Earth Materials and The Lithosphere
(Christopherson Cha. 8)

I. Geologic Time

A. Age of the Earth: approx. 4.6 billion years
B. Geologic Time Scale

•Two EONS in Geologic Time
- Precambrian (4600 - 542mya - stands for million years ago)
- Phanerozoic (542 - present)

•Three ERAS of the Phanerozoic Eon
- Paleozoic (570 - 251mya)
- Mesozoic (251 - 66mya)
- Cenozoic (65.5 - present)

•Two PERIODS of the Cenozoic Era
- Tertiary (65.5 – 1.8 mya)
- Quaternary (1.8 - present)

•Two EPOCHS of the Quaternary Period
- Pleistocene (1.8mya - 10,000ya)
- Holocene (10,000ya - present)

C. Uniformitarianism: (the present is the key to the past) This is the assumption that the processes which we observe today have been operating throughout geologic time.

II. The Structure of the Earth

A. General
1. Radius: 6400km
2. Density: Decreases from core to surface
3. Temperature: 3000°C to 6650°C estimated at core

B. Cross-Sectional View (Three Main Divisions)
1. Core: The core (thickness 3500km) has a solid inner core and a molten, outer core.
2. Mantle: A solid dark and dense layer of rock approx. 2900km thick.
3. Crust: The crust surrounds the mantle. Its thickness varies between 5 - 50km. There are two types of crust.
   a) Oceanic: Averages 5km thick, dark, dense (mostly basalt).
   b) Continental: Averages 30-50km thick, light color, less dense. Much thicker where there are huge mountains.
   c) Mohorovicic Discontinuity or "Moho": The boundary between the crust and the mantle.

C. Critical Structural Subdivisions

1. Lithosphere (includes Crust and Upper Mantle): This is the brittle, outer layer of the earth. This is the layer broken into "lithospheric plates".

2. Asthenosphere: This is the hot, plastic layer of the mantle just below the lithosphere.

III. Composition of Crust

A. Elements

Oxygen (O)	50%	•*Calcium (Ca)	3-4%
Silica (Si)	25%	•*Sodium (Na)	2-3%
•Aluminum (Al)	8%	•*Potassium (K)	2-3%
•Iron (Fe)	5%	•*Magnesium (Mg)	2-3%

•metals *important plant nutrients

B. Minerals: Inorganic chemical compounds, their formation is affected by available elements, heat, pressure, time. An assemblage of minerals in a solid state is a rock.

IV. **Rock Classifications:** Classified by the processes which formed them.

•Igneous: Rock formed from molten material in the earth's core.
•Sedimentary: Rock formed from layered accumulations rock particles or minerals.
•Metamorphic: Rock formed from exposure to extreme heat and pressure.

A. Igneous Rocks: Formed from molten material in the earth's core. They are classified in two different ways, mineral type and cooling environment.

1. Igneous Mineral Types: Commonly contain silicate minerals (Si and O combined). There are two main mineral types, felsic and mafic.

a) Felsic Minerals: (*fel* for feldspar, *sic* for silica). Characterized by their light color and low density.

EXAMPLES

•Quartz - (SiO_2) extremely common, stable, non-reactive.
•Potassium Feldspar - Silicates of Al and K
•Sodium Feldspar - Silicates of Al and Na
•Calcium Feldspar - Silicates of Al and Ca

b) Mafic Minerals: (*ma* for magnesium, *fic* for ferric). Characterized by their dark color and high density.

EXAMPLES

•Mica •Amphibole •Pyroxene	Silicates of Al, Mg, Fe, K, or Ca.
•Olivine (ultramafic)	Mg and Fe (low in silica)

2. Igneous Cooling Environments: Intrusive (beneath the earth) or Extrusive (above the earth)

A. Intrusive: Cooled beneath the surface	B. Extrusive: Cooled above the surface
1. Cooling is SLOW beneath the Earth's surface; thus the minerals have time to grow into large crystal forms.	1. Cooling is RAPID at the Earth's surface; thus the minerals DO NOT have time to grow into large crystal forms.
2. The crystals are often visible to the naked eye	2. The crystals are generally NOT visible to the naked eye
3. The rock appears coarse grained (comprised of larger particles, like the crystals mentioned above)	3. The rock appears fine grained (comprised of individual particles generally too small to see)

3. Igneous Rock Examples

Mineral Type	Intrusive Examples	Extrusive Examples
Felsic	Granite	Rhyolite
Felsic (tending toward Mafic)	Diorite	Andesite
Mafic	Gabbro	Basalt
Ultramafic	Peridotite	Doesn't exist

B. Sedimentary Rocks (Lithification): Formed from rock fragments or mineral particles (called sediment) are eroded, transported, and deposited. They may sit for thousands or millions of years, during which time they undergo compaction and cementation (a process where the fragments are packed down and cemented together). Collectively, this is called lithification.

1. Clastic: Formed when fragments of pre-existing rock collect in one place.

a) Conglomerate: Formed from cobbles and pebbles mixed with finer sediments

b) Sandstone: Formed from sand grains (like at the beach)

c) Siltstone: Formed from silt particles (possibly from a huge, flooding river)

d) Shale: Formed from clay particles that collect and form a rock with distinct layers

2. Chemical : Formed when dissolved minerals precipitate from a solution and collect. Process usually happens in the ocean.

a) Limestone: Calcium Carbonate $CaCO_3$

b) Dolomite: Calcium and Magnesium Carbonates

3. Organic: Formed when dead plant material collects in wet, vegetated environments and becomes covered with other sediments (includes peat and coal; natural gas is a byproduct)

C. Metamorphic Rocks: Any rock which has been exposed to extreme heat and pressure beneath the surface of the Earth.

1. Examples

a) Slate: When shale is exposed to extreme heat and pressure, forming rock that splits into hard, flat plates.

b) Marble: Limestone which is exposed to heat and pressure

c) Gneiss: Refers to most coarse grained rocks which become exposed to extreme heat and pressure (granite, conglomerate)

Plate Tectonics
(Christopherson Cha. 8)

I. Evolution of the Theory of Plate Tectonics

A. First Suggested: Continental fit noted as long ago as 1596. (Ortelius). Suggested by other scientists

B. Alfred Wegener (Father of Continental Drift / Plate Tectonics): German geophysicist and meteorologist publicly announced his theory in 1912. Considered revolutionary.

1. Similar plants
2. Similar rocks
3. Continental fit

(Not sufficient proof for scientists)

C. Pangaea (split in the Triassic; approx. 225mya): Wegener's original supercontinent, split into the two following continents.

1. Laurasia: Eventually became N. America, Europe, and Asia.

2. Gondwana: Eventually became S. America, Africa, Australia, and Antarctica.

D. Continued Movement (the cause of earthquakes): The continents (lithosphere) in constant motion. The lithospheric plates move at a rate of 5-10cm/year (50-100km/one million years). Constantly evolving.

II. Modern Theory: Took shape in the 1960's.

A. Critical Structures

1. Lithosphere (Crust + Uppermost mantle): review earlier description

2. Asthenosphere: review earlier description

B. Critical Processes

1. Sea Floor Spreading: Where sea floor spreads apart and new material comes to the surface. Accretion is the addition of new crust material.

2. Subduction: Where one plate dives beneath another and is consumed. Consumption is the subtraction of plate material.

III. Modern Plate Boundaries (Mechanisms and Processes): There are three types of plate boundaries; divergent, convergent, and transform.

A. Divergent Boundaries (forces of extension): Two plates are moving away from each other and magma is rising to the surface creating new plate material by accretion. There are two types.

