APPENDIX 2

What is a cycle ?

Definitions and terminology in cyclostratigraphy

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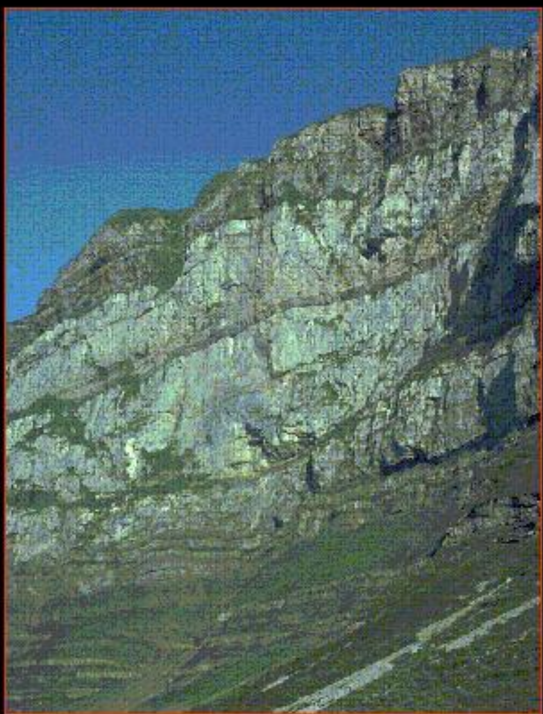
What do we want ?

Goal:

to establish a timescale as precise as possible, which permits to better interpret the geological past:

rates of climate and sea-level changes, ecological changes, sedimentation rates, diagenetic rates, timing of events



A good tool: cyclostratigraphy

This is easy

Cyclostratigraphy
deals with the analysis of cyclic variations in the sedimentary record
that have identifiable time periods

... and nothing new

"... to describe certain regular alternations of strata in Colorado, to correlate these with an astronomical cycle of known period, and to deduce from this correlation an estimate of years of a portion of Cretaceous time."

Gilbert, G.K. (1895): Sedimentary measurement of Cretaceous time. J.Geol. 3, 121-127.

But ...

How do we identify a sedimentary cycle
and how do we know that each cycle represents
the same time period ?

