CYCLOSTRATIGRAPHY

a review

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What is Cyclostratigraphy?

- Cyclostratigraphy is the study of the sedimentary record produced by climatic cycles of regular frequency generated by variations in Earth's orbit and known as MILANKOVITCH CYCLES

- Many types of cycles can be recognized in stratigraphy, but global climate cycles are the most useful for correlation
- Identification of these cycles and their precise frequency is of paramount importance

what does Cyclostratigraphy do?

- It allows us to build an orbital timescale graduated in tens or hundreds of thousands of years for part of the geological column
- It allows us to investigate the way in which orbital cycles have influenced earth's climate, oceans and ice caps
- It let us interpret how the cycles observed in the sedimentary record have formed

a brief history

- **Croll (1875)** said that orbital cycles might affect Earth's climate
- **Gilbert (1895)** identified Cretaceous cycles from Colorado as the product of orbital forcing
- **Bradley (1929)** recognized varves and precessional cycles in the Eocene green River Fm. of CO, UT and WY
- **Milankovitch (1941)**
  - calculated orbital variations mathematically
  - showed the amount of solar radiation reaching the outer atmosphere at different latitudes in time

a brief history, 2

- **Emiliani (1955)** was the first to find cycles that matched Milankovitch's numbers
- **Hays et al. (1976)** found cycles matching Milankovitch's numbers at all resolutions
- **Imbrie et al. (1984)** found evidence of Milankovitch cyclicities from the deep-sea Pleistocene record
- **Shackleton et al. (1995)** established an orbital timescale from the present to the Miocene based on recognition of Milankovitch's cycles

Orbital Cycles

- Calendar Band (hours to 1 year)
- Solar Band (1 year to 10,000 years)
- Milankovitch Band (10,000 yrs to 1 Ma)
- Galactic Band (1 Ma to 1 Ga)
    - M = Million (10^6)
    - G = Giga (10^9)
    - a stands for “anna”, or years in Latin

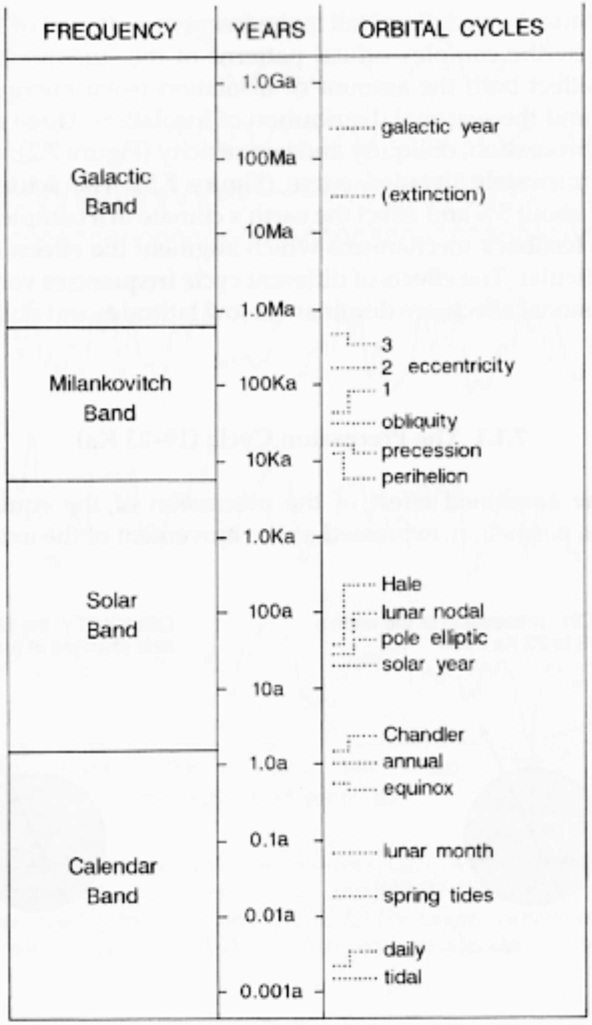


Figure 7.1 *Logarithmic table to show the orbital frequencies which exert an influence on temporal energy reaching the outer atmosphere. [Modified from: House (1995b)]*

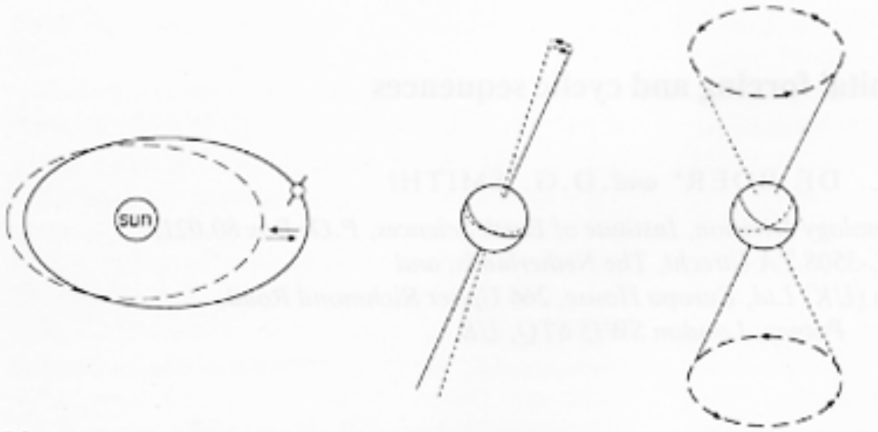
- Many short cycles are found in the geologic record (tidal events, annual growth bands, varves, etc.)
- It is Milankovitch Band lower frequencies that are recognized in bedding of sedimentary rocks

