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INTERIOR STRUCTURE OF THE EARTH

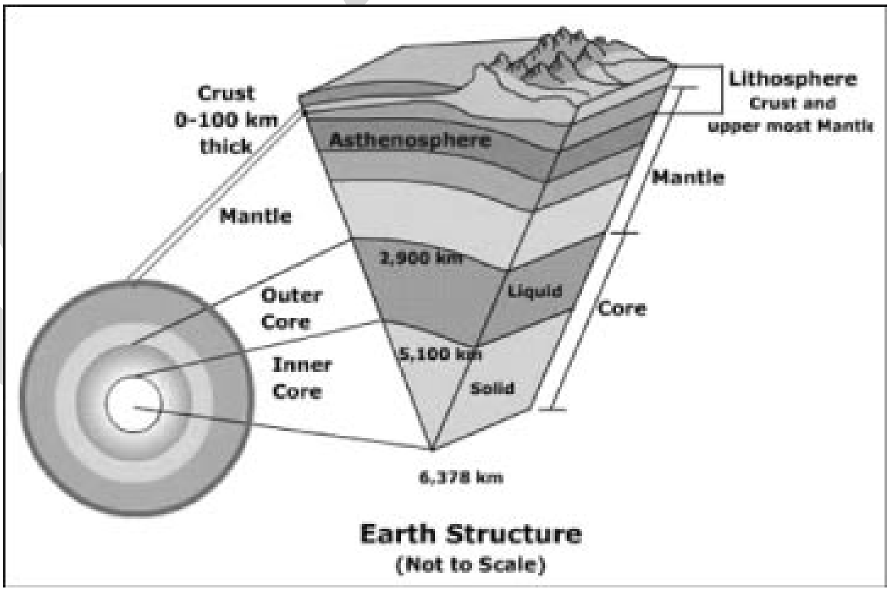
The interior of the earth is not composed of homogeneous or uniform material. The structure of Earth can be visualized in two ways: chemically or by material properties. By comparing material strength, the layering of Earth is categorized as lithosphere, asthenosphere, upper mantle, lower mantle, outer core, and the inner core.

Chemically, a tripartite arrangement for the earth has been suggested by Austrian geologist, Suess. The three concentric shells advocated by him on the basis of their density are outer Sial layer, inner Sima layer and the innermost nickel-iron core of Nife. The scientific study and analysis of various seismic waves of natural and man induced earthquakes unrevealed the mystery of earth's interior and divided the earth in three different layers as explained below.

Thus, the earth's interior has three different layers; they are (i) the crust (ii) mantle and (iii) the core. These layers are distinguished on the basis of their (i) Physical and chemical properties, (ii) Thickness, (iii) density (iv) Temperature, (v) Metallic content and (vi) rocks. The geologic component layers of Earth are at the following depths below the surface:

a) **Earth's Crust**: All of the Earth's landforms (mountains, plains, and plateaus) are contained within it, along with the oceans, seas, lakes and rivers. There are two different types of crust: thin oceanic crust that underlies the ocean basins and thicker continental crust that underlies the continents. These two different types of crust are made up of different types of rock. The thin oceanic crust is composed of primarily of basalt and the thicker continental crust is composed primarily of granite. The low density of the thick continental crust allows it to "float" in high relief on the much higher density mantle below. The boundary between the crust and the mantle is Mohorovicic Discontinuity.

While the crust appears to be solid, it is subjected to repeated movements including bending, folding, and breaking associated with the movement of material in the mantle below. The processes of weathering and erosion are continually wearing the high points of crust away. The low points are being filled in with the debris generated by these destructive processes.



Earth Structure
(Not to Scale)

b) Earth's Mantle: It is the thick, dense rocky matter that surrounds the core with a radius of about 2885 km. The mantle covers the majority of the Earth's volume. This is basically composed of silicate rock rich in iron and magnesium. The mantle is less dense than the core but denser than the outer crust layer.

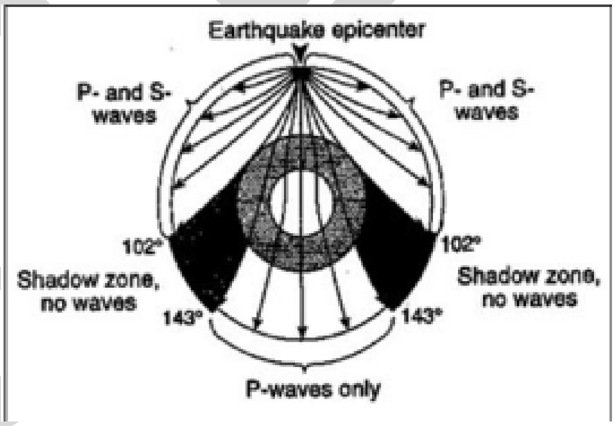
It has different temperatures at different depths. The temperature is lowest immediately beneath the crust and increases with depth. The highest temperatures occur where the mantle material is in contact with the heat-producing core. This steady increase of temperature with depth is known as the geothermal gradient.

The geothermal gradient is responsible for different rock behaviors which divide the mantle into two different zones. Rocks in the upper mantle are cool and brittle, while rocks in the lower mantle are hot and soft (but not molten). Rocks in the upper mantle are brittle enough to break under stress and produces earthquakes. However, rocks in the lower mantle are soft and flow when subjected to forces instead of breaking. The lower limit of brittle behavior is the boundary between the upper and lower mantle. This layer is separated from the core by Gutenberg-Wiechert Discontinuity. The outer and the inner mantle are separated by another discontinuity named Repetti discontinuity.

c) Earth's Core: Earth's Core is thought to be composed mainly of an iron and nickel alloy. This composition is based on calculations of its density. The core is earth's source of internal heat because it contains radioactive materials which release heat as they break down into more stable substances.

The core is divided into two different zones. The outer core is a liquid because the temperatures there are adequate to melt the iron-nickel alloy. However, the inner core is a solid even though its temperature is higher than the outer core. Here, tremendous pressure, produced by the weight of the overlying rocks is strong enough to crowd the atoms tightly together and prevents changing it to the liquid state.

The nature and properties of the composition of the interior of the earth may be successfully obtained on the basis of the study of various aspects of seismic waves mainly the velocity and the travel paths of these waves while passing through a homogenous solid body but these waves are reflected and refracted while passing through a body having heterogeneous composition and varying density zones. If the earth would have been composed of homogenous solid materials the seismic waves should have reached the core of earth in a straight path but this is not the case in reality. In fact the recorded seismic waves denote the fact that these waves seldom follow straight path rather they adopt curved and refracted paths. Thus it becomes obvious that the earth is not composed of homogenous materials. This has helped the scientists in discovering the layered structure of the Earth.



TYPES OF SEISMIC WAVES

There are two types of seismic waves, body wave and surface waves.

- Body waves travel through the interior of the Earth. They follow ray paths refracted by the varying density and stiffness of the Earth's interior which in turn, vary according to temperature, composition, and phase.

Body waves are divided as

P-WAVES (Primary Waves) are compression waves that are longitudinal in nature. These waves can travel through any type of material, and can travel at nearly twice the speed of S waves. In air, they take the form of sound waves; hence they travel at the speed of sound. Typical speeds are 330 m/s in air, 1450 m/s in water and about 5000 m/s in granite.

Thus the seismic waves have divided the earth's structure as:

S.No.	Name of the layer	Chemical Composition	Average Thickness (km)	Density (g cm^{-3})	Physical Properties
A.(i)	Crust	Sial	6 to 45	2.2 to 2.9	Solid part of lithosphere; partly molten under the continents.
(ii)	Inner part of lithosphere	Outer silicate layer, Basaltic	45 to 100		The solid crust and upper mantle
B.(i)	Asthenosphere		50 to 400		It transmits both S- and P-wave but with reduced velocities.
(ii)	Upper Mantle (mainly under oceans)	Sima (Peridotite iron-magnesium-rick silicatre rock)	100 to 1700	3.1 to 4.75	Slightly solid and slightly plastic material close to melting point.
(iii)	Lower Mantle	Sima (Olivine-Ultrabasic rocks)	1700 to 2900	4.75 to 5.6	Transition zone of mixed metals and silicate
C.(i)	Outer core	Nife	2900 to 4980	9.9 - 12.3	Liquid or in a plastic state. Fe, Ni and S mixture.
(ii)	Inner core	Barysphere (heavy metallic rocks)	4980 to 6400	13.5	Iron and nickel. Solid and rigid due to tremendous overlying pressure.

S-WAVES (Secondary Waves) are shear waves that are transverse in nature. These waves typically follow P waves during an earthquake and displace the ground perpendicular to the direction of propagation. S waves can travel only through solids, as fluids (liquids and gases) do not support shear stresses. S waves are slower than P waves, and speeds are typically around 60% of that of P waves in any given material.

- Surface waves are analogous to water waves and travel along the Earth's surface. They travel slower than body waves. Because of their low frequency, long duration, and large amplitude, they can be the most destructive type of seismic wave.

There are two types of surface waves:

Rayleigh waves, also called ground roll, are surface waves that travel as ripples with motions that are similar to those of waves on the surface of water. The existence of these waves was predicted by John William Strutt, Lord Rayleigh, in 1885. They are slower than body waves.

Love waves are surface waves that cause circular shearing of the ground. They are named after A.E.H. Love, a British mathematician who created a mathematical model of the waves in 1911. They usually travel slightly faster than Rayleigh waves, about 90% of the S wave velocity, and have the largest amplitude.

Seismic velocities tend to gradually increase with depth in the mantle due to the increasing pressure, and therefore density, with depth. However, seismic waves recorded at distances corresponding to depths of around 100 km to 250 km arrive later than expected indicating a zone of low seismic wave velocity. Furthermore, while both the P and S waves travel more slowly, the S waves are attenuated or weakened. This is interpreted to be a zone that is partially molten. This zone is called the asthenosphere or "weak sphere."

The asthenosphere separates the strong, solid rock of the uppermost mantle and crust above from the remainder of the strong, solid mantle below. The combination of uppermost mantle and crust above the asthenosphere is called the lithosphere. The lithosphere is free to move (glide) over the weak asthenosphere. The tectonic plates are, in fact, lithospheric plates.

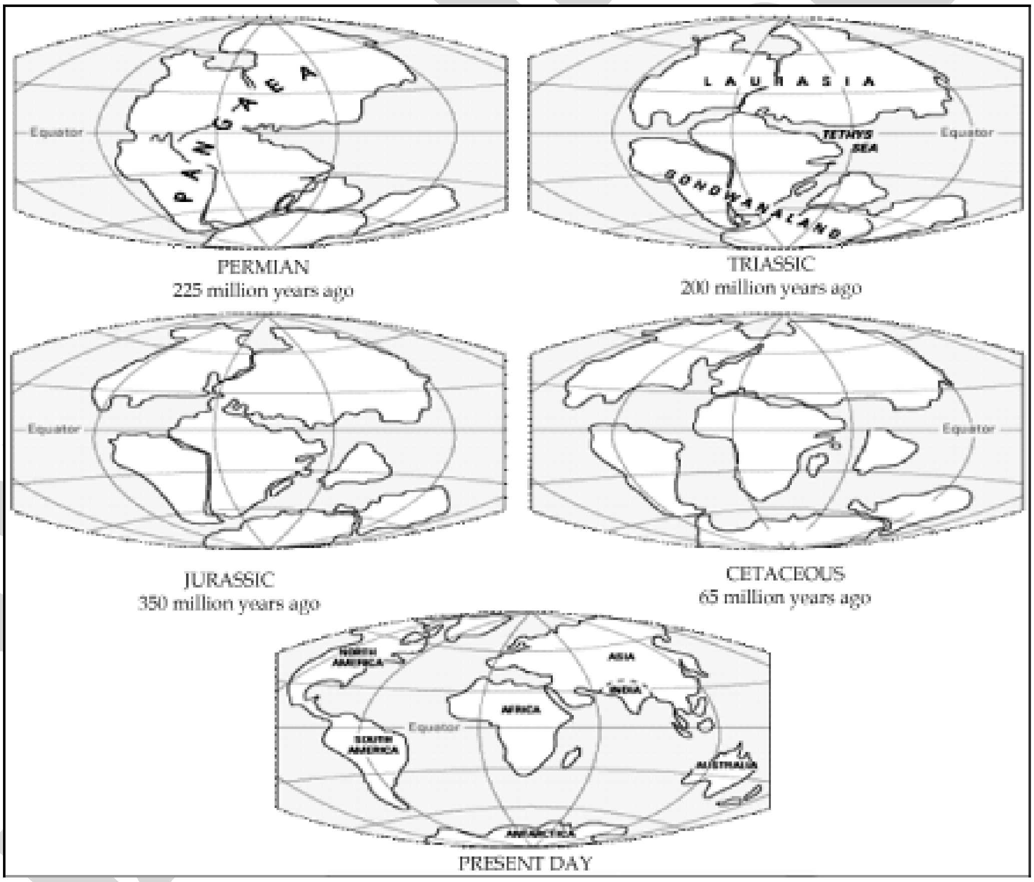
Seismic waves recorded at increasing distances from an earthquake indicate that seismic velocities gradually increase with depth in the mantle (exceptions: at Low Velocity Zone and at discontinuities). However, at arc distances of between about 103° and 143° no P waves are recorded. Furthermore, no S waves are record beyond about 103°. Gutenberg (1914) explained this as the result of a molten core beginning at a depth of around 2900 km. Shear waves could not penetrate this molten layer and P waves would be severely slowed and refracted (bent).

Between 143° and 180° from an earthquake another refraction is recognized (Lehman, 1936) resulting from a sudden increase in P wave velocities at a depth of 5150 km. This velocity increase is consistent with a change from a molten outer core to a solid inner core.

CONTINENTAL DRIFT THEORY

In 1915, the German geologist and meteorologist Alfred Wegener first proposed the theory of continental drift, which states that parts of the Earth's crust slowly drift atop a liquid core.

Wegener hypothesized that there was a gigantic supercontinent 200 million years ago, which he named Pangaea, meaning "All-earth". Pangaea started to break up into two smaller supercontinents, called Laurasia and Gondwanaland, during the Jurassic period. By the end of the Cretaceous period, the continents were separating into land masses that look like our modern-day continents.



Evidences Supporting the Theory of Continental Drift

a) **The Fit of Continental Coastlines -** Wegener used the jigsaw puzzle fit between the South American and African coastlines as his first piece of evidence to support continental drift. He didn't believe that these "pieces" would be so well matched-that is, not unless they had actually once been connected.

b) **Similar Mountain Ranges and Rock Sequences -** Explorers quickly discovered that distant continents contained rock of similar ages and features. These findings

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seemed to show that the continents may not have always been separated as they are now. For example, this is what they found when they looked at the Appalachian Mountain Range of North America:

- This range stretches northward from the eastern United States up into the Atlantic provinces of eastern Canada. There, it seems to suddenly stop at the island of Newfoundland.
- Very similar mountain ranges of the same age and rock-type also appear in eastern Greenland, Ireland, Great Britain, and Norway. When these landmasses are placed together, the mountains form a single long range.

c) **Fossil Evidence -** A fossil is any evidence of ancient life. In the beginning of the 20h Century, fossil evidence was also found to support continental drift. Identical fossilized plant and animal species have been found in many different places, on different continents. It seems hard to believe that such similar organisms would exist so far away from each other, or that they could have swam from one continent to another. It is more likely that these life forms once lived all together on a single continent, as shown in the following image.