... and nomenclature

... and different orders

Cycle

Cyclothem

Genetic sequence

Rhythm

PAC

Parasequence

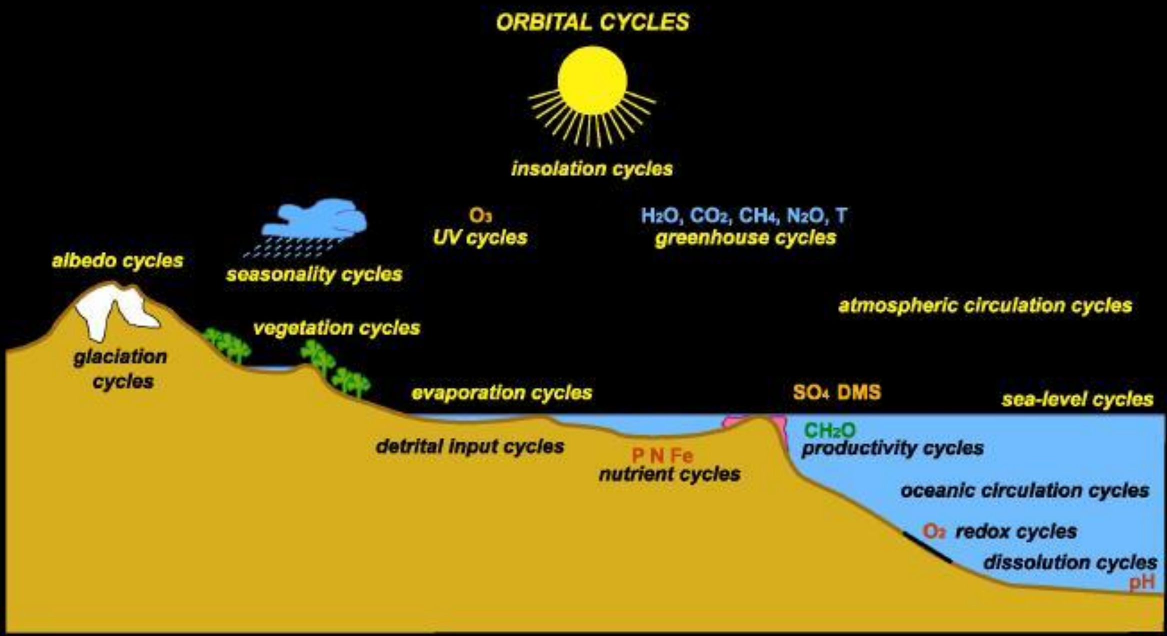
T-R Cycle

Couplet

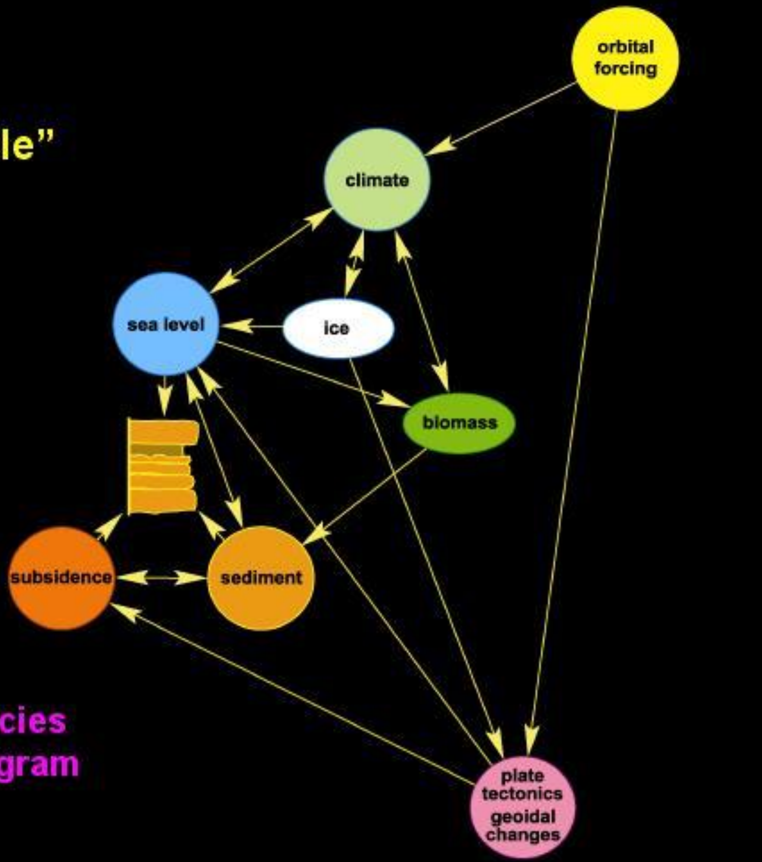
Bundle

Elementary sequence

Cyclic (or periodic, or quasi-periodic) processes influence the sedimentary system



The formation of a sedimentary "cycle" depends on many factors



Amplitudes and frequencies vary strongly in this diagram

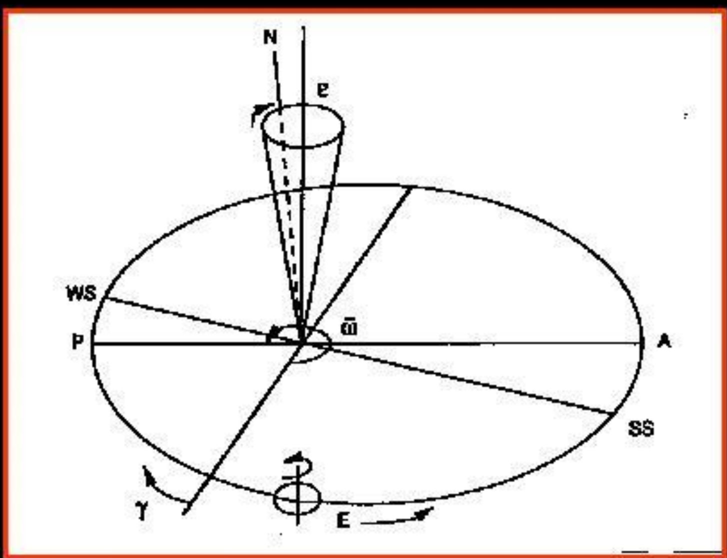
Cycle frequencies vary from twice-daily (e.g., tides) to hundreds of millions of years (e.g., plate tectonics)

