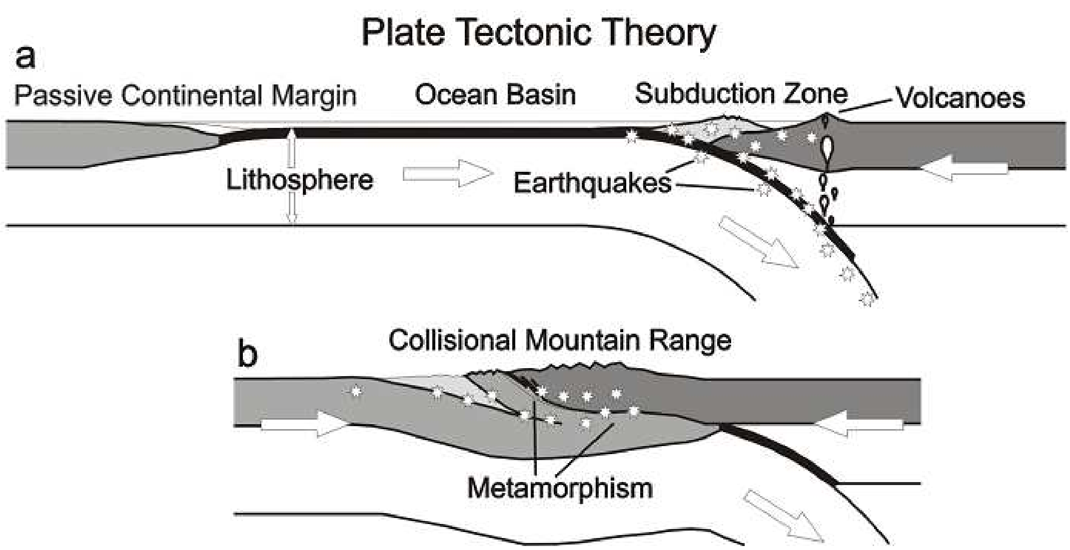
#	Topic
1	Plate tectonics concept
2	Rock types and rock cycle
3	Volcanoes
4	Geologic time
5	Crustal deformation
6	Earthquakes
7	Classic “chemical” divisions of earth interior
8	Modern “physical” divisions of earth interior
9	Types of plate boundaries
10	Geophysical methods
11	Mid-ocean ridges
12	Mantle plumes
13	Concept of deformation
14	Seismic waves and the differences between them
15	The relationship between Vp & Vs
16	Minerals
17	The relationship between stress & strain
18	Concept of convection
19	The differences between continental & oceanic crust
20	The differences between felsic & mafic rocks
21	Types of faults
22	Moho boundary
23	Plate motion forces
24	Gravity and isostasy
25	Focal mechanism solution
26	Uniformitarianism
27	Physical & chemical weathering

#	Topic
28	The differences between the upper and lower crust
29	Seismic velocity averages for crust, mantle, and core
30	Earth major and minor plates
31	The differences between seismic reflection and refraction
32	Poisson's ratio
33	Earth major spheres
34	The differences between active and passive rifting
35	Subduction zones
36	Plate motion forces
37	Elastic modulus
38	The differences between Bouguer and free air anomalies
39	Seafloor spearing hypothesis
40	Receiver function analysis
41	Continental rift extension forces
42	Rock strength and behavior
43	Strength of continental and oceanic lithosphere
44	Rock mechanics
45	The differences between elastic & plastic deformation
46	Strength of continental & oceanic lithosphere
47	Airy and Patt's hypothesis
48	Focal mechanism solution
49	Uniformitarianism
50	Physical & chemical weathering
51	The differences between elastic & plastic deformation

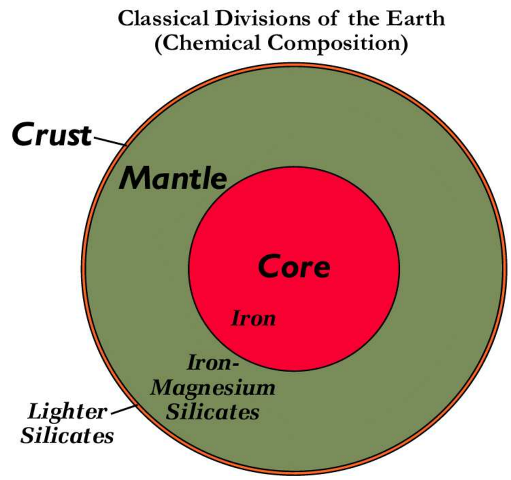
Q. What is the concept of plate tectonics theory?

- It is a scientific theory which describes the large scale motion of Earth's lithosphere. The theory builds on the older concepts of continental drift developed by Alfred Wegner and seafloor spreading. Where the plates are relatively moving towards each others and changing their sizes and shapes. The theory also explain the global distribution of seismicity, volcanism, continental drift, and mountain building in terms of the formation, destruction, movement, and interaction of the earth's lithospheric plates. Tectonic plates are able to move because the Earth's lithosphere has a higher strength and lower density than the underlying asthenosphere. Their movement is driven by heat dissipation from the mantle "convection". The theory describe that the Earth's lithosphere (the crust and upper portion of the mantle) is divided into about (12) large plates and several small ones that float on and travel independently over the asthenosphere. The majority of the earthquakes and volcanoes on the Earth's surface occur along the margins of tectonic plates. The interior of a plate moves as a rigid body, with only minor flexing, few earthquakes, and relatively little volcanic activity.



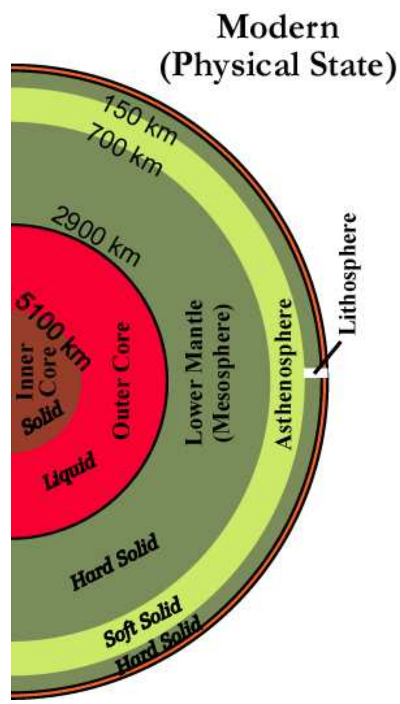
Q. What are the classical "chemical" divisions of earth?

Layer	Rock types	Thickness
Crust	Igneous, metamorphic, and sedimentary	Continental (35-40 km) Oceanic (5-10 km)
Mantle	Igneous rocks "peridotite"	2900 km
Core	Iron-nickel	3400 km



Q. What are the modern "physical" divisions of earth?

Layer	Thickness	Remarks
Lithosphere	200 km (continental & oceanic)	Hard solid
Asthenosphere	600 km (low velocity zone)	Soft and weak with high T & P
Mesosphere	660 – 2900 km (high velocity & density)	Rocks are very hot and flow (hard solid)
Outer core	2270 km (magnetic field)	liquid
Inner core	3486 km (stronger than outer core)	Behave like a solid



Q. What is the significance of earth's layers?

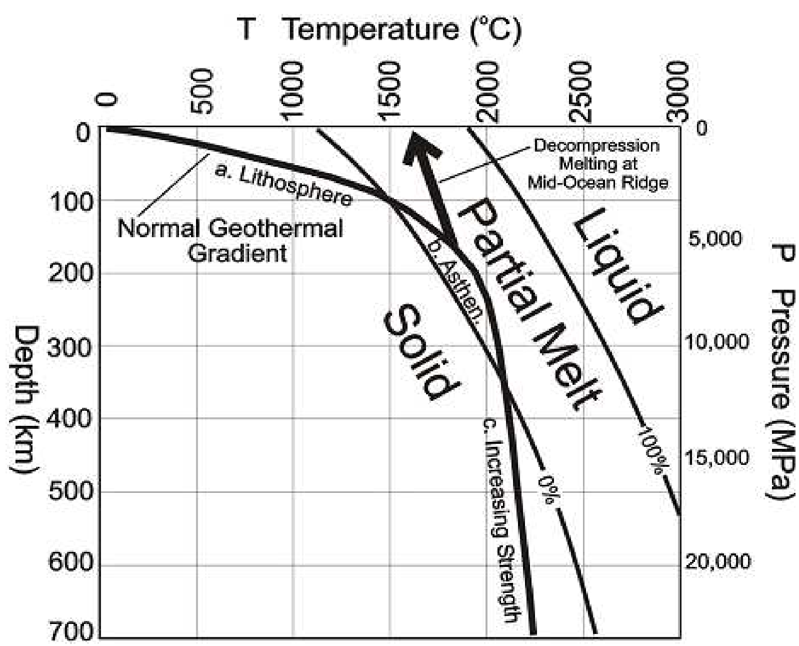
- Without these layers, there would be no plate tectonics. And as a result, there would be no mountains, valleys, earthquakes, volcanoes etc. And the earth will be perfectly covered by water.

Q. Why earth has creamy layer "asthenosphere"?

- Because of: the composition of the mantle, temperature change with depth, and pressure change with depth.

Q. Draw the partial melt occurring at the "asthenosphere"?

- In layer b (from 100-350 km), the temperature is higher than the melting point of some of the minerals in peridotite which explains the weakness of the asthenosphere.

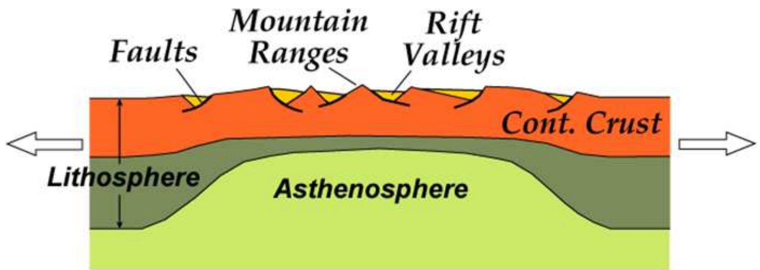


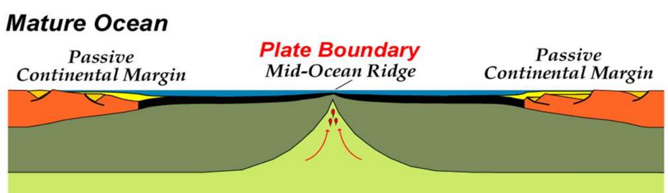
Q. What are the driving forces that control plate motion?

- They are: convection, slab pull, and ridge push.

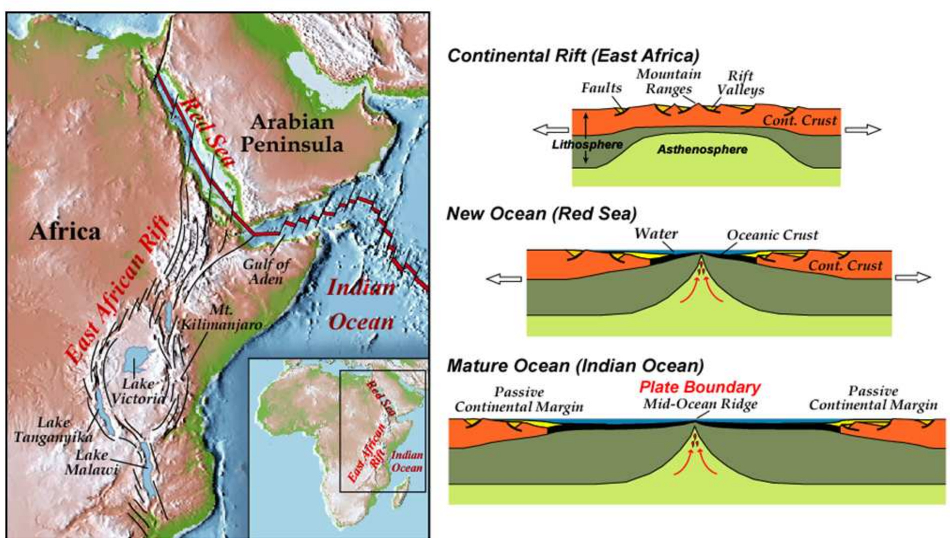
Q. What are the types of plate boundaries?

1. Divergent (construction margins): the direction of motion is perpendicular to the boundary. Major currently active continental rifts: Baikal (Russia), East African, Rio Grande (US), Rhine Graben (Europe), Shanxi Graben (China), and Red Sea. The Basin and Range Province and Rio Grande Rift Display Active Continental Rifting

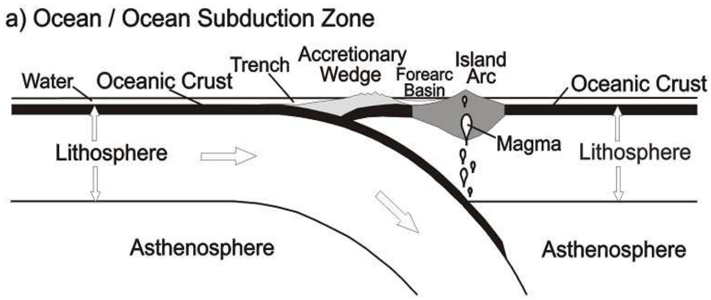


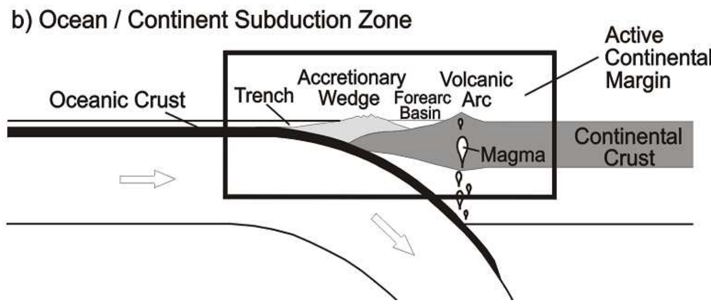


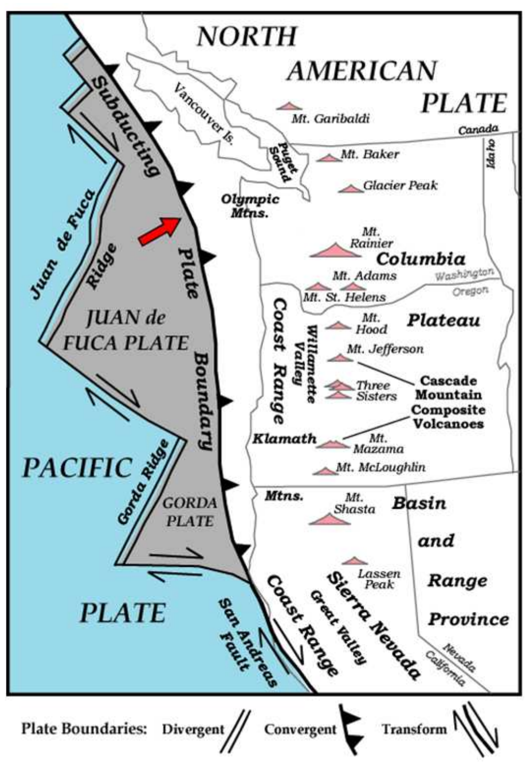
THREE STAGES OF DIVERGENT PLATE BOUNDARY DEVELOPMENT

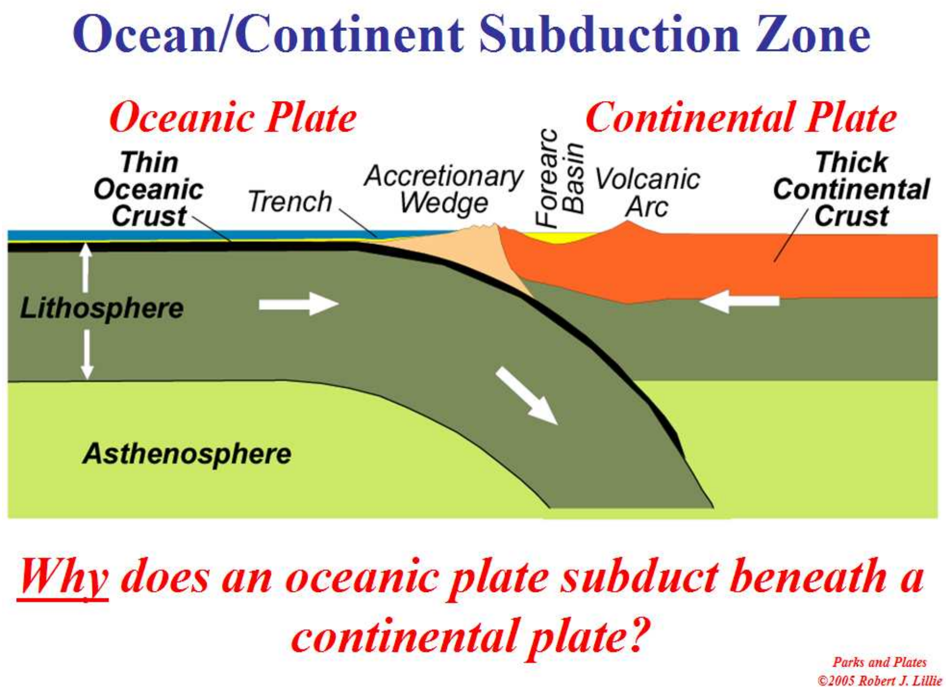


2. Convergent (destruction): the direction of motion is at right angles of the trench as in Nazca, The Himalayas, and S. America. Example: is the subduction of the Juan de Fuca Plate forms the Coastal Ranges and Cascade Volcanoes

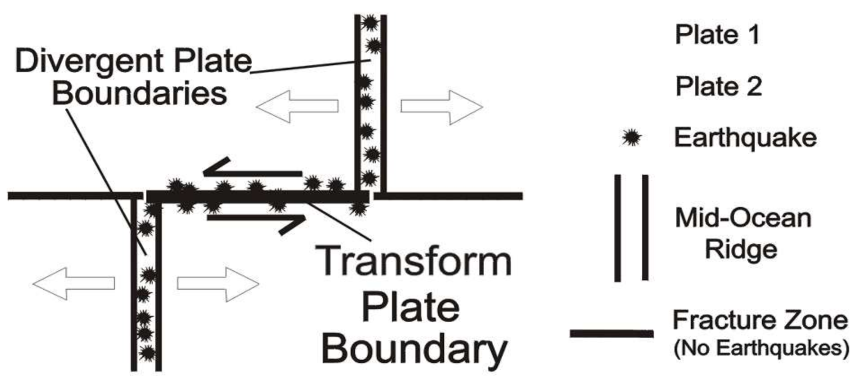


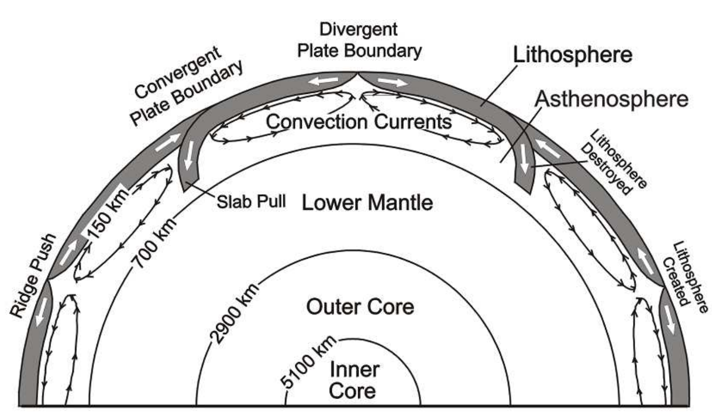






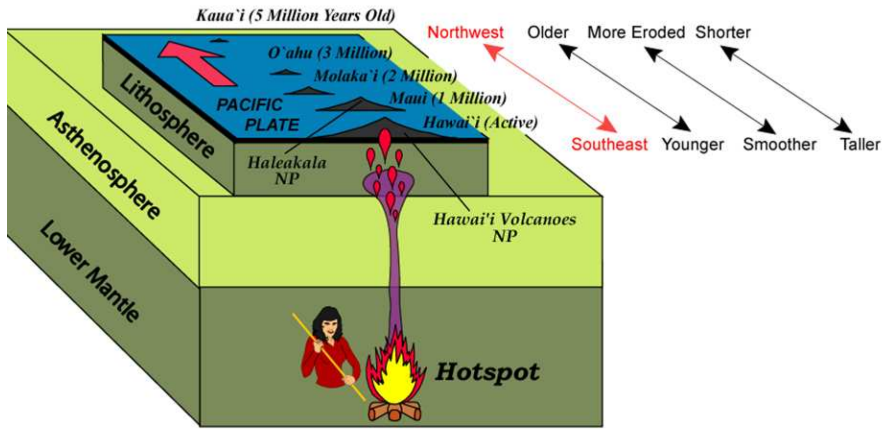
3. Transform (construction): the relative motion is parallel to the fault as in San Andreas Fault.

