Glacial Processes and Landforms

I. INTRODUCTION

  A. Definitions

    1. Glacier- a thick mass of flowing/moving ice

      a. glaciers originate on land from the compaction and recrystallization of snow, thus are generated in areas favored by a climate in which seasonal snow accumulation is greater than seasonal melting

        (1) polar regions
        (2) high altitude/mountainous regions

    2. Snowfield- a region that displays a net annual accumulation of snow

      a. snowline- imaginary line defining the limits of snow accumulation in a snowfield.

        (1) above which continuous, positive snow cover

    3. Water balance- in general the hydrologic cycle involves water evaporated from sea, carried to land, precipitation, water carried back to sea via rivers and underground

      a. water becomes locked up or frozen in glaciers, thus temporarily removed from the hydrologic cycle

        (1) thus in times of great accumulation of glacial ice, sea level would tend to be lower than in times of no glacial ice.

II. FORMATION OF GLACIAL ICE

  A. Process: Formation of glacial ice: snow crystallizes from atmospheric moisture, accumulates on surface of earth. As snow is accumulated, snow crystals become compacted > in density, with air forced out of pack.

    1. Snow accumulates seasonally: delicate frozen crystal structure
      a. Low density: ~0.1 gm/cu. cm
      b. Transformation: snow compaction, pressure solution of flakes, percolation of meltwater
      c. Freezing and recrystallization > density

    2. Firn- compacted snow with D = 0.5D water

      a. With further compaction, D >, firn ---------ice.
      b. Crystal fabrics oriented and aligned under weight of compaction

    3. Ice: compacted firn with density approaching 1 gm/cu. cm

      a. Snow to firn to ice density increases with increasing depth and increasing weight of compaction

      b. Rate of snow to ice transformation function of climate

        (1) Humid Freeze-thaw climate: days to weeks

          (a) Higher snow accumulation rates

        - (2) Polar climate: years to hundreds of years
            - (a) Low snow accumulation rates
    - c. Freezing Process: Liquid to Solid
        - (1) Water to ice: accompanied by x 8% increase in volume
- 4. Glacial Ice
    - a. Requires humid, cold climates of high snow fall
        - (1) e.g. Alaska
    - b. Dry cold areas may not accumulate significant ice thicknesses
        - (1) e.g. Antarctica
    - c. Ice Stratification
        - (1) Annual accumulation layers of snow, ice, and dust/rock debris

III. PROCESS OF GLACIAL ICE MOVEMENT

- A. Mechanical Properties of Ice
    - 1. Pressure Melting: under great overburden of pressure, melting point of ice is lowered
        - a. Pressure Gradient: melting point < 1 degree C for every Kg/sq. cm pressure
        - b. Partial "pressure" melting of ice at base of glacier aids in sliding motion and movement
    - 2. Ice Deformation: Stress-strain Relationships
        - a. Elastic: Strain deformation directly proportion to amount of stress applied, ability for strain to be removed upon removing stress
        - b. Plastic: Rate strain > rate of stress, ice permanently deformed upon removing stress
        - c. Brittle: Stress exceeds internal shear strength of ice, brittle rupture/fracture occurs
- B. Ice Flow Mechanisms-
    - 1. Basal Sliding- the interface between the ice and underlying stratum is most often the site of shear/slip: pressure melting and hydraulic lubrication contributing factors.
        - a. Zone of intense crushing and grindng action, particularly by enclosed rock debris
        - b. Notable in temperate glaciers with freeze-thaw cycles
        - c. Absent in polar regions where ice is frozen to underlying stratum.
    - 2. Plastic Flow-plastic deformation and lateral spreading of glacier over time
        - a. Internal Deformation at Molecular Level-
            - (1) ice behaves brittly until a thickness of 150-200 ft in which the weight of ice causes it to deform plastically and flow

