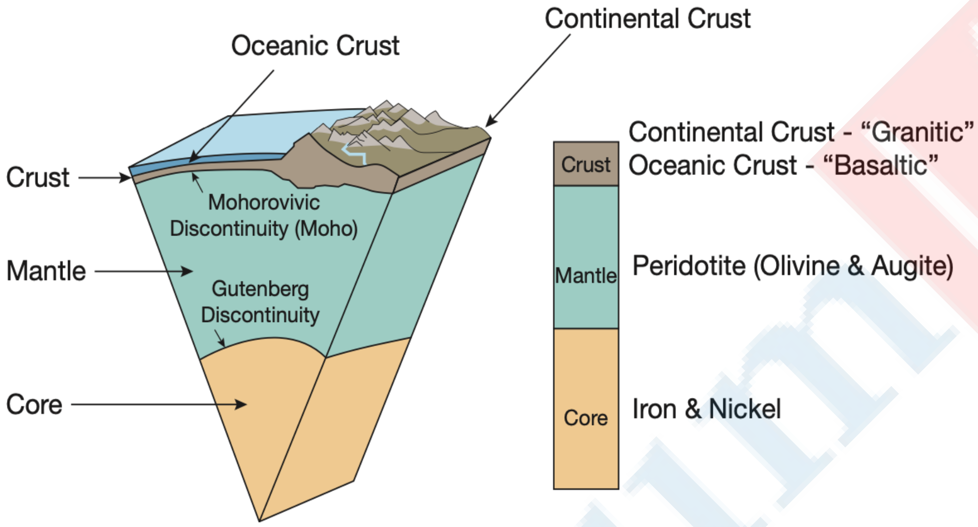
Seismology in Understanding the Earth's Interior

Seismology uses seismic waves to study the Earth's internal structure:
1. Layer Identification
2. Wave Behavior
3. Seismic Tomography
4. Mineral and Density Insights
5. Core Structure
6. Earthquake Monitoring
7. IN supporting earthquake research and mitigation.



Earth's Core and Magnetism

- The **fluid outer core** creates Earth's magnetic field

Magnetic Reversals:
1. Earth's magnetic poles occasionally switch
2. AT REVERSAL increased cosmic radiation during low-field periods,
3. MAY result in some species extinction.
4. During the transi- tion interval of low strength, Earth's surface receives higher levels of cosmic radiation and solar particles
5. Can also impact GPS and satellite communication

Identify correct statements

2025

Which of the following are the **evidence of the phenomenon of continental drift?**

I. The belt of ancient rocks from Brazil coast matches with those from Western Africa.

II. The gold deposits of Ghana are derived from the Brazil plateau when the two continents lay side by side.

III. The Gondwana system of sediments from India is known to have its counterparts in six different landmasses of the Southern Hemisphere.

Select the correct answer using the code given below.

(a) I and III only

(b) I and II only

(c) I, II and III

(d) II and III only

2025

1. Consider the following statements:

Statement I: Scientific studies suggest that a shift is taking place in the Earth's rotation and axis.

Statement II: Solar flares and associated coronal mass ejections bombarded the Earth's outermost atmosphere with a tremendous amount of energy.

Statement III: As the Earth's polar ice melts, the water tends to move towards the equator.

Which one of the following is correct in respect of the above statements?

(a) Both Statement II and Statement III are correct and both of them explain Statement I

(b) Both Statement II and Statement III are correct but only one of them explains Statement I

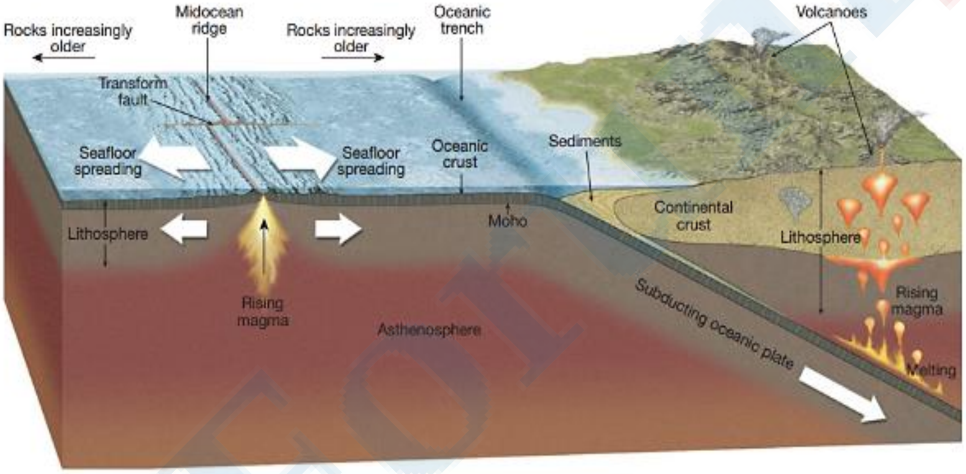
(c) Only one of the Statements II and III is correct and that explains Statement I

(d) Neither Statement II nor Statement III is correct

Sea floor spreading theory -

- Harry Hess and geologist Robert S. Dietz
- Mid ocean ridges → magma rising up → volcanic eruptions → basaltic ocean floor At the **oceanic trenches**–>older lithosphere descends into the asthenosphere in a process called subduction→ where it is ultimately "recycled."

