

*University Of Basrah
College of Science
Department of Geology*

STRATIGRAPHY

Lectures Notes for Third-Class Undergraduate Students

Instructed by

*Dr. Nawrast Sabah Abdalwahab
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Chapter Six

Cyclicality and Sequence Stratigraphy

The fascinated fashion of Earth

- The History of earth is recording in its strata.
- The geological record is of 4.5 Ga years old.
- This record arranges in a fascinated fashion of cyclicality and events.

What is Cyclicality?

- Cyclicality means repetition of patterns in rhythmic order in regular frequency of time.
- It has been recognized in different scales of space and time.
- The recurrent of cyclicality in earth system made geology a historical science.

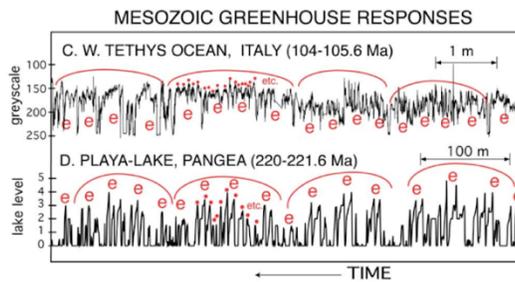
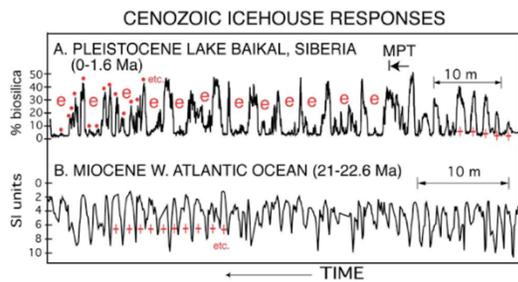
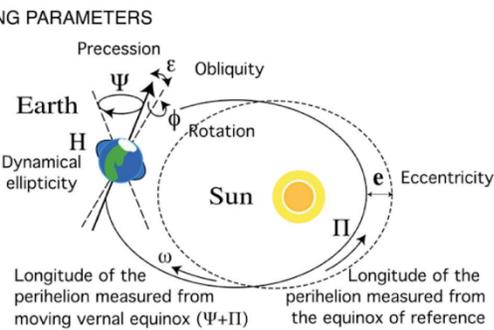
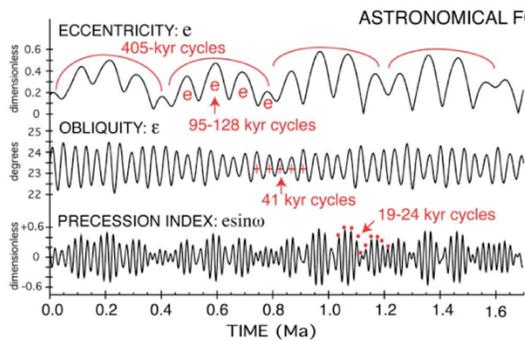
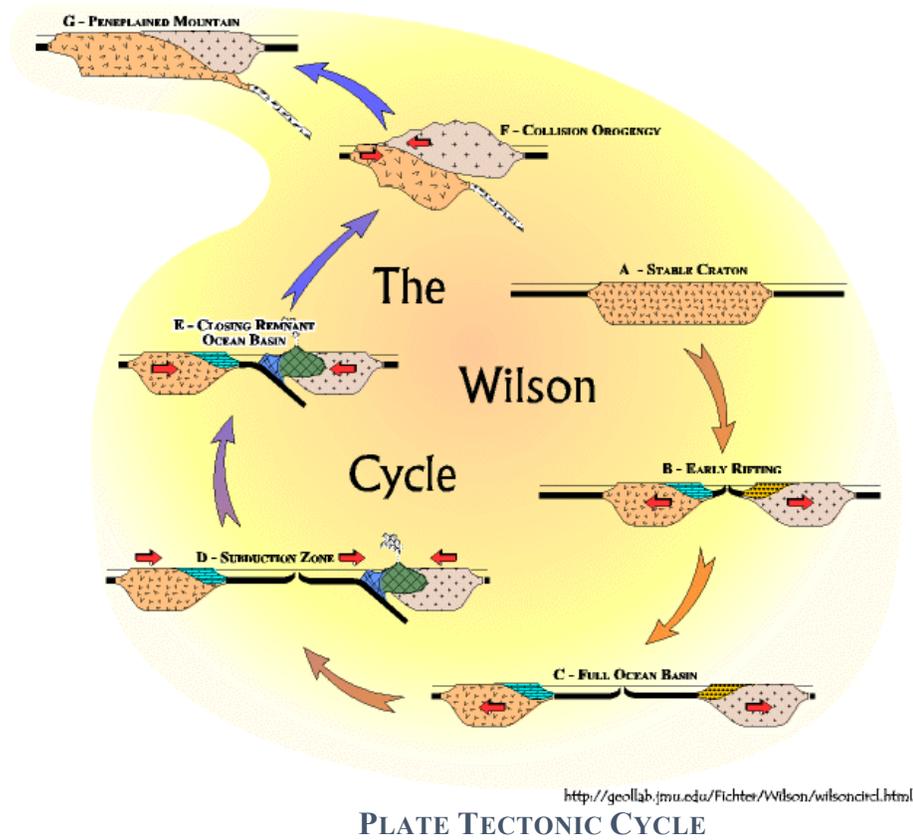
Types of Cyclicality

- Cyclicality can be divided into many types according to:
 1. *Space and time scale:*
 - long scale cycles
 - Short scale cycle
 2. *The driving processes.*
 - Allogenic cycle: like tectonics, sea level and climate
 - Autogenic cycle: like tides and storm

Long scale cycle

- ***Plate tectonic cycle*** is a type of large scale cycle with a periodical of 200 Ma years.
- ***Milankovitch Orbital Cycle*** is another type of large scale cycle that causes by astronomical factors.
- It has a periodical of 0.01 to 2 Ma years.
- The astronomical factors determine many other sedimentation cycles like: *Productivity and Dilution, Redox, Dissolution and Diagenesis Cycles.*

