UNIWERSYTET JAGIELLOŃSKI W KRAKOWIE

Sequence Stratigraphy

Basics, Concepts & Applications

07.-09.03.2016

Dr. Hartmut Jäger

Books

Posamentier, H.W. & Weimer, P. (eds), 1994: Siliciclastic Sequence Stratigraphy: Recent Developments and Applications. (AAPG Memoir)

Loucks, R.G. & Sarg, J.F., 1994: Carbonate Sequence Stratigraphy: Recent Developments and Applications. (AAPG Memoir)

Emery, D. & Myers, K., 1996: Sequence Stratigraphy. Blackwell Science

Catuneanu, O., 2006: Principles of Sequence Stratigraphy (Developments in Sedimentology). Elsevier

Haq, B.U., 2013: Sequence Stratigraphy and Depositional Response to Eustatic, Tectonic and Climatic Forcing. (Coastal Systems and Continental Margins). Springer

Introduction

Stratigraphy

"the science of stratified (layered) rocks in terms of time and space"

(Oxford Dictionary of Earth Sciences, 2003)

Sequence

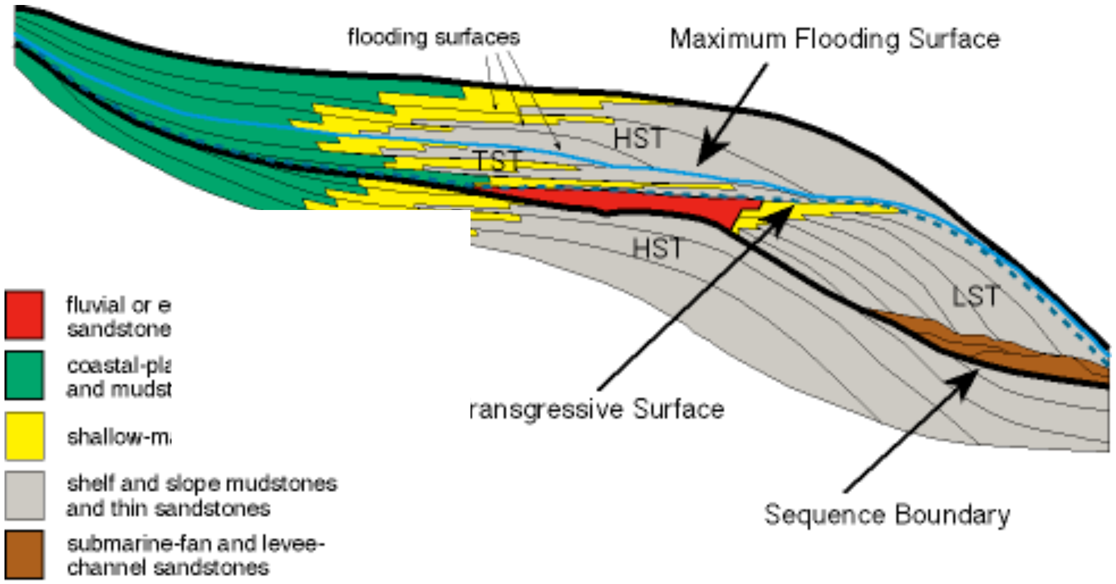
"A chronologic succession of sedimentary rocks from older below to younger above, essentially without interruption, bounded by unconformities."

(Glossary of Geology, 1987)

Introduction

Sequence stratigraphy is one type of **lithostratigraphy**

- used for subdivision of the sedimentary basin fill by a framework of major depositional and erosional surfaces
- creates units of contemporaneous accumulated strata bounded by these surfaces (=sequences)
- developed for clastic and carbonate sediments from continental, marginal marine, basin margins and down-slope settings of basins. The
- surfaces often generated during changes in relative sea level and formed during associated deposition and erosion.

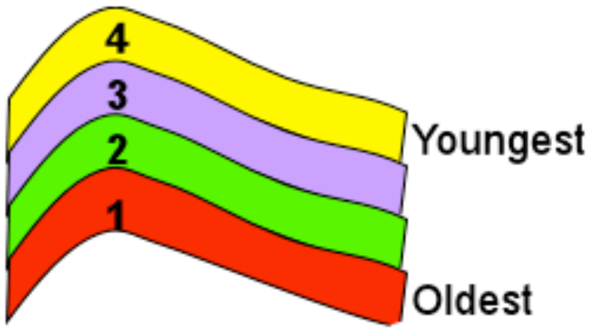


Introduction - basic principles

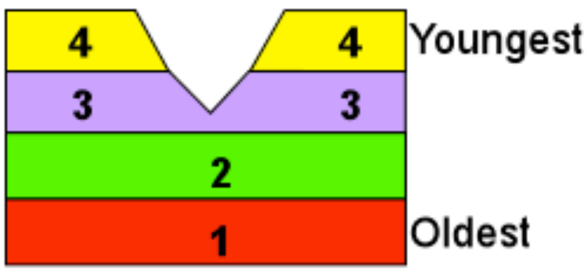
Sequence Stratigraphy is based on ***Steno's principles*** of sediment accumulation

Law of Superposition

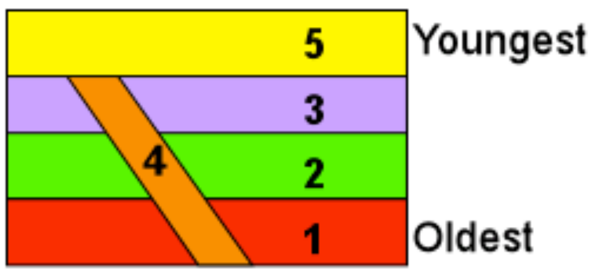
Law of Original Horizontality (originally like figure to the right)



Law of Lateral Continuity



Cross-Cutting Relationship

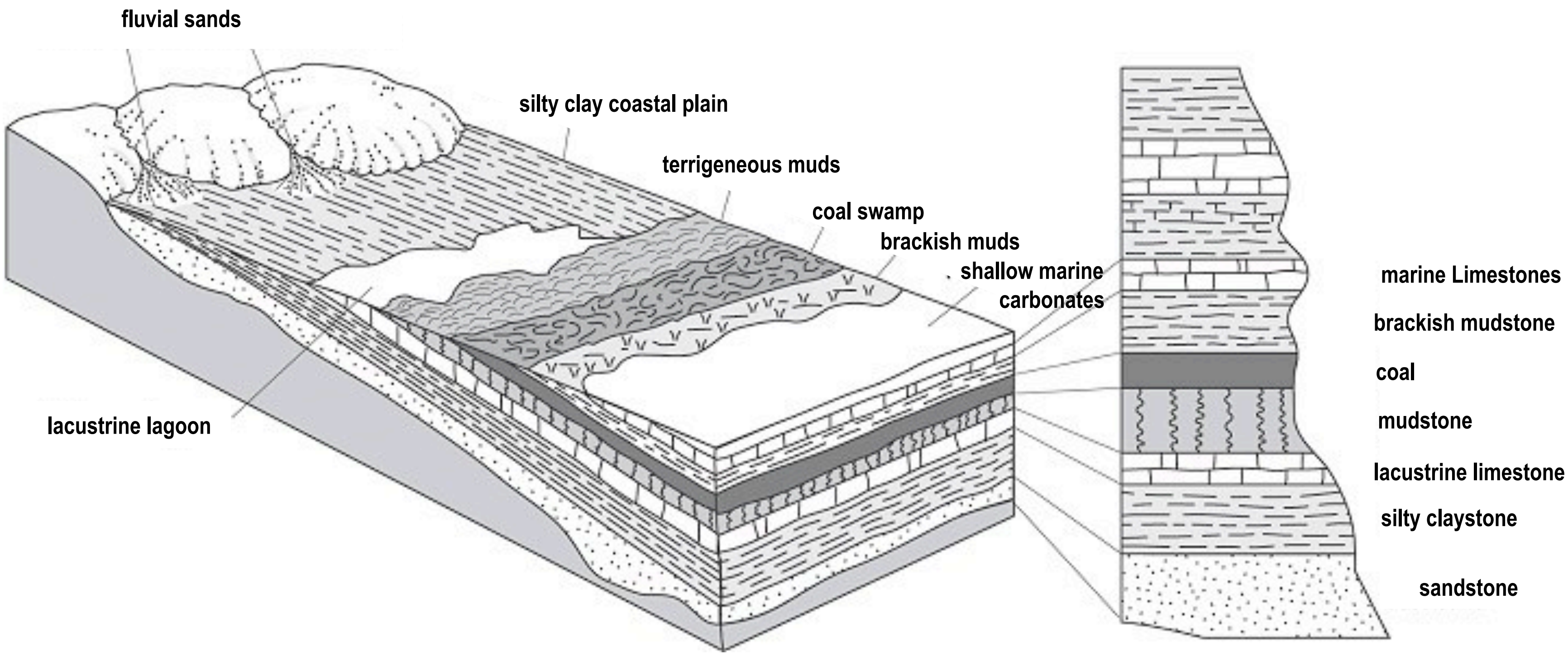


Introduction - basic principles

Sequence Stratigraphy is based on ***Walther's Facies Law*** –

vertical and lateral equivalence of sediments

Only those facies types and lithologies can be deposited on top of each other, which can be observed beside each other at one time level



Introduction - Lithostratigraphy

Lithostratigraphic units recognized and defined by lithic characteristics only, not by age.

Hierarchy: Supergroup – Group – Formation – Member - Bed/Bed sets

2 types of ***contacts*** between units: conformable and unconformable.

Conformable: continuous deposition, no break or hiatus (surface = **conformity**)

Unconformable: period of erosion/non-deposition (surface = unconformity)

Lithostratigraphical correlation based on lithofacies (using key beds or sequences)

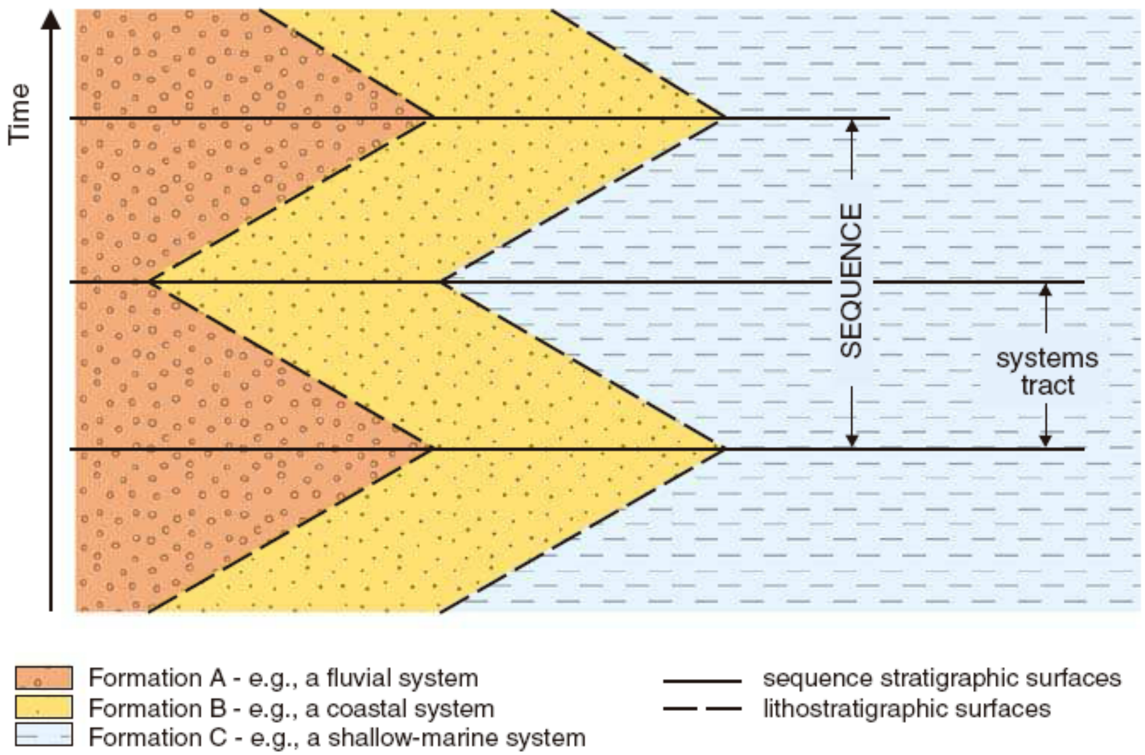
based on lithology, color, structure, thickness…

Lithostratigraphy

Different types of lithostratigraphical frameworks conflicting with sequence stratigraphy:

- Lithostratigraphy (sensu strictu)
- Allostratigraphy
- Trangression-Regression Cycles
- Stratigraphic Sequences
- Seismo-Stratigraphy
- Sequence Stratigraphy

Lithostratigraphy - Allostratigraphy



Time dependent stratigraphic framework

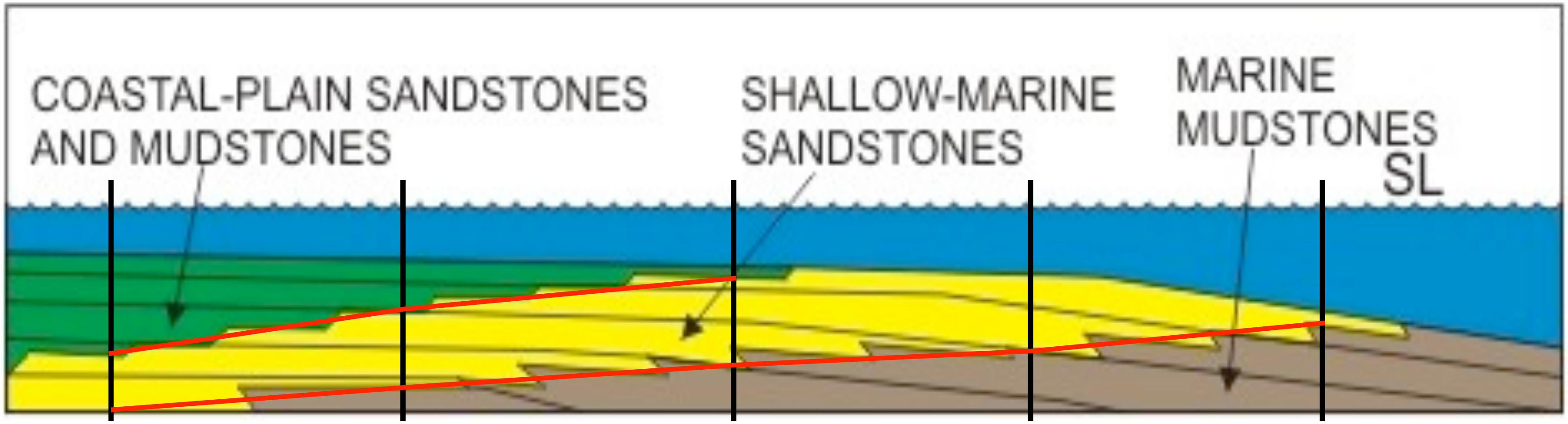
Subdivision by time equivalent surfaces/ layers:

Transgressive/ regressive surfaces (erosional & marine flooding surfaces)

