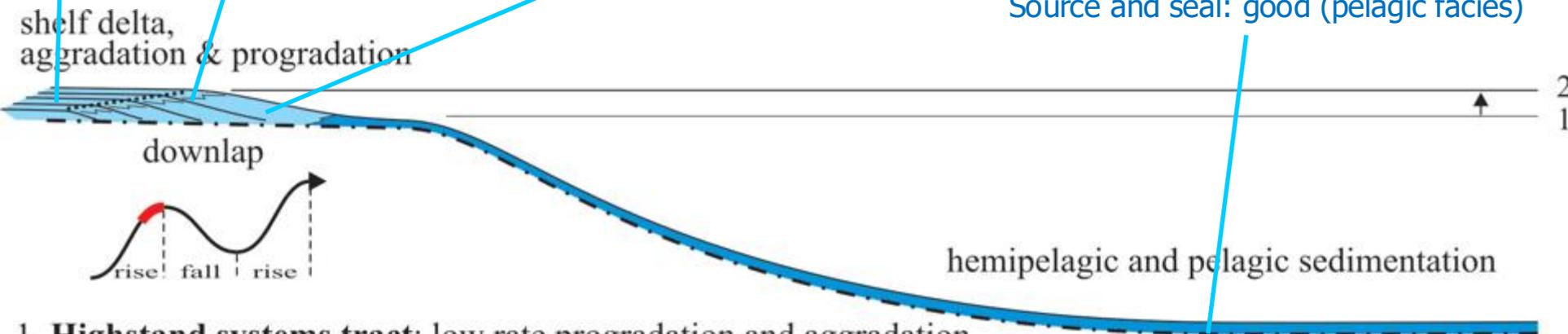
Sediment budget: good (deltas and strandplains)  
Reservoir: good (shoreline sands)  
Source and seal: poor

## Shallow-water

Sediment budget: good (shoreface and shelf facies)  
Reservoir: good (shoreface sands)  
Source and seal: fair (shelf fines)

## Deep-water

Sediment budget: poor  
Reservoir: poor  
Source and seal: good (pelagic facies)



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1. **Highstand systems tract:** low rate progradation and aggradation (base level rise at the shoreline and normal regression)

# Application to reservoir geology: FSST

## Fluvial

Sediment budget: poor  
Reservoir: poor  
Source and seal: poor

## Coastal

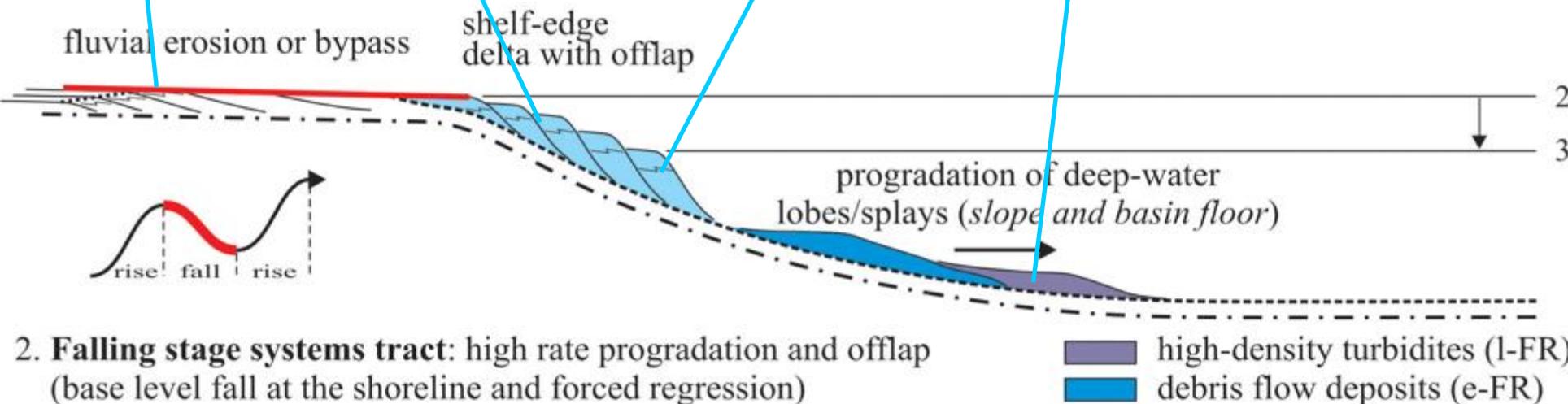
Sediment budget: fair  
(offlapping deltas, downstepping beaches)  
Reservoir: fair (detached shoreline sands)  
Source and seal: poor

## Shallow-water

Sediment budget: fair (shoreface and shelf facies)  
Reservoir: fair (shoreface sands)  
Source and seal: fair (shelf fines)

## Deep-water

Sediment budget: good (debris flows and high-density turbidity flows)  
Reservoir: good (turbidites)  
Source and seal: fair ("overbank" pelagics)



2. **Falling stage systems tract:** high rate progradation and offlap (base level fall at the shoreline and forced regression)

# Application to reservoir geology: LST

## Fluvial

Sediment budget: good (amalgamated channel fills)  
Reservoir: good (channel fills)  
Source and seal: poor

