

Introduction to Geomorphology

I. INTRODUCTION

A. **Geomorphology:** The study of surface landforms, processes and landscape evolution of the Earth.

1. Interdisciplinary Study: cross-over with scientific disciplines of sedimentology, soil science, geography, climatology, hydrology, glaciology, civil engineering and volcanology.
2. Formal Subdisciplines of Study
 - a. Fluvial Geomorphology
 - b. Hillslope Geomorphology
 - c. Glacial Geomorphology
 - d. Tectonic Geomorphology
 - e. Quantitative Geomorph (Civil Engineering)
 - f. Coastal Geomorphology
 - g. Desert Geomorphology
 - h. Biogeomorphology / Landscape Ecology
 - i. karst geomorphology (karst = study of cave processes / hydrology)

B. The Essential Ingredients of Geomorphology

1. Focuses on continental landscapes, landforms, and processes
 - a. Surface processes result in materials and landforms as products
 - b. The landform/material products form a record of Earth surface history
2. Landscape Dynamics
 - a. Tectonic Uplift (continental building) vs. Erosion (continental destruction)
 - (1) E.g. accretionary uplift of Coast Range vs. fluvial erosion / mass wasting
 - b. Surface Deposition vs. Surface Erosion
 - (1) E.g. sediment-filling of Willamette Valley vs. river transport of sediments to Pacific
3. Driving Mechanisms
 - a. Climate / Atmosphere (solar energy)
 - b. Tectonics (geothermal energy)
 - c. Gravity (fundamental / pervasive force in universe)
4. Time-Averaged Processes
 - a. Process Rates: fast vs. slow
 - (1) e.g. catastrophic slope failure vs. rock weathering
 - b. Time-Scaling Factors
 - (1) seconds, minutes, hours, days, weeks
 - (2) years, decades, millenia
 - (3) 10,000 - 1,000,000 's of years

5. System-based Science
 - a. System - collection of components
 - b. system components interact and affect one another
6. Landforms

Class Exercise: let's collectively think of all the different types of landforms that we've seen in Oregon and the processes that form them??.... break into groups and make a list.

C. Classic Perspectives

- a. Father of Modern Geologic Principle: James Hutton (1726-1797) Scottish geologist/physician, "Theory of the Earth"
 - (1) Uniformitarianism: the present is the key to the past,
 - (a) observable surface processes operating today, are assumed to have operated in the past, according to constant laws of nature
- b. Early Geomorphologists
 - (1) Agassiz (1807-1873) French scientist, studied and popularized evidence for ancient glaciations of the Alps
 - (2) T.C. Chamberlin (1843-1928)- Harvard geomorphologist, worked on theories of continental ice sheets in North America, and past glacial advances.
 - (a) T.C. Chamberlin: multiple working hypotheses
 - (3) Westward expansion of U.S. and USGS Land Surveys
 - (a) J.W. Powell, first head of USGS, surveyed landscape and resources of much of the western US
 - i) Noted for expeditions down Colorado River and geological analysis of Grand Canyon stratigraphy
 - ii) First proposed the concept of "Base Level" for streams and rivers: the idea of erosional equilibrium.
 - (b) G.K. Gilbert (1843-1918): worked extensively on geomorphic processes in Utah
 - i) identified ancient pluvial Lake Bonneville
 - ii) discussed faulting/mountain building
 - iii) developed the concepts of "equilibrium"

(4) Modern Luminaries

(a) William Morris Davis (1850-1934)

- i) worked extensively in landscape evolution and river erosion
- ii) "Davisian Cycle" - proposed the concept of landscape erosion cycle: youth, mature, old age, peneplane, and rejuvenation
 - a) Fluvial Example

youth = straight, steep streams

mature = meandering, lower-gradient streams

old age = flat land, very low gradient, oxbow lakes

peneplane = ultimate erosion of land areas into flat planes

(b) Horton / Strahler (1940's - 1950's) - quantitative geomorphology

- i) promoted a shift from landform study to quantitative process study (cross-over with civil engineering)
- ii) numeric quantification of landform characteristics and processes that form them
 - a) Fluvial Example

meandering stream: measured by radius of curvature, meander wavelength

channel geometry: measured by gradient, channel width, discharge

watershed characteristics: measured by drainage area, drainage density, stream ordering