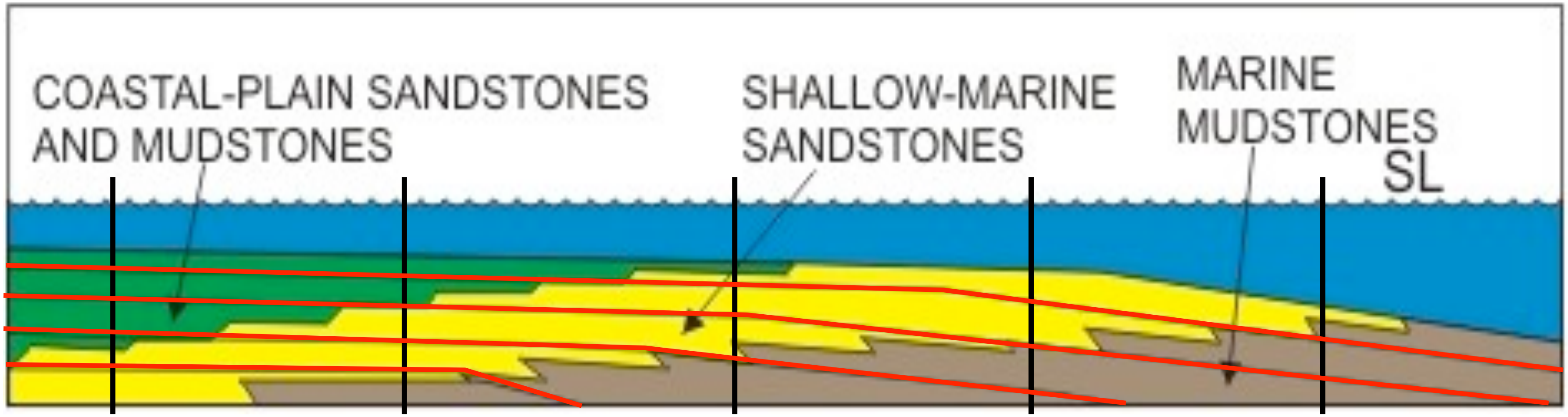
also tuffites, tempestites, turbidites .... (marker beds)

Lithostratigraphy vs. Allostratigraphy

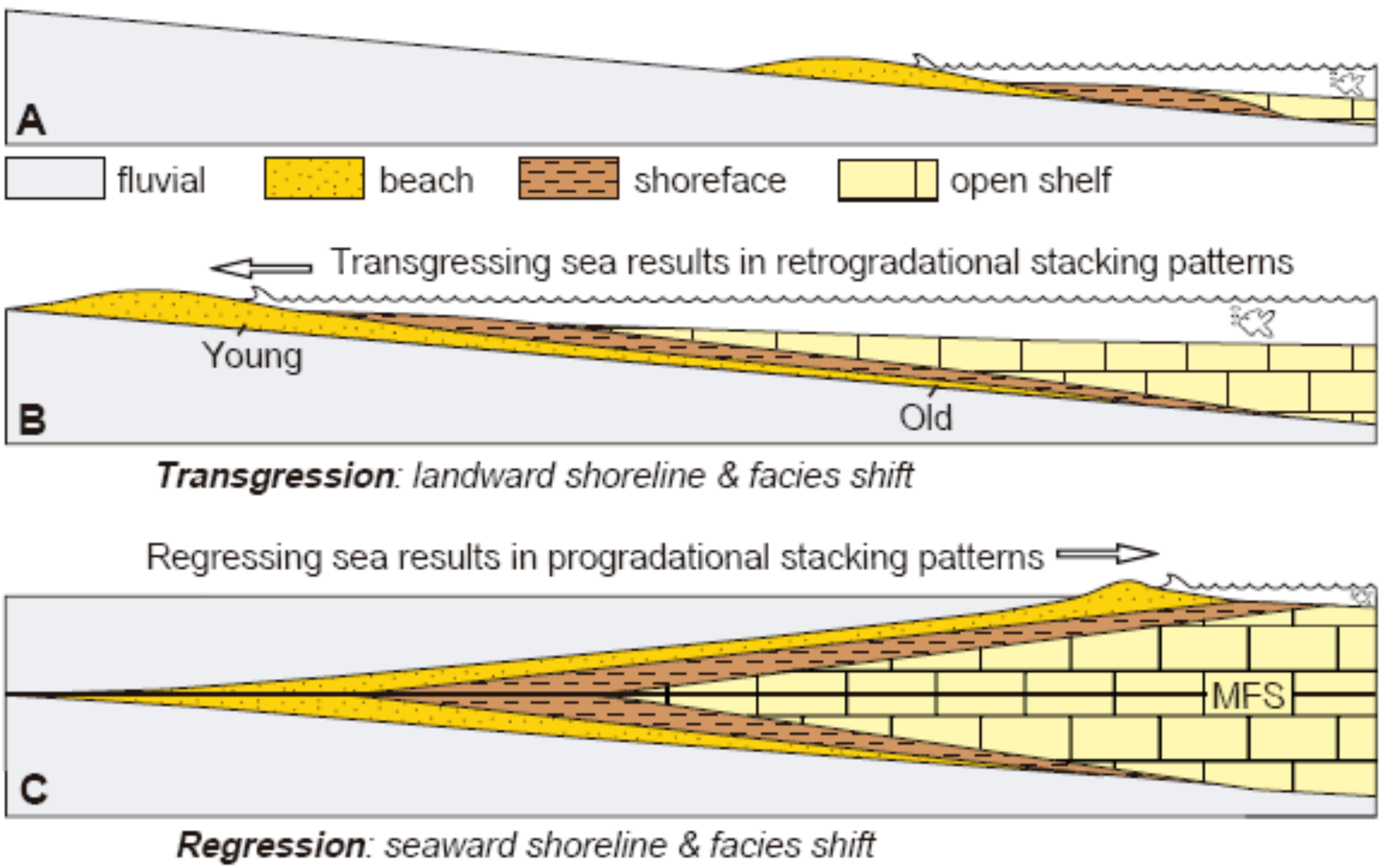
Lithostratigraphic correlation – correlation of similar lithologies



Allostratigraphic correlation – correlation of timelines but different lithologies (facies)



Lithostratigraphy - Transgressive-Regressive Cycles

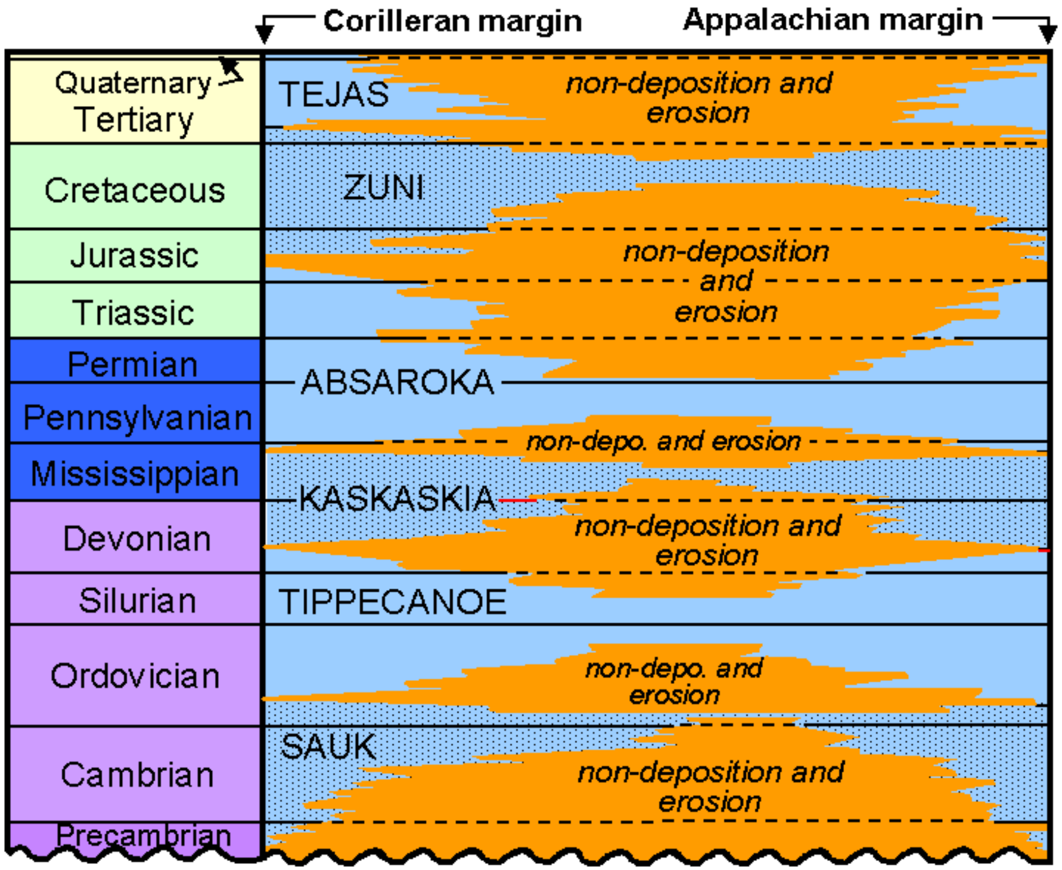


Time dependent stratigraphic framework organized by transgressive / regressive surfaces

Lithostratigraphy - Stratigraphic sequences

Stratigraphic Sequences - assemblage of strata and formations bounded by prominent interregional unconformities

Sloss et al. 1949



Subdivision of the Phanerozoic succession (blue) of N-America into six sequences (blue), limited by times of non-deposition or erosion (yellow)

Sloss 1963

Stratigraphic sequences are based on transgressive / regressive cycles

Sedimentary Cycles

Lithostratigraphical correlations are based on **sedimentary cycles**

Several orders of sedimentary cycles – 0.01 to >100 my

1st-order cycles:

Continental sequence

2nd-order cycles:

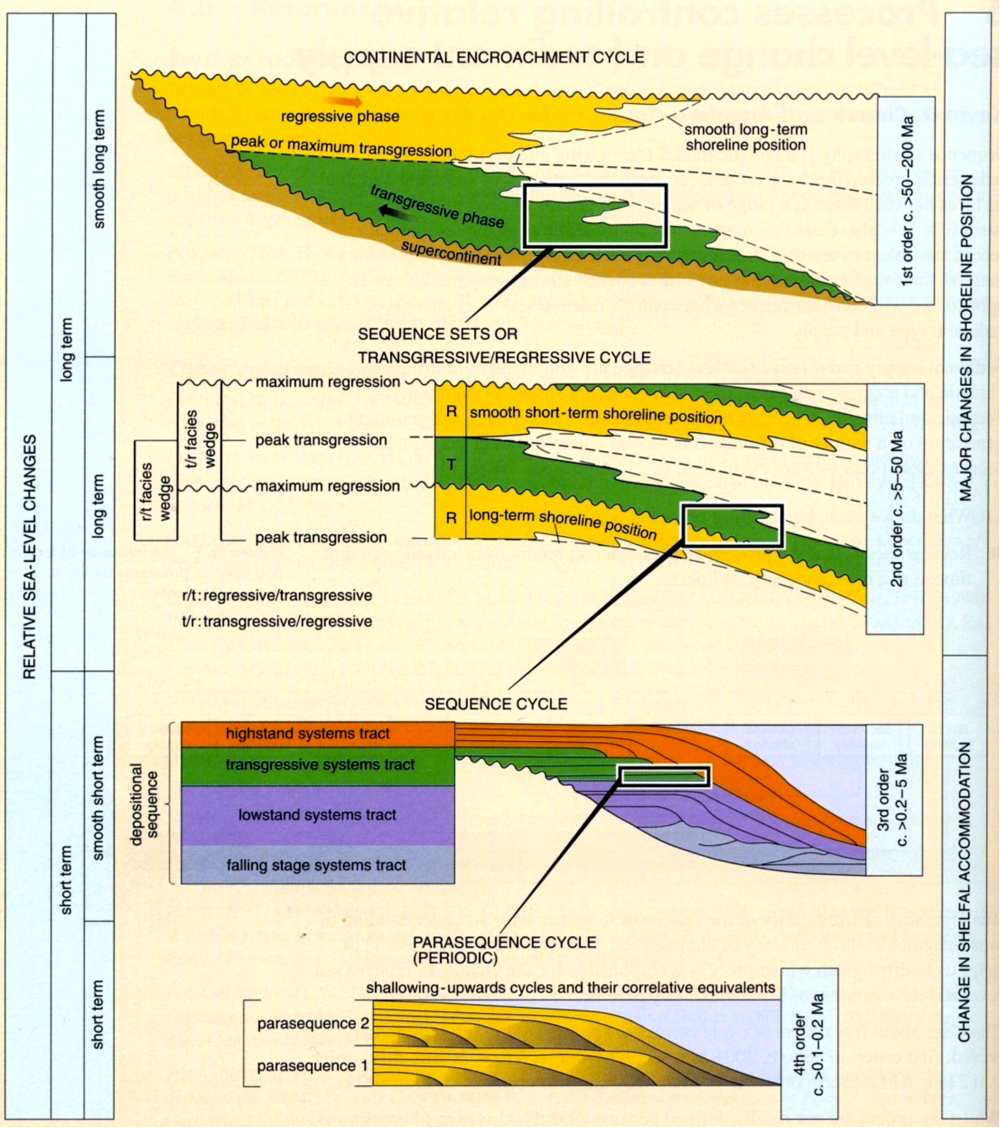
Transgressive/regressive cycle

3rd-order cycles:

Sequence cycle

4/5th order cycles:

Parasequence cycle

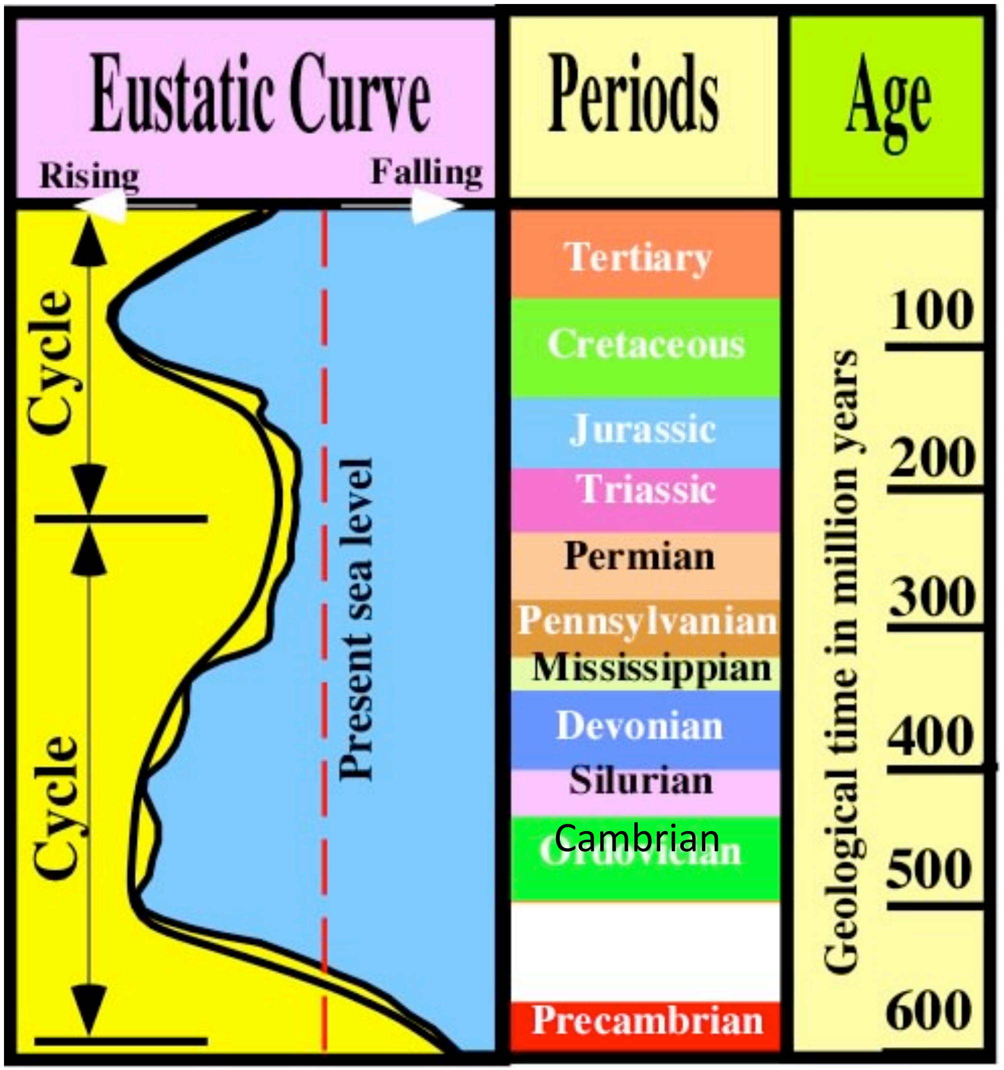


Sedimentary Cycles

Tectono-Eustatic/ Eustatic Cycle Order	Sequence Stratigraphic Unit	Duration (my)	Relative Sea Level Amplitude (m)	Relative Sea Level Rise/Fall Rate (cm/1,000 yr)
First		>100		<1
Second	Supersequence	10-100	50-100	1-3
Third	Depositional Sequence Composite Sequence	1-10	50-100	1-10
Fourth	High Frequency Sequence, Parasequence and Cylce Set	0.1-1	1-150	40-500
Fifth	Parasequence, High-Frequency Cycle	0.01-0.1	1-150	60-700

