

DEPARTMENT OF REMOTE SENSING

Bharathidasan University

Tiruchirappalli – 620 023

Tamil Nadu, India

**6 Year Integrated M. Tech. Geotechnology and
Geoinformatics**

PAPER CODE: MTIGT0301

**PHYSICAL GEOLOGY AND
GEODYNAMICS**

e-Learning Material

By

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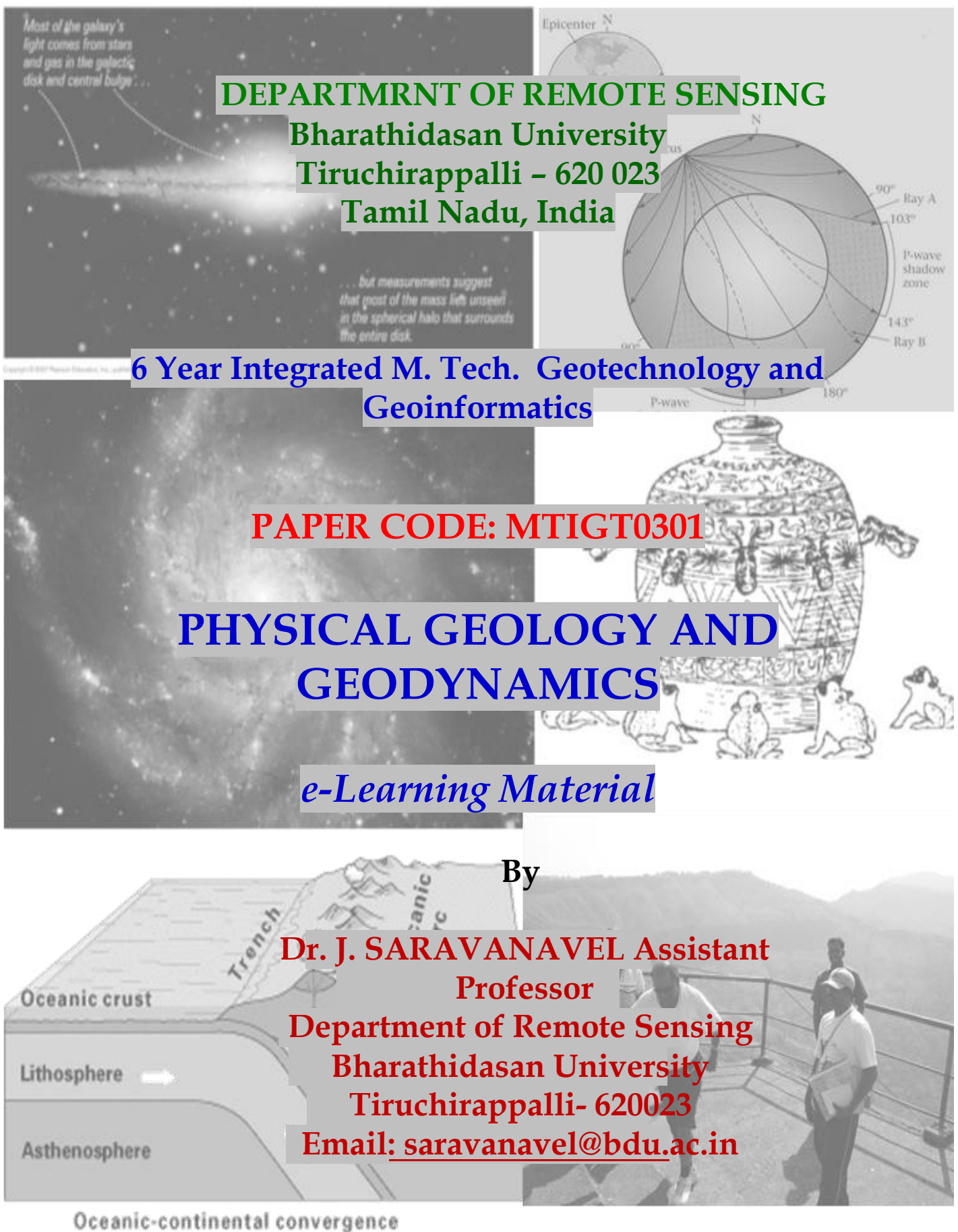
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MTIGT0301: PHYSICAL GEOLOGY AND GEODYNAMICS ----- 3credits

1. **Perspectives of Geology:** Branches of Geology – Epigene and Hypergene Geology- Scientific applications of Geology – Relation of Geology with other Sciences (Physics, Chemistry, Biology and Social Sciences). **6hrs**
2. **Solar System and Earth:** Solar system - Density and Movement of the Earth – Gravitational field of Earth – Origin of the Earth and Age of the Earth (various Hypothesis, concepts and Theories). **6hrs**
3. **Interior of the Earth:** Structure of the Earth Interior (Crust, Mantle and Core) – Earthquakes (Origin and Effects, Earthquake Belts, Epicenter, Seismograph, Magnitude Scale) – Volcanoes (Types and Causes, Types of Eruption, Diapirism) – Tectonic Movements (Isostasy) – Mountain Building Activities. **12hrs**
4. **Earth Surface Processes-I:** River dynamics (Drainage Types and Pattern, Erosion, Transportation, Deposition) – Coastal dynamics (Types of Coasts, Origin of Coasts, Coastal Processes) Seas and Oceans and their Geological Activities (Waves, Currents, Offshore profile, Coastal Erosion – Transportation - Deposition, Marine Deposits, Submarine Canyon)- Interactive dynamics amongst tectonics, Riverine and Oceanographic Processes **12hrs**
5. **Earth Surface Processes-II:** Geological actions of Wind, Sand Dunes, Cycle of Erosion, Transportation and Deposition - Dynamics of Lakes (Origin of lakes, nature and development of lakes, different types of Lakes, lacustrine deposits) –Underground water (Origin, type of Groundwater, Solution Caves and Caverns, Geysers) – Glaciers and their Geological Actions. **12hrs**

Text Books:

1. P.J. Wyllie, The Dynamic Earth, John Wiley and Sons. 1971.
2. J.A. Jacobs, Physics and Geology, R.D. Russel and J.T. Wilson,
3. Duff. P.Mcl.D, Principles of Physical Geology - Holmes, 4th Ed. Chapman and Hall, London. 1992
4. Girija Bhushan Mahapatra, A Text Book of Geology, CBS Publishers & Distributors, 4596/1A, 11 Daryaganj, New Delhi, 1987.
5. Girija Bhushan Mahapatra, Text Book of Physical Geology, CBS Publishers & Distributors, 4596/1A, 11 Daryaganj, New Delhi, 1994

References:

1. International Series in the Earth Sciences, Mc Graw Hill Book Co., 1959.
2. B.F. Windley, The Evolving Continents, John Wiley & Sons, 1978.
3. Allen Cox, Plate Tectonics, Freeman and Company, 1973.
4. Porters and Skinner - Principles of Geology, Printice Hall,
5. Marie Morisawa, Rivers Forms and Process, Geomorphology Texts, Longman Group Limited, 1985.
6. Jauhari V.P., Sustaining River Linking, A Mittal Publications, A-110, Mohan Garden, New Delhi, 2005.
7. Carter R.W.G, Coastal Environments, An Introduction to the Physical, Ecological and Cultural Systems of Coaslines, Academic Press Limited, 1988.
8. Lecture Notes - Remote Sensing Applications in Coastal Geomorphology and Coastal zone Resources, January 3-30, 1991, Sponsored by University Grants Commission, 1991.
9. David H.K. Amiran and Andrew W. Wilson, Coastal Deserts - Their Natural and Human Environments, The University of Arizona Press, Tucson, Arizona, 1973.
10. Ramachandra T.V., Rajasekara Murthy C., and Ahalya N. Restoration of Lakes and Wetlands, Allied Publishers (P) Limited, 751, Anna Salai, Chennai, 2002.

UNIT-1: Perspectives of Geology: Branches of Geology – Epigene and Hypergene Geology- Scientific applications of Geology – Relation of Geology with other Sciences (Physics, Chemistry, Biology and Social Sciences).

PERSPECTIVES OF GEOLOGY

Geology is a science: Greek "geo" = **EARTH**, "logos" = **SCIENCE**. So geology is the science of the Earth

Basic Sciences

The sciences that set the general principles for all the other sciences

- Mathematics
- Physics
- Chemistry

Megasystem Sciences

The sciences that describe the great systems that make up the Universe

- Astronomy - Stars and Galaxies
- Geology - Planets
- Biology - Life

Specialty Sciences

Sciences that examine some smaller, more manageable part of the Basic or Megasystem Sciences

- Zoology
- Botany
- Meteorology
- Mineralogy
-etc.

Amongst all, the Geoscience is a

- ➔ **Resourceful science**
(metals, minerals, oil, water etc.)
- ➔ **Wonderful science**
(Hill, Plain, Riverine, Coastal, Aeolian and other processes & eco systems)
- ➔ **Predictive & Protective science**
(as deals with all natural disasters including predictions ? and mitigation strategies)

GEOLOGY: (From Creek GEO – EARTH, LOGOS – SCIENCE)

The sciences that deal with one or more aspects of the Earth are grouped together as Earth Sciences.

- ➔ **Geology is the science that deals the study of the earth as whole**
- ➔ **Geology is the science that deals with the origin, age and structure of the Earth**
- ➔ **Geology is the science that deals with the evolution, modification and extinction of surface and subsurface features like mountains, plateaus, plains, valleys, basins and coastal and marine and submarine forms.**
- ➔ **Geology also deals with the material made of the Earth, nature of the surrounding gaseous envelope that is Atmosphere and vast expansion of water and frozen water i.e. Hydrosphere**
- ➔ **The interaction of the atmosphere, lithosphere and hydrosphere, the processes and the results caused due to such an interactions are all deals with Geology**
- ➔ **Geology also deals with physical, dynamic and physico-chemical processes operating on and within the earth and agents and forces involved and evolved in such processes**

- ➔ The greatest emphasis in geology is on the study of material exist today and the processes which operate today to establish a record of the past events in the history of the Earth.
- ➔ In Geology, present is the basic key to the past
- ➔ Understanding geology and geosciences is important and relevant in solving problems that are associated with development and human habitation
- ➔ Knowledge of geology is applied through developing natural resources, evaluating engineering structures and foundations, and determining the effects of human activity and natural hazards on environmental quality.

The Geology may be one of the most practical subjects. The geologic phenomena and issues affect our daily lives some time in unexpected way

- ➔ The geohazrds like earthquakes, landslides, volcanoes, floods that destroy property and take lives
- ➔ Oil, coal and Uranium are energy resources whose distribution is controlled by geologic processes
- ➔ Metals comes from geologic material – Ore deposit found by geologist
- ➔ The surface and groundwater are controlled by the geological processes

SUBDIVISION OF GEOLOGY

From the above, it is evident that the subject is very vast. The following are the important and well established branches of Geology

PHYSICAL GEOLOGY

- Physical Geology deals with the origin, development and ultimate fate of various surface features of the Earth and also with its structure
- Physical Geology deals with origin and Evolution of continents and oceans
- Isostasy, Plate tectonics, mountain building activities, sea floor spreading
- The role played by internal agents (Volcanism and Earthquakes) and External agents (Wind, water, ice, and atmosphere) on the physical features of the earth makes a major part of study in physical geology
- River dynamics, coastal dynamics, seas and oceans and their Geological activities
- Interactive dynamics amongst tectonics, Riverine and oceanographical processes

GEOMORPHOLOGY

- Geomorphology (from Greek: *geo* - "earth", *morp* - "form" and *logos* - "knowledge") is the scientific study of landforms and the processes that shape them.
- This branch confines itself to the study of the features of the surface of the earth primarily of the land surface
- Geomorphologists understand the landform history and dynamics and predict future changes through a combination of field observation, physical experiment and numerical modeling.
- Geomorphology is practiced within geology, engineering geology, geodesy, geography, archaeology, geological engineering and pedology,

- Primary surface processes responsible for most topographic features include wind, waves, weathering, mass wasting, ground water, surface water, glaciers, tectonism, and volcanism.
- Landforms evolve in response to a combination of natural and anthropogenic processes. The landscape is built up through tectonic uplift and volcanism. Denudation occurs by erosion and mass wasting, which produces sediment that is transported and deposited elsewhere within the landscape or off the coast. Landscapes are also lowered by subsidence, either due to tectonics or physical changes in underlying sedimentary deposits

MINERALOGY

- ➔ Mineralogy is focused around the chemistry, crystal structure, and physical (including optical) properties of minerals. Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.
- ➔ Physical mineralology : Physical mineralogy is the specific focus on physical attributes of minerals. Description of physical attributes is the simplest way to identify, classify, and categorize minerals, and they include
- ➔ Chemical mineralogy: Chemical mineralogy focuses on the chemical composition of minerals in order to identify, classify, and categorize them, as well as a means to find beneficial uses from them.
- ➔ Biomineralogy: Biomineralogy is a cross-over field between mineralogy, paleontology and biology. It is the study of how plants and animals stabilize minerals under biological control.
- ➔ Optical mineralogy: Optical mineralogy is a specific focus of mineralogy that applies sources of light as a means to identify and classify minerals.
- ➔ Crystal structure: X-rays are used to determine the atomic arrangements of minerals and so to identify and classify them. The arrangements of atoms define the crystal structures of the minerals

PETROLOGY:

Petrology (from Greek: *petra*- rock; and *logos* - knowledge) is the branch of geology that studies rocks, and the conditions in which rocks form. Lithology once was approximately synonymous with petrography, but in current usage, lithology is a subdivision of petrology focusing on macroscopic hand-sample or outcrop-scale description of rocks, while petrography is the speciality that deals with microscopic details.

There are three branches of petrology, corresponding to the three types of rocks: igneous, metamorphic, and sedimentary, and another dealing with experimental techniques:

- Igneous petrology focuses on the composition and texture of igneous rocks (rocks such as granite or basalt which have crystallized from molten rock or magma). Igneous rocks include volcanic and plutonic rocks.
- Sedimentary petrology focuses on the composition and texture of sedimentary rocks (rocks such as sandstone, shale, or limestone which consist of pieces or particles derived from other rocks or biological or chemical deposits, and are usually bound together in a matrix of finer material).
- Metamorphic petrology focuses on the composition and texture of metamorphic rocks (rocks such as slate, marble, gneiss, or schist which started out as sedimentary or igneous rocks but which have undergone chemical, mineralogical or textural changes due to extremes of pressure, temperature or both)
- Experimental petrology employs high-pressure, high-temperature apparatus to investigate the geochemistry and phase relations of natural or synthetic materials at elevated pressures and temperatures

HISTORICAL GEOLOGY

- ➔ Historical geology is the use of the principles of geology to reconstruct and understand the history of the Earth.
- ➔ It focuses on geologic processes that change the Earth's surface and subsurface; and the use of stratigraphy, structural geology and paleontology to tell the sequence of these events.
- ➔ It also focuses on the evolution of plants and animals during different time periods in the geological timescale.
- ➔ The discovery of radioactivity and the development of a variety of radiometric dating techniques in the first half of the 20th century provided a means of deriving absolute versus relative ages of geologic history.

PALAEONTOLOGY

- ➔ Paleontology lies on the boundary between biology and geology since paleontology focuses on the record of past life in fossils, its main source of evidence, which are found in rocks.
- ➔ For historical reasons paleontology is part of the geology departments of many universities, because in the 19th and early 20th centuries geology departments found paleontological evidence important for estimating the ages of rocks while biology departments showed little interest
- ➔ In addition paleontology often uses techniques derived from other sciences, including biology, ecology, chemistry, physics and mathematics.
- ➔ For example geochemical signatures from rocks may help to discover when life first arose on Earth and analyses of carbon isotope ratios may help to identify climate changes and even to explain major transitions such as the Permian–Triassic extinction event.
- ➔ A relatively recent discipline, molecular phylogenetics, often helps by using comparisons of different modern organisms' DNA and RNA to re-construct evolutionary "family trees"

- ➔ Techniques developed in engineering have been used to analyse how ancient organisms might have worked, for example how fast *Tyrannosaurus* could move and how powerful its bite was.
- ➔ Paleontology even contributes to astrobiology, the investigation of possible life on other planets, by developing models of how life may have arisen and by providing techniques for detecting evidence of life.
- ➔ As knowledge has increased, paleontology has developed specialized subdivisions.
- ➔ Vertebrate paleontology concentrates on fossils of vertebrates, from the earliest fish to the immediate ancestors of modern mammals.
- ➔ Invertebrate paleontology deals with fossils of invertebrates such as molluscs, arthropods, annelid worms and echinoderms.
- ➔ Paleobotany focuses on the study of fossil plants, but traditionally includes the study of fossil algae and fungi.
- ➔ Palynology, the study of pollen and spores produced by land plants
- ➔ Micropaleontology deals with all microscopic fossil organisms

STRATIGRAPHY

- ➔ Stratigraphy, a branch of geology, studies rock layers and layering (stratification).
- ➔ It is primarily used in the study of sedimentary and layered volcanic rocks.
- ➔ Stratigraphy includes two related subfields: lithologic or lithostratigraphy and biologic stratigraphy or biostratigraphy
- ➔ The theoretical basis for the subject was established by Nicholas Steno who re-introduced the law of superposition and introduced the principle of original horizontality and principle of lateral continuity in a 1669 work on the fossilization of organic remains in layers of sediment.
- ➔ The first practical large scale application of stratigraphy was by William Smith in the 1790s and early 1800s. Smith, known as the

Father of English Geology, created the first geologic map of England, and first recognized the significance of strata or rock layering, and the importance of fossil markers for correlating strata.

- ➔ **Lithostratigraphy**, or lithologic stratigraphy, is the most obvious. It deals with the physical lithologic, or rock type, change both vertically in layering or bedding of varying rock type and laterally reflecting changing environments of deposition, known as facies change
- ➔ ***Chemostratigraphy*** is based on the changes in the relative proportions of trace elements and isotopes within and between lithologic units.
- ➔ Carbon and oxygen isotope ratios vary with time and are used to map subtle changes in the paleoenvironment. This has led to the specialized field of *isotopic stratigraphy*.
- ➔ ***Cyclostratigraphy*** documents the often cyclic changes in the relative proportions of minerals, particularly carbonates, and fossil diversity with time, related to changes in palaeoclimates.
- ➔ **Biostratigraphy** or paleontologic stratigraphy is based on fossil evidence in the rock layers. Strata from widespread locations containing the same fossil fauna and flora are correlatable in time.
- ➔ Stratigraphy is also commonly used to delineate the nature and extent of hydrocarbon-bearing reservoir rocks, seals and traps in petroleum geology.
- ➔ **Magnetostratigraphy** is a chronostratigraphic technique used to date sedimentary and volcanic sequences. The method works by collecting oriented samples at measured intervals throughout the section. The samples are analyzed to determine their Detrital Remnant Magnetization (DRM), that is, the polarity of Earth's magnetic field at the time a stratum was deposited.

STRUCTURAL GEOLOGY

- ➔ **Structural geology is the study of the three-dimensional distribution of rock units with respect to their deformational histories.**
- ➔ **The primary goal of structural geology is to use measurements of present-day rock geometries to uncover information about the history of deformation (strain) in the rocks, and ultimately, to understand the stress field that resulted in the observed strain and geometries.**
- ➔ **This understanding of the dynamics of the stress field can be linked to important events in the regional geologic past**
- ➔ **A common goal is to understand the structural evolution of a particular area with respect to regionally widespread patterns of rock deformation (e.g., mountain building, rifting) due to plate tectonics.**
- ➔ **The study of geologic structures has been of prime importance in economic geology, both petroleum geology and mining geology.**
- ➔ **Folded and faulted rock strata commonly form traps for the accumulation and concentration of petroleum and natural gas.**
- ➔ **Faulted and structurally complex areas are concentration areas for base and precious metal ore deposits**
- ➔ **Structural geology is a critical part of engineering geology, which is concerned with the physical and mechanical properties of natural rocks.**
- ➔ **Structural fabrics and defects such as faults, folds, foliations and joints are internal weaknesses of rocks which may affect the stability of human engineered structures such as dams, road cuts, open pit mines and underground mines or road tunnels.**
- ➔ **Geotechnical risk, including earthquake risk can only be investigated by inspecting a combination of structural geology and geomorphology.**
- ➔ **Environmental geologists and hydrogeologists or hydrologists need to understand structural geology because structures are sites of groundwater flow and penetration, seepage of toxic**

substances from waste dumps, seepage of salty water into aquifers.

- ➔ Plate tectonics is structural geology on a large scale, usually referring to the structural effects of plate collisions and other plate tectonic features.

ECONOMIC GEOLOGY

- ➔ Economic geology is concerned with earth materials that can be used for economic and/or industrial purposes. These materials include precious and base metals, nonmetallic minerals, construction-grade stone, petroleum minerals, coal, and water.
- ➔ The term commonly refers to metallic mineral deposits and mineral resources.
- ➔ The techniques employed by other earth science disciplines (such as geochemistry, mineralogy, geophysics, and structural geology) might all be used to understand, describe, and exploit an ore deposit.
- ➔ Economic geology is studied and practiced by geologists; however it is of prime interest to investment bankers, stock analysts and other professions such as engineers, environmental scientists and conservationists because of the far-reaching impact which extractive industries have upon society, the economy and the environment.
- ➔ Ore geology: Geologists are involved in the study of ore deposits, which includes the study of ore genesis and the processes within the Earth's crust which form and concentrate ore minerals into economically viable quantities.

- ➔ Study of metallic ore deposits involves the use of structural geology, geochemistry, the study of metamorphism and its processes, as well as understanding metasomatism and other processes related to ore genesis.
- ➔ Ore deposits are delineated by mineral exploration, which uses geochemical prospecting, drilling and resource estimation via geostatistics to quantify economic ore bodies. The ultimate aim of this process is mining.
- ➔ Coal and petroleum geology: The study of sedimentology, structural geology, stratigraphy, palaeontology is of prime importance to the delineation of economic reserves of petroleum and coal energy resources.
- ➔ Mining Geology is the extraction of valuable minerals or other geological materials from the earth, usually from an ore body, vein or (coal) seam. Materials recovered by mining include base metals, precious metals, iron, uranium, coal, diamonds, limestone, oil shale, rock salt and potash.

RELATION OF GEOLOGY TO OTHER SCIENCES

- ➔ In addition to the above major branches of Geology, there are a few other comparatively new branches of science that have geology as very important component. These may be called as sciences allied to Geology
- ➔ For example: Geo-Physics, Geo-Chemistry, Geo-Hydrology, Engineering Geology, Mining Geology, Rock-Mechanics, Metrology, Oceanography, etc.

GEOPHYSICS

- ➔ The science of Geophysics applies the principles of physics to the study of the Earth
- ➔ The term Geophysics meaning the physics of the Earth or study the physical properties of the Earth.
- ➔ Gilbert's discovery that the earth behaves as a great and irregular magnet and Newton's theory of gravitation may be said to be the beginning of geophysics.

- ➔ The branches of geophysics devoted to the Mineral Exploration by appropriate use of physical properties of the minerals in the earth are termed as Applied Geophysics / Exploration Geophysics / Geophysical Prospecting.
- ➔ Depending upon the various physical properties, the geophysical prospecting may be classified as follows Electrical Methods, Magnetic Methods, Electromagnetic, Gravity Methods, Seismic Methods, Radioactive Methods, Well log Methods, Miscellaneous chemical, thermal and other methods.
- ➔ There are large variations or contrasts in the physical properties of different rocks & minerals. It measures the fields of forces
- ➔ which are either naturally present or artificially introduced into the ground. It is the anomalies noticed in each properties is very significant (Electrical, Magnetic, Gravity, Seismic and radioactive properties)

GEOCHEMISTRY

- ➔ The field of geochemistry involves study of the chemical composition of the Earth and other planets, chemical processes and reactions that govern the composition of rocks and soils, and the cycles of matter and energy that transport the Earth's chemical components in time and space, and their interaction with the hydrosphere and the atmosphere.

The most important fields of geochemistry are:

1. Isotope geochemistry: Determination of the relative and absolute concentrations of the elements and their isotopes in the earth and on earth's surface.
2. Examination of the distribution and movements of elements in different parts of the earth (crust, mantle, hydrosphere etc.)
3. Cosmochemistry: Analysis of the distribution of elements and their isotopes in the cosmos.

4. **Biogeochemistry:** Field of study focusing on the effect of life on the chemistry of the earth.
 5. **Organic geochemistry:** A study of the role of processes and compounds that are derived from living or once-living organisms.
 6. **Regional, environmental and exploration geochemistry:** Applications to environmental, hydrological and mineral exploration studies.
- ➔ Victor Goldschmidt is considered by most to be the father of modern geochemistry and the ideas of the subject were formed by him in a series of publications from 1922 under the title 'Geochemische Verteilungsgesetze der Elemente'.

HYDROGEOLOGY

- ➔ Hydrogeology (*hydro-* meaning water, and *-geology* meaning the study of the Earth) is the area of geology that deals with the distribution and movement of groundwater in the soil and rocks of the Earth's crust, (commonly in aquifers).
- ➔ The term geohydrology is often used interchangeably. Some make the minor distinction between a hydrologist or engineer applying themselves to geology (geohydrology), and a geologist applying themselves to hydrology (hydrogeology).

ENGINEERING GEOLOGY

- ➔ It is an applied science developed due to interaction between the civil engineering practice and geological sciences.
- ➔ Engineering geologists investigate and provide geologic and geotechnical recommendations, analysis, and design associated with human development.
- ➔ The realm of the engineering geologist is essentially in the area of earth-structure interactions, or investigation of how the earth or earth processes impact human made structures and human activities.

- One of the most important roles of the engineering geologist is the interpretation of landforms and earth processes to identify potential geologic and related man-made hazards that may impact civil structures and human development

Engineering geologic studies may be performed:

- ❖ for residential, commercial and industrial developments
 - ❖ for governmental and military installations
 - ❖ for public works such as a power plant, wind turbine, transmission line, sewage treatment plant, water treatment plant, pipeline (aqueduct, sewer, outfall), tunnel, trenchless construction, canal, dam, reservoir, building, railroad, transit, highway, bridge, seismic retrofit, airport and park
 - ❖ for mine and quarry excavations, mine tailing dam, mine reclamation and mine tunneling
 - ❖ for wetland and habitat restoration programs
 - ❖ for coastal engineering, sand replenishment, bluff or sea cliff stability, harbor, pier and waterfront development;
 - ❖ for offshore structures, drilling platform and sub-sea pipeline, sub-sea cable; and
 - ❖ for other types of facilities.
- **Soil Mechanics**: Soil mechanics is a discipline that applies principles of engineering mechanics, e.g. kinematics, dynamics, fluid mechanics, and mechanics of material, to predict the mechanical behavior of soils.
- **Rock mechanics** is the theoretical and applied science of the mechanical behaviour of rock and rock masses; it is that branch of mechanics concerned with the response of rock and rock masses to the force fields of their physical environment.
- Together, soil and rock mechanics are the basis for solving many engineering geologic problems.

ENVIRONMENTAL GEOLOGY

Environmental geology, like hydrogeology, is a multidisciplinary field of applied science and is closely related to engineering geology and somewhat related to environmental science.

They all involve the study of the interaction of humans with the geologic environment including the biosphere, the lithosphere, the hydrosphere, and to some extent the atmosphere.

It includes:

managing geological and hydrogeological resources such as fossil fuels, minerals, water (surface and ground water), and land use.

- defining and mitigating exposure of natural hazards on humans
- managing industrial and domestic waste disposal and minimizing or eliminating effects of pollution, and
- performing associated activities, often involving litigation.

METEOROLOGY

- ➔ Meteorology (from Greek - "high in the sky"; *-logia*) is the interdisciplinary scientific study of the atmosphere that focuses on weather processes and forecasting (in contrast with climatology).
- ➔ The study of atmosphere in all aspects (Physical, Chemical and biological falls in the domain of Meteorology
- ➔ After the greatest development in space research, Meteorology has become a important science
- ➔ *Aviation meteorology*: Aviation meteorology deals with the impact of weather on air traffic management. It is important for air crews to understand the implications of weather on their flight plan as well as their aircraft, as noted by the Aeronautical Information Manual
- ➔ *Agricultural meteorology*: Meteorologists, soil scientists, agricultural hydrologists, and agronomists are persons concerned with studying the effects of weather and climate on plant distribution, crop yield, water-use efficiency, phenology of

plant and animal development, and the energy balance of managed and natural ecosystems.

- ➔ ***Hydrometeorology:*** is the branch of meteorology that deals with the hydrologic cycle, the water budget, and the rainfall statistics of storms. A hydrometeorologist prepares and issues forecasts of accumulating (quantitative) precipitation, heavy rain, heavy snow, and highlights areas with the potential for flash flooding. Typically the range of knowledge that is required overlaps with climatology, mesoscale and synoptic meteorology, and other geosciences
- ➔ ***Nuclear meteorology:*** Nuclear meteorology investigates the distribution of radioactive aerosols and gases in the atmosphere
- ➔ ***Maritime Meteorology:*** Maritime Meteorology deals with air and wave forecasts for ships operating at sea. Organizations such as the Ocean Prediction Center, Honolulu National Weather Service forecast office, United Kingdom Met Office, and JMA prepare high seas forecasts for the world's oceans.

MARINE GEOLOGY AND OCEANOGRAPHY

- ➔ ***Marine geology:*** involves geophysical, geochemical, sedimentological and paleontological investigations of the ocean floor and coastal margins.
- ➔ Marine geology has strong ties to physical oceanography and plate tectonics.
- ➔ Marine geological studies were of extreme importance in providing the critical evidence for sea floor spreading and plate tectonics.
- ➔ The deep ocean floor is the last essentially unexplored frontier and detailed mapping in support of both military (submarine) objectives and economic (petroleum and metal mining) objectives drives the research.
- ➔ The study of littoral and deep sea sedimentation and the precipitation and dissolution rates of calcium carbonate in various marine environments has important implications for global climate change.

Oceanography: also called oceanology or marine science, is the branch of Earth science that studies the ocean. It covers a wide range of topics, including marine organisms and ecosystem dynamics; ocean currents, waves, and geophysical fluid dynamics; plate tectonics and the geology of the sea floor; and fluxes of various chemical substances and physical properties within the ocean and across its boundaries.

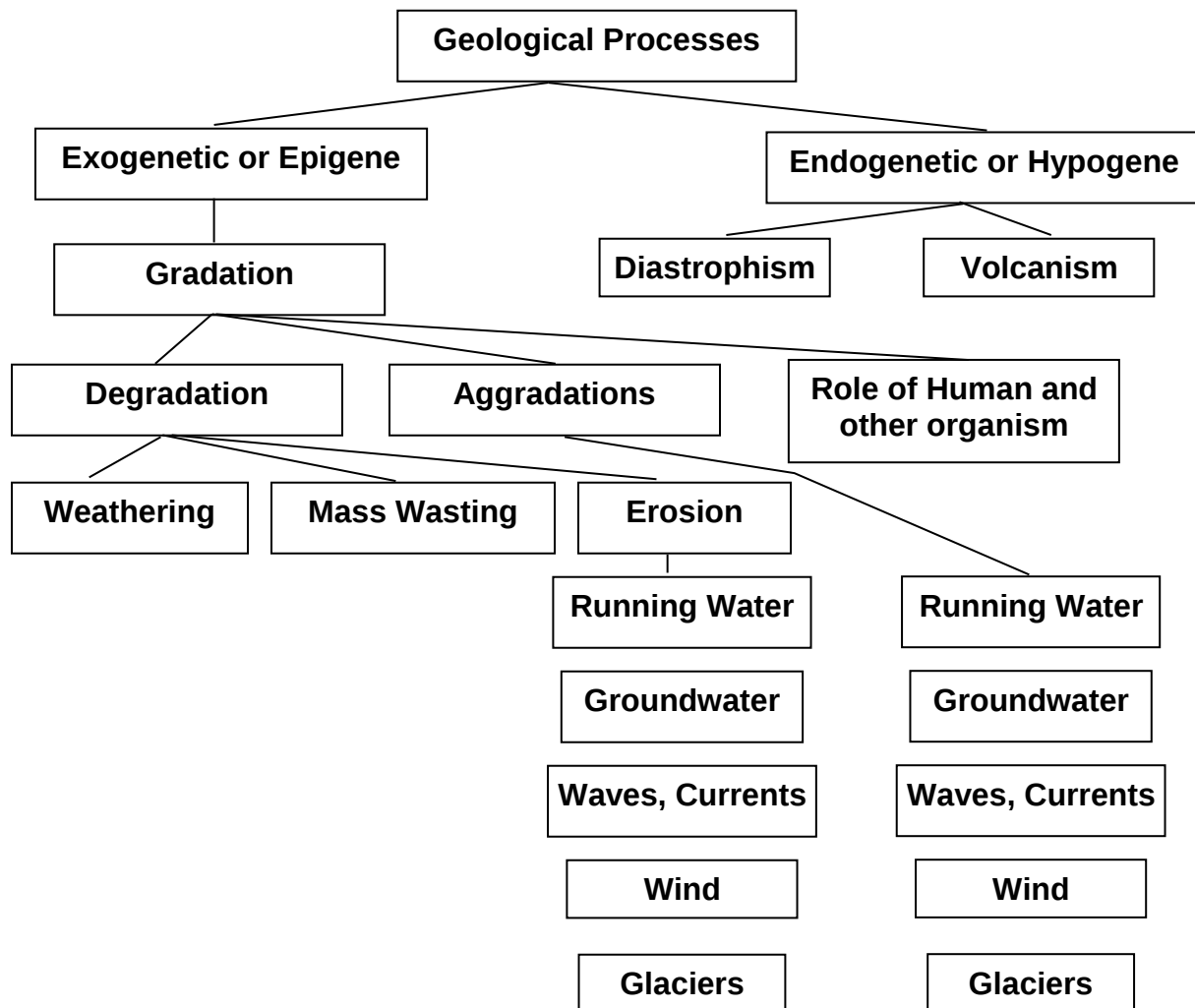
The study of oceanography is divided into a number of branches:

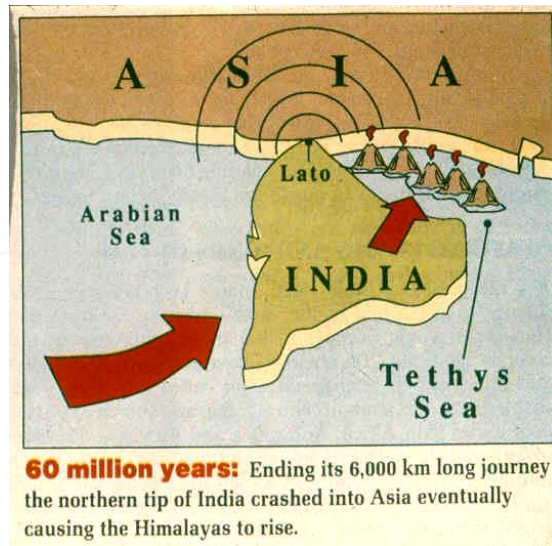
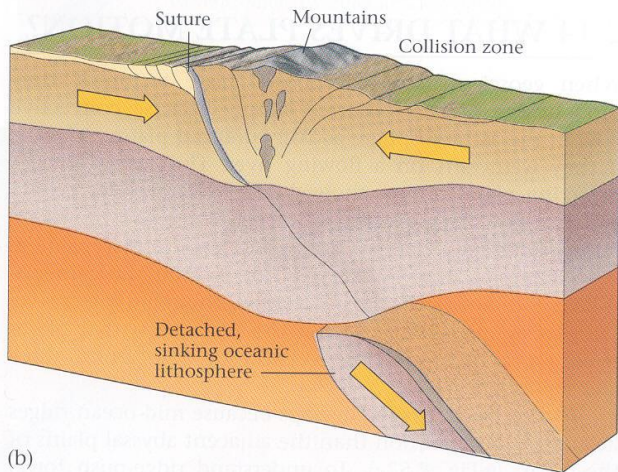
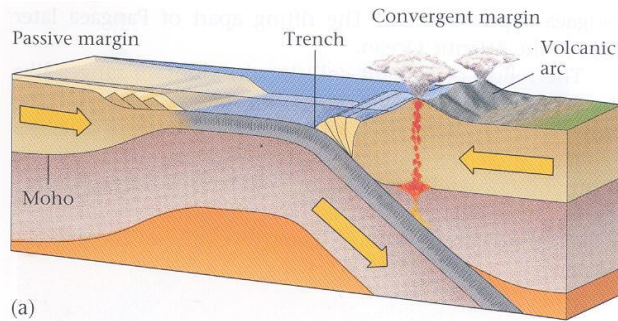
- Biological oceanography, or marine biology, is the study of the plants, animals and microbes (biota) of the oceans and their ecological interaction;
- Chemical oceanography, or marine chemistry, is the study of the chemistry of the ocean and its chemical interaction with the atmosphere;
- Geological oceanography, or marine geology, is the study of the geology of the ocean floor including plate tectonics;
- Physical oceanography, or marine physics, studies the ocean's physical attributes including temperature-salinity structure, mixing, waves, internal waves, tides and currents. Of particular interest is the behavior of sound (acoustical oceanography), light (optical oceanography) and radio waves in the ocean.

Data derived from the work of Oceanographers is used in Maritime Engineering, in the design and building of oil platforms, ships, harbours, and other structures that allow us to use the ocean safely.

Epigene and Hypogene Geology, Earth External and Internal Processes

- Depending upon their individual nature and mode of operation, the natural agencies may be classified broadly into two categories
- Earthmovements, earthquakes and volcanic necessarily have their origin underneath the surface of the earth. Therefore, they may be classified as endogenous or hypogene processes
- That is the geological processes originating and operating within the earth are called endogenous or hypogene processes
- The blowing wind, running and underground water, waves and currents of water bodies (Lakes, sea, oceans), glaciers, blowing sand, etc. are originating and operating on the surface of the earth are called as the exogenous or epigene processes.





- **Endogenous or hypogene processes** are generally develop the irregularities upon the earth surface. For example:- accumulation of lava due to volcanic eruption causes the formation of volcanic mountain or plateau in vast plain surface and the severe earthquakes create the lot of irregularities in the surface of the earth
- **Endogenic processes** expansion of oceanic crust and continual drifting of continental crust
- **Diastrophism:** *is a general term for all crustal movements produced by endogenic Earth forces that produce ocean basins, continents, plateaus and mountains*
- **Diastrophism:** involves orogenic processes marked by the deformation of the Earth's crust and epiorogenic processes which result in regional uplift and subsidence of the crust without large scale deformation
- **Orogenesis**, or mountain building, tends to be a localized process that distorts pre-existing strata

- **Volcanism**: There are nearly 60,000 volcanoes on the earth and about 50,000 occur as seamounts in the Pacific Ocean floor. Accordingly, it is obvious that the volcanoes have an important role in modifying the Earth's surface

Columbia Plateau basalts



The Anatomy



- Upwelling of magma through the vent and fissure type volcanoes naturally modifies the topography
- Extensive flow of magma creates the vast plateaus like Deccan plateau in western India
- The crustal rocks may also be deformed by the intrusion of magma producing domal structures
- The **exogenous or epigene processes** always tend to reduce the surface of the earth to a continuous and gradual slope without any irregularities
- The process of development of a continuous and gradual slope of the land-mass may be defined as the **gradation**
- The mechanism of reducing the altitude of a highland due to its wear and tear processes may be described as the **degradation**
- The materials or sediments result from the degradation are deposited in the low-lying lands like river, lake basins, surface depression are called **aggradation**
- The aggradations and degradation occur simultaneously upon the earth surface to reduce the same to continuous and gradual slope

The natural processes which are play in grading the surface of the globe in four different stages as follows

1. Mechanical breaking down of the rock masses

2. Decomposition of the rock due to chemical reactions
3. Transportation of broken rock debris, sand, silt, etc.
4. Deposition of the transported materials under favourable condition

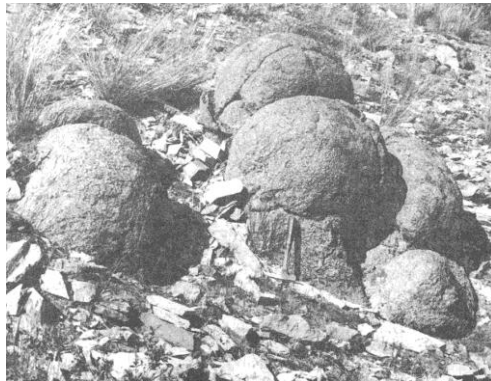
Weathering: Weathering which is responsible for disintegration and decomposition of rocks. Through various processes reduce the great mountains into fine particles (sand, clay)

The factors which influence the weathering are structure of the rock, the topography, vegetation of the terrain, climate, etc.

Weathering may be classified into Physical and Chemical weathering

Physical weathering: also called mechanical weathering due to

- Rocks expand due to unloading of rock masses
- Repeated heating and cooling arising out of fluctuations in temperature
- Activities of organisms



Chemical Weathering: Due to chemical processes, disintegration of rock will take place. The following are the some of important chemical weathering processes such as

- Hydration
- Hydrolysis
- Oxidation
- Carbonation
- Solution

Mass Wasting: Mass wasting (the gravitative transfer of material downslope) involves creep and such actions as earthflow, debris avalanches, and landslides.

There are four major type of mass wasting

- Slow flowage
- Rapid flowage
- Landslides
- Subsidence

The causes which activate the processes may be passive or active

- Passive causes may be due to weak and loose consolidated materials turning slippery When
 - ❖ Wet condition
 - ❖ Presence of thinly bedded and alternating permeable and impermeable beds
 - ❖ Presence of weak zones like faults, joints, and so on
 - ❖ Steep ground slopes
 - ❖ Changes in climate
 - ❖ Poor vegetal cover
- Active causes may be due to Steepening of slopes by running water, overloading by water saturation, excavation of materials by natural and man made processes

Erosion and Transportation of Materials: Erosion encompasses acquisition of loose materials, grinding and wearing down of the bedrock by the material, mutual attrition of particles and transportation of the debris and also taken the materials by solution

The following are the important agents of erosion

- ❖ Running water
- ❖ Groundwater
- ❖ Waves & currents
- ❖ Wind and
- ❖ Glaciers

Human Activity: is also recognized to modify the Earth's surface, large quarries, rock cut and fills and other excavations are some examples



Unit: 2 - Solar System and Earth: Solar system - Density and Movement of the Earth - Gravitational field of Earth - Origin of the Earth and Age of the Earth (various Hypothesis, concepts and Theories.

PHYSICAL GEOLOGY - II

THE UNIVERSE

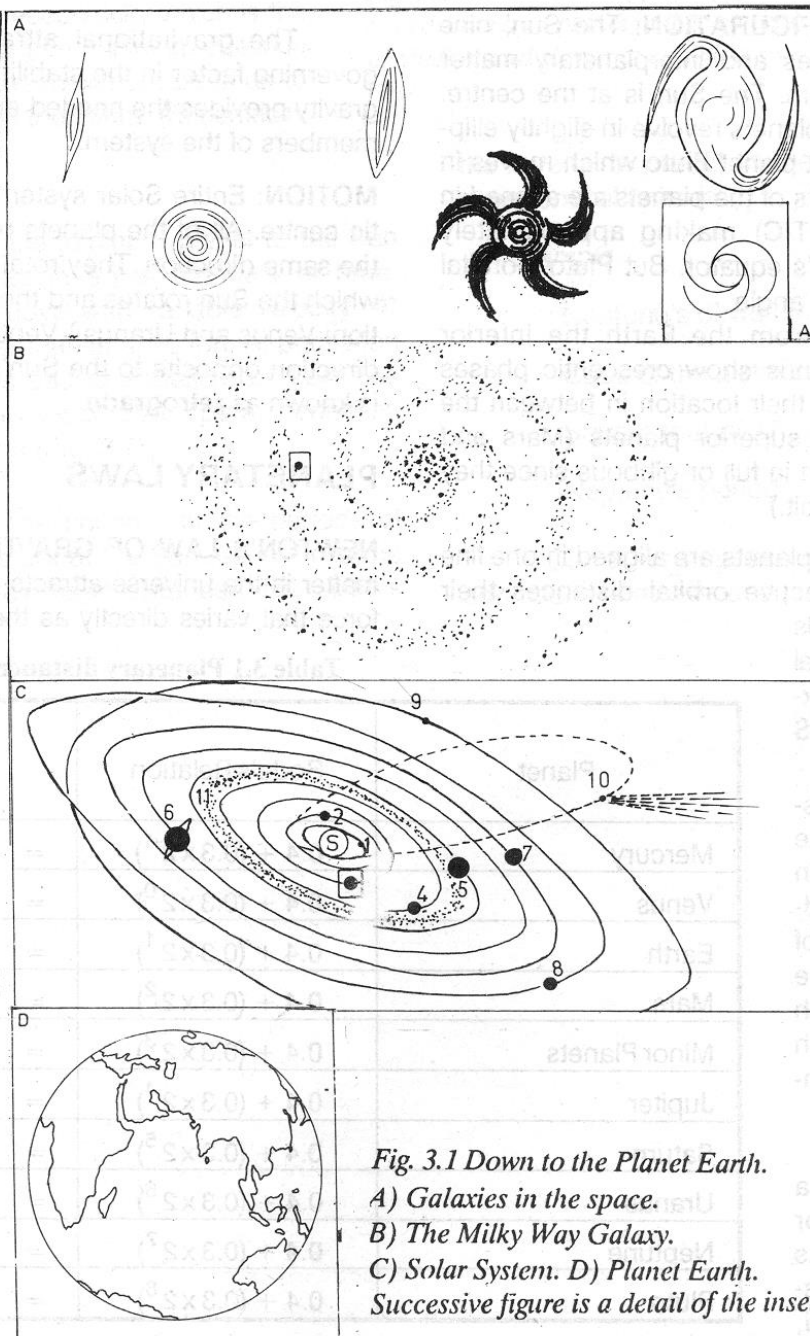
Our Earth is a cosmic body, it is an insignificant speck of dust in the universe

The Universe is a vast infinite expanse of space and matter. Mostly it is space, vacuum, or state of nothingness

The concentration of matter in space have been differentiated by the scientist into

- ❖ Nebulae
 - ❖ Stars
 - ❖ Planets
 - ❖ Asteroids
 - ❖ Comets
 - ❖ Cosmic dust
 - ❖ Galaxies
-
- ❖ Nebulae are enormous masses of gaseous clouds without any structural differentiation
 - ❖ Galaxies are assemblies or association of billions of stars in each case
 - ❖ All stars in galaxy are held together by gravitation
 - ❖ A group of stars is known as constellation
 - ❖ A single galaxy with its hundreds of millions of constituents stars makes a stellar system
-
- ➔ The star may be defined as a huge, massive body of luminescent matter radiating enormous amounts of energy per second
 - ➔ Each star is known to hold around itself under the influence of gravitation
 - ➔ A variable number of relatively small sized non radiant bodies of matter called planets.
 - ➔ Our sun is also a typical star. It has nine planets held around it under gravitation
 - ➔ The sun and the planets together make the solar system

- The solar system is just an insignificant part of our Galaxy, the milky way
- Our solar system consists of the sun, nine planets which orbit around the sun and some smaller bodies like moons and comets.



MOTION:

- ➔ The universe is, at present, expanding.
- ➔ The Galaxies are moving away at a greater speed from one another
- ➔ Galaxies themselves rotate as its star components revolve around its centre
- ➔ For example: solar system travels at a speed of 240 kps around the centre of the galaxy and takes 200 Ma to complete one revolution
- ➔ Individual star rotate themselves
- ➔ Planets are revolving around a star and they themselves are also in rotation.
- ➔ Satellites are revolving around planets rotating themselves.
- ➔ Thus every thing in the space in the space is in certain motion
- ➔ The angular momentum is found to be an inherent property of these objects
- ➔ The angular momentum of an objects is its rotational velocity with reference to its mass
- ➔ Gravitational force is the binding force for all objects of the universe

ORIGIN OF UNIVERSE

Infinitely hot matter of infinite density was thought to be concentrated in a small volume (a point) at the moment of the creation of the universe.

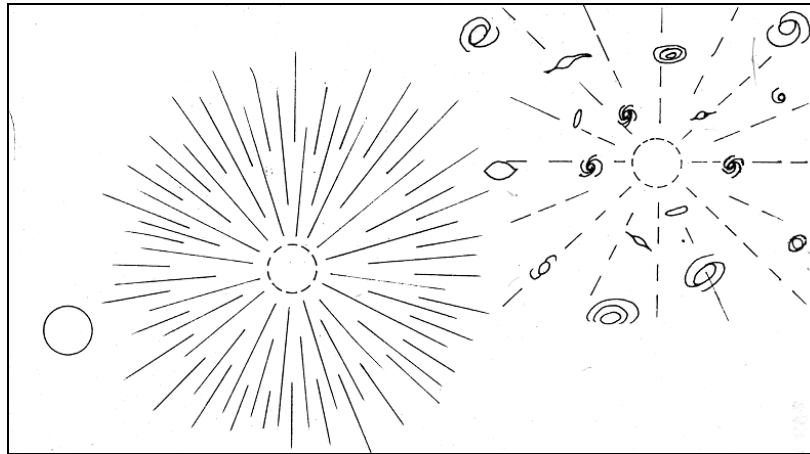
Around 15-20 billion years ago a tremendous explosion started the expansion of the universe. This explosion is known as Big Bang.

The Big Bang theory tells us that our Universe originated from a 'singularity'.

Singularity is a concept (a mathematical concept) which defies our understanding of physical reality and imagination!

What existed prior to the moment of Big Bang is completely unknown and is a matter of pure speculation. The space, time, matter, or energy everything was created with Big Bang.

- Where did our Universe come from? We don't know.**
- Why did it appear? We don't know.**
- Where it is? We don't know.**
- All we know is that we exist inside the universe.**



The origin of the Big Bang theory can be credited to Edwin Hubble (1889-1953).

Hubble made the observation that the universe is continuously expanding.

Matter was created out of Big Bang and energy propagated at the speed of light (300,000,000 meter per second).

The temperature of the universe just after a tiny fraction of a second after the Big Bang explosion was of the order of 1000 trillion degree Centigrade (1 trillion = 1000 billion) as estimated.

As the universe quickly expanded, it had also undergone a rapid cooling enabling the creation of matter from energy.

After a second of the Big Bang, protons and neutrons formed and within a few minutes these particles stuck together to form atomic nuclei, mostly hydrogen and helium.

Hundreds of thousands of years later, electrons stuck to the nuclei to make complete atoms.

After the formations of the complete atoms, different chemical elements from these atomic particles

First lighter element hydrogen was formed and next Helium was formed

Due to gravity various elements were condensed to form a primordial protogalaxy (gaseous).

This condensation could have taken place about 250 Ma after the explosion

The contraction of the universe is also possible when the gravitational force exceeds the expanding rate

But, present findings indicate that the universe is an ever expanding one

The evidences supporting the Big Bang theory:

Experimental observations reveal that the galaxies appear to be moving away from us at speeds proportional to their distance (This is called "Hubble's Law," named after Edwin Hubble.).

This observation supports the expansion of the universe and suggests that the universe was once compacted.

Since the Big Bang, the universe has been continuously expanding and, thus, there has been more and more distance between clusters of galaxies.

This phenomenon of galaxies moving farther away from each other is known as the red shift

If the universe was initially extremely hot as the Big Bang suggests, we should be able to find some remnant of this heat.

In 1965, Arno Penzias and Robert Wilson discovered Cosmic Microwave Background radiation (CMB), which seems to be coming from the farthest reaches of the universe and that is supposed to be left over from the Big Bang.

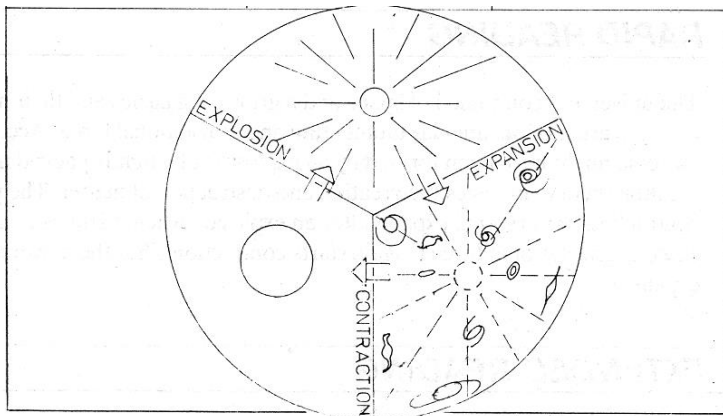
Even more recently, NASA's COBE satellite was able to detect cosmic microwaves emanating from the outer reaches of the universe. These microwaves were remarkably uniform which illustrated the homogeneity of the early stages of the universe.

Finally, the abundance of the "light elements" Hydrogen and Helium found in the observable universe are thought to support the Big Bang model of origins.

Pulsating Universe: This theory envisages an alternating contraction and expansion of the universe begins.

Black holes are clues to the contraction idea where gravitational force is too large to permit even the light rays to escape outward

It is doubtlessly true that the universe at present is expanding



It might have started from a contracted universe by explosion

It may be advancing towards next cycle of contraction and expansion

The gaseous materials of the universe condense around

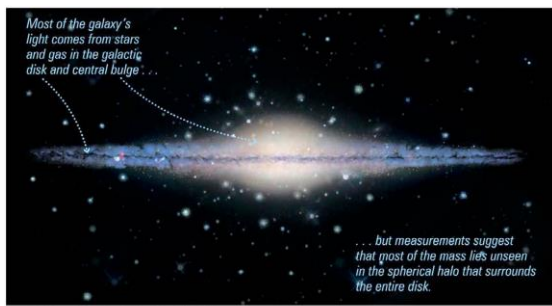
different centres of gravitational attraction and they give rise to several billions of galaxies in the universe

Every individual galaxy undergoes the same type of segregation to form hundreds of millions of stars and their system

Because of the high temperature (20 million degree C at the interior) and the nuclear reactions with the release of radiant energy a star become self luminous. And that is the case of the Sun also

THE GALAXY

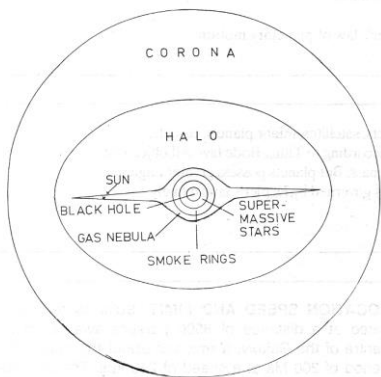
- The Galaxy to which the solar system belongs is known as the Milky Way Galaxy.
- It is a spiral galaxy. In shape it is a flat disc with a central nuclear bulge
- It is 32,600 light years across with a thickness of nearly 10,000 light years in the centre (One light year - distance covered by light in one year)
- It consists of at least one hundred billion stars, the star clusters and interstellar gas and dust
- All the stars visible to the naked eye are members of the galaxy
- The star clusters are groups of stars which move as individual units.



The shape, size and mass of the galaxy is comparable to that of the nearest galaxy the ANDROMEDA SPIRAL GALAXY.

- The core of the Galaxy is occupied by a BLACK HOLE AND SUPERMASSIVE STARS. These

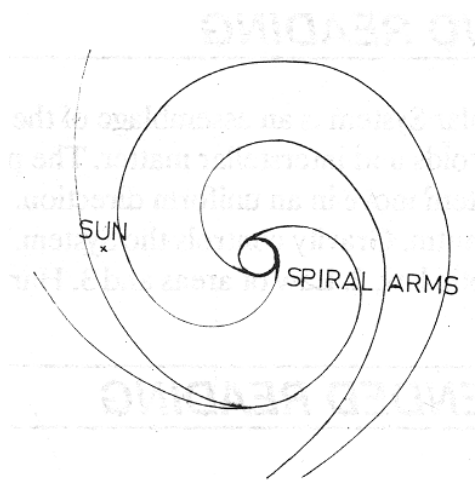
stars are old and dying



- Smoke rings are found surrounding the core and they contain high temperature molecular gas clouds and star clusters
- These smoke rings are enclosed by a ring of giant nebulae and it marks the outer boundary of the central bulge of the Galaxy

→ Young bright stars and radioactive nebulae lie in one of the spiral arms of the Galaxy.

- These three arms forms the outer fringes of the disc of the Galaxy
- The sun is in the inner edge of a spiral arm of the Galaxy centre
- This main part of the Galaxy is surrounded by an ellipse of oldest stars called Halo.

