INTRODUCTORY PHYSICAL GEOLOGY
LECTURE OUTLINES
P.F. HUDAK

INTRODUCTION

- geology: scientific study of earth
- scientific method:
  - observe
  - make hypothesis (tentative explanation)
  - test hypothesis
  - theory (well tested, widely accepted view best explains observable facts)
- earth:
  - composition (rocks and minerals)
  - processes
    - uniformitarianism (Hutton)
    - 4.6 billion years old
- plate tectonics most important theory
  - outer shell (lithosphere) broken into 20 mobile plates (7 major)
  - convection, gravity drive plates
- rock cycle: processes that form and destroy rocks
  - igneous
  - sedimentary
  - metamorphic

MINERALS

- rock = aggregate of minerals
- mineral = naturally occurring, inorganic solid w/ orderly internal structure, definite chemical comp.
- ex: sandstone often includes quartz (SiO_2) and K-feldspar ($KA1Si_3O_8$), among other minerals

- atoms neutral or electrically charged (ions)

- ions or atoms that make up minerals held together by chemical bonds, which may be strong or weak

- 2 major types of bonds in minerals:

  - ionic: formed by electrical attraction between ions of opposite charge (ex: Na^{+1} and Cl^{-1} in halite)

  - covalent: share electrons (ex: diamond = C)

Physical Properties

- used to identify minerals

1. crystal form: shape of mineral crystal

2. hardness: resistance to abrasion or scratching, Moh's Scale

3. cleavage: planes of weakness along which some minerals break

4. fracture: appearance of broken surface (not cleavage planes)

   - conchoidal

   - splintery

5. luster: appearance of light reflected from surface of mineral, metallic vs. nonmetallic

6. color: may vary due to impurities

7. streak: color in powdered form

8. specific gravity: weight of mineral divided by weight of equal volume of water

9. reaction with HCl

Common Mineral Groups

- more than 4,000 known minerals

- approx. 20 common, rock-forming minerals

- 8 elements make up 98.5% of crust (oxygen, silicon, aluminum, iron, calcium, sodium, potassium, magnesium)

1. silicates

   - most common

   - silicon-oxygen tetrahedron: complex ion w/ net charge -4, SiO_4^{-4}

a. ferromagnesian (dark) silicates: contain iron or magnesium

- dark color, specific gravity 3.2-3.6
- ex: olivine, pyroxene (augite), amphibole (hornblende), biotite

b. non-ferromagnesian (light) silicates: don't contain iron or magnesium

- light color, specific gravity 2.7
- ex: feldspar (most plentiful), muscovite, quartz (second most plentiful), clay (shrink-swell causes $3 billion/y damage in US)

2. carbonates: carbonate ion, $C0_3^{-2}$

- ex: calcite ($CaCO_3$)

3. oxides: oxygen with other element, usually metal

- ex: hematite (Fe_2O_3)

4. sulfides: sulfur with metallic element

- ex: pyrite (FeS_2), galena (PbS)

5. sulfates: sulfate ion, SO_4^{-2}

- ex: gypsum ($CaSO_4 \cdot 2H_2O$)

6. halides: F^{-1}, Br^{-1}, Cl^{-1}, or I^{-1}

- ex: halite (NaCl)
- fluorite = CaF_2

7. native elements: Au, Cu, S, C, Ag

IGNEOUS ROCKS

- prevalent in earth's crust, mantle
- form when magma cools and solidifies
- intrusive (magma) or extrusive (lava)
- texture and composition basis of classification

Texture

- size, arrangement of mineral crystals

1. aphanitic: tiny crystals, rapid cooling near surface

2. vesicular: voids (vesicles) left by escaping gases, gaseous eruption

3. phaneritic: lrg. crystals, slow cooling at depth

4. pegmatitic: very lrg. crystals, > 1 cm, formed by water-enhanced crystallization around margins of magma bodies

5. porphyritic: lrg. crystals (phenocrysts) in matrix (groundmass) of small crystals, varied cooling (slow, then fast)

6. glassy: extremely rapid cooling, not enough time for crystals to form

7. pyroclastic: ash, rock fragments ejected during violent eruption

<u>Mineral Composition</u>

- silicates

- Bowen's Reaction Series (BRS) (starting w/ magma of avg. comp.)