Continental break-up
Sea-floor spreading
Eustatic (melting ice caps)
Orogenesis and Rifting
Local tectonical developments
Milankovich cyclicity
Climatic cycle

Sedimentary Cycles - 1st order cycles



Continental-Cycle > 100 My

Controlled by continental break up and formation

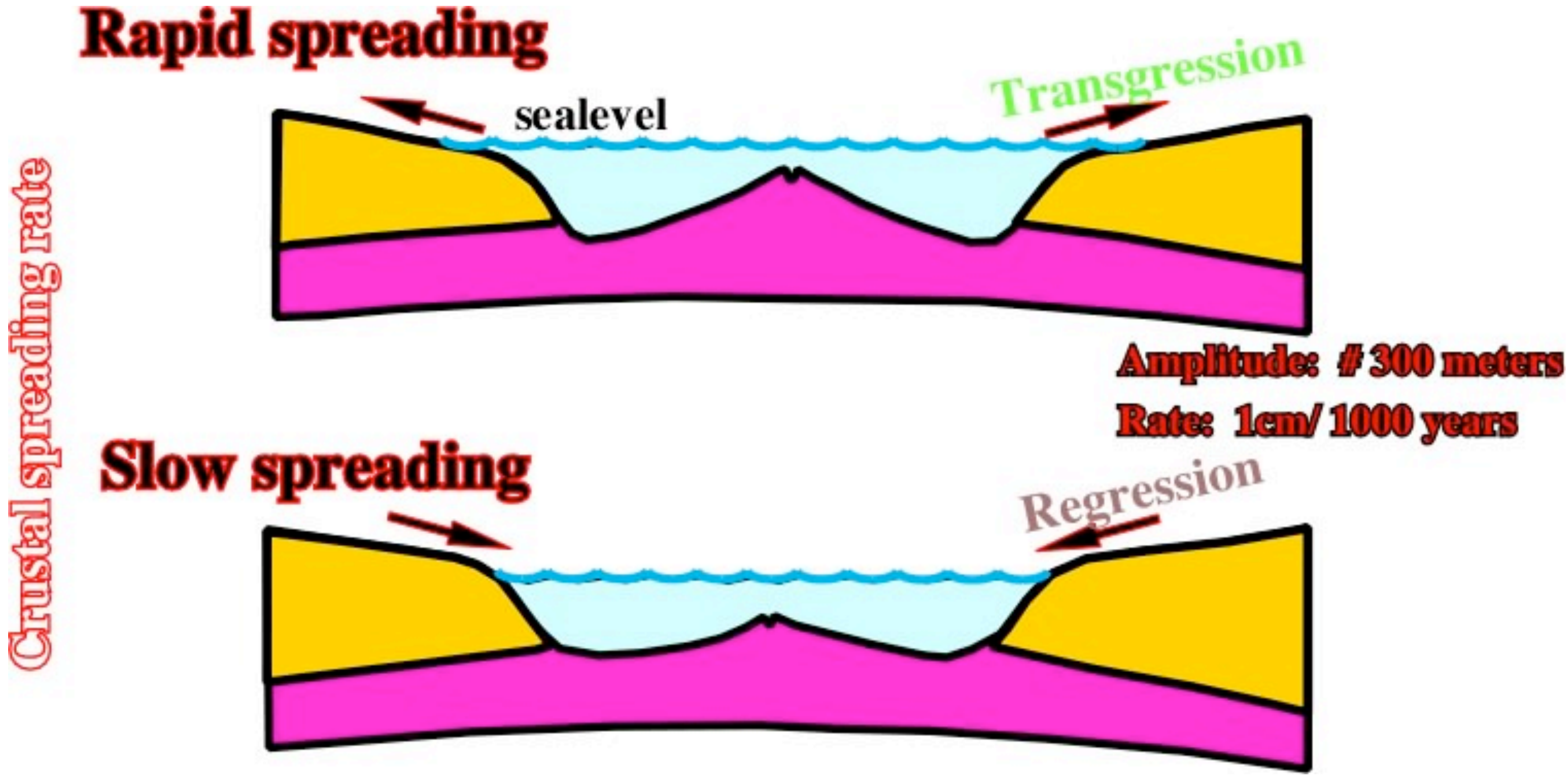
Phanerozoic 1st order eustatic cycle linked to Precambrian (Rodinia or Proto-Pangea) and Permo-Triassic (Pangea) supercontinents.

1st order eustatic cycles are directly related to the volume of oceanic basins

Sedimentary Cycles - 2nd order cycles

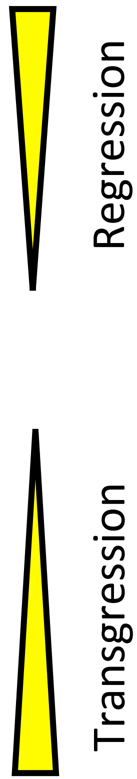
Transgressive – regressive Cycle 10-100 My

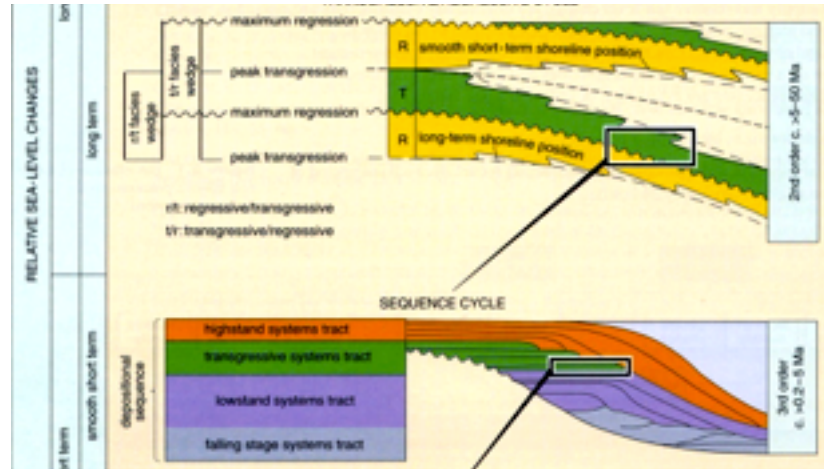
Mainly controlled by sea-floor spreading



Sedimentary Cycles - 3rd order cycles

Sequence Cycle 1-10 My





Based on eustatic sea-level changes

Local to regional volcanic and tectonic events – rifting, orogenesis, freezing/ melting of ice caps

Changes to earth's shape, producing "bulges" or "sags" = ocean level fluctuations.

Sedimentary Cycles - 4-5th order cycles

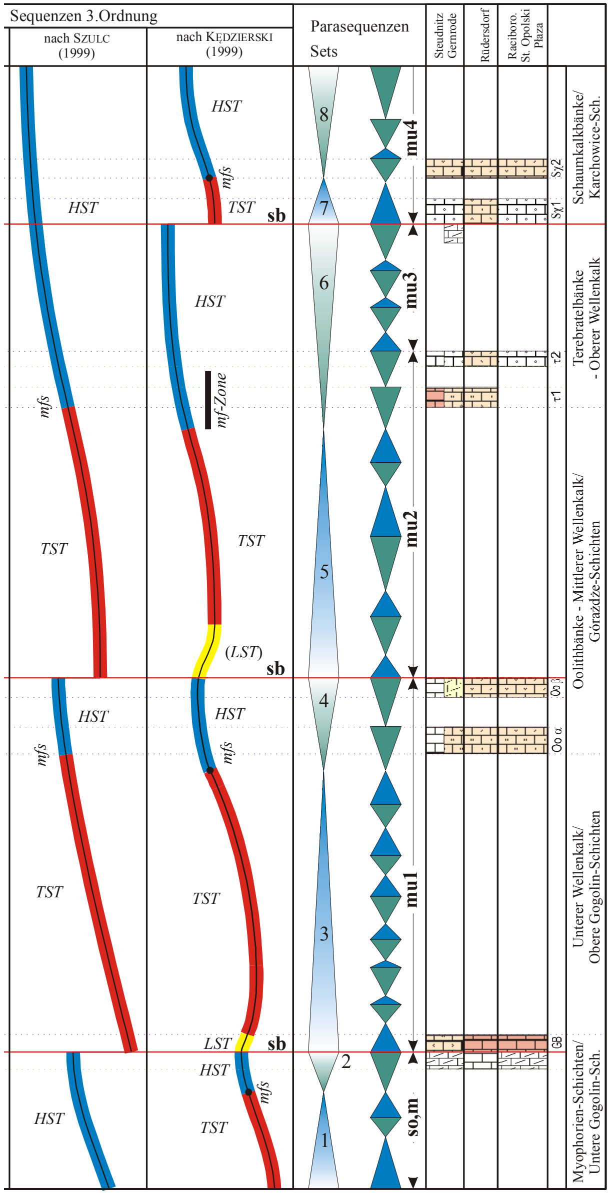
Parasequence Cycle 0,01-1 My

Caused by high-frequency changes in the realitve sea-level
(Milankovich cycles, climate)

Parasequences are defined as a relatively conformable succession of genetically related beds or bedsets bounded by marine flooding surfaces and their correlative surfaces.

Most parasequences are asymmetical shallowing-upward sedimentary cycles

identified in lithological succession or well logs



Parasequences

Parasequence:

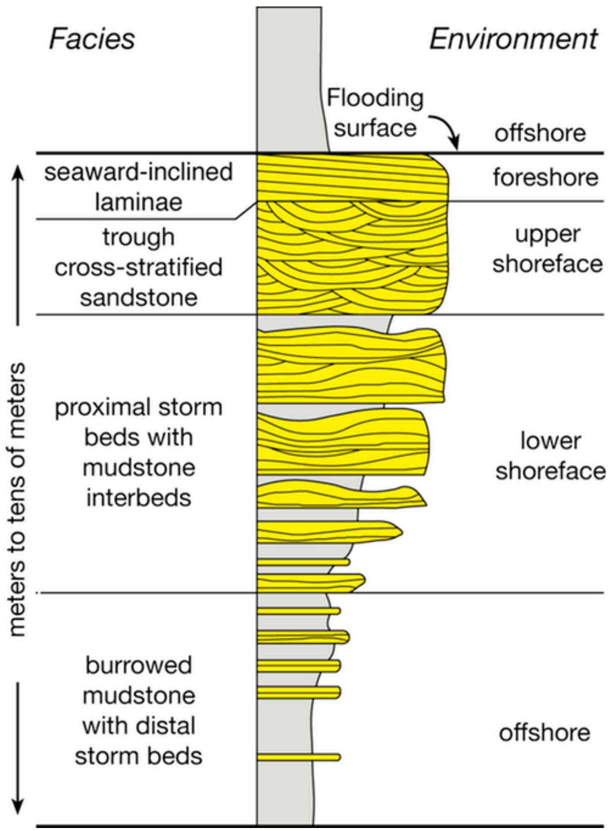
A relatively conformable succession of genetically related beds or bedsets (within a parasequence set) bounded by marine flooding surfaces (Van Wagoner 1985).

Patterns of the stacking of parasequence sets are used in conjunction with bounding surfaces and their position within a sequence to define systems tracts (Van Wagoner et al. 1988).

Sedimentary Cycles - 4-5th order cycles

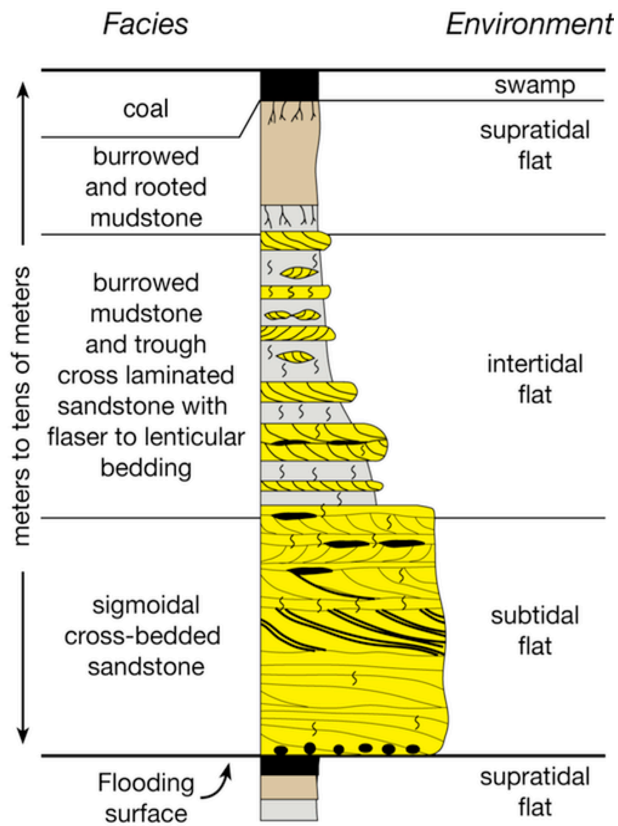
Parasequences

Sand-rich shoreline (deltaic systems):