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MILANKOVITCH ORBITAL CYCLE

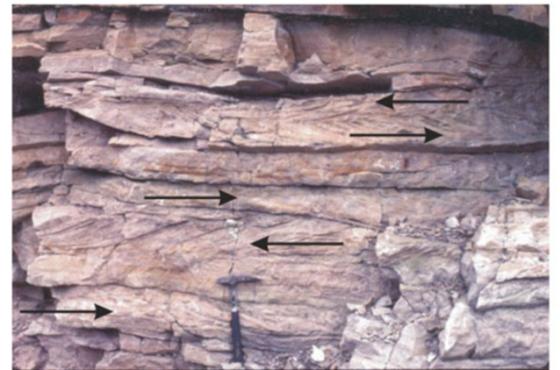
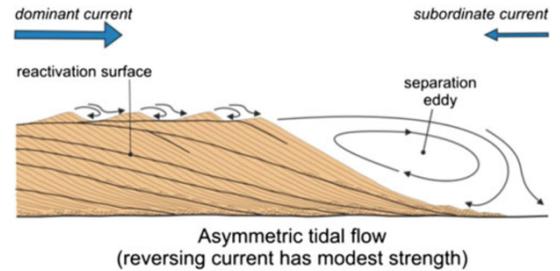
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Short scale cycle

The simplest form being of small scale cyclicity is herringbone structures. It is a type of cross-bedded units with opposite direction of forest laminae in adjacent layers. It is formed under the influence of the reversing currents of tides.

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Other types of cyclicity

- Inversion of magnetic field of earth
- deposition of sediments ore
- sedimentary basin formation
- accentuated and attenuated climate zone
- glaciations
- Volcanism
- Bioevolution Cycle
- Rock Cycle
- Wilson Cycle of opening and closing of oceanic basin.

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The hierarchical order of cycles

Sequence type	Duration (million years)	Other terminology
A. Global supercontinent cycle	200–400	First-order cycle (Vail et al., 1977)
B. Cycles generated by continental-scale mantle thermal processes (dynamic topography), and by plate kinematics, including: 1. Eustatic cycles induced by volume changes in global mid-oceanic spreading centres 2. Regional cycles of basement movement induced by extensional downwarp and crustal loading.	10–100	Second-order cycle (Vail et al., 1977), supercycle (Vail et al., 1977), sequence (Sloss, 1963)
C. Regional to local cycles of basement movement caused by regional plate kinematics, including changes in intraplate-stress regime	0.01–10	3rd- to 5th order cycles (Vail et al., 1977). 3rd-order cycles also termed: megacyclothem (Heckel, 1986), mesothem (Ramsbottom, 1979)
D. Global cycles generated by orbital forcing, including glacioeustasy, productivity cycles, etc.	0.01–2	4th- and 5th-order cycles (Vail et al., 1977), Milankovitch cycles, cyclothem (Wanless and Weller, 1932), major and minor cycles (Heckel, 1986)

Photo from: Miall, Andrew D. 2016. "Stratigraphy: The Modern Synthesis." Pp. 311–70 in Stratigraphy: A Modern Synthesis. Cham: Springer International Publishing.

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Cyclostratigraphy

- Cyclostratigraphy is the study of the sedimentary record produced by climatic cycles of regular frequency, tens to hundreds of thousand years in duration, which are generated by variations in the earth's orbit and are known as Milankovitch Cycles.
- Recognition of these cycles in sedimentary record enabled geologists to develop an orbital timescale graduated in tens or hundreds of thousands of years for parts of the geological column.
- Cyclostratigraphy also investigated the frequently complex way in which orbital cycles have influenced earth's climate, oceans and ice-caps, and attempts to interpret how the cycles seen in the stratigraphic record have formed.
- The expression of climatic cycles in sediments takes a myriad of forms, because climate change has complex effects on physical, chemical and biological system.
- Climatic cycles have been identified from numerous parameters, including: mineralogy and geochemistry which records changing sediment flux or biological productivity, for example; variation in stable isotope ratios of oxygen, reflecting changing temperatures and ice volume; and changes in the relative abundance of fossil species.

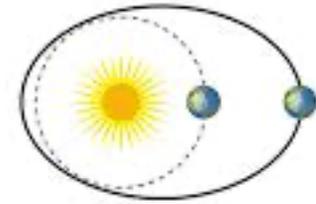
Milankovitch Cycles

- Cycles of Milankovitch Band fall in the frequency interval of *10 Ka to 1 Ma*, and are caused by complex orbital patterns of the sun-moon-earth systems.
- These changes affect both the amount of insolation (solar energy) reaching the earth's surface, and the seasonal distribution of insolation.
- Three main cycles are found: those of precession, obliquity and eccentricity, which combine to produce an intricately detailed curve.
- The actual variations in insolation are of about 5% and affect the earth's mate in a complex manner; they include various feedback mechanisms which augment the effects of the eccentricity cycle in particular. The effects of different cycle frequencies vary latitudinally, such that the precessional effects are dominant at low latitudes and obliquity at higher ones.

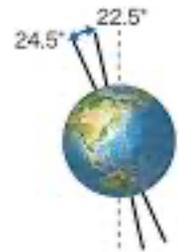
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The Precession Cycle (19-23 ka)

Precession is the combined effect of the precession of the equinoxes and the movement of the perihelion, expressed as the movement of the axial projection of the earth's rotational axis relative to the stars. At the present time, two peaks with periodicities of 19 and 23 ka are dominant.



Eccentricity



Obliquity



Precession



PRECESSION RELATED IN THE PLIOCENE CONTINENTAL SUCCESSION OF PTOLEMAIS
PHOTO SOURCE: [HTTP://WWW.UU.NL/STAFF/FJHILGEN/0](http://www.uu.nl/staff/FJHILGEN/0)

