Igneous rocks Petrology Course (Geo 324)

Igneous Rocks & Magmas (Petrology)

Course Director

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Rocks and Magmas

Objectives:

- The full Petrological description of the igneous rocks will include:
  1. Magma and plate tectonic
  2. Rock-unit in which they occur,
  3. Record of its attitude (outlook),
  4. Structure of the rock’s unit,
  5. Texture,
  6. Rock’s physical appearance.
  7. Mode (actual minerals and/or glass contents),
  8. Their chemical composition,
  9. Age of the rocks together with its origin (petrogenesis),

Thus

Keywords

- **Magma** Molten rock silicate material; always contains a melt in which there are dissolved volatiles and commonly suspended crystals.
- **Magma generation** Creation of **primary magma** by **partial melting** of already hot source rock by local distresses in *P*, *T*, and/or composition.
- **Magmatic differentiation** Processes that modify the composition of a primary magma after leaving its source.
- **Liquid** Volatile fluid or silicate melt.

- **Leucocratic** Refers to rocks that have <30 modal % mafic minerals.
- **Leucosome** Leucocratic felsic part of **migmatite**.
- **Field relations** Chronologic and spatial properties of a mass of rock discerned in exposures (outcrops) in hills, mountains, and manmade road cuts.
- **Exsolution** Process of releasing excess volatiles from a oversaturated melt as their concentration exceeds their solubility.

I. Introduction

- **Definition of Petrology. (i.e. what do we meam by Petrology?**

✓ **Petrology: (*a Greek word means : "Petra i.e"rock" and "logos"mean"knowledge*").**

✓ **So, is the *study of rocks, their occurrences, composition, origin and evolution.***

Thus,

➢ It is the ***study of the Rocks, to know their occurrences, composition, origin and evolution***.

- A ***petrological description :***
  - ***Its rock occurrance***, ***attitude, structure, mineralogy and chemical composition,   and conclusions its origin Petrogenesis).***

- **i.e.** ***petrology :***

  focuses primarily on ***the rock formation, or petrogenesis, whereas***

Petrography ***deals with the detailed description and classification of rocks***,

So, The petrologists tasks are :

1. **To carry out study on rocks which are forming parts of the lithosphere that are clearly different from their surroundings, and**

2. ***To draws conclusive records about evolution and constitution of the Earth beneath its rocky crust***

   - ***It is primarily based on volcanic eruptions, shape and composition of igneous bodies that have reached Earth's surface by tectonic processes and erosion.***

Therefore;

- Most **magmatism** in **Earth occurs along the two linear regimes of tectonic plate convergence and divergence**

Due to

- **where the most interactions between energy and matter take place.**

- **The global magmatism is determined to** ***occur along the world encircling system of oceanic spreading ridges, and covergentg*.**

The most significant processes is to focus on the following:

1. **Tectonic movements of rock masses.**
2. **Volcanic eruptions and injection of magma into the lithosphere.**
3. **Physical, chemical and biological weathering and deposition in the surface areas of rocky crust and in the hydrosphere and atmosphere.**
4. **Mutual chemical reactions and biological processes in aqueous solutions.**

6. Melting, migration, recrystallization, degassing and similar events take place on rocks.

Consequently

1. *The Rocks*, are composed of certain minerals (minerals aggregates Components= Rock),
2. So, *Petrology* is closely associated with the mineralogy.

➢ *So, determination of :*

1. *mineral constituents* and
2. *chemical composition of rocks*

Are necessary to know, and to distinguish minerals components, and also for *resolving the origin of rocks.*

Lastly

- ***Igneous Petrology*** **is** ***closely associated with chemistry, especially mineral chemistry and geochemistry*****, for the purposes of studying the chemical complex reactions and processes.**

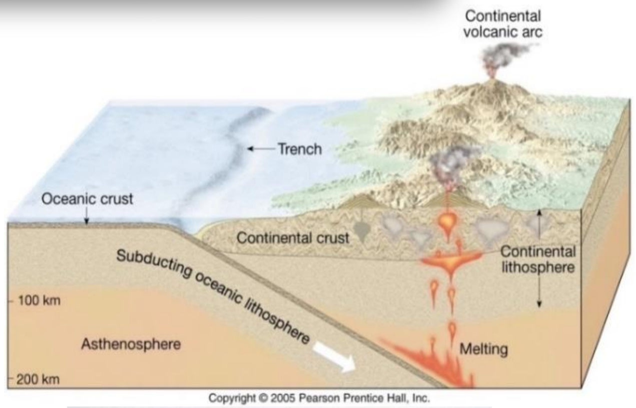
As the results,

1. **The geophysical responses due to the contrast in seismic velocity propagating through certain parts of the rocky crust and underneath of the *different laminate rocks structures distinguished by : either***
   a) Chemical or by
   b) Their * Rheological Properties *in* which the way of study the in which materials deform or flowin response to applied forces or stresses.

- ***This is based on remarkable geophysical response of primary seismic wave in rock's properties, where their discontinuity existence between the two major zones are obtained***

Origin of the Magma- The Earth's Layers

- The o**ceanic decending plate partially melted** to **develop Magmas underneath (deep) the overriding one**,



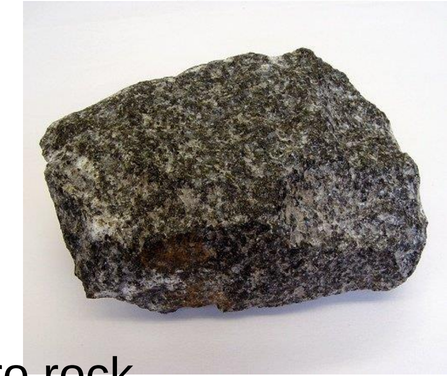
Becuase

- ***It is a heterogenous composition source of rocks*** **(rocks of the crust, and upper mantle (Lithosphere) one), at the time of its sinking down to earth's,**

Thus,

- **due to its increasing heat while its sinking stage, forming and initiating a hot semi-liquid (magma).**

  - ✓ **Partial melt: means the magma formed in two fractions; the melted materials, and the rest remained solid, at its formation time.**



Gabbro rock

Granite rock

Origin of the Magma

Molten Lava flow at the earth's surfaceforming Basalt Igneous rocks

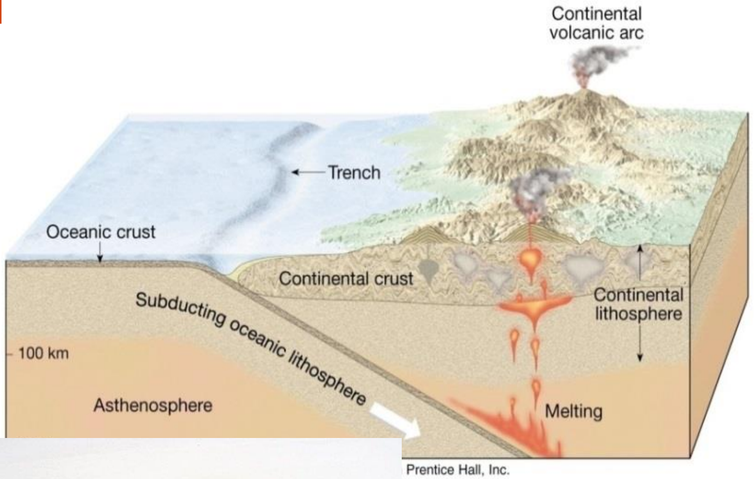
- ***Partial melting*** of subducted oceanic crust (basalt) plate **always produce primary parental basaltic magmas composition in mantle zone.**
- **Partial melting fractionate underneate the continental crust produce an average of andesitic magma composition, and fractionate more to produce granitic magmas composition.**
- **The partial melt rises through crust to the earth's surface, because of its lower density**

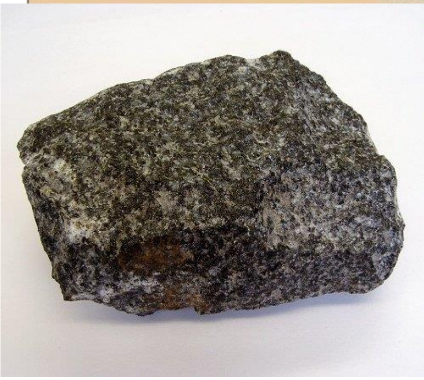
Because,

- ***The upper mantle and crust rocks are heterogeneous (Dissimilar) resources or materials.*** **So they are partially melted.**

Cont'd: Formation of Magma

- About ***95 percent of the Earth's crust consists of igneous and metamorphic rocks.***
- **Granite – Igneous intrusive rock, & Rhyolite igneous extrusive rocks)**
- ***Gabbro- igneous intrusive*** Rock, & (basalt (Lava flow) – igneous extrusive rocks).




Gabbro rock


Granite rock


Molten Lava flow forming Basalt Igneous rocks

Rocks and Magmas

1- Rocks and Magmas:

- The rocks are being **naturally formed body of solid , inanimate (inorganic) matter that has an internal chemical compositions.**

Or

- The rocks are the **sold stuff.   It solidified from a hot silicate molten, or partially molten**.

So,

- All **these magmatic rocks** → are **igneous Rocks "Ignis means main fire.**
- **So, magma is a molten silicate liquids.**
- The **magma term and concept of a single dominat is called PRIMARY MAGMA introduced by G. Poultt Scope (1825).**
- ***Petrology is named after Pinkerton (1981).***
- ***Petrology is derived from a Greek word called Petra mean rock***

Thus

Rocks and Magmas

- ***Localized and volumetrically minor magmatism removed from plate boundaries is commonly related to the mantle plumes ascending through the mantle*.**

- Such ***intraplate activity is manifest,*** for example, as volcanism in the Hawaiian Islands.

Rocks and Magmas

- **The Petrology consists two components, as follow:**
  1. Petrogrphycal study, or description and symbolic classification of the rocks, and
  2. Petrogenesis , which is the study of rock’s origin and evolution.

- **Most of igneous rocks are derived from a single Primary Basaltic Magma.**
- **Magma is produced by the partial melting of the descending slab at deep seated Olivine rich rock Called “ Peridotite”.**

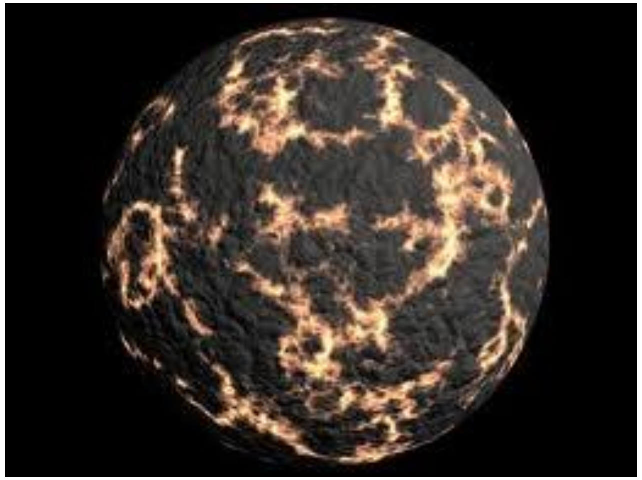
2. Igneous rock’s thin-section:

- The 1st slices of thin section of igneous rock’s suitable and prepared by Henry Clifton Sorby (1826 – 1908), with an approximately 0.03 mm thick.
- It is examined in/with transmitted light.
- Most igneous rock’s minerals appears transparent or translucent (Semi Transparent).
- Their optical properities and and texture relationships observed via Polarized Microscope (PM).

Rocks and Magmas

3- Internal Structure and thermal Properities of the Earth Shells:

Early Earth



- **Homogenous**
- **Very hot formed by swirl produced by the haet of PRIMORDIAL SUN**

- **It tends to be solid earth due to the gravitational attraction force , and due to its rotatation Anti-clockwise .**
- **The heaviest material to concentrated in the center of the earth (core), and these material graded towards the Earth's surface .**
- **Meanwhile, the lightest materials are forming the earth surface.**

ENERGY AND THE MANTLE HEAT ENGINE

- Without a critical amount of thermal energy within the earth's body,

There can be

- *No* movement of lithospheric plates (Lithosphere) or rise of mantle plumes

And hence there is

- ***No*** magmatism, metamorphism, or tectonism

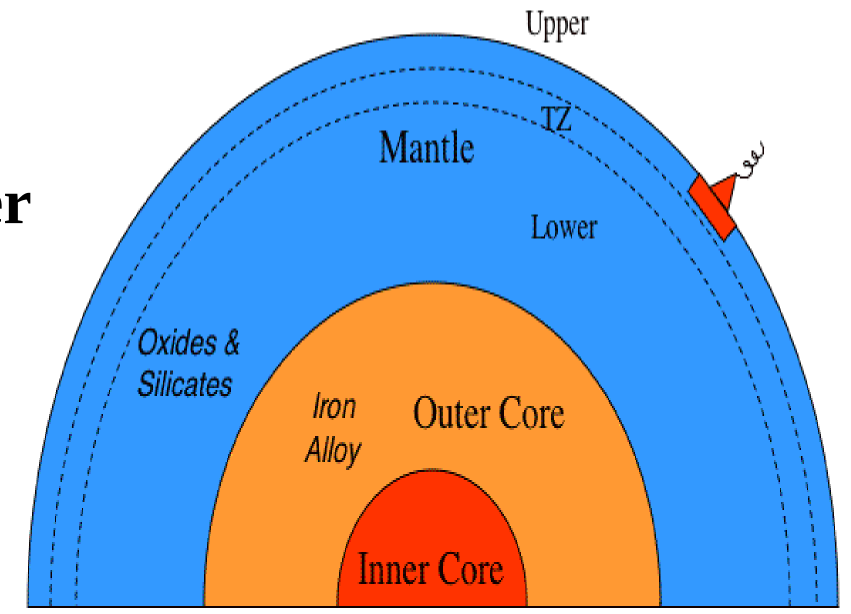
Therefore,

the Earth has acted as a giant heat engine, powering all kinds of geologic processes

- **In this engine,** ***the mantle of the Earth controls supreme as the major source of driving energy.*** **It is by far the most voluminous part (84%) of the planet, has the most mass (68%),** ***and to stores the most thermal energy***

Therefore

- **The earth's entire interior has different type of (heterogenetic) materials formed at the earth's center and graded in density to its surface.**
- **i.e. , the earth has different sequence of concentric shells around its interior, the inner shells is denser than outer shells.**



Depth	0	660	2890	5150	6371	km
Pressure	0	24	136	329	363	GPa
Temperature	300	1800	3000	5500	6000	K

- **The interior of the earth can be divided into 3 main parts according to the their natural silicate materials, and due to its composition using the following geophysical tools, as a result of :**

Seismic Tool (Seismic waves)

➢ **This waves are produced by a blast, they are dividing into:**

***1. <u>Body waves</u>*: (found within the earth body)**

✓ **Involves 2 types of practical motion, named as body waves (<u>because it is orignated and travlled inside the earth</u>).**

✓ **They are not damaging**

✓ **They are travelling so fast in about (7000 mile/s), so they firstly measured and detected.**

✓ **They are:**

1. **Primary (P) wave is the fastest, and 1st wave to arrive earth surface, and**
2. **Secondary “S” waves is the 2nd fastest waves.**

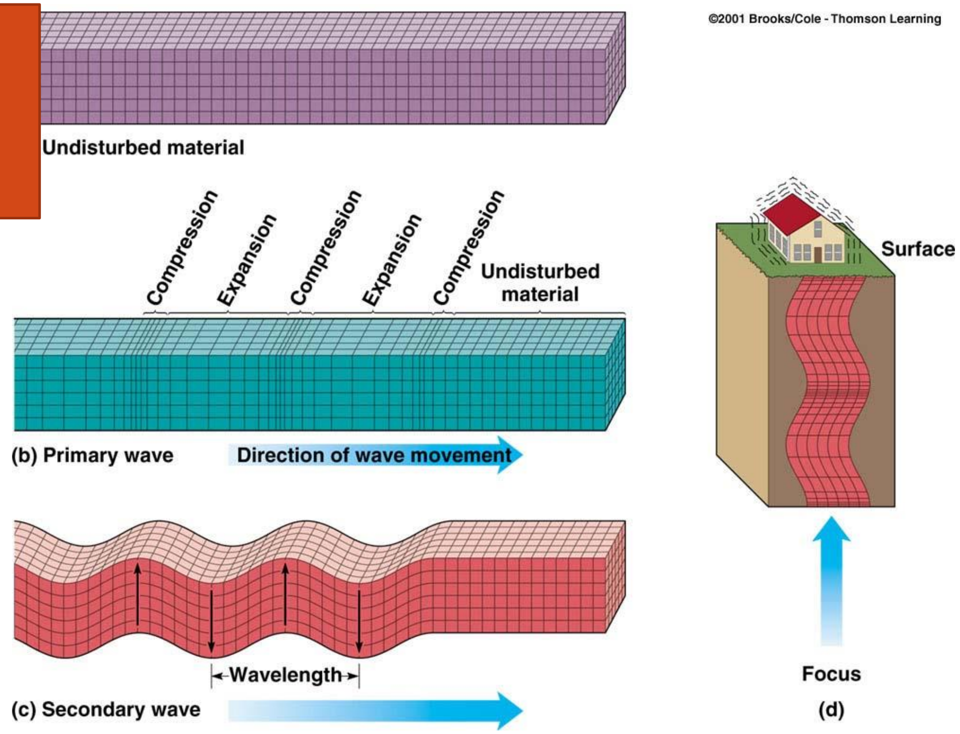
1) Body Waves : 1) P-waves (Primary waves)

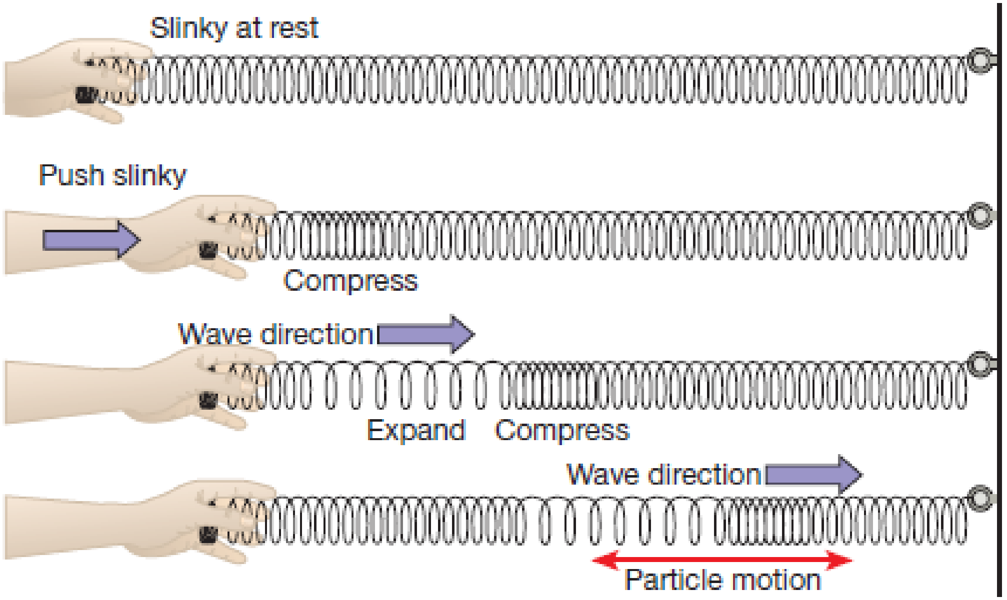
A. ***Primary(P) wave*** (also called a **compressional wave**) **is an elastic wave** that **causes alternate compression** and expansion (open out) in the rock.

1. ***P waves*** **travel through air, liquid, and solid material**.

2. ***P waves travels*** ***at speeds in the Earth's crust and at about 8 kilometers per second in the uppermost mantle.***

➢ **P waves** are also known as ***Primary waves***.