D. Importance of Geomorphology (i.e. applications to gainful employment)

1. Environmental/Engineering

- a. Near Surface Landforms and Hydrogeology (Groundwater) Systems
- b. Landscape stability studies
 - (1) Construction Materials/Materials Engineering
 - (2) Geologic Hazards Analysis
 - (a) Landslide/Hillslope Instability (Construction/Zoning)
 - (b) Flood Control/Planning-Hydrology
 - (c) Shoreline Erosion/Coastal Development
 - (d) Volcano/Historic Eruption Periodicity
 - (e) Seismic Hazard Analysis
- c. Ecologic/Wetlands Studies
- d. Archeological Analysis/Historical Preservation
- e. Environmental Resource Conservation
- f. Watershed/Water Resource Planning
- g. Agriculture: Erosion/Soil Conservation Analysis

II. FUNDAMENTAL PRINCIPLES

- A. Uniformitarianism and Geomorphology: detailed observation of modern surface processes can be used to interpret the origin, evolution and mode of occurrence of landforms.
 - 1. e.g. study of modern glaciers can lead to interpreting the nature and occurrence of ancient glacial systems by examining their products (moraine for e.g.).
- B. Scope of surface geomorphic processes: includes a multitude of physical and chemical processes operating at the earth's surface to influence and modify the landscape.
 - 1. Rock weathering
 - 2. Mass wasting/erosion (gravity-driven)
 - 3. The work of running water (fluvial)
 - 4. Groundwater activity
 - 5. Wind action
 - 6. Glacial Activity/Moving Ice
 - 7. Wave action / Tide Action
 - 8. Tectonic Process
 - a. Volcanism / earthquakes

The rate and magnitude of the geomorphic processes varies, and hence the rate and magnitude of landscape evolution varies spatially

C. Process-Response Models

- 1. Process: action produced as a result of a force of change
- 2. Physical and chemical surface processes operate in such a way as to initiate changes in the landscape.
 - a. If variable X changes in the process system, likewise a proportional change can be expected in the landscape.
- 3. Based on empirical observation, it is possible to quantitatively describe and model process-response relationships on the Earth's surface (cross-over to civil engineering).

D. The concept of Equilibrium Systems

- 1. What is a system? A collection of related objects and the processes relating these objects.
 - a. Isolated system:
 - (1) no energy or matter leaks out of system & none comes in.
 - (a) example - the Universe as a finite entity
 - b. Closed System
 - (1) energy may transfer into and out of the system, but not mass
 - (a) e.g. the Earth as a whole is closed

- c. Open system:
 - (1) matter and energy may flow into and out of the system freely
 - (a) most geomorphic systems are open
 - i) energy and mass transfer functions
 - (2) steady state System
 - (a) (special type of open system) balance between input and out flow.... INPUT + OUTPUT

Class Exercise in Systems.

Identify the following as isolated, open, or closed systems. Once you've identified them, cite your ideas / evidence as to why you answered the way you did.

- (1) an open beaker of water on the lab bench
- (2) a covered beaker of water on the lab bench
- (3) this class room
- (4) the stretch of Willamette River adjacent to Independence
- (5) the ocean
- (6) the atmosphere you are breathing

Can you think of a steady state geologic system? List your ideas.

Is the Earth as a whole, truly a closed system as stated in the notes above? State your reasoning.

- 2. **Equilibrium System:** process-response balance between opposing forces such that any change in any of the controlling variables (independent variables) will necessitate a corresponding response in the dependent variables to maintain overall system equilibrium.
- 3. The elements of the landscape adjust to changes in the process, forming a cause and effect relationship to maintain static equilibrium.
- 4. Many Geomorphic systems are viewed as equilibrium systems
 - a. e.g. River systems: if a river is shifted out of equilibrium by increased sediment load, the river will adjust its geometry to carry the load relative to processes of erosion, transpiration and deposition.
 - (1) G.K. Gilbert and Graded Stream Concept: Streams and rivers display an equilibrium state in that the velocity of the water is in equilibrium with the channel gradient.