  - early forming minerals react with remaining melt, forming new minerals, from approx. 1200 ^oC to 700 ^oC:

    - olivine, pyroxene, amphibole, biotite, K-feldspar, muscovite, quartz

    - Ca-feldspar continually transitions to Na-feldspar

<u>Igneous Rock Names</u>

intrusive:	granite	diorite	gabbro
extrusive:	rhyolite	andesite	basalt
composition:	felsic	intermediate	mafic

- felsic: rich in silica (ex: 70%), low temperature minerals in BRS

- intermediate: interm. in silica (ex: 60%), mid temperature minerals in BRS

- mafic: poor in silica (ex: 50%), high temperature minerals in BRS

<u>Origin of Magma</u>

- melt crust and underlying mantle (most)

- divergent, convergent settings

  - granite approx. 750 ^oC

  - basalt approx. 1000 ^oC

- parent may yield different compositions: crystal settling, partial melting, crustal assimilation

VOLCANOES

- danger to humans, effect on climate, extinctions, outgassing
- mountainous accumulation of material fm by successive eruptions from a vent
- chamber, vent, crater, parasitic cone, fumarole
- gases: H_2O (major constituent), CO_2, N_2, $C1_2$, H_2, SO_2, Ar

Volcanic Deposits

- magma floats up from asthenosphere, enters shallow chamber, pressure builds
- may empty onto surface as molten lava, or violently eject spray of solidified fragments called pyroclasts
- temperature, composition, gas content dictate eruptive style

1. lava flows
   a. basaltic lava: 1000-1200 ^{o}C, low silica, fluid
      - pahoehoe: ropey, most common
      - aa: blocky, slow (rubble)
      - pillow: under water

   b. rhyolitic lava: 800-1000 ^{o}C, high silica, viscous, explosive

   c. andesitic lava: in between (a) and (b)
2. pyroclastic deposits
   - volatile gas released with explosive force, shattering lava and overlying rock into fragments (pyroclasts)
   - nuee ardente: avalanche of hot ash, rock fragments, gases ejected in glowing cloud rolling downhill, speeds up to 200 km/hr
      - ex: Mt. Pelee, Martinique, 1902, St. Pierre, ~30,000 killed

Major Types of Volcanoes

1. shield

- broad (ex: diam. 100 km), domed structures formed by extrusion of fluid lava
- built primarily of basaltic lava flows
  - ex: Hawaiian volcanoes

2. cinder cone
   - variable composition
   - built from ejected lava fragments
   - steep, small, < 300 m high
   - often form as parasitic cones on/near larger volcanoes
3. composite cones (stratovolcanoes)
   - tall, conical (ex: diam. 10 km)
   - built by alternating layers of lava flow and pyroclastic material
   - magma has andesitic or rhyolitic composition
   - potentially violent
   - ex: St. Helens (1980), Pelee (1902), Vesuvius (79)

Other Volcanic Landforms

1. caldera (craters > 1 km diam.)
   - summit collapses into partially emptied magma chamber
2. fissure/plateau
   - low viscosity, basalt, may cover > 100 km
3. volcanic dome
   - bulbous mass rhyolitic lava accumulates around vent
   - often form in assoc. with pre-existing composite cones, after gaseous eruption
4. volcanic neck
   - igneous rocks crystallize in vent, differential erosion
     - ex: Ship Rock (NM), Devil's Tower (WY)

5. volcanic pipe

   - deep conduit feeds volc.

