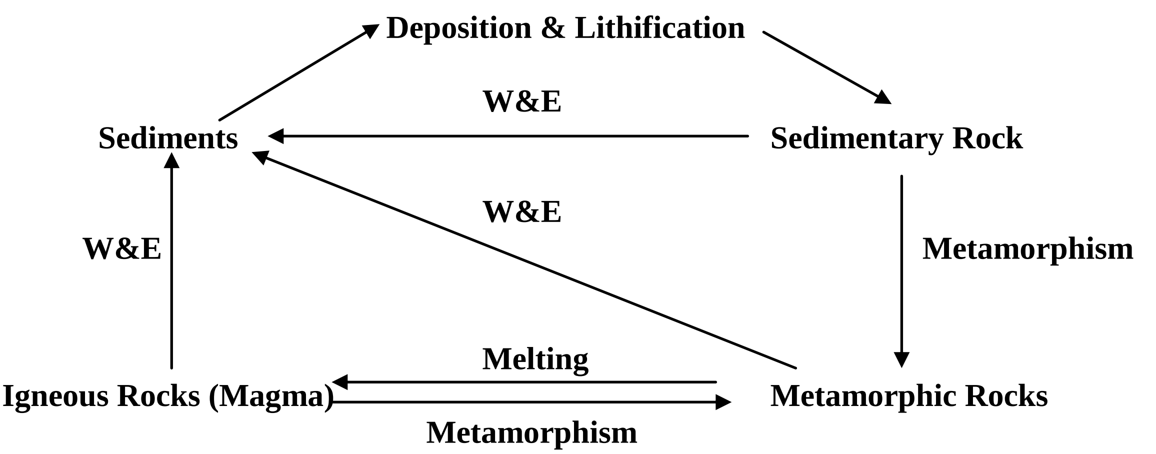
Unit: 1
DEFINITION & INTRODUCTION

The word Geology has been derived from the Greek words 'Ge' meaning the earth and 'Logos' meaning science. Thus, Geology is the science which deals with the study of earth in terms of its development as a planet since its origin. Geology is essentially the observation & interpretation of events that have occurred and are occurring in our earth. The study of geology is mainly concerns itself with the study of the earth's constitution, structure and history of development as well as the outer solid shell of the earth i.e. lithosphere, hydrosphere and atmosphere. The earth consists of air (atmosphere), water (hydrosphere) and land (lithosphere).
The earth's surface have been created, maintained and destroyed by numerous physical, chemical and biochemical processes. They produce the new earth materials necessary for our survival. Collectively such processes are referred to as the geologic cycle. The geologic cycle is a collective form of a group of sub cycles i.e. Tectonic, rock, hydrologic and geochemical sub cycles.

(Figure GEOLOGIC CYCLE)

Hydrologic cycle
The hydrologic cycle is the movement of water from the oceans to the atmosphere and back to the oceans, by way of evaporation, runoff in streams and rivers, and groundwater flow.
Geochemical cycle
Geochemistry is the study of the distribution and migration of elements in earth's processes. The geochemical cycle is the migratory path of elements during geologic change. This cycle involves the chemistry of the lithosphere, asthenosphere, hydrosphere and biosphere.
Tectonic cycle:
Plate tectonics is the relative movement of lithospheric plate with geological activities in geologic past. The earth crust created and destroyed due to forces developed on the earth surface or below the earth surface and they produce earth's external forms such as ocean basins, continents and mountains as in cycling manner i.e. from orogeny and epiorogeny. Collectively such processes are called the tectonic cycle.
Rock Cycle:
The rocks are the aggregate of minerals. The rock cycle is a sequence of processes that produce the three rock families; igneous, sedimentary and metamorphic rocks.



Note: **W&E** = Weathering & Erosion.

Studying Geology:

- The soils and their vegetation may indicate the type of underlying rock; buildings and walls made of local stone may well be worth observing.
- Study of geology gives first hand knowledge about natural environment. E.g. the evaluation of fossils and particle distribution in sedimentary rock reflects the paleo-environment.
- The attitudes (Strike, Dip and Dip direction) existing elsewhere may well be able to walk out what happened in surface and below the surface.
- Geology is useful for the determination of the location of mines, oils, and natural gas. The satellites scanning are recently developed methods for the location of economically important minerals.
- Folded and crumpled rocks give information of hidden forces.

BRANCHES OF GEOLOGY

A. Basic Geology

1. Physical Geology: The study of earth composition, structure, movements & processes by which the earth surface is or has been changed.

2. Mineralogy: The study of minerals. Minerals are inorganic substances & are integral parts of the rocks which form the crust of the earth.

3. Petrology: The study of rocks which provides us with much needed information about the composition of the earth.

4. Structural Geology: the study of the earth structural features like folds, faults, joints etc & their mode & mechanism of formation.

5. Economic Geology: The study of economic products of earth crusts & their application for commercial and industrial purposes.

6. Geomorphology: The study of land forms & surface processes.

7. Geo tectonics: The study of movements of earth crusts & deformation caused by them.

B). Historical Geology: It is the study of the origin & evolution of earth & its inhabitant.

8. Stratigraphy: The study of the origin, composition, proper sequence & correlation of the rock strata.

9. Paleontology: Greek: *Palaios* means ancient *Ontos* means being.
The study of fossils i.e. plant and animals in rock beds of past geological periods.

10. Paleogeography: The study of past geographic condition. It is possible to reconstruct t he relations of ancient lands and sea and the organism that inhibited them.

C) Applied geology*:*

11. Engineering Geology: The application of geological information to engineering problems.

12. Hydrology: The study of surface and subsurface water.

13. Geophysics: The study of the application of physics in geology which is applicable in subsurface exploration.

14. Geochemistry: The study of the application of chemistry in geology. It deals with the chemical constituent of earth, the distribution & migration of various elements in various parts of the earth.

15. Forest Geology: The application of geologic information to forestry problems.

16. Agricultural Geology: The application of geologic information to agricultural problems.

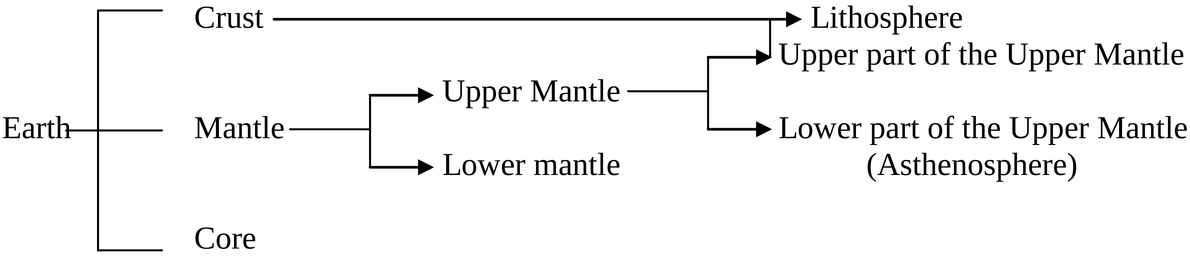
17. Mining Geology: The application of geology in mining & extraction of problems.

18. Photo Geology: The geological interpretation of aerial photographs or the study of satellite photographs.

PLATE TECTONICS

Introduction:

- The crust of the earth consists of about 35km thick layer of solid rock matter which varies in thickness from about 5km in the oceanic areas and 70-80kms in the mountainous regions.
- Evidences derived from paleomagnetic studies and seismic waves show that within the upper mantle there is a soft layer which behaves plastically because of increased temperature & pressure. This layer (approx. 300km thick) of the upper mantle is known as 'asthenosphere'.
- The part of the crust together with the uppermost portion of the mantle which overlies the asthenosphere is known as lithosphere.



- The rigid lithosphere is capable of moving bodily over the asthenosphere and is disjointed into large segments or blocks by fault or thrust. These blocks are known as 'lithospheric plate'.
- The relative movement of the lithospheric plate with geologic activities in geologic past is known as 'Plate-tectonics'.
- The lithospheric plates are move relatively due to the following causes:
  - Formation of ocean crust.
  - Formation of mid oceanic ridge.
  - Rate of motion.
  - Temperature difference.
  - Gravity difference.
  - Mantle convection.

Features of plate tectonics:

- The concept of 'Plate-tectonics' is a world wide network of moving lithospheric plates and formulated by the American scientists Hess & Dietz.
- Le Pichon (1968) divided lithosphere into 6 major plates and the smaller plates (about 20) were incorporated into them. These 6 plates are commonly accepted world widely. These major plates are:
  1. The Pacific Plate → Sea Floor Plate
  2. The American Plate
  3. The African Plate
  4. The Eurasian Plate
  5. The Indian Plate
  6. The Antartic Plate

  (Plates 2–6) → Continental Plate
- All lithospheric plates are large and rigid slab of rocks which moves slowly over the asthenosphere.