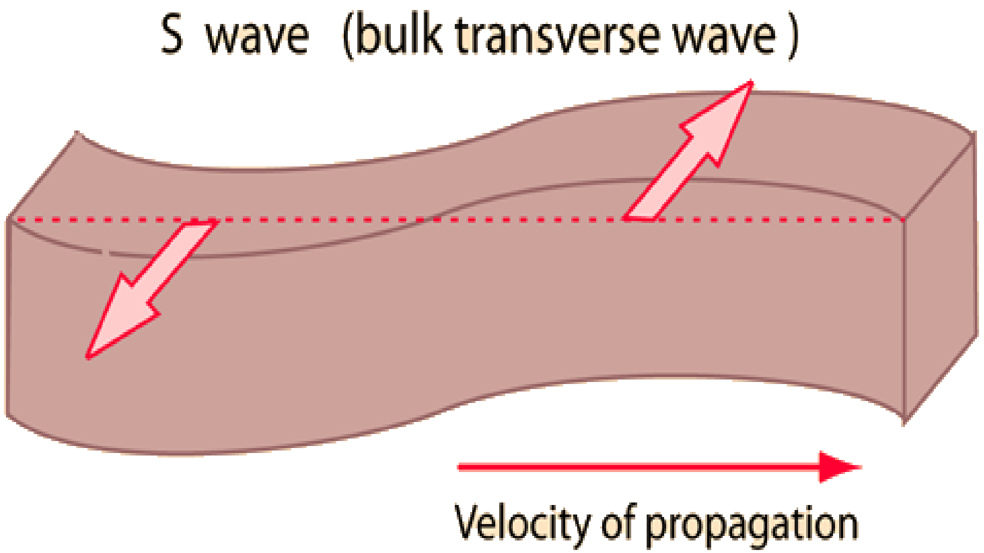
2) Body Waves (Secondary Waves):

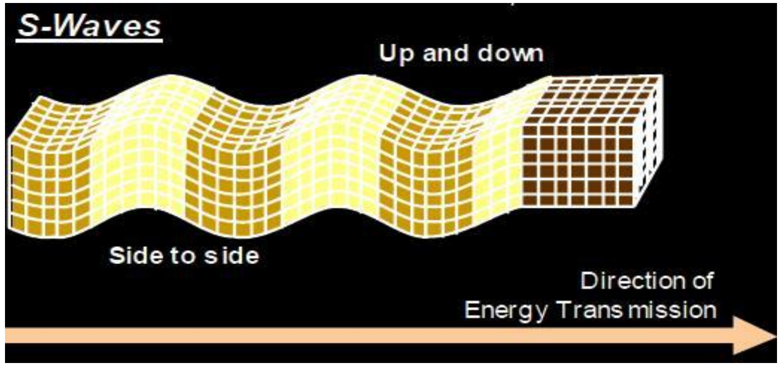
B. Secondary waves (S- wave):

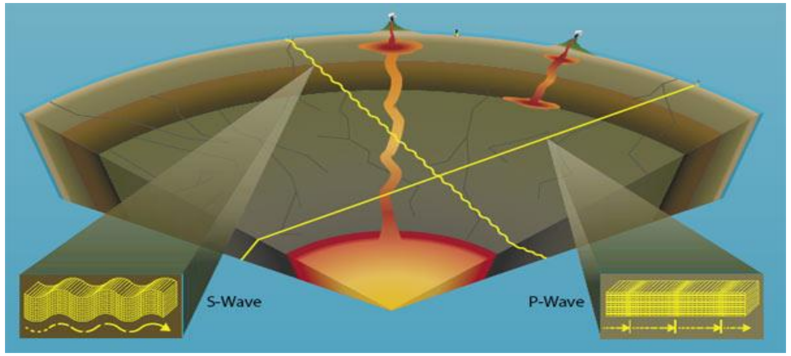
- **It is the 2nd type of body wave, is called an S wave,** is a **shear wave**.

a) They are **transverse waves meaning that wave particles travel perpendicular to the direction of the propagation of the wave.**

b) **The S waves are slower than P waves and travel at speeds between 3 and 4 kilometers per second in the crust.**







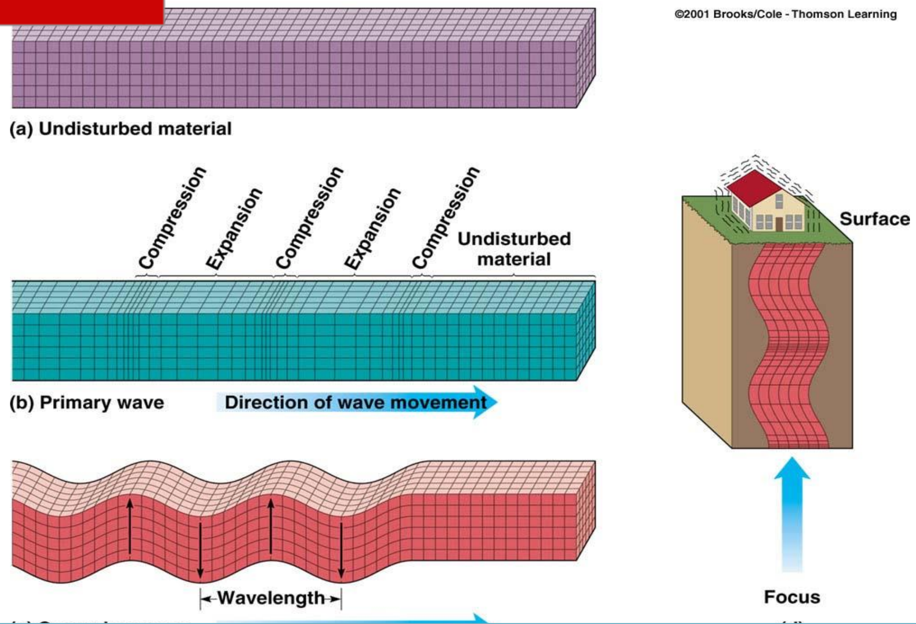
Body Waves: Secondary waves (S waves) :

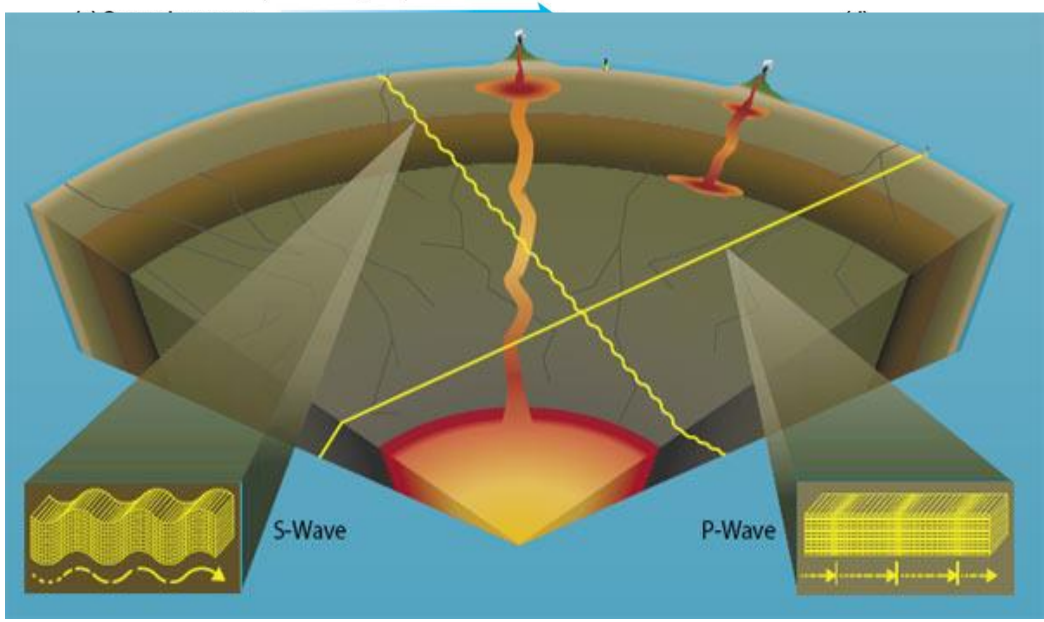
c) The **S waves** arrive after **P waves**.

d) The **S waves** are also known as **Secondary waves**.

e) Unlike P waves moves and propagate in all media materials state.

f) **S waves move only through solids.**





- The seismic elastic waves is reflected or refracted due to its different velocity in materials.
- when it passing and crossing the boundary between two different zones due to its dissimilarity in materials composition

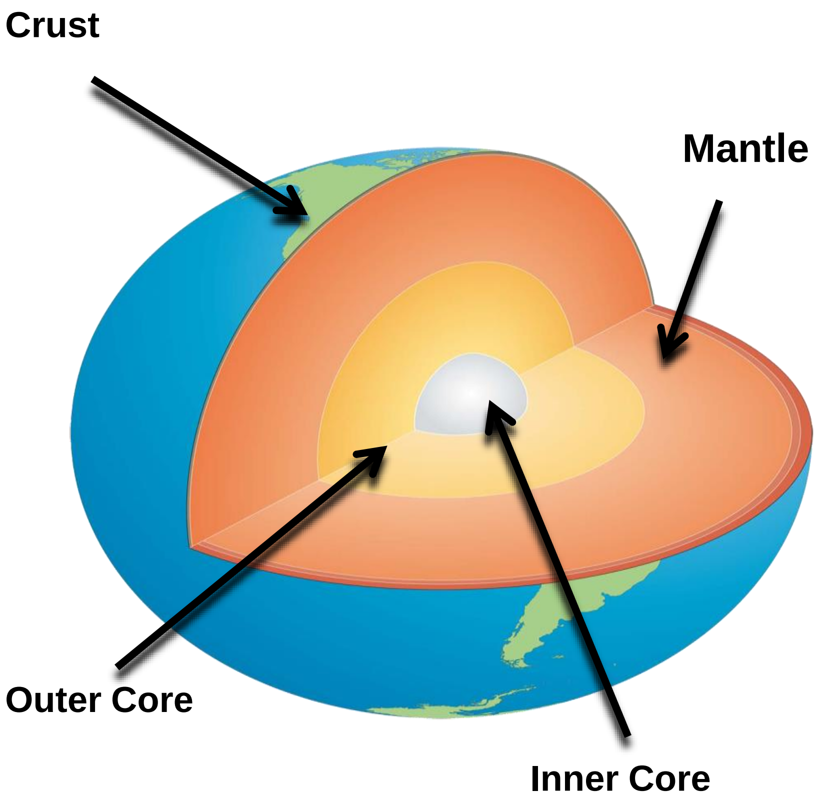
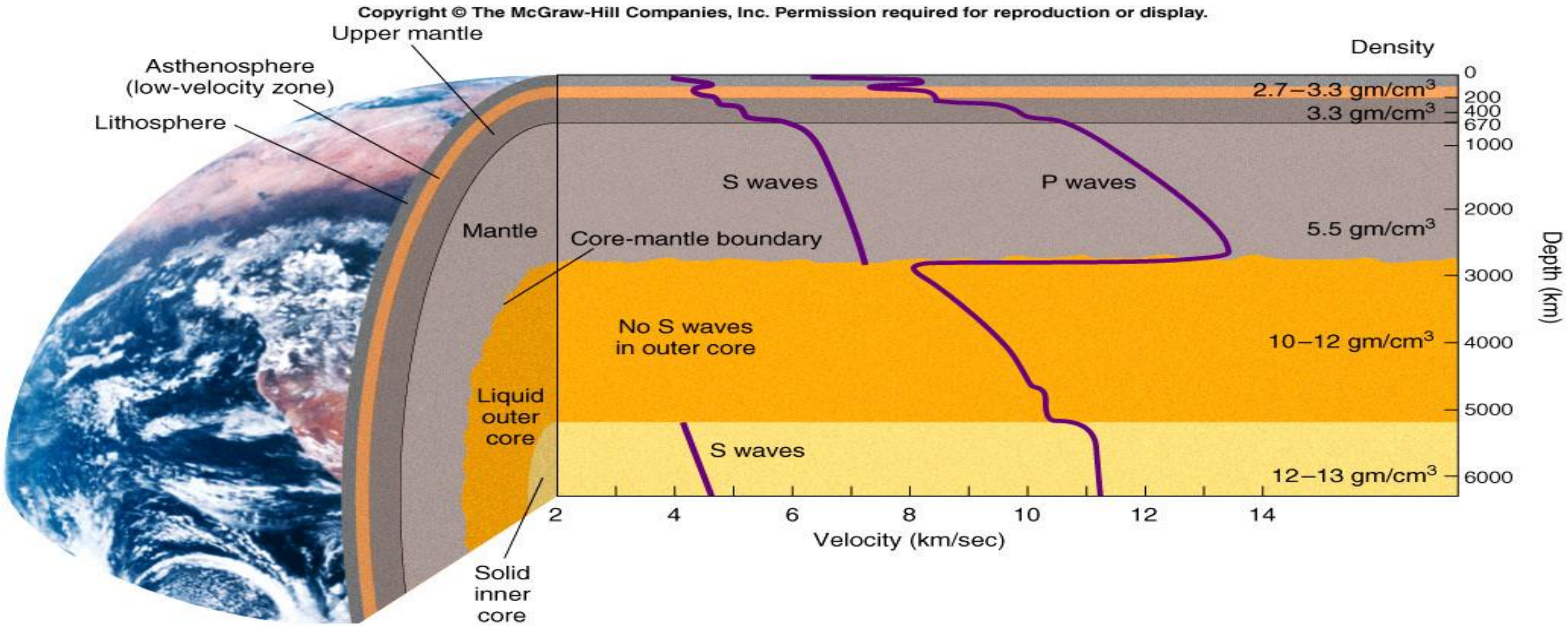
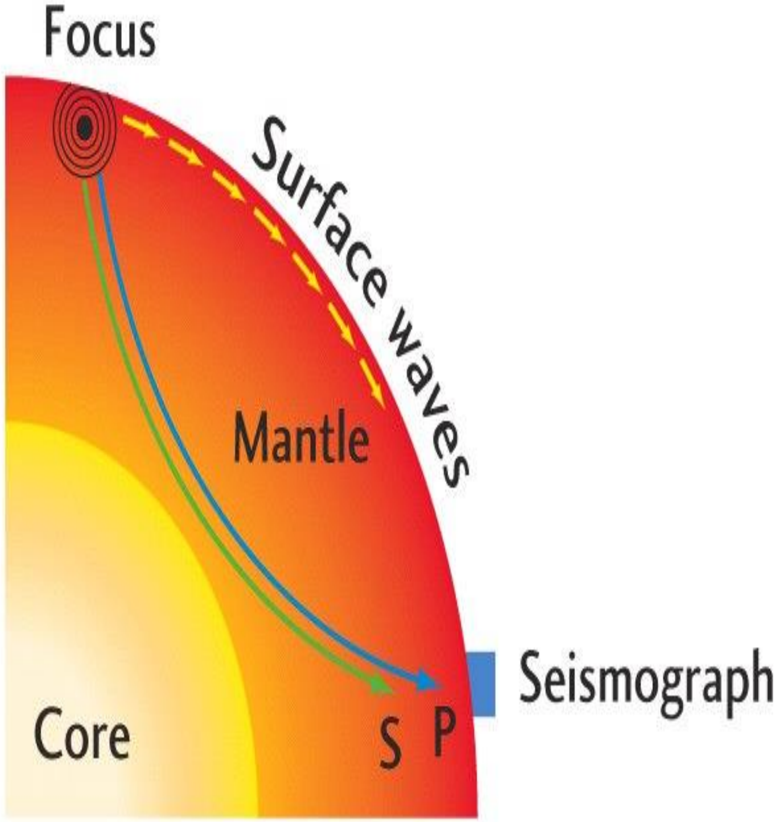
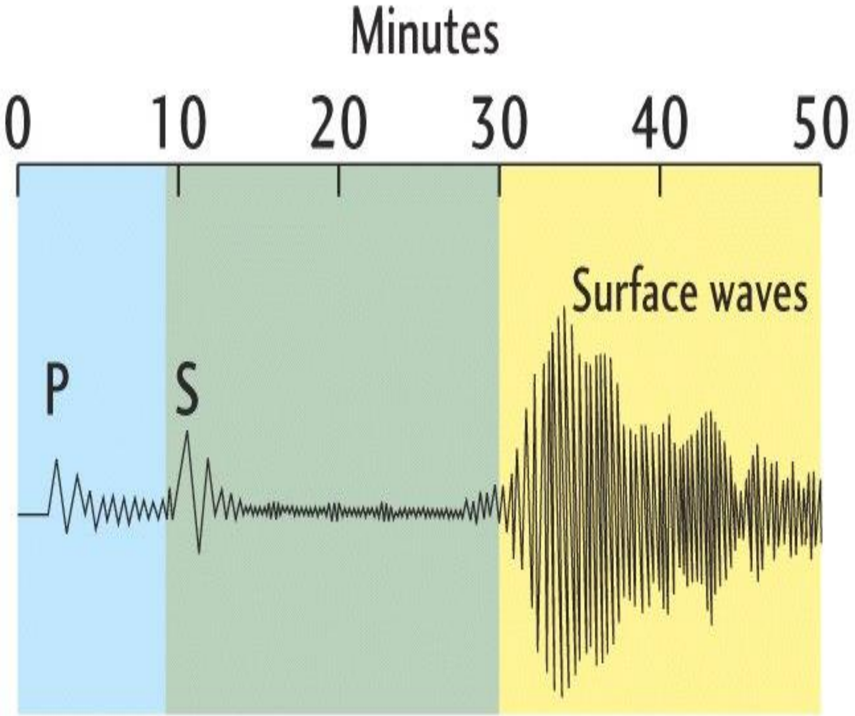


