Cyclicity And Cyclostratigraphy

Course of Stratigraphy G301
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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 cyclicity and events.

What is Cyclicity ?

- Cyclicity 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 cyclicity in earth system made geology a historical science .[1]

Types of Cyclicity

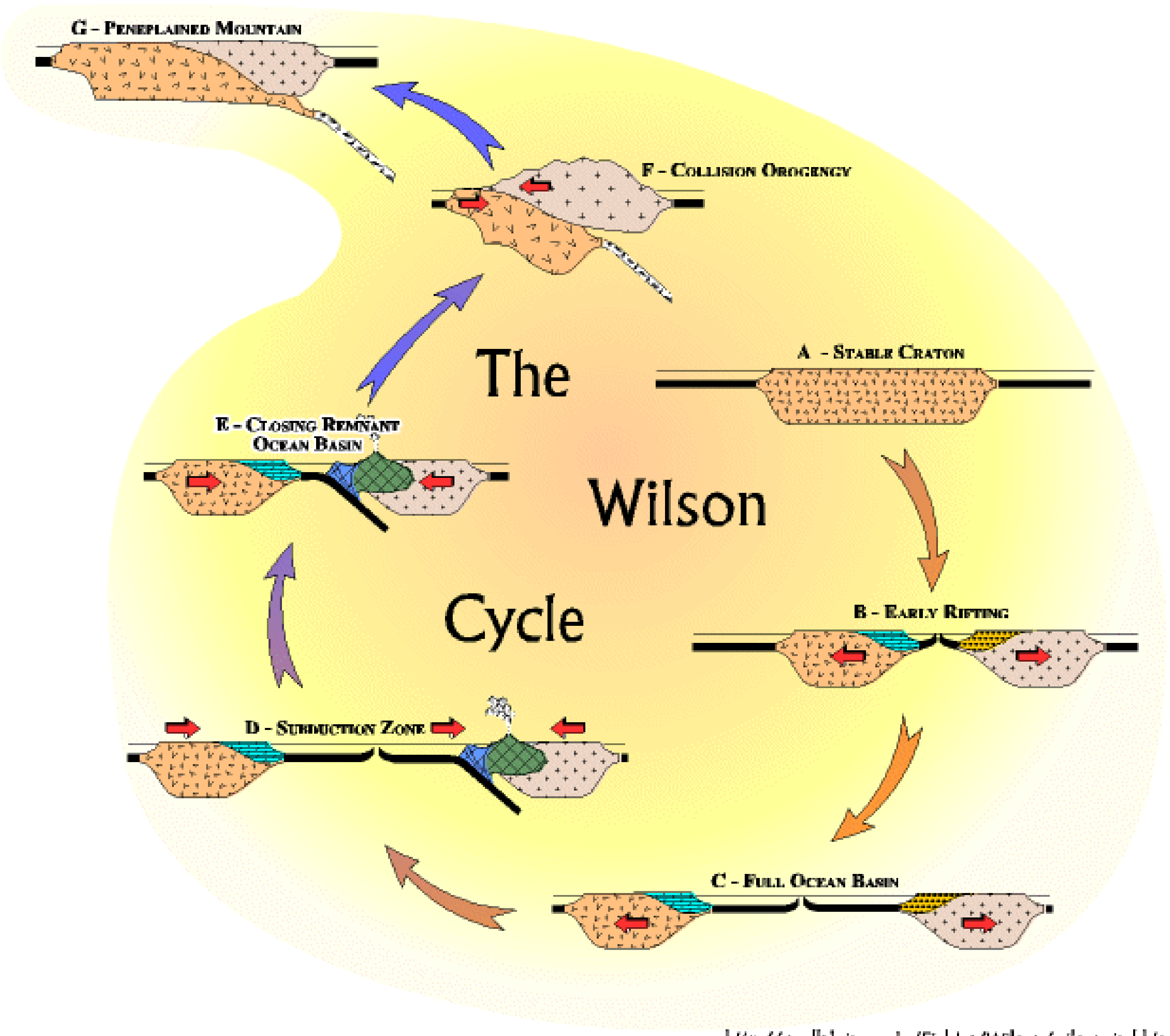
- Cyclicity can be divided into many types according to:

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 .*

Plate Tectonic Cycle



http://geollab.jmu.edu/Fichter/Wilson/wilsoncircl.html

Milankovitch Orbital Cycle

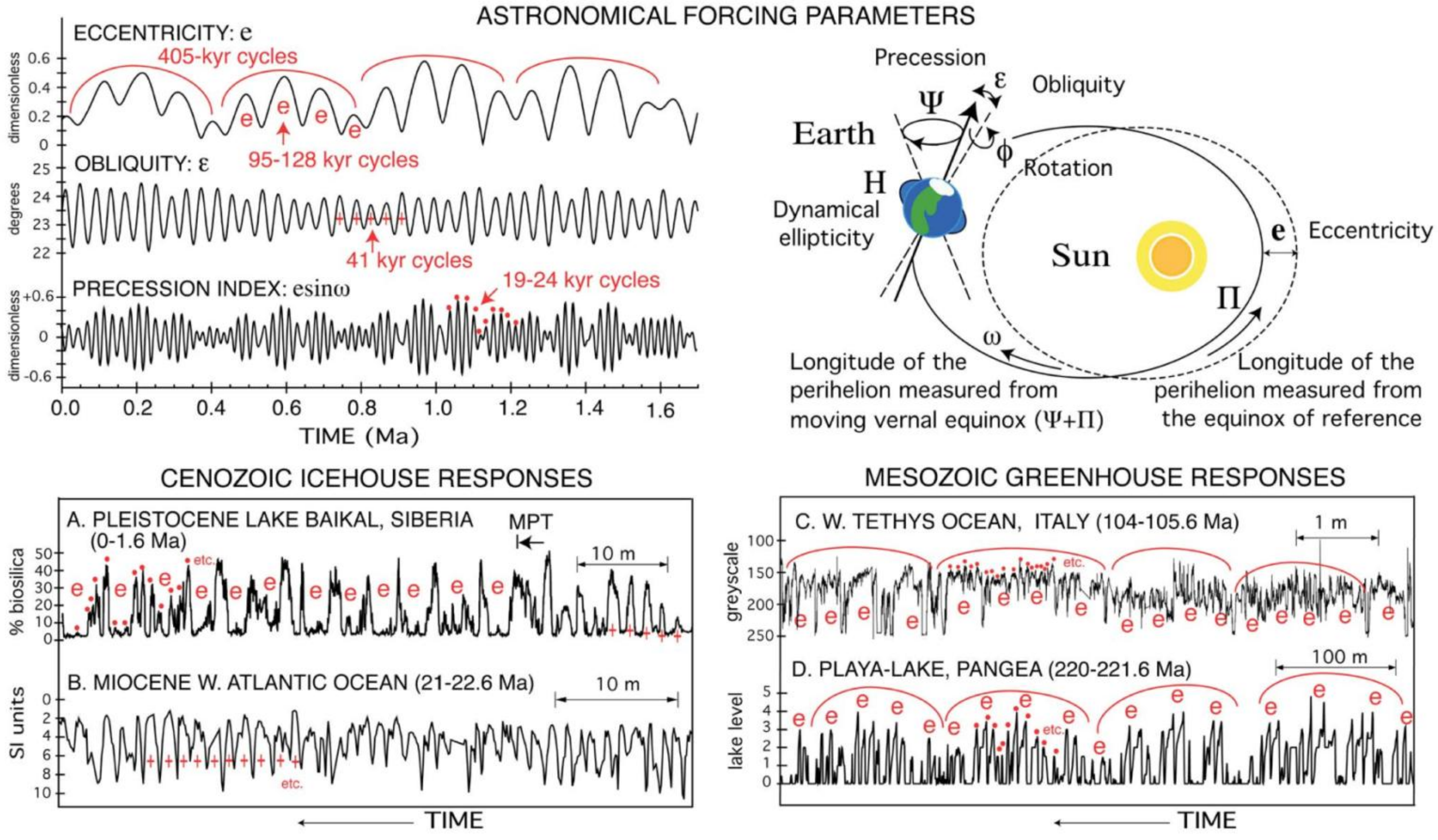
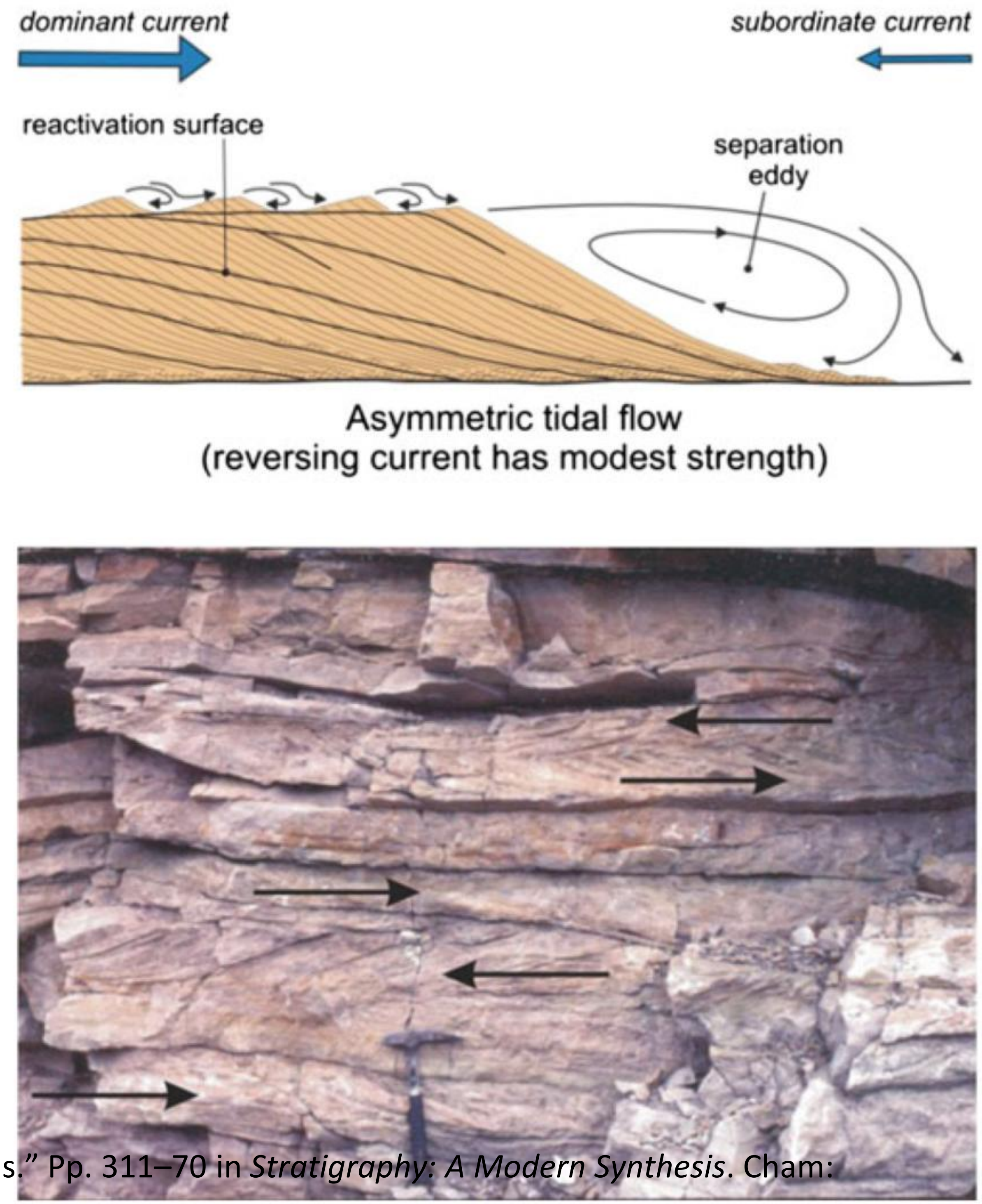