The theory was rejected on following grounds:

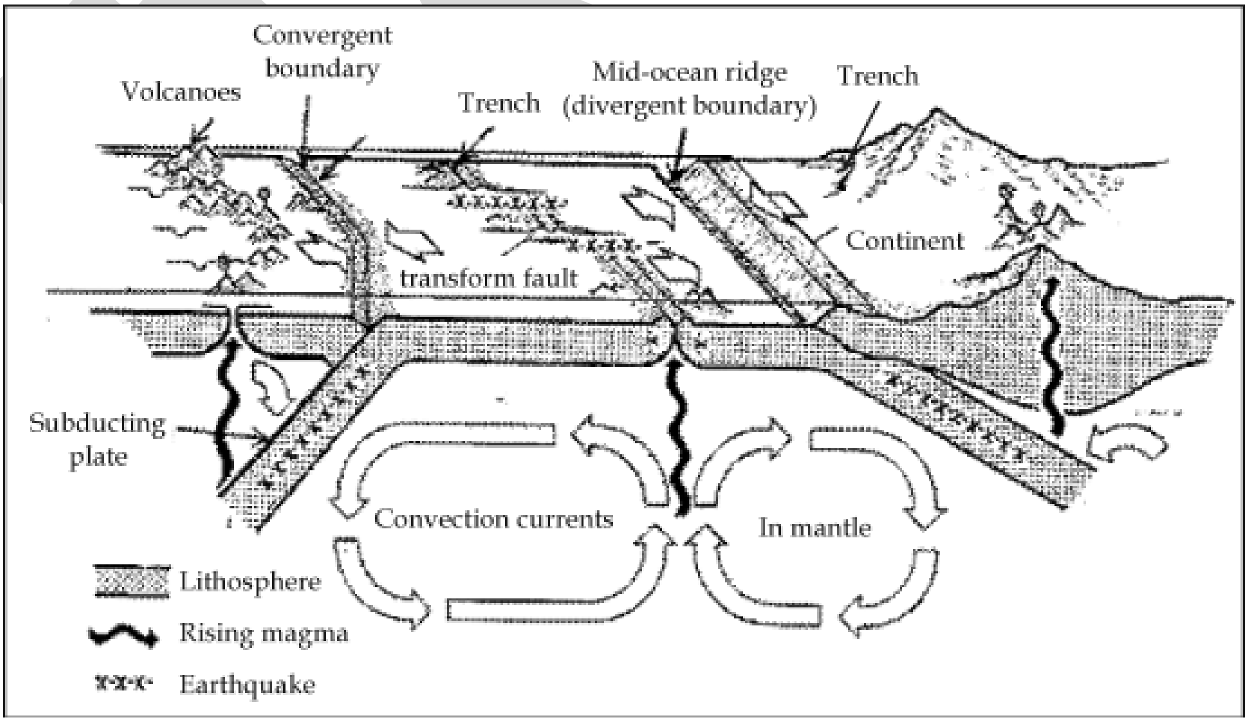
a) First, it had been shown that floating masses on a rotating geoid would collect at the equator, and stay there. Thus mountain building process could not be explained using this theory.

b) Second, masses floating freely in a fluid substratum, like icebergs in the ocean, should be in isostatic equilibrium (where the forces of gravity and buoyancy are in balance). Gravitational measurements showed that many areas are not in isostatic equilibrium.

c) Third, there was the problem of why some parts of the Earth's surface (crust) should have solidified while other parts were still fluid.

SEA-FLOOR SPREADING

The concept of sea floor spreading was first propounded by Harry Hess. According to him the mid oceanic ridges were situated on the rising thermal convection currents coming up from the mantle. The oceanic crust moves in opposite directions from mid oceanic ridges and thus there is continuous upwelling of lavas along the ridge. These molten lavas cool down and solidify to form new crust along the trailing ends of divergent boundary. Thus there is a continuous creation of new crust.



Sea floor spreading and magnetic bands

In 1963, Fred Vine, Drummond Matthews, and others found that the crust surrounding the mid ocean ridges showed alternating bands -- each band magnetized with a polarity opposite to the surrounding bands. They suggested that as new sea-floor crust was formed around the rift in the mid ocean ridge, it magnetized differently, depending upon the polarity of the planet at that time. This supported the theory that Harry Hess had put forth, that the ocean progressively widens as new sea floor is created along a crack that follows the crest of mid-ocean ridges.

Sea Floor spreading is still active in many parts of the world's oceans. This can be observed from under sea vents and trenches. As the sea floor pushes the continents apart the rest of the plates it sink beneath continental plates. This creates deep sea trenches.

PLATE TECTONICS

The theory states that Earth's outermost layer, the lithosphere, is broken into 7 large, rigid pieces called plates: the African, North American, South American, Eurasian, Australian, Antarctic, and Pacific plates. Several minor plates also exist, including the Arabian, Nazca, and Philippines plates.

The plates are all moving in different directions and at different speeds (from 2 cm to 10 cm per year--about the speed at which our fingernails grow) in relationship to each other. The place where the two plates meet is called a plate boundary. Boundaries have different names depending on how the two plates are moving in relationship to each other

These plates lie atop a layer of partly molten rock called the asthenosphere. The plates can carry both continents and oceans, or exclusively one or the other. The Pacific Plate, for example, is entirely oceanic.

Continental plates are composed mainly of granite, while oceanic plates are mostly basalt, which is considerably heavier. Essentially, the continents are lighter and more buoyant; hence, they float higher on the earth's mantle than the ocean's crust does.

A. Convergent boundary: convergent boundaries are the places where plates crash or crunch together. When plates converge, one slips under the other and is said to be subducted. At depths from 185 to 435 miles beneath the earth's surface, the subducted parts of the plate melt and become part of the molten mantle. As new plate material is being formed continuously, and the excess is melted into magma, the earth's rocky crust is constantly recycled.

Oceanic Plate vs. Oceanic Plate Convergence

The older of the two plates descends into the subduction zone when plates of oceanic lithosphere collide along a trench. The descending plate carries water-filled sediments from the ocean floor downward into the mantle. The presence of water alters the physical and chemical conditions necessary for melting and causes magma to form. The magma rises up through the overriding oceanic plate, reaching the surface as a volcano. As the volcano grows, it may rise above sea level to form an island.

Oceanic Plate vs. Continental Plate Convergence

When oceanic lithosphere collides with continental lithosphere, the oceanic plate will descend into the subduction zone. Oceanic lithosphere is denser than continental lithosphere and is therefore consumed preferentially. Continental lithosphere is almost never destroyed in subduction zones. The Nazca Plate dives below South America in a subduction zone that lies along the western margin of the continent.

Continental Plate vs. Continental Plate Convergence

The tallest mountains in the world Himalayas were formed (and continue to grow) as a result of continental collision. Continental lithosphere is relatively light and is deformed adjacent to subduction zones rather than consumed.

B. Divergent boundary: Places where plates are moving apart are called divergent boundaries also called as spreading centres. When the Earth's brittle surface layer (the lithosphere) is pulled apart, it typically breaks along parallel faults that tilt slightly outward from each other. As the plates separate along the boundary, the block between the faults, cracks and drops down into the soft, plastic interior (the asthenosphere). The sinking of the block forms a central valley called a rift. Magma (liquid rock) seeps upward to fill the cracks. In this way, new crust is formed along the boundary. Earthquakes occur along the faults, and volcanoes are formed where the magma reaches the surface.

Where a divergent boundary crosses the land, the rift valleys get formed which are typically 30 to 50 kilometers wide. Examples include the East Africa rift in Kenya and Ethiopia, and the Rio Grande rift in New Mexico. Oceanic ridges rise a kilometer or so above the ocean floor and form a global network tens of thousands of miles long. Examples include the Mid-Atlantic ridge and the East Pacific Rise. Plate separation is a slow process, eg. Divergence along the Mid Atlantic ridge causes the Atlantic Ocean to widen at only about 2 centimeters per year.

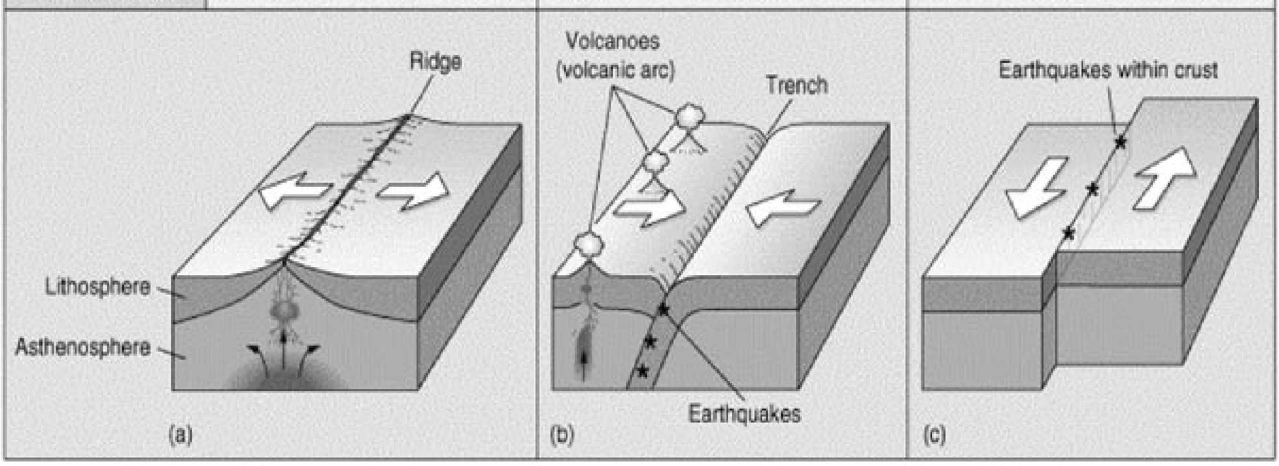
C. **Transform boundary:** Places where plates slide past each other are called transform boundaries. The plates on either side of a transform boundary are merely sliding past each other and not tearing or crunching each other.

The most famous transform boundary in the world is the San Andreas Fault. Although transform boundaries are not marked by spectacular surface features, their sliding motion causes lots of earthquakes. The strongest and most famous earthquake along the San Andreas Fault hit San Francisco in 1906. Many buildings were finished by the quake, and maximum of the city was destroyed by the fires that followed.

Salient points:

- The plate boundaries are mainly represented by oceanic ridges and trenches.
- Interactions at plate boundaries cause volcanic activity and earthquakes
- The plates are in motion, moving away from ridges and toward trenches.
- Plates descend into the mantle below trenches in subduction zones.
- Plates typically contain both oceanic and continental lithosphere.
- Oceanic lithosphere is continually created and destroyed.
- Continental lithosphere cannot be destroyed but continents can be subdivided and assembled into supercontinents.

Type of Margin	Divergent	Convergent	Transform
Motion	Spreading	Subduction	Lateral sliding
Effect	Constructive (oceanic lithosphere created)	Destructive (oceanic lithosphere destroyed)	Conservative (lithosphere neither created or destroyed)
Topography	Ridge/Rift	Trench	No major effect
Volcanic activity?	Yes	Yes	No



ROCKS AND MINERALS

The earth is composed of various kinds of elements. These elements are in solid form in the outer layer of the earth and in hot and molten form in the interior.

About 98 per cent of the total crust of the earth is composed of eight elements like oxygen, silicon, aluminium, iron, calcium, sodium, potassium and magnesium, and the rest is constituted by titanium, hydrogen, phosphorous, manganese, sulphur, carbon, nickel and other.

Rocks are naturally formed and are simply composed of crystals or particles of one or more minerals. There are many kinds of rock, and they can be classified in a number of ways. However, geologists classify rocks based on how the rocks were formed. The three classes are igneous rocks (formed directly from liquid rock), metamorphic rocks (formed by direct alteration of existing rocks), and sedimentary rocks (formed by eroded materials from other rocks).

i. Igneous Rocks

Igneous rocks solidify from a liquid magma as it cools. They are described on two axies: 1) Rocks that are quartz rich (felsic) and magnesium rich (mafic) and 2) fast cooling (small crystals) and slow cooling (large crystals).

When magma cools rapidly, mineral crystals do not have time to grow very large. On the other hand when magma cools slowly crystals grow to several millimeters or more in size. Granite and basalt are opposites on these axies for the description of igneous rocks - granite is a slow cooled quartz rich (felsic) rock, basalt a rapidly cooled magnesium rich (mafic) rock.

Igneous rocks are classified as

a) Extrusive Rocks

Extrusive igneous rocks solidify from molten material that flows over the earth's surface (lava). Extrusive igneous rocks typically have a fine-grained texture (individual minerals are not visible unless magnified) because the lava cools rapidly when exposed to the atmosphere, preventing crystal growth. Common extrusive rocks are basalt, andesite, and rhyolite.

- **Basalt:** Basalt is characteristically a dense, black, massive rock, high in calcium and iron-magnesium- bearing minerals and low in quartz content. Great examples of basaltic lava flows can be found in the deccan region of India.
- **Andesite:** Andesite has higher quartz content than basalt and is usually lighter in color. Crystals of the minerals amphibole, biotite, and feldspar are sometimes visible without magnification. It is found in northwestern portion of Rajmahal traps in India.
- **Rhyolite:** Rhyolite is typically a fine-grained, white, pink, or gray rock, high in quartz and feldspar content with some amphibole and biotite. A well-known example is a rhyolite rock exposure in a hillock of 120 metres (394 ft) height, originally called the "Mountain of Birds", forms the foundation for the imposing Mehrangarh Fort in Jodhpur.

a) Intrusive Rocks

Intrusive rocks form from molten material (magma) that flows and solidifies underground. These rocks usually have a coarse texture (individual minerals are visible without magnification), because the magma cools slowly underground, allowing crystal growth. Common rock types within the intrusive category are granite and diorite.

- **Granite:** Granite is the intrusive equivalent of rhyolite but has a coarser texture. Splendid black and multicolour varieties of granite are available in the states of Karnataka, Andhra Pradesh, Tamil Nadu and Uttar Pradesh. Granite deposits are also widespread over the provinces of Rajasthan, Bihar, West Bengal, and Gujarat. India is the largest exporter of granite and granite products in the world.
- **Diorite:** Diorite has the same texture as granite but has the mineral composition of an andesite, which is diorite's extrusive equivalent. Diorite is a relatively rare rock; source localities include Sondrio, Italy; Thuringia and Saxony in Germany; Finland; Romania; Northeastern Turkey; central Sweden; Scotland; the Darrans range of New Zealand, etc.

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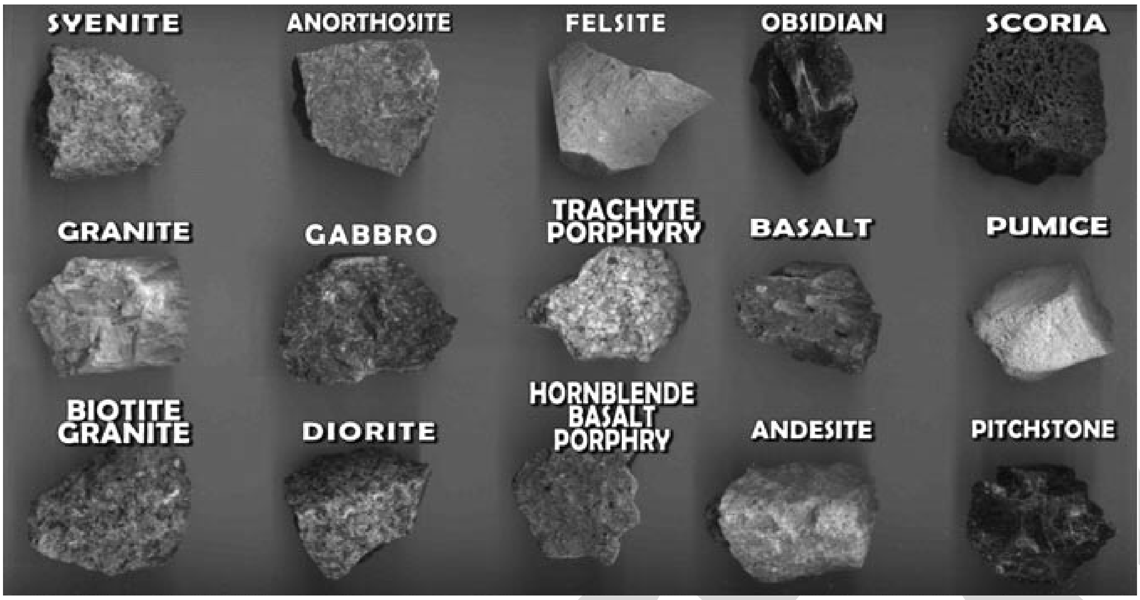


ii. Sedimentary Rocks

Sedimentary rocks are types of rocks created from deposition of layers upon layers of sediments over time. These types of rocks are formed on the Earth's surface, as well as underwater. Wherever sedimentation goes on, sedimentary rocks are formed over time. The sediments that compose these rocks may be of organic, chemical or mineral origin.