## Shallow-water

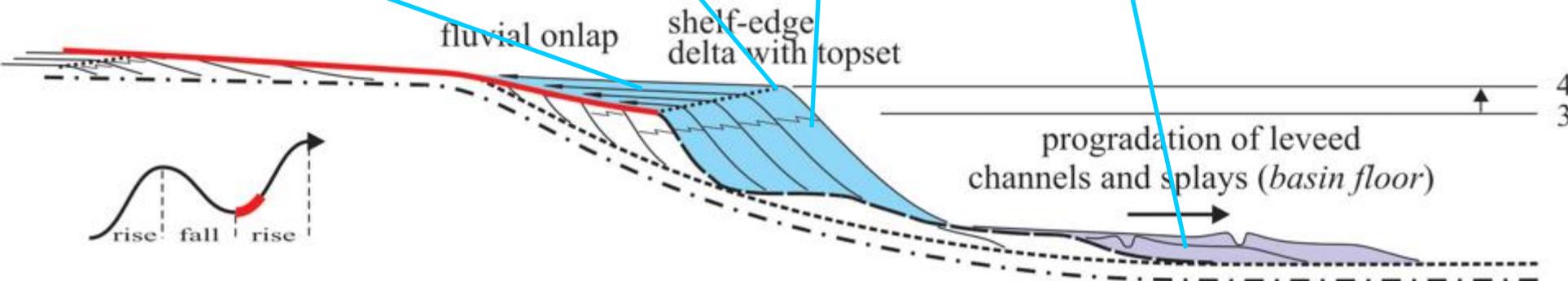
Sediment budget: good (shoreface and shelf facies)  
Reservoir: good (shoreface sands)  
Source and seal: fair (shelf fines)

## Coastal

Sediment budget: good (shelf/shelf-edge deltas, strandplains)  
Reservoir: good (shoreline sands)  
Source and seal: poor

## Deep-water

Sediment budget: fair (low-density turbidity flows)  
Reservoir: good (turbidites)  
Source and seal: fair ("overbank" pelagics)



3. **Lowstand systems tract:** low rate progradation and aggradation (base level rise at the shoreline and normal regression)

low-density turbidites

# Application to reservoir geology: TST

## Fluvial

Sediment budget: good (aggrading systems)  
Reservoir: fair (channel fills, crevasse splays)  
Poor source, fair seal (overbank fines)

## Shallow-water

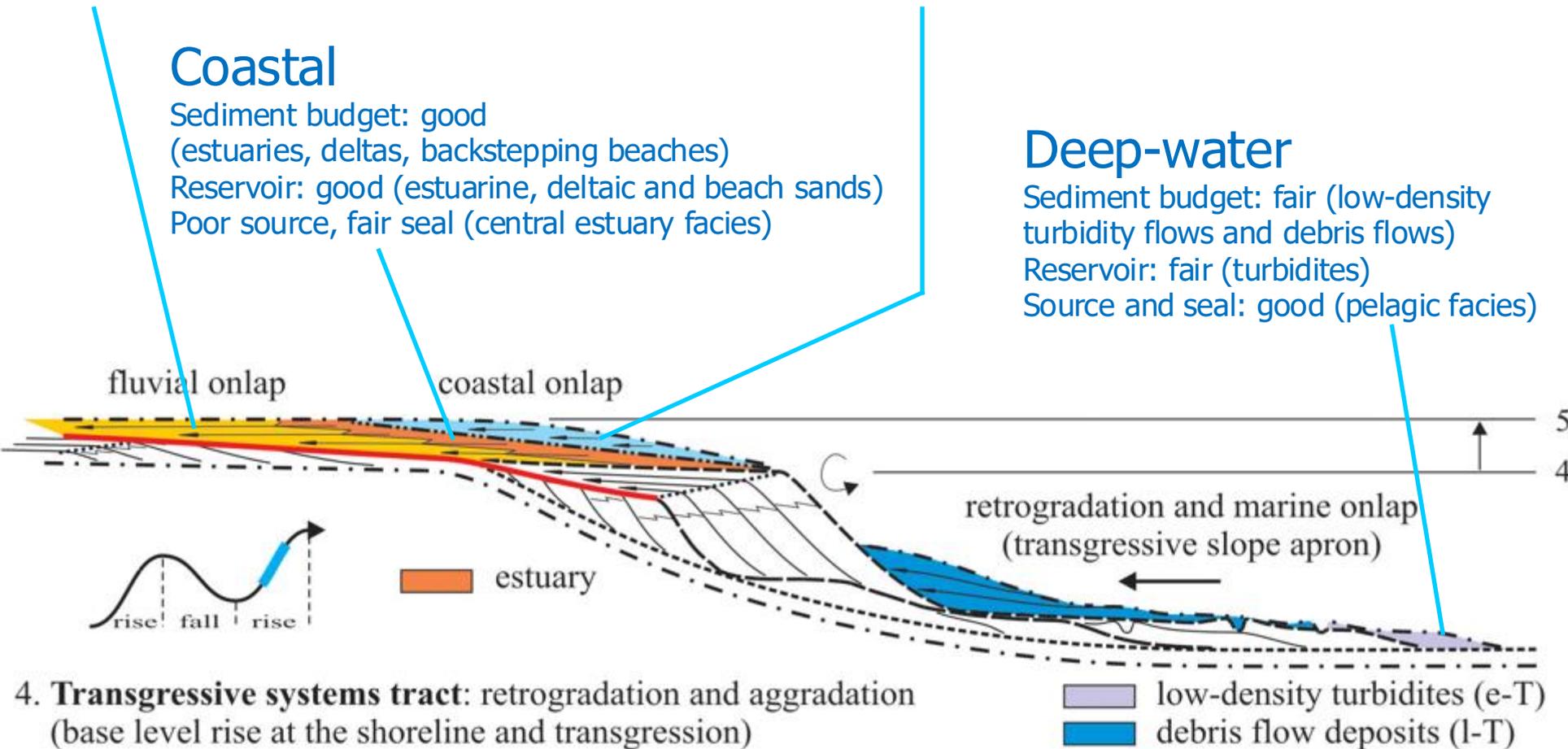
Sediment budget: fair (onlapping shoreface and shelf facies)  
Reservoir: fair (shelf sands, basal healing-phase wedges)  
Source and seal: good (shelf fines)

## Coastal

Sediment budget: good (estuaries, deltas, backstepping beaches)  
Reservoir: good (estuarine, deltaic and beach sands)  
Poor source, fair seal (central estuary facies)