- The lithospheric plates have been moving with respect to each other and to the earth's axis of rotation with velocities ranging from 1 to 6cm per year.
- The surface trace of the zone of motion between two plates is known as Plate boundary. On the basis of plate movement, the plate boundaries are classified into:
    a. Constructive Plate Boundary: Plates move away from each other.
    b. Destructive Plate Boundary: Plates move towards each other.
    c. Conservative Plate Boundary: Plates move past each other.
- All seismic, volcanic and tectonic activities are localized around the plate boundaries.
- Generally devoid of all geological activities (seismic, volcanic and tectonic) below the lithospheric plate.
- Plate margin is the marginal part of the particular plate. Two plate margins meet at a common plate boundary. Where three plate boundaries meet at a point is known as Triple-junction.

Plate boundaries:

Plate boundaries are the site of intense seismic, volcanic, earthquakes & geologic activities due to the movement of plates. On the basis of plate movement plate boundaries are,

1. Constructive Plate boundary (Divergent plate boundary)
    - Oceanic Divergence
    - Continental Divergence or Continental rupturing
2. Destructive Plate boundary (Convergent plate boundary)
    - Ocean-Ocean Convergence
    - Ocean-Continent Convergence
    - Continent-Continent Convergence
3. Conservative or Passive Plate Boundary

Constructive Plate boundary:

- Two plates move away from each other.
- Upwelling of hot molten rock materials.
- Fissure represent zone of spreading.
- Formation of new crust.

a. Oceanic Divergence:

- Two oceanic plates diverge
- Formation of mid oceanic ridge (new materials).
- Intrusion of basaltic volcanism.
- Net effect is sea floor spreading.

b. Continental Divergence/ Continental rupturing:

- Elevation of continent due to mantle plume.
- Formation of rift valley at an elevation.
- Divergence continues in rift valley. Results Ocean between two continents their by sediment deposition.
- Intrusion of basaltic volcanism.
- Formation of new mid oceanic ridge in newly developed oceanic continent.

Destructive Plate boundary:

- Two plates move towards each other.
- The more dense plate is deflected beneath the less dense one.
- The net effect is to destroy the surface of the existing plate i.e. called sinks.

a. Ocean-Ocean Convergence:

- Two Oceanic plates converge.
- One plate more dense) bends downward beneath the other called subductive plate & then formed the trench.
- Formation of tholeitic (first) & Andesitic magma due to frictional & higher geothermal heat along subducting plate.
- Partial melting of over lying plate results magma body rise slowly forms island arc.
- Formation of marginal ocean basin in between island arc & the continent.

b. Ocean-continent Convergence

- Oceanic plate is subducted under the continental plate.
- Formation of volcanic arc in continental plate due to rise of magma from the subduction zone.
- Volcanic arc composed Andesitic lava.
- Young mountain range may form due to the upliftment of the thickened crust.

c. Continent-continent convergence

- Ocean floor exist between two continents.
- Subduction of one continent under ocean floor.
- Continued subduction of continent & narrowing the ocean basin eventually bring the continents into a collision.
- The accumulated sediments of ocean basin squeezed into complicated folds with thrust and faults and then results the mountain range. Example Karakorum Himalayan range or NEFA Himalaya.

Significance of plate tectonics:

1. Origin of Mountain ranges & their distribution.
2. Formation of mid Oceanic ridge & rift valleys
3. Site of valuable mineralization.
4. Formation of island arcs, volcanic arc & Oceanic trenches.
5. Possibility of sea-floor spreading.
6. Possibility of formation of andisol soils.
7. Origin & distribution of earthquakes & volcanoes.
8. Continental drifts (Large-scale horizontal displacement lithospheric plate within Geologic past.)

MINERALS

Minerals are naturally occurring element or compound having an ordered atomic structure and characteristic chemical composition, physical properties and crystal form.

Classification of minerals

1. General classification

   a. Rock forming minerals → Essential minerals; → Accessory minerals

   b. Minerals of economic values.

1. Classification on the basis of chemical composition

Edward Salibary Dana (1947) classified minerals on the basis of chemical composition.

a. Native elements → Metals E.g., gold, silver; → Semi-metals E.g., antimony, arsenic; → Non-metals E.g., carbon, sulphur.
b. Sulphides – Pyrite (FeS_2), Galena (PbS)
c. Sulphosalt – Gypsum ($CaSO_4.2H_2O$), Barite ($BaSO_4$)
d. Oxides – Hematite (Fe_2O_3), Magnetite (Fe_2O_4)
e. Halides- Rock salt (NaCl),Fluorite (CaF_2)
f. Silicates- Quartz (SiO_2),Feldspar ($RAlSi_3O_8$), where R = K, Na &Ca.
g. Oxygen salt – Calcite ($CaCO_3$), Siderite (Fe_2CO_3)
h. Salts and Organic acids – Oxalates ($CaC_2O_4.H_2O$)
i. Hydro carbon compounds –Petroleum (CnH_{2n+2})

PHYSICAL PROPERTIES OF MINERALS

A. **Characters depending upon light:**

1. Color:

The **c**olor of a mineral depends upon either to the selective absorption of light or reflection of light within the body of minerals. Color variation due to chemical impurities. E.g. Azurite –Blue, Malachite –Green, Pyrite –Yellow, Hematite –Gray.

2. Streak:

It is the color of a mineral when it is finely powdered. It can be determined by rubbing the minerals on the piece of unglazed white Porcelain plate i.e. Streak plate. E.g. Haematite – Cherry Red.

3. Lusture :

It is the appearance of mineral surface in reflected light. On the basis of variation in nature of the reflecting surface lusture can be divided into following categories.

- Metallic lusture: The shining surface to that of broken piece of metal. E.g. gold
- Non-metallic lusture: The shining surface to that of non-metal. Non-metallic lusture are as given below.
  I. Adamantine: The lusture of brilliant glossy i.e. Diamond. E.g. Corundum
  II. Vitreous: The lusture of broken glass. E.g. Quartz, Topaz
  III. Resinous: lusture of yellow resin. E.g. Sphalerite
  IV. Greasy: The lusture of an oily glass. E.g. Nepheline
  V. Pearly: The lusture of the pearl. E.g. Talc, Brucite
  VI. Silky: The fibrous feature found in mineral like as silk. E.g. Asbestos

Degree of Intensity of Lusture:

- Splendent: The reflecting surface with brilliancy and giving well-defined image e.g. Hematite.
- Shining: The surface is producing an image due to reflection but giving undefined image. E.g. Celestite
- Glistening: The mineral is affording a general reflection from the surface without image. E.g. Talc
- Glimmering: The mineral affording imperfect reflection only from the points over the surface. E.g. Flint, Chalcedony
- Dull: The total absence of lusture in minerals. E.g. Chalk, Kaolin

4. **Transparency:** It is the ability of mineral to transmit light. The varying degree of transparency is given below.
   - Transparent: Light passes through the mineral and the outline of an object can be seen clearly. E.g. Halite, Calcite
   - Translucent: Light passes through the mineral but an object cannot be seen through it. E.g. Chalcedony
   - Opaque: No light passes through the minerals. E.g. Galena, Pyrite

B. **Characters Depending Upon Cohesion & Elasticity:**

5. **Hardness:** The hardness of a mineral is its resistance to scratching or abrasion. In 1824 German Mineralogists Friedrich Mohs selected set of minerals in order of increasing hardness i.e. 1 to 10 in number on the basis of test. Such scale of hardness is known as *Mohs Hardness Scale.*

   I. Talc- $Mg_3Si_4O_{10}(OH)_2$
   II. Gypsum- $CaSO_4.2H_2O$
   III. Calcite- $CaCO_3$
   IV. Fluorite- CaF_2
   V. Apatite- $Ca_5F(PO_4)_3$ or $Ca_5Cl(PO_4)_3$
   VI. Orthoclase- $KAlSi_3O_8$
   VII. Quartz- SiO_2
   VIII. Topaz- $Al_2F_2SiO_4$ or $Al_2SiO_4(OH)_2$
   IX. Corundum- Al_2O_3
   X. Diamond- C

Some other possible hardness test can be done by using the following common objects.