For chronostratigraphic purposes, astronomically controlled cycles of a few thousand to a few hundred thousand years are well suited (stability, link to biostratigraphic resolution and radiometric dating)

Orbital (Milankovitch) cycles

Milankovitch cycles

are caused by the perturbation of the Earth's orbit by the gravitational pull of the Sun, the Moon, and the planets (mainly Jupiter and Saturn)



Schwarzacher (1993)

E Earth
A aphelion
P perihelion
WS winter solstice
SS summer solstice
γ position of vernal equinox
ω longitude of the perihelion
ε obliquity
N North pole

Orbital elements:

climatic precession

(revolution of the vernal point relative to the moving perihelion)

average quasi-period: 21,700 years

astronomical precession of the equinoxes

(revolution of the vernal point relative to the fixed perihelion)

average quasi-period: 25,700 years

obliquity (inclination of the Earth's axis)

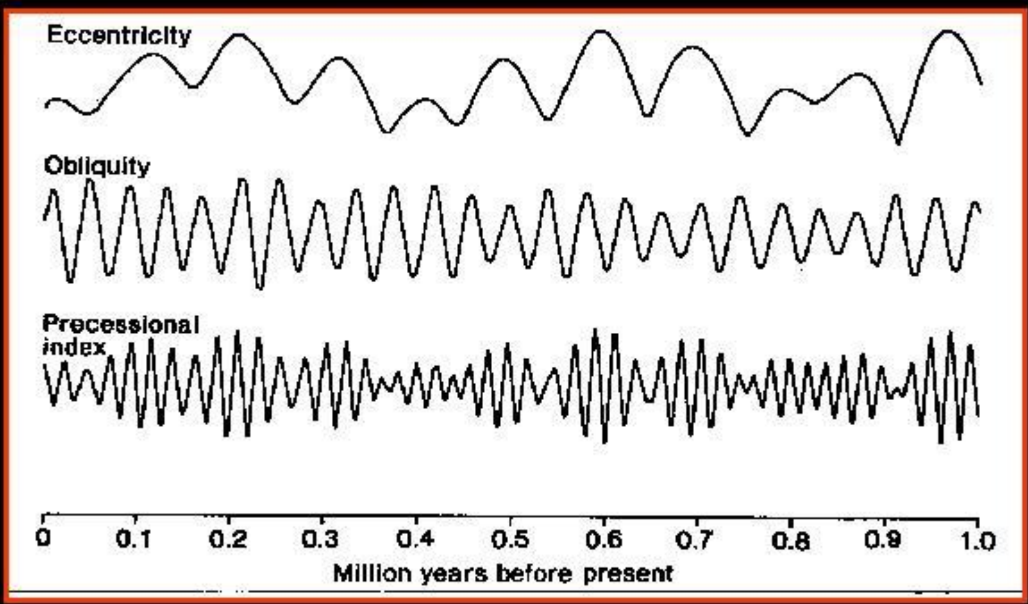
average quasi-period: 41,000 years

eccentricity (of the Earth's orbit around the Sun)