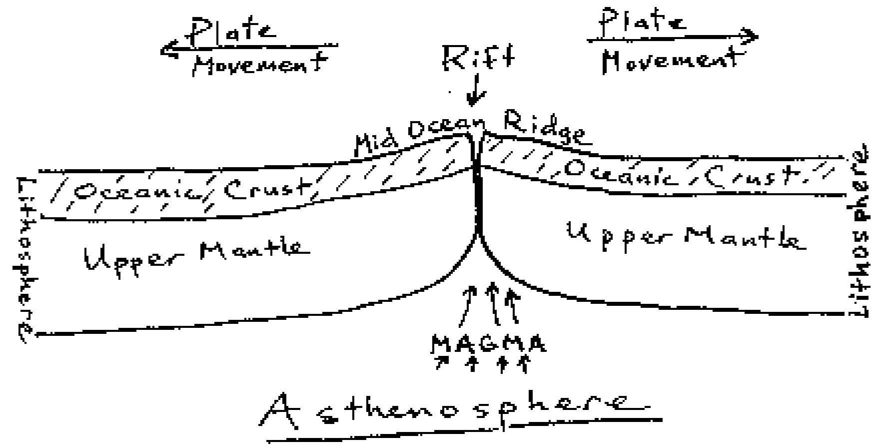
1. Sea-Floor Spreading: Molten material rises to surface, causing sea floor to spread. Molten material then fills the gap.

Mid-ocean ridge: Magma rises to the surface and creates a bulge.

Mid-ocean rift: The actual break in the sea floor.

Undersea volcanic activity: Lava extrudes into the sea, creating new crust (accretion).

Sea Floor Spreading



Examples: Mid Atlantic Ridge, The Red Sea

2. Continental Spreading (continental rupture): When molten material rises beneath a continent, causing it to split apart. This forms rift valleys on land. Molten material then fills the gap (creating volcanoes).

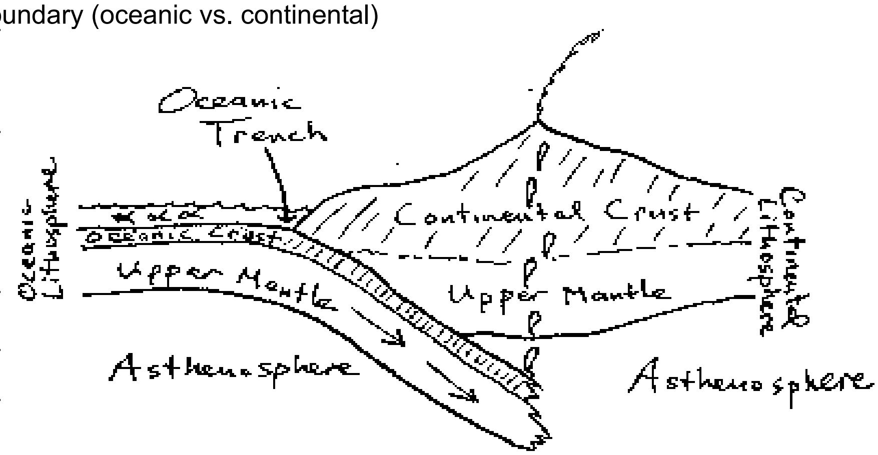
   Examples: East African Rift Valley, Great Basin, North America

B. Convergent Boundaries (forces of compression): Occur where two plates collide.

- Results in <u>orogenesis</u> (the formation of mountains) through volcanic activity or thrusting up of rock.
- Often creates metamorphic rock. Discuss accreted terranes here.
- Three Types

1. Oceanic lithosphere vs. continental lithosphere: Oceanic subducts (dives) beneath continental, creating Volcanic Mountain Arc, and also causing scraping of material onto crust.

Convergent Boundary (oceanic vs. continental)



Example of Volcanic Mountain Arc: Andes (Peru-Chile Trench)

2. Oceanic lithosphere vs. oceanic lithosphere: Oceanic subducts (dives) beneath oceanic, creating Volcanic Island Volcanic Arc.

   Examples of Volcanic Island Arcs: Japan and Marianas Islands
   (Japan and Marianas Trenches)

3. Continental lithosphere vs. lithosphere continental (continental suture): Where continents converge on continents neither will subduct, causing the uplift of a huge mountain chain.

   Example: Himalayas

C. Transform Boundaries (shearing forces): When two plates slide side by side this is referred to as a transform boundary.

   •Example: San Andreas Fault

V. The Proof for Plate Tectonics

A. Biologic Arguments: When related taxa (orders, families, genus, species, etc.) of plants or animals have separated ranges. Since they share the same ancestor, there must be a reason for their separation

B. Extrusion of Magma at the Sea Floor: It was only recently (last ten years) that this was actually observed.

C. Magnetic Reversals:
   •Before lava cools into a solid state, the tiny metallic minerals align themselves like a compass. •By studying volcanic rocks, scientists discovered that the Earth's magnetic field has reversed at irregular intervals (10,000-100,00yrs) in the past.
   •This pattern of reversals was mapped along the ocean floor.
   •The basalt at the rift had the same magnetic pattern as new lavas anywhere in the world.

Volcanic and Tectonic Processes and Landforms
(The Building Processes)
(Christopherson Cha. 9)

I. Introduction and Review

A. Landforms: Features on the surface of the land (mountains, valleys, plains, beaches, etc)

B. Geomorphology: Geomorphology is the study of the history and processes which shape landforms.

C. Exogenic and Endogenic Processes: Endogenic processes are driven from within the Earth (by Earth's internal heat) and exogenic processes are driven by forces at the Earth's surface.

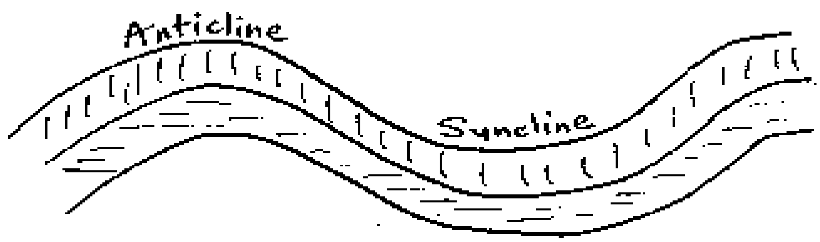
II. Crustal Deformation Processes:

Crustal Deformation Processes: As a result of Plate Tectonics, the lithosphere is under constant stress (compression, extension, shearing stresses). This stress manifests itself in theee main ways

A. Broad Warping: The bending of the crust over a large area. Usually accomplished by isostatic rebound, where the crust rises in response to a weight being lifted from it. This is common when large ice sheets have melted. The crust will actually rebound. This can also be cause by the rising of a large body of magma.

B. Folding (compressional forces): Sedimentary strata, when compressed, will be bent into a series of wave like features. The wave crests are anticlines and the troughs are synclines.

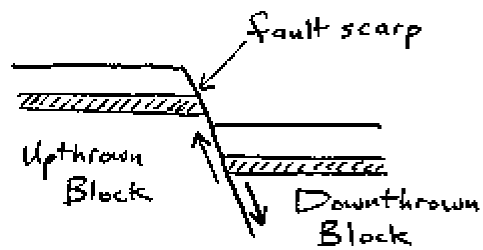
Folding



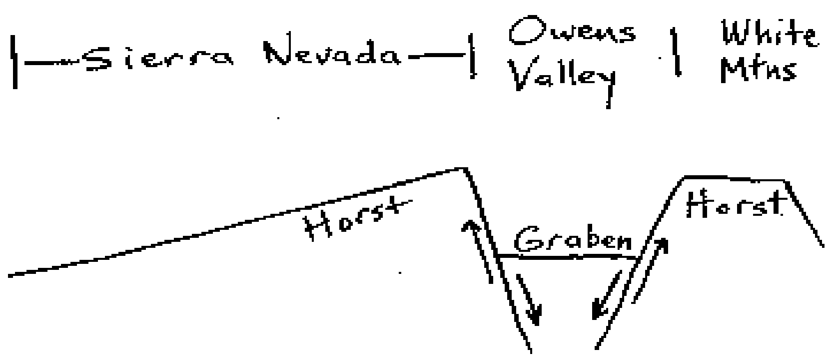
C. Faulting:
•Faults are planar fractures (fault plane) in the Earth's crust along which slippage (earthquake) occurs. They take many forms.
•Found commonly at plate boundaries; but also elsewhere.

i. Normal Fault (tensional forces): Results in vertical movement of land.
   •Fault Scarp is a cliff formed by faulting.