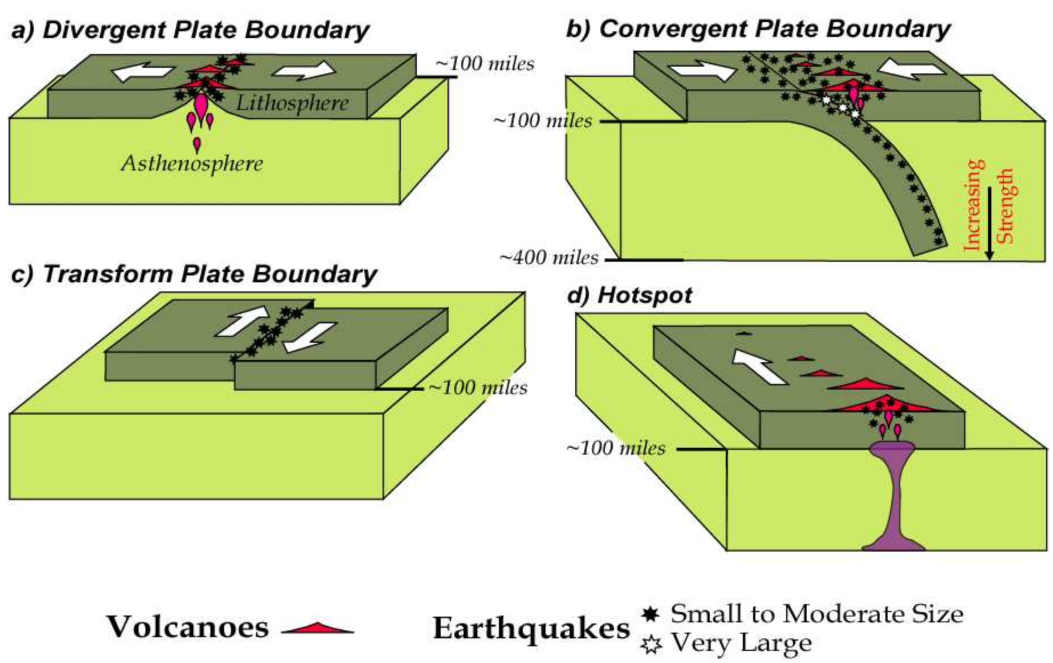




Q. What is hotspot?

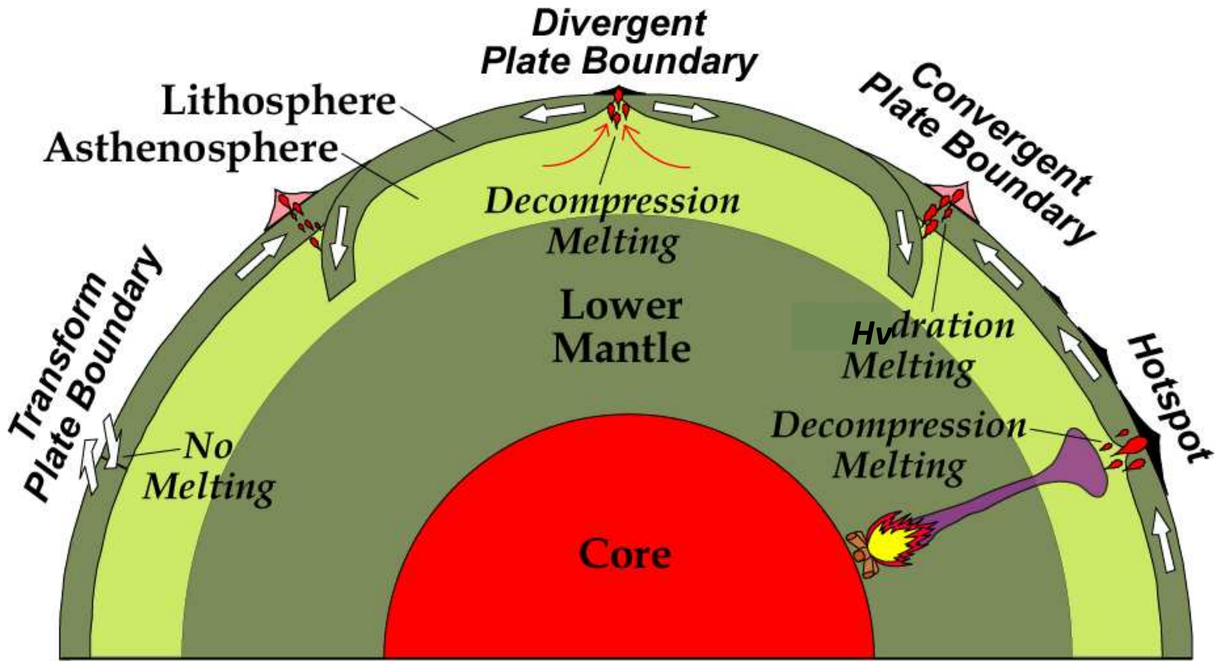
- Hotspot occurs where the convection of the Earth's mantle creates a column of hot material that rises until it reaches the crust, which tends to be thinner than in other areas of the Earth. The Hawaiian Islands are thought to be formed in such a manner, as well as the Snake River Plain, with the Yellowstone Caldera being the part of the North American plate currently above the hot spot.



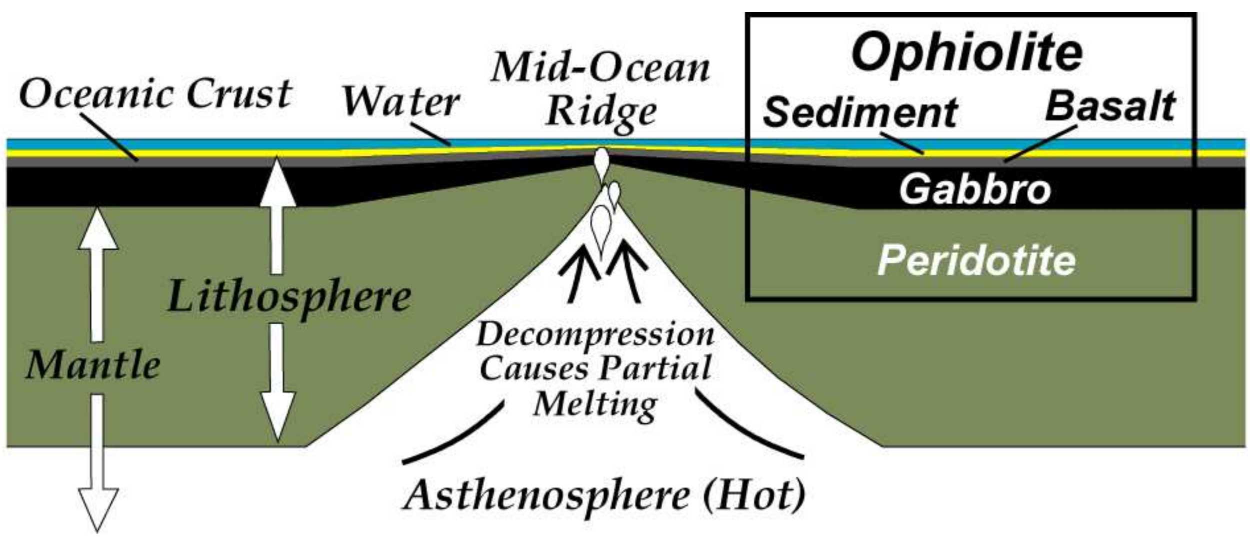


Q. Where do volcanisms occur?

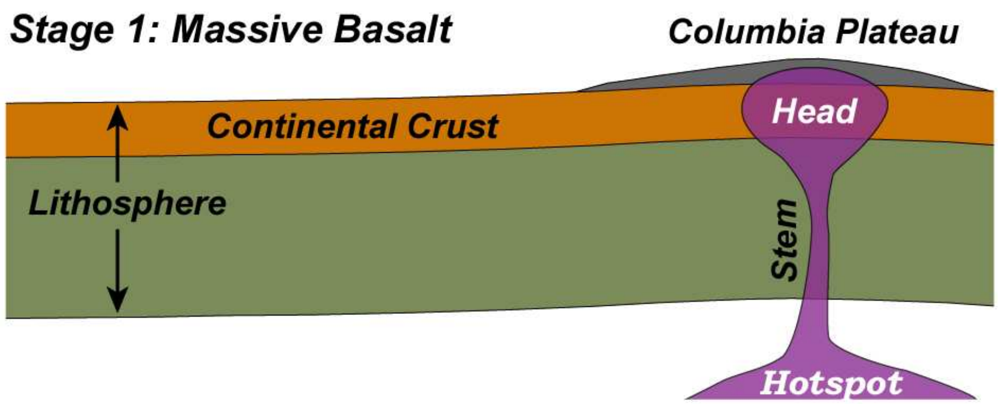
- It occurs at the divergent and convergent plate boundaries, slab pull areas, and hotspot areas.

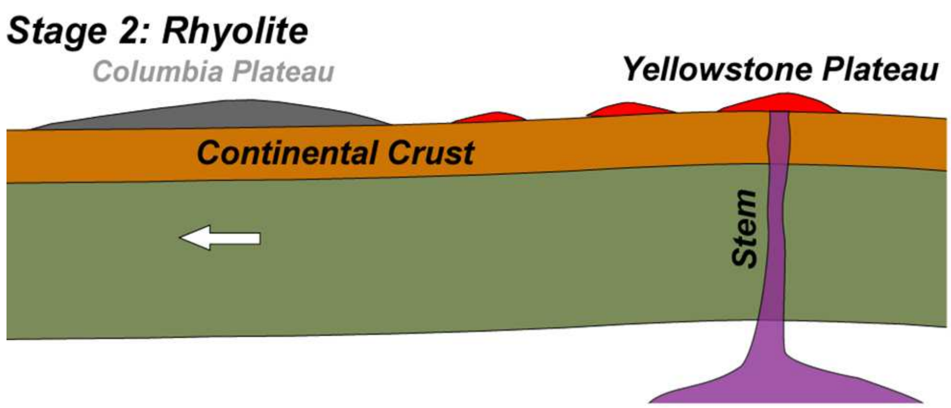


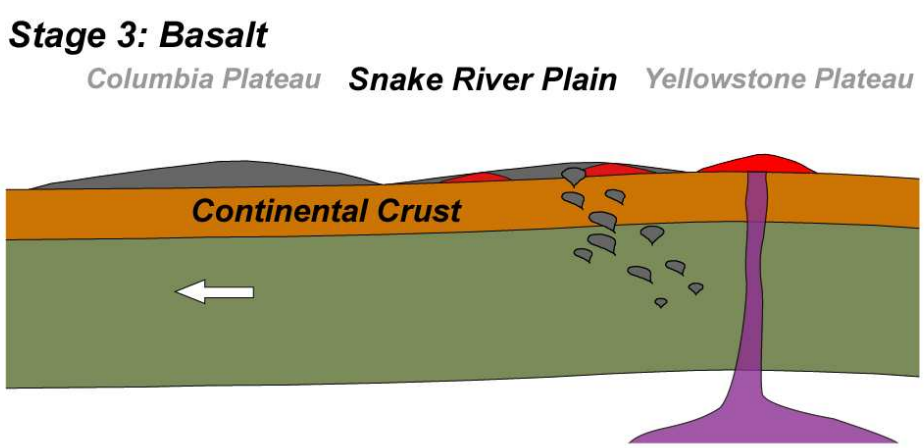
Q. Draw the formation of an oceanic crust?



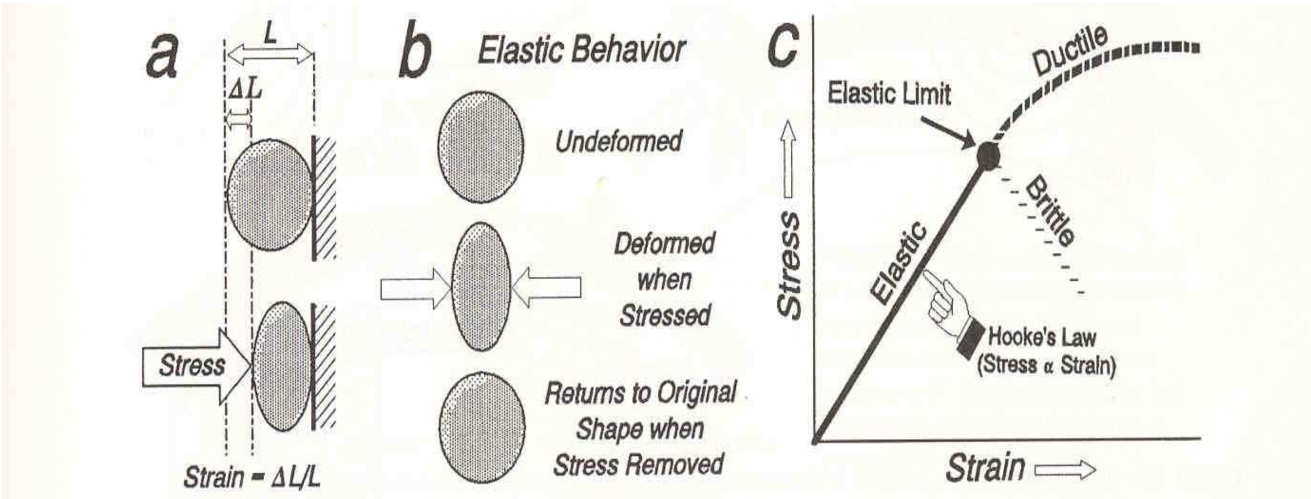
Q. Draw the three stages that creat Yellowstone Plateau?







Q. Draw the curve relationship between stress and strain?



Q. What are the differences between stress and strain?

Stress:

1. Force acting in unit area (F/A).

2. Unit in Pascal = 1 N/m^2

3. Types:

   1. Normal "tensional": when stress tend to stretch a rock unit perpendicular to the face of the rock.

   2. Shear "differential": when stress is applied unequally in different directions parallel to the face of a rock.

Strain:

1. The resulting deformation of stress. When a solid is stressed, it becomes strained.

2. Rocks move relative to each other without any change in size or shape.

3. Types:

   1. Elastic: Deformations which are recovered after the external forces have been removed. Seismology focus on this type.

   2. Plastic: When deformation remain after removing the external forces. Rupture occurs.

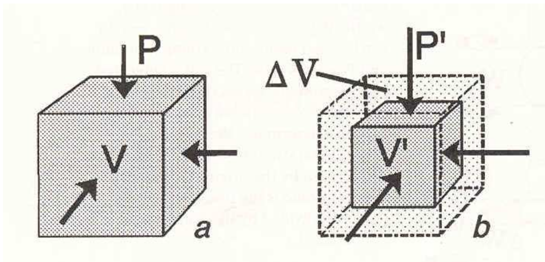
Q. What do elastic constants describe?

- They describe the strain of a material due to applied stress.

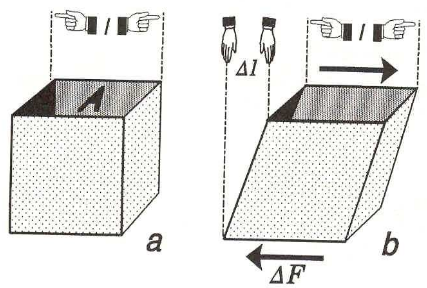
Q. How can you measure the strength of a material? Explain?

- Strength of a material can be measured by one of the elastic modulus: Bulk Modulus, Shear Modulus, Young's Modulus, and Poisson's ratio.

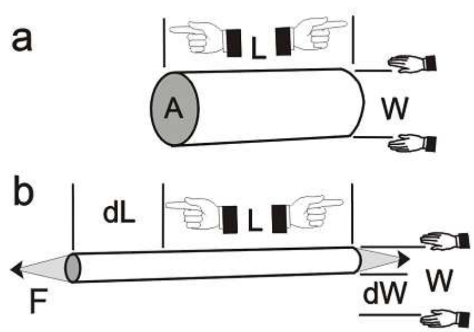
Bulk Modulus: It is defined as the pressure increase needed to cause a given relative decrease in volume. Its base unit is Pascal. The material will be smaller by applying more force.



Shear Modulus: It is defined as the ratio of shear stress to the shear strain. Shear modulus is usually measured in GPa.

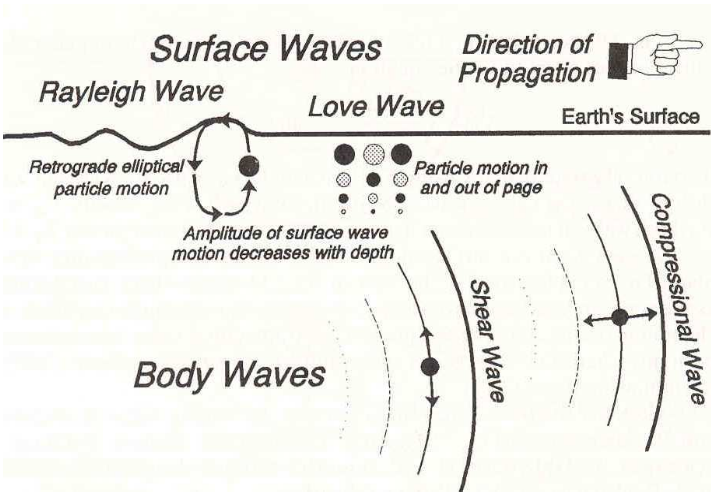


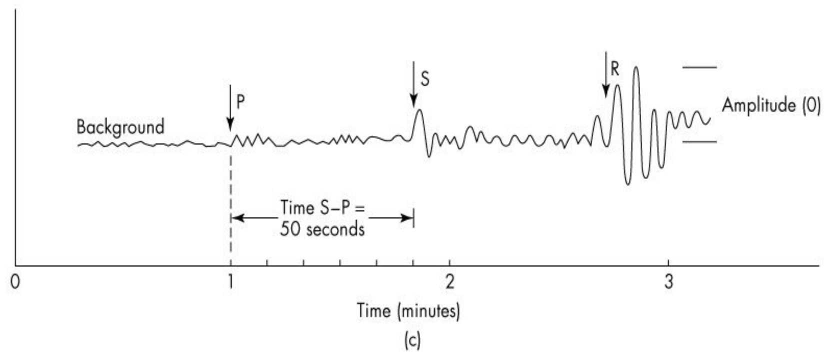
Young's Modulus: It is defined as the ratio uniaxial stress to the uniaxial strain. Young's modulus has the unit of pressure (Pascal).



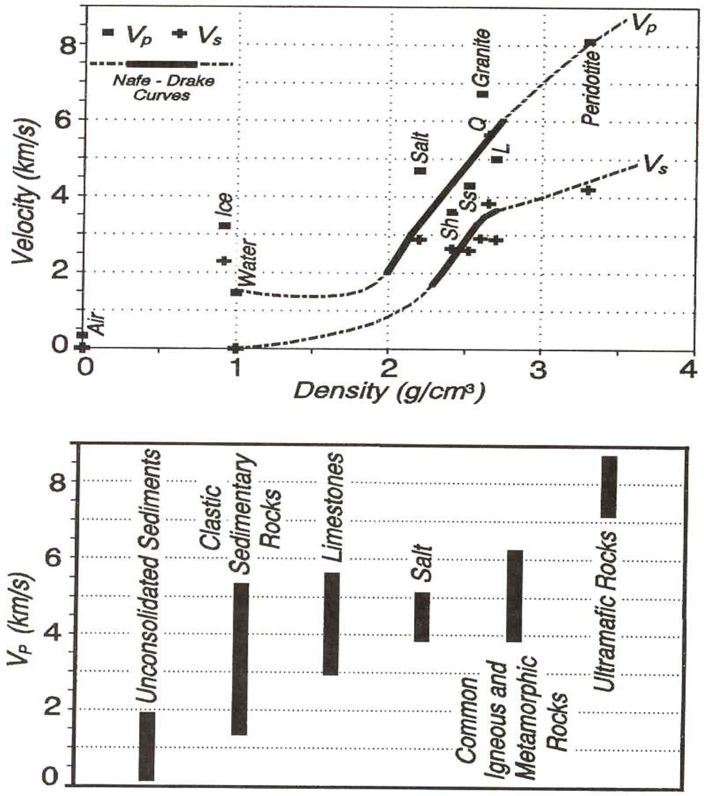
Q. What are the most important types of seismic waves?