- Milankovitch cycles are caused by complex orbital patterns of the Sun-Moon-Earth system, with smaller influence from other celestial bodies

- Changes in Earth’s orbit modify:
  - the amount of solar radiation reaching Earth
  - the seasonal distribution of insolation

There are three main cycles:

- Precession
- Obliquity
- Eccentricity
    - these cycles combine in complex patterns
    - the actual variations in insolation are about 5%
    - feedback mechanisms enhance variations
    - eccentricity is modulated by precession and obliquity
    - precession dominates at low latitudes
    - obliquity dominates at high latitude



(a) eccentricity (100 000 years)

(b) obliquity (41 000 years)

(c) precession
(19 000-23 000 years)

Fig. 1. Schematic representation of the astronomical variables influencing the climate on Earth. From de Boer (1983).

PRECESSION

- Precession is the spinning of Earth’s axis
- Its period is 26,000 years (ka)
- Since Earth’s orbit also rotates, actual periodicities are at about 19 ka and 23 ka
- Precession is 180° out of phase between the Northern and the Southern Hemisphere

OBLIQUITY

- Obliquity of Earth's axis is its tilting with respect to the perpendicular to the ecliptic
- Obliquity varies between 22° and 24.5° with a period of about 41 ka
- Obliquity determines seasons, particularly at high latitudes:
  - if obliquity were 0°, there would be no seasons
  - if obliquity were 90°, we would have six months of summer and light, and six months of winter and darkness in each hemisphere

ECCENTRICITY

- Eccentricity describes the variation of the shape of Earth’s orbit around the Sun
- The orbit shape shifts from circular to elliptical and back over an average period of 100 ka
- Superimposed variations also occur at about 400 ka, 1.3 Ma and 2 Ma
- Eccentricity, per se, does not have a lot of influence, except that it determines when and how precession and obliquity affect climate

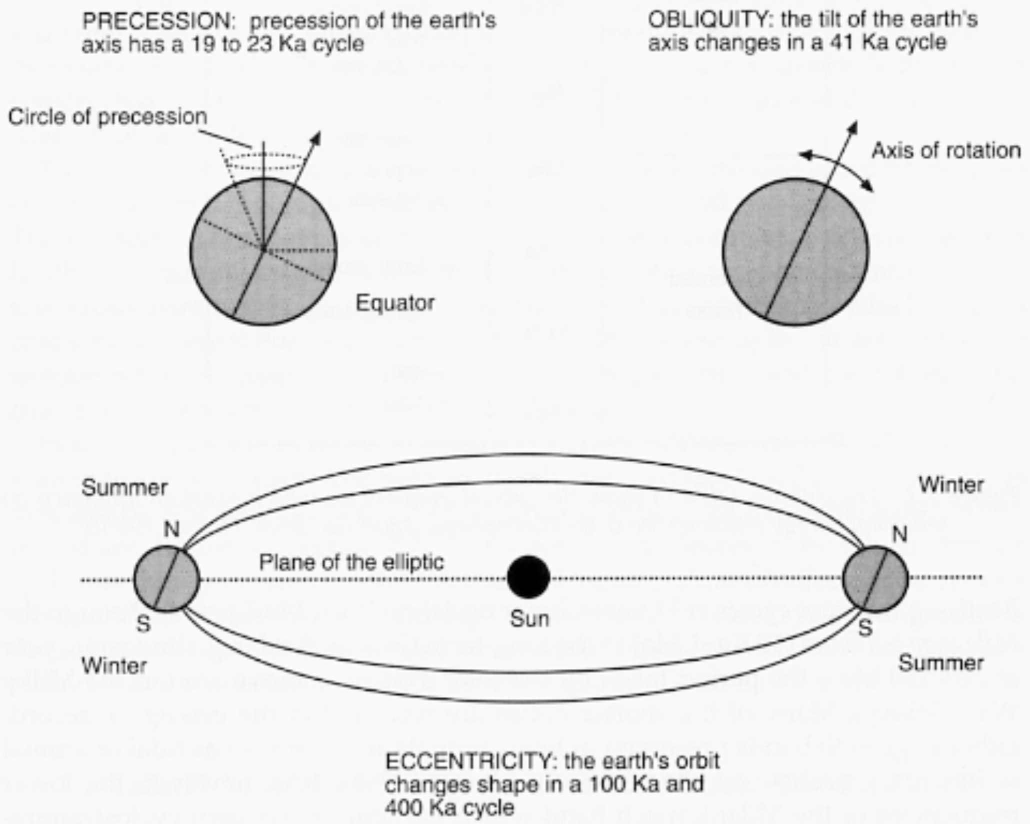


Figure 7.2 *Diagram of the earth–moon–sun system and the oscillations that produce changes in insolation. These may lead to orbitally forced signatures in the sedimentary record. [Modified from: House (1995b)]*

- The combination of P, O, e, and E cycles vary the spatial distribution of solar energy on Earth, thus shifting climate zones