Fig. 17.7

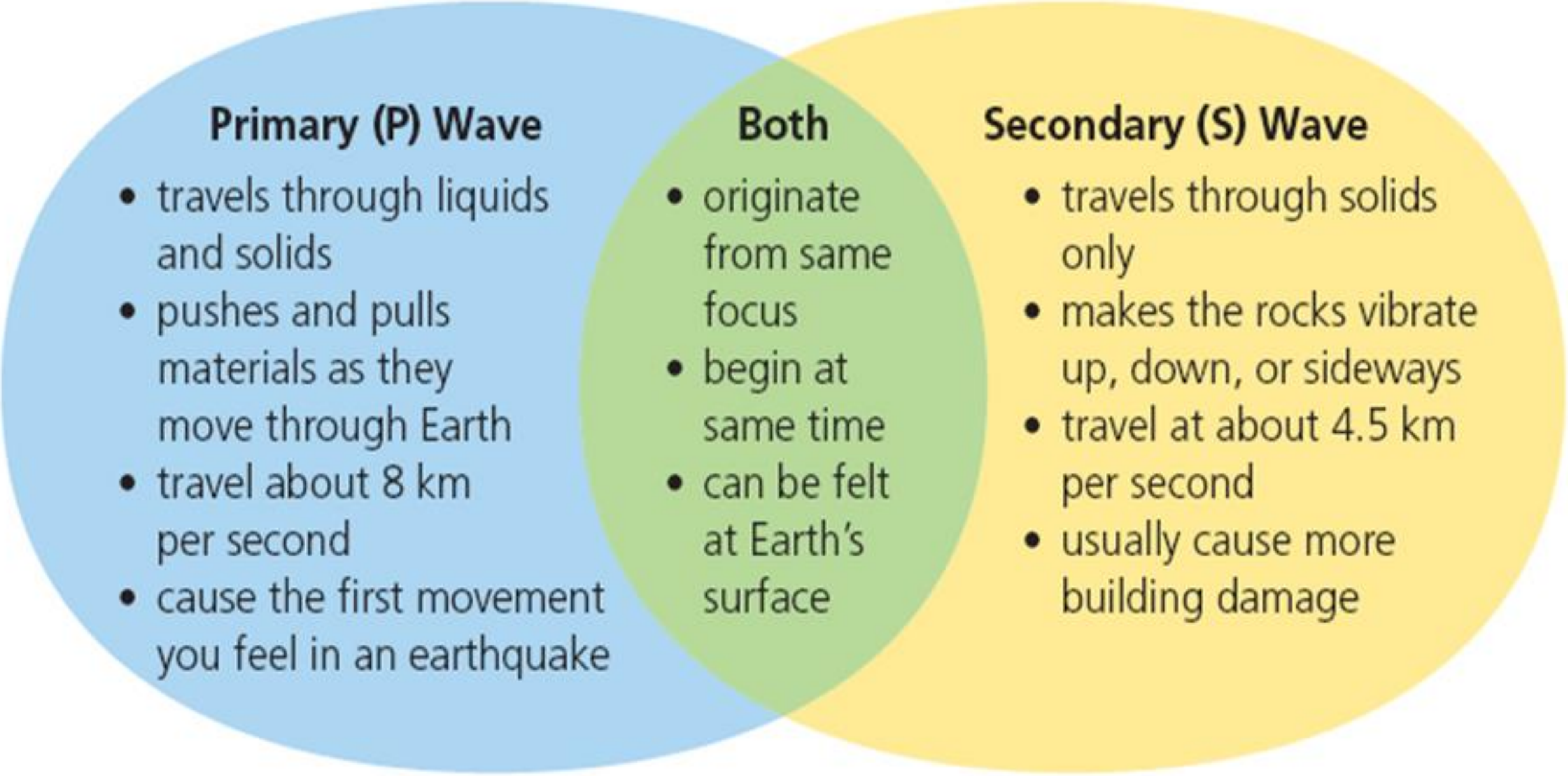


THE THREE DIFFERENT TYPES OF SEISMIC WAVES MOVE AT DIFFERENT SPEEDS



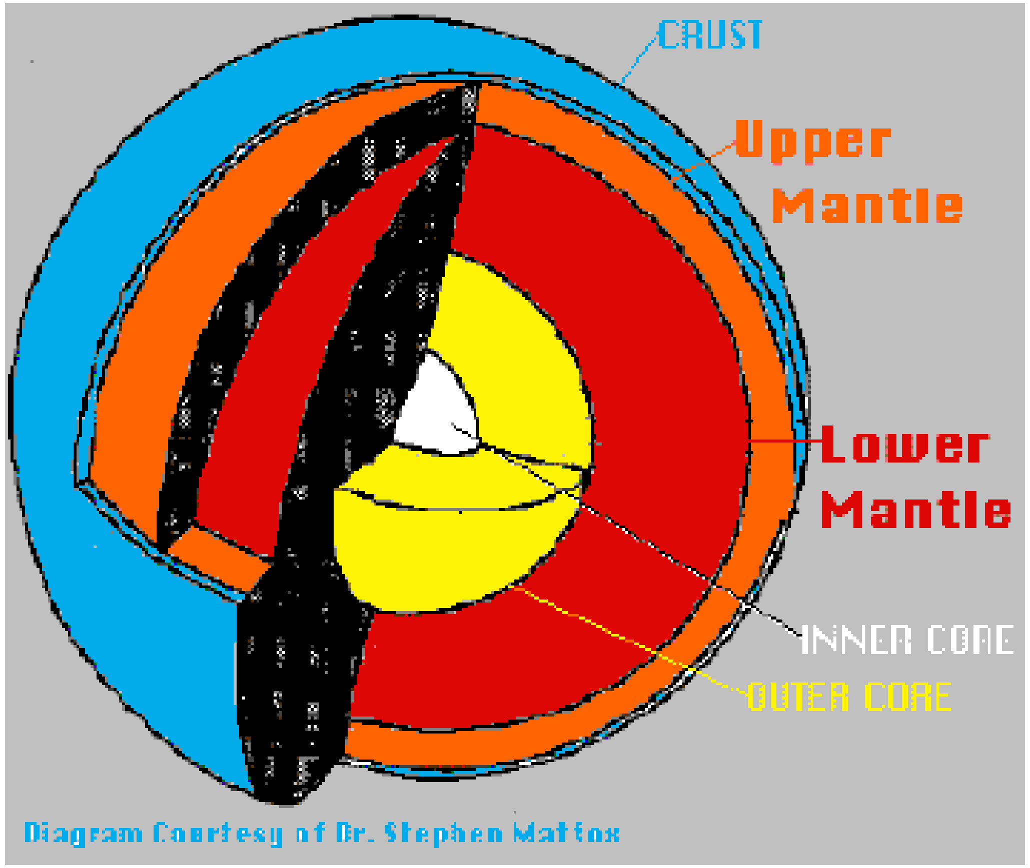


Comparing Seismic Waves



The Seismic waves types produced are causing different influences.

Thus,

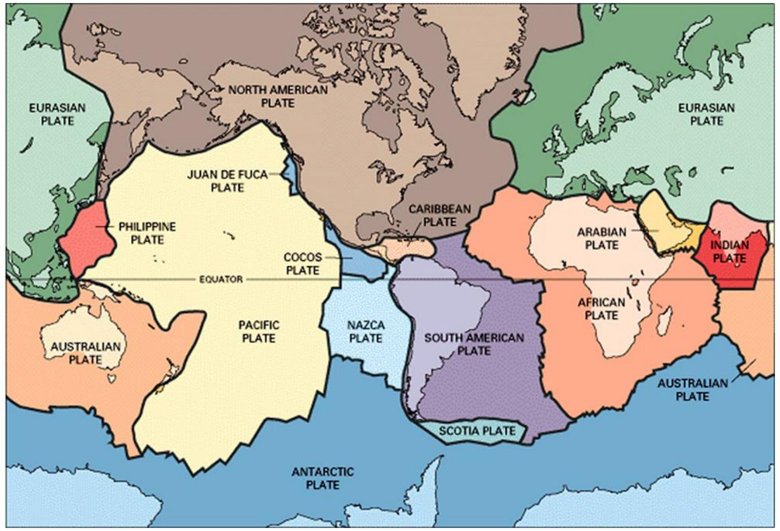


✓The Earth is composed of three different layers, as follows:

1. The crust is the layer that you live on, and it is the most widely studied and understood(Continental & Oceanic)
2. The mantle is much hotter and has the ability to flow.
3. The outer core.
4. and inner core are even hotter with pressures so great you would be squeezed into a ball smaller ,to the center of the Earth.

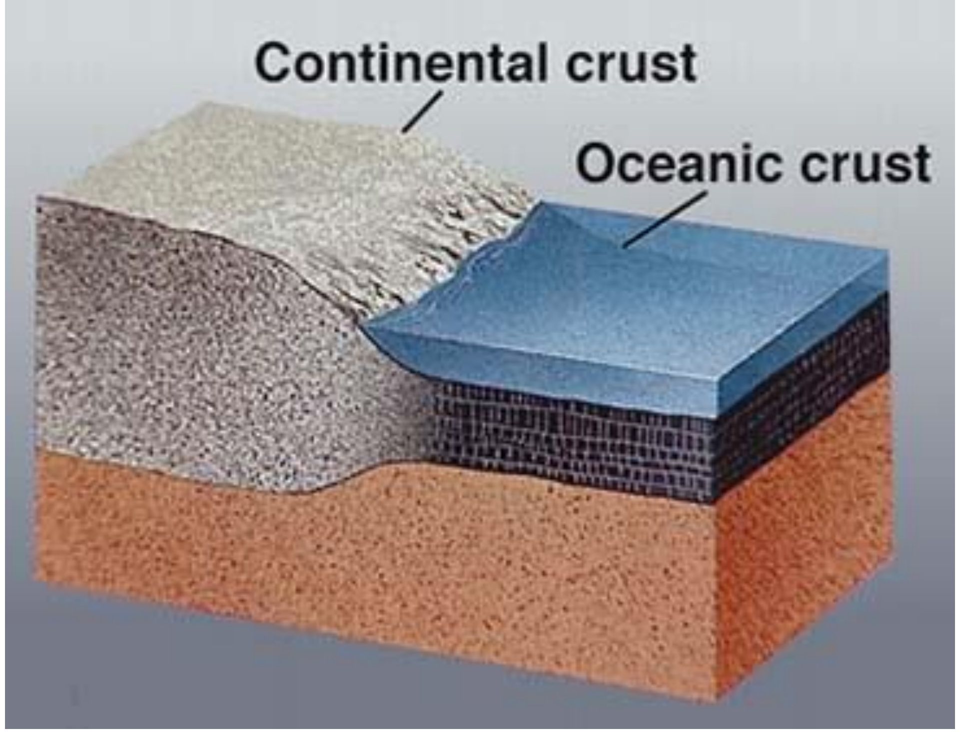
The Lithospheric Plates

- ✓The crust of the Earth is broken into many pieces called Tectonic plates; consists of (Crust & lithosphere).
- ✓The plates "float" on a soft, semi-rigid (semi liquid) asthenosphere state condition.



1- The Crust

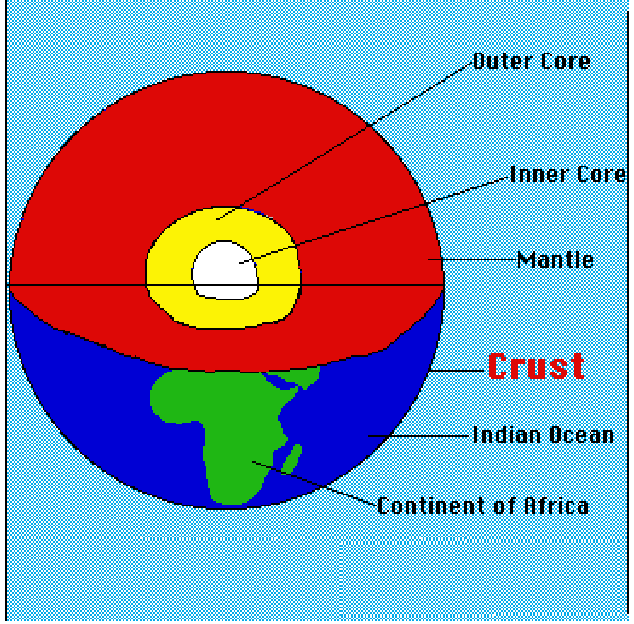
- It is the outer most part of the earth, it is rigid and comes in two forms or compositions:



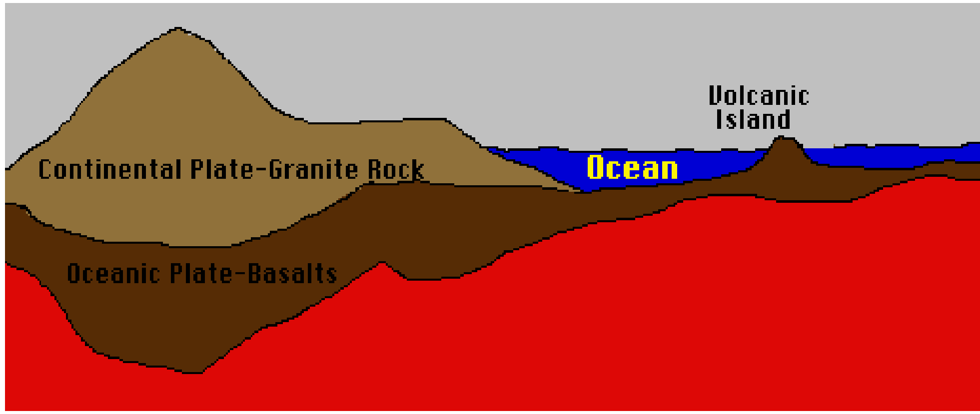
1. **Oceanic crust (lower crust)**
   - It is from 5 - 8 km thick it is forming the Oceanic floor.
   - it is mainly basaltic (pyroxene + plagioclase),
   - and it has a density around 3.0 gram/cubic centimeter fresh,
   - increasing as it cools.
   - ceanic crust is elastic-brittle all the way through.
   - It contains elements of Aluminum (Al) , Mg, and silicon (Si). It is called Sima. Its density 3.0 gr/cc.

✓ The crust is composed of two rocks:

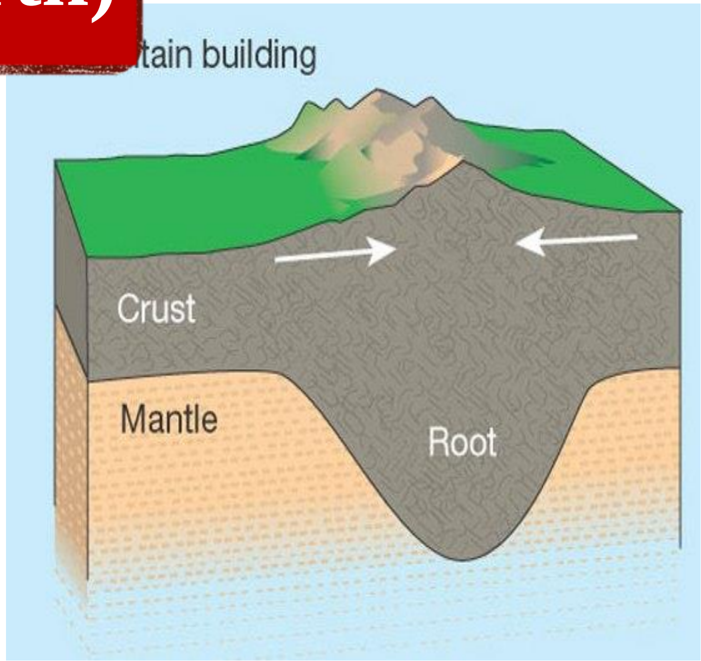
1. The continental crust is mostly granite rocks.
2. The oceanic crust is basaltic rocks.



✓The *Basalt is much denser than the granite.* Because the less dense continents always ride on the denser oceanic plates.



Cont.: The Crust (the outer most part of the Earth)



2.The Continental crust (Upper crust):

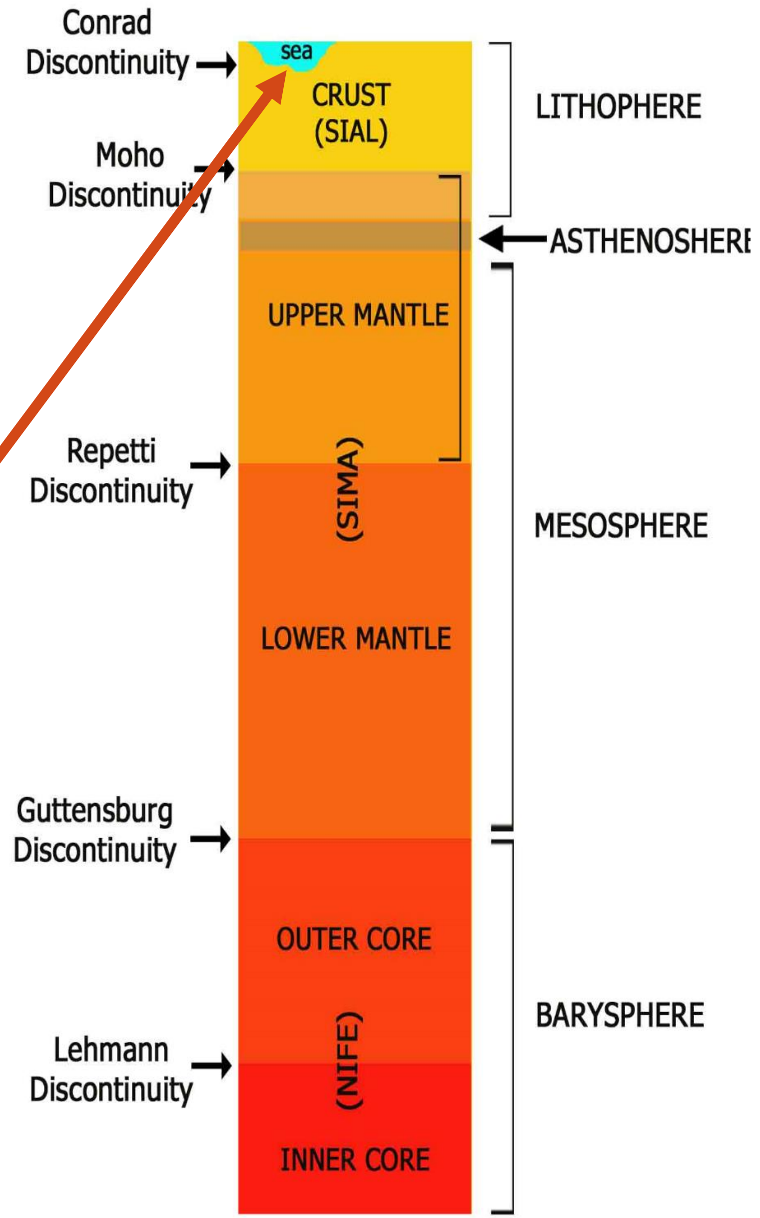
- It is about 30 to 70 km (Thick) under the land surface,
- It is mainly Granodioritic to granite rocks
- Its density around 2.7gr/cc. (Granodiorite has intermediate-to-Sodic plagioclase + K-spar +assorted mafic [mainly amphibole]+ minor quartz), it is called Sail. Its density 2.7 gr/cc.

- **The continental crust thickness under the mountains, crust can be much thicker up to 4^{th} to 5^{th} times of its elevation (Isostasy Theory).**

Cont.: The Crust zone (outer most part of the earth

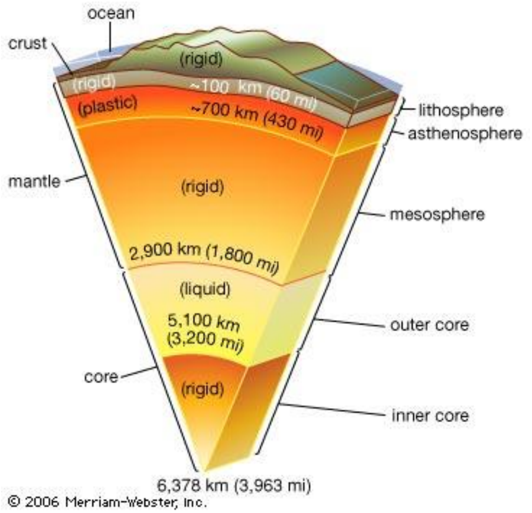
- **Crustal columns usually have the same total mass:**
  - The **(Crust) floats** like blocks of wood in the liquid-like mantle. Mountain chains have low-density roots (they're like icebergs).
  - Trenches have complex density structure.

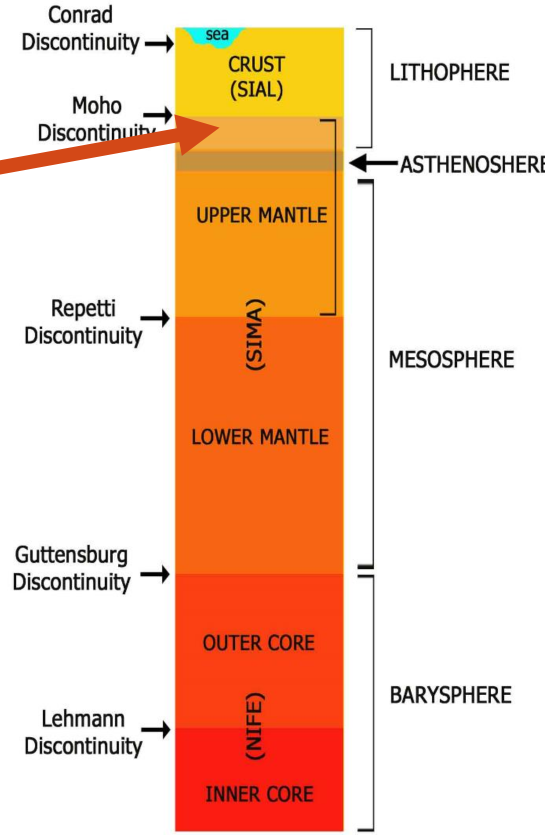
    - **The Continental and oceanic crust *separated by a discontinuity line called CONNRAD DIS.***



2- The mantle Zone

- It is 800 Km thick below the earth surface.
- It start at depth of 100 km to 2900 km deep.
- It has density ranged from 3.3gr/cc to 5.5 gr/cc at the bottom **due to compression and phase changes**.