Fingernail	about- 2.5
Copper coin	2.5 - 3
Glass	5 – 5.5
Knife Blade	5.5 – 6
Steel File	6.5 – 7

6. **Cleavage:** It is the ability of a mineral to break along certain plane within specific direction. The following parameters are used to evaluate the quality of cleavage.
   - Perfect Cleavage: Mineral breaks into very thin sheets with mirror like surfaces. E.g. Mica, Gypsum.
   - Good Cleavage: The mineral break in definite direction to form smooth surface. E.g. Calcite, Galena, Halite.
   - Distinct Cleavage: Mineral broken with rough irregular surface. E.g. Feldspar, Hornblende.
   - Indistinct Cleavage: Mineral broken with undulated surface. E.g. Beryl, Apatite.

- Non-Cleavage: No any broken plane in definite direction.

The cleavage can be observed in set i.e. I, II, III etc.

7. **Fracture:** It is the breaking down of the mineral mass in a direction other than cleavage direction. They are not parallel to each other. Fracture is defined by using the following terminology.
   - Conchoidal: The fracture having smooth and curved surface. E.g. the surface developed on a piece of broken glass.
   - Even: The fracture having more or less smooth and plane surface.
   - Uneven: The fracture having rough surface.
   - Hackly: The irregular fracture with sharp elevations.
   - Splintery: The mineral separate out in fibers. E.g. Asbestos
   - Earthy: Like the appearance of hard clay.

8. **Parting:** The mineral split fairly from weakness plane. The weakness plane produced by deformation, inclusion etc.

9. **Tenacity:** The measurement of mineral deformation or disintegration under outer force i.e. hammering. The tenacity can be defined as the given below.
   - Brittle: When parts of mineral separates in powder form. E.g. Calcite
   - Sectile: Mineral cuts without powder. E.g. Gypsum, Graphite
   - Malleable: Mineral flattens out under a hammer. E.g. Gold
   - Flexible: Mineral bends without breaking, when the force is removed. E.g. Talc
   - Elastic: When the mineral attains its previous position after the withdrawal of the force. E.g. Micas

C. Characters Depending Upon Density Compared With That Of Water:

10. **Specific Gravity:** It is the ratio of the weight of a given volume of mineral to the weight of an equal volume of water. Specific Gravity can be determined by the chemical balance, Jolly's spring balance or Specific Gravity Bottles.

The weight of mineral in air = W1
The weight of mineral in water = W2
The weight of an equal volume of water = W1-W2

Specific Gravity = W1/ (W1-W2)

D. Others:

11. **Habit (Form):** 98% of the minerals are crystalline & few are amorphous. The major habits are as given below.
    - Crystalline: Minerals have recognizable crystal forms.
    - Massive: Minerals have no recognizable crystal forms.
12. **Taste:** Example: Halite (Rock salt)
13. **Odour (Smell):** Example: Pyrite gives strong smell in heating.
14. **Feel:** Smooth or greasy. Example: Talc
15. **Magnetic:** Example: Haematite

IMPORTANCE OF STUDY OF MINERALS IN FORESTRY SCIENCE

1. Minerals play important role in weathering process or soil derived from minerals.
2. Most of the plant nutrients namely essential elements derived from minerals.
3. Production of Chemical Fertilizers. Example: Lime from Calcite mineral.
4. Used in building stone & raw materials in watershed management & Soil Conservation.
5. Enhances the national economy due to export of valuable minerals and mineral products. Due to that nation can invest the sufficient money in Forestry and Watershed management.
6. Give guideline to analyses erosion prone areas.

CHEMICAL COMPOSITION OF MINERALS

The average composition of crystal in rocks is given below which has been calculated from many chemical analysis.

SiO_2	59.26%
Al_2O_3	15.35%
Fe_2O_3	3.14%
FeO	3.74%
MgO	3.46%
CaO	5.08%
Na_2O	3.81%
K_2O	3.12%
H_2O	1.26%
P_2O_5	0.28%
TiO_2	0.73%
Rest	0.77%
Total	**100%**

Out of 105 elements, eight elements are abundance in crystal rocks.

Si + O = 75%

Al + Fe + Ca + Na + K + Mg = 23%

Others = 2%

Occurrence of most abundant elements

Oxygen	46.60%
Silicon	27.72%
Aluminum	8.13%
Iron	5.00%
Calcium	3.63%
Sodium	2.83%
Potassium	2.59%
Magnesium	2.09%
Total	**98.59%**

ROCKS

The rocks are naturally occurring aggregate of minerals. They can be broadly categorized as:

1. Monominralic Rock: The rock containing only one minerals.
2. Polyminralic Rock: The rock containing more than one mineral.

On the basis of their mode of formation & occurrence, the rocks can be categorized as:

Rock →
- Igneous rock →
  - volcanic rock
  - Hypabyssal rock
  - Plutonic rock
- Sedimentary rock
- Metamorphic rock

IGNEOUS ROCK:

- Derived from Latin word 'ignis' meaning fire.
- A rock that solidified from molten or partially molten materials i.e. magma.

Characteristics of Igneous rocks:

- Interlocking of mineral grains.
- Devoid of any layering except pyroclastic materials.
- Cross-cutting relationship.
- Lack of fossils.
- Massive, hard & compact.

MAGMA:

Magma is a molten & mobile rock material which is naturally occurring high temperature solution of silicates, water and gasses. They may be derived from homogenous basaltic magma within the greater depth of earth's crust or in upper mantle as a result of partial melting and frictional crystallization.

Characteristics of Magma:

- Chemically abundance of 8 elements i.e. O_2, Si, Al, Fe, Ca, Na, K & Mg.
- Temperature ranges from 500 to 1200 ^{o}c. (where average geothermal gradient 30 ^{o}c/km.)
- Mobility depends upon water, $CO_{2,}$ magma composition and other gasses.

ORIGIN OF MAGMA (Highly debated topic)

The primary magmas are originated from solid rock by melting and partial melting of rocks in the lower crust and upper mantle. The secondary magma results from frictional crystallization i.e. melt segregation or other means. According to modern concepts of magma genesis in subduction zone due to partial melting as given below.

a. In the upper mantle, Peridotite overlying a subducting lithospheric slab.
b. In the subducting zone from Basaltic slab.
c. In the lower continental crust above the subducting plate.
d. The mechanism 'a' and 'b'are the well account for origin of magma in island arcs and continental margins. They produce mafic magma in mantle.
e. An older continental salic crust involved in granitic magma production due to 'c' mechanism.

A. Role of heat

- Rocks in the lower crust and upper mantle are near their melting points.
- Any additional heat (from rocks descending into the mantle or rising heat from the mantle or accumulation of radioactive element) may induce melting.

- Temperature increases within Earth's crust (called the geothermal gradient) average between 20°C to 30°C per kilometer.

B. Role of pressure

– An increase in confining pressure causes an increase in a rock's melting temperature or conversely, reducing the pressure and lowers the melting temperature.
– When confining pressures drop, decompression melting occurs.

C. Role of volatiles

– Volatiles (water, carbon dioxide etc.) cause rocks to melt at lower temperatures.
– This is particularly important where wet oceanic lithosphere descends into the mantle.

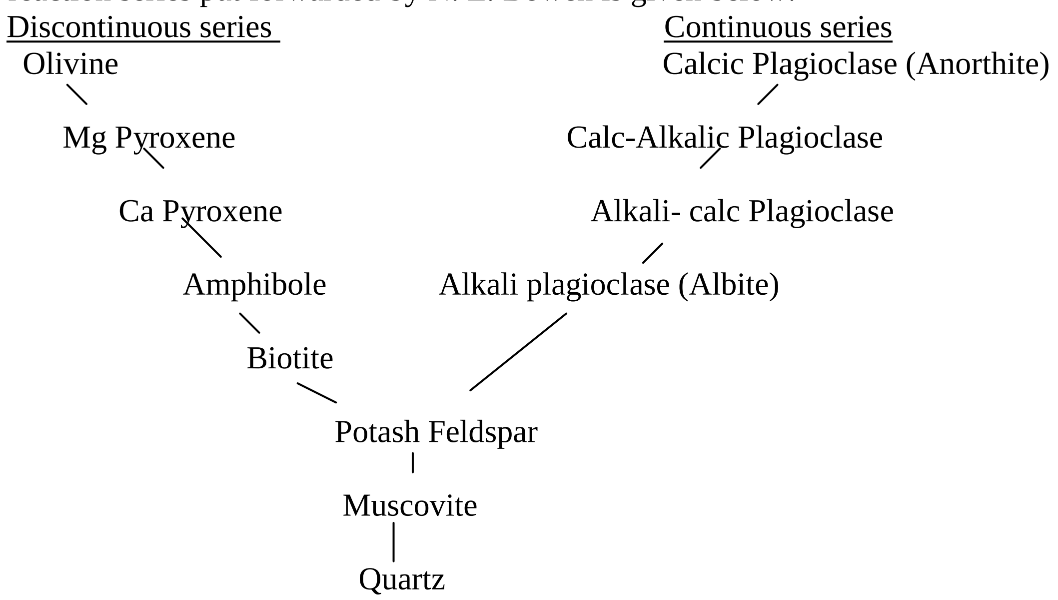
Processes of formation of igneous rocks

Old view:

