GLACIAL DEPOSITION and PAST GLACIATIONS

notes from lecture

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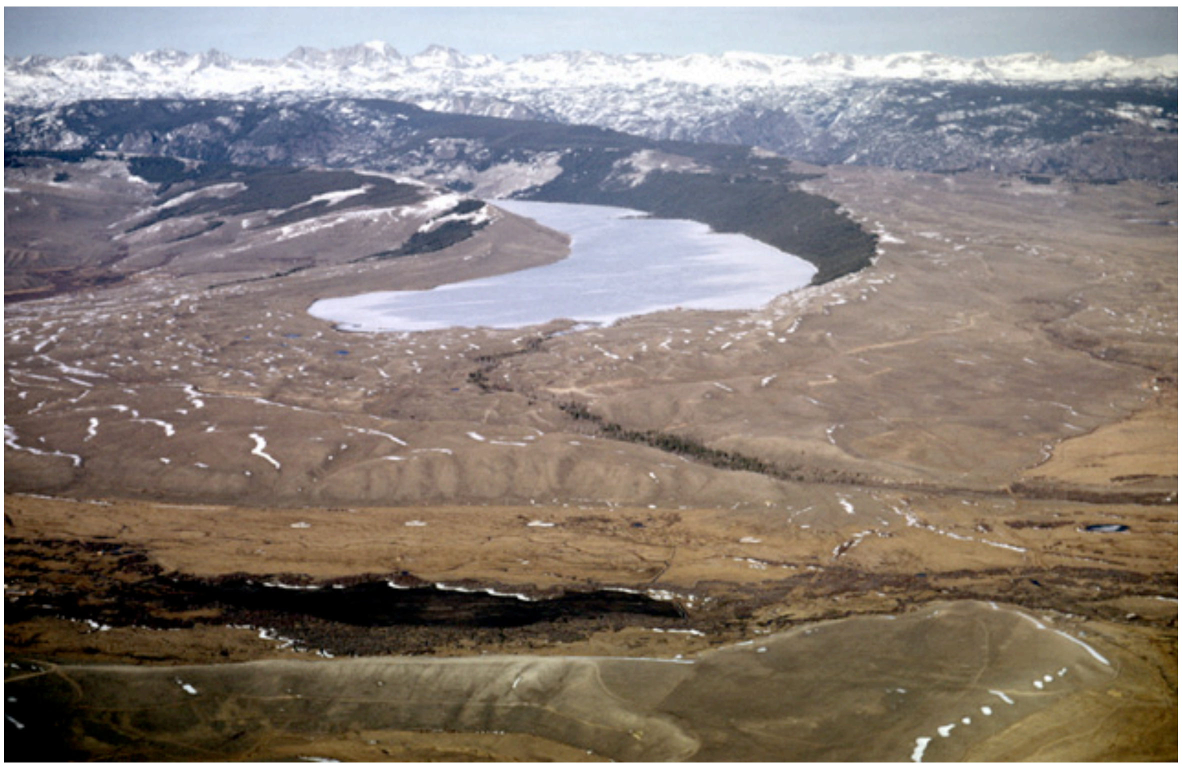
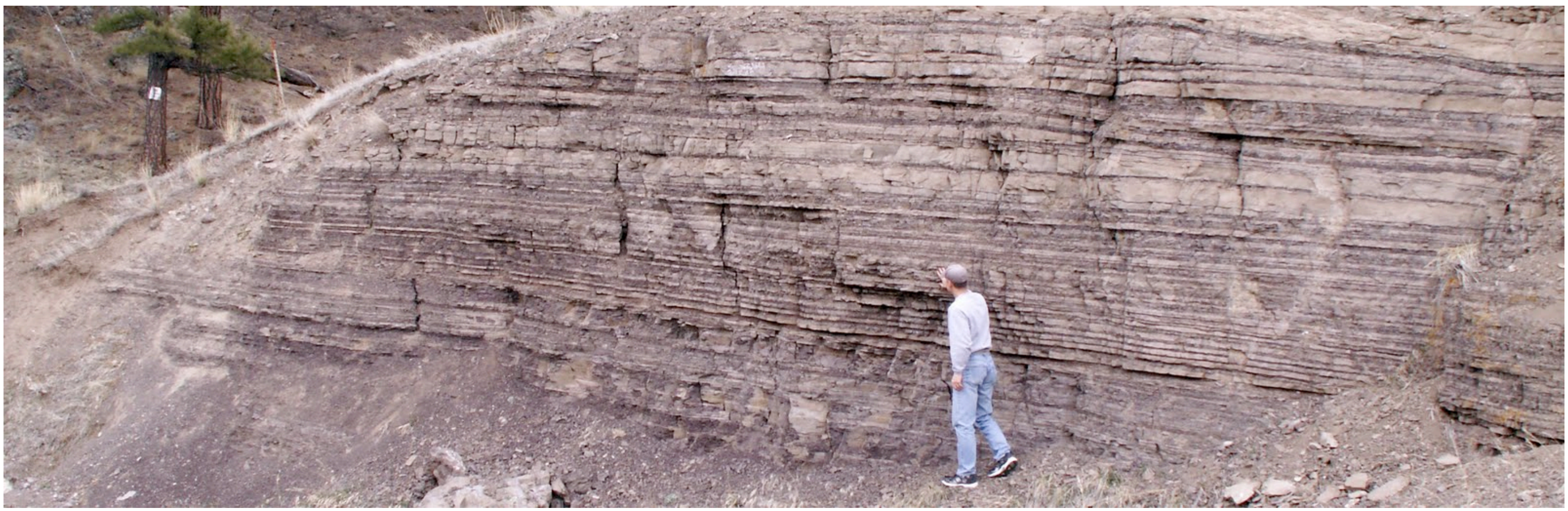
Varves