- (a) Coarse debris in stream requires greater velocity by river, deposition of the coarse debris will increase the gradient to the point at which velocity will $>$, and the coarse debris is transported downstream
 - (b) Opposite relation: if velocity of stream is greater than that required for the load, the stream will erode its channel, reducing gradient, $<$ velocity to the point of balance with the sediment load.
- b. **Dynamic Equilibrium:** Hack (1960's) - elements of the landscape rapidly adjust form in response to changes in the processes operating on them.
- (1) continual change-response-adjustment
 - (2) short time-scale adjustments

****Dynamic Equilibrium contrasts with the traditional "Davisian" model of landscape evolution - Davis suggested that the landscape constantly evolves towards the ultimate equilibrium state of the peneplane over very long periods of time (millions of years)****

Thus... Hack says that the landscape is in constant adjustment and subsequent equilibrium, whereas Davis says that the landscape is out of equilibrium for very long periods, driving towards the "peneplane"

E. Driving Force vs. Resistive Framework

1. Driving Forces

- a. Force = (mass)(acceleration); expressed as a vector with magnitude and direction
- b. Energy: capacity to do work
 - (1) Kinetic Energy: energy of motion
 - (2) Potential Energy: energy of position
 - (3) Heat / Thermal Energy - molecular kinetic energy
- c. Work = Fs ; where F = Force and s = distance
 - (1) force is applied to a mass, work occurs when the mass is displaced
 - (2) e.g. Geomorphic Work
 - (a) transport of sediment / rock material
 - (b) alteration of landforms on significant time scale
- d. Driving Force: Application of energy in the context of performing work on earth materials (e.g. hydraulic force + particles = erosion)
- e. Driving Forces in Geomorphic Systems: **Climate, Gravity, Internal Heat/Tectonics**

(1) **Climate** (Exogenic Force: from without)- average weather conditions at any place over a long period of time.

(a) Climate and the sun

i) Driven by solar energy of sun, i.e heat

a) Solar Energy Source = hydrogen fusion

ii) solar insolation variable around planet depending upon geometry and latitudinal position (highest at equatorial belt, lowest at poles)

iii) Solar energy transferred as heat in atmospheric/oceanic systems of the earth-----climate systems driven by the heat transfer of these systems (i.e. atmospheric and oceanic circulation patterns)

(b) Climate largely driven by heat transfer of sun's energy about atmosphere and ocean waters

(c) Climate as a 1st order controlling factor, influences:

i) rainfall/solar insolation of area

ii) vegetative growth

iii) style of weathering/erosion process

iv) hydrologic processes (fluvial, glacial)

(2) **Gravity as a controlling factor**

(a) Force of attraction between the earth's center of mass and surface materials (sediment, soil, water) drives landscape evolution

(b) $F = mg = \text{"weight"}$ where m = mass of object, g = acceleration due to gravity

i) g = acceleration of a falling object (e.g. sediment) due to gravitational force F , assumed to be constant at $980 \text{ cm/sec}^2 = 9.8 \text{ m/sec}^2$

(c) Gravity obviously influences surface water flow, mass wasting/hillslope movement processes, serving as a driving force

i) Driving force for flowing water and ice

ii) Driving force for density-driven currents

a) e.g. air flow / weather

b) ocean currents

c) convection in mantle / tectonics

(3) **Internal Heat of the Earth (i.e. Tectonics)**

- (a) Internal Heat of Earth: supplied primarily by:
 - i) radioactive decay with exothermic heat loss
 - ii) frictional heat by earth tides and internal rock deformation

- (b) How do we know the inside of the Earth is hot?
 - i) volcanic eruptions
 - ii) seismology
 - iii) deep mines / wells

- (c) Internal Heat Transfer
 - i) Mantle convection: physical movement of rock material as a heat transporting medium
 - a) hot, deeper mantle rises as it is of < density
 - b) cooler, shallower mantle sinks as it is of > density

- (d) Internal heat transfer of the earth thought to be the driving mechanism of plate tectonics and plate motion
 - i) oceanic spreading centers/volcanism
 - ii) plate subduction and volcanic arcs
 - iii) plate collision and rock uplift/deformation/mountain building

Class Exercise - Convection

Convection is the process of heat transfer by transfer of mass. Convection is an important process in the atmosphere, oceans, and interior of the Earth. Create your own convection system by using a heating element and a fish tank. Place the heating element in the fish tank full of water. Place a light in front of the tank and shine it through the water, onto the projector screen. Turn on the light and heating element, and answer the questions below:

(1) What water circulation patterns do you observe on the screen? Draw a sketch of what you see.

(2) Explain the process of convection in terms of:

(A) How is the heat being transferred from the heating element to the tank of water?

(B) Why is the water circulating the way it is? Answer in terms of heating, volume change, and density contrast (remember that density = mass/volume).

(3) List 1 example each of how convection influences geomorphic systems in terms of atmospheric process, ocean process, and plate tectonic process.