average quasi-period: 95,000 years

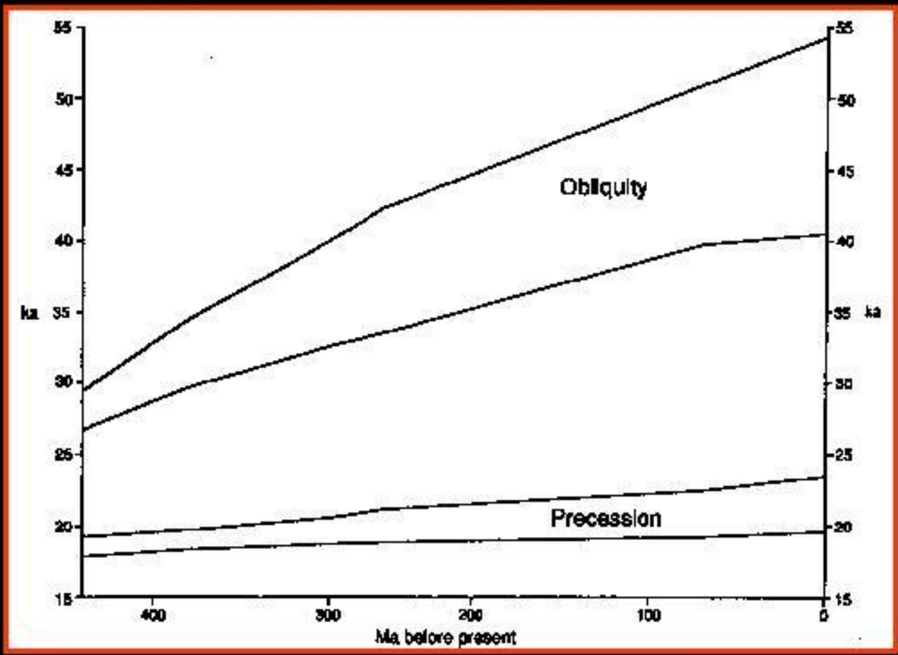
Berger (1980)

Eccentricity, obliquity, and precessional indices for the last million years



Schwarzacher (1993)

Change of obliquity and precession in the geologic past



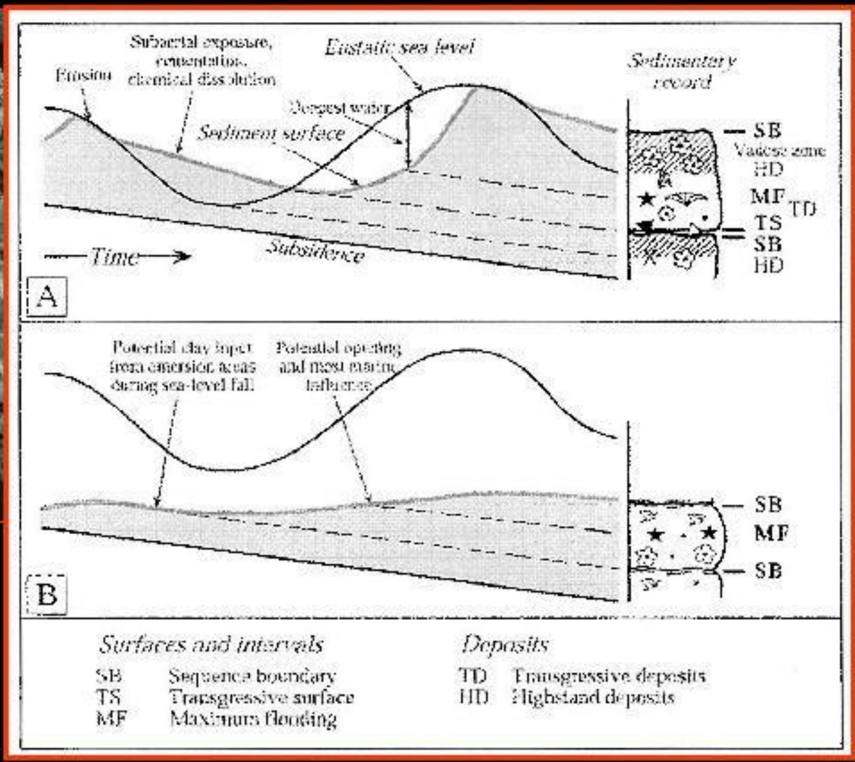
Berger et al. (1989)

Milankovitch cycles

If it can be shown that the orbital cycles translate into periodic changes that influence the sedimentary system and are recorded,
then a relatively precise time control is available for the interpretation of ancient sedimentary successions

However, this translation is often distorted, the record of some cycles may be missing, or "autocyclic" processes may be superimposed