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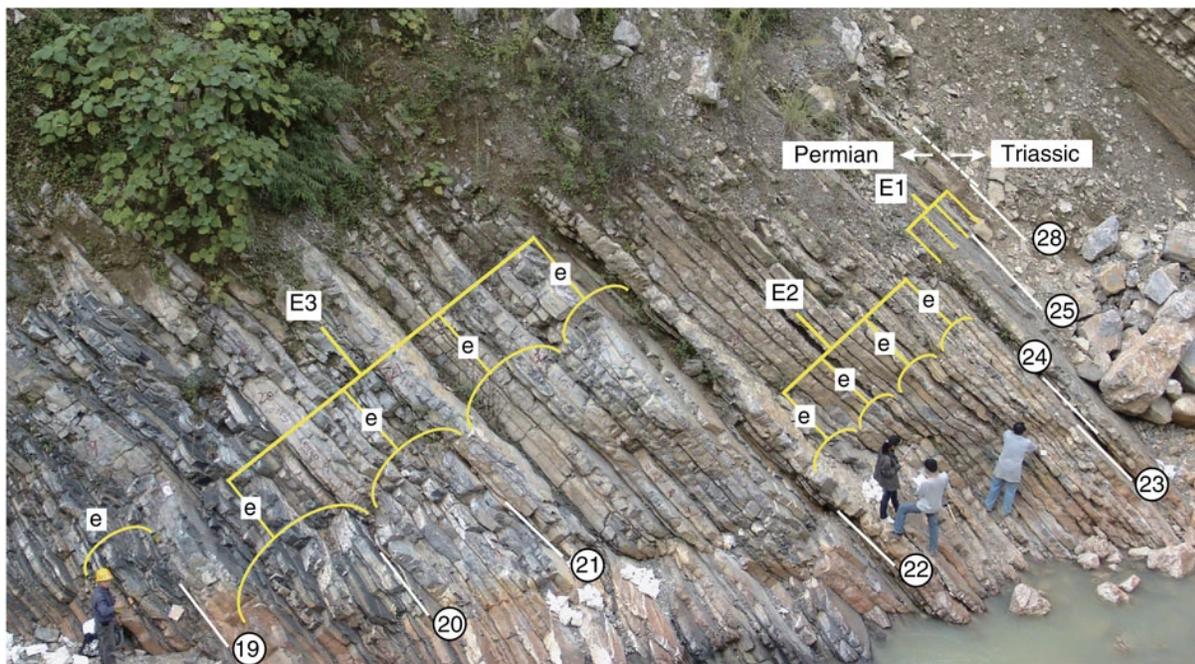
The Obliquity Cycle (41 ka)

The angle between the earth's celestial equator (projection of the equator onto the sky) and plane of the earth's orbit-the ecliptic- varies by about 3.5, fluctuating between 21.5 and 24.4 with a periodicity of 41 ka. This affects the insolation received by the earth by changing the intensity of the seasonal cycle, and affecting the latitudinal insolation gradient.

The Eccentricity Cycle (106, 410 ka)

There is considerable variation in the orbit of the earth-moon system around the sun, which results in more and less strongly elliptical pathways of orbit. The most important of these are the 106 and 410 ka cycles.

There is good evidence the duration of the lunar day and the lunar month have changed with time, and it is requisite that the periods of precession and obliquity must have changed. The periods of these frequencies have increased slowly through time. It is important to note that the duration of eccentricity has not changed.



TIME-CALIBRATED MILANKOVITCH CYCLES FOR THE LATE PERMIAN. PHOTO OF THE UPPER CHANGHSINGIAN DALONG FORMATION AT SHANGSI SECTION

Five thin precession-scale beds are bundled into 100-kyr eccentricity cycles (e) and four ~100-kyr cycles are bundled into 405-kyr eccentricity cycles (E). Eccentricity maxima are recorded by pronounced, thin precession beds, whereas the eccentricity minima correlate to thick limestone beds. Circled numbers indicate bed numbers; white lines mark bed boundaries (Huaichun Wu et al., 2013) (<http://www.nature.com/articles/ncomms3452#auth-1>).

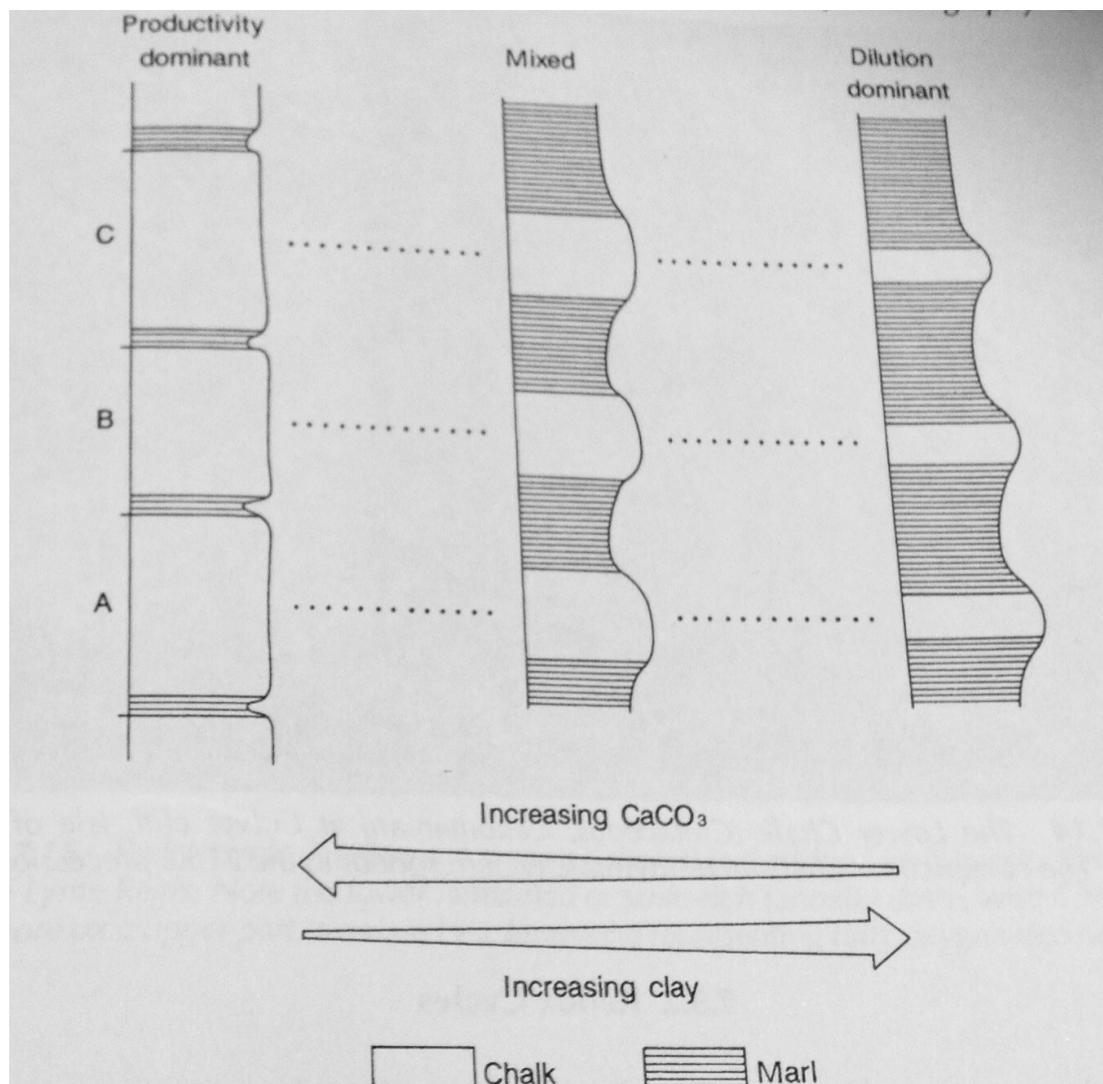
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Sedimentary Expression and interpretation of cycles