- Glacial lakes can from between a retreating lacier and older end moraine



Varves

- Varves are alternating couples of light- and dark-colored sediment



Varves

Dark-colored clay, containing decayed organic matter (deposited in winter)

Light-colored silt and fine sand (deposited in summer)

Each varve represents 1 year

Counting varves works as a calendar. In this image 4.5 years are represented

PAST GLACIATION

- Louis Agassiz was the first to say (1837) that, in the past, most of Europe and North America were covered by extensive ice masses
- Many areas currently not covered by ice, were affected by glaciation
- Climate change first theorized
- Skepticism from:
  - scientists: against theory of Uniformitarianism
  - traditionalists and religious fanatics: the world does not change

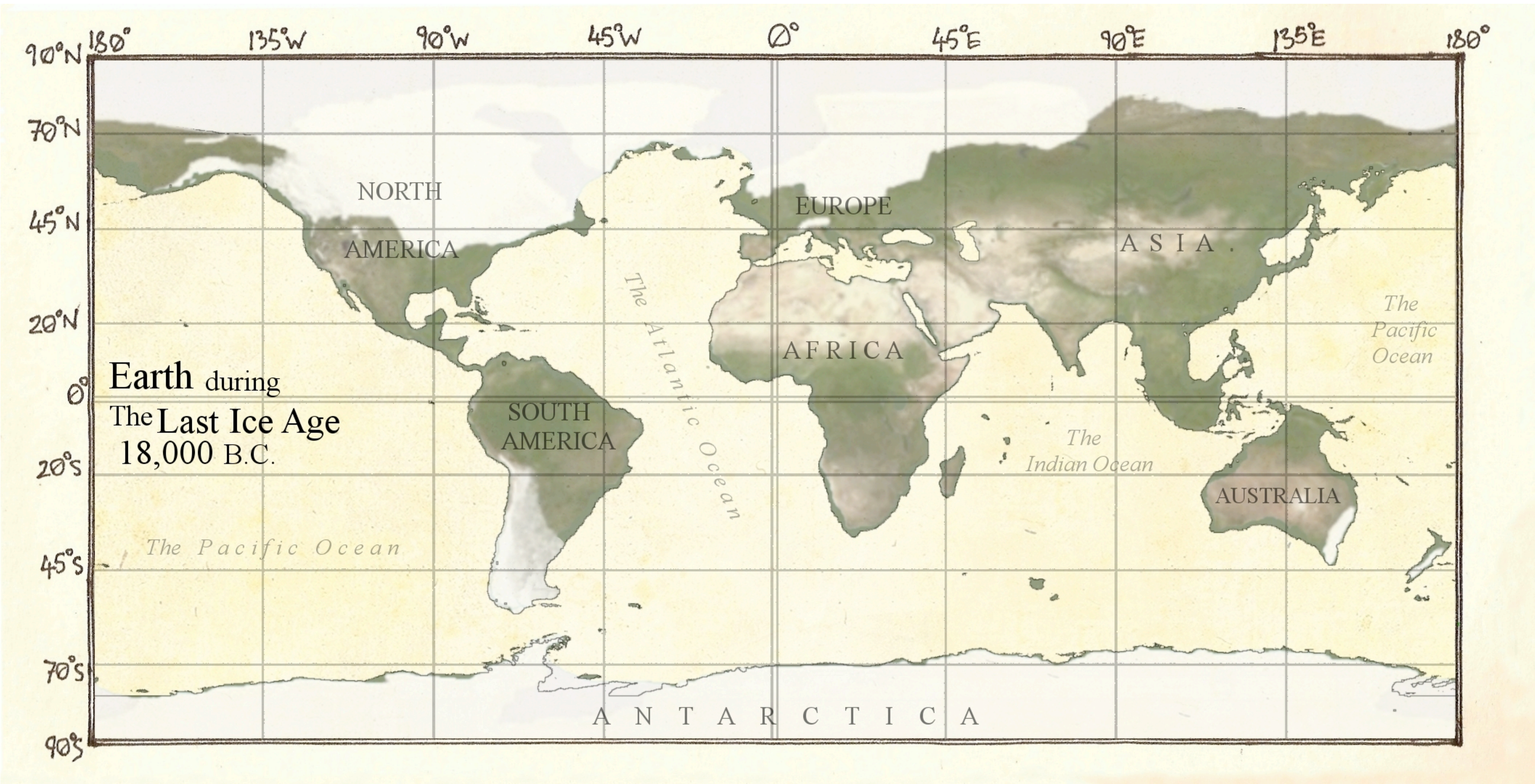
Theory of Glacial Ages

- At times in the past, colder climates prevailed, during which more land was glaciated than at present

- In a few years it became evident that much of Northern Europe, North America and parts of Australia, New Zealand, Russia, and South America had been covered by ice sheets

- That came to be known as the “Ice Age”

Earth, 20,000 years ago



How do we know about ancient glaciations?

- Earth warms and cools on average every 20,000 years
- The most recent glaciations left till and other evidence
- Older, weathered till is found underneath recent till
- $^{18}O/^{16}O$ studies of fossil shells provide us with temperature variations in oceans

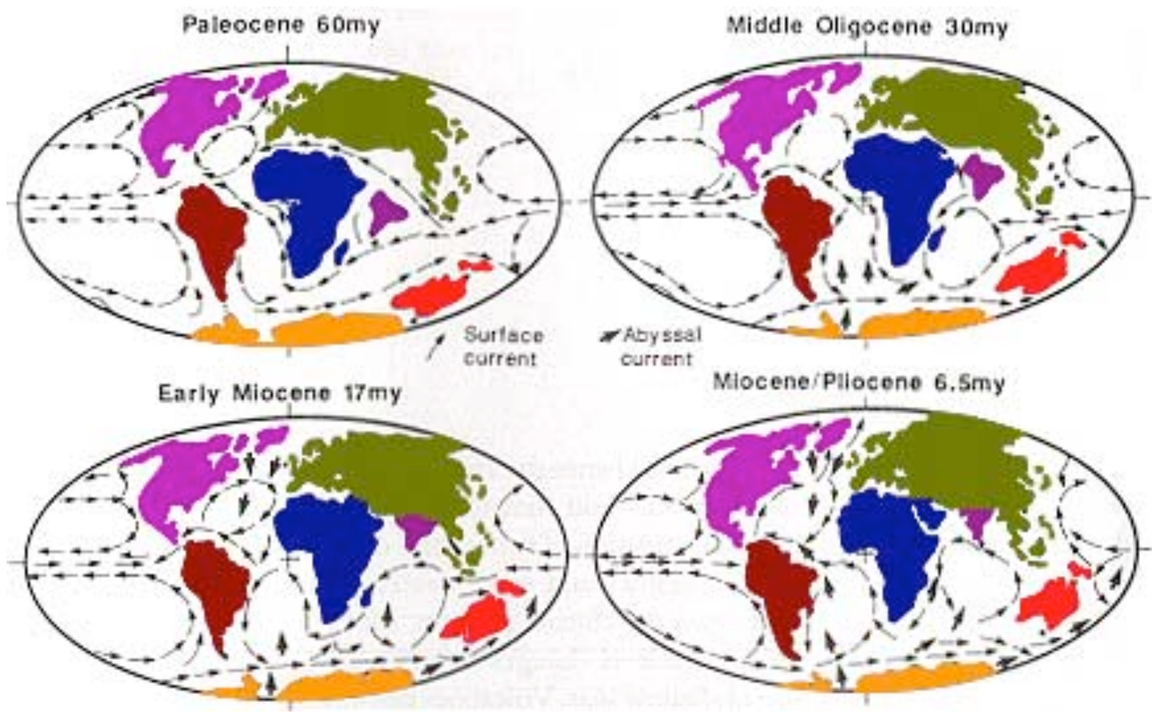
For how long did we have glaciations?