2. Resisting Framework (that which the force is acting upon to create landscape)

a. Geology of Land Area

(1) Lithology: rock types

(a) various rock types have variable resistance to erosion depending on mineralogy and chemistry and the climatic/weathering regime

(b) Igneous, Metamorphic, Sedimentary

i) Resistant vs. Non Resistant Rocks

a) e.g. sandstone vs. shale

(2) Rock Structure

(a) Folded rocks

(b) Faults, Fractures, Joints

i) Preferred zones of erosional weakness

(c) Mountain Belts/Uplifted Rock Areas

- (3) Rock Structure generally forms zones of weakness upon which other surface processes can act to carve the landscape

F. Thresholds and Complex Response

1. **Threshold Concept:**

- a. Within an equilibrium system, an equal state of disequilibrium also exists
 - (1) results from severe imbalance within the system
 - (2) system undergoes period of disequilibrium prior to re-establishment of equilibrium conditions

- b. Geomorphic Thresholds: represent the limits of equilibrium or critical limits, as processes extend beyond thresholds, disequilibrium or response occurs.
 - (1) E.g. as thresholds for hillslope water moisture are exceeded, the system may respond in the form of slope failure or landslide.
 - (a) implies a critical threshold of moisture content beyond which slopes will fail

- c. Extrinsic (external) vs. Intrinsic (internal) Thresholds
 - (1) e.g. Extrinsic -
 - (a) meteorite impact,
 - (b) storm/rainfall event - flood discharge
 - (2) e.g. Intrinsic -
 - (a) roof collapse of a cave / sinkhole
 - (b) channel cutoff of a meander loop

SIMPLE THRESHOLD EXPERIMENT:

Determine the slope-angle threshold at which the following materials will begin moving under the influence of gravity

(1) On a board, systematically place the following materials:

- (a) a puddle of water
- (b) a small pile of sand
- (c) a rock sample (a block of rock)

(2) For each of the materials, elevate one side of the board until the material starts moving. Record the critical angle at which the materials move in the table below

Material	Critical Angle	Is there motion when slope is less than critical?	Is there motion when slope is greater than critical?
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Puddle of
Water

Pile of
Sand

Block of
Rock

Which materials are more sensitive to gravity-driven motion? Why?

Which materials are less sensitive to gravity-driven motion? Why?

On the Earth's surface, list mechanical (geological) methods by which the angle of slope could be increased, like in your experiment

G. Time/Evolution/Rates of Change

1. Landscape Evolution: concept of progressive change of landforms in response to surface processes operating over a period of time.
 - a. Landforms/landscapes will display characteristic features at successive stages of development.
 - (1) Provides an avenue for relative dating of landforms on the basis of developmental stage
 - (a) If rates of process/change are known, ages of landforms and landscapes can be determined through deductive reasoning

In-Class Exercise: Hypothetical Example of a Geomorphic Rate Problem

The High Cascades of Oregon are spectacular mountains comprised of active volcanoes. Volcanic mountains in this area are created by repetitive eruptions of lava and tephra, that build up on the landscape. The average relief between High Cascade volcanic peaks and the older western Cascades is about 7000 ft (in a ball-park kind of way). For the sake of argument, let's assume that the average thickness of an individual eruptive deposit is 20 feet. And that the average High Cascade volcano erupts once every 1500 years. Calculate the following:

- (A) What is the average rate of volcanic mountain growth in feet / yr?
 - (B) What is the average rate of volcanic mountain growth in feet / 1000 years?
 - (C) What is the average rate of volcanic mountain growth in meters / 1000 years?
 - (D) How many years has it taken for the average High Cascade volcano to build its "edifice" above the older western Cascades?
 - (E) In that we've only considered volcanic processes building up the Cascade landscape, consider all of the other surface processes that are operating to erode (i.e. lower) the High Cascades. Make a list with a brief discussion.
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2. Time is an essential ingredient in any geologic process
 - a. In terms of geomorphic process, variable levels of time are required for desired products of change
 - (1) e.g. time scale variation between slow steady-state soil creep vs. instantaneous slope failure

3. Cyclicity and Time

- a. Geologic processes are by nature cyclic and repetitive over time.
- b. Geologic cyclicity readily evident in geomorphic systems
 - (1) e.g. Flood cyclicity of river basins