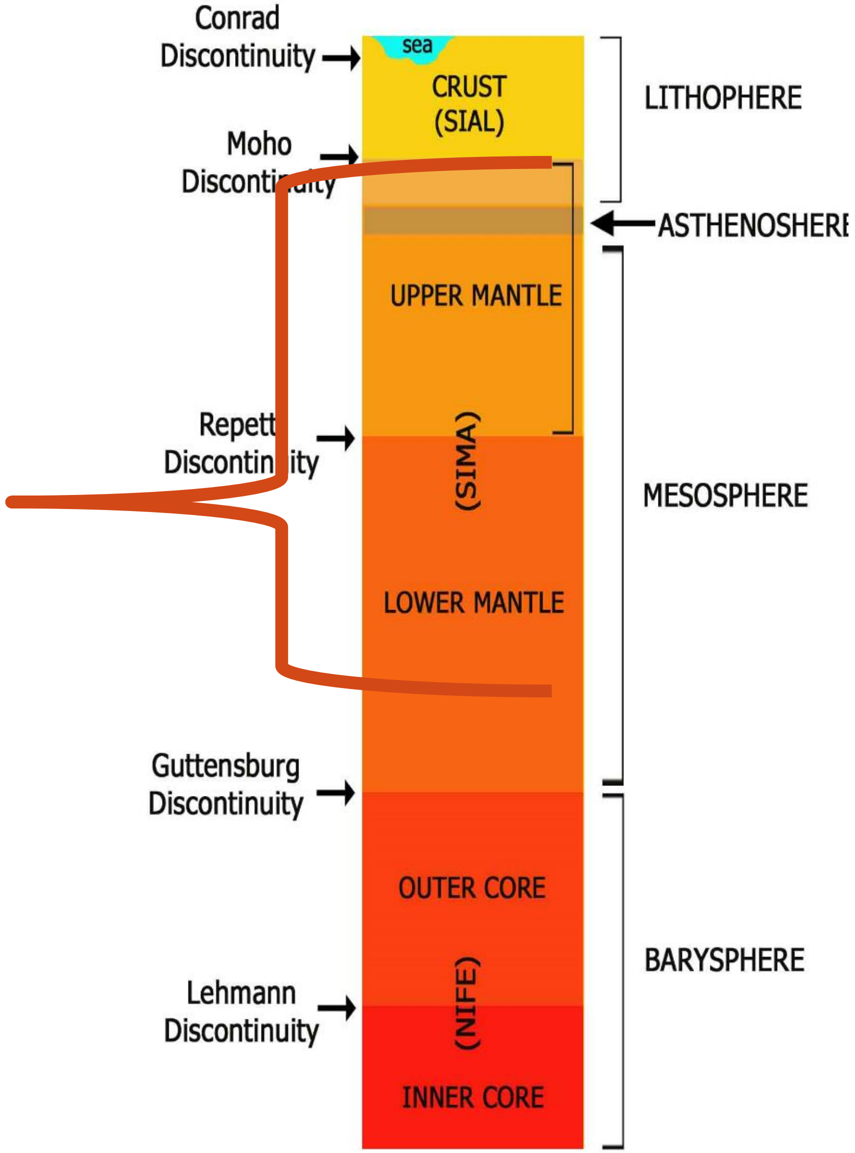




- **A Moho discontinuity boundary; named after Andrija Mohorovicic ,1909), It is found between the crust and upper part of the mantle**

2- Cont'd: The mantle zone

- **The Mantle is the largest zone of the Earth is composed of very hot dense rock; that flows like asphalt under a heavy weight.**
- The mantle forms about 80 to 83 % of the total volume of the earth, its density about 4.5 gr/cc..
- The seismic waves (P & S) velocity is reduced in this zone that's because of :
  - ✓It is too hot,
  - ✓Elastic .

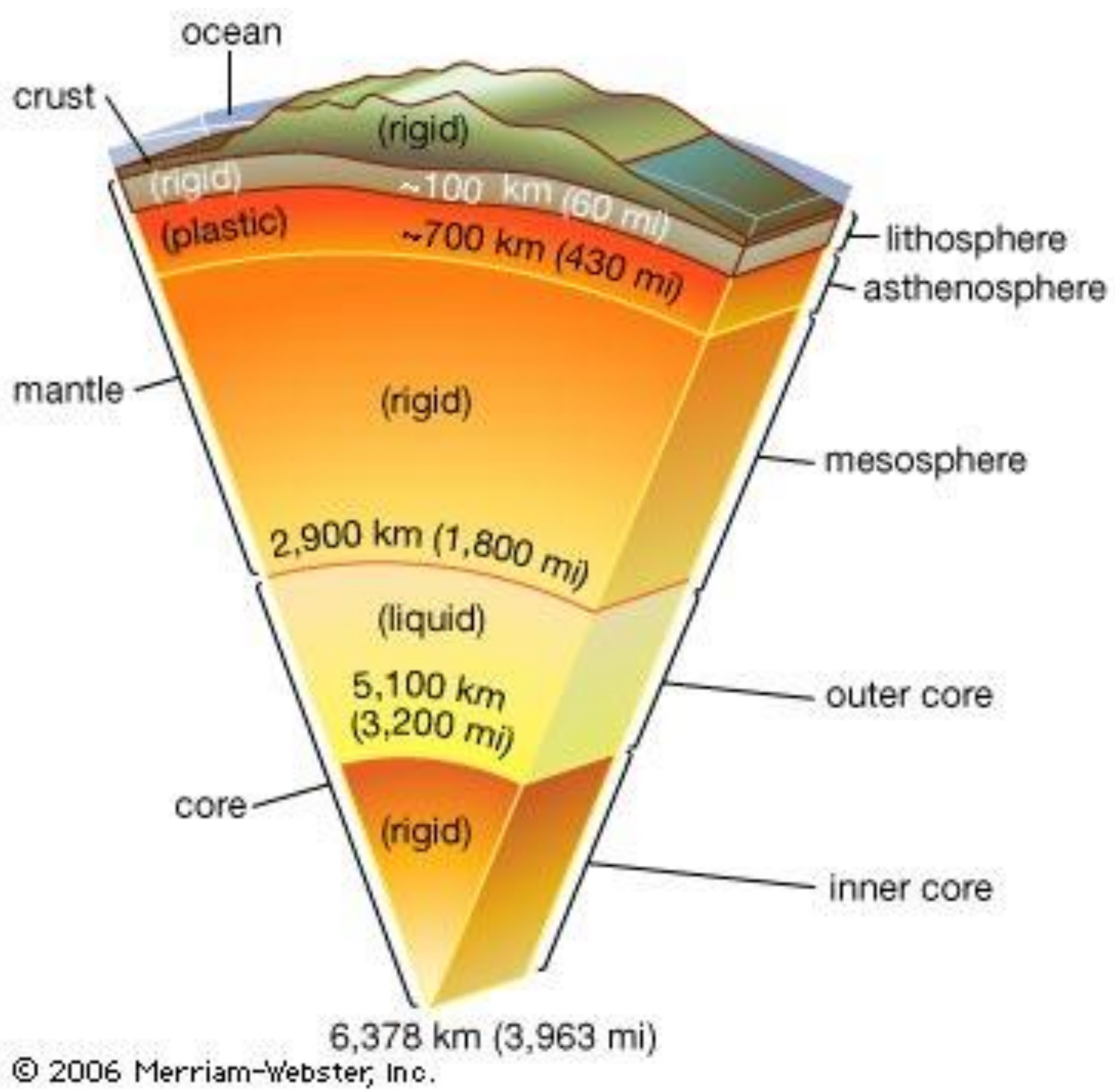


- The **mantle is a thick section** that has a **peridotite** (olivine + pyroxene) composition.

2- Cont'd: The mantle

The **mantle** is divided into several 3 different zones:

1. the upper mantle Lithosphere).
2. The middle mantle (Asthenosphere).
3. The lower mantle (Mezosphere).



Quizz

Anwser the following True (✓) or False (X)

1. **The Earth has different zones in concentric sequences, the inner zone is has has lighter materials than the it outermost zone.**

   True ( ) or False ( )

2. **What is the Zone's name of the semi-liquid mantle zone.**

   Mezosphere ( ), Lithosphere ( ), Non of these ( ), determine: ……………………

3. **The crust and Ashenosphere earth's zones are forming the plate tectonic**

   True ( ) or False ( )

4. **Moho. Discontinunity is located between the oceanic and continental crust.**

   True ( ) or False ( )

Quizz / Answers

True (✓) or False (X)

1. The Earth has different zones in concentric sequences, the inner zone is has has lighter materials than the it outermost zone. True ( ) or False (X)

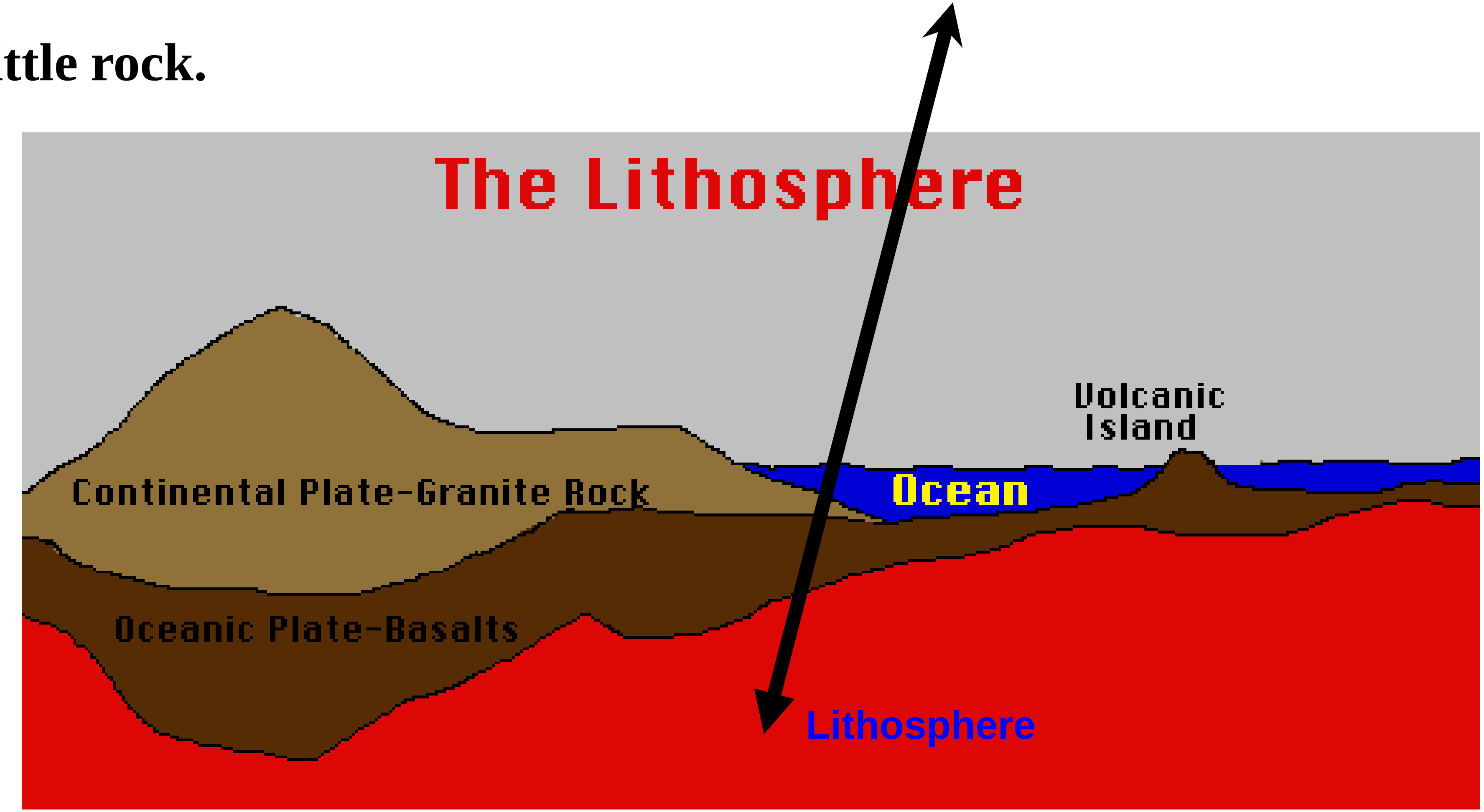
1. What is the Zone's name of the semi-liquid mantle zone.
   1. Mezosphere ( ), Lithosphere ( ), Non of these ( ), determine: Asthenosphere

2. The crust and Ashenosphere earth's zones are forming the plate tectonic. True ( ) or False (X)

1. Moho. Discontinunity is located between the oceanic and continental crust. True ( ) or False (X)

1- The Lithosphere (Upper Mantle)

The crust and the upper layer of the mantle (Lithosphere) together make up a zone of rigid, brittle rock.

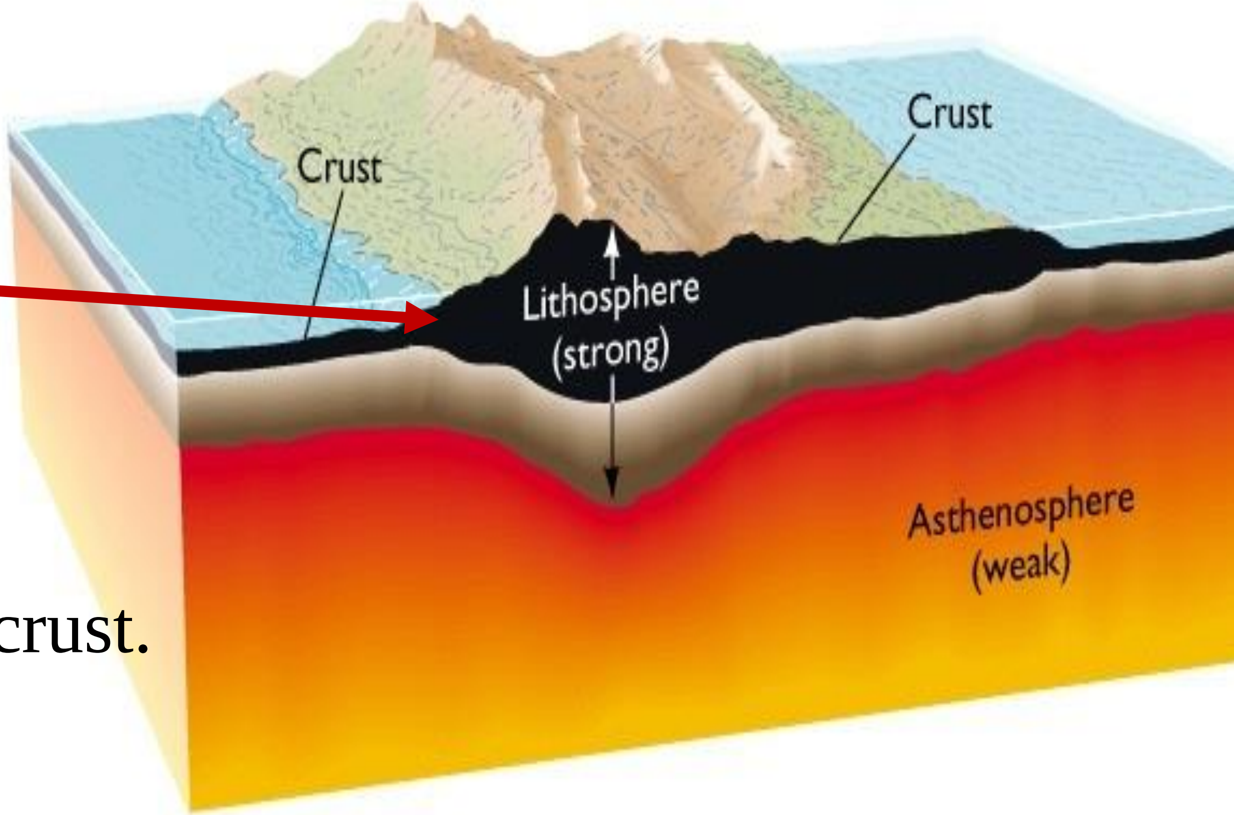


Cont'd: The Lithosphere (Upper Mantle)

1. Upper mantle (Lithosphere):

- It is **rigid** , consists of olivine, amphibole , pyroxene, plagioclase , pyrope (Garnet), Jadeite, Omphacite, Spenil.

- It **(Lithosphere)** composed of :
  - ⦿**Dunite rocks,**
  - ⦿**Peridotite rocks,**
  - ⦿**Ecologite rocks.**

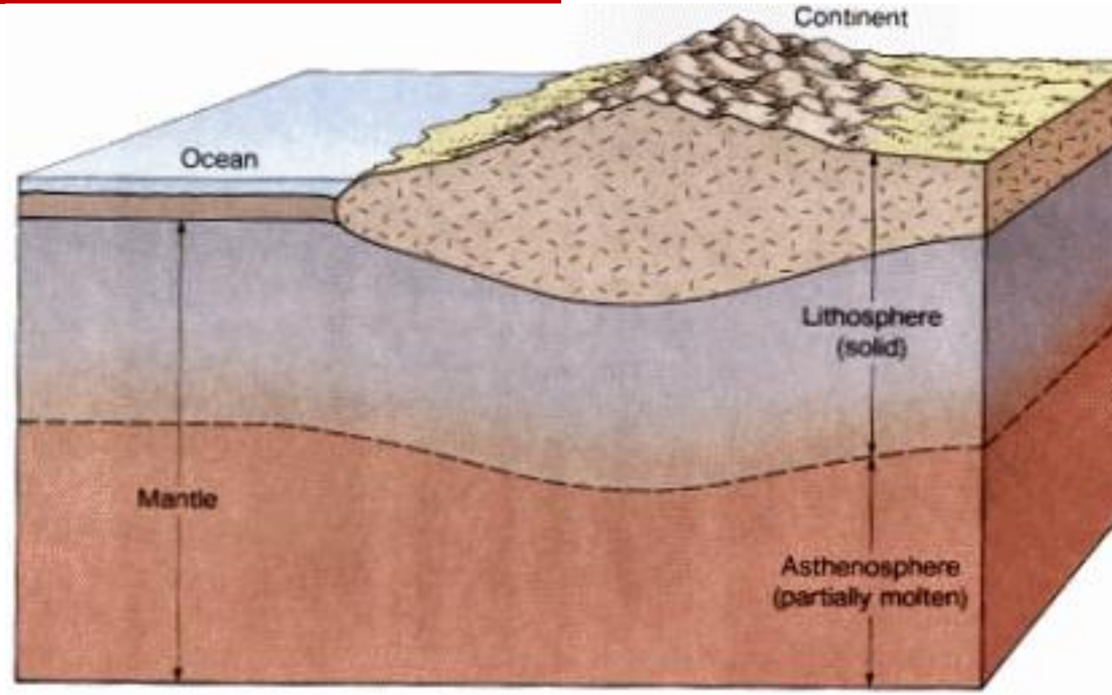


➢**Lithosphere thickness is about**100 km.

✓It is rather rigid and bound in its top by crust.