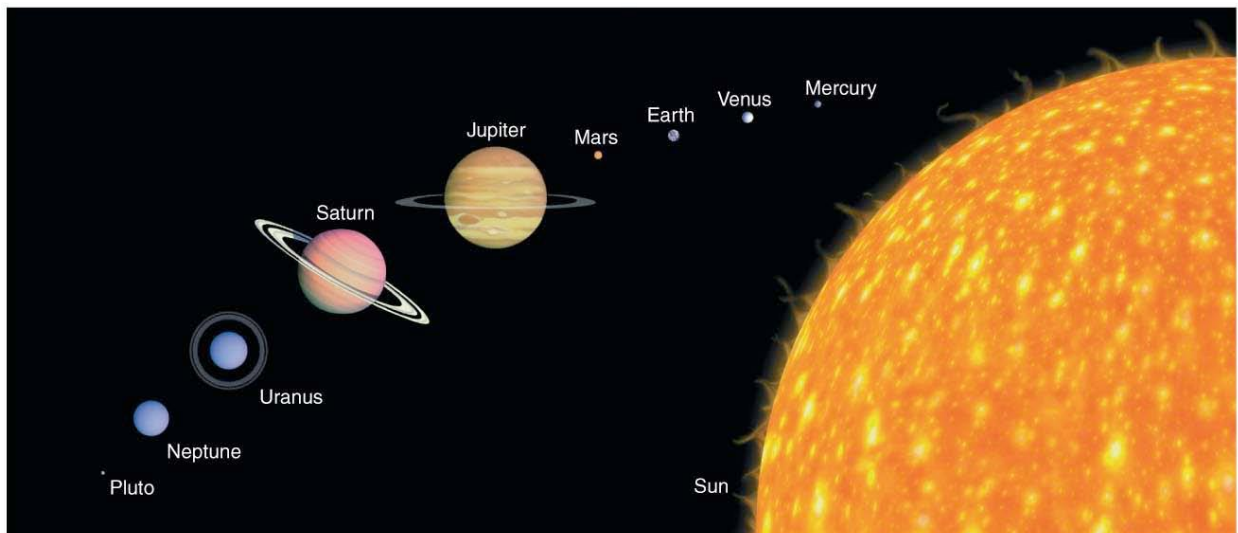


- The Halo surrounded by the Corona having a greater dimension and a very high mass. This region is not understood properly. The Magellanic clouds and Dwarf clouds may be in this region
- The Galaxy rotates about an axis perpendicular to the disc of the galaxy passing through the Centre
- Sun and other star move in a orbit around the centre
- It is theorized that the Galaxy would have been evolved through a contracting process from an initial spherical mass of gas
- The evolution of stars began in great numbers with the increment of the density of the gas cloud
- The early formed stars have been concentrated to form a central bulge and have varying directions of motion.
- The later formed stars or young stars form disc and move in horizontal plane
- The spiral arms are the sites of new star formation at present



THE SOLAR SYSTEM

- ➔ The Solar system includes the sun, nine planets, Asteroids and comets which revolve about it, held by gravity
- ➔ The sun is one star among the hundred billion stars of the Milky Way Galaxy
- ➔ The Solar System is 28,000 light-yrs from the galactic centre
- ➔ located in the disk It revolves about the centre in a period of 200 Ma at speed of 240 kps
- ➔ Diameter of Solar system is about 10,000 mkm
- ➔ The Sun is at the Centre of the system around which nine planets revolving in oval shaped paths called ELLIPSES
- ➔ There are 33 satellite revolve around different planet



a This painting shows the Sun and planets at their scaled sizes. (Distances are not to scale in this painting.)

Sun as a Star

- ➔ The Sun is the nearest star and forms the centre of the solar system
- ➔ It may be considered head of the solar family
- ➔ All the members of the family revolve about the sun
- ➔ Sun is a self luminous body radiating light and radiant energy and it is source of energy for all activities in the solar system
- ➔ Sun is the heaviest body in the system and 1000 times as heavy as the rest of the members of solar system

- ➔ The temperature at the centre of sun to the order of millions of degree Celsius.
- ➔ At this high temperature and pressure, a nuclear fusion of hydrogen takes place resulting in the production of Helium
- ➔ This nuclear reaction is the reason why the sun is so shiny, so hot and so energetic
- ➔ Because of heavy mass, the gravity will be high which controls the entire solar system
- ➔ The sun occupies a place in the inner edge of the disc of the Galaxy
- ➔ The mean distance from the sun to earth is 150,000,000 kms (One astronomical unit)
- ➔ The diameter of the sun is 1,392,000 kms (109 times that of the earth)
- ➔ The mass of the sun is 1.99×10^{30} (Earth mass * 333,000)
- ➔ The sun has a surface area of $6.087 \times 10^{12} \text{ km}^2$ (12,000 times the earth area)
- ➔ The volume is $1412 \times 10^{18} \text{ km}^3$ (1,306,000 times the Earth's volume)
- ➔ The sun radiates thermal energy released out of nuclear fusion of hydrogen.
- ➔ Every second 4,000,000 tons of hydrogen is spent in this processes
- ➔ The temperature of the external glowing layer of gas is 6000°C and at the core the temperature exceeds $15,000,000^{\circ} \text{K}$
- ➔ The pressure is about 109 Earth atmospheres

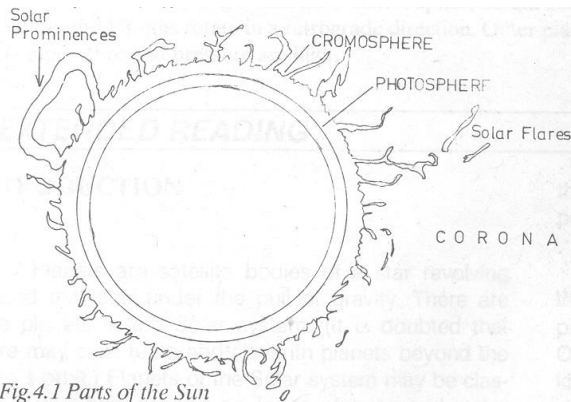


Fig.4.1 Parts of the Sun

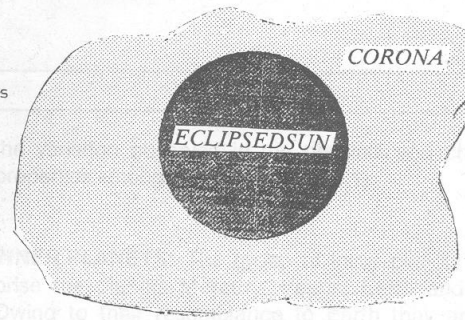


Fig. 4.2 Corona as seen during solar eclipse.

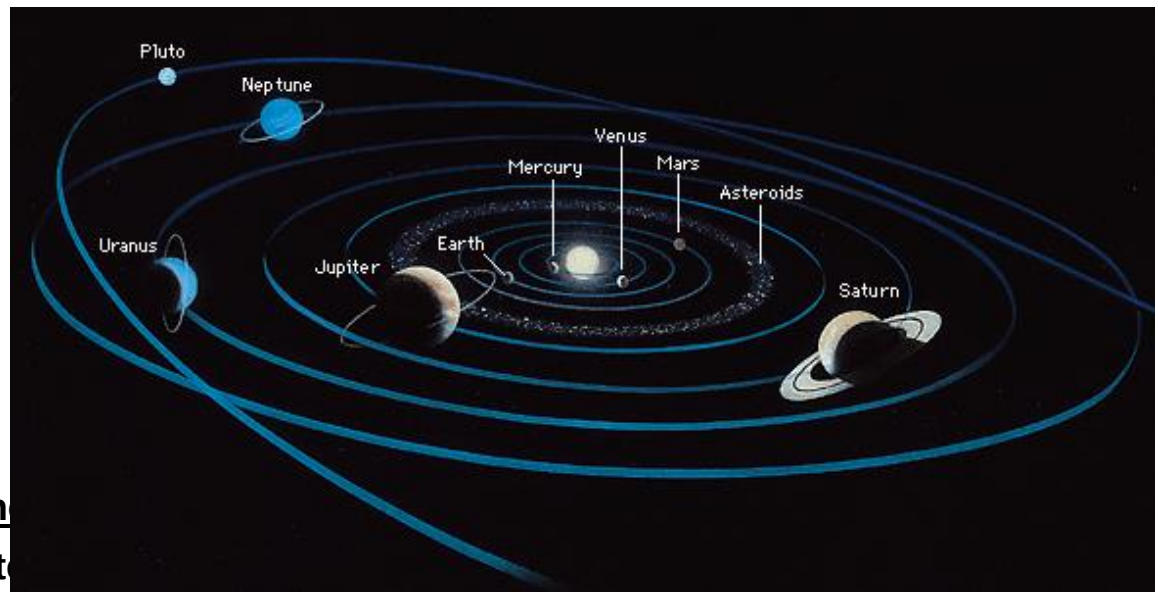
- ➔ The visible luminous surface of the sun is photosphere. The Chromosphere is the inner atmospheric layer enveloping the photosphere. The Corona is the high temperature gaseous layer surrounding the Chromosphere
- ➔ Dark spots of granulated photosphere are known as Sunspots.
- ➔ Eruptions of solar material to a height of several thousand kilometers in various form known as Solar prominences
- ➔ From the sun, a stream of electrons and ionized atoms passes outward (Solar Wind) and it effect magnetic field of the earth. Solar wind reach the earth at a speed of 2000 kps

PLANETS

- ➔ Planets are satellite bodies of a star revolving around that star under the pull of gravity
- ➔ There are nine planets in the solar system
- ➔ Planets of the solar system may be classified into two groups as inner planets and outer planets on the basis of physical and chemical properties of the planets

Inner planets:

- ➔ The group of inner planets comprises the planets Mercury, Venus, Earth and Mars. They are also called as Terrestrial planets as they resemble Earth
- ➔ They have their orbit within a distance of 250 mkm from the sun
- ➔ The terrestrial planets are small in size, less volume, more dense, low angular momentum and composed of rock and minerals



Outer planets

- Jupiter and Saturn are the **outer planets**. They are also called **Giant planets** or **Jovian planets**
- They are large in size, volume, low density, high angular momentum, vast atmosphere
- Their orbital zone extent from 750 mkm to 5900 mkm from the sun

TABLE 6.2 *Comparison of Terrestrial and Jovian Planets*

<i>Terrestrial Planets</i>	<i>Jovian Planets</i>
Smaller size and mass	Larger size and mass
Higher density	Lower density
Made mostly of rock and metal	Made mostly of hydrogen, helium, and hydrogen compounds
Solid surface	No solid surface
Few (if any) moons and no rings	Rings and many moons
Closer to the Sun (and closer together), with warmer surfaces	Farther from the Sun (and farther apart), with cool temperatures at cloud tops

Asteroids (C)

- ❖ Most asteroids can be found in the **Asteroid Belt**, which is located between Mars and Jupiter.

- ❖ Asteroids are rocky and metallic objects that orbit the Sun, but are too small to be considered planets. They are known as *minor planets*.
- ❖ Asteroids range in size from Ceres, which has a diameter of about 1000 km, down to the size of pebbles.



Comets:

Comets are sometimes called dirty snowballs or "icy mudballs" and have elliptical orbits.

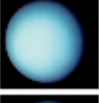
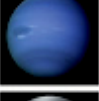
They are a mixture of ices (both water and frozen gases) and dust that for some reason didn't get incorporated into planets

This makes them very interesting as samples of the early history of the solar system.



Comet Halley in 1910

TABLE 6.1 Planetary Data*

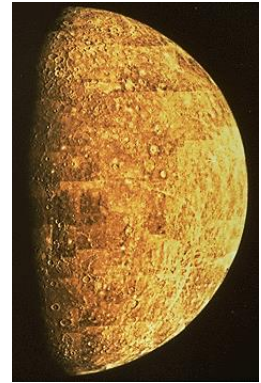
Photo	Planet	Relative Size	Average Distance from Sun (AU)	Average Equatorial Radius (km)	Mass (Earth = 1)	Average Density (g/cm ³)	Orbital Period	Rotation Period	Axis Tilt	Average Surface (or Cloud Tops) Temperature†	Composition	Known Moons (2004)	Rings?
	Mercury	•	0.387	2,440	0.055	5.43	87.9 days	58.6 days	0.0°	700 K (day) 100 K (night)	Rocks, metals	0	No
	Venus	•	0.723	6,051	0.82	5.24	225 days	243 days	177.3°	740 K	Rocks, metals	0	No
	Earth	•	1.00	6,378	1.00	5.52	1.00 year	23.93 hours	23.5°	290 K	Rocks, metals	1	No
	Mars	•	1.52	3,397	0.11	3.93	1.88 years	24.6 hours	25.2°	240 K	Rocks, metals	2	No
	Jupiter	●	5.20	71,492	318	1.33	11.9 years	9.93 hours	3.1°	125 K	H, He, hydrogen compounds [§]	61	Yes
	Saturn	●	9.54	60,268	95.2	0.70	29.4 years	10.6 hours	26.7°	95 K	H, He, hydrogen compounds [§]	31	Yes
	Uranus	●	19.2	25,559	14.5	1.32	83.8 years	17.2 hours	97.9°	60 K	H, He, hydrogen compounds [§]	24	Yes
	Neptune	●	30.1	24,764	17.1	1.64	165 years	16.1 hours	29.6°	60 K	H, He, hydrogen compounds [§]	13	Yes
	Pluto	•	39.5	1,160	0.0022	2.0	248 years	6.39 days	112.5°	40 K	Ices, rock	1	No

INNER PLANETS

MERCURY: The smallest planet in the solar system, after Pluto, and the one nearest to the sun.

It is only slightly larger than the Earth's moon. The surface is covered with craters and shallow cliffs of few 100 of km in length. This tiny planet does not have any rings or moons.

It has the dense iron core making 80% of the interior

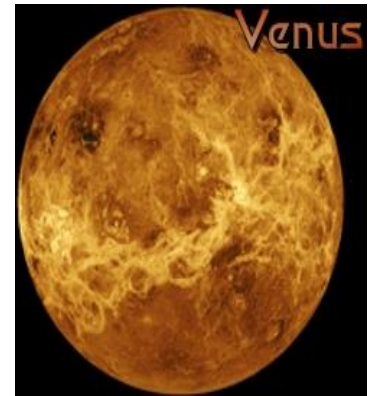


VENUS: Venus is the sixth largest planet in the solar system and the second in distance from the sun.

Venus is the brightest planet in the solar system and the one that comes closest to the earth

It rises and sets with the Sun each day and also called morning and evening star

Similar to Earth's size, density and volume and It is Geologically active, recent volcanic flows have been reported



The dense atmosphere composed of chiefly CO₂ produces the green house effect and rotate fast compared to planet. It may have liquid iron core

EARTH: The Planet Earth is unique amongst other planets, because it has biosphere. Only planet having water and is geologically active

Earth atmosphere made up of 78% Nitrogen and 21% Oxygen. The young Ocean floor and continents are the surface feature

Plate tectonics, volcanoes, earthquakes, atmospheric circulation, hydrological cycle are the major geological processes

Earth interior made up of three distinct layer such as Crust, Mantle and core. Earth has one satellite called Moon



Surface features: Highest land—Mount Everest, 29,035 feet (8,850 meters) above sea level. Lowest land—shore of Dead Sea, about 1,310 feet (399 meters) below sea).

Temperature: Highest, 136 °F (58 °C) at Al Aziziyah, Libya. Lowest, -128.6 °F (-89.6 °C) at Vostok Station in Antarctica. Average surface temperature, 59 °F (15 °C).

MARS: Mars is the fourth planet revolving around the Sun beyond the earth. Mars is very bright, which makes it easy to spot in the night sky.

It was named after the Roman god of war because its reddish colour reminded the people of blood. Red color soil gives reddish shine to Mars

Mars atmosphere is thin and consists of water, ice, CO₂, Nitrogen, Krypton and Xenon

The surface features such as valleys, volcanoes and craters and also evidences for past fluvial activities. Olympus Mons is the largest volcano in Mars in our solar system

Mars has two satellite namely Phobos and Deimos, they are smaller and are comparable to asteroids. It has been escaped from asteroids belt and recaptured by the Mars



OUTER PLANETS



JUPITER: Jupiter is the largest planet in the solar system. Its diameter is 88,846 miles (142,984 kilometers), more than 11 times that of Earth, and about one-tenth that of the sun.

It would take more than 1,000 Earths to fill up the volume of the giant planet.

When viewed from Earth, Jupiter appears brighter than most stars. It is usually the second brightest planet—after Venus.

Several dark belts and light zones of atmospheric clouds are found parallel to the equator of the planet. The surface may contain liquid hydrogen and Helium

The core may have a temperature of 30,000 K. This enveloped by the liquid hydrogen layers. The atmosphere for the thickness of 1000 km

Jupiter has great red spot with width of 14000 km and length of 30000-40000 km. It is look like a gigantic hurricane like one



Jupiter has a ring system for thickness of 6000 km

Fifteen known satellite of Jupiter may be grouped into inner group, smaller group and outer group (Size ranging from Mercury to Earth moon). Some important Satellite are Io, Europa, Ganymede and Callisto

SATURN: Saturn, the sixth planet from the Sun, is the second largest planet in our solar system having lower density than water. It is often called the ringed planet because many rings of dust and rocks surround it.



Saturn is a multilayered globe of gas (Helium and Hydrogen) with a core of iron and rocky material to a radius of 13,700 km. It is nine times the size of the earth

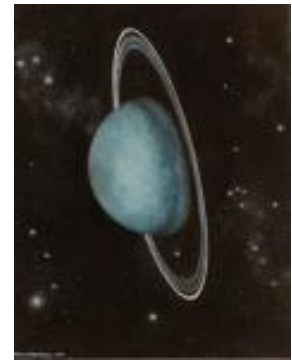
Saturn also has over 31 moons. Divided into two as inner satellites (Janus, Mimas, Enceladus, Tethys, Dione) and outer satellites (Titan, Hyperion, Lapetus, Phoebe). Titan is the largest satellite. Nitrogen is the chief component of the atmosphere. Rivers and Lakes of Methane may be found on its surface. Chemically life form may exist



URANUS: Uranus is the seventh planet from the sun. it is 31/2 times bigger than earth. It rotates around this axis, making it look like a ball rolling around in a circle around the Sun

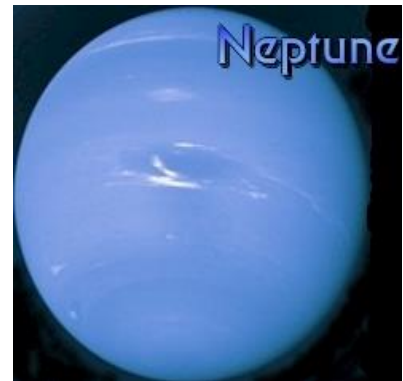
Its rotation is retrograde like Venus and posses the ring system with nine rings. Each pole of the planet will be illuminated by sunlight for a period of 42 years

Satellites: Miranda, Ariel, Umbriel, Titania and Oberon are the satellite revolving the Uranus.



NEPTUNE: usually the eighth planet from the Sun, is a very cold place. Occasionally, Pluto crosses Neptune's orbit and becomes the eight planet. Its bluish colour comes from its atmosphere of methane gas.

This planet is invisible to naked eye. Size is four times the earth's size and mass 17 times that of Earth. It is similar to Uranus in size, mass and composition.



Neptune has two satellite namely Triton and Nereid

PLUTO: Pluto, usually the ninth planet from the Sun, is the smallest planet in our solar system. Some scientists believe that Pluto once was one of Neptune's moons, and that it pulled out away from Neptune and made its own orbit.

Pluto having peculiar orbital plane which inclined by 17° and highly elliptic.



It may composed of sold methane. Pluto has one satellite having more than half of the planet's diameter and may form a double planet system

THE PLANET EARTH

The Earth is the third planet from the Sun and occupies a place in between Venus and Mars

The Earth is also a celestial body that revolves around the sun and reflects the sun's light. It obeys the laws set by the sun

The size: Eratosthenes first gives a fairly accurate value for the circumference of the Earth (24,900)

He observed that the Sun's rays are vertical on one day of the year at Syene, Egypt. But at the same time and day at Alexandria, the sun rays cast a shadow

He calculate angle between the vertical rays and inclined rays ($7^{\circ}12'$)

Using the arc value and the distance between the two places he determined the circumference of the Earth

$7^{\circ}12' = 5,000$ stadia

$= 5000 \text{ stadia} / 7^{\circ}12' * 360^{\circ} = \text{approx. } 24900 \text{ miles}$

The shape of the Earth is approximately spherical, slightly flattened at the poles and bulged along the equator. The polar radius is 6356.8km and equatorial radius is 6378.2 km. polar radius is 21.4 km less than equatorial radius.

The shape of the earth may described as spheroid or triaxial ellipsoid

The reason for Earth ellipsoidal shape attributed to the compositional difference in interior of the earth and gravitational attraction

Gravity is always toward the centre of the earth. But when the earth rotates the centrifugal force try to carry the material from the axis of rotation

The combined effects of gravitational and centrifugal force lead to the equatorial bulge and flattening at poles

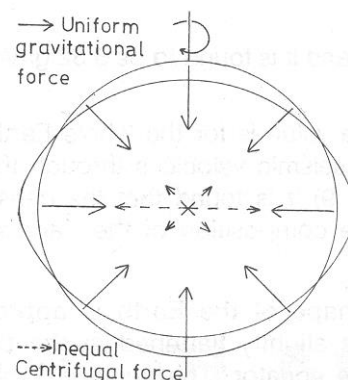


Fig. 6.2 A rotating spherical body attains an ellipsoidal shape due to unequal centrifugal force

The Mass: The mass of the earth may be calculated using the law governing the gravitational force and the centrifugal force

$$\text{Mass of Earth} = r^3 / G (2\pi / T)^2$$

T = Period of rotation of Moon around the Earth

R = Distance between the Earth and moon

G is the gravitational constant of Earth

Density: To calculate the density of the Earth, volume and mass of the earth needed

$$\text{Volume} = 4/3 \pi r^3$$

$$\text{Mass of Earth} = r^3 / G (2\pi / T)^2$$

$$\text{Density of the Earth} = M/V$$

The density of the Earth is 5.51 grams per cubic centimeter.

This is an average (If we could mix up the Earth so all of its mass was evenly distributed, and then took a 1 cm cube and put it on the scale, it would weigh 5.51 grams).

This makes Earth the densest planet in the Solar System.

Just for comparison, the density of water is 1 g/cm³, the density of rock is 2-3 g/cm³, and the density of iron is 7.87 g/cm³. So, the density of Earth is somewhere in between the density of rock and pure iron.

The surface of the Earth is mostly water and rock, so scientists have long suspected that our planet's high density comes from large quantities of iron in the core.

This suspicion was confirmed in 1936 by seismologist Inge Lehmann, who was measuring how seismic waves passed through the Earth. He detected that waves bounced off the solid iron core of the Earth.

MOVEMENTS

The earth movements in the space are complex controlled by different parameters like gravity, density, physical state of material, etc.

There are three principal movements such as Galactic movements, Revolution and Rotation

Galactic Movement: The movement of entire solar system around the centre of Galaxy. The period of revolution is 200 ma

Revolution: The movement of the earth around the Sun in 365 $\frac{1}{4}$ days in elliptical orbit. This movements causes the seasonal changes on the earth

During revolution, the earth is 147,000,000 km away from the sun on January 3 called as aphelion distance and 152,000,000 away from the sun on July 4 called as perihelion

Rotation: The earth takes 24 hrs to rotate once about its axis in counter clockwise direction. This makes the seasonal changes

Solstices: On June 22 north pole of the earth makes 23.5⁰ angle with the plane of the ecliptic when the northern Hemisphere experiences a longer day light and is called summer Solstice.

At the same time at southern hemisphere experiences longer night is called Winter Solstice

ORIGIN OF THE EARTH

The Earth is one of the family members of the solar system. There are some regularity in the placing and behavior of the members of the solar system

Its indicate that they must have a common origin

Characteristic of the Solar system

- ➔ The orbits of all the planets fall in the same plane except Pluto's orbit
- ➔ Planets revolve about the sun in same direction as the sun rotates
- ➔ Distribution of planets in the space is according to the Titus-Bode rule

	Mercury	Venus	Earth	Mars	Asteroids	Jupiter	Saturn	Uranus	Neptune	Pluto
	0	3	6	12	24	48	96	192	384	768
ADD4	4	7	10	16	28	52	100	196	388	772
Divide by 10	0.4	0.7	1	1.6	2.8	5.2	10	19.6	38.8	<u>77.2</u>
Actual distance in astronomical unit	0.39	0.72	1	1.5	2.8	5.2	9.5	19.2	30.0	<u>39.5</u>

- ➔ As per bode rule, calculated values not much different from actual value except Pluto
- ➔ Physical and chemical properties of the sun and the planets and of the outer and inner planets vary
- ➔ The sun has 99% of the mass of the solar system. But it has low angular momentum
- ➔ Over 98 % of the angular momentum resides with the planets despite their low mass
- ➔ Several types of celestial bodies exist as planets, satellites, asteroids, meteoroids and comets

- ➔ A lot number of theories have been proposed by various scientists. But no single theory fully explained the origin of solar system with valid reasons for physical and chemical features exhibited by system
- ➔ All the theories may grouped under three heads
 1. Evolutionary Theories: These are based on later modification of preexisting gas clouds. Forces responsible for it are all internal
 2. Multistar Theories: Based on the collision or close by crossing of two or more stars. External force
 3. Protosun Theories: Sun is supposed to form earlier and latter gathered the interstellar materials to form the disc

NEBULAR Hypothesis

- ➔ In 1775, Kant proposed a hypothesis for the origin of Earth. Later it was modified to suit the other requirements of the solar system by Laplace
- ➔ This theory has been called as Kant Laplace's Nebular hypothesis

According to this theory

- ➔ A rotating disc of hot gaseous nebula had been the parent body of the solar system
- ➔ This nebula got cooled because of energy lost by radiation
- ➔ The cooling of nebula lead to contraction and gravity
- ➔ This shrinking nebula had to rotated faster and faster in order to conserve angular momentum

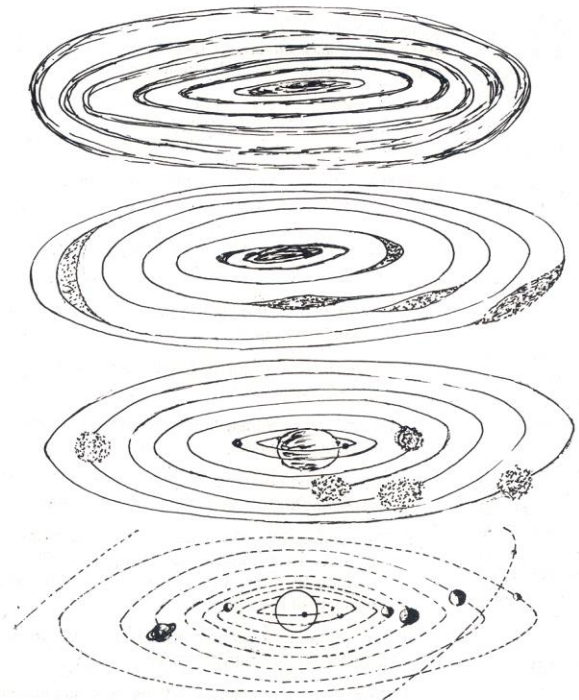
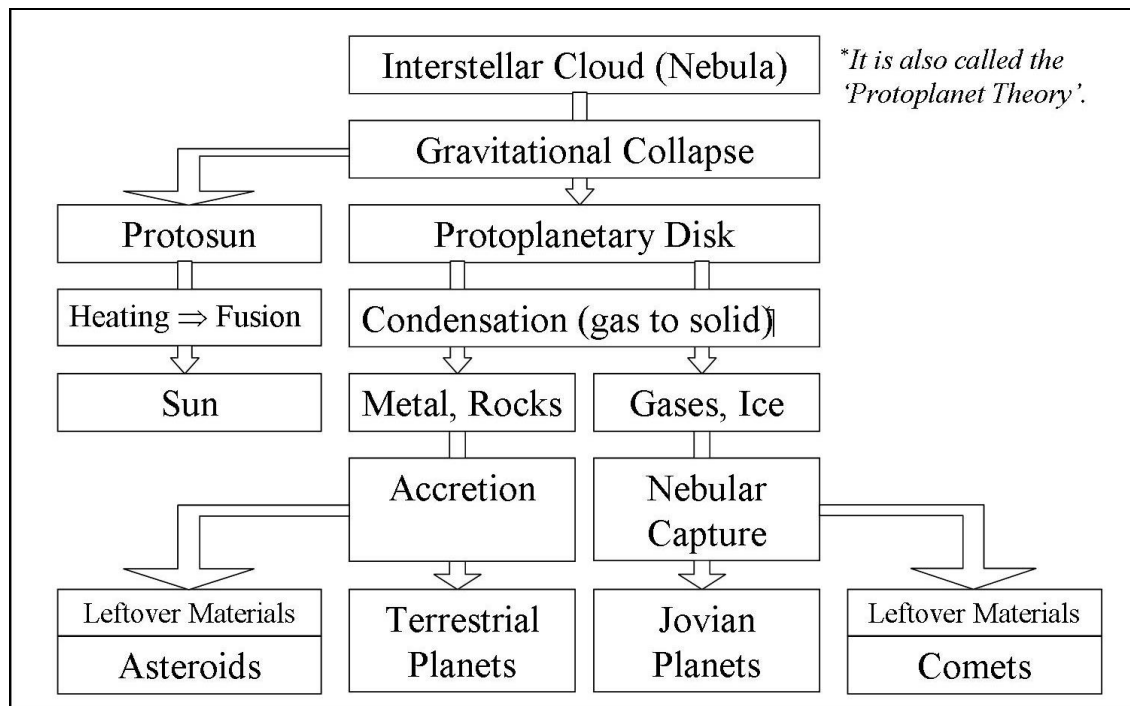


Fig..7.1 Nebular Hypothesis: Rings separate from gas cloud; and condense into Planets.

- ➔ But at the boundary region of the nebula because of rapid rotation the centrifugal force become equal to gravitational force
- ➔ So, at this stage, materials of this region would maintain their orbital positions
- ➔ But continued contraction of inner portion separated from the outer stable region
- ➔ The outer rings in due course condensed into a planet
- ➔ In this way all the planets were formed
- ➔ The innermost materials become the Sun

NEBULAR THEORY



- ➔ But this theory fail to account the distribution of angular momentum and hence it has to rotate still faster than now
- ➔ Why the rings are formed instead of discs is also another question left unanswered by this theory

Planetesimal Hypothesis

- The planetesimal hypothesis was postulated by Chamberlin and Moulton
- This theory brought an external force is to account for the separation of planet formation materials from the already existing sun
- The sun in its journey through the space would have met another star of appreciable mass
- This visiting star in its own journey once made a close by-pass.
- Because of close by-pass of a star, tidal attraction was induced due to gravitational effect of two stars
- Due to tidal attraction, some materials removed from the sun
- Further, because of angular momentum, these materials began to form a disc of particles around the Sun. This disc had been held by the Sun's gravity
- The particles in the disc were set in motion following the direction of passing star
- These solid particles are known as planetesimals. Merging of these planetesimals gave rise to planets
- This theory also not explains the angular momentum
- The ejection of materials from the sun is possible only when passing the star very close to sun. In that case the ejected material would be traveling with escape velocity

Tidal Theory:

- Jeans attempted to explain the origin of the solar system in terms of tidal effect on stars due to gravitational attraction
- According to this theory, when the sun is passed by a similar star within a few

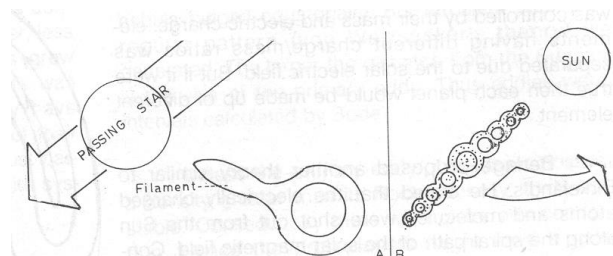


Fig. 7.2 Tidal Hypothesis: A: Passing star pulls out a filament from the Sun. B: Planets form from the filament revolving around the Sun.

diameters of star would result in the ejection of filaments of material from the surfaces of both the stars

- ➔ These filament materials may have been dragged by passing star for some distance in space.
- ➔ Ultimately when the pull decreased, the filament was left behind, where it cooled down and broke in to planet like parts
- ➔ These primitive planets were forced into circular orbits by the transverse gravitational attraction of the receding star
- ➔ This hypothesis explains to some extent, but fails in many other respects
 1. Very rare possibility of encounter of two stars in the space
 2. The stars are so far apart from each other so nearer of stars is impossible
 3. Russel pointed out that the materials torn off in that way would escape from the stars
 4. According to Spitzer, the temperature of the materials would be enormously high and thus condensation of planets from those materials is ruled out
 5. This theory did not explains the satellite system

SUPER NOVA THEORY:

- ➔ Hoyle suggested an explosion of a companion star of binary star system into a Super Nova.
- ➔ Small portion of the exploded material was caught by the sun's gravity
- ➔ These materials had condensed into planets
- ➔ The observation of existence of binary and triple star systems and the super nova explosions in the space makes a plus point to Hoyle's super nova theory

Electromagnetic Theories

The concept of electromagnetics was first explained by Birkeland

- ➔ The atoms of the nebula were ionized. The motion of these ionized particles was controlled by their mass and electric charge
- ➔ Elements having different charge/mass ratios was separated due to the solar electric field
- ➔ But if it were true each planet would be made up of different elements

Berlage proposed another theory similar to Birkeland's

- ➔ The electrically charged atoms and molecules were blast out from the sun along the spiral path of the solar magnetic field
- ➔ Concentric rings of electrically charged particles having same charge/mass ratio were formed
- ➔ The planets evolved from these rings

Following the lines of Birkeland and Berlage, Alfven developed a theory

- ➔ The sun having a strong magnetic field.
- ➔ Surrounding nebular materials got ionized electro magnetically
- ➔ Thus the atoms become charged and aligned into rings
- ➔ The charged materials of these rings condensed into small grains
- ➔ Further agglomeration of these grains give rise to planets
- ➔ Due to the rotation of the sun, magnetic field lines were affected. It is tutored the faster movement on the nebular ring materials
- ➔ But magnetic drag slowed down the rotational speed of the sun
- ➔ Thus differential distribution of angular momentum is accounted

VON WEIZSACKER'S HYPOTHESIS or NEBULAR-CLOUD THEORY

- ➔ Sun surrounded by a cloud of dust and gas particles called proto planetary cloud or disc shaped nebula with about 1/10 of the sun's mass
- ➔ Attained the disc shape due to resultant frictional force developed during revolution around the sun
- ➔ Due to Condensation of nebular disc the planets formed
- ➔ The composition of the planets themselves varies. Inner planets are of silicate-iron minerals. The outer ones are of gaseous nature
- ➔ This variation is due to the distance of the planet forming materials from the sun
- ➔ Slow condensation of planet forming materials near the sun because of high temperature give rise to smaller and dense inner planets
- ➔ Rapid condensation of planet forming materials far away from the sun give rise to giant planets

DUST CLOUD HYPOTHESIS

- ➔ In 1946, Fred Whipple proposed a theory which states that the solar system might have evolved from a dust cloud
- ➔ The contraction of dust and gas cloud gave rise to the sun
- ➔ From the original dust cloud smaller clouds developed the condensation of the dust cloud and later accretion of the particles resulted in the development of planets
- ➔ The circular orbits of the planets forming clouds is due to collisions
- ➔ The Sun's radiant energy blew away the excess gases of the inner planets. So the higher density of the inner planets has been explained by their nearness to the sun
- ➔ The original cloud had a little angular momentum. The condensation and accretion of planetary particles had increased the angular momentum

Schmidt's Hypothesis (Similar to Weizascker)

- ➔ Proto planetary cloud of dust and gas surrounded the sun
- ➔ Dust particles possessed small random velocities because of their friction with gaseous part
- ➔ Due to the random velocities, these dust particles collected into equatorial plane as an equatorial disc of dust.
- ➔ The dust particles agglomerated in many bodies of smaller size as present day asteroids – due to mutual sticking or tendency to establish local gravitational stability or may be both.
- ➔ These proto planets revolved around the sun in a circular orbits in the plane of the original sun plane
- ➔ Gradual growth in size acquired strong gravitational pulls on one another and this caused slight irregularities in their circular orbit now to slightly elliptical and inclined.
- ➔ The proto planetary bodies close to the sun, received the matter from smaller distance (keeping their angular momentum low), but the furthest proto planetary bodies received matter from for the sources, there by causing more angular momentum.

AGE OF THE EARTH

It is unanimously believed that earth took its birth in a hot, gaseous, molten state

- ➔ No method is devised so far to say the precise age of the Earth
- ➔ Whatever the method proposed, it based on a change or process which is taking place presently
- ➔ Total change and rate of change are measured. Dividing the total change by the annual change gives the age of the Earth
- ➔ The change or process may be denudation and depositional process or decaying of radioactive elements or cooling temperature
- ➔ The Geochronology is the science of estimating the age of the rocks or minerals
- ➔ Absolute dating refers to the determination of the time of an event in terms of years
- ➔ The relative dating refers to the chronological order of a sequence of events that is cross-cutting relations of the materials involved in it

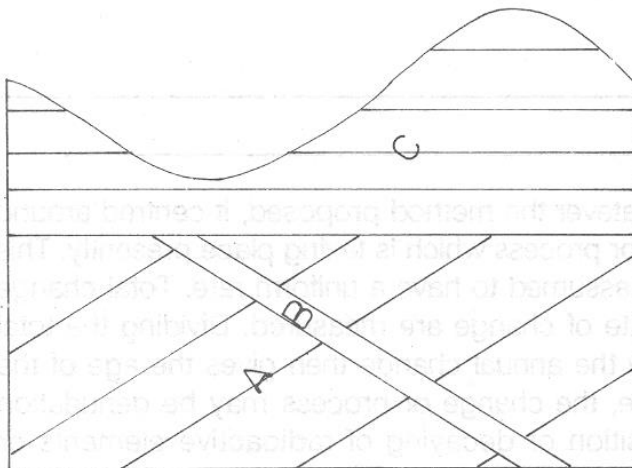


Fig. 8.1 Relative dating

ACCUMULATION OF SEDIMENTS

- ➔ Calculate the annual rate of sediment deposition (1 ft per 755 years)
- ➔ Measure the total thickness of sediments from beginning of Cambrian to recent period
- ➔ Divide the total thickness of sediments by annual rate of deposition, then we can work out age of the sedimentary rock
- ➔ It comes to about 510 million years
- ➔ This method is not a precious one. The amount of sedimentation is always constant

VARVE CHRONOLOGY

- ➔ A varve may be described as a sedimentary layer consists of thick, light coloured, coarser sediment layer of summer season and a thin, dark coloured finer sediment layer of winter season
- ➔ These are lake deposits commonly associated with glaciers. The alternating bands of light and dark color indicate one year of deposition
- ➔ Thus the count pairs of varves gives the time in years.
- ➔ Varves over 600 m thick occur in Green River basin, USA indicating 6.5 Ma

SNOW LAYERING

- ➔ Seasonal accumulation of snow result in layering in Arctic and Antarctic
- ➔ A drill core of the solid ice would show the layers and the count of which would give the duration of deposition

THERMAL METHOD

- ➔ Lord Kelvin calculated the age of the earth as 100 Ma
- ➔ According to him, the Earth is cooling body
- ➔ He assumed the initial temperature of the earth as 3900⁰ C.
- ➔ Using the rate of cooling and present day temperature he made calculated the age of the earth as 100 Ma
- ➔ The theory failed as it did not account for the radioactively generated heat

SODIUM IN SEA

- ➔ The salinity of the ocean was used to determine the age of the earth
- ➔ Three fourths of the dissolved material in the Ocean is sodium chloride
- ➔ Running water dissolves the sodium present in the rock and deposit in the ocean
- ➔ Calculating the total sodium in the ocean and annual sodium increment in the ocean and from the above the age of the earth was calculated.
- ➔ This method shows age of the earth is 100 my
- ➔ This based on assumptions such as Oceans at first were fresh water, all the sodium brought into ocean has remained in solution, the annual increment taken as average, the volumes of ocean and water is constant
- ➔ The above assumption is go wrong when analysis made

EVOLUTION CLOCK

- ➔ Evolutionary changes of animals give rough estimation of the age of the earth
- ➔ Biologist have determined the age of the earth to 1000 my
- ➔ Considering the development of unicellular organism to man
- ➔ But it is to be remembered that life appeared on the earth after a long span of time

RADIOACTIVITY

- In the 20th Century, the problem of age of the earth has been dealt with considerable success by Radioactivity
- The French physicist Becquerel discovered in 1895 that
- “Nuclei of certain elements are inherently unstable and are actually in a process of spontaneous disintegration at a constant rate to form stable end products”
- Further research by Marie Curie, Pierre Curie and Rutherford make this science as a subject of great importance in numerous field
- In geology, it has been used to determine the age of the earth

PRINCIPLES

- Suppose a rock sample obtained from the crust of the earth contains a radioactive element A. Necessarily, it will also be containing some amount of the end product B
- Which has formed from A due to its radioactive decay at a particular rate of disintegration
- If relative amounts (In terms of atoms) of elements A & B present in the rock are precisely known and the rate of radioactive decay of A to B is also known, then the time that has elapsed since the formation of the radioactive substance can be calculated.
- For example: Uranium-238 (A) disintegrate to form lead-206 (B) through the a series of unstable isotopes of different elements
- The radioactive element A reduces itself into half through radioactivity decay in particular period of time is called half life period

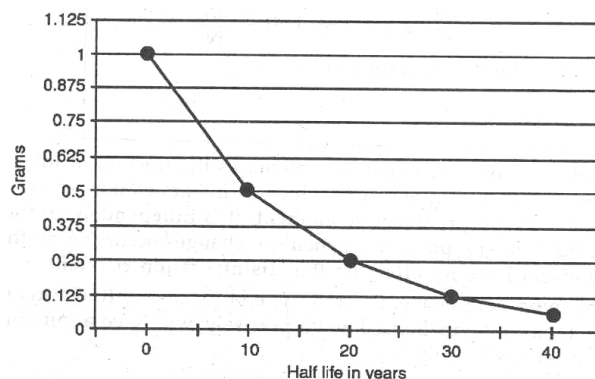
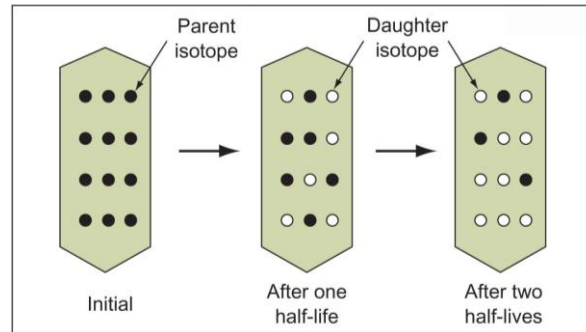


Fig. 2.3A. Half-life explained.



- ➔ Dating through radioactivity means is called radiometric dating
- ➔ The mass spectrometer is the instrument used in the detection of several radio isotopes
- ➔ In the radiometric dating, the half-life period of a particular element is used
- ➔ The rate of transformation of a parent element to daughter element is a constant
- ➔ Hence by finding the percentages of these parent and daughter elements in the rock, the age of the rock calculated
- ➔ In calculating the geological age, the following basic equation have been in use

$$t = \frac{1}{\lambda} \log e \left[1 + \frac{D}{P} \right]$$

t = age, λ = decay constant, D = Amount of Daughter elements

P = Amount of Parent elements

Calculate the age of the rock given the ratio of Pb-206 to U-238 is 1:10 and decay constant λ for U-238 is 0.0000668

$$t = \frac{1}{0.0000668} \log e \left[1 + \frac{1}{10} \right]$$

$$t = \frac{1}{0.0000668} \log e \frac{11}{10}$$

$$t = \frac{1}{0.0000668} * 0.0953$$

$$t = 14270000 \text{ or } 14.27 \text{ my}$$

Table 8.1 Data used in Radiometric Dating

ISOTOPES				Half-life in Ma	Effective range in Ma	Datable materials
Radio active Unstable Parent	Non radio active isotope	Stable/ daughter element	Decay * constant			
Uranium-238		Lead-206	0.0000668	4500	10-4600	Zircon, Uraninite and pitchblende
Uranium-235		Lead-207	0.0004239	710	10-4600	Zircon, Uraninite and pitchblende
Thorium-232		Lead-208	0.0000216	13900	10-4600	Columbite-tantalite-Monozite, muscovite, phlogophite, biotite, hornblende, nepheline, sanidine, plagioclase, syl-vite (arkose, sandstone, siltstone) volcanic rocks, meteorites.
Potassium-40	-39, -41	Argon-40	0.0000252	11900	0.1-4600	
		Calcium-40	0.0002047			
Rubidium-87	-85	Strontium-87	0.0000064	47000	10-4600	Muscovite, biotite, lepidolite, orthoclase, microcline, glauconite, metamorphic rocks, granites and granitoids
Carbon-14	-12	Nitrogen-14	52.53	5730 + 30 years	100-5000 years	Vegetative and animal matter, cloth, shell stalactites, tufa, ground water, ocean water.
Polonium-212						

* Decay constant (λ) is obtained by dividing the natural logarithm of 2 half-life period in million years

POTASSIUM – ARGON METHOD

- ➔ Potassium-40 decays forming two different stable products namely calcium-40 and argon-40
- ➔ Ca-40 is ordinarily found to be a component of common rock types. It can not be easily distinguished from radiogenic Ca-40
- ➔ Transformation of K-40 to Ar-40 is used in dating
- ➔ Rocks older than 0.1 My and younger than 4600 My are effectively dated using this K-Ar method
- ➔ Biotite, muscovite, hornblende, nepheline, sanidine and plagioclase minerals and also meteorite also dated by this K-Ar method
- ➔ In K-Ar method minerals need not be separated out, the whole rock sample may be directly used

RUBIDIUM-STRONTIUM METHOD (Rb-87 to Sr87)

- Rubidium-87 by beta radiation transform into strontium-87
- Two values 47000 and 50000 My are suggested as the half lives of rubidium
- The radiogenic Sr-87 maintains a closed system in the rock specimen. That is at low temperature radiogenic Sr-87 diffuses out of rubidium bearing minerals
- So that it is help in estimating the time interval between the time of intrusion and the metamorphism

URANIUM METHODS

- Two isotopes of Uranium (U-238 and U-235) and one isotopes of thorium present in the same mineral helps to determine that age of the mineral in three ways
- Uranium methods important one among the other methods
- Uranium-238 transforms into lead-206 by alpha and beta radiations
- In this processes several intermediate radioactive elemental nuclides are formed and decayed

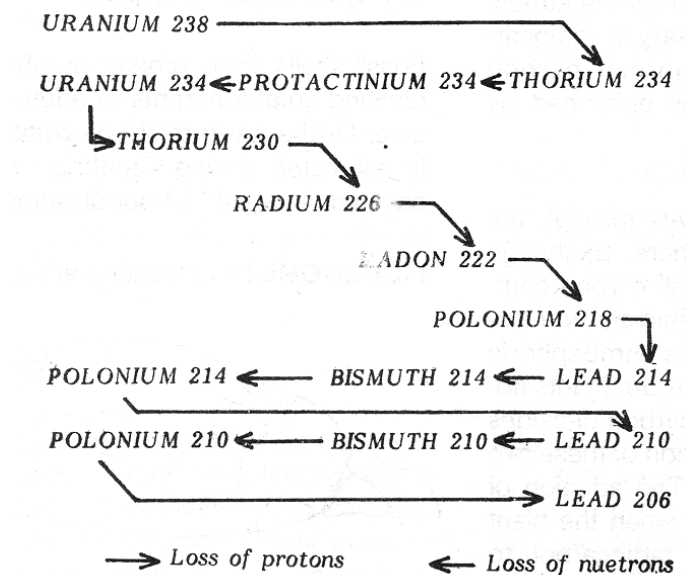


Fig.. 8.3 Transformation of Uranium 238 into Lead 206

→ Similarly, U-235 and Th-232 produce daughter elements Pb-207 and Pb-208 radioactively

U-238 → Pb-206 + 8 alphas + 6 betas

U-235 → Pb-207 + 7 alphas + 4 betas

Th-232 → Pb-208 + 6 alphas + 4 betas

→ The quantity of U-238 and U-235 and the radiogenic lead-206 and lead-207 of a specimen are determined and the following equation used in calculating the age of the specimen

$$t = \frac{1}{\lambda} \log_e \left[1 + \frac{D}{P} \right]$$

$$t = \frac{1}{0.0000668} \log_e \left[1 + \frac{\text{radiogenic Pb-206}}{\text{U-238}} \right]$$

LEAD – LEAD / LEAD RATIO / 207-206 METHOD

- The decay of U-238 and U-235 and production of Pb-206 and Pb-207 are time dependent
- Using this ratio of Pb-206 to Pb-207 of mineral, the age of that mineral may be found
- This may be from an analysis of lead isotopes
- Common lead in four different isotopes such as Pb-208, Pb-207, Pb-206 and Pb-204 of which Pb-204 is a non radiogenic one
- When the formation of these elements, the ratio of radiogenic lead to non radiogenic lead is zero or minimum
- As time passed this ratio also have had increased
- If we calculate the initial and present ratio between the Pb-208, Pb-207, Pb-206 and Pb-204
- From the above time elapsed to present ratio can be calculated

FISSION TRACK DATING

- Certain radioactive elements are found trapped in crystal structures
- When these elements decay, atomic particles are thrown out at high velocity
- These atomic particles damage the crystal structure along their path
- These damaged areas are known as Fission tracks and are made visible under high powered microscopes
- The number of damaged areas is equal to number of radioactive disintegration
- From the above, the age is calculated using the number of fission tracks and the concentration of radionuclide that caused the damage

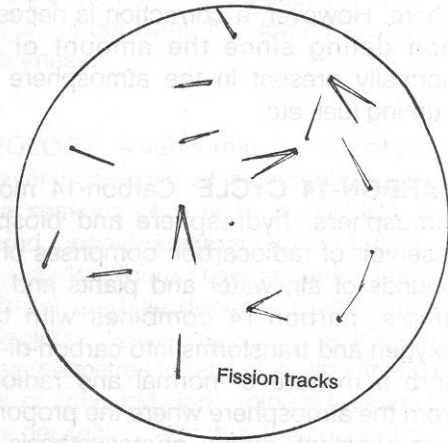
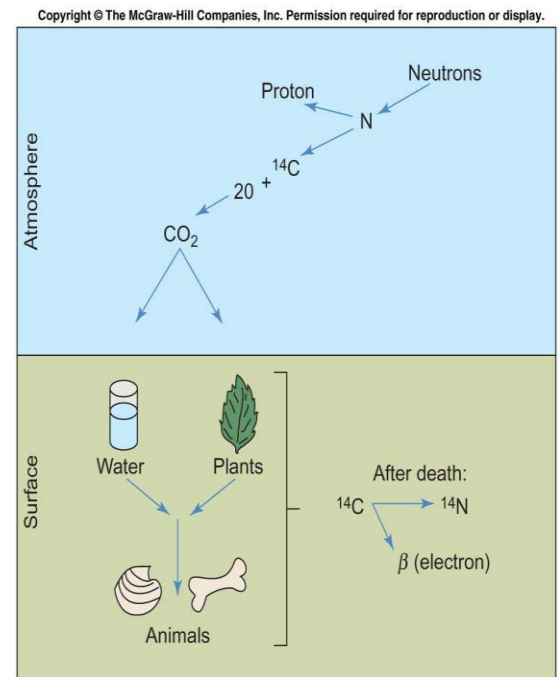


Fig. 8.4 Nuclear fission of radioactive elements produce tracks in the containing material which help estimation of age of the material

RADIOCARBON DATING

Radiocarbon dating has been widely used to date events and materials of recent past since its half life period is 5370 years only

- Cosmic rays bombarded the earth atmosphere
- Neutrons are released when the energized particles of cosmic rays strike the atoms of upper atmosphere
- Thus produced neutrons was absorbed by atmospheric nitrogen to form the radioactive Carbon-14
- The amount of decayed C-14 was replaced by reproduction of new C-14
- The production and decay rate of C-14 in equilibrium



- ➔ Thus amount of C-14 in the atmosphere always constant
- ➔ The C-14 move through atmosphere, hydrosphere and biosphere and reach the animals and plants
- ➔ Once animals and plants are death, their intake of C-14 from the atmosphere was stopped
- ➔ Then, the C-14 of death organism started decay
- ➔ From the amount C-14 present in the sample, we can calculate the age
- ➔ Lesser C-14 indicate older age

CONCLUSION

- ➔ The oldest intact rocks found on Earth date back to about 3-4.0 billion years ago.
- ➔ Tiny grains of zirconium silicate (zircons) found embedded in sedimentary rocks have been radiometrically dated to 4.4 billion years ago.
- ➔ Moon rocks brought by Apollo astronauts are older than any Earth rocks – volcanism and other geological processes 4.4 billion years ago.
- ➔ The Earth's crust appears to have already differentiated from the interior approximately 4.5 billion years ago
- ➔ Isotopic analysis of meteorites suggests the Earth and the rest of the solar system formed 4.57 billion years ago.
- ➔ From all the above, a safe figure for the maximum age of the earth is 4.6 billion years

UNIT: 3 - Interior of the Earth: Structure of the Earth Interior (Crust, Mantle and Core) – Earthquakes (Origin and Effects, Earthquake Belts, Epicenter, Seismograph, Magnitude Scale) – Volcanoes (Types and Causes, Types of Eruption, Diapirism) – Tectonic Movements (Isostasy) – Mountain Building Activities.

INTERIOR OF EARTH

- ➔ In deducing the Earth's internal structure and composition, direct evidences are very less
- ➔ All attempts are to be made from the surface since there is no access to the centre of earth

Direct Evidences:

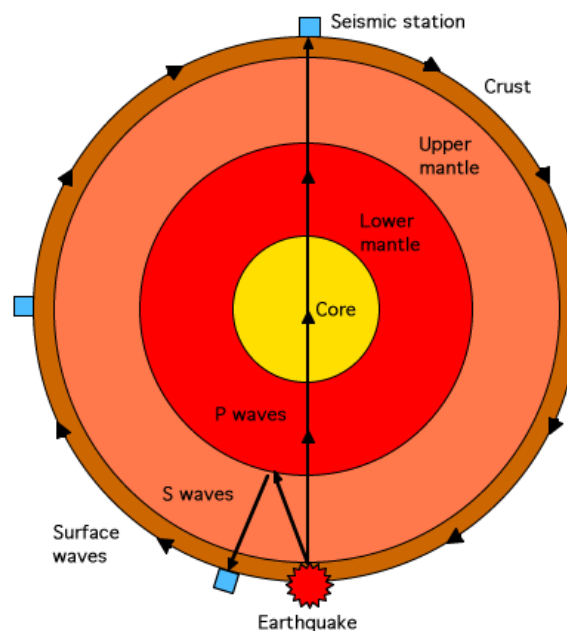
- ➔ Volcanoes pour out materials of not more than 200 km depth
- ➔ Erosion has exposed only rocks of 20-25 k depth
- ➔ Man made bore hole only up to 8 km depth (oil well, Texas, USA)
- ➔ Mines are not than few km deep
- ➔ Thus directly observed depth is very small when compare to radius of earth (6378 kms)
- ➔ A project was formulated by American scientists to drill a bore hole to penetrate the crust-mantle boundary. The project was called Mohole project
- ➔ To minimize the depth, the test bore hole was made in eastern Pacific ocean
- ➔ Bore hole was drilled up to a depth of 2.2 km only, after that they could not able to proceed



Indirect Evidences:

- ➔ The structure and composition of the Earth interior are understood indirectly by the use of seismic waves

- ➔ Seismic waves travel at different velocities and are reflected or refracted depending upon the nature of the medium through which they traveled
- ➔ The earth variable nature is explained not only by seismic wave behavior but also by a study of the mass, shape and motion of the earth and by meteoritic study
- ➔ Physical and chemical nature of the earth vary with the depth
- ➔ Density of the earth: The surface rock have the density of 2.6 to 3.0. But earth average density is 5.5. So density high materials must be below the surface.
- ➔ The earth spheroid shape also indicate the earth does not have uniform density from the surface to centre of the earth
- ➔ The behaviour of earthquake waves shows that clearly earth composed of different layers
- ➔ These waves travel through the earth at different velocity and in different paths according to the physical properties of the interior
- ➔ A thorough analysis of the seismic records shows a three major concentrically layered structure of the earth such as Crust, Mantle and Core
- ➔ Subdivision of these three zones also inferred by seismic wave



SEISMIC WAVES AND THE EARTH'S INTERIOR

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- ➔ There are three kinds of seismic waves namely primary waves, secondary waves and surface waves
- ➔ P-Wave or Primary wave or Compressional or longitudinal waves. The motion of particles is parallel to the direction of propagation. It can travel through all media (solids, liquid and gas)
- ➔ S-waves - Secondary wave – transverse wave or shear wave. The motion of particles is perpendicular to the direction of propagation. It can travel only through solids
- ➔ L-Waves or Surface wave is travel along the surface of the Earth. There are two type of surface waves such as Rayleigh wave and Love wave
- ➔ Rayleigh wave – Particles motion is in a vertical plane with elliptical motion to the direction of propagation. Maximum axis of the elliptical wave is perpendicular to the direction of propagation.
- ➔ Love wave - Particles motion is horizontal & transverse to the direction of propagation

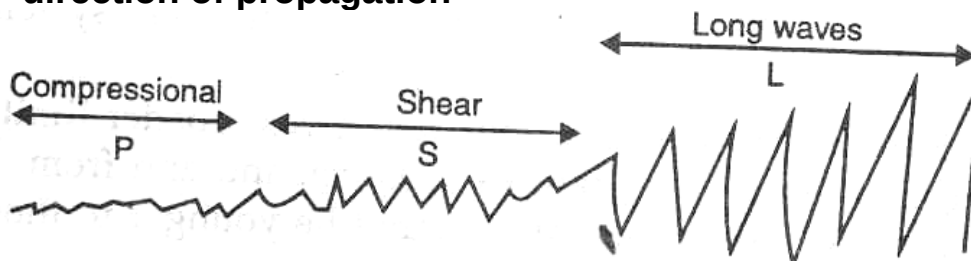


Fig. 2.3. A Typical Seismogram (Highly simplified).