Photo from: Miall, Andrew D. 2016. “Stratigraphy: The Modern Synthesis.” Pp. 311–70 in *Stratigraphy: A Modern Synthesis*. Cham: Springer International Publishing.

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.



Asymmetric tidal flow
(reversing current has modest strength)

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

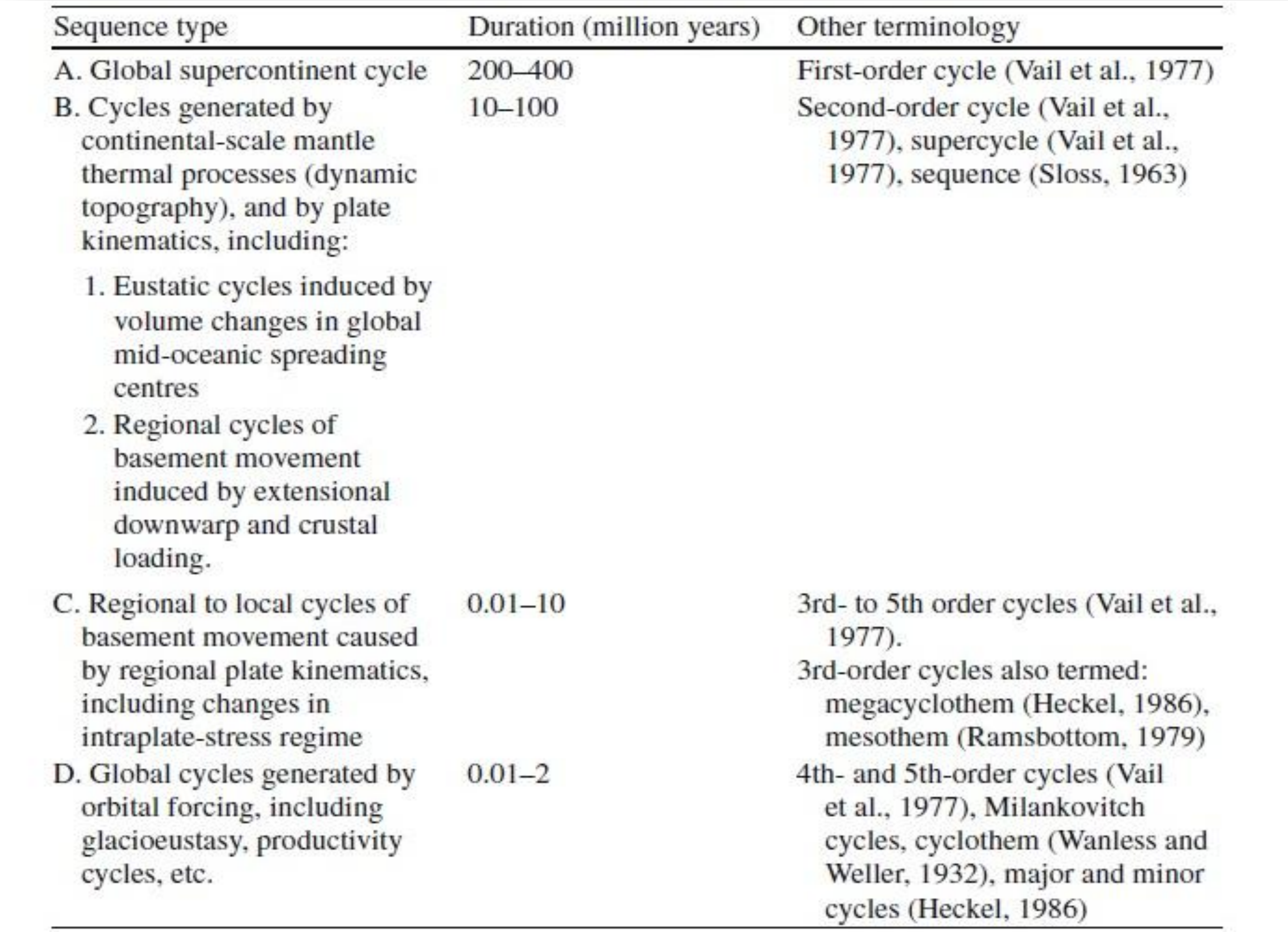
Other types of cyclicity

- 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 .