MORs - Spreading centres



Evidences -

1. Pacific reduction and MORs near the east coast of N. America
2. Iceland - Volcanic origin (formed over the MORs region)
   Greater temperature over MORs also suggests volcanic activity → importance in Geothermal Energy Production
3. Age of oceanic crust - 100 to 150 mya whereas the age of Continental crust is around 4.5 Bn Years ago
4. Equidistant rocks of same age
5. Evidences of paleomagnetism

Plate tectonic Theory -

- Term plate - by J Wilson -1965
- Mckenzie and Parker - Mechanism of Plate Motion
- Morgan - 1968 - Elaborated plate tectonics

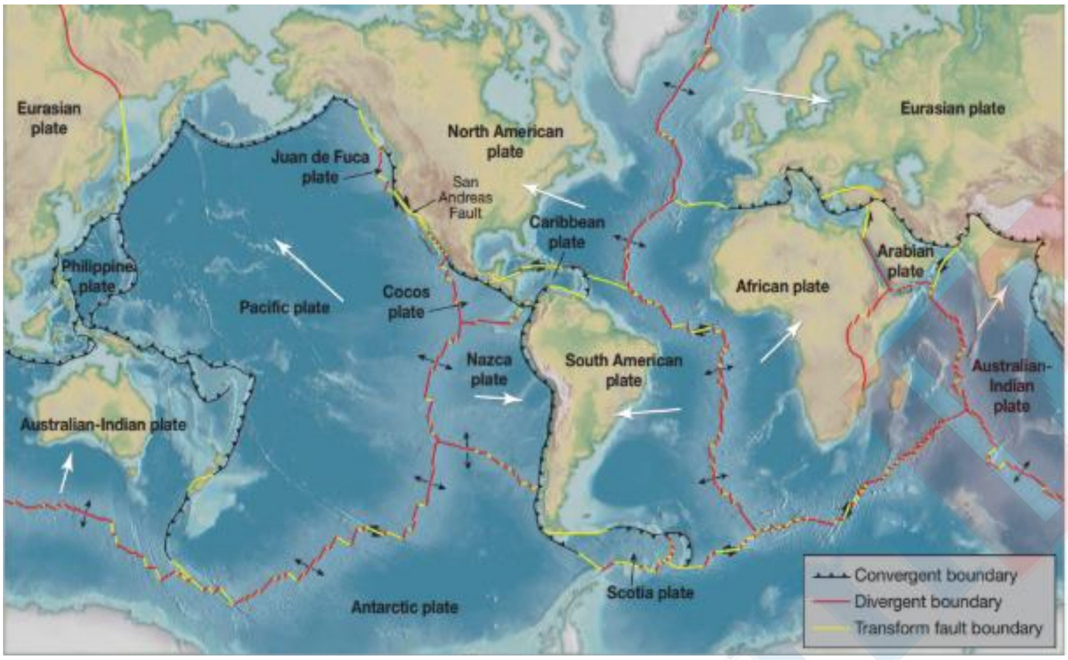
Based on -

- CDT and Sea floor Spreading

Plate Movement, effects and Outcome - **Plate Tectonic**

Plate tectonics include -

- The processes of upwelling of magma
- Lithospheric plate movements
- Sea-floor spreading and lithospheric subduction
- Earthquakes and volcanic activity
- lithospheric deformation -folding, and faulting



Driving mechanism -

- A very *sluggish thermal convection* system + Slab Pull

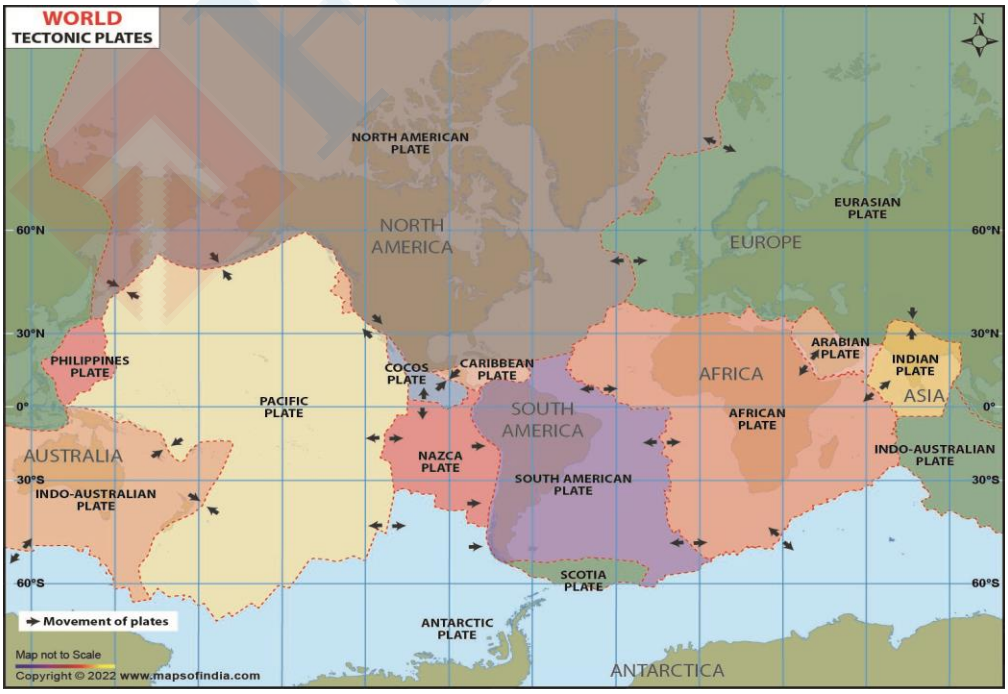
PLATE BOUNDARIES

Plates are relatively **cold and rigid** → deformed significantly only at the edges

Three types of plate boundaries are possible:

- Most of the Plates are **mixture of Oceanic and Continental** parts
  - **Exception - Pacific - Entirely Oceanic and Eurasian - Largely Continental*****

Plates and Plate tectonics



Major plates	Minor -
1. North American 2. S. American 3. Pacific - largest and Oceanic 4. African 5. Eurasian 6. Indo- australian 7. Antarctic plate	• Nasca (Andese) • Juan-De-Fuca (Hot springs, yellow national Park) • Cocos (San Andreas fault) • Arabian (Bhuj Fault) • Philippines • Burmese plate (Tsunami)

Plate Margins -

1. **Convergent / destructive** • O-C • C-C • O-O	2. **Divergent /** Constructive	3. **Transform /** Conservative