Although sedimentary rocks constitute only 5% of the total crust volume, they extensively cover most continental surfaces. Most of the natural energy resources like coal and the fossil fuels are contained within the layers of sedimentary rock.

Types of Sedimentary Rock

Depending on the nature of sediments that create them, sedimentary rocks can be classified into three prime types:

- **Clastic:** The clastic sedimentary rocks are composed of broken down fragments of minerals and remnants of weathered rocks. One example of this type of sedimentary rock is sandstone. They are mostly made up of quartz, amphiboles, feldspar, clay minerals and other minerals derived from weathering of igneous and metamorphic rocks.

- **Biochemical:** The deposition of the biological remains of various organisms can create certain types of sedimentary rock. Some examples are limestone (from the deposition of calcium carbonate containing remains of corals, foraminifera and mollusks), stromatolites (formed from deposition of microorganism biofilms of blue green algae), oil shale and coal shale.

- **Chemical Precipitate:** Sediments formed from deposition of chemical reaction precipitates of mineral solutions are called chemical sedimentary rocks. Chemical sedimentary rock formation occurs when water dissolves many minerals and deposits them on evaporation. Examples of this type of sedimentary rock are gypsum, barite, rock salt and sylvite.

Process of Sedimentary Rock Formation

In the process of sedimentary rock formation, there are some basic steps, like weathering, erosion, transportation and deposition.

Weathering

"Weathering is the first step responsible for formation of sedimentary rocks. It involves mechanical and chemical breakdown of rocks, minerals and soil under the influence of atmospheric conditions. Elements like water, ice, heat and pressure altogether affect the rates of weathering. The weathered rock, soil and mineral particles are then carried away to other places by means of erosion.

Erosion

"Erosion is defined as the process of breaking down larger objects into smaller ones and transporting them. Take the example of a newly formed mountain, which appears tall and steep. After being exposed to the effects of wind, water, glacier and rain for several years, its height is reduced and the shape becomes rounded. This is brought about by erosion. In the meantime, the eroded rock and mineral particles are carried away by natural agents to several places.

Sediment Transportation

The smaller particles generated by erosion are collectively known as sediments. Ultimately, most of the broken rocks, minerals and soil particles are transported by water and wind to other places. Besides these, dead plants and organisms are also carried in the flow of wind, water and ice. They are also used in the formation of sediment rocks.

Deposition of Sediments

Another step in sedimentary rock formation is deposition of the sediments by water and other transporting agents. Particles that flow downstream in water bodies like river, streams and lakes settle down at the bottom, because of the influence of gravity. In due course of time, layers of sediments are piled up one after the other, either in the earth's surface or under water bodies. This settling down of particles at the bottom of a water body is called sedimentation.

During the process of sedimentation, the bottom layers are pressurized by the above layers, resulting in compaction and formation of sedimentary rocks. The layers of sediments are called strata or beds. During this process, dead plants and animals also get buried in between the beds, which become fossils afterward.

This is the conclusive stage of sedimentary rock formation.

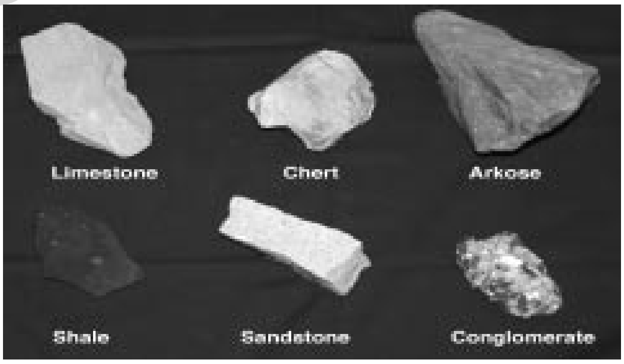
Some common sedimentary rocks are shale, sandstone, limestone, and conglomerate.

Shale: Shale is a fine-grained sedimentary rock that forms from the compaction of silt and clay-size mineral particles that we commonly call "mud". Shales are typically deposited in very slow moving water and are often found in lakes and lagoonal deposits, in river deltas, on floodplains and offshore from beach sands. They can also be deposited on the continental shelf, in relatively deep, quiet water. This process could have taken millions of years to complete.

Sandstone: Sandstone is composed of cemented sand grains. Sandstone reserves in India are spread over the states of Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Madhya Pradesh, Meghalaya, Mizoram, Karnataka, Orissa, Punjab, Rajasthan, Uttar Pradesh, Tamil Nadu and West Bengal. Over 90% of the deposits of sandstone are in Rajasthan, spread over the districts of Bharatpur, Dholpur, Kota, Jodhpur, Sawai-Madhopur, Bundi, Chittorgarh, Bikaner, Jhalawar, Pali, and Jaisalmer.

Limestone: Limestone is composed of more than 50% calcium carbonate (calcite). The remainder of the rock may contain fine rock fragments, clay, quartz, and seashells. Andhra Pradesh has the privilege of possessing about 32% of the country's total reserves of limestone. Limestones are extensively utilised for manufacturing of cement and also building stones, particularly flooring and roofing.

Conglomerate: Conglomerate is well-rounded gravel in a matrix of sand, clay, and natural cementing agents. Two of the many conglomerates in Utah are the Price River Formation visible along Highway 6 between Thistle and Soldier Summit, Utah County, and the Shinarump Conglomerate Member of the Chinle Formation exposed along the central part of the Burr Trail, east of Boulder, Garfield County.



iii. Metamorphic Rocks

Metamorphic rocks are any rock type that has been altered by heat, pressure, and/or the chemical action of fluids and gases. The meaning of the term 'metamorphic', in fact, is 'changed'. When igneous rocks, or sedimentary rocks, or even metamorphic rocks get buried very deep under the earth's surface, a process that takes millions of years, they get changed into something

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else by the enormous pressure and heat inside the earth.

"Some examples of metamorphic rocks are:

- Limestone being changed into marble
- Shale turning into slate
- Granite being changed into gneiss
- Sandstone turning into quartzite

Metamorphic rocks are classified by their structure and their dominant minerals. Metamorphic rock structure is either foliated (has a definite planar structure) or non-foliated (massive, without structure).

Foliated Metamorphic Rocks

Common foliated metamorphic rocks are slate, schist, and gneiss.

Slate: This metamorphic rock is fine-grained, containing perfect cleavage, which enables it to be split into fine sheets. Slate generally contains dark to light brown streaks. Slate is formed by comparatively low pressures and temperatures, which is referred to as low-grade metamorphism. Not being very hard, slate can be engraved quite easily. It has been used in various ways over the years, for example as grave markers or headstones. However, one of the problems with slate is the perfect cleavage it has, which resulted in grave stones splitting and cracking along the cleavage lines. It is also commonly used for chalkboards. These days, due to its cracking and splitting, and its weight, slate is not used much.

Schist: This is a metamorphic rock that is classified as medium grade, which means it has been formed by more pressure and heat compared to slate. This rock is coarse grained with the individual grains of the minerals that it is made up of being visible to the naked eye. Most of the original minerals are transformed into flakes, and since it has experienced far more pressure, it is usually found crumpled or folded. Usually, schists are named according to the main mineral they have been formed from. For example: talc schist, garnet mica schist, hornblende schist, and bitotite mica schist.

Gneiss: This metamorphic rock is classified as high grade, which means that compared to schist it has been subjected to more pressure and heat. Gneiss is distinctly banded and is coarser than schist. The banding comprises alternating layers, which are made up of different minerals. One of the most important minerals that gneiss is made up of is feldspar, along with quartz and mica. Gneiss can form from the metamorphosis of sedimentary rock like shale or sandstone, or from igneous rock like granite. Gneiss is used as a building stone and for paving.

Non-foliated Metamorphic Rocks

Common non-foliated metamorphic rocks are quartzite and marble.

Quartzite: Quartzite is typically a metamorphosed form of sandstone. Unweathered quartzite has a "sugary" looking surface. Individual quartz grains are deformed, interlocked, and fused together. When the rock breaks, it typically breaks through the grains. Some quartzite formations retain their original bedded (layered) structure such that when broken they form flagstones that are commonly used in landscaping or as veneer for buildings.

Marble: This is formed due to the metamorphosis of dolomite or limestone. Both dolomite and limestone contain calcium carbonate in large concentrations. Compared to its parent rock, marble is much harder. This enables it to be polished, which is why it is such a popular material used in buildings, such as bathtubs, floor tiling, sink tops, kitchen counter tops, and so on. Artists also use it as a carving material. Marble is made up of various sized crystals and also has many variances in color because of the impurities that are present during the formation. Hence, marble can be white, gray, black, red, green, pink, banded and mottled.

THE ROCK CYCLE

The rock cycle consists of a series of constant processes through which earth materials change from one form to another over time. As within the water cycle and the carbon cycle, some processes in the rock cycle occur over millions of years and others occur much more rapidly. There is no real beginning or end to the rock cycle, but it is convenient to begin exploring it with magma.

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Magma, or molten rock, forms only at certain locations within the earth, mostly along plate boundaries. When magma is allowed to cool, it crystallizes. Rocks that form from cooled magma are called igneous rocks; intrusive igneous rocks if they cool below the surface (like gabbro), extrusive igneous rocks if they cool above (like basalt).

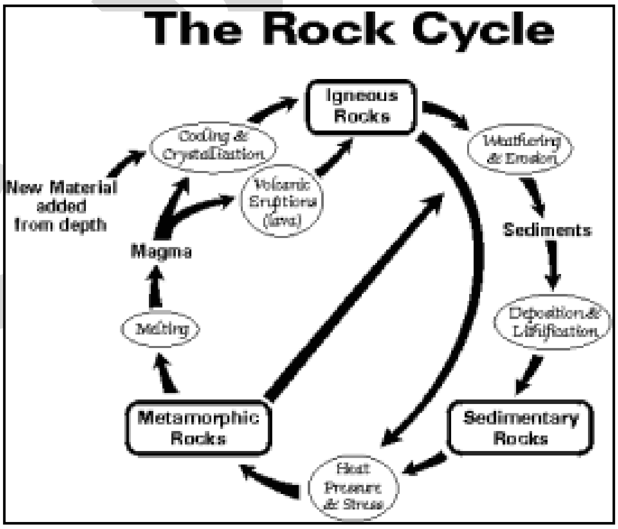
Rocks like basalt are immediately exposed to the atmosphere and weather. Rocks that form below the earth's surface, like gabbro, must be uplifted and all of the overlying material must be removed through erosion in order for them to be exposed. In either case, as soon as rocks are exposed at the earth's surface, the weathering process begins. Physical and chemical reactions caused by interaction with air, water, and biological organisms cause the rocks to break down. Once rocks are broken down, wind, moving water, and glaciers carry pieces of the rocks away through a process called erosion.

Moving water is the most common agent of erosion, all of these rivers carry tons of sediment weathered and eroded from the mountains of their headwaters to the ocean every year. The sediment carried by these rivers is deposited and continually buried in floodplains and deltas.

Under natural conditions, the pressure created by the weight of the younger deposits compact the older, buried sediments. As groundwater moves through these sediments, minerals like calcite and silica precipitate out of the water and coat the sediment grains. These precipitants fill in the pore spaces between grains and act as cement, gluing individual grains together. The compaction and cementation of sediments creates sedimentary rocks like sandstone and shale.

If sedimentary rocks or intrusive igneous rocks are not brought to the earth's surface by uplift and erosion, they may experience even deeper burial and be exposed to high temperatures and pressures. As a result, the rocks begin to change. Rocks that have changed below the earth's surface due to exposure to heat, pressure, and hot fluids are called metamorphic rocks.

Some of the processes within the rock cycle, like volcanic eruptions, happen very rapidly, while others happen very slowly, like the uplift of mountain ranges and weathering of igneous rocks. Importantly, there are multiple pathways through the rock cycle. Any kind of rock can be uplifted and exposed to weathering and erosion; any kind of rock can be buried and metamorphosed. As Hutton correctly theorized, these processes have been occurring for millions and billions of years to create the earth as we see it: a dynamic planet.



ENDO-GENETIC FORCES

The forces coming from within the earth are called as endogenetic forces which cause two types of movements in the earth, viz, (i) Horizontal movements, and (ii) Vertical movements.

These movements motored by the endogenetic forces introduce various types of vertical irregularities which give birth to numerous varieties of relief features on the earth's surface, eg., mountains, plateaus, plains, lakes, faults, folds, etc.

This energy is mostly generated by radioactivity, rotational and tidal friction and primordial heat from the origin of the earth. This energy due to geothermal gradients and heat flow from within induces diastrophism and volcanism in the lithosphere. Due to variations in geothermal gradients and heat flow from within, crustal thickness and strength, the action of endogenic forces are not uniform and hence the tectonically controlled original crustal surface is uneven.

The endogenetic forces and movements are divided, on the basis of intensity, into two major categories:

a) Sudden forces
b) Diastrophic forces

Sudden forces are the result of long period preparation deep within the earth. Only their cumulative effects on the earth's surface are quick and sudden. Geologically, these sudden forces are termed as 'constructive forces' because these create certain relief features on the earth's surface.

Diastrophic forces include both vertical and horizontal movements which are caused due to forces deep within the earth. These diastrophic forces operate very slowly and their effects become discernable after thousands and millions of years. These forces also termed as constructive forces, affect larger areas of the globe and Produce meso-level reliefs, for example, mountains, plateau, plains, lakes, big faults, etc.

They include: (i) orogenic processes involving mountain building through severe folding and affecting long and narrow belts of the earth's crust; (ii) epeirogenic processes involving uplift or warping of large parts of the earth's crust; (iii) earthquakes involving local relatively minor movements; (iv) plate tectonics involving horizontal movements of crustal plates.

(A) Epeirogenetic movements: Epeirogenetic word consists of two words, viz: 'epiros' (meaning thereby continent) and 'genesis' (meaning thereby original). Epeirogenetic movement causes upliftment and subsidences of continental masses through upward movements are infact, vertical movements. These forces and resultant movements affect larger parts of the continents. These are further divided into two types: upward movement and downward movement.

(B) Orogenetic movement: The word orogenetic has been derived from two Greek words, 'pros' (meaning thereby mountain) and 'genesis' (meaning thereby origin or formation). Orogenetic movement is caused due to endogenetic forces working in horizontal movements. Horizontal forces and movements are also called as tangential forces.

Orogenetic or horizontal forces work in two ways, namely, (i) in opposite direction, and (ii) towards each other. When it operates in opposite directions it is called as 'tensional force'. Such types of force and movement are also called as divergent forces. Thus, tensional forces create rupture, cracks, fracture and faults in the crustal parts of the earth.

The force that operates face to face is called compression force or convergent force. Compressional force causes crustal bending leading to the formation of folds or crustal warping leading to local rise or subsidence of crustal parts.

Through the processes of orogeny, epeirogeny, earthquakes and plate tectonics, there can be faulting and fracturing of the crust. All these processes cause pressure, volume and temperature (PVT) changes which in turn induce metamorphism of rocks.

Folds

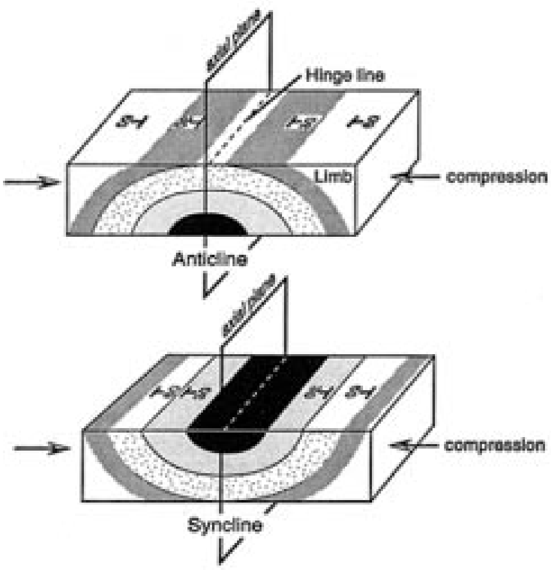
A layered rock that exhibits bends is said to be folded. The layered rock was at one time uniformly straight but was stressed to develop a series of arches and troughs. A compressive stress compact horizontal rock layers and forces them to bend vertically, forming fold patterns. Folds in rocks vary in size from microscopic crinkles to mountain-sized folds. They occur singly as isolated folds and in extensive fold trains of different sizes, on a variety of scales.