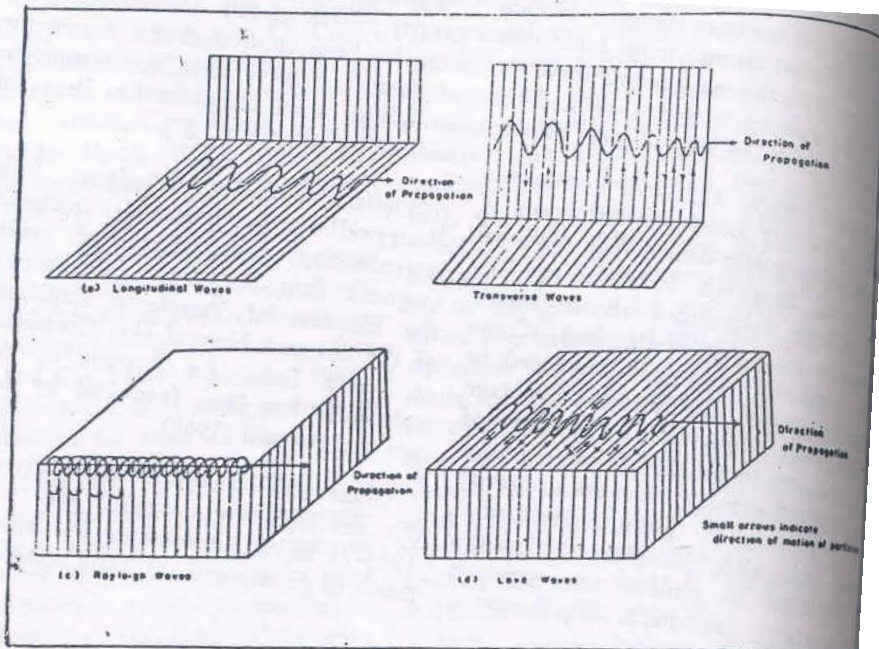
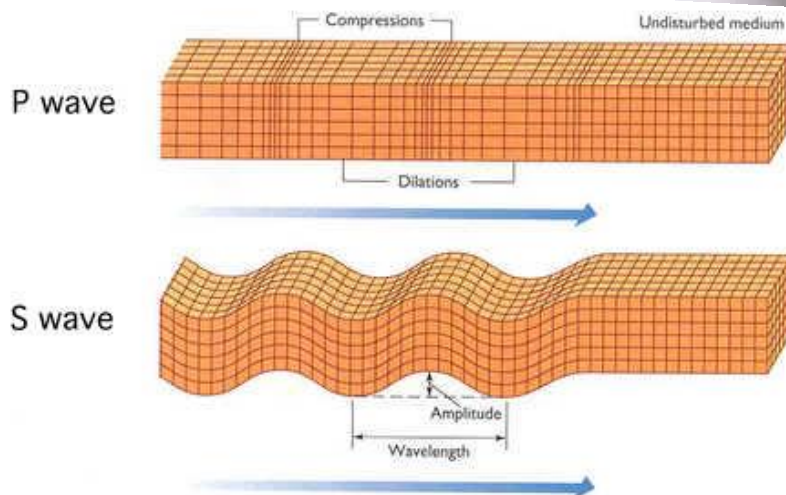


FIG. 154. Diagram showing propagation of elastic waves and direction of motion of particles (a) Longitudinal waves (b) Transverse waves (c) Rayleigh waves (d) Love Waves (after C. A. Heilbrunn)

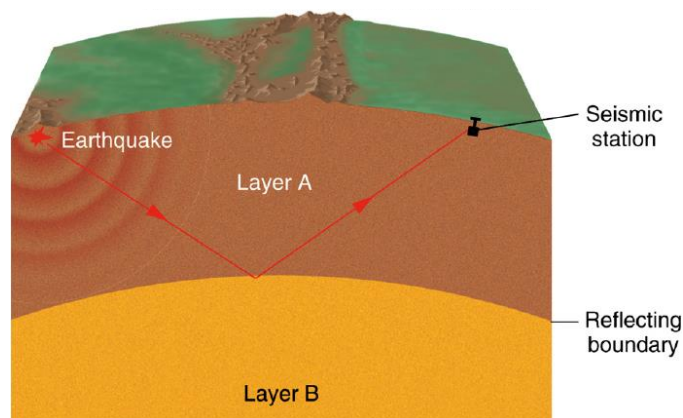


- ➔ P- wave reaches first with greater velocity and low amplitude for a duration of few seconds
- ➔ S- wave reaches second with relatively less velocity than P wave, but with higher amplitude, but will last for same or slightly longer duration
- ➔ Both “P” and “S” waves are called “ Body Wave “ because they are transmitted through the body of the material

- L-waves --- Much greater amplitude, less velocity than 'S' wave and longer periods are noticeable & denote much stronger displacement of the ground
- This is called "Surface Wave" as because they travel only or nearly along thin zone of free surface of material
- Because of change in velocity & the related difference in arrival time the epicenter or focus of earthquake is determined
- One seismogram data – only the epicenter distance only can be estimated
- Minimum three seismogram data needed for precise positioning of epicenter
- All these waves provided information of the internal structure of earth.

Seismic reflection

- Return of seismic energy to surface
- Rock layers of different density
 - ❖ boundary reflects energy like a mirror
 - ❖ time since earthquake gives depth to boundary



Seismic refraction

- Bending of seismic waves passing from one rock to another
 - ❖ similar to light rays passing through eyeglasses
 - ❖ generates curved ray paths

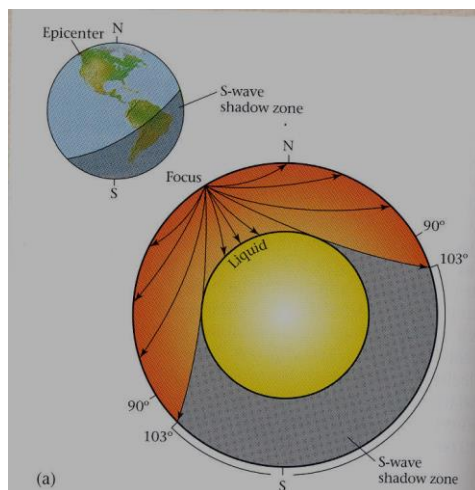
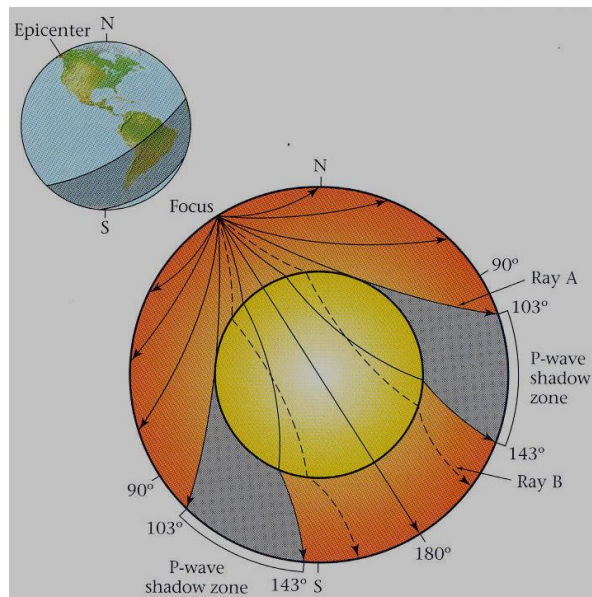
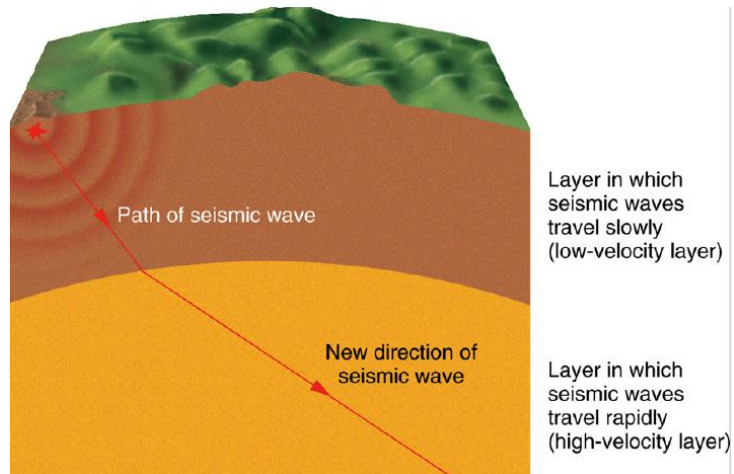
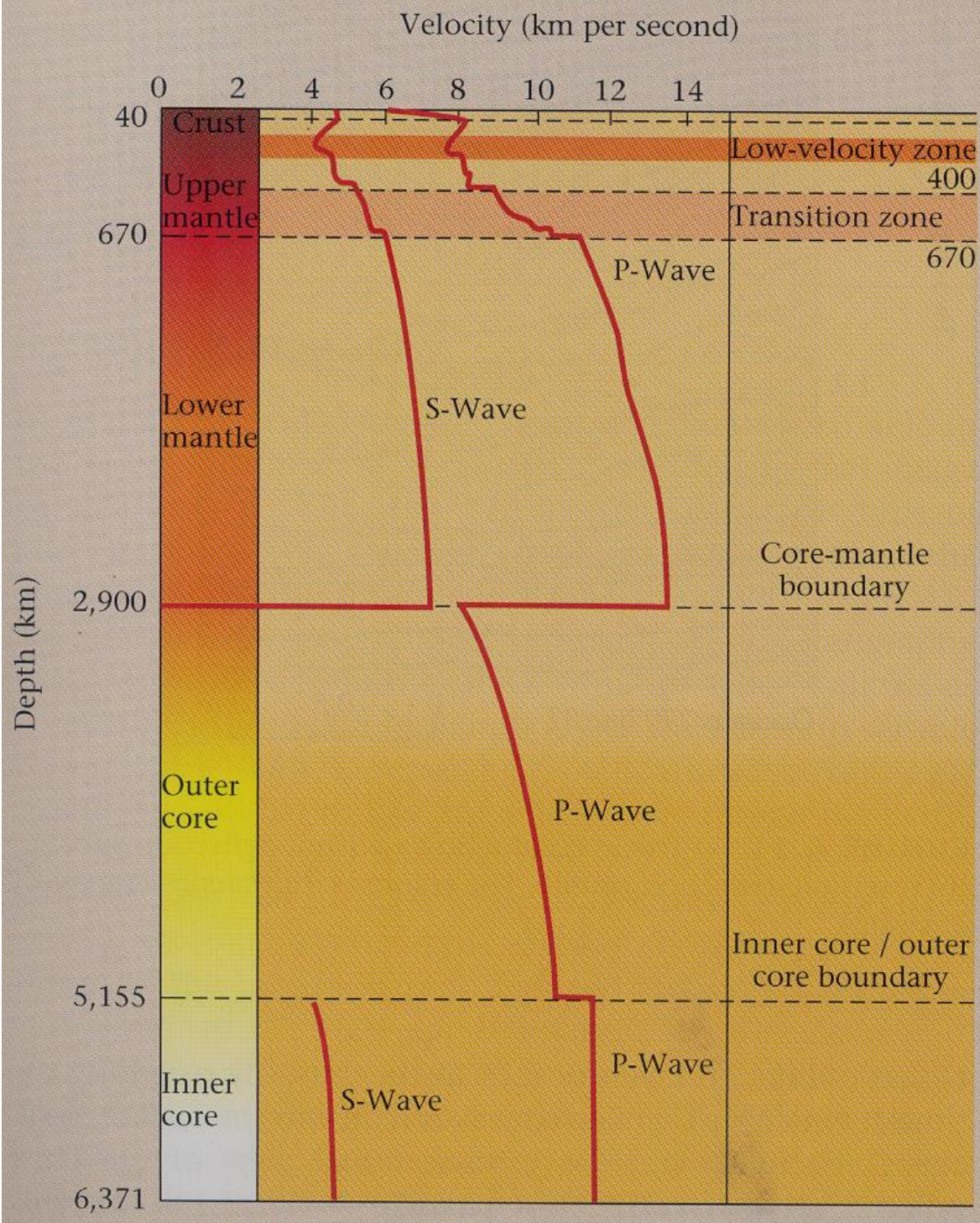
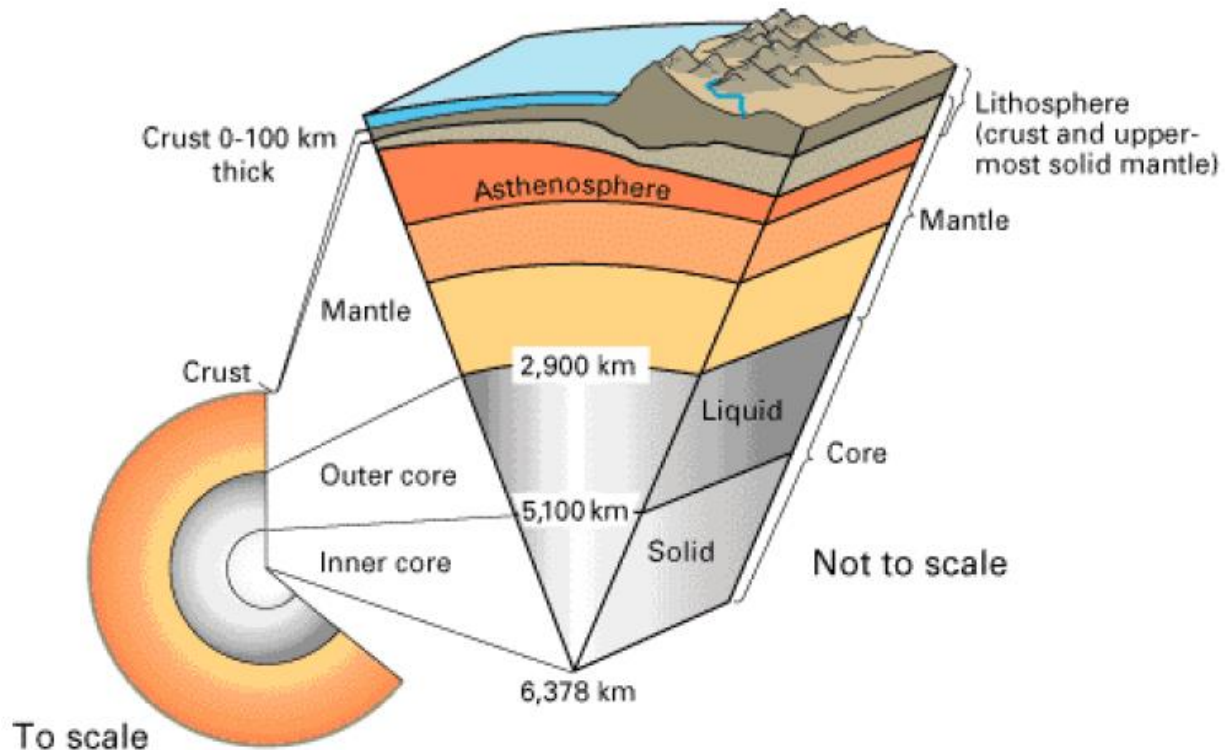


FIGURE C.12 The velocity-versus-depth profile for the Earth.





- The internal structure of the earth through seismic observation shows that the earth has three major distinct zones such as Crust, Mantle and Core

THE CRUST

- The crust is the upper most shell or layer of the Earth. Its thickness varies from 5 km to 65 km
- Thickness of the crust beneath the ocean bottom is 5 to 8 km and beneath the continents is 30 to 70 km
- Crustal thickness increases with an increase in the elevation. In mountains region like Himalayas and Alps, the crustal thickness goes upto 70 km and under the plain of the continents, it is 30 to 35 km
- Two layers are recognizable within the continental crust from seismic study such as SIAL and SIMA
- These two layers separated by a discontinuity is called CONRAD DISCONTINUITY as a transitional zone between Sial and Sima

- This Conrad discontinuity found only under the continent
- The upper layer above the Conrad discontinuity is in Granitic composition chiefly consists of silicon and aluminum so it is called as SIAL
- Sialic layer is absent under the ocean
- A layer below the Conrad discontinuity is in Basaltic composition mostly composed of silicon and magnesium. So it is termed as Sima
- The velocity of P-wave in the crust is 6.1 kps in sial and 6.8 in sima
- The S-wave travel at velocity of 3.4 kps in sial to 4.4 kps in sima
- P and S waves attain a greater velocity at a depth of 65 km. This marks the base of the crust and called as the MOHOROVICIC DISCONTINUITY

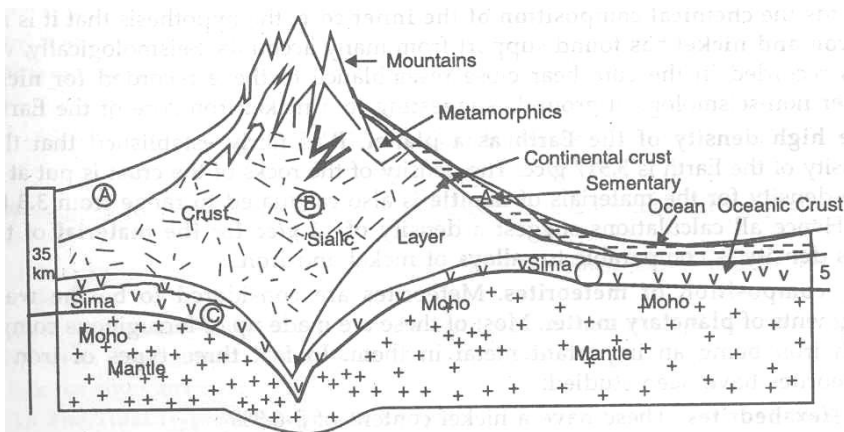


Fig. 2.6. Structure of the Earth (not to scale)

A = Sedimentary layer; B= Granitic layer (SIAL); C= Basaltic layer (SIMA)

The Earth's Interior

Crust:

Oceanic crust

Thin: 5-10 km

Relatively uniform stratigraphy

= ophiolite suite:

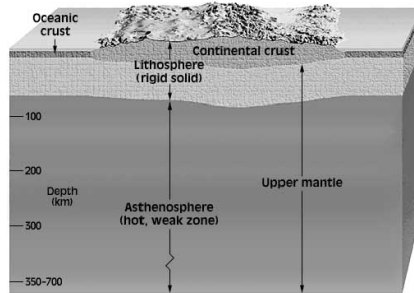
- ☞ Sediments
- ☞ pillow basalt
- ☞ sheeted dikes
- ☞ more massive gabbro
- ☞ ultramafic (mantle)

Continental Crust

Thicker: 20-90 km average ~35 km

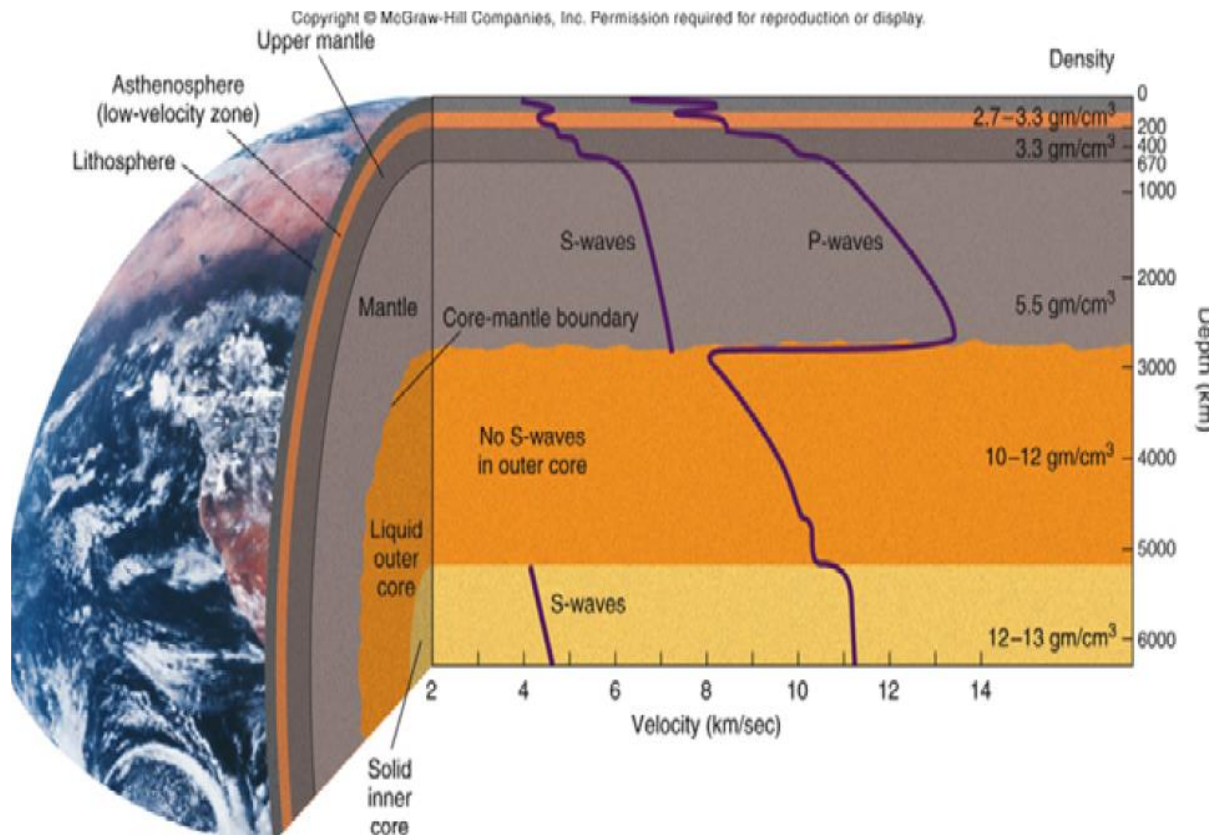
Highly variable composition

- ♦ Average ~ granodiorite



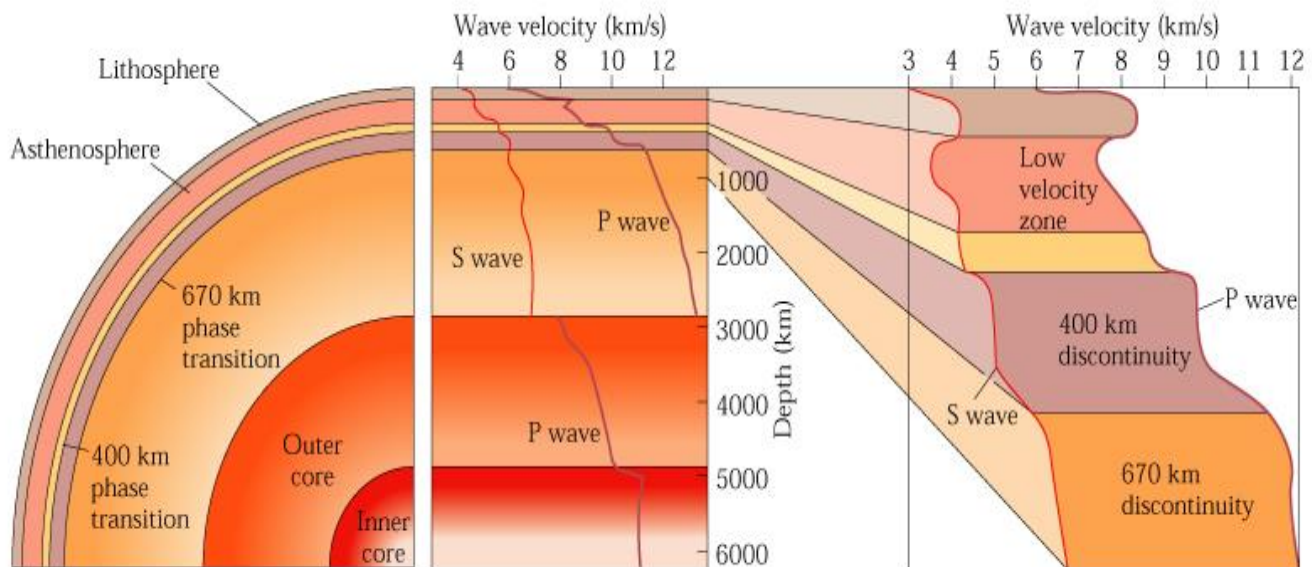
THE MANTLE

- ➔ The mantle of the earth forms a 2885 km thick layer surrounding the core
- ➔ In volume, it is the largest part of the earth
- ➔ Moho separates the mantle from crust. After the Moho, the velocity of P and S waves suddenly increases.
- ➔ The P and S waves travel at 8.1 kps and 4.5 kps respectively. This is due to the variation in the nature of the Earth's material
- ➔ The increase in velocity of P and S waves are not uniform at depth in mantle
- ➔ At first velocity increases then decreases and increases due to chemical and physical state changes
- ➔ Peridotite is the rock type found in the mantle.
- ➔ From the laboratory study, it is found that the Peridotite having the similar seismic velocity as in mantle
- ➔ Another suitable rock type is Eclogite, but it requires high pressure condition, which is not available in mantle condition
- ➔ Volcanic eruption from 60-100 km depth having the Peridotite fragments



- ➔ Outcrops of Peridotite exposed in the surface by combined action of erosion and tectonism
- ➔ Stony meteorite are Peridotite in composition which represent the mantle of an exploded planet
- ➔ Low Velocity Layer: From 50-250 km, the seismic wave velocities decrease indicating a layer of varying nature
- ➔ In this region, P-wave velocity 8.1 kps to 7.8 kps and again increase at 250 km to 8.1 kps
- ➔ The temperature at this level is enough to make Peridotites mobile so that velocity of seismic wave reduced in this region
- ➔ It is believed that the magma of basaltic composition generating from this region
- ➔ This layer is called as Asthenosphere. Volcanoes may have their chambers in this region
- ➔ This is overlain by the lithosphere (Crust and part of upper mantle)
- ➔ Asthenosphere underlined by the Mesosphere

- Two more discontinuities have been recognized at 400 km and 700 km depth. Where the rate of increase of seismic velocities are large
- The deep earthquakes are located upto 700 km depth that is in the upper mantle



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- **LOWER MANTLE**: In composition, it is a magnesium – iron silicate (similar to Pallasite).
- Beginning from a depth of 1000 km, lower mantle or mesosphere extends down to a depth of 2900 km
- In this zone, P-wave velocity increases from 8.1 kps to 14 kps, density increases from 3.3 to 5.6 kg / M³, pressure increases from 9 to 1400 kilobars, temperature goes up to 3000°C and gravity increases upto 1.025 m s⁻²

The Earth's Interior

Mantle:

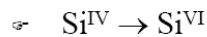
Peridotite (ultramafic)

Upper to 410 km (olivine → spinel)

- ♦ Low Velocity Layer 60-220 km

Transition Zone as velocity increases ~ rapidly

- ♦ 660 spinel → perovskite-type



Lower Mantle has more gradual velocity increase

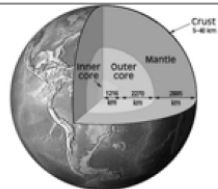


Figure 1-2. Major subdivisions of the Earth.
Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

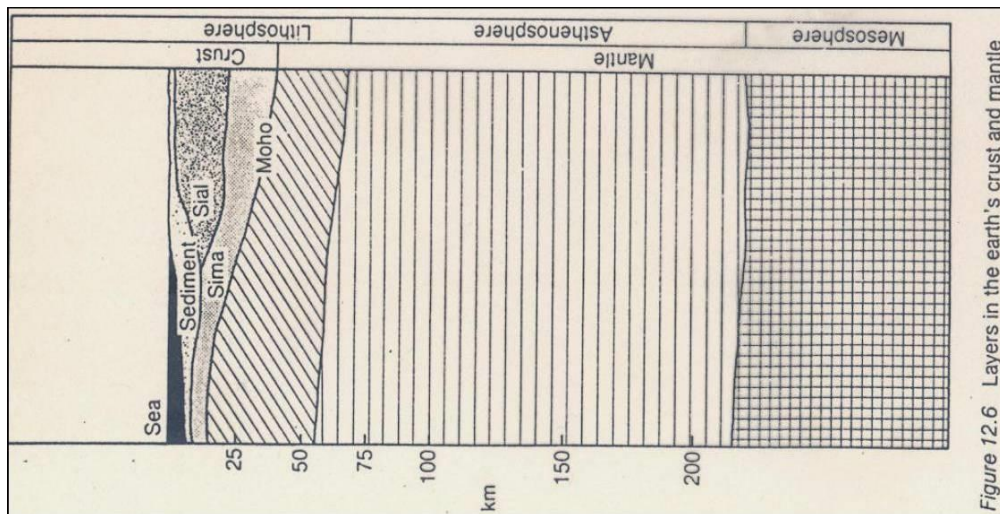
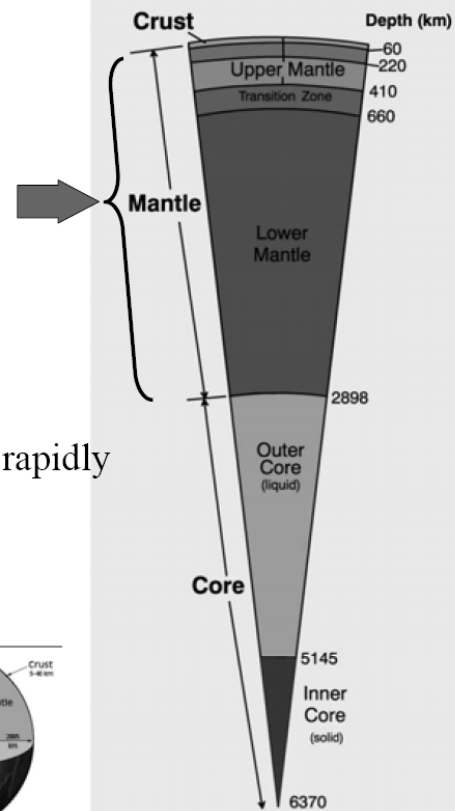
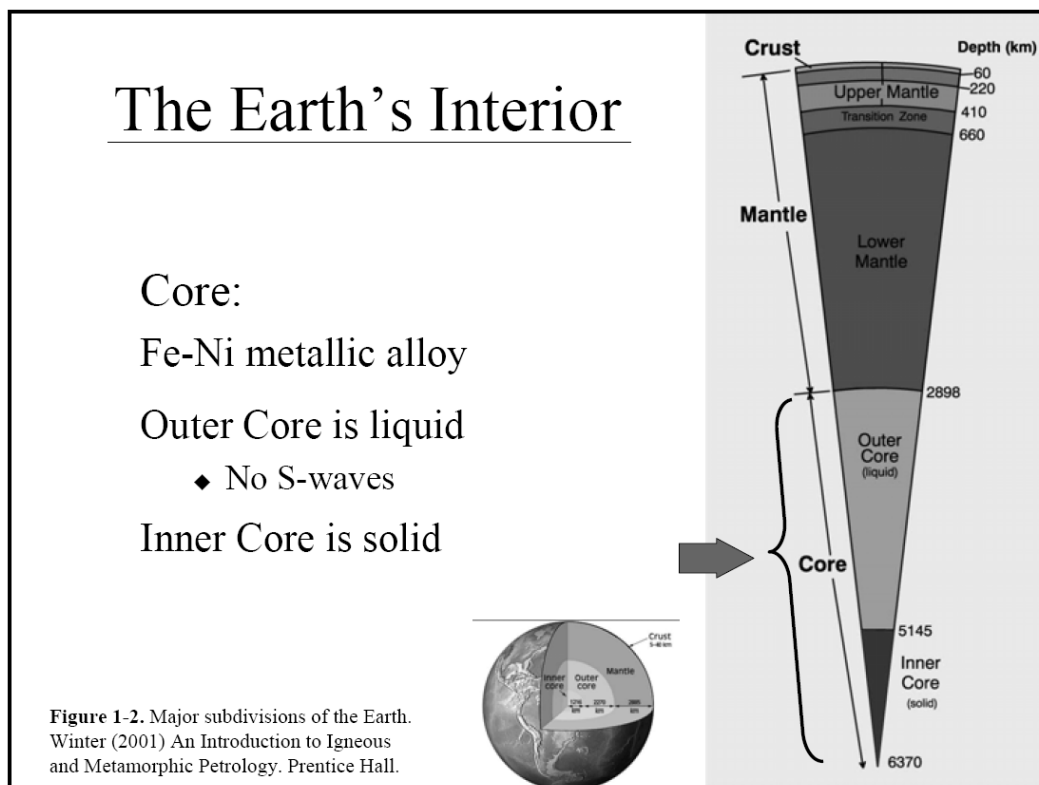


Figure 12.6 Layers in the earth's crust and mantle

THE CORE

➔ The central zone of the earth begins at the base of the mantle at 2900 km. At this depth, a sudden decrease in the wave velocity

- ➔ P-wave velocity decreases from 13.7 kps to 8.1 kps and S wave velocity drops from 7.2 kps to 0 kps. This indicates that the phase change at this level is from solid to liquid.
- ➔ This boundary of core and mantle marked by a discontinuity is termed as WEICHERT-GUTENBERG discontinuity
- ➔ The core is composed of two zones such as outer core (between 2,900 km and 5,155 km) and inner core (5,155 to 6371 km)
- ➔ The outer core is probably liquid in state. P-wave velocity increases from 8.1 to 10.3 kps at the inner core boundary
- ➔ Density increases to 11.8 kg / M³ and pressure increases to 3180 kilobars
- ➔ The probable composition of outer core is an alloy of iron and nickel in liquid state. Because temperature is so high
- ➔ As it is in liquid state, the iron alloy of outer core can flow. This flow generates the Earth's magnetic field
- ➔ The inner core with a radius of about 1220 km and a density of 13 g/cm and is a solid iron alloy



- ➔ The temperature may reach upto 4300⁰C. Even though it is hotter than outer core, the inner core is solid because it is deeper and subjected to great pressure
- ➔ The pressure keeps the atoms from wandering freely, so they pack together tightly
- ➔ An increase in the P-wave velocity at 5155 km indicates a phase change from liquid to solid
- ➔ There may be transitional zone of about 100 km thick
- ➔ P-wave velocity increases to 11.2 kps. The solid nature of the inner core is also evident from the recent investigation of low strength S-waves appearance above 143 degree
- ➔ The inner core probably grows through time at the expense of the outer core as the earth slowly cools
- ➔ Recent data suggest that the inner core rotates faster than the rest of the earth because of the electromagnetic force applied to it by the outer core

Earthquakes (Origin and Effects, Earthquake Belts, Epicenter, Seismograph, Magnitude Scale)

Earthquakes have affected the Earth since the formation of its solid crust almost 4 billion years ago

An earthquake is a shaking or trembling of Earth caused by sudden release of stored energy, usually along faults.

Building of stress stores the energy that is released suddenly as the rocks "break", resulting in an earthquake.

All earthquakes are generated in the crust or the upper mantle.

Most earthquakes take place in response to motion along a fault

Earthquakes can be caused by

- The sudden formation of a new fault**
- A new, sudden, episode of slip on an existing fault**
- A sudden collapse of the crystal lattice in the minerals of rock due to great pressure**
- The cracking of rock beneath a volcano when magma rises**
- The explosion of a volcano**
- Giant landslides**
- A meteorite impact**
- Underground nuclear bomb tests**

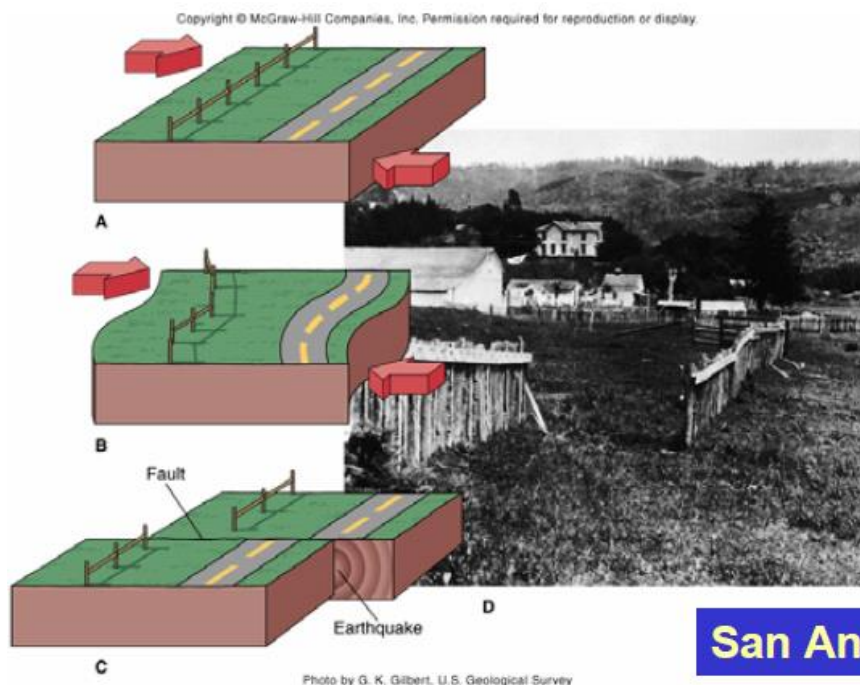
Usually associated with faulting or breaking of rocks

Continuing adjustment of position results in aftershocks

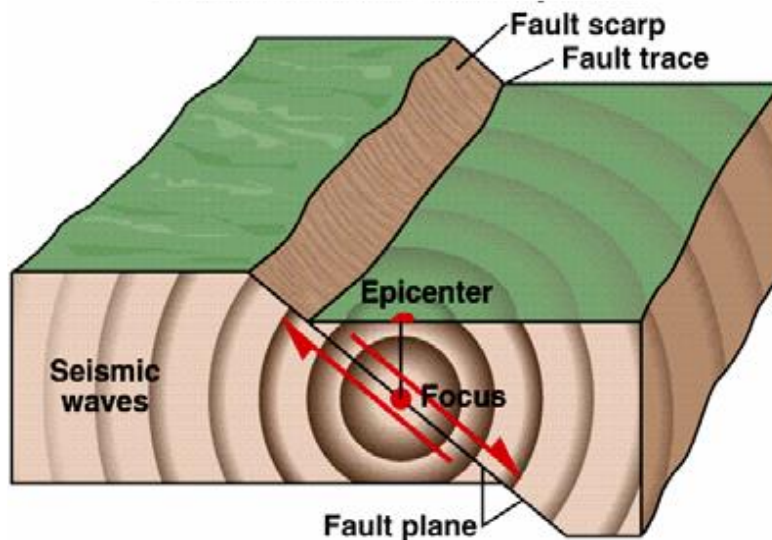
Elastic Rebound Theory

- A blade breaks when it bend. The broken parts vibrate for a little while**
- It explains that during the breakage of the blade, the accumulated energy of the applied force (bending) is released in the form of vibrations. The same principal applies to Earth also**

- ➔ Rocks are being affected by the stresses. Continued stress culminates strain
- ➔ Rocks are capable of withstanding strains up to a certain limit
- ➔ When the pressure is excessively applied, the rock suddenly breaks snapping back and forth to restore its strain-free state
- ➔ Through that rebounding action elastic strain energy is released causing the earth to vibrate
- ➔ Due to rupture and vibration, energy is released in waves that radiate outward from the fault

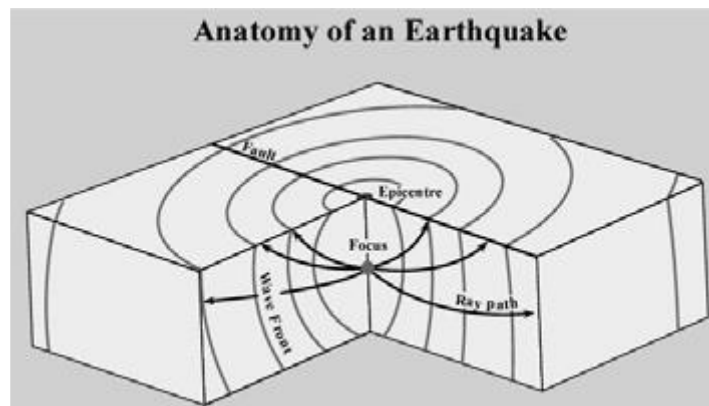


- ➔ The focus or hypocenter of an earthquake is the location within the earth where the energy of the earthquake produced or the place where earthquake originated
- ➔ The epicenter is the point on the earth's surface directly above the focus.



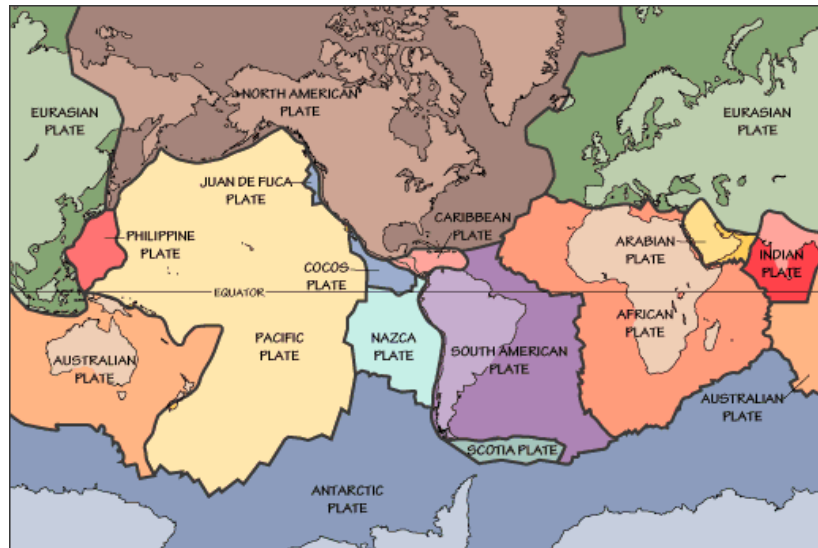
Wave front: surface defining the front of the shockwaves emitting outward from the focus.

Ray path: the direction of propagation of the shockwaves.



Earthquake Belt

- ➔ The Earth's surface is composed of a number of mobile "tectonic plates" which are in constant motion
- ➔ Most earthquakes are found at plate margins



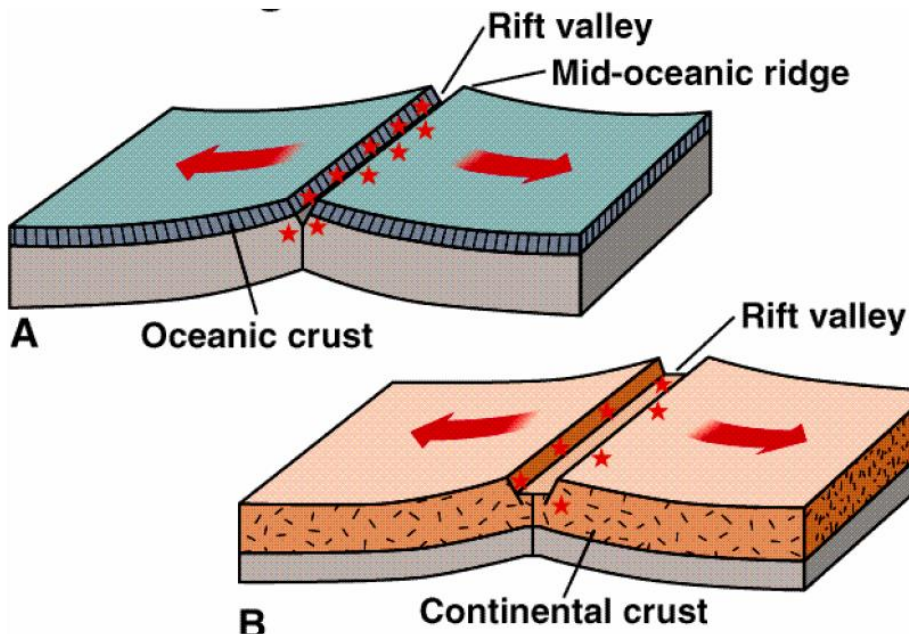
➔ The constant movement of the plates is referred to as plate tectonics

➔ There are three main types of plate boundaries:

- ❖ divergent
- ❖ convergent
- ❖ transform

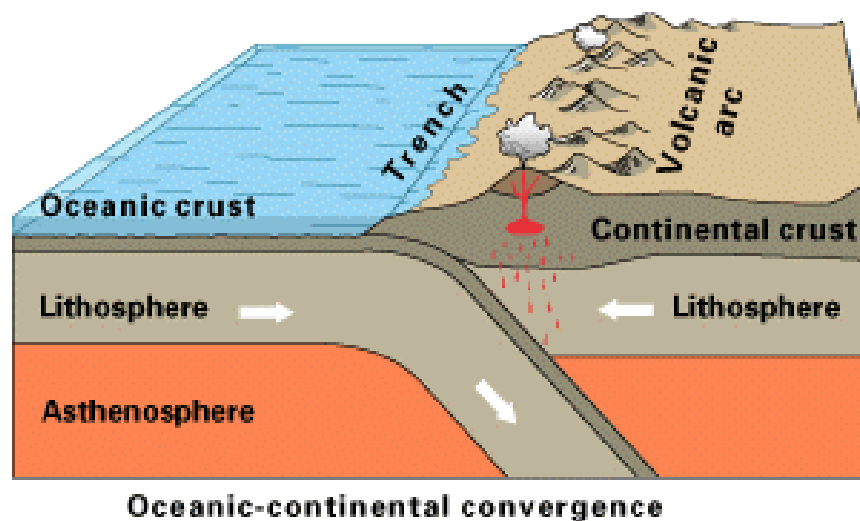
Divergent margins:

- ❖ Here two tectonic plates are in the process of being created
- ❖ Magma is injected into a crack, then cools and becomes new crust
- ❖ Two plates are moving away from each other
- ❖ The middle of the Atlantic Ocean is a divergent margin which is being torn, or rifted, apart and the two plates are separating continuously at a rate of several cm/yr



Convergent margins:

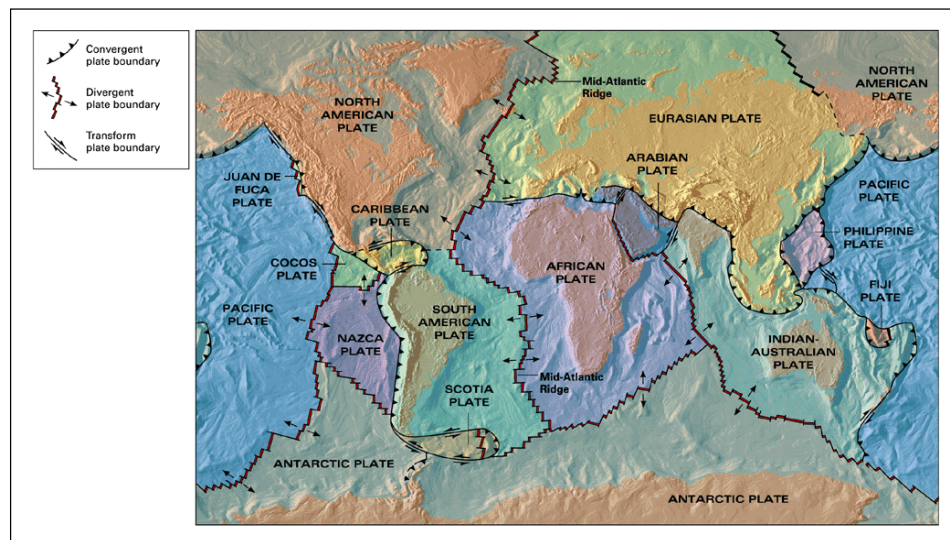
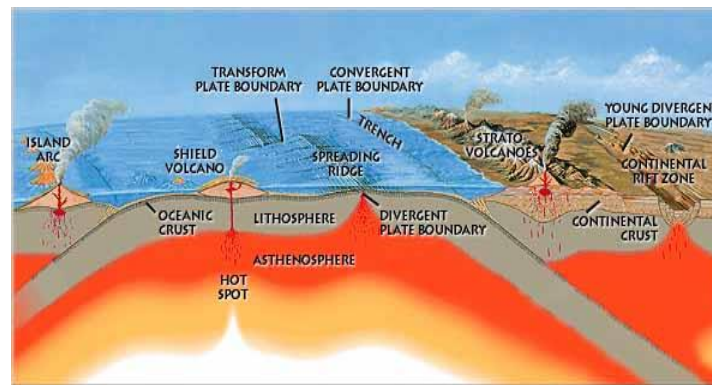
- Instead of two plates being created, they are being consumed...
- Here an oceanic plate slides beneath a continental plate, since the former is denser
- geologists refer to this process as subduction
- Large, destructive earthquakes occur here



- If two continental plates collide, they do not subduct, because they are too buoyant
- Instead, intense compression with crustal shortening and thickening occur
- Large, destructive earthquakes also are generated in this situation

Transform margins:

- The third type of plate margin is called a transform boundary
- Here, plates are neither created nor destroyed...
- they simply slide by one another

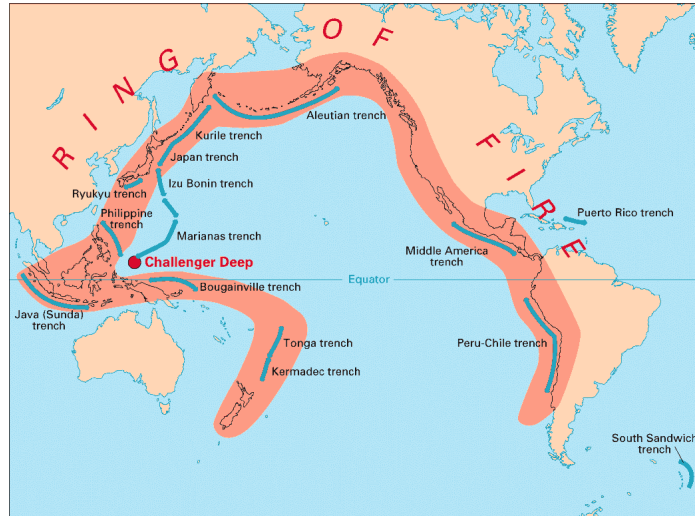


EARTHQUAKE BELTS OF WORLD

- ❖ Seismic belts coincide with the plate boundaries and volcanic belts
- ❖ Over 95% of the earthquakes occur in the plate boundaries

The CIRCUM-PACIFIC BELT

- ❖ 80% earthquakes occur in a continuous belt along the peripheral zone of Pacific Ocean
- ❖ The Pacific Ocean is enclosed by different plate boundaries and volcanic activity witnessed all along the belt
- ❖ The belt extends from Aleutian islands through Alaska, Coast of North and South Americas, New Zealand, East Indies, Philippines, Japanese islands to Kuril islands
- ❖ In the Pacific plate, 99% of deep earthquakes, 90% of intermediate and 80% of the shallow ones



THE ALPINE BELT

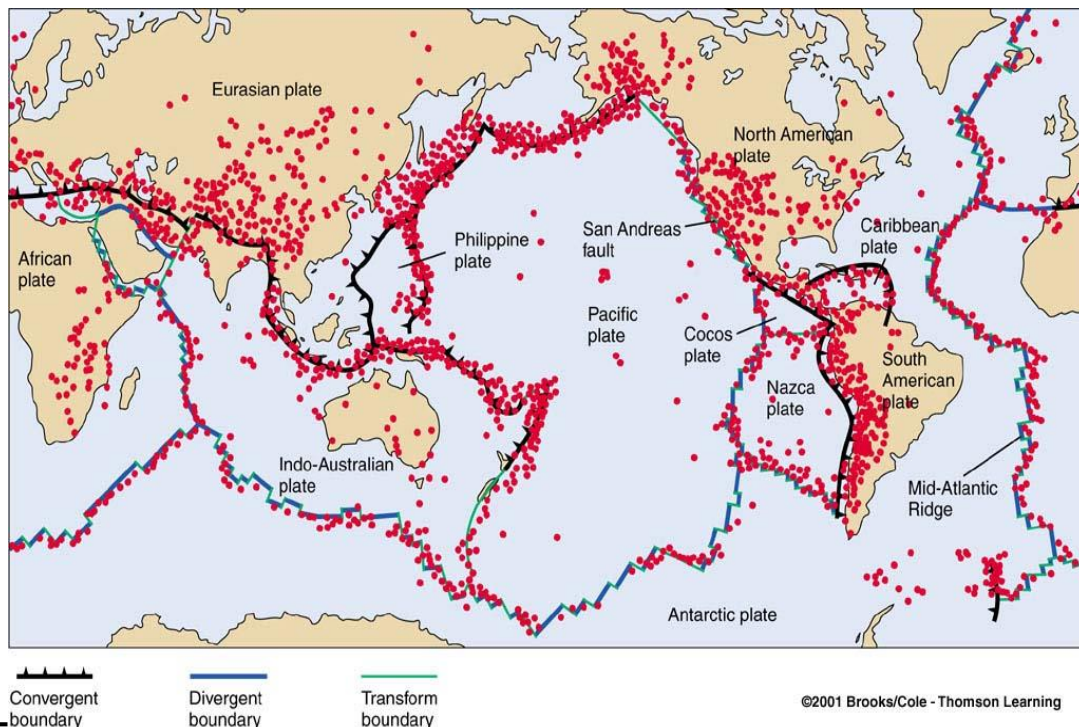
- ❖ It is the Mediterranean transasiatic belt
- ❖ The belt run through the Mediterranean, Himalayan, Sumatra, Java and Timor
- ❖ Intermediate to shallow earthquakes are common in this belt

THE PAMIR BAIKAL BELT

- ❖ This central Asian Belt is a zone of shallow earthquakes
- ❖ It extends from pamirs northwardly to Baikal of USSR

MID OCEAN BELTS

- ❖ Earthquakes of shallow type occur frequently along the mid-oceanic ridges, arctic and Indian ocean ridges



RIFT ZONES

- ❖ East African rift valleys are frequently visited by shallow earthquakes

HAWAIIAN ISLANDS ZONE

- ❖ In the Central Pacific ocean earthquakes occur in the Hawaiian islands

EASTERN ASIA ZONE

- ❖ In the east of Alpine and Pamir-Baikal belts lies an earthquakes prone triangular zone
- ➔ The great majority of earthquakes are located at plate margins
- ➔ This where magmatism, friction, faulting, etc., are most intense
- ➔ Earthquakes in plate interiors are comparatively less

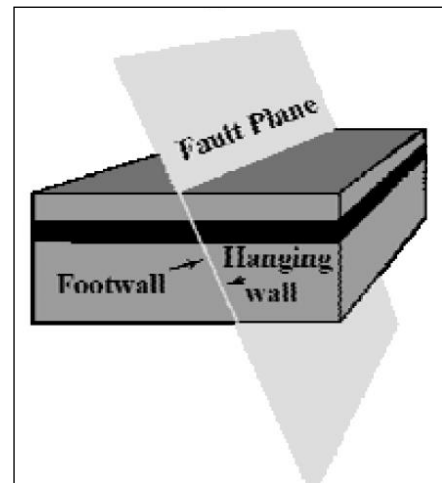
EARTHQUAKES ASSOCIATED WITH FAULTS

Faults: Planes along which rock bodies are displaced in response to forces acting in opposite directions on either side of the plane

Fault plane: plane along which movement takes place.

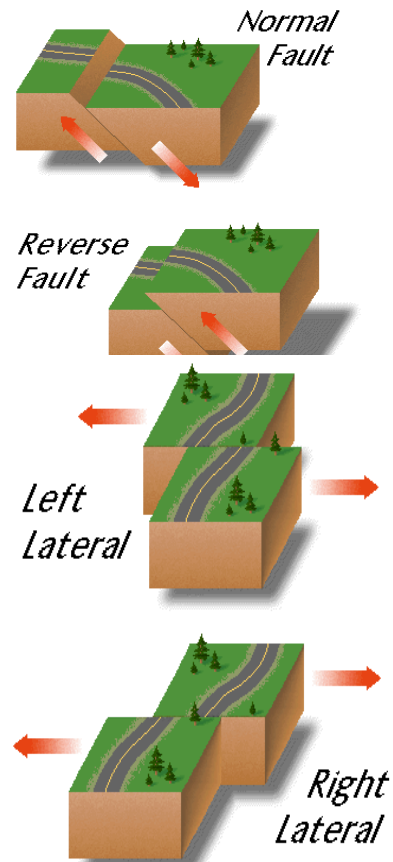
Hanging wall: rock body above the fault plane.