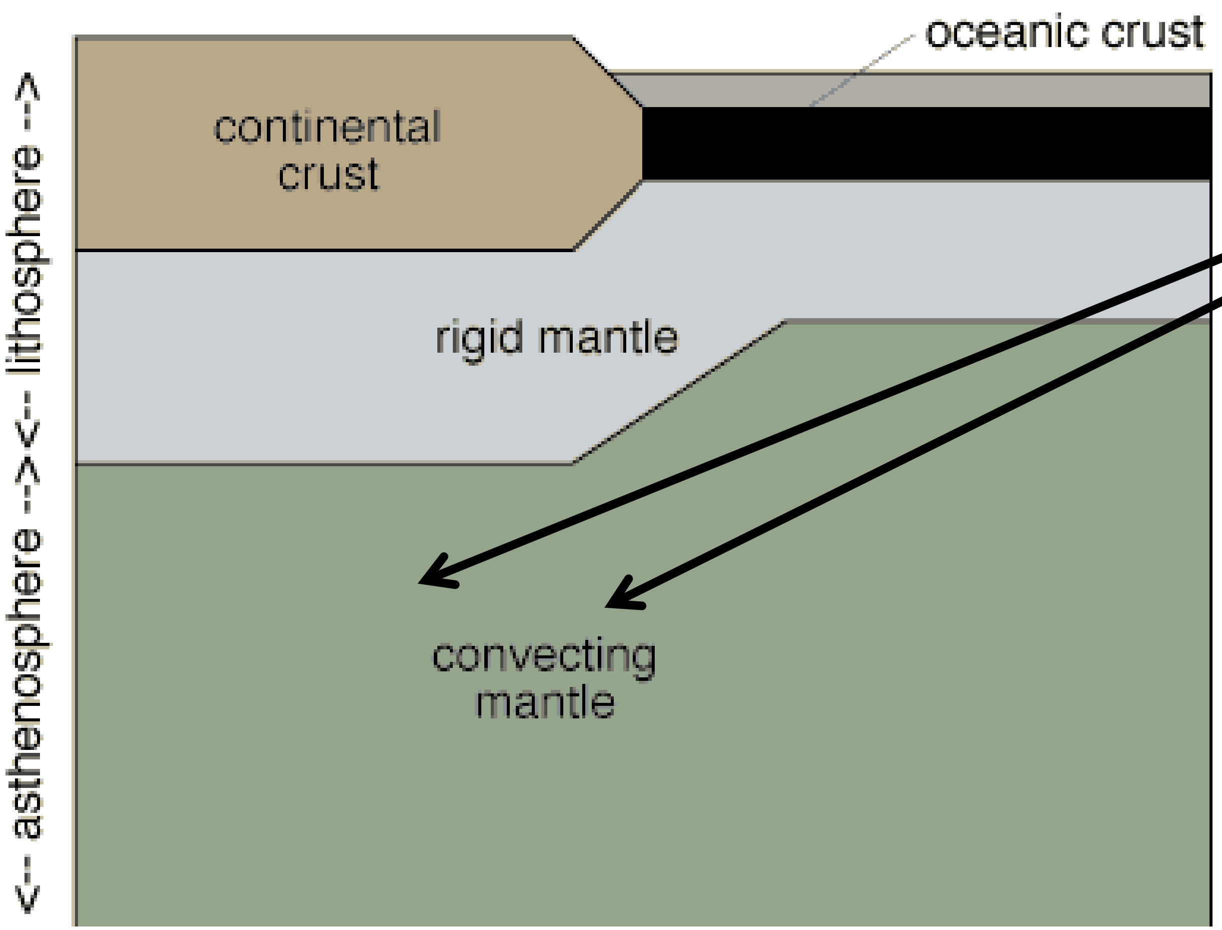
Cont’d: The Lithosphere (Upper Mantle)

- ✓The crust+Uper mantle called (Lithosphere) = is consisting of a plate(s) is/are floating on the the middle mantle (Asthenosphere), because the Asthenosphere is a semi liquid zone in the earth.



- ✓ that is causing the crust & Lithospheric zones a rigid and **soft and spongy** plates overlain & moving or **flows plastically on the middle mantle (Asthenosphere).**

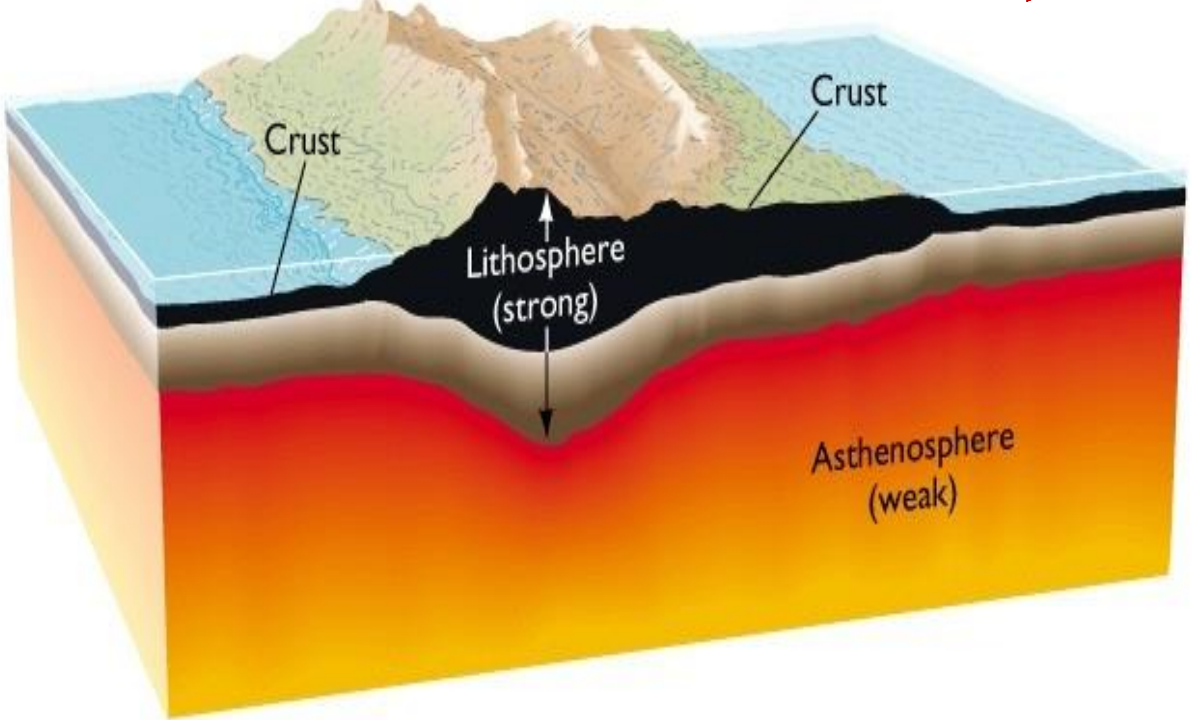
2- The Asthenosphere (Middle Mantle)



The Asthenosphere is the semi-rigid part of the middle mantle that flows like hot asphalt under a heavy weight.

2. The middle mantle (Asthenosphere):

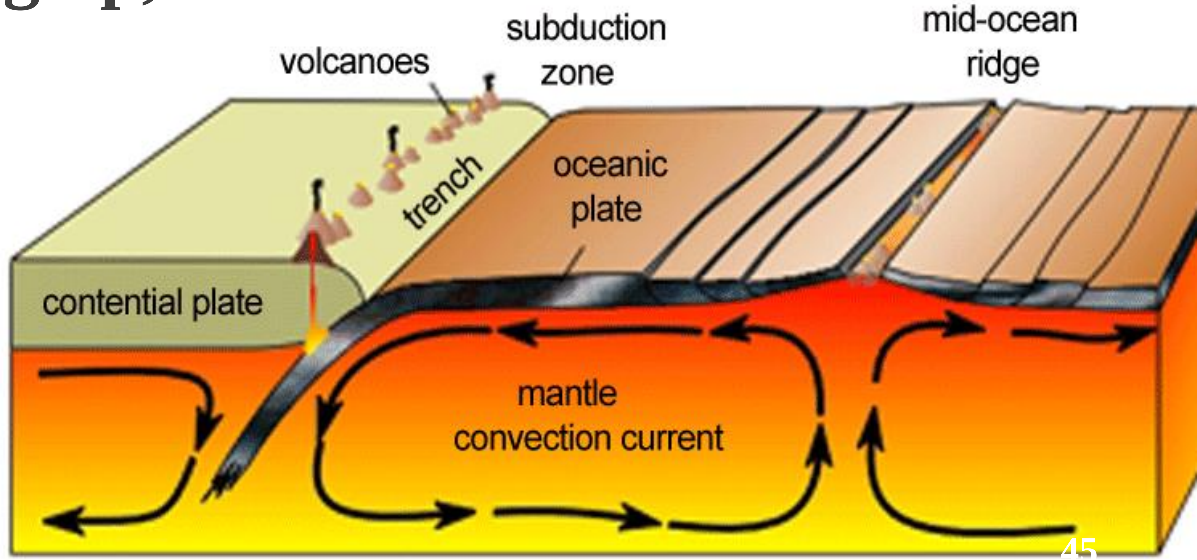
- It is **elastic** zone .
- It lies between the upper mantle and lower mantle from depth of 100 km to about 350 or 700 km (thickness of about 600 km).
- Its **minerals do not resist the pressure and heat acted in this zone,**
  - ✓ **so it becomes elastic (not rigid).**
- Due to **its elasticity the upper rigid part above it is easy to move.**



Convection Currents in (Middle Mantle)

- ✓The middle mantle “Asthenosphere” "flows or move" due to its convection currents formation.

- ✓The Convection currents are caused by a very hot material at the deepest (bottom) part of the middle mantle rising up, then its cools down and sinking again.

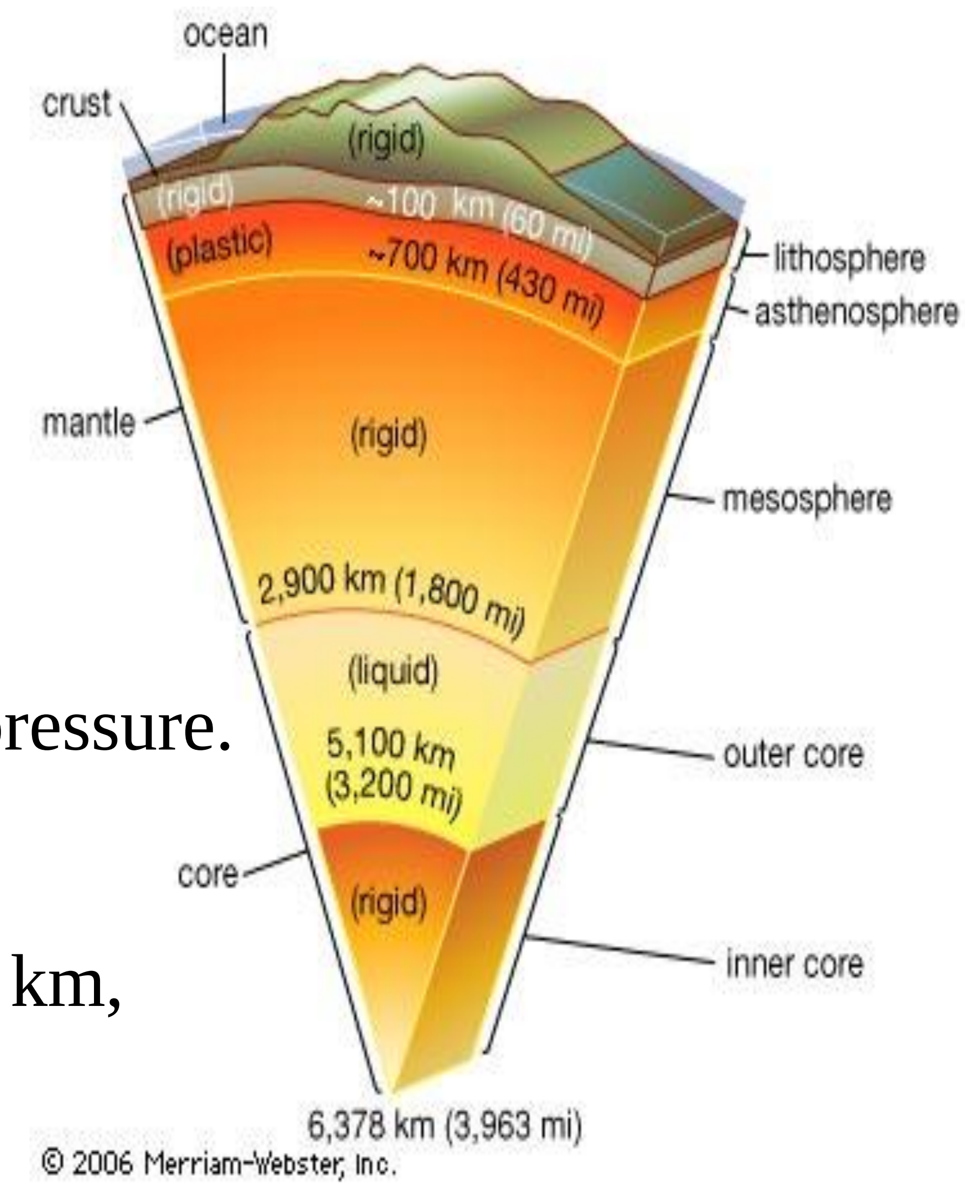


- ✓This cycles are repeated over and over.

Cont.: mantle

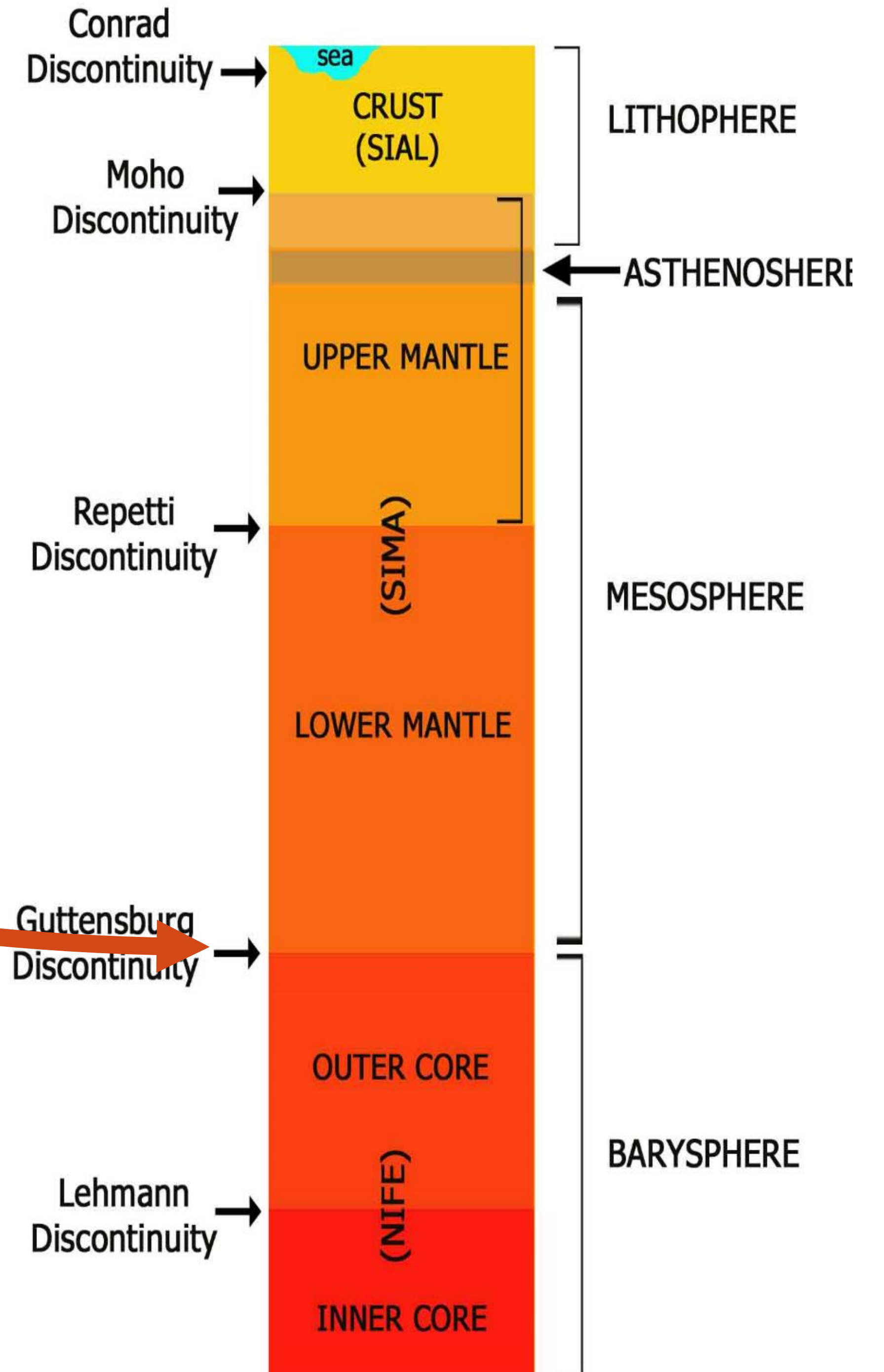
3. **The lower mantle (called Mesosphere):**

- It is rigid.
- It is formed of Mg, Fe, Cr, and Si.
- Its minerals can resist the zone's heat and pressure.
- Its depth starts from about 400 km to 2900 km, with thickness of about 2500 km.



Cont.: mantle

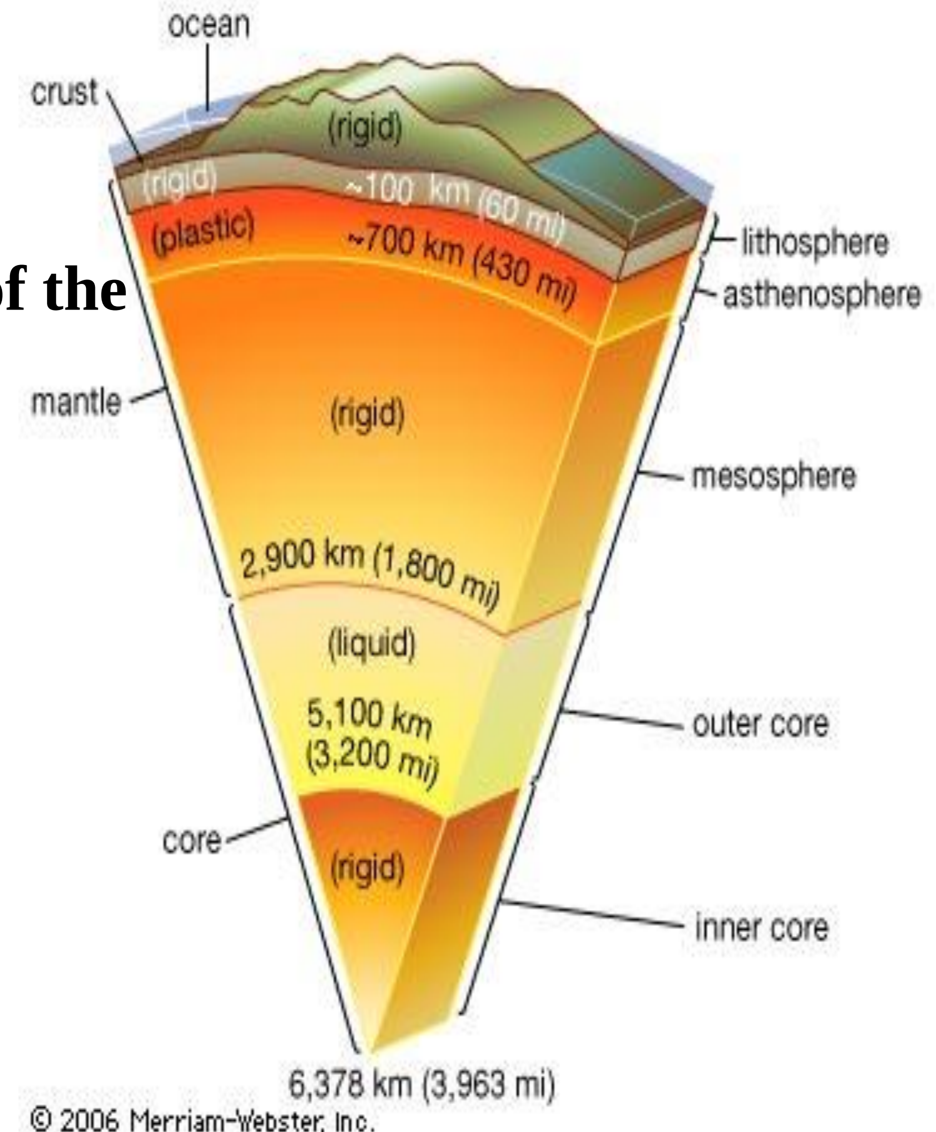
- *The Gutenberg Discontinuity* **surface is separating the bottom of the lower mantle (Mesosphere) from the surface of the outer core.**



3- The core (inner most zone of the earth)

➢ The core lies at the center of the earth .