- Since the effects of Milankovitch cycles on climate are global in extent, sedimentary responses to the changes they cause should be identifiable in all depositional environments.
- In practice, ancient cycles are more readily interpreted in marine environments, why?
- The mechanisms outlined below are believed to have been important in the sedimentary expression of climatic cycles in the Milankovitch Band.

Productivity and dilution cycles: extremes of a continuum

Dilution and productivity cycles are set of opposite ends of a continuous spectrum, and the real problem is identification of the dominant process.

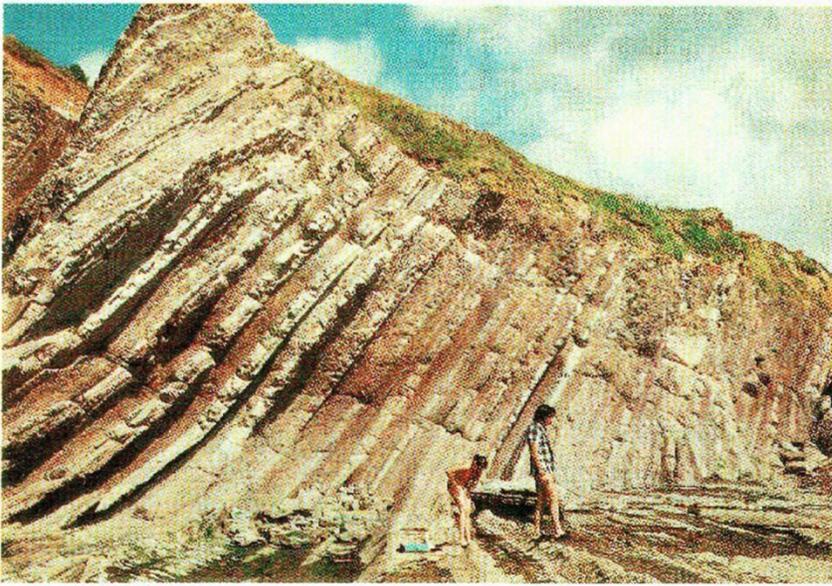
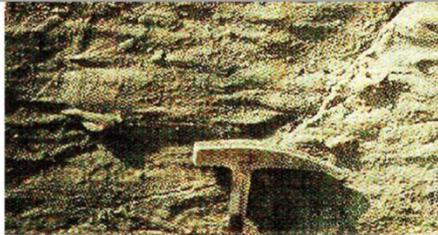


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Carbonate-marls rhythms in the Pliocene Punta di Maiata section of the Rossello composite on Sicily PHOTO SOURCE: [HTTP://WWW.UU.NL/STAFF/FJHILGEN/0](http://www.uu.nl/staff/FJHILGEN/0)

Figure 29—Rhythmic intercalation of red marlstones and light-gray limestones deposited on a relatively deep sea floor or under an elevated CCD. Red marlstones may represent periodic clastic dilution of pelagic carbonate flux, or the carbonate beds may be pelagic turbidites deposited below the CCD. Upper Cretaceous, Zumaya, Spain.



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Sea Level

- **Base level:** is an imaginary and dynamic 4D surface of equilibrium between deposition and erosion, largely dependent on environmental energy and sediment supply.
 - Marine Base level = sea level
 - Fluvial Base level = graded Fluvial Profile
- *Stratigraphic base level include a continental portion (fluvial base level= graded fluvial profile) and a marine portion (marine base level= sea level)*
- **Eustasy:** is the sea level relative to the center of Earth.
- **Relative Sea-level:** is the sea level to a datum that is independent of sedimentation.
- **Water depth:** is the sea level relative to the seafloor.