## Deep-water

Sediment budget: fair (low-density turbidity flows and debris flows)  
Reservoir: fair (turbidites)  
Source and seal: good (pelagic facies)



4. **Transgressive systems tract:** retrogradation and aggradation (base level rise at the shoreline and transgression)

# Continuity of reservoirs in continental settings

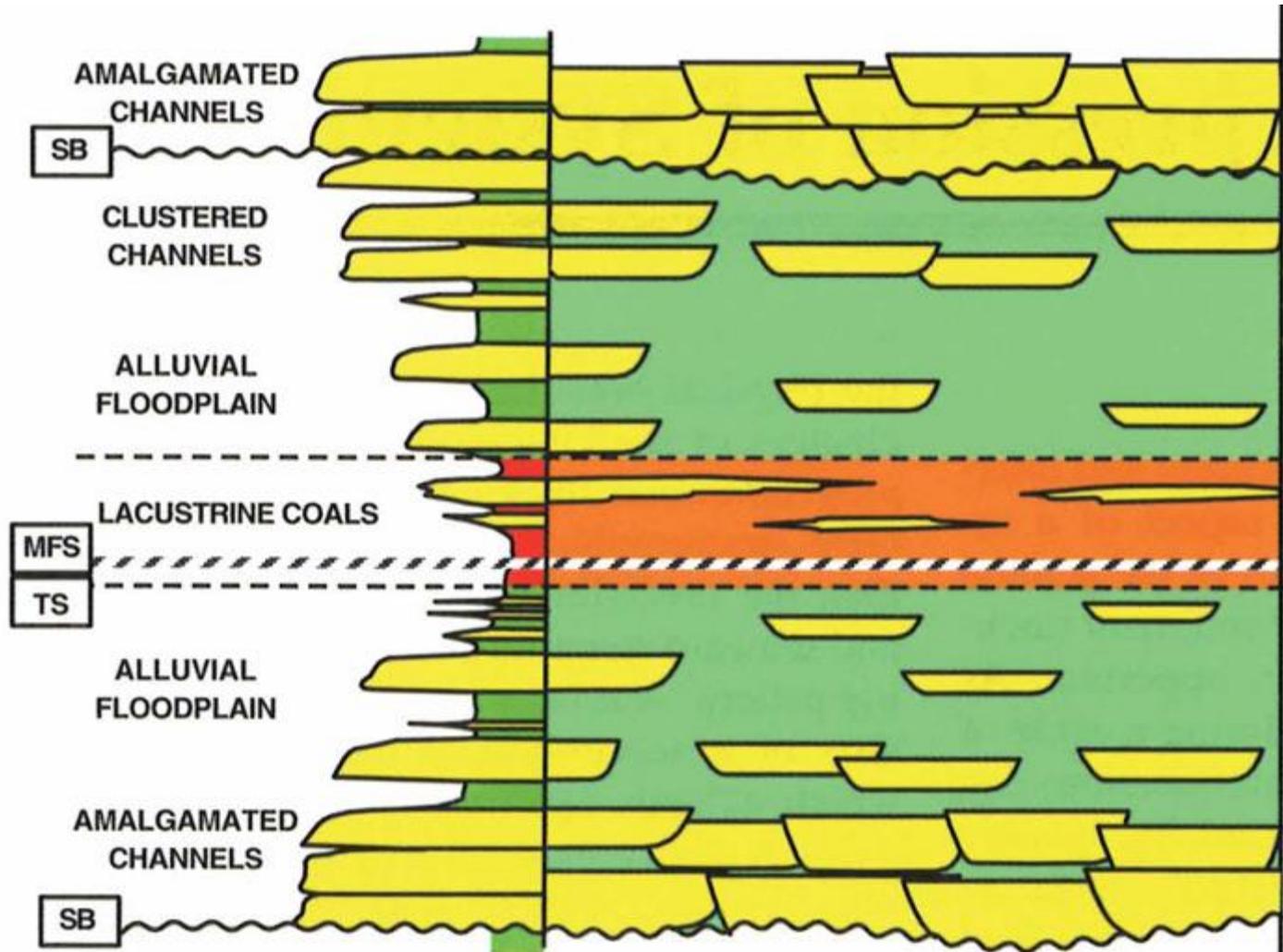
Good reservoir continuity

Isolated reservoirs

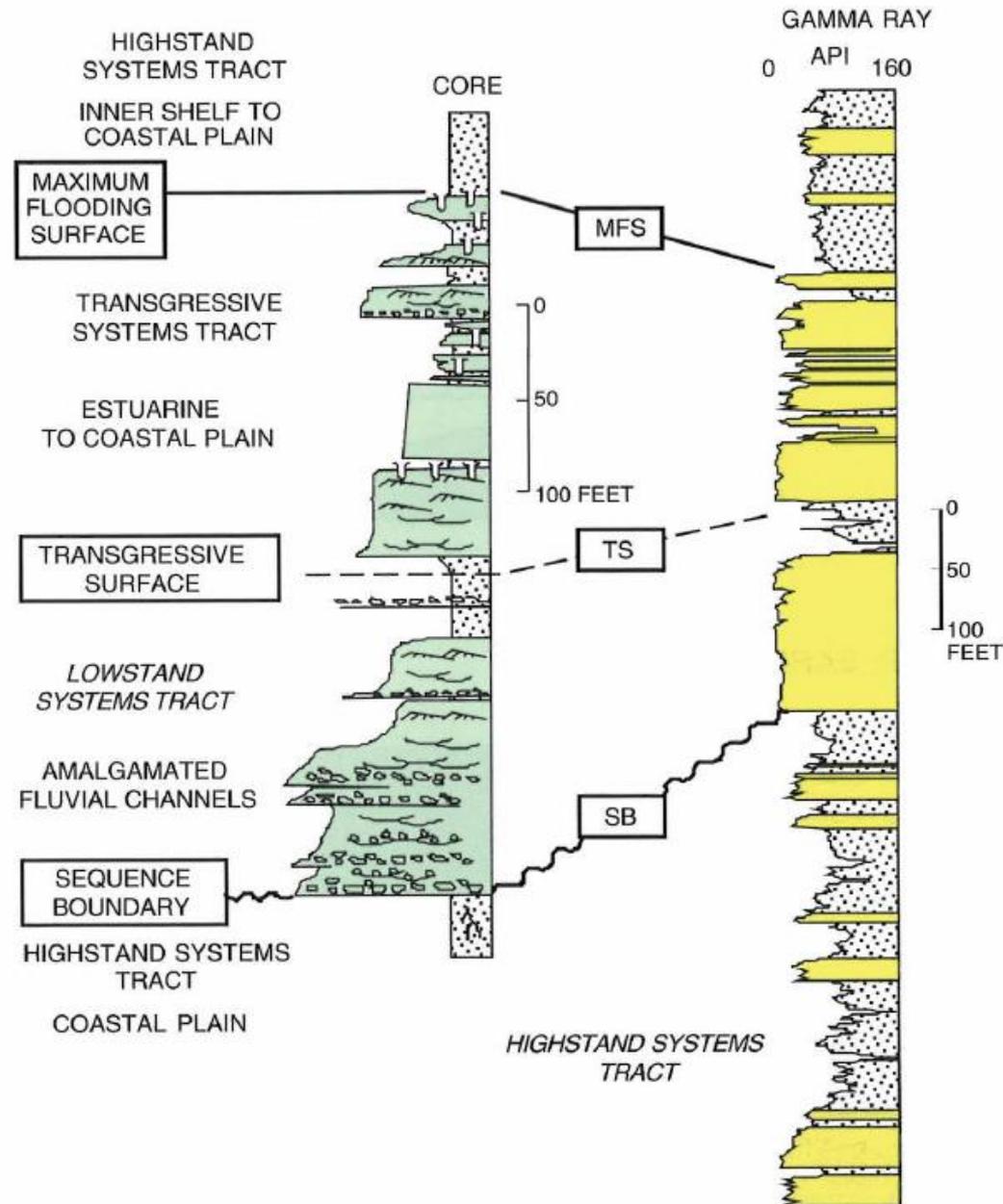
Potential source rock