- It is very hot .
- It is forming of about 6% of the total volume of the earth.
- Its depthstarts from 2900 km and extend to the center of the earth about 6378 km.



➢ The Eart Core is divided into:

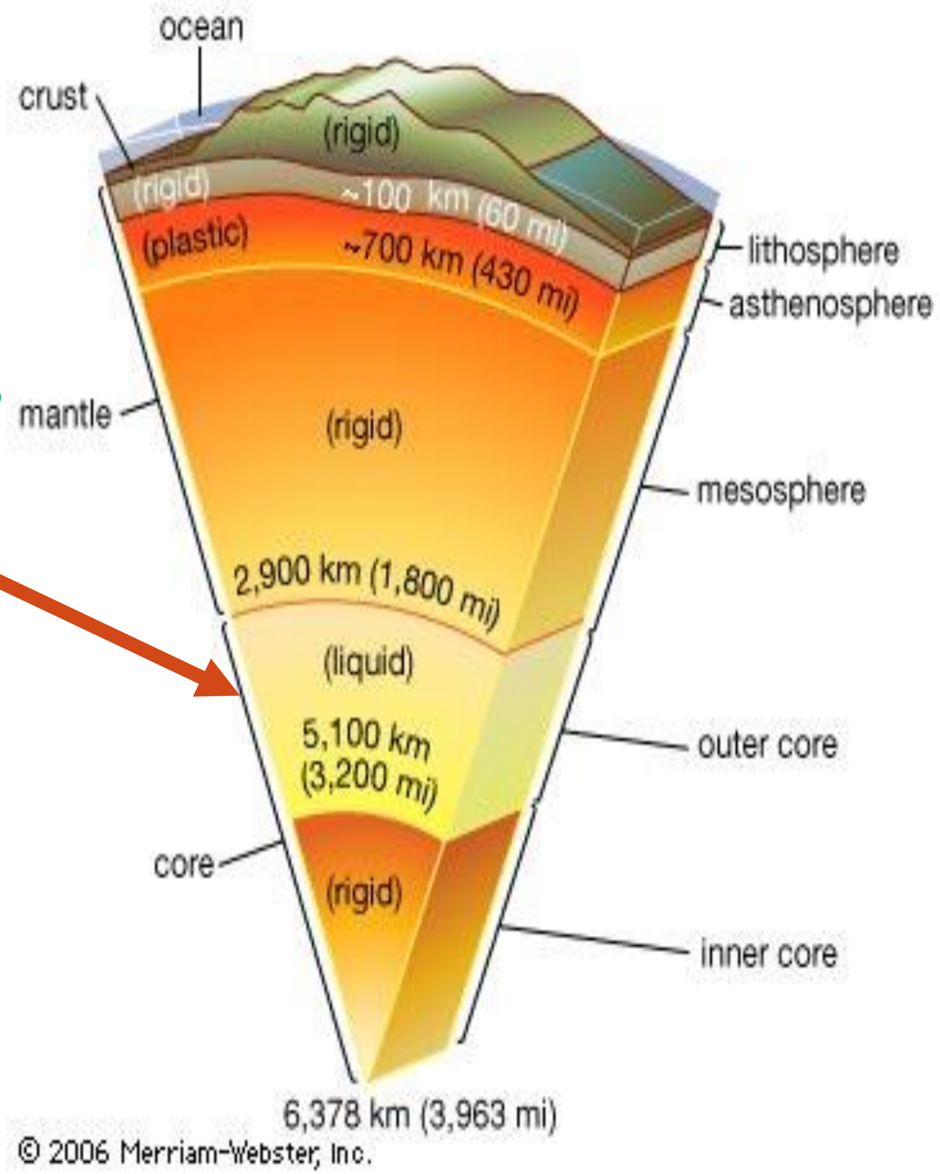
1. The outer Core.
2. The Inner Core.

Cont.: the core (the inner most of the earth)

1.The outer core:

- ***It forms of a melted material of FE, Ni, plus20 % of Si, and S,***
- ***So, due to this composition the outer core becomes liquid.***

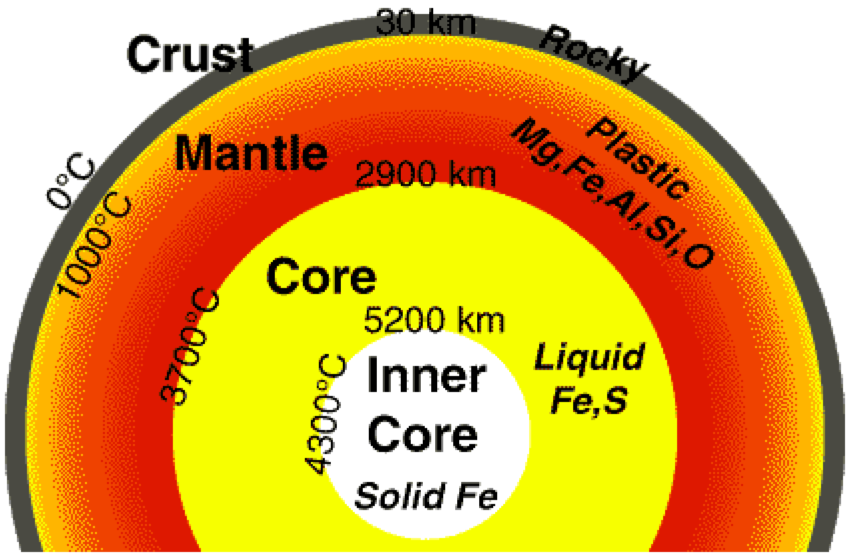
  - It is extremely hot .

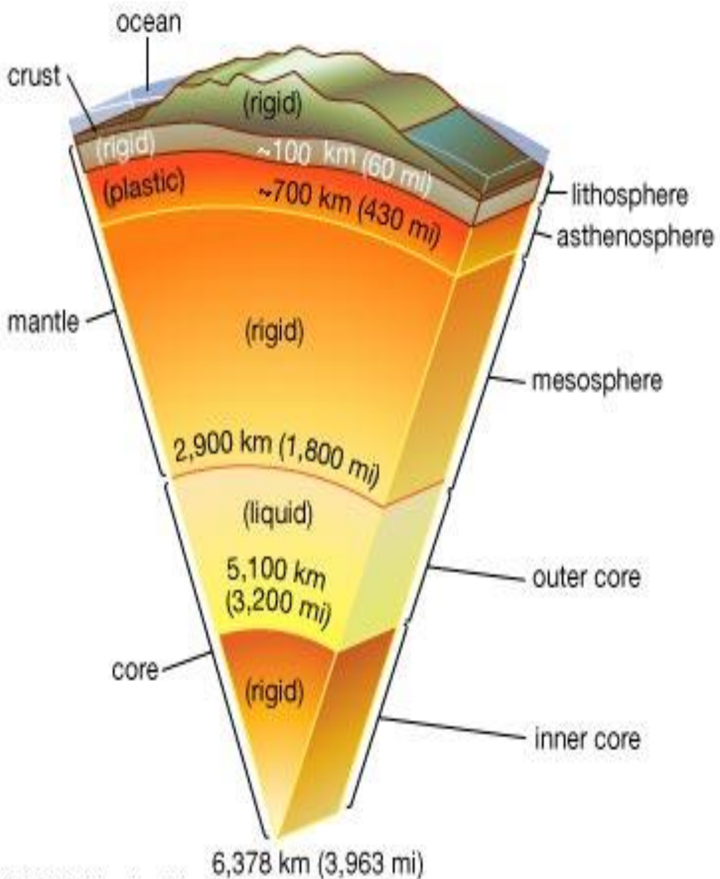


Cont.: the core

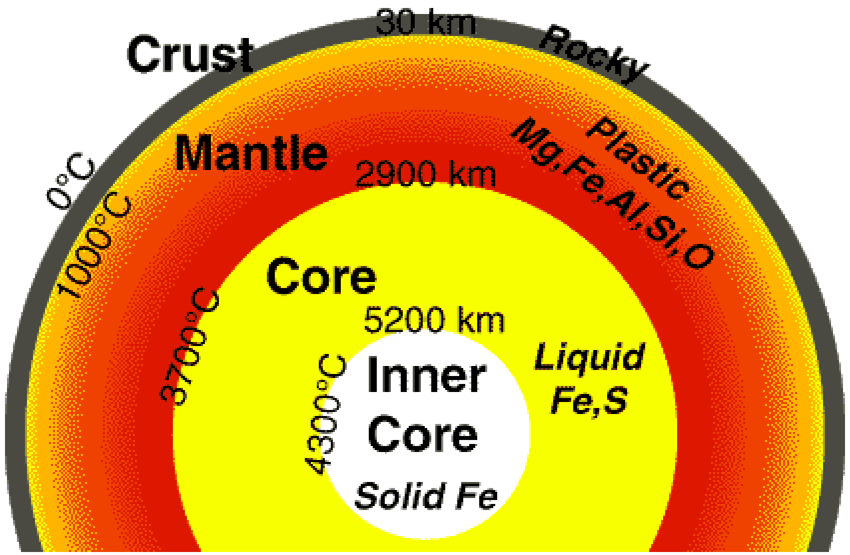
2. The inner core:

- It consists of Fe and Ni in a solid state.
- It starts at a depth of about 5100 km ended in the center of the earth at 6378 km with a thickness of about 1220 km.
- Its composition meteorite alike
- Its density about 12 to 15 gr/cc.



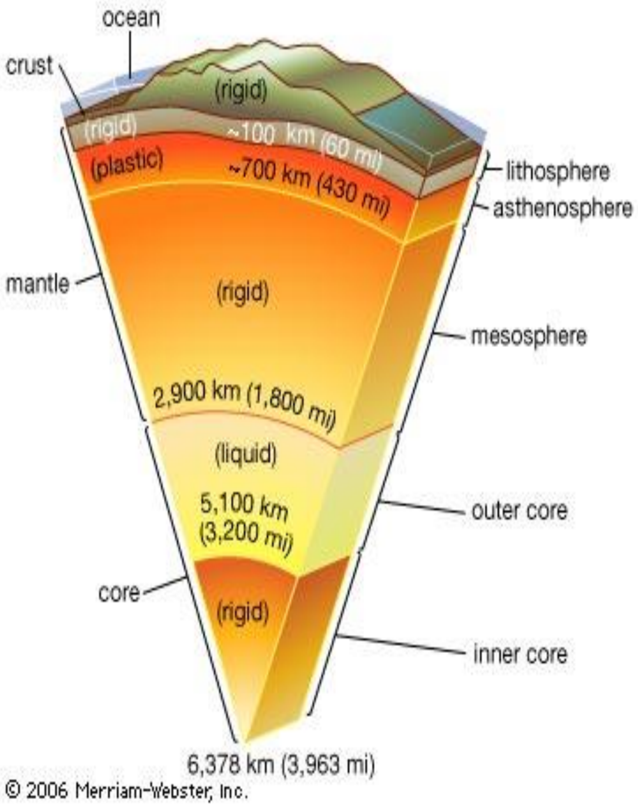


Cont'd: The core:



2- The Inner Core

- The **inner core** of the Earth is a very high temperatures and pressures,
- Thus, the metals and elements are squeezed together.
- and are not able to move as a liquid,
- it is forced in place as a **solid**.



Note

as far as the crust+Lithosphere are placed on top of the elastic zone (Asthenosphere) ,

The Asthenosphere acted as an greasy layered materials.

- **It is causing the crust+ lithosphere to move, to float and to slide on it, and to initiate what we call a PLATE TECTONIC**

STRUCTURE OF THE EARTH.mp4

Earth's internal Heat

Geo 324

The Source of the Earth's heat: Forms of Energy

- **Energy:**
  - ✓ is commonly defined as the capacity for doing work.
- **Work, *w*, :**
  - ✓is defined as the product of force, *F*, times a displacement over a distance, *d*, in the direction of the force

Thus,

$$W = F * d$$

For example,

- ✓ ***The energy*** is required to perform the work of ***pushing a thrust plate*** in an actively growing compressional mountain system

or

- ✓ ***throwing a fragment of rock throughout an explosive volcanic vent.***
- ✓ ***Thus, an important type of work in geologic systems is called:***

PV work,

Where:

- ***P*** **is the pressure, such as possessed by a volcanic gas, and**
- ***V*** **is the volume of the gas**

Thus,

An increase in the internal thermal energy of a solid is associated with greater kinetic energy via faster motion of the atoms and its evident is a greater temperature, *T*.

- **This motion can become sufficiently strong to break atomic bonds quickly.**

So,

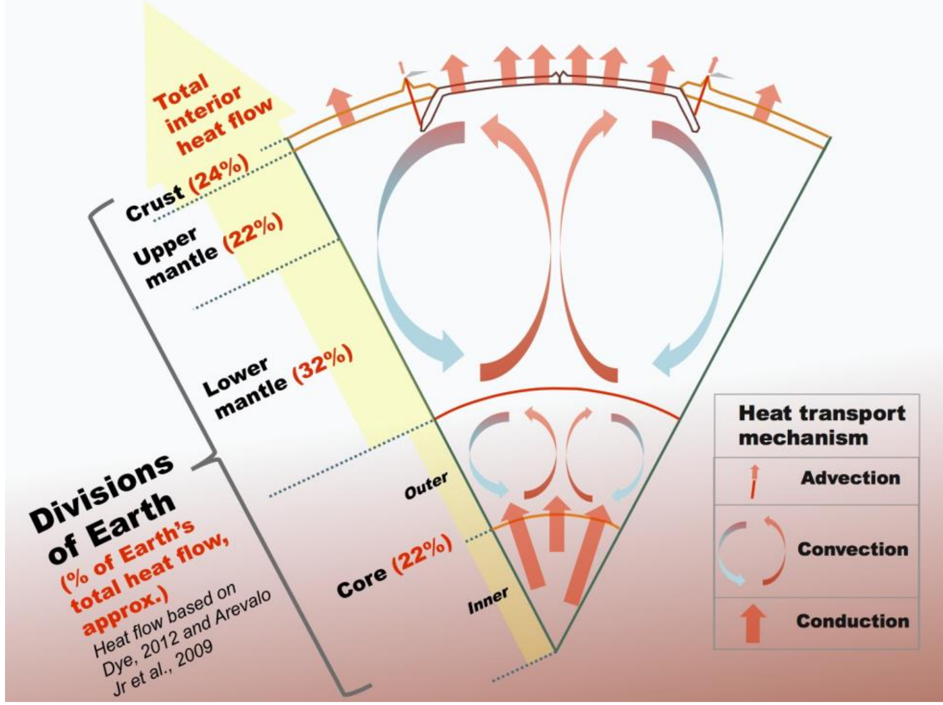
- The solid becomes a flowing liquid, or, if bonds are fully broken, a gas.

- **The term *heat* is sometimes used synonymously with *thermal energy*, but, strictly speaking, *heat is transferred thermal energy caused by a difference in temperature between bodies.***

The Source of the Earth's heat: **Forms of Energy**

2- **The Earth's Interior Heat :**

- The total heat flow is estimated from Earth's interior to surface in a span of a range from 30 to 200 terawatt (TW), or 10^{12} Watt of the interior heat budget.



- Recently, it is estimated in about 47 TW which is equivalent to an average heat flux of 91.6 mW/m², and is based on more than 38,000 measurements.

- The mean world heat flows of continental and oceanic crust are 70.9 TW and 105.4 mW/m².

The Source of th Earth's heat:

- Thus, ~99% of Earth's internal heat loss at the surface is by conduction through the crust,
- and the mantle convection which is the dominant control on heat transport from deep within the Earth.
- *Heat arrives to the surface of the Earth from its interior and from the Sun* by the two following sources:
  - **Heat from the Sun arriving at the Earth is $2x10^{17}$ W.**
  - **Averaged over the surface of the earth is about $4x10^{2}$ W/m^2**
- The **heat is tranfering from the interior earth is $4x10^{13}$ W and $8x10^{-2}$ W/m^2 as mentioned above.**

The Source of the Earth's heat:

Earth's Energy Equation, simplified

$$Q_{surface} \approx H_{radioactive} + H_{mantle\ secular\ cooling} + Q_{core}$$

$Q_{surface} \approx$ 44 TW (surface heat flow measurements)

$H_{radioactive} \approx$ 20 TW (chondrite-based composition models)

$H_{secular\ cooling} \approx$ 9-18 TW (50-100 K/Ga, based on petrologic studies and rates of continental uplift)

As a result, the

$Q_{core} \approx$ 2-15 TW (geodynamo requirements, age of inner core, conductive heat flow across core/mantle boundary layer, heat transport by plumes)

The essential Heat effect asSource on the Earth’s :

- The heat created from the interior of the Earth, and governed the geological evolution of the Earth,
- It is controlling plate tectonics, igneous activity, metamorphism, the evolution of the core, mantle convections, and hence the Earth’s magnetic field.
- The Earth’s thermal resources controls the activity of the lithosphere and asthenosphere and the development of the basic structure of the Earth.
- Earths heat transport by conduction-heat from mantle convection and hydrothermal circulation and volcanic advection to upper mantle.
- Earth's internal heat flow to the surface is thought to be 80% due to mantle convection, with the remaining heat mostly originating in the Earth's crust, with about 1% due to volcanic activity, earthquakes, and mountain building.

Heat mechanisms & heat transfer:

Three mechanisms for heat transfer: طرق التبادل الحراري وآلياته (توجد 3 طرق

1- Conduction

It is theHeat transfer through a material by atomic or molecular interaction within the material.

هو طاقة الحرارة المنتقلة من جسم لآخر بسبب الإهتزازات الجزيئية للمادة بواسطة الطاقة الحراية .

2- Radiation

Direct transfer of heat as electromagnetic radiation.

تتكون عندما تنتج العناصر المشعة الطاقة الإشعاعية الحرارة بإنشطارها وتكسرها .

هذه الطاقة تنتشر على هيئة موجات كهرومغناطيسية مثل وصول أشعة الشمس للأرض.

Heat mechanisms & heat transfer:

3- **Convection**

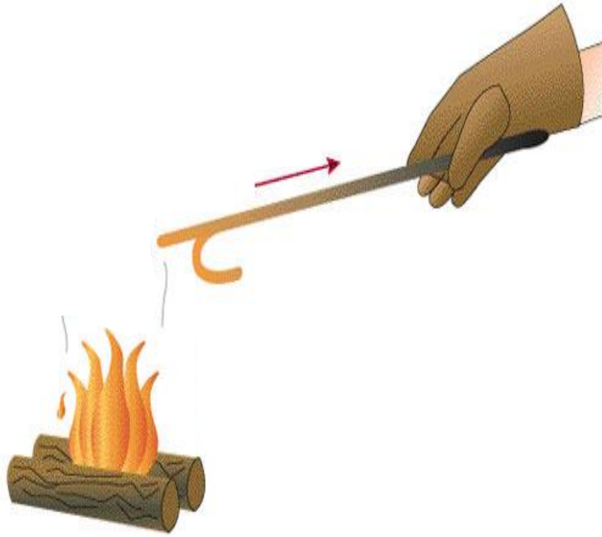
- Transfer of heat by the movement of the molecules themselves
- Advection (Advection is a lateral or horizontal transfer of mass, heat,) is a special case of convection.

- وهو إنتقال الحرارة رأسيا نتيجة لحركة دورانية للغاز أو السائل أو أي مادة لدنة.
- تنتج عن هذه الحركة تسخين غير متساوي للمادة المسخنه

هذا بسبب إالإختلاف في كثافة المادة

Heat mechanisms & heat transfer:

Conduction(Conductive Heat Flow):



- It is A diffusive process wherein molecules transmit their kinetic energy to other molecules by colliding with them.