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.
- This hierarchical order is characterizing by fractal model, where the same pattern is repeated at finer and finer scales .[4]

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)

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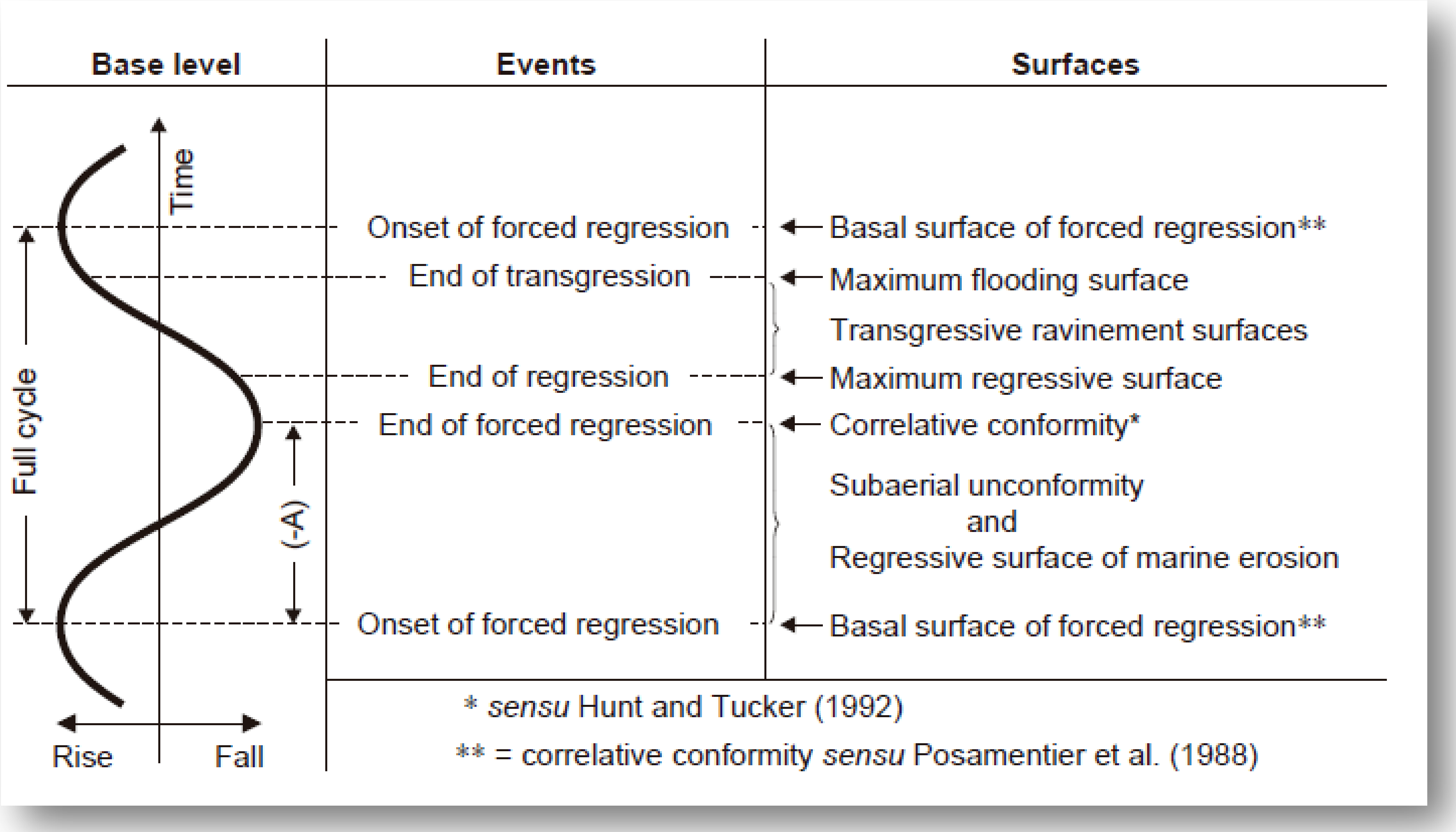
Sea level cycle



Events	Surfaces
Onset of forced regression	Basal surface of forced regression**
End of transgression	Maximum flooding surface
	Transgressive ravinement surfaces
End of regression	Maximum regressive surface
End of forced regression	Correlative conformity*
	Subaerial unconformity and Regressive surface of marine erosion
Onset of forced regression	Basal surface of forced regression**

* *sensu* Hunt and Tucker (1992)

** = correlative conformity *sensu* Posamentier et al. (1988)

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.

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 Milankovithch 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.

- These effects often have significant lag time, and complex interferences and feedback mechanisms are common.

- 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 .

Orbital cycles: the astronomical perspective

- Metronomic variations of the earth-moon and earth-sun orbital patterns result in cycles of greatly varying frequencies.

- 1- Calendar Band: for example the twice daily tidal cycles, the lunar month, the equinoxes, the annual cycle.

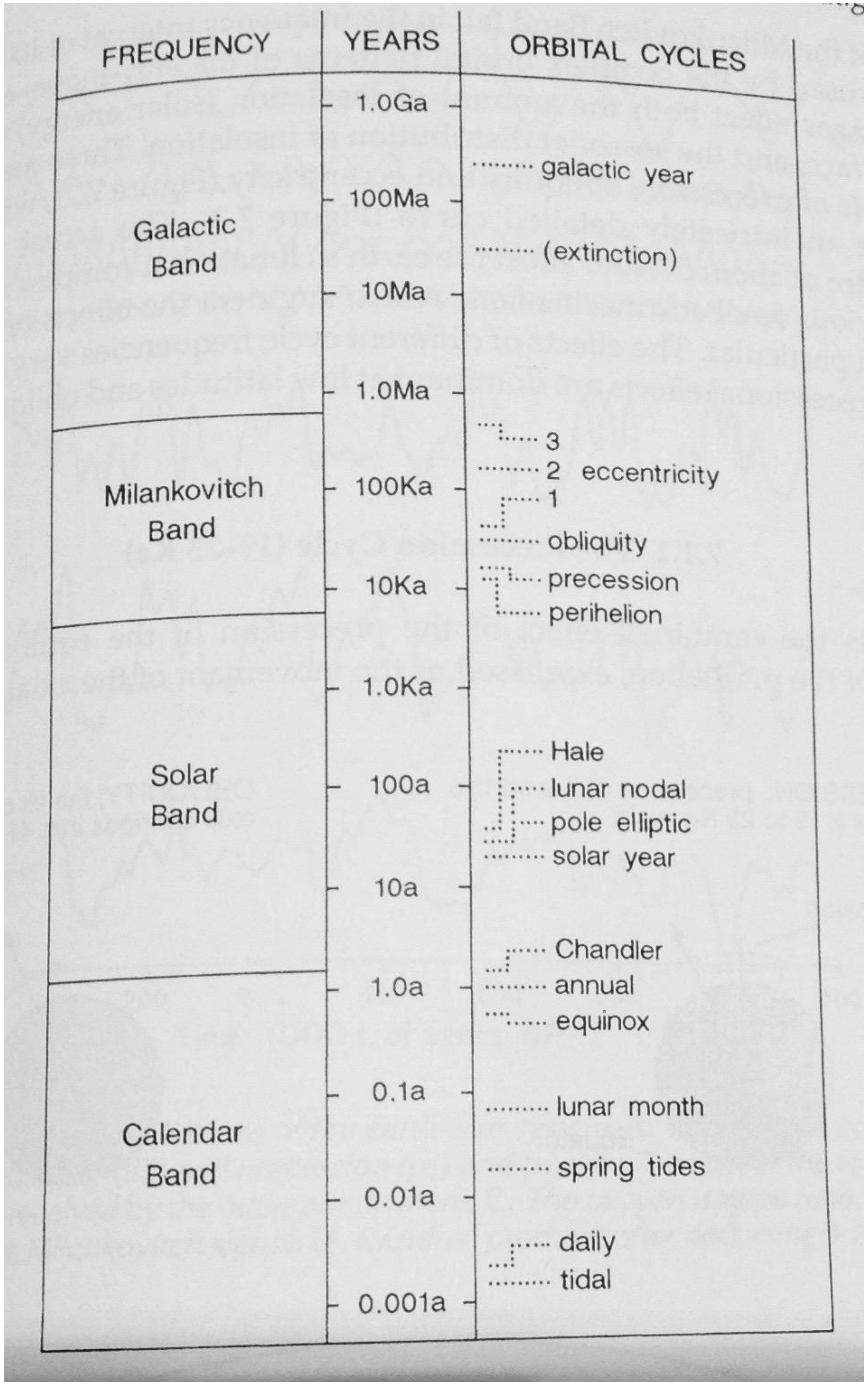
- 2- Solar Band: for example the sunspot cycles at 11 years, lunar nodal cycles at 18.61 years.

- 3- Milankovitch Band: 10 Ka- 1 Ma.

- 4- Galactic Band: for example the cosmic year at 220-250 Ma- the period taken by the solar system to move around the Milky Way Galaxy.