Footwall: rock body below the fault



Faults associated with earthquakes

- Faults are planes of weakness along which the Earth has been broken
- Movements on a fault can be either slow (ductile deformation) or fast (brittle fracture)
- When a fault behaves in a brittle manner and breaks, earthquakes are generated
- A normal fault is the result of tensional forces (e.g., rifting)
- Reverse and thrust faults are the result of horizontal compression
- These faults are termed strike-slip faults
- They are a small-scale version of transform plate tectonic margins
- They are termed left-lateral (sinistral) or right-lateral (dextral) according to their movement



CLASSIFICATION OF EARTHQUAKES

→ Earthquakes generally classified on the basis of depth of focus

- 1) Shallow focus earthquakes – Surface to 70 km
- 2) Intermediate focus earthquakes – 70 to 300 km
- 3) Deep focus earthquakes – 300 to 700 km

- ❖ Most of the earthquakes are shallow focus earthquakes
- ❖ Shallow focus earthquakes occur along mid-oceanic ridges and rift valleys
- ❖ Intermediate and deep focus earthquakes are concentrated along convergent plate boundaries

SEISMOMETERS, SEISMOGRAPHS AND SEISMOGRAMS

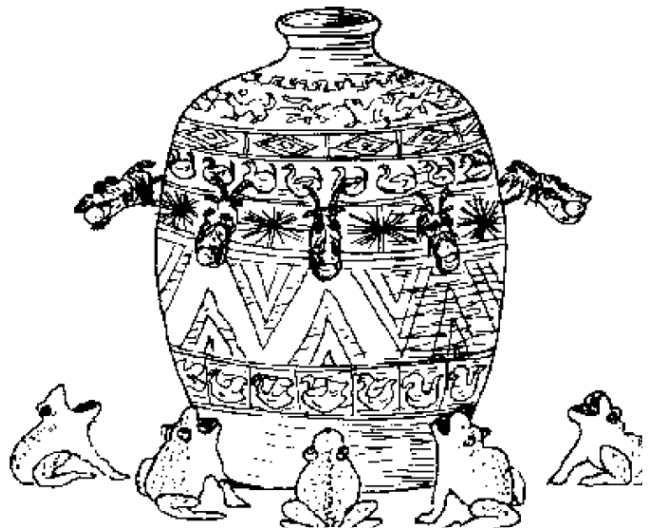
- ❖ Seismometer: an instrument that detects the passage of a shock wave through the crust.
- ❖ Seismograph: the instrument that records the passage of a shock wave
- ❖ Seismogram: the printed record of the shock waves.

SEISMOGRAM

Chinese philosopher Chang Hêng invented the first seismometer in 132 AD.

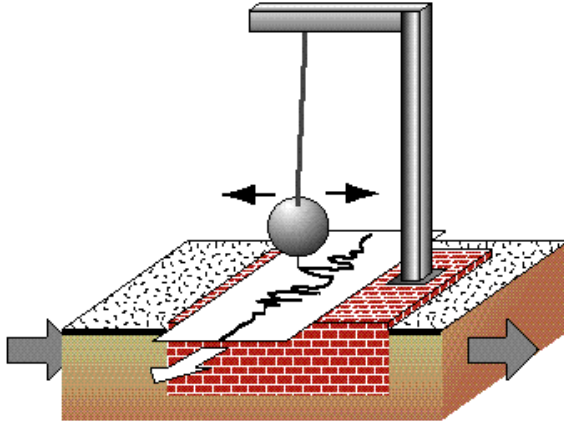
2 metres in diameter with 8 balls oriented with the principle compass points.

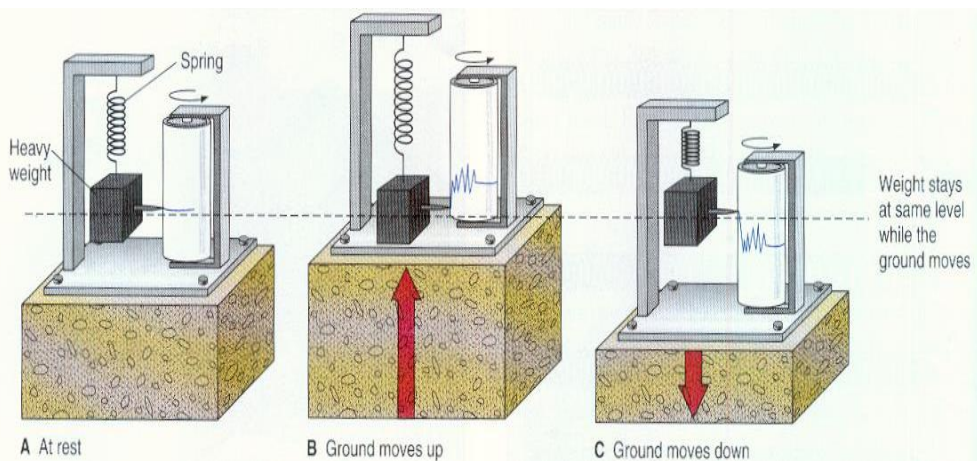
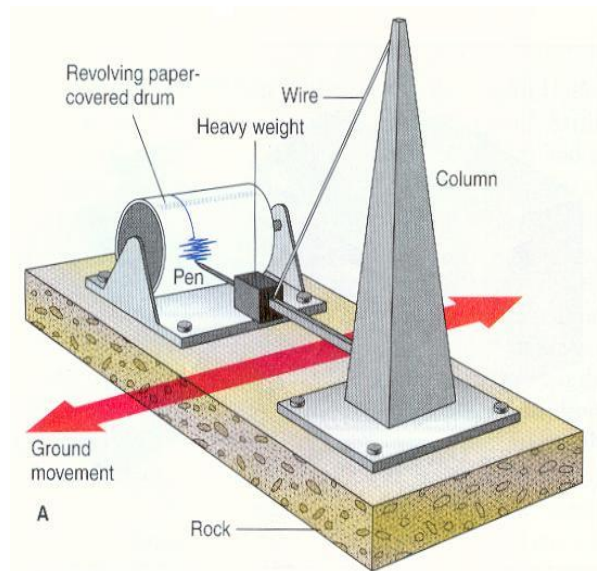
When there was an earthquake, one of the mouths would open and drop its ball into a bronze toad at the base, making a sound and supposedly showing the direction of the earthquake



Later seismographs were based on the property of Inertia

- ➔ According to Newton's law of motion
- ➔ "Every object tends to keep its state of rest unless it is disturbed by an external force". This property is known as Inertia
- ➔ In seismographs, the principal of inertia is used by adding one inertial element. So that one part of the instrument can be motionless while rest of the instrument affected by the earthquakes
- ➔ An ideal seismograph consists of a pillar. The pillar is well founded to the bed rock. A heavy metal weight is suspended by a spring from the top of pillar
- ➔ A drum is synchronized with a clock. The drum rotates and advances along the axis of the drum
- ➔ Suppose an earthquake occurs, the ground is set in motion. This motion affect the pillar and drum.
- ➔ But the heavy weight remains unaffected due to its inertia
- ➔ Thus a trace is marked by the pen on the revolving papers of the shaking drum
- ➔ Recording pen is on a free swinging heavy weight that remains stationary as the recording chart moves in response to the shock waves.

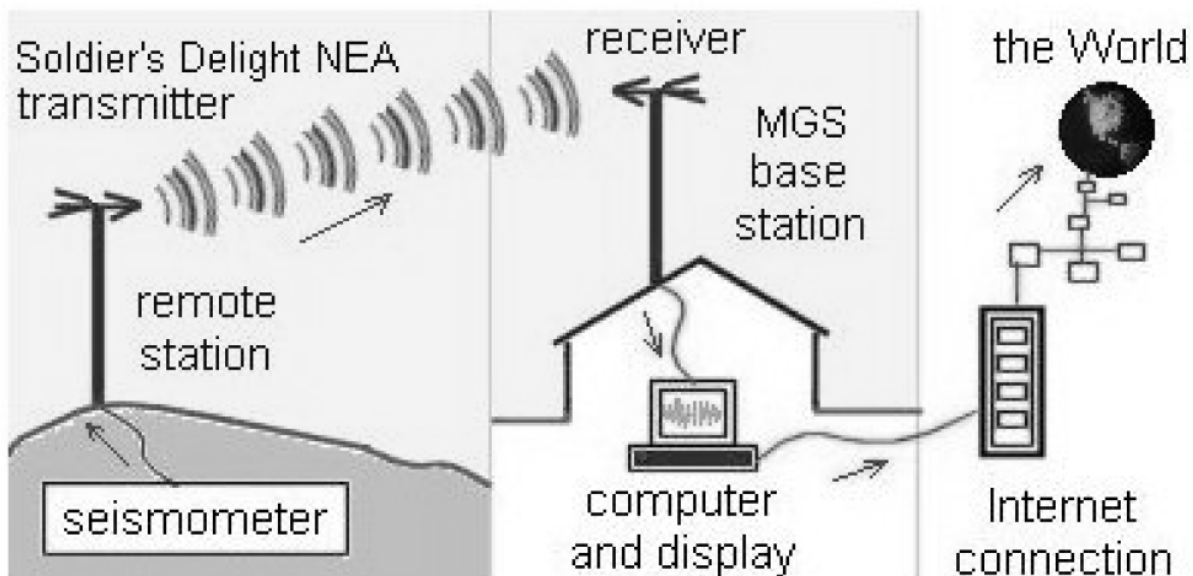




- ➔ A simple seismograph for detecting vertical rock motion.
- ➔ The pen records the ground motion on the seismogram as the spring stretches and compresses with up and down movement of the spring.
- ➔ Frame and recording drum move with the ground. Inertia of the weight keeps it and the needle relatively motionless.

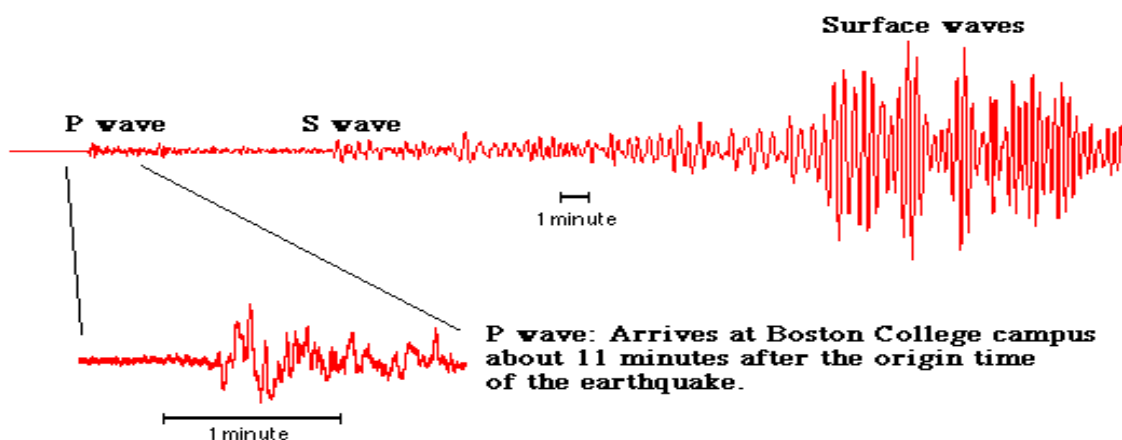
Modern seismometers have electronic sensors and transmit their records digitally.

The seismogram is produced remotely from the seismometer.



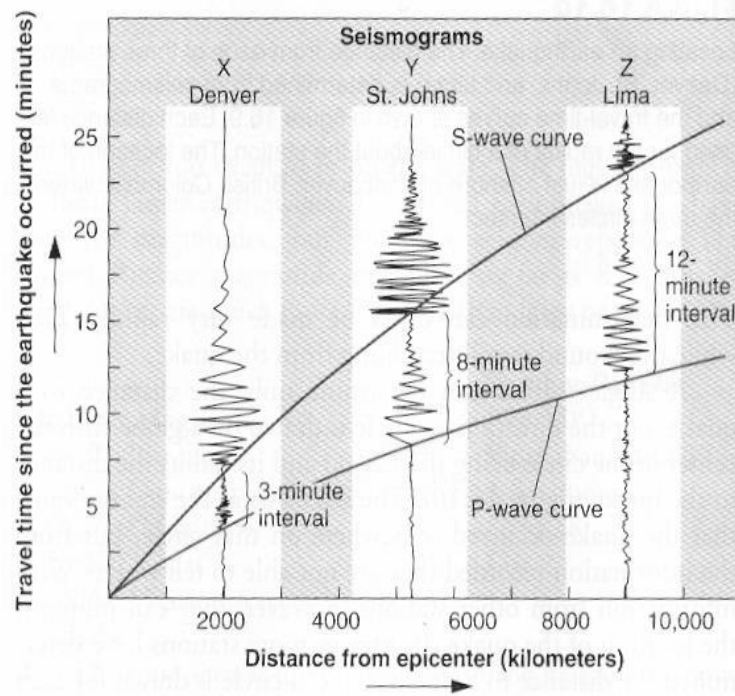
Seismogram :

➔ **A seismogram is the record of an earthquake in the form of trace marking the passage of the seismic wave**



Determining the Distance to an Earthquake

➔ **Travel-time curve: a plot of seismic-wave arrival times against distance**



A travel time curve is used to determine the distance to an earthquake.

Note that the time interval between the first arrival of P and S waves increases with distance from the epicenter.

Seismogram X has a 3-minute interval between P and S waves corresponding to a distance of 2,000 km from the epicenter, Y has an interval of 8 minutes, so the earthquake occurred 5,300 km away, and Z an interval of 12 minutes, and is a distance of 9,000 km from the epicenter

→ The distance to the earthquake epicentre may be calculated using the time lag for the arrival of S-waves after the arrival of P-waves and the P and S wave velocities

→ $T_d = T_s - T_p$ (T_d is the time lag, T_s and T_p is the arrival time of P and S wave)

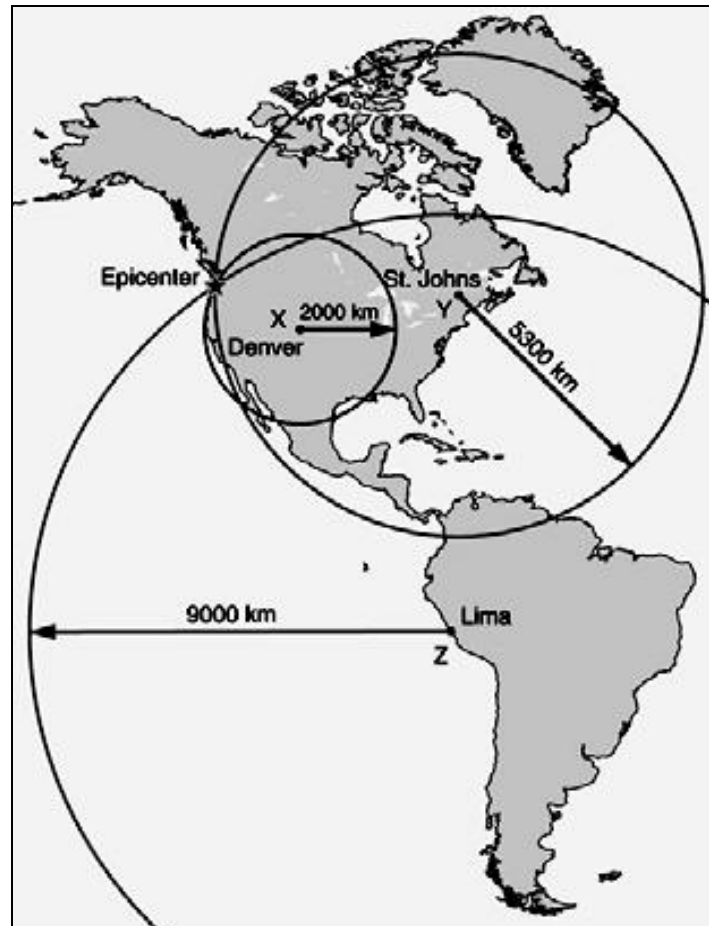
→ Using the following formula distance to the epicentre can be calculates

$$d = T_p \frac{V_p V_s}{V_p - V_s}$$

Determining the Geographical Location of an Earthquake

→ For determining the location of an epicentre, seismic data from at least three station needed

- ➔ The distance of each station from the epicentre can be calculated using the above formula
- ➔ On a map, circles are drawn around the seismic station with a radii of their epicentral distance
- ➔ The intersection point of three circle is the Epicentre



SCALES OF EARTHQUAKES

INTENSITY SCALE

- ➔ A scale devised by Mercalli (later modified by Wood and Neumann) on the basis of the damage and loss to structure and life due to earthquakes
- ➔ Maximum at the epicentre, decreasing with distance from it

I. Instrumental

Detected only by seismographs

II. Feeble

Noticed only by sensitive people.

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III. Slight	Resembling vibrations caused by heavy traffic.
IV. Moderate	Felt by people walking; rocking of free standing objects.
V. Rather strong	Sleepers awakened and bells ring.
VI. Strong	Trees sway, some damage from overturning and falling objects.
VII. Very strong	cracking of walls, Plaster falls
VIII. Destructive	Chimneys fall and there is some damage to buildings.
IX. Ruinous	Ground begins to crack, houses begin to collapse and pipes break.
X. Disastrous	Ground badly cracked and many buildings are destroyed. There are some landslides.
XI. Very Disastrous	Few buildings remain standing; bridges and railways destroyed; water, gas, electricity and telephones out of action.
XII. Catastrophic	Total destruction; objects are thrown into the air, much heaving, shaking and distortion of the ground.

MAGNITUDE SCALE

- In 1932, Richter devised a scale based on the magnitude of the earthquakes is called Richter scale**
- Based on the amplitude of seismic waves measured on a seismograph, corrected for distance from the epicentre.**
- Proportional to the amount of energy released at the focus.**
- Value does not vary with distance from epicentre.**
- Logarithmic: a 1 unit increase in the scale represents an increase in energy release by a factor of 31.**

Earthquake Magnitude Scale

Magnitude	Earthquake Effects	Estimated Number Each Year
2.5 or less	Usually not felt, but can be recorded by seismograph.	900,000
2.5 to 5.4	Often felt, but only causes minor damage.	30,000
5.5 to 6.0	Slight damage to buildings and other structures.	500
6.1 to 6.9	May cause a lot of damage in very populated areas.	100
7.0 to 7.9	Major earthquake. Serious damage.	20
8.0 or greater	Great earthquake. Can totally destroy communities near the epicenter.	One every 5 to 10 years

Magnitude (Richter Scale)	Approximate Maximum Intensity	Number Per Year	Approx. energy release (Kg of TNT equivalents).
1		2,900,000	20
2	II	360,000	600
3		49,000	20,000
4	III	6,200	600,000
5	VI	800	20,000,000
6	VII	120	600,000,000
7	X	18	20 billion
8	XII	1	60 billion
9		Decades apart	20 trillion

Upper limit, about 9.5 on the Richter Scale.

Destructiveness of an earthquake based on

- ❖ Earthquake magnitude
- ❖ Distance to epicenter
- ❖ Depth
- ❖ Strength of building

- ❖ Nature of soil or bedrock on which foundations are built
- ❖ Other local conditions

EFFECT OF EARTHQUAKES

- Aftershocks
- Liquefaction
- Landslides
- Tsunamis
- Building destruction
- infrastructure loss
- Fires
- Personal loss

Aftershocks

- Aftershocks normally occur after a major earthquake
- There may be many thousands of aftershock events over the space of months or even years
- Although their magnitudes generally decrease with time, aftershocks have potential to cause significant damage to already weakened materials (e.g., rocks, soils, buildings, power and gas lines)

Liquefaction

- Loss of sediment strength due to rapid upward flow of pore waters in response to vibration.
- Sandy soil turns to quicksand.
- Buildings sink and tilt

Landslides

- The ground vibrations and severe shaking associated with an earthquake can induce landslides in mountainous areas
- Surface waves send loose debris moving down slopes.

- ➔ Dangerous in areas of high relief
- ➔ Rock and debris slides down slope
- ➔ Can dam rivers to cause floods and/or mudslides
- ➔ Damage can be distant from area affected by surface vibration
- ➔ This example in the Santa Susana Mtns. was caused by the 1994 Northridge event near Los Angeles

Tsunamis

- **Tsunamis** are ocean waves caused by displacement of water column by
 - ➔ Underwater volcanic eruptions
 - ➔ Underwater earthquakes
 - ➔ Underwater landslides
 - ➔ Asteroid/comet impacts

Waves are generated above the disturbance and propagate outward from that point

They can be devastating at great distances from the epicenter

Building destruction

- Buildings are damaged or destroyed by **ground vibrations and shaking**
- The **magnitude and duration** of shaking are important factors in the extent of damage
- **Liquefaction and aftershocks** increase the damage
- **Masonry** is not capable of withstanding significant bending stresses
- **Wood** is more resistant because it is more yielding
- But wood is vulnerable to **fires**...

Fires

- The ground shaking will **rupture** power and gas lines...

- ...and damage to water mains prevents or hinders fire fighting efforts

Personal loss

- After the earthquake, there is no account for personal loss

Appropriate building codes which can withstand earthquake damage

- ➔ Bedrock foundations best
- ➔ Avoid asymmetrical buildings
- ➔ Bolt house firmly to foundations
- ➔ Appliances firmly bolted down
- ➔ Gas lines flexible
- ➔ Cupboards, shelving attached to walls
- ➔ Heavy objects at low levels; anchor heavy furniture
- ➔ Beds away from windows to avoid broken glass

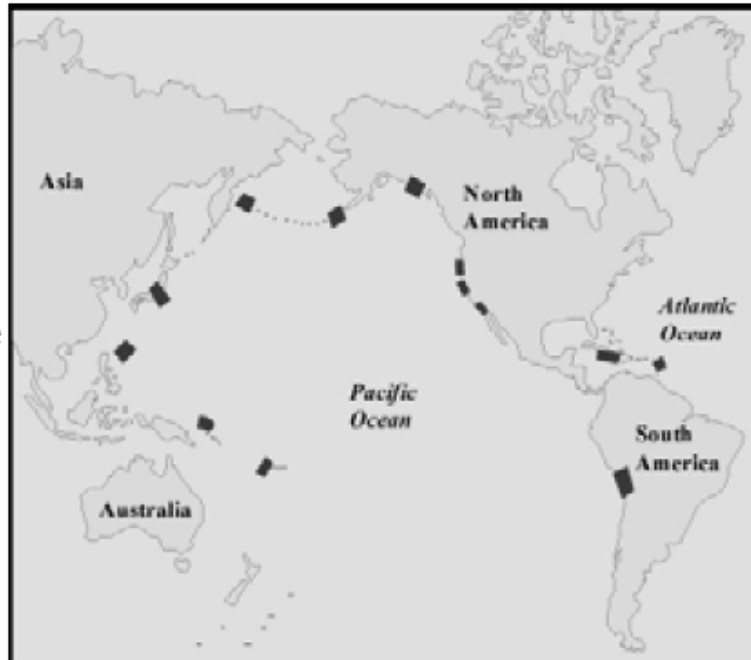
Warning and prediction

- Precursory seismicity
- Precursory deformation
- Changes in physical properties of rocks near a fault
- Changes in water levels, soil gases
- Unusual behaviour of animals
- earthquake recurrence interval...seismic gap
- role of paleoseismology
- Yet our predictive ability is rudimentary, so we use probabilities
- e.g., 86% probability that a destructive quake of $M > 7$ will hit southern California in the next 30 years (1994 estimate)
- Thermal anomaly and radon gas emission

Seismic Gaps

Regions where earthquakes do not take place with the frequency and/or magnitude expected for the tectonic setting.

Gaps are regions where powerful earthquakes may be expected despite the historical record.



In gaps plates may be sliding smoothly past each other (no earthquakes).

OR

Plates may be stuck and storing strain energy to be released as a large magnitude earthquake.

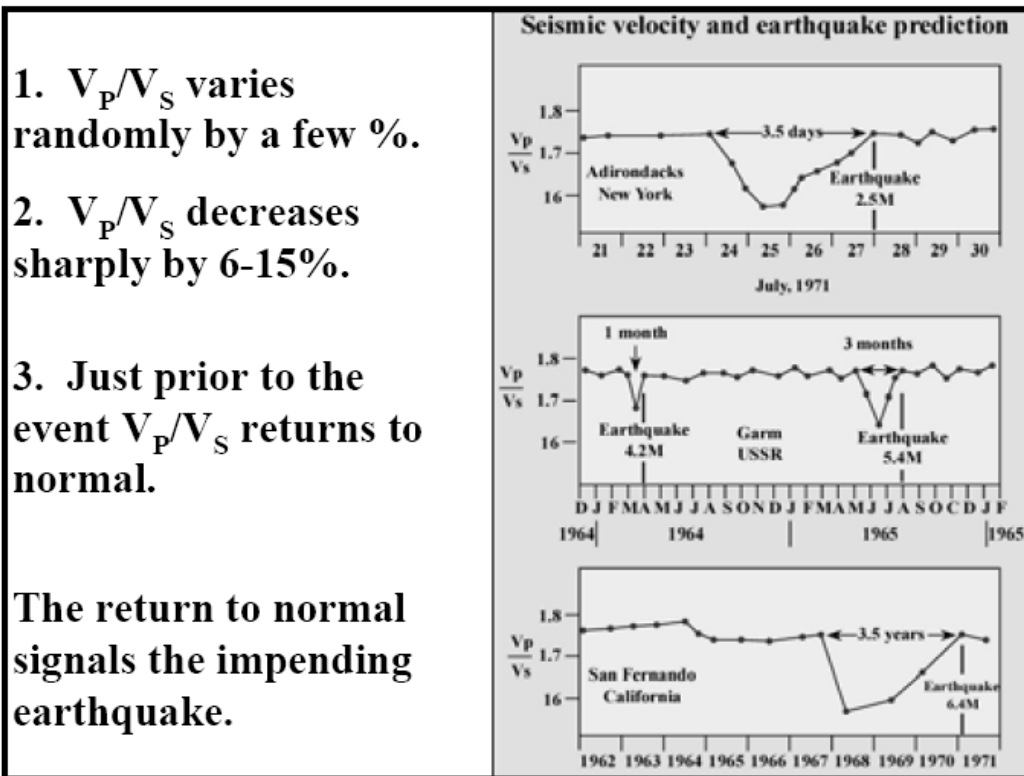
Seismic risk may be extreme in some seismic gaps.

Short term prediction

A variety of methods that identify precursor events, events that occur prior to earthquakes that can be used to provide warning.

Seismic wave velocities

Changes in the ratio of V_P/V_S over time (V_P and V_S measured from induced shockwaves – explosive charges).



Why does V_P/V_S vary in this manner?

Building strain causes microfractures.

$$V_P = \sqrt{\frac{K + \frac{4}{3}n}{d}} \quad V_S = \sqrt{\frac{n}{d}}$$

K = bulk modulus (incompressibility)

n = rigidity

d = density

Microfractures reduce K and n .

V_P varies with K and n whereas V_S varies only with n .

Therefore there is a net decrease in V_P/V_S .

Ground level deformation

Microfractures cause the rock to dilate (increase in volume).

On the ground surface above the site of strain accumulation the dilation causes the ground to rise.

Measuring ground level elevation in seismically active areas can show where strain is accumulating and where earthquakes may occur.

Not feasible when strain is accumulating deep in the crust.

Groundwater Chemistry

Microfractures can release gases from rocks.

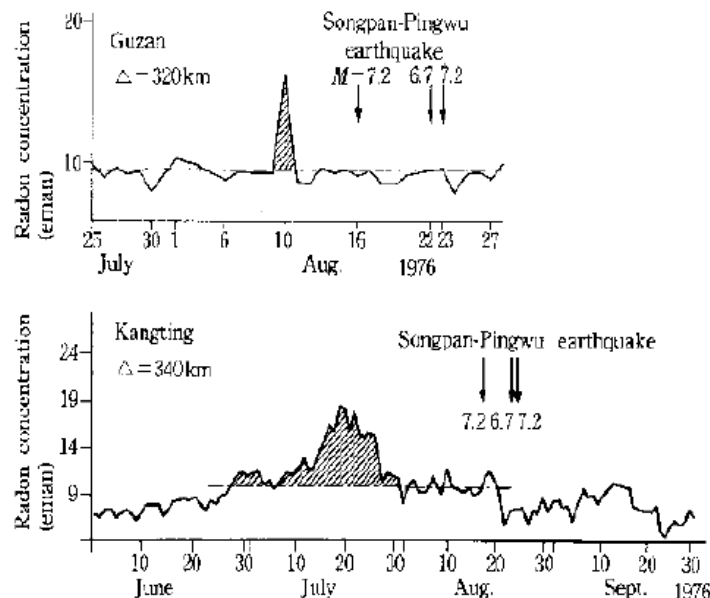
These gases dissolve in groundwater and turn up in well water.

Monitoring concentrations of gases can provide evidence for microfractures and the strain accumulation that causes them.

Radon gas is one such gas that has been useful in some areas.

It forms in the rock as a product of the radioactive decay of Uranium-238.

Just prior to an earthquake the concentration of radon has been observed to increase sharply in deep water wells.



Microearthquake swarms

Microfractures involve the release of a small amount of energy, producing microearthquakes.

Microearthquakes can be measured with very sensitive seismometers.

As strain builds thousands of microearthquakes are generated.

Monitoring the microearthquakes can identify locations of strain accumulation risk of an earthquake.

Direct Sensors

Monitoring primary seismic waves directly.

P-waves arrive first so they give direct warning of incoming surface waves.

e.g., focus 200 km away, P-waves will arrive about 30 seconds before surface waves.

Off the coast of Japan, near the trench, underwater seismometers send signals to shore when the first p-waves arrive.

Sirens go off giving several providing tens of seconds to take action (get under furniture, etc.).

**Anecdotal evidence that animals may be able to
forewarn of an Earthquake**

Place	Earthquake	When observed	Description
China Tientsin Zoo	July 18, 1969 (7.4M)	2 hours before	Tiger depressed; pandas screamed; turtles restless; yak did not eat; swans stayed away from the water.
China Haicheng	Feb. 4, 1975 (7.3M)	1.5 months 1-2 days 20 minutes	Snakes came out of hibernation. Pigs did not eat and climbed walls. Turtle jumped out of water and cried
Japan Tokyo	Nov. 11, 1855 (7.3M)	1 day before	Wild cats cried; rats disappeared.
Japan Sanriku	March 3, 1933 (8.5M)	1 week before 2-3 days before 1 day before Several hours	Rats disappeared; Rats and cats unusually quiet; Seagulls left their usual habitat; Duck stayed away from usual sleeping place.

Place	Earthquake	When observed	Description
San Francisco	April 18, 1906 (8.2M)	Night before Few seconds	Dogs barked. Horses and cows snorted and stampeded; cats felt aftershocks before people.
US	Aug. 17, 1959 (7.1M)	Conflicting	Water birds left lake area.
Italy	May 6, 1976 (6.7M)	2-3 hours before	Cats left houses and villages; mice and rats left hiding places; fowl refused to roost.
Italy Calbria	Feb. 5, 1783 (?M)	?	Geese cackled; dogs howled so unbearably loudly that they had to be shot!

Devastating Historic Earthquakes			
Date	Location	Magnitude	Fatalities
1556	China	9.0	850,000
1737	India	?	300,000
1905	India	?	370,000
1908	Messina, Italy	7.5	86,926
1920	China	8.6	100,000
1923	Japan	8.3	200,000
1970	Northern Peru	7.7	66,794
1988	Armenia	6.8	55,000
1999	Turkey	7.8	15,000
2001	India	7.7	20,103

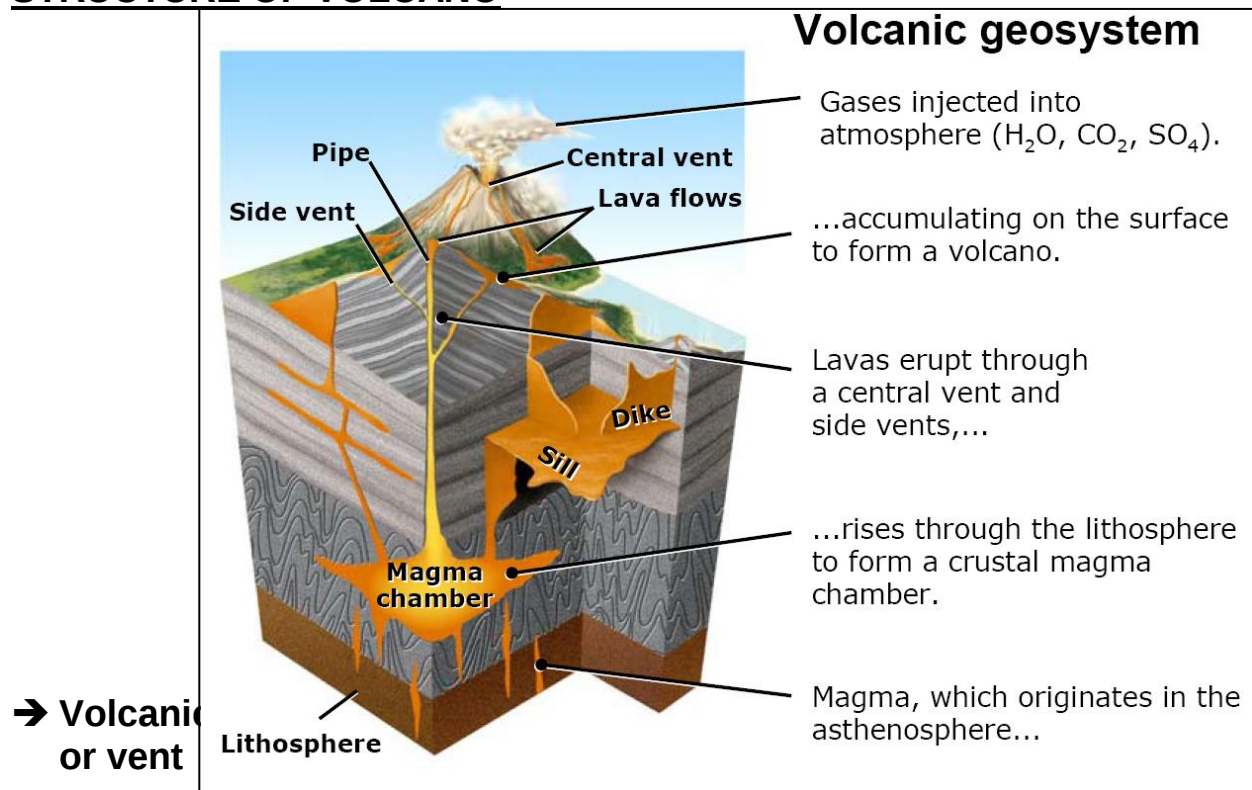
Table 1: Some Past Earthquakes in India

Date	Event	Time	Magnitude	Max. Intensity	Deaths
16 June 1819	Cutch	11:00	8.3	VIII	1,500
12 June 1897	Assam	17:11	8.7	XII	1,500
8 Feb. 1900	Coimbatore	03:11	6.0	X	Nil
4 Apr. 1905	Kangra	06:20	8.6	X	19,000
15 Jan. 1934	Bihar-Nepal	14:13	8.4	X	11,000
31 May 1935	Quetta	03:03	7.6	X	30,000
15 Aug. 1950	Assam	19:31	8.5	X	1,530
21 Jul. 1956	Anjar	21:02	7.0	IX	115
10 Dec. 1967	Koyna	04:30	6.5	VIII	200
23 Mar. 1970	Bharuch	20:56	5.4	VII	30
21 Aug. 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 Oct. 1991	Uttarkashi	02:53	6.6	IX	768
30 Sep. 1993	Killari (Latur)	03:53	6.4	IX	7,928
22 May 1997	Jabalpur	04:22	6.0	VIII	38
29 Mar. 1999	Chamoli	12:35	6.6	VIII	63
26 Jan. 2001	Bhuj	08:46	7.7	X	13,805

VOLCANOES

- **Volcanoes:** opening in Earth's crust through which molten rock, gases, & ash erupt to the land around the opening
- Volcanoes is the Windows of Earth's interior
- Volcanoes are also called burning mountains
- Volcanic mountains are build result of volcanic activity
- The term volcano derived from 'Vulcan' the god of fire
- Molten magma rises within the Earth and is erupted either quietly (lavas) or violently (pyroclastics)

STRUCTURE OF VOLCANO



- Funnel shaped top of the mountain called crater is connected to the magma chamber by volcanic pipe or vent
- Magma chamber is located at mantle
- Parasitic or Secondary cones are the cones developed on the flank of the main cone by the eruption

→ Caldera is the enlarged crater

CLASSIFICATION or TYPES OF VOLCANOES

Volcanoes can be classified on the basis of

- The state of the volcano
- The Mode of eruption
- The types of eruption

BASED ON THE STATE OF THE VOLCANOES

Active volcano

- are those which are active at present or have been in eruption at least during the historic past. Vesuvius, Italy and Mauna Loa, Hawaii

Dormant or Slumbering volcano

- are those which have not been in eruption in the historic period but at the same time may have time to erupt in future. Barren island, Bay of Bengal

Extinct volcanoes

- these are geologically ancient and have totally stopped all their activities. Narcondam and Popa islands, Bay of Bengal

VOLCANOES BASED ON THE MODE OF ERUPTION

- Volcanoes may be classified on the basis of their mode of eruption
- That is whether the eruption takes place from subsurface to surface through a pipe like channel or through a fissure or crack in the earth surface

1. CENTRAL VENT TYPE :

Based on eruptive force, composition and Viscosity of the magma ...

- VOLCANIC CONES (due to low viscosity magma)
- CINDER CONES (glassy material around the cone)
- COMPOSITE CONES (alternating layers of pyroclastic material and lava)

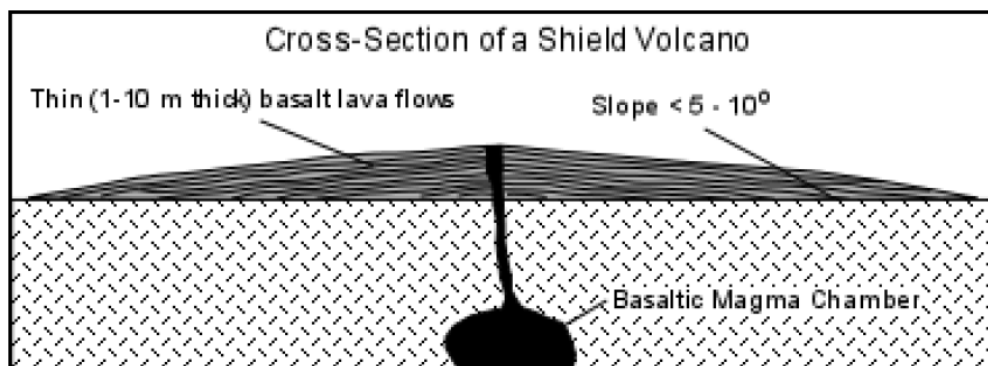
2. FISSURE TYPE :

Lava eruption takes place through fractures and fissures.

1. CENTRAL VENT TYPE :

VOLCANIC CONES / SHIELD VOLCANOES:

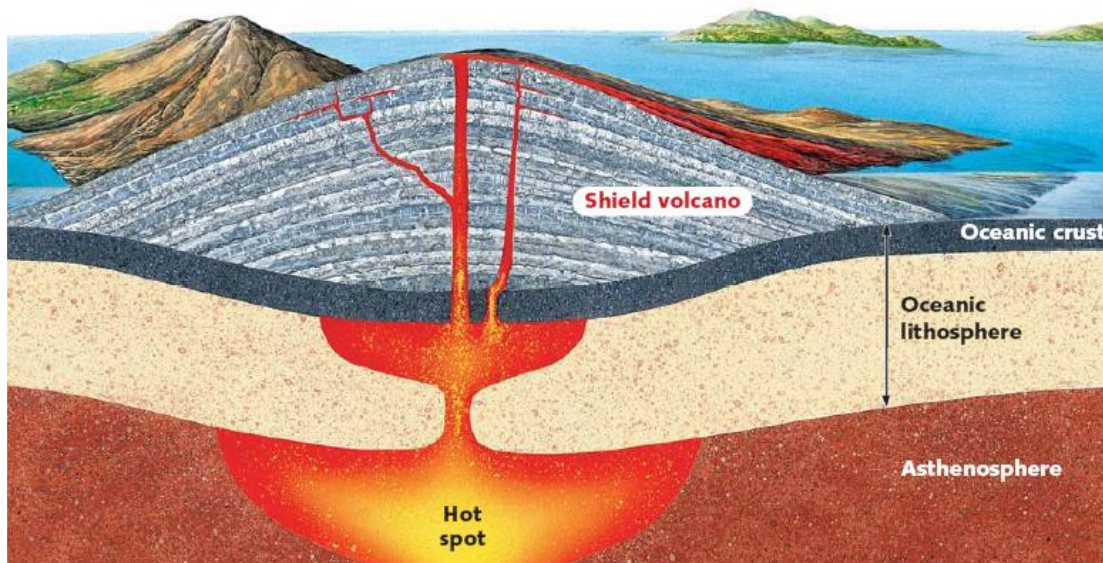
- These are developed when eruption is central. Ratio of height to perimeter will be very less.
- These are composed almost entirely of relatively thin lava flows built up over a central vent.
- Such broad based low elevated volcanic cones are termed as shield volcanoes or lava cones



- A shield volcano is characterized by gentle upper slopes (about 5°) and somewhat steeper lower slopes (about 10°).
- Most shields were formed by low viscosity basaltic magma that flows easily down slope away from the summit vent.

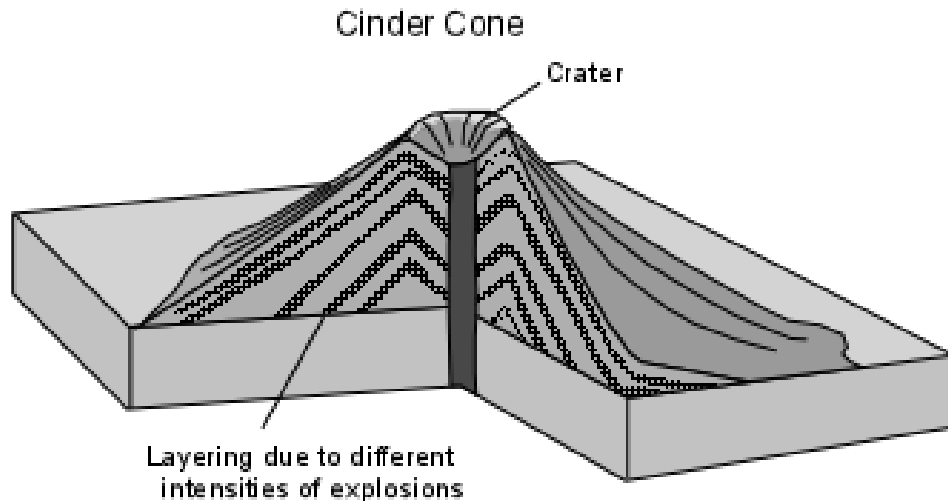
- Most shield volcanoes have a roughly circular or oval shape in map view.
- Very little pyroclastic material is found within a shield volcano, except near the eruptive vents, where small amounts of pyroclastic material accumulate as a result of fire fountaining events.
- Shield volcanoes thus form by relatively non-explosive eruptions of low viscosity basaltic magma.
- However, flows may be frequent & large in volume and results in damage to homes, highways, & other property
- Tend to form over hotspots & in oceans (b/c oceanic crust is made of basalt)

MAUNA LOA is a **shield volcano** on the Island of Hawaii.



CINDER CONES / TEPHRA CONES

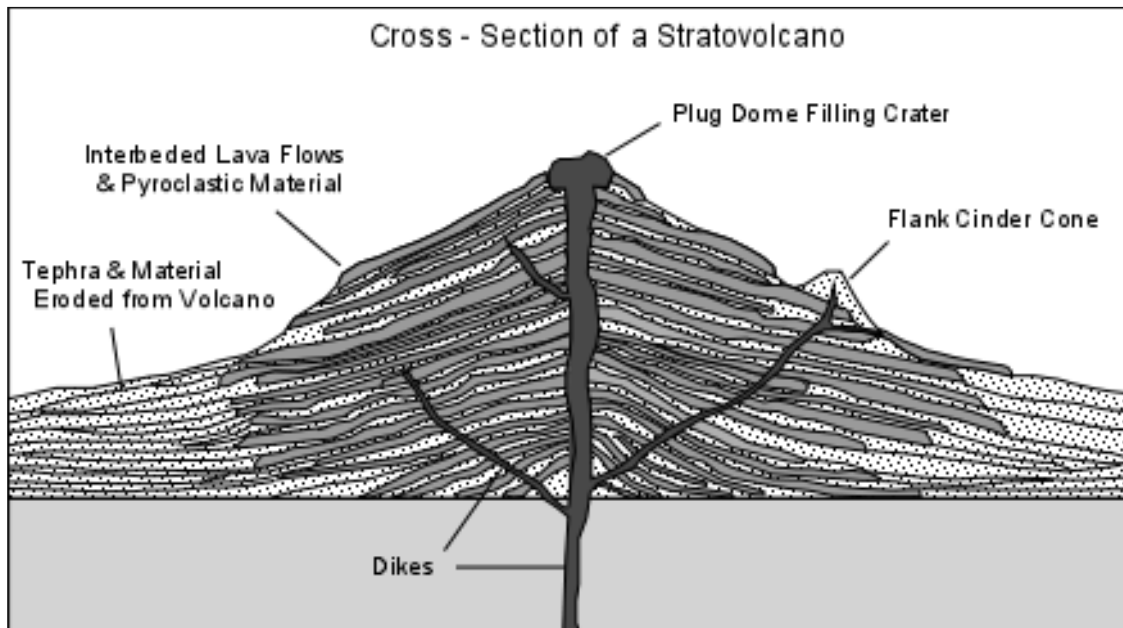
- Volcanic conical hills are developed as a result of accumulation of materials thrown in gas generated explosion around the opening
- They are explosive, but small in size
- Glassy and solid fragments fall closet to opening.
- Such cones formed by cinders of tephra and lapilli



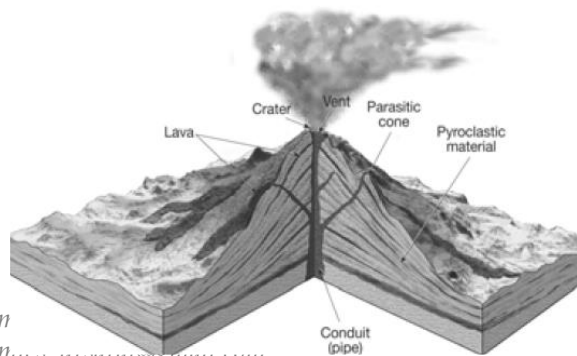
- Cone is symmetrical in cross section and base is circular
- With the angle of repose of 20 – 80 degree, the fragments accumulated and form steep sided cone
- Height of the cinder cone up to 400m
- The cinders are generally of basaltic composition
- The eruptive activity typically lasts a few months or years
- Parícutin volcano in Mexico is a classic cinder cone
- The region contains many cinder cones
- It consists of both pyroclastics and lava

COMPOSITE CONES / STRATO VOLCANOES

- Have steeper slopes than shield volcanoes, with slopes of 6 to 10° low on the flanks to 30° near the top.
- The steep slope near the summit is due partly to thick, short viscous lava flows that do not travel far down slope from the vent.
- They show an internal layered structure due to varying intensities of the explosions that deposit different sizes of pyroclastics.



- ➔ The gentler slopes near the base are due to accumulations of material eroded from the volcano
- ➔ Stratovolcanoes show inter-layering of lava flows and pyroclastic material, So it is also called composite volcanoes. Pyroclastic material can make up over 50% of the volume of a stratovolcano.
- ➔ Lavas and pyroclastics are usually andesitic to rhyolitic in composition.
- ➔ Due to the higher viscosity of magmas erupted from these volcanoes, they are usually more explosive than shield volcanoes.
- ➔ Stratovolcanoes sometimes have a crater at the summit that is formed by explosive ejection of material from a central vent. Sometimes the craters have been filled in by lava flows or lava domes, sometimes they are filled with glacial ice, and less commonly they are filled with water.
- ➔ Long periods of repose (times of inactivity) lasting for hundreds to thousands of years, make this type of volcano particularly dangerous, since many times they have shown no



historic activity, and people are reluctant to heed warnings about possible eruptions.

2. FISSURE TYPE:

- Sometimes, plate tectonics results in a long, narrow crack (fissure) in Earth's surface
- Basaltic lava pouring from the fissure spreads across the land, forming a lava plateau
- Plateau or Flood basalts are extremely large volume outpourings of low viscosity basaltic magma from fissure vents. The basalts spread huge areas of relatively low slope and build up plateaus.



- The only historic example occurred in Iceland in 1783, where the Laki basalt erupted from a 32 km long fissure and covered an area of 588 km² with 12 km³ of lava. As a result of this eruption, homes were destroyed, livestock were killed, and crops were destroyed, resulting in a famine that killed 9336 people.
- In Oregon and Washington of the northwestern U.S., the Columbia River Basalts represent a series of lava flows all erupted within about 1 million years to 12 million years ago.

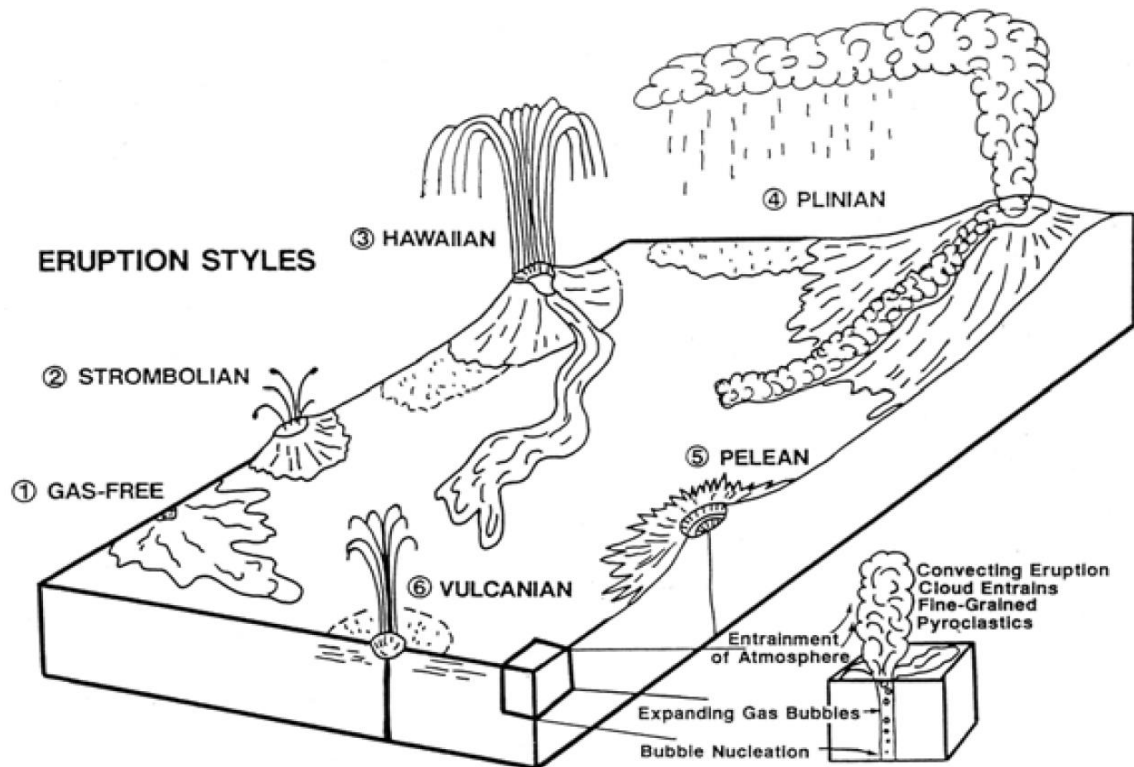


- In western India are the Deccan plateau basalts, whose extrusions for more than 70 million years are related to the collision of India against the southern margin of the Asian plate.

- Deccan trap forms unique and self styled geological formation with rhythmic and repetitive layers of volcanic flows numbering over 40 – 50
- These 40 – 50 flows have repetitively erupted intermittently
- Due to erosional processes the plateau gives Mesa and Buteau

VOLCANOES BASED ON THE TYPES OF ERUPTION

- **Hawaiian:** Volcanoes with mild eruption belong to this phase is free from explosion (e.g. Hawaiian volcanoes). Lava is ejected mildly. Such quite eruption build shield volcanoes and lava plateaus and plains. Low silica basaltic composition make the lava mobile.
- **Strombolian:** Eruption of lava punctuated by periodic, mild explosions is known as Strombolian phase. (e.g. Stromboli, Italy). In this type of eruption lava is ejected out in fountains with bombs and scoria and light-colored clouds (mostly steam) reach upward only to moderate heights.
- **Vulcanian:** More Viscous and less mobile lavas; allowing gas buildup below surface; over longer periods of quiet until lava crust is broken up, ejecting bombs, pumice, ash and thick clouds and built the Composite cone. (e.g. Vulcano, Sicily)
- **Vesuvian:** More stronger then Strombolian or Vulcanian types; extremely violent expulsion of gas; eruption occurs after long interval of quiescence of mild activity; vent tends to be emptied to considerable depth; lava ejects in explosive spray, repeated clouds (cauliflower) that reach great heights and deposit tephra.
- **Plinian:** More violent form of Vesuvian eruption; Calderas are formed. Volume of erupted materials is enormous. It is named after the observer Pliny who lost his life during the observations.
- **Pelean:** Results from high-viscosity lavas, erupts pyroclastics in violent explosion, forming the Volcanic domes, Glowing cloud is typical are typical feature of Pelean phase (e.g. Mount Pelee, West Indies)
- No volcano erupts in the same manner through out its life. A single Volcano may erupt in different types at different times



on it by the lithosphere above it, but some materials do melt

Conditions for Magma Formation in the Asthenosphere

1. A decrease in pressure can lower the melting temperature of the materials.

→ along rift valley at mid-ocean ridge where the lithosphere is thinner & exerts less pressure

2. An increase in temperature can cause materials to melt.

→ at a hotspot

3. An increase in the amount of water in the asthenosphere can lower the melting temperature of the materials.

❖ at subduction boundaries

→ So magma is generated at depth according to the prevailing conditions of

❖ Temperature

❖ Pressure

❖ Water content

❖ Composition

COMPOSITION OF MAGMA

- The rock consist of different minerals and each mineral having different melting points
- Rising temperature first melt the low melting point minerals
- So a magma of different composition from same parent rock at different depth is possible
- Once magma generated, it automatically rises upward owing to its low density

→ There are three basic type of magma

❖ Basaltic Magma, Andesitic magma, Rhyolitic magma

Basaltic Magma: Basalt being made up of water free ferromagnesian minerals such as olivine, pyroxene and feldspar indicate partial melting of upper mantle which is believed to have composition of peridotites

The presence of water lowers the melting point. As a result basaltic magma may be generated at shallow depth

Found generally at divergent plate boundary, rift valley

Andesitic magma: Andesite magma must have been produced either by complete melting of continental crust or partial melting of oceanic crust

Laboratory evidence indicate that water soaked basalts on partial melting contribute andesitic magma

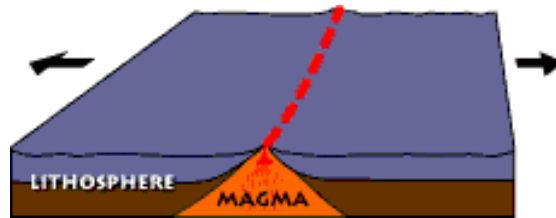
Generally associated with the subduction zones

Rhyolite Magma: may be formed from the partial melting of continental rocks

VOLCANOES AND PLATE TECTONICS

Magma generation at mid-ocean ridges

- ❖ In these zones, the mantle rises and melts, producing magma of silicate composition
- ❖ the magma continues to rise, and erupts mainly as basaltic lava flows
- ❖ Most magma that reaches the Earth's surface is at divergent boundaries along mid-ocean ridges
 - ❖ Most volcanic activity takes place beneath oceans
 - ❖ Iceland → Mid-Atlantic Ridge is ABOVE sea-level

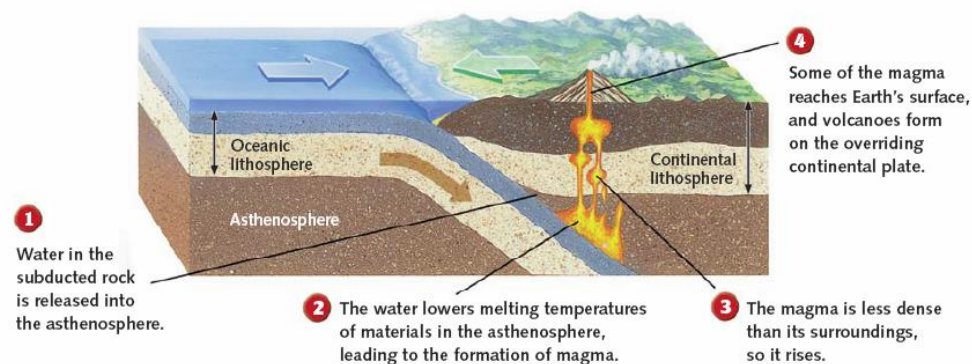


Magma generation at subduction zones

- ❖ During subduction, the subducted oceanic plate is heated as it plunges into the mantle
- ❖ At a depth of 80-120 km, melting begins, and volcanoes are produced which parallel the subduction zone
- ❖ Andesitic magmas are typical of these volcanoes

Volcanic Activity at a Subduction Boundary

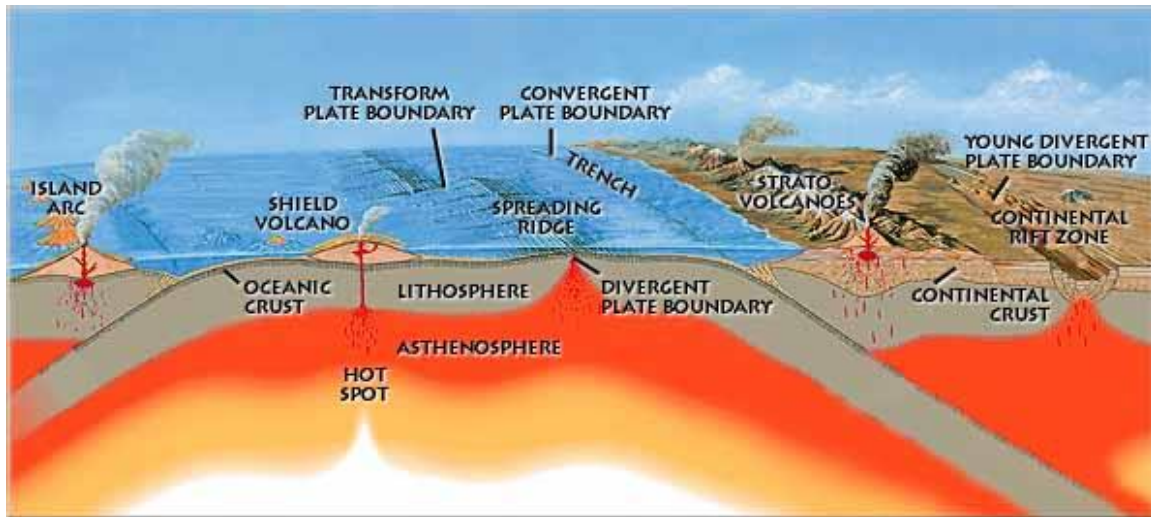
BETWEEN AN OCEANIC PLATE AND A CONTINENTAL PLATE



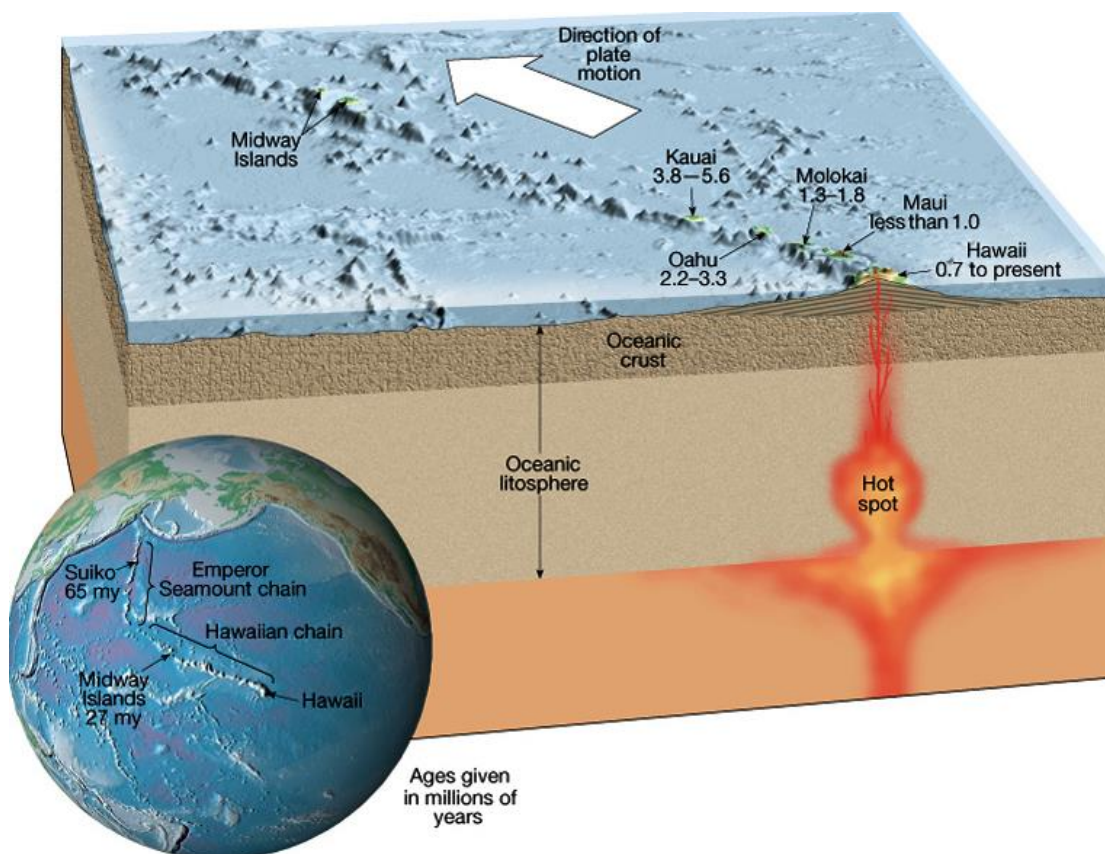
BETWEEN OCEANIC PLATES

The process by which magma forms at an oceanic-oceanic subduction boundary is similar to the process at an oceanic-continental boundary. Notice that the difference between the two processes occurs at step 4.