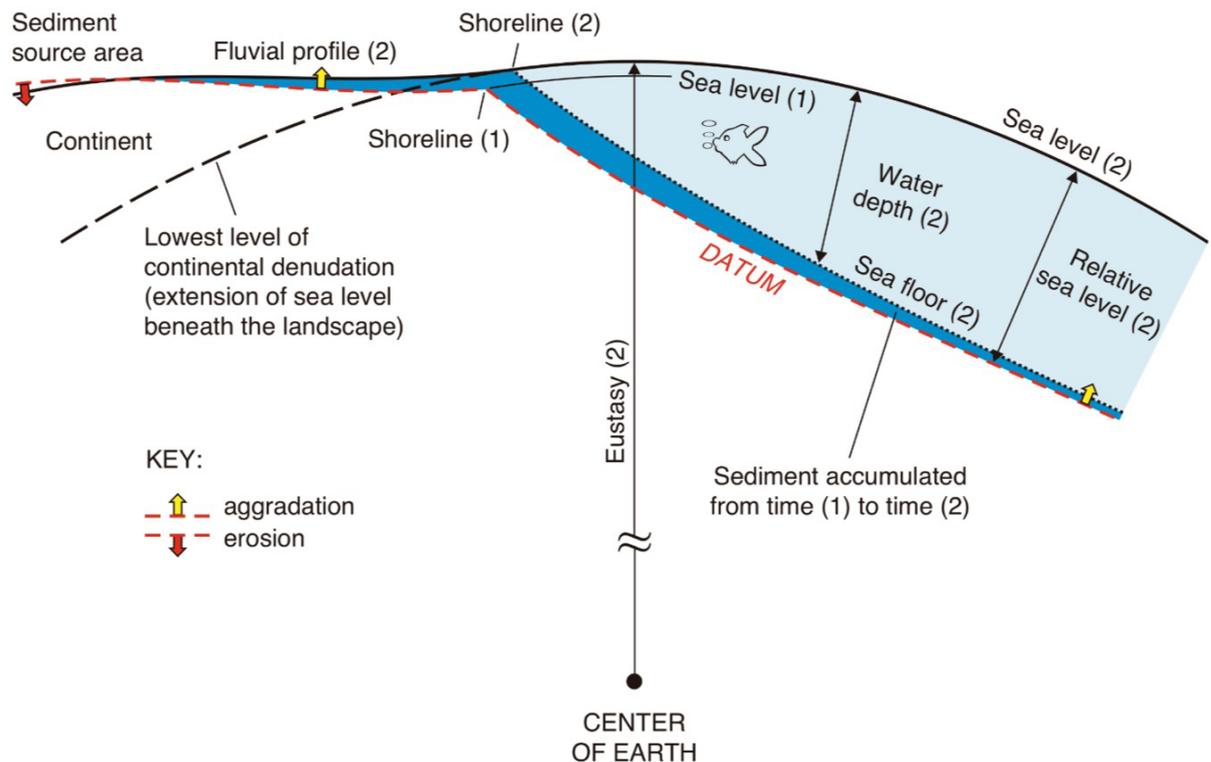


FIGURE 3.12 Eustasy, relative sea level, and water depth as a function of sea level, seafloor, and datum reference surfaces (modified from Posamentier *et al.*, 1988). The datum is a subsurface reference horizon that monitors the amount of total subsidence or uplift relative to the center of Earth. In this diagram, the datum corresponds to the ground surface (subaerial and subaqueous) at time (1). Sedimentation (from time 1 to time 2 in this diagram) buries the datum, which, at any particular location, may be visualized as a G.P.S. that monitors changes in elevation through time (i.e., distance relative to the center of Earth).

Definition concepts of base level

Base level (Twenhofel, 1939): highest level to which a sedimentary succession can be built.

Base level (Sloss, 1962): an imaginary and dynamic equilibrium surface above which a particle cannot come to rest and below which deposition and burial is possible.

Base level (Bates and Jackson, 1987): theoretical limit or lowest level toward which erosion of the Earth's surface constantly progresses but rarely, if ever, reaches. The general or ultimate base level for the land surface is sea level.

Base level (Jervey, 1988): ... is controlled by sea level and, at first approximation, is equivalent to sea level ... although, in fact, a secondary marine profile of equilibrium is attained that reflects the marine-energy flux in any region.

Base level (Schumm, 1993): the imaginary surface to which subaerial erosion proceeds. It is effectively sea level, although rivers erode slightly below it.

Base level (Cross, 1991): a surface of equilibrium between erosion and deposition.

Base level (Cross and Lessenger, 1998): a descriptor of the interactions between processes that create and remove accommodation space and surficial processes that bring sediment or that remove sediment from that space.

Base level (Posamentier and Allen, 1999): the level that a river attains at its mouth (i.e., either sea level or lake level), and constitutes the surface to which the equilibrium profile is anchored.

There are two schools of thought regarding the concept of base level:

(1) Base level is more or less the sea level, although usually below it due to the action of waves and currents. The extension of this surface into the subsurface of continents defines the ultimate level of continental denudation. On the continents, processes of aggradation versus incision are regulated via the concept of graded (equilibrium) fluvial profile. Graded fluvial profiles meet the base level at the shoreline.

(2) The concept of base level is generalized to define the surface of balance between erosion and sedimentation within both marine and continental areas (the "stratigraphic" base level of Cross and Lessenger, 1998). In this acceptance, the concept of graded fluvial profile becomes incorporated within the concept of base level. The stratigraphic base level will thus include a continental portion (fluvial base level = graded fluvial profile) and a marine portion (marine base level ~ sea level).

The drawback of the second approach is that fluvial base-level shifts are controlled by marine base-level shifts, especially in the downstream reaches of the river system, and hence the two concepts are in a process/response relationship. This suggests that it is preferable to keep these two concepts separate as opposed to incorporating them into one "stratigraphic base level". This is the approach adopted in this book, where the fluvial base level is referred to as the fluvial graded profile, and the marine base level is simply referred to as the base level.

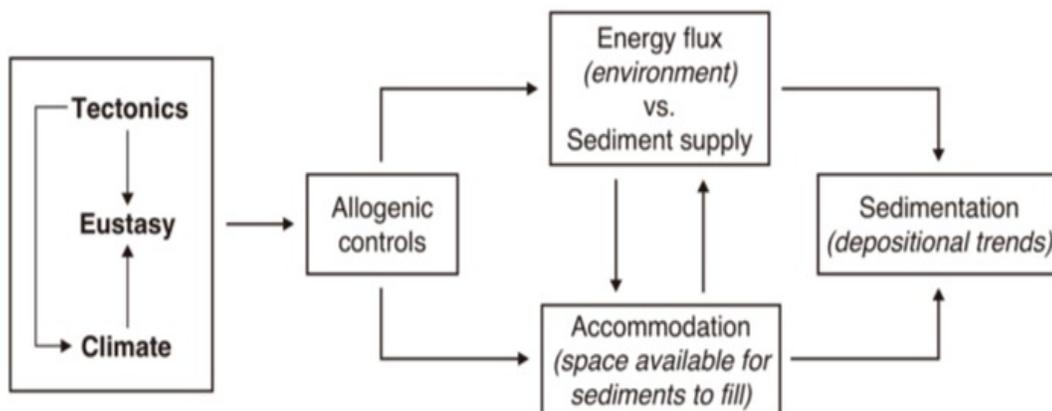
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Sequence stratigraphy

- The concept of cyclicity has a major development in much more predictive science as Sequence Stratigraphy.
- **Sequence:** is genetically related strata that bounded by unconformities (or sequence boundaries).
- The origin of sequence is interaction between the rate of Eustasy (global sea-level change), tectonics, and climate.
- **The sequence boundary:** is surface imprint a sudden change in sea-level cycle.
- The hierarchies of cyclic sea-level change were ranked by their duration as first, second, third, fourth and fifth orders.