- b. Areal distribution of ice flow
  - (1) Glacial ice flows fastest in central portions of valley glaciers and slowest along valley walls due to friction
  - (2) Plastic deformation controlled by:
    - (a) Thickness and weight of ice pile
    - (b) Steepness of slope and tangential gravitational force
  - (3) Compressing flow: pile-up and plastic thickening of ice
  - (4) Extending flow: extension and plastic thinning of ice

- 3. Internal Shearing:
  - a. Ice motion along shear fracture planes
  - b. Fracture planes dip up-valley
    - (1) upward thrust of ice and debris at toe of glacier

- 4. Crevassing- process of ice brittly fracturing into cracks (tensional stress/bending stress)
  - a. Zone of Fracture- uppermost portion of glacier nearest the surface where the ice deforms brittly.

- 5. Ogives: wavy ridges and swales on glacier surface

- C. Rates of ice flow- from very slow (cm's per 10's of years) to very rapid (several meters/day)
  - 1. glacial surging- periods of time in which glaciers flow very quickly (up to 180 ft/day!).
    - a. possibly results from hydroplaning/sliding along bottom of glacier- due to increase in hydraulic/lift pressure reducing friction at base of glacier.

IV. GLACIAL CLASSIFICATION

- A. Thermal Classification: based on temperature of glacial ice, climatically and latitudinally controlled.
  - 1. Temperate: ice at pressure-melting temperature
    - a. Meltwater common throughout body of glacier
    - b. "wet" glaciers
      - (1) basal sliding, surging and hydroplaning common
    - c. relatively fast glacial advance
  - 2. Polar: ice below pressure-melting temperature
    - a. Meltwater absent, frozen throughout
    - b. basal sliding negligible, frozen ice-rock base
  - 3. Subpolar
    - a. Frozen to substrate
    - b. seasonal melting of upper portions

- B. Morphological Classification: topographic configuration

1. Alpine Glaciers- glaciers generally confined to mountain valleys
    a. Cirque Glaciers- confined to circular depressions at head of valley.
    b. Valley Glaciers- extend down drainage/valley
        (1) presently found in Pacific Northwest, Canadian Rockies, Swiss Alps, and other mountainous regions
        (2) High mountain elevations, cold temperatures, abundant seasonal snowfall
    c. Outlet Glaciers
        (1) Valley glacier fed by polar ice cap
    d. Tidewater Glaciers
        (1) Glacial advance to coastal regions
            (a) e.g. Glacier Bay Alaska
2. Piedmont Glaciers- valley glaciers that extend to mouth of valley, where ice spreads out broadly along base of mountain front.
    a. "Glacial Fans" analogous to alluvial fans
3. Ice Sheets and Ice Caps
    a. Continental Glaciers- massive accumulations of ice that cover extensive areas of the earth's surface.
        (1) Unconfined glaciers
            (a) Flow controlled by internal mechanisms rather than topographic slope
        (2) Ice Cap < in size compared to Ice Sheet
        (3) Present examples include: Greenland and Antarctica
            (a) Greenland: 1.7 million sq. km
            (b) Antarctic: 13 million sq. km
    b. Highland Icefields- occur in mountain areas, ice accumulates in a relatively unconfined sheet through coalescence of valley glaciers (e.g. wester Canada and Alaska)
4. Dynamic Classification of Glaciers: mass balance relationships
    a. Advancing Glacier
    b. Neutral Glacier
    c. Retreating Glacier

V. MASS BALANCE PERSPECTIVES

A. Zone of Accumulation: Upper reaches of glacier where net accumulation of snow and ice occurs year-round

B. Zone of Ablation: lower reaches of glacier where snow and ice are lost

1. melting processes: air temperature and solar radiation

C. Line of Equilibrium: position of zero accumulation and zero ablation

1. Firn Line: Point of snow transformation to firn

2. Snow line- the elevation above which the temperature is cool enough for some winter snow to show a net accumulation.

   a. Equatorial regions: snow line above 20,000 feet grades downward with > latitude

   b. Polar regions: snowline @ sealevel.

