

GS106 - Introduction to Oceanography and the Seafloor

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I. Introduction

- A. Significance of the Oceans / Oceanography / Oceanographic Exploration
 - 1. 71% of Earth Covered by Oceans!!!
 - 2. Oceans = important source of life in terms of evolution and geohistory
 - 3. Expanding Human Horizons
 - a. Boats + Oceans = travel / mobility
 - 4. Global Exploration / Mapping
 - 5. Expanding Resources / Economic Trade
 - 6. Migration of Human Populations
 - a. Most of the Worlds Population Lives near water / oceans
 - 7. Oceans = important source of food, resources, and rich ecological habitats
 - 8. Scientific Exploration and Research

- B. Significant Events in the History of Oceanography / Oceanographic Exploration
 - 1. 10,000-12,000 years ago: Early Settlement of the Americas: By Land or Sea?
 - 2. 100-2000 BC - Greeks, Romans and Phoenicians sailing the Mediterranean
 - 3. ~1000 AD - Norse Vikings in north Atlantic (Greenland and Newfoundland)
 - 4. 1400-1600 - Spanish Exploration and Conquest of New World via Atlantic
 - 5. 1700-1800's Ocean Exploration: James Cook in Pacific, Ben Franklin in Atlantic, Charles Darwin in Pacific
 - 6. 20th Century Oceanography
 - a. Oceanographic Institute
 - (1) Scripps in La Jolla, CA
 - (2) Lamont-Dougherty, Columbia University
 - (3) Rosentiel School - Miami
 - b. Wordwar I and II - Advances in Oceanography
 - (1) seafloor mapping
 - (2) echo sounding / depth detectors
 - (3) magnetometry studies
 - (4) submarines
 - c. 1960's-1970's
 - (1) Deep Sea Drilling Program (Oregon State part of collaborators)
 - (2) Glomar Challenger- drilling to depths of 6000 m (3.7 mi) in ocean
 - (3) Ocean-Based Plate Tectonic Studies
 - (a) Mid-Ocean Ridge System
 - (b) Submarine Volcanism
 - (c) Magnetic Seafloor Stripes
 - (d) Deep-Ocean Submarines
 - d. 1980's - Ocean Drilling Program
 - e. 1990-2000
 - (1) Satellites / Remote Sensing
 - (2) Global Positioning Systems
 - (3) Geographic Information Systems
 - (4) Robotic submarines
 - (5) Automatic Data Collection Devices / Internet Technology

II. Introduction to Sea Floor Tectonics

A. General

1. The theory of plate tectonics is a recent development in the geological sciences, really accepted by scientific community since the early 1960's.
2. Earlier in the century geologic paradigm was dominated by the belief that ocean basins and continental land masses were permanent and fixed on the surface of the earth.
3. The theory of Plate Tectonics now recognizes that the positions of land masses are not fixed and that they have moved about the earth's surface over geologic history
 - a. Ocean basins/oceanic crust are continually being created and destroyed through tectonic processes.

B. Terminology

1. "Tectonics" - is a term that refers to the deformation of the earth's crust.
2. "Plate" - refers to the subdivision of the earth's crust and lithosphere into a number of tectonically coherent blocks
3. "Plate Tectonics" - refers to the formation and migration of these lithospheric plates,
 - a. Problem: time spans of plate motion on order of 10' of to 100's of million's of years,
 - (1) theory has been deduced from evidence recorded in earth's rocks, often difficult to interpret and sometimes inconclusive.

C. Overview of Earth Interior

1. Crust- a relatively thin outer layer
 - a. oceanic crust- thin on order of several km's thick
 - (1) volcanic / basalt in composition
 - b. continental crust-thicker on order of 10's of kms thick
 - (1) plutonic/sedimentary/"granitic" in composition
2. Mantle- rocky layer located below the crust and having a thickness of 2885 km
 - a. Mantle- dense, iron-magnesium silicate rocks
 - b. "Moho"
 - (1) Mohorovicic discontinuity or Moho-seismic discontinuity in which velocity of earthquake waves increases abruptly below a depth of 50 km
 - (2) now known to be boundary between crust and upper mantle
 - c. Asthenosphere- soft zone of partially melted rock
3. Lithosphere- outer solid portion of the earth which includes the upper mantle above the asthenosphere and the crust.
4. outer core- 2270 km thick, possesses characteristics of mobile liquid
 - a. Liquid, iron-rich,

5. inner core- 1216 km thick, solid metallic sphere
 - a. Core- thought to be composed of iron and nickel, very speculative, based on study of meteorites and speculation that they represent the interior composition of earth.