Normal Fault

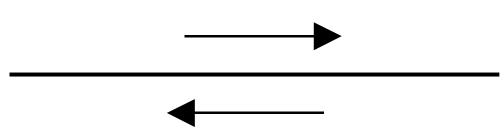


Normal Faults in a Series (Graben and Horst)

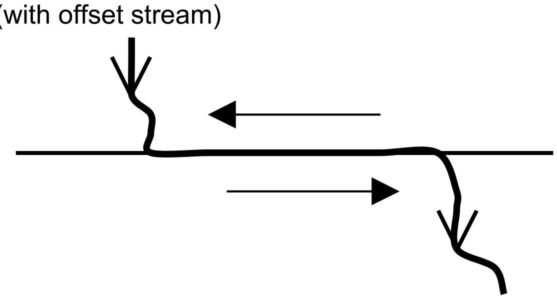


ii. Strike-Slip (shearing forces): Results in side to side horizontal movement. Leaves a fault trace, possibly a slight scarp. Can form an offset stream.

Right Lateral Strike-Slip Fault (topview)

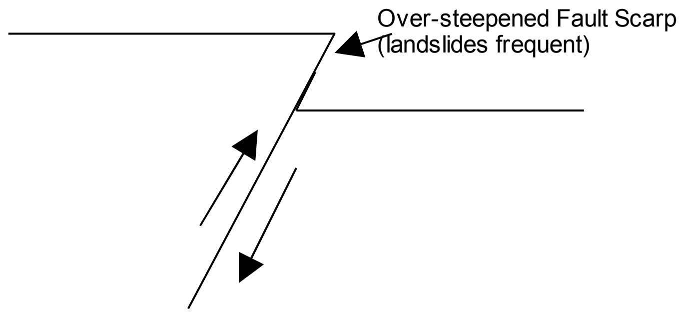


Left Lateral Strike-Slip Fault (topview) (with offset stream)



iii. Reverse Fault (compressional forces): Results in vertical movement of land. Causes oversteepening, and subsequently, landslides.

Reverse Fault



1. A special case of reverse fault is called a thrust fault, usually reserved for very low-angle thrusts such as the Northridge, CA quake. Any type of reverse or thrust fault indicates compressional forces.

III. **Earthquakes:** Sudden slippage along a fault, occur at all types of plate boundaries

A. Elastic Rebound Theory:

1. Helps to explain movement along faults.
2. Fault Lock: Energy stored as stress builds up.
3. Stress exceeds friction, resulting in sudden break at the fault.

B. General Terminology

i. Seismic Waves: Ripples of energy which pass through the crust.

ii. Focus: The subsurface point where the maximum energy is released (ie, where the actual break occurs).

iii. Epicenter: The point on the surface directly above the focus.

C. Measuring Intensity and Magnitude

i. Mercalli Scale (measures intensity): Arbitrary scale (I-XII) which rates damage to terrain and structures.

ii. Seismograph: Measures vibrations caused by an earthquake.

iii. Moment Magnitude Scale: Quantitative scale of the energy released. Represents the updated version of the old Richter Scale.

D. San Andreas Fault: Transform boundary between Pacific and North American Plates.

i. Fault System: Includes many related faults.

ii. Type of Fault: Right Lateral Strike Slip Fault

iii. Evolution: Until about 15-30mya, there was a subduction zone on the west coast of North America. Much of the western United States is made of crust which was "scraped" onto the North American Plate. Eventually, this boundary evolved into a transform type of boundary.

III. Volcanism - Processes and Landforms

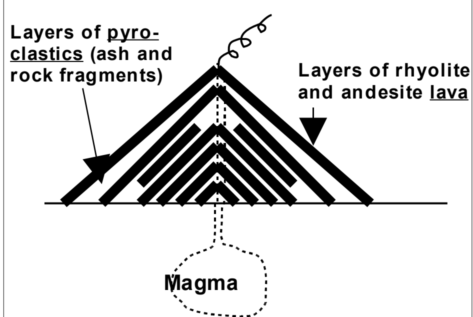
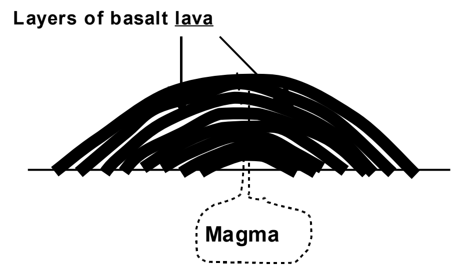
A. Locations of Activity

i. Convergent Plate Boundaries: Where subduction occurs

ii. Divergent Boundaries: Sea Floor spreading centers or continental ruptures.

iii. Hot Spots: Caused by a single stationary mantle plume. See below

B. Two Major Types of Volcanic Eruptions

CHARACTERISTICS	EXPLOSIVE ERUPTIONS: This is just what the name implies. Gasses are trapped by the thick lava. Pressure builds up.	EFFUSIVE ERUPTIONS: This a more gentle, oozing type of erruption. The gasses are able to escape easily through the thin lava.
Type of Volcano	Composite volcano: Steep cone comprised of layers of rhyolitic and andesitic lava.	Shield volcano: Gently sloping cone comprised of layers of basaltic lava.
Sideview of volcano		
Viscosity (Thickness)	high, allows for steep cone to be built	low, results in lava flowing long distances, forms shield shaped (or gently sloping) volcano
Mineral Type	felsic (high in Si)	mafic (high in Mg and Fe)
Rock Types	rhyolite, andesite	basalt
Associated Landforms	Crater or caldera (large depression formed by explosion)	flood basalts (huge areas covered by basalt flows)
Location of Volcanic Activity	convergent boundaries (subduction zones)	(1) Divergent boundaries (sea floor spreading) and (2) hot spots
Examples	Andes, Japan, & Pacific Northwest (Mt. St Helen's, Mt. Hood, Mt. Shasta, etc.)	Iceland (Sea-floor spreading) & Hawaii (Hot Spot)

Focus on Hot Spots:

- Hot spots represent a single point of volcanic activity.
- This is referred to as a "stationary mantle plume"
- This type of activity has helped scientists determine the speed of plate movement.
- As a plate moves across a hot spot, a chain of islands is formed (the Hawaiian Islands is a great example).
- The youngest island is over the current hot spot location, while the older islands have since moved away from the activity.

PROBLEM (see Figure 8.19): How fast (in centimeters per year) is the Pacific Plate moving over the Hawaiian Hotspot? To figure this out, determine the distance from the current hot spot location (in kilometers), to the island of Midway. Since the age of Midway island is about 25 million years, follow this formula to calculate the rate:

[distance from hot spot (km)] x [100,000 cm/km] / [age of island (yrs)] = ? cm/yr

C. Explosive eruptions can also cause...........

1. *nueé ardent* (glowing avalanche): This is a cloud of searing hot acidic gas and ash which travels like a shock wave down slope, burning everything in its path.

2. lahar: Mud and debris flow which results from the rapid melting of ice and snow during an eruption. Composed of volcanic ash, water, mud, and sediment of all sizes.

D. Other Features of Volcanic Activity

1. Geothermal Activity (Hot Springs and Geysers): Ground water seeps into cracks in the earth and comes into contact with hot rock. It then rises under pressure.

2. Cinder Cones: Formed in the rare situation where basaltic lava has a high gas content and is exploded from a small vent. This forms much tephra and builds a small, steep sided cone (less than 450 meters).

E. Special Note: Pacific Ring of Fire… (see maps in text of world-wide volcano distribution)

Weathering and Mass Movement
(Christopherson Cha. 10)

I. Introduction: We have previously looked at the processes which build mountains (orogenisis resulting form the endogenic processes). We will now begin to look at the collective processes which denude or tear down those mountains (through exogenic processes).