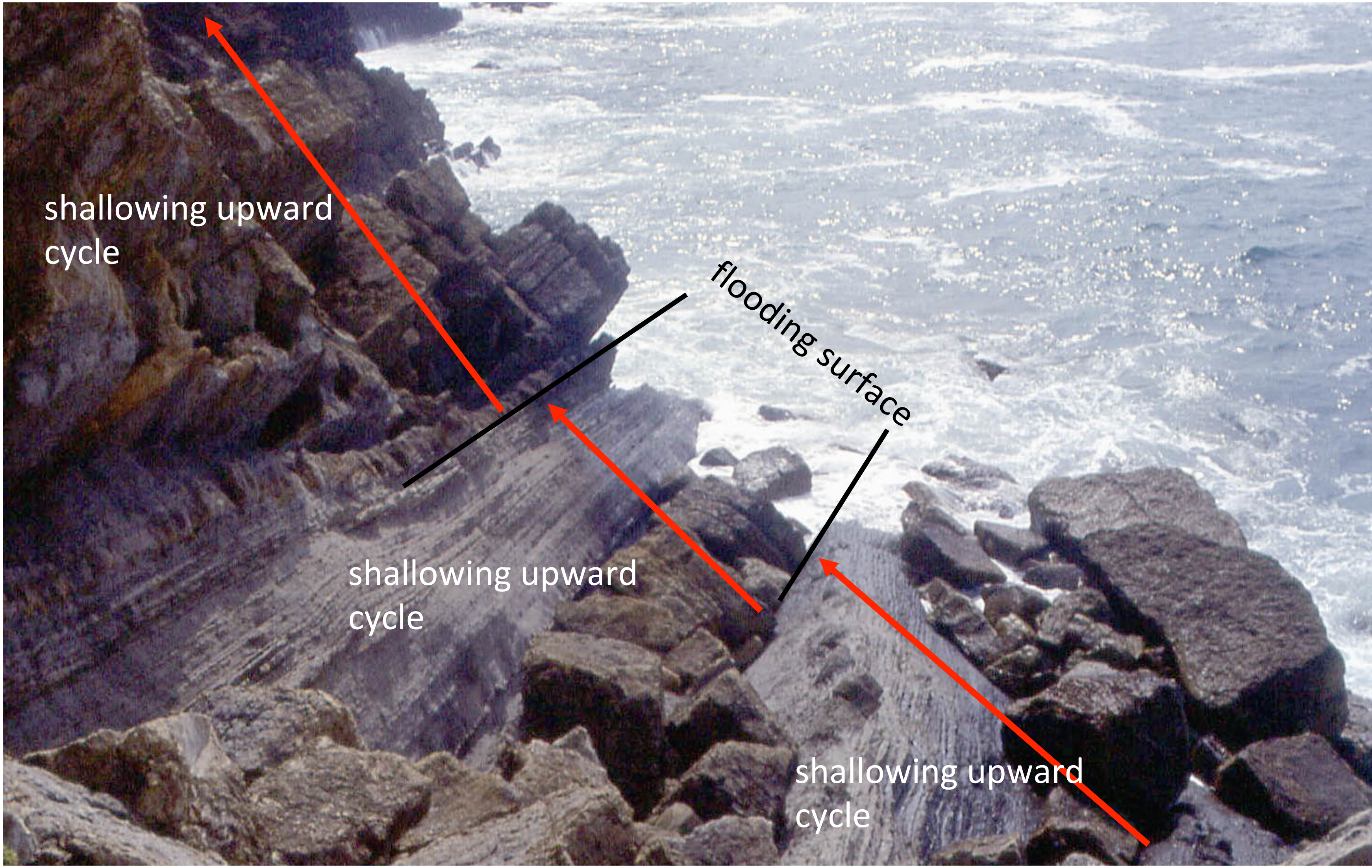
coarsening-upward succession, mud/sand mixed sediments (offshore) to sand dominated lower shoreface to pure sands of upper shoreface/foreshore

Muddy coastline:

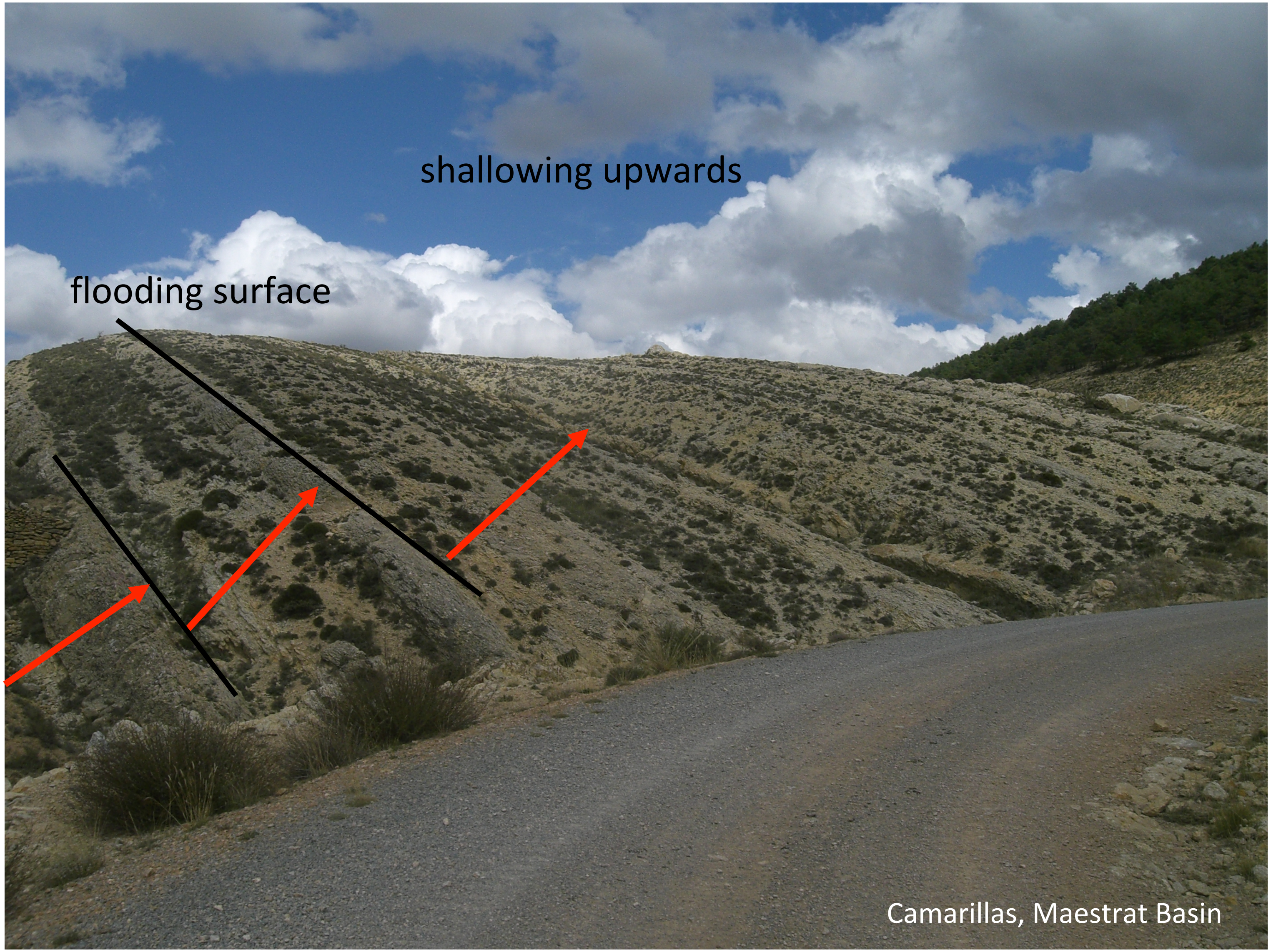


cross-bedded subtidal sands to mudstone/rippled sands alternations (intertidal) to entirely bioturbated (coaly) mudstones (supratidal).

Sedimentary Cycles - 4-5th order cycles



Sedimentary Cycles - 4-5th order cycles



Sedimentary Cycles - 4-5th order cycles

Parasequences

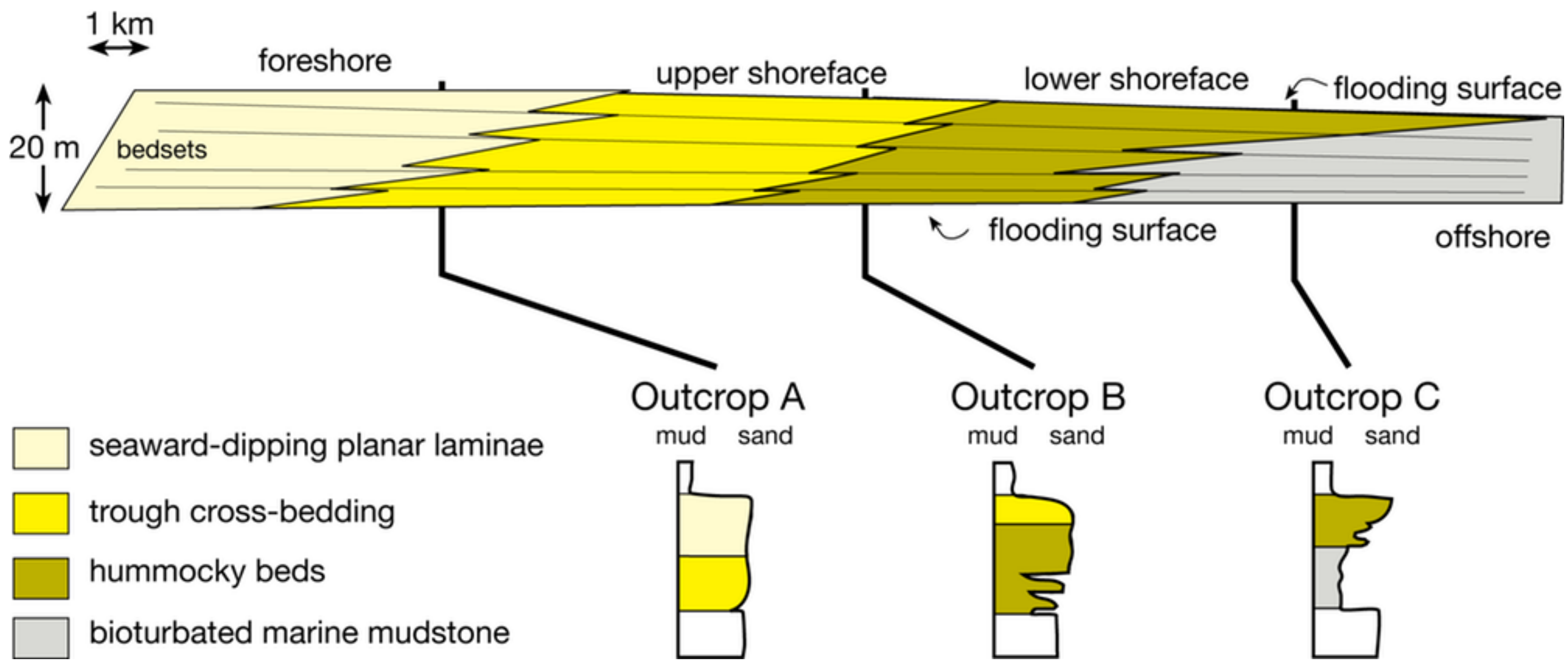
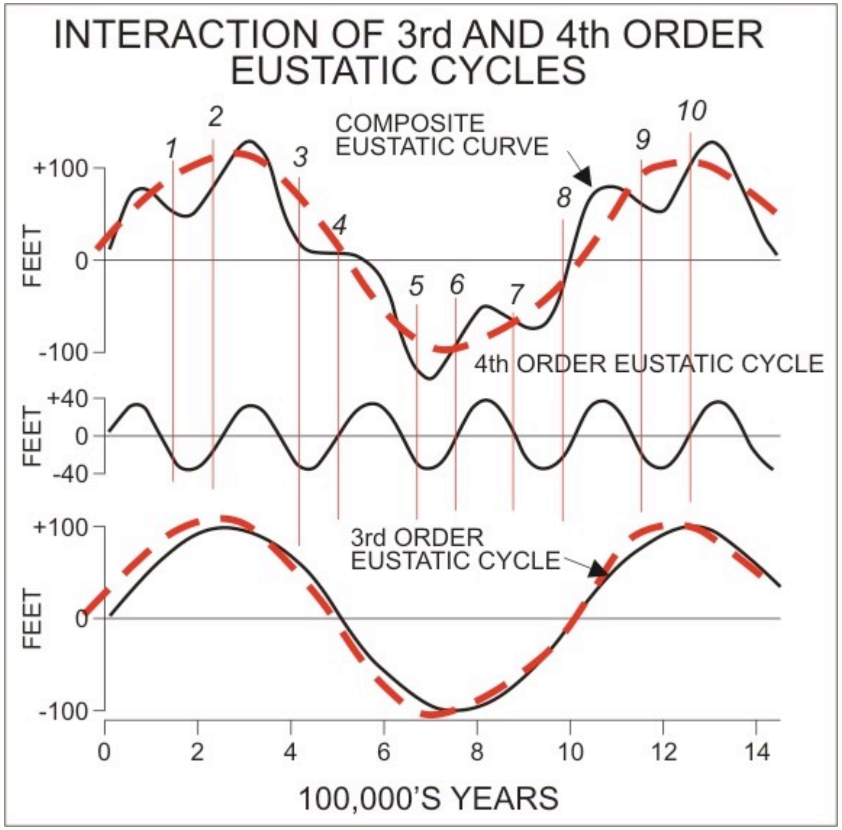


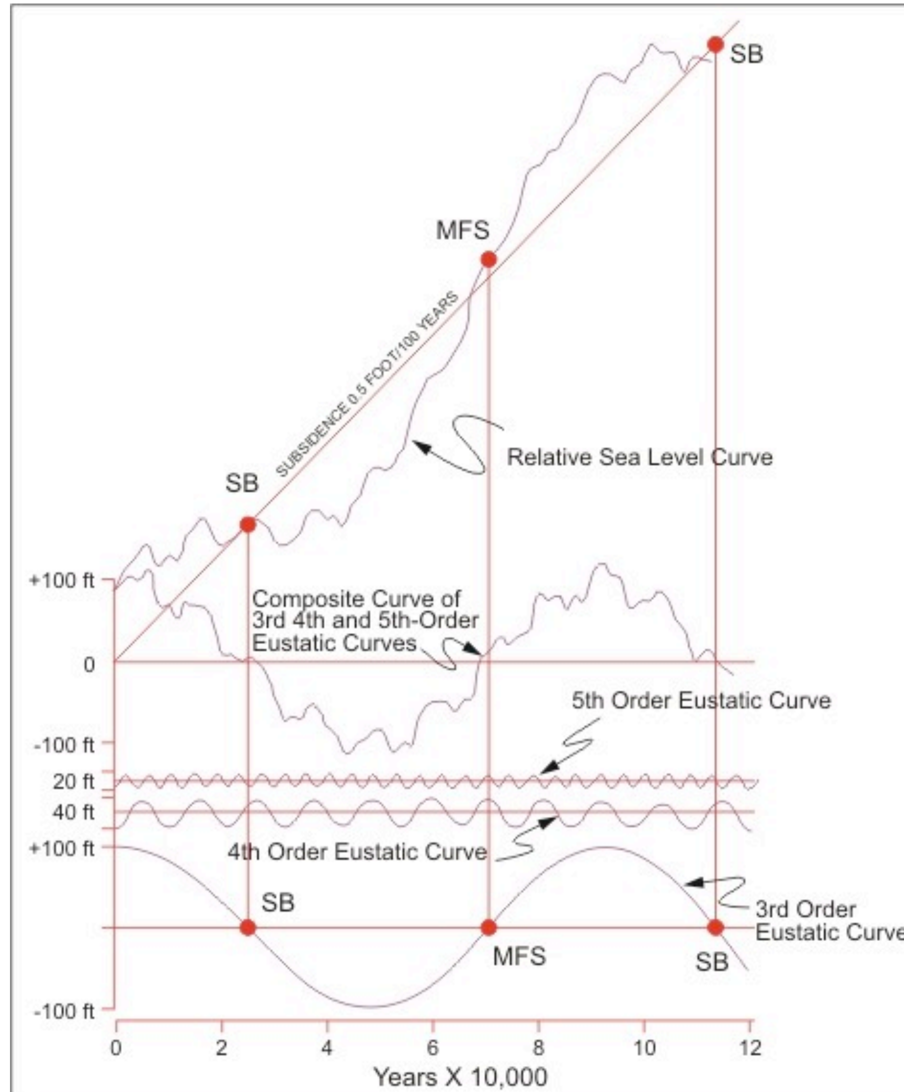
figure adapted from Van Wagoner et al. (1990)

- facies within a parasequences changes laterally, therefore a single parasequence will not be composed of the same facies everywhere
- composed of deeper water facies downdip and shallower water facies updip
- parasequence boundaries may become obscure in coastal plain settings and in deep marine settings due to the lack of facies contrast indicating flooding surfaces

Sedimentary Cycles - 4-5th order cycles

Parasequence Cycle





Overlapping of sea-level cyclicity of different orders leads to complex sequence pattern (4-5th order)