- Example: shifting of the caloric equator

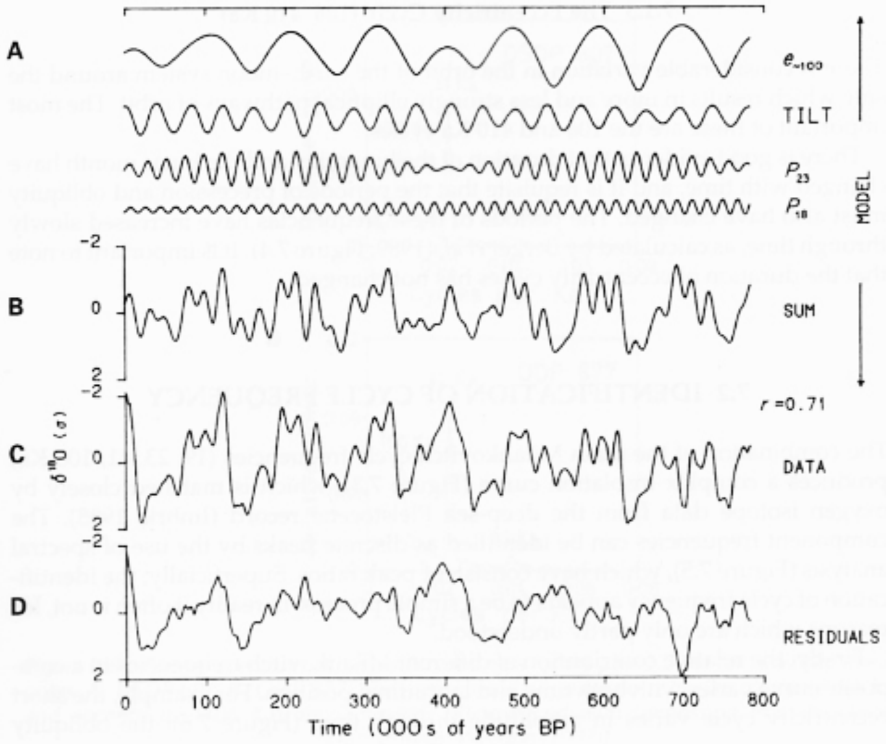


Figure 7.3 Variations in oscillations of the earth–sun system. **A**. Oscillations caused by eccentricity ($e_{\sim 100}$), obliquity (tilt) and precession (p_{23} and p_{18}). **B**. The sum of the four signals, a measure of energy received by the outer atmosphere. **C**. The oxygen isotope record, the manifestation of the Milankovitch signal. **D**. Residual products after deducting **B** from **C**.

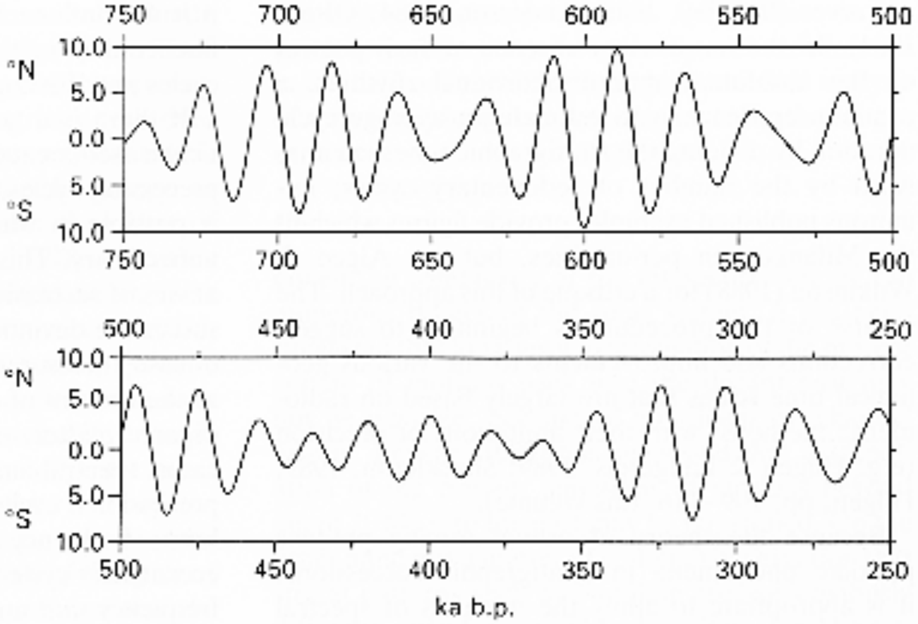


Fig. 2. Changing position of the caloric equator between 750 ka and 250 ka BP. Note the varying frequency. Periods between extreme (N or S) latitudinal positions of the caloric equator vary between 14 ka and 28 ka. From Berger (1978b).