→ the magmas are fed by deep mantle plumes which are stationary relative to the drifting tectonic plates



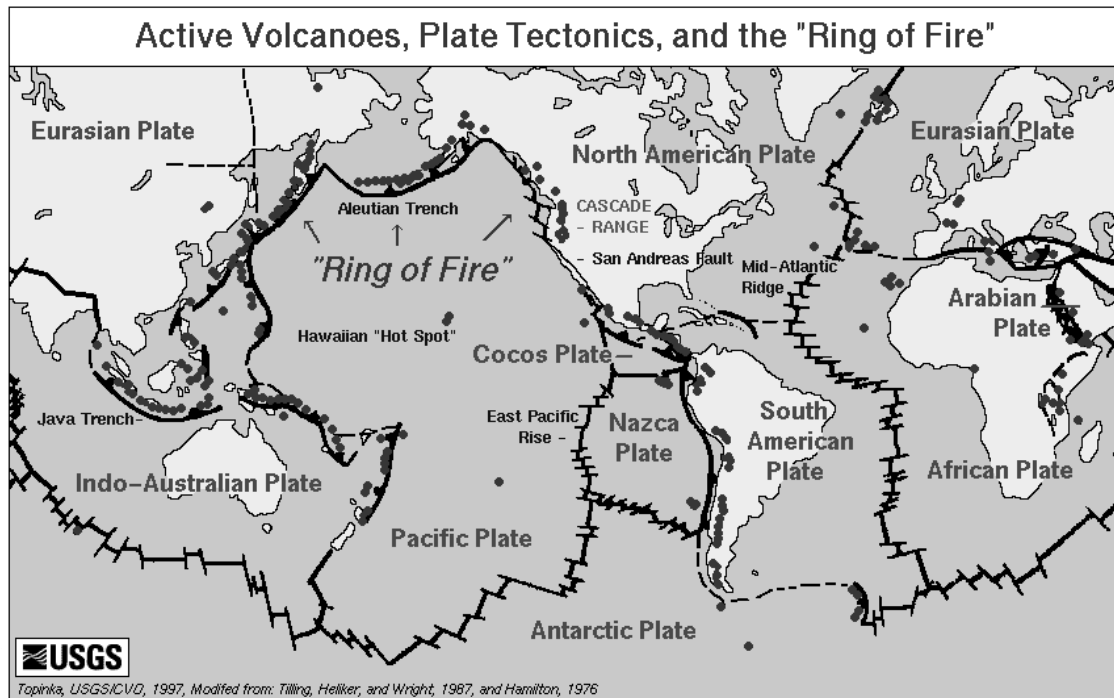
More than 60 % of active volcanoes Ring of Fire (follows the convergent boundary of the pacific plate), Alaskan volcanoes

MEDITERRANEAN BELT

About 20 % of active volcanoes Mount Etna, Italy.

Rest of the active volcanoes are at or near mid- oceanic ridges.

The longest of these ridges is the MID-ATLANTIC RIDGE.



- ❖ Lava flows, including flood basalts
- ❖ Pyroclastic falls and pyroclastic flows
- ❖ Lahars and debris avalanches
- ❖ Volcanic gases

LAVA FLOWS

- ❖ This is a basalt lava flow in a channel
- ❖ Due to its low silica content and high temperature, it is quite fluid
- ❖ Yet lava usually flows fairly slowly

LAVA FLOWS ON LAND

→ Hotter basaltic lava

❖ Flows quickly out of vents

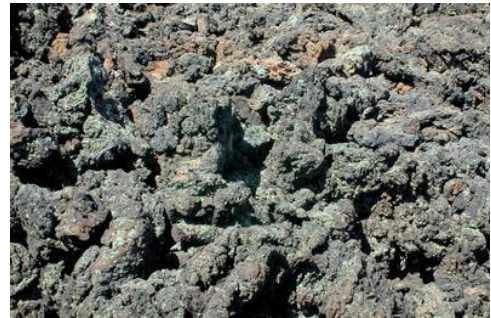
- Forms pahoehoe lava
- Smooth, ropelike surfaces
- It generally exhibits fluid-like textures
- This is a Hawaiian term for smooth, ropy lava



→ Cooler basaltic lava

❖ Moves slowly, cools quickly

- Forms aa lava
- Rough, jagged surfaces
- This type of lava is quite blocky on the surface, and comparatively cool
- Yet below the surface, the lava is fairly massive and much hotter
- Also called Blocky Lava



UNDERWATER

→ Distinctive shape

❖ Rounded, pillow-like, hard crust

- Forms pillow lava

❖ Tubular-shaped pillows of basalt photographed in the central rift of the East Pacific Rise, at a water depth of about 500 m.



Fire Fountaining

- Sometimes, basaltic lava can contain lots of gas
- Then, small explosive eruptions form fire fountains
- As partially liquid drops fall back to the ground, they may coalesce to form a lava flow



Flood basalts

- The previous examples represent small-scale activity
- But basaltic eruptions can be huge, forming lava plateaus
- These huge outpourings may occur quickly (1-3 Ma) and may contribute to mass extinctions
- (e.g. Deccan Plateau, Columbia Plateau)

Pyroclastic falls and pyroclastic flows

- “A *Pyroclastic flow* is a fluidized mixture of solid fragments and hot, expanding gases that flows down the volcano vent.
- If a volcano's lava is thick and stiff, the lava may explode into the air and harden into ash, cinders, and bombs
- Pyroclastic flows are suspensions of hot pyroclastic material, air, and gas which descend under the influence of gravity
- Their velocity is generally very high (50-500 km/hr)
- This example is a flow from Mt. St. Helens
- Pyroclastic materials may be classified by size
 - ❖ Smallest → ash
 - ❖ Intermediate → lapilli
 - ❖ Largest → blocks & bombs



Volcanic blocks
Volcanic dust and ash:

- Volcanic dust consisting of particles having less than 2.5 mm diameter
- Volcanic dust comprising particles less than 4mm in diameter
- They are fine particles traveling through upper atmosphere and take several years settle. Hardened ash is called Tuff



Volcanic bombs

Lapilli



Volcanic ash



Lapilli

- Lapilli are larger particle than ash and dust, 4mm to 32 mm in diameter

Bombs

- Bombs are elliptical or oval shaped pieces with twisted ends called volcanic bombs

Pumice:

- A lava foam is formed when there is sudden release of gas pressure

Scoria:

- When lava flows are extremely vesicular giving a spongy look they are described as scoriaceous
- During explosive volcanic eruptions, ash falls downwind of the volcano



- In the case of very large eruptions, the ash may be deposited over a vast area

Debris avalanches

- Lahar is an Indonesian word for volcanic debris flow
- Lahars are flows of water and loose volcanic debris
- They are especially prevalent at snow-clad and ice-clad volcanoes



Volcanic activity: gases

- Volcanic gases are typically highly acid
- Major constituents include H₂O, CO₂, HCl, SO₂, and HF
- Many fatalities have resulted from exposure to toxic gases, or suffocation from the displacement of oxygen by denser volcanic gases

How do predict eruptions?

Measuring Small Quakes

- Before eruption, increase in number & intensity

Measuring Slope

- Bulges may form with magma (tiltmeter)

Measuring Volcanic Gases

- Outflow of volcanic gases
 - Sulfur dioxide, carbon dioxide

Measuring Temperature from Orbit

- Measure changes in temperature over time

ISOSTASY

Isostasy (Greek isos = "equal", stásis = "standstill") is a term to refer to the state of gravitational equilibrium between the earth's lithosphere and asthenosphere such that the tectonic plates "float" at an elevation which depends on their thickness and density.

This concept is invoked to explain how different topographic heights can exist at the Earth's surface. When a certain area of lithosphere reaches the state of isostasy, it is said to be in *isostatic equilibrium*.

Isostasy is not a process that upsets equilibrium, but rather one which restores it (a negative feedback).

Certain areas (such as the Himalayas) are not in isostatic equilibrium. The elevation of Himalayas is due to the plate collision between the Indian plate and Asian plate.

In the simplest example, isostasy is the principle of buoyancy observed by Archimedes in his bath, where he saw that when an object was immersed, an amount of water equal in volume to that of the object was displaced.

When large amounts of sediment are deposited on a particular region, the immense weight of the new sediment may cause the crust below to sink.

Similarly, when large amounts of material are eroded away from a region, the land may rise to compensate.

Therefore, as a mountain range is eroded down, the (reduced) range rebounds upwards (to a certain extent) to be eroded further.

Some of the rock strata now visible at the ground surface may have spent much of their history at great depths below the surface buried under other strata, to be eventually exposed as those other strata are eroded away and the lower layers rebound upwards again.

An analogy may be made with an iceberg - it always floats with a certain proportion of its mass below the surface of the water. If more ice is added to the top of the iceberg, the iceberg will sink lower in the

water. If a layer of ice is somehow sliced off the top of the iceberg, the remaining iceberg will rise. Similarly, the Earth's lithosphere "floats" in the asthenosphere.

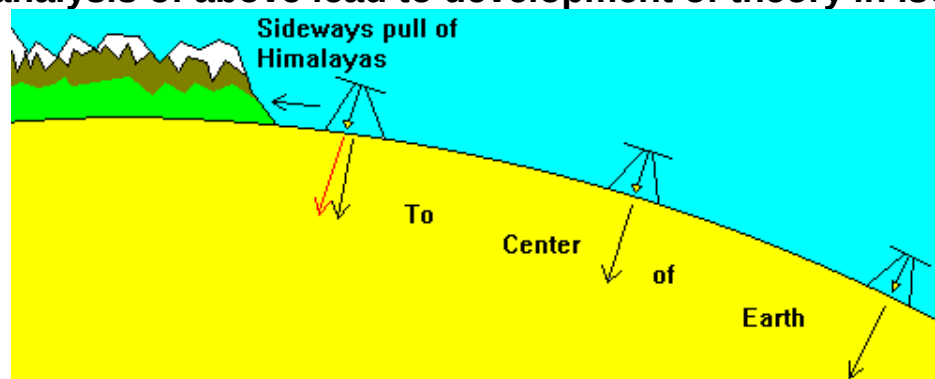
The isostatic adjustments are a balance of rock masses on regional scale and not a local scale

The Earth possesses elevated mountains and continents and depressed deep ocean basins

Dutton explained the above fact as due to the tendency of lighter materials to bulge and denser materials to sink on rotation. He proposed the term isostasy to describe such gravitational equilibrium.

HYPOTHESIS OF ISOSTASY

- ❖ When Sir George Everest, the Surveyor General of India and his team were attempting to make a map of northern India near the Himalayan foothills during the mid 1800s, they discovered that their plumb bobs did not hang straight down but were deflected towards the Himalayas.
- ❖ Such type of deflection of plumb bobs also witnessed at Andes mountains by Bouger
- ❖ The most logical explanation for the excessive attraction is that the deep rocks of an underlying "mountain root" are less dense than the surrounding rocks at those depths.
- ❖ The analysis of above lead to development of theory in isostasy



THE PRATT HYPOTHESIS

John Pratt was the archdeacon of Calcutta and a mathematician of great power.

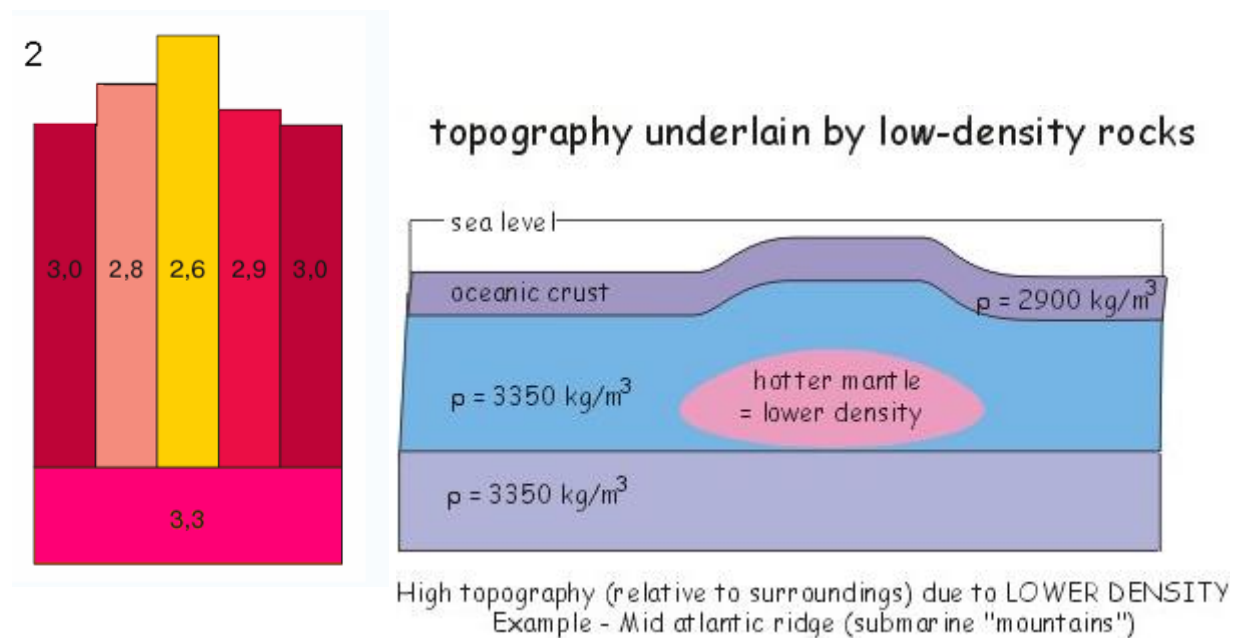
*Dr.J.Saravanavel, Assistant Professor, Centre for Remote Sensing, Bharathidasan University,
e-Learning Material: Physical Geology and Geodynamics: drsaraj@gmail.com*

According to him when blocks of varying densities are set afloat in the denser medium and all the block will have a common depth level which he called the depth of compensation

But above the surface of the denser medium, the blocks will stand at different heights proportionate to their densities

Similarly, the lithosphere float on the denser Asthenosphere. So the earth's materials having different densities accordingly will project as mountains or plateau or basins

His isostatic model features a horizontal crustal base. The crustal density varies from high under the seas to low in high mountains. Thus the pressure is everywhere equal at the base of the crust.



THE AIRY HYPOTHESIS

George Airy was the royal astronomer. In his view isostasy is realized by means of a crust of low and uniform density "floating" on a mantle of high and uniform density.

He was the first person to suggest that mountains, plateaus and ocean float in a substratum of higher density materials as ice berg float in the seawater

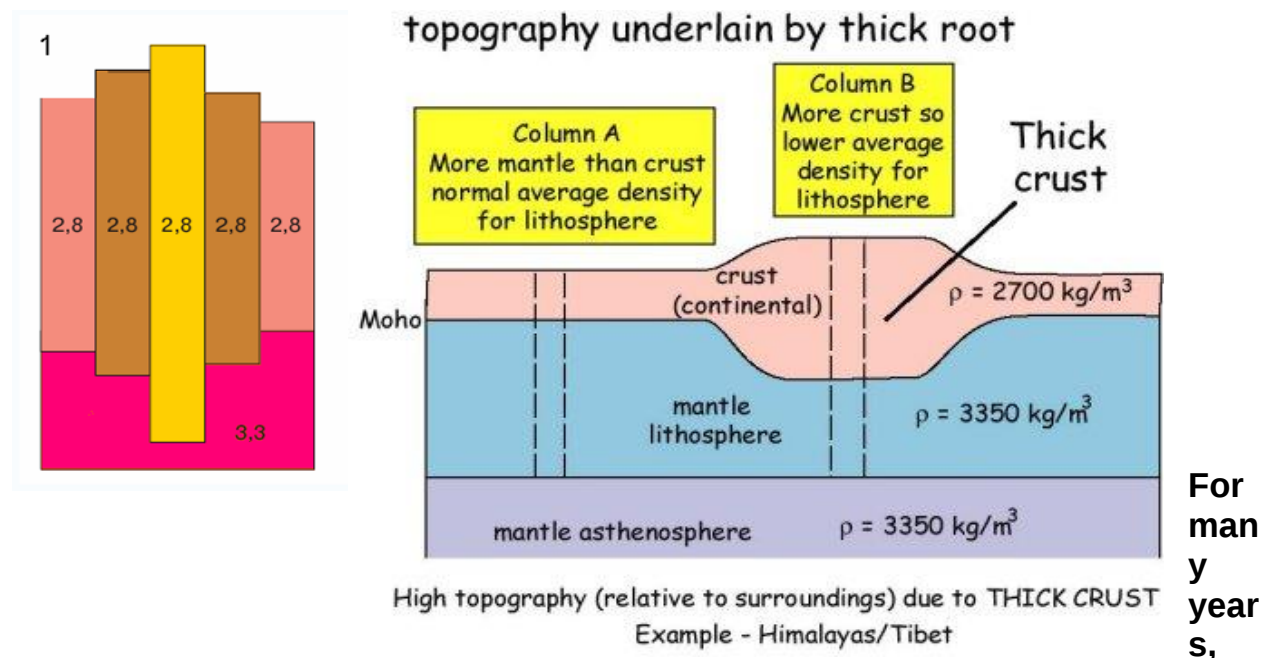
Under mountains the crust is thick and elevations correspondingly high.

Under the sea the crust is thin and correspondingly deep.

The base of the crust undulates as an exaggerated mirror of the topography.

The depth of uniform pressure lies below the base of the crust (the "Moho").

Today the Airy model is thought to provide a good explanation for the elevation difference between the continents and the oceans.



no one knew which model is a more accurate depiction of reality. But as geologists learned about the earth's interior (through studying shock waves created by earthquakes and nuclear explosions), it became apparent that Airy's model is a better one for most continental mountain ranges.

However, Pratt's model is better at explaining why mid-oceanic ridges rise above the surrounding ocean floor, so both models have application to the "real" world.

APPLICATIONS

The principle of isostasy suggests that the earth's crust should adjust to any changes in mass that occur at the earth's surface (we call these "isostatic adjustments"). There are basically two types of responses:

1. SUBSIDENCE

- a. Definition: the slow, sinking of the earth's crust
- b. Cause: the addition of mass to the crust
- c. Example: the advance of glacial ice sheets

2. REBOUND

- a. Definition: the slow, vertical rise in earth's crust
- b. Cause: the removal of mass from the earth's crust
- c. Example: post-glacial rebound (Scandinavia) (U.S.)

It should also be noted that isostasy explains why continental plates cannot be subducted: the forces that drive subduction cannot overcome the "buoyancy" of these low density plates.

MOUNTAIN BUILDING ACTIVITIES

DIASTROPHISM

Diastrophism is the large-scale deformation of the Earth's crust by natural processes. It leads to the formation of continents and ocean basins, mountain systems, plateaus, rift valleys, and other features. The deformations are caused by mechanisms such as lithospheric plate movement (plate tectonics), volcanic loading, faulting, folding, etc.

There are two types of diastrophic movements

- **Epeirogenesis and Orogenesis**
 - ➔ **Epiorogenic processes which result in regional uplift and subsidence of the crust without large scale deformation**
 - ➔ **The mountain building activities are known as Orogenesis. The plate tectonics gives the acceptable mechanism for the Orogenies**

Orogeny is the variety of processes that occur during mountain-building, including:

- ➔ **Distinctive Patterns of Deposition**
- ➔ **Deformation**
- ➔ **Metamorphism**
- ➔ **Intrusions**
- ➔ **Volcanic Activity**
- ➔ **Oceanic Trenches**
- ➔ **Seismic Activity**

Mountains are classified in to two on the basis of mode of origin

- ➔ **Tectonic mountains**
- ➔ **Relict (Erosional) Mountains**

Tectonic Mountains

- Mountains are formed due to extensive volcanic activity. Volcanic ejecta are heaped to form mountains surrounding the volcanic vent are called Volcanic mountains
- Mountains resulting from the depression or elevation of blocks of the Earth crust on a large scale due to faulting are called fault block mountains
- The folded mountains are formed due to folding and related upwarping of earth crust

Volcanic Mountains

- Volcanic mountains are created when magma from beneath the Earth makes its way to the surface. When it gets to 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.

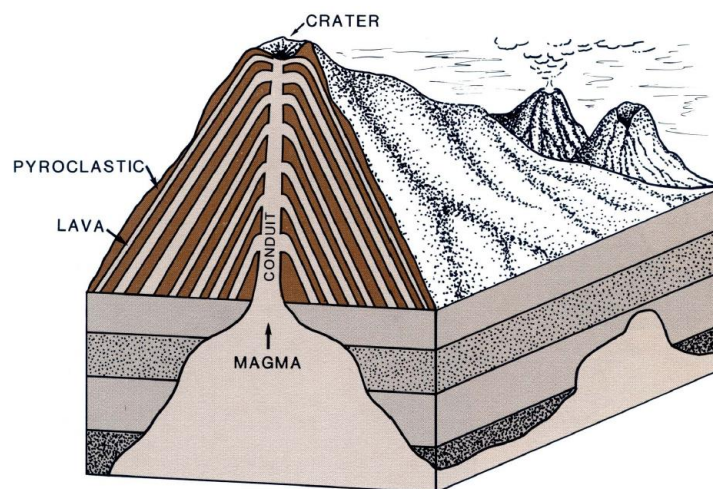
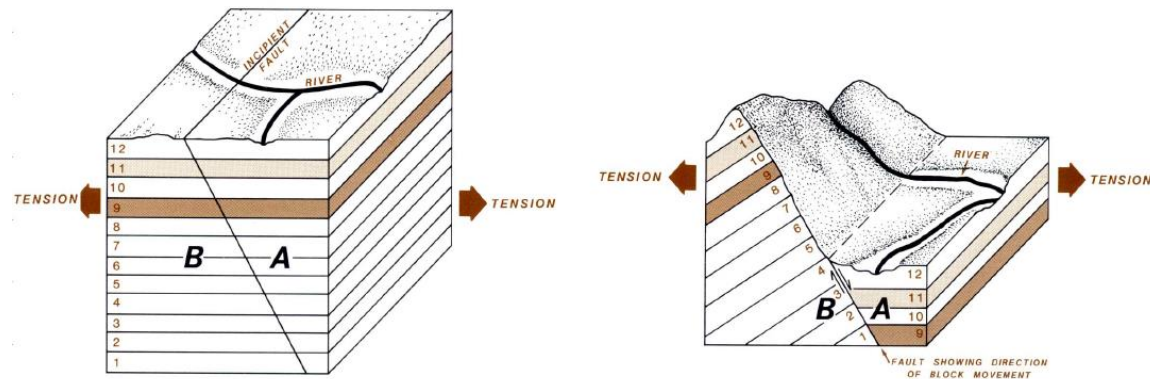


Figure 2. Generalized cutaway showing the growth of a volcano.

Fault Block Mountains

Fault-block mountains are formed by the movement of large crustal blocks along faults formed when tensional forces pull apart the crust

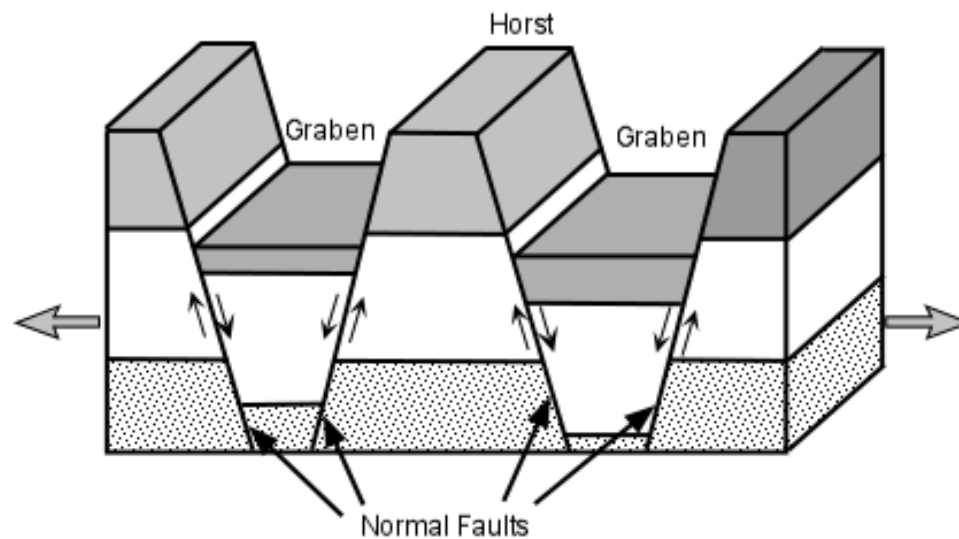
Fault-block mountains are present in the Great Basin of the southwestern United States. They may have been present in the western and central parts of West Virginia about 550 million years ago.

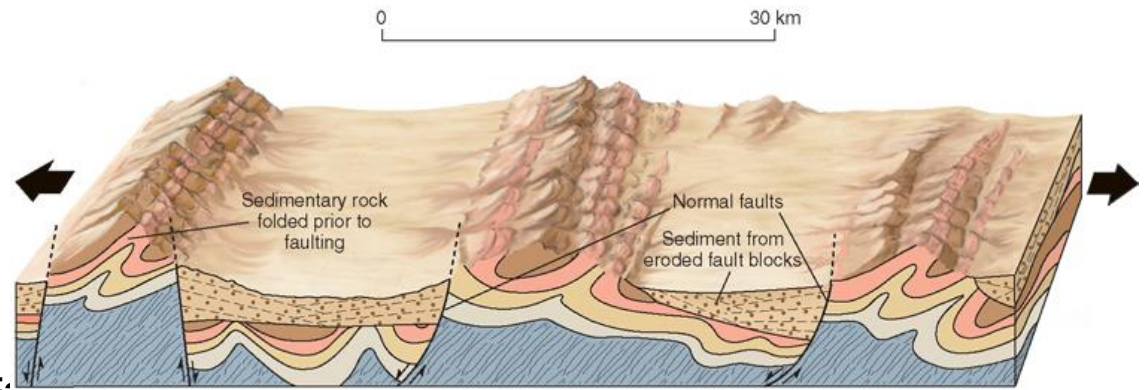


Horsts & Gabens - Due to the tensional stress responsible for normal faults, they often occur in a series, with adjacent faults dipping in opposite directions.

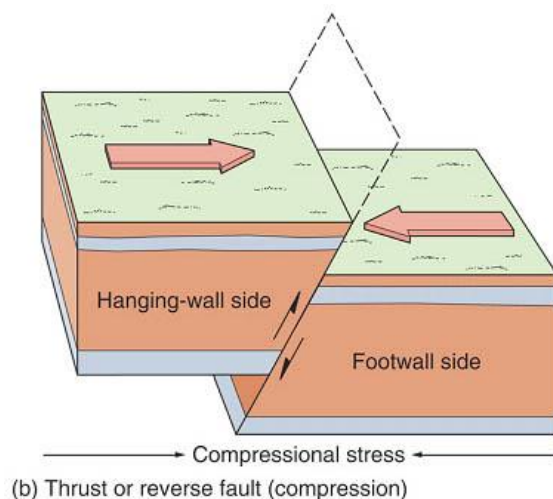
In such a case the down-dropped blocks form grabens and the uplifted blocks form horsts.

In areas where tensional stress has recently affected the crust, the grabens may form rift valleys and the uplifted horst blocks may form linear mountain ranges.





Reverse Faulting - The same can occur from horizontal compressional stresses in brittle rocks, where the hanging-wall block has moved up relative the footwall block.

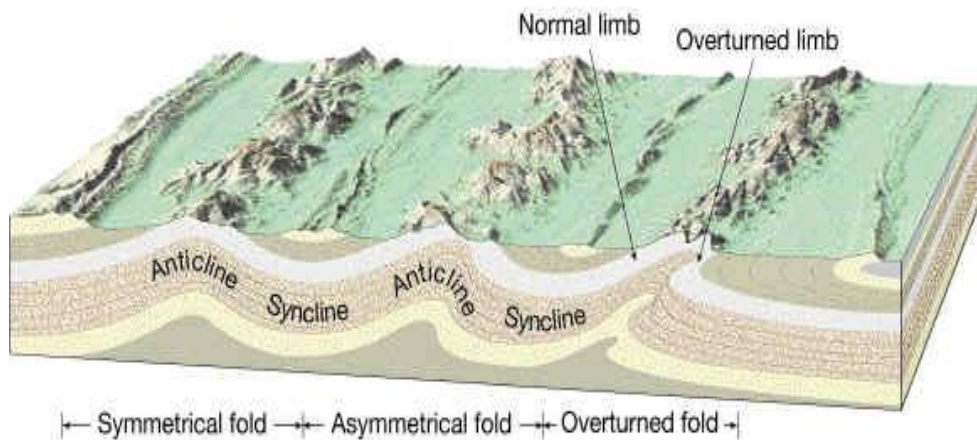


Folded Mountains

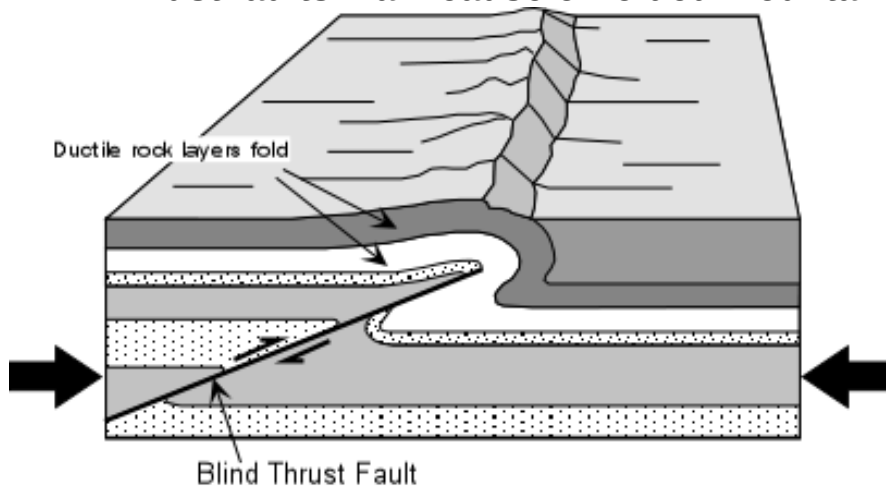
Fold & Thrust Mountains - Large compressional stresses can be generated in the crust by tectonic forces that cause continental crustal areas to collide.

When this occurs the rocks between the two continental blocks become folded and faulted under compressional stresses and are pushed upward to form fold and thrust mountains. i.e.

The Himalayan Mountains (currently the highest on Earth) are mountains of this type and were formed as a result of the Indian Plate colliding with the Eurasian plate.

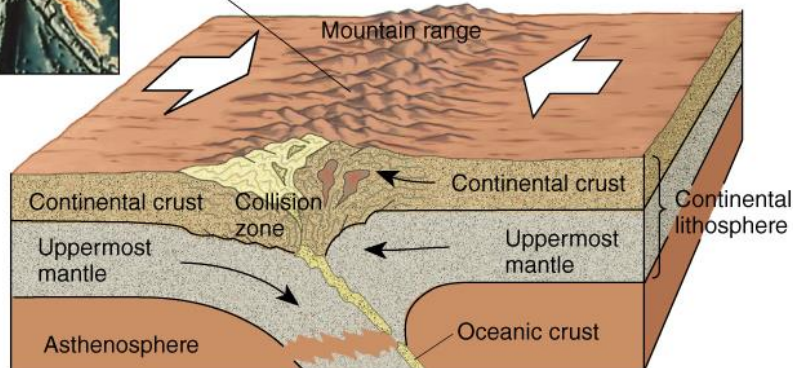


➔ **Thrust faults main cause of folded mountains**

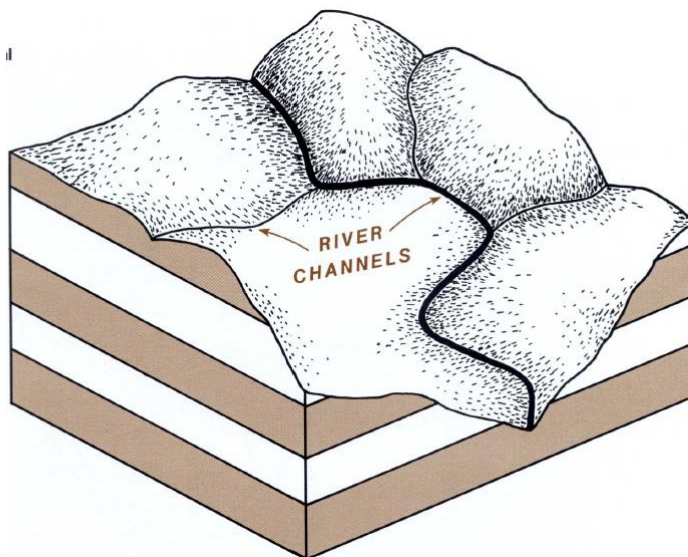


Complex Mountains

- ➔ During and after their formation, these mountains have been repeatedly bend, wrapped and faulted leading to present day complicated structures exhibited by them
- ➔ All major mountains belts in the world fall in this category \
- ➔ Each complex mountain system has its own geological history like folding, faulting and volcanism
- ➔ The Himalayas, the Alps and Appalachian systems are the best examples of this category

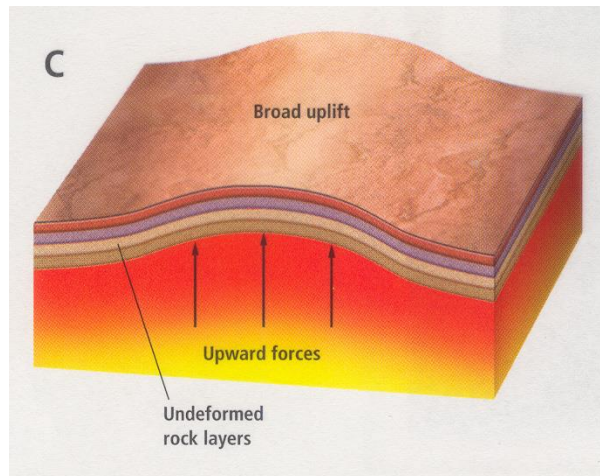


- ➔ Differential rate of erosion by different geological events over the geological time form the topographic features like mountains and plateaus
- ➔ Rocks from some regions may be eroded away to form valleys whereas in adjoining regions they may left high forming mountains of residual type
- ➔ Such mountains are the remnants of the pre-existing landmass
- ➔ Western and Eastern Ghats hill ranges of Peninsular India



Domed Mountains: are isolated and elevated domes when igneous intrusion occur

When an igneous rock body intruded beneath overlaying sediments, the are sediments upwarped to form domes



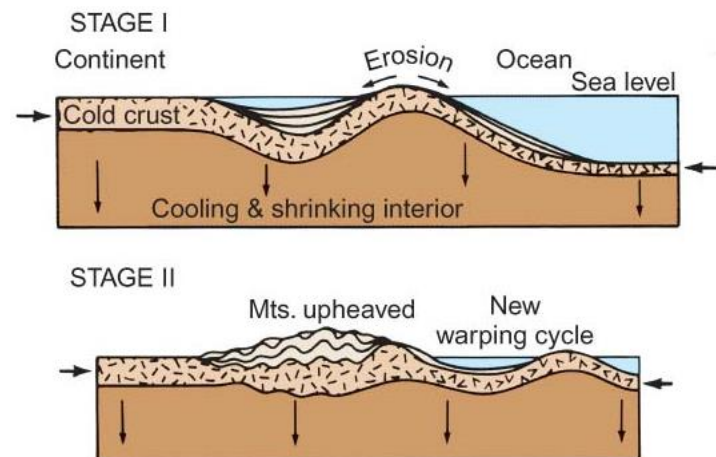
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ORIGIN OF MOUNTAINS

Contraction Theory

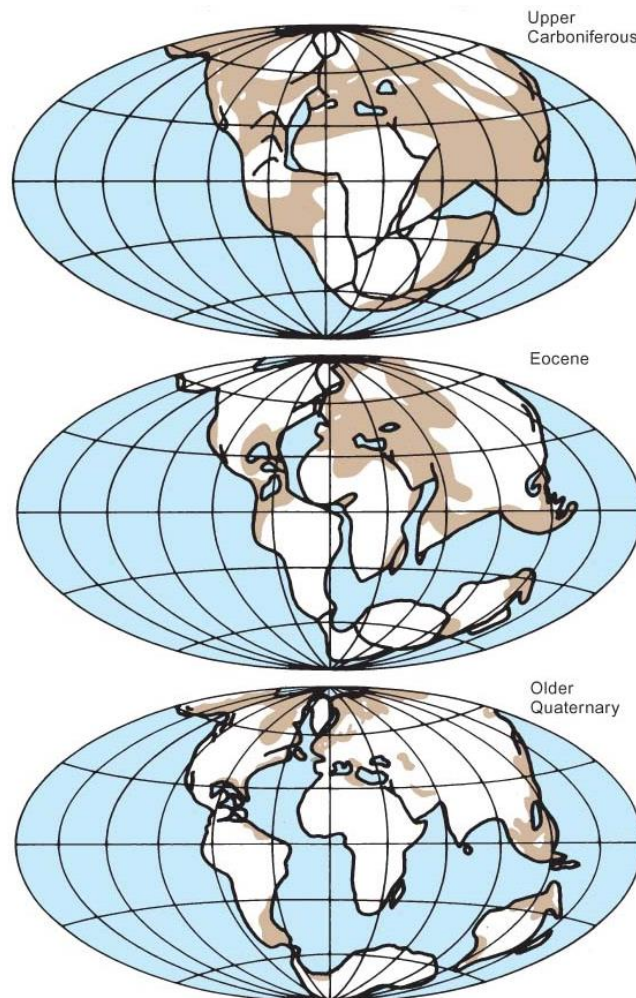
- ➔ According to this view (B. Dana 1873), the earth was a ball of molten materials at some initial stage. It has attained the present stage due loss of heat on gradual cooling
- ➔ At certain stage in its life, the outer portion must have cooled completely to form crust. The inner part, remained molten and continued to loss heat and as a consequence shrunk in volume
- ➔ As a result of this shrinkage, the outer cooled crust had to fit on a reduced inner surface
- ➔ This would lead to the compressional forces in the outer crust. That force created the folded mountains
- ➔ This hypothesis is fails to explain many things. For example: if the mountains formed out of above processes, the mountains building activities should be vigorous in earliest geological times. But most of the mountain building activities formed in recent geological past

B. Dana's theory



Drift Hypothesis

- This hypothesis propounded by Taylor and Wagner.
- According to this hypothesis, the outer crust of the earth was a single unit in the earlier part of the geological time called as Pangea, a super continent
- This super continents was then broken into blocks due to a processes of rifting. Individual crustal blocks started away or drift from the each other under the influence of the tidal forces over a much viscous and hot substratum
- During this movement, great friction is supposed to have developed because of different densities of moving blocks and substratum
- Because of this friction frontal edges of the blocks were compressed in to buckles or mountains
- This hypothesis got lot of objection mainly the source of force causing the rift and drift
- Tidal forces are definitely quite insufficient to produce such effects
- But recently modified form of this hypothesis received tremendous support. The concept of plate tectonics evolved from this.



Convection Current Hypothesis

- ➔ This theory propounded by Holmes (1928). According to Holmes, the mountain ranges were initiated and developed due to convection currents present in the plastic type mantle
- ➔ The origin of the currents may be due to the very hot liquid core of the earth. This may take circulating paths within the mantle
- ➔ Convection currents rise up at certain places in the mantle below the crust of the earth
- ➔ On meeting the crustal boundary, they will travel horizontally under the crust
- ➔ The rising currents are hot and exerts a dragging effect on the rocks at base of the continents
- ➔ Where the current is divergent at the continental margin, the crust is under the tensional force. Conversely where the currents convergence at the continental margin, the crust is under the compressive force
- ➔ This processes create a large depression and then geosyncline.
- ➔ Accumulated materials in the geosyncline because of heavy load, it started sinking
- ➔ While sinking accumulated materials subjected to compressive force and highly folded and contorted

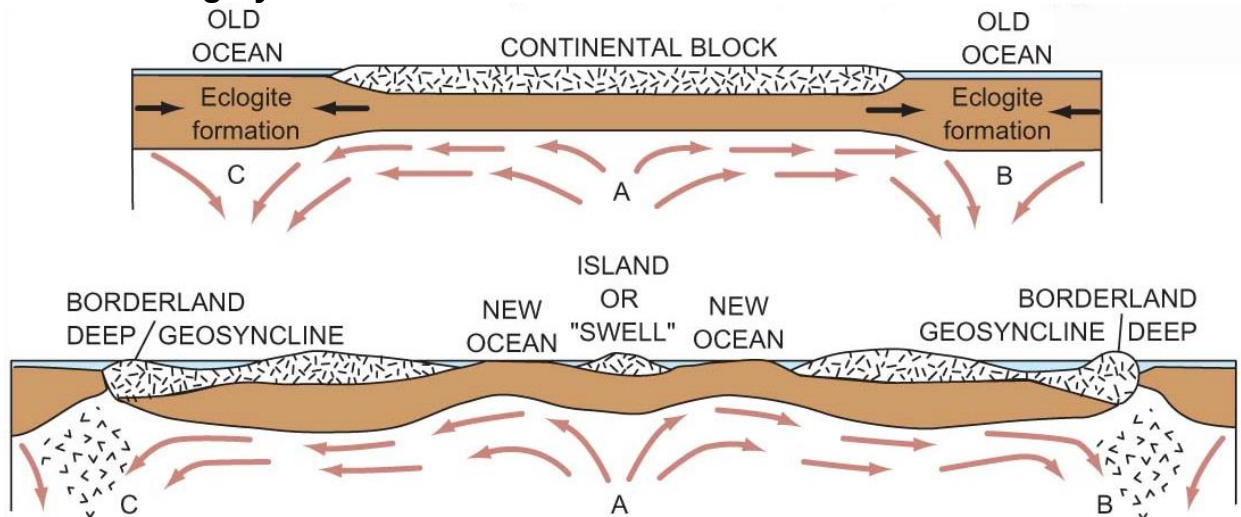


Plate Tectonics and Mountain Building

- ➔ The Earth's surface is composed of a number of mobile "tectonic plates" which are in constant motion

- ➔ These plates are floating over the Asthenosphere
- ➔ The crust and part of upper mantle together forming the plates is called Lithosphere
- ➔ The driving mechanism for plate movements is convection currents
- ➔ There are three main types of plate boundaries
 - ❖ divergent
 - ❖ convergent
 - ❖ transform
- ➔ There are two type of plates such as continental plates and oceanic plates
- ➔ The convergent or collision of plates are three types such as
 - ❖ Collision between the Oceanic plate and Oceanic plate
 - ❖ Collision between the Oceanic plate and Continental Plate
 - ❖ Collision between the Continental plate and Oceanic Plate

Collision between the Oceanic plate and Oceanic plate

- ➔ Orogenies occur where oceanic crust is subducted beneath another oceanic plate
- ➔ Characterized by volcanic island arcs and subduction complexes (accretionary wedge)
- ➔ Emplacement of plutons
- ➔ Back-arc basin receives volcanic and continental sediments, which are faulted and fused to the continent

Ocean-Ocean Convergence

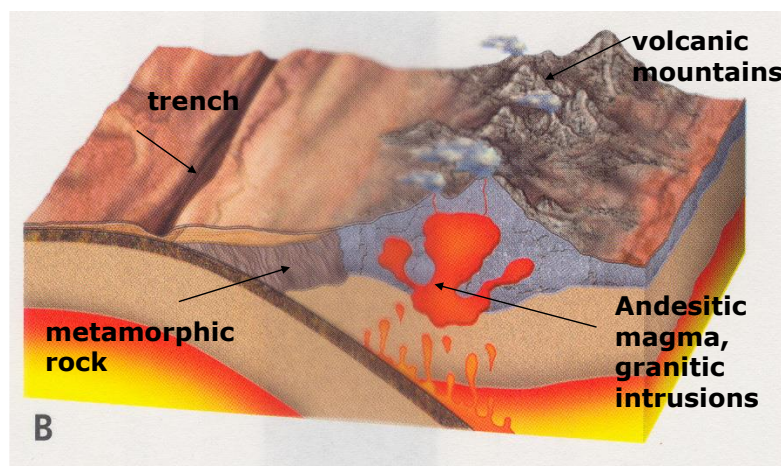


Examples: Aleutian Islands,
Phillipines, Japan

Oceanic-continental boundaries

- Oceanic crust is subducted beneath continental crust
- Partial melting results in a chain of andesitic volcanoes
- Deformed accretionary wedge rocks found seaward
- Folded and faulted sedimentary rocks found landward
- Volcanism and seismicity are common

Ocean-Continental Convergence

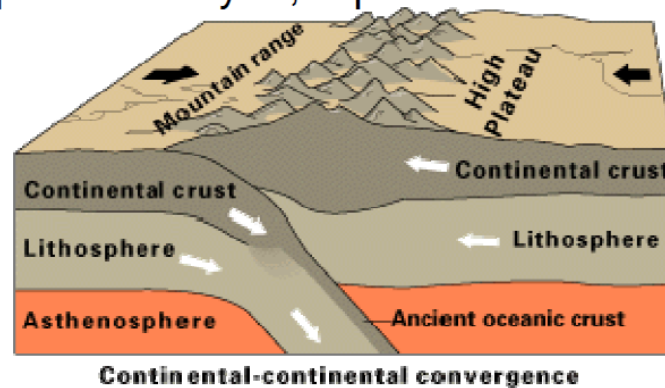


Examples: Cascades , Andes

Continental-continental boundaries

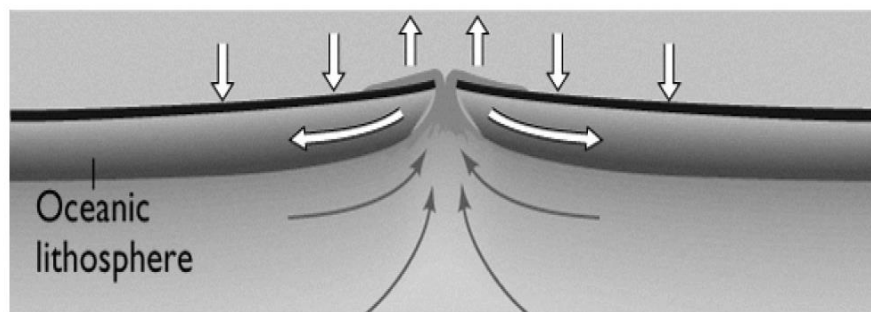
- Himalayas are the best example
- Oceanic crust is consumed in an oceanic-continental boundary until the two continents meet
- Crustal thickening, uplift, and thrusting
- Marine sediments are thrust upward and form the folded mountains

Example: Himalayas, Alps



The Mid-Ocean Ridge is a Fault Block Mountain

- Divergent Plate Boundaries are where the crust has thinned, stretched, and broken into faults.



Unit: 4- Earth Surface Processes-I: River dynamics (Drainage Types and Pattern, Erosion, Transportation, Deposition) - Coastal dynamics (Types of Coasts, Origin of Coasts, Coastal Processes) Seas and Oceans and their Geological Activities (Waves, Currents, Offshore profile, Coastal Erosion - Transportation - Deposition, Marine Deposits, Submarine Canyon)- Interactive dynamics amongst tectonics, Riverine and Oceanographic Processes

EARTH SURFACE PROCESSES-I

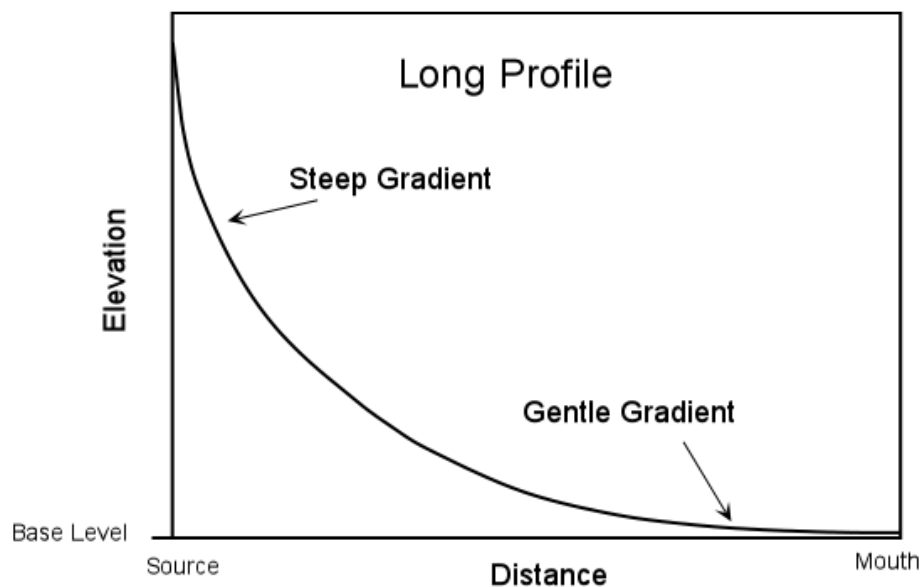
River dynamics

- ➔ A River is a body of water that carries rock particles and dissolved ions and flows down slope along a clearly defined path, called a River.
- ➔ Rivers may vary in width from a few 100 m to several kilometers
- ➔ River flow from higher elevation to lower elevation. The direction of flow determined by the local condition
- ➔ Rivers plays an important role in grading the Earth surface through its erosional, transportational and depositional processes
- ➔ Rivers carry most of the water that goes from the land to the sea. They are an important part of the water cycle
- ➔ Rivers carry billions of tons of sediment to lower elevations and one of the main transporting mediums in the production of sedimentary rocks
- ➔ Rivers carry dissolved ions, the products of chemical weathering, into the oceans and thus make the sea salty
- ➔ Rivers are a major part of the erosional process, working in conjunction with weathering and mass wasting. Much of the surface landscape is controlled by stream erosion
- ➔ Rivers are a major source of water and transportation for the world's human population. Most population centers are located next to streams

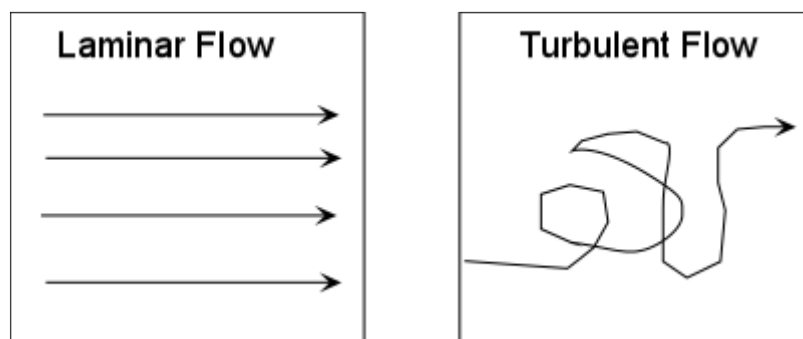
Terminology

- ➔ Stream – A flow of water
- ➔ River – Big flow of water through channel
- ➔ Perennial – River flowing through out the year
- ➔ Intermittent – Water flowing at irregular interval
- ➔ Epimeral Streams – Purely Rainfed river
- ➔ Tributary – Small rivers joining into a main stream
- ➔ Distributary – branching off of main river at confluence

River Profile - Usually shows a steep gradient near the source of the rivers and a gentle gradient as the stream approaches its mouth



- ❖ **Velocity** - A stream's velocity depends on position in the stream channel, irregularities in the stream channel caused by resistant rock, and stream gradient. The average velocity is the time it takes a given particle of water to traverse a given distance
- ❖ Stream flow can be either laminar, in which all water molecules travel along similar parallel paths, or turbulent, in which individual particles take irregular paths.



Discharge - The discharge of a stream is the amount of water passing any point in a given time.

$$Q = A \times V$$

Discharge (m³/sec) = Cross-sectional Area [width x average depth] (m²) x Average Velocity (m/sec).

Load - The rock particles and dissolved ions carried by the stream are the called the stream's load.

Stream load is divided into three parts.

Suspended Load - Particles that are carried along with the water in the main part of the streams. The size of these particles depends on their density and the velocity of the stream. Higher velocity currents in the stream can carry larger and denser particles.