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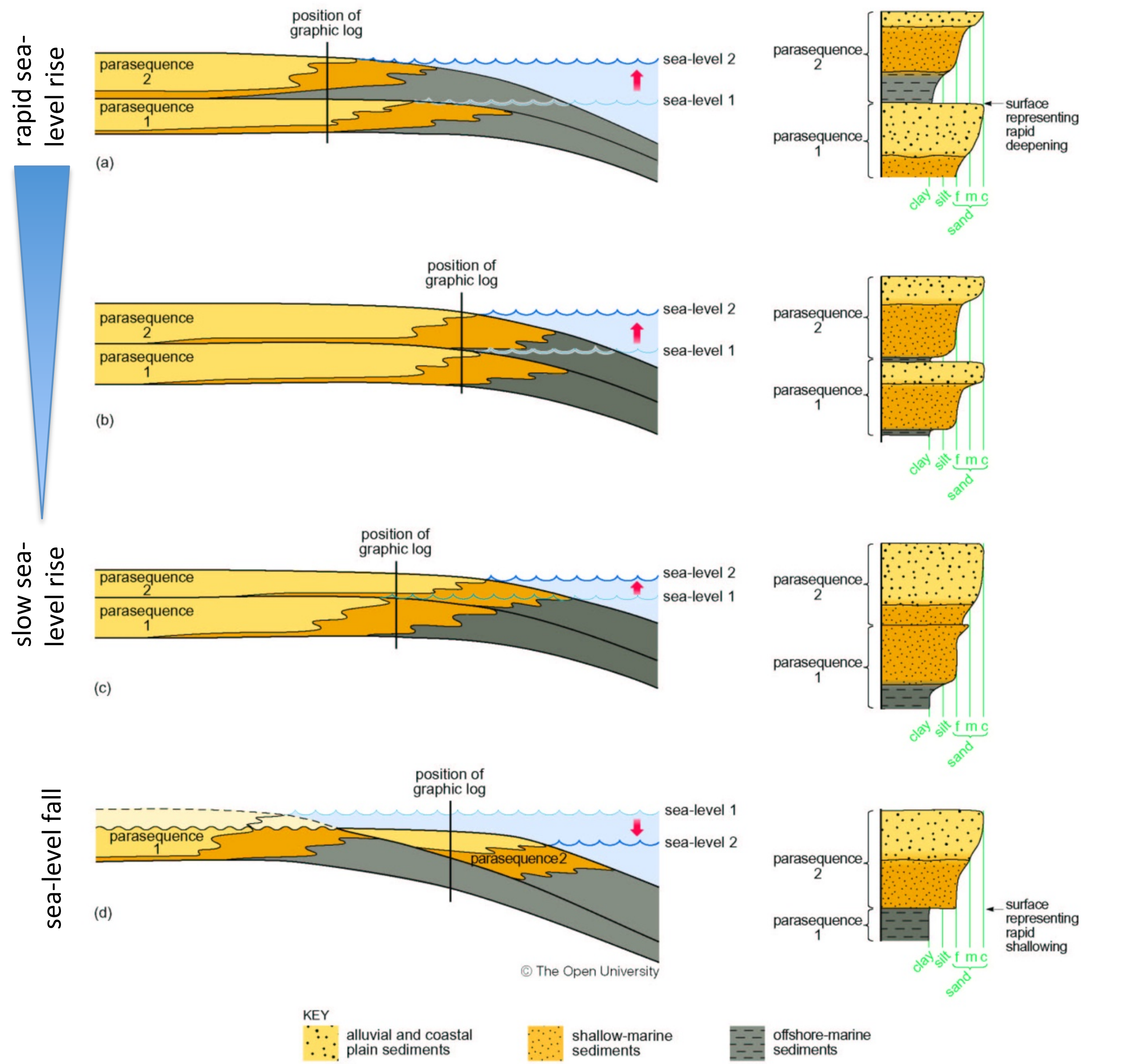
Parasequence - Stacking pattern

Stackin pattern of parasequence sets indicate the type of sea-level changes

transgression / regression

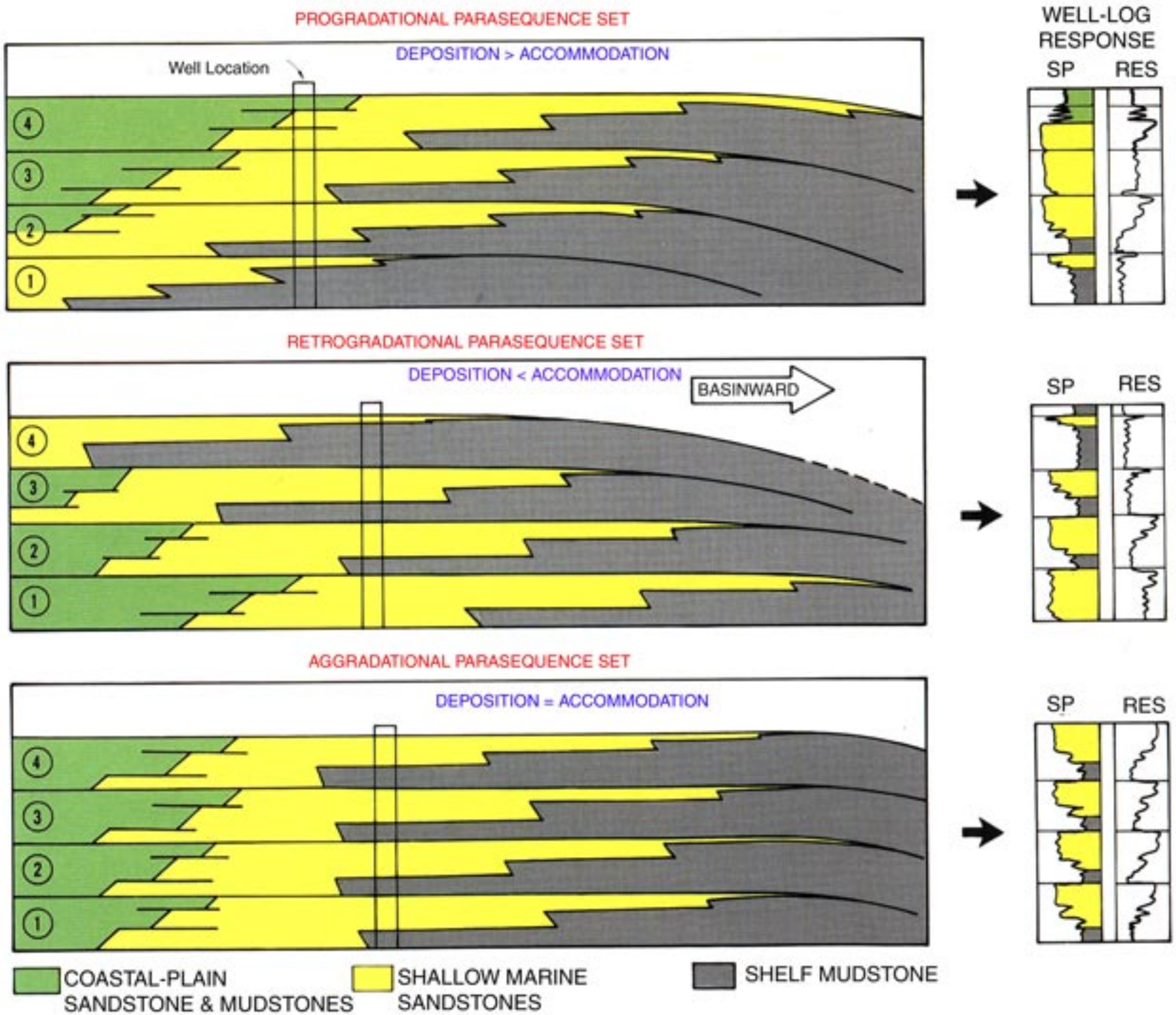


Parasequence - Stacking pattern

Progradation
Regression
Sediment input >
Accomodation space

Retrogradation
Transgression
Sediment input <
Accomodation space

Aggradation
stable sea-level
Sediment input =
Accomodation space



85 min

23 slides

Sequence Stratigraphy - Accomodation space

General opinion

Sequence stratigraphy is defined by sea-level variations,
a stratigraphic framework of transgressive / regressive cycles

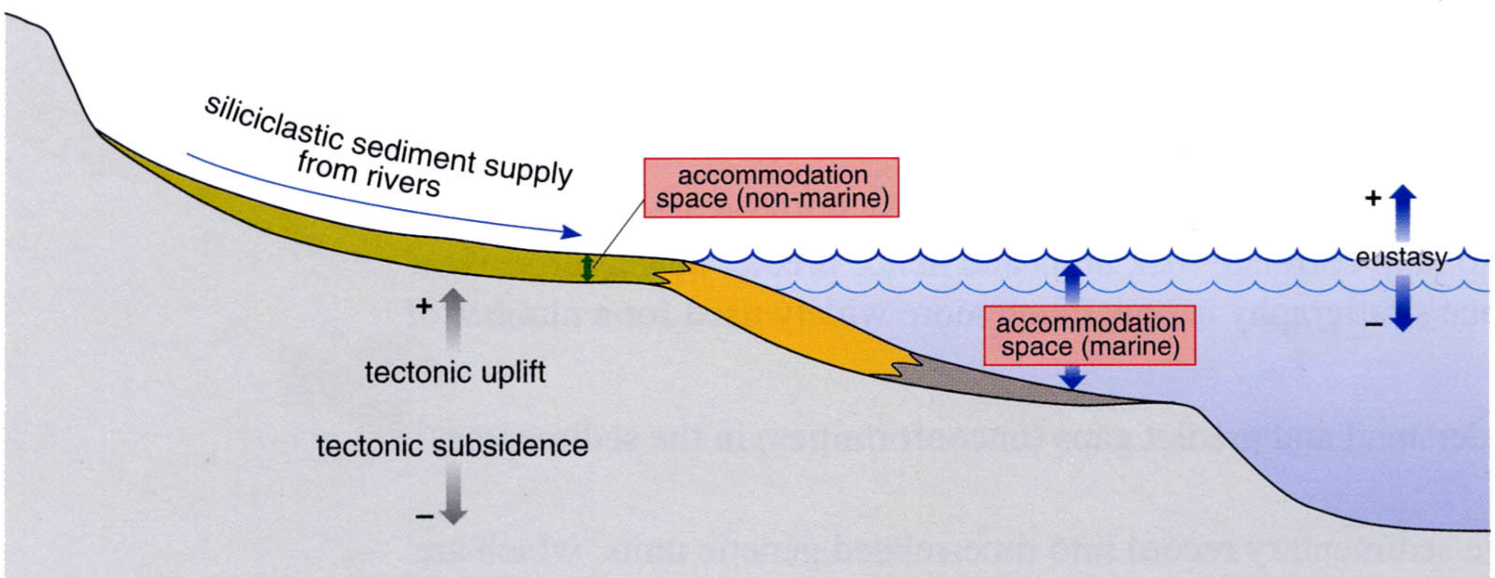
No !!

Sequence stratigraphy is defined by changes in accomodation space

Accommodation space

"*the space available for potential sediment accumulation*" (Jervey 1998)

Distribution and deposition of sediments in a siliziclastic shelf system (passive continental margin) is controlled by accommodation space



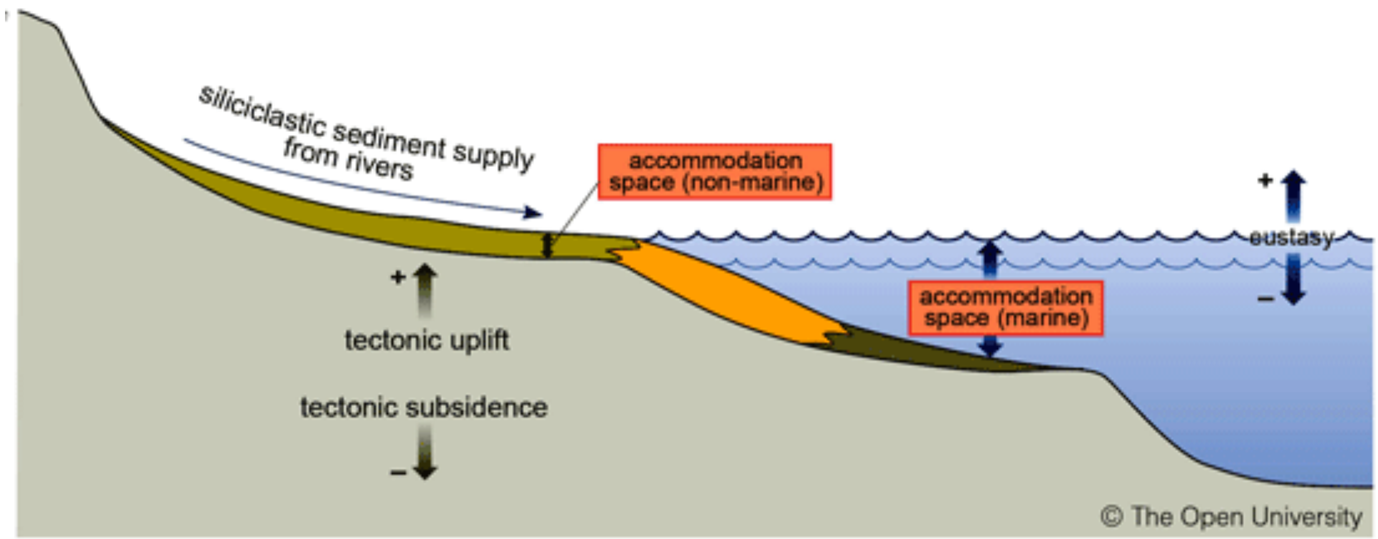
Accommodation space

Accommodation space is controlled by:

Sea level variations: eustatic sea-level rise and fall, regional to global variation

Sediment input: sediment supply into the basin, local to regional variation
weathering, erosion, transport energy (climate, tectonic development)

Basin subsidence: basement variations, regional variation, geodynamic tectonical basin development