Isolated reservoirs

Good reservoir continuity



# Potential continental to coastal reservoirs

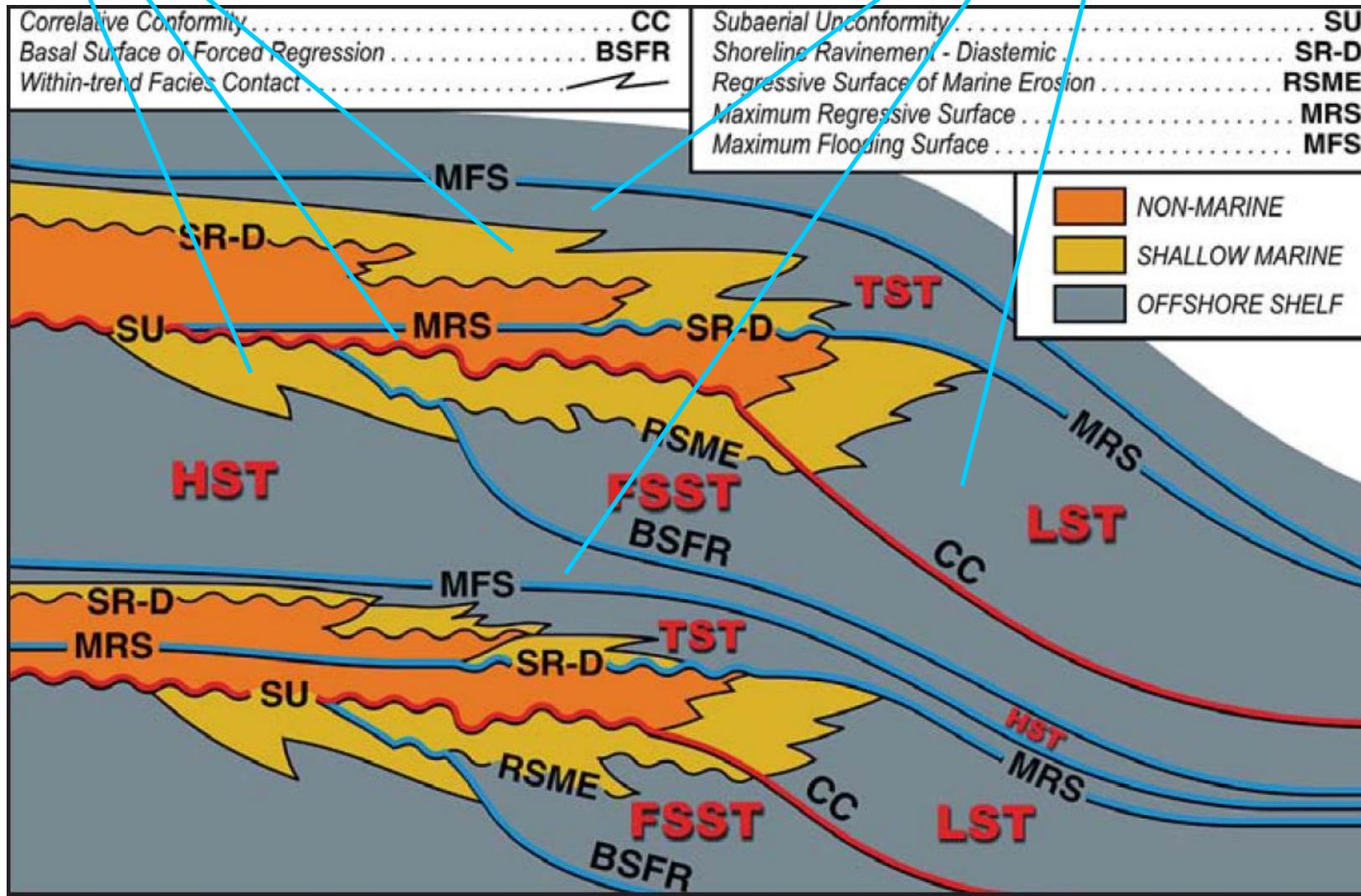


Paleocene of Colombia

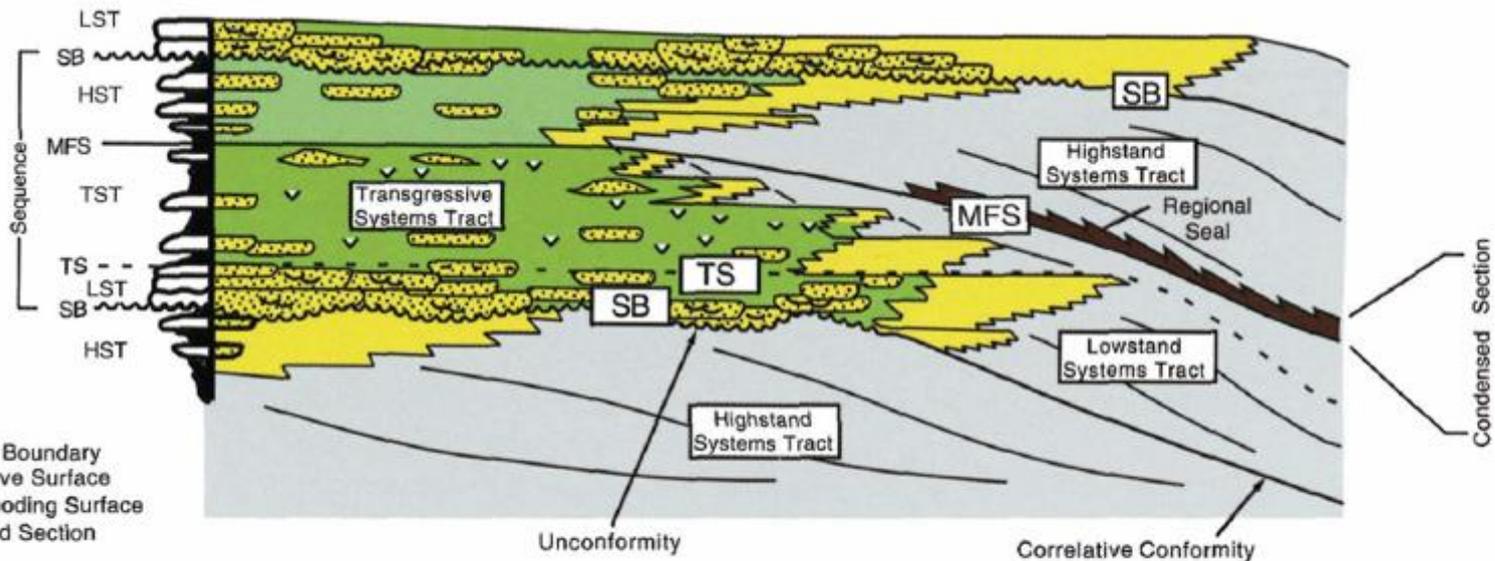
# Continental to shallow-marine reservoirs