   - diamonds

Forms of Intrusive Igneous Rock Bodies

- studied only after uplift and erosion

1. dike: discordant mass forms when magma intrudes fracture, tabular shape

2. sill: concordant, tabular body forms when magma seeps between layers, fluid magma, shallow depths

3. laccolith: magma seeps between layers, dome-shaped, viscous (sluggish)

4. batholith: largest intrusive body, massive, commonly granitic, cores mountain systems

Global Distribution of Volcanism

1. divergent margins (greatest volume)

   - basaltic magma, fissure eruptions

2. convergent margins (subduction zones)

   - most common

   - variable comp.

3. intraplate

   - variable comp.

   - conical structures or flood basalts

SEDIMENTARY ROCKS

- 75% of rocks exposed on continents

1. detrital

   - composed of solid particles (sediment) derived from weathering

2. chemical

   - precipitation of dissolved substances

   - organic if organisms extract dissolved substances

- inorganic if organisms not involved (ex: evaporation)

Characteristics of Detrital Rocks

1. texture: size, shape, sorting of grains that make up the rock
   a. particle size -> energy in environment of deposition
   b. shape: degree of rounding -> distance or time involved in transport of particles
   c. sorting: similarity in particle size -> transport agent
      - wind is good sorting agent, only carries few sizes
      - water is moderate sorting agent, variations in current velocity segregate sediment according to size
      - glaciers are poor sorting agents, carry all sizes
2. mineral composition: substantial weathering and long transport lead to destruction of less stable minerals
   - quartz, hematite stable
3. color -> environment of deposition
   - red -> oxygen (land or shallow water)
   - black -> organic matter -> lack decay -> lack oxygen -> ocean, deep water

Detrital Rock Types

- shale
- sandstone
- conglomerate

Chemical Rock Types

- coal: organic
- limestone: inorganic, organic
- dolostone: inorganic, organic
- chert (flint): inorganic, organic
- rock gypsum: inorganic
- rock salt: inorganic

Lithification

- compaction, cementation
- calcite, silica, iron oxide common cements

Sedimentary Environments

- terrestrial (continent), transitional (shoreline), marine
  - ex terrestrial: lake, flood plain, river, swamp, dune
  - ex transitional: lagoon, beach, delta
  - ex marine: shelf, deep water
    - oil/gas

Sedimentary Structures

- form during or after deposition, before lithification
- provide clues to environment of deposition

a. cross bedding: layers deposited at angle to horizontal (ex: sand dunes, river deltas)

b. graded bedding: particles within single layer change from coarse at bottom to fine at top

c. ripple marks: small waves of sand develop on surface of sediment layer by action of moving water or air

   - asymmetrical -> current in 1 dir.
   - symmetrical (oscillation) -> current in both dir.

d. mud cracks: alternate wetting and drying

   - shallow lakes, desert basins, tidal flats

METAMORPHIC ROCKS

- transformation of pre-existing rocks by elevated pressure, temperature, hot and chemically active fluids
- pressure and heat that drive metamorphism are consequences of internal heat of earth, weight of overlying rocks, pressures at plate boundaries
- temperatures: 200-800 ^{o}C
- pressures: 5000-40,000 atm

Changes During Metamorphism

1. mineralogical (chemical)
   - existing minerals and ions in water recombine to form new minerals

- ex: limestone with quartz sand: $CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$

- water = medium for ion transfer

2. textural: re-alignment of mineral grains (foliation)

Principle Settings

1. convergent boundaries (regional meta.), along convergent margins

   - most common

2. near mass magma (contact meta.)

   - zone of alteration (aureole) forms in host rock around magma

3. along fault zones (cataclastic meta.)

   - rock broken and distorted as crustal blocks on opposite sides grind past one another

4. at mid-ocean ridges (hydrothermal meta.)

   - seawater percolates through fractures in basalt at ridge flanks, incr. temp. causes chem. reactions between seawater and rock

5. sedimentary basins (burial meta.)