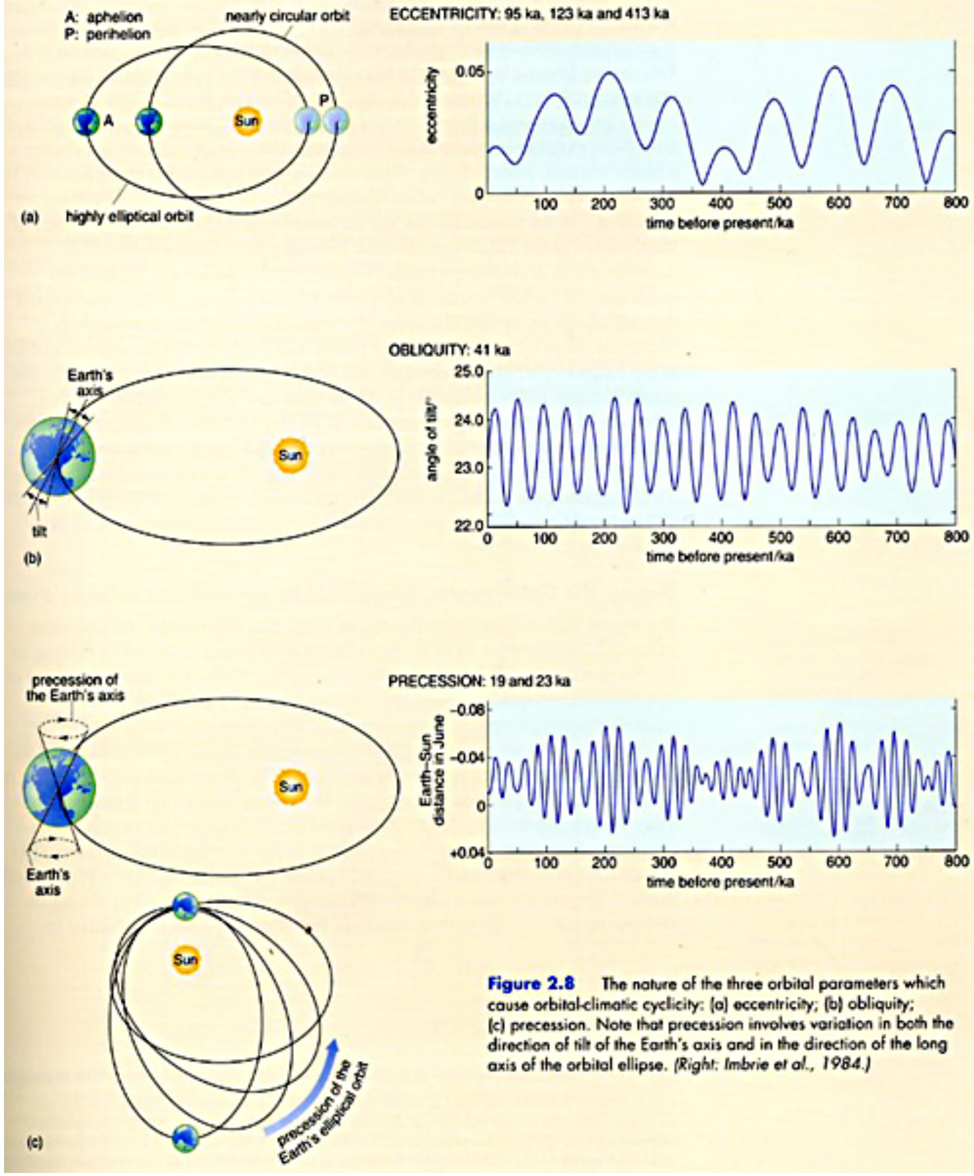


Figure 2.8 The nature of the three orbital parameters which cause orbital-climatic cyclicity: (a) eccentricity; (b) obliquity; (c) precession. Note that precession involves variation in both the direction of tilt of the Earth's axis and in the direction of the long axis of the orbital ellipse. *(Right: Imbrie et al., 1984.)*

Milankovitch cycles periodicity changed in time

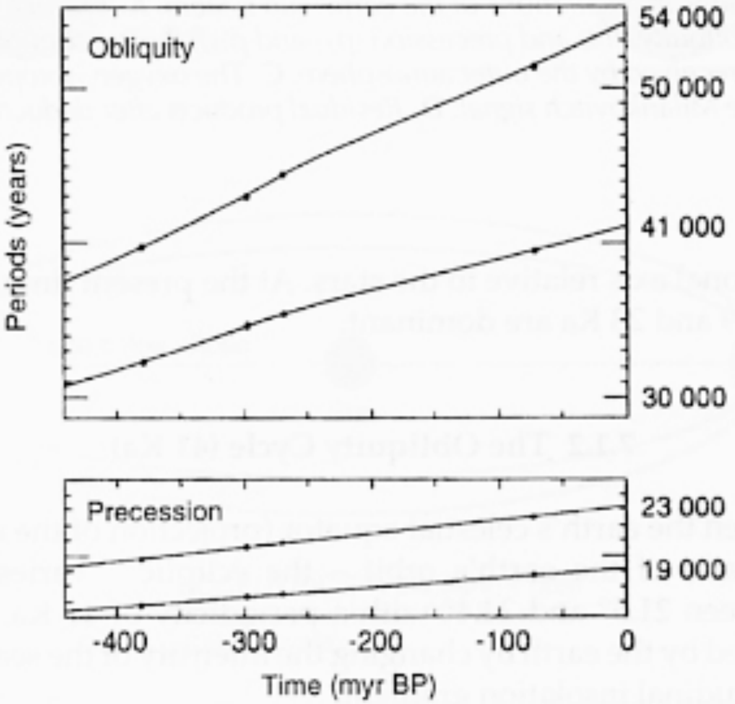


Figure 7.4 *Changing periods of obliquity and precession through time. [Modified from: House (1995b)]*

How do we identify Milankovitch cycles?