Bed Load - coarser and denser particles that remain on the bed of the stream most of the time but move by a process of saltation (jumping) as a result of collisions between particles, and turbulent eddies.

Note that sediment can move between bed load and suspended load as the velocity of the stream changes.

Dissolved Load - ions that have been introduced into the water by chemical weathering of rocks. This load is invisible because the ions are dissolved in the water.

The dissolved load consists mainly of HCO₃⁻ (bicarbonate ions), Ca⁺², SO₄, Cl⁻, Na⁺², Mg⁺², and K⁺.

These ions are eventually carried to the oceans and give the oceans their salty character. Streams that have a deep underground source generally have higher dissolved load than those whose source is on the Earth's surface.

Sources of Streams / Water

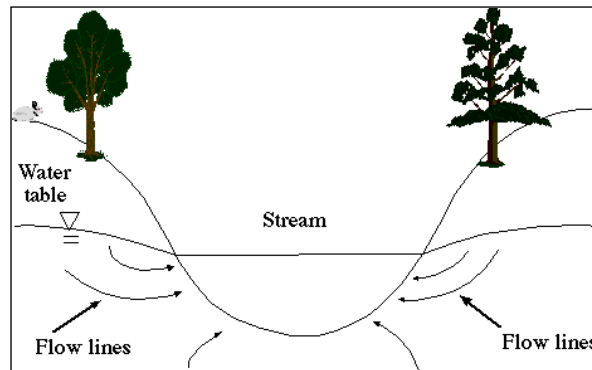
- Rainfall
- Water Table
- Snow melt

TYPES OF STREAMS

1. Effluent Streams:

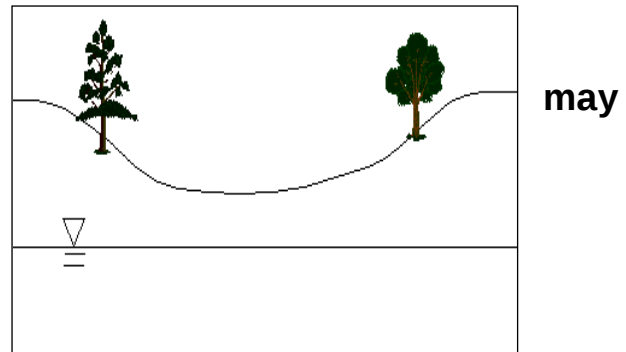
When the stream intersects groundwater level, the groundwater may enter into streams.

The stream receiving the water from the water table is called effluent streams



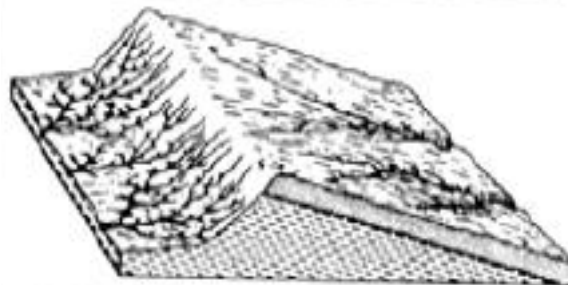
2. Influent streams:

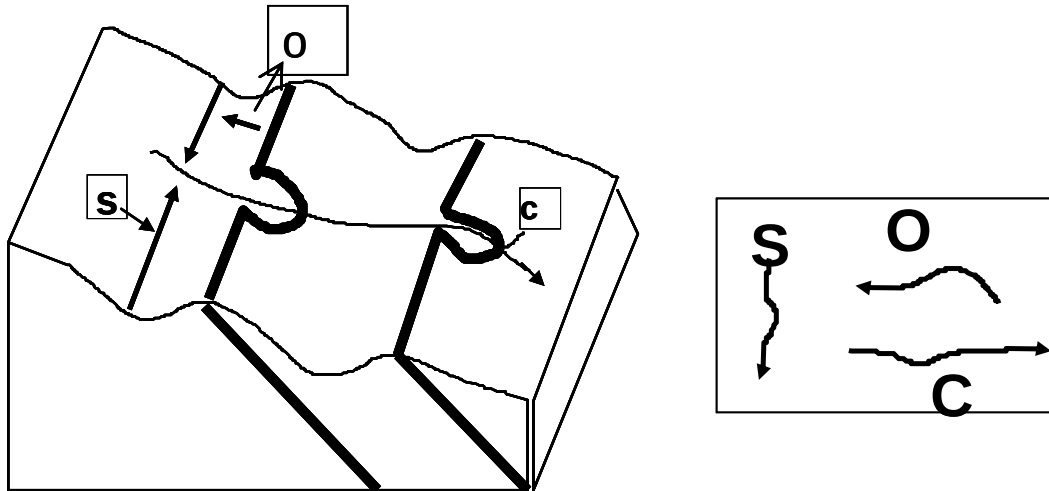
The channel of an influent stream lie above the water table or The groundwater level occur below the river is influent stream



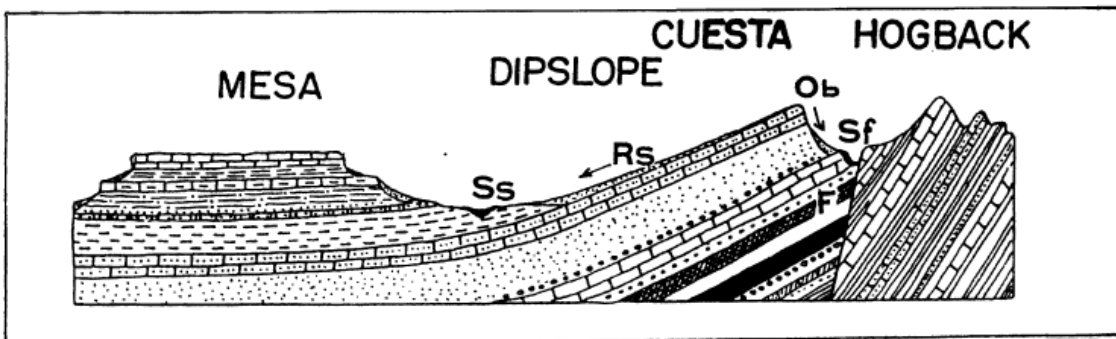
3. Consequent streams are streams whose course is a direct consequence of the original slope of the surface upon which it developed, i.e., streams that follow slope of the land over which they originally formed. Drainage flowing in the dip slope

4. Obsequent streams are streams flowing in the opposite direction of the consequent drainage. Dainages flowing against or in opposite direction to the dip slope



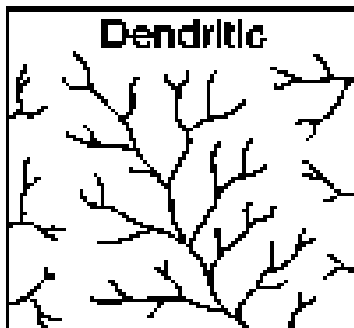


5. Subsequent streams are streams whose course has been determined by selective headward erosion along weak strata. These streams have generally developed after the original stream. Drainages orthogonal to consequent drainage (or) drainages parallel to strike (or) drainages perpendicular to dip.



6. Insequent streams have an almost random drainage often forming dendritic patterns. These are typically tributaries and have developed by a headward erosion on a horizontally stratified belt or on homogeneous rocks. These streams follow courses that apparently were not controlled by the original slope of the surface, its structure or the type of rock.

DRAINAGE PATTERN



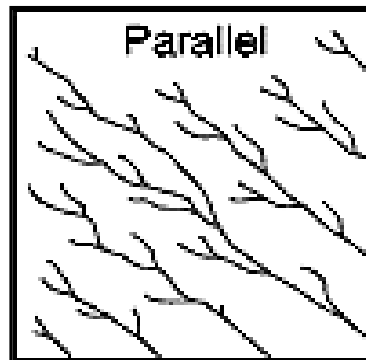
Dendritic: Irregular branching pattern (tree like) in many direction.

It is common in massive rocks and in flat lying strata

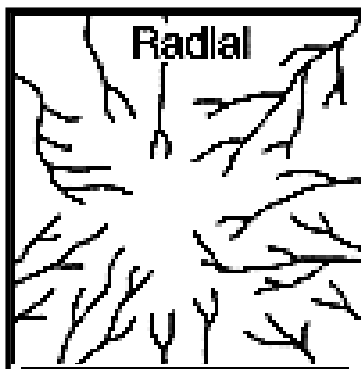
Due to strong resistance of rocks headward development of valley is negligible.

Parallel: parallel or that have formed on underlain by

- Dune
- Dip slope

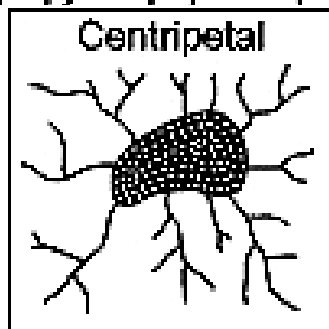


subparallel channels sloping surfaces homogeneous rocks.

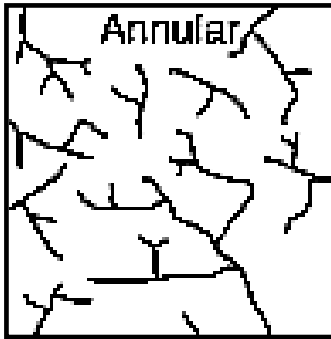


Radial: channels radiate out, like the spokes of a wheel, from a topographically high area, such as a dome or a volcanic cone.

- (a) Radial centrifugal - domes
- (b) Radial centripetal - basin

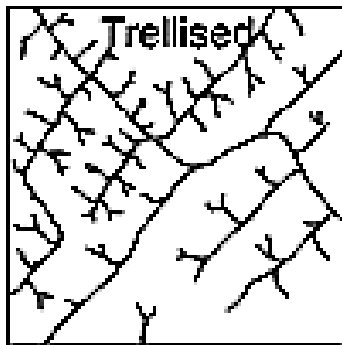


Streams converge toward a central depression. Such as a volcanic crater or caldera, a structural basin, a breached dome, or a basin created by dissolution of carbonate rock



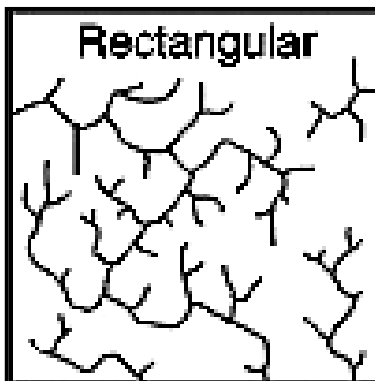
Annular Drainage: Streams follow nearly circular or concentric paths along belts of weak rock that ring a dome or basin

- indicates surficial and subsurface domes and basins
- if deep vertical cutting is observed in such annular areas the same will indicate recent and ongoing doming



Trellis: Rectangular arrangement of channels in which main tributaries are parallel and very long.

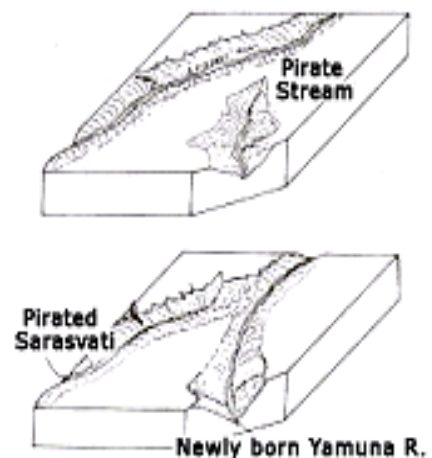
This pattern is common in areas where the outcropping edges of folded sedimentary rocks, both weak and resistant, form long, nearly parallel belts



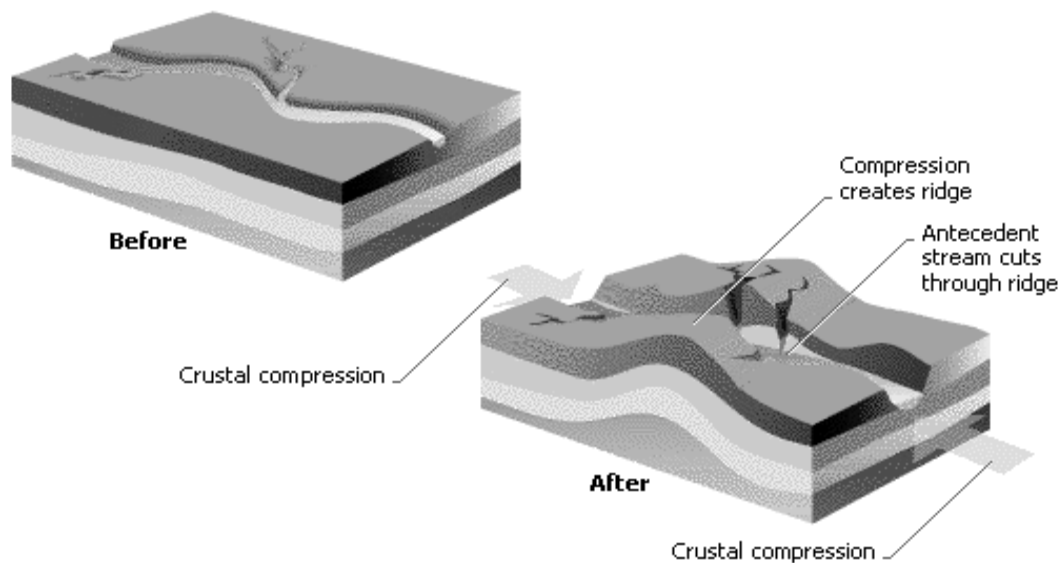
Rectangular drainages are seen in zones of mutually perpendicular Joints

Channels marked by right-angle bends

PIRATED DRAINAGES: Drainage of one water shed being captured by the drainage of other watershed is called Pirated drainages for e.g. Capturing of Saraswathi by Indus

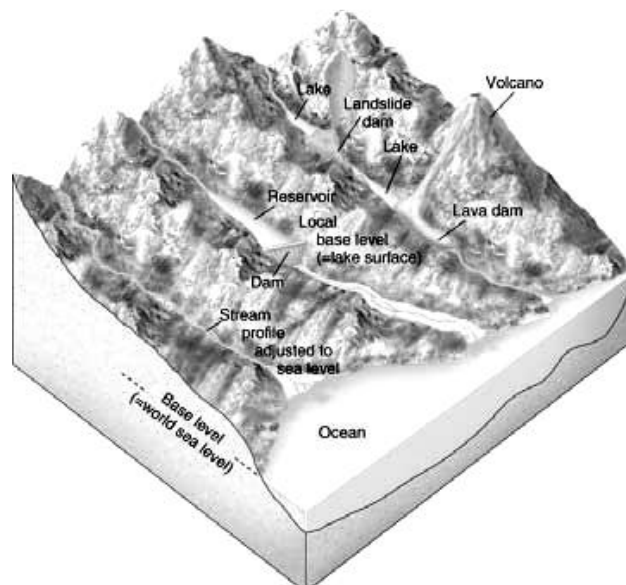


Antecedent Drainage or superimposed drainage : An antecedent stream is a stream that was established before the land beneath it was uplifted through geologic processes such as crustal compression. An antecedent stream will maintain its course in spite of crustal compression, and the stream will continue to erode the land at almost the same rate as the crustal compression uplifts it.



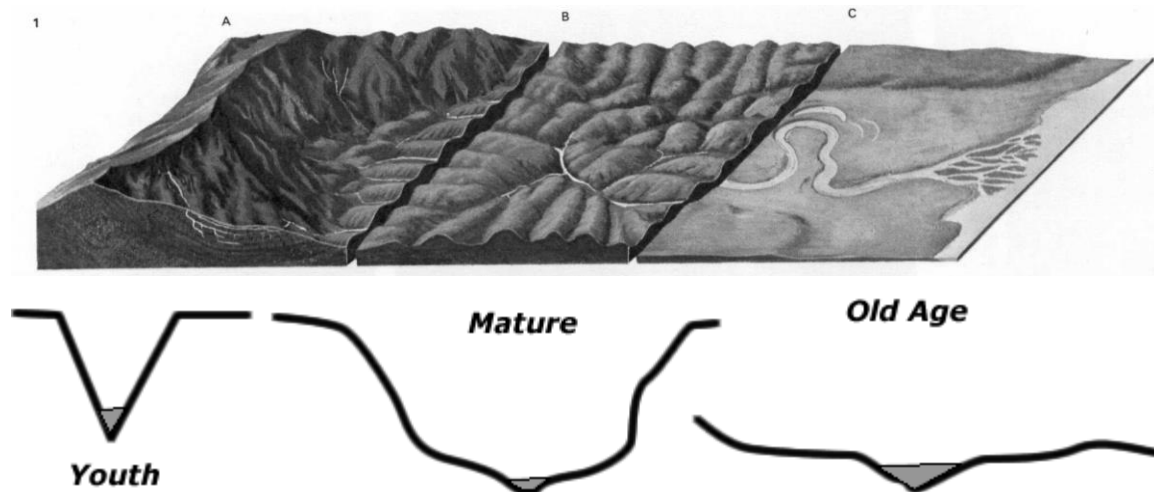
Base Level of Erosion

As a stream flows downslope, its potential energy decreases and finally falls to zero as it reaches the sea. The limiting level below which a stream cannot erode the land is called the base level of the stream. The base level for most streams is global sea level.



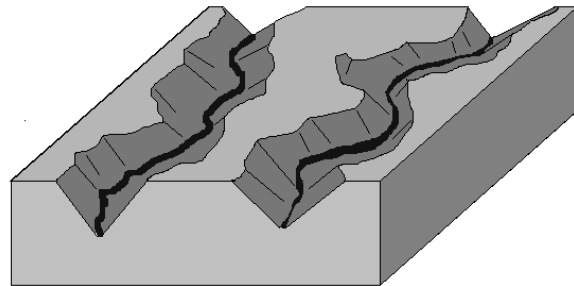
Life History of Rivers

- ➔ Youthful stage – Hilly area- much above MSL / base level of erosion – Extensive erosion
- ➔ Mature stage – Claimed down the hill – Lost considerable elevation – Watch and Walk phase – both erosion and deposition
- ➔ Old stage – at coastal zone – at base level of erosion – losing of all energy – Deposition / delta building is the only process



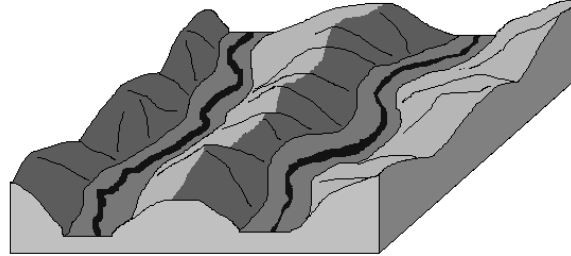
Youthful Stage

- ➔ River is in catchment area
- ➔ Terrain gradient high
- ➔ River has more energy
- ➔ Much above sea level
- ➔ Hence erosion is the dominant process
- ➔ Called *Torrential phase*
- ➔ V-Shaped Valley
- ➔ Waterfalls
- ➔ No Flood Plain
- ➔ Drainage Divides Broad and Flat, Undissected by Erosion
- ➔ Valley Being Deepened



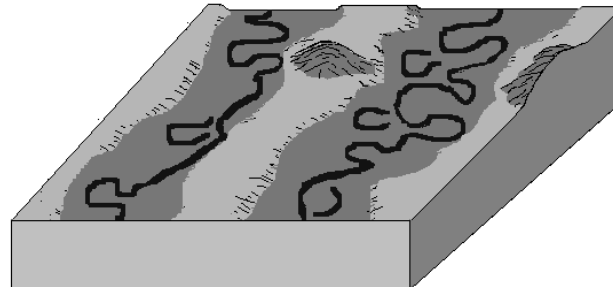
Mature Stage

- River runs in the plains
- Little above MSL
- Hence both erode and deposit
- Mostly controlled by geological structures
- *called as “watch & walk phase”*
- Valley has flat bottom
- Narrow Flood Plain
- Relief diminishes
- River begins to meander



Old Age

- Coastal zone
- Sluggish movement
- Terrain is flat
- Only deposition will take place
- *called “brownian phase or movement”*



RIVER: THE GEOLOGICAL AGENT

- ➔ As the river develop extensive landforms through its erosion and deposition processes, it is called the geological agent
- ➔ The dynamic of the rivers on the earth surface may be studied in the following headings
 1. Erosion
 2. Transportation
 3. Deposition
- ➔ The dynamic of the rivers on the earth surface may be studied in the following headings

River Erosion

- ➔ Erosion can take place through the following processes

Abrasion: is the process in which the bedrock is worn out through rubbing action. Due to continued abrasion, the surface of the bedrock is modified with smooth concave and convex surfaces

Corrosion: Describe the process of removal material by dissolution of soluble materials. The dissolved materials transported in solution. The rainwater that flows into the river all along its length is very slightly acid. This acid very slowly dissolves minerals such as calcium carbonate in limestone.

Impact: Larger particles (grains size of sand and above) dash against walls and floor of the rivers and dislodges materials.

Hydraulic Action: is the removal of loose materials by moving water

Attrition: is the wear and tear of the transported rock particles through mutual rubbing, grinding and dashing

Characteristics of Stream Erosion

- ➔ Stream erosion develop ridges and valleys

- ➔ **Pebbles of rounded because of their prolonged rolling in bed rock**
- ➔ **The bedrocks shows lot of pits and holes produced by grinding as well as solution activity**

Transportation

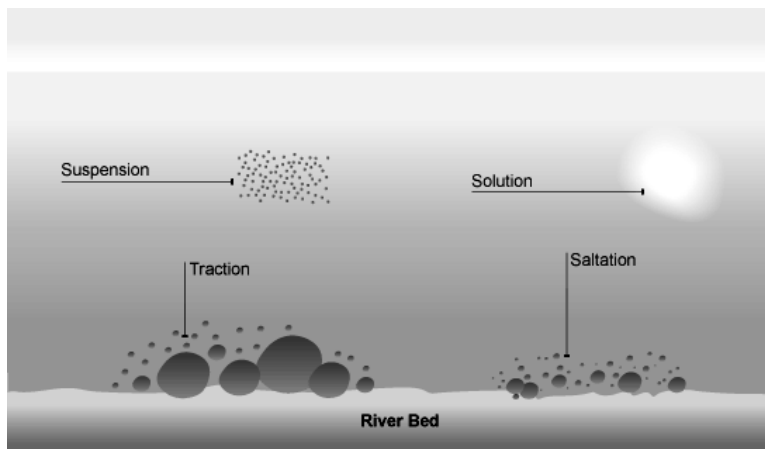
Rivers pick up and carry material as they flow downstream. A river may transport material in four different ways:

Solution - minerals are dissolved in the water and carried along in solution.

Suspension - fine light material is carried along in the water.

Saltation - small pebbles and stones are bounced along the river bed.

Traction - large boulders and rocks are rolled along the river bed.



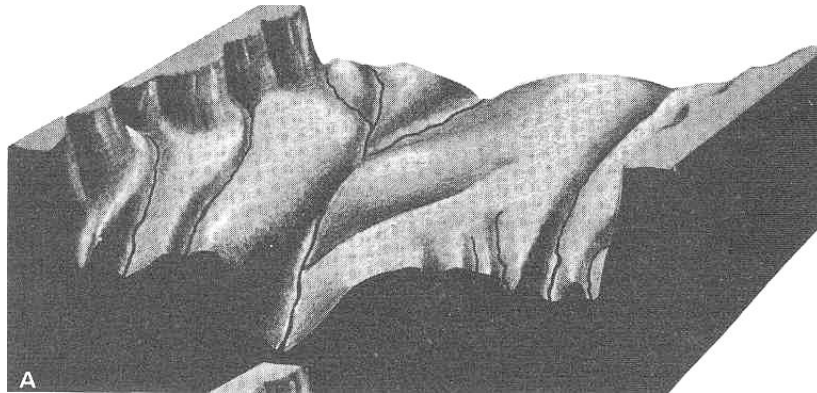
DEPOSITION

In sections of the river where the water velocity slows down, so the river could not able carry its load its starts deposits and create various type of landforms.

Erosional Features of the Rivers / Stream at Youthful stage

Valleys

- ➔ A valley is a longitudinal depression whose cross section is V shaped
- ➔ Three processes in valley developments such as 1.valley deepening, valley widening and valley lengthening
- ➔ Valley deepening due to the bedrock erosion



Waterfall

- ❖ Plunging down of water over a cliff is termed as water fall
- ❖ A rapid is one on which water flows along a steep slope
- ❖ If water flows through step like terraces is called cascade
- ❖ Suitable site for hydroelectric projects



Pot holes

- ❖ Pot holes are smaller depression found on bed rock of stream
- ❖ Plunge pools are larger pot holes usually found on the bottom of the water falls



Alluvial fan: gently sloping, conical accumulation of coarse alluvium deposited by a braided stream

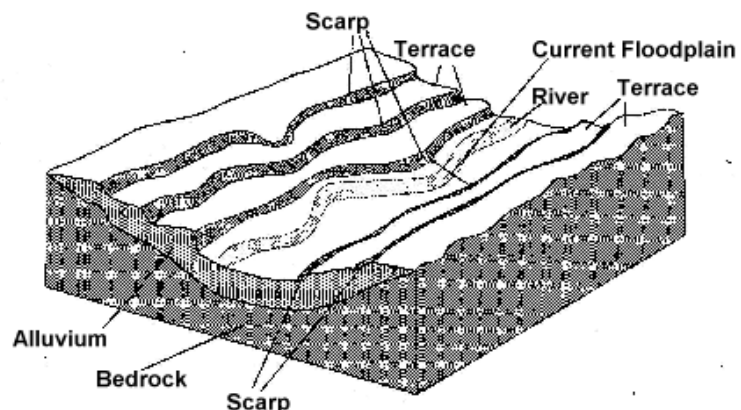


Features of the Rivers / Stream at Mature stage

- (i) Hills with diminished relief
- (ii) Flat topped hills, wide valleys
- (iii) Well developed dendritic drainages
- (iv) Absence of water falls, rapids

River terraces

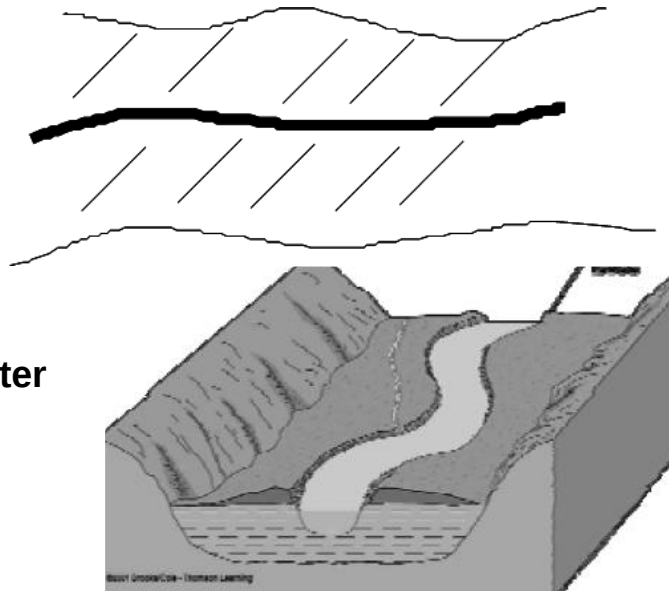
- ➔ Step like flat level surfaces cut by stream erosion
- ➔ Due to fall of Flow rate
- ➔ Rise of land
- ➔ Fall of sea level



Flood plains

- when the river floods, the river deposits the loose sediments on either banks called Flood plains
- Flood plains are the broad flat plains parallel to the river channel found by the lateral deposition of the stream during flood times.

- ❖ It will have loose unconsolidated sediments
- ❖ Retain more moisture
- ❖ Accumulate better Ground water
- ❖ Better recharge zone from river

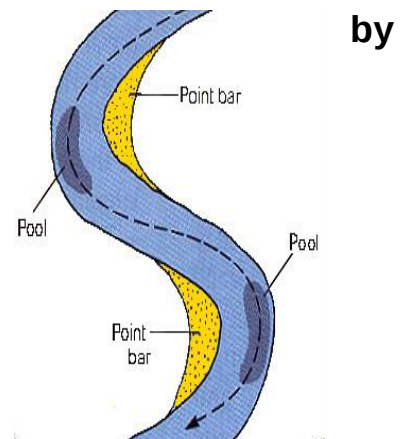


Natural Levees: Natural Levees: are created during overbank flooding, when sand and silt are deposited next to the channel creating belts of higher land on either side of the channel

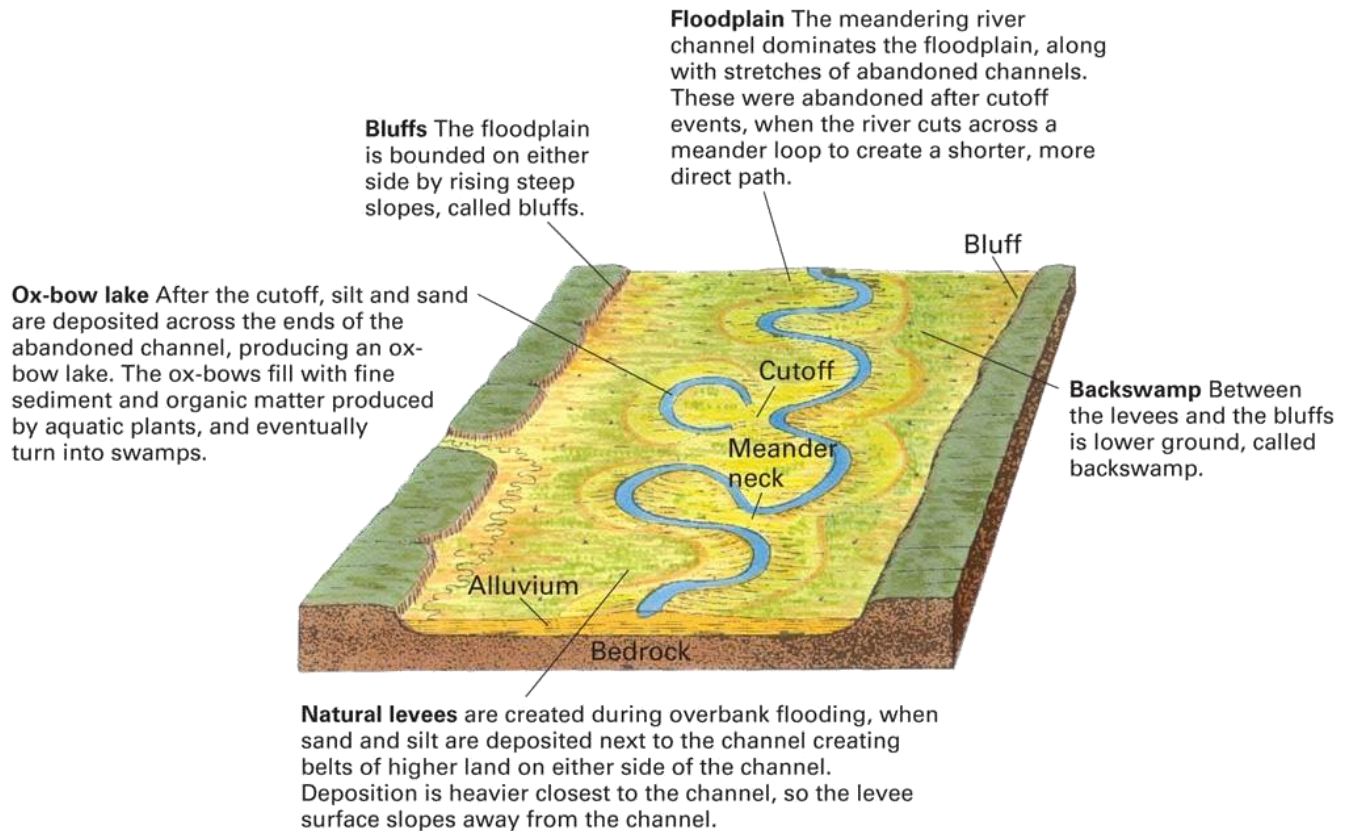
Bluffs: The floodplain is bounded on either side by rising steep slope is called bluffs

Point Bar: Point bar: these are deposits formed inside a meander curve or at the river's mouth

Meander loop: Low velocity, low sediment streams flowing on nearly flat floodplain form meanders. Meanders shift from side to side by snaking motion



Cut Off Meanders / Oxbow Lakes: As the erosion and deposition processes continues, the heads grow closer and the point bar bigger. During a major flood when velocity and water volume increase, the river takes a new shorter course cutting across the loop. The abandoned loop remains as an oxbow lake



Features of the Rivers / Stream at Oldstage

→ River changes its works from erosion to deposition

→ The valley floor is very broad and flat

→ Slope are greatly gentle

Delta: A body of alluvium, nearly flat and fan-shaped, deposited at or near the mouth of a river or stream where it enters a body of relatively quiet water, usually a sea or lake is called delta

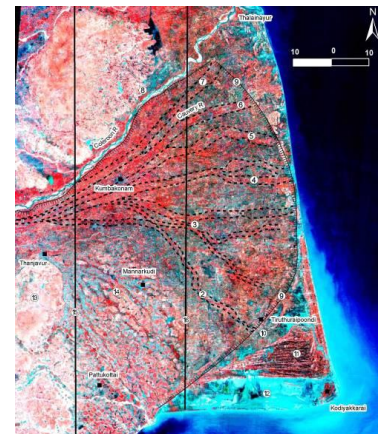
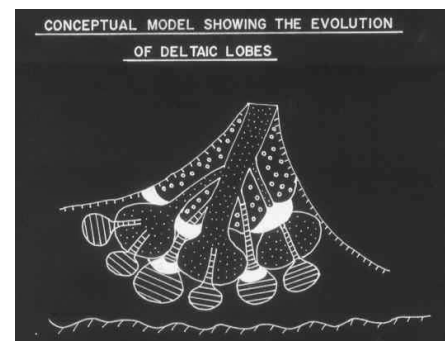
Deltas signify the land-ocean interactive dynamics and the related geological processes

Lobate delta covers the river derived sediments (e.g. ancient Mississippi river delta)

lobate deltas symbolize constant emergence of land or withdrawal of sea and the resultant progradation of deltas by developing lobes after lobes

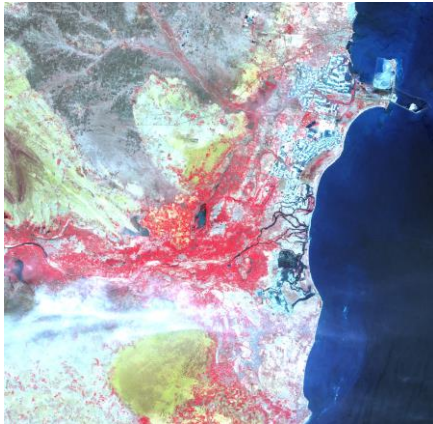
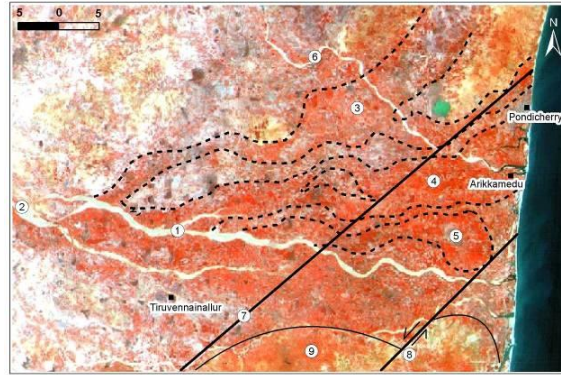
An **arcuate delta** has three sided outline with seaward margin convex or arcuate

The Nile and the Cauvery delta has this morphology



Cusplate Delta: Triangle shaped deposits accumulate on either side of the main channel. (e.g. Brazos river delta, Texas, Tiber river delta)

Digitate Delta: Digitate delta indicates that the delta might have been in the process of subsidence inviting the tidal waters since its inception



Estuarine Delta: This delta is funnel shaped has the length several times greater than maximum width. The distributaries are braided and are separated by sandbars or islands

RIVER REJUVINATION

Rapid tectonic uplift increases the river's gradient and velocity, so it cuts down into the bedrock

Entrenched Meanders: Entrenched meanders: winding, sinuous valley produced by degradation of a with trenching into the bedrock by downcutting



stream

COASTAL DYNAMICS

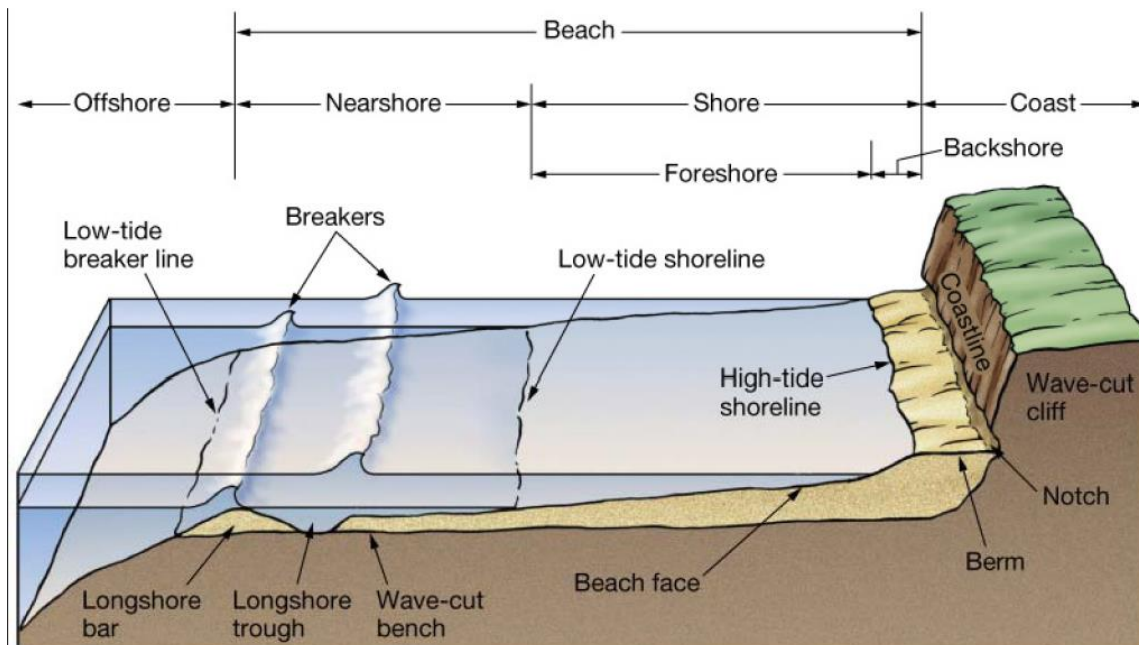
COASTAL ZONE:

“The space in which terrestrial environs influence marine (or lacustrine) environs and vice versa

- Variable in width and composition
- May be highly dynamic over time
- Zonal boundaries often difficult to define (highly ephemeral)
- Coastal zone may be strongly characterized by
 - a. Physical
 - b. Biological
 - c. Cultural Criteria

Coastal Zone Classified into to four sub units

- (1) Coast
- (2) Shore
- (3) Near shore
- (4) Off shore



Coast: Transition zone where the land meets water. It extends from the continental shelf break to the first major change in topography

Coastline: is the maximum reach of storm waves

Shore: Extends from the low-water line to the coastline

- (1) backshore (or berm)
- (2) foreshore (or beach face).

Foreshore: From the low-water line to the limit of wave uprush at high tide

Backshore: That part of the beach that is usually dry, being reached only by the highest tides

Nearshore: Low tide breaker zone to Low tide shoreline

Offshore: Below the low tide breaker zone

TYPES OF COASTS

Coasts are highly varied and complex systems. The number and variety of coastal classifications is large and often subject to an author's personal bias or background.

Mostly classifications are based on influencing factor such as geologic history and sea-level changes, tectonic environment, glaciation, sediment supply, wave and tidal regime, biological factor, etc.

Johnson (1919) Classify the coast on the basis of Tectonic and relative sea level changes (eustatic and isostatic).

→ **Submergent: Fjord or ria coast (Chesapeake Bay, Martha's Vineyard)**

Submerged shoreline formed when water comes in contact with partially submerged land. This type of coast is very irregular. This produces long and narrow bays called estuaries. Due to wave action, sea cliffs, wave cut terrace, sea caves, stacks, beaches, hooks, spits, hooks, etc. are developed

→ **Emergent: Tidal flats and barrier islands**

Emerged shoreline formed when water comes in contact with partially emerged land. This type of coast is regular and flat. Water is shallow to some distance.

→ Neutral

In this types, effects of submergence and emergences of land is not represented (e.g) shoreline produced by streams (deltas), organic growth (coral reef)

→ Compound coast

- ❖ **Some emerging coast has the some submergent coastal features**
- ❖ **Some submerging coast has the features of an emergent coast landforms(e.g. barrier islands)**

Classification of the coasts on the basis of marine processes or non marine processes by Shepard (1973)

Primary coast: Unmodified--morphology controlled by non marine processes

Secondary Coasts: Modified by marine processes

Primary coast:

1. Land erosion coasts

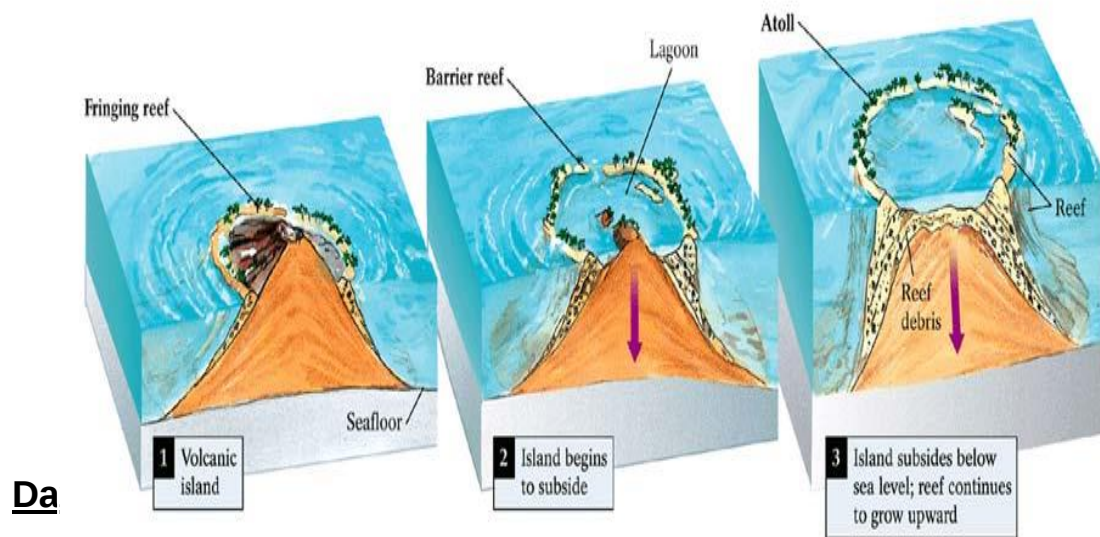
- Drown river valley coast : indented--shape controlled by drainage basin pattern**
- Drowned glaciated coast (e.g. Deep coastal valleys--fiords)**

2. Subaerial deposition coasts

- River deposition coasts**
- Glacial deposition coasts**
- Wind deposition coasts**
- Landslide coast**
- volcanic coasts**
- shaped by diastrophic movements (faulted coasts)**
- Ice coasts**

Secondary Coasts (modified by coastal processes)

- Wave erosion coasts
 - ❖ Wave straightened cliffs
 - ❖ Differentially eroded coasts
- Marine deposition coasts
 - ❖ Barrier beach
 - ❖ Barrier island
 - ❖ Barrier spit
- Coasts built by organisms (Coral reef coasts (fringing reef, barrier reef, atoll, etc.))
 - ◆ Fringing Reef- initially surround land, grow seaward
 - ◆ Barrier Reef- separated from coast by a lagoon
 - ◆ Atoll- circular structure from great depth that encloses shallow lagoon
 - ◆ Mangrove coast



- Mesotidal coasts (tidal range = 2-4 meters)
- Macrotidal coast (tidal range >4 meters)

- ❖ Microtidal = wave dominant
- ❖ Macrotidal = tide dominate
- ❖ Mesotidal = mixed energy

Inman and Nordstrom, 1971, Classified the coasts on the basis of plate tectonics

1. Collision Coasts (active coasts)

*Dr.J.Saravanavel, Assistant Professor, Centre for Remote Sensing, Bharathidasan University,
e-Learning Material: Physical Geology and Geodynamics: drsaraj@gmail.com*

e.g.. Pacific coasts of North and South America (thick and thin plates collide)

Island Arc Collision Coasts

e.g.. Philippines, Indonesian and Aleutian Island arcs (thin plates collide)

2. Trailing Edge Coasts

- **Neo-Trailing Edge Coast: New trailing edge coasts formed near beginning separation centers and rifts**
e.g.. Red Sea and Gulf of California
- **Afro-Trailing Edge Coast**

Opposite coast of the continent is also trailing thus potential for terrestrial erosion and deposition is low e.g.. Atlantic and Indian Ocean coasts of Africa

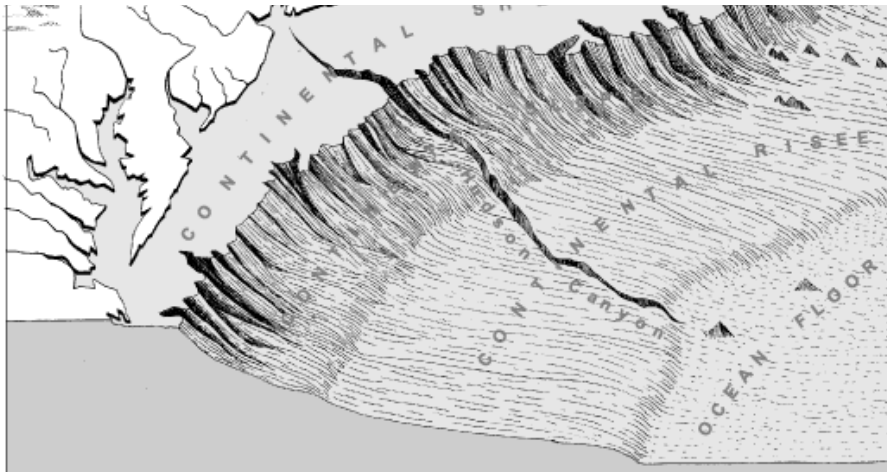
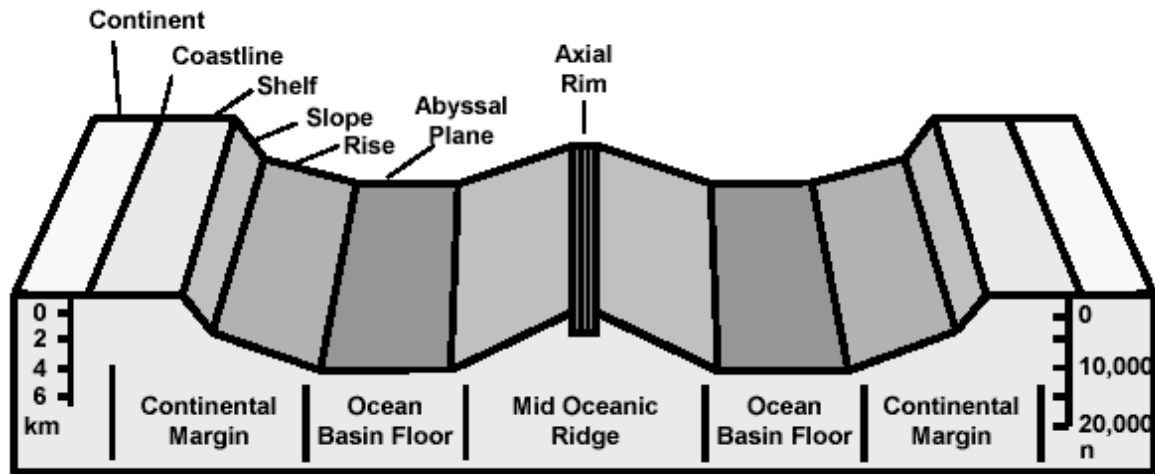
- **Amero-Trailing Edge Coast**

Trailing edge of a continent with a collision coast modified by depositional material and erosive effects from high interior e.g.. East coasts of North and South America

3. Marginal Sea Coasts

Coasts fronting on marginal seas and protected by island arcs from the open sea
e.g. Vietnam, South China, Korea, Gulf of Mexico, Northeast Australia

OFFSHORE PROFILE



The shallow platform adjacent to the coast is the Continental Shelf and extended up to the Shelf Break

At Shelf Break the seabed steepens and the Continental Slope begins.

At the foot of the continental slope is the Continental Rise where the gradients are about 1:300. In a water depth of about 5000m this merges with an almost flat Abyssal Plain.

Dynamic coastal processes

1. Wave action
2. Littoral current Action
3. Rip currents

4. Tide Rips
5. Tides Action
6. Organisms And Their Action

1. Wave action

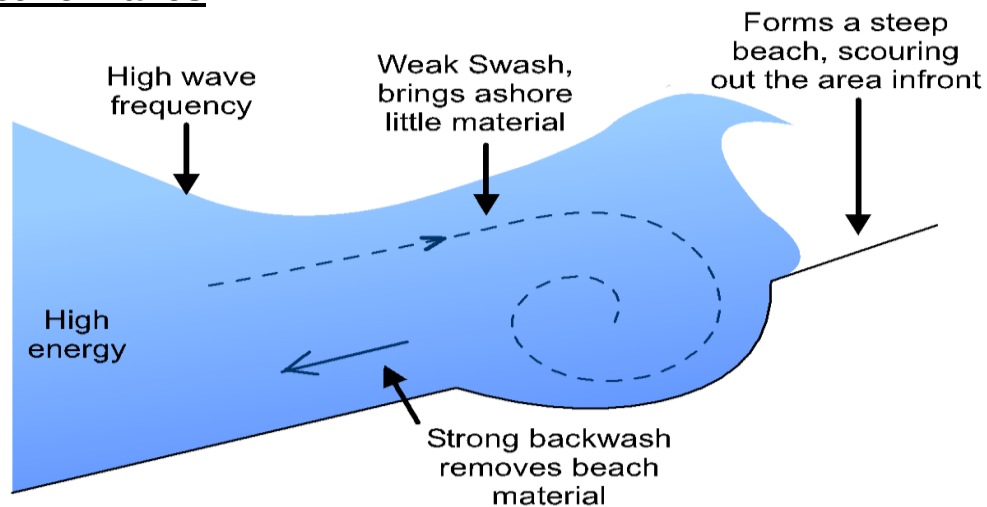
(a) Causes of waves

- (1) Earth Tides
- (2) Lunar Tides
- (3) Sub marine earthquakes
- (4) Landslides
- (5) Wind
- (6) Movement of boat / ships
- (7) Tsunamis

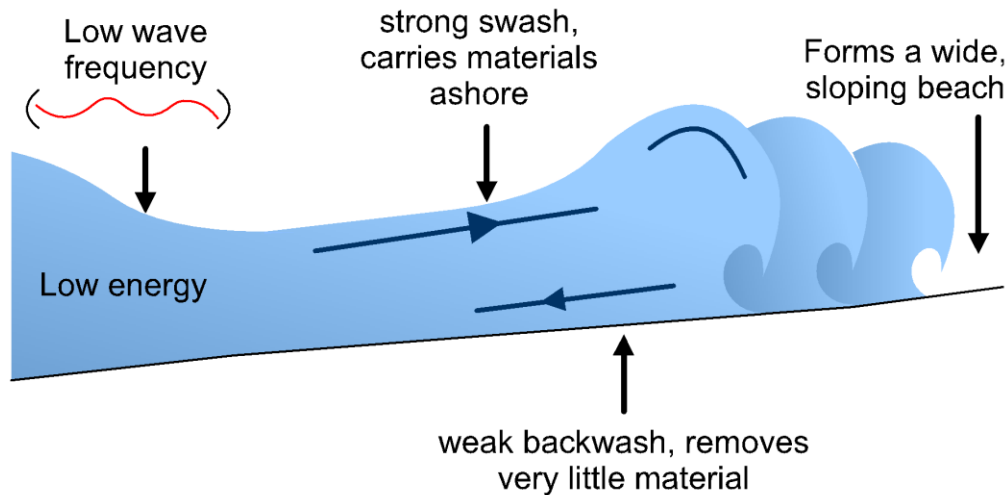
The coastal system is an ever-changing physical environment, powered primarily by the waves. These come in two main forms: **destructive** (or **erosive**) waves, and **constructive** (or **depositional**) waves

b)Types of Wave

Destructive Waves

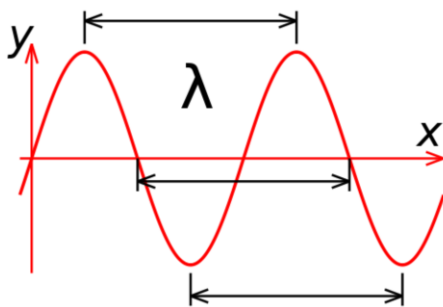


Constructive Waves



- ❖ **Swash:** Upward movement of water on to the beach occurs at an certain oblique angle.
- ❖ **Backwash:** Return of water is at right angle to the beach
- ❖ **Beach Drift:** the endless cycle of swash and backwash

(c) Height of waves : Depend upon the Source (5-40 ft)



(d) Wave length of waves

(e) Depth of wave action: Wave motion decreases rapidly at depth, They carry fine sediments below their surface

Wave Motion:

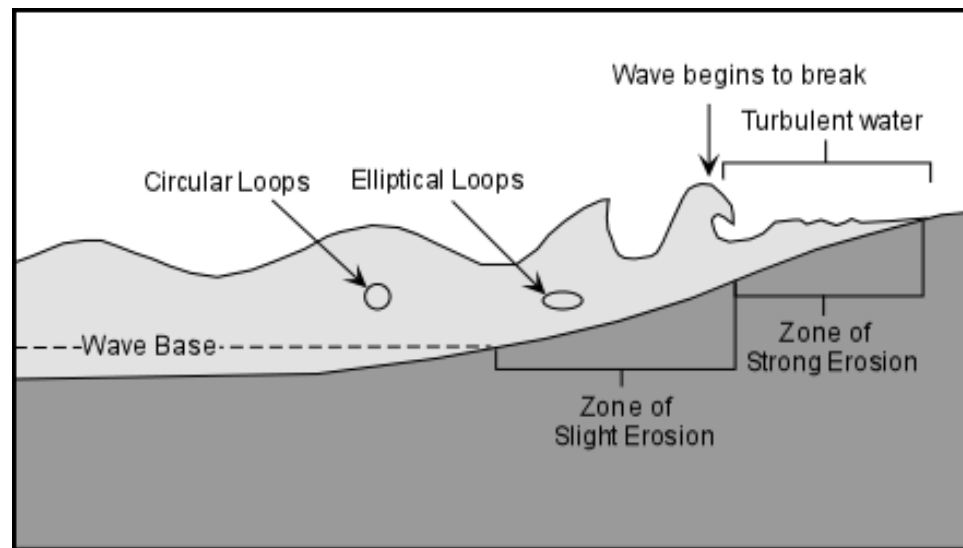
1. Oscillatory motion

Individual water particle move in circular fashion. They move forward in the crest of the wave and backward in the trough

But during heavy winds the forward motion is accelerated and causes asymmetrical waves

2. Translatory motions

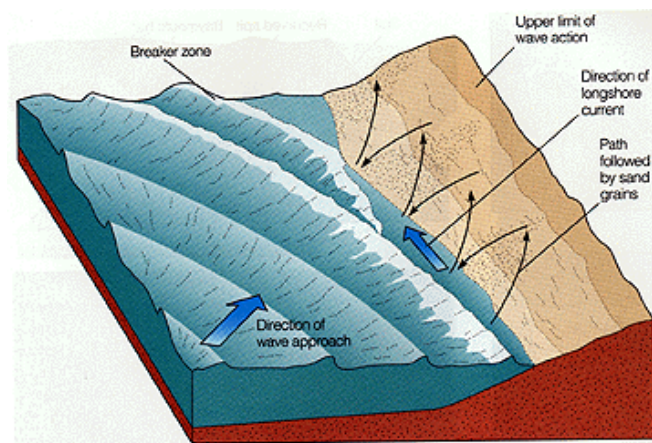
In asymmetrical waves particles will have translatory motion



LITTORAL CURRENT ACTION

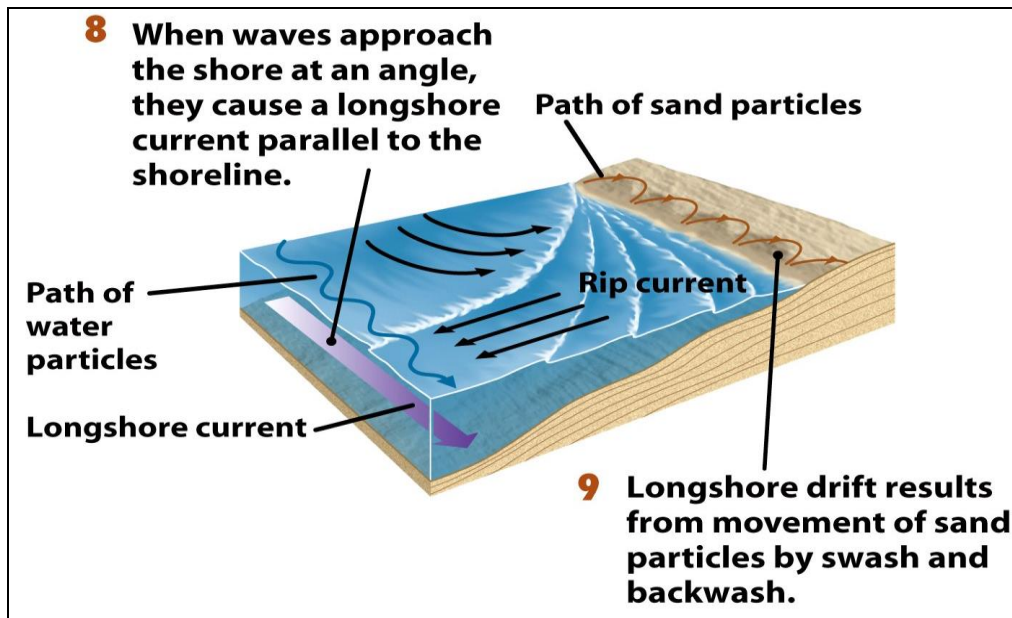
It is a current moving parallel to the coast

The tangentially or obliquely hitting waves get resolved into two one parallel to shore another backward. Such parallel current is littoral current



RIP CURRENTS

- ☛ When waves hit the coast and resolved into littoral currents and the seaward drifted currents such seaward drifted currents will be pushed back to the shore by wave
- ☛ This cause Rip currents



TIDE RIPS

The interference between wave front and littoral current will cause eddies. This is called as tide rips.