Body wave		Surface wave	
P-wave	S-wave	Rayleigh	Love
Compressional wave	Shear wave “no volume change”	Motion dies down with depth	Perpendicular to the wave propagation direction “ no vertical movement”
Particles moves at the same directions as the wave’s propagation direction	Particles move parallel to the wave’s propagation direction	Amplitude decrease with depth	No vertical movement
Used for oil “shallow” exploration	Travel half of the speed of V_p	No volume change because of shear stress	Surface wave are noise waves

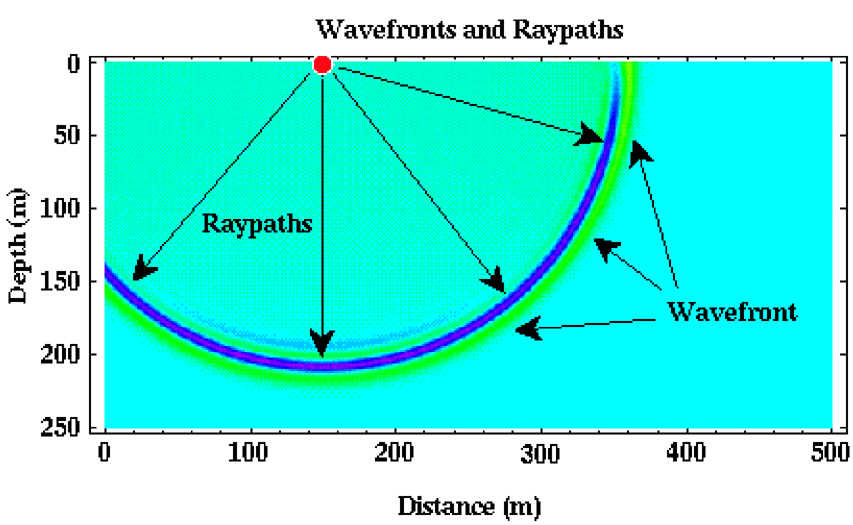




Q. Draw a figure showing the various of Vp & Vs for rock types?



Q. Draw the raypaths for a wave?

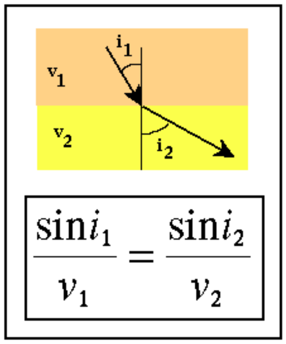


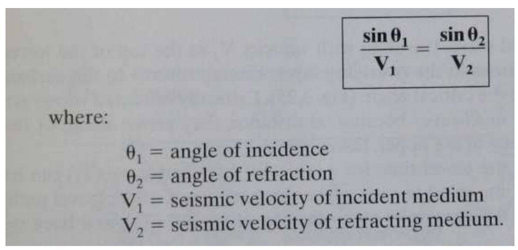
Q. Describe the following: Huygens' Principle, Fermat's Principle, and Snell's Law?

Huygens' Principle: every point on an advancing wave front of elastic wave energy is the source of new elastic wave energy that also travels out as an expanding sphere of energy.

Fermat's Principle: states the first arrival of elastic wave energy (at a recording station/geophone) travels the shortest time path.

Snell's Law: describes how elastic waves are reflected and refracted across a boundary separating layers of differing velocity.



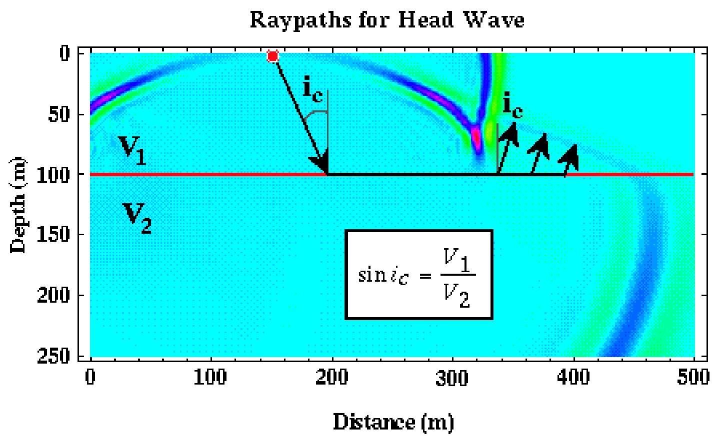


$$\frac{\sin\theta_1}{V_1} = \frac{\sin\theta_2}{V_2}$$

where:

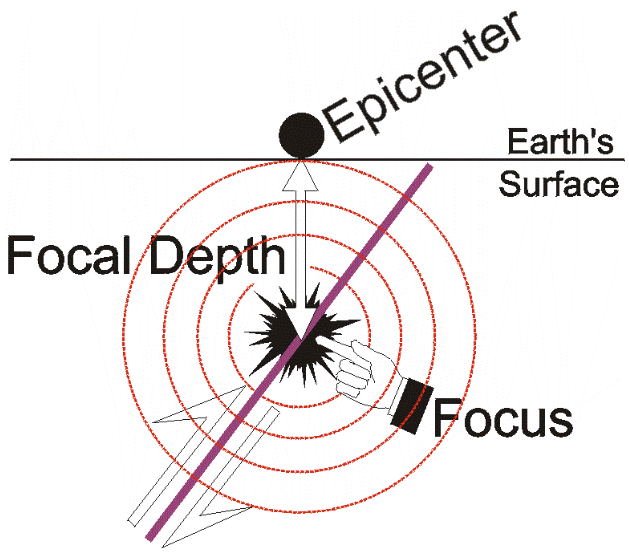
θ_1 = angle of incidence
θ_2 = angle of refraction
V_1 = seismic velocity of incident medium
V_2 = seismic velocity of refracting medium.

Q. What is the critical angle?



- Ic is called the critical angle, and it describes the angle that the incident raypath, i1, must assume for i2 to be equal to 90 degrees.

Q. Draw a figure of epicenter and focus?



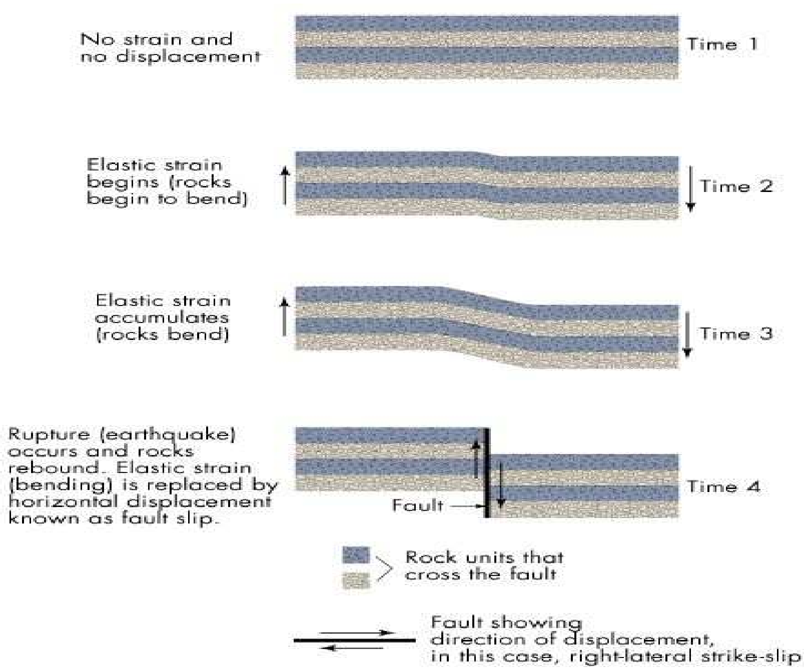
Q. What are the focal depth ranges?

1. Shallow: 0-70 km occurs in all plate boundaries.

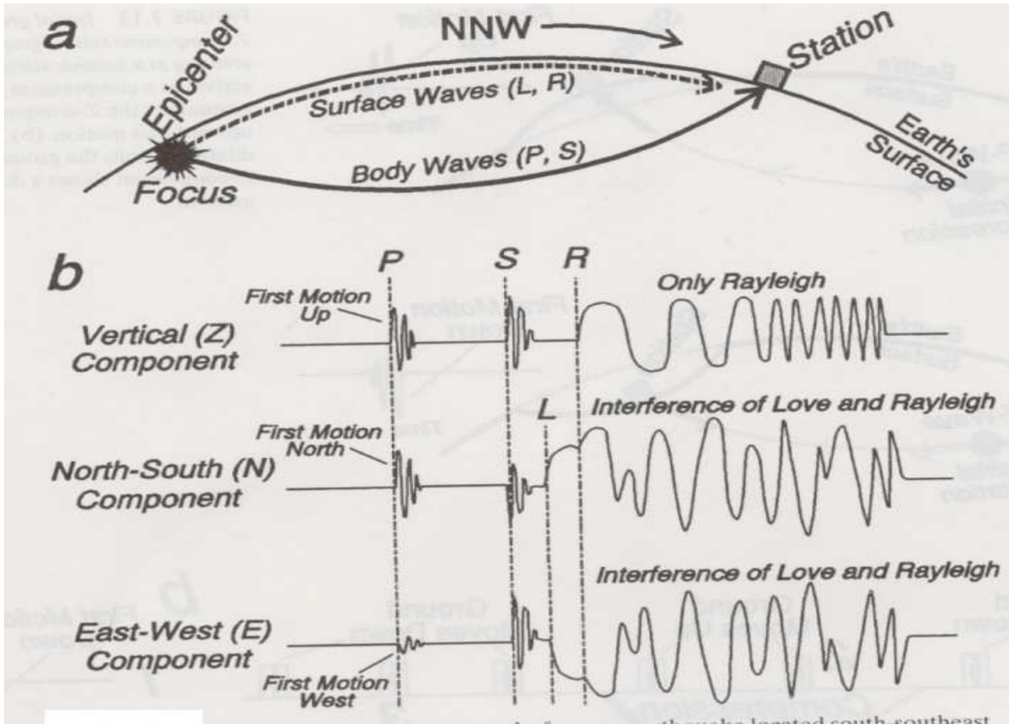
2. Intermediate: 70-300 km occurs in convergent plates.

3. Deep: 300-700 km occurs in convergent plates.

Q. Draw the mechanism of earth generation?



Q. Draw the seismic wave generated from an earthquake?

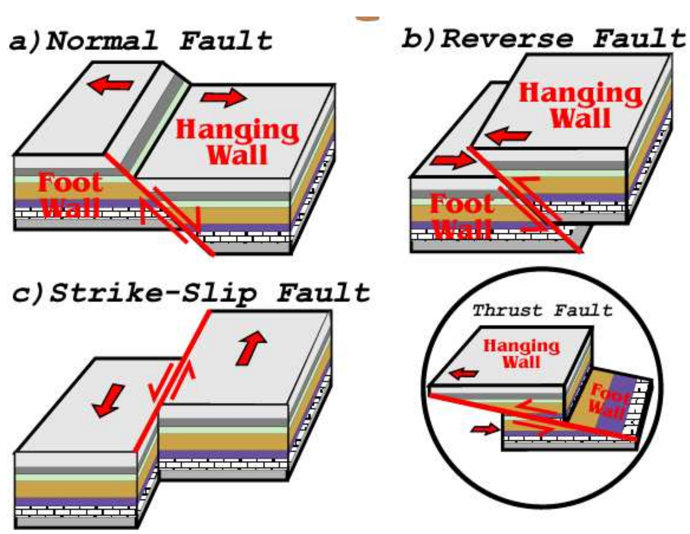


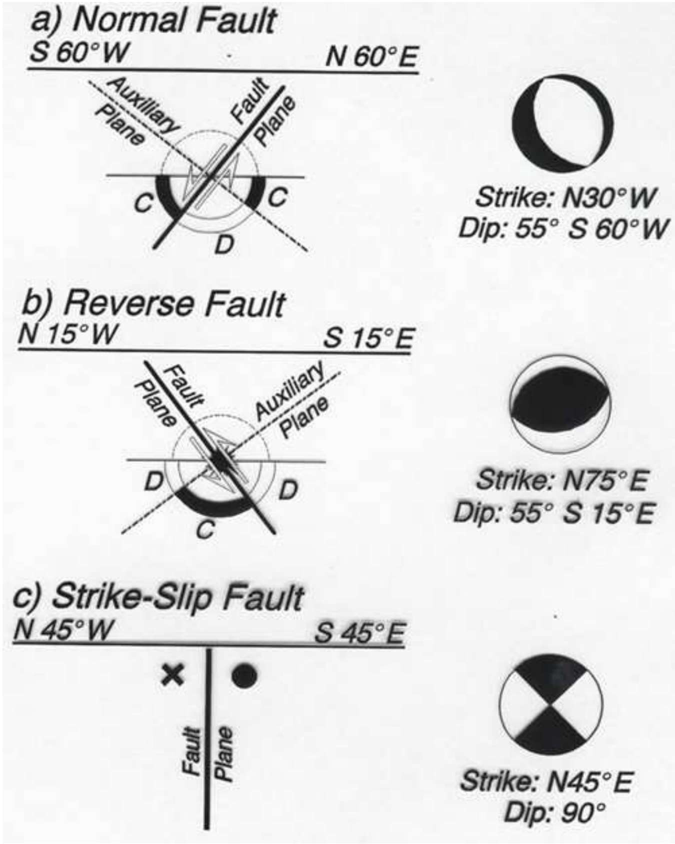
Q. Draw types of faults?

1. Normal: hanging wall moves away for foot wall.

2. Reverse: hanging wall moves towards foot wall.

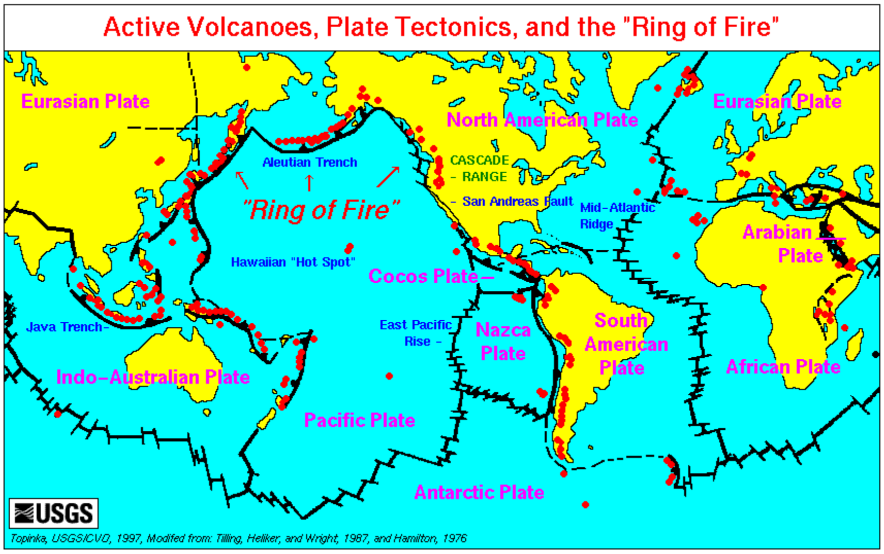
3. Strike-Slip: moves parallel to each others.





Q. What are the major & minor plates? And their ages?

- Earth seven major plates: continents: African (3 Ga), Antarctic, Australian, Eurasian, Indian, S. American, N. American (4 Ga). Oceanic: Pacific (180 Ma) and Atlantic (85 Ma). Earth minor plates: Arabian, Caribbean, Coco, and Nazca

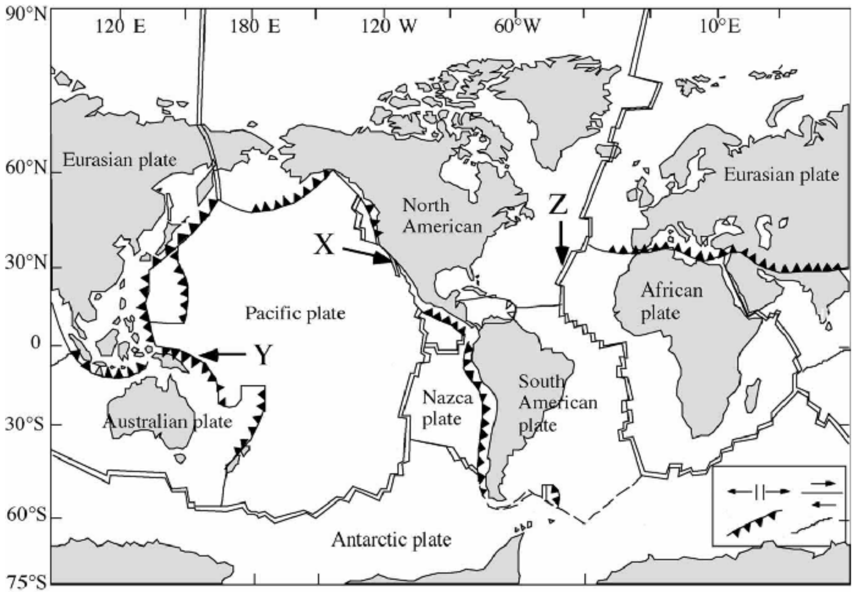


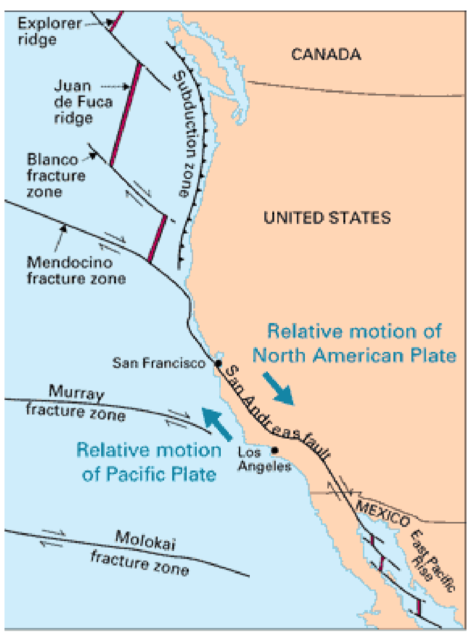
Q. How many continental & oceanic crusts are there?

- Continents: African (3 Ga), Antarctic, Australian, Eurasian, Indian, S. American, N. American (4 Ga). Oceanic: Pacific (180 Ma) and Atlantic (85 Ma)

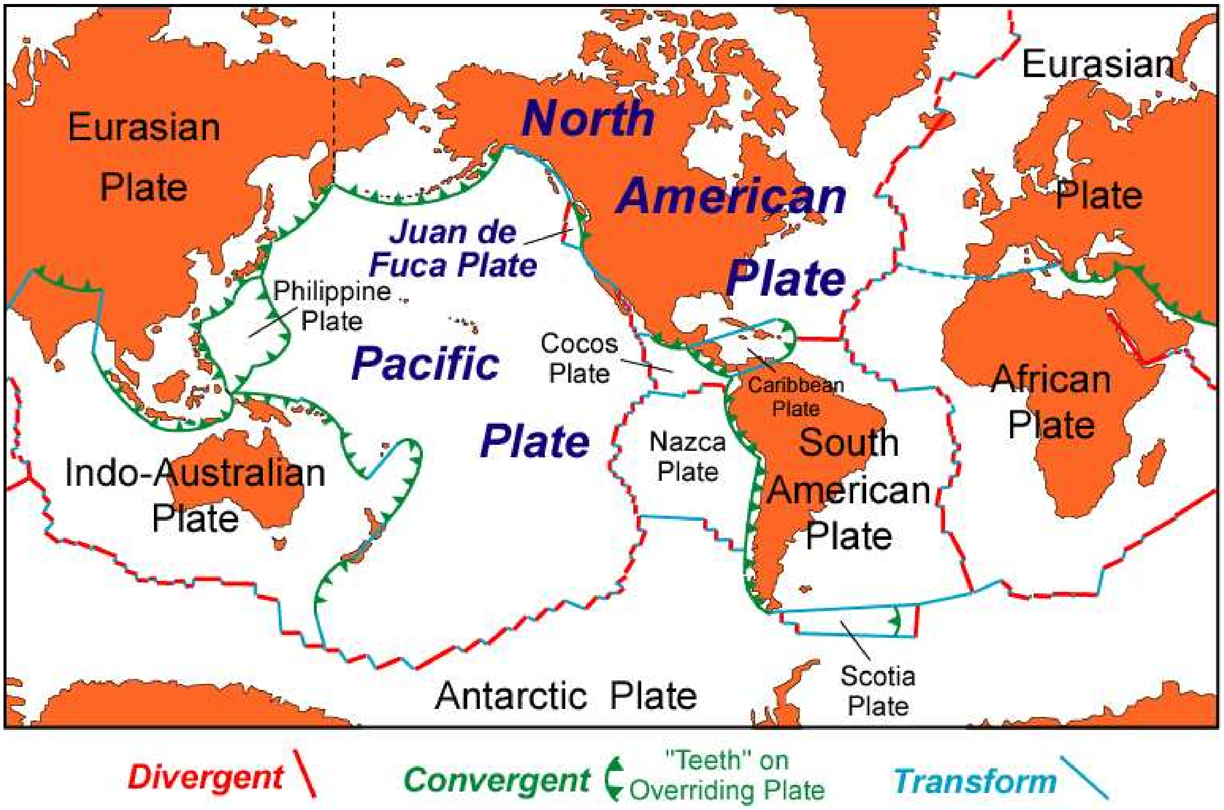
Q. What is subduction zone? Locate them in the world? Name the ones inside and near the US boarded?