OR

- Heat flows from hot things to cold things.
- The rate at which heat flows **is proportional to the temperature gradient in a material, so:**

Large temperature gradient – higher heat flow

Small temperature gradient – lower heat flow

Conductive heat flow:

Heat flow (or flux) (q):

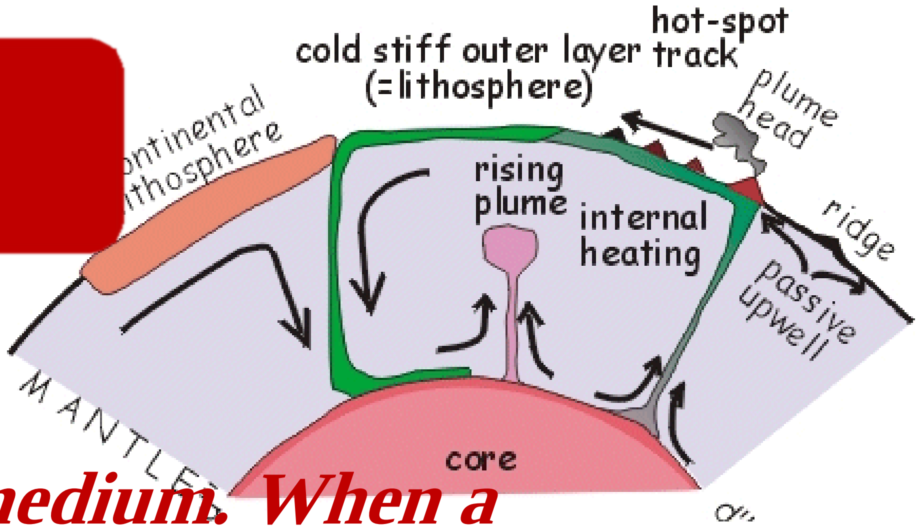
- is rate of flow of heat per unit area.
  - The unit = watts per meter squared, W/m^{-2}
- Watt is a unit of power (amount of work done per unit time)
  - A watt: is watt is a joule per second
  - Old heat flow units, 1 hfu = 10^{-6} cal cm^{-2} s^{-1}
    - 1 hfu = 4.2 x 10^{-2} W m^{-2}
    - Typical continental surface heat flow is 40-80 mW m^{-2}

Where:

- **Thermal conductivity k**
  - The units are watts per meter per degree centigrade, W m^{-1} °C^{-1}
  - Old thermal conductivity units, cal cm^{-1} s^{-1} °C^{-1}
- 0.006 cal cm^{-1} s^{-1}°C^{-1} = 2.52 W m^{-1} °C^{-1}
- Typical conductivity values in W m^{-1} °C^{-1} for:

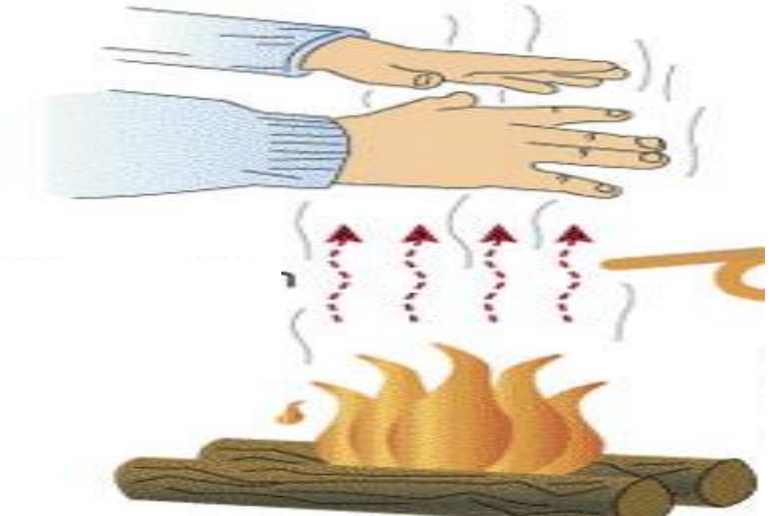
Silver	420	W m^{-1} °C^{-1}
Magnesium	160	W m^{-1} °C^{-1}
Glass	1.2	W m^{-1} °C^{-1}
Rock	1.7-3.3	W m^{-1} °C^{-1}
Wood	0.1	W m^{-1} °C^{-1}

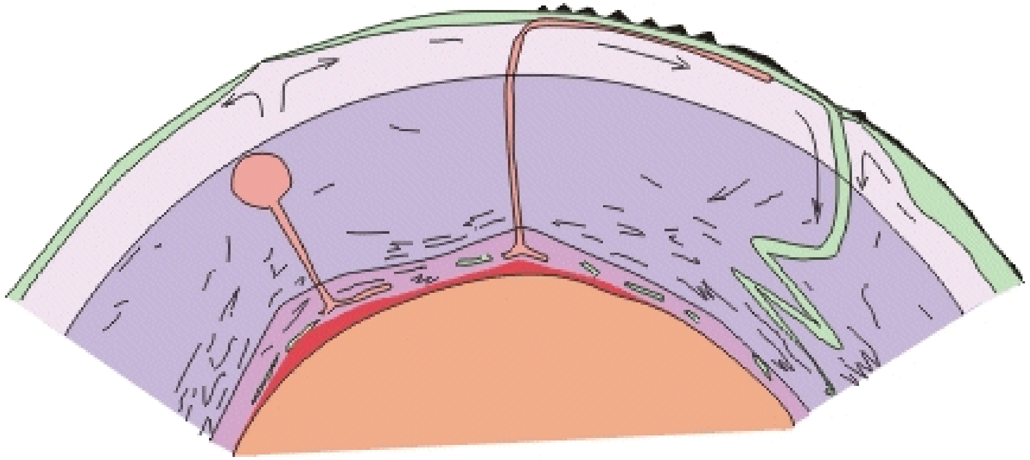
Heat mechanisms & heat transfer:

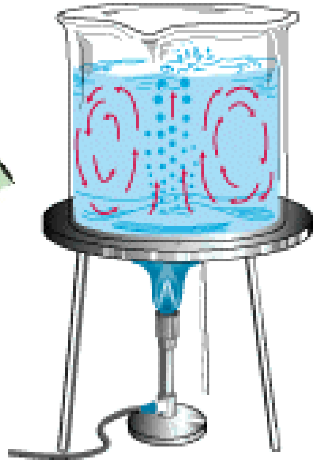


CONVECTION HEAT

Is a ***process associated with the motion of the medium. When a hot material flows into a cold material, it will heat the region - and vise versa.***



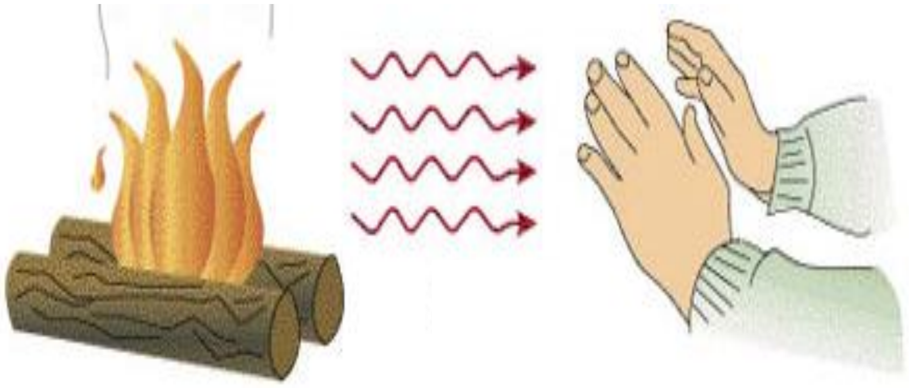


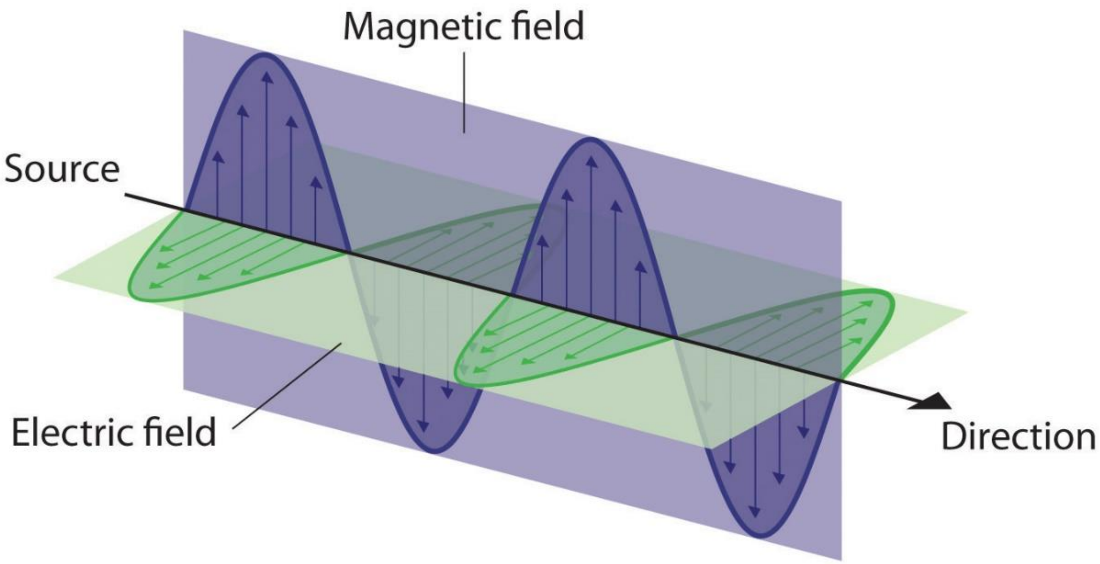


Heat mechanisms & heat transfer:

RADIATION HEAT

Is the transfer of heat via electromagnetic radiation. Example - the Sun.





Heat transfer (Flow of Heat):

Heat flux :**is the flow per unit area and per unit time of heat**. It is directly **proportional to the temperature gradient**.

One dimensional Fourier's law: $q = -k \frac{dT}{dy}$,

where:

q is the heat flux
k is the coefficient of thermal conductivity
T is the temperature
y is a spatial coordinate

Units:

- **q = represents [Wm^{-2}]**
- **k = represents [$Wm^{-1}K^{-1}$]**

where W is read "watt", and it is equal to Joule per second.

Joule/s is a unit equal to a **joule** multiplied by a **second**, used to measure action. The action of a system has the dimensions of energy integrated over time; measured in **joule-seconds**. The **joule-second** is the unit used for Planck's constant.

Heat transfer (Flow of Heat):

- **Fourier's law**, **the rate of flow of heat energy per unit area through a surface is proportional to the negative temperature gradient across the surface,**

- **A *substance with a large value of (k) is a good thermal conductor*, whereas a substance with a small value of k is a poor thermal conductor or a good thermal insulator.**

Question: why is the minus sign?

Question: is q a vector or a scalar?

Heat transfer (Flow of Heat):

- **In the Earth,** both : 1- conduction, and 2- convection. } are very important.

- The **heat transfer in the lithosphere, and the temperature gradient is controlled mainly by conduction**,

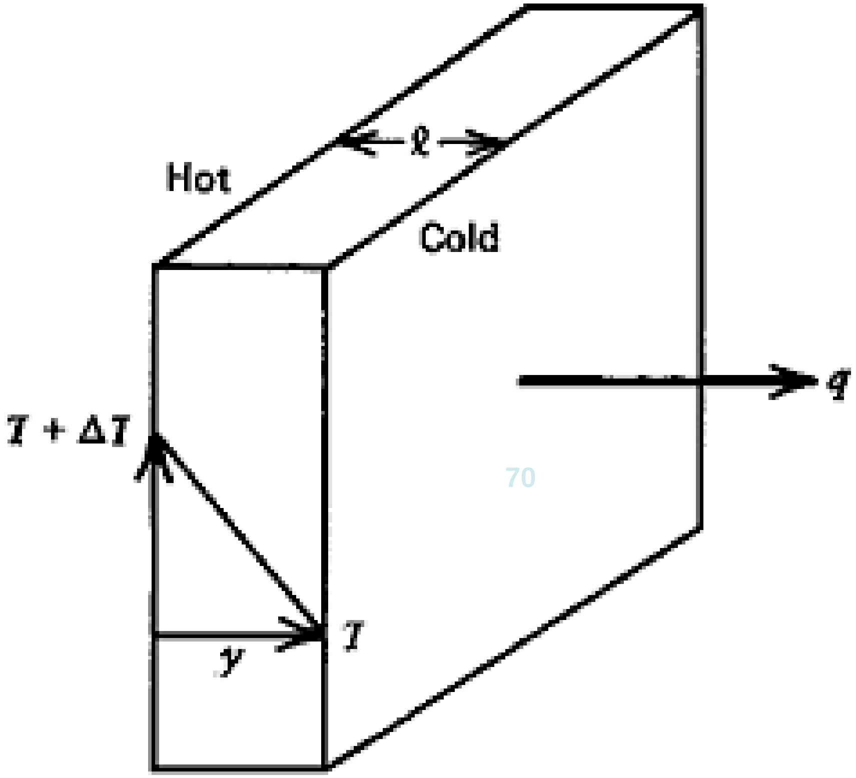
- and the **Maximum Heat flow found in sea floor spreading (*East ridge* of Pacific Ocean**), and **the min. hf. found in (the Mid-oceanic ridge).** I.e. (أن حرارة التوصيل تتناسب عكسيا مع مربع الزمن)

- Convection in the **lithosphere does play a role in**:
  - **In the form of hydrothermal ocean circulation (**Mid-ocean ridges) .
  - **Volcanism and emplacement of magmatic bodies.**

Heat transfer (Flow of Heat):

Example 1: a slab of thickness l, and a temperature difference of ΔT:

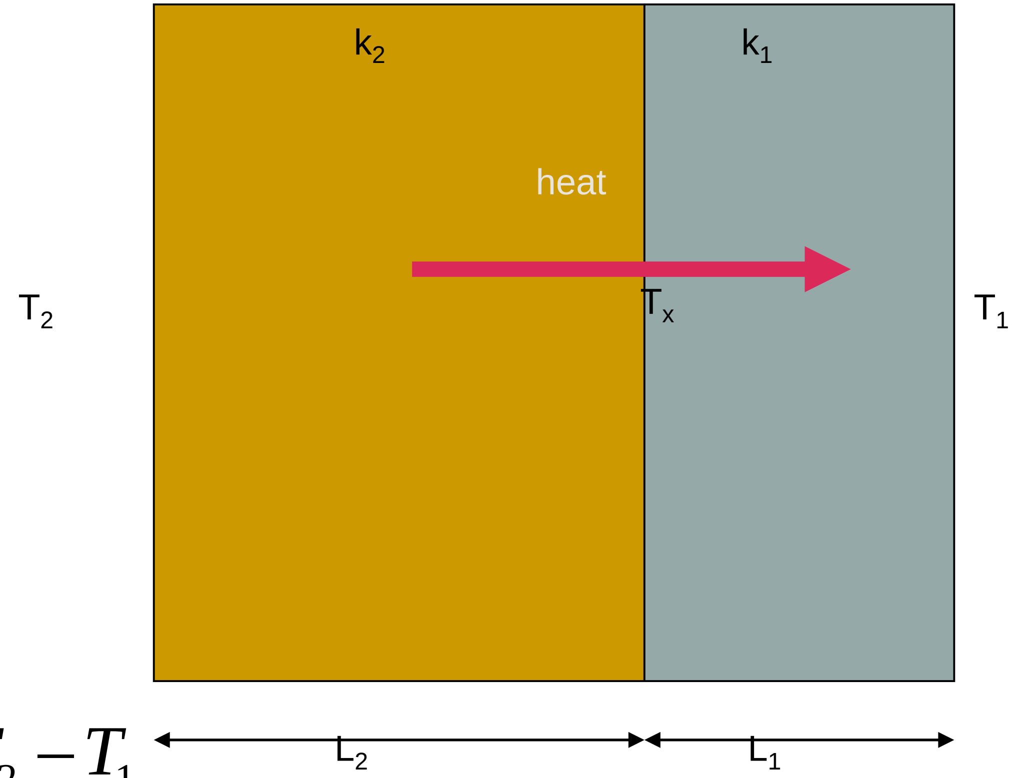
$$q = -k\frac{dT}{dy} \quad ,$$



The heat flux is given by:

Heat transfer (Flow of Heat):

Example 2: a composite slab



H.F. through slab 2: $$q_2 = k_2 \frac{T_2 - T_x}{L_2}.$$

H.F. through slab 1: $$q_1 = k_1 \frac{T_x - T_1}{L_1}.$$

In steady-state q_1=q_2, we get: $$q_1 = q_2 = \frac{T_2 - T_1}{(L_1/k_1) + (L_2/k_2)}.$$

Or more generally: $$q_n = \frac{T_n - T_1}{\sum_{i=1,n} L_i / k_i}.$$

Note:

The trade-off is found between thermal conductivity, k, and the medium thickness, L.

Thus, , the important quantity is L/k, often referred to as thermal resistance.

Heat transfer: heat flow over continental stable area

- **Highest heat loss at mid-ocean ridges** and lowest at old oceanic crust.

- With **temperature gradient of 20-30 K/km**, and **thermal conductivity of 2-3 $WK^{-1}m^{-1}$**, the **heat flux is 40-90 mWm^{-2}**.

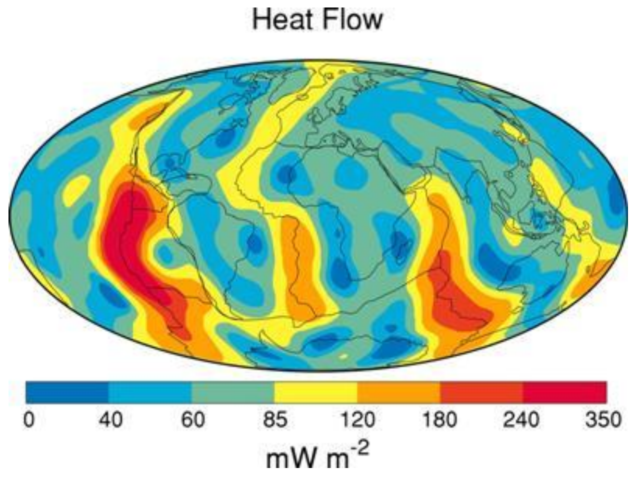


Table 7.3 *Heat loss and heat flow from the Earth*

	Area (10^6 km^2)	Mean heat flow (10^3 $W m^{-2}$)	Heat loss (10^{12} W)
Continents (post-Archaean)	142	63	9.0
Archaean	13	52	0.7
Continental shelves	46	78	3.5
Total continental area	201	65 ± 1.6	13.1 ± 0.3
Oceans (including marginal basins)	309	101 ± 2.2	31.2 ± 0.7
Worldwide total	510	87 ± 2.0	44.2 ± 1.0

Heat transfer: heat flow over continental stable area

Whereas

- In **the** **Continental areas surface heat flow is strongly correlated with the surface concentration** **of the** **radioactive heatas heat produced elements**.