TIDAL CURRENTS

Tides are due to the gravitational attraction of Moon and Sun on the Earth

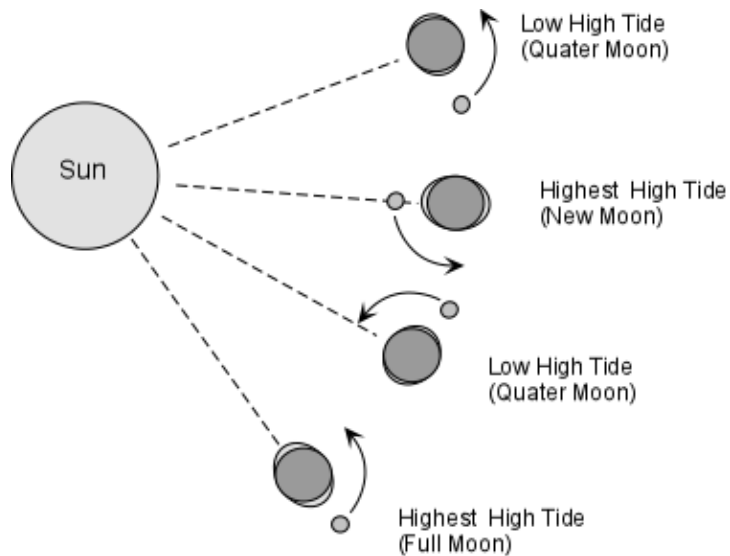
Causes the Earth to bulge toward the moon result in rise and fall of ocean surface

As a result water moves horizontally in the form of currents called as tidal currents

They rise and fall twice a day. Normal height only 1 1/2 feet

SPRING TIDE: Highest high tides - When the Sun, Moon and Earth in same line (new Moon & full Moon).

NEAP TIDE: The lowest high tides occur when the Sun the Moon are not opposed relative to Earth (quarter Moons)

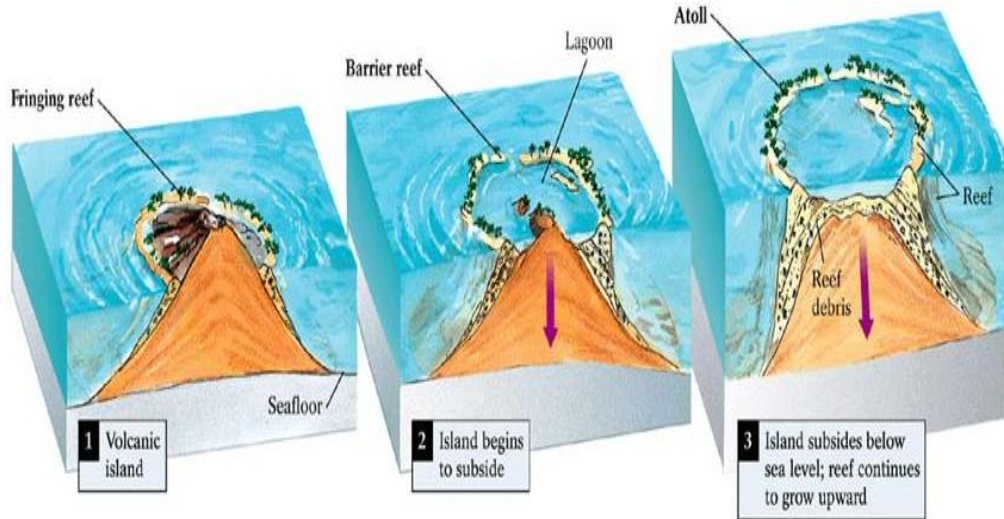


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Organisms And Their Action

Polyps live in 150 - 200' deep water and when water has more CaCO_3 and the temperature is above 68 degree, these organisms segregate and build reefs which finally grow into Islands



BARRIER REEFS: Lagoon between Island and Reef

ATOLL: Circular coral reef with central lagoon

SEAS AND OCEANS AND THEIR GEOLOGICAL ACTIVITIES

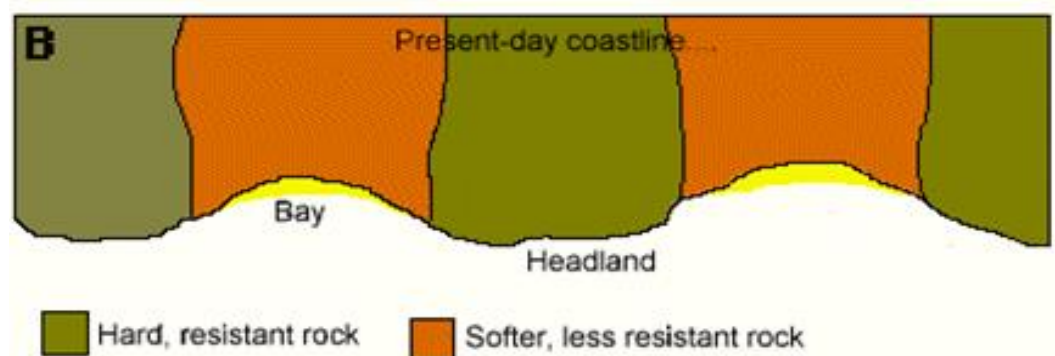
- ❖ As other geologic agents sea also eroding, transporting and depositing materials and modify the coastal areas

Erosion by Sea

- ❖ Erosion accomplished by waves through
- ❖ Attrition : As the sediment is hurled against the cliff, bits are chipped off, the sediment gets smaller & rounder. Also as sediment roll against each other on a beach.
- ❖ Abrasion: The waves pick up the sediment & hurl it against the cliffs (uses the sediment as ammunition).
- ❖ Hydraulic Action: Water forcefully enters into the cracks and fissures and compresses air within these fractures. On the retreat of waves air expands with an explosive action. Repeated compression and expansion of air by the sudden impacts waves cause disintegration of cliff rocks
- ❖ Solution: Salt & other chemicals in sea water attack & dissolve the cliffs.

EROSIONAL FEATURES

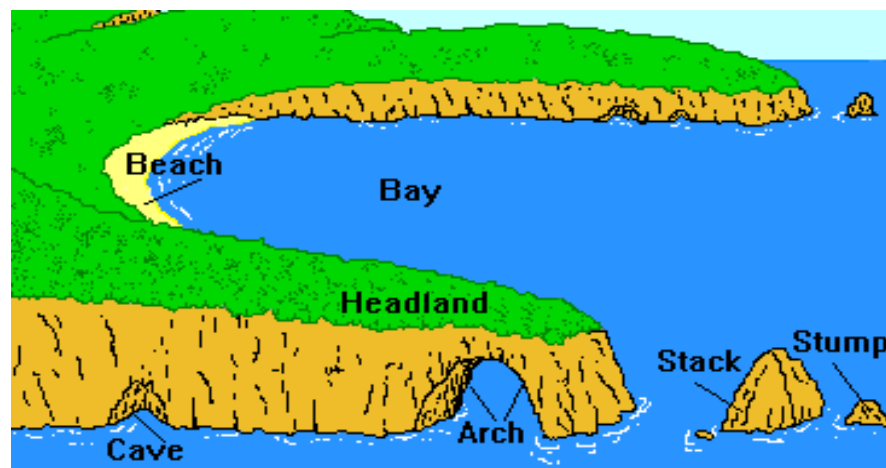
Headlands & Bay: If there is alternate hard rock and weak rock, results in unequal erosion. The hard rock extending into the sea is called as Headland and the weak rock extending into the land is called Bay



Crack, Inlet or Geo: Wave attack picks out cracks, joints & weaknesses in the cliff. In time these weaknesses are widened, to form inlets or Geos

Sea Cave: The inlet is further widened & deepened to form a cave

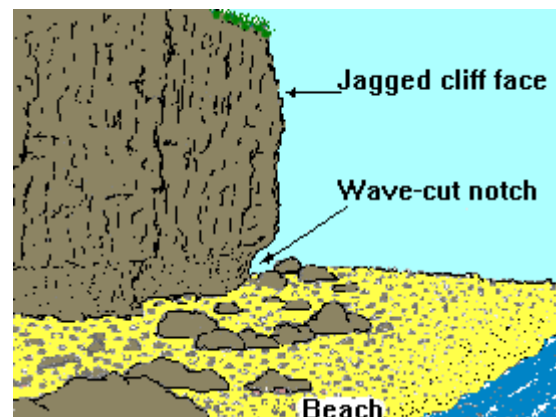
Natural Arch: Eventually the cave deepens enough for it to pass through the headland, or it meets another cave coming the opposite direction.



Stack: Continual erosion of the arch causes the roof to become unstable & collapse and form the pillar like structure called stack

Stump: Continual attack of the stack reduces its height & width gradually disappears

Wave Cut Platform: The cliff above the wave cut notch eventually collapses leaving the further back. Repeat this process & a wave cut platform left at the cliff foot, indicating retreat.

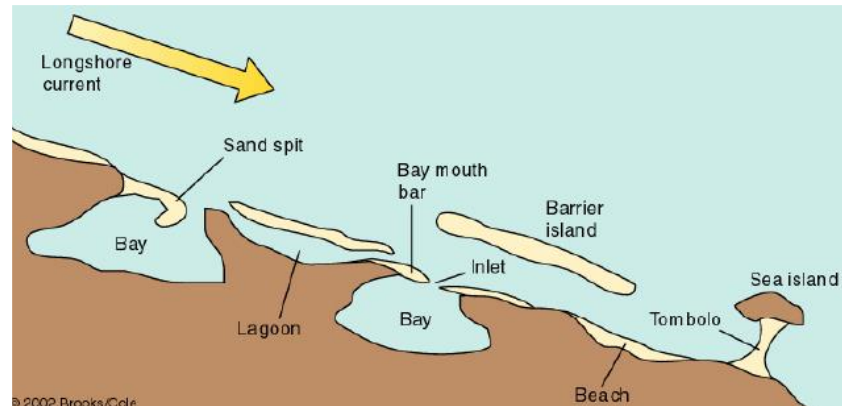


& it
cliff
is

Cliff: Constant wave attack at the base & leave a steep, near vertical cliff.

Depositional Features

- ❖ Beach
- ❖ Spit
- ❖ Bay barrier
- ❖ Tombolo
- ❖ Barrier Island
- ❖ Delta
- ❖ Lagoons
- ❖ Bay mouth bar



Beach: Loose material deposited on the shore by wave action

Barrier Beach: When current and wave deposit material parallel to shore (few meters inside the sea)

Spit: Landforms due to longshore drift and wave action. Growth of sandbar at an angle to the shore or at mouth of an embayment or at faulted segments are called spit. Hook is the Curved spit. Migrate in direction of drift.

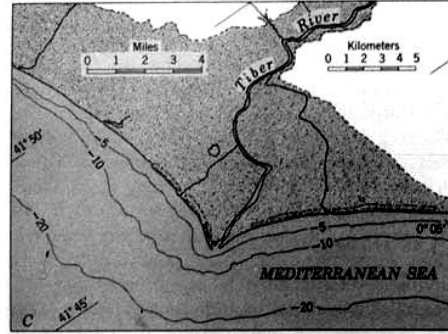
Where a spit crosses a bay is called **Baymouth Bar**

Barrier Bars and Islands: Barrier Islands are offshore sand islands usually <5m high Separated from mainland by a lagoon extend up to several hundred kms separated by inlets Very susceptible to storm erosion

Tombolo: Sediment “bridges” that connect beach to an island Wave power decreases in the lee of the island by refraction. Sandbar connecting mainland with island is called **Tombolo**

Backwaters / Lagoons: Seawater comes through creeks, swales, fractures and fill the adjoining lowlands areas are called backwater. Water caught up between barrier and shore is called lagoons

Delta: A body of alluvium, nearly flat fan-shaped, deposited at or near the mouth of a river or stream where it enters a body of relatively quiet water, usually a sea or lake



and

Beach ridges: Beach ridges are long and linear sub parallel swarms of sand ridges occurring parallel to the coast for several kilometers both continuously and discontinuously.



the

These represent the ancient shorelines along which the littoral currents and the waves have dumped the sediments and built beaches.

the

Swales: The set of linear depressions sandwiched between the long and linear sand ridges running for several kilometers parallel to the coast are called as swales.

Mud Flats / Tidal Flats: Fringing the creeks, river mouths, swales, backwaters and near the shore, the mudflats and saltpans are found. These normally occur under the grip of the tidal activities

Extensive land , alternately covered and uncovered by the tide activities consists of unconsolidated sediment (clays, silts and/or sands)

- a. Supra Tidal Flats: Above the MSL
- b. Inter Tidal Flats: At MSL level
- c. Sub Tidal Flats: Below MSL

Marine Deposits

Ocean deposits may be grouped into two classes as

1. Shallow water deposits
2. Deep water deposits

Shallow Water Deposits: The deposits formed on continental shelf and slope. Mostly materials derived from the land. It extends to 500 km off the shore

Size of the materials decreases as distance increases from shore. Deposits covers range of particles from gravel, cobble, sand, silt to clay.

Deep Sea Deposits: Deep sea sediments are finer in size. Classified in to two

1. Terrigenous (Land Derived)
2. Pelagic (Oceanic)

Terrigenous (Land Derived): Include the volcanic ash, glacier transported silt and sand and silt and clay derived from land

Red or brown clay are more abundant in deep regions. Turbidites is a deposits which having coarse to fine grained from bottom to top are more in continental margin.

Pelagic Deposits: Consists of biochemical and chemical deposits. Deep sea deposits of organic origin. Accumulation of shells and remains of tiny organisms and plants.

Oozes are the commonly found deposits. These are may be calcareous or siliceous Globigerina and pteropod ooze are common calcareous ooze.

Radiolarian and diatomaceous oozes are siliceous oozes

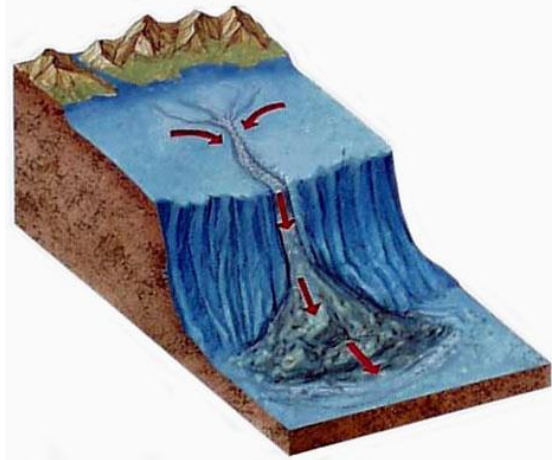
Some inorganic deposits are phillipsite (a silicate mineral). Polymetallic nodules of iron, manganese, cobalt, nickel and zirconium.

Submarine Canyon: Submarine Canyons Form at the Junction between Continental Shelf and Continental Slope

Submarine canyons: major conduits of siliciclastic sediment from the continental shelf to the abyssal plain.

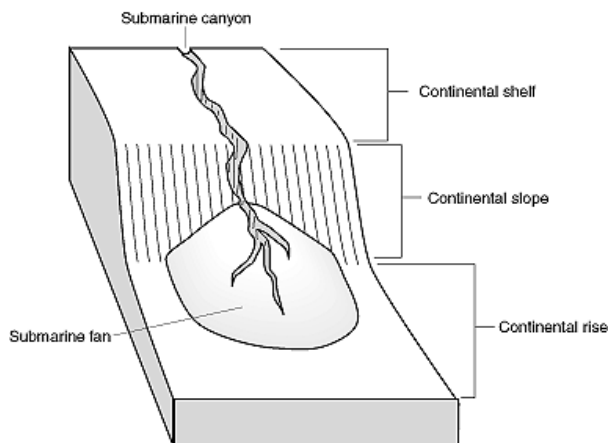
These are features of some continental margins. They cut into the continental shelf and slope, often terminating on the deep-sea floor in a fan-shaped wedge of sediment.

Steep V shape channel, incised in the continental slope (and shelf). Created by rivers during the last low stand (some) and Turbidity currents



Submarine fans: accumulations of siliciclastic sediment from the shelf break onto the base of the continental slope

- ❖ Submarine canyons cut all continental shelves and slopes and carry sediment to the deep ocean basins.
- ❖ There are many small submarine canyons and few large ones.
- ❖ Large canyons are always associated with large coastal rivers.
- ❖ Submarine canyons may be formed, in part, by downcutting of coastal rivers during intervals of low sea level.
- ❖ Later continued flow of water and suspended sediment through the submerged channels might lead to their further development and extension into the deep sea.
- ❖ Submarine canyons may also be periodically “flushed” by submarine slides. Continued flow through the depressions might lead to their further development and extension into the deep sea.
- ❖ Submarine fans are found at the base of canyons around the world.



Unit: 5 - Earth Surface Processes-II: Geological actions of Wind, Sand Dunes, Cycle of Erosion, Transportation and Deposition - Dynamics of Lakes (Origin of lakes, nature and development of lakes, different types of Lakes, lacustrine deposits) -Underground water (Origin, type of Groundwater, Solution Caves and Caverns, Geysers) - Glaciers and their Geological Actions.

EARTH SURFACE PROCESSES-II

Geological actions of Wind, Sand Dunes, Cycle of Erosion, Transportation and Deposition

Wind is common in arid desert regions because:

- ➔ Air near the surface is heated and rises, cooler air comes in to replace hot rising air and this movement of air results in winds.
- ➔ Arid regions have little or no soil moisture to hold rock and mineral fragments.
- ➔ Wind has the ability to transport, erode, and deposit sediment.

DESERT: Where wind is the dominant geological agent

- ❖ A desert is an area with less than 25 cm (10 inches) of annual precipitation
- ❖ aridity index = potential evaporation/precipitation greater than 4.0
- ❖ Deserts may be cold, temperate or hot. All major continents have one type of desert or the other.
- ❖ Deserts cover about 1/5th of the land

SOURCES OF SAND

- ➔ Sandy beaches with onshore winds
- ➔ Streams with sandy bottoms exposed during dry season
- ➔ Dry areas / desert areas where disintegration of sandstone & other rocks provides the sand
- ➔ Glacial outwash deposits and sandy glacial lakebed

GEOLOGICAL ACTION OF ACTION

- ★ Wind erosion
- ★ Wind transportation
- ★ Wind deposition

Wind Erosion : Wind can be effective agent of erosion anywhere that it is strong enough to act.

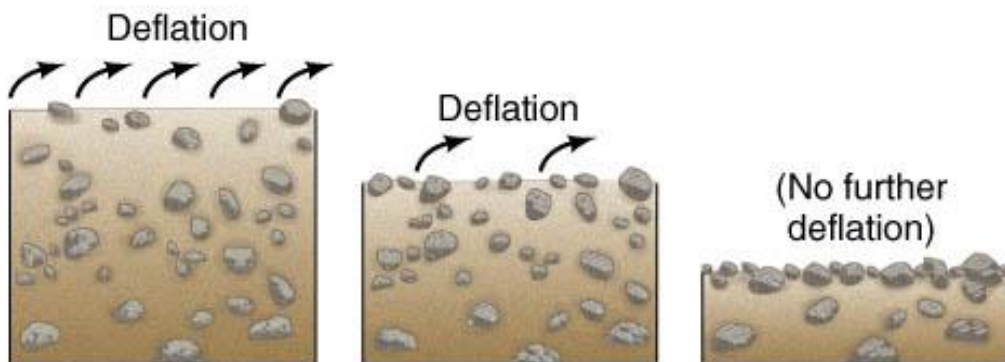
Removal of material by wind Through following Processes

Deflation:

- ❖ Blowing of fine sand particles leaving the coarser material
- ❖ This process scoop out the material and cause depressions. These depressions cause 'lakes'
- ❖ In Arabian desert – 10 Km long X 3 miles wide and 300' deep

Collision: Wind with sands collide with rocks and cause wind sculptured features

Abrasion: The wearing down of solid rocks by the impact of wind borne materials is called Abrasion. The intensity of abrasion depends on the hardness, concentration, velocity and mass of moving particles.



FEATURES OF WIND EROSION

Wind sculptures / Cavernous features In Hard rocks

- Wind carved hills
- Mushroom, Table and Pedestal or Pinnacled rocks
- Natural bridges
- Yardang
- Ventifacts
- Desert Varnish

In Soft rocks and Unconsolidated material

- Forms bowels and caves
- Deflation Basin
- Desert Lakes
- Desert pavements

Wind Carved Hills: Underside of some hills are removed by the abrasion and impact of wind transported sand particles. The top of the hill would be bigger in size relative to the bottom. This is due to transportation of sand grains in near surface.

Cave Rocks: The impact and abrasion of sand cut cave like features in the sides of rock

Frog rocks: The impact and abrasion of sand cut features like frog is called frog rocks. This is due to the wind sculpturing. This transportation of sand grains in above the near surface



Mushroom and Pedestal or Pinnacled rocks: These are isolated rocks from which the base has been partially cut by undercutting of wind blown sand and create feature like mushroom.

Wind erodes away the bottom portion of a rock and giving a feature of large mass of rock resting on the pillar. This is called pedestal rock

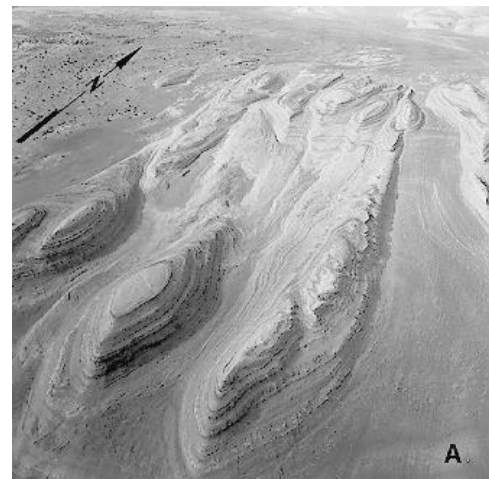


Yardangs:
Yardangs are elongated and stream lined ridges

that look like an overturned ship's hull.

They are typically found grouped in clusters aligned parallel to the prevailing winds. They probably form by differential erosion in which depressions, parallel to the direction of wind, are carved out of a rock body, leaving sharp, elongated ridges.

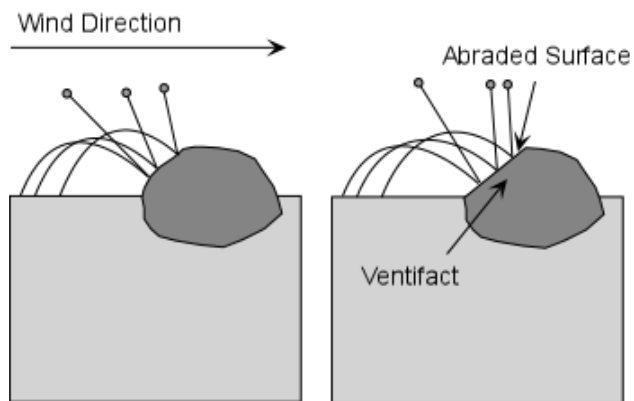
These ridges may then be further modified by wind abrasion into their characteristic shape



At some region where hard and soft rocks alternate wind erodes away the softer rocks. The hard rocks protruding in between grooves are also known as yardangs.

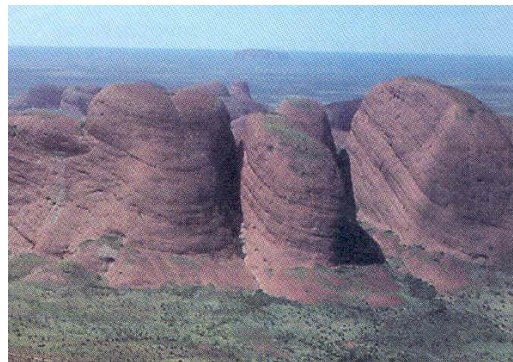
Ventifacts: Ventifacts form when wind blowing predominantly from one direction abrades desert floor stones, creating flat surfaces and sharp edges. As the wind changes direction or the stones shift

position, exposing other surfaces to wind abrasion, more facets are produced on the newly exposed surfaces



Rock varnish: An interesting feature seen in many deserts is a thin, red, brown or black shiny coating on the surface of many rocks called rock varnish, is composed of iron and manganese oxides

Inselberg: In many arid and semiarid regions there occur steep-sided mountains ridges or isolated hills rising abruptly from adjoining monotonously flat plains called inselbergs (German for “island mountains”) resemble rocky islands standing above the surface of a broad, flat sea.



Wind sculptures / Cavernous features In Soft rocks and unconsolidated material

- ❖ Deflation Hollows or Blow outs
- ❖ Deflation Basin
- ❖ Desert Lakes
- ❖ Desert pavements

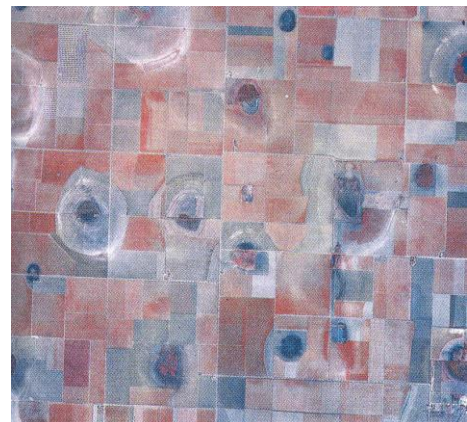
Deflation Hollows or Blow outs:

These shallow depressions of variable dimensions result from differential erosion of surface materials.

The size ranging from several kilometers in diameter and tens of meters deep to small depressions only a few meters wide and less than a meter deep. Similar pot holes by stream



Deflation Basins: are produced where solution activity in the layers of horizontal bedrock dissolves the cement that binds the sand grains together. The loose sand is removed by the wind and a basin is formed. Water trapped in the basin dissolves more cement and the basin is enlarged



Desert Pavement (lag deposits): Sorting action of wind during deflation produces desert pavements. Wind can move only sand and dust-size particles, so deflation leaves concentrations of coarser material called lag deposits or desert pavement. These striking desert features of erosion stand out in contrast to deposits in dune fields and playa lakes



Desert Oases: Oases occur in arid climates where artesian water rises to the surface, such as along a fault or anticline or wind erosion up to water table



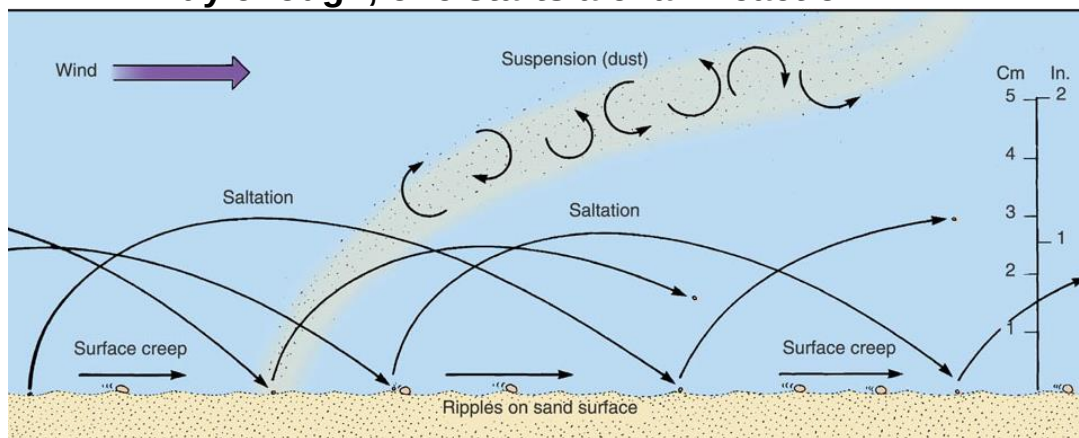
Wind Transportation

Wind transports sediment near the surface by saltation and suspension.

Saltation

Wind transports sediment near the surface by saltation. Just as in the bed load of streams, saltation refers to short jumps of grains dislodged from the surface and jumping a short distance. As the grains fall back to the surface they may dislodge other grains that then get carried by wind

- ➔ **Bed Load-** sediments moved along or near the ground
- Moves by Traction (rolling) or Sliding (rare)
 - or saltation (bouncing) - bed loads lifted off the ground momentarily due to force of collision with other grains. If windy enough, one starts a chain reaction



- ➔ **Suspension-** most suspended grains consist of dust (silt, clay, pollen, bacteria, salt crystals from evaporation, etc. Can be high and travel thousands of miles.

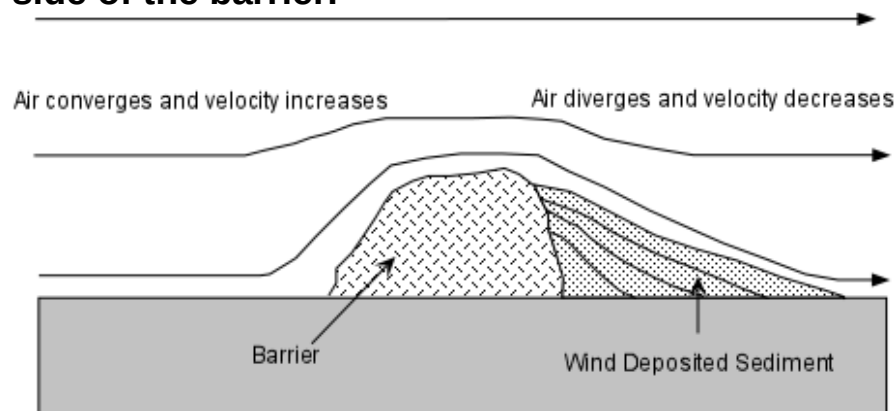
Dust or Sand Storm: When a sediment layer is disturbed, silt and clay sized particles are easily picked up and carried in suspension by the wind, creating clouds of dust or even dust storms. Once these fine particles are lifted into the atmosphere, they may be carried thousands of kilometers from their source



Dust storm or haboob: are results when cool air descends and moves laterally over the surface as a density current. As the dense, cool air moves across the surface it sweeps up dust and sand by its turbulent flow, creating a dust storm or haboob

Wind Deposition:

Wind can deposit sediment when its velocity decreases to the point where the particles can no longer be transported. This can happen when topographic barriers slow the wind velocity on the downwind side of the barrier.



As the air moves over the top of the barrier, streamlines converge and the velocity increases.

After passing over the barrier, the streamlines diverge and the velocity decreases. As the velocity decreases, some of the sediment in suspension can no longer be held in suspension, and thus drops out to form a deposit.

Reduced wind velocity results in sediments deposition and create various landforms

Depositional Features

Ripples

Loess

Dunes :

- A. Longitudinal Dunes**
- B. Transverse Dunes**
- C. Barchan Dunes**
- D. Parabolic Dunes**
- E. Sand Dunes**



Ripples: small sand waves with a wavelength of about 1 m.

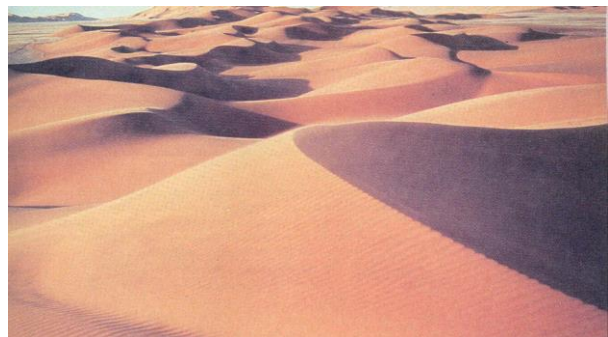
They are ephemeral and mobile, i.e. move, disappear and reform during wind storms common the windward slopes of sand dunes

Loess: Windblown silt and clay deposits composed of angular quartz, feldspar, micas and calcite are known as loess. The distribution of loess shows that is derived from three main sources: deserts, Pleistocene glacial outwash deposits and the flood plains of rivers in semiarid regions.



It must be stabilized by moisture and vegetation in order to accumulate. Because of its unconsolidated nature, loess is easily eroded and as a result, eroded loess areas are characterized by steep cliffs and rapid lateral and head ward stream erosion

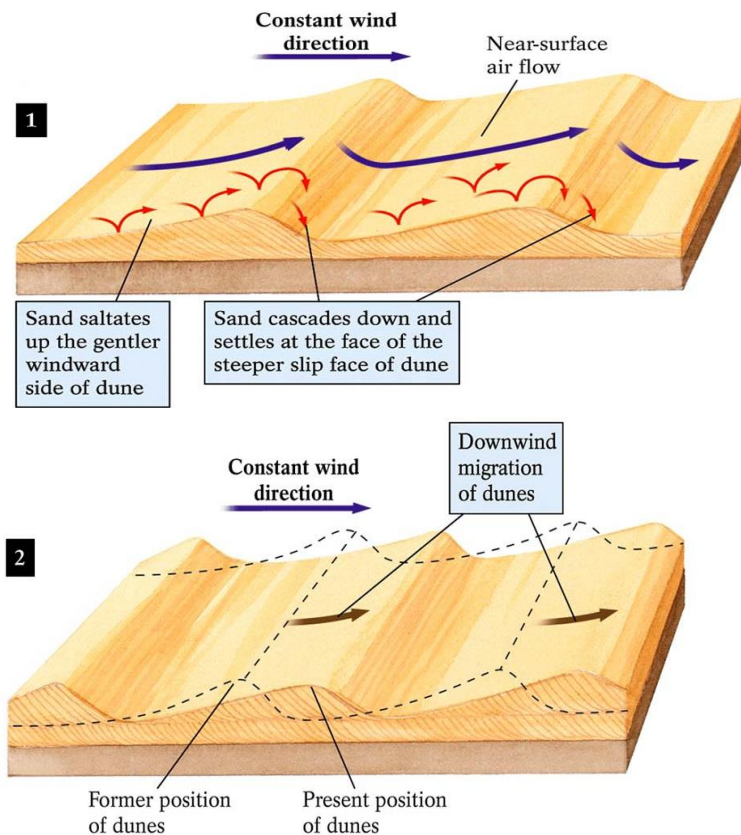
Sand dunes: Classic aeolian landform stable or advancing landform of windblown sand. Originate as a mound of free sand from a sandy surficial deposit (e.g. beach, weathering sandstone). It develops the dune asymmetry characterized by a gentle windward slope and a steep leeward slip face.



Migration of Sand dune

Once sand begins to pile up, ripples and dunes can form. Wind continues to move sand up to the top of the pile until the pile is so steep that it collapses under its own weight.

The collapsing sand comes to rest when it reaches just the right steepness to keep the dune stable. This angle, usually about 30-34°, is called the angle of repose.

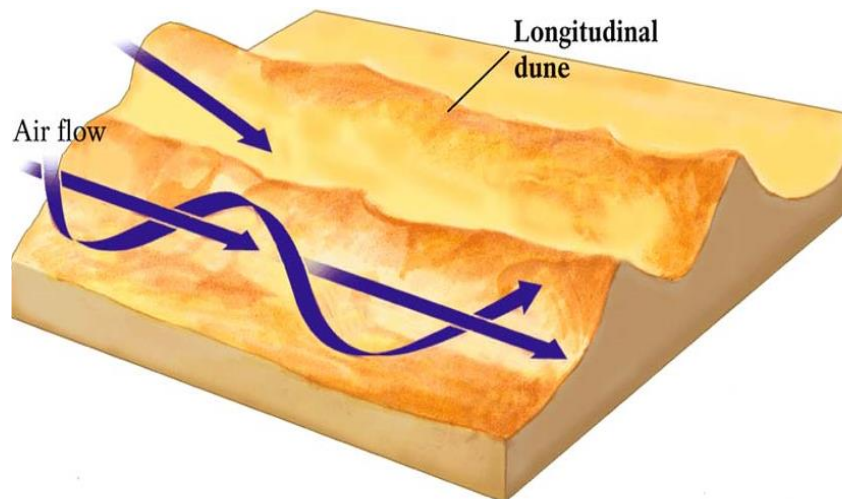


Sand dunes are further classified according to its alignment with wind and shape

- a. Longitudinal dunes**
- b. Transverse dunes**
- d. Barchan dunes**
- e. Parabolic dunes**
- f. Star dunes**

Longitudinal Dunes: Longitudinal dunes are parallel ridges and oriented parallel to the prevailing wind direction. They form when sand supply is moderate and constant

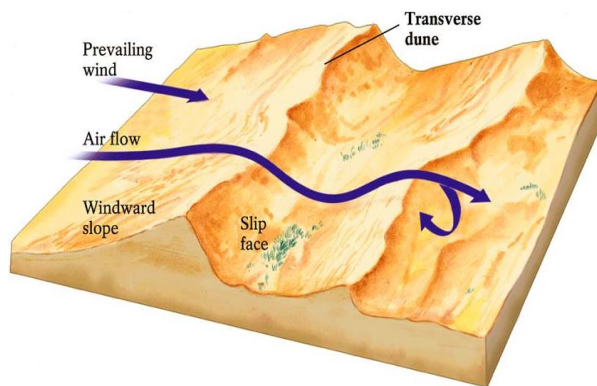
- ➔ Long, nearly straight ridges, parallel to the wind direction
- ➔ Where strong prevailing wind in a constant direction
- ➔ Symmetrical cross section, width several times the height
- ➔ Height < 15cm and several Kms long (200 – 300 km)



Longitudinal dunes

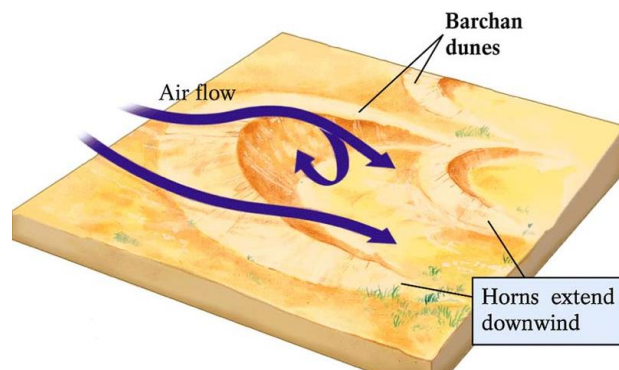
Transverse dunes: Transverse dunes are a series of parallel ridges that typically occur in arid and semi-arid regions where sand is plentiful, wind direction constant and vegetation scarce.

These dunes form perpendicular to the prevailing wind direction and have a gentle windward slope and steep leeward slip face. They also develop along the shores of oceans and large lakes where abundant sand is shaped by strong onshore winds

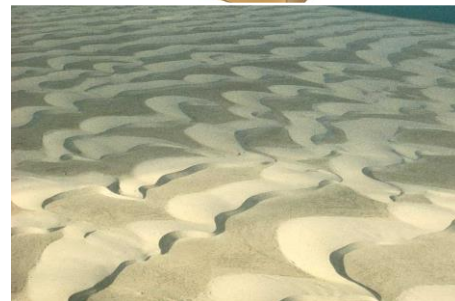


Barchan Dunes:

→ **Barchan dunes** (pronounced bar'-kane) are crescent shaped ridges that form perpendicular to the prevailing wind as sand begins to accumulate around small patches of desert vegetation.



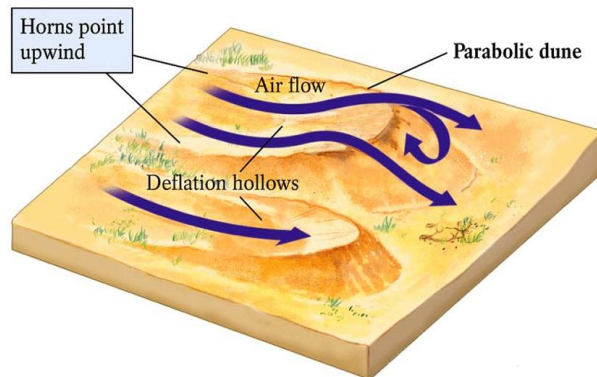
→ Barchans develop in arid regions on flat, hard ground where there is little available sand and wind direction is fixed.



→ Their horns, the points of the crescents are thinner than their centers the horns migrate downward rapidly, thus extending the barchan with its characteristic sharply pointed horns in the downwind direction

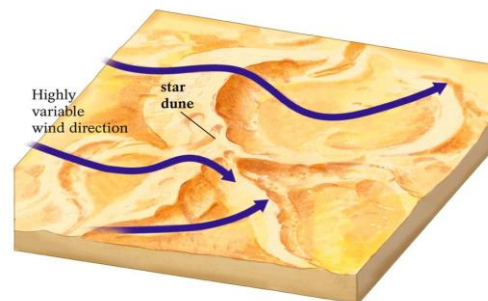
Seif Dunes: Formed due to occasional shift in wind direction. These dunes are similar to BARCHANS where one wing is not developed.

Parabolic dunes are horseshoe-shaped, differing from barchans in that their horns point upwind. They commonly form along sandy ocean and lake shores, the only appreciable dune areas outside of deserts. Parabolic dunes develop from transverse dunes that are exposed to accelerated wind deflation, especially after removal of some vegetation.



U-shaped mounds of sand with convex noses trailed by elongated arms are parabolic dunes. Sometimes these dunes are called U-shaped, blowout, or hairpin dunes, and they are well known in coastal deserts.

Star Dunes, the most complex of the dune types form when winds blow from three or more principal directions or when wind direction is constantly shifting.



They tend to grow vertically to high central point and may have three or four arms radiating from the center. Continued variability of wind direction causes star dunes to remain relatively fixed in position



Dynamics of Lakes (Origin of lakes, nature and development of lakes, different types of Lakes, lacustrine deposits)

- ➔ Lake may be described as the standing bodies of water on land.
- ➔ Any depression when filled with water becomes a lake. The lake may vary in size from small pond to sea
- ➔ Water in lakes & streams - 0.02% of water on earth. Covers <2% of world's land area
- ➔ Most lakes are much smaller, shallower (<20 m).
- ➔ Lakes can be formed in many ways. Two general categories are
 - ❖ Catastrophic
 - ❖ Non-catastrophic

Classification of Lakes

- ❖ Lakes may be classified on the basis of composition – Freshwater lakes and Saline water lakes
- ❖ On the basis of location, classified into arid region lake and humid region lake
- ❖ Lakes in the arid regions are more mostly saline or alkaline as they do not have any outlets
- ❖ Lakes in the humid regions are more mostly freshwater as they have outlets and changing water frequently

Origin of Lakes

- ❖ A lake may be formed when two condition are satisfied such as a basin or depression and sufficient water supply to store in it.
- ➔ Lakes can be formed in many ways. Two general categories are
 - ❖ Catastrophic
 - ❖ Non-catastrophic

Catastrophic Lakes are formed by

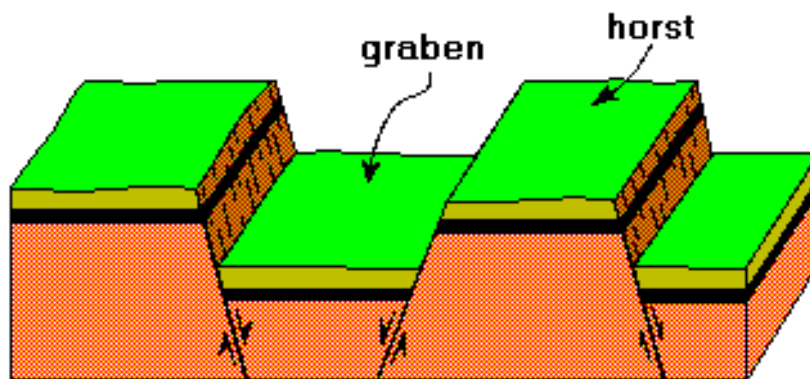
- ❖ Tectonic movements or diastrophism
- ❖ Glaciations
- ❖ Volcanism

Non-Catastrophic Lakes are formed by

- Solution activity
- Wind activity
- River
- Shoreline processes
- Organisms

Tectonic movements or diastrophism:

- Lakes formed by faulting, folding, warping of earth's crust (non-volcanic)
- Most common form - graben
- Depressed block between adjacent highlands



HORST AND GRABEN

Examples for tectonic lakes

- Lake Tahoe
 - Lake Tanganyika
 - Lake Baikal
 - Great Salt Lake
-
- Earthquake lakes - basins formed by earthquake activity
 - Reelfoot Lake, KY/TN
 - Overnight formation (?) after earthquake produced lowlands, filler with water from Mississippi River

Volcanic Lakes

- The Craters of the extinct volcanoes filled with water formed the crater lakes
 - Deepest U.S. lake - 608 m
- Lakes may also be formed due to damming or obstruction of river valleys by the lava flows
- Volcanic activity related Landslide, rockslide, mudflows may obstruct the river or streams flows and create the lakes. It is often short-lived

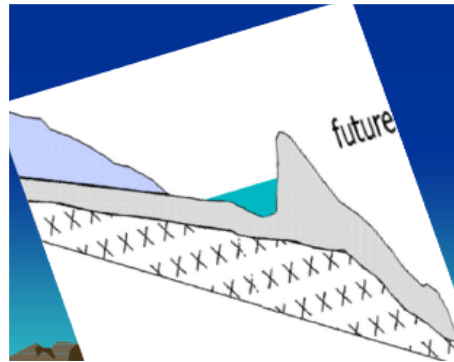
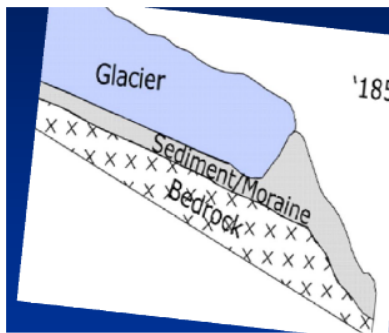


Glacial Lakes

- ➔ Erosion and deposition by glacial ice movements formed the variety of lakes
- ➔ Glacial erosion leaves huge depressions that can hold the water and form the lakes. Cirque lakes is one type of glacier lake. It is formed at upper end of glacial-scoured valley
- ➔ Glacial lakes may formed when streams dammed by tongues of ice or huge ice blocks
- ➔ Detached, isolated huge ice blocks in create depression while glacial outwash or moraine melt. These depression latter filled with water. Forms the irregular kettle lakes



➔ During the retreat of glaciers, moraines are deposited. These moronic ridges act as dams and impound water



➔ A supraglacial lake is any pond of liquid water on the top of a glacier. Although these pools are ephemeral, they may reach kilometers in diameter and be several meters deep. They may last for months or even decades at a time, but can empty in the course of hours.



Non-Catastrophic Lakes are formed by

- River
- Solution activity
- Wind activity
- Shoreline processes
- Organisms



River or stream Lakes

- River meanders cut off from main river flow and forms the oxbow lake
- Plunge pools formed beneath waterfalls
- Lake formed parallel to river during flooding
- Delta lakes: lakes formed during the delta progradation



Lake formed by the Solution activity

- Lake formed when water dissolves soluble rock formations and create a depression – Generally in Limestone region



Wind-formed Lakes

- Dunes with depressions or damming of streams by sand dune create the desert lake. May be very short-lived
- Some times, inter-dune depression filled with water formed desertic lake

- Playa Lake: In arid regions, after an infrequent and particularly intense rainstorm, excess water that is not absorbed by the ground may accumulate in low area and form playa lakes. These lakes are temporary, lasting from a few hours to several months, most of them are shallow and have rapidly shifting boundaries as water flows in or leaves by evaporation in the ground. The water is often very saline



Origin of Salt Lake: Salt lake formed in region. They have no out let. During the summer season, water will evaporate leaving the salt behind. Further, the salt be added by the incoming streams. As they have no outlets, water become more saline over the years.



arid
and
will

Salt lake also formed when part of sea off by the sedimentation or diastrophism. Sambhar lake, Rajasthan cut-

Shoreline Lakes

→ Bays cut off from main lake by longshore wave action and sand bars



Lakes formed by Organisms: Dams, reservoirs, ponds, tanks, etc. constructed by the man fall in this category.

Beaver dams are created by the Beavers as a protection against predators, such as coyotes, wolves and bears, and to provide easy access to food during winter. Beavers always work at night and are prolific builders, carrying mud and stones with their fore-paws and timber between their teeth. (Beavers may create a series of dams along a river.)



Geological Action of Lakes

Like river, seas and oceans, lakes also act as a geological agent through erosion, transportation, depositional processes. But in small scale

Lake erosion: is similar sea erosion. Water cut terraces, cliffs, caves and arches are some of the erosional features of lake

Lake Deposition: beaches, barriers, sandbars, delta, etc. are the lake depositional features

Accumulation of plants, small organism, shells, etc. in the lake floor may lead to deposition. Generally floor of the lake covered by the land derived deposits. Micro delta developed in the lake.

Marl is the lake deposits light gray in colour and carbonate of lime in composition. Thickness ranging from 1.5 m to 6m.

Decaying vegetable matter accumulate in lake floor and swamps form the peat deposits

In arid region, lakes have various salt deposits like halite, gypsum, borax, calcite, etc.

Lakes of India

Along the east and west coast of India numerous lakes has been formed by waves and shore currents.

Chilak lake of orissa, Pulicat lake of Tamil Nadu, Kayals of Keralas are imporants lakes

In Maharastra, there is a lake called Lonar lake of 1.6 km dia and a depth of 93m. This is a saline lake. The origin of lake is due to escape of lava and gases from deep surface

Sambhar lake in Rajasthan is the salt lake.

Underground water (Origin, type of Groundwater, Solution Caves and Caverns, Geysers)

Groundwater is water that exists in the pore spaces and fractures in rock and sediment beneath the Earth's surface. It originates as rainfall or snow, and then moves through the soil into the groundwater system.

Groundwater is the largest reservoir of fresh water that is readily available to humans. Nearly one percent of the water on Earth is groundwater.

Water is present everywhere beneath the land surface, but more than half of all groundwater, including most of what is usable, occurs above a depth of 750m.

Below a depth of about 750 m, the amount of groundwater gradually diminishes. Russian scientists encountered water at more than 11 km below the surface.

The volume of groundwater is a equivalent to a 55 meter thick layer spread out over the entire surface of the Earth.

Groundwater and the Hydrologic Cycle

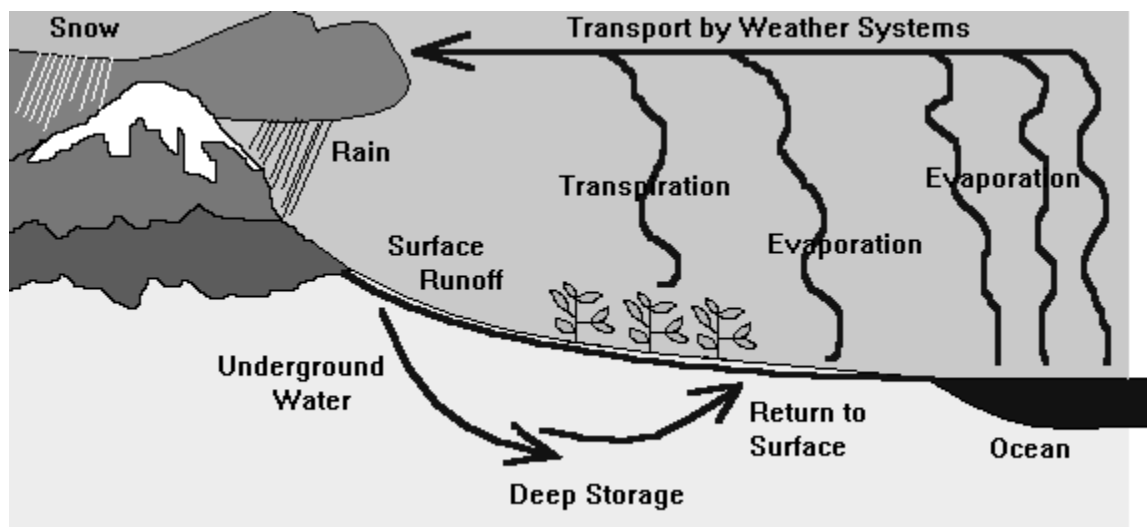


Table 10.1 Fresh water of the hydrosphere

Parts of the Hydrospher	Volume of Fresh Water (km ³)	Share of Total Volume of Fresh Water (percent)	Rate of Water Exchange
Ice sheets and glaciers	24,000,000	84.945	8000 years
Groundwater	4,000,000	14.158	280 years
Lakes and reservoirs	155,000	0.549	7 years
Soil moisture	83,000	0.294	1 year
Water vapor in the atmosphere	14,000	0.049	9.9 days
River water	1,200	0.004	11.3 days
Total	28,253,200	100.00	

Source: U.S. Geological Survey Water Supply Paper 2220, 1987.

Origin and Types of Groundwater

- ➔ Water added to groundwater system through Magmatic processes is called Juvenile water
- ➔ Water thus trapped for longer times in sedimentary layers and released later due to sedimentary rock formation is called connate water. Connate water also called as fossil water
- ➔ The largest portion of the groundwater derived from the atmosphere through rainfall. The water derived from the atmosphere is called Meteoric water

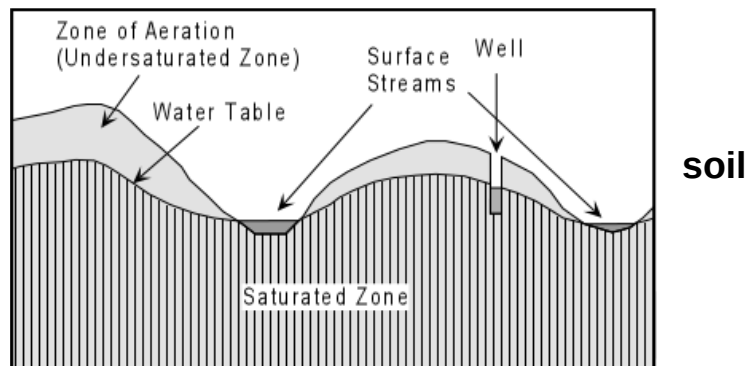
The Water Table

The zone of aeration (also called the unsaturated zone) is a layer of moist followed by a zone in which open spaces in regolith or bedrock are filled mainly with air.

Beneath the unsaturated

zone is the saturated zone, a zone in which all openings are filled with water. The upper surface of the saturated zone is the water table.

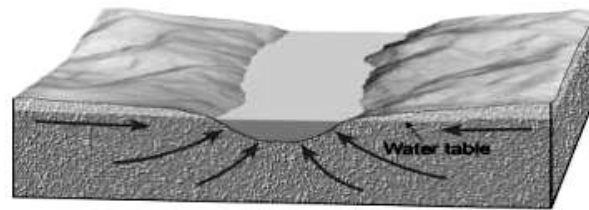
Capillary fringe: Extends upward from the water table. Groundwater is held by surface tension in tiny passages between grains of soil or sediment



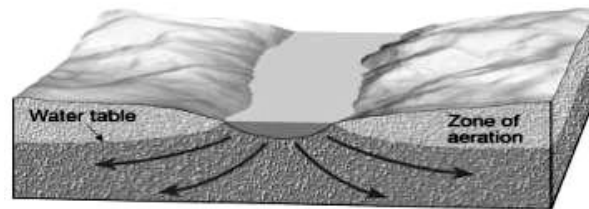
Interaction between groundwater and streams is the basic link in the hydrologic cycle

Three types of interactions

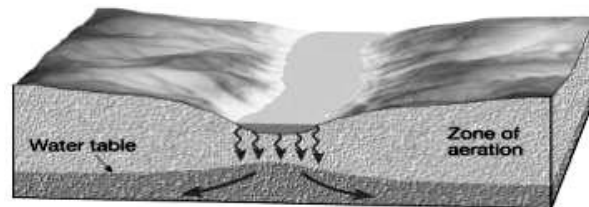
- Gaining streams—gain water from the inflow of groundwater through the streambed
- Losing streams —lose water to the ground-water system by outflow through the stream-bed
- A combination of the two—streams can gain in some sections and lose in others



A. Gaining stream



B. Losing stream (connected)



C. Losing stream (disconnected)

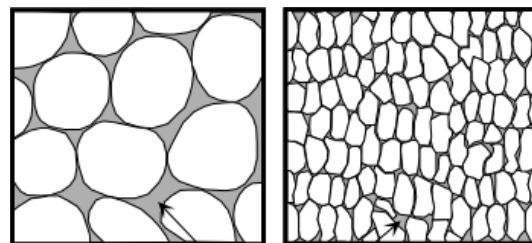
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Factors influencing the storage and movement of groundwater

- The rate of groundwater flow is controlled by two properties of the rock: *porosity* and *permeability*

Porosity is the percentage of the volume of the rock that is open space (pore space). This determines the amount of water that a rock can contain.