   - heat and pressure exerted by overlying sediments

Common Metamorphic Rocks

1. foliated (from low to high grade): slate, phyllite, schist, gneiss

2. non foliated: marble, quartzite

WEATHERING AND SOILS

- weathering: disintegration and decomposition of rock at or near earth's surface

Mechanical Weathering

- disintegration into smaller pieces, each retaining chem. characteristics of original material

1. frost wedging (water freezes, expands, exerts outward force)

2. minerals crystallizing from solutions in cracks (calcite, gypsum, halite)

3. thermal expansion (heating causes expansion, cooling causes contraction)

   - ex: heat from fire

4. expansion from unloading (igneous bodies exposed by erosion, reduction in pressure causes exfoliation)

5. biological activity

Chemical Weathering

- chem. transformation of rock into one or more new compounds

- water is key agent

1. hydrolysis (hydration)

   - H_2O dissociates to H^+ and OH^-

   - H^+ attacks and replaces other positive ion in crystal lattice

   - ex: hydrolysis of feldspar produces kaolinite (H^+ replaces K^+)

2. dissolution

   - water is polar molecule, dissolves certain minerals (ex: halite)

   - most minerals insoluble in pure water, but small amount acid increases corrosive force (ex: carbonic acid produced when carbon dioxide in atmosphere dissolves in rain)

3. oxidation

   - rusting: oxygen combines w/ iron to form iron oxide

   - decomposes ferromagnesian silicate minerals

   - water required to release iron via dissolution, which then combines w/ oxygen from atmosphere

Factors That Control Type, Rate of Weathering

1. rock type (ex: basalt vs. granite)

2. climate

   - warm, moist favors chemical weathering

3. topography

   - influences amt rock exposed to forces weathering (irregular topography more exposed)

  - determines amount precip.

  - determines amount, type vegetation

Soil

- loose mantle on rock or sediment, formed by weathering

- rely upon for food, building

- combination of mineral and organic matter (humus), water, air

Factors Controlling Soil Formation

1. climate

  - influences type, rate of weathering

  - hot, wet: thick layer chemically weathered soil

  - cold, dry: thin layer mechanically weathered soil

2. parent material

  - bedrock or unconsolidated sediment

  - residual soils form on bedrock

  - transported soils form on unconsolidated sediment

  - affects soil fertility, stability

3. time

  - average 1000s y for soil to form

4. plants, animals

  - furnish organic matter to soil which releases nutrients

  - decaying organic matter forms organic acids which hasten weathering

  - organic matter has good water retention

  - worms mix soil, aiding in passage of water and air

5. slope

  - influences amt. erosion and water content

  - steep slope = poorly developed soil

Soil Profile

- 5 basic horizons (layers): O,A,E,B,C (top to btm.)

  - O: organic matter (humus), biological activity
  - A: mineral matter
  - E: leaching, eluviation
  - B: zone accumulation, of material removed from E (possible hard pan)
  - C: partially altered rock debris

- wide variety types (12 soil orders, > 19,000 series)

  - much water: soluble material such as $CaCO_3$ leached from soil; less soluble iron oxides and clays accum. in B horizon; forests

    - leaching may form mineral ore (ex: bauxite)

  - little water: calcium carbonate (caliche) accum. in B horizon; less clay because less chem. weathering; grassland

Soil Erosion

- natural process

- accelerated by human actions such as farming, logging, construction, that remove vegetation, also causes sediment pollution

MASS WASTING

- downslope movement of rock or soil under influence of gravity

Controls

1. gravity
2. slope steepness
3. slope material (unconsol. soil vs. consol. bedrock)
4. water: destroys cohesion among particles
5. vegetation: binding, weight
6. earthquakes

Classification

1. rock

   a. rockfall

   b. rockslide

      - especially when sloping strata or fractures parallel sloping land surface

   c. rock avalanche

- flow composed or large mass of rocky material moving at high velocity, trap cushion of air, speeds over 100 mi/hr
- ex: Peru, 1970, 20,000 killed