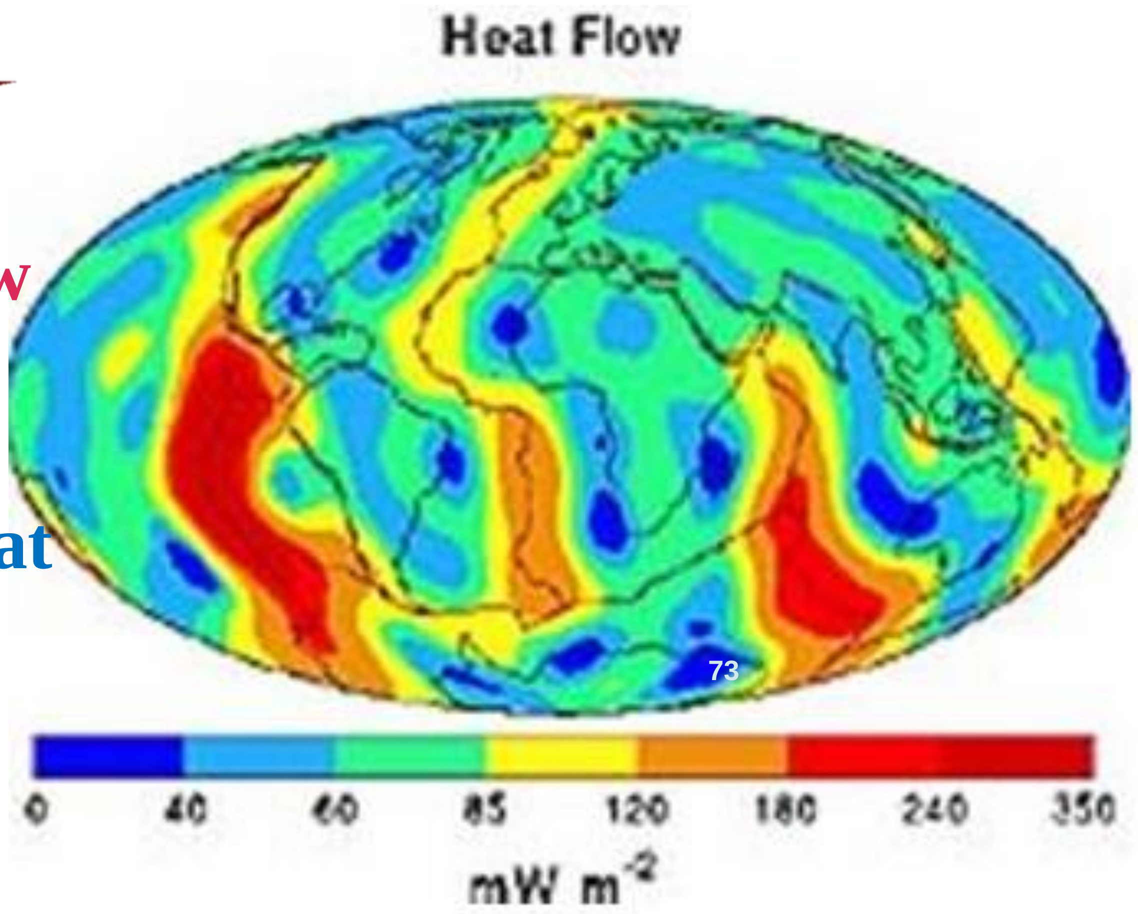


Figure from Turcotte and Schubert textboo

Heat transfer: heat flow over continental stable area

- In the **stable continental areas, surface heat flow systematically decreases** with the age of the surface rocks.
- **we will notice that this effect can be attributed to the decrease in the crustal concentrations of the heat producing isotopes due to progressive erosion.**

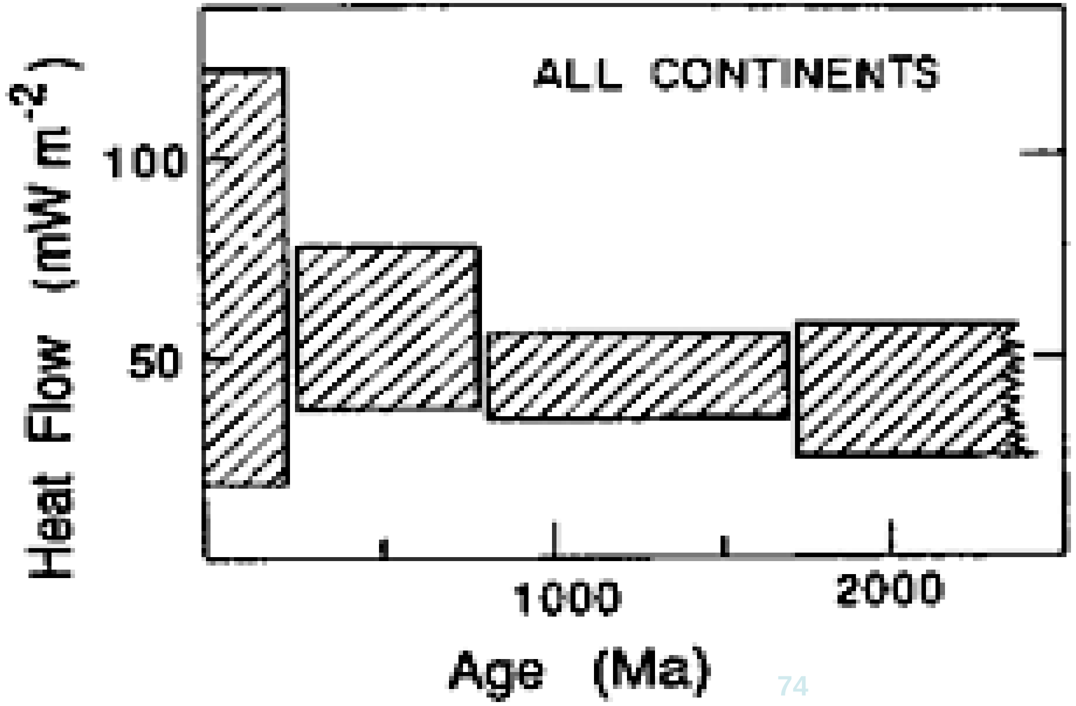


Figure 7 11 Heat flow versus age for the continents The height of the boxes represents the scatter in heat flow, and the width represents the age range (From Sclater et al. 1981)

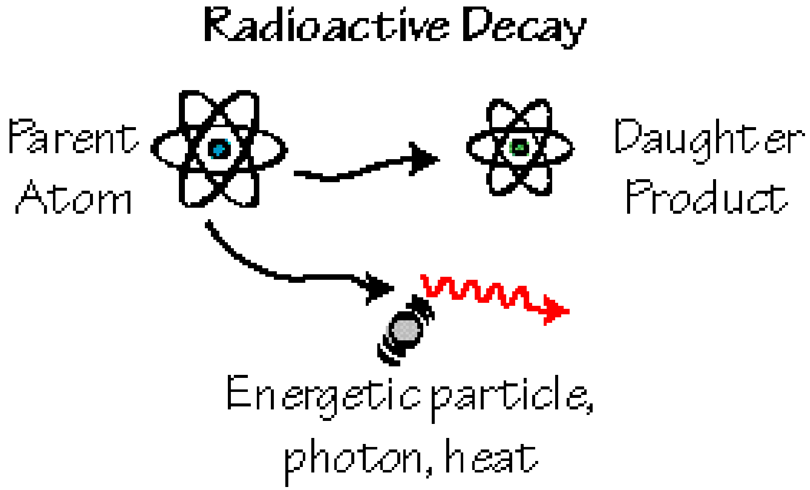
Earth Heat Sources

1. The Radiogenic Heat:

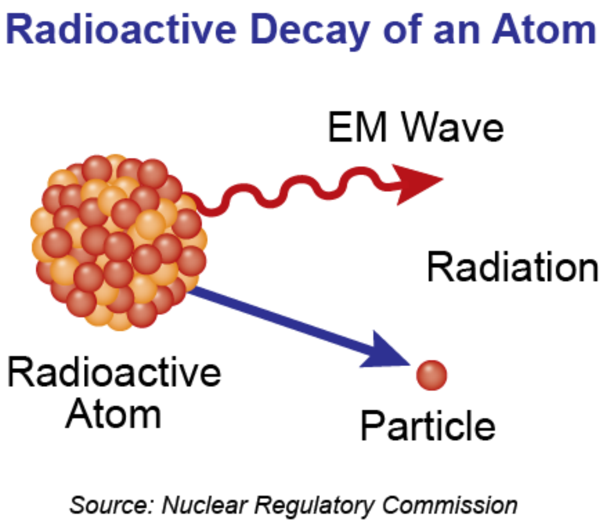
- It is **produced by the radioactive decay of isotopes** **in the mantle and crust**,
  - The **elements in the Earth's mantle and crust results in production of daughter** and **release particles and heat energy.**
  - Four **radioactive isotopes are responsible for the majority of radiogenic heat,** (^{238}U), (^{235}U), thorium isotope, (^{232}Th), and Potassium – 40.
  - **Due to a lack of rock samples** to collect it from depth of 200 km deep, ***it is not possible to do a simple radiogenic heat estimate of known radioactive isotope concentrations*** in rock throughout the whole mantle.

Continued : Earth Heat Sources

- For the Earth's core, Geochemical studies indicate that it would not be a significant source of radiogenic heat due to an expected low concentration of radioactive elements.



- Radiogenic heat production in the mantle is linked to the structure of mantle , a topic of much debate, and it is thought that the mantle may either have a layered structure with a higher concentration of radioactive heat-producing elements in the lower mantle, or small reservoirs enriched in radioactive elements dispersed throughout the whole mantle.



Continued : Earth Heat Sources

2- **Primordial Heat:**

- It is the **heat left over since the evolution of the Earth's heat flow over time.**
- Or it is **the heat lost by the Earth, as it continues to cool from its original formation,** and this is in gap and its still actively-producing radiogenic heat.
- The Earth core's heat flow, i.e. the ***heat is leaving the core flowinp uo into the overlying mantl,***
- It is thought to be ***due to primordial hea***t, and **it is estimated at about 5–15 TW.**
- The Estimated loss range of mantle primordial lie between 7 and 15 Tw from the earth's internal heat.

Continued : Earth Heat Sources

Cont'd: Primordial Heat:

- The **early formation of the Earth's dense core could have initiated superheating and rapid heat loss**,
- The ***rate of heat loss would be slow once the mantle solidified.***
- **Heat flow from the core is necessary to maintaining the convecting outer core** and the geodynamo and **generate earth magnetic field**,
- Therefore, the **primordial heat from the core** **enabled Earth's atmosphere and helped retain Earth's liquid water**

Continued : Earth Heat Sources

3- **Geothermal energy:**

- **It** is a **consume energy generated and stored and in the earth.**
- The **Thermal energy determines temperature of matter.**
- The geothermal energy of the Earth's crust ***originated from the original formation of the planet and from Radioactive elements decay of materials***, but it is possible roughly equal proportions.
- The geothermal gradient, which **is the difference in temperature between the core of the planet and its surface,**
- **It drives a continuous thermal conduction in the form of Heat from the core to the earth's surface**

Earth Thermal Heat الحرارة الأرضية

- عليه، بما أن كافة الصخور تتطلب الحرارة في تكوينها بإزدياد العمق ، إلا أن درجة الحرارة بالقرب من سطح الأرض تتراوح ما بين 10 – 20 درجة مئوية و تزداد الحرارة بعد خط الأرض الحراري الثابت (Isothermal Lines) (هو عبارة عن متوسط الحرارة السنوي لمكان ما سطحقريب جدا من سطح الأرض.

✓ ففي باريس يبلغ عمق هذا الخط 28 متر ، و تعادل حرارته 11.23 درجة مئوية

و عليه فإنه لابد لنا من معرفة :

1- مصادر الحرارة الأرضية.

2- أنماطها

3- و سبل و طرق إنتقالها و تبادلها.

Earth Thermal Heat الحرارة الأرضية

1. **مصادر (أنماط) الحرارة الأرضية Sources of the Earth's Heat :**
   a) الإشعاعات الذري Radio Active Radiation:

والتي تنتج من تحطم و إنشطار بعض العناصر المشعة ، وهي نظائر كيميائية غير ثابتة وتتغير من مرور الزمن لتفتتها وتحللها لتعطي:

هناك نظائر كيميائية أكثر ثباتا و إستقرارا ينبعث منها طاقة حرارية هائلة تعمل على تسخين الصخور.

و من أهم هذه النظائر هي Th232, U 238 وهي المسؤولة عن العمليات الأرضية التالية :

1. البركنة Volcanism.
2. تحول الصخور etamorphic Rocks
3. حركات بناء الجبال Orogeny (ies).
4. حركة الصفائح التكتونية الأرضية Plate tectonic

Earth Thermal Heat الحرارة الأرضية

B. الإحتكاك Friction.

إحتكاك الصخور بين بعضها البعض مما يولد حرارة عالية، وهذا عادة يحدث في :

1. مناطق الإندساس Subduction Zones.
2. مناطق نشاط الحركات الأرضية البانية للجبال

C. *الحرارة المخزونة المتبقية* من الحالة المنصهرة للأرض البدائية (أي منذ وقت تكوينها).

أي أن الأرض لم تبرد تماما بعد تكوينها، وأنها مازالت تبرد و تفقد حرارتها ولكن ببطء شديد جدا جدا.

D. الحرارة المنبعثة من طاقة الجاذبية الناتجة من إعادة توزيع العناصر الثقيلة تحاه و ناحية مركز الأرض ، هذا يتسبب في توليد كميات من الحرارة تساهم في صهر المواد ارضية وزيادة حرارة الكرة الأرضية.

Earth Thermal Heat الحرارة الأرضية

2. الأنتقال أو التبادل الحراري فى الأرض(The Earth's Heat transfer and exchanging heat (Mechanisims :

يوجد 3 عوامل تلعب دورا هاما في التبادل الحراري للأرض ، وهي:

A. التدفق الحراري Heat Flow .

B. الممال الحراري Geothermal Heat Flow .

C. التوصيل الحراري للأرض Geothermal Conduction .

A. التدفق الحراري Heat Flow :

هو عبارة عن كمية الحرارة التي تفقدها الأرض إلى الخارج ، حيث تنساب الحرارة من باطن الأرض إلى سطحها (القشرة ألرضية) ثم إلى الفضاء.

يعبر عنها بوحدة القياسHFU =(وات/متر مربع) أو ميلليوات/متر مربع.

1 وات/متر مربع = 41.8 وحدة تدفق حراريز

Earth Thermal Heat الحرارة الأرضية

- إذا التدفق الحراري يحدث وتتميز فيه مناطق مرتفعات وسط المحيطات(حيث تتدفق كمية كبيرة من الحرارة الأرضية.
  - في حين أن مناطق Benioff Zone تتميز بقلة الدفق الحراري فيها، لماذا ؟

لأن مناطق ال Benioff Zones عبارة عن مناطق ضغط.

عليه نجد أن التدفق الحراري في:

المنطقة	HFU
درع ما قبل الكامبري	0.9
حزام بناء الجبال	1.75
النطاق البركاني	2.20
مرتفعات وسط المحيط	2.00
مناطق ال Benioff Zone	1.20

Earth Thermal Heat الحرارة الأرضية

B. الممال الحراري Geothermal Heat Flow .

يعبر عنها بأن الحرارة تتدفق من المناطق الساخنة إلى المناطق الباردة ***عبر المادة***

حتى يتساوى الفرق بين الطرفين

لهذا سميت ممالا حراريا

وعليه كلما زاد الفرق في درجات الحرارة ← زادت تبعا لذلك كمية الحرارة التي تنتقل عبر المادة (أي زدياد النشاط الحراري اللازم لإحداث التوازن).

عليه يعرف الممال الحراري *Geothermal Heat Gradient* :

أنه عبار عن معدل التغير في درحة الحرارة مع العمق

و= التغير في درجة الحراره/التغير في العمق= درجة مئوية/ كم -1

Earth Thermal Heat الحرارة الأرضية

C. التوصيل الحراري Geothermal Conduction

It is the ability of the earth's zones, rocks to transfer heat, thus

Increasing the quantity of heat flow **Will** Increase the quality of rocks heat conductivit

Thus,

The Heat conductivity will be measured directly by studying different rock's sam

types.

We found the igneous rock is the most rocks in transfering heat in compered wi

the other rocks, There is a relationship among the heat mechanisms mentioned

above, as follows:

Heat flow = Geothermal Gradient X Geothermal Conduction

So,

The heat Flow will increased as Geithermal gradient's increases. In addition, to the rocks' abilities to transferring Heat,

Mechnisms of transferring Heat أولا: آلية التبادل الحراري للكرة الأرضية

1. *The heat is transferring essentially from the Lithosphere to crust by conductivity phenomena*.

2. **Meanwhile, the heat mechanism transfered within the Asthenosphere that produced by convection current (semi aqueous media) , and then transferred to lithosphere by conduction.**

So,

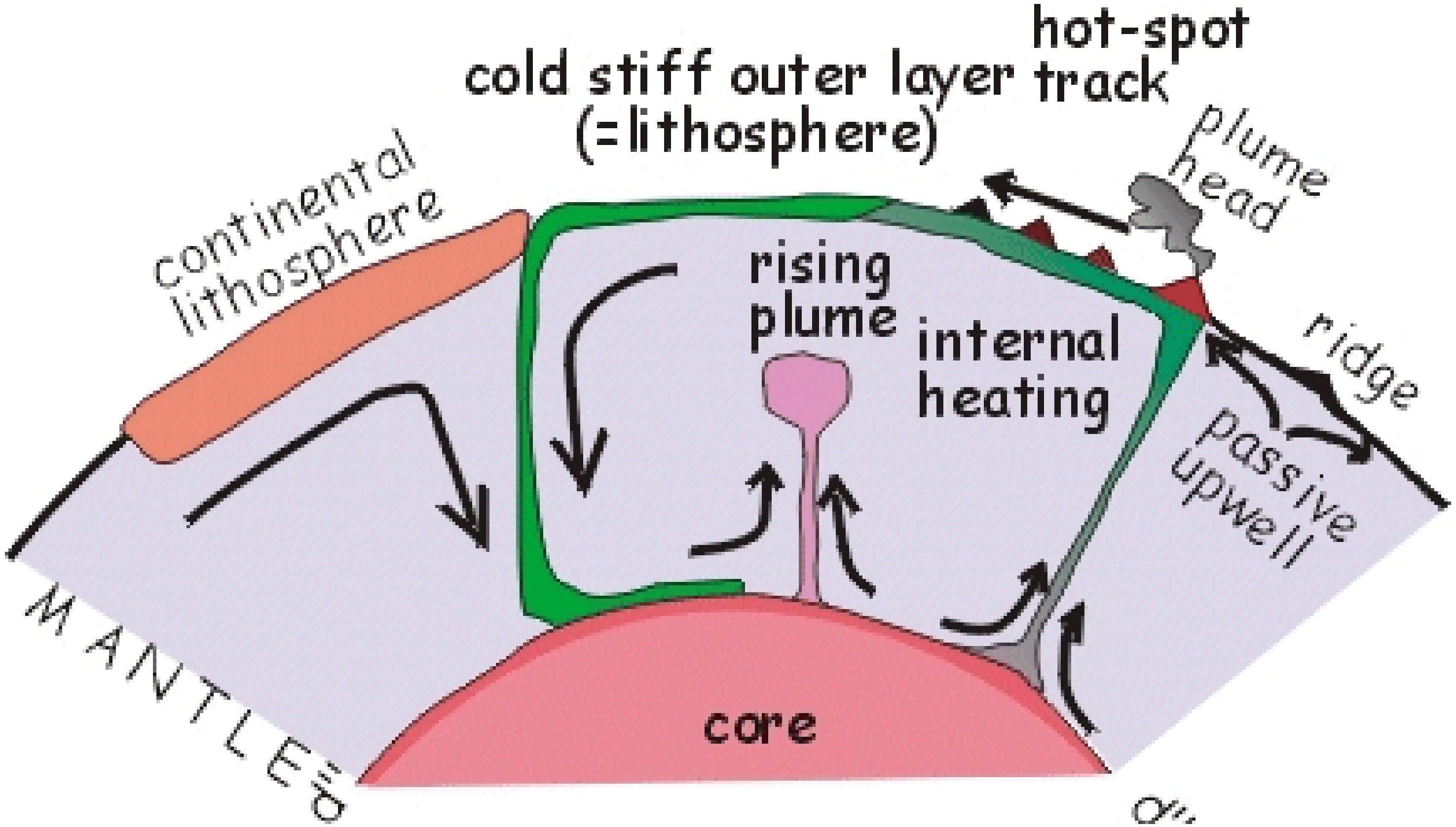
The Asthenosphere Zone transferred the Heat in different rate

Therefore, the convection current is causing tectonic plate drifting

And causes a major changing of the earth's surface morphology

ثانيا: آلية الحمل الحراري و النشاط البركاني للكرة الأرضية

- تنتقل الحراة من الوشاح الأوسط للأرض بواسطة الحركة الرأسية الدورانية للمواد المنصهرة فيه



Thank you