ES 106 Glaciers and Ice Ages

I. Glacier thick mass of ice accumulated over years, decades, centuries
   A. Function of recrystallization of fallen snow
   B. Types
      1. alpine—valley:
         a. high elevations worldwide
         b. piedmont—coalescence of valley glaciers in lowlands
      2. ice sheets—presently Antarctica and Greenland
         a. Antarctica is 4300 m thick
         b. Contains 2/3 of fresh water and 4/5 of ice
         c. ice cap—smaller than sheets
   C. Plastic flow from highlands, or from central accumulation area
      1. upper surface brittle: cracks into crevasses
      2. sides affected by friction: center moves faster
II. budget of a glacier
   A. snow falls: stays or leaves
      1. accumulation zone: snow stays
         a. more snowfall than loss due to evaporation, melting, calving
         b. becomes glacial ice upon recrystallization
      2. wastage zone: snow leaves
         a. loss exceeds accumulation—‘ablation’
            1) melting
            2) evaporation
            3) calving into icebergs into the sea
               a) iceberg mostly submerged
               b) navigation hazard in high mid-latitudes
         b. divided from accumulation zone at the ‘snowline’
   B. advance vs. retreat
      1. advance—tip further from source area: downward or outward
         a. increase in accumulation
         b. increase in rate of movement
      2. retreat—tip closer to source area
         a. always moving away from source area
         b. ablation exceeding accumulation
III. glacial erosion
   A. striations and polish
      1. plucks rocks from its bed
      2. grinds its bed with these rocks—abrasion
      3. makes the rocks into rock flour
   B. valley glacier landforms
      1. changes stream-carved drainage
         a. straighter
         b. u-shaped instead of v-shaped
      2. landforms include hanging valley, arête, cirque, horn

IV. Glacial deposition
   A. collectively called ‘drift’: originated with Great Flood explanation
      1. moraines from ice moving material
         a. lateral, medial along valley glaciers
         b. terminal, end in both types
         c. continental have numerous unique landforms: drumlin, esker, kettle lakes
      2. outwash plains beyond reach of glacier

V. Ice Ages—
   A. Earth’s climate oscillates between glacial and interglacial states
      1. glacial stage more stable than interglacial
      2. stable beyond predicted stability conditions, due to energy requirement to cross threshold
   B. Characteristics of glacials and interglacials
      1. glacial
         a. about every 100,000 years
         b. 10^{O} C worldwide average temperature
         c. CO_2 about 200 ppm
      2. Interglacial—ice remains on Greenland and Antarctica
         a. shorter duration than glacial
         b. 15^{O} C worldwide average temperature
         c. CO_2 about 280 ppm
   C. Pliocene-Pleistocene
      1. Extensive areas of high mid-latitudes covered with ice sheets
         a. Most recent period of ‘Ice Age’ shows up to 20 periods of ice advance and melting in the past 3 million years
         b. Polar landmass of Antarctica has had ice at least 14 million years
      2. Area
         a. ice extended into central Midwest, central to southern Europe, central Asia
         b. some parts of Alaska, Siberia not ice covered—desert-like precipitation, protected from flow by mountain ranges
         c. effects
            1) drift
            2) deranged drainage
            3) pluvial lakes
            4) changes in sea level

D. More ancient Ice Ages
    1. Karoo
        a. 260 to 350 mya
        b. Lasted 90 million years
        c. Wegener’s evidence of continental movement
    2. Andean-Saharan
        a. 430 to 460 mya
        b. Lasted 30 million years
    3. Cryogenian
        a. 630 to 850 mya
        b. Lasted 200 million years
        c. Periods of all Earth covered with glacier
    4. Huronian
        a. Over 2 billion years ago
        b. Lasted 300 to 400 million years