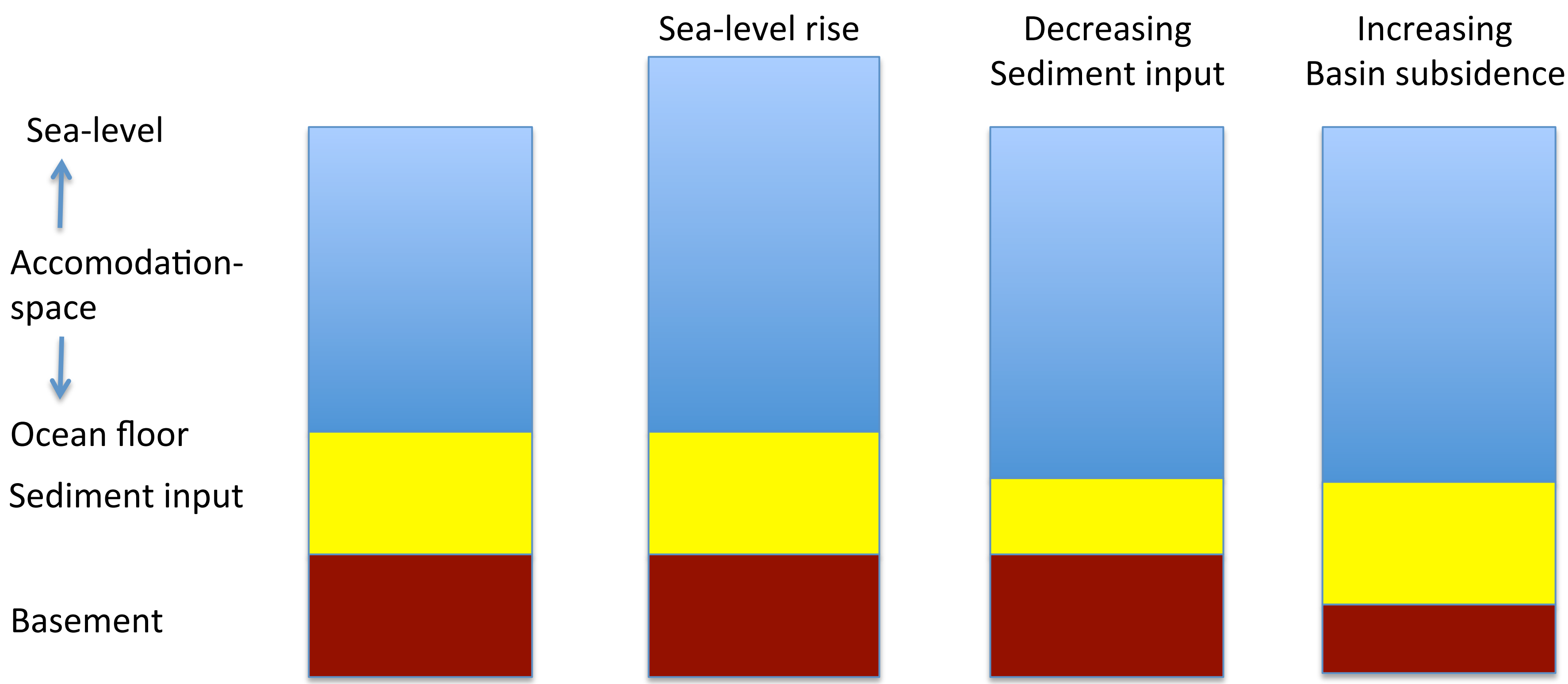


Δ Accommodation space / t = Δ Eustasy + Δ Subsidence – Δ Sedimentation

Accommodation space

Controlling factors: sea-level, sediment input, subsidence

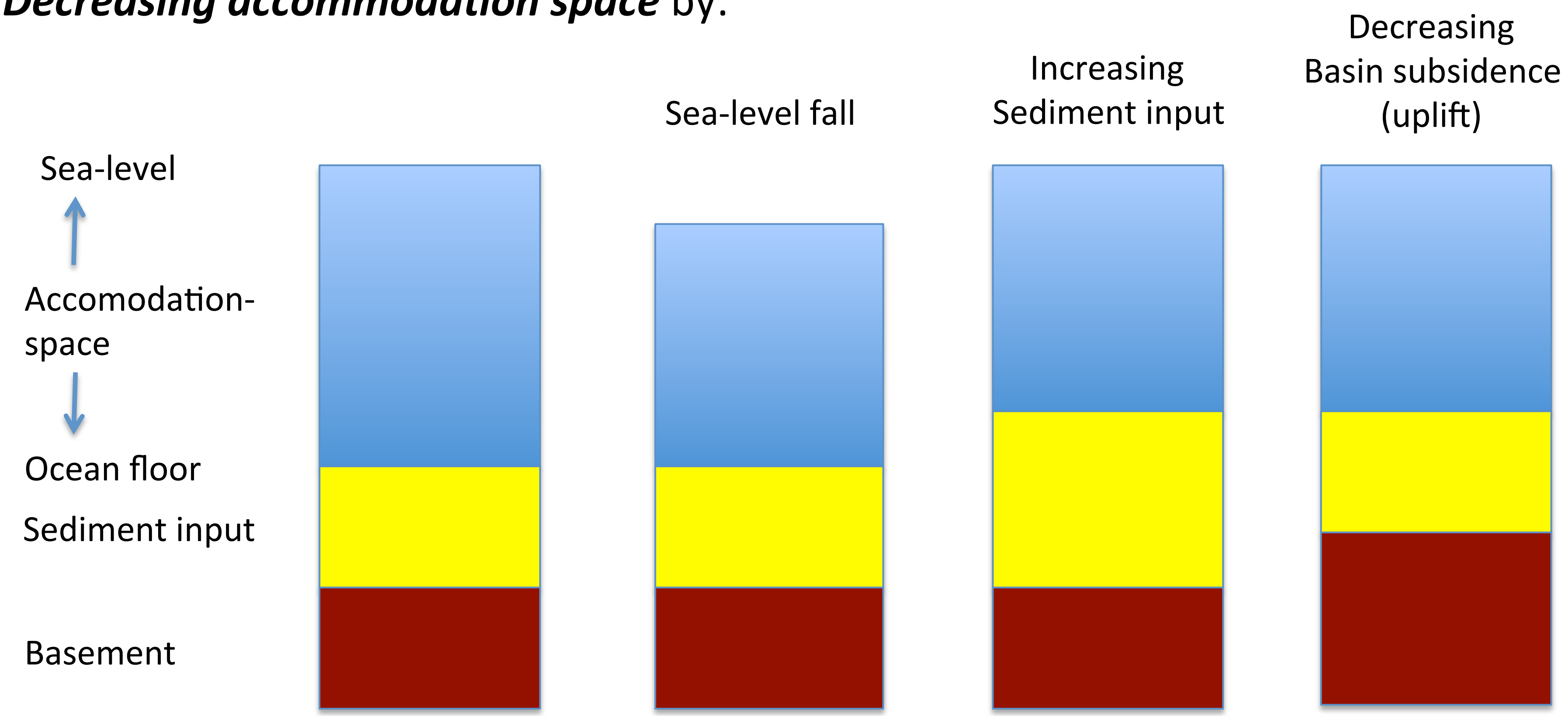
***Increasing accommodation* space** by:



Accommodation space

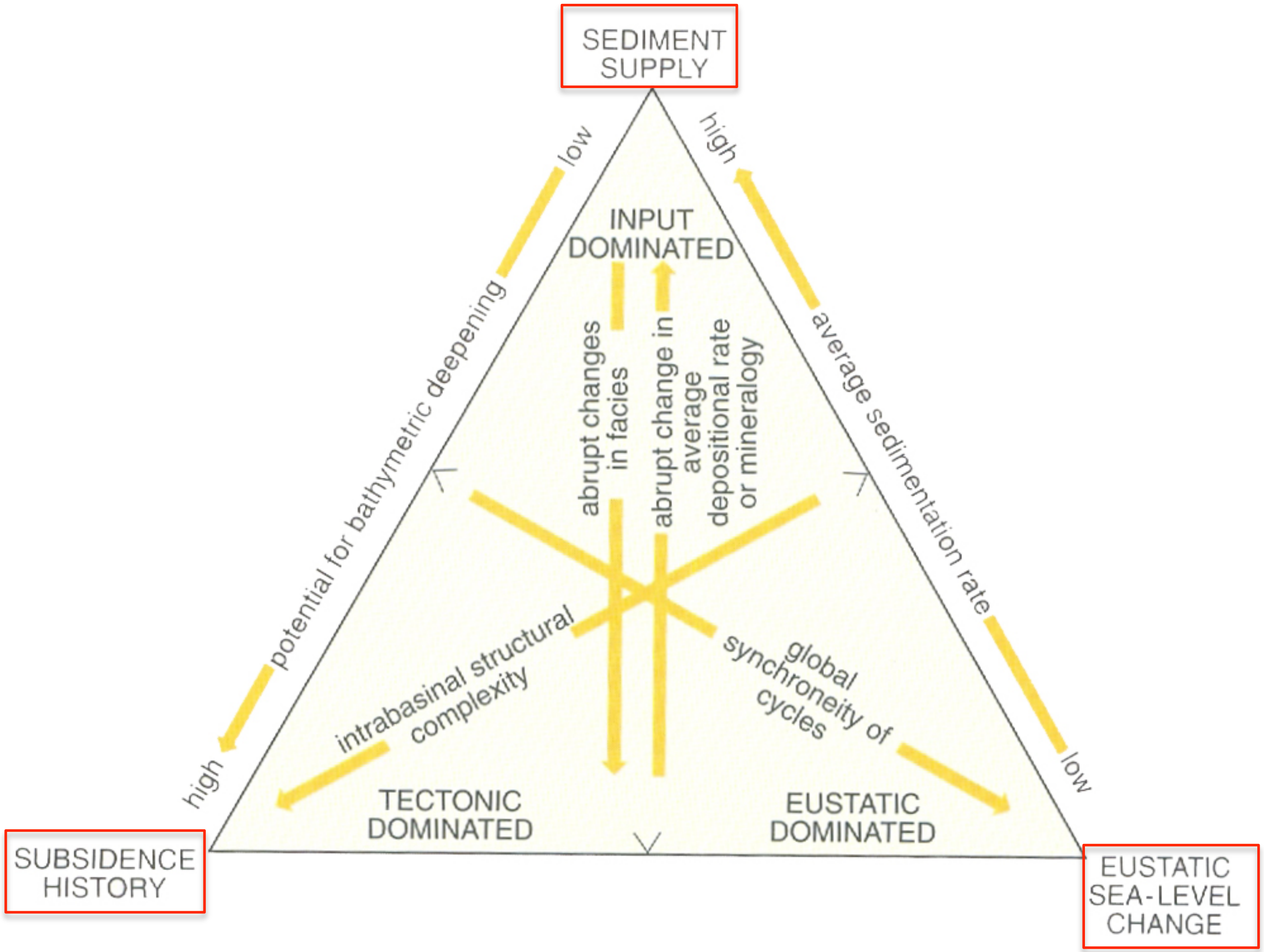
Controlling factors: sea-level, sediment input, subsidence

Decreasing accommodation space by:

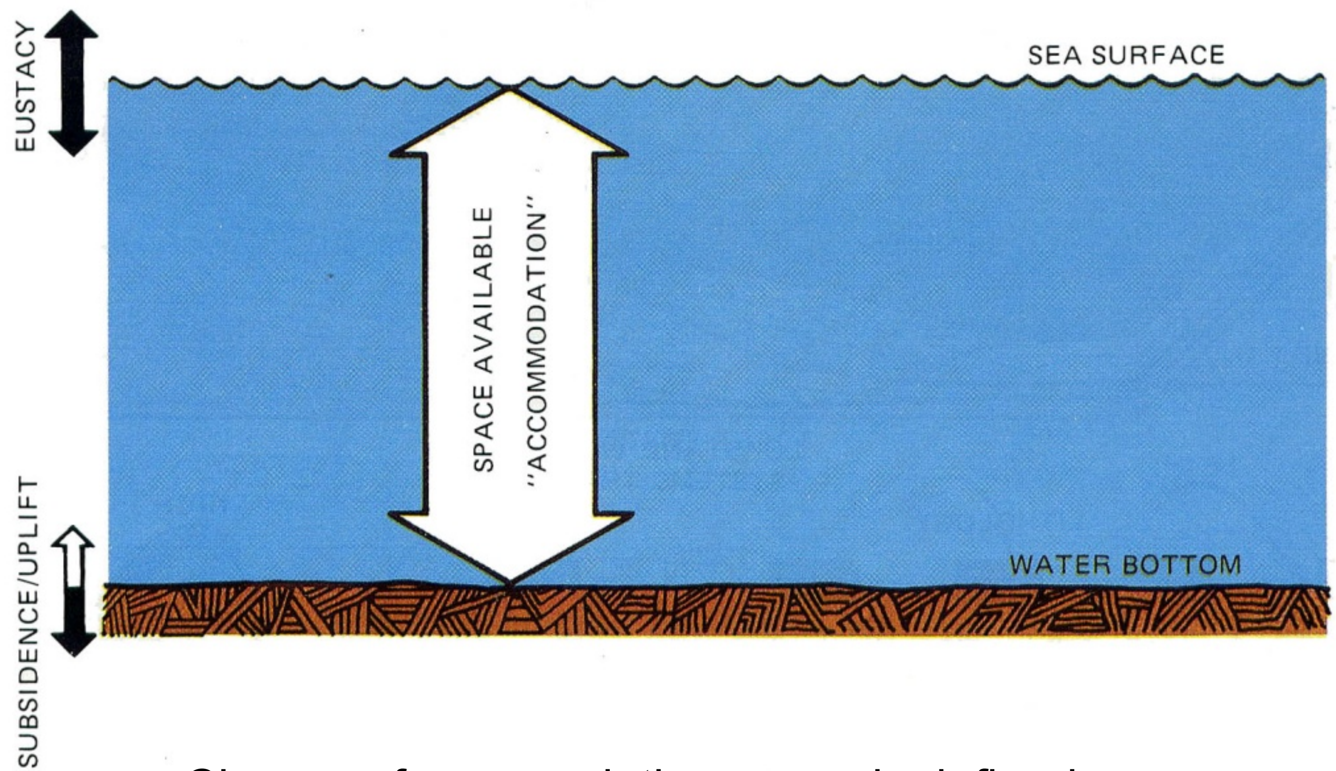


Accommodation space

Complex interactions between controlling factors



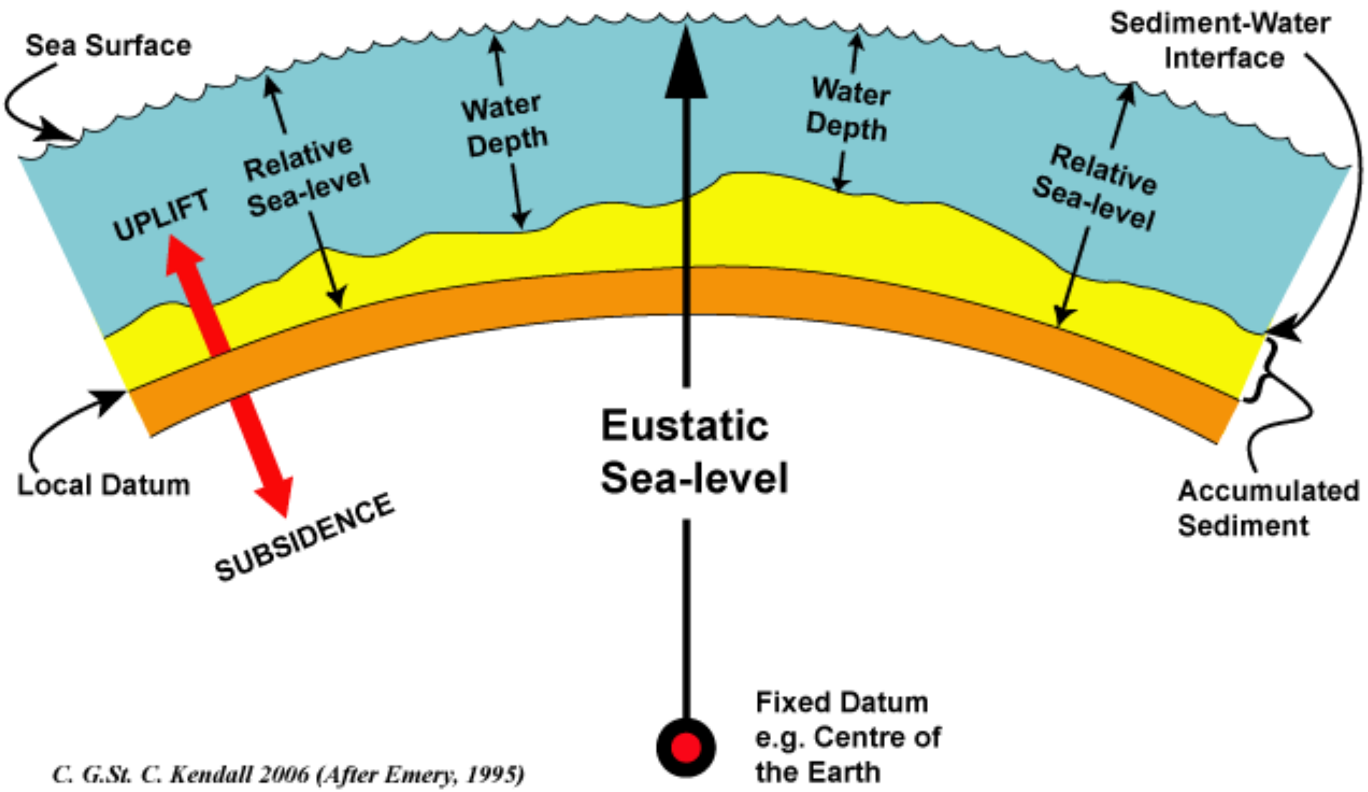
Accommodation space



Change of accomodation space is defined as:

Δ Accommodation space = Δ Eustatic sea level + Δ Subsidence – Δ Sedimentation

Accommodation space - sea-level change

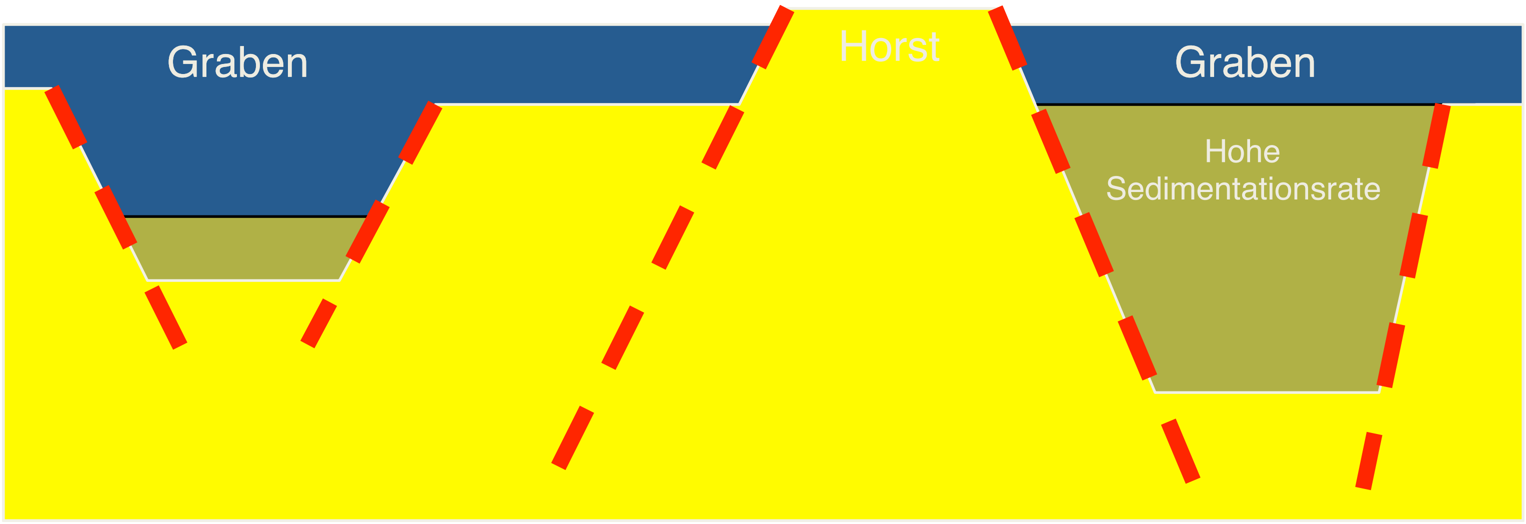


Eustatic sea level: Fixed point (e.g. centre of the earth)

Relative sea level: local point – fixed to crust (eustasy + tectonics + sediment compaction)

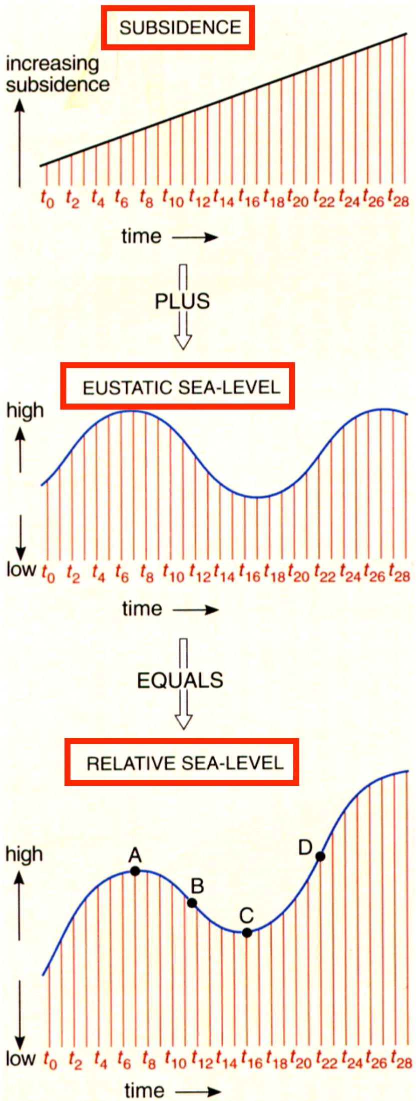
Accommodation space - relative sea-level change

Relative sea-level changes is controlled by eustatic sea-level changes, basin subsidence and sediment input



Accommodation space - relative sea-level change

Relative sea-level in passive continental margin



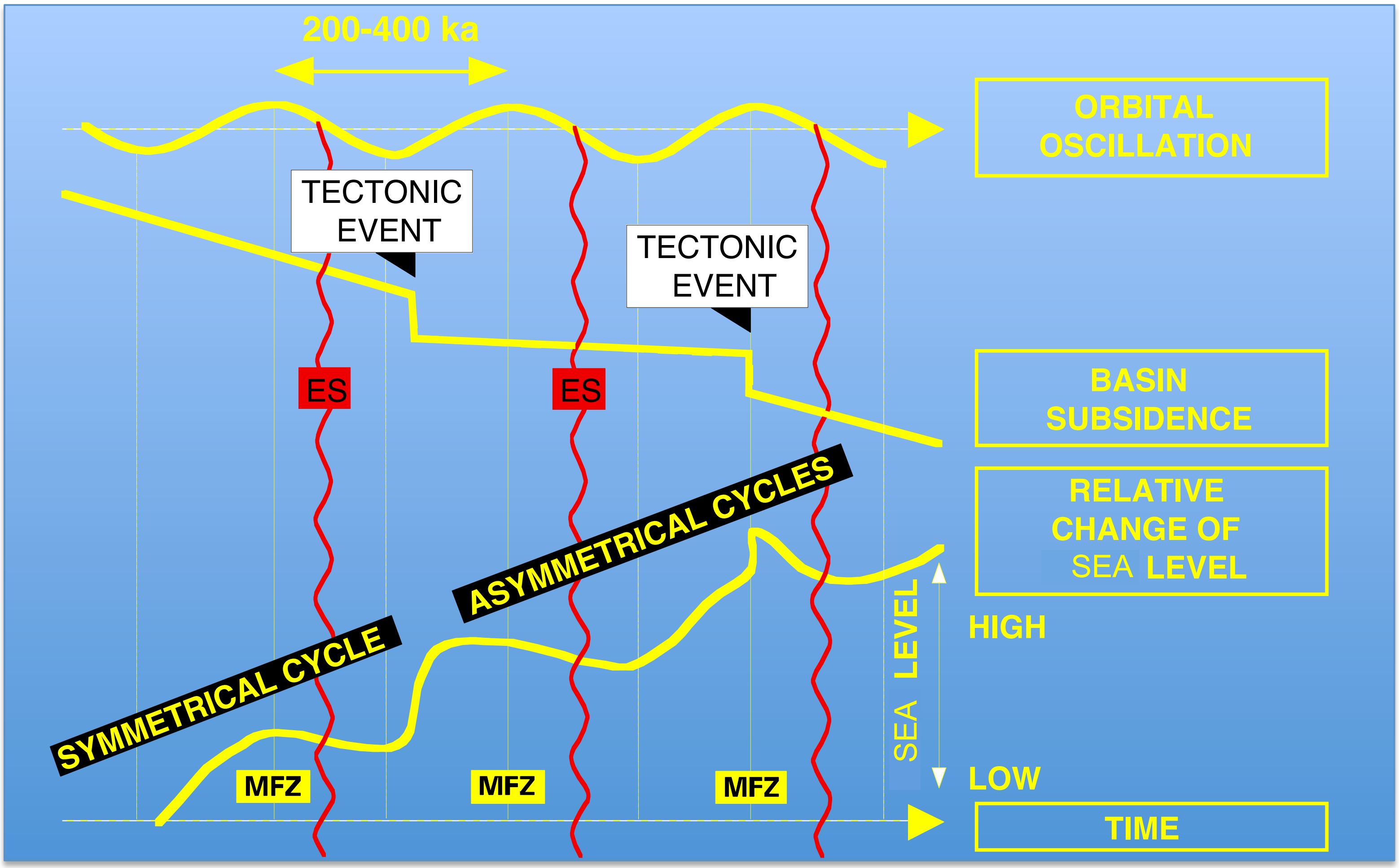
- Low subsidence (10-100m/ma)
- Continuous Subsidence
- No uplift

- eustatic SL curve = Sinus-curve
- Transgessions/regressions start slowly
- maximum speed at *Inflection Point* (B / D)

- Relative SL rise and fall (sinus curve)
- Overall trend: increasing sea-level
- Increasing accomodation space

Accommodation space - relative sea-level change

Relative sea-level in complex tectonic settings



Accommodation space - relative sea-level change

Relative sea-level depends on global parameters

- Orbital parameters (Milankovich cycles)
- continental distribution
- rate of glaciation (polar ice caps)
- global climate (changing water volumes due to temperature)

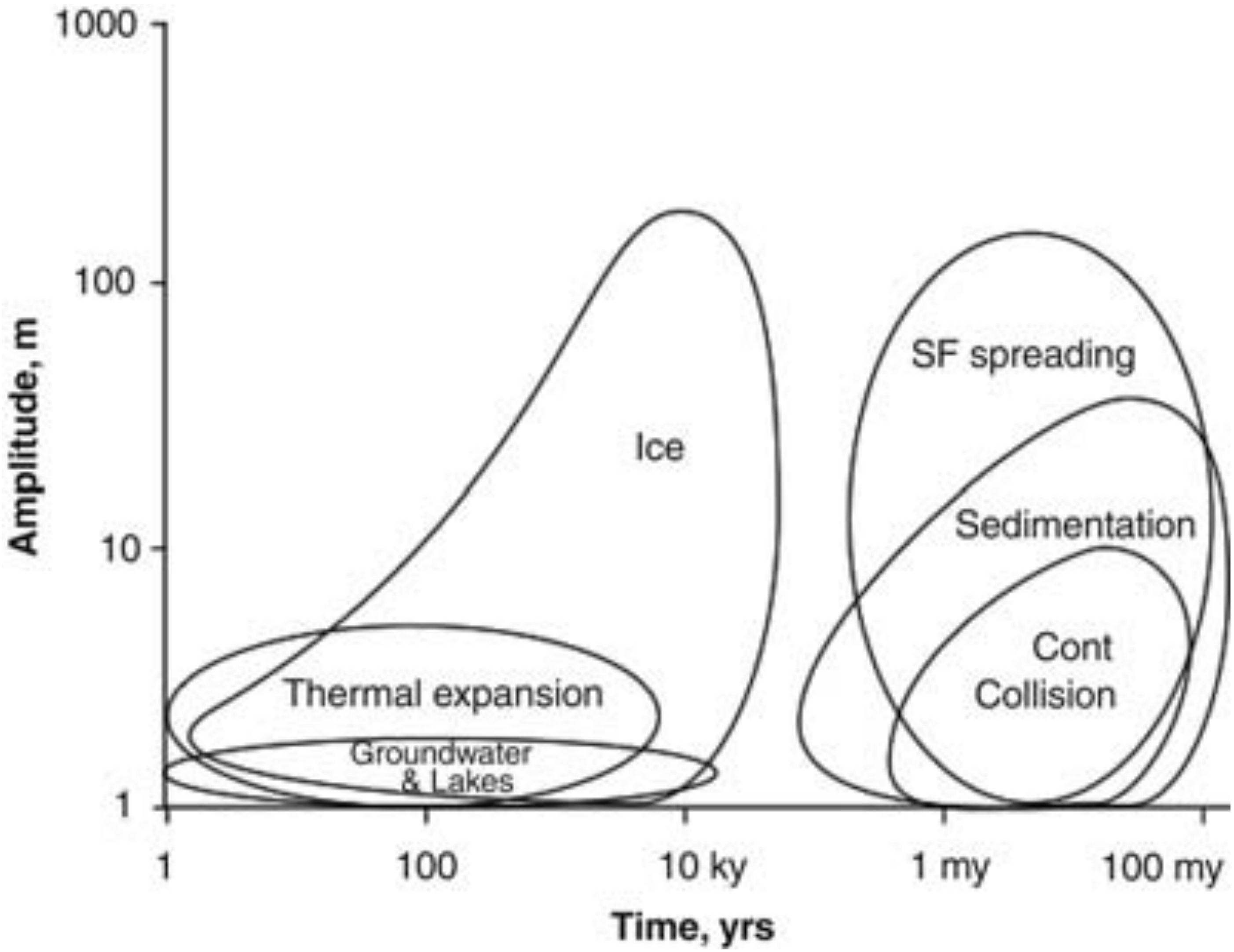
Accommodation space - relative sea-level change

Relative sea-level depends on Hinterland development

- Tectonical und climatical parameter
- uplift (Hinterland) increases sediment supply
- fluvial system tend to get base level again (more sediment input)
- active orogens (continuous uplift), increased numbers of sediment mass flows (turbidites, debris flows)

Accommodation space - relative sea-level change

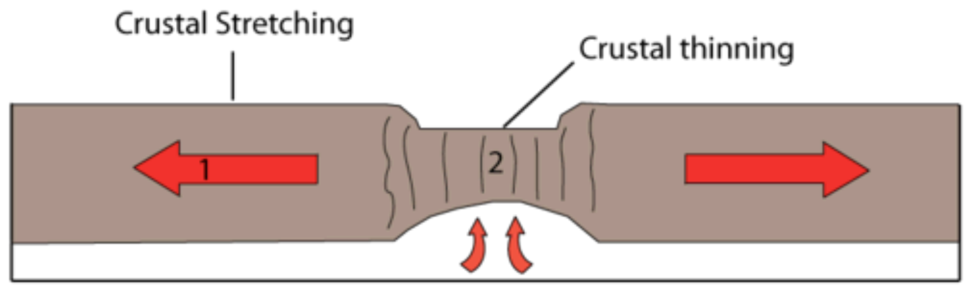
Impact of the different parameters on sea level changes