D. Mass Balance Relationships for Glaciation

1. Function of rate of snow accumulation above snowline vs. rate of ice melting below snow line

   a. Rate of snow accumulation high above snowline

   b. Ablation or snow melting occurs below snowline

      (1) Calving- blocks of glacial ice break off from glacial at snout of glacier, may form ice bergs in cases of snout at water/ocean front.

2. If rate accum > rate of ablation = ice advance
If rate accum < rate of ablation = glacial retreat
If rate accum = rate of ablation = static equilibrium

   a. Important Note: in all cases above ice continually flows downslope, but in case of retreat, downslope movement can not keep pace with melting of glacial snout.

E. Glacial Surging

1. Sudden dramatic advance of glacial front

   a. Brief rapid advance of terminus

      (1) up to 200 Ft/day

   b. Cause: >hydraulic lift, hydroplaning and reduced friction??

VI. GLACIAL EROSION AND DEPOSITION PROCESSES

A. Erosional Processes- The movement of ice and the pressure exerted on the underlying earth surface result in capability of glaciers to perform great amounts of erosion and earth sculpturing.

1. Abrasion- ice as a belt sander- ice incorporates rock fragments at its base and operates as a rasp on underlying rock strata

   a. Direct Evidence of Abrasion
      (1) May produce Rock Flour or
      (2) Glacial striations: on polished bedrock surfaces- linear scratches on bedrock surface that preserve clues as to the direction of glacial motion

   b. Controlling Factors of Abrasion Rates

      (1) Concentration of basal rock debris
      (2) Supply of rock debris to glacier base (ice flow path mechanisms)
      (3) Hardness of debris vs. hardness of bedrock
      (4) Basal meltwater wash-out mechanism (removal of rock

flour)
(5) Glacial flow velocity
(6) Thickness of ice: pressure of overburden (> P, > abrasion)
(7) Basal hydrostatic pressure (> Hp, < Friction, < abrasion)
(8) Grain shape of basal rock debris (>angularity, > abrasion action)

2. Plucking/Quarrying

a. Plucking Process- as ice flows over fractured bedrock surface, the ice/movement loosens and lifts blocks of rock/debris and incorporates them into the ice via a freeze/thaw process. Meltwater from ice generated via friction and temperature, water fills cracks of rock, frost wedging breaks and pulverizes rock.

b. Friction Cracks-stick-slip motion/freeze action produces small-scale fractures in underlying bedrock

(1) Chatter Marks: small-scale concentric fractures of gouges (mm to cm in scale)

(a) Paleoflow Indicator:

i) "smooth polished" direction = ice flow direction
ii) "rough" direction = up flow direction

3. Subglacial Fluvial Erosion

a. Glacial Meltwater: subglacial flow and channelization
(1) "englacial" flow: within body of ice
(2) "subglacial" flow: at base of ice
(3) Channel patterns parallel to topographic gradient and ice flow directions

b. Seasonally fluctuates according to temperature/melting

(1) glacial conduits expand and contract seasonally

B. Transportation and Depositional Processes: Deposition of eroded debris occurs when glacial ice melts, sediment may be deposited directly by the glacial ice or by melt waters flowing away from the glacial ice.

1. Transportation Process: massive amounts of debris generated, debris deposited directly from glacial ice or from glacio-fluvial meltwater

2. Debris Terminology

a. Glacial Drift: all deposits derived from glacial process (either directly or from meltwater)