Controls on Sedimentation

- sedimentation is generally controlled by a combination of autogenic and allogenic processes, which determined the distribution of depositional elements within a depositional systems, as well as, the large- scale stacking patterns of depositional systems within a sedimentary basin.
- Autogenic processes (e.g.' self-induced avulsion in fluvial and deep-water environments) are particularly commonly studied using the methods of conventional sedimentology and facies analysis.
- Allogenic processes, are directly relevant to sequence stratigraphy; as they control the larger-scale architecture of the basin fill.



ALLOGENIC CONTROLS ON SEDIMENTATION, AND THEIR RELATIONSHIP TO ENVIRONMENTAL ENERGY FLUX, SEDIMENT SUPPLY, ACCOMMODATION, AND DEPOSITIONAL TRENDS (CATUNEANU, 2006)

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Hierarchies order

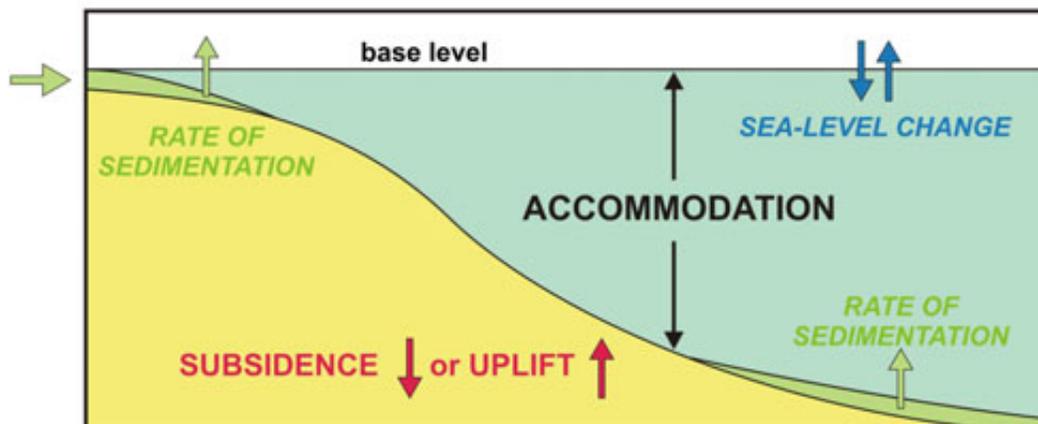
Hierarchical order	Duration (My)	Cause
First order	200-400	Formation and breakup of supercontinents
Second order	10-100	Volume changes in mid-oceanic spreading centers
Third order	1-10	Regional plate kinematics
Fourth and fifth order	0.01-1	Orbital forcing

FIGURE 3.2 Tectonic and orbital controls on eustatic fluctuations (modified from Vail *et al.*, 1977, and Miall, 2000). Local or basin-scale tectonism is superimposed and independent of these global sea-level cycles, often with higher rates and magnitudes, and with a wide range of time scales.

Accommodation

- Accommodation: defines the space available for sediments to fill (Jervey 1988).
- Accommodation may be modified by the interplay between various independent controls which may operate over a wide range of temporal scales.
- Marine accommodation is controlled primarily by basin tectonism and global eustasy, and, over much shorter time scales, by fluctuations in the energy flux of waves and currents.

SEDIMENT SUPPLY



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- Depositional trends of aggradation, erosion, progradation and
- retrogradation may be explained by changes in accommodation or by the
- interplay between accommodation and sediment supply.
- Positive accommodation promotes sediment aggradation, whereas negative
- accommodation results in downcutting.

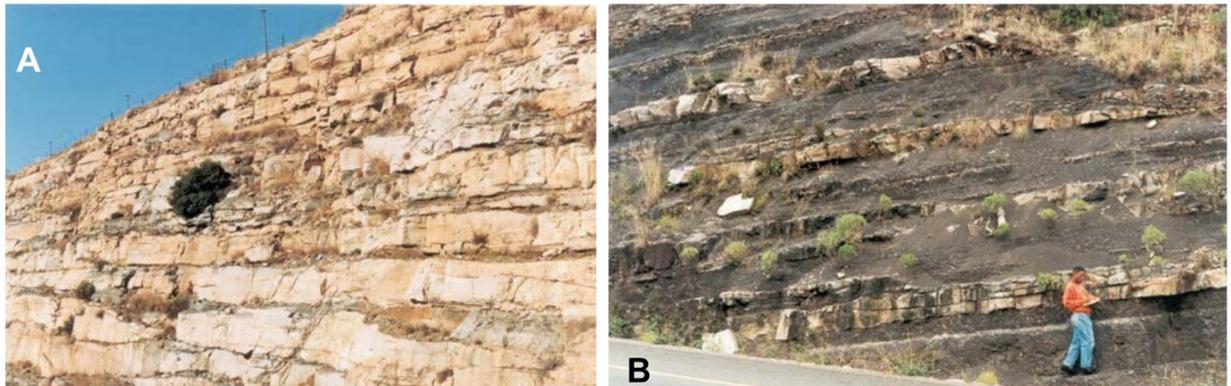


Fig. 9. Stratal stacking patterns in upstream-controlled fluvial systems. A – channel-dominated succession (low-accommodation setting: Katberg Formation, Early Triassic, Karoo Basin); B – overbank-dominated succession (high-accommodation setting: Burgersdorp Formation, Early-Middle Triassic, Karoo Basin).

Shoreline Trajectories

Definition:

- The interplay between base-level changes and sedimentation controls the fluctuations in water depth, as well as the transgressive and regressive shifts of the shoreline.
- Note// The types of shoreline shifts are critical in sequence stratigraphy framework, as they determined the formation of package of strata associated with particular depositional trends and hence characterized by specific stacking patterns, known as system tract.