Formation of elementary sequences due to sea-level change



Strasser et al. (1999)

Link to sequence stratigraphy:

Sedimentary sequence (= depositional sequence):

"a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities" (Mitchum et al. 1977)

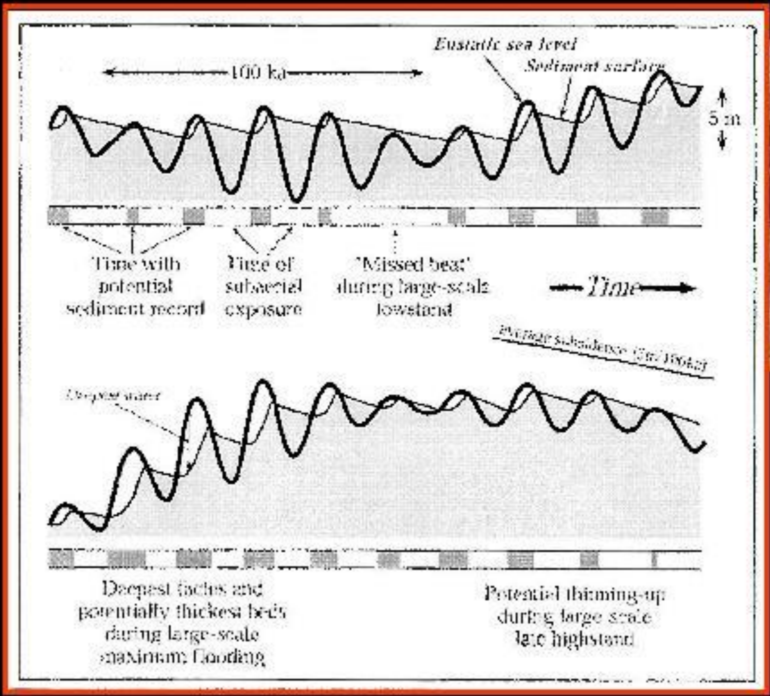
↓

Sediments belonging to the same sequence were deposited (and preserved) in the same time interval

↓

High time resolution for elementary sequences

Much time is missing in the sedimentary record



Strasser et al. (1999)

but distribution and duration of the hiatuses is not arbitrary

Limestone-marl alternations (couplets)

Controls:

- pelagic productivity
- carbonate import
- clay import
- diagenesis

One environmental cycle may produce one couplet,
or two couplets (threshold passed twice during a cycle),
or no couplet (environmental changes too weak)

A sedimentary succession commonly records cyclic processes of several orders
as well as random processes and events

Consequences:

- A cyclostratigraphical interpretation of the sedimentary record is only possible if the processes producing the observed cyclicity are known

- Analyse as many parameters as possible:
    - Bed thicknesses (decompacted)
    - Stacking pattern of beds
    - Facies evolution
    - Geochemical proxies
    - Clay minerals
    - Colour changes

- Correlate between sections to filter out local and/or "autocyclical" effects

- Establish a biostratigraphic, magnetostratigraphic, and/or sequence-stratigraphic frame

- Run spectral analyses on proxies of known origin

Towards a stratigraphic classification:

1999: ISSC Working Group on Cyclostratigraphy:
Frits Hilgen, Walther Schwarzacher, André Strasser

2000: First Report of the Cyclostratigraphy Working Group (ISSC Circular No. 97), with invitation to comment

2001: International Workshop "Multidisciplinary Approach to Cyclostratigraphy", May 26-28, Sorrento, Italy

2001: Second Report of the Cyclostratigraphy Working Group

2004: International Workshop "Post-Hedberg Developments in Stratigraphic Classification", August 27, Florence, Italy

Principle:

Keep classification and terminology as simple as possible

The processes involved and the resulting sedimentary record already are diverse and complex enough

Propositions of the Cyclostratigraphy Working Group:

The term <u>sedimentary cycle</u> should be restricted to these repetitive changes in the stratigraphic record that have, or are inferred to have, a time significance

Before an astronomical influence has been demonstrated, other terms (such as "depositional unit" or "sedimentary sequence") should be used

Cyclostratigraphy:

Subdiscipline of stratigraphy that deals with
the identification, characterization, correlation,
and interpretation of cyclic
(periodic or near-periodic) variations
in the stratigraphic record and,
in particular, with their application in
geochronology by improving the accuracy
and resolution of time-stratigraphic frameworks.