- Cycle counting
- Time-Series analysis (sedimentary sequences are turned into mathematical curves)
- Cycle Ratios: Precession-Eccentricity Syndrome

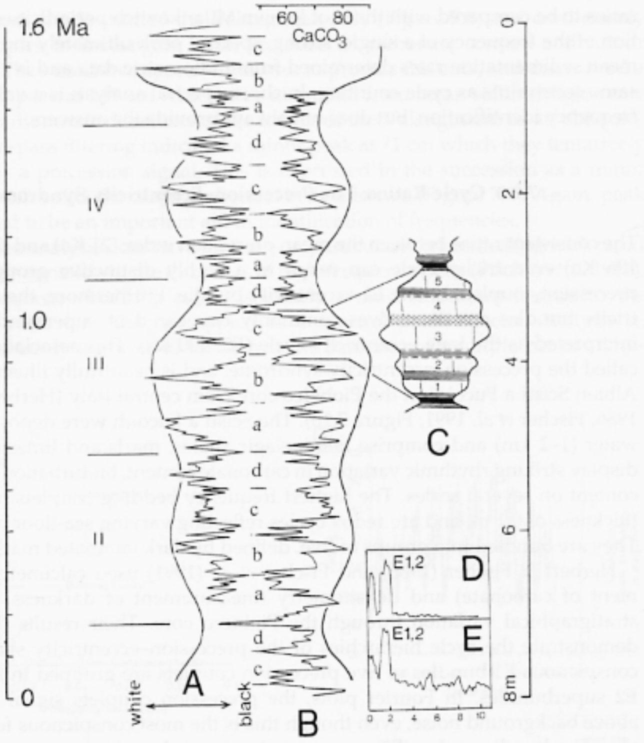


Figure 7.10 *An 8 m segment of (Albian) Scisti a Fucoidi in the Piobbico core from Umbria, Italy, to illustrate the precession–eccentricity syndrome. The bundles II–IV represent long eccentricity (E2: 400 Ka) cycles. Time-series are based on darkness values obtained by microdensitometry (**A**), and carbonate values are based on 2 cm spaced samples (**B**). **C**. An enlarged 100 Ka segment of the core to show its fivefold precessional structure. **D** and **E**. Spectral analysis of the carbonate data; note the 100 and 400 Ka peaks, and the lack of a high-frequency peak. [Modified from: Fischer* et al. *(1985)]*

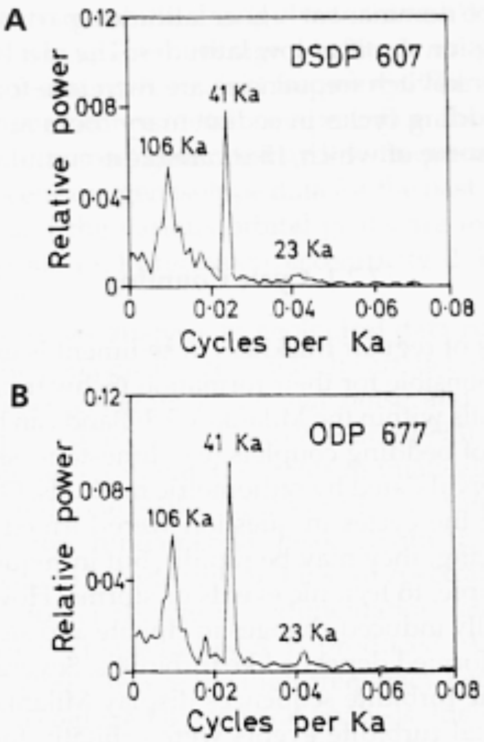


Figure 7.5 *Fourier spectrum of oxygen isotope data for the past 2.5 Ma for two deep ocean cores.* **A**. *DSDP 607.* **B**. *ODP 677. The major peaks of precession (23 Ka), obliquity (41 Ka) and eccentricity (106 Ka) are indicated. [Reproduced with permission from Blackwell Science, from: Weedon (1993)]*