- A subduction zone is an area on earth where two tectonic plates move towards one another and subduction occurs. Rates of subduction are typically measured in centimeters per year, with the average rate of convergence being approximately 2 to 8 centimeters per year

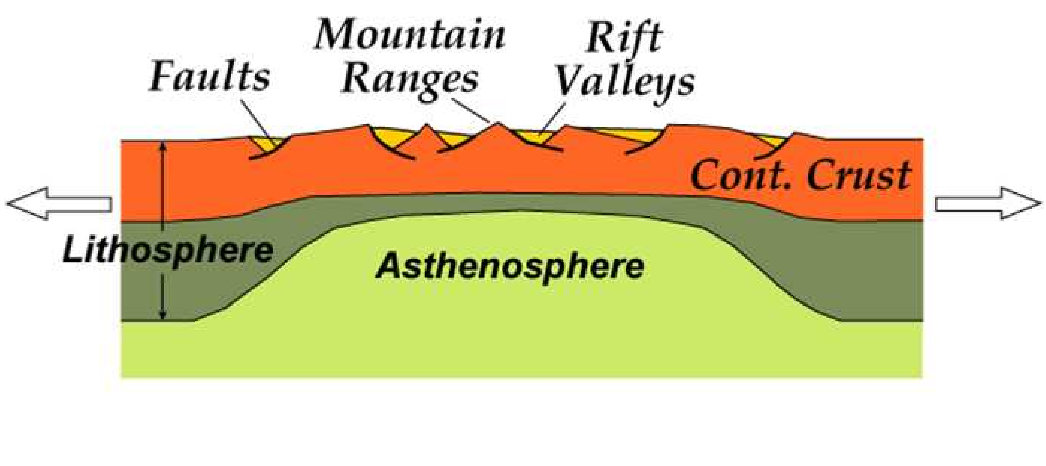




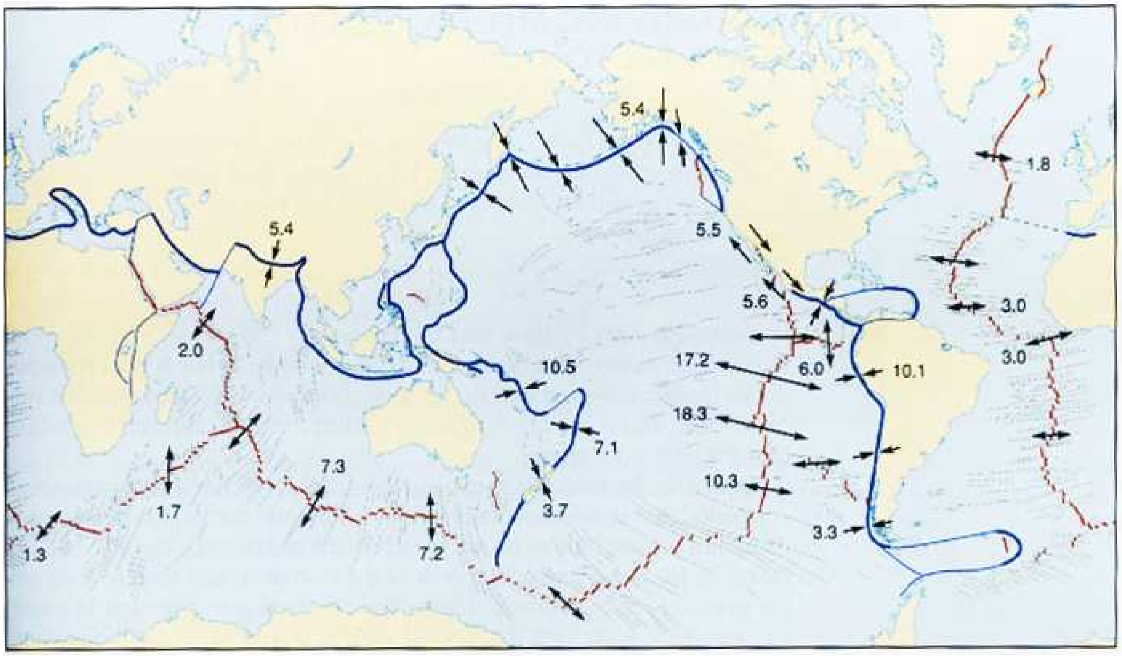
Q. What are plate boundaries collision types? Give examples?



Q. Draw the major aspects of plate collisions forming mid-oceanic ridge and rifting areas?

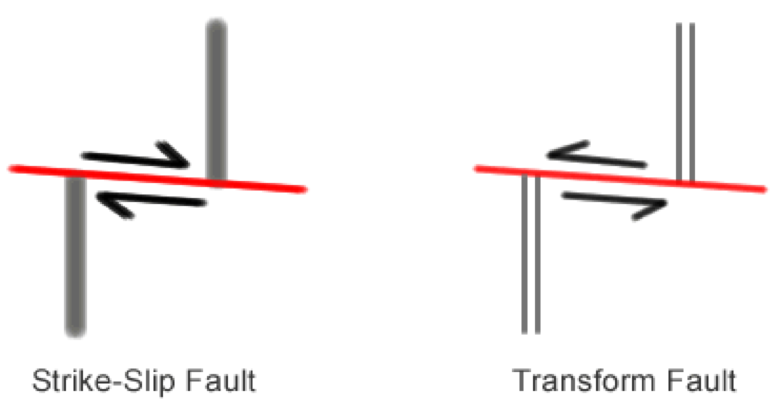


Q. What are the plate motion rates in the global? Which one is the fastest and the slowest ones?



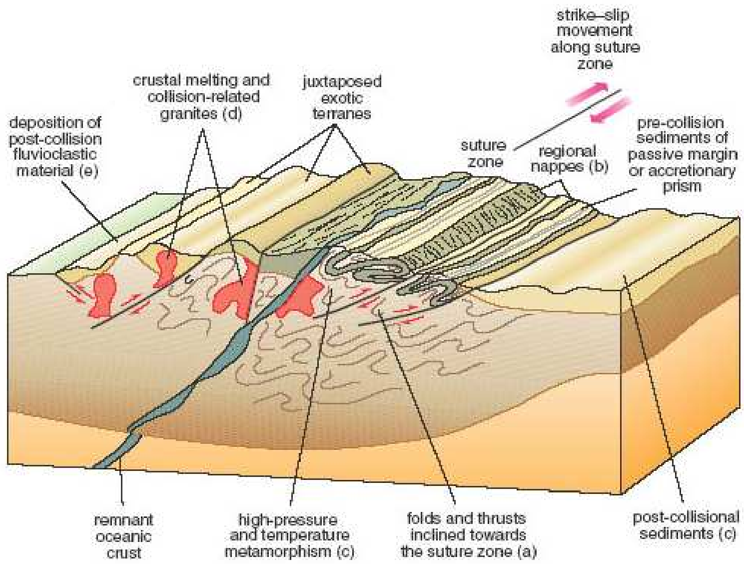
Q. What are the differences between strike-slip and transform faults?

- Transform faults can be distinguished from the typical strike-slip faults because the sense of movement is in the opposite direction. A strike-slip fault is a simple offset, however, a transform fault is formed between two different plates, each moving away from the spreading center of a divergent plate boundary. When you look at the transform fault diagram above, imagine the double line as a divergent plate boundary and visualize which way the diverging plates would be moving.



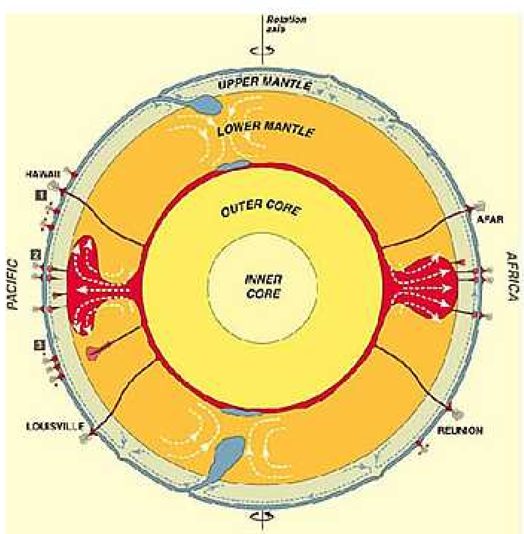
Q. What is the suture zone?

- The area where two continental plates have joined together through continental collision. Suture zones are marked by extremely high mountain ranges, such as the Himalayas and the Alps.



Q. What is mantle plume? Draw a figure of it and give examples?

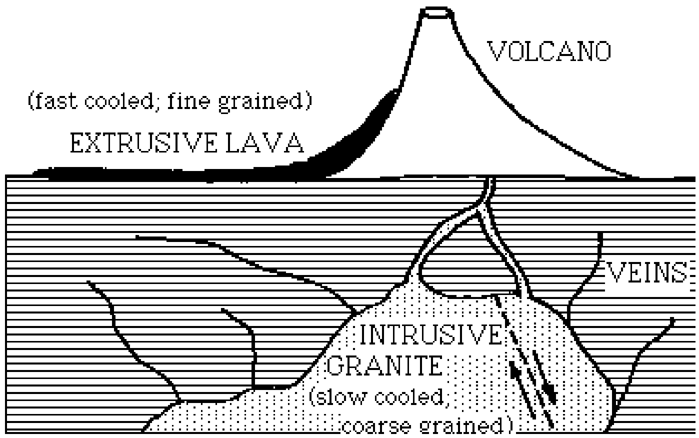
- It is an upwelling magma that rises from the mantle into the crust. It erupts as lavas when reach the surface. It produces volcanic rocks when it's remains below surface. It produces volcanoes, hotspots, and flood basalt. Examples are Africa and Pacific. A mantle plume is a secondary way that Earth loses heat, much less important in this regard than is heat loss at plate margins.



Q. What are the differences between Intrusive and extrusive rocks?

- Intrusive rocks formed by the crystallization of magma at a depth within the Earth are called intrusive rocks. Intrusive rocks are characterized by large crystal sizes. Examples are diorite, gabbro and granite.

- Extrusive rocks formed by the crystallization of magma at the surface of the Earth are called extrusive rocks. They are characterized by fine-grained textures because their rapid cooling at or near the surface did not provide enough time for large crystals to grow. Examples are basalt and rhyloite.



Q. What are the differences between gabbro and basalt rocks?

IGNEOUS ROCK CLASSIFICATION				
COLOR	LIGHT COLORED	MEDIUM COLOR	DARK COLOR	
CHEMISTRY	FELSIC	INTERMEDIATE	MAFIC	ULTRA MAFIC
COARSE GRAINED	GRANITE	DIORITE	GABBRO	PERIDOTITE
FINE GRAINED	RHYOLITE	ANDESITE	BASALT	KOMATIITE

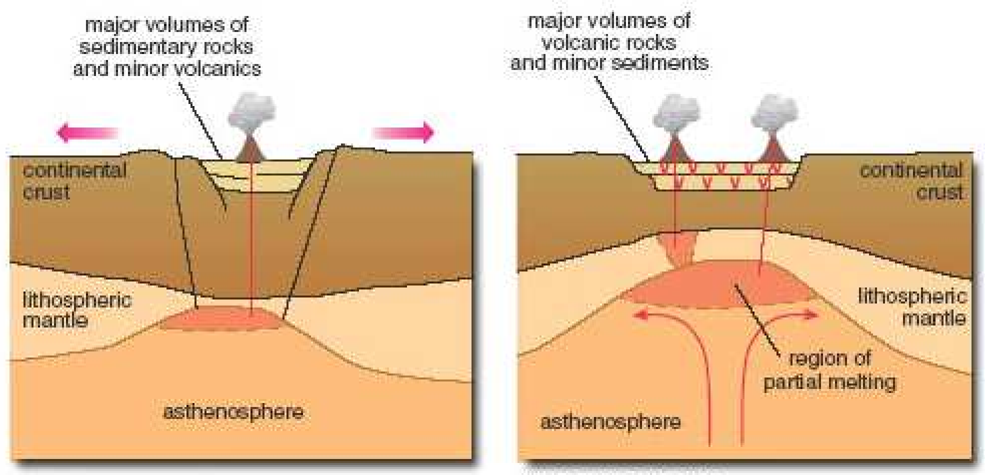
Q. What is the concept of gravity?

The outer core is not under enough pressure to be solid, so it is liquid even though it has a composition similar to that of the inner core

Q. What are the differences between passive and active rifting?

1. Active: results from local tension and drive by mantle plume.

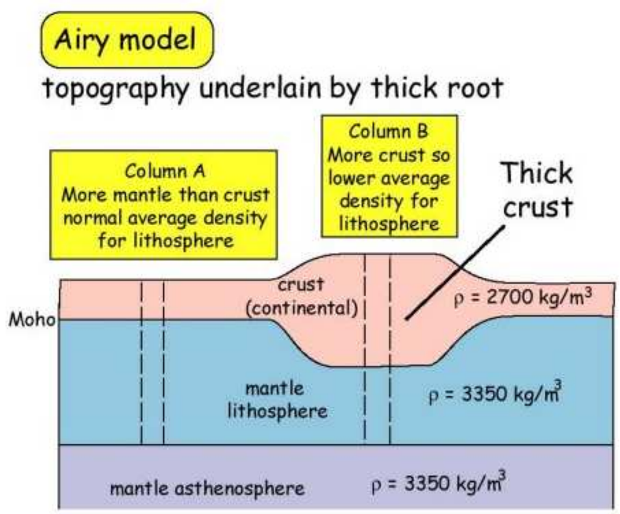
2. Passive: response to regional far field stress drive by slab pull.



(ii) PASSIVE RIFTING (iii) ACTIVE RIFTING

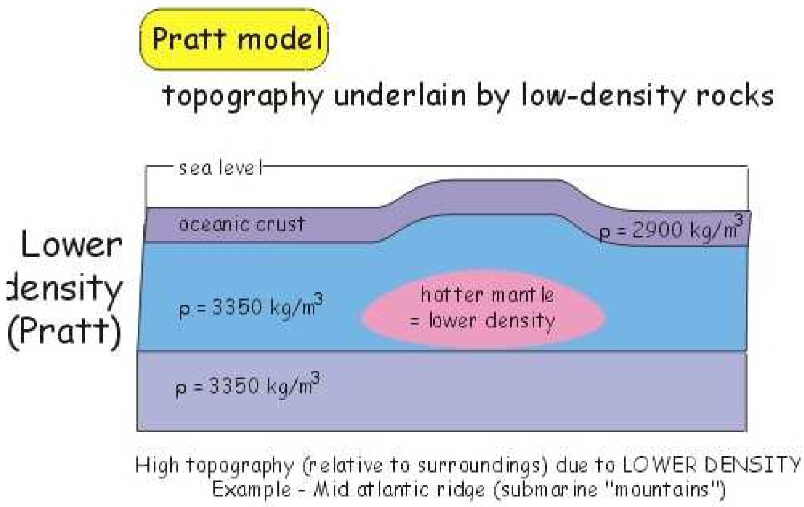
Q. What are the differences between Airy and Pratt's models?

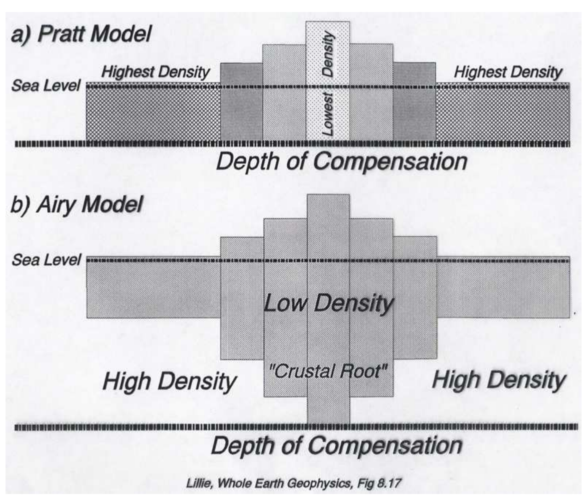
- Airy model is a model to account for isostasy which in the lithosphere assumes a constant density (ρ_c = 2670 kg/m^3), but in which topographic elevations (*h*) are compensated by the presence of 'roots' replacing high-density mantle rocks (ρ_m = 3300 kg/m^3) by lower-density lithospheric rocks. The depth of the root (*d*) is equal to $h\rho_c/(\rho-\rho_c)$.



High topography (relative to surroundings) due to THICK CRUST
Example - Himalayas/Tibet

- **Pratt model** is a model for the lithosphere that accounts for isostatic anomalies by assuming there is a level of compensation that lies at a constant depth everywhere. Below the level of compensation all rocks have the same density, but above it density decreases as topographic elevation increases. For a column of material anywhere on Earth, the mass lying above the level of compensation will be the same, and ρ_c^h a constant, where ρ_c is the density of the crust and *h* the topographic elevation. If the rocks are on the sea bed, then $\rho_c^h + \rho_w^d$ is a constant, where ρ_w is the density and *d* the depth, of sea water.





The principle of isostacy: The weight of rock columns of the same horizontal crust section area must be the same above the depth of compensation. Beneath a mountain, there are two ways to reach isostatic balance: 1). A flat "Moho" and different crustal density ("Pratt's model"). 2). A varying "Moho" and same crustal density ("Airy's model"). Note: Airy model is more realistic on the Earth

Q. What are the differences between Bouguer gravity and air-free gravity?

- Bouguer anomaly is computed from a free-air anomaly by computationally removing from it the attraction of the terrain, the Bouguer reduction. Bouguer = expected value of gravity (location) - actual value. It corrects the observed gravity value.

- Free-air gravity anomaly, often simply called the free-air anomaly, is the measured gravity after a free-air correction is applied to correct for the elevation at which a measurement is made. The free-air correction does so by adjusting these measurements of gravity be what would have been measured at sea level. Free-air = observed gravity - theoretical gravity. It measures the increase/decrease in mass within the earth.

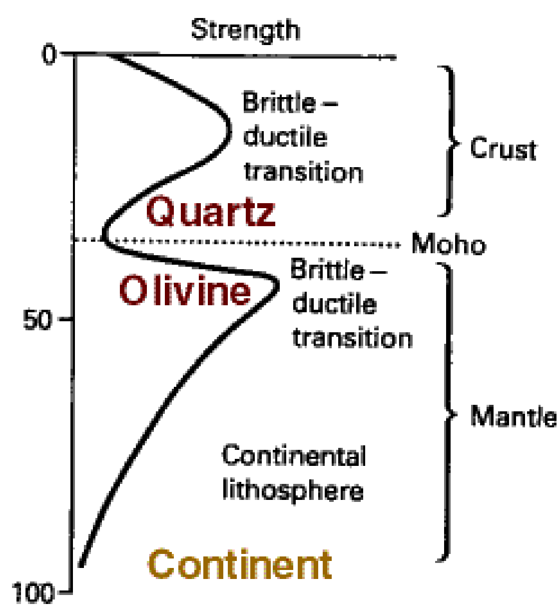
Q. Explain the strength profile for continental and oceanic lithosphere?

Strength of lithosphere is the strength of the lithosphere (i.e. the total force per unit width necessary to deform a lithospheric section at a given strain rate) is a function of composition, crustal thickness, and geotherm.