(1) Till: debris deposited directly from glacial ice

(a) poorly sorted admixtures from flour to boulders

(2) Outwash: sorted and stratified debris deposited by meltwaters

3. Deposition

a. Nonstratified, Poorly Sorted Sediments

- (1) Diamictons: deposits of poorly sorted glacial clasts
- (2) Till- sediment deposited directly by glacial ice
  - (a) Process:
    - i) Deposited by ice when it melts
    - ii) Unsorted mixture of sediment of many sizes (clay to boulder)
      - a) Polished and striated clasts
    - iii) Highly compacted from weight of ice
  - (b) Lodgment Till: till derived from melt of basal ice, debris subsequently compacted and plastered to ground surface by over-riding ice
  - (c) Ablation Till: debris released from melting ice as the glacier undergoes ablation (not over-ridden by ice sheet directly, later ice advances notwithstanding)
- (3) Glacio- marine/lacustrine Drift: glacial debris derived directly from melting ice in standing water
  - (a) Calving and floating ice bergs on water
  - (b) "dropstones": rain of debris from ice onto lake/sea bottom
    - i) poorly sorted admixtures
    - ii) fossil evidence of sea/lake critters
- (4) Glacial erratics- anomalously large boulders that have been glacially derived, transported large distances, now forming an exotic rock type not indiginous to the site of depostion.
  - (a) Polished and striated

b. Stratified, Sorted Sediments

- (1) Outwash Deposits (Glacio-fluvial): sediment deposited by melt water from the glacier (at glacier terminus and downstream of terminus)
  - (a) Well sorted sediment that is sorted according to its size and weight (coarsest sediment deposited closer to glacial front, finest generally carried farther from the glacial front).
    - i) Pebble imbrication may provide paleocurrent indicators
  - (b) Braided Outwash Plains: found along vast regions beyond the terminus of large glaciers
    - i) characteristic coarse-load, braided fluvial pattern
- (2) Glaciolacustrine Deposits: lakes commonly form in conjunction with glacial and post-glacial activity (ice margin lakes, scour lake basins, debris-dammed drainages)
  - (a) Glacial Varves: seasonal rhythmic deposits of sediment associated with freeze-thaw cycles

- i) Yearly Couplets
  - a) Summer Runoff Deposits: coarse silt to sand deposits
  - b) Winter Deposits: finer clays settling from quiet-water suspension

- (3) Glacioeolian Deposits: windblown sand, silt and clay derived from glacial deposits of Pleistocene
  - (a) Eg. Sand Hills of Nebraska: eolian reworking of Pleistocene glacial deposits
  - (b) Loess: windblow silt and clay, may accumulate very thick blanket deposits covering land surface
    - i) E.g. Palouse Loess of Eastern Washington- steeply rolling wheat country comprised of a loess blanket derived from westerly winds from across Columbia River Basin

VII. EROSIONAL GLACIAL LANDFORMS:

(Massive sculpturing of landscape, extremely high rates of erosion compared to "normal" weathering and mass wasting processes)

- A. Cirques- a bowl shaped depression located at the head of a glacial valley, steep walls on three sides of cirque, with open end leading down valley
  - 1. cirque- represents the cradle of the glacier where snow accumulated most with ice formation, glaciers flowing away from cirque.
  - 2. Bowl shaped depression results from plucking rock from sides, and scooping out at base of glacier.
  - 3. Headwall Erosion: intense freeze-thaw (frost shattering) and plucking action along headwall of cirque
    - a. Bergschrund-crevasse formed between head of glacier and headwall of cirque
  - 4. Tarn Lakes: lake-filled cirque basins
  - 5. Compound Cirques: coalesced cirque basins, scalloped surface topography
  - 6. Nivation Cirques: development of cirques on non-glacial topography, depression-hollows found commonly on north slope areas (northern hemisphere)
    - a. Aspect Control: North slope areas: decreased influx of solar radiation, extended periods of snow cover prior to melting
      - (1) freeze/thaw + mass wasting
        - (a) creep, soliflution, rill wash
      - (2) snow melt water moves debris down slope
    - b. Possibly may form precursor to formation of cirque glacier

B. Aretes, Cols and Horns

1. Aretes- saw-toothed ridge which separates two glacial valleys (a glacial valley divide)

2. Cols- A sharped-edge pass or saddle between two adjacent cirques. Occurs when two adjacent cirques cut back to remove part of arete between them resulting in col.