Acidic magma: composition as silica, alumina and alkali E.g. Granite
Basic magma: composition as iron, magnesia and lime E.g. Basalt
Intermediate magma: admixture of acidic and basic magma E.g. Diorite

Recent worldwide-accepted view:

- Single parental magma (homogeneous magma) of basaltic composition was put forwarded by N.L. Bowen (1928). The basaltic magma contains diverse type of minerals. The resulting rock formed due to this magma depends upon reaction series.
- Reaction series is sequences in which early-formed minerals react with melt to form new minerals that are further down in the series. Reaction series represented as continuous and discontinuous series. Continuous series is one in which there are no abrupt phase changes during the reaction of early-formed crystals with later melts. The series is of feldspar minerals i.e. Plagioclase. Discontinuous series is one in which reaction of early-formed crystals with later melts represents the sharp phase changes. E.g. early-formed Olivine minerals react with melt to form Pyroxene.
- The reaction series put forwarded by N. L. Bowen is given below:



Bowen's reaction series

- Magmatic differentiation: The internal diversification processes that separate an initially homogenous closed magma body into two or more daughter magmas of different chemical composition, thus forming more than a single type of igneous rock from a common magma. A variety of mechanisms have been suggested, of which principal ones are:

1. Liquid immiscibility: involves the separation of two compositionally different liquid phases from an initially homogenous melt. E.g. immiscibility between Sulphide and Silicate liquids for the formation of magmatic Nickel- Sulphide ore deposits.
2. Fractional crystallization: It is an effective differentiation process. Crystals that form at high temperatures are prevented from equilibrating with parent magma, either by mantling with an overgrowth of another mineral or by separation from magma. Or the separation of first formed minerals of different melting points from parent magma due to precipitation or gravitational means. The mineral crystallized out in a magma mass due to the formation of solid and liquid phases. This produces a series of residual magmas with composition that are more and more depleted in the components of the early-formed minerals and very different from that of the original magma.
3. Gravity settling: The crystallized mineral is of a specific gravity higher than that of the fluid magma, the former would naturally have a tendency to sink down towards the floor of the magma chamber i.e. from settling of crystals due to gravity.
4. Filter pressing: The driven out of the fluid magma from the solid crystals due to severe lateral pressure set up within mountain building movement or operation.
5. Gaseous transfer: During crystallization of magma, the volatile matters tend to move towards the regions of comparatively less pressure and their transfer from one place to another may be accompanied by the removal of some of the magmatic constituents from the original magma. This process of separation of some of the magmatic constituents due to movement of volatile matters may be called gaseous transfer.
6. Assimilation: The process of incorporation of the country- rock within the erupted magma- mass is known as assimilation.

The above mention mechanisms of origin of magma, they reflect the following rock types.

- When Olivine mineral is completely separated out from the magma, the resulting rock is Dunite i.e. ultramafic rock.
- If Pyroxene and Calcium rich Plagioclase separated out together, forming basic rocks i.e. Gabbro, Basalt etc.
- If minerals like Quartz, Orthoclase, Biotite and Sodic plagioclase as a principal constituent, forming acidic rock E.g. Granite.

VOLCANISM:

Volcanism is the phenomena related to the eruption of magma to the surface of the earth. Volcanism is dynamic and endogenous in nature. Volcanism is considered to be the outcome of the release of high pressures which build up within the magma chambers below the ground surface.

Causes of Volcanism: The volcanism may be produce due to following factors.

a. Geothermal gradient i.e. the increase of temperature with depth.
b. Accumulation of radioactively generated heat.
c. Relaxation of pressure locally.
d. Water vapor within the magma chambers (Water percolation through the crust).

Volcanic Products: Volcanoes contain three types of materials i.e. solid, liquid and gases.
a. Solid Products: Fragments of rocks or pieces of already cooled lava. The rock fragments ejected during volcanic eruption are called Pyroclast or tephra. The Pyroclastic material are classified as: Volcanic blocks (angular >32mm diameter), Volcanic bombs (rounded >32mm in diameter), Cinders or Lapilli (rounded but 4mm to 32mm diameter), Ash (.25mm to 4mm) & Fine Ash or Volcanic dust (<0.25mm in diameter)
b. Liquid Products: Lavas are the major and most important liquid products. Lava may be of 3 types i.e. Acidic, Intermediate and Basic.
c. Gaseous Products: Water vapor (60-90%), Carbon dioxide, besides them HCl, SO2, H2, N2 etc.

Types of Volcanoes:
The volcanoes are classified from the following bases.

1) **Continuity of eruption:**
   i. Active: Still erupt.
   ii. Dormant: Long gap in eruption but may active in anytime
   iii. Extinct: Stopped eruption over a long time.
2) **Nature of Eruption:**
   Due to the factors like chemical compound, the amount of gas content, the pressure and temperature etc. The volcanic eruption may be quite, intermediate, or violent.
   - Quite type: Eruption without any explosion. E.g. Lava of basaltic compound.
   - Intermediate type: Explosive in beginning and gradually quiet in later.
   - Violent: Explosive eruption. E.g. Lava of acidic composition.
3) **Mode of Eruption:**
   - Central type: where creator, Vent & Magma chamber present. E.g. Hawian.
   - Fissure type: where eruption through fissure. E.g. Dykes

Distribution of Volcanoes:
The most important places of volcanisms are given below.

- The circum-pacific belt: This belt also known as Ring of Fire. More than 60% of the active volcanoes are located.
- Atlantic belt:
- Mediterranean Himalayan belt:

TEXTURE OF IGNEOUS ROCKS

Texture of igneous rocks is the actual relations between crystals or in between crystal and glassy matter under physiochemical environment. It gives the cooling history of magma.

I. Crystallinity: The degree of crystallization.
a. *Holocrystalline*: Consisting wholly of crystal (e.g., Granites).
b. *Holohyaline*: Consisting wholly of glass (e.g., Pitchstone, Obsidian)
c. *Hypo crystalline*: Consisting partly of glass and partly crystals, (e.g. Rhyolites, Andesites).
(Crystallization depends on rate of cooling, viscosity, depth of cooling and volume of magma)

II. Granularity: The size of the grains or crystals.
a. Phanerocrystalline / Phaneritic/ Eucrystalline: Crystal visible to the naked eye /pocket lenses.
i. Coarse –Grained : When the average crystal diameter >5mm
ii. Medium –Grained : When the average crystal diameter1 to5mm

iii. Fine –Grained: When the average crystal diameter <1mm

b. Aphanitic: Crystal cannot be seen with unaided eye.

i. Microcrystalline: Crystals distinguishable only under microscope.
ii. Merocrystalline: Intermediate in range.
iii. Cryptocrystalline: Crystals too small to be distinguishable even under powered microscope.
iv. Glassy: No crystallization at all.

III. Fabric

A. Shapes of crystals: The degree of development of crystal faces.

1. With reference to development of crystal faces:

i. *Euhedral:* Crystals completely bounded by faces.
ii. *Subhedral:* Crystal faces partly developed.
iii. *Anhedral*: Crystal faces altogether absent.

2. With reference to relative dimensions in 3 spaces –direction:

i. *Equidimensional /Equant*: Equally developed in every direction. (E.g. Polyhedral crystals of Garnet, Augite, Leucite).
ii. *Tabular*: Better developed in 2 spatial directions than 3rd. They form plates, tablets, flakes (e.g. Micas).
iii. *Prismatic:* Better developed in one direction than other two. They form columns, prisms (thick & thin) Rods, Needles, (e.g., Hornblende, Apatite).
iv. *Irregular*: Wisps, shreds, ragged patches, veins, skeletons. (e.g., Lattice-like skeletal crystals of Limestone).

B. Mutual Relations of crystals:

It is relative (not absolute) size, shape and dimensions of crystals & their mutual arrangement to one another.