Orbital Cycles

Logarithmic table to show the orbital frequencies which exert an influence on temporal energy reaching the outer atmosphere.

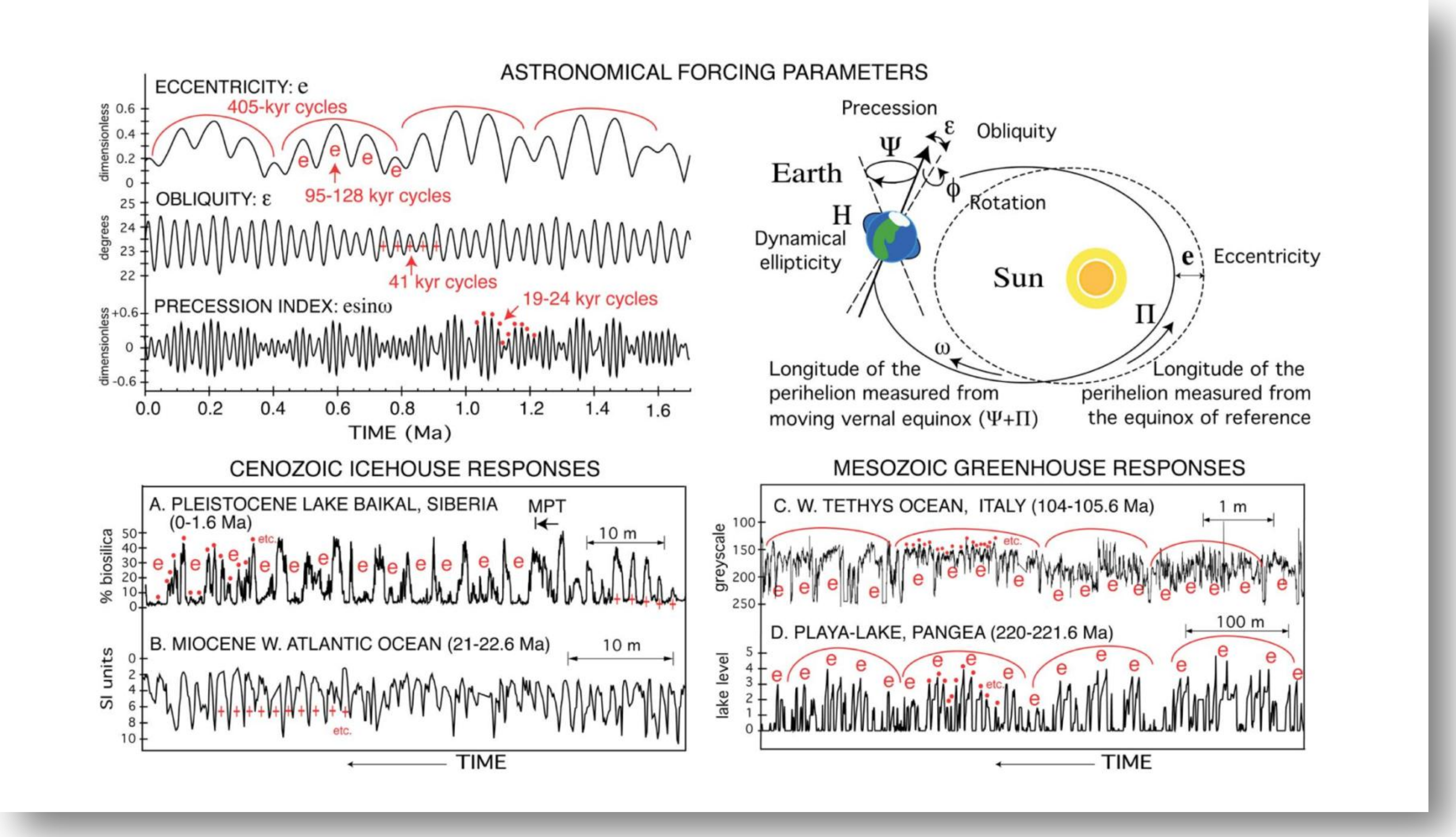


FREQUENCY	YEARS	ORBITAL CYCLES
Galactic Band	1.0Ga	
		galactic year
	100Ma	
		(extinction)
	10Ma	
	1.0Ma	
Milankovitch Band		3
		2 eccentricity
	100Ka	1
		obliquity
	10Ka	precession
		perihelion
Solar Band	1.0Ka	
		Hale
	100a	lunar nodal
		pole elliptic
		solar year
	10a	
		Chandler
Calendar Band	1.0a	annual
		equinox
	0.1a	lunar month
		spring tides
	0.01a	
		daily
		tidal
	0.001a	

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.

Milankovitch Orbital Cycle



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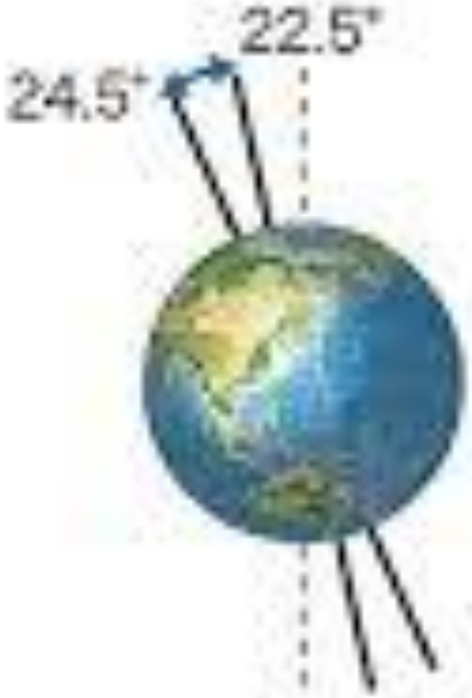
Eccentricity



Obliquity

Precession

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.

Precession related in the Pliocene continental succession of Ptolemais.

From http://www.uu.nl/staff/FJHilgen/0

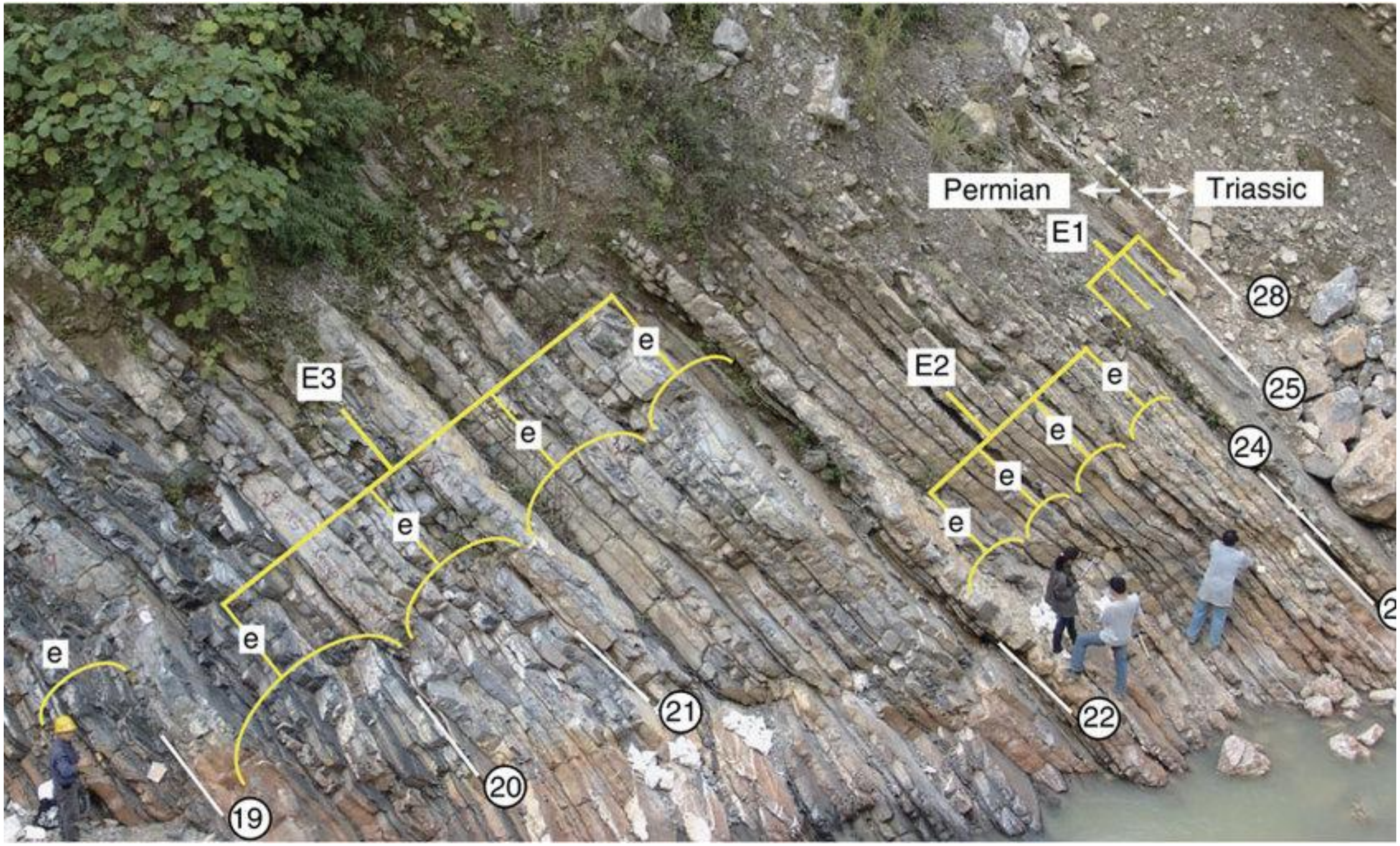
The Obliquity Cycle (41 ka)