A. Two Views of Landform Development

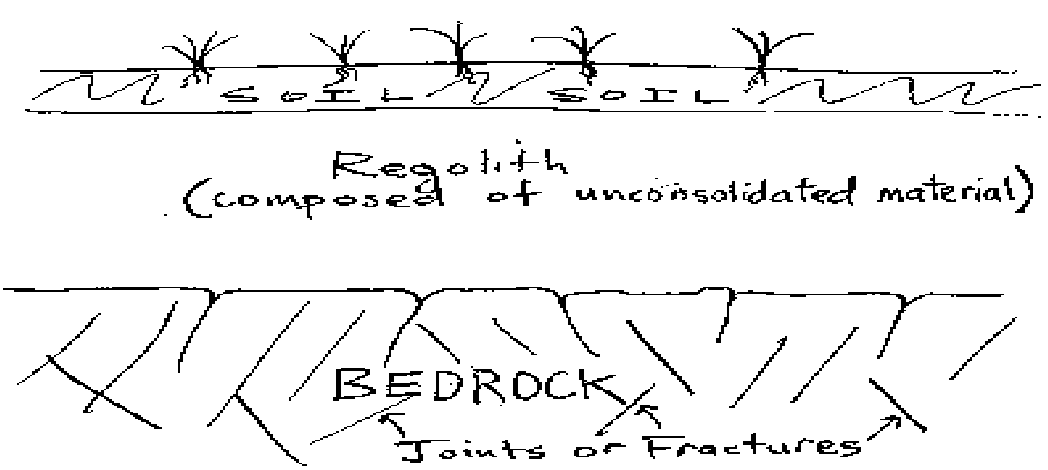
1. Geomorphic Cycle Model (William Morris Davis, 1850-1934): No longer accepted; stated that landscapes initially undergo one major uplift, and are subsequently denuded over time to a flat surface.

2. Dynamic Equilibrium Model: States that the variables that shape landforms are constantly changing. Landforms respond to these changes in a dynamic fashion.

B. Weathering and Mass Movement: This is the beginning of the story of the denudational processes. Weathering is the general term for the combined processes which cause rock to break down at or near the earth's surface. Weathering can either be chemical or physical. Mass Movement is the downslope movement of weathered material under the force of gravity (not carried by wind, water, or ice).

II. Weathering: The outer rocks of the Earth are influenced by the weathering processes. Literally, they are exposed to the weather. The immediate surface is soil (1-2m thick), which is the most highly weathered. The weathered bedrock below is referred to as regolith (literally a mixed pile of dirt, gravel, rocks, etc.). Fractures in the bedrock (joints) are what allow for the increased exposure of the rock to the external elements.

Profile of a Weathered Surface



A. Physical Weathering Processes: The mechanical breakdown of solid rock into smaller pieces. It is important to note that physical and chemical weathering often operate together in complex ways. We separate them for convenience.

1. Frost Action: The expansion of ice as it freezes generates a strong force capable of fracturing and plucking small particles from coarse grained rock. This occurs when water enters pore spaces between the grains and repeatedly freezes and thaws. This can happen on a larger scale as water collects in cracks in the rock. In high mountain environments jagged rocks fractured loose from cliffs collect in piles at the base. These are known as talus slopes.

Frost Action

2. Crystallization (Salt-Crystal Growth): The formation of crystals (salts, other minerals) creates a wedging action in the pore spaces of grainy rock (like sandstone). As the crystal lattice forms, it wedges loose grains. This happens especially in arid environments where water (with salts in solution) flows through rock, often flowing from the sides of cliffs. The water evaporates when it comes into contact with outside air, leaving behind the salts to form crystals. This results in large arches at the base of cliffs.

3. Pressure Release Jointing
   a) Deep rock under pressure: Rock at depth (plutons of granite, metamorphic rock, etc) is slightly compacted under the pressure of the overlying rock.

   b) Roof rock eroded: As the roof rock is eroded away and the underlying rock is uncovered, it expands slightly as the weight is released.

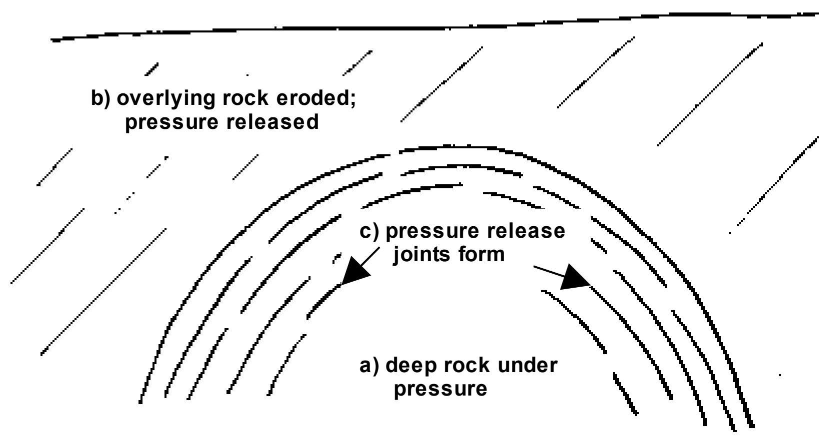
   c) Pressure release joints form: Sheets of rock slip off in a process called sheeting or exfoliation (creates exfoliation domes).

4. Temperature Expansion & Contraction: Expansion and contraction following the daily cycle of temperature

5. Plant Roots: Plant roots grow into cracks and pry apart rocks

6. Hydration: Expansion due to absorption of water

Pressure Release Jointing



B. Chemical Weathering Processes: The chemical alteration of rock minerals through exposure to water and atmosphere. Quartz is the most resistant mineral when it comes to chemical weathering.

1. Oxidation and Hydrolysis: This is the chemical union of oxygen and water, respectively, with minerals to form other more stable minerals. Oxygen, in particular, combines with metallic elements. (Oxidized iron is rust.... $Fe + O_2$ = Iron oxide) This process results in the breakdown of the original rock.

2. Carbonation (creates karst topography): CO_2 and H_2O combine to form a weak concentration of carbonic acid (H_2CO_3), which is capable of dissolving limestone ($CaCO_3$) into solution. Where water runs through joints in limestone, caves can be formed. This can also for karst topography.

3. Organic Acids: Plants can produce acids which also aid in the chemical breakdown of minerals.

C. EXAMPLE-- Spheroidal Weathering: Where rocks have been exposed to the elements for a long time, they begin to take on a rounded (spheroidal) shape. This is because non-rounded rock (uneven surfaces, protrusions, etc) has much more surface area than rounded rock. Increased surface area means increased rates of weathering. Eventually the rock becomes rounded.

II. Mass Movement: The movement of material propelled by gravity.

A. The Slope: Slope refers to a land surface tilted from the horizontal. It is the fundamental unit we are working with. The Earth is comprised of a series of slopes with different degrees of steepness.

1. Angle of Repose: The steepness of a slope where materials (rock, sand, gravel, cobbles, etc) are at rest. Different with different materials. Solid rock would have a steeper angle of repose. Sand would be lower.

2. Driving Force vs. Resisting Force: This is essentially gravity versus the strength (or cohesiveness) of the rocks or material. A slope at the angle of repose indicates that the resisting force balances the driving force.

3. Oversteepening: Oversteepening is any process which makes a slope steeper. Steeper slopes are more susceptible to the force of gravity because there is less supporting

material beneath. This is naturally caused by tectonic uplift. When the driving force wins out, mass movement will occur.

B. Classes of Mass Movement (Figure 10.19)

1. Soil Creep: Slow, downslope movement of soil and regolith. Aided by freeze-thaw cycles. Can tilt trees and human made objects imbedded into the ground. Takes hundreds of years.

2. Flows: High water content (saturated). Includes earthflows (viscous, stays reasonably in tact, but moves in a plastic motion) and mudflows (higher water content and much faster moving than an earthflow).