- Icehouse time vs. Greenhouse time
  - Icehouse time: permanent ice is present on land at sea level (as today)
  - Greenhouse times: there is no permanent ice on land at sea level (but there might be glaciers at high elevation in mountain chains)

- The switch between Greenhouse and Icehouse started about 32 million years ago

What happened 32 million years ago?

- Antarctica separated from South America
- That changed ocean water circulation patterns, causing cooling and build-up of ice on a global scale



Climate Variations

- Small scale variations occur either during Greenhouse and Icehouse times
- During an Icehouse time, such as the last 32 million years, it can be colder (like 20,000 years ago) or warmer (like now)
- The cold period is called a Glaciation (Ice Age)
- The warm period is called an Interglacial
- We as humans have thrived during an Interglacial

Climate Change

- Varying solar output
- Varying amounts of greenhouse gases
- Varying atmospheric and ocean circulation (function of plate tectonics)

- Varying incoming solar radiation due to astronomical changes (most important factor over imposed to others, during both Greenhouse and Icehouse times)

Astronomical 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

Astronomical Cycles

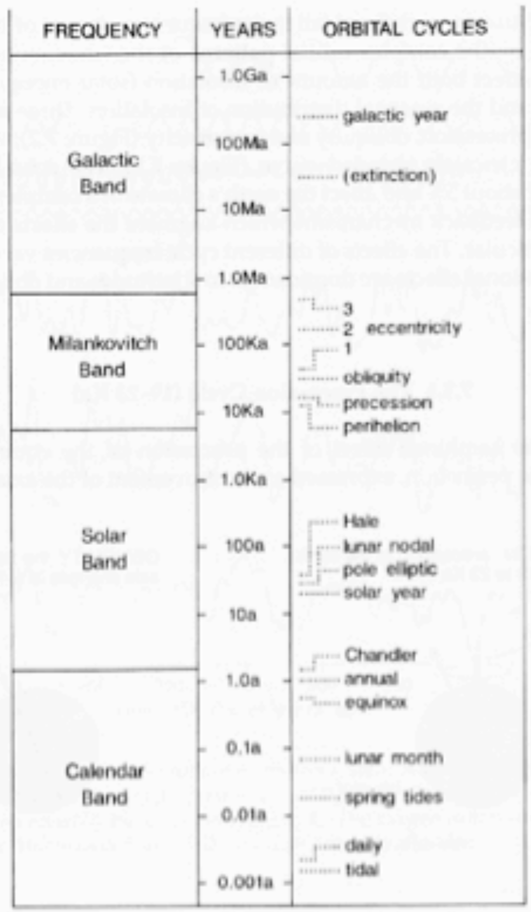


Figure 7.1 *Logarithmic table to show the orbital frequencies which exert an influence on temporal energy reaching the outer atmosphere. [Modified from: House (1995b)]*

Milankovitch Cycles

- Milutin Milankovitch (Serbia, 1941)
  - calculated Earth's orbital variations mathematically
  - showed the amount of solar radiation reaching the outer atmosphere at different latitudes in time

- Milankovitch orbital cycles are caused by complex interactions within 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

- Milankovitch cycles
  - Eccentricity of Earth's orbit
  - Obliquity of Earth's axis
  - Precession of the Equinoxes