3. Horns- 3 to 4-sided pyramid shaped mountain peaks, produced by the adjoinment of 3-4 cirques on each side of the peak.

   a. Process: result as erosional remnant from the plucking and frost wedging action at the head of glacial tributary valleys.

   b. Effectively produced by glacial "headward" erosion

C. Glacial Valleys: U-shaped Cross Section

1. U-shaped Valleys- flat valley bottoms and steep valley walls, result of shear stress and glacial erosion along valley walls

   a. Valley glaciers tend to conform to original fluvial topography

   b. Through Glacial erosion they tend to:

      (1) Widen a valley
      (2) Deepen a valley
      (3) Straighten valleys

   c. Depth of valley modification dependent upon thickness of glacial ice

   d. Massive amounts of rock eroded during valley glaciation

2. Hanging Valleys- tributary valleys left hanging high above the main glacial trough upon melting of glacial ice.

   a. Process: result from glaciers cutting main valleys deeper than tributary valleys due to greater accumulations of icen in main valleys, upon melting, tributary valleys were not cut as deep as main valley, thus leaving them hanging.

3. Fjords- glacial valleys which have been inundated by the sea (i.e. a drowned U-shaped valley).

4. Paternoster Lakes- a string of glacial lakes in line along a glaciated valley

5. Finger Lakes (Upstate NY)

   a. Glacial scouring and deepening of pre-glacial valleys by continental ice sheets
   b. Scoured to 1000's of ft depth, partially filled with unconsolidated sediment
   c. Lakes 600-700 Ft deep

D. Glacial Scour and Streamlined Forms

1. Whale Backs: streamlined erosionally abraded rock outcrops

2. Roches Moutonnees- phenomena in which pre-existing bedrock hills are sheared off and rounded by moving ice, with plucking dominant on lee side forming a smooth sloping stoss side and more steeply

inclined irregular lee side.

3. Striated Glacial Pavements: on bedrock via the abrasion process.
    - a. Striations: abrasion scratches on underlying bedrock pavement, evident upon removal of glacial ice
        - (1) Scale: fractions of mm to 100's of m's
            - (a) depends on size of abrading fragments
        - (2) Groove orientation provides paleo-flow indicator
    - b. By-product: striated/polished clasts in till deposits,

VIII. DEPOSITIONAL LANDFORMS

A. Moraines- layers or ridges of till (unsorted glacial deposits) deposited from glacial ice (commonly curvilinear in shape conforming to lobate form of ice front)

1. End Moraines- may be applied to both continental and valley glaciers- till deposited at the terminus of a glacier at any given time (thus may be later bull dozed by the glacier)
    - a. Terminal Moraine- deposited at the point of furthest advance of a glacier
    - b. Recessional Moraine- deposited at the terminus of a glacial as it recedes back up the valley., accumulated during stillstands of retreat process

2. Lateral Moraines- associated only with alpine glaciers, moraine/till deposited along valley walls.
    - a. Debris derived from direct glacial scour and from freeze-thaw frost shattering along valley walls
    - b. Eventually grade into terminal moraines

3. Medial Moraines- till deposited at the juncture of two alpine glaciers which coalesce as tributaries (i.e. lateral moraines which come together as medial moraines)
    - a. Eventually grade into terminal moraines

4. Interlobate Moraines-accumulates between two adjacent lobes of ice
5. Ground Moraine- applied to continental glaciers: till deposited irregulary as the glacier recedes forming a gently undulating surface, fills in low spots
    - a. comprised of lodgment and ablation till
    - b. forms irregular hummocky blanket of till over land surface

B. Drumlins- (continental glaciers)- streamlined, tear-drop shaped, asymetrical hills composed of till, the tail of the drumlin points in direction of ice movement, round/wide steep side points in opposite direction of flow.