1. Convergence -

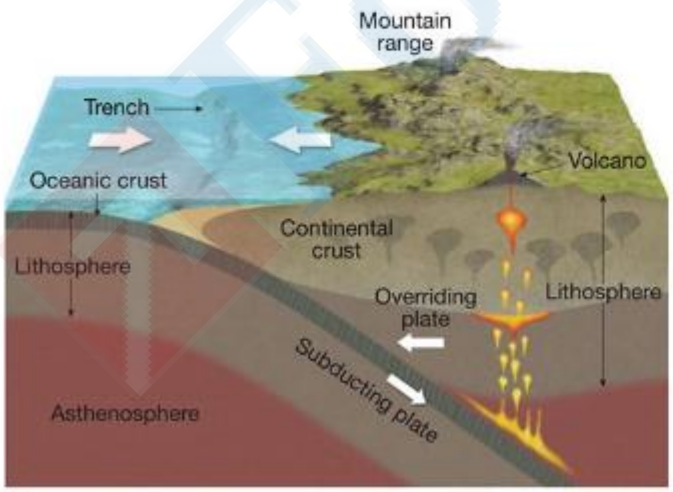
- When Two plates move towards each Other
- **At such convergent boundaries**
- Collision → Rocks can be squeezed and contorted → **uplifted** and greatly deformed or **metamorphosed**.

A. Oceanic - Continental (O-C)

Because **oceanic lithosphere** → denser → **underrides continental lithosphere**
The dense oceanic plate → **sinks into the asthenosphere** → subduction.

O-C features

1. **A mountain range is formed on land** eg the Andes range
2. **A parallel oceanic trench develops**



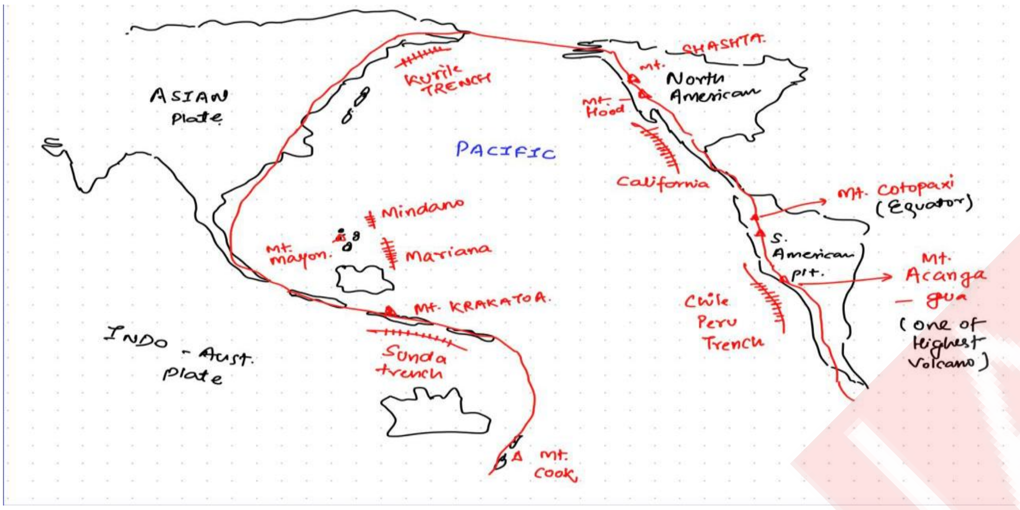
Earthquakes: (*along the margin of a subducting plate.*): **Shallow-focus earthquakes are common** at the trench, → the earthquakes **become progressively deeper** with subduction

Volcanoes

- Develop from magma generated in the subduction zone.
- The **chain of volcanoes that develops in association** → a continental volcanic arc.

- As we will see later in this chapter, such subduction zone **volcanoes frequently erupt explosively.**

Metamorphic rocks often develop in association with subduction zones.



Note : Pacific Plate is subducting in all the directions under - Indo - Australia, Asian Plate, North and South american plate, Philippine and Mindanao plates

B. Continents -Continent (C-C)

Eg - Himalayas formation

No subduction takes place because continental crust is too buoyant to subduct.

Instead, **huge mountain ranges, such as the Alps,** are built up.

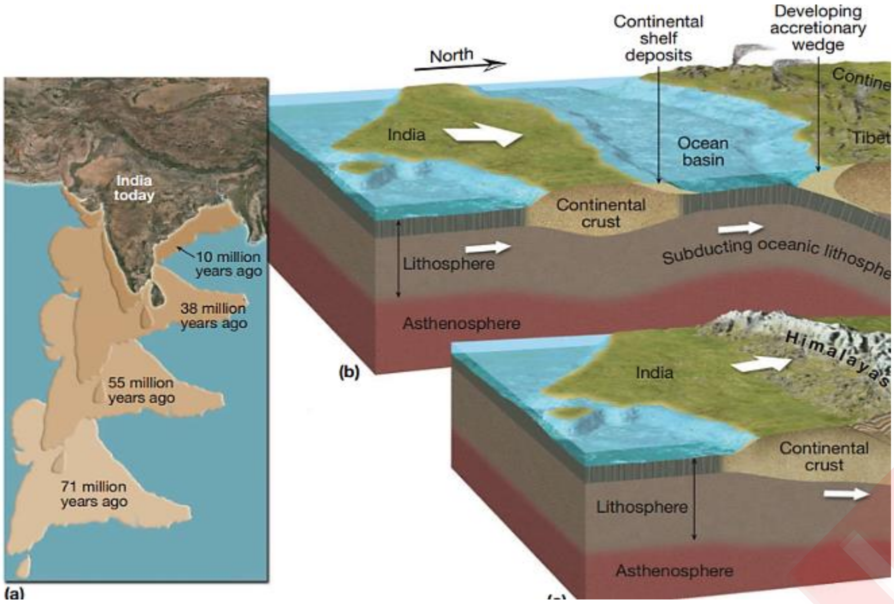
The plate having comparatively more weight (denser) and moving slightly faster, undergoes **partial subduction.**
Eg - Indian plate having more oceanic part is heavier and partially goes below
Note : **Doubling of crust** under Himalayas (No Volcano)

Formation Of Himalayas :