The three Milankovitch periodicities

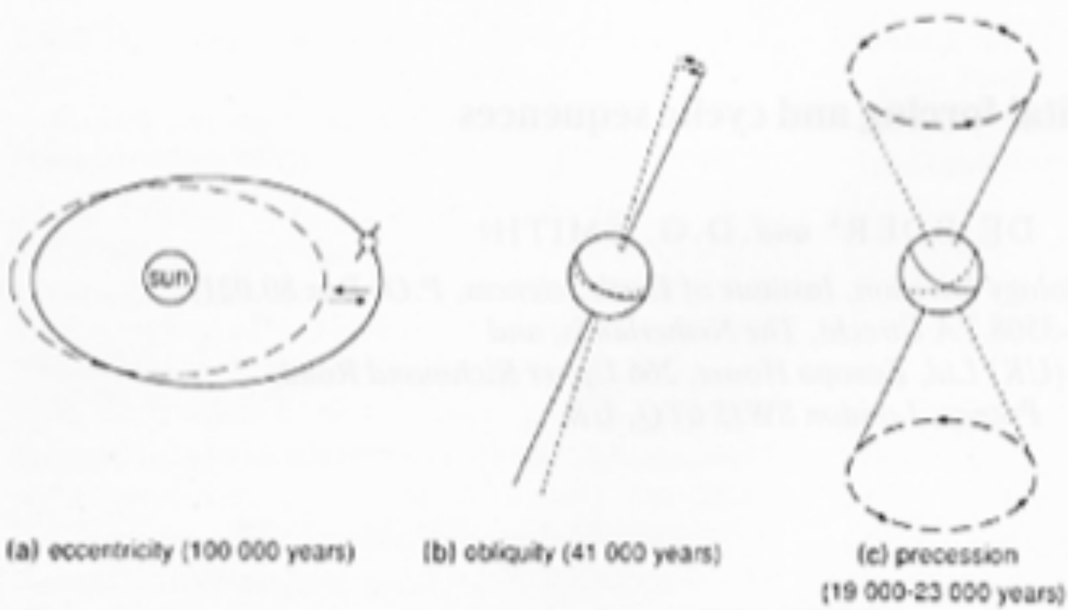


Fig. 1. Schematic representation of the astronomical variables influencing the climate on Earth. From de Boer (1983).

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

Milankovitch Cycles

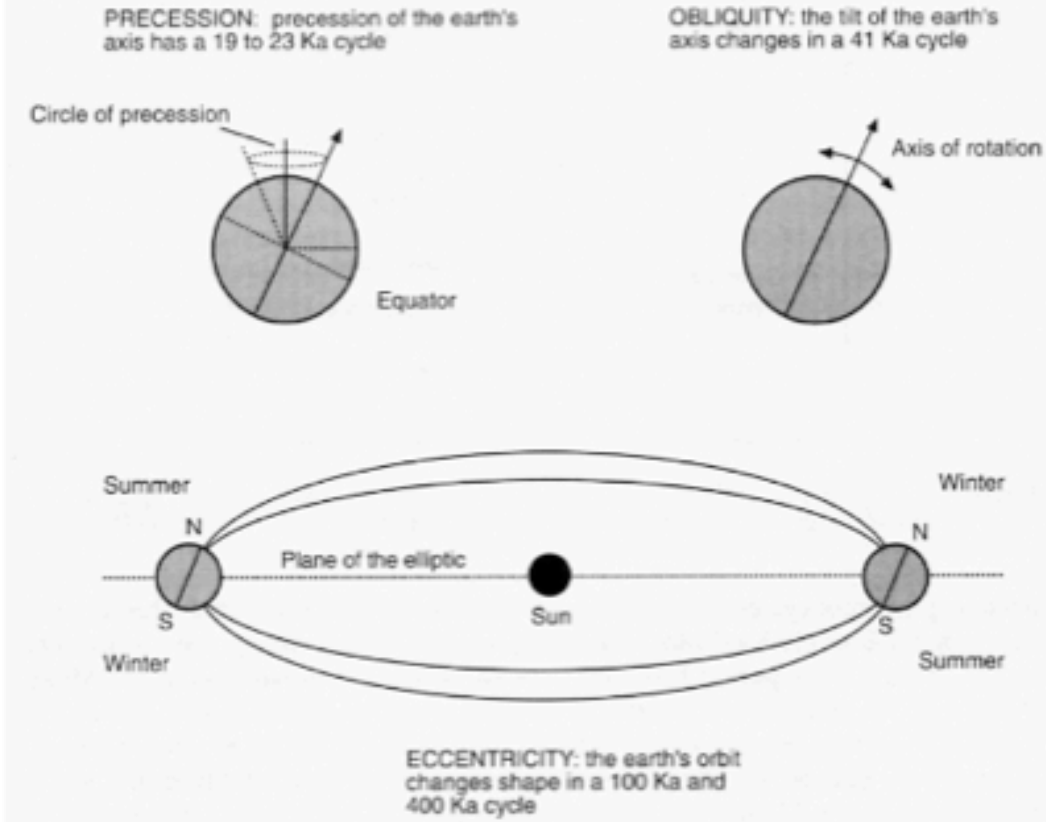


Figure 7.2 *Diagram of the earth–moon–sun system and the oscillations that produce changes in insolation. These may lead to orbitally forced signatures in the sedimentary record. [Modified from: House (1995b)]*

How does that work?