VI. Documentation
- A. Drift deposits
    1. moraine and loess
    2. four major intervals of ice advance
    3. successive advances obliterate previous deposits
- B. loess and marine sediments show better than drift
    1. at least 18 (counting most recent)
    2. regular advances over past 2.5 million years
- C. oxygen isotope record
    1. two common isotopes of oxygen
        a. oxygen-16 and oxygen-18 are stable (not subject to decay)
        b. have differing numbers of neutrons in nucleus gives different atomic mass
        c. at colder temperatures, more oxygen-18 incorporated into skeletons
        d. also, heavier oxygen water less likely to evaporate
            1) more oxygen-16 in vapor→ precipitation→ storage on land
            2) more oxygen-18 left behind in water
            3) reinforces the temperature effect
    2. oxygen isotope ratio in planktonic organisms show dozens of climate swings over past 3 million years
- D. ice cores contain trapped air—record of carbon dioxide content

VII. Causes

A. land mass configuration
   1. need high latitude land masses to accumulate ice
   2. high elevations in westerly wind belt help keep ice on land

B. reinforcement of temperature changes created by changes in Earth's movement around Sun—predictable 'Milankovich Cycles'
   1. amount of deviation from circular orbit: eccentricity
      a. greater eccentricity causes greater difference in seasons from northern to southern hemisphere
         1) more sunlight at perihelion than at aphelion
         2) varies between nothing, to 6% (is 1.7% at present)
         3) 100,000 year cycle and 400,000 year cycle
         4) Direction of elongation changes with time too
      b. less results in more consistent seasons
   2. change in axial tilt: obliquity
      a. degree of tilt of axis of rotation: between 22 and 24.5^{O}
      b. increases contrast of summer to winter temperatures
         1) more results in greater seasonal variation of temperatures
         2) less has a smaller change in seasonal temperatures
      c. about 41,000 year period of change in obliquity
   3. change in direction of tilt—precession of axis
      a. Important in its relation to the others—superimposed upon them
      b. spin axis oriented toward Polaris at present
         a) complete circle over 25,700 years
         b) axial precession opposite direction from precession of obliquity, results in 19,000 to 23,000 year period
         c) effect changes which hemisphere is closer to Sun during summer,
            i. causing that hemisphere to have greater seasonal contrast than the other
      c. total amount of sunlight received does not change, just the seasonal distribution of it
      d. at present, southern hemisphere has greater seasonal contrasts, with milder seasons in north
   4. Data from sea sediments support the astronomical influence
      a. Oxygen isotope ratios in shells of marine organisms
   5. summary: glaciation favored by low obliquity (low seasonal contrast), high eccentricity, and precession to have land hemisphere summer at aphelion to reduce melting

C. CO_2 levels—which may be partly a function of glaciations

VIII. Feedbacks in glacial climate system
A. albedo—reflectance: by clouds and ice=positive feedback loop
1. ice
a. more ice—greater albedo
b. greater albedo--less heating
c. less heating—more ice
2. cloud
a. cloud seeds: aerosol sulfur compounds
b. elevated during glacial times
c. source: organic—algae
1) more algae, more sulfur aerosols
2) more sulfur aerosols, more clouds
3) more clouds, more albedo and more precipitation
B. carbon dioxide changes
1. rapid, and nearly identical pattern to oxygen isotope changes
2. causes
a. biological creation of CO_2 by photosynthesis,
1) function of nutrient-utilization
a) high utilization, low CO_2
b) low utilization, high CO_2
2) high productivity in glacial periods?
b. Shelf nutrient hypothesis: phosphate
1) Nutrients supplied from rivers, removed by sedimentation
2) Lowered sea levels allow deposits on shelf to be weathered, eroded, delivered to sea by rivers
3) Greater phosphate availability, greater productivity, larger amount of sedimentation of CO_2 in hard parts
4) However, indicators show lack of increase in phosphate
c. Iron fertilization hypothesis
1) Iron is trace nutrient for algae
2) Climate change in glacial period intensifies wind
3) Brings more iron to sea in dust storms
d. Coral reef hypothesis
1) Reef growth will increase CO_2 content of atmosphere
a) Coral makes calcium carbonate skeleton
b) Byproduct of the reaction is release of CO_2
2) Flooding of shelves with rise in sea level leads to reef growth
3) As reefs are weathered, CO_2 leaves atmosphere
4) Unbalanced response of sea-level changes to CO_2 in atmo.
e. Forest cover
1) Increased desert belts reduced tropical forest
2) Increase in CO_2 to sea increases atmospheric CO_2 in glacial
3) Negative feedback overshadowed by the positive feedbacks