Sedimentary cycle (as used in cyclostratigraphy):

One succession of lithofacies that repeats itself
many times in the sedimentary record and that is,
or is inferred to be, causally linked to an
oscillating system and, as a consequence,
is (near-)periodical and has a time significance.

Different cycles can be described by their period,
for example as a 100-ka cycle or, if this is not
precisely known, as a cycle in the order of 100ka.

Definitions

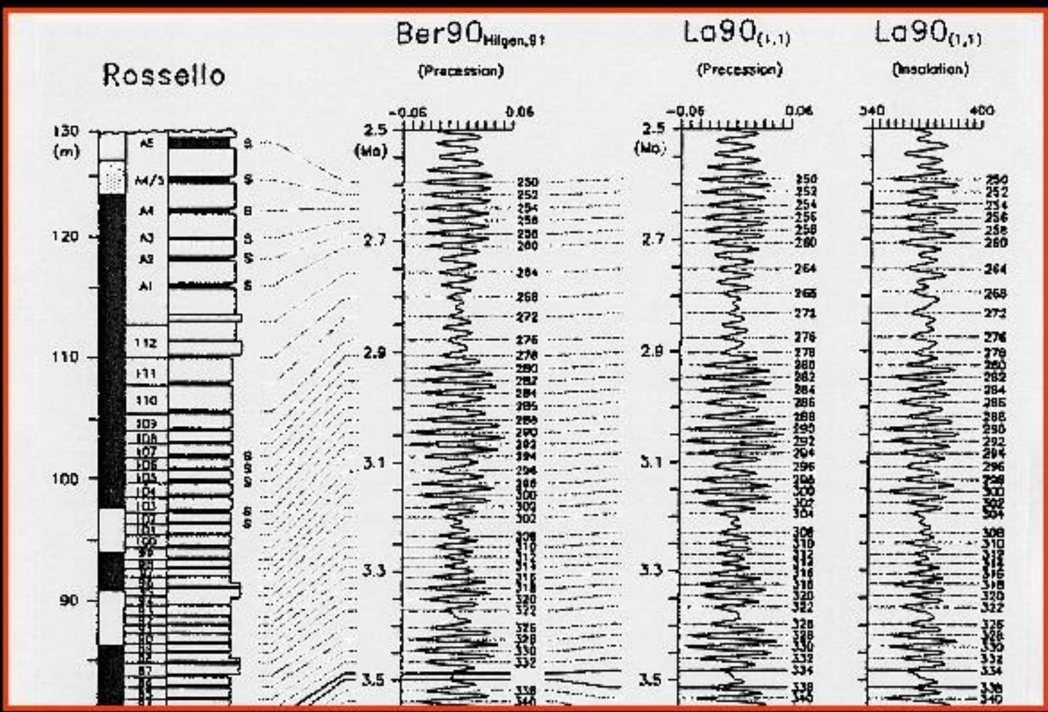
Astronomical time scale (ATS):

A geological time scale with absolute ages derived from the calibration of sedimentary cycles and other cyclic variations in sedimentary successions to astronomical time series.

Chron boundaries and biostratigraphic events are directly tied to such a timescale via first-order calibrations, i.e. they have been located in the same astronomically dated sections that have been used to construct the time scale.

