I. Glaciers
   A. definition
      1. slowly flowing ice mass
         a) semi-permanent features
         b) cover ~10% of the Earth's surface
      2. glaciers originate on land from the accumulation of snow
         a) above the snow line
         b) more snow falls then melts
      3. come in two main types valley and continental
   B. valley glaciers
      1. relatively small features in mountain valleys
         a) tend to follow existing stream valleys
         b) end in either the ocean or by melting on land
      2. may be 100's of meters thick
      3. there are thousands of these in existence
         a) North America has lots
            (1) high mountains
            (2) lots of precipitation
            b) some even in Africa, New Guinea
   C. continental glaciers
      1. ice sheets
         a) continental scale features that cover a land mass
         b) may be >3000 m thick
         c) only two ice sheets are in existence today
            (1) Greenland
            (2) Antarctica
         d) covered much of the earth in the geologic past
      2. ice shelves
         a) extension of an ice sheet (cap) into the open ocean
         b) Antarctic shelves are 100's of meters thick
         c) smaller shelves at some Canadian islands
   D. ice caps
      1. refers to ice located at the polar regions
      2. Antarctic ice sheet and shelves make up the southern cap
      3. the northern cap is over water and is not a glacier

II. How glaciers grow
   A. snow accumulates and gets buried
      1. consistent low temperatures
      2. plenty of snow
3. temperature is more important
   a) some places get lots of snow
   b) snow melts each year, so no accumulation
4. need more snow to fall than melts
B. changes into ice as it ages and gets buried
   1. evaporation
   2. recrystallization

III. How glaciers dissipate
A. loss of ice is called ablation
B. mechanisms for loss of ice
   1. melting
   2. breaking up into icebergs, called calving
   3. sublimation
   4. wind erosion, this would be hard to separate from sublimation
C. balance between ablation and accumulation
   a) if ablation exceeds accumulation, glacier retreats
   b) if accumulation exceeds ablation, glacier advances
D. retreats can be dramatic as glaciers and shelves can break apart during retreat
   1. huge chunk broke off the Antarctic ice shelve in 1995 and 2002
   2. 1995 break include an 80 km long iceberg

IV. How glaciers move
A. plastic flow
   1. ice depth reaches about 50 meters
   2. confining pressure allows plastic deformation
   3. microscopic ice particles slip past one another
   4. gravity is the driving force
   5. dominant mechanism in bitterly cold regions
   6. flow within a glacier is like a stream, only slower
      a) velocity is slow - cm/day
      b) fastest in the center and near the top
      c) friction along bottom and edges slows flow
B. basal slip
   1. thin layer of water at the bottom of the glacier
   2. can result from either pressure or temperature
   3. water acts as a lubricant to the moving ice
   4. in valley glaciers, basal slip can lead to a period of fast movement called a surge
C. crevasses
   1. top surface is not under confining pressure
      a) brittle
      b) it fractures rather than flows
2. resulting crevasses may be 50 m deep
   a) not likely to close suddenly, like in movies
   b) often covered by snow bridges
3. valley glaciers
   a) curves
   b) changes in slope

V. **Glacial erosion**

A. importance
   1. streams are the most important erosional agent on earth
   2. glaciers are the most powerful
   3. glaciers are very important during ice ages

B. glacial abrasion
   1. ice is heavy
   2. contains rock fragments
   3. essentially grinds the rock down
      a) polished rock
      b) striations
         (1) grooves cut in bedrock
         (2) show direction of advance
   4. valley glaciers grind the valley walls
      a) sides steepen
      b) tops collapse
      c) fall on glacier

C. plucking
   1. process of lifting and moving intact blocks
      a) frost wedging causes the block to rise
      b) block is then lifted (plucked)
      c) incorporated into the glaciers load
   2. blocks can be transported up to hundreds of miles
   3. individual blocks may be huge (house size)

VI. **Erosional glacial landforms**

A. ice sheets
   1. flow over everything but significant peaks
   2. tend to smooth off the existing topography
   3. bedrock knobs
      a) gentle slopes pointing towards the source,
      b) steep slopes in the direction of movement