Folds form under varied conditions of stress, hydrostatic pressure, pore pressure, and temperature - hydrothermal gradient, as evidenced by their presence in soft sediments, the full spectrum of metamorphic rocks, and even as primary flow structures in some igneous rocks. A set of folds distributed on a regional scale constitutes a fold belt, a common feature of orogenic zones.

Anticlines and Synclines

An anticline is a fold that is arched upward to form a ridge; a syncline is a fold that arches downward to form a trough. Anticlines and synclines are usually made up of many rock units that are folded in the same pattern. The tip of a fold is called the nose. The center axis of a fold is called the hinge line and lies in the axial plane that separates the rocks on one side of the fold from the rocks on the other side that dip in the opposite direction. Extensive folding is represented by a repeated pattern of anticlines and synclines. Two anticlines are always separated by a syncline, and two synclines are always separated by an anticline. One side of the fold is called the limb; a side-by-side syncline and anticline share a limb. Frequently, an anticline or syncline can be identified only from the systematic change in the dips of the sloping rock units from one direction to the other, identifying the hinge line of the fold.

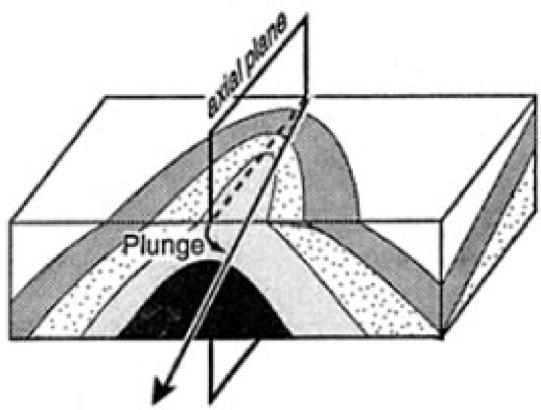
An Anticline and a Syncline



Plunging folds

Plunging folds have been tipped by tectonic forces and have a hinge line not horizontal in the axial plane. The angle between the horizontal and the hinge line is called the plunge and, like dip, varies from less than 1 degree to 90 degrees. Plunging folds characteristically show a series of V patterns on a bedrock surface.

A Plunging Anticline



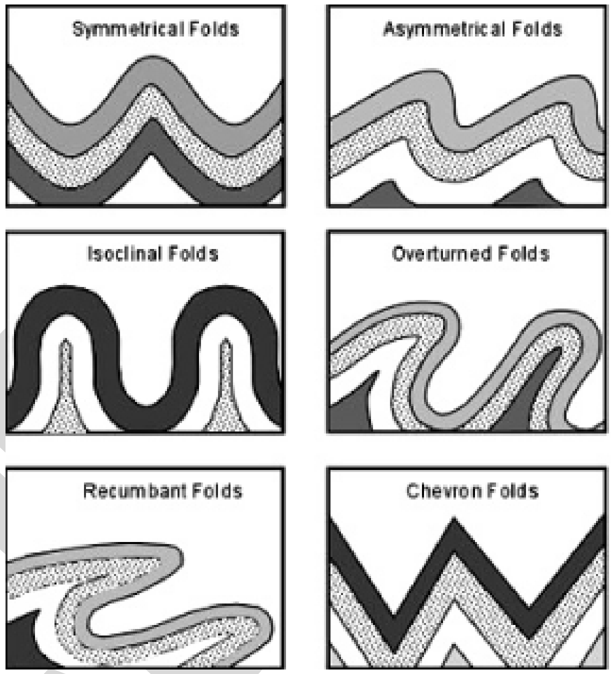
Open, isoclinals, overturned, and recumbent folds

A variety of kinds of folds generally reflects increasing amounts of tectonic stress.

Open folds are those in which the angle between the two limbs of the fold is more than 900 but less than 1800.

Closed folds are those in which the angle between the two limbs of a fold is acute angle.

Symmetrical folds are simple folds in which both the limbs incline uniformly.



Monoclinal folds are those in which one limb inclines moderately with regular slope while the other limb inclines steeply at right angle and the slope is almost vertical.

Isoclinal folds are those in which the compressive forces are so strong that both the limbs of the fold become parallel but not horizontal.

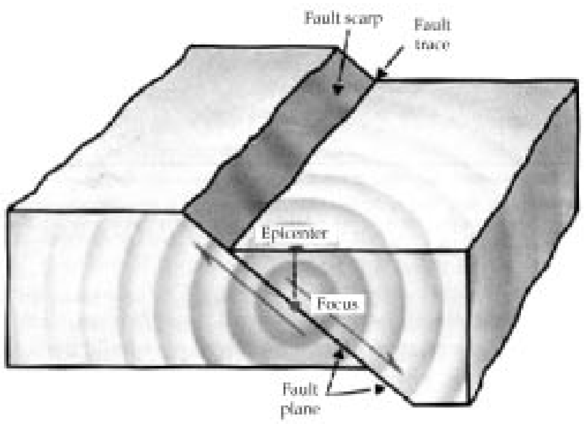
Recumbent folds are formed when the compressive forces are so strong that both the limbs of the fold become parallel as well as horizontal.

Overturned folds are those folds in which one limb of the fold is thrust upon another fold due to intense compressive forces. Limbs are seldom horizontal.

Faults

A fault is a fracture or zone of fractures between two blocks of rock. Faults allow the blocks to move relative to each other. This movement may occur rapidly, in the form of an earthquake - or may occur slowly, in the form of creep. Faults may range in length from a few millimeters to thousands of kilometers. Most faults produce repeated displacements over geologic time. During an earthquake, the rock on one side of the fault suddenly slips with respect to the other. The fault surface can be horizontal or vertical or some arbitrary angle in between.

The parts of a fault are (1) the fault plane, (2) the fault trace, (3) the hanging wall and (4) the footwall. The fault plane is where the action is. It is a flat surface that may be vertical or sloping. The line it makes on the Earth's surface is the fault trace. Where the fault plane is sloping, the upper side is the hanging wall and the lower side is the footwall. When the fault plane is vertical, there is no hanging wall or footwall.



Any fault plane can be completely described with two measurements: its strike and its dip. The strike is the direction of the fault trace on the Earth's surface. The dip is the measurement of how steeply the fault plane slopes-if you dropped a marble on the fault plane, it would roll exactly down the direction of dip.

Faults are distinguished on the basis of the movement of the footwall relative to the hanging wall.

- **Normal-fault**

A normal fault is a dip-slip fault in which the block above the fault has moved downward relative to the block below. This type of faulting occurs in response to extension and is often observed in the Western United States Basin and Range Province and along oceanic ridge systems.

- **Thrust fault**

A thrust fault is a dip-slip fault in which the upper block, above the fault plane, moves up and over the lower block. This type of faulting is common in areas of compression, such as regions where one plate is being subducted under another as in Japan and along the Washington coast. When the dip angle is shallow, a reverse fault is often described as a thrust fault.

- **Strike-slip fault**

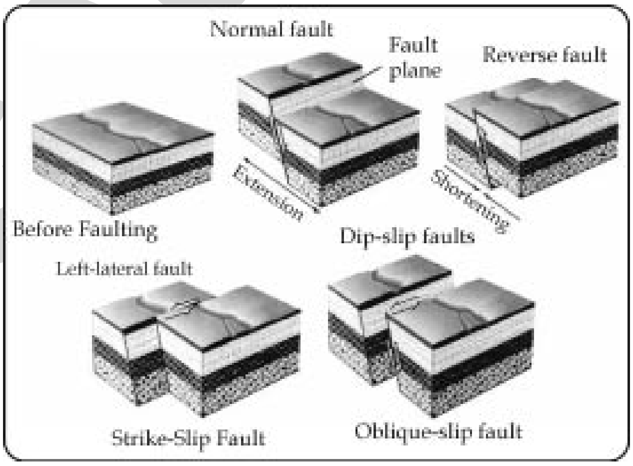
A strike-slip fault is a fault on which the two blocks slide past one another. These faults are identified as either right-lateral or left lateral depending on whether the displacement of the far block is to the right or the left when viewed from either side. The San Andreas Fault in California is an example of a right lateral fault. Strike-slip faults are either right-lateral or left-lateral. That means someone standing near the fault trace and looking across it would see the far side move to the right or to the left, respectively.

In reality, many faults show a combination of dip-slip and strike-slip motion. Geologists use more sophisticated measurements to analyze these fault movements.

Landforms formed by faulting

1. Block Mountains

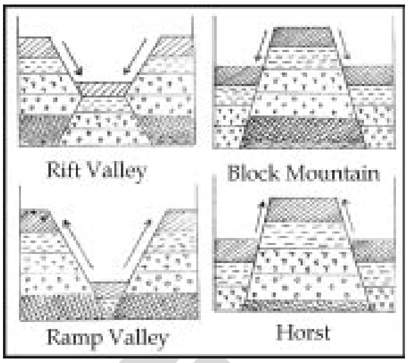
Block mountains form when the layers of the Earth's crust are forced upward near fault lines.



Fault-block mountains have a steep, sharp front side and a gentler, sloping back. Examples of block mountains are the Black Forest of Germany, the Alps in Europe and the Urals. California's Sierra Nevada is a 350-mile long block of granite containing Mt. Whitney, the highest mountain peak in the lower 48 states. This granite mountain was lifted during the formation of the Basin and Range Province, centered in Nevada and stretching from southern Oregon to west Texas.

2. Rift Valley

When a depression appears between two block mountains, that depression is called a rift valley, which can be thousands of miles long. In the United States, one example of these flat-bottomed valleys is Death Valley in California. Some of the largest rift valleys include the East African Rift Valley, Russia's Baikal Valley, Germany's Rhine Valley and the Red Sea. Ocean rift valleys occur where tectonic plates on the seafloor spread apart. The largest lakes in the world are all found in rift valleys.



EXO-GENETIC FORCES

Exogenetic forces also called as denudational processes. These forces are engaged in destruction of the relief features by the process of weathering, erosion etc.

Weathering

It is "the breakdown and decay of rocks in-situ related to elements of the weather (e.g. temperature, rainfall, frost etc.

Weathering is the first stage in the denudation of the landscape. Rocks are weakened and loosened by weathering processes. This weakened material is then removed by agents of erosion (e.g. ice, water etc.)

Weathering can be classified as:

a) Physical Weathering

Physical weathering is also known as mechanical weathering and it involves the physical breakdown of rock - it does not involve chemical change.

- ***Freeze Thaw***

This is the breakdown of rocks due to the expansion of water during freezing, a process common in upland Britain where evening temperatures often fluctuate around 0°C. Freeze thaw is most effective in jointed rock (e.g. granite). During freezing, water expands by 9% in volume. Water freezing in cracks in rocks, exerts pressure. Alternating freeze-thaw cycles gradually force the rock to split or cause rock fragments to break off. Where this process occurs on steep slopes, rock fragments collect at the base of the slope due to gravity in the form of a scree slope.

- ***Pressure Release (also known as dilation)***

Rocks such as granite, formed as Igneous intrusions are formed under pressure. When weathering and erosion removes overlying rocks, the pressure is released and the underlying rock expands. This expansion results in the fracturing of the rock, which weakens it by making it susceptible to other weathering agents. If cracks develop parallel to the surface, sheeting of rock layers may occur.

- ***Thermal Expansion (insolation weathering)***

This process results from large diurnal temperature ranges which result in heating and cooling of the rock. When heated, expansion of the rock occurs, whilst during cooling the rock contracts. This expansion and contraction during cycles of temperature change results in stresses in the rock layers. Outer layers of rock heat and cool quicker than inner layers and over time the upper layers flake / peel off (exfoliation). It should be noted that the effectiveness of this process is heavily debated and some believe that it is only really effective when water is also present.

- ***Salt Crystallisation***

Water passing through crevases and joints in rocks, may be saline (carrying salts in solution). As the water evaporates, the dissolved salts precipitate and crystalise froming salt crystals. This may also take place where in rocks such as chalk, the rock is decomposed by solution to form salt solutions such as sodium carbonate which will then crystalise upon evaporation of the mosture. The salts may expand up to 3 times their original size, and therefore the crystals put stresses upon the rock as they grow, resulting in granular disintegration (gradually breaking off individual grains of rock).

b) Chemical Weathering

Chemical weathering is where rocks are decomposed by chemical reaction between

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elements of the weather and rock minerals, resulting in either the alteration of a rock's internal mineral structure or the formation of new minerals (e.g. feldspar forming Kaolin in the process of hydrolysis). Weakened rock or the consequent deposits are then more easily removed by erosion processes. Water plays a key role in most chemical reactions and also provides a transport mechanism for other elements that carry out weathering. Chemical weathering is most dominant in hot and humid areas such as equatorial zones and least effective where there is little rain such as in desert or polar regions (where most water is held as ice). The susceptibility of rocks to chemical weathering is determined by the types of minerals they contains and their mineral structure. There are a number of different types of chemical weathering.

- ***Oxidation***

The exposure of rocks to oxygen in air or water can result in a reaction between the oxygen and iron-based minerals in the rocks. Iron readily oxidises and during oxidation, blue grey ferrous iron (Fe^{2+}) is transformed to red ferric iron (Fe^{3+}). This causes a weakening of the rock structure enabling them to crumble easily and making them more susceptible to other weathering processes.

- ***Carbonation***

Rainwater contains dissolved CO_2 which forms a weak carbonic acid ($H_2O + CO_2 = H_2CO_3$). Carbonic acid is able to react with calcium carbonate (common in rocks such as limestone and chalk) to form calcium bicarbonate which is then easily removed in solution in water. Limestone is gradually dissolved in this way as the calcium carbonate is converted to calcium bicarbonate and carried away in solution by running water.

- ***Solution***

Water can act as a solvent by breaking down chemical bonds in minerals causing them to dissolve in a process known as solution - carbonation is therefore a form of solution although it is mineral specific in relation to calcium carbonate. Solution rates tend to increase with an increased acidity of water.

- ***Hydrolysis***

This is where acidic water reacts with rock forming minerals such as feldspar. This is a common process in the weathering of granite. Hydrogen ions in the water displace potassium ions in the feldspar. This causes the feldspar to break down into a secondary mineral, Kaolin (China Clay). Whilst the feldspar in granite decomposes, the quarz and mica remain relatively unaffected but the structure weakened.

- ***Hydration***

This occurs as the addition of water causes minerals in rock to swell (by about 0.5%) due to a chemical reaction as the mineral absorbs water ('hydrates'), thus involving both chemical and physical (mechanical weathering). Gypsum is formed when water combines with anhydrite Calcium sulphate and water ($CaSO_4$ (anhydrite) + $2H_2O$ (water) = $CaSO_4.2H_2O$ (gypsum)). Gypsum is fairly soluble and can then be fairly easily removed by solution.

c) Biological Weathering

Usually consists of a combination of physical (growth of roots into joints in rocks) and chemical (e.g. impact of organic acids) processes.

- ***Tree Roots***

As roots of plants and trees grow downwards, they often enter and exploit cracks joints in rock. As they grow they are able to gradually wedge the joints further apart, eventually resulting in detatchment of rock fragments (simillar to freeze-thaw)

- ***Organic Acids***

As roots as well as surface litter decayse, organic acids are released into the ground. Percolating rainwater, moves these acides further down and the organic acids may react with minerals in the rock through a process called chelation. The combination of rainwater and organic acids combines with aluminium and iron which are washed out of the soil.

Respiration of bacteria and tree roots also releases CO_2 which when becomes dissolved in water forms a weak carbonic acid which can increase the chemical weathering process, carbonation.