Potential reservoirs

Sealing deposits



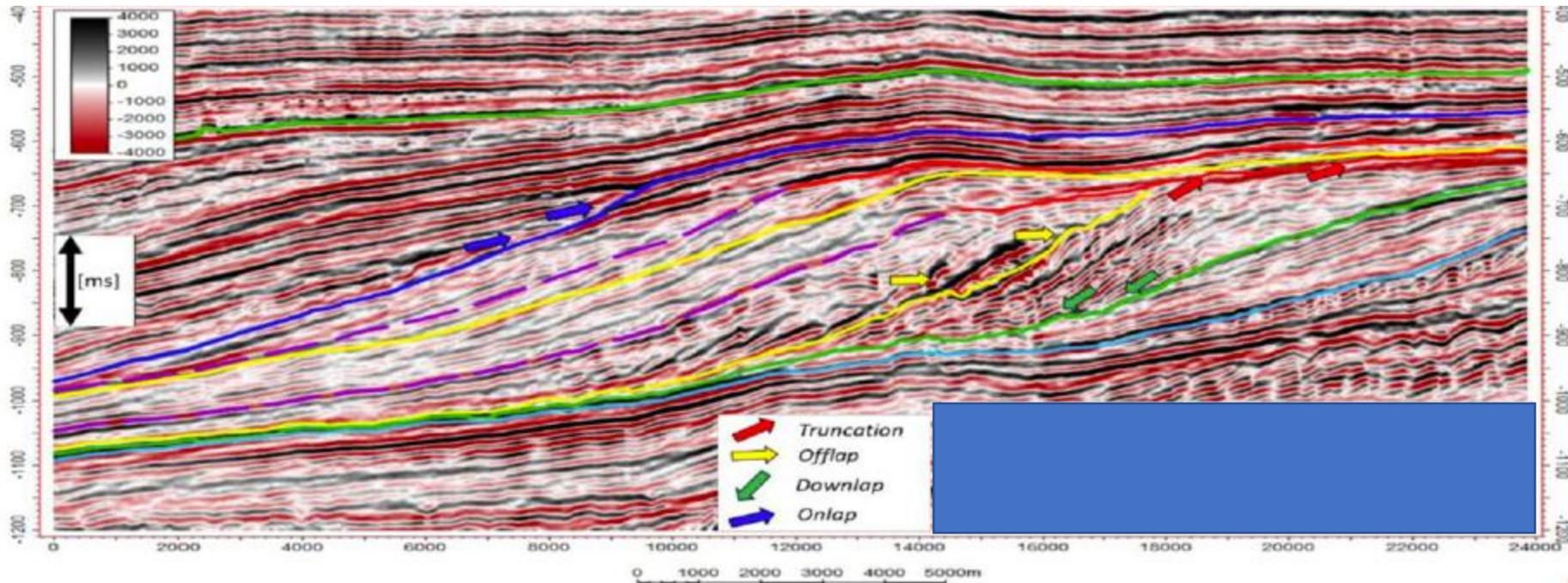
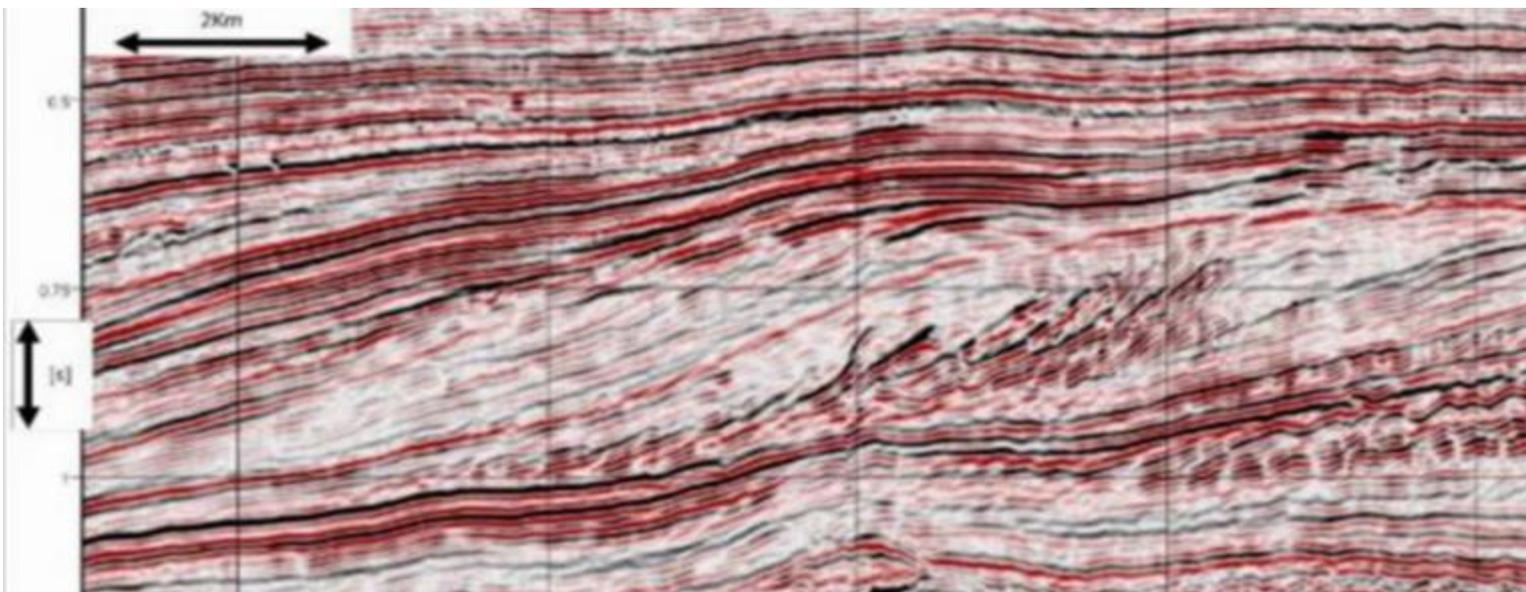
# Continental to shallow-marine reservoirs