1. Equigranular / Granular textures:

All constituent minerals of approximately same size, thus rock are evenly granular (e.g. many Plutonic rocks & Pegmatites are coarsely granular; dykes and lavas are finely granular)

i. Panidiomorphic/Idiomorphic / Automorphic granular:
   Rock has euhedral grains (e.g. lamprophyres) and also called Lamprophyric texture.
ii. Hypidiomorphic Granular /Hypautomorphic/ Granitic: All grains are subhedral (e.g. most Granites)
iii. Allotriomorphic / Xenomorphic granular: All grains are anhedral; includes Aplitic/Sugary/Sacchraoidal (i.e., of Aplites).

2. Inequigranular Textures: Constituent minerals show pronounced differences in size.

   ii. Seriate: Grain size varies gradually smallest to largest.
   iii. Texture with two dominating grain sizes (with few crystals of intermediate size).
      a. Porphyritic texture: Large crystals (Phenocrysts) embedded in fine grained i.e.glassy matrix (Groundmass).
         - Phenocrysts are recognizable to unaided eye (Megaphenocryst) and the texture is Megaporphyritic.
         - Phenocrysts are detectable only with microscope the texture called Microporphyritic.
         - Groundmasses have dense intergrowth of quartz and feldspar (felsite) in Felsophyric texture.
         - Groundmass of feldspar has no slender laths but they are stumpy rectangular in forms called the Orthophyric texture. (e.g., in some Trachytes).

- Phenocrysts gathered into distinct clusters (spot) in Glomero-porphyritic texture.

b. Poiklitic Texture: Smaller crystals are enclosed in the larger ones without common orientation. The enclosing crystal is Oikocrysts and the enclosed crystal is Chadacrysts.

- E.g. In acid Plutonic rocks (syenite, Monzonite) plates of potash feldspar (Orthoclase) enclose abundant laths of Plagioclase.
- In some ultrabasics (Peridotite,Picrite) plates of hornblende/ Biotite may enclose granules of Olivine /Pyroxene.

STRUCTURE OF IGNEOUS ROCKS

The large scale features of igneous rocks called the structure of igneous rocks. They are dependent on composition and viscosity of magma, temperature and pressure at cooling and presence of gases and other volatiles. The igneous structures are mainly formed in the flow stage of magma i.e. in extrusive rocks.

i. **Vesicular and amygdaloidal structures**: Near the top of the flows, empty cavities of variable dimensions are formed due to lavas with gases and other volatiles. The individual cavity called the vesicles and as a whole resulted structure called the vesicular structure. The empty cavities filled by secondary minerals are called the amygdales. The lavas with amygdales are said to have amygdaloidal structure.

ii. **Lava drain tunnels**: The hollow structure developed due to drain out of interior fluid lava.

iii. **Block lava**: A very rough surface developed during acidic lava flows due to their high viscosity. They are also called ‘aa’ structure.

iv. **Ropy lava**: A very smooth surface developed during basic lava flows due to their low viscosity. They are also known as ‘Pahoehoe’ structure.

v. **Pillow structure**: It consists of isolated pillow shaped masses piled one upon another.

vi. **Sheet structure**: The horizontal slices developed on the massive igneous rock due to one set of well defined jointing.

vii. **Platy structure**: The plate like structure developed in rocks due to the development of different set of joints.

viii. **Columnar structure**: The formation of columns due to development of vertical sets of joints through contraction of lava.

ix. **Flow structure**: The lavas and crystallized particles are arranged parallel to the direction of flow of the lava.

x. **Rift and grain**: The equally spaced joints are producing cubical blocks. These joints are known as rift and grain.

Geological relation of igneous rocks (Igneous rock formation)

Igneous Rock → Extrusive (On surface through lava flows)
Igneous Rock → Intrusive (Below the surface through solidification of magma)

The contact of igneous rock with surrounding rocks may either be concordant or discordant.

- Concordant: Igneous rocks parallel to the bedding or foliation plane.
- Discordant: Contact makes an angle with bedding or foliation plane.
- Vesicles: Gas bubbles within igneous rocks. It results vesicular structure.
- Foreign materials within igneous rocks are called inclusions. Inclusion may be,

- Xenolith: Inclusion of rock fragments. It results xenolithic structure.
- Xenocryst: Inclusion of crystals.

Types of intrusion:
The intrusive magma results the following relations to the surrounding rocks for the formation of igneous rocks.

1. Sills: Concordant tabular bodies that are emplaced essentially parallel to the foliation or bedding of the surrounding rocks.
    - They are commonly sheet like masses.
    - Mostly they are basaltic in composition with high fluidity.
    - They may be simple (only one injection) and multiple (more than one injection) or differentiated (composition variation from upper to lower surface).
2. Laccoliths: These are mushroom-shaped (dome) concordant igneous bodies.
    - Silicic or intermediate in composition with higher viscosity.
    - They are occurring relatively in undisturbed sediments at shallow depth.
3. Lopoliths: These are funnel shaped concordant igneous bodies.
    - Large, mostly Mafic to Ultramafic in composition.
4. Phacoliths: It is concordant intrusive body associated with folded rocks.
    - Igneous materials accumulated in zone of minimum stress (i.e. crest and trough of folds) at relatively deep zones.
5. Dykes: These are tabular discordant igneous bodies that cut across the foliation or bedding plane of country rocks.
    - They are commonly found in cracks within surrounding rocks.
    - They may be more or less vertical.
    - Veins are small tabular or sheet like mineral filling within crack of country rocks..
6. Batholiths: These are large discordant plutonic mass more than 100 Sq.km in area and with no visible or clearly inferred floor.
    - Mostly Silicic in composition.
    - They are irregular in outline with greater depth.
    - The smaller (up to 100 Sq. km) outcrop is known as stocks.
    - Many batholiths are concordant to the regional structure and are highly discordant when mapped in detail.

Types of extrusion:

Igneous extrusions have varieties of forms on the basis of nature & amount of erupted materials, & their relationship with country rocks.

- Lava flows:
  Magma solidified as in flow with a low gas content and low viscosity on the surface of the earth.
  - The most lava flows are basaltic and lesser amount have intermediate in composition.
- Sub aerial lavas:
  Pahoehoe: They are glassy and smooth with ropy surface in large areas.
  Aa lava: They are rough and fragmented with vesicular surface.
  Blocky lava: They are fragmented & smooth with irregular surface.
  Pillow lava: Lava flows with ellipsoidal or pillow-shaped bodies radial jointing.

(figure)

Pyroclastic rocks:

- The accumulation of tephra (solid fragmented materials).
- Many volcanic structures consist of mixture of both lava & tephra.

CLASSIFICATION OF IGNEOUS ROCKS

Igneous rocks are classified on the basis of

1. Chemical classification: On the basis of SiO2 percentage.
2. Mineralogical classification: On the basis of mineral content in volume percentage (IUGS classification).
3. Geological mode of occurrence and texture: i.e. Volcanic, Hypabyssal, Plutonic rocks.

SIMPLE CLASSIFICATION OF IGNEOUS ROCKS (according to chemical and geological mode of occurrence)

	Acid or Over Saturated (SiO2 > 66%)	Intermediate (SiO2 66% - 55%)	Basic (SiO2 55% - 44%)	Ultrabasic (SiO2 < 44%)
Volcanic	Rhyolite, Dacite	Trachyte, Andesite, Phonolite	Basalt, Alkali basalt	Limburgite, Olivine-basalt
Hypabyssal	Microgranite, Pegmatite	Micro-syenite, Micro-diorite	Dolerite	
Plutonic	Granite, Grano-diorite	Syenite, Diorite, Nepheline-syenite	Gabbro, Anorthosite	Peridotite, Dunite, Picrite, Perknite

Mineralogical classification:

Simple mineralogical classification is given below on the basis of the relative amount of the various minerals in rocks. According to them the classes are,