3. Landslides: Low water content (not saturated). Sudden movement of intact blocks of regolith or bedrock. Can be translational or rotational.

4. Falls and Avalanches: Fastest. Includes rockfall (individual rocks fall and collect in a slope) and debris avalanches (huge mass of falling rock, debris and soil). The sudden sliding of bedrock from steep mountain slopes. Often initiated by earthquakes. Not common, but catastrophic.

C. Scarification (Human Induced Mass Movement): Human activity can result in increased mass movement by oversteepening slopes. This happens with roadbuilding, mining, construction, etc.

D. Rates of Mass Movement: Very sticky question. What is more effective, infrequent catastrophic events, or frequent small events? The story of Anders Rapp:

Karkevagge, Sweden. Late 1950s. 9 year study of mass movement (carpets, stakes, painted lines, repeat photography). Then, 8 inches of rain fell in 3 days. More movement was recorded from this event that in 9 years.

Fluvial Processes and Landforms
(River Systems)
(Christopherson Cha. 11)

I. Introduction: Recall that running water is one of the flowing substances which erode, transport, and deposit earth materials to create terrestrial land forms. The others are ice, wind, and waves. The forces of running water (fluvial processes) are the dominant processes shaping landforms, mainly because they aren't as geographically restricted as the other three. The study of fluvial landforms is termed fluvial geomorphology.

II. Drainage Basin: The area (or areal unit) in which all precipitation drains to a specific point. Also called watershed. All rivers have a drainage basin, which may include many smaller tributaries.

A. Open Systems: Matter (water, sediment, organic material, etc) and energy enter and exit the system.

B. Drainage Density: Length of all stream channels in basin divided by total area of basin.

C. Drainage Pattern: Arrangement of all stream channels in an area. See dendritic, trellis, and radial.

D. Discharge: The volume of water moving past a given point in a given unit if time. Usually measured in cubic feet per second (cfs or ft^3/s).

$Q = wdv$, where Q is discharge, w is width, d is depth, and v is velocity

III. Fluvial Erosion: The process of water dislodging sediment. Water moving down steep slopes has a great deal of kinetic energy to erode earth materials.

A. Categories of Slope Erosion (Overland Flow): This refers to the action of rain water and subsequent overland runoff. The eroded materials include particles of organic matter, clays, silt, sand, and gravel (mostly soil materials).

1. Splash Erosion: A raindrop colliding with bare soil on a slope will dislodge soil particles and deposit them a little way downslope. A large rainstorm can move a great deal of material in this manner.

2. Sheet Erosion: When overland flow removes uniform, thin layers of soil from a slope.

3. Rill Erosion: When overland flow begins to concentrate and cut many small parallel channels into a slope. These may widen and deepen and become gullies.

B. Categories of Stream Erosion (Streamflow): The erosive powers of moving water are highly concentrated and focused in the channel. There are three forms of stream erosion.

1. Hydraulic Action: The dragging force of the water and the materials carried by the water constantly dislodge materials from the stream bed and banks.

2. Abrasion: Abrasion is the physical crushing of bedrock fragments by boulders carried along by the stream. If rock is highly resistant to weathering in general, abrasion is the only effective process.

3. Corrosion: Chemical weathering (dissolving) of rock from the stream channel

IV. **Stream Transportation:** The solid material carried by a stream is the stream load.

A. Types of Load

1. Dissolved Load: Dissolved minerals in solution.

2. Suspended Load: Sediment pulled up into the water column. Most of the stream load is in this form

3. Bed Load: Sediment dragged along the bed (the bottom of the stream).

B. Capacity and Competence: Capacity refers to the total amount of sediment a stream can carry; competence refers to the size of sediment a stream can carry. Capacity and Competence increase with increased velocity and turbulence. High velocity will drag more "stuff" along the bed, and high turbulence will cause the stream to retain more suspended materials.

V. **Stream Deposition:** The term for material deposited by a stream or river is alluvium.

A. Role of Velocity and Turbulence: When velocity and turbulence diminish, bed load and suspended load will come to a rest and be deposited. The stream no longer has the energy to carry this material.

B. Sorting of Materials: Where velocity and turbulence are highest, the largest sized sediment will be deposited. Where velocity and turbulence are lowest, the smallest sized sediment will be deposited.

VI. **Examples of Fluvial Systems**

A. High Gradient (Steep) Stream: After tectonic uplift creates steep slopes, this is the first type of stream to form.

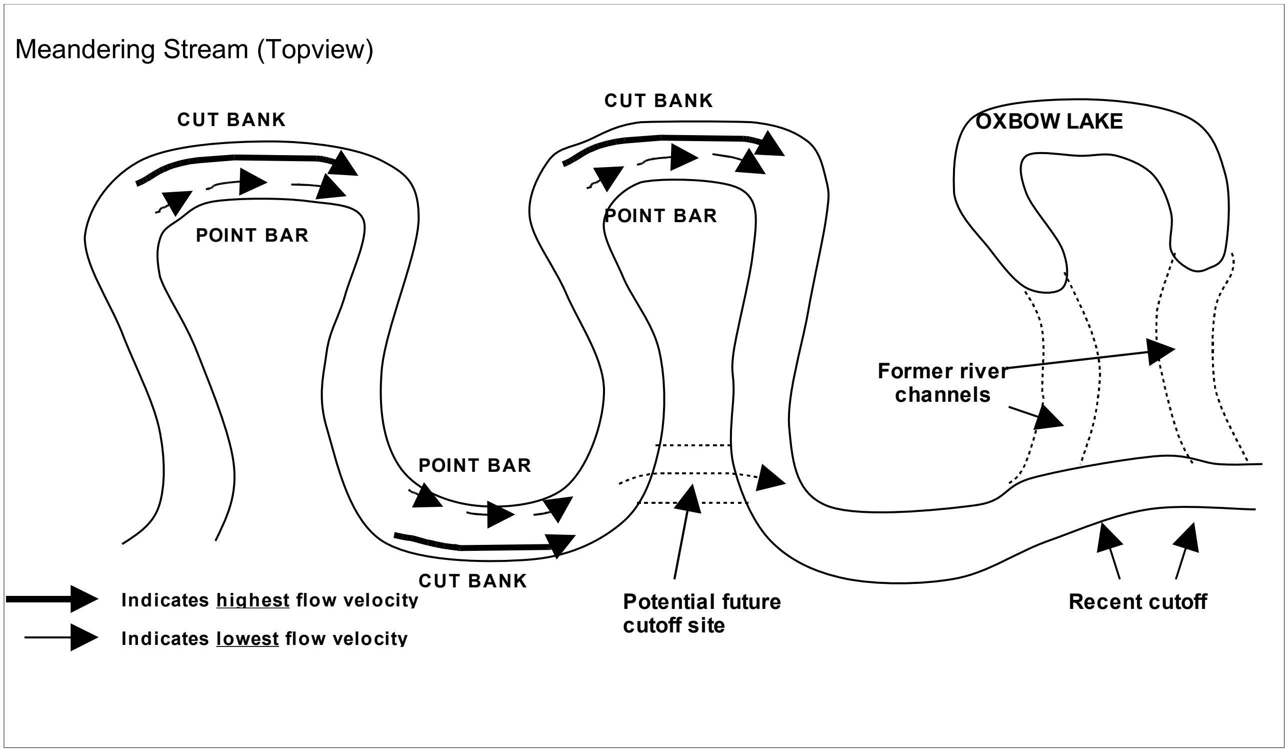
1. V-Shaped Valleys: High gradient streams downcut rapidly, resulting in oversteepening of slopes and a deep V-Shape. Mass movement and slope erosion increase.

2. Nickpoints: This is where the bedrock is resistant to erosion, creating a quick, steep drop (falls and rapids)

B. Meandering Stream Example: Gentle gradient streams will generally only transport and deposit finer materials, such as sand, silt and clay size particles. This creates a meandering stream.