H. Constructional vs. Destructional Processes

1. **Constructional Landforms:** those land units that have been or are being built (i.e. increasing in mass, height, or area)
 - a. Constructional Landforms created by mass redistribution
 - b. Examples
 - (1) Tectonic
 - (a) Volcanic Accumulation/Mountain Building (Orogeny)
 - i) Cascades = volcanic
 - ii) Coast Range = accretion
 - (b) Fold/Fault Block Mountains (Orogeny)
 - i) Steens Mountain
 - (c) Isostatic Uplift of Land areas
 - (2) Depositional
 - (a) Loess regions (e.g. Palouse / SE Washington)
 - (b) Dune fields
 - (c) Glacial Terrain
2. **Destructive and/or Erosionally-Derived Landforms:** those landforms that are derived by weathering and erosion (destruction)
 - a. Includes erosion of rock material and deposition of sediment
 - b. Examples
 - (1) Glacial scouring / valleys (e.g. Yosemite Valley)
 - (2) Fluvial erosion / valleys (e.g. Grand Canyon)
 - (3) Coastal cliffs

III. Exogenic vs. Endogenic Processes

A. Mass Balance: Exogenic vs. Endogenic Processes

1. Exogenic Processes: destructive geomorphic processes that originate at or above the earth's surface
 - a. Weathering-erosion-denudation processes
 - (1) e.g. Chemical/Physical Rock Weathering
 - (2) e.g. Rilling/Gullying/Fluvial Erosion
 - (3) e.g. Glacial scouring/erosion
 - b. Theoretically: if exogenic processes were to operate on a landscape, unimpeded by opposing forces, there would be a tendency to reduce the landscape to a relatively flat, featureless surface with few topographic irregularities ("Peneplanation" concept)
 - (1) "Base Level" = theoretical surface of erosional equilibrium at which, the land surface will no longer be eroded.
 - (a) Ultimate baselevel: Sea level, theoretical end point of continental erosion.
 - c. Climate is an exogenic process that fluctuates and upsets geomorphic equilibrium in the landscape.
2. Endogenic Processes: internal processes within the earth that result in uplift and rejuvenation of the landscape
 - a. e.g. Tectonic Mountain Building Processes
 - (1) Rock Folding, Faulting, Uplift
 - (2) Epeirogeny
 - b. Volcanism
 - c. Endogenic Processes result in an influx of lithospheric mass and energy, rejuvenating the landscape and tipping geomorphic equilibrium out of balance

B. Endogenic Effects

1. Diastrophism or Tectonism: Collective processes that deform the earth's crust
 - a. Epeirogeny: regional uplift or depression of the earth's crust over large areas with little internal deformation of original rock structure (broad, regional, gentle uplift)
 - b. Orogeny: relatively intense deformation of the crust to form structural mountains (folded, faulted, uplifted terrane).

- c. Isostasy: principle based on density contrasts within the crust of the earth. Less dense rock material (e.g. granitic continental rocks) will tend to ride at a higher elevation compared to more dense rock material (e.g. basaltic oceanic rocks).
- (1) The driving force of isostasy is gravity, which is responsive to a heterogenous distribution of rock density.
 - (2) Isostatic Equilibrium: Masses of crustal rock of a given density will adjust themselves relative to the earth's gravitational field, density and loading.
 - (a) As loads are removed from the crust (e.g. melt of ice sheets or denudation via erosion), the upper mantle should adjust in combination with the over-riding crust, resulting in net "bouyant" uplift of the crustal surface
 - (b) As loads are added to the crust (e.g. glacial ice advance, or sediment accumulation in a basin), the upper mantle should adjust in combination with the over-riding crust, resulting in net depression or subsidence of the crustal surface.
 - (c) Much of the isostatic compensation is likely taken up by the asthenosphere or "plastic" upper mantle between 60 and 200 km depth beneath the earth's surface.
 - (d) Rates of isostatic rebound decay exponentially as the crust gets closer to equilibrium/stasis. Conversely, rates of isostatic rebound are high initially as crustal disruption occurs
 - (3) Isostasy intimately related to epeirogenic movements of the earth's crust on a regional scale

Class Exercise on Isostasy

Build a simple model of the Earth's crust and upper mantle (i.e. a lithospheric plate).

Materials needed: -6" x 4" x 2" blocks of styrofoam (a crustal plate)
 -a tank or tray of water (analogous to the upper mantle or asthenosphere)
 -a handful of pebbles, gravel, or other rock pieces

(1) Float the lithospheric plate (the block of styrofoam) in water. Note the relative position of the water line on the side of the "boat".