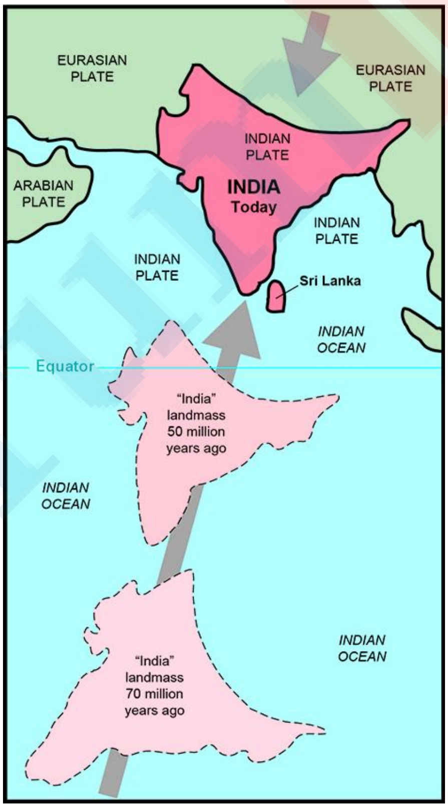
The Himalayas began to form more than **45 million years ago** when the subcontinent of India started its collision with the rest of Eurasia.

Note : Under the conditions of continental collision→ **volcanoes are rare** but **shallow-focus earthquakes** and regional metamorphism are common.

Formation of Himalayas -



- In The Mesozoic era , the **Indian plate started moving towards the north.**
- In the **cretaceous period**, Indian western part came in contact with Reunion hotspot and therefore, Basaltic flood plains were formed i.e. the Deccan Plateau
- The Tethys sea subducted under Eurasian plate, **gave rise to Trans-Himalayas** formation.
- With collision - lateral compression, squeeze and folding result in formation of Fold mountain - Himalayas



Note : Himalayas are still rising

Features -

- Earthquakes : Shallow focus but of Great Intensity
- High Mountains : Himalayas and Alps
- Volcanoes X (No Subduction)
- Trench : No
- Metamorphism : Yes

Evidences -

- Himalayas still rising
- Marine sediments and Fossils
    - Sea buckthorn

- Petroleum reserves
- Saline lakes at tibet plt

Features -

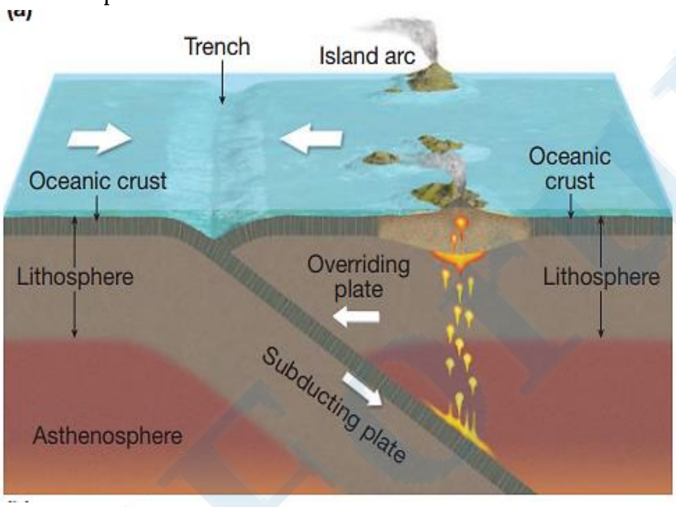
- Syntaxial bends - 2 pushes → Rivers in India are brought like - Indus and Brahmaputra
- Western Himalayas are older and wider
- Hogback Appearance -highest in center - Clay and loose sediments
- Steeper southern side
- Arc shape
- Marine Fossils

Question -

Arrange oldest to Youngest
- Aravallies
- Deccan plateau
- Trans- himalayas
- Himalayas
- Plains

C. **Ocean- Ocean Collision :**

Where two oceanic plates meet, the older, denser one will subduct below the younger, less dense oceanic plate



Features

- Subduction → volcanoes → major island arcs on the overriding plate
- The **Aleutians, the Kuriles, and the Marianas** are all examples of island arcs near oceanic trenches that border the Pacific plate
  - Caribbean islands - n.america and caribbean plate
  - Japan islands - Asian + Philippine || pacific
- Earthquakes : s**hallow- and deep-focus earthquakes**

2. Divergent boundary

(a) A **continental divergent plate boundary** breaks continents into smaller landmasses.

- The roughly triangular-shaped Sinai Peninsula → The Red Sea rift and the narrow Gulf of Aqaba are both zones of spreading.

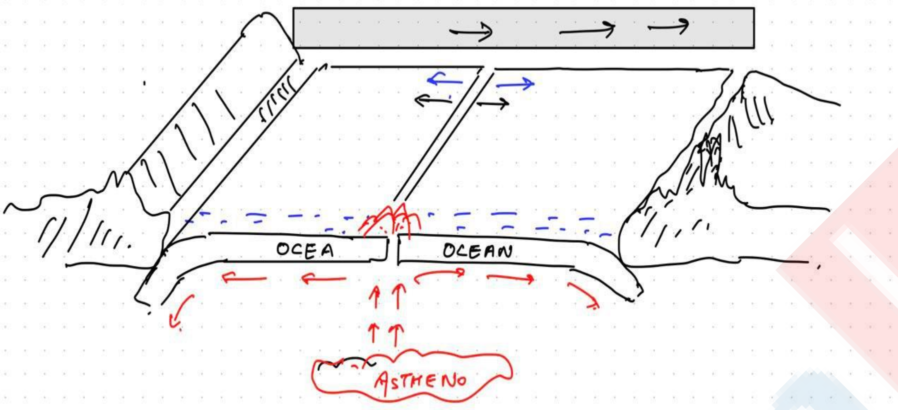
Divergent Boundaries

At a divergent boundary → **magma wells up** → produces a line of volcanic vents that spill out **basaltic lava onto the ocean floor**

Features :

- **Mid Ocean Ridges**
- **shallow-focus earthquakes**
- Volcanic activity, and **hydrothermal metamorphism**—as well as the presence of remarkable marine life-forms thriving in the hostile environment of hydrothermal vents on the ocean floor.
- Divergent boundaries are **"constructive"** because material is being added to the crustal surface at such locations

3. Transform/ conservative /Shear plate margin



Features -

- Powerful EQs
- Faults and Rift Valleys -
  Eg **San Andreas Fault**

Mantle plume theory

Hot Spots and Mantle Plumes

- While **plate tectonics explains** most volcanic and tectonic activity **at plate margins** Many volcanoes occur **far from plate boundaries**.
- These are locations not associated with plate boundaries. These are called **hot spots**.