- ***Animal Activity***

Burrowing animals help to open up joints in rock and also help to bring rock fragments to the surface, where they are exposed to further

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weathering. At the coast, animals such as limpets increase the rate of chemical weathering through the acids secreted as they cling to rock surfaces.

EROSION

Water Erosion

Water is the most important erosional agent and erodes most commonly as running water in streams. However, water in all its forms is erosional. Raindrops (especially in dry environments) create splash erosion that moves tiny particles of soil. Water collecting on the surface of the soil collects as it moves towards tiny rivulets and streams and creates sheet erosion.

In streams, water is a very powerful erosional agent. The faster water moves in streams the larger objects it can pick up and transport. This is known as critical erosion velocity. Fine sand can be moved by streams flowing as slowly as three-quarters of a mile per hour.

Streams erode their banks in three different ways: 1) the hydraulic action of the water itself moves the sediments, 2) water acts to corrode sediments by removing ions and dissolving them, and 3) particles in the water strike bedrock and erode it.

The water of streams can erode in three different places: 1) lateral erosion erodes the sediment on the sides of the stream channel, 2) down cutting erodes the stream bed deeper, and 3) headward erosion erodes the channel upslope.

Wind Erosion

Erosion by wind is known as aeolian (or eolian) erosion (named after Aeolus, the Greek god of winds) and occurs almost always in deserts. Aeolian erosion of sand in the desert is partially responsible for the formation of sand dunes. The power of the wind erodes rock and sand.

Ice Erosion

The erosive power of moving ice is actually a bit greater than the power of water but since water is much more common, it is responsible for a greater amount of erosion on the earth's surface.

Glaciers can perform to erosive functions - they pluck and abrade. Plucking takes place by water entering cracks under the glacier, freezing, and breaking off pieces of rock that are then transported by the glacier. Abrasion cuts into the rock under the glacier, scooping rock up like a bulldozer and smoothing and polishing the rock surface.

Wave Erosion

Waves in oceans and other large bodies of water produce coastal erosion. The power of oceanic waves is awesome, large storm waves can produce 2000 pounds of pressure per square foot. The pure energy of waves along with the chemical content of the water is what erodes the rock of the coastline. Erosion of sand is much easier for the waves and sometimes, there's an annual cycle where sand is removed from a beach during one season, only to be returned by waves in another.

PLAINS

Plains are flat and broad land areas on the earth's surface, e.g. prairies, steppes, Great Plains of India etc. The elevations of these landforms are relatively low, when measured with reference to the mean sea level.

Plant life on plains is controlled by the climate. Thick forests usually thrive on plains in humid climates; grasslands cover fairly dry plains such as the Great Plains in the United States. Plains are usually well populated because the soil and terrain are good for farming, and roads and railways are easily built between rural towns and cities.

Origin and development of plains

- Plains are formed primarily by erosion and the deposition of sediment. Erosion is the gradual wearing away of Earth surfaces through the action of wind and water. Sediment is rock debris such as clay, silt, sand, and gravel (or even larger material) that is being carried from its place of origin or has already been deposited on Earth's surface by wind, water, or ice eg. Ganga-Yamuna plains of India.
- Sometimes coastal lands are submerged under the sea water because of transgressional phase of sea. Such coastal lands submerged under shallow water receive sediments regularly and continuous sedimentation leads to formation of coastal plains.

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- Deposition of enormous volume of lavas over extensive areas forms volcanic plains.
- Submerged coastal lands emerge as marine coastal plains due to withdrawl of sea water during regressional phase of sea.

Types of plains

1. Erosional Plains

Erosional plains are developments on the Earth's surface caused by natural weathering of glacier activity, wind movement or water (sea, river & stream) torrent and are subdivided on the basis of the type of erosional agent. Here we will discuss the glacial plain, wind-eroded plain & alluvial plain. Erosional plains are likely to develop on landscapes that are relatively flat with low height elevations and shallow depressions. Some plains may develop below sea level but not higher than the surrounding region; this is a result of endogenetic factors and diastrophic movements.

Types of Erosional Plains

a) Alluvial Plain

The alluvial plain is an erosional plain that occurs from weathering caused by water currents in the sea, river or stream. Fluvial (water) movement comes from higher land regions and wear away landmasses to produce low relief plains. This is what is known as the alluvial plain. These landforms are made up of the deposition of sediment over a long period of time from the fluvial movement to form alluvial soil. An alluvial plain is characterized by its relatively flat and gently sloping landform and is normally formed at the base of a range of hills. Continuous fluvial weathering of these hills is what causes sediments to move and spread across lower levels to produce this type of plain. These plains are formed mostly by slow running rivers, as slower fluvial movement picks up less sediment off the river floor causing more particles to settle and develop into an alluvial plain. Areas where more particles are dropped off are sometimes referred to as flood plains, and the particles that settle are called alluvium.

b) Wind-Eroded Plain

Wind-eroded plains develop in dry land expanses. These formations are created by continuous abrasive wind activity wearing down land formations by a grinding action and a sandblasting of wind-borne particles to shape and disfigure landscape surfaces. Wind-eroded plains are found in arid regions with large supplies of unconsolidated sediment. Vegetation is sparse, as a result of such severe wind erosion. These plains are usually infertile since the most fertile parts of the soil are removed by abrasive wind activity. Soil productivity and maintenance is poor, which impacts seedling survival and growth and ultimately the survival of any type of plant life.

c) Glacial Plain

These are structures formed by the movement of ice from highland areas to low land levels. Slow and continuous glacial movement takes place over time to cause sizable erosive work to produce a glacial plain. There are two types of glacial structures - true glacial plains, formed of pure glacial material and outwash plains, formed from deposition of materials such as sand, marl, gravel, silt & clay after the ablation (melting) of glaciers and ice sheets. Marl deposits from a glacial plain are often used to make cement and are great fertilizers as well. Outwash glacial plains often form an alluvial plain when the ice has melted. As ablation occurs, the water rises and moves away from the glacial plain and takes with it fine, eroded sediment. As the speed of the water decreases, so does its capacity to carry objects in suspension. The water then gradually deposits the sediment across the landscape and creates an alluvial plain.

Location of Erosional Plains

Erosional Alluvial Plain - These are formed all over the globe from the effects of vast water movement. Prominent alluvial plains are the Mississippi Delta, Plain of Lombardi (Italy), Yangtze Plain (China), Indus Plain (Ganga), Amazon Plain (Brazil) and Mekong Plain (Cambodia).

Wind-Eroded Plain - These are very uncommon and take the longest to form as they exist in dry regions lacking vegetation. Wind-eroded plains can be found in Libya - The Hamada Red Plain (Sahara Desert) and India - Aravalli Range (Jaisalmer -Thar Desert).

Glacial Erosional Plain - These are found in colder regions with temperatures slightly above and below zero degrees Celsius. Actual glacial plains exist in Sweden, Finland, Ladakh, Imphal Basin and Canada.

2. **Depositional Plains -** Deposition is carried on by rivers, glaciers, winds, sea waves, etc. Plains result as a product of deposition. Types of depositional plains are:

a) **Plains of Fluvial Deposition-** The Rivers start deposition as a result of the decrease in the speed of rivers and the volume of water. An accumulation of sediment also contributes to deposition. There are three areas of deposition-the floor, the mouth and the valley of the river where the slope suddenly decreases. The following plains are described as belonging to this type:

- **A flood plain** is the floor of a river valley beyond the riverbed. A flood plain is formed of mud, sand, and silt that are left behind when the river overflows its banks. These materials are carried off by the river as it erodes the land upstream. A river in flood conditions can carry a large amount of eroded material, which the overflow waters deposit onto the flood plain.
- **Piedmont alluvial plains** are formed at the foothill zones of the mountains.
- **Delta plains** are formed by rivers through gradual deposition of sediments while entering the seas and oceans.

b) **Plains of Glacial Deposition -** Many plains are formed due to glacial deposition. These plains have great importance. These plains are found in North America and Europe in areas, which were affected by glacial action. Till covers mainly the plains. The size of the till particles varies from fine particles to boulders. Though a lot of till is local yet erratics are also common. The base rock of till have been eroded by ice. The surface is lightly undulating and has low and broad ridges and depressions. Drumlins, Eskers, Moraines, etc., are a common feature of these plains.

c) **The Desert Plains -** The plains where sand accumulates in large quantity are desert plains and are developed by wind action. The wind produces sand by sand-abrasion of sandstones. The sand does not blow much far away from its place but accumulates in various form. The main characteristics of these plains depend upon the accumulation of sand, the strength of the winds, the persistence of the direction of winds and vegetational cover. A few examples of such plains are the Sahara of Africa, the Koum of Russian Turkistan, the north-central Nebraska, etc.

d) **Lava plains -** These are formed due to deposition of thin sheets of lavas coming out through fissure flows. These are found in Iceland, USA, Deccan plateau of India etc.

e) **Lacustrine plains -** These are formed when the lakes are filled with sediments either due to filling of lakes by the sediments brought by the rivers or by the upliftment of the beds of lakes due to diastrophic movements caused by endogenetic forces.

PLATEAUS

A plateau is a large highland area of fairly level land separated from surrounding land by steep slopes. Some plateaus, like the plateau of Tibet, i.e. between mountain ranges. Others are higher than surrounding land. Plateaus are widespread, and together with enclosed basins they cover about 45 percent of the Earth's land surface. Some plateaus, such as the Deccan of India and the Columbia Plateau of the United States, are basaltic and were formed as the result of many lava flows covering hundreds of thousands of square kilometers that built up the land surface. Others are the result of upward folding; still others have been left elevated by the erosion of nearby lands. Plateaus, like all elevated regions, are subject to erosion, which removes great amounts of the upland surface. Low plateaus are often farming regions, while high plateaus are usually suitable for livestock grazing. Many of the world's high plateaus are deserts. Other plateaus are the Colorado Plateau of the United States, the Bolivian plateau in South America, and the plateaus of Anatolia, Arabia, Iran, and the Tibet region of China and the

Canadian Shield or Laurentian Plateau, a U-shaped region of ancient rock, the nucleus of North America, stretching north from the Great Lakes to the Arctic Ocean. Covering more than half of Canada, it also includes most of Greenland and extends into the United States as the Adirondack Mountains and the Superior Highlands. The first part of North America to be elevated above sea level, it has stayed almost wholly untouched by many encroachments of the sea upon the continent.

Classification based upon the methods of Formation - The plateaus are formed by many methods. The emission from the earth, water glacier, wind, etc., form plateaus.

- **Plateaus formed by Lava -** Lava comes out of the surface of the earth through zones of weakness. This lava spreads in the surroundings areas and forms plateau. The southern plateau of India is an extensive lava plateau. Its area is 13 million sq. km. The plateau of Columbia has an area of 250,000 sq. km.

- **Plateaus formed by Running Water -** High Mountains are eroded down by rivers. Plateau is formed as a landform in the last part of the cycle of erosion. Endogenetic force makes peneplain and plateaus. Brazil is one such a Plateau.

- **Plateaus formed by Glaciers -** Glaciers also do erosional and depositional work. Hence, glaciers form mountains in two ways:- (a) by deposition and (b) by erosion. The Russian plateau and the plateau of Finland are examples of plateaus formed by deposition. Among the plateaus formed by erosion are the plateaus of Greenland and Antarctica..

- **Plateaus formed by Wind -** When winds blow from a desert in a certain direction, fine dust particles along with the winds reach far-off places. For example, the western winds coming from the Gobi desert have built up the loess plateau of China. The Potwar plateau of the district of Rawalpindi in Pakistan was built up in this way.

The Classification of Plateau according to Situation - The plateaus are also classified according to their situations. Some plateaus are surrounded by mountains, others piedmont and continental.

- **Intermontanne Plateau -** These plateaus extend along with mountains and are known as the highest plateaus of the world. The plateaus of Bolivia and Tibet belong to this type. Other similar examples are the plateaus of Peru and of Mexico.

- **Piedmont Plateaus -** These plateaus extend along with mountains. One side of the plateaus is mountain while the other side has a plain or a sea. It appears that these plateaus rose with the mountains under pressure of endogenetic forces. Examples of such plateaus are those of Colorado (N. America), Patagonia (South America), etc.

- **Continental Plateaus -** These plateaus are away from the mountains. They rise abruptly from the plains of seas. Some scholars think that these plateaus are created by the rise of a plain area under endogenetic forces. Sometimes the emission of lava and its spread close by form these plateaus. The Deccan Plateau of India, the Arab plateau, the plateaus of Spain and Australia are some of the examples of this type of plateaus.

MOUNTAINS

A mountain is defined as "a natural elevation of the earth surface rising more or less abruptly from the surrounding level and attaining an altitude which, relative to the adjacent elevation, is impressive or notable". Mountains can be classified on the basis of their structure or their origin.

Mountains may have several forms. A mountain ridge is a system of long, narrow and high hills. A mountain range is a system of mountains and hills having several ridges, peaks, summits and valleys. A mountain chain consists of several parallel long and narrow mountains of different periods. A mountain system consists of different mountain ranges of the same period. A mountain group consists of several unsystematic patterns of different mountain systems. Cordillera consists of several mountain groups and systems.

The different mountain types are formed in different ways, through tectonic plates crunching into each other, or sliding past one another, or even from magma coming up out of the Earth. The mountains are different in their appearance, and in their formation.

- **Fold Mountains**

The most common type of mountain in the world are called fold mountains. When you see vast mountain ranges stretching on for thousands of kilometers, those are fold mountains. Fold mountains are formed when two of the Earth's tectonic plates collide head on; like two cars crashing together. The edges of each tectonic plate crumple and buckle, and these create the mountains. Some examples of fold mountain ranges include the Rocky Mountains in North America, and the Himalayan Mountains in Asia.

- **Fault-Block Mountains**

Fault-block mountains (or just "block mountain") are created when faults or cracks in the Earth's crust force materials upward. So instead of folding, like the plate collision we get with fold mountains, block mountains break up into chunks and move up or down. Fault-block mountains usually have a steep front side and then a sloping back side. Examples of fault-block mountains include the Sierra Nevada mountains.

- **Dome Mountains**

Dome mountains are created when a large amount of magma pushes up from below the Earth's crust, but it never actually reaches the surface and erupts. And then, before it can erupt, the source of the magma goes away and the pushed up rock cools and hardens into a dome shape. Since the dome is higher than its surroundings, erosion works from the top creating a circular mountain range.

- **Volcanic Mountains**

Here's a fairly familiar kind of mountain. Volcanic mountains are created when magma from beneath the Earth makes its way to the surface. When does get the surface, the magma erupts as lava, ash, rock and volcanic gases. This material builds up around the volcanic vent, building up a mountain. Some of the largest mountains in the world were created this way, including Mauna Loa and Mauna Kea on the Big Island of Hawaii. Other familiar volcanoes are Mt. Fuji in Japan and Mt. Rainier in the US.

- **Plateau Mountains**

Plateau mountains are actually formed by the Earth's internal activity; instead, they're revealed by erosion. They're created when running water carves deep channels into a region, creating mountains. Over billions of years, the rivers can cut deep into a plateau and make tall mountains. Plateau mountains are usually found near folded mountains.

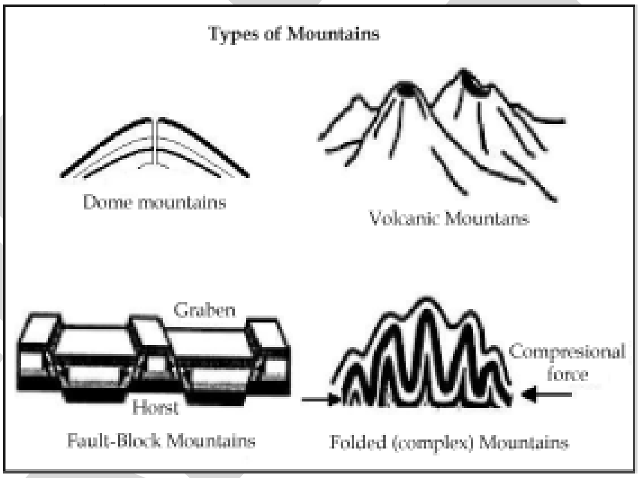

Plate tectonics and formation of folded mountains

When two continents carried on converging plates ram into each other, they crumple and fold under the enormous pressure, creating great mountain ranges.

