GLACIATION AND LONG-TERM CLIMATE CHANGE

5th Century to 14th Century- Great Climate
1300- Little Ice Age
- ⇒ Norway glacial advance destroyed farms
- ⇒ Unterer Gandelwald Glacier – Switzerland

<u>Glaciation</u>
2¼% Earth's water is in Glaciers

Pleistocene Glaciation (1.6MYA-10K years ago)
- ⇒ 30% land area covered by glaciers
- ⇒ Midwest is glacial deposits

Glacial melt water today provides drinking water as well as hydroelectric too.

Origin and Distribution of Glaciers

There are two types of glaciated terrain:
1) Alpine Glaciation – found in mountainous regions (*high altitudes*)
2) Continental Glaciation – exists where a large part of a continent is covered by glacial ice. (*high latitude*)

Formation and Growth of Glaciers

Snow converts to glacier ice in somewhat the same way as sediment turns to sedimentary and later into metamorphic rock.

Snow→Granular Snow→Firn→ Glacier Ice
Peat→ Bituminous Coal→Anthracite
Sand→ Quarts sandstone→Quartzite

Theory of Glacial Ages – states that at times in the past, colder climates prevailed during which much more of the land surface of the earth was glaciated then at present.
- ➔ Hypotheses began in 1800's
- ➔ First not believed, then Agassiz bought into it
- ➔ Last glaciation was at its peak 18K years ago
- ➔ Many of our national parks were made by glacial action

Types of Glaciers

1) Mountain Glaciers – confined to a valley and flows from a higher to a lower elevation.
➔ Corresponding to alpine terrains (*higher altitudes*)
   - a) Valley Glaciers: confined to a valley
   - b) Piedmont Glaciers: form where valley glaciers coalesce and spread out over flatter land at the base of a mountainous region.
   - c) Cirque Glaciers: found in amphitheatre-like hollows at the head of a glacial valley.

2) Ice sheet – mass of ice that is not restricted to a valley, but covers a large area of land (over 50,000 km²) – Associated with continental glaciation (*therefore high latitudes*)

Ice Caps – similar to ice sheet but smaller, and can exist in high altitudes or high latitudes
→ Arctic coast – Canada, Russia, Scandinavia

As ice moves to lower elevations, it will eventually be ablated (or lost).
Types of Ablation:
1) Melting
2) Sublimation
3) Calving – forms icebergs

Glacial Budgets
Positive – Accumulation > Ablation – Advancing Glaciers
Negative – Ablation > Accumulation – Receding or Retreating Glaciers
Balanced → Accumulation = Ablation
Surging: (8-10m/day, 26-32ft/day) (100m/day-fastest)

EQ Line = 0° Isotherm = Snow line
Zone of Accumulation – perennial snow cover
Zone of Ablation – melting zone – zone of ice loss
Terminus – lower edge of the glacier

Advancing or receding glaciers are significant and sensitive indicators of climate change
→ Advancing does mean more precipitation, not necessarily a cold trend.
→ Global warming has diminished glacier size (in both South America and Glacier National Park)

Movement of Valley Glaciers
→ Move down slope due to gravity
→ Range – a few mm to 15m a day
→ Glaciers in temperate areas tend to move faster than ones in colder regions

Velocity also varies within the glacier itself (Figure)

Types of Movement

1) Basal sliding – glacier moves as a single unit over the underlying rock

➔Can have freeze-on of boulders, rock at the base, which can then move with the glacier in the basal sliding process

➔ Due to pressure of the Glacier, a thin film of meltwater at its base aids in the movement

2) Plastic Flow – movement that occurs within the glacier due to the plastic or deformable nature of ice itself. (FIG. 12.8)

➔ Easier flows at depth due to the pressure

➔ Near the surface of the ice, the glacier is more rigid (hence the Rigid Zone) (Lithosphere VS. Asthenosphere of the earth)

Rigid Zone – grains of ice do not move separately due to pressure, as a result, the ice cracks.