2. unconsolidated

   a. creep: gradual downhill movement of soil

      - aided by freeze/thaw

   b. earth flow: vegetated mass of soil oozes downhill

      - humid climates

   c. debris/mudflow: rapidly flowing masses of mud, soil, rock, water

      - arid climates, volcanoes (lahar)

   d. slump: mass slides along curved surface

Prevention

- active or passive measures
- active: rockbolts, retaining walls, steel or wooden piles, fluid removal, ground cover, grading, mass removal
- passive: divert water, land use planning

RUNNING WATER

- stream (river) channel vs. floodplain
- rivers provide benefits, cause problems (flooding)

Hydrologic Cycle

- continuous circulation of earth's water supply, between reservoirs, powered by sun
- earth's water: 97.2% in oceans, 2.2% in glaciers and polar ice, 0.6% in lakes, rivers, and groundwater, 0.001% in atm.
- key processes: precipitation, evaporation, transpiration, infiltration, runoff, groundwater flow, sublimation

Stream Flow

- water flow is laminar or turbulent
- laminar: slow moving, smooth channel, particles flow in "straight" paths parallel to channel, little mixing

- turbulent: high velocity, irregular channel, chaotic flow, high mixing, most common in streams

Stream Loads

- suspended: all material in suspension
- bed: material carried along bottom
- dissolved

Velocity

- determines ability to erode and transport materials
- as velocity increases, suspended load and bed load increase
- faster at outside of meander (bend)
- velocity determined by gradient (slope), shape, roughness of channel
  - gradient: velocity incr. as gradient incr.
  - channel shape: determines frictional drag, wide and shallow is inefficient, semicircular is efficient
  - channel roughness: smooth channel = efficient flow

Measuring Velocity

- floating object or flow meter

Stream Discharge (Q)

- discharge: velocity times cross-sectional area
  - avg. Q Mississippi = 46 million gal/sec
  - avg. Q Amazon = 460 million gal/sec (15% of all)

Effects of Urbanization

- increases magnitude of flooding
- decreases lag time between rain and flood
- increases frequency of flooding
- engineers try to mitigate flooding with channelization, levees, dams

Changing Base Level

- base level = elevation at which stream enters larger body of water

- rising base level -> deposition

- falling base level -> downcutting (erosion)

Drainage Networks

1. dendritic: most common, underlying rocks flat

2. rectangular: right angle bends, joints and faults

3. radial: domes, volcanoes

4. trellis: alternating bands resistant and less resistant rocks

GROUNDWATER

- 50% of Texas supply, 40% of US

Occurrence of Groundwater

- water table separates saturated, vadose (aerated) zones
    - subdued replica of land surface
- groundwater in saturated zone
- groundwater can supply streams (gaining streams) or be fed by streams (losing streams)

Aquifers

- aquifers transmit useful quantities groundwater
    - ex: sand/gravel, sandstone, limestone, fractured rock
- aquicludes restrict groundwater movement
    - ex: clay, shale, granite
- confined vs. unconfined aquifers

Flow of Groundwater

- generally from high to low water table elevations
- recharge vs. discharge areas
- typically moves (seeps) slowly, less than 10 m/y, in some cases faster
- large, interconnected pores favor more rapid flow, fastest in underground caverns

- naturally emerges at springs, geysers

Problems Associated With Pumping Groundwater

- causes cone of depression in water table

1. supply well contamination
2. subsidence
3. saltwater intrusion
4. rising energy costs

Other Groundwater Problems

1. sinkholes

2. contamination

   - ex pollution sources: septic systems, sewage effluent, landfills, underground fuel storage tanks, holding ponds (lagoons), oilfield brine

GLACIERS

- thick mass of ice, originates on land from accumulation, compaction of snow, shows evidence of movement

- cover 10% earth's land area

Types

1. valley glacier (alpine)

   - follow mountain valleys, V -> U

2. continental (ice sheets)