Strength of continental lithosphere:

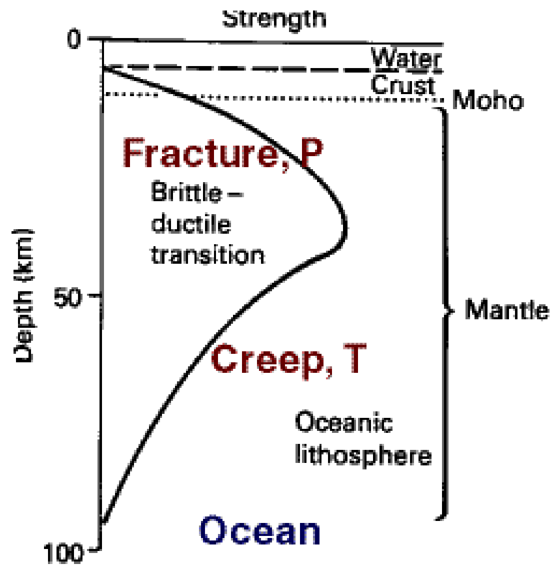
1. The limit of continental lithosphere strength depends on the contents of quartz and olivine.

2. The continental lithosphere is characterized by a layer of weakness at lower crust depth.



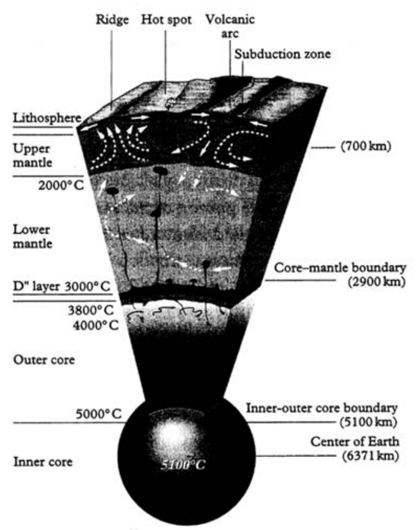
Strength of oceanic lithosphere:

1. The upper brittle crust gives a way to a region of high strength at depth of 20-60 km depending on the temperature gradient.



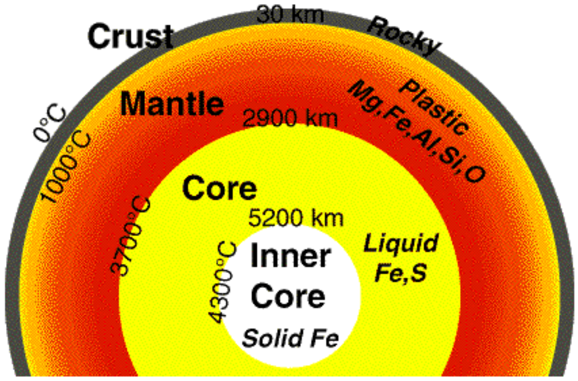
Q. What is "D" layer?

A strong change of density characterizes the core-mantle interface; it looks very abrupt so that this boundary acts as a quite perfect reflector for the seismic waves (200-300 km). There is, additionally, at the bottom of the lower mantle a layer called D" where an important change in the speed of P waves appears. That layer is a thermal and chemical boundary layer showing important lateral variability. (D" layer) is characterized by a decrease in seismic velocity.



Q. What are minerals assemblage for the crust and the mantle?

- Oxygen and Silicon are the two most common elements in the Earth's crust. These two elements bond to create silicates, which are the most abundant minerals in the earth's crust.
- Mantle rocks shallower than about 410 km depth consist mostly of olivine, pyroxenes, spinel-structure minerals, and garnet.



Q. What are the famous rift zones in the US?

- The Great Rift Zone. Other famous examples are the East African Rift and the Baikal Rift Zone.

Q. Explain left and right lateral motion?

- Left lateral is a type of strike-slip fault where the left block moves toward you and the right block moves away.

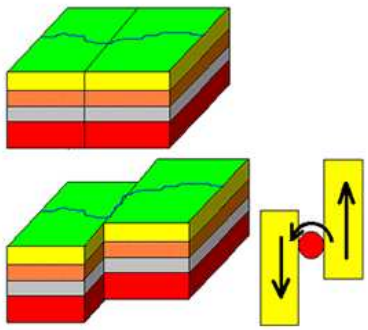
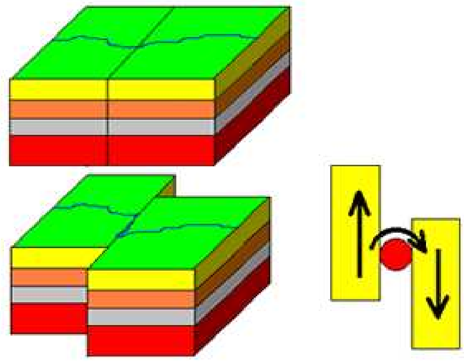


Diagram of left-lateral motion on fault. (Image courtesy of Steven Dutch, University of Wisconsin)

- Right lateral is a type of strike-slip fault where the right block moves toward you and the left block moves away.



(Image courtesy of Steven Dutch, University of Wisconsin)

Q. What are the differences between continental and oceanic crust?

Rock types	Continental	Oceanic
	Sedimentary, igneous and metamorphic	Mafic
layers	Upper: granite (50% silica) Lower: basalt (30 % silica)	1^{st}: unconsolidated sediments 2^{nd}: pillow lavas & sheeted dike 3^{rd}: gabbro
Thickness	35-40 km (exceed 70 km)	Less than 10 km
Density	Low (2.7 gm/cm^3)	High (3.3 gm/cm^3)
Age	4 billion years old	180 million years old

Q. What is the back azimuth?

a. **Back Azimuth**. A back azimuth is the opposite direction of an azimuth. It is comparable to doing "about face." To obtain a back azimuth from an azimuth, add 180 degrees if the azimuth is 180 degrees or less, or subtract 180 degrees if the azimuth is 180 degrees or more (Figure 6-3). The back azimuth of 180 degrees may be stated as 0 degrees or 360 degrees. For mils, if the azimuth is less than 3200 mils, add 3200 mils, if the azimuth is more than 3200 mils, subtract 3200 mils.

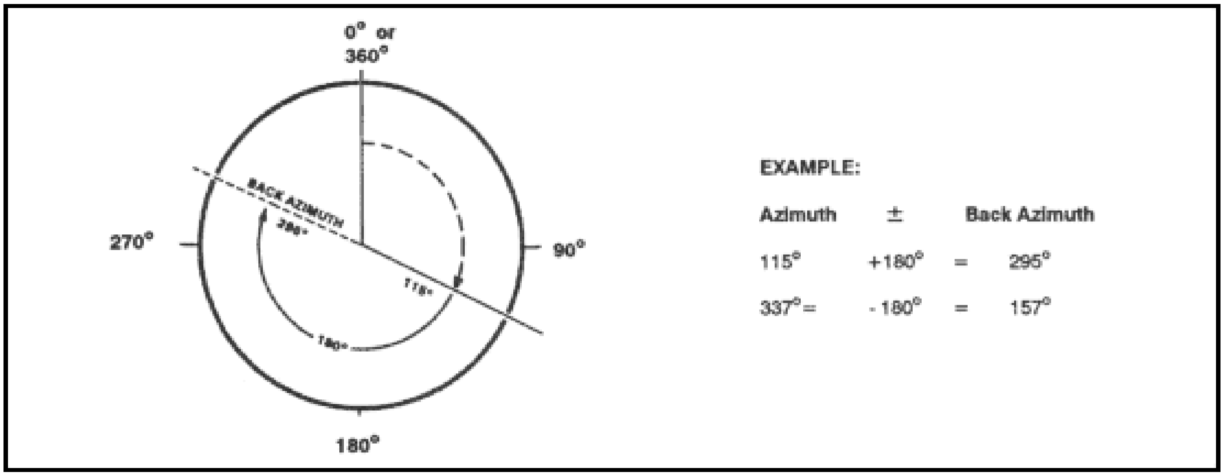


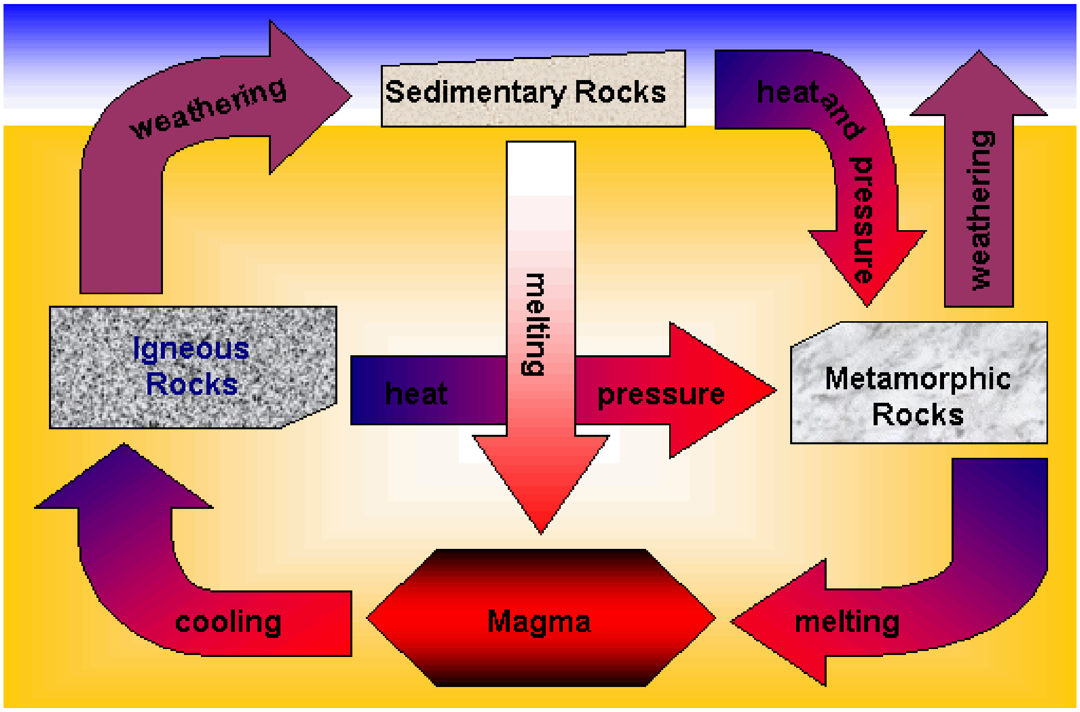
Figure 6-3. Back azimuth.

Q. Why the outer core is liquid?

- The outer core is not under enough pressure to be solid, so it is liquid even though it has a composition similar to that of the inner core

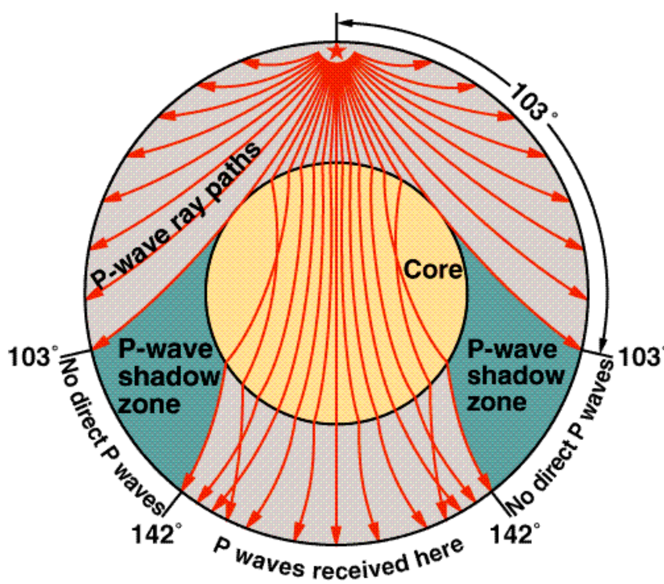
Q. Explain the formation of igneous, sedimentary, and metamorphic rocks?

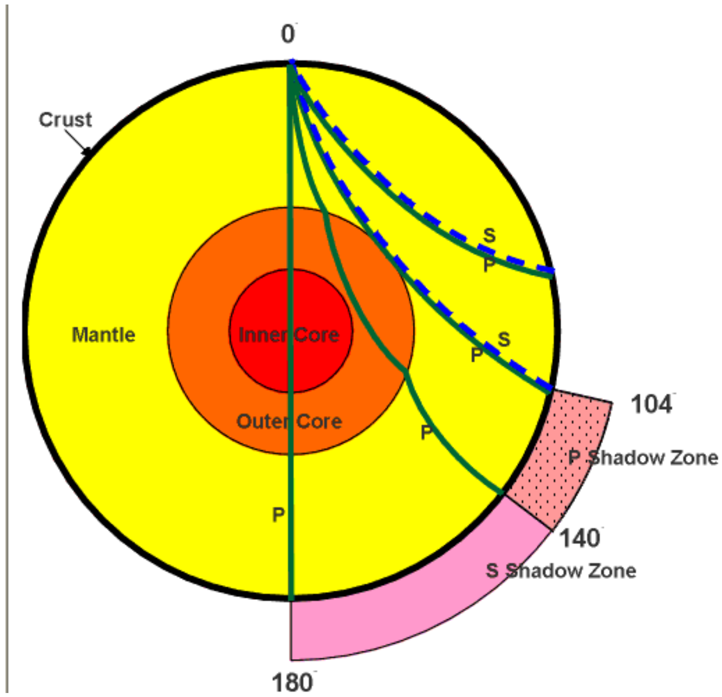
Rock types	Composition	Examples
Igneous	Form as molten rock cools and solidifies	Basalt, gabbro
Sedimentary	The products of mechanical and chemical weathering	Limestone, coal, and quarts
Metamorphic	produced from preexisting igneous, sedimentary, or even other metamorphic rocks	Marbles, schist, and slate



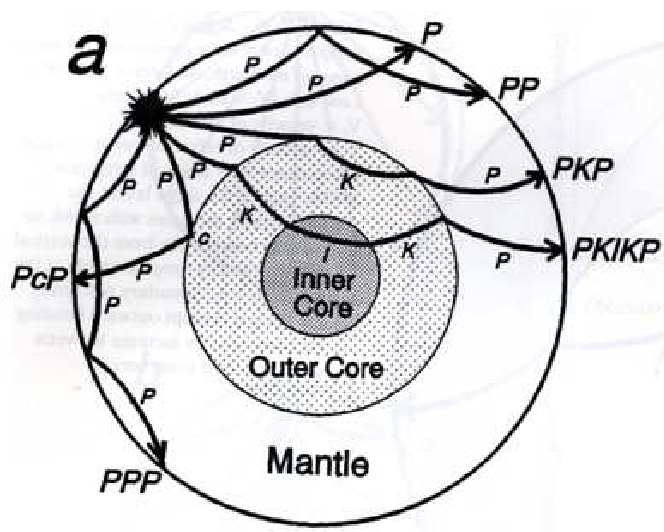
Q. What is the shadow zone?

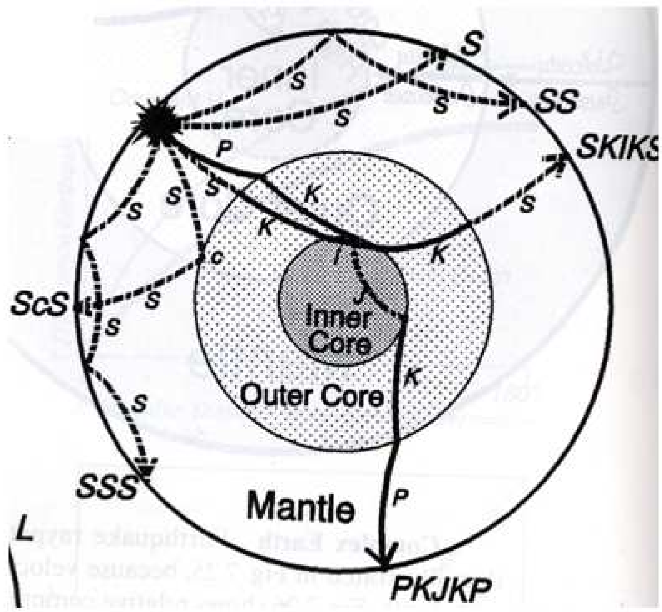
- A shadow zone is an area in which an S-Wave (secondary seismic wave) is not detected due to it not being able to pass through the outer core of the earth due to it being liquid.



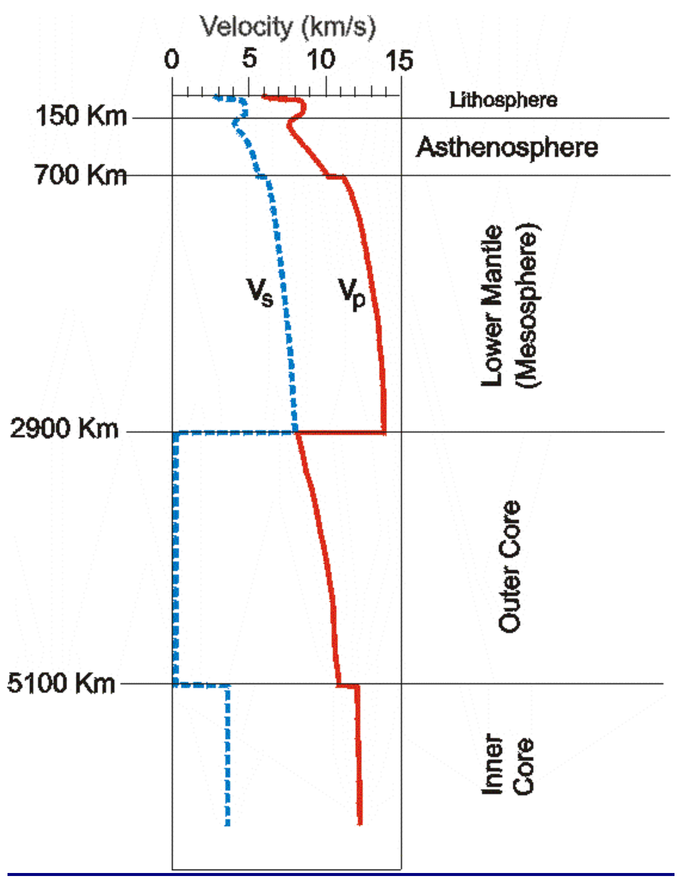


Q. Draw the figure for the converted P and S wave inside the earth body?

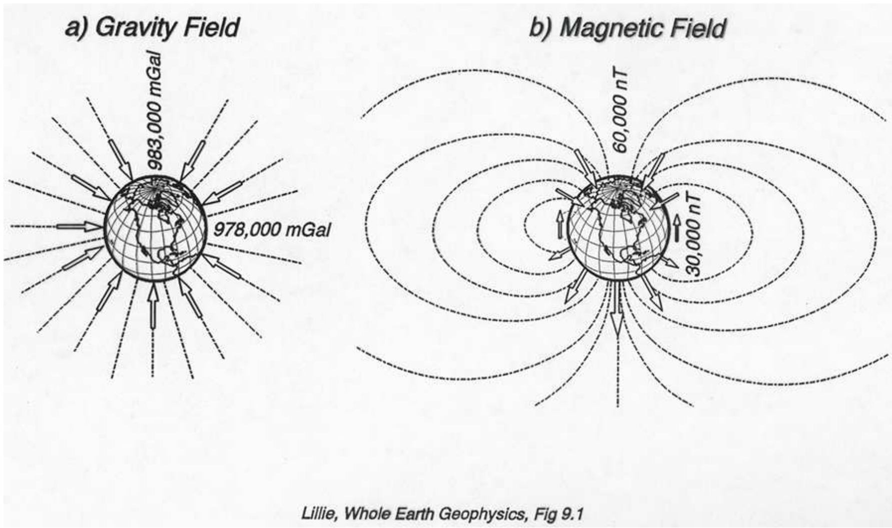




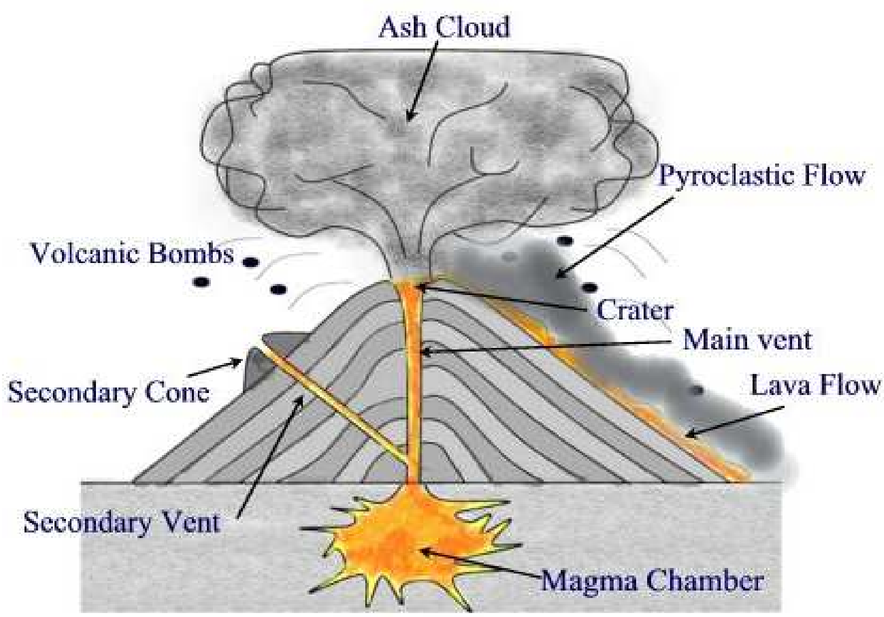
Q. Draw the P and S velocity curve inside the earth body?