The highest mountain range in the world, the snow-capped Himalayas, is an example of a continent-to-continent collision. This immense mountain range began to form when two large landmasses, India and Eurasia, driven by tectonic plate movement, collided. Because both landmasses have about the same rock density, one plate could not be subducted under the other. The pressure of the colliding plates could only be relieved by thrusting skyward. The folding, bending, and twisting of the the collision zone formed the jagged Himalayan peaks.

About 220 million years ago, India was an island situated off the Australian coast, and separated from the Asian continent by a vast ocean called the Tethys Sea. When Pangaea broke apart about 200 million years ago, India began to move northward. Scientists have been able to reconstruct India's northward journey. When

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India rammed into Asia about 50 million years ago, its northward advance slowed. The collision and decrease in the rate of plate movement mark the beginning of the Himalayan uplift.

When two oceanic plates collide the subducted part melts and the magma rises above the oceanic surface volcanic islands are formed in arc form like Aleutian Islands, Kuril Islands, and Ryukyu Islands. Near the arcs trenches are also formed like Mariana, Mindanao, etc.

When the oceanic lithosphere subducts beneath the continental plates the down went plate melts and produces magma. The magma being less dense than the surrounding rises slowly and emerges as intrusive igneous rock in the form of volcanic mountain range on the continental crust. And, at the edge of continental crust trench is formed.

LAKES

Lakes are inland bodies of water found in natural depressions surrounded by higher ground. Lakes are extremely varied in terms of origin, occurrence, size, shape, depth, water chemistry, and other features. Lakes can be only a few hectares in surface area (i.e., less than a square kilometer), or they can be thousands of square kilometers. Their average depth can range from a few meters to more than a thousand meters. Lakes can be nearly uniformly round, or they can be irregularly shaped. Their water can be highly acidic (as in some caldera lakes), nearly neutral, or highly alkaline (as in soda lakes). Lakes can be low in nutrients (oligotrophic), moderately enriched (mesotrophic), or highly enriched (eutrophic). Lakes may be fresh-water or salt-water (saline).

The different types of lakes are described below:

Glacial Lakes: By far the most important agents in the formation of lakes are the catastrophic effects of glacial ice movements that occurred 10,000 to 12,000 years ago. Gigantic sheets of ice and snow are created in climates where snow falls but does not meltAlthough these glaciers did eventually melt, ten percent of the earth is presently covered with glaciers. Some of these glaciers can still be seen in the mountainous areas of the world.

As a glacier moves back and forth across the land, scraping off the tops of hills and bluffs and taking rocks with it, lakes are formed. The material picked up by the glacier is later dropped off at other sites. This back and forth and stop and go movement of the glaciers permanently alters the landscape. This movement creates several important landforms. When the glacier stops, it leaves behind piles of rocks and materials that it carried over time, called moraines. These dam up rivers and smaller streams to form lakes. Sometimes, huge blocks of ice are broken off and covered by sand and gravel. When the ice melts, the sand and gravel cave in, leaving a large hole behind. These kettles may form large marshes or lakes. As the large mass of ice melts, rivers form beneath the glaciers.

Solution Lakes: Lakes can form when underground deposits of soluble rocks are dissolved by water running through the area, making a depression in the ground. Rock formations made of sodium chloride (salt), or calcium carbonate (limestone), are most likely to be dissolved by acidic waters. Once the groundwater has dissolved the rocks below the surface, the top of the land caves in, usually forming a round-shaped lake, called a solution lake. Typically, the depressions are deep enough to extend below the groundwater table and are permanently filled with water. Solution lakes are common in Michigan, Indiana, Kentucky and particularly in Florida.

Oxbow Lakes: The flow of water from rivers has a great deal of energy and erosive strength that may create lake basins. As a river winds over the earth's surface, a greater amount of erosion occurs on the outer river bend, where the flow of water is the fastest. Materials carried by the river are deposited on the inner portion of the bend, where currents are reduced. As time passes, erosion continues and more materials are left off until the U-shaped meander of the river closes in. The main course of the river cuts a new channel to the inner end of the meander. Oxbow lakes are usually shaped like the letter C.

Man-made or Animal-made Lakes: Many small lakes in India have been formed by the activities of the dam construction. Sticks, aquatic plants and mud are used to build dams across small streams to form an impoundment of the water. These ponds are usually very shallow and are rich in nutrients and plant life. Humans have constructed artificial lakes (reservoirs) to supply drinking water to the public, to provide power, to aid in navigation, to provide flood control and for recreational purposes. These reservoirs are usually well engineered by humans to hold back a certain quantity of water with the use of dams.

Volcanic Lakes: Sometimes, disastrous events associated with volcanic activity form lake basins. The formation of volcanic lakes can occur in different ways. As volcanic material, including magma, is discharged out of the volcano, empty depressions or cavities are formed within the volcano. Some of these depressions cannot drain and become sealed holes on top of the volcano. Rainfall and runoff eventually fill the depression with water and a new lake is formed.

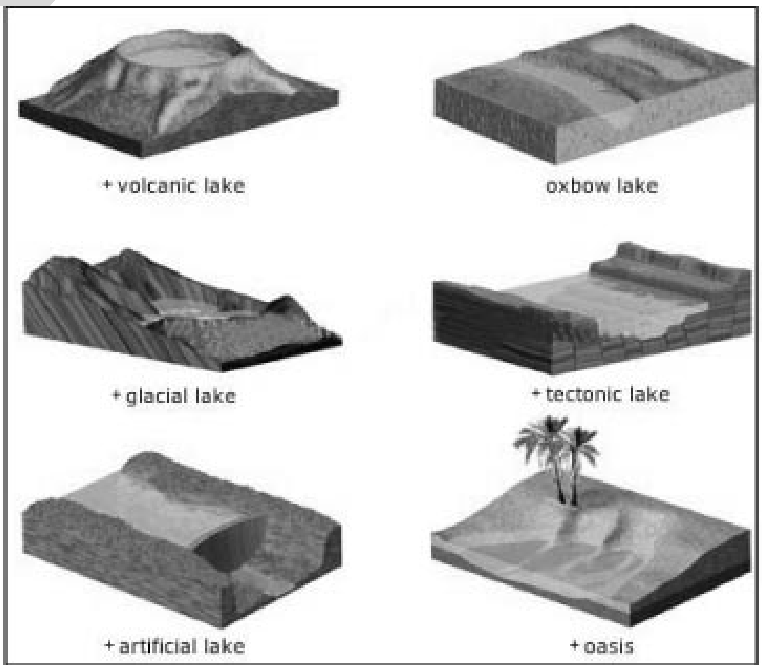
Lakes that form in the craters of volcanoes, or crater lakes, are more common in areas that are subject to volcanic activity. Lakes formed by the caving in of a roof of a partially empty magmatic chamber are termed calderas. One of the most spectacular lakes formed in this way is Crater Lake in Oregon. Volcanic basins, like Crater Lake, are usually very round in shape.

Lava flows from volcanic activity can also form lakes. The surface lava cools, and becomes solid, while the inside of the lava flow remains hot enough to continue moving. Eventually, the surface of the hardened lava collapses, forming a depression. These depressions eventually fill with water to form smaller lakes. Lava streams also flow into existing river valleys and solidify into a dam. This solid mass of rock backs up the river water into a new lake.

Landslide lakes: Large quantities of materials that fall from the sides of steep valleys into the floors of stream valleys can cause dams that create new lakes. Such landslides usually occur as a result of abnormal meteorological events, such as excessive rains acting on an unstable slope. Landslide dams may be a result of rockfalls, mudflows or even iceslides. Lakes that are formed by landslides are usually only temporary because they may be susceptible to erosion by the flow of the river or stream. If the dam is very large, the lake may become permanent.

Tectonic lakes: Tectonic basins are depressions formed by the movements of the earth's crust deep underground. The major types of tectonic basins are formed from faulting. A depression forms when a weak section of the earth's crust separates, resulting in an earthquake. Rainfall and groundwater may collect in this depression, forming a lake. This type of basin is referred to as a graben and is the mode of origin of a large number of the most spectacular relic lakes in the world containing a vast number of native plant and animal species. The deepest lake in the world, Lake Baikal in Siberia, was formed from tectonic activity.

The formation of a lake and the structure and form, or morphology, of the lake basin affects how the lake functions throughout its life stages. Characteristics like the lake length, width, depth, area and volume are all important to how the lake water quality may be affected by changes to the land. As humans develop the land surrounding the lake, they disturb the soils, exchange trees for driveways or rooftops and replace the natural vegetation. These changes result in an increased flow of surface runoff and an increase in the amount of nutrients to the lake. The lake structure dictates how the lake will react to these cultural changes in the surround lands. Knowing the lake morphology and how the lake was formed are important tools used by scientists to help protect our lakes from pollutants that can deteriorate their health.



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ISOSTASY

Isostasy is essentially the principle of hydrostatic equilibrium applied to the Earth. In its simplest form, it considers rigid blocks of the Earth (usually taken to be the crust) to be buoyantly supported in an underlying fluid medium (usually taken as the mantle) and free to move vertically. These blocks will then move until their weight is exactly balanced by their buoyancy, at which point they are said to be 'in isostatic equilibrium'.

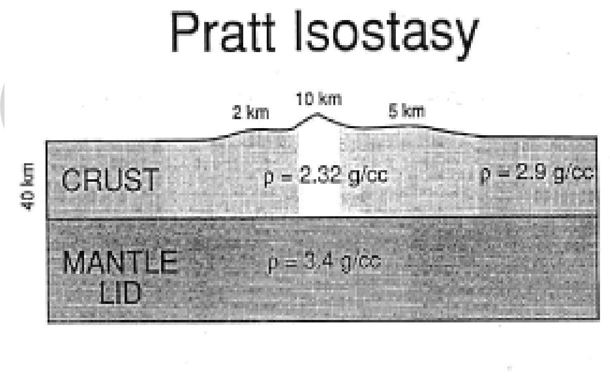
The concept was originated by French surveyors in the eighteenth century working around the Andes, who noted that the observed gravitational attraction of the mountains was less than that predicted. They inferred the presence of a low-density 'root' that balances the excess weight of the mountain range and also reduces its gravitational attraction. The theory was further developed by the English geodesists Pratt and Airy in the nineteenth century, who has given their names to two forms of the theory.

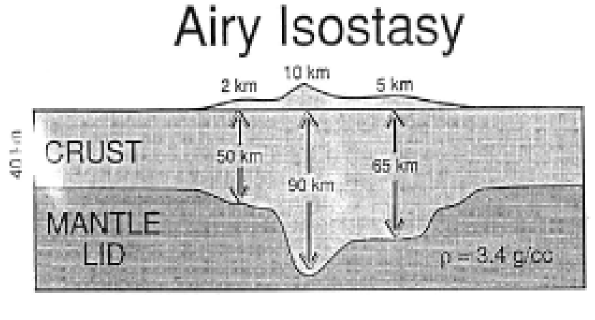
PRATT'S MODEL

Pratt hypothesized that elevation is inversely proportional to density. Therefore, the higher the mountain, the lower is its density (i.e., light rocks "float" higher).

AIRY'S MODEL

Airy hypothesized that mountains have "roots" which extend down into the mantle. Therefore, elevation is proportional to the depth of the underlying "root".





The main difference between the two models is that in the Airy model all blocks have the same densities but different thicknesses, whereas in the Pratt model all blocks have different densities but float to the same depth. Generally speaking though, the Airy model is used for continental topography, especially mountain ranges; and the Pratt model is used for mid-ocean ridges. Continental mountain ranges have thick crustal roots which are more easily explained using the Airy model. In the Airy model, the elevation is proportional to this root. The higher the elevation is, the thicker the block and root.

At mid ocean ridges the topography is supported by density changes. This is due to increased temperature at the ridges which causes the rocks to expand resulting in a lower density. According to the Pratt model, all blocks float at the same depth. This depth is where the asthenosphere begins. The difference in elevations is due to the density of the rocks. Higher elevations indicate lower density rocks and this higher ground means the lithosphere is thicker. The compensation depth is always the same in the Pratt model. The height equation is the same for both models.

Isostatic effects of sedimentation and erosion

Where sedimentation occurs, the weight of the sediment may cause the crust below to sink. Similarly, where erosion occurs the crust may rebound.

Likewise, when ice sheets form the crust may sink. Conversely, when they melt the crust may rebound, such as what is happening around the Baltic Sea and Hudson Bay area of Canada. Unfortunately, climate change makes things worse --- global warming makes the oceans warmer, which raises the sea level due to thermal expansion. Furthermore, the oceans are receiving more and more water from melting glaciers. Both factors cause the sea level to rise.

Isostatic forces are thus of major importance in controlling the topography of the Earth's surface.

EARTHQUAKE

An earthquake is a sudden movement of the Earth, caused by the abrupt release of strain that has accumulated over a long time. For hundreds of millions of years, the forces of plate tectonics have shaped the Earth as the huge plates that form the Earth's surface slowly move over, under, and past each other. Sometimes the movement is gradual. At other times, the plates are locked together, unable to release the accumulating energy. When the accumulated energy grows strong enough, the plates break free.

The magnitude or intensity of energy released by an earthquake is measured on the richter scale. The place of the origin of an earthquake is called focus which is hidden inside the earth. The place on the ground surface which is perpendicular to the buried focus is called 'epicentre'. Seismic waves are recorded by an instrument called 'seismograph'.

Earthquakes can be caused by a variety of things, including meteor impacts and volcanic eruptions, and even sometimes man-made events like mine collapses and underground nuclear tests. But most naturally occurring earthquakes are caused by movement of pieces of the earth's surface, which are called tectonic plates.

Different theories that explain the origin of earthquakes

a) Faulting and Elastic Rebound Theory:

The horizontal and vertical movements caused by endogenetic forces result in the formation of faults and fold which in turn cause isostatic disequilibrium in the crustal rocks which ultimately causes earthquakes of varying magnitudes depending on the nature and magnitude of dislocation of rock blocks caused by faulting and folding. In fact, sudden dislocation of rock blocks caused by both tensile and compressive forces trigger immediate earth tremor due to sudden maladjustment of rock blocks.

A fault is a fracture in the Earth's crust along which two blocks of the crust have slipped with respect to each other. Faults are divided into three main groups, depending on how they move. Normal faults occur in response to pulling or tension; the overlying block moves down the dip of the fault plane. Thrust (reverse) faults occur in response to squeezing or compression; the overlying block moves up the dip of the fault plane. Strike-slip (lateral) faults occur in response to either type of stress; the blocks move horizontally past one another. Most faulting along spreading zones is normal, along subduction zones is thrust, and along transform faults is strike-slip.

According to the theory the underground rocks are elastic like rubber and expand when stretched and pulled. The stretching and pulling of crustal rocks due to tensile forces is slow process. The rocks continue to be stretched so long as the tensile forces do not exceed the elasticity of the rocks but as the tensile forces exceed the rocks elasticity they are broken and broken rock blocks try immediately to occupy their previous positions so that they may adjust themselves. All these processes occur so rapidly that the equilibrium of the concerned crustal surface is suddenly disturbed and hence earth tremors are caused.

b) Hydrostatic Pressure and Anthropogenic Causes:

Certain human activities such as pumping of ground water and oil deep underground mining, blasting of rocks, nuclear explosion, storage of huge volume of water causes tremors. The introduction of additional artificial, superincumbent load through the construction of large dams and impounding of enormous volume of water cause disequilibrium of already fragile structures due to faults and fractures.

c) Volcanic Eruptions

When volcanoes erupt it is because the molten magma under the crust of the earth is under enormous pressure and to release that pressure it looks for an opening and exerts pressure on the earth's crust and the plate in turn. A place, which is the seat of an active volcano, is often prone to earthquakes as well. Earthquakes are also caused after a volcanic eruption since the eruption also leads to a disturbance in the position of plates, which either move further or resettle and can result into severe or light tremors.