- 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).

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.

1- Productivity and Dilution Cycles

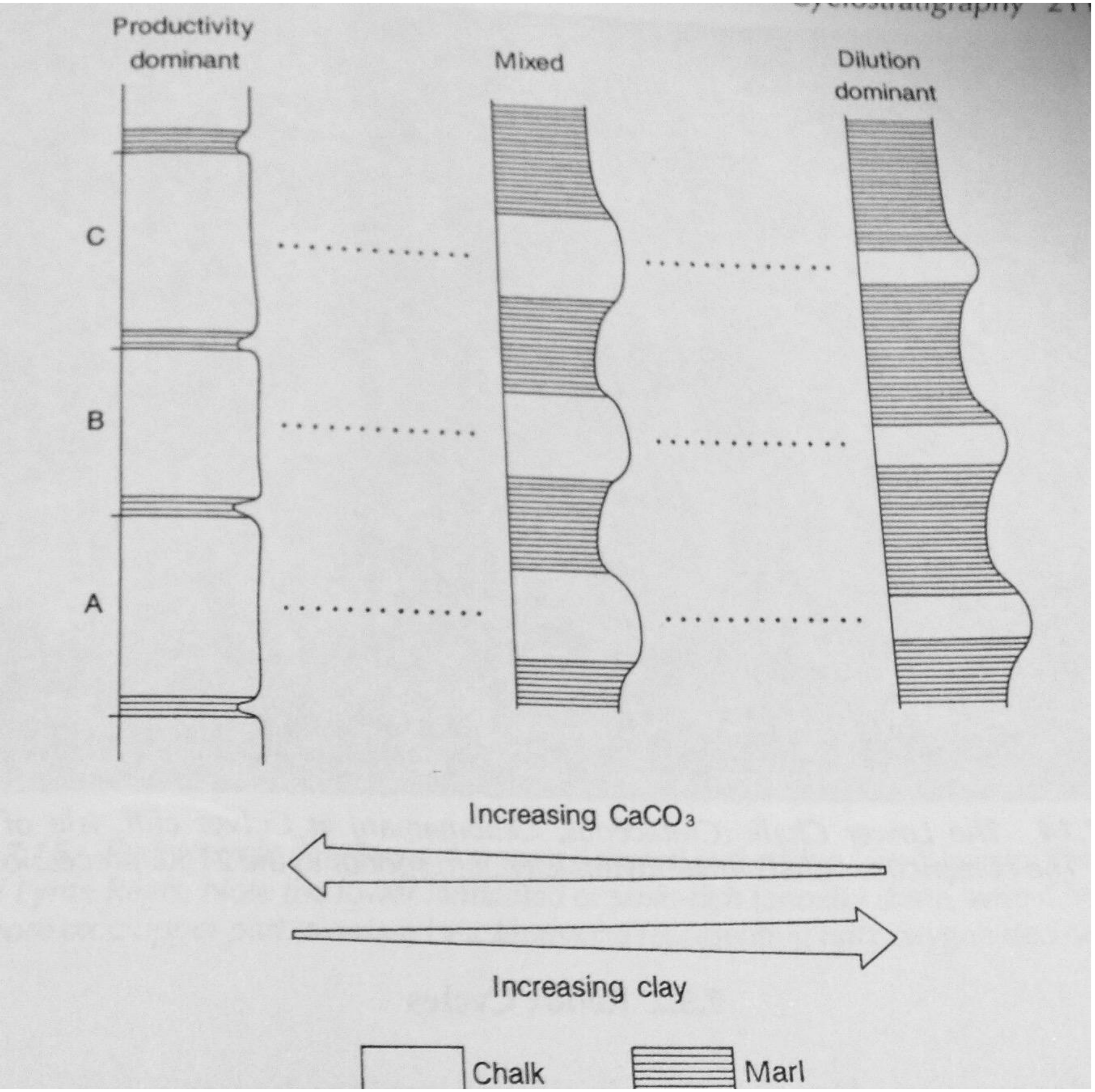
- Productivity cycles are generated when carbonate supply varies against a background of constant fine clastic deposition, sometimes called a 'clay clock'. Carbonate supply is determined by productivity, which is dependent upon upwelling and surface mixing to supply nutrients to phytoplankton.

- Dilution cycles are the product of fluctuating clastic supply against a background of constant carbonate productivity, and are controlled by climatic factors at least in pelagic and hemipelagic settings.

- Note: in hemipelagic settings, clay is originally supplied in runoff, which is highly responsive to source-area climate. In pelagic facies, clay is mostly carried in by wind.

- Both types of cycle produce similar alternations of carbonate-dominated beds with clay-rich calcareous shales or marls, one of commonest outer-shelf facies of Mesozoic.

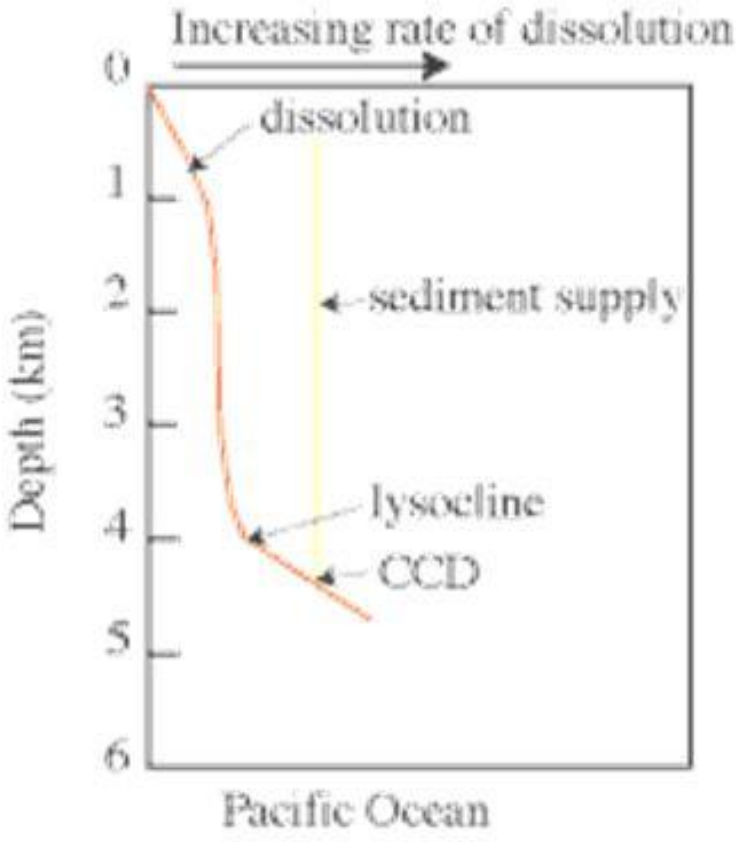
Productivity and dilution cycles: extremes of a continuum



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

Carbonate Compensation Depth

- At depths of >4,500m, the dissolved CO_2 concentration is so high it causes $CaCO_3$ to dissolve. As a result, calcareous shells are not found below ~5,000m.
- The depth where carbonate supply is equal to the rate of dissolution is the Carbonate Compensation Depth.
- This occurs around 6000m in Atlantic and 3500-4000 m in parts of the Pacific.