Explaining Hot Spots

Mantle plume model in the **late 1960s**.

- This theory suggests that **mid-plate volcanic activity** is caused by **narrow plumes of heated material** that rise from deep within the mantle, possibly from as deep as the **core–mantle boundary**.
- As the plume rises→ it melts part of the crust above it→ producing **volcanoes or hydrothermal features** at the surface.
- Some eruptions also begin with large volumes of lava called **flood basalts**
- The **tectonic plate above the plume moves**, while the **plumes and Hot spots stay fixed**. This means volcanic islands or features formed over the plume **are carried away** and eventually **become inactive**.
- New volcanoes form over the plume's current position, creating a **linear chain of volcanic islands** called a **hot spot trail**.
- Their trails indicate the **direction and speed of plate movement**. Older volcanic islands lie farther from the present hot spot.

Eg : The Hawaiian Hot Spot

The **Hawaiian Islands** are the **most famous modern example** of a hot spot.

Besides Hawaii, other famous hot spot locations include:

- **Yellowstone National Park (USA)**
- **Iceland**

- **The Galápagos Islands**

World distribution of Volcanoes
Volcanic activity is primarily associated with plate boundaries.

1. At a **divergent boundary**
2. At **convergent boundaries**
3. **Hot spots**

1. Convergent Plate Boundary and Volcanoes

a) Ocean-Ocean Convergence

- When one oceanic plate is forced beneath another oceanic plate, it creates a chain of volcanic islands known as **island arcs**.
- **Caribbean Arc,Aleutian Arc, Kurile-Kamchatka Arc,Japan, Philippines, and Indonesian Arc**

b) Ocean-Continent Convergence

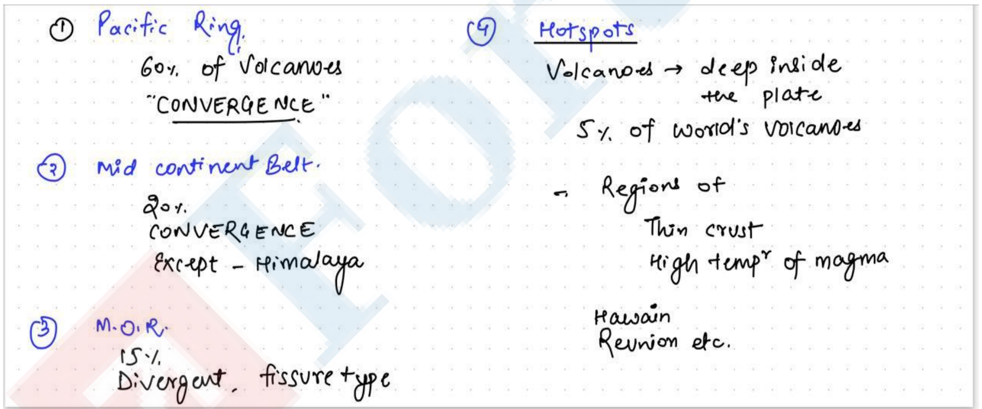
- **Andes Mountains (South America),Central American Volcanic Belt, Mexican Volcanic Belt, Cascade Mountains (Western USA)**

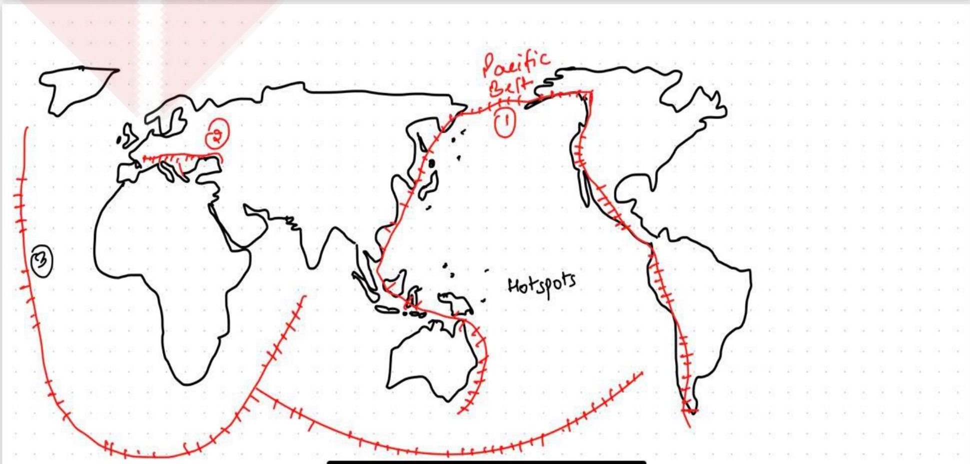
The islands of Tonga (20°S, 175°W) are on the Indo-Australian plate just to the west of the Tonga Trench. The melt of the **Pacific subducting plate below the Indo-Australian plate.**
Best Eg: → **Ring of Fire (Circum-Pacific Belt).**
Contains about 75% of the world's active and inactive volcanoes.