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

- In other words, it changes where, when and how much solar radiation reaches Earth

Combining Milankovitch cycles provides us with a curve for solar insolation

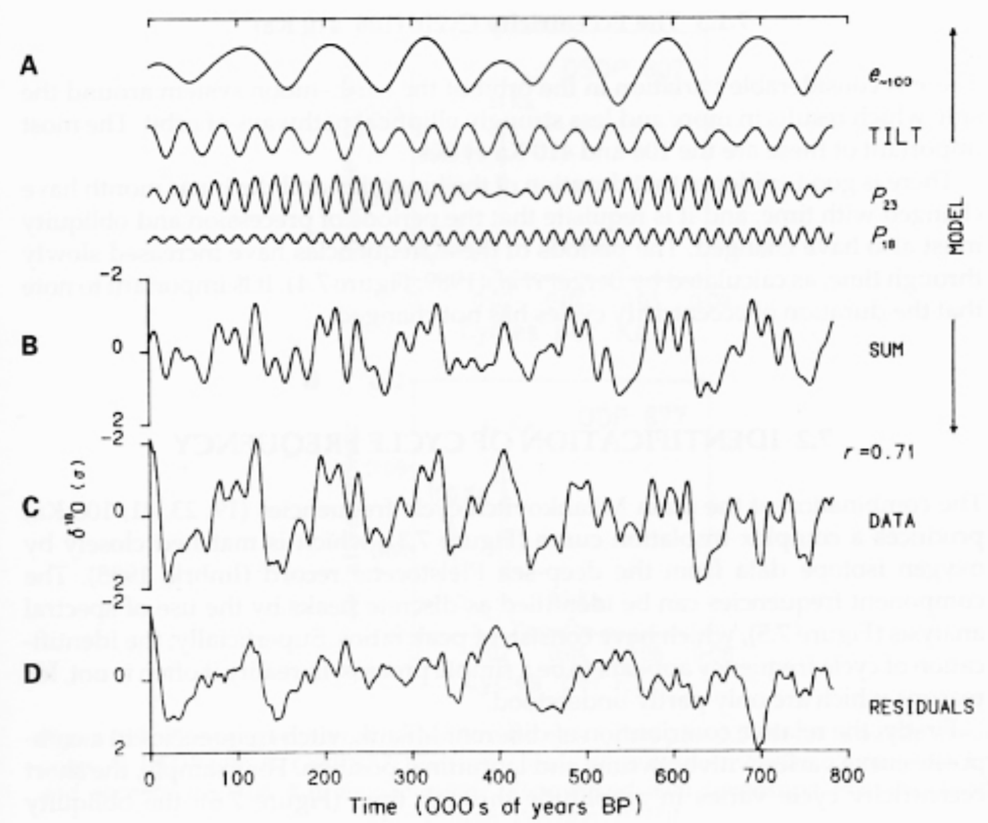


Figure 7.3 *Variations in oscillations of the earth–sun system.* **A.** *Oscillations caused by eccentricity (e_{-100}), obliquity (tilt) and precession (p_{23} and p_{18}).* **B.** *The sum of the four signals, a measure of energy received by the outer atmosphere.* **C.** *The oxygen isotope record,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