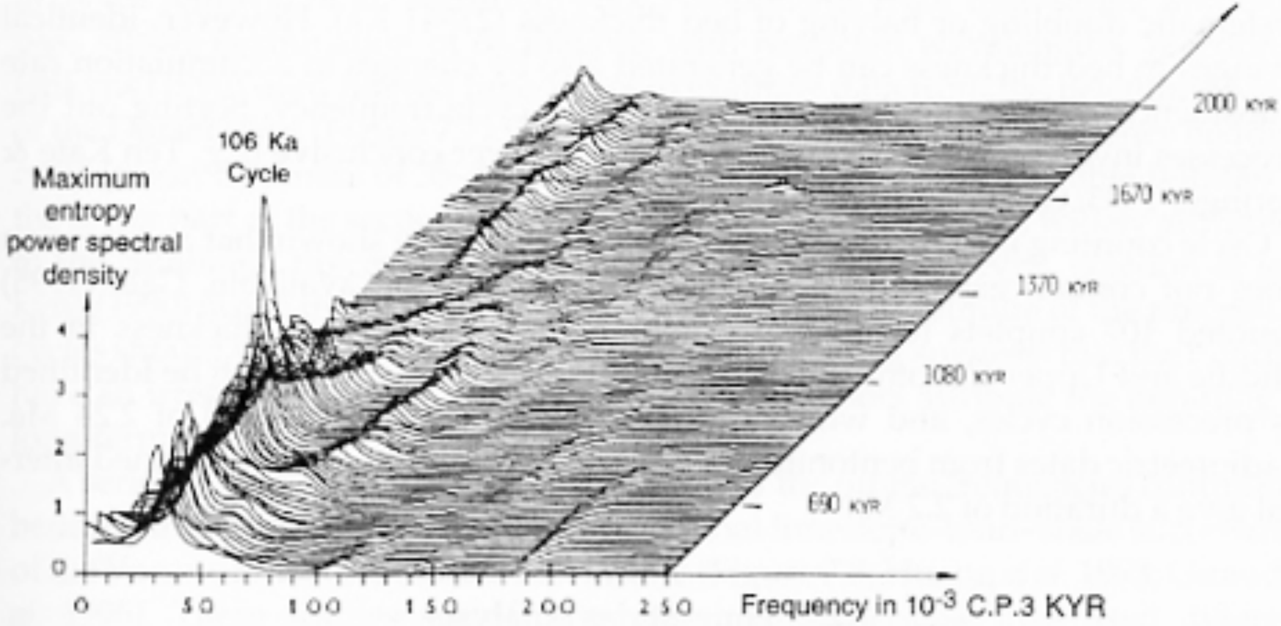


Figure 7.6 *Evolutive maximum entropy spectral analysis of a deep-sea Atlantic core, to show in three-dimensions the changing amplitude of the 106 Ka eccentricity cycle over the past 2–3 Ma. [Modified from: Berger (1988)]*

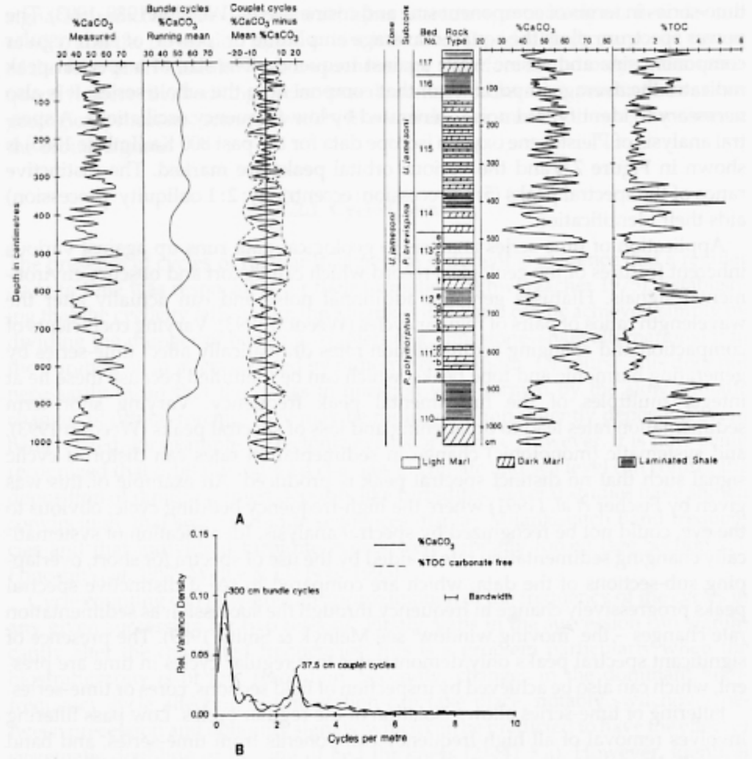


Figure 7.7 ***A.*** *Time-series from the Belemnite Marls (Lower Jurassic) on the Dorset coast, based on carbonate analysis and Total Organic Carbon. Note the conspicuous bundling.* ***B.*** *Time-series analysis of these data shows clearly both high-frequency cyclicity and bundling.* ***C.*** *Isolated bundle and couplet cycles, produced by smoothing the data; the envelope around the couplet cycles is out of phase with the bundle cycles. Weedon & Jenkyns (1990) interpreted the bundling as an irregular long-term climatic cycle, unrelated to eccentricity. [Reproduced with permission from the Geological Society, from: Weedon & Jenkyns (1990)]*

Where do we see Milankovitch cycles?

- Milankovitch cycles are global and synchronous: they should be recognizable in all sedimentary environments
- As a matter of fact, Milankovitch cycles are more readily interpreted from deep marine sequences, because:
  - they are more common
  - they are more complete (no unconformities or "missing cycles")
  - marine control biostratigraphy has a higher resolution than terrestrial biostratigraphy

Cycles in a pelagic sequence

(with 2m-thick level of Black Shales)

Where do we see Milankovitch cycles?

- Productivity cycles: when carbonate supply varies against a background of constant clay deposition
  - depends on coccoliths/foraminifers abundance
  - which depends on nutrients (upwelling and water mixing)
- Dilution cycles: when clay supply varies against constant carbonate productivity
  - depends on climate in hemipelagic settings (river runoff)
  - depends on climate in pelagic settings (wind)