1. Steep and wide stoss side, narrow tail on lee side
    - a. Avg. 1 mi long, 150 Ft high, 1500 Ft wide

2. Drumlins often found in clusters, possibly related to re-advance

of a glacier over end moraine, resulting in bulldozing and shaping drumlins into the forms.

C. Flutes: amalgamated, elongate drumlins forming parallel ridges as opposed to well defined drumlin hills

IX. GLACIAL STAGNATION: MELTWATER LANDFORMS

A. Eskers- (continental glaciers)- sinuous ridges composed of sorted sand and gravel, deposited by sub-glacial streams flowing in tunnels beneath the ice, near the terminus of the glacier.

1. composed of coarse, stratified, sorted sand and gravel

B. Kames- (continental glaciers) irregular steep-sided hills that are composed of sand and gravel, thought to represent sediment deposited in hollows within glacial ice.

1. "Dump-truck" glacial deposits

C. Outwash Plains- (continental and/or alpine glaciers)- melt water from the glacier flows over end moraines, eroding them and carrying sediment further downslope, sediment becomes sorted and deposited downslope of most end moraines.

D. Kettle Holes (term applied to continental glaciers)- depressions found in deposits- represents situation where an isolated block of ice became buried in drift, subsequently melted, leaving a pit in the glacial sediment.

1. Kettle Lakes: kettles filled with water

X. PLEISTOCENE GLACIATIONS: EPISODIC GLACIAL HISTORY

A. Pleistocene Glacial Record

1. Overview

a. Periods of extensive glacial activity are evident from preserved rock/glacial record, field investigations have provided proof that many ice ages have existed in past.

(1) Evidence of more recent Pleistocene glaciations come from geomorphological evidence reflecting glacial-related landscape modifications.

(a) Geomorphological evidence is somewhat limited in longevity as glacial geomorphic phenomena are readily destroyed by subsequent weathering and fluvial surface erosion as well as subsequent glacial modifications.

i) Most recent ice advances are best preserved

(2) Geologic evidence of ancient glacial periods comes from the sedimentary rock record.

(a) Poorly sorted "Tillite" deposits

(b) "Dropstone" deposits

i) Ice Rafted Debris in Fine Mud/Shale

(c) Paleofossil/Paleoclimatological Evidence

b. Pleistocene Ice ages- characterized by complex periods of glacial advance and retreat, separated by periods of warm climates

  (1) Pleistocene Epoch- geologic time period between 10,000 years and 2.5 million years ago.

  (2) Character of Pleistocene: refrigeration of high latitude and high altitude portions of earth, and subsequent development of extensive ice sheets and alpine glaciers.

  (3) Glacial/interglacial relations: Find evidence for four major glacial periods during the Pleistocene in North America (in order of occurrence)

    (a) Nebraskan,
    (b) Kansan,
    (c) Illinoian, and
    (d) Wisconsinan (most recent).

      i) Each period was separated by a warm time known as an interglacial period; represented by paleosol development on till.

      ii) Wisconsin glaciation most recent: from 30,000 yr B.P. to 5,000-10,000? year B.P.

  (4) Extent of Pleistocene Glaciation

    (a) Total of 1/3 land area of earth with ice thickness ranging from 10's of feet to several thousands of feet.

    (b) Pleistocene glaciation grew out from poles to lower latitudes

      i) Covered most of Canada, extending down into the northern tier states of the U.S. (northern Washington, Idaho, Montana, North Dakota, Eastern South Dakota/Nebraska, Wisconsin, Minnisota, Illinois, Michigan, Ohio, Indiana, Iowa, northern Pennsylvania, New York and the New England/Maritime states).

      ii) Europe, glaciers covered all of the scandinavian countries, northern Russia, Great Britain, Ireland, Denmark, Sweden, Poland.