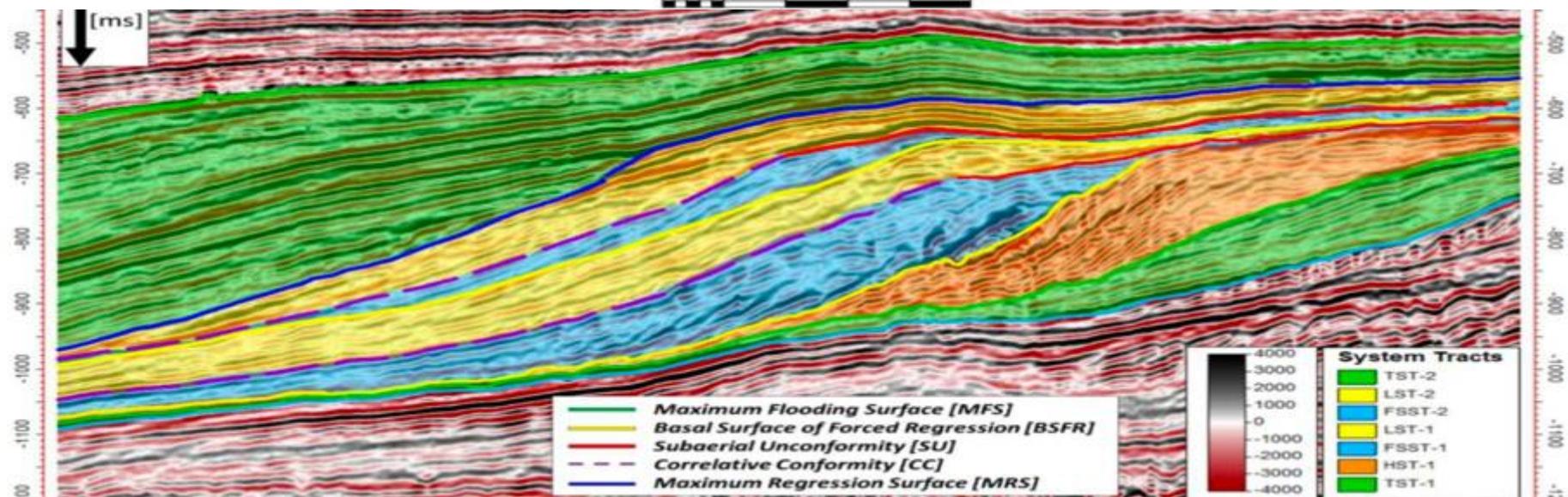
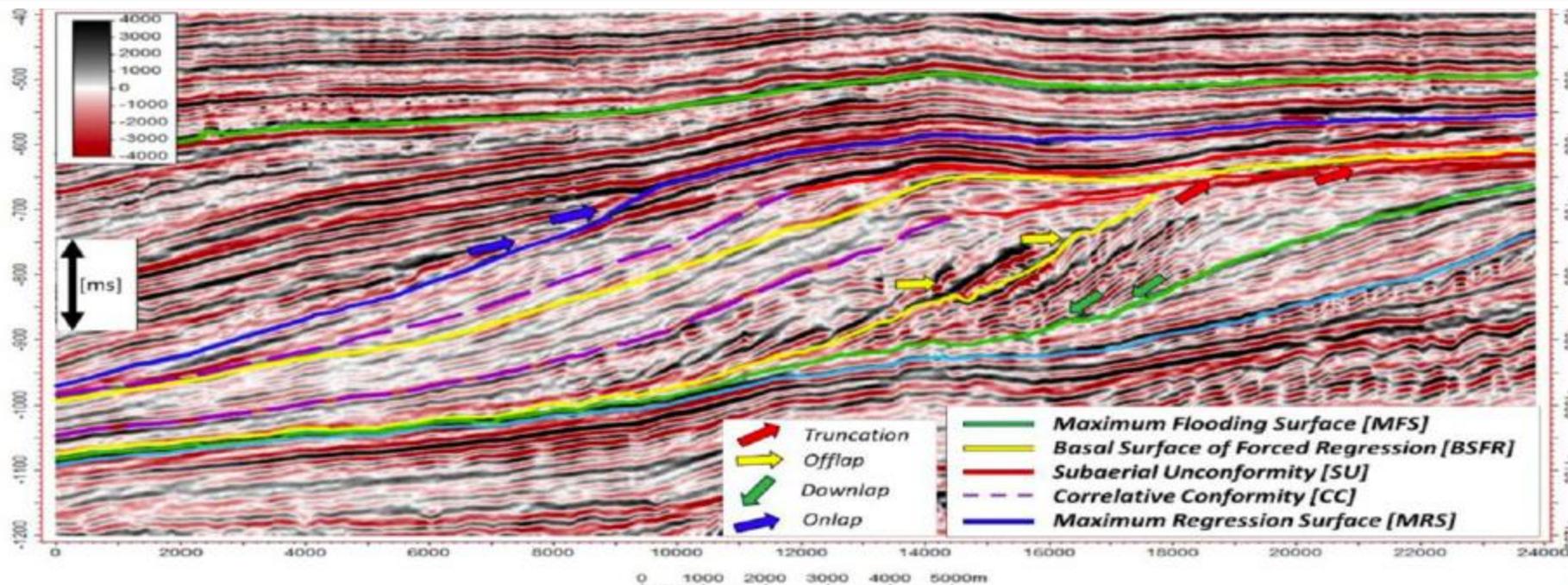


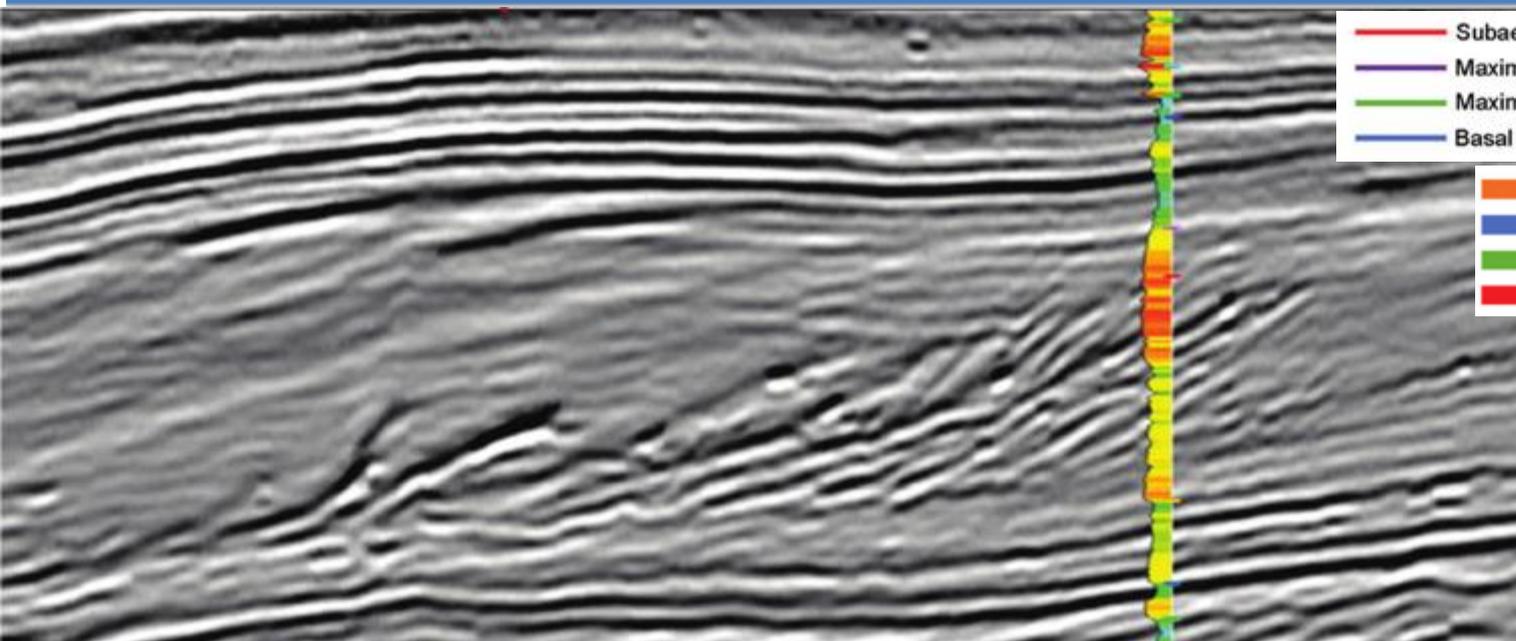
SEDIMENTARY FACIES	
	Highstand coastal-plain mudstone and fine sandstone
	Transgressive coastal-plain mudstone with carbonaceous mudstone and coal
	Lowstand floodplain mudstone and fine sandstone
	Offshore marine mudstone
	Marine condensed section; black shale glauconitic, sideritic shale, etc.
	Coastal-plain and shoreface sandstone
	Fluvial and amalgamated shoreface sandstone