Milankovitch Cycles

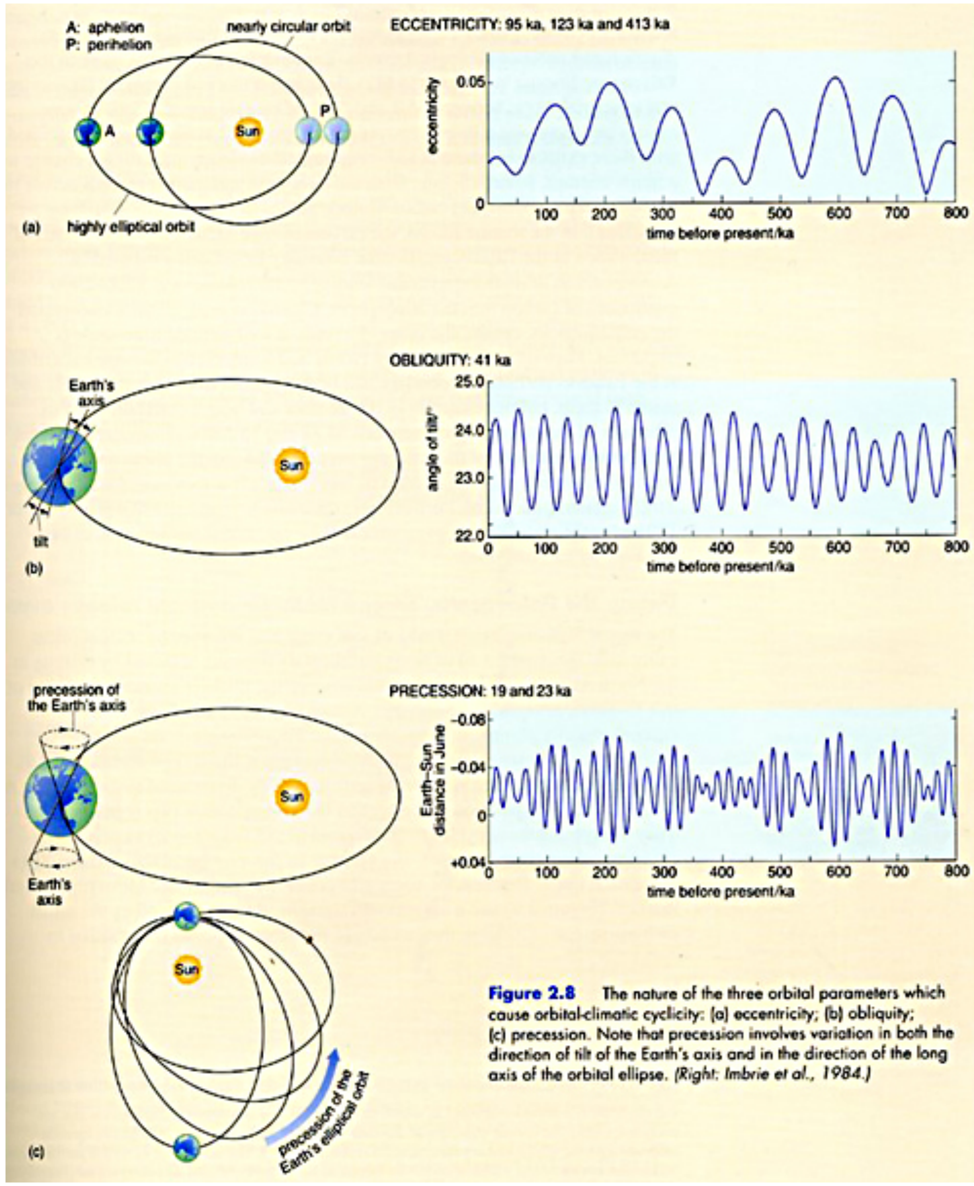


Figure 2.8 The nature of the three orbital parameters which cause orbital-climatic cyclicity: (a) eccentricity; (b) obliquity; (c) precession. Note that precession involves variation in both the direction of tilt of the Earth's axis and in the direction of the long axis of the orbital ellipse. *(Right: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

How does all this apply to the present?

- So, Milankovitch cycles always affect Earth, with a period of about 20,000 years
- During an Icehouse time, we either have a Glaciation or an Interglacial
- About 20,000 years Earth was at a peak Glaciation
- Right now Earth is at a peak Interglacial
- We are bound towards another Glaciation

EFFECTS OF PAST GLACIATIONS in North America

- Direct effects:
  - scraping and scouring of rocks and soils
  - moraines and outwash
  - rock flour generated loess