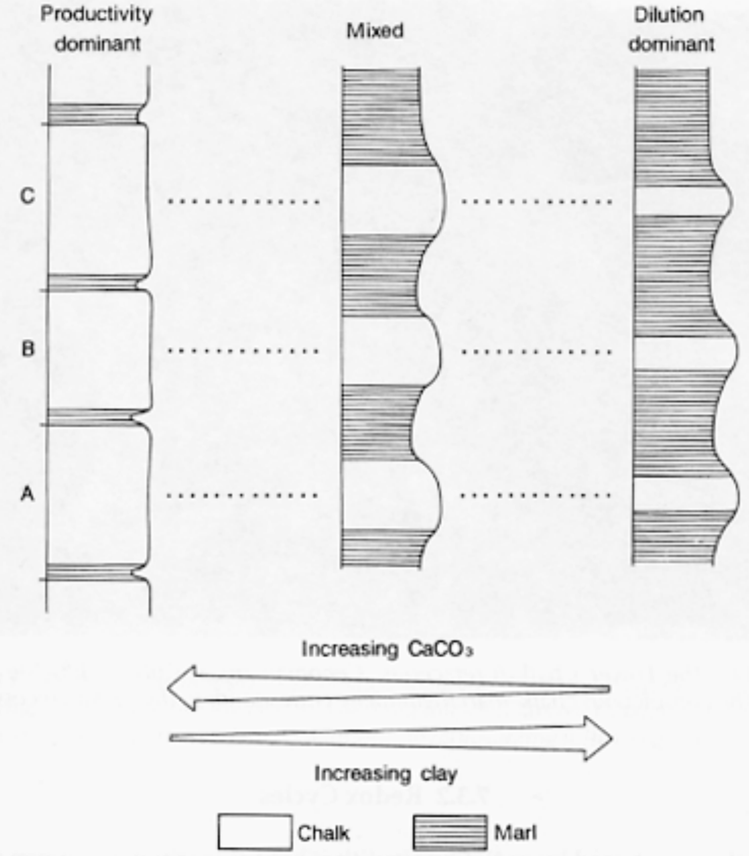
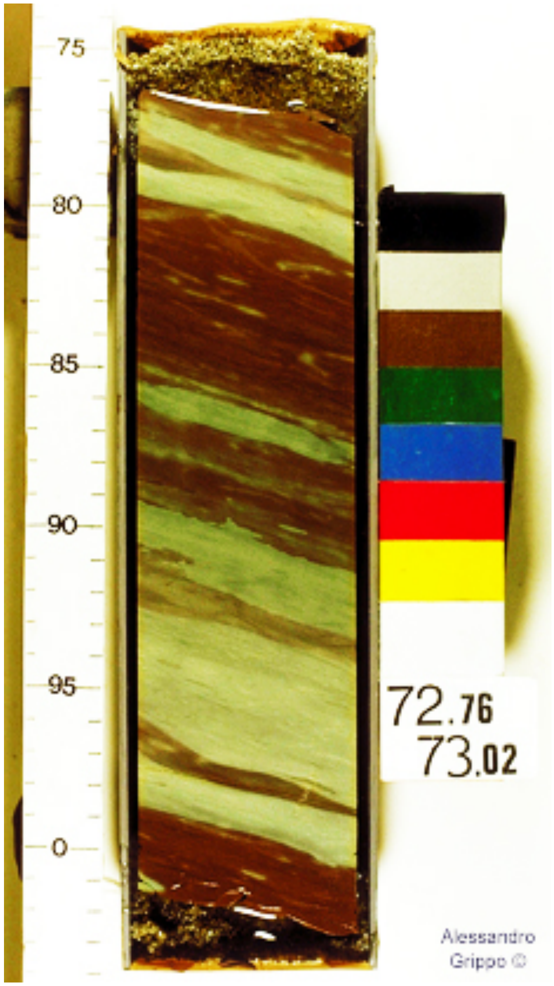


Figure 7.13 *Productivity and dilution cycles: extremes of a continuum*

Where do we see Milankovitch cycles?

- Redox cycles
  - Caused by variations in either Oxygen or organic C supply to deep marine areas
  - controlled by oxygen supply and productivity (which controls organic flux)

- Dissolution cycles
  - caused by the cyclic change in depth of CCD, as function of climate change
  - Thick limestones vs. thinner marls (limestone/clay mixtures)



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Where do we see Milankovitch cycles?

- Diagenesis can increase evidence of cycles (example, chert beds in limestones)
- Diagenesis can also hide some primary cycles, such as isotopic signatures

- Eustasy and Orbital Cycles

Where else?

- Lake deposits
- Terrigenous clastics
- Aeolian deposits
- Paleosols
- Shallow-marine carbonates
- Calciturbidites
- Paleomagnetics

Applications of the Milankovitch Cycles Concepts

- Absolute Time and Cycle Calibration
- Estimating the duration of Stratigraphic Stages
- Understanding of Past Climates

