Glacial Cycles

I. Why interested in glacial cycles
- **A.** relationship between climatic glacial cycles and atmos CO_2 **PAGES ice core data**
  1. chicken and egg problem - CO_2 and climate
  2. feedbacks involved here may play a role in understanding how the current rise in CO_2 may affect climate
- B. glacial periods **Fig. 7.6 and 14-1**
  1. extensive ice cover - colder avg global temps (5-6°C)
  2. sea level lower - ~100 m or so
  3. ocean circ. likely different
     - a. much of N Atl. (where BW forms) was ice covered
     - b. atmos CO_2 and methane lower
- C. glacial periods (ice houses) have occurred several times in earth's history
  1. focus on Pleistocene glaciation

II. Most recent ice ages
- A. causes
  1. generally thought to be related to changes in the earth's orbit around the sun
  2. coupled with other factors that allowed these changes to express themselves in glacial cycles
- B. Pleistocene glaciation began ~1.8 myb - start of the Quaternary **Fig. 12.9**
  1. part of a general erratic cooling of the earth that began ~25-30 mybp
- C. timing of glacial cycles **show Raymo figure**
  1. initial cycles were 40-50 kyr cycles
     - a. glacials and inter-glacials roughly equal in length
     - b. $\delta^{18}O$ of benthic forams
       - i. records ice volume
       - ii. seawater becomes heavier as water is transferred from the oceans to ice via precipitation (snow)
  2. more recent cycles very different
     - a. longer glacials (~100 kyr) separated by shorter inter-glacials
     - b. contrast in extent of glacial/interglacial ice has also increased

III. Changes in orbital characteristics and causes of seasons **Fig. 14-21**
- A. gravitational attraction between the Earth and other bodies in the solar system
  1. affects the Earth's orbit
  2. changes 3 general characteristics of the Earth's orbit
  3. lead to differences in the contrast between seasons
  4. also leads to differences in total input of solar energy to the Earth
- B. Tilt (obliquity)
  1. earth's axis is tilted (presently 23°) rel. to plane of the orbit
  2. changes the relative amount of solar lumination each hemisphere receives seasonally
     - a. this is the primary control on the seasons
       - i. more important at high latitudes
       - ii. affects seasonal changes in the intensity of solar radiation

3. varies with 41 kyr periodicity **Fig. 14-6**

C. Eccentricity **Fig. 14-21**

1. earth's orbit is an ellipse
2. closer to sun = more radiation received
   a. can also lead to some "seasonality"
3. changes in the rel. lengths of the long and short axes of the ellipse **Fig. 7-9**
   a. earth/sun distance changes with time
   b. gravitational attraction between earth and other planets
4. roughly 100 kyr periodicity

D. the relationship between tilt and Earth's orbit eccentricity

1. controlled by orbital precession **Fig. 14-21**
   a. earth's axis precesses like a top
   b. caused by gravitational attraction between the Earth and the Sun **Fig. 7-9**
2. affects whether the tilt and distance seasonal factors oppose or reinforce one another
   a. when a given hemisphere is tilted towards the sun it receives more sunlight **Fig. 7-10**
   b. in the extreme this can be either opposed by or reinforced by orbital eccentricity
   c. of the two, tilt has the greater effect on seasonal solar insolation changes
3. currently in the N Hemisphere these 2 factors oppose one another **Fig. 7-11**
   a. in S Hemisphere these 2 factors now reinforce one another
   b. Dec/Jan - tilt effect leads to less NH sunlight and Earth is closest to the sun
   c. Jun/Jul - tilt effect leads to more NH sunlight yet Earth is farthest from sun
4. major cycle has a 23-4 kyr periodicity
   a. also a minor precession cycle at 19 kyr
5. 12 kyr bp these two factors reinforced one another in N Hemisphere
   a. like today in S Hemisphere
   b. presently they oppose one another in the N Hemisphere

IV. Astronomical theory of the ice ages

A. Changes in these seasonal contrasts over geologic time causes glacial cycles

1. called the Milankovitch theory

B. lead to differences in the contrast between seasons

1. also lead to differences in total input of solar energy to the Earth

V. Three dominant factors

A. Precession, tilt (obliquity) and eccentricity

B. combination of these 3 effects

1. leads to a complex pattern of variability in solar radiation – **color figure**
   a. varies latitudinally
   b. tilt effects more prominent at high latitudes
   c. eccentricity changes equal at all latitudes
2. eccentricity changes effect total heat budget of Earth
   a. ~0.3% change in total heat received by Earth
   b. other changes effect only latitudinal and seasonal heat distribution

VI. History

A. astronomical theory of ice ages first conceived by James Croll in 1867

1. final form worked out in calculation by Milankovitch 70 years later
2. initially discarded
3. could not reconcile these results with existing data - primarily land based records

B. 1976 Science paper by Hays, Imbrie and Shakleton **Fig. 42 and Raymo fig**
1. provided convincing evidence based on marine sediment core data
2. spectral analysis of $\delta^{18}O$ record predicted 100, 41-43, and 19-23 kyr frequencies

C. problems **Fig. 14-8**
1. $\delta^{18}O$ record also shows that 100 kyr band is the strongest
2. its effect on solar insolation is the smallest (~10% of the other bands) – upper plots
3. must be positive feedback forces in climate signal that amplify the weak eccentricity forcing

VII. These astronomical changes drive/affect glacial cycles

A. “pacemaker” of the ice ages is these Milankovitch cycles

B. exact connection(s)/mechanisms not well understood

C. at certain times Earth conditions are be poised for the occurrence of glacial cycles
1. at such times, astronomical cycles then initiate glacial cycles
2. positive feedback to this astronomical forcing leads to onset of glacial periods

VIII. Why are there ice ages only during certain geological time periods?

A. astronomical effects occur constantly

B. changes during the Cenozoic led to the initiation of glacial-interglacial cycles **Fig. 12-9**

C. several possibilities
1. initial cooling during the early Cenozoic may have been caused by a decrease in mid-ocean spreading rates **show carbonate silicate figure**
2. this doesn’t explain the sharp change in cooling ~39 my bp.

D. one explanation is the perturbation of the carbonate-silicate cycle by plate tectonics
1. collision of India with Asia to form the Himalayas and Tibetan plateau **Fig. 12-16**
2. formation of the Tibetan plateau also creates the seasonal rain (monsoons) to drive the weathering of these new mountains
3. accelerates silicate weathering and draws down CO_2 levels to near present day values
4. changes in global temp change ocean circulation and global heat transport
5. these then also further draw down CO_2

E. see M Raymo’s web site for details

IX. Several important points **back to Fig. 14-8**

A. feedback loops likely amplify the initial astronomical signal due to eccentricity band
1. have to be positive feedbacks

B. will see that these feedback loops likely relate to CO_2 changes
1. positive feedbacks between global climate and atmos. CO_2