D. Historical Perspective on the Evolution of Plate Tectonic Theory: Continental Drift a Precursor to Tectonic Theory

1. Continental Drift - Alfred Wegner (German earth Scientist) proposed a hypothesis in early 1900's that the world continents have been drifting about on the earth's surface
 - a. Supercontinent of "Pangaea" existed 200 M.Y. ago in which all of major worlds continents were once amalgamated together, and have since broken apart and migrated or drifted to their present positions/configurations.
 - b. Evidence for Wegner's hypothesis of Continental Drift
 - (1) Jig-saw puzzle fit of the Continents:
 - (2) Fossil Evidence
 - (a) Mesosaurus which is only found on east coast of South America and west coast of Africa.
 - (b) How did these critters migrate across the ocean basins?
 - (3) Similar Rock Types and Structural Rock Deformation across ocean basin
 - (4) Paleoclimatic Evidence
 - (a) Evidence for glacial conditions 250 m.y. ago are found in similar aged rocks from southern Africa, South America, India and Australia
 - c. Problem with Wegner's ideas
 - (1) not widely accepted
 - (2) suggested on the continents were "drifting" not ocean basins
 - (3) did not have a viable mechanical explanation as to how continents would "drift"

E. Modern Plate Tectonic Theory

1. Basic Model - Based on early work by Wegner, more recent mapping of seafloor, magnetic surveys of earth's magnetic field, and observation of earth's seismic activity or earthquake activity.
 - a. Plates- Plate tectonics model suggests that the outer, rigid lithosphere of the earth consists of about twenty rigid segments known as "plates".

- (1) Plate Mobility - it is recognized that each moves as a distinct rigid unit in relation to other plates.
 - (a) These plates move on top of a semi-plastic asthenosphere, and interact with one another along their boundaries.

b. Plate Boundaries and Nature of Interaction between Plates

- (1) 3 types of plate boundary interaction: Divergent, Convergent, or Transform fault boundaries
- (2) Divergent Boundaries - boundary condition in which tectonic plates move apart, resulting in upwelling of magma and volcanic material to create new seafloor: i.e. creation of new crust.
 - (a) located at crests of mid-oceanic ridges, where plates move apart and molten rock is injected and cooled to form new seafloor.
 - i) Mid-Oceanic Ridge System
 - (b) Seafloor spreading- process of plate divergence and injection of magma.
 - i) E.g. Atlantic ocean basin, has undergone seafloor spreading over last 165 m.y. at avg. rate of 6 cm/year.
 - ii) e.g. Red Sea in Middle East is an example of a very young ocean basin that is just beginning the process of seafloor spreading.
 - (c) Continental Rifting
 - i) Pulling apart of continental crust by faulting
 - ii) Incipient seafloor spreading center
- (3) Convergent Boundaries- plate boundaries in which two plates move toward one another or collide.
 - (a) Collision of one plate into another results in downbending of one plate and descent of that plate beneath the other,
 - (b) subduction zone- a zone of plate convergence in which where an oceanic plate descends into the upper mantle beneath the overriding plate.

- (c) trenches - zone where subducting slab dives beneath over-riding plate
 - (d) volcanic arc - an arcuate chain of volcanoes on continental crust that result from subduction of oceanic crust beneath continental crust.
 - i) Cascade mountains in U.S., Andes in SAM, Sierra Mtns in CA are eroded core of volcanic arc.
 - ii) Forearc region - zone in front of arc, towards trench
 - a) e.g. Willamette Valley, west of Cascades
 - iii) Backarc region - zone behind the arc, away from trench
 - a) e.g. central Oregon, east of Cascades
 - (e) Types of convergent boundaries
 - i) Oceanic-Continental Plate Convergence-
 - a) e.g. W. Coast of North America
 - ii) Oceanic-Oceanic Plate convergence
 - a) e.g. Japan
 - iii) Continent-Continent Plate Convergence
 - a) e.g. India / Asia / Himalayas
- (4) Transform Fault Boundaries: condition where plates slide horizontally past one another along a fault (or fracture along which there is movement)
- (a) Crust is neither consumed nor destroyed.
 - (b) Transform faults connect convergent and divergent boundaries into a worldwide network of interconnected plate boundaries.
 - i) (e.g. San Andreas Fault in Ca).