Crevasses – open fissures that exist in the ice due to stress.

➔ Crevasses can close in areas of compression (FIG. 12.9)

Icefall – where glaciers flow over steep slopes.

Glacial Features

Erosional Landscapes Associated with Alpine Glaciation

Glacial Valleys – U-shaped compared to a V-shaped river-crowded valley

Primary valleys erode faster and deeper, which produce *hanging valleys*, which are high above the main valley

➔ Waterfall of Yosemite

Truncated Spurs – process of carving the sides of a river valley.

➔ produces triangular facets where carving takes place

Rock – Basin lakes (or tarns)

➔ form due to variable resistance to erosion

➔ freeze/thaw weakens fractured bedrock

➔ can also form at the base of a cirque

➔ a series of these lakes → *pater-noster lakes*

Roche Moutonneés – rounded knobs of rock

➔ resemble grasing sheep

Cirque – steep-sided, half bowl shaped recess carved into a mountain at the head of a valley by a glacier

➔ usually north or east-facing

Horn – sharp peak created by the merging of several cirques

Arêtè – sharp ridge between 2 glacial valleys

Erosional landscapes associated with continental glaciation

➔ tend to round everything off

<u>Glacial Depositional Features</u>

Till – unsorted and unlayered rock debris carried or deposited by a glacier.

Erratic – ice-transported boulders from a different area, usually of unlike composition.

<u>Moraines – glacial deposits</u>

1) Lateral – elongate, low mounds of till that form along the sides of a valley glacier
2) Medial – created by the merging of two lateral moraines from tributary valleys
3) End – deposit at the edge of the glacial ice (usually the temporary terminus)
4) Recessional – end moraine built as the glacier was receding
5) Ground – material deposited on the underside of the glacier – usually thin
6) Terminal – the end moraine marking the farthest advance of the glacier.

Glacial Depositional Features Associated with Continental Glaciers

Drumlin – streamlined hills of till that were formed under a glacier.

Flute – elongated drumlin

Outwash – melt-water that runs in front of the glacier that can come from anywhere on the glacier.

➔ can be stratified because of its genesis

Esker – long sinuous feature of stratified and sorted sediment that formed within or under the glacier, where meltwater landed with sediment flows under and out of the ice.

At the terminus of the glacier, mounds of sediment buildup on top of the ice. As the glacier recedes, pieces of ice fall off the edge of the glacier and can get buried by the tons of sediment.

➔ the ice chunks (if they are of size) can form *kettles* once they melt (a glacier lake)

➔ the mounds of sediment can form *kames* (a type of glacial sediment)

They are frequently found together and form *kame and kettle topography*.

Varves – two layers of sediment representing one year's deposition in a lake.

➔ low energy environment

THE EFFECTS OF GLACIATION

Distribution of Soils

- ⇒ Some of the best agricultural soils are found on glaciolacustrine or glascioeolian (loess) deposits,
- ⇒ However, some are very rocky or poorly drained

Ground-Water Resources

Glacial outwash: Sediment deposited in the front of a glacier by melt water streams.

- ⇒ Moraines associated with outwash are poor aquifers due to low porosity (permeability due to their clay content).
- ⇒ Sand and gravel can be mixed

Sea-Level Changes

During the Pleistocene, continental glaciation took up enough water to lower seal level by 100 meters (330 feet).

- ⇒ Florida real estate -30% larger
- ⇒ New Orleans- no more problems

During global warming maximum, sea level would rise 40 meters (130 feet)

- ⇒ London, New York, Tokyo and Los Angeles would all be under water.

During the Ice Age, land bridges such as the Bering Bridge were formed.

- ⇒ Between 20-30k years ago humans came from Asia
- ⇒ By 10-13k years ago the bridge was under water.

Isostatic Rebound

Continental glaciers weigh a lot (they can be 1-2miles thick or more) and depress the continental landmass.