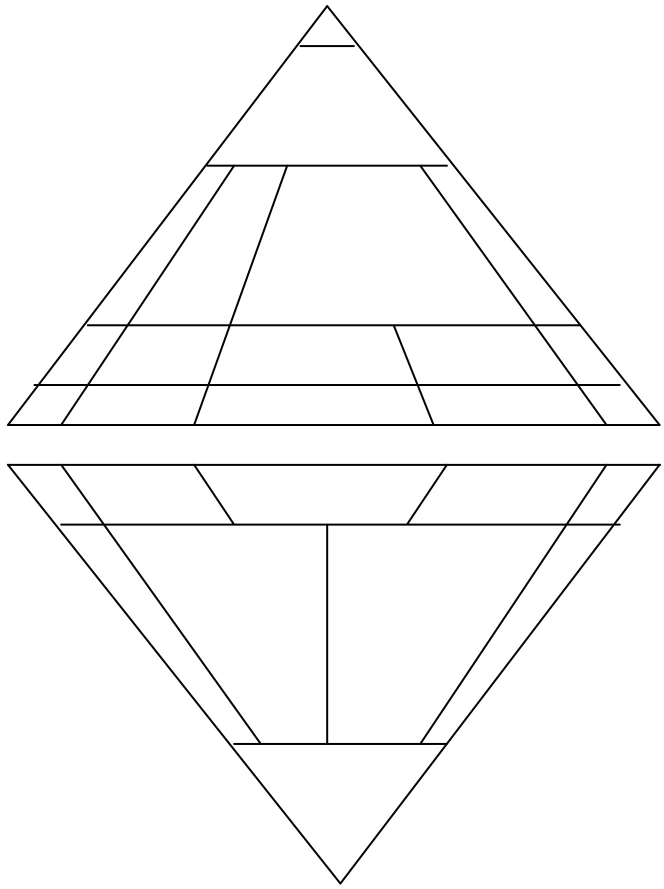
1. Essential minerals: They have great role in naming of the rocks. E.g. Feldspar and Quartz in granite rock.
2. Accessory minerals: These are minor constituents of rocks and have no role in naming of rocks. E.g. Biotite, Pyroxene etc. in Granite rock.
3. Secondary minerals: Minerals alters through the processes of weathering, metamorphism etc.

Mineralogical classification by International union of geological sciences (IUGS 1967):

- This classification also known as Albert Streakaisens classification.
- Igneous rocks are classified on the basis of mineral content in volume percent.
- Most of the igneous are found in nature contains Feldspar (Alkali feldspar and plagioclase), silica rich mineral (Quartz) and silica deficiency minerals (Feldsfathoids).
- The felsic, intermediate and mafic rocks are described in Q-A-P-F classification but ultramafic rocks do not described in this classification. Such classification based on dark colored mineral contents.
  Felsic rock: Less than 40% dark colored minerals.
  Intermediate rock: Dark colored minerals in between 40 to 70%.
  Mafic rock: Dark colored minerals in between 70 to 90%.
  Ultramafic rock: More than 90% dark colored minerals.

- The IUGS classification scheme is show in double triangle Q-A-P-F. The relative percent may be calculated as Q+A+P=100% and A+P+F=100%.

1= Quartzolite	10= Q. Monzodiorite (Andesite)	19= Nephelene bearing Monzonite (Latite)
2= Quartz rich Granitoid	11= Q. Diorite (Q. Andesite)	20= Nephelene bearing Monzogabbro (Basalt)
3= A. Granite (Rhyolite)	12= A. Syenite (Trachite)	21= Nephelene bearing Diorite/Gabbro (Andesite/Basalt)
4= Granite (Rhyolite)	13= Syenite (Trachite)	22= Nephelene Syenite (Phonolite)
5= Granodiorite (Dacite)	14= Monzonite (Latite)	23= Nephelene Monzosyenite (Tephritic Phonolite)
6= Tonalite/ Quartz Diorite (Q. Andesite)	15= Monzogabbro (Latite/Basalt)	24= Nephelene Monzodiorite/ Monzogabbro (Phonolitic Tephrite)
7= Q. A. Syenite (Trachyte)	16= Diorite/Gabbro (Andesite/Basalt)	25= Nephelene Gabbro (Tephrite)
8= Q. Syenite (Q. Trachite)	17= Nephelene bearing A. Syenite (Trachite)	26= Izolite
9= Q. Monzonite (Q. Latite)	18= Nephelene bearing Syenite (Trachite)	



Note: Q= Quartz, A= Alkali Feldspar, P= Plagioclase and F= Feldspathoid minerals
Ultramafic rocks (not in Q-A-P-F classification): E.g. Dunite, Hornblendite, Pyroxinite etc.
The rocks without bracket represent plutonic rocks and the rocks in bracket represent volcanic equivalent.

SEDIMENTARY ROCKS:

Introduction:

A rock resulting from the consolidation of loose sediments which are derived from the pre-existing rocks & minerals, chemical precipitation from solution and an organic remains of plants and animals at or near the earth's surface.

- The sedimentary rocks that originate with the accumulation of discrete mineral or rock particles derived from weathering and the erosion of pre-existing rocks (i.e. deposited by mechanical means). Such rocks are called clastic or detrital sedimentary rock. The particles in those rocks called clastic/detrital and sometimes fluvial (deposited by river).
- The sedimentary rocks that originate from the chemical precipitation as well as from the biologic means are called non-clastic sedimentary rock. The particles in those rocks called chemically deposited and biological sediment.

Stages of formation of sedimentary rocks:

1. The breaking down of the pre-existing rocks. (By weathering i.e. due to decomposition & disintegration.)
2. Erosion of weathering products due to the action of natural agencies like water, wind, glaciers etc.
3. Transportation of eroded materials due to those natural agencies.
4. Deposition of transported materials under suitable condition.
5. Transformation of deposited materials (sediments) into sedimentary rocks due to the process of diagenesis.

Diagenesis is the sum of physical, chemical or biochemical changes in a sedimentary deposit after its initial deposition and before metamorphism. Diagenesis occurs at temperature below 300^{o}c and pressures less than 1kbar and under static load. Diagenesis involves following processes:

I. Consolidation: It is the process of removing pore water under static load. It is a time dependent phenomenon. For coarse sediment, drainage is sufficient and consolidation is instantaneous.
II. Compaction: It is the reduction of pore space in response to pressure. It occurs by the readjustment & preferred orientation of equi-dimensional grains.
III. Dissolution: The water moving through the pores dissolve the grains and reduce the grain size. It depends upon composition of water and grains. Evaporites, limestone are more soluble and form solution channels.
IV. Pressure Solution: It is a process in which a solid dissolves at its contact with another solid and with pore water; because increased pressure has increased its solubility. Due to this, grains are welded together and the pore space is reduced.
V. Replacement: The pore water contain various ions, they may replace the grains and change partially or wholly the composition of grains. Calcites are replaced by silica, phosphorite, magnesium etc.
VI. Decomposition (Matrix Formation): Decomposition of feldspar or unstable rock fragment occurs during the deep buried of sediments.
VII. Cementation: It is the process of binding of grains to form an aggregate mass. It is due to the precipitation of minerals in the pore spaces. Common cementing minerals are calcite, silica, clay minerals, ferromagnesians, gypsum etc.
VIII. Neomorphism: New shape formation due to either grain size increase or decrease.

The above mention processes are not dominance in all type of sediment but one kind of process may be dominant in one kind of sediment. Simply as,
Limestone: Recrystallization

Shale: Compaction
Sandstone: Cementation & Composition

Texture of Sedimentary Rocks:

Texture is the relationship among the mineral grains and includes size, shape and arrangement of the constituent particles in rock.

a. Grain Size: The principal factors which determine the size of grain are: Mode of weathering, Composition of pre-existing rocks, the kind & amount of transport suffered by the materials. The size grades of clastic particles are as follows:

S.N	Size (mm) diameter	Name	Equivalent rocks	Classification
1	>256	Boulder	Boulder gravel/ Boulder conglomerate	Rudaceous rock
2	64 to 256	Cobble	Cobble gravel/ Cobble conglomerate	
3	4 to 64	Pebble	Pebble gravel/ Pebble conglomerate	
4	2 to 4	Granule	Granule gravel/ Granule stone	Arenaceous rock
5	1/16 to 2	Sand	Sandstone	
6	1/16 to 1/256	Silt	Siltstone	Argillaceous rock
7	< 1/256	Clay	Shale/ Mudstone	

b. Shape of Grains: Shape also depends upon mode or type of weathering, composition of the parent rocks and distance traveled by eroded materials or resistance of the transported materials. It varies within wide limits as well rounded, rounded, sub rounded, smooth, angular, platy etc. The roundness deals with the sharpness of the edge and corners of clastic elements. The roundness of the grain may indicate a greater amount of abrasion (high mutual collision or rubbing or rolling) and greater distance of transportation, where as the angularity of grains will indicate less amount of abrasion and a little or no amount of transportation. Wadell (1932) defined roundness as the ratio of the average radius of curvature of the several corners or edges to the radius of curvature of the maximum inscribed sphere.
   Roundness= r_i/R
   Where, $r_i = r_1+r_2+r_3+\ldots$ and R= radius of maximum inscribed sphere.

c. Sorting: The process by which sedimentary particles are naturally separated accordingly to size, shape and specific gravity from associated but dissimilar particles or size variation in sediment. It is defined as well sorted (same size) & Ill sorted (dissimilar size).

d. Sphericity: The degree to which the form of sedimentary particle approaches that of sphere.