Accomodation space - Basin subsidence

Basin subsidence mainly controlled by tectonic events

Rifting



sea-floor spreading

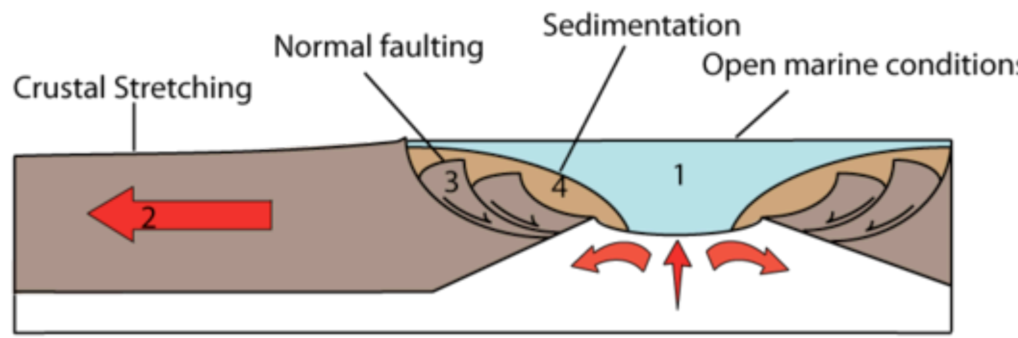
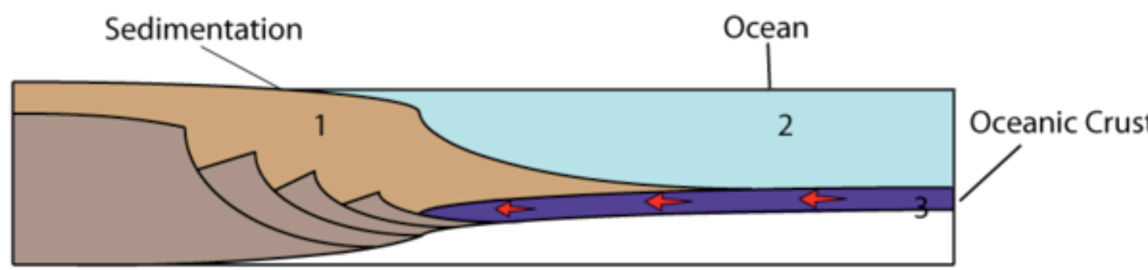
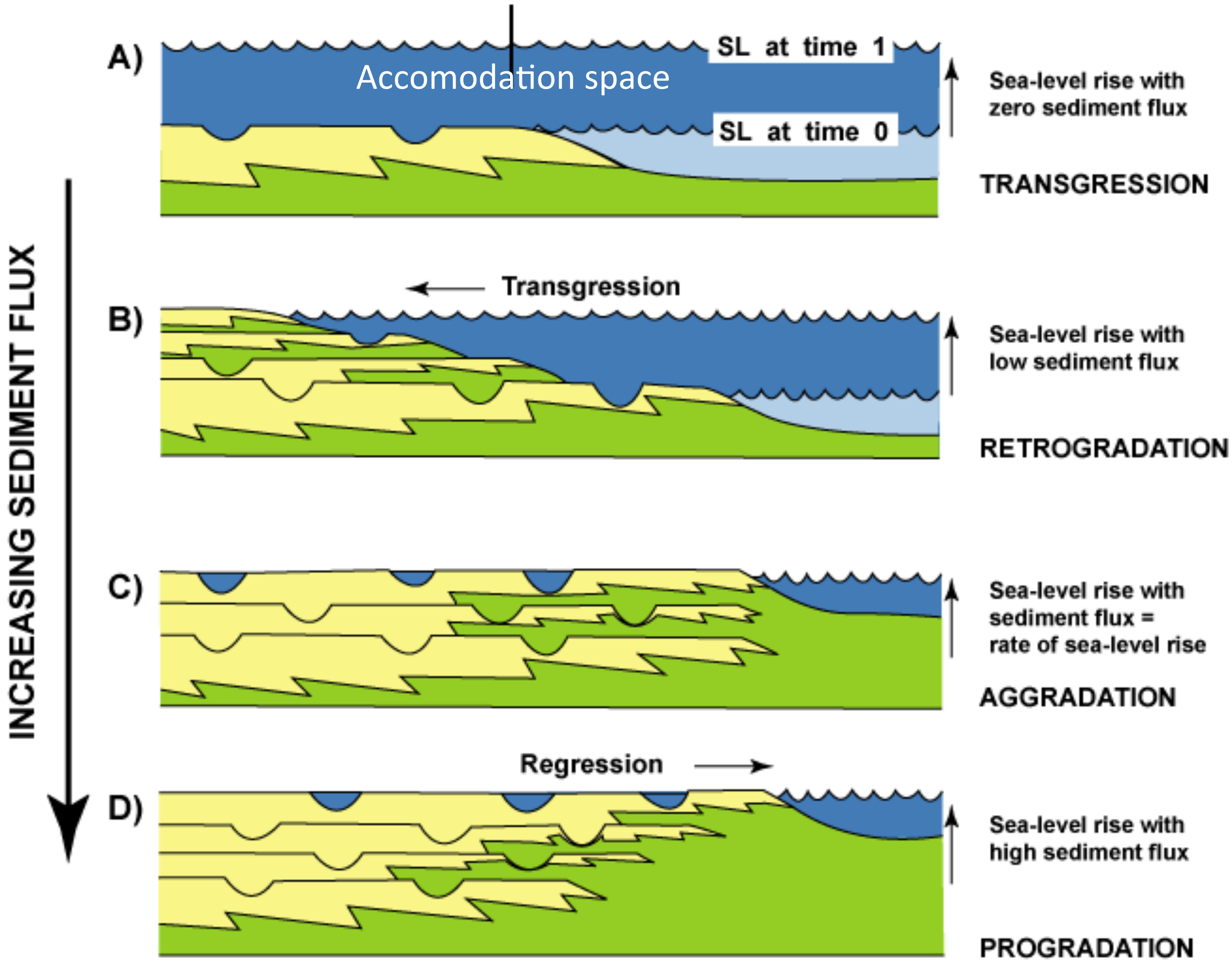


plate subduction



Accomodation space - Sediment input

Effect of changing sediment input on accomodation space



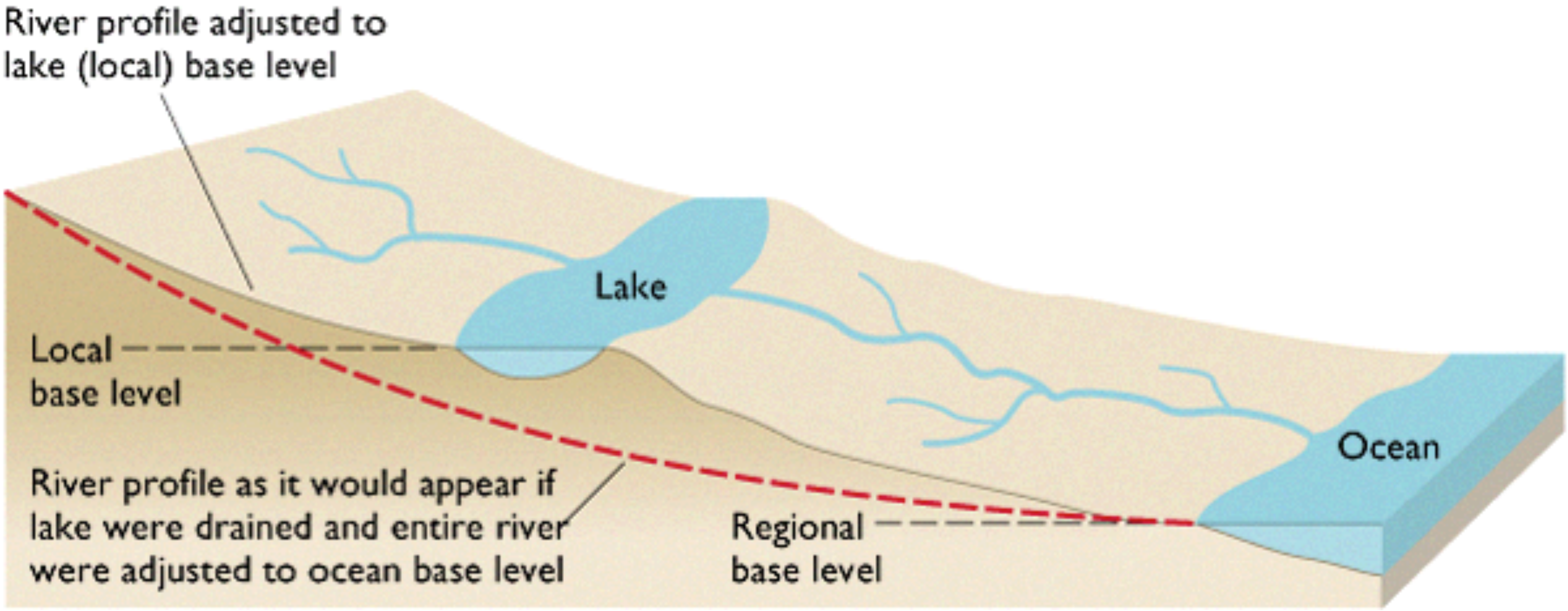
After Posametier & Allen, 1999

Accomodation space - Sediment input

Rate of sediment supply is controlled by erosion base level

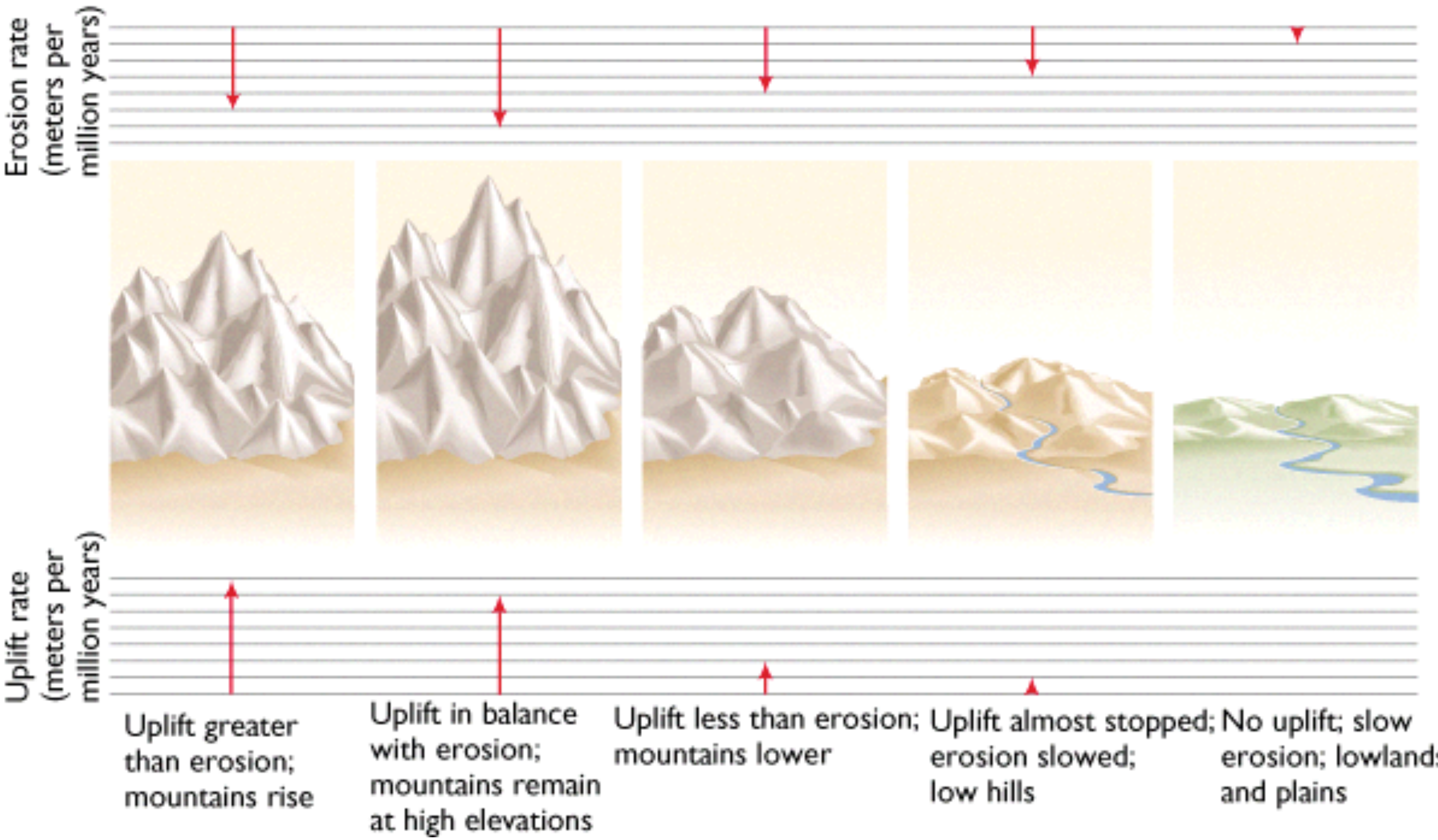
erosion base level is the ideal erosion profile adjusted to the ocean (global base level) or to lakes (local base level)

rate of erosion strongly controlled by relief



Accomodation space - Sediment input

Relief is controlled by interaction of erosion and uplift



Accomodation space - sediment input

Silicates - sediment availabilty controlled by

- climate (precipitation & temperatures)
- vegetation (soil development)
- weathering processes: chemical, physical & biological weathering
- climatic changes often increase erosion (sediment supply)

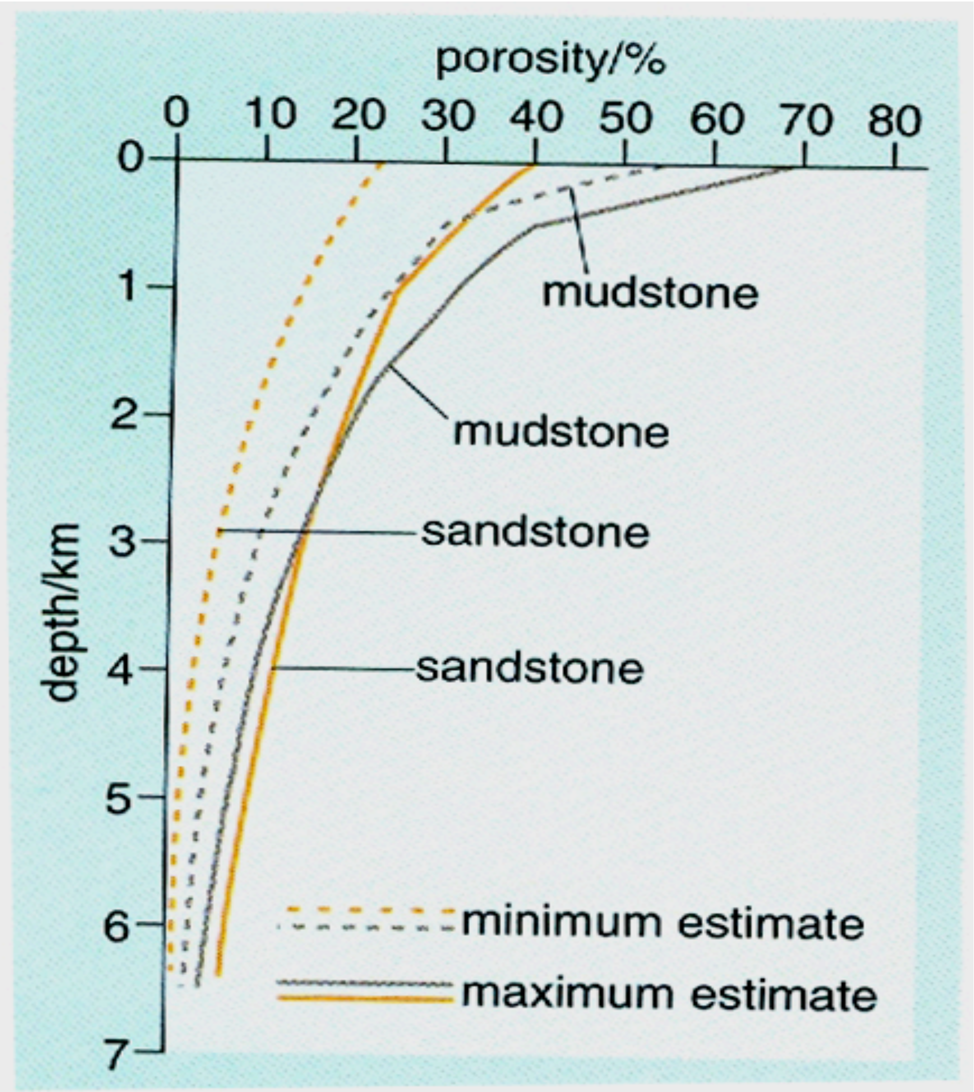
Accomodation space - sediment input

Carbonates - sediment availabilty controlled by

- climate more important as in siliciclastic sediments
- mostly biogenic in-situ production
- specific conditions for carbonate producing organisms (mostly climatic)
  - light (low dispersed sediment)
  - water temperature
  - salinity
  - oxygen (water circulation)

Accomodation space - Sediment input

sediment compaction



- increasing accommodation space at stable relative sea-level
- sandstone compaction up to 30%
- mudstone compaction up to 80%
- mainly in areas of high sediment input (deltas, turbidite fans)
- difficult to seperate from subsidence

50 – 60 min

22 slides