Transgression

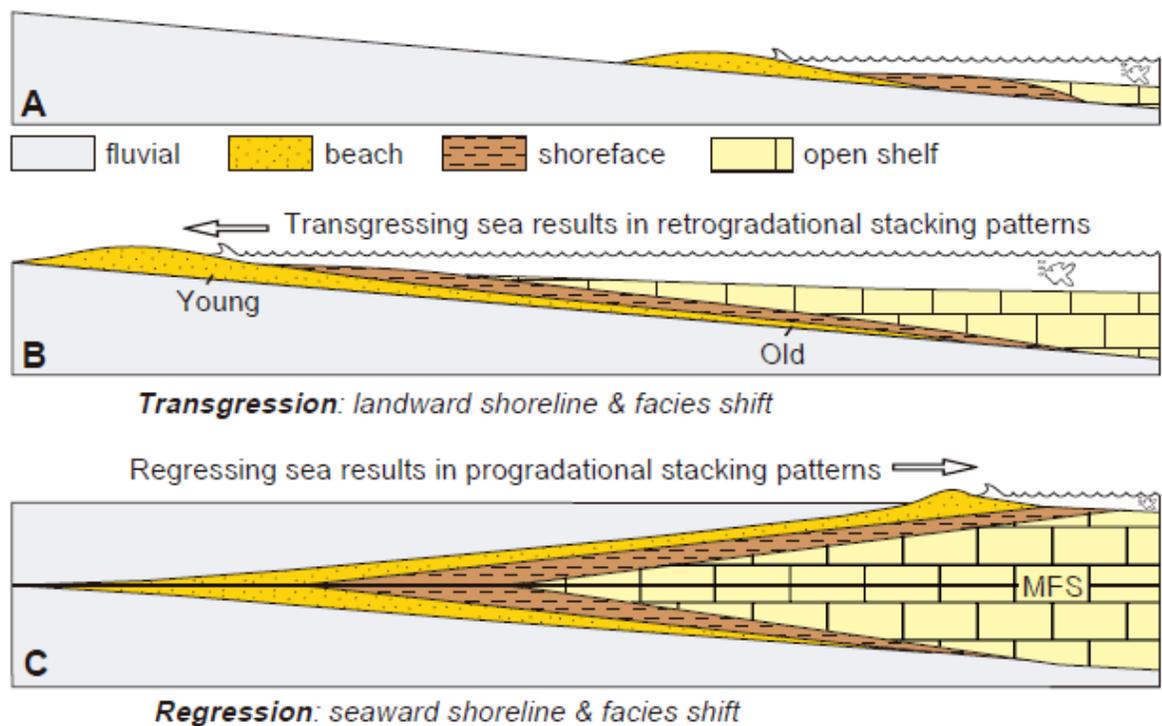
- **Transgression:** is defined as the landward migration of the shoreline.
- This migration triggers a corresponding landward shift of facies, as well as a deepening of the marine water in the vicinity of the shoreline.
- Transgressions result in **retrogradation stacking patterns**, e.g., marine facies shifting towards and overlying nonmarine facies.
- Retrogradation is the diagnostic depositional trend of transgressions.

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Regression

Regression: is defined as the seaward migration of the shoreline.

- This migration triggers a corresponding seaward shift of facies, as well as a shallowing of the marine water in the vicinity of the shoreline.
- Regression result in **progradation stack patterns**, nonmarine facies shifting towards and overlying marine facies.
- Progradation is the diagnostic depositional trend for regression.

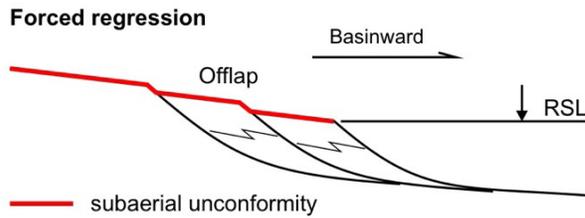


TRANSGRESSIONS AND REGRESSIONS.

NOTE THE RETROGRADATION AND PROGRADATION (LATERAL SHIFTS) OF FACIES, AS WELL AS THE SURFACE THAT SEPARATES RETROGRADATIONAL FROM OVERLYING PROGRADATIONAL GEOMETRIES. THIS SURFACE IS KNOWN AS THE MAXIMUM FLOODING SURFACE (MFS).

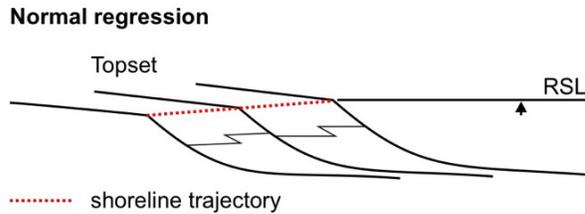
SOURCE: CATUNEANU (2006)

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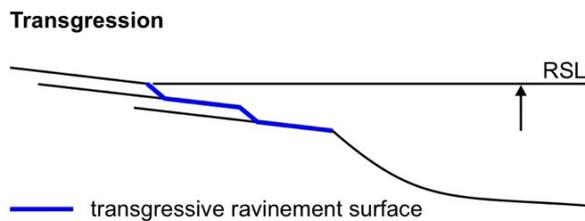
Stacking pattern: progradation with downstepping

Interpretation: progradation driven by relative sea-level fall (negative accommodation). The coastline is forced to regress, irrespective of sediment supply.



Stacking pattern: progradation with aggradation

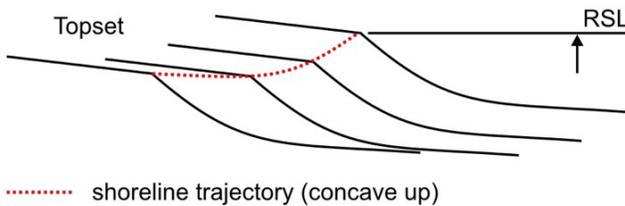
Interpretation: progradation driven by sediment supply. Sedimentation rates outpace the rates of relative sea-level rise (positive accommodation) at the coastline.



Stacking pattern: retrogradation.

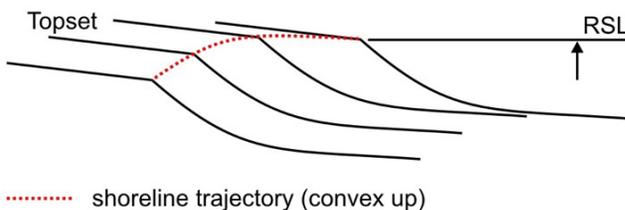
Interpretation: retrogradation (backstepping) driven by relative sea-level rise. Accommodation outpaces the sedimentation rates at the coastline.