- ⇒ After the melt by 10k years ago, the land where the glacier was located had been rising.

Isostatic Rebound: Uplift due to the release of the mass of ice.

- ⇒ Norway 2feet/century
- ⇒ Viking ruins are 20 feet asl
- ⇒ Great Lakes Region

Human Transportation Routes

Columbian Glacier on Prince William Sound, Alaska has been retreating (and calving) since 1970.

- ⇒ New fjord forming
- ⇒ Shoal protects ice chunks from floating into PWS

Juneau, Alaska is the only state capital without highway access.

- ⇒ Glaciers threaten the only potential path for a road.

Eskers provide good travel routes through boggy regions in New England.

Pleistocene Lakes

Pleistocene Climates were cooler and wetter.

⇒ Pluvial Lakes formed between the fault-block mountain ranges of the Great Basin – Owens, Lake Mankey, Diaz Lake, Rogers Dry Lake (Edward AFB) Lake Bonneville- Great Salt Lake

⇒ Great Lakes and Finger Lakes

Proglacial Lakes: Created by the damming of melt water by ice.

⇒ Once the ice melts an apocalyptic amount of water is released.

⇒ Lake Aguasiz

Glaciation and Climate Change

Pleistocene: ice age

⇒ At least four pulses exist in North America and Europe

⇒ Actually closer to ten during the whole time period

⇒ Global T: 4-10˚C (7-18˚F) cooler

⇒ Winters were colder, summers moderate

⇒ Climate zones shifted toward the Equator

Climate: Long term average of day-to-day weather.

Factors That Control Climate

Relatively constant factors that dictate climate:

1) Intensity of the sun (heat, Earth atmosphere)
2) Distribution of land and water masses
3) Winds and atmosphere circulation
4) Circulation of the oceans
5) Mountain Barriers

51% of sun energy gets here in the form of visible light.

⇒ This is converted to longer curve wave radiation, or infra-red, which heats our atmosphere from the ground up.

⇒ Greenhouse gasses (CO_2, H_2O and others) do most of the absorbing- Greenhouse Effect.

Winds and Atmospheric Circulation

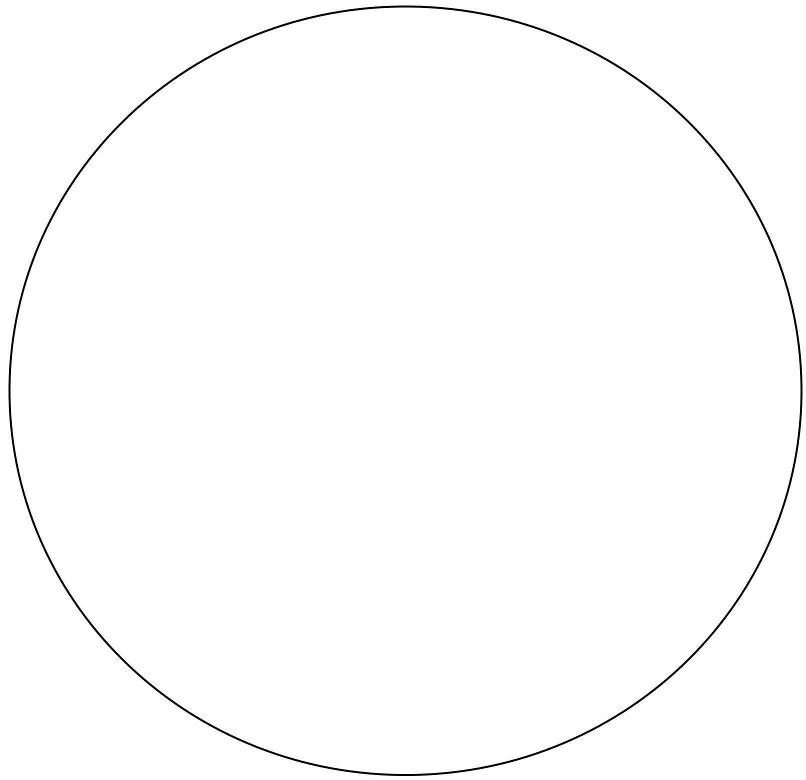
Coriolis Effect: Bending of or deflection of wind and water to the right in the northern hemisphere (or to the left in the southern hemisphere).