STRUCTURE OF SEDIMENTARY ROCK:

Any varieties of large scale features are produced in sedimentary rocks by sedimentary processes are called the sedimentary structure. The principal types of sedimentary structures are given below:

1. Primary Structure: Formed at time of deposition. E.g. Bedding.
2. Secondary Structure: Formed after the time of deposition. E.g. Nodules
3. Organic Structure: Developed due to action of organic matter. E.g. Stromatolite, Track & Trails etc.

Primary Structures:

The structures are developed at the time of sediment deposition.

a. Stratification: Arrangements of sediment in layers called the stratification which is characterized by the differences in color, composition, texture or structure. I.e.
   > 1cm = Bed, < 1cm = laminae.

b. Cross Bedding: Layering inclined at an angle to the main bedding planes of general stratification. Mainly in steeply dipping forest bed.
c. Graded Bedding: Layers are formed with sharply distinct grains. Typical in marine deposit.
d. Ripple Marks: The wavy structures were developed in sedimentary strata. Such structures were formed due to the drag of waves and current of water or wind over sediments i.e. mainly in sand and silt size sediment. They may be symmetric and asymmetric in nature.

Ripple marks →
- Wave Ripple Mark: Symmetric, through waves in sediment of stagnant water.
- Current Ripple Mark: Asymmetric, through flowing water and wind in sediment.

e. Mud Cracks: Formed due to shrinkage of mud at dry. River flood plain or floors of lakes are suitable sites of mud cracks.

Organic Structure:
Track & Trails: The movement of organisms on the loose & soft sediment. Organisms may develop the markings, impressions or foot prints in the sediment. Such structures are called are known as track & trails.

Importance of primary sedimentary structures:
The primary sedimentary structures provide valuable information as,
- Show palaeocurrent condition through the analysis of sedimentary particles.
- Rate of supply of sediments from source area.
- Mode of transportation of sediment due to the analysis of particles.
- Environment of deposition through sediment analysis.
- Gives information about top and bottom of bed i.e. younger and older.

Classification of sedimentary rocks:
The classification of sedimentary rocks has been a problem till now. The classification is an organization of knowledge and schistematic representation of ideas. Single classification schemes for all sediments encounter difficulties due to polygenetic nature of sedimentary rocks. Few most important scheme of classification of sedimentary rocks are given below:
1. The classification based on genesis of sediments:
   a) Residual sedimentary rocks: The rocks were formed from weathering residue at in situ place. E.g. Laterite, Bauxite
   b) Mechanical sedimentary rocks: The rocks were formed due to deposition under suitable condition. E.g. Shale, sandstone, conglomerate
   c) Chemical sedimentary rocks: The rocks were formed due to precipitation and consequent accumulation of the soluble constituents. E.g. Limestone, dolomite
   d) Organic sedimentary rocks: The rocks were formed due to the organic matter accumulation and their preservation under suitable condition. E.g. Coal, Fossiliferous limestone.
2. The classification based on grain size: See texture.
3. Classification by Greensmith (1957):

A. Clastic:
   I. Rudite- Boulderbeds, Conglomerates
   II. Arenite- Sandstone
   III. Lutite- Siltstone, Claystone

B. Non-clastic:

I. Calcareous- Carbonate of Ca, Mg. E.g. Magnesite
II. Carbonaceous- Organic, E.g. Lignite
III. Ferriginous- Fe_2o_3, Mno_2 e.g. Ironstone
IV. Siliceous- Silica, E.g. Chert
V. Aluminous- Al_2o_3, hydrous oxides e.g. Laterite
VI. Phosphetic- E.g. Phosphorite

METAMORPHIC ROCKS

Introduction:

- In Greek word 'meta' meaning change 'morphe' meaning shape or form.
- Any rock derived from pre-existing rocks by mineralogical, chemical, structural or textural changes in solid state, in response to marked changes in temperature, pressure and chemical environment at depth in earth's crust i.e. below the zone of weathering and cementation. The rocks are derived from igneous rocks are called orthometamorphic rocks e.g. Gneiss. The rocks are derived from sedimentary rocks are called Para metamorphic rocks e.g. Slate.
- Metamorphism: The processes which changes pre-existing rocks into new ones.

Agents of Metamorphism:

1. Heat:
   - Thermal energy results recrystallization and dehydration.
   - Thermal energy breaks chemical bonds.
   - They increase rate of reaction. Heat leads to changes in mineralogical composition and crystals and, that leads to make coarse texture.

2. Pressure:
   → Uniform Pressure (Equidimensional pressure)
   → Directed pressure (differential force)

   - Uniform pressure leads to changes of volume by pore space reduction due to closer atomic packing.
   - Directed pressure leads to changes of shape, texture & structure.

3. Chemically active fluids:
   - The changes take place through partial or complete solution of the minerals.
   - The most important chemically reactive fluids derived from magma and other source i.e. water, CO_2 etc.
   - They lead to chemical changes in rocks.

Texture of metamorphic rocks:

Textures are the small scale features developed in metamorphic rocks. Texture refers to the shape, size, orientation and arrangement of mineral grains in a metamorphic rock.
In describing metamorphic texture the term "blastic" or "blast" are used as a suffix to represent the metamorphic equivalent of igneous texture e.g. Porphyroblastic or porphyroblast for porphyritic texture of igneous and prefix "blasto" is used to describe relict texture of pre-existing rocks e.g. Blasto- porphyritic of relict porphyritic texture of igneous rocks.

METAMORPHIC STRUCTURE

Five major types of metamorphic structure are given below on the basis of texture and agent included in formation of metamorphic rocks. The metamorphic structures are the large scale features developed in metamorphic rocks. They are measured in hand specimen.

1. Cataclastic structure: under directed pressure i.e. stress. E.g. Granite, Mylonite.
2. Maculose structure: From thermal metamorphism in argillaceous rocks. Dark colored minerals giving a spotted appearance. E.g. Slate.
3. Schistose structure: under stress platy or flaky minerals in parallel orientation. In micas & inequidimensional minerals. E.g. Biotite, Schist
4. Granulose Structure: From heat & uniform pressure in equi-dimensional minerals by the process of recrystallisation. E.g. Quartzite, Marbles
    - Also known as Sacchroidal structure. E.g. Marble
5. Gneissose structure: banded structure due to alternation of dark colored & light colored minerals by highest grade of metamorphism through regional metamorphism. E.g. Granite, Gneiss

RECOGNIZATION OF METAMORPHIC ROCK

1. **Foliation**:

   Refers to the parallel orientation of platy or ellipsoidal minerals or mineral banding in rocks,which is formed by the segregation of minerals. It includes compositional layering and slaty cleavage, as in slates; schistosity, as in schist and compositional layering as in Gneiss.

a. **Schistosity**: A parallel arrangement of Micas or other platy minerals giving a more or less planar fissility with decrease in grain size. This structure is easily measured in Schist and Phyllite.

b. **Slaty cleavage**: The parallel arrangement of very fine grained minerals or micas which gives it very good planar fisility. This structure is easily measure in slate.

c. **Gneissocity**: The alternation o lighter and darker layers in a rock. This structure is easily measured in Gneiss.

d. **Lineation**: The parallelism or alignment of linear elements in the rock, which are formed by aligned prismatic grains, aggregates of minerals, axes of micro folds and lines of intersection of two or more planar element.

TYPES OF METAMORPHISM

Metamorphism is broadly classified into three major categories on the basis of the dominant agent involved in the formation of the rocks.

1. Contact metamorphism: (Thermal metamorphism)

- Resulted from emplacement of a hot igneous intrusion into cooler country rocks at relatively low pressure.
- Heat is dominating factor.
- The metamorphism operation area around the magma intrusion called *Contact Aureole.*
- Changes in mineral composition & Texture.
- Commonly formed in carbonate –rich country rocks.
- Contact metamorphic rocks are usually massive.
- Example, Limestone to Marble.

2. Regional metamorphism: It occur over wide areas (hundreds of kilometer) & within large *Orogenic* (mountain building process) belts.