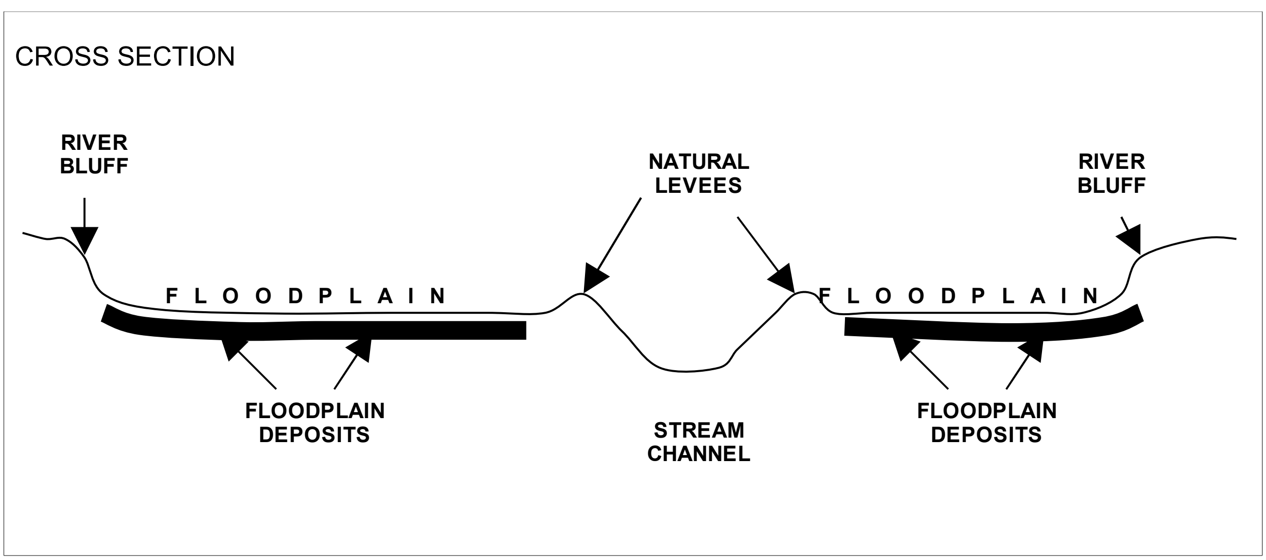
TOPVIEW

1. Alluvial Meanders: One full wave in a meandering stream.
2. Stream Velocity: Maximum velocity is always on the outside of a meander in a meandering stream.
3. Point Bar: Inside of a meander where deposition exceeds erosion.
4. Cutbank: Outside of a meander where erosion exceeds deposition.
5. Cutoff: Point where river jumps its bank creating a shorter course.
6. Oxbow Lake: Old river course created where a meander is cutoff. Also called abandoned meander.



CROSS SECTION

7. Floodplain: Area occupied by water that exits a river channel during a flood.
8. Floodplain deposits: Materials deposited in floodplain during a flood.
9. Natural Levee: Raised area created precisely where river exits its channel during a flood. Happens because this is where turbulence and velocity diminish rapidly.
10. Increased Sediment Load: This can fill a river channel, thus causing it to more easily exit its bank. Caused by natural process (glaciation) or human processes (mining , construction, etc).



C. Braided Stream: Braided streams are formed when a stream carries excess sediment. The sediment is constantly deposited along the stream bed, eventually choking the stream and causing the water to take another path. The process continues.

D. River Deltas: The ability of rivers to transport sediment is ultimately stopped at the ocean. There is usually a massive area of deposition at the ocean. This area is called a delta.

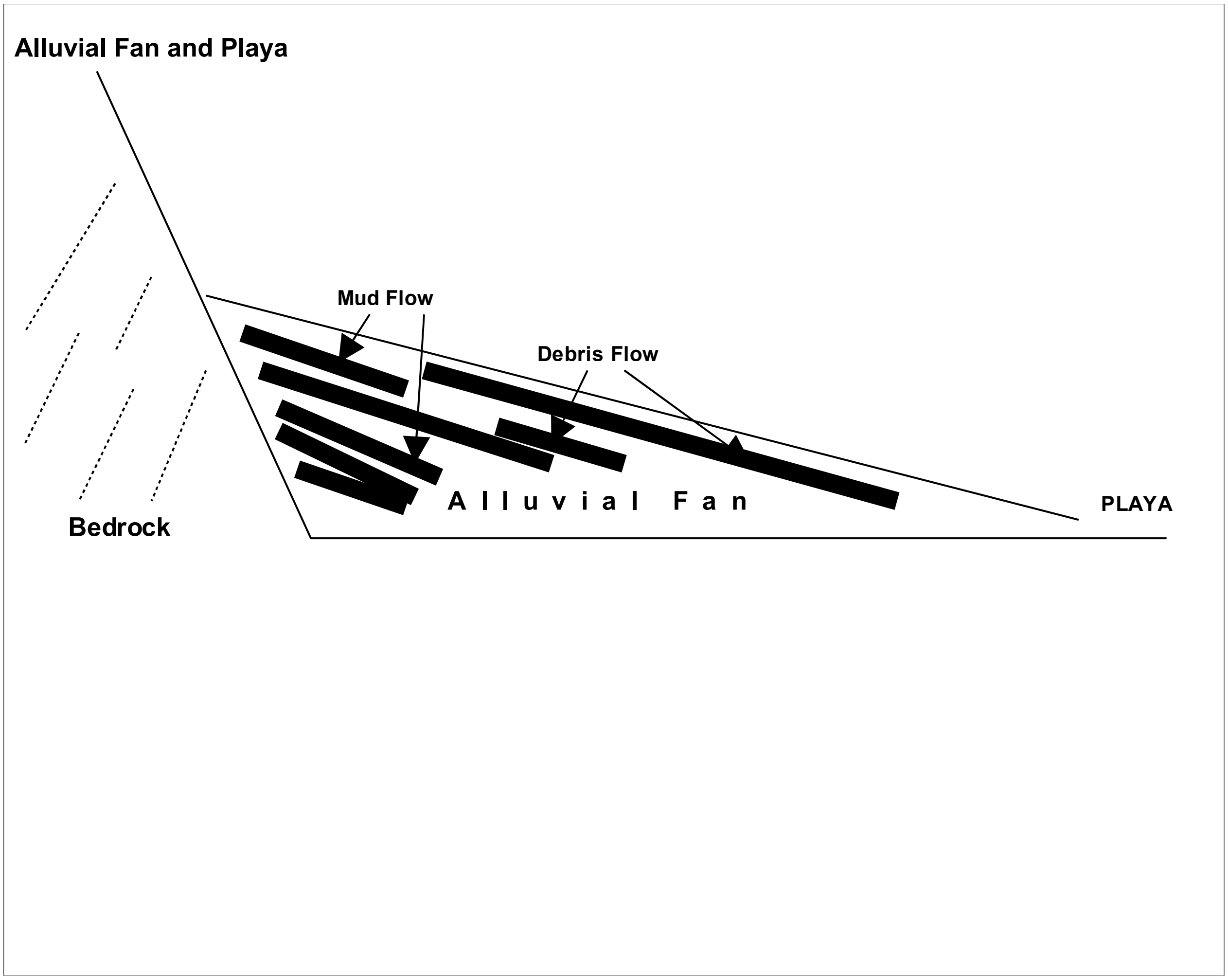
VII. Fluvial Activity in Arid Regions: Desert landforms show significant evidence of being influenced by flowing water, in spite of the fact that there is often little rain.

A. Alluvial Fan: Surfaces in the desert are often (1) hard and impervious (almost baked) and (2)unvegetated. This causes the occasional rains to run swiftly over the surface, unslowed by vegetation. This creates mud flows and debris flows, which empty out of the canyons and fan out onto the valley floors. This forms an alluvial fan.

Notice the flow of ground water in an alluvial fan.

Notice that the coarser materials nearest canyon mouth, finer materials furthest.