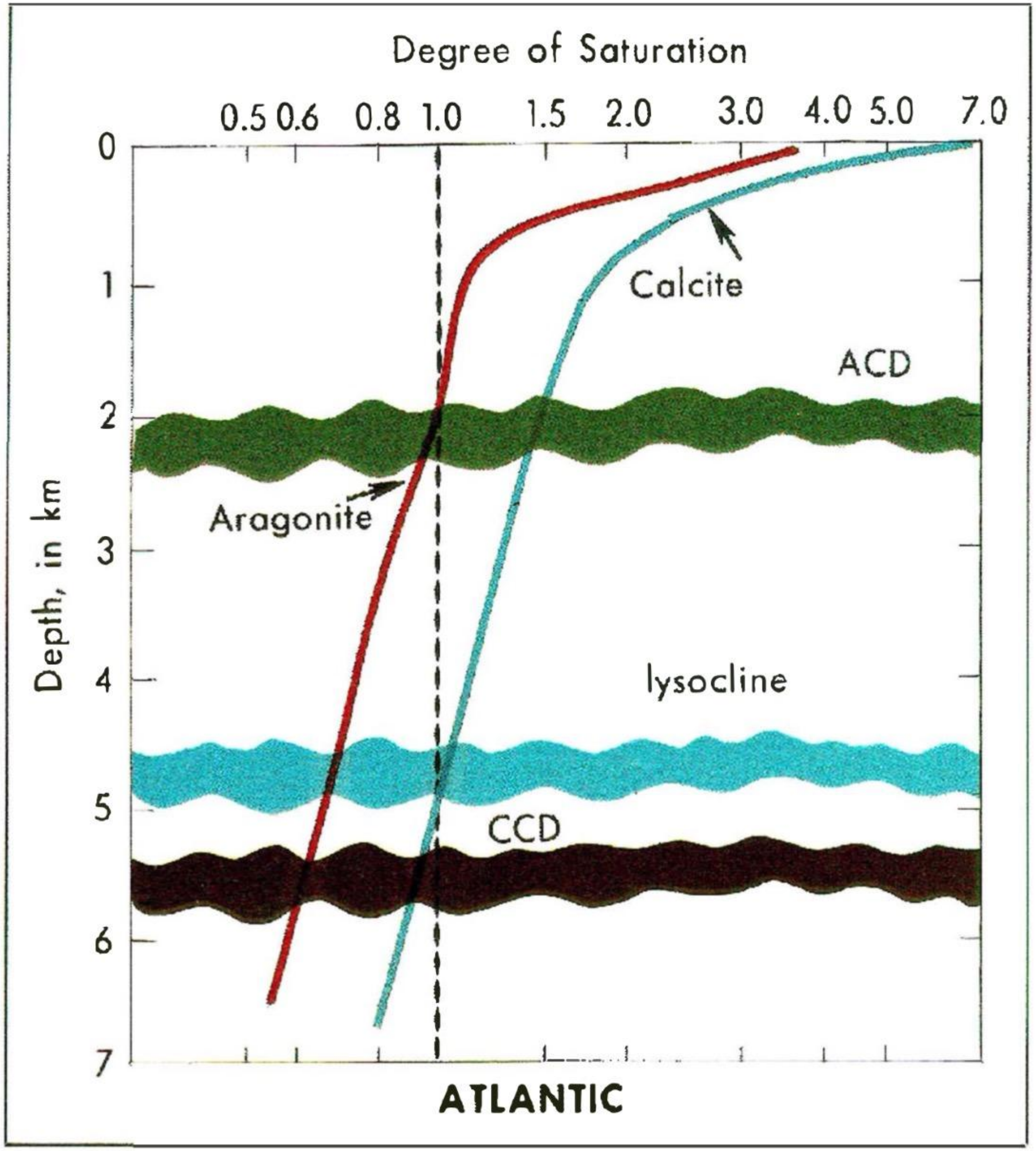
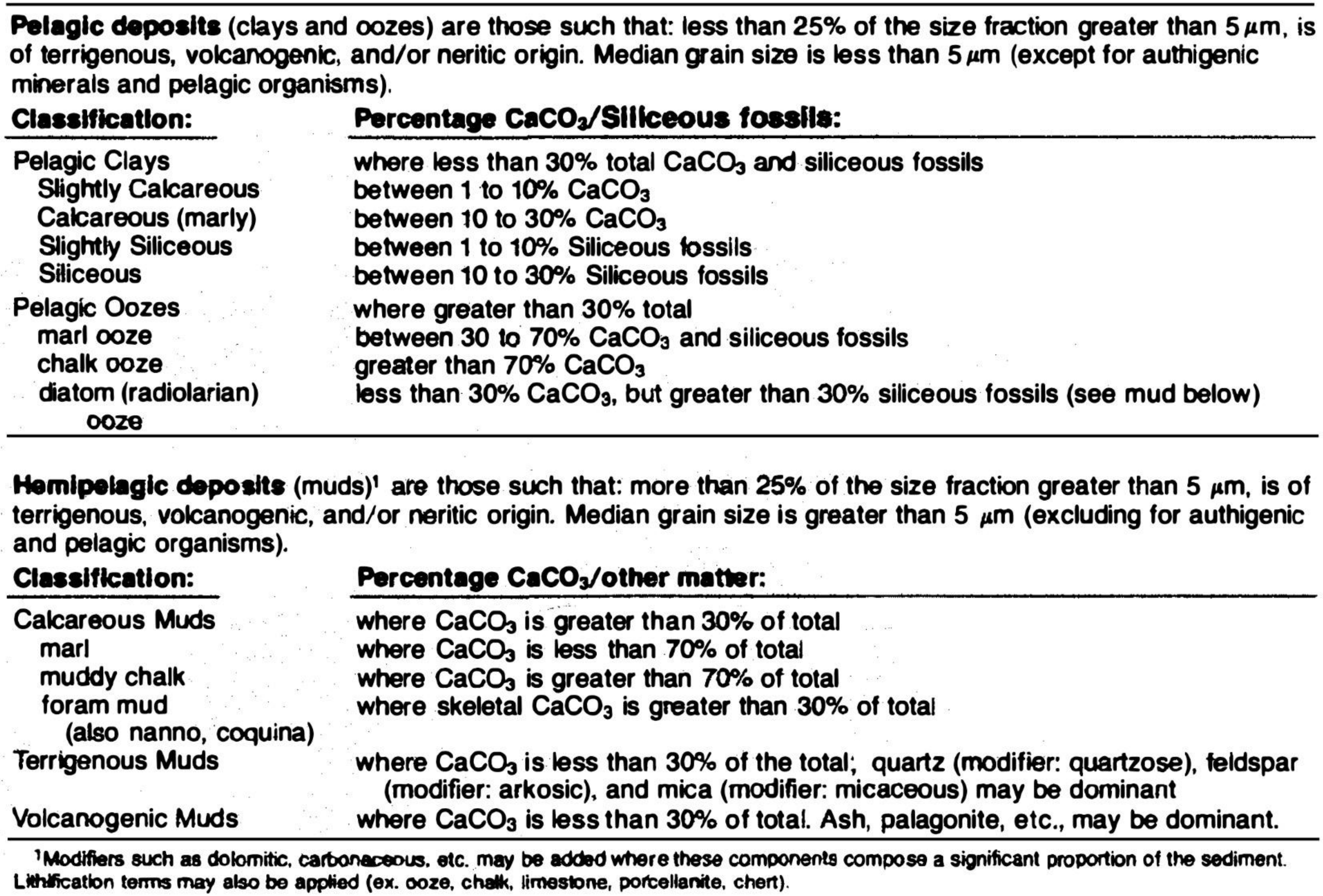


Figure 8A—Diagrammatic representation of the degree of saturation of seawater with respect to aragonite and calcite in the Atlantic Ocean. The lysocline marks the top of a zone of greatly increased rates of dissolution. The carbonate compensation depth (CCD) marks the depth below which no calcite is preserved. The aragonite compensation depth (ACD) is at much higher levels (approximately 2,000 m depth) than the CCD (after Broecker, 1974).



Pelagic deposits (clays and oozes) are those such that: less than 25% of the size fraction greater than 5 μm, is of terrigenous, volcanogenic, and/or neritic origin. Median grain size is less than 5 μm (except for authigenic minerals and pelagic organisms).