Q. Draw gravity and magnetic filed of the earth?



Q. Draw a figure showing the main features of a volcano?



Main Features of a Volcano

Q. Why there are no earthquakes beyond 700 km?

1. No convection and slabs deeper than 700 km.

2. The end of subduction zone.

Q. Define density?

Density is defined as material mass per unit volume	
Crust	Mantle
2.7 gm/cm^3 or 3.3 gm/cm^3	4.1 gm/cm^3
Change of density	
Pressure	Temperature
Pressure increase → density increase	Temperature increase → density increase

Q. What are the differences between the upper and the lower crust?

Type	Upper	Lower
	Felsic	Mafic
Density	Low (2.7 gm/cm^3)	High (3.1 gm/cm^3)
Vp/Vs	Low (1.74)	High (1.84)
Rich in	Quartz	Iron/magnesium
Rock	Granite	Olivine

Q. What are the differences between felsic and mafic rocks?

	Felsic	Mafic
Color	Black/dark brown	Light
Mineral	High % of heavy minerals	Low % of heavy minerals
Eruptions	Gently	Violently
Represent	Deeper materials	Melting materials
Specific gravity	Less than 3.0	Greater than 3.0
Rich in	Quartz	Iron/magnesium
Example	Granite	Olivine

Q. What are the average velocities for P and S waves in the crust and the mantle?

Layer	V_p	V_s
Crust	6.7 km/s	2.9 km/s
Mantle	8.1 km/s	4.2 km/s

Q. What are the differences between seismic refraction and reflection?

	When	Where	Why
Reflection	Changes in V and ρ	Lower crust and Moho.	Oil exploration, cross section, and details structure.
Refraction	Changes in V	Within the crust.	Composition and crustal thickness.
Seismic velocities	Changes in V	Deeper crust.	Compositions and deep layers.
Snell's law	Relation between the angles of incidence and refraction	At the boundary between layers	Determine the direction of refracted ray-path.

Q. Explain Passion's ratio?

1. It is the changes of the diameter proportional to the change of length.

2. Material is stretched in one direction it tends to get thinner in the other direction.

3. High Poisson's ratio indicates mafic composition of the crust.

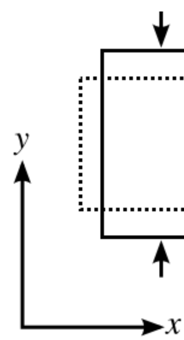
4. The range for most materials is from 0-0.5. Continental is 0.256 and oceanic is 0.30.

5. Poisson's ratio can be affected by:

    1. Temperature and pressure: the ratio will increase with increased pressure.

    2. Minerals contents: less heavy minerals will increase the ratio.

    3. Silica contents: more silica will increase the ratio.



Q. What are the earth's major spheres?

1. Hydrosphere "water".

2. Atmosphere "air".

3. Solid earth "rock".

4. Biosphere "life".

Q. Where do subduction zones occur?

- It takes place at the convergent boundaries. The edge of one lithosphere plate is forced below the edge of another. The denser plate will sink down. The plate will generate seismic and volcanic activity in the above plate. Examples: Japan, S. America, and Indonesia.

Q. Define Convection?

- Heat transfer in gas or liquid by circulation of currents from one place to another. When a fluid is heated from below. Convection takes place in a fluid when it is heated from below.

Q. What is deformation?

- Deformation is all changes in the original form, size, and shape of a rock. It also changes in location and orientation of the rock.

Q. What is the Moho?

1. Is the layer that separates the crust from the upper mantle.

2. It is a chemical boundary.

3. Ranges from 5-40 km.

4. The deepest one is 70 km depth beneath Tibetan Plateau.

Q. What does low amplitude of recorded Ps conversion means?

- A weak Moho transition zone.

Q. What is 420 km discontinuity?

1. The zone where velocities changes.

2. The zone where there are changes in the elastic properties of the rocks.

Q. Explain the velocity structure of the earth?

1. Velocities increases with depth because of pressure.

2. Sudden drop of P-wave at the outer core.

3. Sudden change in velocity and density at 670 km.

Q. What are the separation rates for oceanic ridges?

1. Fast: > 9 cm/year as in East Pacific Ridge.

2. Intermediate: 5-9 cm/year as in Northern East Pacific Rise.

3. Slow: 10-50 mm/a as in Atlantic Ridge.

Q. What do seismic velocities depend on?

- Elastic constants (bulk, young's, shear, Poisson's) and density.

Q. What is seafloor spreading hypothesis?

- An upwelling of mantle that creates new seafloor. The old seafloor descends into the mantle.

Q. What is wave coda?

- They are the directed converted phase (Pms), and the multiples waves (PPms and PSmS)

Q. Where do P-to-S contrasts observe?

1. At the Moho boundary.

2. At 410-km.

3. At 660-km.

Q. What are the continental rift extension forces?

1. Extensional fault.

2. Lower crustal attenuation.

3. Lower crustal intrusion forming pluton.

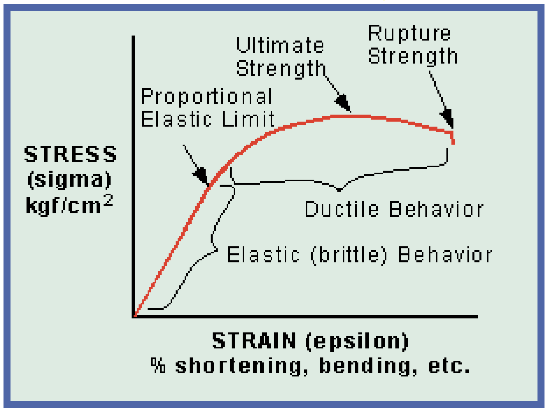
4. Example: East African Rift where the entire tectonic plates are in the process of breaking apart to create new plates.

Q. Explain ductile deformation (Plastic)?

1. When rocks bend or flow, like clay, it is called ductile deformation.

2. Most rocks have a very small region of elastic behavior and behave more like a plastic with increased stress (pressure).

3. The strength of the rock depends on temperature, pressure and composition.

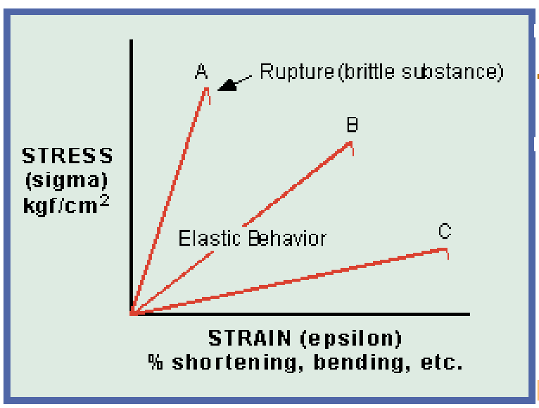


Q. Explain brittle Deformation (Elastic)?

1. When a rock breaks, it is called brittle deformation. Any material that breaks into pieces exhibits brittle behavior.

2. When the magnitude of an applied tensional stress exceeds the tensile strength of the material.

3. The strength of brittle rocks increase with confining pressure but decrease with temperature.



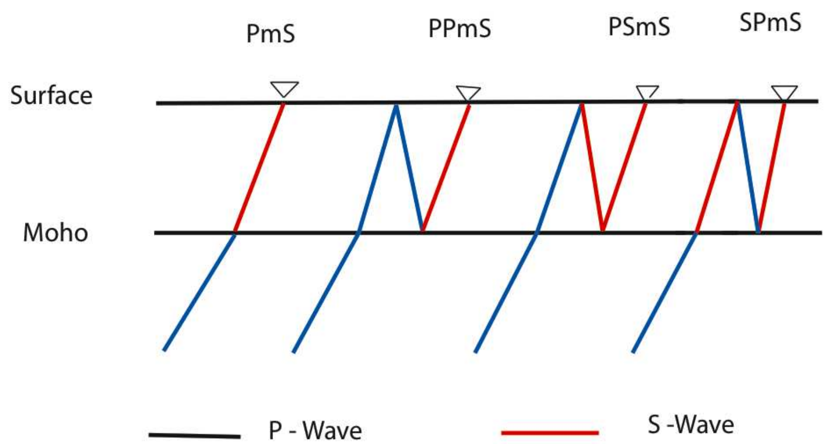
Q. What is receiver functions analysis?

1. Model the structure of the earth.

2. Image the depth to major velocity discontinuities in the crust and the uppermost mantle.

2. Use information from teleseismic earthquakes data recorded at three components seismograms “the first arrival is a refracted P-wave”.

3. Receiver functions calculated by the de-convolving the vertical from the radial and tangential components.



Q. What is seismology? And its importance?

- It is the study of earthquakes and waves produced by them. Seismology is the main tool to explore the Earth’s internal structures.

Q. What is the deepest focal depth of present earthquakes?

- At depth of 700 km.

Q. How many possible locations are there for the epicenter using data from tow station?

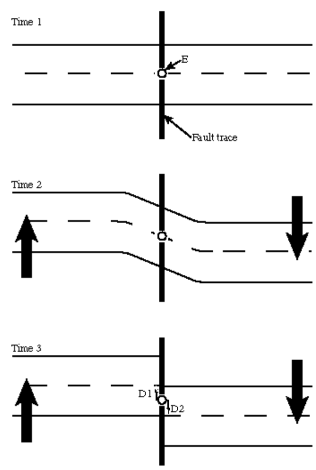
- There will be one or two locations, depending on where the circles intersect.

Q. How many possible locations are there for epicenter using data from 3 stations? Does a fourth station help to further pinpoint the epicenter?

- There is only one location will fits the data from the three stations. Yes, the fourth data set will confirm the location of the epicenter

Q. How do earthquakes occur?

- Earthquakes occur as plates on opposite sides of a fault are subjected to force and shift, they accumulate energy and slowly deform until their internal strength is exceeded. At that time, a sudden movement occurs along the fault, releasing the accumulated energy, and the rocks snap back to their original undeformed shape.

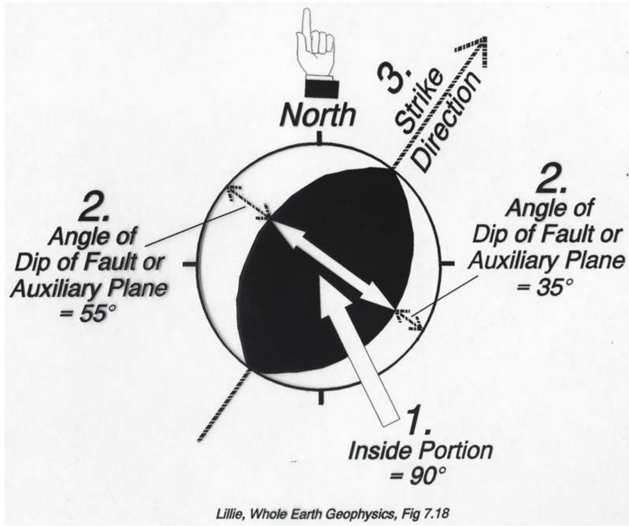


Q. What is earthquake cycle?

- Earthquakes most often occur along existing faults whenever the frictional forces on the fault surfaces are exceeded. The processes repeat over time and called earthquake cycle.

Q. What is focal mechanism of an earthquake?

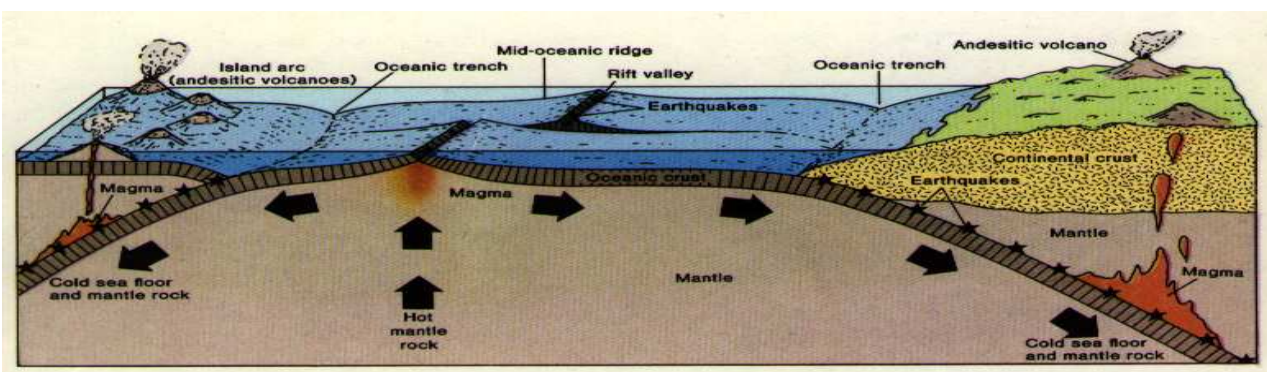
- The focal mechanism of an earthquake describes the inelastic deformation in the source region that generates the seismic waves. In the case of a fault-related event it refers to the orientation of the fault plane that slipped and the slip vector and is also known as a fault-plane solution. Focal mechanisms are derived from a solution of the moment tensor for the earthquake, which itself is estimated by an analysis of observed seismic waveforms.



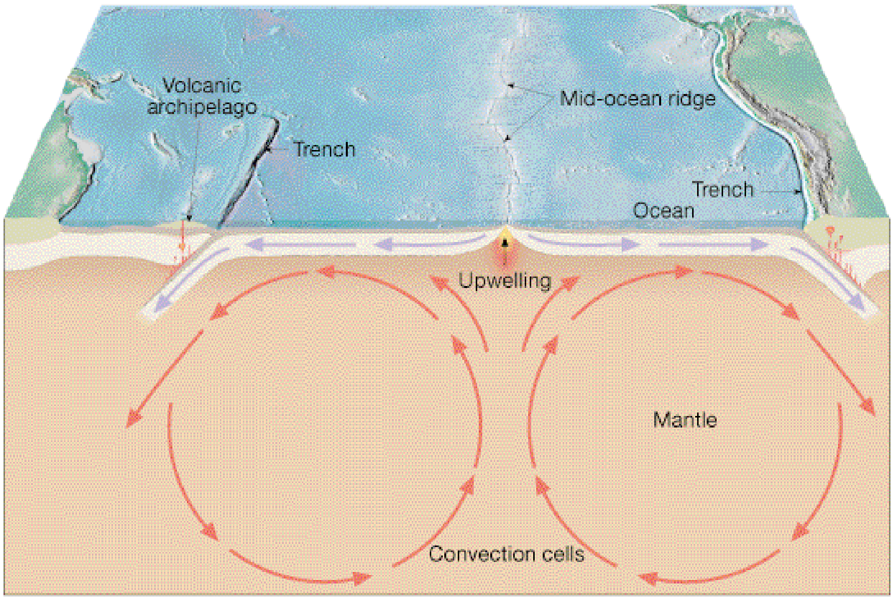
Q. What is crustal delamination?

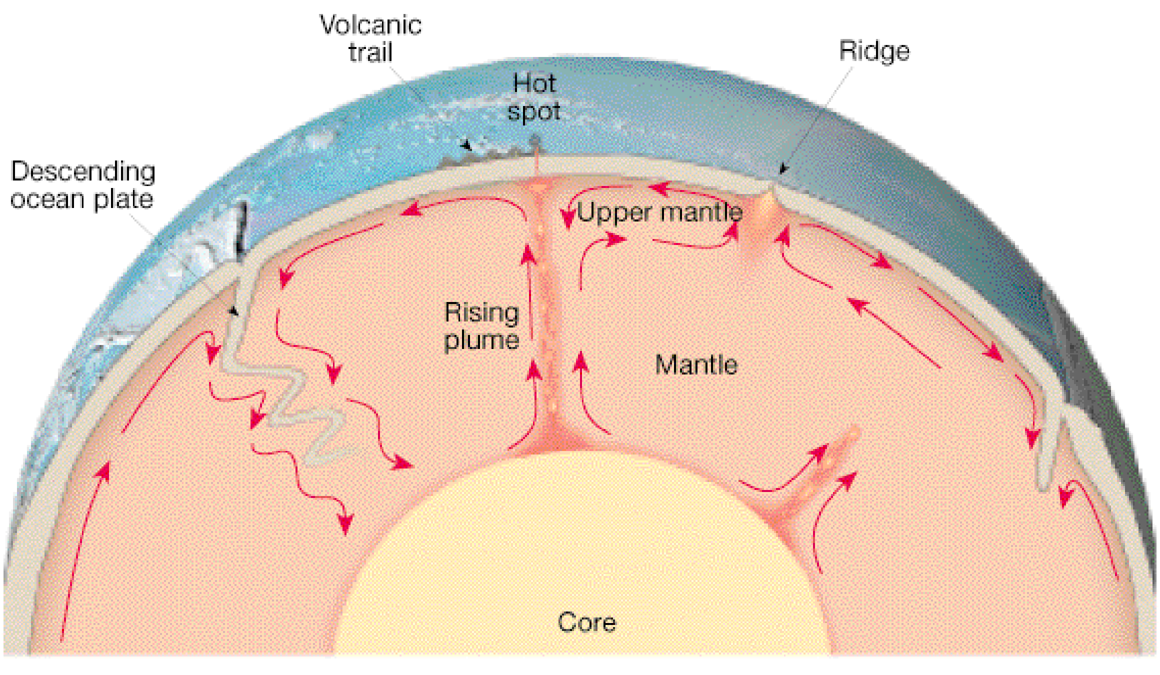
- In areas with thickened crust, the combination of pressure and temperature will turn the rocks in the "normal" lower crust to eclogite, which is heavier than the upper mantle. This instability will cause the sinking of the lower crust to the mantle and lead to delamination.

Q. Draw a figure of an oceanic trench?



Q. Draw a figure of mantle convection currents?





1

- **Geology**: is the science that pursues an understanding of planet earth.
- **Physical geology**: examines the materials composing earth and seeks to understand the processes that operate beneath and upon its surface.
- **Historical geology**: understand the origin of earth and its development through time.
- The study of physical geology logically comes first the study of earth history because we must first understand how earth works before we try to unravel its past.
- Earth is always changing either in fast rate or low, in large size or small.

2

- A great deal of geology is based on observations and experiments conducted in the field.
- **Uniformitarianism**: the physical, chemical, and biological laws that operate today have also operated in the geologic past. "The present is the key to the past".
- Some important geologic processes are not currently observable, but evidence that they occur is well established.
- **Erosion**: processes that wear land away.
- using radioactivity for determining the age of the earth. The age of the earth is at about 4.5 billion years.

3

- **Relative dating**: the events are placed in their proper sequence or order without knowing their age in years.
- **Law of superposition**: the youngest layer of rocks or lava flow layer is on top and the oldest in on the bottom, example like Grand Canyon.
- **Fossils**: the remains or trace of prehistoric life.
- **Principle of fossil succession**: fossil organisms succeed one another in a definite and determinable order, and therefore any time period can be recognized by its fossil content.

4

- a geologic event that occurred 100 million years ago may characterized as recent, and a rock sample that has been dated at 10 million years may be called young.
- Scientific facts are gathered in many ways, including laboratory studies and field observation and measurements.
- **Hypothesis or model**: untested explanation.
- Science is the acceptance of what works and the rejection of what does not.
- **Theory**: is a well-tested and widely accepted view the scientific community agrees on.

5

- **Scientific method**: researches gather facts through observations and formulate scientific hypotheses and theories.
- **Scientific investigations**:

1. Collection of scientific facts through observations and measurements.
2. Develop hypotheses/models to explain these facts.
3. Test the hypotheses.
4. Accept or reject the model.