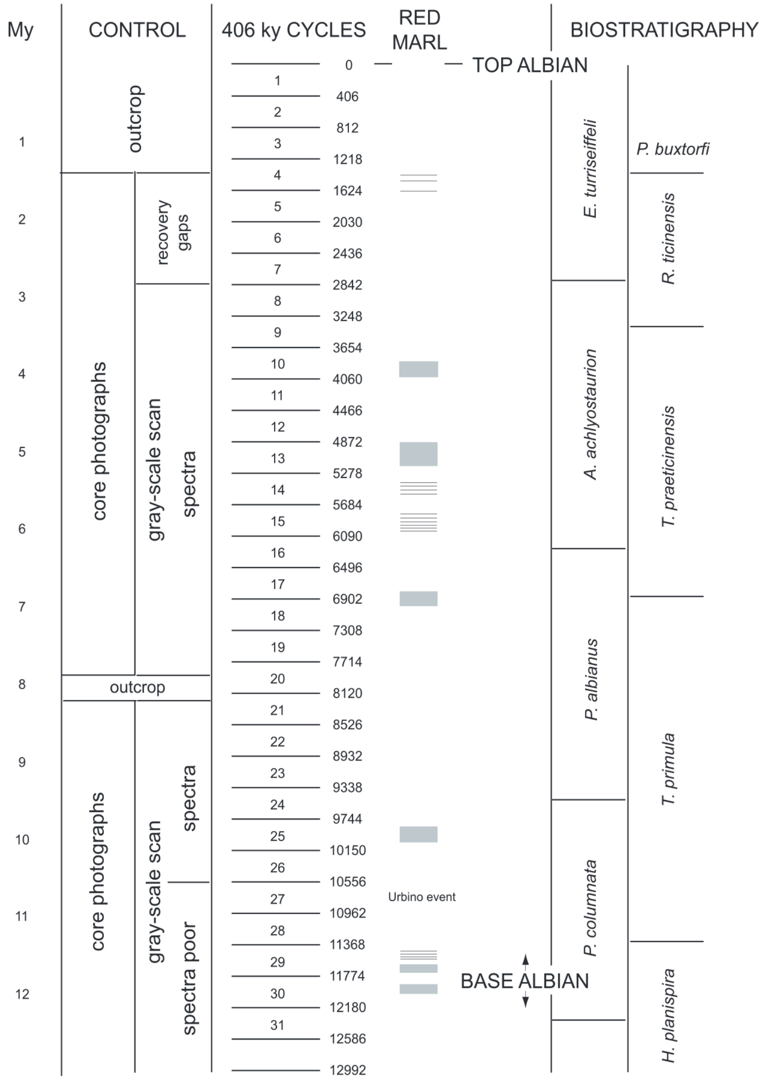
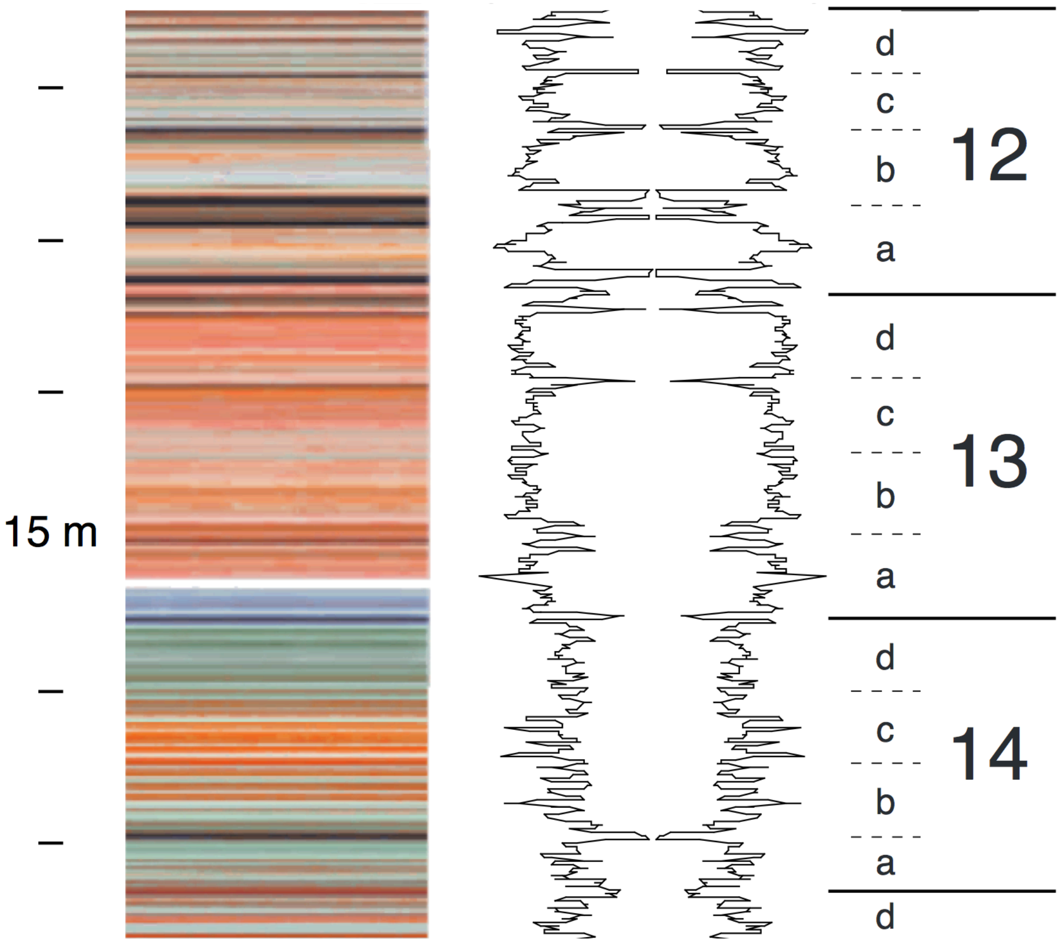


FIG. 15.—Albian cyclochronology as deduced from the Scisti a Fucoidi–Scaglia Bianca sequence in the Apennines of Umbria and Marche (Italy). Observations mainly on Piobbico core, supplemented by data from outcrop (Herbert et al., 1995). Paleontology after Premoli Silva (1977) and Erba (1986, 1988, 1992) and Tornaghi et al. (1989). Duration of the Albian is estimated at 11.9 ± 0.5 My.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