F. Evidence to Support Modern Plate Tectonic Theory

1. Magnetism and Paleomagnetism (result of search for German submarines in WWII)
 - a. Earth has a magnetic field about it with a magnetic north pole and south pole similar to a bar magnet with lines of magnetic force flowing from North to south.
 - b. Paleomagnetism - iron-rich minerals such as magnetite (Fe_3O_4) act as tiny magnets, when these minerals cool from a magma there is a temperature at which they align with the magnetic field of the earth (curie point),

- (1) Polar Wandering -
- (2) Polar Reversals
 - (a) Normal Polarity -So rocks have been found with paleomagnetism similar to todays polar arrangement termed "normal" polarity
 - (b) Reversed Polarity- rocks which indicate magnetic north pole at current position of south magnetic pole
- (3) Seafloor Stripes

2. Evidence from Seismic Records of Earthquakes

- a. the distribution of earthquake focii or origination points of earthquakes was examined around the world and at convergent plate boundaries or subduction zones.

3. Evidence from Ocean Drilling

4. Evidence from obducted slabs of seafloor / upper mantle

- a. Ophiolite Complexes
 - (1) Sheet Dike (Gabbro) overlain by Pillow Lavas (Basalt) overlain by deep water sedimentary rocks

5. Hot spots tracks

- a. Hawaiian Islands

G. Driving Mechanism for Plate Tectonics: what force causes the plates to move about the earth's surface?

1. Heat Transfer/Convection within Mantle

- a. Model: the lower or inner portion of the mantle, near the core, is hotter than the upper mantle, this unequal distribution of heat results in circulation of heated, semi-plastic mantle material...warm, less dense material of lower mantle rises very slowly in regions of spreading centers, spreads laterally, cools, and slowly sinks back into the mantle and reheating process repeats, these mantle convection currents result in shear force being applied to overriding crustal plate and drive plate tectonic motion.

2. Other Ideas

- a. active subduction pull
 - (1) cold, dense subducting slab pulls plate into interior of Earth
- b. ridge push
 - (1) active spreading centers push slab into interior of Earth

Oceanography - Marine Provinces and Sediment Sources

III. Shape of Seafloor

A. Bathymetry- measurement of depths from sea surface to seafloor

1. negative elevation measurements
 - a. units: meters, feet, miles, fathoms
 - b. 1 fathom = 6 ft
2. Ocean Floor Depths
 - a. abyssal plains: 4 - 6 km depth
 - b. average depths
 - (1) Atlantic 3900 km
 - (2) Pacific 4300 km
 - (3) Indian 3900 km

B. Sea Level and Sea Level Change

1. Tidal Fluctuation diurnal, vertical fluctuation of sealevel under the influence of planetary gravity. Results in bulging of sealevel sytematically throughout the day, around the world.
 - a. tides set in motion by gravitational attraction of the moon and sun (heavenly bodies close and large enough respectively to influence force of gravity on earth).
 - (1) gravitational pull of sun and moon result in pulling at the ocean surface, causing it to bulge. Since the earth's crust is rigid and relatively unaffected by this gravitational pull, tidal fluctuations of sea level occur relative to land. (tidal pull is relatively negligible in surface bodies of water, i.e. lakes)
 - (2) Moon has most significant daily impact on tidal levels. Gravitational effectiveness of sun relative to the moon is 44%.
 - b. Normal tidal bulges: influenced by moon primarily, moon in line with equator, pulling bulge equatorially, low tides at top and bottom, high tides at equator
 - (1) tidal bulge follows the moon as it orbits around earth, water facing the moon is drawn/bulged towards the moon, side opposite moon is also bulged outward because the solid portion of the earth (facing the moon) is pulled away from the ocean on the side opposite the moon.
 - (a) at same time as tidal bulge, there are compensating low tides at 90 degrees to the bulge
 - (2) Entire effect is complicated by the earth's revolution from east to west, also coupled with moon's revolution around earth: result in 2 complete tidal cycles every 24 hours and 50 minutes. (i.e. 2 high and 2 low tides in a little over each day)

2. Global Sea Level Change

a. Sea Level Relative to Global Ice Budget

- (1) > Ice Storage, < Sea Level
- (2) < Ice Storage, > Sea Level
 - (a) presently melt all glacial ice: > SL by 60 m globally
 - (b) Last Glacial Maximum: SL < by 100 m

C. Slope of Seafloor

1. Slope = rise / run = change in elevation / change horizontal distance

- a. units
 - (1) dimensionless, ft/mi, m/km, percent
- b. Percent Slope

$$\%slope = 100\% * \text{inv tan} (\text{rise/run})$$

e.g. $100\% = 100\% * \text{inv tan} (45^\circ)$

- c. steep slopes at oceanic trench ~5 degrees
- d. gentl slopes at continental shelf ~0.2 degrees
- e. continental slope ~ 2 degrees
- f. Slope morphology as function of age of seafloor
 - (1) old seafloor = colder, > density
 - (a) steeper slopes at trench
 - (2) younger seafloor = warmer, < density
 - (a) gentler slopes at mid-oceanic ridge