- Earth four major spheres:

1. Hydrosphere "water".
2. Atmosphere "air".
3. Solid earth "rock".
4. Biosphere "all life on the plant".

6

- **Hydrosphere**: is a dynamic mass of water that is continually on the move, evaporating from the oceans to the atmosphere, precipitating to the land, and running back to the ocean again (71% global ocean, it account for about 97% of earth's water). Radius of solid earth is about 6400 km.
- Earth system is powered by energy from two sources: 1. The sun: weather & climate, ocean circulation, and erosional processes "produce sedimentary rocks". 2. Earth's interior "create igneous & metamorphic rocks."
- **Rock cycle**: is the loop that involves the processes by which one rock changes to

7

- **Magma**: is the molten material that forms in certain environments in earth's interior where temperature and pressure are such that rock.
- **Crystallization**: when magma cools and solidifies. May occur beneath the surface or at the surface. The resulting rocks are called igneous rocks.
- If igneous rocks are exposed at the surface, they will undergo weathering "full of fire".
- **Lithification**: sediment is usually into sedimentary rock when compacted by weight of overlying layers or when cemented as percolating water fills the pores with minerals matter.

8

- If the resulting sedimentary rock is buried deep within earth and involved in the dynamics of mountain building, or intruded by a mass of magma, it will be subjected to great pressure and/or intense heat. The sedimentary rock will react to the changing environment and turn into metamorphic rock "form change".
- When metamorphic rock is subjected to additional pressure changes or to still higher temperatures, it will melt, creating magma, which will eventually crystallize into igneous rock.

9

- **Divisions of earth's surface**:

1. Continents: elevation is about 840 m above sea level. 40% of earth's surface.
2. Ocean basins: average depth is 3800 meters. 60% of earth's surface.

- Examination of mountainous terrains reveals that most are places where thick sequences of rocks have been squeezed and highly deformed.
- The oceanic ridge system consists of layer upon layer of igneous rock that has been fractured and uplifted.
- Earth is one of nine planets that along with several dozens moons and numerous smaller bodies revolve around the sun.

10

- the nebular hypothesis suggests that the bodies of our solar system evolved from an enormous rotating cloud called the solar nebula, composed mostly of hydrogen and helium, with a small percentage of the heavier elements.
- Earth three layers defined by their chemical compositions: crust, mantle, and core.
- Earth also can be divided into five layer based on physical properties. The physical properties used to define such zones include whether the layer is solid or liquid and how weak or strong it is.

11

- **Crust**: usually thin, rocky outer skin, and is generally divided into oceanic and continental crust.

1. Oceanic: is roughly 7 kilometers thick and composed of dark igneous rocks called basalt. Rocks are younger (180 Ma or less and more dense about 3.0 g/cm^3)
2. Continental: curst average 35-40 kilometers thick but may exceed 70 kilometers. The upper crust consists of granitic rock called granodiorite, whereas the composition of the lowermost crust is more akin to basalt (rocks are old than an oceanic crust 4 billion years old and less dense about 2.7 g/cm^3).

12

- **Mantle**: over 82 percent of earth's volume is contained in the mantle and extend to a depth of 2900 kilometers.
- The boundary between the crust and mantle represents a marked change in chemical composition.
- The dominant rock type in the upper mantle is peridotite that has a density of 3.3 g/cm^3.
- **Core**: the composition of the core is thought to be an iron-nickel alloy with minor amounts of oxygen, silicon, and sulfur. The iron-rich material has an average density of nearly 11 g/cm^3 and approaches 14 times the density of water at earth's centre.

13

- Temperature at a depth of 100 kilometers is between 1200^{0}C and 1400^{0}C. Temperature at earth's centre may exceed 6700^{0}C.
- The increase in pressure with depth causes a corresponding increase in rock density.
- Earth can be divided into five main **layers based on physical properties** and mechanical strength:

1. Lithosphere "crust".
2. Asthenosphere "upper mantle".
3. Mesosphere "lower mantle".
4. Outer core.
5. Inner core.

14

- The deepest mine in the world is 4 km in South Africa, and the deepest drilled hole in the world is 12 km in Russia.
- **Lithosphere** averages about 100 km but may be more than 250 km thick below the older portions of the continents. In the ocean, lithosphere is only a few km thick along the oceanic ridges but increases to perhaps 100 km in regions of older and cooler oceanic crust.
- **Asthenosphere** is up to 660km, soft comparatively weak layer. The top layer has a temperature/pressure regime that results in a small amount of melting.

15

- At the depth of the uppermost asthenosphere, rocks are close enough to their melting temperature that they are very easily deformed.
- **Mesosphere** is the depth when rocks gradually strengthen with depth. Depth between 660 and 2900 km. rocks are very hot and capable of very gradual flow.
- **Outer core** is a liquid layer 2270 km thick. It is the convective flow of metallic iron that generate earth's magnetic field.
- **Inner core** is a sphere having a radius of 3486 km. materials are stronger than the outer core and behaves like a solid.

16

- **Continental drift**: continents moved about the face of the planet.
- **Theory of plate tectonics**: earth's lithosphere is broken into numerous slabs called plates that are in motion and are continually changing shape and size.
- **Seven major lithosphere plates**: North America, South America, Pacific, African, Australian, and Antarctic. Intermediate-size plates include the Caribbean, Nazca, Philippine, Arabian, Cocos, and Scotia plates.
- Lithospheric plates move relative to each other at a very slow but continuous rate that averages about 5 cm a year.

17

- The movement of the plates is driven by the unequal distribution of heat within earth. This movement generates earthquakes, volcanoes, and mountains.
- **Plate boundaries**: 1. Divergent: where plates move apart, resulting in upwelling of material from the mantle to create new sea floor. 2. Convergent: where plates move together, resulting in the subduction of oceanic lithosphere into the mantle. Convergence can also result in the collision of two continental margins to create a major mountain system. 3. Transform: where plates grind past each other without the production or destruction of lithosphere.

18

- **Divergent**: occur at the mid-ocean ridge. Hot material slowly cools to hard rock, production new slivers of seafloor. This happens over millions of years, adding thousands of square kilometers of new seafloor [Mid-Atlantic Ridge] that extend for over 70,000 km through all major ocean basins.
- This mechanism has created the floor of the Atlantic Ocean during the past 160 Ma and is appropriately called **seafloor spreading**.
- Low spreading rate is 2.5 cm/yr as in North Atlantic. Fast spreading rate is 20 cm/yr as in East Pacific Rise.

19

- The thickness of oceanic lithosphere is age dependent. The older (cooler) it is, the greater its thickness.
- Although new lithosphere is constantly being added at the oceanic ridges, the planet is not growing in size; its total surface area remains constant.
- **Convergent**: as two plates slowly converge, the leading edge of one slab is bent downward, allowing it to slide beneath the other [Nazca plate].
- **Subduction zone**: plate margins where oceanic crust is being consumed.
- As the subducted plate moves downward, it enters a high-temperature, high-pressure environment.

20

- **Volcanic island arc**: chain of volcanic structure that emerged from the sea [Aleutian, Mariana, and Tonga Island].
- **Transform**: located where plates past each other without either generating new lithosphere or consuming old lithosphere. These faults form in the direction of plate movement [San Andreas Fault and the Alpine fault of New Zealand].

21

- All of the processes studied by geologists are in some way dependent on the properties of the basic earth materials' rocks and minerals.
- **Minerals**: any naturally occurring inorganic solids that possess any orderly internal structure and a definite chemical composition.
- For any earth material to be considered a mineral, it must exhibit the following characteristics: 1. It must occur naturally. 2. It must be inorganic. 3. It must be a solid. 4. Its atoms must be arranged in a definite pattern. 5. It must have a definite chemical composition that may vary within specified limits.

22

- **Rock**: is any solid mass of mineral or mineral-like matter that occurs naturally as part of our planet. A few rocks are composed almost entirely of one mineral like limestone [calcite].
- **Aggregate**: minerals are joined in such a way that properties of each mineral are retained.
- Around 4,000 minerals are defined by its chemical compositions and internal structure.
- Most minerals are chemical compounds with unique properties that are very different from the elements that comprise them.

23

- A rock is a mixture of minerals, with each mineral retaining its own identity.
- **Physical properties of minerals**:

1. Crystal form. 2. Luster: is the appearance or quality of light reflected from the surface of a mineral. 3. Color. 4. Hardness. 5. Cleavage: the tendency of a mineral to break along planes of weak bonding. 6. Fracture: most minerals fracture irregularly. 7. Specific gravity: the ratio of the weight of a mineral to the weight of an equal volume of water.

24

- **Igneous rocks**: form as molten rock cools and solidifies; they make up the bulk of earth's crust.
- **Magma** is formed by a process called partial melting that occurs within earth's crust and upper mantle to depths of 250 km. Magma exists beneath earth's surface
- **Lava** formed from magma that reaches earth's surface and has lost materials as gas or water vapor.
- **Extrusive/Volcanic** when igneous rocks solidify at the surface.
- **Intrusive/Plutonic** when igneous rocks form at depth before reaching the surface.

25

- The solid components in magma are silicate minerals that have already crystallized from the melt. As the magma body cools, the size and number of crystals increase.
- Water vapor (H_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2) are the most common gases found in magma.
- **Volatiles**: are those materials that will readily vaporize at surface pressure.
- **Crystallization**: when magma cools, the ion in the melt begin to lose their mobility and arrange themselves into orderly crystalline structure.
- In the process of crystallization, cooling reverses the event of melting.

26

- Magma may generate rocks with widely differing compositions.
- Igneous rocks are classified by their texture and mineral composition.
- **Texture**: is used to describe the overall appearance of the rock based on: size, shape, and arrangement of its interlocking crystal.
- Three factors contribute to the textures of igneous rocks: 1. The rate at which magma cools. 2. The amount of silica present. 3. The amount of dissolved gases in the magma.
- The rate of cooling is the dominant factor.

27

- Slow cooling promotes the growth of fewer but larger crystal.
- **Aphanitic**: igneous rocks that from at the surface or as small masses within the upper crust where cooling is relatively rapid possess a very fine-grained texture.
- Fine-grained rocks are defined as light, intermediate, dark in color.
- **Phaneritic**: when magma slowly solidify far below the surface. Rocks consist of a mass of intergrown crystal, which roughly equal in size and large enough so that the individual minerals can be identified without the aid of microscope.

28

- **Viscosity**: measure the fluid's resistance to flow.
- The products of mechanical and chemical weathering constitute the raw materials fro **sedimentary rocks**.
- Sedimentary rocks account for only about 5% of earth's outer 16 km.
- About 75% of all rock outcrops on the continents are sedimentary, and they are deposited at the earth's surface.
- Sedimentary rocks contain within them indications of past environments in which their particles were deposited and clues to the mechanisms involved in their transport.

29

- Sedimentary rocks contain fossils which are vital tools in the study of the geologic pas.
- Coal is an important for energy. Petroleum and gas are associated with sedimentary rocks.
- Change can occur to sediment from the time it is deposited until it becomes a sedimentary rock and is subsequently subjected to the temperature and pressure that convert it to metamorphic rock.
- The deeper sediment is buried, the more it is compacted and the firmer it become.

30

- **Pore pressure**: is the open space between particles.
- An orange or dark red color in a sedimentary rock means that iron oxide is present.
- **Types of sedimentary rocks**:

1. **Detrital sedimentary rocks**: derived from both mechanical and chemical weathering, like clay minerals, quartz, feldspars and mica. The presence in sedimentary rocks indicates that erosion and deposition were fast enough to preserve some of the primary minerals from the source rock before they could be decomposed.

31

- Particle size is the primary basis fro distinguishing among various detrital sedimentary rocks, plus the size of component grains.
- Currents of water or air sort the particles by size; the stronger the current, the larger the particle size carried. Very little energy needed to transport clay
- Common detrital sedimentary rocks, in order of increasing particle size, are shale, sandstone, and conglomerate or breccia.

32

2. **Chemical sedimentary rocks**: produced largely by chemical weathering.
- **Inorganic**: processes such as evaporation and chemical activity can produce chemical sediments.
- **Limestone** represents about 10% of the total volume of all sedimentary rocks, which is the abundant chemical sedimentary rock. It is composed of the mineral calcite ($CaCO_3$).

33

- Sedimentary rocks are important in the interpretation of earth history. By understanding the conditions under which sedimentary rocks form, including information about the origin of its component particles, the method and length of sediment transport, and the nature of the place where the grains eventually came to rest; that is, the environment of deposition.
- Each site characterized by a particular combination of geologic processes and environmental conditions. That is, their component minerals originated and were deposited in the same place.

34

- **Sedimentary environments** are placed into one of three categories: 1. Continental environments: are dominated by the erosion and deposition associated with streams. The nature of the sediments deposited is influenced by climate 2. Marine environments: shallow marine and deep marine. 3. Transitional (shoreline): the zone between marine and continental environments.
- Changes in past can be seen when a signal nit of sedimentary rock is traced laterally.

35

- Sedimentary rocks form as layer upon layer of sediments accumulates in various depositional environments. These layer, called **strata** “deposit as horizontal layer”, or **beds**, are the single characteristics feature of sedimentary rocks.
- The variations in texture, composition, and thickness reflect the different conditions under which each layer was deposited.
- **Bedding planes** are flat surfaces along which rocks tend to separate or breaks. Change in the grain size or in the composition of the sediments can create bedding planes.

36

- Each bedding plane marks the end of one episode of sedimentation and the beginning of another.
- **Ripple marks** are small waves of sand that develop on the surface of a sediment layer by the action of moving water or air.
- **Metamorphism** occurs deep within earth, beyond our direct observation.
- The study of metamorphic rocks provides important insights into the geologic processes that operate within earth’s crust and upper mantle.
- **Metamorphic rocks** are produced from preexisting igneous, sedimentary, or even other metamorphic rocks.

37

- Every metamorphic rock has a **parent rock**, the rock from which it was formed.
- Metamorphism takes place where preexisting rock is subjected to temperature and pressure unlike those in which it formed.
- They begin to occur a few kilometers below earth's surface and extending into the upper mantle.
- During metamorphism the rock must remain essentially solid.
- **Regional metamorphism**, which produces the greatest volume of metamorphic rock, occurs at convergent boundaries where lithospheric plates collide.

38

- **The agent of metamorphism**: heat, pressure "stress", and chemically active fluids.
- In the upper crust the increase of temperature with depth, (**geothermal gradient**), average between 20-30^{o}C per kilometer.
- The deeper one goes, the hotter it gets.
- Pressure increase with depth as the thickness of the overlying rock increases.
- **Confining pressure** which is analogous to water pressure, where the forces are applied equally in all directions.
- **Differential stress**: when rocks are subject to direct pressure where tectonic plates collide to generate mountains.

39

- A **geologic time scale** was developed to show the sequence of events based on relative dating principles.
- **Eons** represent the greatest expanses of time. The eon that began about 540 million years ago is the **Phanerozoic,** "visible life". The Phanerozoic eon is divided into **eras**. The three eras within the Phanerozoic are the **Paleozoic** "ancient life", the **Mesozoic** "middle life", and the **Cenozoic** "recent life". Each era is subdivided into time units known as **periods**. The Paleozoic has seven, the Mesozoic three, and the Cenozoic two. Each period is divided into smaller units called **epochs**.

40

- The **Cambrian** is divided into three eons, the **Hadean** "world of departed spirit", the **Archean** "ancient", and the **Proterozoic** "before life". They are also referring as the **Precambrian**.
- The farther back we go, the less that is known.
- The results of tectonic activity are strikingly apparent in earth's major mountain belts.
- **Deformation** refers to all changes in the original form and/or size of a rock body. It also produces changes in the location and orientation of rock.
- Most crustal deformation occurs along plate margins.

41

- Plate motions and the interactions along plate boundaries generate tectonic forces that cause rock units to deform.
- **Types of stress**:

1. **Differential stress**: when stress is applied unequally in different directions. Differential stress that shortens a rock body is known as compressional stress which is associated with plate collisions tend to shorten and thicken earth's crust by folding, flowing, and faulting.
2. **Tensional stress**: when stress tends to elongate or pull apart a rock unit. Where plates are being rifted apart, tensional stresses tend to lengthen those rock bodies located in the upper crust.

42

3. **Strain**: where differential stress causes rocks to move relative to each other in such a way that their original size and shape are preserved. Strained bodies do not retain their original configuration during deformation.

- **Seismic energy** travels out from its source in all directions as waves. **Ray** is the path taken by these waves.
- The velocity of seismic waves depends on the density and elasticity of the intervening material. Crystalline rock transmits seismic waves more rapidly than does a layer of unconsolidated mud.

43

- **The speed of seismic waves** generally increases with depth because pressure increases and squeezes the rock into a more compact elastic material.
- **P-waves** "compressional wave" vibrate back and forth in the same plane as their direction travel, are able to propagate through liquids as well as solids because, when compressed, these materials behave elastically; that is, they resist a change in volume and, like a rubber band, return to their original shape as a wave passes. P-wave travel faster than S-wave

44

- **S-wave** "shear wave" vibrate at right angles to their direction of travel, cannot propagate through liquids because, unlike solids, liquids have no shear strength. That is, when liquids are subjects to forces that act to change their shapes, they simply flow.
- **Discontinuity** is the boundary between the two dissimilar materials.
- Compositional layering in earth's interior resulted from density sorting that took place during an early period of partial melting. During this period heavier elements, like iron and nickel, sank as the lighter rocky components floated upward.

45

- The **crust**: earth's comparatively thin outer skin that ranges in thickness from 3km at the oceanic ridges to over 70km in some mountain belts, such as the Andes and Himalayas.
- The **mantle**: a solid rocky 9silica-rich) shell that extends to a depth of about 2900km.
- The **core**: an iron-rich sphere having a radius of 3486 km.
- The increase in pressure with depth causes a corresponding increase in rock density.
- Pressure also increases with depth and tends to increase rock strength.

46

- **The five main layers of earth based on their physical properties**:

1. **Lithosphere**: average about 100 km in thickness but may be 250 km thick or more below older portions of the continent. Within the ocean basins, lithosphere is only few kilometers thick along the oceanic ridges but increases to 100 km in regions of older and cooler oceanic crust.
2. **Asthenosphere**: is soft and weak layer. The rocks get progressively hotter and weaker with increasing depth "more easily deformed". The uppermost is weak because it is near its melting point.

47

3. **Mesosphere**: between the depth of 660 km and 2900 a more rigid layer. The rocks are still very hot and capable of very gradual flow.
4. **Outer core**: is a liquid layer 2270 km thick. It is the convective flow of metallic iron within this zone that generates earth's magnetic field.
5. **Inner core**: is a sphere having a radius of 3486 km. the material is stronger than the outer core and behaves like a solid.

- **Moho**: the boundary that separates crustal materials from rocks of different composition in the underlying mantle.

48

- P-wave velocities decrease by 40% as they enter the core, because melting reduced the elasticity of rocks.
- **Wave shadow zone**: P-wave diminishes and eventually dies out completely about 105^o from an earthquake. Then, about 140^o away, the P waves reappear, but two minutes later than would be expected based on the distance traveled.

49

Continental crust:

- Earth's crust averages less than 20 km thick, making it the thinnest of earth's divisions.
- Crustal rocks of the stable continental interiors average about 35-40 km thick. However, the crust may exceed 70 km.
- The oceanic crust is much thinner, ranging from 3-15 km thick and averaging about 7 km thick. Further, crustal rocks if the deep-ocean basins are compositionally different from those of the continents.
- Continental rocks have an average density of about 2.7 g/cm^3 and some exceeds 4 billion years old.

50

- The average composition of upper continental rock is estimated to be comparable to the Felsic igneous rock **granodiorite**.
- The continental crust is enriched in the elements potassium, sodium, and silicon.
- Large quantities of basaltic and andesitic rocks are also found on the continents.
- The lowermost crust is thought to have a composition similar to basalt.

Oceanic crust:

- The rocks are younger 180 million years or less and more dense about 3.0 g/cm^3.
- Most composition of ocean floor is basalt.

51

- Over 82% of earth's volume is contained within the **mantle**, a nearly 2900 km thick shell of silicate rock extending from the base of the crust (Moho) to the liquid outer core.
- The mantle is described as a solid rocky layer, the upper portion of which has the composition of the ultramafic rock peridotite.
- The mantle is divided into mesosphere "lower mantle" and asthenosphere "upper mantle". At a depth of about 410 km a relatively abrupt increase in seismic velocity occurs.