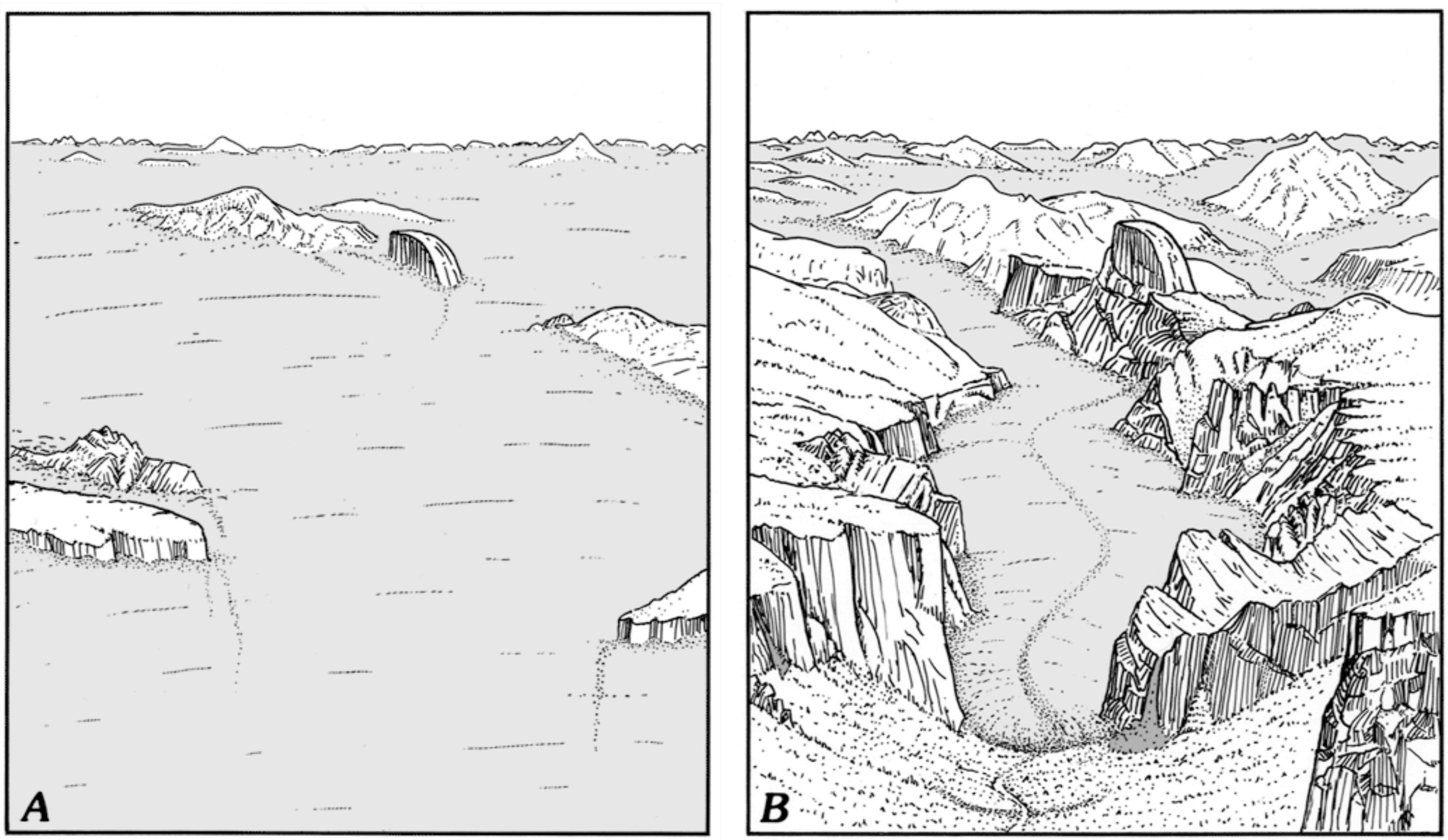
  - from action of continental glaciers:
    - Great Lakes
    - lakes of Minnesota, Ontario, Quebec
    - Finger Lakes, and more

  - from action of alpine glaciers
    - U-shaped valleys and glacial landscape (Sierra Nevada, Cascades, Rocky Mountains)

Continental and Alpine Glaciers extension in North America

The Great Lakes and the Finger Lakes

Yosemite and the Sierra Nevada



EFFECTS OF PAST GLACIATIONS in North America

- Indirect effects:
  - Glacial lakes
    - Lake Winnipeg (remnant of Lake Agassiz)
    - Glacial Lake Missoula (Montana)
  - Pluvial lakes
    - Great Salt Lake (remnant of Lake Bonneville)
    - Death Valley
  - Climate change
    - deeply incised valleys in the Santa Monica Mountains

EFFECTS OF PAST GLACIATIONS in North America

- Rise and fall of sea level
  - Sea level changes because of
    - More or less water available (Greenhouse vs. Icehouse)
    - More or less space in the ocean (Plate Tectonics)
    - Thermal expansion (warm water takes more space)
- Crustal rebound
  - Antarctica: the continental shelf is at -350 m below sea level while in the rest of the world it is at -150 m
  - Alaska, Canada, Greenland, Norway, Siberia

The coastline of North America during the last Ice Age

Older Glaciations?

- During most of Earth’s history we had a Greenhouse. Our Icehouse time is odd
- Tillites (lithified till) from the Late Proterozoic: evidence of ice at low latitudes
- Snowball Earth hypothesis: only a small area around the equator was free of ice in the Precambrian
- Faint Sun?