Ocean Circulation

Pacific Ocean Currents: [Insert notes here]

Upwelling occurs with currents on the eastern side of the ocean (Eastern Boundary Currents, like the California Current).

Atmospheric Circulation



Related Ocean Circulation

Causes of Climate Change

1) Variation in the Earth's Orbit
   ⇒ Popularized by Milankowitz
   ⇒ Originally John Croll's work (Scot) late 19th century
   ⇒ Three variations
      a) Obliquity- Earth's tilt: 21.2˚ to 24.5˚ (41,000 year cycle)
      b) Eccentricity of Earth's Orbit: 110,000 year cycle
      c) Precession: Time of year when we are closest to the sun
2) Plate Tectonics and Variation in Atmospheric CO_2
   ⇒ Chemical weathering generally decreases atmospheric greenhouse gasses like CO_2 and H_2O (g).
   ⇒ Volcanic activity increases CO_2 levels
   ⇒ Diatoms appear to step up productivity during higher CO_2 levels
3) Variations in Solar Radiation
   ⇒ Sunspots increase solar output
   ⇒ During sunspot maximums – more warming
   ⇒ Maunder Minimum: Few sunspots, restricted in "Little Ice Age"
   ⇒ Main cycle: 11 years
   ⇒ If increased solar radiation was involved in global warming, one would expect warming in the upper and lower atmosphere as well as the surface – this is not he case.
4) Greenhouse Gasses
   ⇒ CO_2, H_2O, CH_4 (methane), NO_2 or NO_3 (nitrogen oxides), CFCs
   ⇒ CFCs weaken the ozone layer
   ⇒ Ozone loss was discovered in the 1970's
      - Skin cancer for us: In 1950's, 1/1500 chance; 1990's, 1/75 chance
      - Damages DNA too: fogies
   ⇒ Nitrogen oxides are released at high altitudes by planes
   ⇒ Lower atmosphere NO_x and hydrocarbons from smog
   ⇒ Upper atmosphere NO_x and CFCs, both break down ozone
5) Dust and Aerosols
   ⇒ During global cooling events, lower sea level, more dust, less transparent atmosphere.
   ⇒ SO_2 from volcanoes
      - 1815 eruption of Tanborn in Indonesia
      - 1982 El Chichoa in Mexico
      - 1991 Mount Pinatubo

   Volcanoes blow the crap to the upper atmosphere.

   When humans release it, it goes to the lower atmosphere, increasing global warming.
6) Change in Ocean Currents: Surface vs. Deep Ocean Currents

Deep ocean flows is thermohaline, and works much like a conveyor belt.
   ⇒ Coldest, saltiest water sinks
   ⇒ Increased melting of ice sheets could disrupt this flow

Glacier Evidence of Climate Change

O^{16}/ O^{18} ratios – forams use what is available

Bubbles of ancient atmosphere are trapped in glacier ice.

Human Scale, from pre-industrial society

⇒ CO_2: 40%, CH_4: 100%

Evidence of Global Warming

1) Increasing Temperatures of the Earth's surface and lower atmosphere
    - ⇒ 1.1˚F in the 20th century, as much as 5.5˚C between 1965 and 2000 in higher latitudes of Canada, Alaska and Eurasia
    - ⇒ Present T is as warm as 1400 AD, and may be the warmest time in the last 100,000 years.
    - ⇒ 1998 and 2002 were the warmest years
2) Changes in the Modern Glaciers
    - ⇒ GNP – only 35 of 150 ice fields are remaining
    - ⇒ Swiss too
    - ⇒ Mount Kenya – lost 92% of its mass
    - ⇒ Alaska Glaciers
        - High elevation 18m (or 60ft) of thinning
        - Low elevation – several hundred feet
    - ⇒ Mountain glaciers hold only 6% of ice
    - ⇒ Worried about Antarctic and Greenland Ice
3) Thawing in Boreal and Subacrtic Regions