Classification:	**Percentage $CaCO_3$/Siliceous fossils:**
Pelagic Clays	where less than 30% total $CaCO_3$ and siliceous fossils
Slightly Calcareous	between 1 to 10% $CaCO_3$
Calcareous (marly)	between 10 to 30% $CaCO_3$
Slightly Siliceous	between 1 to 10% Siliceous fossils
Siliceous	between 10 to 30% Siliceous fossils
Pelagic Oozes	where greater than 30% total
marl ooze	between 30 to 70% $CaCO_3$ and siliceous fossils
chalk ooze	greater than 70% $CaCO_3$
diatom (radiolarian) ooze	less than 30% $CaCO_3$, but greater than 30% siliceous fossils (see mud below)

Hemipelagic deposits (muds)[1] are those such that: more than 25% of the size fraction greater than 5 μm, is of terrigenous, volcanogenic, and/or neritic origin. Median grain size is greater than 5 μm (excluding for authigenic and pelagic organisms).

Classification:	**Percentage $CaCO_3$/other matter:**
Calcareous Muds	where $CaCO_3$ is greater than 30% of total
marl	where $CaCO_3$ is less than 70% of total
muddy chalk	where $CaCO_3$ is greater than 70% of total
foram mud (also nanno, coquina)	where skeletal $CaCO_3$ is greater than 30% of total
Terrigenous Muds	where $CaCO_3$ is less than 30% of the total; quartz (modifier: quartzose), feldspar (modifier: arkosic), and mica (modifier: micaceous) may be dominant
Volcanogenic Muds	where $CaCO_3$ is less than 30% of total. Ash, palagonite, etc., may be dominant.

[1] Modifiers such as dolomitic, carbonaceous, etc. may be added where these components compose a significant proportion of the sediment. Lithification terms may also be applied (ex. ooze, chalk, limestone, porcellanite, chert).

Table 3—Classification of deep-sea pelagic and hemipelagic sediments (after Berger, 1974).

Carbonate-marls rhythms in the Pliocene Punta di Maiata section of the Rossello composite on Sicily

-2Redox Cycles

- Redox cycles are caused by variations in either organic carbon or oxygen supply to deep marine area, and appear characteristically as an alternation of dark, organic-rich, often laminated marl or clay and lighter bioturbated carbonate-rich marl.
- They represent movement of the redox layer (oxic-anoxia boundary) from beneath the sediment-water interface to a level in the water column above it.
- Beneath the carbonate compensation depth, redox cycles may be represented by alternations of organic-rich mudstone and radiolarites.
- The two most probable controls on formation of redox cycles are oxygen supply, which is most common in restricted, periodically stagnant basins, and productivity, which controls organic flux.
- Productivity is almost invariably the main cause of anoxia. Productivity it itself controlled by nutrient supply from upwelling or surface mining, which are both related to climate changes.

Redox cycle (limestone-laminated shales) in Blue Lisa Formation

Detailed view of rhythmically alternating shale and limestone sequences typical of the Lower Jurassic blue lias rock formation at Church Cliffs, Lyme Regis, U.K.
Lyme Regis

Dissolution Cycles

- The accumulation of carbonate in deep eater is moderated by dissolution at the sediment-water interface,, and at the Carbonate Compensation Depth (CCD) total carbonate dissolution occurs.

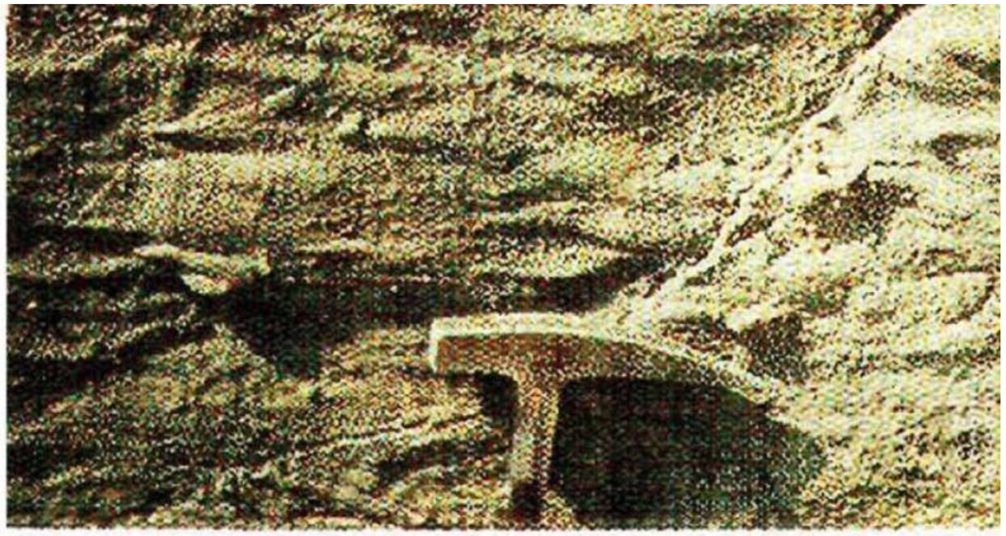
- The CCD will vary in its depth depending on many factors, such as temperature, the supply of carbonate, and the concentration of dissolved CO2, all of which can controlled by climate.

- Dissolution cycles produce thick limestone and thinner marls, rather similar to productivity cycles in appearance.

- It is likely that dissolution cycles were common during the Cretaceous, because the CCD was located at shallow depths (2-3 km.(

Note the lower laminated organic-rich (anoxic) shale, with Chondrites in the more oxide upper part, overlain by a limestone representing fully oxygenated conditions.

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.



Diagenesis Cyclicity

- After deposition, all sediments undergo changes at relatively low temperatures and low pressures, which are referred to collectively as diagenesis.
- Much early diagenesis is bacterially moderated, and commonly involves the precipitation of carbonate and silica cements, often as concretions.
- The precise stratigraphical distribution of concretionary layer is therefore often controlled by primary depositional features such as original concentration of carbonate, or presence of minor hiatus above concentrations.
- Diagenesis commonly augments primary cyclic sedimentary features by, for example, cementing limestone beds, or the formation of rhythmically bedded flint nodules in pelagic carbonates, which in Cretaceous chalks dominantly have a precession frequency.