B. Playa: Low point (valley floor) in an arid region. This is where water drains, carrying only fine and dissolved sediments. Evaporation dominant, usually salty.



Alluvial Fan and Playa
Mud Flow
Debris Flow
Alluvial Fan
PLAYA
Bedrock

Coastal Processes and Landforms
(Christopherson Cha. 13)

I. Oceans and Tides:

A. Cause: Tides result from the gravitational attraction between the Earth and Moon and the Sun and Moon.

B. Spring Tide (the highest tidal range): Occurs approximately twice a month when the Moon is in a perfect line with the Earth and Sun. With both the Moon and Sun's gravitational pull along the same axis, a large tidal bulge is created. This causes the highest and lowest tides to occur.

C. Neap Tide (the lowest tidal range): Occurs approximately twice a month, when the moon is at a right angle with an imaginary line joining the Earth and Sun. In this case, the Sun and Moon are pulling at right angles, resulting in a cancellation of their forces. The difference between high and low tides is minimal compared to Spring Tides.

D. Tidal Currents: Occurs in bays and estuaries, caused by the rise and fall of water level. The *ebb current* flows seaward (falling tide), while the *flood current* flows landward (rising tide).

1. Can produce high velocity currents in narrow inlets; keeps them from being blocked with sediment.
2. Can carry large suspended load of mud and silt. Eventually forms tidal current deposits, mudflats, and salt marshes.

II. Waves

A. Causes

1. Wind: Most waves are wind-driven. Normally a smooth undulation of the sea surface (in the open ocean), the wavelength rises and the velocity slows when they reach shore (a function of wavelength vs. water depth). The distance over which the wind blows is termed fetch. The longer the fetch, and the faster the winds, the higher the swell (and resulting waves).

2. Volcanic Activity: Eruptions at sea-floor spreading centers and volcanic islands can cause seismic sea-waves (tsunamis).

3. Tectonic Activity: Earthquakes (faulting/uplift, undersea landslides, and related movement) and large turbidity currents/flows can also cause tsunamis.

B. Coastal Geomorphology

1. Erosion

a) Hydraulic Action: The force of the water acting against a solid object. Can exert tons per square inch of pressure (plenty enough to fracture rocks and move large boulders).

b) Abrasion: Movement of sand, rocks, and gravel across the surfaces of headlands, cliffs, rocks, etc. Acts like a big industrial sanding machine continually whacking you about the head and shoulders.

c) Corrosion: Chemical action, dissolution of rocks crystallization of salts in rock pores (similar to salt-crystal growth in arid environments).

d) Pneumatic Action: Abrupt compression and expansion of air in rock as a wave breaks on the shore. This is especially effective on loose shore material (sand, etc).

2. Transport
   a) Longshore Currents: Ocean currents which flow parallel to the shore. They carry sediment along the coast.

   b) Beach Drifting: Beach drifting is the movement of sand along the coast which results from the swash and backwash of waves which hit the coast at an angle.

   c) Littoral Drift: Combination of longshore drift (material transported by a longshore current) and beach drift. Caused by wind/wave angles striking a beach.

3. Deposition The primary depositional forms on a coast are beaches.

   a) In the shallow water, waves of translation capture some sediment from the sea floor. As they approach shoreline, waves slow down, often to a point where they can deposit the sediments. Thus beaches are formed.

   b) Coastal erosion and deposition are very dynamic. When the energy of waves changes, the balance between erosion and deposition also shifts. Normally, beaches grow during quiet weather and retreat (they are eroded) during storms.

   c) Some shores experience long term trend of either accumulation and erosion:

      (i) Progradation - building out of shore (accumulation).
      (ii) Retrogradation - cutting back of a shore (erosion).

4. Coastal Landforms
   a) Beaches: Beaches are depositional landforms made up of sand and larger sediments - gravel, cobblers. Smaller particles (silt, clay) are usually carried in suspension and not deposited.

   b) Cliffs/Benches/Terraces: Coastal erosion eats away coastal cliffs (by notching, undercutting, slope collapse), causing them to retreat. If erosion is strong and prolonged, a broad erosional platform is cut at the base of shore cliffs, called a wave-cut bench. It is a gently sloping bedrock surface slightly below water level. The material wasted from the slope is further eroded and carried away by backwash. It is then often deposited behind a bench to form a wave-built terrace. In time, this terrace may grow so large as to cover the wave-cut bench => a beach is formed.

   c) Barrier islands/Lagoons: Barrier islands are long, narrow and low islands stretching along coastlines. The main cause of their formation is believed to be the breaking of big waves (during storms) in the shallow waters close to the shoreline. A lagoon is an isolated (or almost isolated) body of water, separated from the sea by a barrier island or a sand spit across a bay. Over time, as fine sediments accumulate in a lagoon, it transforms into mudflats, and then, after grasses set in, a marsh.

   d) Coral reefs/Atolls: Coral polyps grow in warm tropical waters. In addition, water has to be shallow (about 50 m or less), since polyp requires sun light for its growth.

      (i) Fringing reefs - coral reef developed on the underwater slope of the volcano.
      (ii) Barrier reef - volcano is slowly destroyed by waves, however reef continues to grow and build itself upward.
      (iii) Atoll - the volcanic island is completely destroyed.

5. Types of Coastlines

a) Submergent Coasts: Coasts that experience rising water. In these cases we have partial drowning of a coast. Two prominent types of submergence coasts are

(i) Ria coast - deeply embayed coast. Long and narrow bays are, in fact, former lower portions of stream valleys, now under water - they are known as estuaries.

(ii) Fiord coast - submerged glacial troughs. Lower parts of U-shape glacial valleys are inundated with seawater forming fiords -steep-walled long and deep inlets.

b) Emergent coasts: Coasts where former submarine landforms are now exposed on land. Among the emergence coasts are

(i) Barrier-island coast – low-lying, gently sloping, young sedimentary deposits, subsequently uplifted. Islands form by wave and wind action from bars and dunes, held together by beach grasses and other vegetation.

(ii) Volcano and lava coast – Volcano coasts usually have low cliffs of lava, and narrow, steep beaches.

(iii) Coral-reef coast – Only new land created by organisms. New colonies are built on top of old ones; pieces of dead coral (calcium carbonate) are eroded to form beaches. Requires water temperatures above 20º C.

(iv) Delta coast - formed by deposition of new material (river sediments) that gets worked by waves and currents. The Mississippi river discharges about 1 million metric tons of sediment per day.

(v) Fault coast - a coastline can be defined by a geologic fault.

Glacial Processes and Landforms
(flowing ice as an agent of erosion)
(Christopherson Cha. 14)

I. Introduction: Glaciers have in the past covered vast areas of the world, especially compared to the present. Glacial activity has been particularly high over the course of the last 1.65 million years. Despite the relative lull at present, glaciers have been responsible for shaping many landscapes we see today.

A. Two Main Types of Glaciers

1. Alpine (high elevation): Alpine glaciers form for the most part in mountainous areas, filling narrow valleys with "rivers" of ice. Orographic precipitation is the primary factor involved in their formation. Starts out as a cirque.

2. Continental (high latitude): Continental Glaciers (or ice sheets) are huge expanses of ice many kilometers across (and thick) which form in cold, polar regions. The only two ice sheets in existence today are Greenland and Antarctica.

B. Formation of Glaciers

1. Annual snowfall must exceed snowmelt: In simple terms, glaciers will form when more snow falls than melts.

2. Snowline: The term snowline is loosely applied to mean that elevation in a mountainous environment above which snow remains through the next year's first snow. It is only above this line that there is the possibility for snow accumulation (and glacial development)

3. Transformation to Ice: When layers of snow accumulate, a slow process begins which ultimately results in the transformation of that snow to ice. This process is one of densification and expulsion of air. When there are no longer air spaces between the ice crystals, the snow has become glacial ice. The transitional term is firn.

II. Glacial Geomorphology: There are many similarities between alpine and continental glaciation; we will focus mostly on alpine as it presents a good model. See continental below.