   - flow out in all directions

Glacial Budget

- gains, losses of ice

- zones accumulation, ablation (wastage), snowline

Glacial Movement

- slow, typically few cm/d

- two flow mechanisms

   1. plastic flow within ice, below about 50 m

2. basal slip: entire ice mass slips along ground due to meltwater within glacier

- frictional drag, flows faster in middle

- crevasses at top, as ice arches over bedrock

Glacial Erosion

1. plucking

2. abrasion

Glacial Deposits

- 2 distinct types:

   1. till: deposited directly by glacier, poorly sorted, "erratics"

   2. stratified drift (outwash): sand, gravel laid down by glacial meltwater, well sorted

Effects of Advancing Ice Sheets During Pleistocene Glaciation

- Pleistocene Epoch 10,000 y ago to 2 million y ago, multiple glacial advances, w/ warmer intervals in between

   1. drop in sea level (estimated 130 m), Bering Land Bridge

   2. massive erosion, deposition

   3. depression of land surface (ice 3 km thick)

   4. change routes of rivers

- advances caused by changing climate (Milankovitch: variations in earth's orbit)

DESERTS

- dry

- common in subtropics and mid latitudes

   - subtropical realm due to descending air

   - mid lat. realm due to large land masses, rainshadow, isolation

Geological Processes in Deserts

1. wind transport

   - bedload (sand)

- suspended load (silt)

2. wind erosion

   - deflation: lifting and erosion of loose material results in lowering of land surface, desert pavement (veneer coarser particles)

   - abrasion: cutting and polishing exposed rock surfaces (ventifacts)

   - sculpting: yardangs

3. wind deposition

   - sand deposits (dunes) from bedload, wind shadow effect

   - silt blankets from suspended load

4. mechanical weathering, little chemical

5. flash floods, water erosion

Desert Landforms

1. dunes

2. alluvial fans

3. bajada

4. intermittent streams

5. playa lakes

Desertification

- expansion of desert-like conditions into surrounding areas

   - plowing, clearing vegetation, livestock

SHORELINES

- waves provide most of energy that shapes and modifies shorelines

Zones Near Shoreline

- surf zone: region of breaking waves

- swash zone: sloping front of beach, uprush and downrush of water

Key Processes

1. wave refraction

- bending of waves
- causes greatest erosion at headlands

2. longshore drift
   - net transport parallel to shoreline
   - in surf zone and swash zone

Sources of Sand

- rivers are major source
- some derived locally: corals, cliffs

Shoreline Features

- erosional
  1. sea arch: caves on opposite sides of headland unite
  2. sea stack: arch collapses
  3. wave-cut cliffs
- depositional
  1. spits: elongate ridges of sand projecting from land into mouth of adjacent bay, baymouth bar if crosses bay
  2. barrier islands: low ridges of sand parallel to coast, offshore
     - over 300 from Mass. to Texas (ex: S. Padre)
     - formed by truncated spit or rising sea level inundating beach ridge
     - susceptible to hurricanes, ex: Galveston, 1900, 7,000 deaths, worst natural disaster in US history

Erosion Prevention

1. groin: linear structure perpendicular to shoreline, used to maintain or widen beaches losing sand
2. jetty: pair of linear structures perpendicular to shoreline, used to keep entrance to rivers open
3. breakwater: linear structure parallel to shoreline, used to protect ships, property
4. seawall: behind beach

5. beach nourishment

   - muddy sand = coral kills

Sea Level is Rising

- about 3 mm/y
- related to natural melting of polar ice, made worse by global warming
- flatter land more susceptible

OCEAN FLOOR

- profile determined by echo sounder
   - D = vt/2
   - v = 1500 m/s
- 3 major topographic units
   - continental margin
   - ocean basin floor
   - mid-ocean ridge