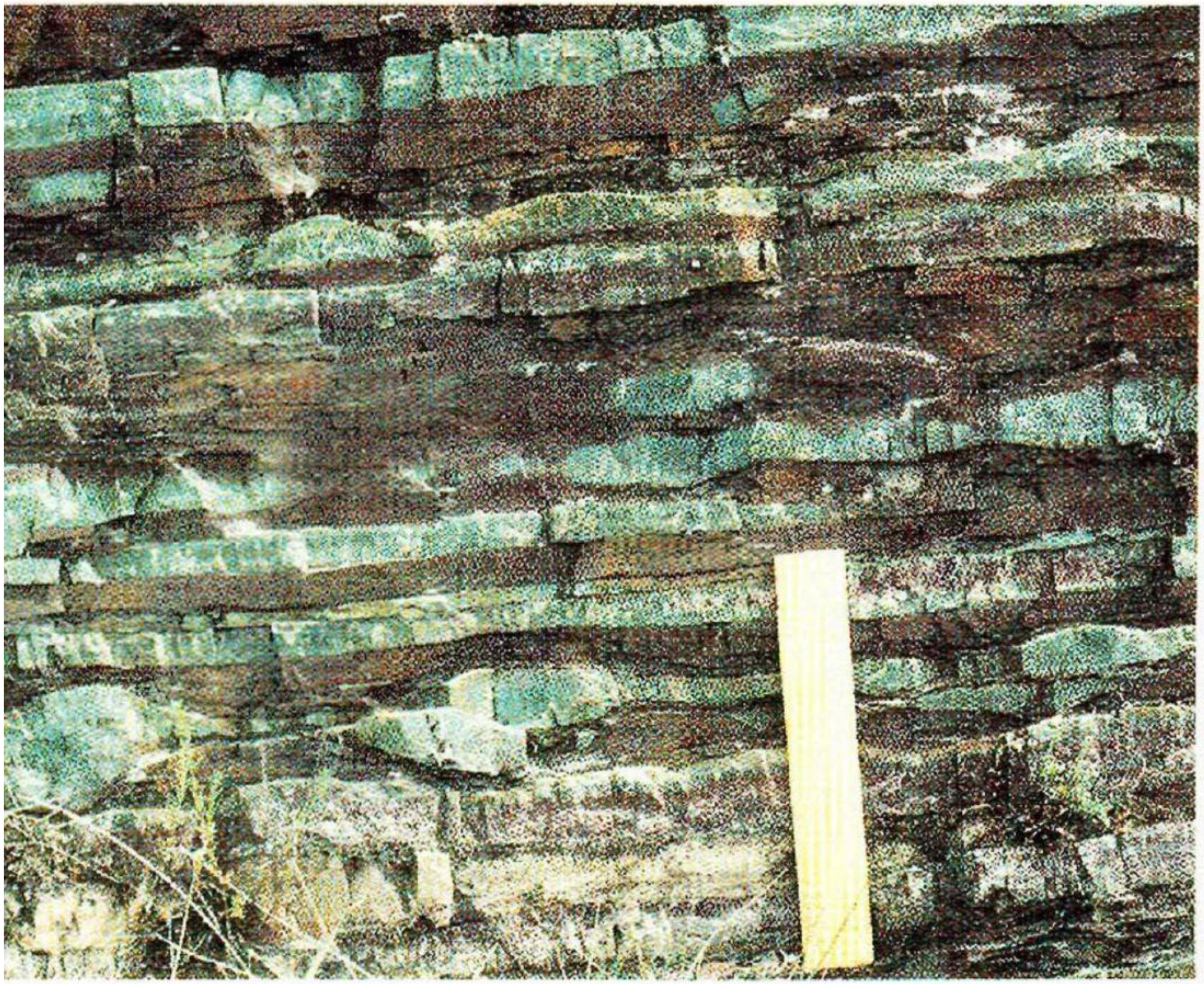


Figure 42—Interbedded chert
green) and hemipelagic (red) s
Chert layers range from even
regular to nodular; variations i
thickness are largely related t
diagenetic history. Uncertainty
to whether the chert precurso
radiolarian ooze or silicified lin
Jurassic, Lagonegro basin, Ba
Italy (photograph by E. F. McB
Scale is 15 cm long.

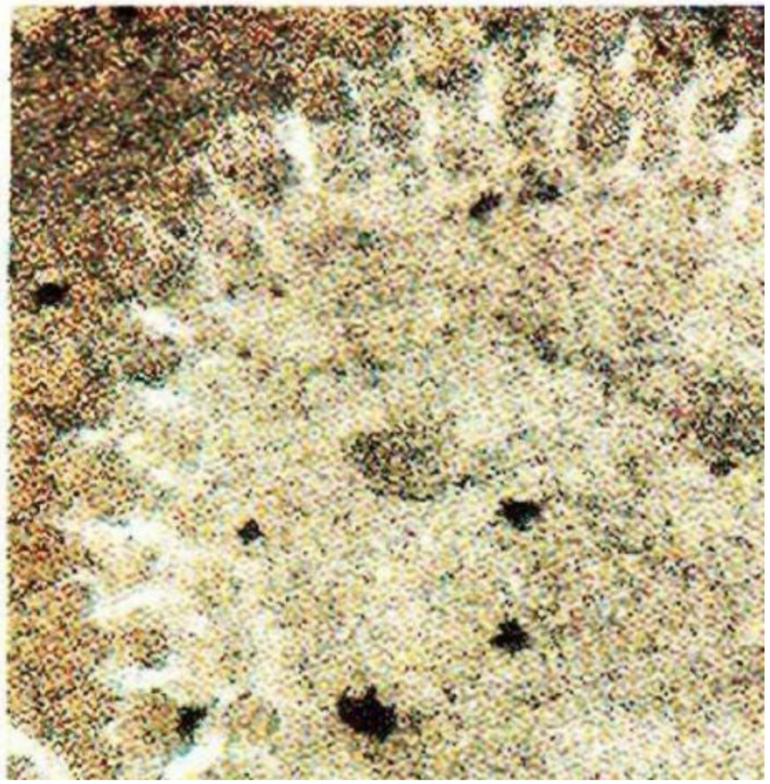


Figure 103—Chert nodules (flint) in pelagic limestone of Upper Cretaceous chalk, near Etretat, France. Chertification is the result of early diagenetic mobilization of biogenic silica. Shape of chert nodules is partially controlled by a pre-existing *Thalassinoides* burrow system. Dark areas are only partially silicified.

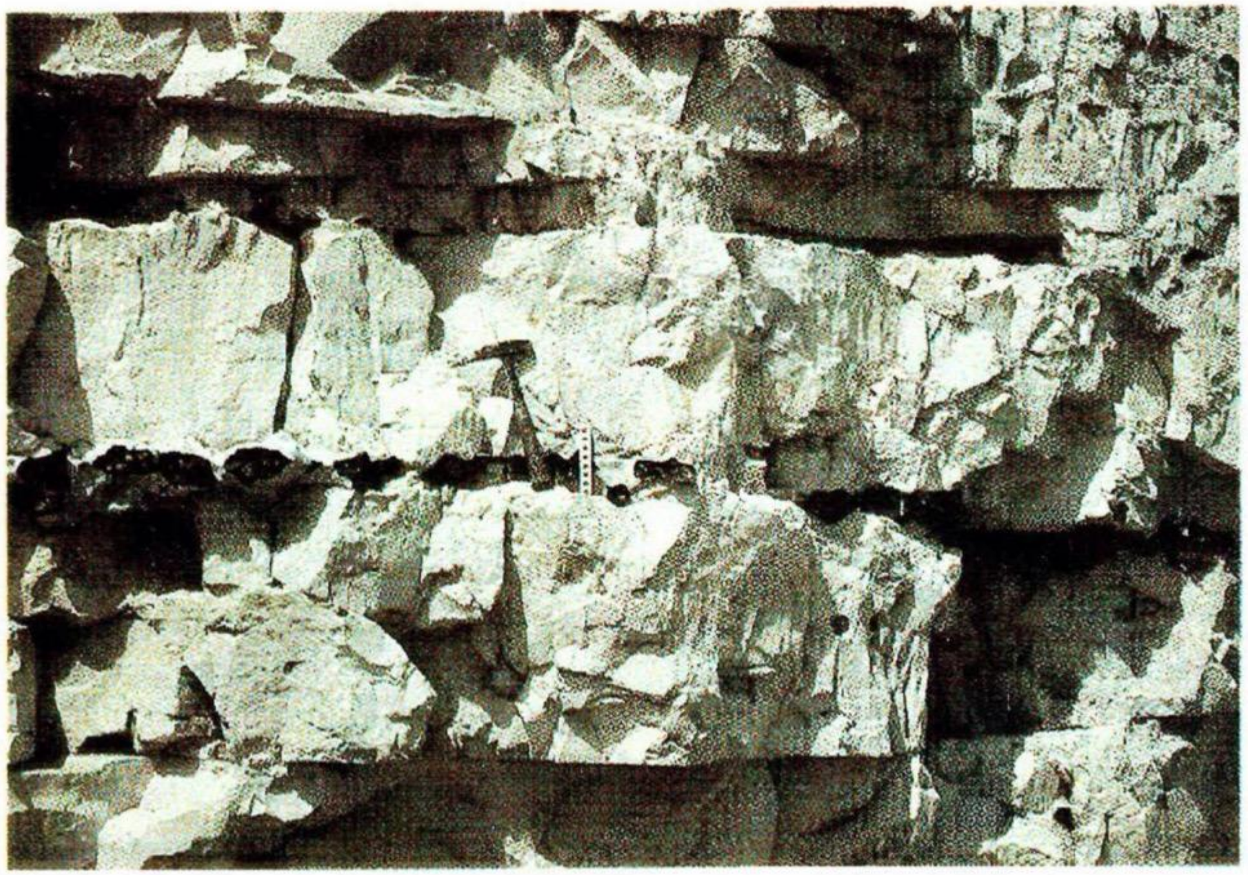


Figure 104—Tabular chert nodules along bedding plane in chalk. Distribution of chert is presumably controlled by variations in permeability and organic carbon content of replaced sediment. Bedding surfaces in this chalk sequence commonly represent zones of increased winnowing and improved permeability. Source of silica in this relatively shallow-water example was mainly from siliceous sponges; distribution of siliceous sponges, therefore, also can control sites of chertification. Upper Cretaceous Upper Chalk, southern England. Scale bar is 15 cm long.

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