In sediments or sedimentary rocks, the porosity depends on grain size, the shapes of the grains, and the degree of sorting, the degree of cementation.

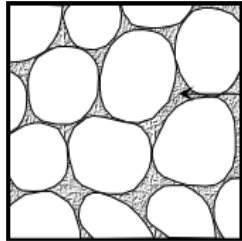


and

Pore Space

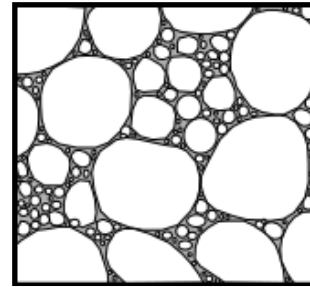
A Well-rounded coarse grained sediments usually have higher porosity than fine grained sediments, because the grains do not fit together well.

Poorly sorted sediments usually have lower porosity because the fine-grained fragments tend to fill in the open space.



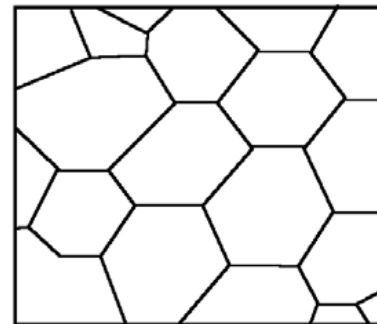
Cement

Since cements tend to fill in the pore space, highly cemented sedimentary rocks have lower porosity.



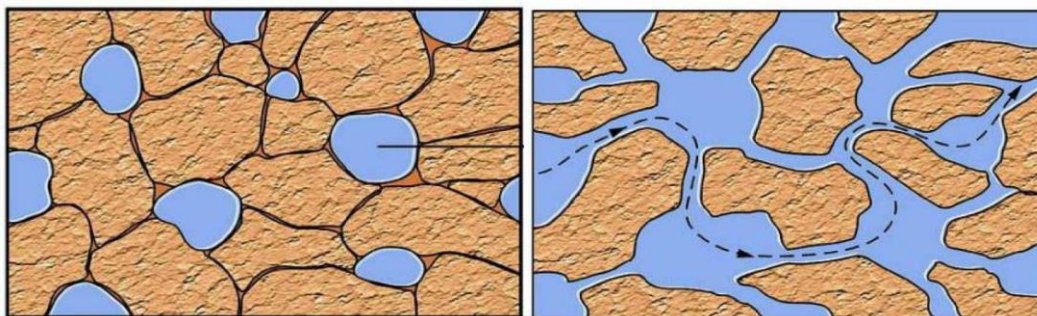
fill

In igneous and metamorphic rocks porosity is usually low because the minerals tend to be intergrown, leaving little free space. Highly fractured igneous and metamorphic rocks, however, could have high porosity



Permeability is a measure of the degree to which the pore spaces are interconnected, and the size of the interconnections. Low porosity usually results in low permeability, but high porosity does not necessarily imply high permeability.

It is possible to have a highly porous rock with little or no interconnections between pores. A good example of a rock with high porosity and low permeability is a vesicular volcanic rock, where the bubbles that once contained gas give the rock a high porosity, but since these holes are not connected to one another the rock has low permeability.



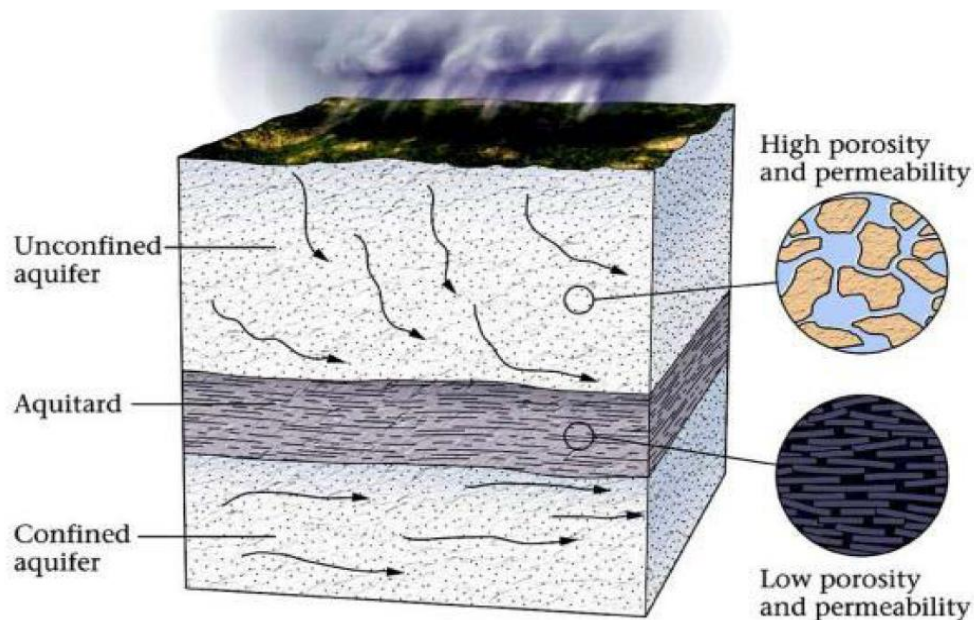
Aquifers

- An aquifer is a body of highly permeable rock or regolith that can store water and yield sufficient quantities to supply wells.
- Bodies of gravel and sand generally are good aquifers, because they tend to be highly permeable and often have large dimensions
- Many sandstones are also good aquifers.

Aquitard—an impermeable layer that hinders or prevents water movement such as clay

Unconfined Aquifers - the most common type of aquifer, where the water table is exposed to the Earth's atmosphere through the zone of aeration. Most of the aquifers depicted in the drawings so far have been unconfined aquifers.

Confined Aquifers - these are less common, but occur when an aquifer is confined between layers of impermeable strata.



Movement of Groundwater - Darcy's Law

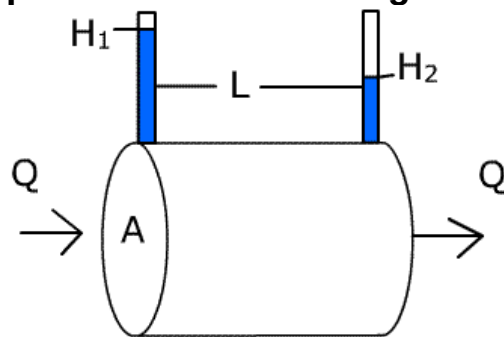
Hydraulic gradient—the water table slope determined by dividing the vertical difference between the recharge and discharge points by the length of flow between these points

Hydraulic head—the vertical difference between the recharge and discharge points

Hydraulic conductivity (K) —takes into account the permeability of the aquifer and the viscosity of the fluid

Groundwater flow is from high hydraulic head (high water level) to low hydraulic head (low water level). Calculations of groundwater flow rate Q , can be made by Darcy's Law.

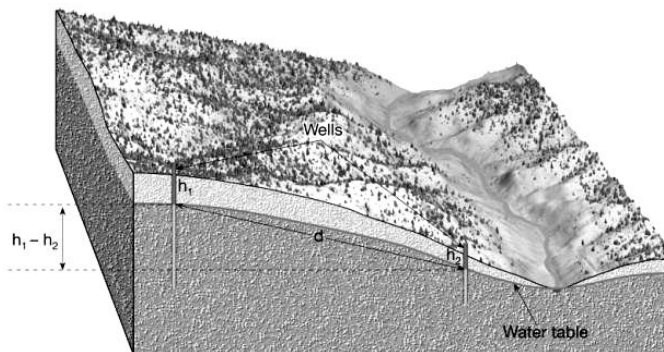
Henri Darcy, a French engineer, was in charge of drinking water treatment in Dijon in the 1800s. Treatment involved passing water through sand filters. Darcy conducted experiments into the parameters controlling the water flow rate through the filters.



Darcy found that the cross-sectional area (A), difference in water level from the entrance to the exit of the filter pack ($H_1 - H_2$) and length of the filter pack (L) had the following relationship to water flow rate, Q , for a given sand.

- Q proportional to A
- Q proportional to $H_1 - H_2$
- Q proportional to $1/L$

For that particular sand in the filter, he could use a proportionality constant, K , which allowed him to use the following equation to calculate flow rates, Q .



$$\text{Hydraulic gradient} = \frac{h_1 - h_2}{d}$$

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Rate of flow of groundwater (Q)

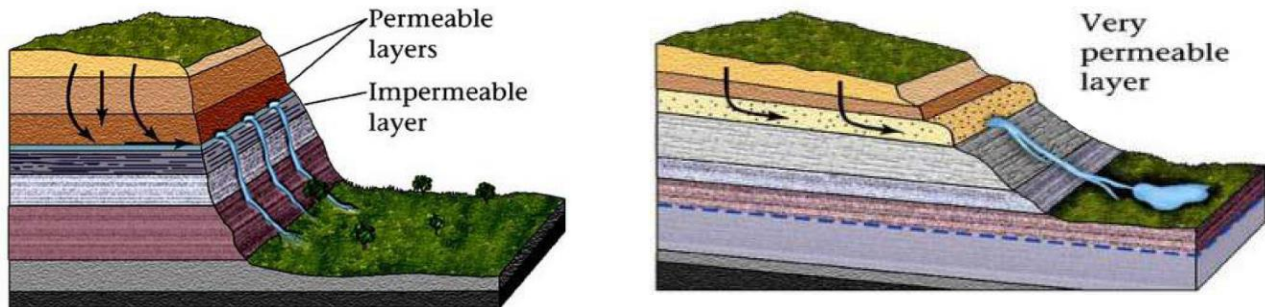
$$Q = K A [H_1 - H_2] / L \text{ — Darcy Law}$$

Springs

❖ Springs are locations of

natural groundwater discharge.

- ❖ when percolating water reaches the water table or impermeable layer, it flows laterally and may intersect the surface and create the springs

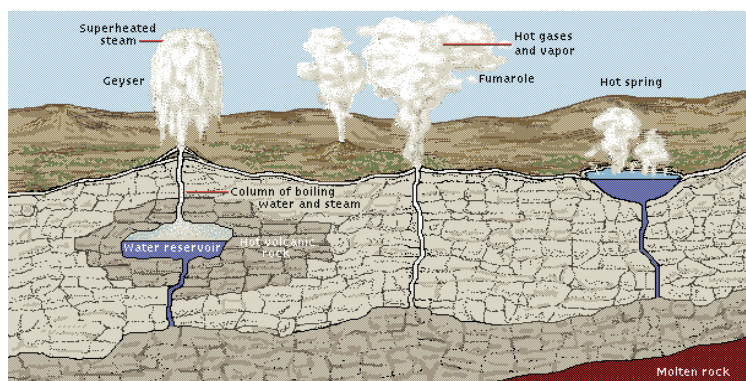
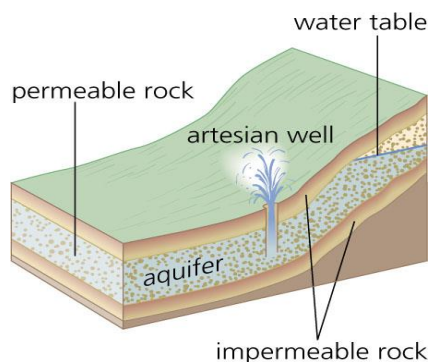


Artesian well – Confined groundwater that flows at the surface under Hydrostatic pressure. Artesian wells generally in confined, tilted aquifers

Hot springs: Hot spring (thermal spring or warm spring) is a spring in which the water temperature is warmer than the human body (37° C). The heat for most hot springs comes from magma or cooling igneous rocks

Geysers; a type of hot spring that periodically erupts hot water and steam

Mudpot – a type of hot spring that contains thick boiling mud and strong sulfurous acids



Geologic Work of Groundwater

Like other Geological agents, Groundwater also modify the surface and subsurface of the earth by erosional and depositional processes through solution activities

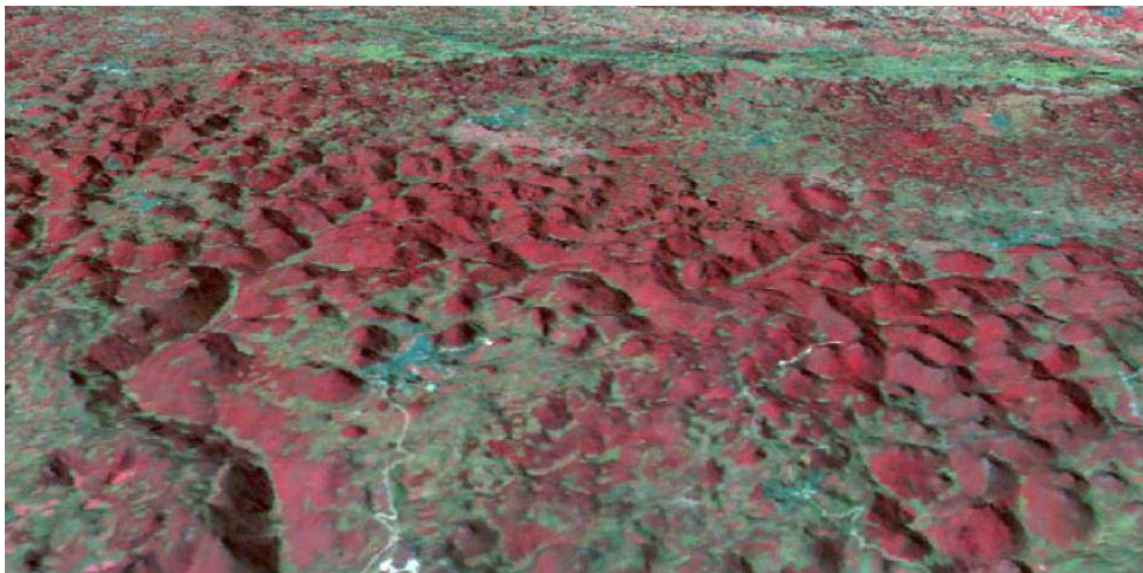
When soluble rock is exposed at the surface, water can attack minerals chemically and become a significant erosional agent and create the various erosional and depositional landforms

Limestone, dolostone, and marble are the most common carbonate rocks and underlie millions of square kilometers of the Earth's surface

The resulting topography with shallow depression and small mounts due to solution activity of groundwater is termed Karst Topography (After the area Karst in Italy)

The Karst topography are generally associated with limestone region (because limestone easily soluble and taken as solution by water)

Karst Topography Definition by Jennings (1985): “A terrain with distinctive landforms and drainage arising from greater rock solubility in natural water that is found elsewhere.”



Dissolution Reactions

Groundwater is often mildly acidic. Contains weak carbonic acid. Forms when rainwater dissolves carbon dioxide from the air and from decaying plants. Carbonic acid reacts with calcite in limestone to form calcium bicarbonate, a soluble material

→ water + carbon dioxide → carbonic acid



→ carbonic acid + limestone → calcium + bicarbonate



Chemical Cementation and Replacement

The conversion of sediment into sedimentary rock is primarily the work of groundwater. Substances in solution in the water are precipitated as cement in the spaces between rock and mineral particles of the sediment. Calcite, quartz, and iron compounds (mainly hydroxides such as limonite) are the chief cementing substances.

Groundwater can also replace other molecules in matter on a molecule by molecule basis, often preserving the original structure such as in fossilization or petrified wood.

Caves and Caverns: If large areas of limestone underground are dissolved by the action of groundwater first forms the cavities. These cavities can become caves or caverns (caves with many interconnected chambers) once the water table is lowered.

Once a cave forms, it is open to the atmosphere and water percolating in to the caves and can precipitate new material such as the common cave decorations like stalagmites (hang from the ceiling), stalagmites (grow from the floor upward), and dripstones and flowstones, etc.

Cave formation

→ Caves are produced mainly by a chemical process involving the dissolution of carbonate rock by circulating groundwater.

→ Limestone caves are generally believed to result from dissolution by carbonic acid.

→ Some caves, like Carlsbad, USA may have resulted from dissolution by sulfuric acid.

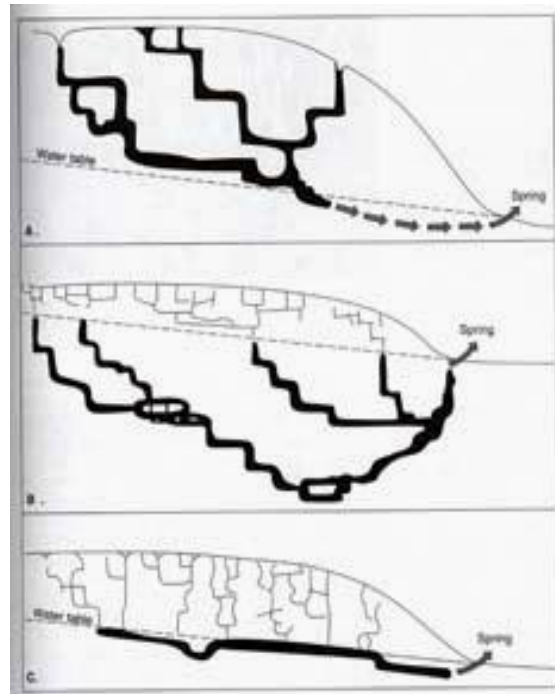
- ➔ The rate of cave formation is related to the rate of dissolution. A fully developed cave system may take 10,000 to 1 million years to produce.
- ➔ Initial dissolution along a system of interconnected open joints and bedding planes by percolating groundwater.
- ➔ Enlargement of a cave passage along the most favorable flow route by water that fully occupies the opening.
- ➔ Deposition of carbonate formations on the cave walls while a stream occupies the cave floor.
- ➔ Continued deposition of carbonate on the walls and floor of the cave after the stream has stopped flowing.

Caves may be classified on the basis source of water.

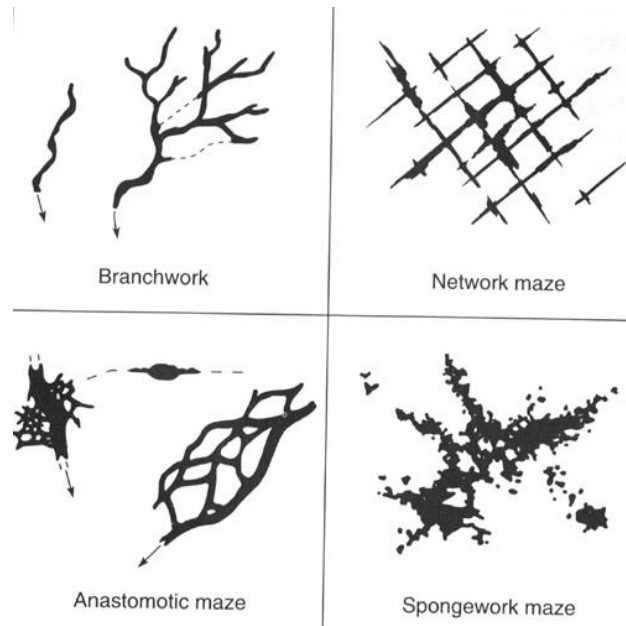
- ➔ If the caves formed by the percolating surface water are called Epigenic caves. 90% of the caves are
- ➔ If the caves formed by the deep seated water sources (Magmatic water) are called Hypogenic caves.

Three principle theories of Cave origins

- 1) Form above water table by *vadose water* (unsaturated zone water)
- 2) Form beneath water table by circulation of *phreatic water* (=saturated zone water)
- 3) Form at water table = *water table caves*



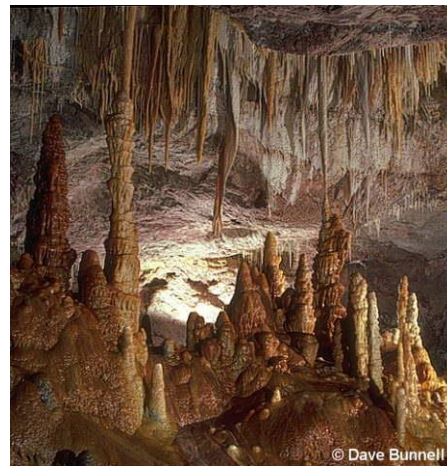
Cave Patterns

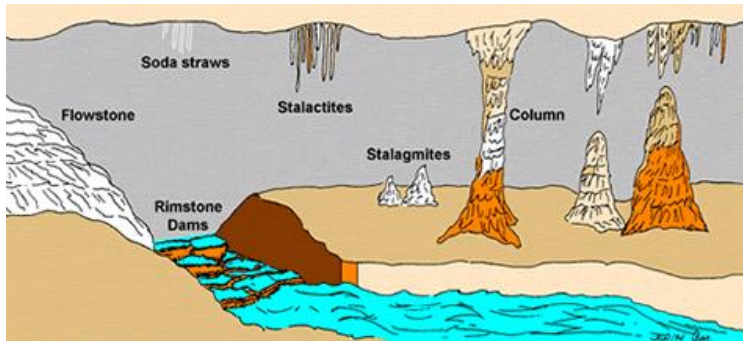


Depositional features in Caves

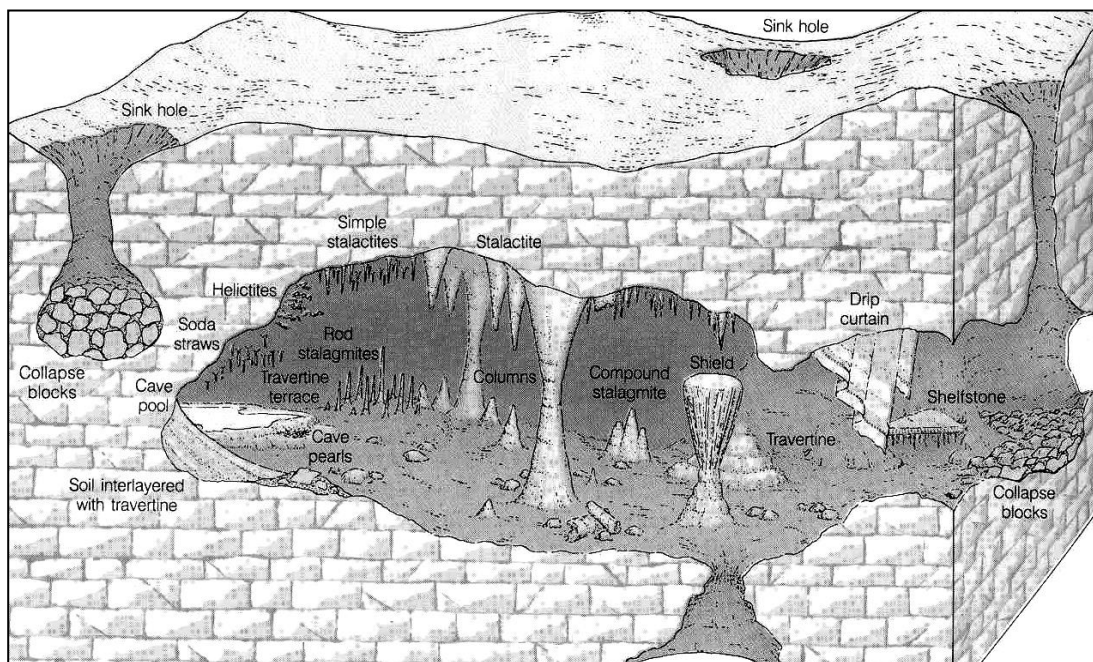
When groundwater with dissolved Ca and 2HCO_3 seeps into an open cavity, it releases CO_2 and deposits CaCO_3 and create various type of landforms. Calcite deposited as dripping water evaporates is called dripstone, collectively called Speleothems includes

- ❖ Stalactites
- ❖ Stalagmites
- ❖ Columns
- ❖ Flowstone
- ❖ Cave popcorn
- ❖ Helictites

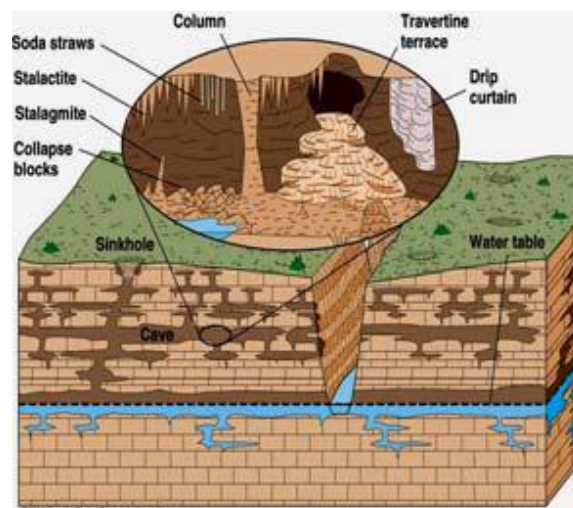




Cave features



- ❖ **Stalactite-** icicle like deposit from dripping water from cave ceiling
- ❖ **Stalagmite-** same as above but builds from cave floor up
- ❖ **Flowstone-** produced by flowing water over a wall
- ❖ **Column:** Stalactites hanging from the cave ceiling and stalagmites growing upward from the floor merge to form a column



- ❖ **Flowstone**- produced by flowing water over a wall
- ❖ **Drip Curtains**: are the curtain like deposits hanging from the ceiling formed by the percolation of water through fractures
- ❖ **Helictites** form by capillary action and can grow in any direction

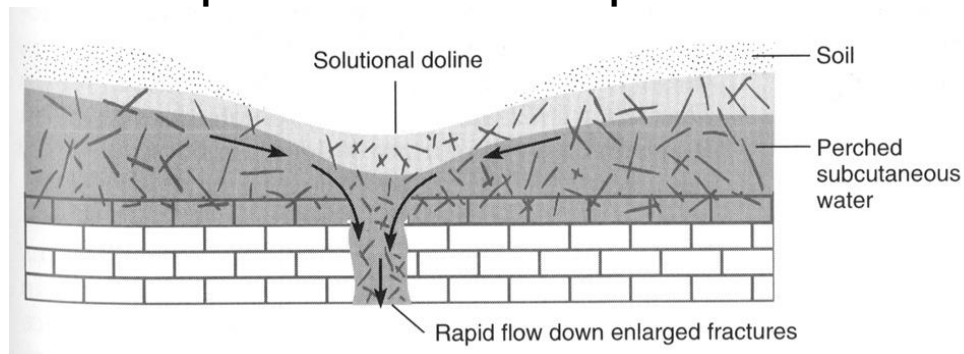


Sinkholes – are large solution cavities. In karst regions, sinkholes are numerous and in some sinkholes streams may disappear

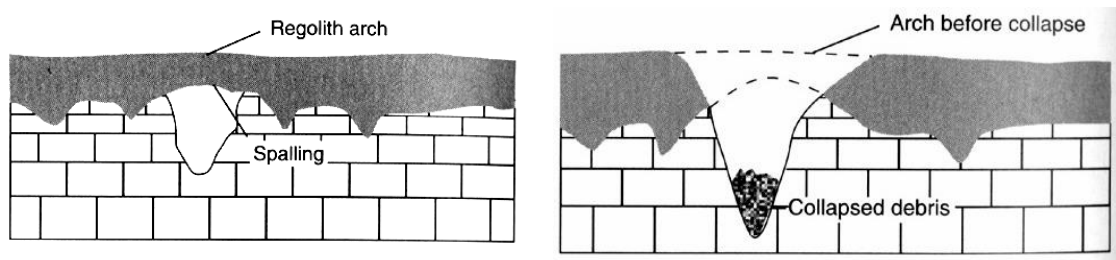
For example, in Florida, which is underlain by limestones, a new sinkhole forms about once each year, gobbling up cars and houses in process

Dolines or Solution sinkholes: Sink holes developed mainly by solution activity are known as Dolines. These are generally shallow basins to depth of 2-100 m and are 100 – 1000 m across.

The sides are rocky or covered with vegetation Concentration of joints are suitable place for Doline development



Collapse Sinkhole: Roof collapse over the solution cavities and as a result depression was formed on the surface, it is known as Collapse Sinkhole. It is common in florida





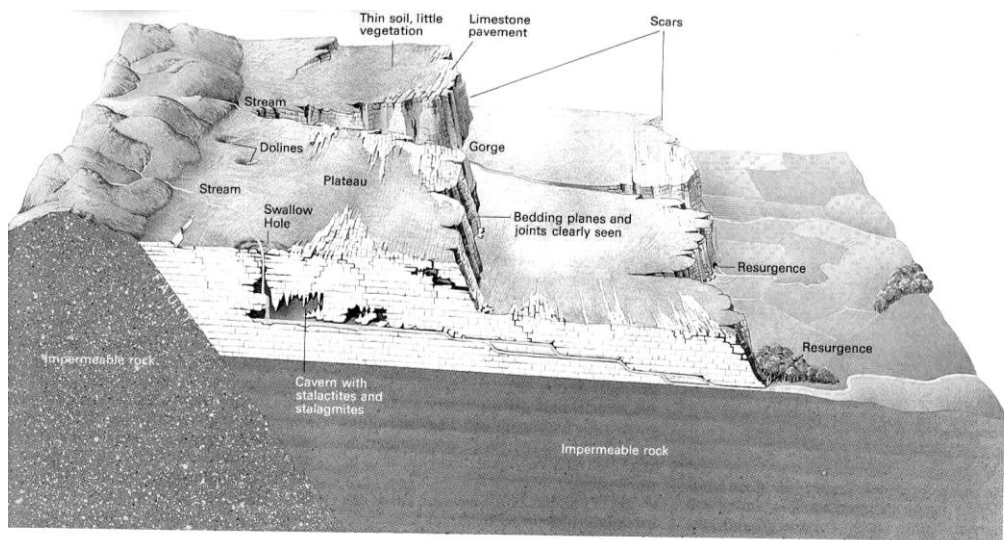
Swallet (swallow hole): A place where water disappears underground in karst region. Swallet commonly used to describe loss of water in stream bed.

Blind Valley: A valley that end abruptly where stream vanishes underground.

Sinking Stream: stream that vanishes underground, usually at terminus of blind valley.

Resurgence: point where waters from sinking stream reemerges from underground.

Dry Valley: Valley that no longer exhibits channelized flow.



GLACIERS AND THEIR GEOLOGICAL ACTIONS

Glaciers constitute much of the Earth that makes up the cryosphere, the part of the Earth that remains below the freezing point of water.

A glacier is a permanent (on a human time scale, because nothing on the Earth is really permanent) body of ice, consisting largely of recrystallized snow, that shows evidence of downslope or outward movement due to the pull of gravity.

Glaciers develop where annual snow doesn't melt away in warm seasons

- ❖ Polar regions
- ❖ Heavy winter snowfall (Alaska, Southern Andes)
- ❖ High elevations
- ❖ 85% are in Antarctica and 10% are in Greenland
- ❖ 5% mountain belts (Andes, Himalaya, Alps, North American Cordillera)

Most glaciers are found in high altitudes (like Himalayan region) or at high latitudes (Like Antarctic, Arctic, Greenland).

Formation of Glaciers

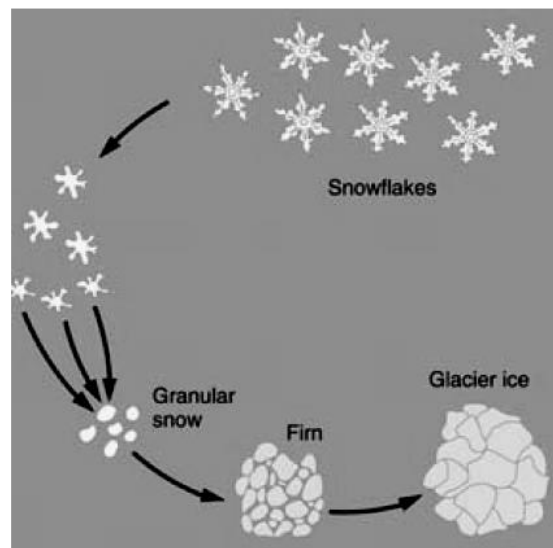
At any place on the land where more snow accumulates than is melted during the course of a year, the snow will gradually grow thicker.

When snow accumulated for several meter thickness, it is compressed into a more compact form termed firn

When snow/firn layer is more than 30m thick, the material is compacted into pure ice

Glacial ice recrystallise under pressure of the overlying snow/firn to form a polygonal tecture

When the accumulating snow and ice become so thick that the pull of gravity causes the frozen mass to move, a glacier is born.



Glaciers can only form at latitudes or elevations above the snowline, which is the elevation above which snow can form and remain through out the year.

The snowline, at present, lies at sea level in polar latitudes and rises up to 6000 m from MSL in tropical areas.

Zones of Accumulation & Ablation

Zone of Accumulation

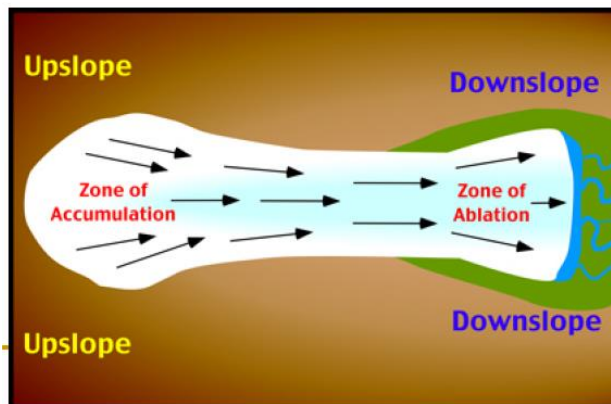
- ❖ Area where glacier is gaining precipitation
- ❖ Upslope –higher elevations

Zone of Ablation

- ❖ Area where glacier is melting
- ❖ Downslope–lower elevations

Sublimation

- ❖ Occurs when ice is directly changed into water vapor



The difference between accumulation and ablation is a measure of the glacier's mass balance.

The equilibrium line (snow line) marks the boundary between the accumulation area and the ablation area.

Glacial Budgets

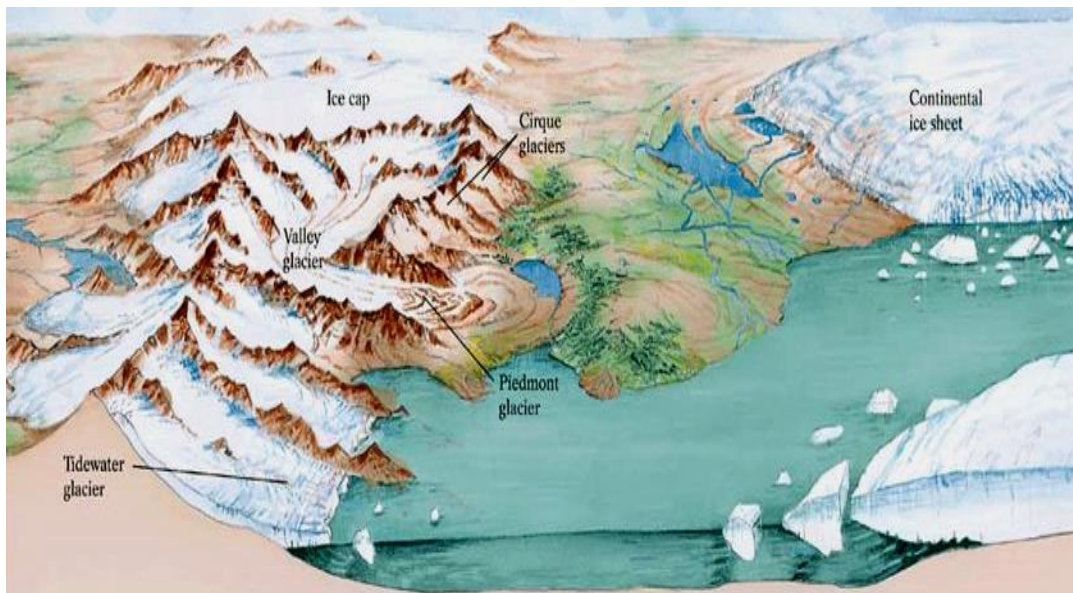
- ❖ Negative budget- *Receding glacier (Ablation more than Accumulation)*
- ❖ Positive budget- *Advancing glacier (Ablation less than Accumulation)*

TYPES OF GLACIERS

Mountain Glaciers - Relatively small glaciers which occur at higher elevations in mountainous regions.

Mountain Glaciers are classified into different types

- Smallest of these occupy hollows or bowl-shaped depressions on sides of mountains are called cirque glaciers.
- As cirque glaciers grow larger they may spread into valleys and flow down the valleys as valley glaciers. Paths these valley glaciers take are controlled by existing topography.



- If a valley glacier extends down to sea level, it may carve a narrow valley into the coastline. These are called fjord glaciers, and the narrow valleys they carve and later become filled with seawater after the ice has melted are fjords.

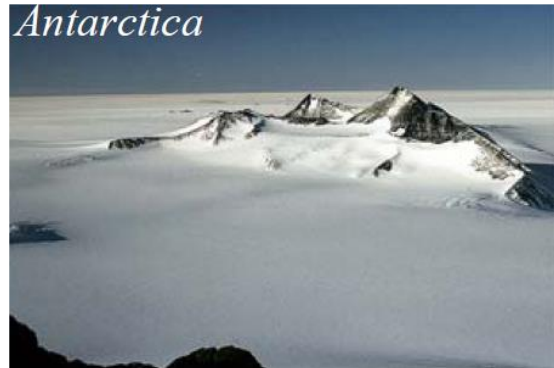


- If a valley glacier extends down a valley and then covers a gentle slope beyond the mountain range, it is called a piedmont glacier.
- If all of the valleys in a mountain range become filled with glaciers, and the glaciers cover then entire mountain range, they are called ice caps.

Continental glaciers (Ice Sheets): are the largest types of glaciers on Earth. They cover large areas of the land surface, including mountain areas. Modern ice sheets cover Greenland and Antarctica.

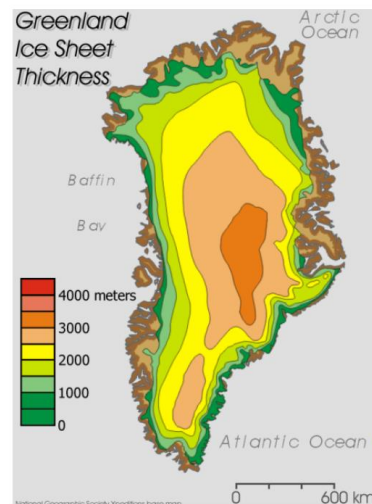
These two ice sheets comprise about 95% of all glacial ice currently on Earth. They have an estimated volume of about 24 million km³. If melted, they contain enough water to raise sea level about 66m (216 ft.).

This would cause serious problems for coastal cities (L.A., NY, Washington DC, New Orleans, Miami, SF etc). The Greenland ice sheet is in some places over 3000 m (9800 ft) thick and the weight of ice has depressed much of the crust of Greenland below sea level.



Antarctica is covered by two large ice sheets that meet in the central part along the Transantarctic Mountains. These are the only truly polar ice sheet on earth (North Pole lies in an ocean covered by thin layer of ice).

Ice Shelves: Ice shelves are sheets of ice floating on water and attached to land. They usually occupy coastal embayments, may extend hundreds of km from land and reach thicknesses of 1000 m.



Glaciers can also be classified by their internal temperature



❖ Temperate glaciers - Ice in a

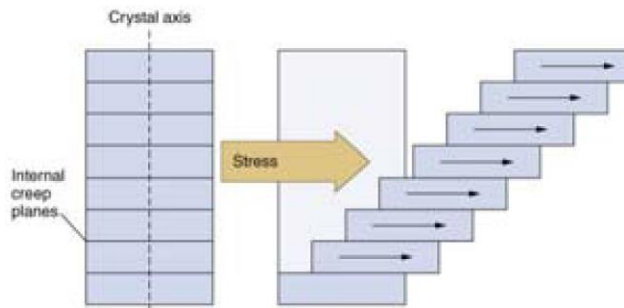
temperate glacier is at a temperature near its melting point.

- ❖ Polar glaciers - Ice in a polar glacier always maintains a temperature well below its melting point.

Movement of Glaciers

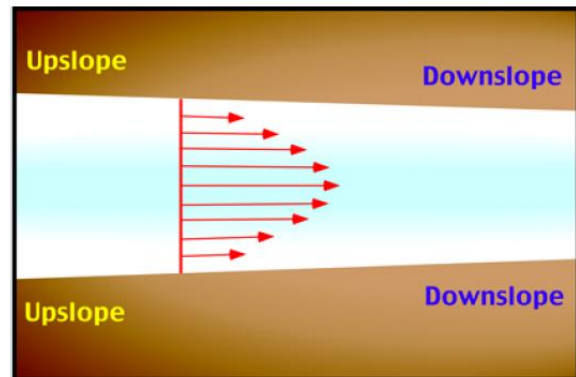
When an accumulating mass of snow and ice reaches a critical thickness, the mass will begin to deform and flow downslope under the pull of gravity by two different processes

Internal or Plastic flow: called creep results from deformation of the ice crystal structure, the crystals slide over each other like deck of cards, under the influence of gravity. The movement of glaciers may be several meters per year



Basal slip: under sufficient pressure the basal ice in a glacier will melt allowing the entire glacier to undergo basal slip up to a kilometer per year

- ❖ Movement within glacier is not uniform.
- ❖ Middle and top of glacier moves faster than sides and bottom.



Crevasses in a glacier

Crack or fissure in a glacier resulting from stress due to movement, Glacial crevasses may be 20 m wide, 45 m deep and several hundred meters long.

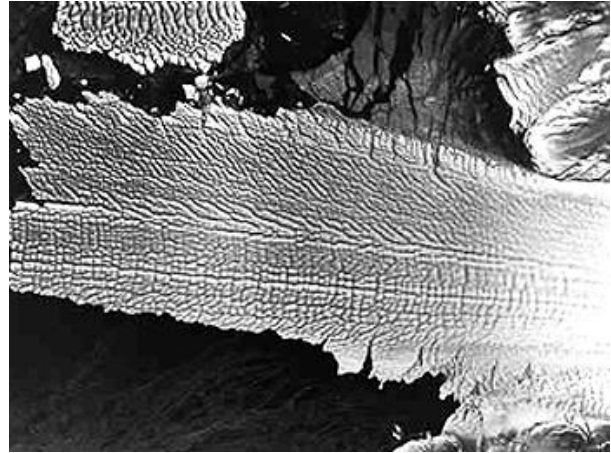
Longitudinal crevasses develop in areas of compressive stress, transverse crevasses develop in



areas of tensile stress, marginal crevasses occur when the central portion of the glacier flows faster than the outer edges.

Geological Action of Glaciers

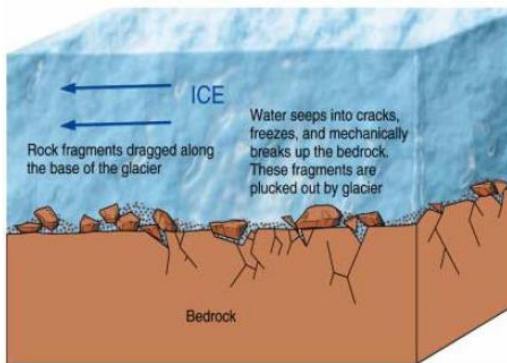
Glaciation is the modification of the land surface by the action of glacier ice. Glaciation involves erosion and the transport and deposition of sediment.



Erosional Processes of Glaciers

→ Plucking

- ❖ Water gets in cracks, freezes, lifts up bits of rock and carries them in the glacier itself
- ❖ Leaves a blocky and irregular surface



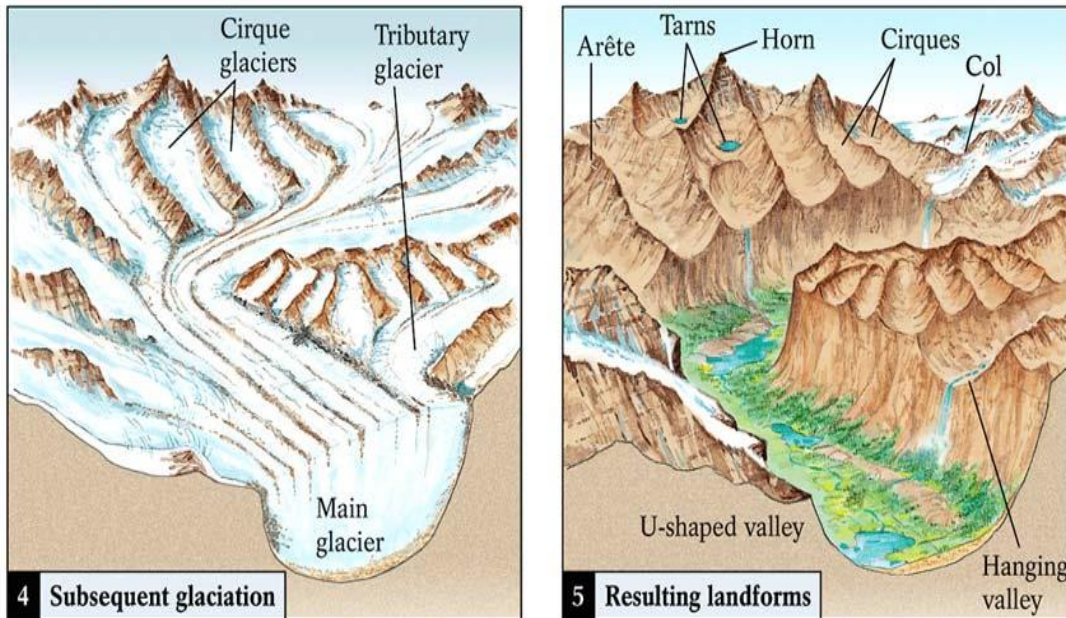
→ Scouring or Abrasion

n

- ❖ Abrasive action of rocks within glacier as glacier moves over surface
- ❖ Small fragments of rock embedded in the basal ice scrape away at the underlying bedrock forming glacial striations and Rock flour (pulverized rock)
- ❖ Enough scouring creates a polished surface
- ❖ Because striations and grooves are aligned with the direction of ice flow, geologists use these to reconstruct the flow paths of former glaciers.

Erosional features or landforms of Mountain Glaciers

Cirques - bowl shaped depressions that occur at the heads of mountain glaciers that result from a combination of frost wedging, glacial plucking, and abrasion. Sometimes small lakes, called **tarns** occur in the bottom of cirque.



Glacial Valleys - Valleys that once contained glacial ice become eroded into a "U" shape in cross section.

Arêtes - If two adjacent valleys are filled with glacial ice, the ridges between the valleys can be carved into a sharp knife-edge ridge, called an arête.

Horns - Pyramidal peak that forms when three or more cirques carve a mountain from 3+ sides

Hanging Valleys - When smaller tributary valley glaciers meet the main valley glacier, the tributary glacier usually does not have the ability to erode its base to the floor of the main valley glaciers.

Thus, when the glacial ice melts the floor of the tributary valley hangs above the floor of the main valley and is called a hanging valley. Waterfalls generally occur where the hanging valley meets the main valley.

Fjord: A glacially eroded or modified U-shaped valley that extends below sea level and connects to the ocean. Filled with

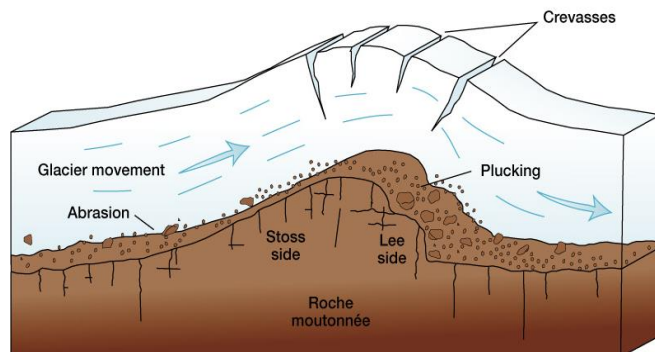
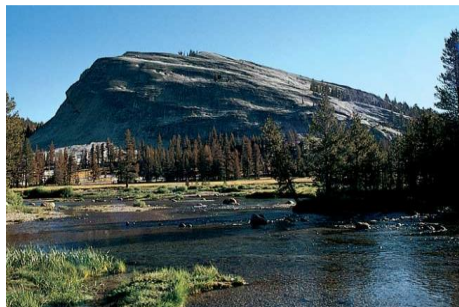


seawater, depths may reach more than 1,000 feet below sea level. The largest Alaskan fiords are more than 100 miles long and more than 5 miles wide. Also spelled *Fiord*.

Erosional Landforms by continental Glaciers

- ➔ Huge U-shaped troughs, including Finger Lakes, Great Lakes, Puget Sound, and Loch Ness were all once valleys excavated by glaciers
- ➔ Abrasional features - The large-scale abrasional features such as striations and glacial polish can occur beneath ice caps and ice sheets, particularly in temperate environments

Roche moutonnee: A glacially eroded hill that becomes elongate in the direction of flow and asymmetric; glacial rasping smooths the upstream part of the hill into a gentle slope, while glacial plucking erodes the downstream edge into a steep slope.



Glacial Transportation & Deposition

- ➔ Since glaciers are solid they can transport all sizes of sediment, from huge house-sized boulders to fine-grained clay sized material.
- ➔ The glacier can carry this material on its surface or embedded within it. Thus, sediment transportation in a glacier is very much different than that in a stream.
- ➔ Thus, sediments deposited directly from melting of a glacial can range from very poorly sorted to better sorted, depending on how much water transport takes place after the ice melts.
- ➔ All sediment deposited as a result of glacial erosion is called *Glacial Drift*.

Till - Nonsorted glacial drift deposited directly from ice. Till consists of fines grains from abrasion and coarse grains from plucking. A till that has undergone diagenesis and has turned into a rock is called a tillite.

Erratics – Boulders or rock fragments that are carried far from their place of origin by a glacier. Erratics are often found many kilometers from their source, and by mapping the distribution pattern of erratics geologists can often determine the flow directions of the ice that carried them to their present locations.



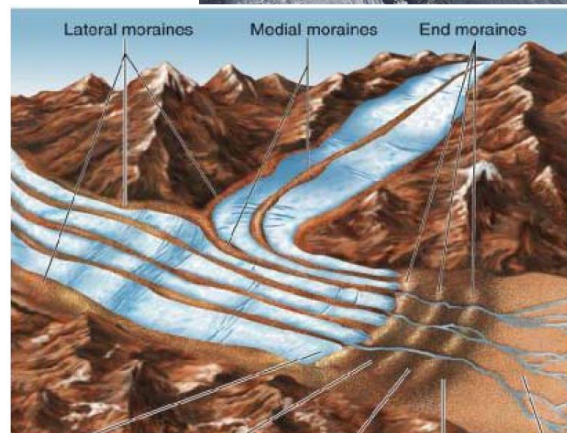
Moraines – the deposition of till by the glaciers is called Moraines. Depending on where it formed in relation to the glacier, moraines can be classified into

→ **Ground Moraines** - these are deposited beneath the glacier and result in a hummocky topography with lots of enclosed small basins.

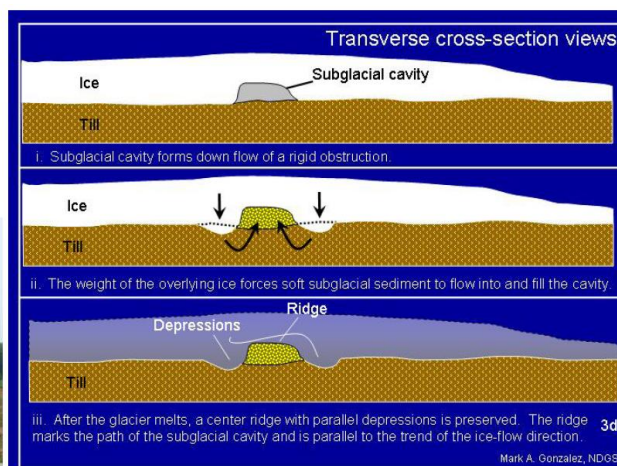
→ **End Moraines and Terminal Moraines** are deposited at the low elevation end of a glacier as the ice retreats due to ablation

→ **Lateral Moraines** are deposits of till that were deposited along the sides of mountain glaciers.

→ **Medial Moraines** - When two valley glaciers meet to form a larger glacier, the rock debris along the sides of both glaciers merge to form a medial moraine.



Kames: Steep-sided, conical hill of debris that originally collected in a hole in the glacier.

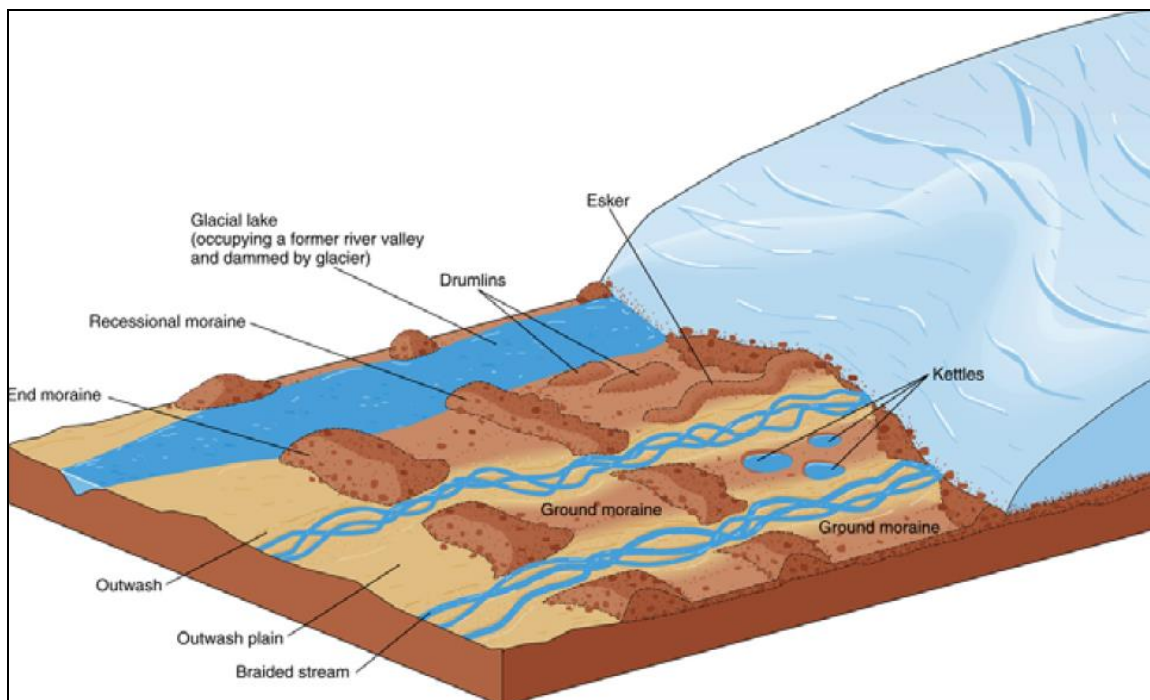


Drumlins: In areas where continental glaciers have deposited till, the till has been reshaped into elongated hills known as drumlins. Some drumlins measure as much as 50 m high and 1 km long but most are much smaller.

From the side, a drumlin looks like an inverted spoon with the steep end on the side from which the glacial ice advanced and the gently sloping end pointing in the direction of ice movement



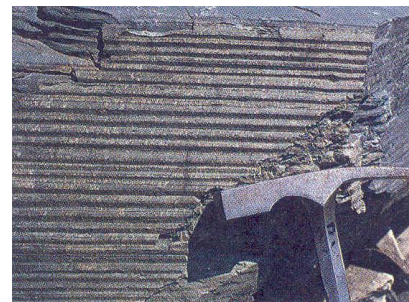
Kettles: Large chunks of ice leave a depression in the landscape. These depression latter filled with water forms the **Kettle lakes**



Eskers: Eskers are long sinuous ridges of sediment deposited by streams that ran under or within a glacier. The sediment deposited by these streams becomes an esker after the ice has melted. Eskers can range from feet to miles in length and may exceed 100 feet in height.



Varves: are thin, alternating layers of light and dark sediment deposited in a glacial lake. A layer of relatively coarse grained, light colored sediment accumulates during the spring and summer runoff. During the winter, when the lake is frozen over, fine, dark mud settles to form a dark layer. Each set of light and dark layers therefore represents a year's accumulation



Outwash Plains - Streams running off the end of a melting glacier are usually choked with sediment and form braided streams, which deposit poorly sorted stratified sediment in an outwash plain. These deposits are often referred to as outwash.

Glacial Marine drift - Glaciers that reach the oceans or even lakes, may calve off into large icebergs which then float on the water surface until they melt. Upon melting, the rock debris that they contain becomes immediately deposited on the sea floor or lakebed as an unsorted chaotic deposit. Sometimes single large rock fragments fall out on the floor of the water body, and these are called dropstones.