1. continental margins

   a. passive

      - shelf, slope, rise
         - shelf: flooded extension of continent
         - slope: approx. boundary between continental and oceanic crust, submarine canyons, turbidite deposits
         - rise: gradual descent to deep ocean

   b. active

      - little or no shelf, steep slope, no rise

2. ocean basin floor

   - flat abyssal plains
   - steep volcanic peaks (seamounts)
      - many form near ocean ridges, erode, sink
      - called guyots if planed

- atolls

- ocean trenches: long narrow, fm deepest parts of ocean (up to 10 km deep), sites where moving plates destroyed as plunge into mantle

3. mid-ocean ridges

   - elevated, extensive faulting, volcanic structures

   - worldwide, spreading rates 2-17 cm/y

   - Pacific fast, Atlantic slow

Sea Floor Sediment

1. terrigeneous: mineral grains weathered from continental rocks and transported to ocean, sand near shore and mud further out

2. biogeneous: shells, skeletons of marine organisms

   - calcareous ooze

   - siliceous ooze

3. hydrogeneous: sediment w/ minerals that crystallize directly from water

   - ex: limestone, gypsum, halite

EARTHQUAKES AND EARTH'S INTERIOR

- earthquake: vibration of earth's surface caused by rapid energy release

- usually occurs when rocks being deformed suddenly break along a fault

- elastic rebound

- pulses of energy (seismic waves) radiate in all directions from focus

   - focus: pt. at which slip initiates

   - epicenter: projection of focus to surface

- most, not all, along plate boundaries

- foci 5 km - 700 km, 90% < 100 km, larger magnitudes at shallower depths

Seismic Waves

1. surface

2. body

   a. P (primary): compressional, oscillate in direction of wave transmission, through solids and liquids, fastest

   b. S (secondary): shear, oscillate at right angles to direction of wave transmission, not through liquids, slower

<u>Locating the Epicenter</u>

- use differences in arrival times between first P and S waves
- need at least 3 stations
- homework assignment

<u>Earthquake Intensity</u>

- effects of quake at particular location, depends on:
  - strength of earthquake
  - distance from epicenter
  - population
  - geology (rocks and soil)
  - building materials
- Mercalli Intensity Scale

<u>Earthquake Magnitude</u>

- strength (amt. energy released)
- Richter Scale (logarithmic)
  - measures maximum amplitude of ground shaking recorded on seismic record (seismogram), adjusted for distance
  - one unit increase = 10 times the ground shaking and 32 times the energy
  - approx. 8.9 largest ever recorded, Chile (1960), 100,000 times the power of an atomic bomb
- Moment magnitude for large earthquakes, based on amount of displacement, area of rupture surface, strength of rock ruptured (approx. 9.6 largest, Chile, 1960)

Earthquake Destruction

1. seismic vibrations (pipes, wells, roads, buildings, houses, dams)

2. tsunamis: seismic sea wave, to 30 m

   - ex: Indian Ocean, 2004; 280,000+ deaths; M 9.0; lack pressure-sensing buoys like Pacific; waves to 10 m

3. fires: severed gas, electrical lines

4. landslides, subsidence

Earthquake Control

- use fluids

- controversial

Earth's Interior

- deepest drill hole only about 17 km deep

- knowledge from seismic waves generated by earthquakes, nuclear explosions

- measure travel times of seismic waves, depends on rocks traversed

   - shadow zones (no arrivals)

   - ex: S wave shadow zone -> liquid outer core

- internal structure:

   1. crust

      - continental: 35 km, density = 2.8 g/cc, "granitic"

      - oceanic: 5 km, density = 3.0 g/cc, "basaltic"

      - Moho = base of crust (denser rocks beneath)

   2. mantle

      - 2900 km thick

      - > 80% earth's volume

      - density 3.3 to 5.5 g/cc

      - peridotite (olivine, pyroxene)

      - diamonds

- rocky, but flows

3. outer core
   - 2300 km thick
   - liquid, metallic
   - iron, nickel, others
   - 11 g/cc

4. inner core
   - radius 1200 km
   - solid (based on P waves speeding up)
   - iron, nickel
   - density = 13 g/cc at center