52

- The **core** is larger than the planet Mars, the core is earth's dense central sphere, with a radius of 3486km. The core consists of a liquid outer layer about 2270km thick and a solid inner sphere with a radius of 1216km.
- The average density of the core is nearly 11 g/cm^{3,} and the earth's center it approaches 14 times the density of water.
- **Meteorites** provided an important clue to earth's internal composition, because they are assumed to be representative samples of the material from which earth originally accreted.

53

- **Convection** is the transfer of heat by the mass movements or circulation in a substance. Convection flow in the mantle is the most important process operating earth's interior.
- This thermally driven flow is the force that propels the rigid lithospheric plates across the globe, and it ultimately generates earth's mountain belts and worldwide earthquake and volcanic activity. Recall that plumes of superheated rock are thought to form near the core-boundary and slowly rise towards the surface.

54

Structure of the oceanic crust:

- Ocean floor consists of three distinct layers. The upper layer is composed mainly of basaltic **pillow lavas**. The middle layer is made up of numerous interconnected dikes called **sheeted dikes**. Finally, the lower layer is made up of gabbro; the coarse-grained equivalent of rocks is called an **ophiolite complex**. The magma that migrates upward to create new ocean floor originates from partially melted peridotite in the asthenosphere.

55

- **Continental drift**: a single supercontinent called **Pangaea** “all earth” once existed. At about 200 million years ago this supercontinent began breaking into smaller continents, which then drifted to the present positions. The fit of the geographic distribution of fossils, rock type and structural similarities, and ancient climates all seemed to support the idea that these now separate landmasses were once joined. One of the main objections to **Alfred Wegener’s hypothesis** stemmed from his inability to provide a mechanism capable of moving the continents across the globe.

56

- Examples of active continental rifts include the **East African rift valleys** and the Baikal Rift. Extensional forces must be acting on the lithospheric plate is the main cause for continental splitting. These forces are thought to arise from the “pull” of cold lithospheric plates as they subduct along the margins of a continent. These extensional forces are not great enough to tear the lithosphere apart. The rupture of the lithosphere is initiated only in those settings where plumes of hot rock rise from the mantle. The rift valleys in these areas will lengthen and deepen.

57

- Plate tectonics is the first theory to provide a unified explanation of earth’s major surface features.
- Within the framework of plate tectonics, geologists have found explanations for the geologic distribution of earthquakes, volcanoes, and mountain belts.
- The theory of plate tectonics, although a powerful tool, is nonetheless an evolving model of earth’s dynamic processes.

Whole Earth Geophysics

Robert J. Lillie

1

- **Geophysical techniques** provide information on the internal structure and tectonics development of the earth.
- Some of the **geophysical methods** are: refraction, reflection, earthquake, gravity, magnetism, and heat flow.
- **Travel time**: is the time it takes the waves to get from their source to a seismometer:
- **Seismic velocity**: the speed of the waves passed through a region of the earth.
- **Attenuation "Q":** the amount and type of ground motions reveals how readily the region absorbed/scattered wave energy.

2

- **Refraction**: when waves encounter regions of changing velocity.
- **Reflection**: when waves due to changes in acoustic impedance (density, time, velocity).
- **Volcanic eruption and igneous intrusion**: come from magma that originated at lower crustal or upper mantle depths, generally within the upper 200km.
- **Seismic reflection data** shows details within sedimentary basin, lower crust, and "Moho" the crust/mantle transition.
- **Seismic refraction data** provide constraints on crustal thickness changes and seismic velocities within the crust.

3

- **Seismic velocities** give constraints on the composition and physical state of portions of the earth.
- **Plate tectonic theory** explains the origins of many mountains ranges, earthquakes, volcanoes, and the metamorphism of rocks.
- **Classic divisions of earth interior**:
1. Crust "hard solid".
2. Mantle "soft solid".
3. Core "liquid".
- **Modern divisions of earth** "which describe physical state of those chemical under high P and T"**:** 1. Lithosphere. 2. Asthenosphere. 3. Mesosphere. 4. Outer core. 5. Inner core.

4

- **Crust 'lithosphere"**: comprised of silicates that are so cold that they are rigid.
- **Mantle "Asthenosphere"**: include of iron/magnesium-rich silicate and relatively cold and rigid.
- Asthenosphere: the same mantle materials undergo slight partial melting, forming the softer layer.
- **Outer core**: composed of heavy (iron-rich) materials which are liquid.
- **Inner core**: the same material exists as a solid.
- The rock undergoes increasing degrees of a partial melting until it becomes totally liquid at about 1900^{o} C.

5

a) In the upper 100 km, the peridotite is cold and rigid, resulting in a solid **lithosphere**.
b) Between about 100 and 350 km the temperature rise causes a small amount of partial melt, giving the softer **asthenosphere**
c) Below about 350 km the pressure is so great that, even though the temperature is hooter, there is a transition (increasing strength) to the solid **mesosphere**.
- The lithosphere consists of both the crust and uppermost mantle.
- The boundary between the crust and mantle, called the **Moho discontinuity**.

6

- **Compressional seismic waves** travel at about 6.5 km/s in the lower crust were refracted along the higher velocity in the uppermost mantle of about 8.2 km/s and slow down to about 7.8 km/s at depth of 75 to 200 km, indicating a transition to the softer asthenosphere. The velocity jump to 12 km/s in the mesosphere
- The **lower crust** in generally **gabbroic** (≈50% silica), while the **upper mantle** is composed of **peridotite** (≈30% silica).
- Peridotite comprises the three zones of the mantle: lower lithosphere, asthenosphere, and mesosphere.

7

- Lithosphere plates are though to be driven by convection currents within the upper mantle. Where magma is generated and the cooling of it forms new lithosphere.

Types of plate boundaries:

1. Divergent plate: where plates moves away from one another the lithosphere thin, so that underlying, buoyant asthenosphere elevates a broad region. The elevated regions are **continental rift zones** or **mid-ocean ridges**, depending on whether the lithosphere is capped by continental or oceanic crust. Divergent plate boundaries are characterized by tensional forces that produce fissures, ..

8

.. normal faults, and rift valleys.

- New oceanic lithosphere is created between the continents, at a mid-ocean ridge. If the process continues long enough, a large ocean basin forms.

- Continental rift zones: as content pulls apart it stretches, thinning the crusts and entire lithosphere. The region is raised to high elevation because the underlying asthenosphere is hot and buoyant. The upper part of the crust deform in a cold, brittle fashion, causing earthquakes and elevated ridges, separated by down-dropped valleys. Areas of this kind are **East African Rifts** and Basin and Range Province.

9

- **Mid-Ocean Ridges**: when continents completely rift apart, new oceanic lithosphere forms, as in the **Red Sea** separating Saudi Arabia from Africa. With continues divergence the buoyant asthenosphere elevates a ridge on the seafloor that may be a few hundred to as much as 4000 km wide, depending on how fast the plates move apart. Although the region of the ridge is hot, the upper part of the oceanic crust can be cold and brittle, causing earthquakes and normal faults.

10

2. Convergent plate: where lithospheric plates converge, the plate with thinner, less buoyant crust commonly dense beneath the other plate. The region where a lithospheric plate descends deeply within the mantle is called a **subduction zone.** Two types of subduction zone are common; depending on whether the overriding plate is capped by thin (oceanic) or thick (continental) crust.

- Ocean/ocean subduction zone: if both of the converging plates contain oceanic crust, one plate subduct beneath the other. Magma that makes it to the surface erupts as a chain of volcanic ….

11

… islands, called an island arc. Examples of that are The Aleutian and Philippine islands.

- Ocean/continent subduction zone: continental crust is thicker, and therefore more buoyant, than oceanic crust; a plate with oceanic crust will subduct beneath one capped by continental crust. The volcanic arc is on the continental crust, because that crust is part of the overriding plate. Examples include Japan, western South America, and the Pacific Northwest of the US.

- **Continental collision zone:** at collisional mountain ranges, two plates that both thick (continental or island arc)

12

.. crust converge. Collision occurs after the thinner, oceanic crustal part of the downgoing plate is consumed through subduction. Example is the Indian subcontinent extends beneath Asia that results the highest mountains on Earth, the Himalayas.

3. Transform plate: where plate slide horizontally past one another, lithosphere is neither created nor destroyed. A common example is the San Andreas Fault, the Alpine Fault of New Zealand.

- **Fracture zones** are the inactive extensions of transform boundaries.

13

- **Plume**: the heat rise from deep within the mantle.
- **Hotspot**: is a region in the mantle where magma forms due to a plume. As a lithosphere plate moves over a hotspot, the line of volcanoes forms, examples include Hawaiian Islands and the Columbia Plateau. Hotspots provide the determination of the absolute motions of plates.
- Mantle plumes and associated hotspots are thought to be fixed relative to the deep mantle

14

- **Earthquakes:** earthquakes occur because materials are stresses to their breaking point. Two factors are important: 1. the presence of brittle material; and 2. motion that builds stress in the brittle material. Most earthquakes occur along or near plate boundaries, within the brittle regime near the top of the rigid plates.
- **Shallow earthquakes** occur in the upper depth of 70 km. deep ones can extend as deep as 700 km.
- **Very large earthquakes** occur due to sudden stress release where the two plates are locked together, at their boundary.

15

- **Earth materials commonly melt in two situations**: 1. the presence on hot material drops. 2. cold material is subjected to higher temperature.
- Most volcanic eruptions are associated with divergent or convergent plate boundaries. Volcanism is normally absent from transform plate boundaries because materials remain at their normal depth; there is no significant temperature rise or presence drop.

16

- A great deal of what we know about the interior of the earth comes from the recording of **seismic waves** that have traveled through various portions of the earth. Controlled source seismic techniques provide seismic velocity information, as well as some detail of layering, for the crust.
- **Seismic refraction data** are useful for mapping depth to bedrock, crustal thickness, and uppermost mantle velocity.
- **Seismic reflection profiles** show details of layering within sedimentary basins and gross structure of the deeper crust.

17

- Earth materials may be **elastic** under some conditions, inelastic under others: 1. the magnitude and orientation of the deforming stress (amount of compression, tension, or shearing). 2. the length of time the material takes to achieve a certain amount of distortion (strain rate)
- Deformation beyond the elastic limit may be **ductile**, whereby the material flows like silly putty, or **brittle**, like a pencil breaking or the lithosphere rupturing as an earthquake.

18

- **Seismic waves** can be categorized by whether they travel through the earth (**body waves**) or along earth's surface (**surface waves**).
- **Isotropic**: means that the material has the same physical properties (density and rigidity) in all directions.
- **Elastic constant**: describes the strain of a material under a certain type of stress. The **bulk modulus** describes the ability to **resist** being compressed. The **strain** is the change in volume divided by the original volume. The bulk modulus is the stress divided by the strain.
- **Shear modulus**: refers to the ability of a material to **resist** shearing.

19

- **Young's modulus** describes the behavior of a rod that is pulled or compressed.

Types of body waves:

1. **Compressional wave**: is a "primary" or "P" wave because compressional waves arrive first from earthquakes; they also called "longitudinal" and "push-pull" waves because particles of the material move back and forth, parallel to the direction the wave is moving.
2. **Shear wave**: particle motions are perpendicular to the direction of propagating. Shear waves are also referred to as "secondary" or "S" because they arrive from an earthquake

20

.. after the initial compressional waves, and as "transverse" waves because of their particle motions.

- **Seismic velocities depend on** the elastic constants (bulk modulus, shear modulus, Young's modulus, and Poisson's ratio) and density of the material.
- S-wave always travels slower than P-wave.
- S-wave can not travel through fluids, however P-wave travel slower through liquid.

21

Factors that lead to an increase in seismic velocity:

1. Increasing depth within the earth.
2. Increasing in density.
3. Decreasing porosity.
4. Change from liquid to solid.

Types of surface waves:

1. **Rayleigh waves:** have retrograde elliptical motion; at the top of the ellipse, particles move opposite to the direction of wave propagation.
2. **Love waves**: are surface waves that behave like shear waves; the particles move horizontally in directions perpendicular to the direction of propagation.

22

- Seismic waves can be used to determine depths to interfaces within the earth and velocities of layers between the interfaces.
- The **sources of the seismic waves** can be natural (earthquake) or produced artificially (controlled source).
- The receivers used on land, called **geophones**, measure ground movement (either the displacement, the velocity, or the acceleration of the ground surface).
- At, sea, **hydrophones** measure changes in water pressure caused by passing seismic waves.

23

- The **travel time** of a seismic wave from a source to a receiver depends on the seismic velocities of the earth materials traversed, the distance from the source to the receiver, and the geometry of boundaries separating earth materials.
- For many earth materials:

$\mathbf{V_s \approx 0.6\ V_p}$ [P-wave is faster than S-wave], $\mathbf{V_R \approx 0.9\ V_s}$ [Rayleigh wave is slower than S-wave], and $\mathbf{V_R \approx 0.5\ V_p}$ [Rayleigh wave is about half the speed of P-wave].

- A **wave front** is a surface along which portions of a propagating wave are in phase.

24

- In a homogenous medium (constant seismic velocities), the body waves (P and S) radiate outward along spherical wavefronts, while Rayleigh waves (R) roll along the surface.
- Seismic energy travels along trajectories perpendicular to wavefronts, known as **raypaths**.
- A **seismic trace** is the recording of ground motion by a receiver, plotter as a function of time.
- Arrival of each of the P, S, and R waves starts as initial movements of the ground, followed by reverberations that die out with time.

25

- Travel time is commonly increasing downward in refraction and reflection studies.
- **Acoustic impedance**: the product of seismic velocity and density.
- **Direct Arrival**: the compressional wave that goes directly from the source to a receiver is a body wave traveling very close to the surface.
- Snell's Law describes three situations:
1. If the velocity decreases across the interface, the ray is refracted away from the interface. 2. If the velocity remains the same, the ray is not bent. 3. If the velocity increases across the interface, the ray is bent toward the interface.

26

- **Critical refraction** occurs when the angle of refraction (θ_2) reaches 90^o, and it only occurs when $V_2 > V_1$
- The angle of incidence (θ_1) necessary for critical refraction is called the critical angle (θ_c)
- **Waves refract because** they encounter changes in seismic velocity. Velocity changes relate to changes in bulk modulus, rigidity and density; measuring how waves refract thus tells us something about those properties traversed by the seismic waves.
- **The refraction methods illustrates on two problems**: 1. crustal thickness. 2. depth of bedrock.

27

- **Receivers must extend well beyond the crossover distance** fro the deepest refractor of interest. A general rule is that the length of the array of receivers "spread length" should be at least twice the crossover distance.
- Unlike reflection experiments, where the spread length is about equal to the depth of the deepest refractor, seismic refraction spread lengths are about five to ten times the depth of the deepest refractor.
- The single-layer case illustrates the utility of the seismic refraction method to **map changes in crustal thickness**.

28

- **The depth to the crust/mantle boundary** often relates to **tectonic history**. Regions of plate divergence commonly have shallow Moho depths (continental rift zones, passive continental margins, mid-ocean ridges). Low mantle refraction velocities can indicate zones where hot asthenosphere is shallow at mid-ocean ridges and continental rifts. In continental collision zones, the crust may thicken to twice its normal value for continual areas.
- The seismic reflection method is popular for tow areas: 1. Resembling geologic cross sections.2. Offering high resolution of subsurface detail

29

- The **seismic reflection method** is a tool for oil and gas exploration in sedimentary basins. Reflections occur when there are changes in seismic velocity and/or density; boundaries or layers that are nearly flat and continuous are especially resolvable.
- **The rifting of a continental craton thins the crust as well as the entire lithospheric plate.** As a continental rifts apart, the upper and lower crusts thin, but through different mechanisms (brittle and ductile failure)

30

- **Earthquakes** show to the fact that dynamic forces are operating within the earth. Stress builds up though time, storing strain energy; earthquakes represent sudden release of the strain energy.
- Most tectonic activity occurs due to interaction between plates; the distribution of earthquakes thus dramatically outlines lithospheric plate boundaries.
- There are only **shallow** earthquakes at **divergent** and **transform** plates, but earthquakes occur over a **broad range** from shallow to deep where **plate converges**.

31

- **For earthquake to occur**, two factors are thus necessary: 1. there must be some sort of movement that will stress the material beyond its elastic limit. 2. the material must fail by brittle fracture. The region of the earth that fits the above criteria is the lithosphere.
- **Elastic rebound theory** state that rock can be stresses until it reaches its elastic limit.
- The location of an earthquake can be described by the latitude, longitude, and depth of the zone of rupture. The **focus** is the actual point within the earth where the earthquake energy is released.

32

- The **focal depth** is the distance from the epicenter to the focus.
- The **epicenter** is the point on earth's surface directly above the focus.
- Earthquakes occur in the upper 700 km of the earth, because they are confined to the rigid lithosphere, which can undergo brittle failure.
- Most earthquakes are shallow focus, from the surface to 70 km depth; shallow focus earthquake occur at all types of plate boundaries.

33

- Most **intermediate** focus (**70 to 300 km depth**) and virtually all **deep** focus earthquakes occur in convergent (subduction) settings, where lithosphere extends deeply through the asthenosphere.
- **Magnitude** is related to the amount of energy released by the earthquake. It is based on precise measurements of the amplitude of seismic waves. It is expresses according to a **logarithmic** scale, whereby an increase in magnitude by one unit correspond to a 10-fold increase in amplitude of the seismic waves. **Richter scale**, reports of earthquakes magnitude, is based on ….

34

… P-wave amplitude and It is a base-10 logarithmic scale
- **Intensity** is qualitative, describing the severity of ground the severity of ground motion at a given location. It is based on effects at the surface, as witnessed by people. Intensity is reported as Roman Numerals according to the **Mercalli Scale** which is a base-12 scale.
- Factors tend to increase intensity: 1) magnitude of the earthquake. 2) proximity to the earthquake focus. 3) loose soil as opposed to firm bedrock.
- Seismic wave amplitude get smaller with increasing distance from the earthquake source, so that intensity …..

35

…. generally decrease with distance from the focus.
- **Seismic stations** typically have at least three seismometers, each sensitive to a different direction of ground motion. The directions are perpendicular to one another, responding to vertical, north-south, and east-west motions.
- When there are many, very thin layers, critically refracted rays emerge at steeper angles for deeper, higher velocity interfaces. Each angle of emerged relates to the velocity the ray traveled horizontally at the top of the critically refracting layer

36

Major Divisions of Crust, Mantle, and Core:

- Lithosphere: the crust has P-wave velocities generally below 7 km/s. in many areas the crust consists of sedimentary rock with velocities from 2 to 5 km/s, underlying by igneous and metamorphic rocks with velocities slightly greater than 6 km/s. Across the Moho, P-wave velocities increase abruptly, from 6-7 km/s to about 8 km/s. The Moho is about 10 km deep beneath oceans, but much deeper (20 to 70 km) under continents. The uppermost mantle has P-wave velocities just over 8 km/s to 100 to 200 km depth.

37

- **Asthenosphere**: it can be broken into two parts. In the upper part (about 100 to 300 km depth), P and S wave velocities are about 6% lower than for the overlying lithosphere and underlying material. The upper asthenosphere is thus a soft substratum, over which the more rigid lithospheric plates ride. In the lower part of the asthenosphere (about 300 to 700 km), P and S wave velocities gradually increase, suggesting an increase in shear strength.

- If waves arrive late, the lithosphere is thin. Early arriving waves suggest a thick lithosphere.

38

- **Mesosphere:** at the top (about 700 km depth) there is an abrupt increase in velocity; pressure is so great that the mantle reverts back to a harder solid. Through the depth range of 700 to 2900 km, there is a gradual increase in P- and S- wave velocities, as the shear and bulk moduli increase.

- **Outer Core:** extends from about 2900 to 5100 km depth. A region where no initial S-wave is recoded extends beyond 103^{o} angular distance; this “shadow zone” is evidence that S-wave is not transmitted through the outer core. At the mantle/core boundary P-wave velocity drops from 13.5 to 8 km/s.

39

- A P-wave shadow zone develops between 103^{o} and 143^{o} due to abrupt, inward bending of seismic rays.

- Inner Core: Some weak P-waves arrive on the other side of the earth earlier than expected “PKIKP”, suggesting an abrupt increase in velocity at about 5100 km depth. This higher velocity suggests that the inner core is solid. Some weak arrivals have been interpreted as waves that travel through the inner core as (converted) S-wave energy “PKJKP”. The inner core has the same chemical compositions as the outer core, but is solid because it is under greater pressure.