2. Constructive Margin or Divergent Plate Boundary and Volcanoes
Basalt has a low silica content and is very fluid.

The eruption takes place not through a narrow vent but a**long the long fissure created by a plate divergence.**

Eg. *<u>hekla and Laki fissure eruptions Iceland, East Pacific Rise, Carlsberg ridge etc</u>*





3. Hot Spots
Hotspot volcanic activity can be seen in both the Atlantic and Pacific Oceans, but it is more common in the Pacific due to the ***faster movement of tectonic plates.***

- Hawaiian-Emperor Seamount Chain
- Austral-Marshall-Gilbert Chain

Oceanic Intraplate Volcanism.
Hawaii, Samoa, Galpagos and Easter Islands in the Pacific ocean, Azores, Madeira, Canary islands, St. Helena, Tristan
Continental Intraplate Volcanism.
The East African rift system and the Rhine graben are the best examples

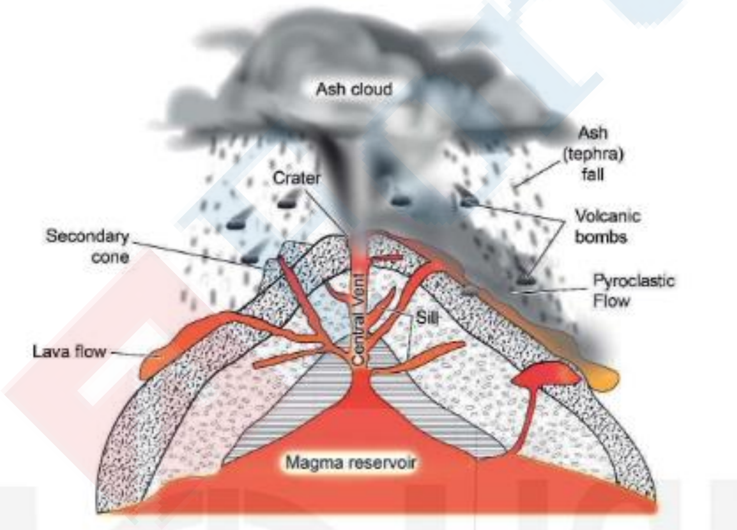
4. Mid continental Belt :in Alps (Stromboli, vesuvius etc) and rift valley of Africa Kilimanjaro, Meru, Elgon, Birunga, Rungwe etc

Volcano and Volcanism
Volcanism or Vulcanicity -

- The process or mechanism related to the *origin of magma, gases and vapour, their rise and appearance on the earth's surface* in different forms. It involves both **endo and exogenetic** environments
- **Volcano -** is a fissure or a vent, communicating with the interior, from which Lava flows and volcanic ashes are erupted out at the surfaces.

Components of volcano

- Volcanic cones - mountain like structures
- Vent or opening
- Volcanic pipe - Connects vent with the interior
- Volcanic crater or Caldera - Enlarged form of vent



Volcanic material
1 **vapour and gases :** steam and vapour - 60 to 90 % , gases like CO2, NOx, SO2,H,CO etc. Other - HCL, Chlorides of Iron, potassium and other metallic matter
2. **Magma :** molten rock material

Acidic / Felsic	Basic / Mafic
High % of Silica Viscous and can't cover long distances	Low silica Fluid and flows up to long distances

create s high mountains Lighter Granitic lava	Creates plains and plateau Darker Eg basaltic Lava Hottest lava (1000 to 1200 degree C)

Magma in hawaiian

1. **Pahoehoe -** fluid and spreads in thin sheets. It is also known as **Ropy** lava
2. **AA Aa** Lava- **more viscous** and solidifies in the forms of pillows, aka **Pillow lava**
3. **Fragmental pyroclastic** material consolidated live lava - tephra, volcanic dust(finest), volcanic Ash(2mm) , **Lapilli** (pea Size), **Volcanic Bomb** (6cm or more)

Classification of Volcanoes

1. Based on frequency/periodicity of eruption
2. Based on mode of eruption

A) Based on Frequency or Periodicity of Volcanic Eruption

Volcanoes can be categorized into three major types based on their frequency of eruption:

1. **Active Volcano**
2. An active volcano is one that has erupted recently or **within the past few thousand years and is considered to be currently active.**
   These volcanoes are **often found near tectonic boundarie**s, especially in the **Ring of Fire**.
   Example: Mount Stromboli, **Barren Island,India.**
3. **Dormant Volcano**
4. A dormant volcano has erupted in the past but is currently **inactive for a long period**.
   Dormant volcanoes **can remain inactive for thousands of years** before erupting again.
   Examples: Vesuvius in 79 AD (which destroyed Pompeii), Mount Fuji in Japan, Mount Kilimanjaro in Tanzania.
5. **Extinct Volcano**
6. An extinct volcano has **not erupted in recorded history and is unlikely to erupt in the future.**
   Eg. Narcondam in Andman

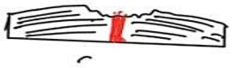
B) Based on Mode of Volcanic Eruption

Volcanoes can also be classified based on how they erupt. These eruptions can be divided into two main types:

1. **Fissure or Quiet Eruption**
2. **Central or Explosive Eruption**

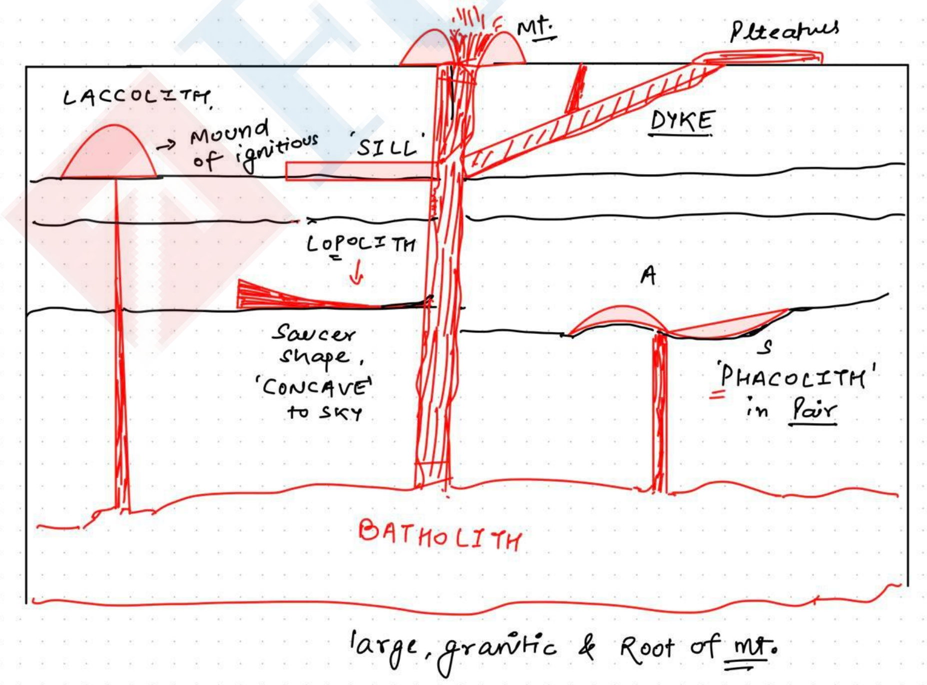
2) Volcanoes of Fissure or Quiet Eruption