PLATE TECTONICS

- theory that outer, rigid lithosphere composed of several mobile plates overlying asthenosphere

- lithosphere about 100 km thick, includes crust and upper mantle, overlies plastic asthenosphere

- comprehensive theory developed in 1960s

- precursor idea (continental drift) in early 1900s by Wegener, supported by:

  1. fit of continents
  2. fossil similarities on separated land masses
  3. rock type and structural similarities
  4. glacial deposits on land currently near equator
  5. limestone on land currently at high latitude

- later evidence:

  - ocean drilling: age basalt and sediment directly above basalt incr. away from ridge

  - oldest oceanic crust 170 million y vs. 4.0 billion y continental crust -> oceanic crust destroyed at subduction zones

  - earthquake patterns, Wadati-Benioff zones

  - hot spots, age patterns

Plate Boundaries

1. convergent
2. divergent
3. transform

Driving Mechanism

1. convection: flow of rock in mantle

   - layered or whole mantle

2. slab/pull

3. ridge push

4. slab suction

MOUNTAIN BUILDING

- elevated belt produced by deformation of earth's crust

Deformation

- change in volume or shape of rock body

- caused by stress, force/area

   1. compressive: squeeze and shorten rock body

   2. tensional: stretch and elongate rock body

   3. shear: sliding motion

Deformational Environments

1. sedimentary basins: compaction

2. plate margins

   a. divergent: tensional

   b. convergent: compressional

   c. transform: shear

Types of Deformation

1. brittle: fracture, low pressures and temperatures, near surface

2. ductile: plastic, flowing, high pressures and temperatures, deep

Deformational Features

1. folds: wavelike undulations, generally caused by compression
   a. anticlines: upfolds (arches)
   b. synclines: downfolds (troughs)
2. joints: fractures w/ out displacement
3. faults: fractures w/ displacement
   a. dip slip (vertical motion)
      - normal (extension)
      - reverse (compression)
   b. strike slip (horizontal motion), shear

Mountain Types

1. fault block
   - tensional stress
   - uplifting, elongation, breaking
   - ex: SW US, E Africa
2. domes
   - broad arching, batholith may arch overlying strata
   - ex: Black Hills, SD
3. folded (belts)
   - most common
   - convergent settings
      a. oceanic-oceanic (ex: Japan, Aleutian Islands)
         - accretionary wedge, volcanic islands
      b. oceanic-continental (ex: west coast South America, NW US)
         - accretionary wedge, volcanic mountains on land
      c. continental-continental (ex: Himalayas)
         - subduction precedes continental collision

4. (hot spot) volcanic mountains

GEOLOGIC TIME

1. relative: establish sequence of events

2. absolute: establish age

Principles of Relative Geologic Time

1. original horizontality: layers of sediment initially horizontal

2. superposition: in undeformed sequence, sedimentary rocks progressively younger in upward direction

3. unconformities: breaks in rock record, surfaces of erosion or non-deposition that modify (occur after) underlying rock

4. cross-cutting relationships: feature (fault, igneous intrusion) that cuts a rock is younger

5. inclusions: pieces contained in larger rock are older

Absolute (Radiometric) Dating

- employs radioactive isotopes (isotopes: atoms of the same element having different atomic masses)
    - ex: K-39, K-40 (radioactive), K-41 (all atomic number 19)
- parent decays to daughter
    - half life is amount of time for 50% of parent to decay into daughter
    - decay curve: percent parent remaining vs. time
- approach: collect fresh rock sample, determine percent parent remaining from parent/daughter ratio (using mass spectrometer), use decay curve to estimate age
    - ex: 1P/3D -> 25% parent
- after 10 half lives elapse, not enough parent -> parent-daughter pairs with short half lives not useful for dating old samples (and vice versa)
- assumptions
    1. half life constant (exponential decay)
    2. no daughter present when sample formed
    3. closed system