Systems Tract	Play Significance	Risk	Facies Examples
Lowstand	Reservoir	Source, Charge	<b>Reservoir:</b> Shelf-edge deltas, incised-valley fill fluvial deposits, forced-regression shoreface/deltaic deposits deep-waterturbidite and bottom-current reworked deposits
Transgressive	Source, Seal, Reservoir	Reservoir	<b>Source:</b> Marine shale (mid- to outer-shell/slope/basin floor (condensed section), bay and lagoon deposits, coal <b>Seal:</b> Condensed-section shale <b>Reservoir:</b> Transgressive lag, incised-valley fill estuarine deposits, basal healing-phase-wedge deposits, backstepped shoreface deposits
Highstand	Reservoir; Source and Seal (Distally)	Seal (Proximally)	<b>Source:</b> Marine shale (slope/basin-floor condensed section) <b>Seal:</b> Condensed-section shale (slope and basin floor), alluvial-floodplain shale <b>Reservoir:</b> Shelf deltas; bayhead (estuary-head) deltas, coastal/alluvial-plain deposits

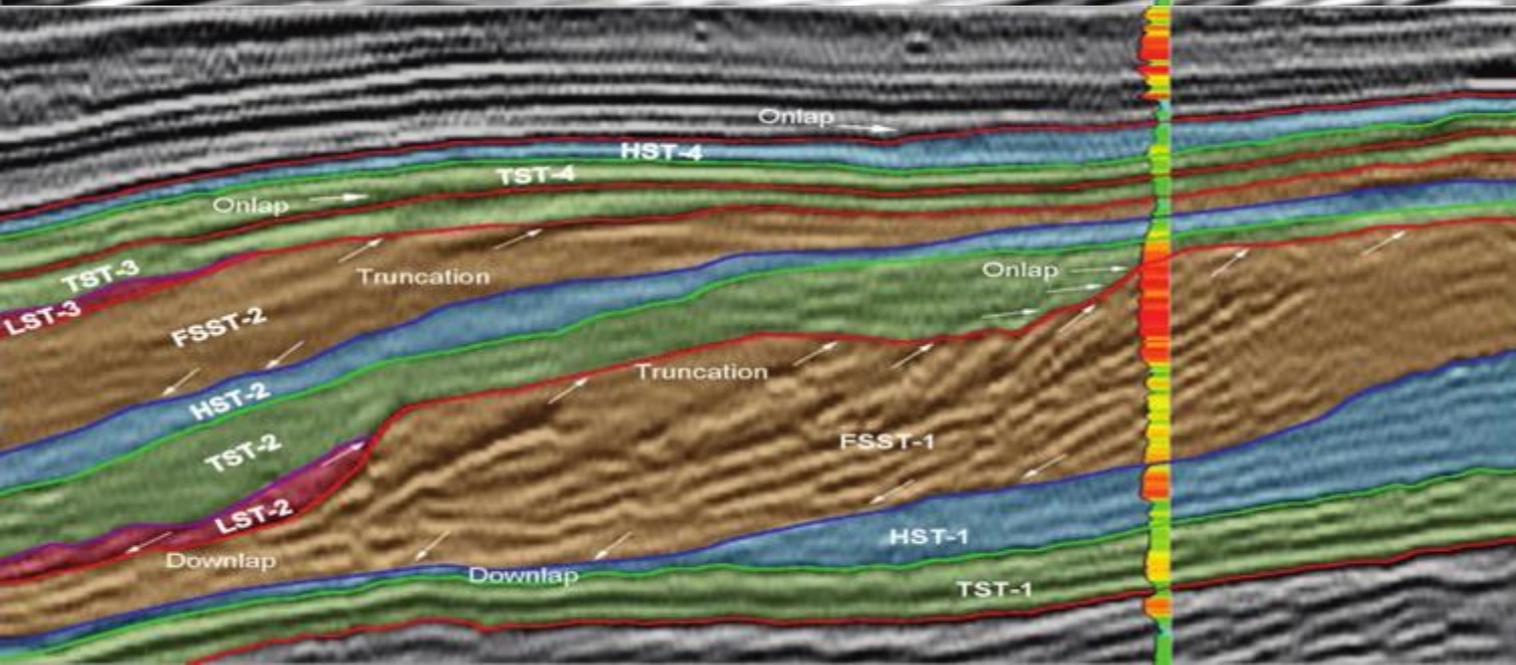
Illidge E., Camargo J., Pinto J. (2016)  
Turbidites  
Characterization  
from Seismic  
Stratigraphy  
Analysis:  
Application to the  
Netherlands  
Offshore F3 Block.  
Search and  
Discovery Article  
41952







- Subaerial Unconformity (SU)
- Maximum Regressive Surface (MRS)
- Maximum Flooding Surface (MFS)
- Basal Surface of Forced Regression (BSFR)
- Falling-stage Systems Tract (FSST)
- Highstand Systems Tract (HST)
- Transgressive Systems Tract (TST)
- Lowstand Systems Tract (LST)



Li et al. (2017)  
Depositional  
sequence  
characterization  
based on  
seismic  
variational  
mode  
decomposition.  
Interpretation  
5, SE97-SE106