Alaskans have had several impacts

a) less sea ice in Bering Sea and storm surges have greater effect
b) Nature peoples have been affected by sea ice conditions (so have animals): more dangerous
c) Due to thawing permafrost: more slope instability, landslides, and erosion
d) More forest fires and bugs which hurt timber yields
e) Permafrost Thawing: Changes in forest, bog, grassland and wetland ecosystems
f) Ice Road Travelers: 200 day season to 100 day season

4) Rising Sea Level
    - ⇒ At 20k years ago, sea level was 120m (393feet) lower
    - ⇒ Thermal expansion compounds rise
    - ⇒ 19th century: 12cm, 20th century: 25cm
5) Biological Response
    - ⇒ See case study 11.4
6) Thinning of the Polar Ice Cap
    - ⇒ As much as 40% loss of volume between 1958-1990's of Arctic Ice
    - ⇒ AO – Arctic Oscillation – decades long, varies from cold and still to warm and windy

Causes of Today's Global Warming
Of the five factors most responsible:

Three vary naturally
1) Stratospheric volcanic sulfate aerosols
2) Climate variability
3) Solar radiation

Two are related to humans
1) Greenhouse Gas increase
2) Anthropogenic sulfate aerosols

Forcing: change due to a factor
- ⇒ Natural forcing
- ⇒ Anthropogenic forcing

IPCC in 1995, human forced since about 1950

<u>Weathers Puzzling Signals</u>
1) Conflicting reports

2) Clouds: A wild card

<u>Living with Uncertainty</u>
- ⇒ "Regrettably, global warming has become political."

Implications for the Future
"Getting a group of scientists to agree on nearly anything, such as forecasting the long-term effects of global warming, is (according to a group of scientist) like trying to herd a bunch of cats."

Rate of greenhouse gas buildup has decreased about 25% since 1980
- ⇒ Where are the gasses going?
- ⇒ Emissions have not decreased…

Kyoto Protocol – set standards for reductions of CO_2
- ⇒ U.S. withdrew, reduce our levels below level – Thank the conservatives for that one.

Projections:
1) Very Probable
    - ⇒ Mean surface T increase of 0.5˚-2˚C by 2050
    - ⇒ Mean precipitation will increase
    - ⇒ Arctic Ocean and Northern Hemisphere sea ice will be reduced
    - ⇒ Arctic land areas will experience winter-time warming
    - ⇒ Globally, sea level will rise

2) Probable
   - ⇒ Precipitation at high latitudes
   - ⇒ Summer dryness will increase in the mid-latitudes of the northern hemisphere
   - ⇒ Volcanism will cause short term cooling

3) Uncertain
   - ⇒ Details of climate A
   - ⇒ Biosphere – climate feedback
   - ⇒ Changes in climate variability
   - ⇒ Regional-scale climate change will differ from global averages
   - ⇒ Tropical storm intensity may change

What Individuals can do:
1) Buy products that reduce energy consumption
2) Use energy more efficiently
3) Actively recycle

What Industry and Governments can do:
- ⇒ Increase in efficient vehicles

Case Studies
11.1 When a Glacier Surges

11.2 The Carbon Cycle
Where:
Biosphere: critters contain carbon in all cells
Hydrosphere: dissolved CO_2
Atmosphere and Pedosphere: CO_2 gas
Lithosphere: Petroleum and hydrocarbons, $CaCO_3$ in limestone and marble

11.3 Is There a New Beat to the Rhythm of the Ice Ages?

Heinrich and Flicker Events

11.4 Early Effect of Global Warming on Plants and Animals