Lowstand normal regression (accelerating RSL rise)



The rates of progradation decrease with time, the rates of aggradation increase with time.

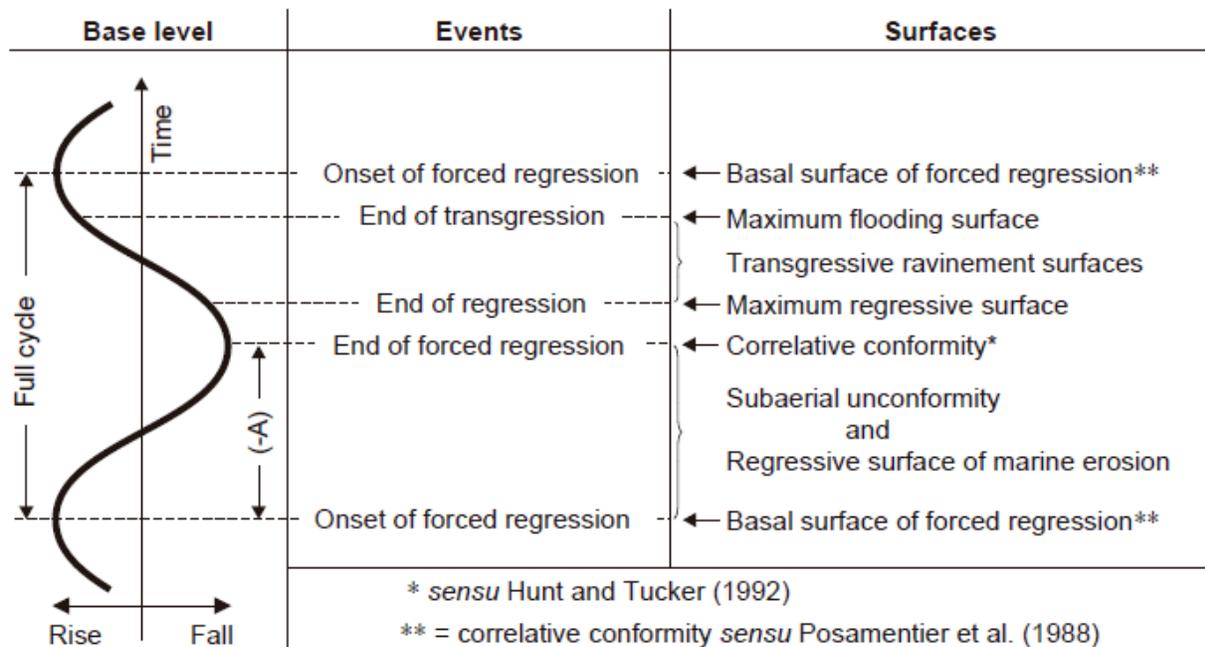
Highstand normal regression (decelerating RSL rise)



The rates of progradation increase with time, the rates of aggradation decrease with time.

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Sea level cycle



TIMING OF SEQUENCE STRATIGRAPHIC SURFACES RELATIVE TO THE MAIN EVENTS OF THE BASE-LEVEL CYCLE.

PHOTO FROM: CATUNEANU, OCTAVIAN. 2006. PRINCIPLES OF SEQUENCE STRATIGRAPHY. ELSEVIER.

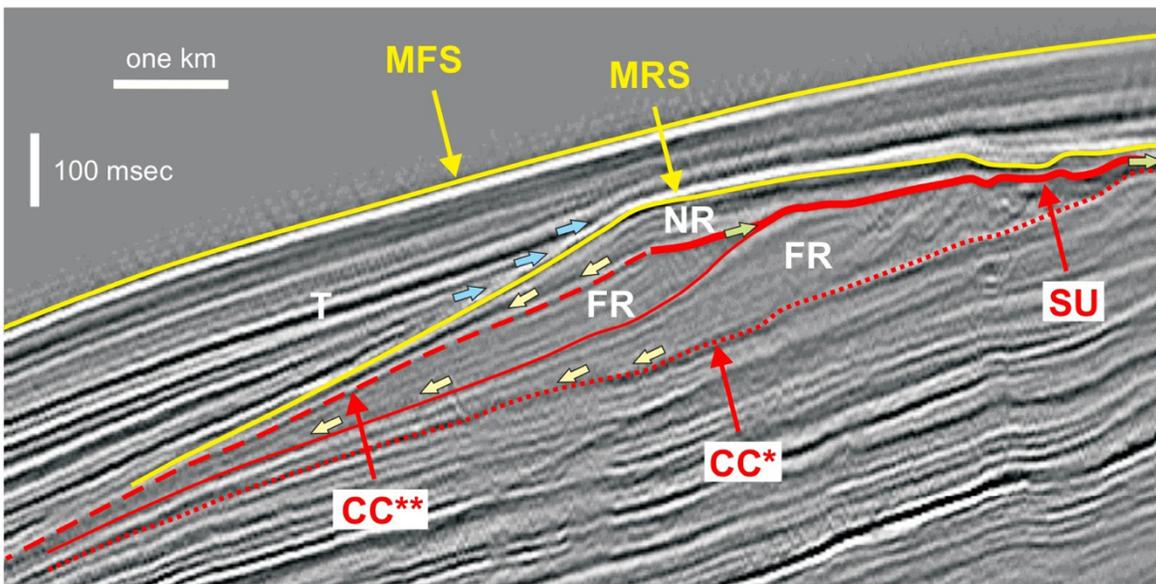


Fig. 8. Types of shoreline trajectory: seismic example (Plio-Pleistocene to Holocene, Gulf of Mexico; modified from Posamentier and Kolla 2003). Stratal terminations: green arrows – offlap; yellow arrows – downlap; blue arrows – onlap. Abbreviations: FR – forced regression; NR – normal regression; T – transgression; SU – subaerial unconformity; CC* – correlative conformity in the sense of Posamentier and Allen (1999) (= basal surface of forced regression); CC** – correlative conformity in the sense of Hunt and Tucker (1992); MRS – maximum regressive surface; MFS – maximum flooding surface.

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