- Fissure eruptions occur when magma escapes **from cracks in the Earth's crust** rather **than from a central vent.**
- These eruptions are typically less explosive but produce **large amounts of lava.**
- **Laki fissure** eruptions in Iceland

Fissure iceland Type	Basic & Basaltic, fluid lava, Quiet eruptions Laki fissure eruptions, ICELAND.	
Hawaiin type	Highly Fluid lava It makes shield volcanoes THREADS of molten magma = Pele's Hairs	
Volcanian	viscous magma & erupts with Explosion viscous & pasty lava other Eg – Krakatao, Indonesia	
STROMBOLIAN	Rhythemic eruptions with regular intervals Ejects incandescent lava with less gases	
PLINIAN TYPE	Similar to Volcanian Most violent type with vertical explosion of Ash + gases + Pyroclastic material	
PELEAN TYPE	Extremely Explosive Named after Mt. Pelee @ Caribbean islands	
VESUVIAN	Bursts with Huge gases + Ash + lava in Air. Eg - ETNA	

Volcanic landforms

1. Intrusive



2. **Extrusive -**
   a. Cones
   b. Craters
   c. Volcanic plt. And plains
   d. Hot Springs and Geysers

Cones

1. **Cinder cones / Ant mountains**
   - Most abundant, Small cones consisting mostly of **pyroclastic debris**.
   - Vulnerable to erosion as permeable to water

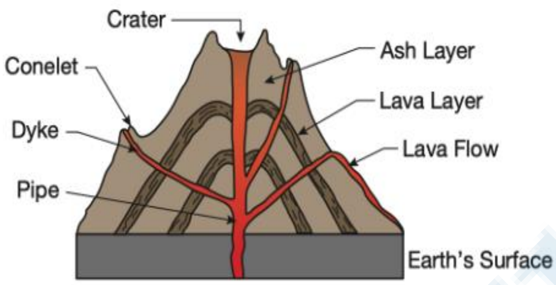
     Eg : Volcano De Fuego (Guatemala) and **Paricutin (Mexico).**
     1. **Mt. jorullo, Mexico**
     2. **Izalco, San salvador, Central America**
     3. **Lanzarote Island of Canary Islands**

Lava cones

A.Composite or Strato - highest

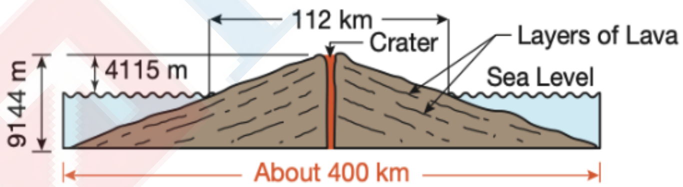
Alternate layers of lava and ash →Grows in Height

Mount Kilimanjaro, in Tanzania with a height of 5,895 m, and Vesuvius, Etna, and Stromboli, all in Italy, are examples of composite cones.



Other Eg - Shasta, Rainier, Mt hood, Aconcagua and Cotopaxi

2. **Parasitic Cones/ adventive or Lateral Cones** : when several branches of pipes come out from the main volcanic pipe, it gives rise to secondary volcanoes or smaller cones over the main volcano
   a. Eg : **mt. Shasta**
3. **Shield Cones - Basic lava**
   Are formed of less viscous lava, due to fluid lava, they are of shield like formation
   Also known as basic cones or **havana cones**



Craters and calderas

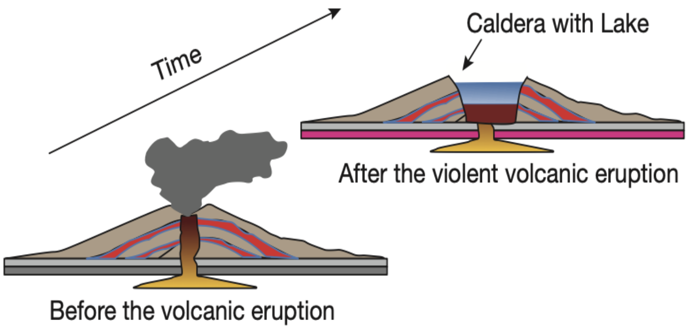
- The crater is a **bowl or funnel**-shaped **depression or cavity** usually of volcanic origin. It is usually **more or less circular** with a diameter commonly less than 1.6 km.
  Crater of **Aniakchak,** Alaska
  crater **lake of Oregon**, USA
- When the crater of volcano **becomes extensive** and if there are few eruptions of small intensity in it , small craters are formed inside the big crater - known as **crater Inside crater/ Incised crater / nested crater / Groped Crater**
  - **Mt Taal, Philippine**
  - **Etna**

- **Vesuvius**

Caldera

- The huge **crater-like depression is called Caldera**. Formed due to repeated volcanic eruptions.
- Eg. **Kuriles Islands** of Russia.
- The **Buldir caldera** → ***<u>Aleutian</u>*** ***<u>i</u>****<u>sland</u>*
- ***Apolaki Caldera****, located in the* ***Philippine Sea***

  Crater lake, USA
  Aira, and Aso San in Japan
  Tarso Yega, SAHARA
  Lonar lake MH India (meteoritic)



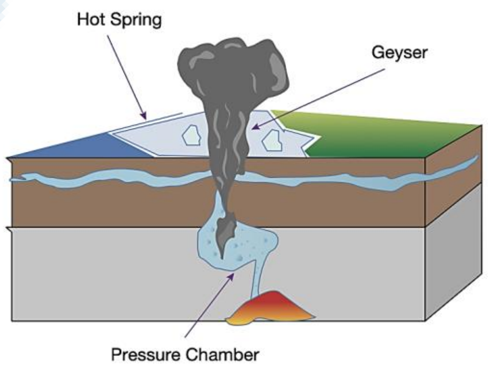
Volcanic plt. -

The largest lava plateau in **Great Britain is in Antrim** (Northern Ireland).
The **Columbia and Snake Plateau in the United States** is over 5,00,000 km2 whilst the **Deccan lava plateau** is almost 6,50,000 km2.