(2) Load the lithospheric plate with several pebbles, carefully balancing them so the "boat" does not topple.

What happens to the Earth's crust when it is loaded with large volumes of sediment, ice, or tectonic blocks of rock? ... record your observations and analogies here...

(3) Incrementally erode your crustal plate by taking 1 pebble off the "boat" at a time.

Make a sequence of sketches and record your observations as to what happens to the Earth's crust as it is unloaded by erosion. Record them here....

(4) Provide a brief summary discussion regarding surface erosion, tectonic motion of the crust, and isostatic adjustment.

(5) Comment on how realistic it is to apply the "Davisian" peneplane concept to mountain ranges, i.e. is it very realistic to think that a mountain range could be eroded to a "peneplane". Explain your answer in terms of erosion and isostatic adjustment.

2. Uplift of earth's crust: creates potential energy that available for conversion to kinetic energy via exogenic geomorphic systems
 - a. In Comparison: Rates of crustal uplift are much higher than those of crustal denudation (a much slower process)
 - (1) E.g. calculations of vertical displacement rates based on dated events:
 - (a) Surface Subsidence Rates Range to -1200 cm/1000 yr
 - (b) Surface Uplift Rates Range up to +2400 cm/1000 yr (uplift).
 - (2) Range of calculated denudation rates (based on river sediments)
 - (a) Range 1 cm/1000 yr - 14 cm/1000 yr
 - (b) Average ~ 3-4 cm /1000 yr
 - i) High: Asia: 14 cm / 1000 yr

C. Mass Balance: Endogenic vs. Exogenic Processes

1. Thus exists a balance between crustal uplift (endogenic) and crustal denudation (exogenic) in the form of "dynamic equilibrium"
2. If rates of uplift far exceed rates of denudation, equilibrium threshold will be crossed and the geomorphic/landscape system will be thrown into disequilibrium
3. e.g. climatic conditions could be such to trigger extensive erosion and denudation of the landscape, resulting in "de-loading" of the crust, thus promoting regional epeirogenic uplift.
4. Equilibrium System: based on principles of mass balance and mass distribution
 - a. uplift: addition of mass to crustal region
 - b. denudation: redistribution of mass out of region

IV. GEOMORPHOLOGY AND THE QUATERNARY PERIOD

A. Quaternary Period: Upper portion of the Cenozoic Era

1. Quaternary divided into (1.6 Ma-Present):
 - a. Pleistocene Epoch(1.6 Ma-10,000 Yr. B.P.)
 - b. Holocene Epoch (10,000 Yr B.P.-Present)

Ma = Mega "ans" = Millions of Years; B.P. = Before Present

2. We live in the (late) Holocene Epoch of the Quaternary Period

B. Quaternary Strata: Characteristics and Significance

1. Relatively recent sedimentary and volcanic strata
2. Amenable to absolute dating techniques (C-14, radiometric dating)
3. Period known for its association with dramatic climatic fluctuations

- a. Glacial (cold and wet) vs. Interglacial (warm) climate fluctuations
 - (1) Over 22 significant glacial advances now recognized in North America over past 2 Ma.
- b. Climatic record of Quaternary being used to develop quantitative climatic models from which climatologists attempt to predict future climatic trends
 - (1) Greenhouse effect/global warming
- 4. Excellent record of marine micro-fossils and evidence for sea-level fluctuations
 - a. Global "eustatic" changes of sea level in conjunction with advance and retreat of continental ice sheets
 - (1) Glacial Climate = Low Sea Level (100-140 m below present)
 - (2) Interglacial Climate = High Sea Level (up to 20 m above present)
 - (a) present sea level = high stand
- 5. Excellent terrestrial pollen record / paleoclimate
- 6. Quaternary record forms host medium for archeological fossils, ancient civilizations, and mammal evolution of the recent past
 - a. Early man and ape-like ancestors
 - (1) Hominid artifacts date back 2.5 m.y. to Pliocene
 - (2) Evidence for modern Homo Sapiens dates to at least 400,000 years
 - (a) Homo Sapiens in North America dates to latter half of Wisconsin Ice Age (10,000-20,000 years B.P.)
- 7. Quaternary record provides framework to analyze periodicity of earthquake activity in seismic/tectonic zones
- 8. Many Quaternary-Recent sequences form the geologic framework for environmental contamination problems
 - a. E.g. River valley alluvium as aquifers and contaminant systems