A. Erosion: Glaciers have amazing erosive powers, not readily noticable. Glacial till is the collective term for any glacier related sediment.

1. Types of Erosion

a) Abrasion: The glacial ice collects gravel, boulders, sand, etc and drags this material along the bedrock surface scraping off rock particles. The very fine material is called glacial flour. This process often leaves scars in the rock called striations.

b) Plucking: This is when the glacial ice freezes to chunks of jointed bedrock and dislodges them. It is difficult to know which one of these two processes is more effective, as they are difficult to observe.

2. Erosional Landforms

c) Cirque (depression left by a cirque glacier)
d) Horn
e) Arete
f) U-shaped valley (also called trough)
 (i) Hanging Valley
 (ii) Fiord (glacial trough filled by sea)
g) Striations (scratches) and glacial polish

B. Transport

1. Mass Balance: A glacial system has inputs and outputs.

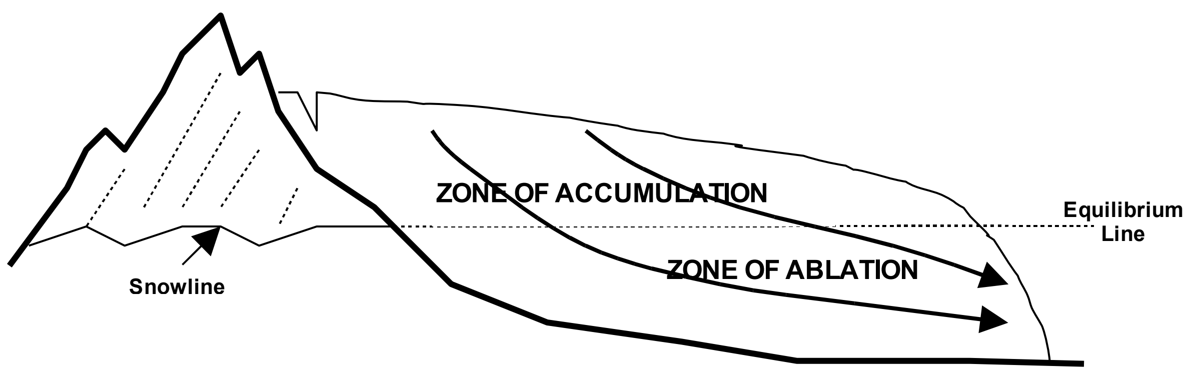
a) Accumulation Zone: The area above the snowline is termed the accumulation zone. Snowfall exceeds snowmelt here.

b) Ablation Zone: The area below the snowline is termed the ablation zone. Snowmelt exceeds snowfall here.

c) Equilibrium Line: The boundary between the ablation zone and the accumulation zone. Snowfall equals snowmelt here. Often called the snowline.

d) Flow: Ice flows from the accumulation zone to the ablation zone. Carries glacial till like a conveyer belt.

Mass Balance of an Alpine Glacier (sideview diagram)



2. Types of Flow

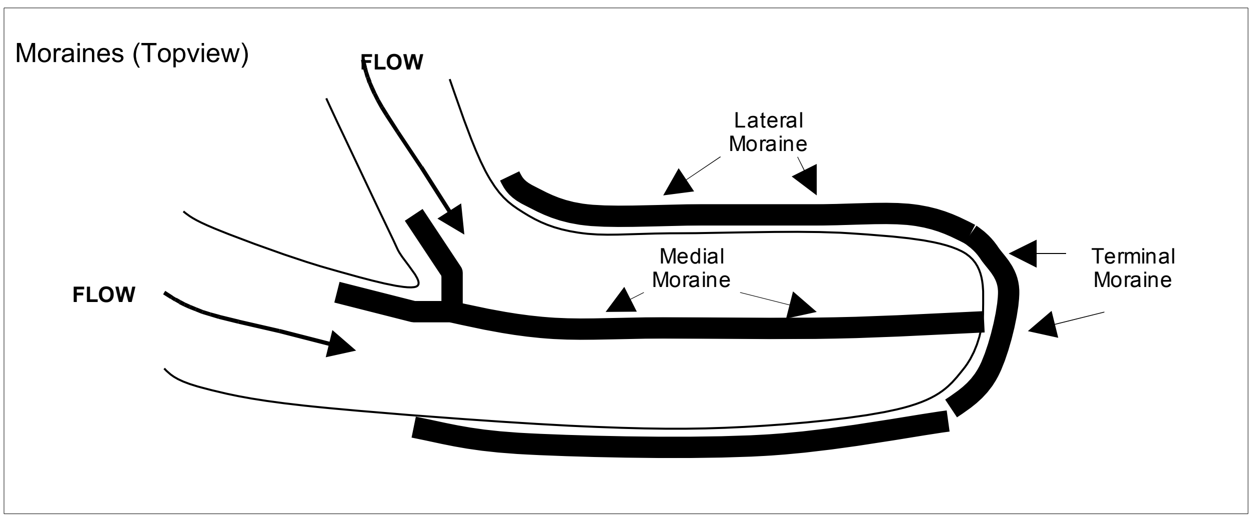
a) Plastic Flow: Under pressure, the ice at depth flows like a plastic.

b) Basal Sliding: Sliding motion where ice meets bedrock, aided by the lubrication of meltwater.

3. Evidence of Flow
    a) Crevasses: Cracks in the glacier where the glacier pulls away from the mountain (bergschrund), where it turns corners, and where it flows down a steep portion (icefalls).
    b) Experimental Evidence: Stakes were pounded in a straight line across glacier (perpendicular to flow). All stakes moved in relation to the stationary points alongside the glacier; the stakes in the middle flowed fastest (friction is least in the center of a glacier.

4. Rate of Flow: (Between a few centimeters to 100m/day)

C. Deposition (and Depositional Landforms): When a glacier melts it drops its load.
1. Moraines: Mounds of deposited glacial till.
    a) Medial: Glacial till transported and deposited down the center of a glacier.
    b) Lateral: Glacial till transported and deposited down the side of a glacier.
    c) Terminal: Glacial till transported and deposited at the end of a glacier.



2. Erratics (or ice rafted boulders): Single large boulders deposited by glaciers. Often look out of place and often are of a different rock type than the local bedrock.

III. Continental Glaciation - Common Landforms

1. Esker: Snakelike ridge deposited by a sub-glacial stream.
2. Drumlin: Deposited till streamlined in the direction of glacial ice movement.
3. Kettle: Depression left behind when a block of glacial ice breaks off and takes many years to melt.
4. Terminal Moraine: The moraine formed at the furthest reaches of the glacier.
5. Recessional Moraine: Like a terminal moraine, formed when the glacier stalls during a retreat.
6. Outwash / Outwash Plain: Masses of materials deposited by meltwater rivers beyond the furthest reaches of a glacier.

IV. Pleistocene: Sometimes called the Ice Age (1.65 million - 10,000 years ago). There have been a series of glaciations during this time. They are referred to as glacials (when glaciers advance) and interglacials (when glaciers retreat). See Figures 17-27 and 17-28.

A. Extent of Glacial Ice: As recently as 15-18, 000 years ago, massive continental ice covered much of N. America from Canada south well into the present day United States. These ice sheets scoured off all regolith, soils, and plants in their path.

B. Sea Level Fluctuations: Continental glaciation has a profound effect on global sea level.

1. Continental Glaciers Increase......... Sea Levels Decrease

2. Continental Glaciers Decrease........ Sea Levels Increase

C. Mechanisms of Climate Change: There are many factors which have contributed to climate change over time. Some are reviewed here

1. Changing Orbital Relations

a) Changing Orbital Shape (100,000 yr cycle)

b) Changing Direction of Tilt (26,000 yr cycle): Called precession.

c) Changing Degree of Tilt (40,000 yr cycle): Tilt, currently at 23.5 deg., varies between 24 deg. And 22 deg.

2. Solar Variability

3. Tectonics

4. Volcanic Activity

5. Human Activity