<u>Other forms of volcanic activity-</u>

<u>Hot springs and Geysers</u>

Superheated water may flow quietly, as in hot springs, or it may be thrown out with great force and accompanied by steam, as in geysers.



Geysers : A hot spring which spouts hot water and steam from time to time

Hot spring	Geyser
Continuous hot water	**Hot water + steam** with intervals Ejection of water - With Great force Connected with a narrow pipe Temperature of water - 75 to 90 degree Eg. **Old faithful geyser,** yellowstone N.P. **Grand geyser**, Iceland (30 Min) Distribution : No certain pattern USA, iceland and NZ

Fumaroles: vent through which gases and water vapour are ejected, often in intervals

- Directly linked with **volcanic activities**
- Fumaroles are the **last sign of activeness** of a volcano
    - Eg. katmai Volcano, Alaska, valley of 10,000 smokes
- Fumaroles dominated by sulphur are called **Solfatara**

Earthquake:

Shaking induced by the rupture or breaking and subsequent movement of rocks
Earthquakes are classified into -

- **Volcanic earthquakes** are triggered by volcanic activity.
- **Tectonic earthquakes** occur when the crust is subjected to strain, which causes the **crust to break and shift during** faulting activity. The largest earthquakes arise along the faults. Eg Gujarat 2001
- **Isostatic** - due to imbalance in geological processes. Eg. in the active zones of mountain building
- **Plutonic EQ :** deep focus EQs - 250 to 650 km from the depth
- **Man made EQ:** triggered by human activities such as pumping of water and mineral oil from underground aquifers. Eg. **koyna EQ in Maharashtra in 1967**

Further classification based on depth of focus :

1. **Shallow focus or moderate EQs** : Depth of 50 km
2. **Intermediate -** 50 to 250 Kms
3. **Deep focus :** 250 Km to 650 kms

Classification based on Casualties caused

1. **Moderately Hazardous:** human deaths less than 50000
2. **Highly hazardous** : 50k to 1 lakh deaths
3. **Most hazardous :** more than 1 lakh deaths

Measuring an Earthquake

(1) **Magnitude of an Earthquake**

- The **magnitude** /the **amount of energy generated by the Earthquake** → called as Richter Scale
- This scale is based on the **amplitude of seismic waves**; the more powerful the Earthquake, the more powerful the seismic vibrations.

- The ***logarithm to the base 10*** of the amplitude
    - **A magnitude 6.0 earthquake, for example, generates ten times the shaking of a magnitude 5.0 earthquake.**

(2) Earthquake Intensity

- This approach looks at how **individuals felt and how much damage** was done. This is referred to as an ***earthquake intensity*** .
- **Intensity spanning from Roman numeral I to XII**
- **qualitative estimate of the actual shaking** → *Impacts of the earthquake on people, furniture, buildings, and geological structures, among other things. Within the disturbed zone,* the intensity varies from place to place.

Distribution of Earthquakes and Plate Tectonics

- Plate tectonic theory has been accepted as the **most possible explanation of causes of the earthquakes**. The connections between earthquakes and plate boundaries are very obvious
- Seismic centers are closely related to weaker and isostatically disturbed areas.

a) Earthquakes along Divergent Plate Boundaries

- Earthquakes are widespread along divergent boundaries such as the **mid-oceanic ridge** and its branches where a new lithosphere is created and spreads on either side of the ridge. The **shallow earthquakes stretch out mostly** in the mid-Atlantic ridge, the East Pacific Rise, although they are limited to a narrow zone close to the ridge.

b) Earthquakes along Convergent Plate Boundaries

- The majority of earthquakes, including **shallow, moderate, and deep earthquakes,** are located near convergent plate boundaries where **oceanic plates are subducting**.
- The best examples of great subduction boundary earthquakes are experienced in J**apan, Alaska, Chile** and volcanic arcs of the **Circum-Pacific Zone.**

c) Earthquakes along Transform Plate Boundaries

- Transform faults, such as the **San Andreas Fault, are also prone to shallow earthquakes**. Moderate to **strong earthquakes** are found to be occurring along this zone.

The greatest earthquakes on transform boundaries are of **8 magnitude.** In fact, all of the **extremely big earthquakes (9 or above) occur along subduction** barriers because a slightly dipping boundary has the potential for a wider rupture zone than a steep transform boundary

Four zones :

1. **Circum pacific Ring of Fire :** This belts accounts for 65% of total earthquakes this belt has -
    a. Ocean - continent margin
    b. Zone of young fold mountains
    c. Active volcanoes
    d. Zone of subduction

    Collision of pacific and Asiatic plate - create kamchatka, japan and Philippines EQs
2. **Mid continental belt : Alpine Himalayan belt**, accounts for about 21% of EQs. This belt represents a weaker zone of fold mountains. Fault based and isostatic EQs are induced in this belt majorly.
3. **Mid Atlantic ridge** : **moderate to shallow focus** Earthquakes are induced in such Divergent plate boundaries.

EQs induced at the margins of plate can be explained with plate tectonic theory but mid plate EQs are difficult to be explained with PTT
For Eg. - Koyna EQ, 1967, MH
Kutch 1819, Bhadrachalam 1969 Andhra and Broach 1970

Indian Seismic foci
3 zones

1. **Himalayan Zone :** Zone of maximum intensity, zone of collision of Indian and Eurasian plate Uttar kashi EQ of 1991 and Chamoli EQ of 1999
2. **Plains :** zone of moderate intensity. Also includes earthquakes of Assam Eg 1934, Bihar, Assam 1950, Kolkata 1737 and Darbhanga 1988 etc
3. **Peninsular India** : zone of min. intensity