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d) Plate Tectonic Theory

Finally, in the mid-1960s, researchers in the United States and Great Britain came up with a theory that explained why the Earth shook.

The theory, called plate tectonics, is that the Earth's crust, or lithosphere, is comprised of many plates that slide over a lubricating asthenosphere layer.

Plate tectonics confirms that there are four types of seismic zones. The first follows the line of mid-ocean ridges. Activity is low, and it occurs at very shallow depths. The point is that the lithosphere is very thin and weak at these boundaries, so the strain cannot build up enough to cause large earthquakes. Associated with this type of seismicity is the volcanic activity along the axis of the ridges (for example, Iceland, Azores, Tristan da Cunha).

The second type of earthquake associated with plate tectonics is the shallow-focus event unaccompanied by volcanic activity. The San Andreas fault is a good example of this, so is the Anatolian fault in Northern Turkey. In these faults, two mature plates are scraping by one another. The friction between the plates can be so great that very large strains can build up before they are periodically relieved by large earthquakes. Nevertheless, activity does not always occur along the entire length of the fault during any one earthquake. For instance, the 1906 San Francisco event was caused by breakage only along the northern end of the San Andreas fault.

The third type of earthquake is related to the collision of oceanic and continental plates. One plate is thrust or subducted under the other plate so that a deep ocean trench is produced. In the Philippines, ocean trenches are associated with curved volcanic island arcs on the landward plate, for example the Java trench. Along the Peru - Chile trench, the Nazca plate is being subducted under the South American plate which responds by crumpling to form the Andes. This type of earthquake can be shallow, intermediate, or deep, according to its location on the downgoing lithospheric slab. Such inclined planes of earthquakes are known as Benioff zones.

The fourth type of seismic zone occurs along the boundaries of continental plates. Typical of this is the broad swath of seismicity from Burma to the Mediterranean, crossing the Himalayas, Iran, Turkey, to Gilbraltar. Within this zone, shallow earthquakes are associated with high mountain ranges where intense compression is taking place. Intermediate- and deep-focus earthquakes also occur and are known in the Himalayas and in the Caucasus. The interiors of continental plates are very complex, much more so than island arcs. For instance, we do not yet know the full relationship of the Alps or the East African rift system to the broad picture of plate tectonics.

Effects

- Landslides and damming of the rivers in highland regions.
- Causes depression forming lakes. May cause faults, thrusts, folds, etc
- Formation of cracks or fissures in the epicenter region and sometimes water, mud, gas are ejected from it.
- Causes the raising or lowering of parts of the sea floor e.g. "Sangami bay" in 1923. This causes "tsunamis" or tidal waves.
- May change surface drainage & underground circulation of water like the sudden disappearance of springs in some places.
- Rising and lowering of crustal regions for example in Alaska in 1899-16 m upliftment.
- Devastation of cities, fires, diseases, etc.

Distribution of Earthquakes

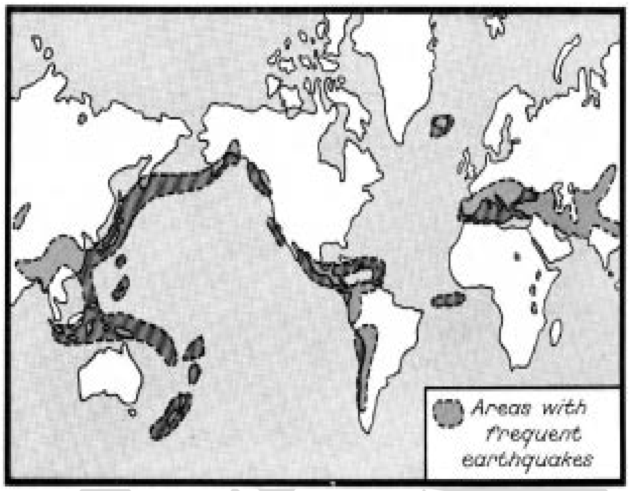
The world maps of the distribution of earthquakes prepared by the seismologists on the basis of computer analysis and simulation of 30,000 earthquakes have identified the three main zones of earthquake.

1. **Circum Pacific Belt or Ring of Fire surrounding the Pacific Ocean.** It is a junction of continental and oceanic margins; it is a zone of young folded mountains; it is a zone of active volcanoes thus this belt accounts for the 65 per cent of the total earthquakes of the world.

2. **Mid-Continental Belt representing Alpine-Himalayan chains of Eurasia and northern Africa and epicenters of east African fault**

zone. This belt represents the collision or subduction zones of continental plates. About 21 per cent of the total seismic events occur in this belt.

3. **Mid-Atlantic Belt representing the earthquakes located along the mid-Atlantic Ridge and its offshoots.** This belt records moderate and shallow focus earthquakes which are essentially caused due to creation of transform faults and fractures because of divergent movement of plates.



VOLCANOES

A volcano is an opening or a vent through which heated materials consisting of gases, water, liquid lava and fragments of rocks are discharged. Magma is molten rock within the Earth's crust. When magma erupts through the earth's surface it is called lava. Lava can be thick and slow-moving or thin and fast-moving. Rock also comes from volcanoes in other forms, including ash (finely powdered rock that looks like dark smoke coming from the volcano), cinders (bits of fragmented lava), and pumice (light-weight rock that is full of air bubbles and is formed in explosive volcanic eruptions - this type of rock can float on water).

Although there are several factors triggering a volcanic eruption, three predominate: the buoyancy of the magma, the pressure from the exsolved gases in the magma and the injection of a new batch of magma into an already filled magma chamber.

As rock inside the earth melts, its mass remains the same while its volume increases--producing a melt that is less dense than the surrounding rock. This lighter magma then rises toward the surface by virtue of its buoyancy. If the density of the magma between the zone of its generation and the surface is less than that of the surrounding and overlying rocks, the magma reaches the surface and erupts.

Magmas of so-called andesitic and rhyolitic compositions also contain dissolved volatiles such as water, sulfur dioxide and carbon dioxide. For example, in an andesitic magma saturated with water and six kilometers below the surface, about 5 percent of its weight is dissolved water. As this magma moves toward the surface, the solubility of the water in the magma decreases, and so the excess water separates from the magma in the form of bubbles. As the magma moves closer to the surface, more and more water exsolves from the magma, thereby increasing the gas / magma ratio in the conduit. When the volume of bubbles reaches about 75 percent, the magma disintegrates to pyroclasts (partially molten and solid fragments) and erupts explosively.

The third process that causes volcanic eruptions is an injection of new magma into a chamber that is already filled with magma of similar or different composition. This injection forces some of the magma in the chamber to move up in the conduit and erupt at the surface.

The nature of this eruption depends mainly on the gas content and the viscosity of the magma material. Viscosity is just the ability to resist flow -- essentially, it is the opposite of fluidity. If the magma has a high viscosity, meaning it resists flow very well, the gas bubbles will have a hard time escaping from the magma, and so will push more material up, causing a bigger eruption. If the magma has a lower viscosity, the gas bubbles will be able to escape from the magma more easily, so the lava won't erupt as violently.

Of course, this is balanced with gas content -- if the magma contains more gas bubbles, it will erupt more violently, and if it contains less gas, it will erupt more calmly. Both factors are determined by the composition of the magma. Generally, viscosity is determined by the proportion of silicon in the magma, because of the metal's reaction to oxygen, an element found in most magmas. Gas content varies depending on what sort of material melted to form the magma.

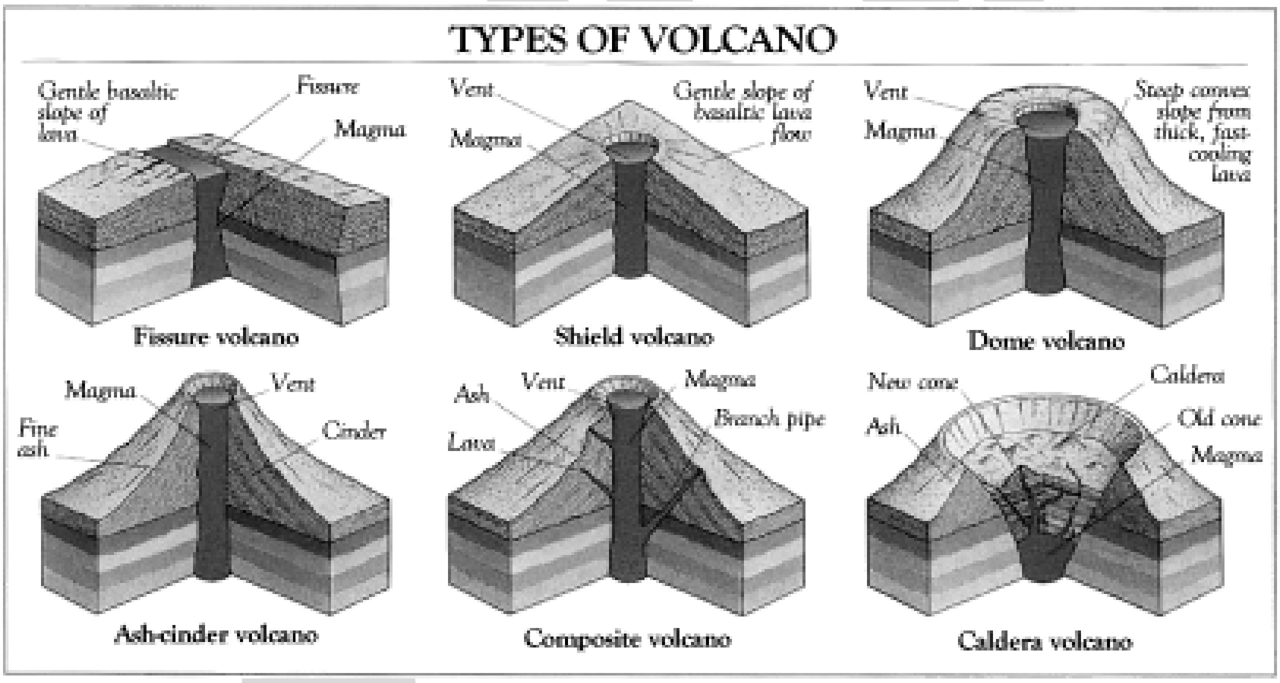
As a general rule, the most explosive eruptions come from magmas that have high gas levels and high viscosity, while the most subdued eruptions come from magmas with low gas levels and low viscosity. Volcanic eruptions don't often fall into easy categories, however. Most eruptions occur in several stages, with varying degrees of destructiveness.

If the viscosity and the gas pressure are low enough, lava will flow slowly onto the earth's surface when the volcano erupts, with minimal explosion.

Although volcanologists are well aware of these three processes, they cannot yet predict a volcanic eruption. But they have made significant advances in forecasting volcanic eruptions. Forecasting involves probable character and time of an eruption in a monitored volcano. The character of an eruption is based on the prehistoric and historic record of the volcano in question and its volcanic products. For example, a violently erupting volcano that has produced ash fall, ash flow and volcanic mudflows (or lahars) is likely to do the same in the future. Determining the timing of an eruption in a monitored volcano depends on measuring a number of parameters, including, but not limited to, seismic activity at the volcano (especially depth and frequency of volcanic earthquakes), ground deformations (determined using a tiltmeter and/or GPS, and satellite interferometry), and gas emissions (sampling the amount of sulfur dioxide gas emitted by correlation spectrometer, or COSPEC).

Types of volcanoes

The most common eruption types are:



The most common type of volcanic eruption occurs when magma (the term for lava when it is below the Earth's surface) is released from a volcanic vent. Eruptions can be effusive, where lava flows like a thick, sticky liquid, or explosive, where fragmented lava explodes out of a vent. In explosive eruptions, the fragmented rock may be accompanied by ash and gases; in effusive eruptions, degassing is common but ash is usually not.

Volcanologists classify eruptions into several different types.

a) Hawaiian Eruption

In a Hawaiian eruption, fluid basaltic lava is thrown into the air in jets from a vent or line of vents (a fissure) at the summit or on the flank of a volcano. The jets can last for hours or even days, a phenomenon known as fire fountaining. The spatter created by bits of hot lava falling out of the fountain can melt together and form lava flows, or build hills called spatter cones. Lava flows may also come from vents at the same time as fountaining occurs, or during periods where fountaining has paused. Because these flows are very fluid, they can travel miles from their source before they cool and harden.

b) Strombolian Eruption

Strombolian eruptions are distinct bursts of fluid lava (usually basalt or basaltic andesite) from the mouth of a magma-filled summit conduit. The explosions usually occur every few minutes at regular or irregular intervals. The explosions of lava, which can reach heights of hundreds of meters, are caused by the bursting of large bubbles of gas, which travel upward in the magma-filled conduit until they reach the open air.

This kind of eruption can create a variety of forms of eruptive products: spatter, or hardened globs of glassy lava; scoria, which are hardened chunks of bubbly lava; lava bombs, or chunks of lava a few cm to a few min size; ash; and small lava flows (which form when hot spatter melts together and flows downslope). Products of an explosive eruption are often collectively called tephra.

Strombolian eruptions are often associated with small lava lakes, which can build up in the conduits of volcanoes. They are one of the least violent of the explosive eruptions, although they can still be very dangerous if bombs or lava flows reach inhabited areas. Strombolian eruptions are named for the volcano that makes up the Italian island of Stromboli, which has several erupting summit vents. These eruptions are particularly spectacular at night, when the lava glows brightly.

c) Vulcanian Eruption

A Vulcanian eruption is a short, violent, relatively small explosion of viscous magma (usually andesite, dacite, or rhyolite). This type of eruption results from the fragmentation and explosion of a plug of lava in a volcanic conduit, or from the rupture of a lava dome (viscous lava that piles up over a vent). Vulcanian eruptions create powerful explosions in which material can travel faster than 350 meters per second (800 mph) and rise several kilometers into the air. They produce tephra, ash clouds, and pyroclastic density currents (clouds of hot ash, gas and rock that flow almost like fluids).

Vulcanian eruptions may be repetitive and go on for days, months, or years, or they may precede even larger explosive eruptions. They are named for the Italian island of Vulcano, where a small volcano that experienced this type of explosive eruption was thought to be the vent above the forge of the Roman smith god Vulcan.

d) Plinian Eruption

The largest and most violent of all the types of volcanic eruptions are Plinian eruptions. They are caused by the fragmentation of gassy magma, and are usually associated with very viscous magmas (dacite and rhyolite). They release enormous amounts of energy and create eruption columns of gas and ash that can rise up to 50 km (35 miles) high at speeds of hundreds of meters per second. Ash from an eruption column can drift or be blown hundreds or thousands of miles away from the volcano. The eruption columns are usually shaped like a mushroom (similar to a nuclear explosion) or an Italian pine tree; Plinian eruptions are extremely destructive, and can even obliterate the entire top of a mountain, as occurred at Mount St. Helens in 1980. They can produce falls of ash, scoria and lava bombs miles from the volcano, and pyroclastic density currents that raze forests, strip soil from bedrock and obliterate anything in their paths. These eruptions are often climactic, and a volcano with a magma chamber emptied by a large Plinian eruption may subsequently enter a period of inactivity.

e) Pelean Eruptions

Pelean eruptions are explosive eruptions resulting from the collapse of a lava dome or spire to produce an incadescent pyroclastic flow (Nuee Ardente). Pelean eruptions are associated with highly viscous acid and intermediate (rhyolite, dacite and andesite) magmas and generally occur after the growth of lava domes and spires, but can also be triggered by landslides. The products of Pelean eruptions are pyroclastic flows which can be block and ash flows or ignimbrites with eutaxitic textures.

f) Lava Domes

Lava domes form when very viscous, rubbly lava (usually andesite, dacite or rhyolite) is squeezed out of a vent without exploding. The lava piles up into a dome, which may grow by inflating from the inside or by squeezing out lobes of lava (something like toothpaste coming out of a tube). These lava lobes can be short and blobby, long and thin, or even form spikes that rise tens of meters into the air before they fall over. Lava domes may be rounded, pancake-shaped, or irregular piles of rock, depending on the type of lava they form from.