B. valley glaciers
   1. create some of the most spectacular landforms on earth
      a) tend to follow stream valleys
         (1) hollow out a U shape
         (2) side walls collapse on top of glacier
2. erosion is a function of glacier thickness
   a) main glaciers cut deep valleys
   b) tributaries shallow ones
      (1) form hanging valleys
      (2) spectacular waterfalls
3. cirque
   a) head of a valley glacier
   b) bowl shaped feature in the mountains crest
   c) great for skiing
4. arete
   a) sharp ridge between cirques
5. horn
   a) multiple cirques can leave a very steep spire
   b) Matterhorn
6. fjord
   a) steep flooded valley formed by glacial erosion
   b) unlike streams glaciers can cut below base level
   c) ocean levels drop during glacial periods
7. loch ness
   a) valley glacier gouge out weak rocks along a fault zone
   b) the moraine plugged the end
   c) lake is ~23 miles long, 1 mile wide, averages 600 feet deep

VII. Depositional glacial landforms

A. glaciers carry a huge load of sediment
   1. all sizes are carried with equal ease
   2. particles are not sorted by size within the glacier
B. when the glacier melts, that load is dumped
   1. material of all sizes
   2. called glacial till
C. glacier is like a conveyor belt
   1. builds up a hill at the end point
   2. called an end moraine
      a) destroyed during glacial advance
      b) glacial retreat leaves a series of these
      c) upper Midwest is covered by moraines
      d) Long island is an end moraine
   3. lateral moraines are found along the sides of glaciers
D. eskers
   1. streams along the underside of melting glaciers
   2. carry sand and gravel
   3. makes sort of an upside down river bed called an esker
   4. long winding hill of sand and gravel
E. glaciers calve icebergs on land during retreat
1. big chunk or ice is left behind
2. glacier deposits sediment around the ice
3. leaves a kettle lake
4. Michigan, Wisconsin are covered in these

VIII. Glacial outwash
   A. melt water runs across the glacial till
      1. erodes the till
      2. carries finer particles away
      3. deposits them elsewhere as glacial outwash
   B. wind picks up the finest (smallest) material
      1. grinding of the glacier creates lots of rock flour
      2. can be carried long distances by wind
      3. deposited as a fine dust called loess
      4. makes fertile farmland
         a) Illinois, Nebraska, Missouri
         b) large portions of China

IX. Ice ages
   A. currently ice covers about 10% of the earth’s land
   B. in the past around 30% was covered
   C. North America
      1. ice sheets advanced over the continent
      2. evidence of four major episodes
         a) named after the southernmost deposit
         b) Nebraskan, Kansas, Illinoian, Wisconsin
   D. effects of ice age
      1. numerous plants and animals went extinct
      2. drainage patterns changed significantly;
         a) the Missouri river used to flow north
         b) the Great lakes were originally river valleys
            (1) glaciers scooped out much of the rock
            (2) receding ice left big depressions behind
      3. weight of the glaciers compressed the underlying rock
         a) these areas are now rebounding upward
         b) Cleveland rises a little each year
      4. sea levels dropped dramatically ~130 m
         a) water was transferred into the ice sheets
         b) exposed much of the sea floor to erosion
         c) opened land bridges between continents
      5. Pluvial lakes
         a) the climate was generally wetter than it is today
         b) great lakes formed in Utah, Nevada, Washington
            (1) Great Salt Lake is a remnant
(a) water evaporated
(b) the dissolved materials remained
(2) Pyramid lake is less salty
c) many pluvial lakes were dammed by glaciers
   (1) dams eventually broke
   (2) huge floods carved gorges
   (3) Truckee, Columbia rivers

6. drowned river valleys
   a) sea level dropped
   b) rivers to the ocean carved downwards
   c) river valleys are now drowned
   d) Chesapeake bay

X. Permafrost
A. soil that remains continually frozen
   1. up to 500 m thick
   2. covers about 25% of the earth
   3. Alaska, northern Canada, Siberia, Tibet
B. near surface layer may thaw during the summer
C. headaches
   1. drainage stinks
      a) surface layer is swampy
   2. thawing the soil
      a) buildings, roads etc. add heat
      b) soil loses its strength
   3. huge problem for the Alaska pipeline
      a) oil must be hot to flow
      b) pipe below ground
         (1) had to be insulated
         (2) sometimes even refrigerated
         (3) construction changed water flow
      c) at the ground surface
         (1) base had to be insulated
         (2) interferes with wildlife
      d) caribou migration