    (c) High Mountain areas also were significantly impacted by Pleistocene glaciation: Cascade Range, Sierra Nevada Mountains, the northern Rockies of Montana, Wyoming and Idaho, the intermountain west of Utah/Nevada, and the southern Rockies of Colorado and New Mexico. As well as the Alps, and Pyrenees of Europe.

  (5) Landscape modification: both in the glaciated regions as well as in "periglacial zones"

    (a) Periglacial zones- areas lying in the foreland of the glaciers, areas that were never covered by ice, but received extensive modification by erosional/depositional processes of meltwater. As well as sites of cold climate weathering/mass wasting processes (freeze/thaw, and permafrost conditions)

2. Early Pleistocene

3. Middle Pleistocene

4. Late Pleistocene

B. Isostatic Rebound Processes

1. Crustal depression- under the weight of a great thickness of ice, the earth's crust in depressed downward into the asthenosphere. After the ice melts and the weight is removed, the crust is subsequently uplifted back to densiometric equilibrium.

C. Eustatic Sea-Level Fluctuations

1. Glacio-eustatic Sea Level Fluctuations- ice buildup on continents removes water from the hydrologic cycle, most of which comes from evaporation of sea water. Net result is lowering of sea level during glacial periods, and raising of sea level during interglacial periods. Drastically effects base level and fluvial response conditions.

D. Pluvial Lake History

1. Glacial/Pluvial Lake development- concomitant with increased moisture/evaporation during glacial periods, along with melt water, more water was available on continents, thus large glacial lakes often form.

a. The Great Lakes are a remnant of glacio-pluvial processes.

E. Channel Scablands: Glacial Deluge

F. Oxygen Isotope Record

1. Sea Floor Record

a. Global Glacio-eustatic sea level curve: based on the examination of oxygen isotope ratios found in skeletal tests of microfossils in sea deposits. Examines the ratio of O16/O18 in skeletal tests (which fix oxygen from the ocean, and are presumed to be a reflection of oxygen isotopic ratios present in past seawater). Under evaporative process, only O16 in H2O molecules is evaporated from sea water, subsequently moved inland to form snow/ice... O18 is left behind in the ocean water. Hence, during glacial periods, one would expect a < in the ratio of O16/O18 as the relative proportion of O18 has increased due to evaporation/locking of O16 up in glacial ice. Vice-versa during interglacials. Examining the record of oxygen isotopes can provide a record of glacial/interglacial periods.

2. Ice Cores

XI. CAUSES OF PLEISTOCENE GLACIATIONS

A. Models of Glaciation

1. Any model must accommodate two givens:

        a. climatic changes that lead to lower average temperatures,

        b. the alternation of glacial and interglacial stages on orders of several 100's of thousands of years.

B. Solar Activity

C. Astronomical Variation (Milankovitch Theory)

    1. Milankovitch theory:

        a. based on premise that variations in climate are associated with incoming solar radiation.

        b. solar radiation may be influenced by eccentricity or shape of earth's orbit about the sun

        c. solar radiation may be influenced by obliquity, or changes in angle that earth's axis is oriented with plane of orbit.

        d. solar radiation may be indluenced by precession or wobbling of the earth's axis.

The premise of the Milankovitch Theory is that these celestial variables doe not result in overall change in total solar radiation striking earth, but do influence the relative variation between seasonal climatic variations; i.e. milder winters in middle to high latitudes means greater snowfall totals, while cooler summers would bring a reduction in overall snow melt

D. Other Factors

    1. Plate Tectonics- ice can only accumulate on continents when they are located at the higher latitudes, thus only when plate locations are favorable can glaciation occur.

Provides explanation for large scale occurrence of glaciation

ARE WE PRESENTLY IN AN INTERGLACIAL PERIOD WITH YET ANOTHER GLACIAL TO FOLLOW IN THE FUTURE, HAS THE CYCLE OF GLACIATION CEASED FOR THE TIME BEING?