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Lava domes are not just passive piles of rock; they can sometimes collapse and form pyroclastic density currents, extrude lava flows, or experience small and large explosive eruptions (which may even destroy the domes!) A dome-building eruption may go on for months or years, but they are usually repetitive (meaning that a volcano will build and destroy several domes before the eruption ceases).

Volcanic Belts of the world

1. The Circum-Pacific belt:

This is the most important belt of volcanoes. This is the also called Ring of Fire. The belt extends through the Andes of South America, Central America, Mexico, the Cascade Mountains of Western United States, the Aleutain Islands, Kamchatka, the Kuril Isles, Japan, the Philippines, Celebes, New Guinea, the Solomon Islands, New Caledonia and New Zealand.

This belt has 80 active volcanoes. The Circum-Pacific belt meets the mid- continental belt in the East Indies. This belt is characterised by high volcanic cones and volcanic mountains. The volcanoes of the Aleutian Island, Hawaii Island and Japan are found in Chains.

Cotapaxi is the highest volcanic mountain (6035m) in the world. Other important volcanoes found in this belt are Fuziyama, Shasta, Rainier and Hood.

In Alaska there is a Valley of Ten Thousand Smokes. It may be pointed out that in this belt volcanic eruptions occur because of the subduction of the Pacific plate below the Asiatic plate.

In Equador, South America, there are about 22 volcanoes out of which 15 are more than 4450 metres above the sea level. Besides, other high volcanic mountains are St. Helens (Washington, U.S.A.), Kilauea (Hawaii Island, U.S.A.), Mt. Taal, Pinatubo and Mayon (Philippines). It may be mentioned that the volcanoes of Hawaii Island are situated in the intra- plate region.

2. The Mid-Continental belt:

This belt has various volcanoes of the Alpine mountain chain, Mediterranea Sea (Stromboli, Vesuvius, Etna etc.), Volcanoes of the Aegean Sea. Mt. Ararat, Elburz and Hindukush are also included in this belt.

It is interesting to note that there are several volcanic free zones found along the Alps and the Himalayas. The Rift Valleys of Africa have volcanoes such as Kilimanjaro, Elgon, Birunga and Rungwe etc.

In the region where the boundaries of Persia, Afghanistan, and Baluchistan meet, there are several volcanic cones of large size, and one or two of them emit steam and other gases. This region has also a few extinct volcanoes.

3. The Mid- Atlantic belt:

As the name indicates, this belt includes the volcanoes of the Mid-Atlantic Ridge. The volcanoes associated with the Atlantic Ocean are located either on swells or ridges rising from the sea floor, or on or near the edge of the continent where it slopes abruptly into the deep oceanic basins. However, in each case, the volcanoes are associated with zones of crystal movement.

The volcanoes formed along the Mid-Atlantic Ridge actually represent the splitting zone of the American plate moving towards west and the Eurasian plate moving towards east.

In the splitting zone stated above there is constant upwelling of magmas. Thus, it is a zone of crustal weakness. Volcanoes in this belt are generally of fissure-eruption type. Volcanoes of Lesser Antilles, Azores, St. Helens etc. are included in this belt.

HOT - SPOT VOLCANOES

About five percent of volcanoes are not near the margins of tectonic plates. They are over especially hot places in the Earth's interior called HOT SPOTS.

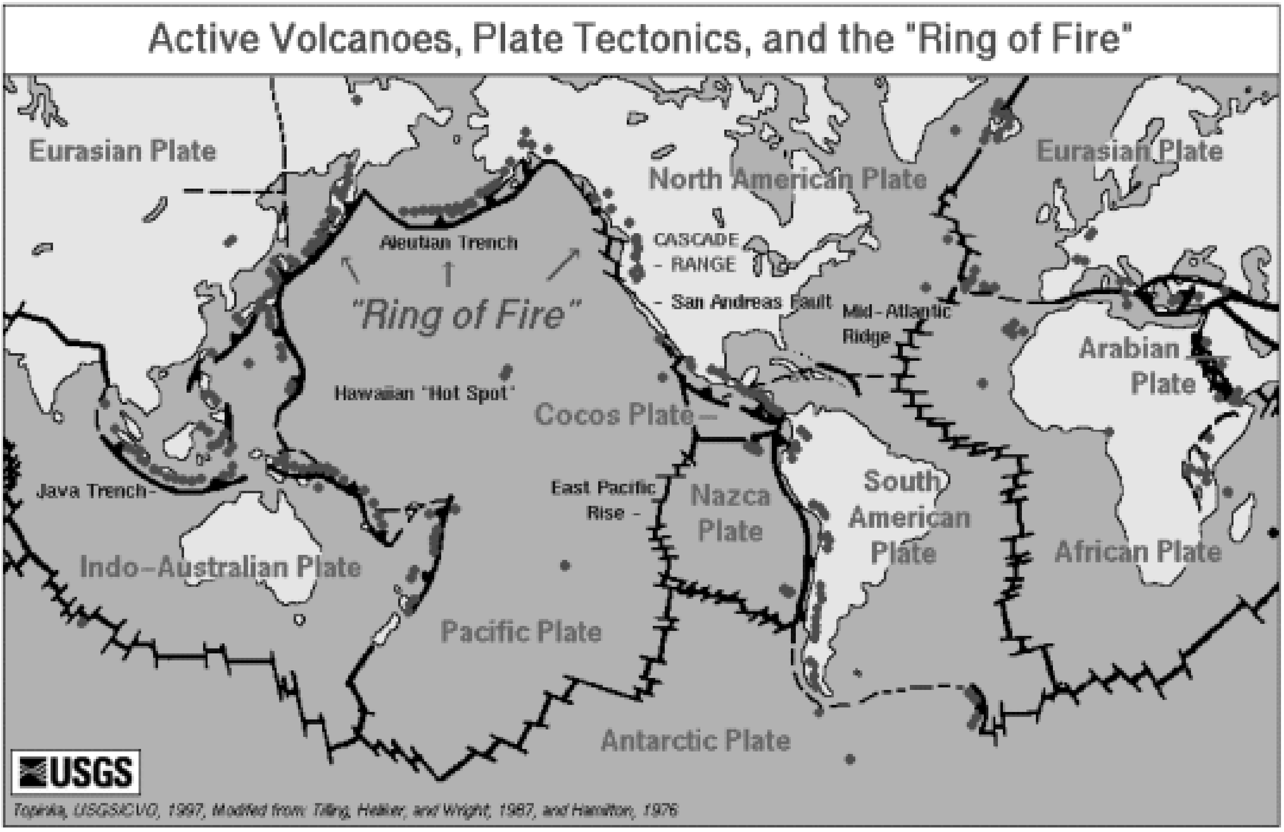
HOT SPOTS are created by mantle plumes - hot currents that rise all the way from the core through the mantle. When mantle plume come up under the crust, they burn their way through to become hot-spot volcanoes.

Famous hot-spot volcanoes include the Hawaiian island volcanoes and Réunion Island in the Indian Ocean.

Hot-spot volcanoes ooze runny lava that spreads out to create shield volcanoes. Lava from hot-spot volcanoes also creates plateaux, such as the Massif Central in France. The geysers, hot springs and bubbling mud pots of Yellowstone National Park, USA, indicate a hot spot below.

Yellowstone has had three huge eruptions in the past 2 million years. The first produced over 2000 times as much lava as the 1980 eruption of Mt St Helens. Hot spots stay in the same place while tectonic plates slide over the top of them. Each time the plate moves, the hot spot creates a new volcano.

The movement of the Pacific plate over the Hawaiian hot spot created a chain of old volcanoes 6000 km long. It starts with THE MEIJI SEAMOUNT under the sea north of Japan, and ends with THE HAWAIIAN ISLANDS.



FLUVIAL CYCLE OF EROSION

Rivers are a sizable stream of freshwater flowing through a natural channel in the land. Rivers are among the most powerful natural forces in shaping the earth's surface. In draining the land of surplus water, rivers wear down mountains, plateaus, and other high landforms. In a never-ending process, eroded material is carried by rivers. Some is deposited to form floodplains in the valleys, some forms deltas at the rivers' mouths, and some is deposited in the sea.

A river passes through development stages in its lifecycle.

Youthful stage

When streams first form channels they tend to have specific topographic features independent of climate zones and other factors. These characteristics include: Steep gradients; No floodplain; Flat divides; Steep valley sides; "V" shapes profiles; Straight course.

The early stages of stream development are closely linked to uplifts of the crust, and therefore tectonic activity. In other words, the early stage of stream development is generated by uplift of the crust, lowering of sea level, or both. This increases the stream gradient so that the primary erosional work of the stream is a downcutting action. This produces the steep valley sides characteristic of an early stage stream valley. Since the stream gradient is high and the stream quickly cuts down into bedrock, there is little opportunity for the stream to meander. Therefore the stream tends to be straight. Because the stream cannot meander, it also cannot erode laterally to produce a floodplain. When observing topographic maps, remember that the contours in the valley of the early stage stream should be closely spaced down to the edge of the stream indicating the steep valley walls and "V" shaped profile. No flat floodplain areas at the base of the stream will be

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present. The map should also display a relatively straight course. Away from the stream valley the divides will be flat; this is indicated by high elevation values but widely spaced contours.

Some characteristics:

- Tributaries are small and the flow is turbulent.
- Bedload dominates making the water clear.
- Downward erosion predominates creating deep, narrow valleys.
- The gradient is steep and many waterfalls and rapids are present.

Mature valley

The mature stage of stream valley development is marked by the development of a floodplain. As an early stage stream continues to downcut vertically over time the stream channel approaches the base level. The base level of a stream is defined as the lowest level to which a stream may erode its channel- usually this is sea level. When the stream channel elevation approaches the base level the stream begins to erode laterally producing a series of meanders. The meanders are confined to the floodplain. The floodplain itself can be recognized as the very flat area adjacent to the stream channel. The floodplain is usually quite swampy and is often marked with the map symbols for swamp or marsh terrain. This area of the floodplain that is swampy is known as the backswamp.

As lateral erosion produces meanders, the meanders progressively become more pronounced. This is produced by the tendency of the stream to flow at a higher velocity on the outside of a meander curve where water is deeper and less subject to frictional drag. This increases erosion of the channel on the outside of the meander. On the other hand, the shallow water depth and corresponding higher drag on the inside of the meander bend produces a lower than normal stream velocity. This causes deposition of sand particles to form a point bar. Point bars are one of the most common types of sand bars found in meandering river systems. As this trend of erosion and deposition occurs the meander bends become more and more extreme until finally adjacent bends may "neck down" to form a cutoff.

When a cutoff actually forms, portions of the former main channel become silted-in isolating the meander bend from the rest of the river. This leaves an isolated lake termed an oxbow because it retains the arcuate shape of the meander bend. Most mature river system floodplains are littered with oxbow lakes. In addition to the oxbow lakes, the adjacent point bar deposits that are deposited on the inside of a migrating meander tends to build numerous arcuate sandy ridges that are parallel. These features are termed meander scars.

Stream systems are continually in a state of flux. During the spring when most areas of the northern hemisphere experience increased precipitation, the stream systems may be at or above flood stage. When the volume of water in a stream surpasses the size of the channel the river spills over its banks into the adjacent floodplain. Before this event, the velocity of the stream is commonly very high, therefore, the stream carries a large sediment load while it is confined to its channel. When the water leaves the channel, however, the velocity of the water drops dramatically. This loss of velocity rapidly decreases the ability of the stream to transport sediment. Directly adjacent to the stream channel the largest particles - usually coarse sand - are deposited first. The smaller clay sized particles settle less rapidly throughout the floodplain. The annual cycle of flooding builds up deposits of sand along the banks of a river to produce a linear ridge termed a levee.

Following key features are formed in mature stage:

(1) Well-developed floodplain

(2) Rounded instead of flat divides

(3) Oxbow lakes

(4) Levees

(5) Backswamp

(6) Meander scars

(7) Cutoffs

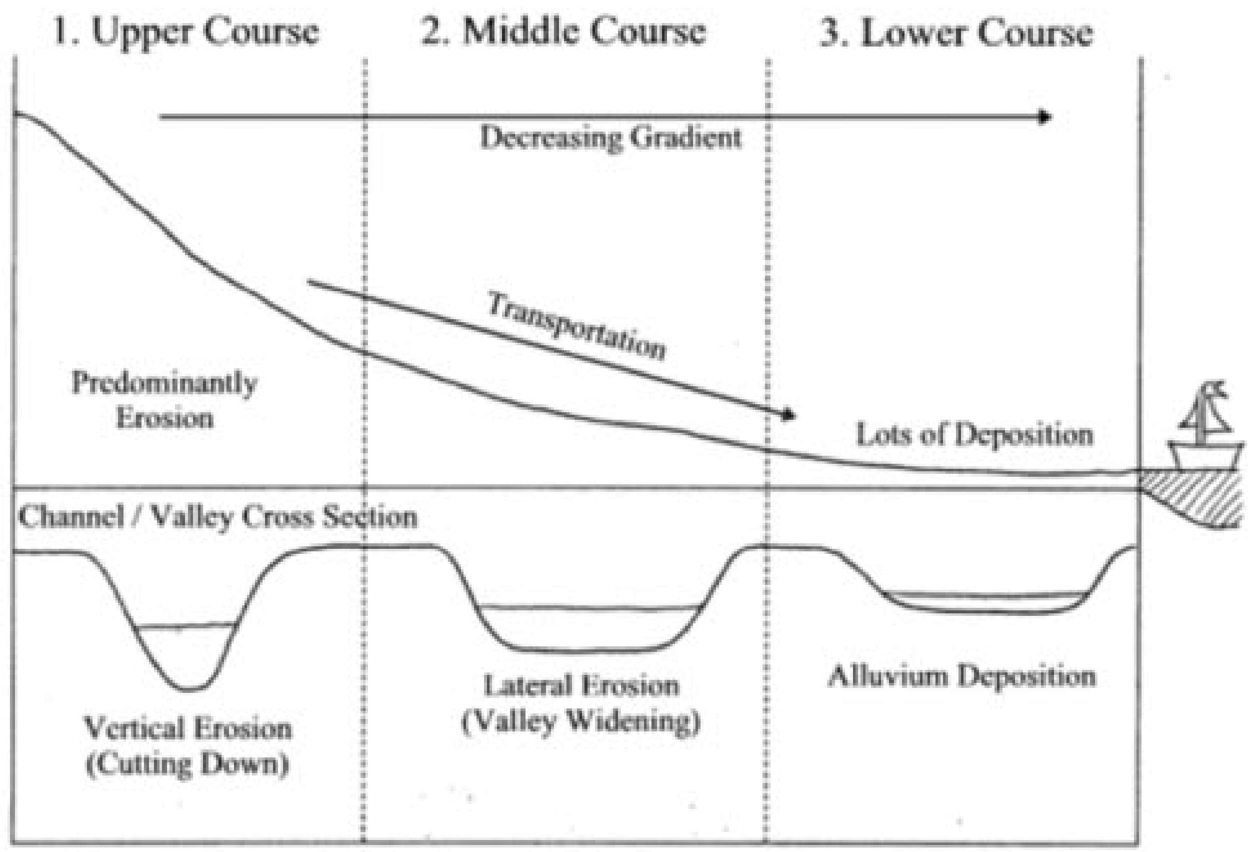
(8) Yazoo tributaries

Old age stage

In this (old) stage, as erosion continues and the flood plains are widened by continued slope retreat, finally reach a point where the slope is so low that no net erosion occurs any more, and erosion on the slopes is balanced by deposition on the floodplains. The hills are further reduced and the floodplains rise by overbank deposition (flooding), until finally end up with a landscape that is reduced to a fairly featureless, flat surface that gently slopes towards the ocean. This surface is also called a peneplain. From now on the rivers just sweep over the floodplain and rework the sediment, creating various floodplain features, such as oxbow lakes, meander scars etc. Isolated remants of resistant bedrock may rise over the peneplain surface, the so called monadnocks or inselbergs.

Some characteristics are:

- gradient is gentle, velocity decreases
- more deposition than erosion
- valley is wide and flat and meanders are numerous
- suspension dominates and laminar flow occurs
- a wide floodplain, levees are present
- deltas occur at the river mouth
- oxbow lakes occur



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