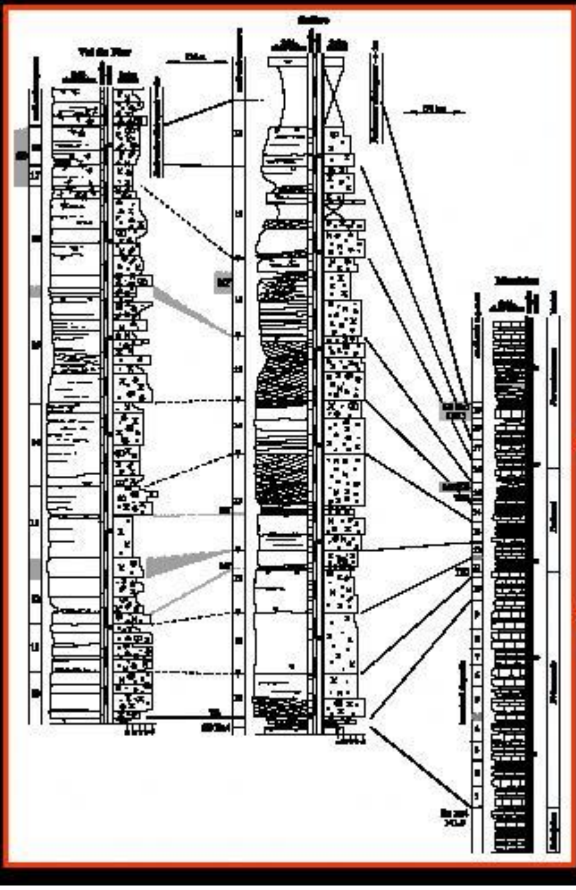
Time scales

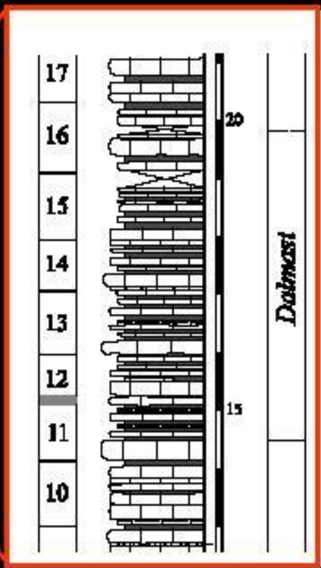
Astronomical time scale tied to the Recent



Lourens et al. (1996)

Floating astronomical time scale





Strasser et al. (2004)

Floating astronomical time scale

	T-R facies cycles	Sequences	Ammonite subzones	zones
L. Valang.	regressive	136.49 —SB Va 1—		Pertransiens 136.49
		—MFS/CS—		Otopeta
Upper Berriasian	trans-gressive	137.44 —SB Be 8—	136.99 Alpillensis	
		—MFS/CS—		
		138.08 —SB Be 7—	137.90 Picteti	Boissieri
	regressive	—MFS/CS—		
		138.61 —SB Be 6—	138.61 Paramimounum	
		—MFS/CS—		
		139.33 —SB Be 5—		

Berriasian - Valanginian boundary: 137 ± 2.2 Ma

Cyclostratigraphy: ± 100 ka

Berriasian-Valanginian example (between SB Be6 and SB Va1)

Sequence type	Number (including/excluding sequence boundary zones)		Inferred time span (ma)		Time span according to Hardenbol *et al.* (1998) (ma)
	Saleve	Montclus	Saleve	Montclus	
Elementary	**difficult to define**	**110+/104+**		**2.2+/2.08+**	
Small-scale	**24/20**	**24/22**	**2.4/2.2**	**2.4/2.2**	138.6 - 136.5 = 2.1
Medium-scale	**6**	**difficult to define**	**2.4**		

Strasser et al. (2000)

Formal codification of Milankovitch cycles:

Already in use:
- Oxygen-isotope stages in the Pleistocene, linked tochron nomenclature via magnetostratigraphy
- Sedimentary cycles in the Mediterranean Plio-Pleistocene coded after the precession cycles numbered back from the Recent

Proposition:
- Codify the 400-ka eccentricity cycle because it is the most stable longer-term orbital cycle
- Count backwards from the Recent
- Tie to well-dated stratigraphic intervals deeper in the geologic past

Conclusions:

- **Cyclostratigraphy has a great potential to improve geological time scales**
- **Cyclostratigraphy is necessary to evaluate rates of processes in the geological past**
- **Cyclostratigraphy should be applied in conjunction with other stratigraphic methods**
- **A simple terminology is proposed, which should not conflict with other stratigraphic definitions**
- **Formal codification of the 400-ka eccentricity cycles may be useful**

Thank you for your attention

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