D. Depth / Bathymetry Measurment Techniques

1. Sonar
 - a. side scanning sonar
2. Seismic Surveys

IV. Marine Provinces and Seafloor Features

A. Deep Ocean Basin - offshore marine depths (depths > 4000 m)

1. Tectonic Features
 - a. trench - at subduction zone
 - b. spreading center
 - (1) mid-ocean ridge
 - (2) mid-ocean "rise"
 - (3) hydrothermal vents (100 to 300 deg. C)
 - (a) white smokers
 - (b) black smokers
 - i) sulfides
 - (4) Hot spot tracks
 - (a) trail of submarine volcanoes
 - c. abyssal plain- flat expanse, low relief, deepest depths

- d. Guoyotes and submarine volcanoes
 - (1) fringing reefs
 - e. Volcanic arc at subduction zone
 - f. fracture zones at transform boundaries
- B. Continental Margin - nearshore
- 1. Tectonic classification
 - a. passive margins - cont. margins removed from plate boundaries
 - (1) e.g. Atlantic passive margin
 - b. active margins - cont. margins near plate boundaries
 - (1) e.g. Pacific type margins
 - 2. Seafloor topography (in offshore direction)
 - a. continental shelf
 - (1) shelf break
 - (2) submarine canyons
 - (a) turbidity currents
 - b. continental slope
 - c. continental rise
 - (1) submarine fans
 - d. abyssal plain

V. Marine Sediments and Sediment Sources

A. Sediment- derived from latin sedimentum = "a settling", sediment may be defined as regolith, or weathered bedrock that has been transported. May include both physical particles (sand, gravel, silt, clay), or dissolved ions that are carried in solution and re-precipitated as chemical and/or biochemical deposits.

B. Sediment Types

- 1. Clastic Sediments: those that are weathered, eroded and physically transported in a solid state before being deposited (i.e. particles, e.g. sand).
 - a. Lithogenic - sediment derived from pre-existing rock material
 - (1) River sediment
 - (2) wind-blown sediment
 - (3) ice-rafted debris
 - b. chemical - chemical deposits
 - c. biogenic - marine plant and animal remains
- 2. Nonclastic Sediments: those that are weathered and transported in solution (dissolved ions) and subsequently chemically precipitated in situ from solution, i.e. as mineral crystals. These sediments were not transported physically as solid objects.
 - a. chemical
 - b. biogenic

C. Clastic Sedimentary Particles

- 1. Weathering Products of Pre-existing Rocks
 - a. Siliciclastic Sediment (Inorganic Composition): Physical particles that are derived from the weathering and erosion of terrigenous, pre-existing, rock material. Siliciclastic sediment is largely comprised of silicate-based mineral and lithic fragments.

- (1) Sediments are derived by
 - (a) chemically and physically weathering bedrock,
 - (b) erosion/transportation via mass wasting processes, and/or
 - (c) the crushing and grinding action of glacial activity.

D. Chemically-Derived Sedimentary Particles: includes 1) animal-secreted skeletal debris, 2) nonskeletal calcium carbonate materials, and 3) glauconite minerals

1. Animal-secreted Skeletal Debris: comprised of either calcium carbonate or silica
 - a. Calcium Carbonate Skeletal Debris: includes whole-body tests of animals as well as broken and fragmented pieces. Largely marine-based organisms and fossil material. Fragments for "bioclastic" sediments available for transport and deposition.
 - b. Siliceous Skeletal Particles: skeletal tests composed of SiO_2 , primarily diatoms and radiolaria, microscopic sea critters.

Siliceous deposits are not abundant on seafloor, but do occur.

2. Evaporite minerals
 - a. precipitates from sea water as evaporation occurs
 - b. gypsum, rock salt, anhydrite

VI. Classification of Marine Sediments

- A. Neritic Sediments - shallow water, continental margins
 1. lithogenous sediments from offshore river deposition
 - a. sand, silt, clay primarily
 2. Turbidites
 - a. graded bedding
 - b. turbidity deposition of sediment-laden water
- B. Deep Ocean Sediments
 1. chemical oozes
 - a. biogenous origin
 2. pelagic or abyssal clays
 3. fecal pellets
 4. skeletal / bioclastic sediment