- Temperature and directed pressure are dominating factors.
- Regional metamorphism also classified into following two types.

a. Regional Dynamothermal metamorphism:
   - Results from the thermal gradient in broad region.
   - The rocks are characterized by a parallelism of platy and elongated minerals.
   - Changes both mineral composition &texture.

b. Regional burial metamorphism: (high grade diagenesis)
   - Results from the thick piles of hydrous sediments or fragmental volcanic materials due to several hundred degrees temperature with high water pressure.
   - Lack of significant parallelism of metamorphic mineral grain.
   - Difficult to identify but only possible in polarizing microscope.
   - Example, Geolite, Glaucophane etc are burial metamorphic mineral.

3. **Dynamic metamorphism**: (Cataclastic metamorphism)
   - Occurs in zone of intense deformation as fractures, faults etc at shallow depths.
   - Change in texture i.e. decrease in grain size.
   - Mechanical deformation produces rocks ranging from Breccias to Mylonites.
   - Directed pressure is dominating factor.

CLASSIFICATION OF METAMORPHIC ROCKS

The metamorphic rocks have been classified on the following basis.

1) The parent rocks from which they have been metamorphosed.
   a. Orthometamorphic rocks: From igneous rocks.
   b. Parametamorphic rocks: From sedimentary rocks.
2) Structure, texture and predominance of agents.
   a. Foliated rocks: The rocks were formed by parallel arrangement of minerals during regional metamorphism e.g. Slate, Phyllite, Schist etc.
   b. Non-foliated rocks: The rocks were formed by equidimentional mineral grains during contact metamorphism e.g. Quartzite and Marble.

Unit 6: Geological time

Historical geology: The origin and evolution of the earth and its inhabitants.
Stratigraphy: The branch of geology dealing with the definition and interpretation of stratified rocks; especially their lithology, sequence, distribution and correlation.

PRINCIPLES OF STRATIGRAPHY

The most fundamental principles of stratigraphy (in 19th century) had been recognized. They are given below.

1. **Principle of superposition (Stenoes principles):**
   - In undisturbed sequence, the bottom layers are older than overlying layer.
   - In disturbed sequence, determine top and bottom of beds.

   A. Stratigraphic criteria: Original features were developed at the time of deposition. E.g. Graded bedding, cross bedding etc.

   B. Tectonic criteria: Features were developed due to tectonic movements. E.g. drag fold, overthrust etc
2. **The principle of funnal succession:**
   An older rock contain primitive organism and younger rock contain more advanced life.
3. **Principle of uniformatism (actualism):**
   The geologic processes of the past were pronounced by the same processes acting today. or Present is key to the past.
4. **Walther's law of facies correlation:**
   The succession of facies and lateral variation of deposition may be taken place at the same time of different environment.
5. **Principle of cross cutting relationship:**
   Any body of rock that cut across the boundaries of other unit of rock must be younger.
6. **Principle of inclusion:**
   The enclosed rocks are older than enclosing rocks.
7. **Law of palaeogeography:**
   This is the distribution and relationship of ancient seas and land masses. Ancient geography is reconstructed through an interpretation of the sedimentary rocks and fossils of a certain age. E.g. the fossiliferous sediment of Mt. Everest shows once it was the bottom of an ocean floor in historic time.
8. **Law of unconformities:**
   At any places of geologic record, there is an evidence of crustal upliftment followed by long period of erosion. Such break or gap in the record called unconformities.
9. **Principle of correlation:**
   Correlation is the matching of rock strata of the relative same age. Similar stratigraphic units can be correlated to each other. Few most important evidences of correlation are given below.

A. Palaeontological evidences:
   a. Similarities of fossils.
   b. Index fossils
   c. Palaeontological sequences.
   d. Palaeontologic similarity
   e. Evolutionary development.

B. Physical evidences:
   a. Continuity of strata.
   b. Lithologic similarity
   c. Position of stratigraphic sequence
   d. Metamorphism
   e. Radioactivity.etc.

Stratigraphic nomenclature:
All stratigraphic units require distinctive names or comparable designations in order that they may be identified and differentiated from each other. The stratigraphic names derived from,

- Due to more recognized place.
- Due to geographic features.
- Due to distinguishing physical features.
- Due to characteristic fossils, formations etc.

General introduction to Lithostratigraphy and Chronostratigraphy:

Lithostratigraphy:
It is the branch of stratigraphy concerned with the organization of strata into units based on lithological characters and the correlation of that unit. Or
It is the branch of stratigraphy in which the division, classification, correlation of rock strata on the basis of their lithologic characters.
Lithostratigraphic units: It is body rock having certain unifying lithological features. They are naming by locality, lithology and unit terms. They are identified by following characters.

- Defined and classified on the basis of rock strata.
- Characterized by lithozones, lithohorizons.
- Key beds, marker beds and unconformities are boundaries of lithostratigraphic units.
- Different rocks unit are divided and identified on the basis of color, textures, density etc.

The basic lithostratigraphic units are given below just like as to animal classification.
Super group (Complex)
Group
Formation
Members
Beds

(Additional fundamental units are designated as adding prefix super and sub for larger and smaller respectively.)
Geologically mapable units:

a. Small scale: 1: 5000000 to 1: 1000000
b. Intermediate scale: 1: 1000000 to 1:25000
c. Large scale: 1: 25000 to 1: 1000

Complex:

- It is regional stratigraphic unit generally used in metamorphic rocks.
- The mapable scale as 1: 5000000
- E.g. Nuwakot and Kathmandu complex.

Group:

- Group is naming by geographic region.
- It covers large area and large thickness.
- It includes several different formations.
- The mapable scale as 1: 1000000
- Group is equivalent to the ‘system’ of chronostratigraphic units.
- E.g. Kathmandu complex: a. Phulchouki group
  b. Bhimphedi group

Formation:

- Basic unit of lithostratigraphic units.
- It covers several hundred of meters.
- Mapable in intermediate scale i.e. generally 1: 50000

- Named after the combination of type locality and rock types. E.g. Dhading dolomite and Malekhu limestone of lower Nuwakot group of central Nepal.
- It includes different members and beds.
- It is comparable with 'series' of chronostratigraphic unit.

Members:

- It includes several beds of distinct lithologic composition.
- It covers several tens of meter thickness.
- It is mapped in larger geological scale i.e. 1:10000 to 1: 25000
- E.g. Riri member in Kaligandaki super group of Palpa.

Beds:

- It is smallest lithostratigraphic unit.
- Thickness ranges from few cm. to few meters.
- It is lithologically and economically important unit i.e. for mine location.
- E.g. Jhiku calcareous bed of the formation Benighat slate of central Nepal.

Chronostratigraphy:

Chronostratigraphy is that area of stratigraphy dealing with the age and time relation of strata.
or
It is the branch of stratigraphy in which division, classification, correlation of rocks and geologic history is based on time interval.

- The chronostratigraphic classification is the organization of rock strata into units on the basis of their age of time of origin.
- The applied units in chronostratigraphy are rock time units which are also called chronostratigraphic unit and derived from the geochronologic units where the rocks formed during the specific interval of time.
- The chronostratigraphic units were naming on the basis of geographic and any geological features. E.g. Jurassic period – From Jura Mountain of Europe, Carbonaceous period- from coal area etc. Other naming by priority rule.

The recognized chronostratigraphic units and their equivalent time units from most inclusive to least exclusive are as given below.

Chronostratigraphic unit	Equivalent time unit (Span of time)
Eonothem	Eon
Erathem	Era
System	Period
Series	Epoch
Stage	Age
Chronozone	Chron

Methods of chronostratigraphy (In rock classification, correlation and age determination):

I. Direct (Absolute): From radiometric dating i.e. Uranium lead method, Potassium-Argon method, Carbon method etc.

II. Indirect (Relative):
   a. Palaeontological method: From the analysis of index fossils or assemblage of fossils.
   b. Palaeomagnetic method: Due to magnetic reversal.

Biostratigraphy:

It is the branch of stratigraphy in which division, classification, correlation of rocks and geologic history is based on palaeontological features (Fossils) developed in rock strata. Biostratigraphic units are the body of strata that is identified by the particular fossil content. The basic unit of Biostratigraphy is 'biozone'.

Fossils and condition of fossilization:

Fossils: The remnant or trace of organisms buried by natural cases and preserved in the earth's crust. Or the remnants of ancient life were preserved in geologic past.

Fossilization: The processes of formation of fossils and their preservation in rock strata are known as fossilization. The most important conditions of fossilization are given below.

I. Quick burial in protective medium: The deposited organisms did not decompose by Bacteria and did not disturb by oxidation or by other means.

II. Presence of hard part: The hard part of organisms had good preservation in rock strata i.e. bones, teeth, shell, woody tissue of plants etc. The soft parts were easily decomposable but rarely preserved.

Types of fossilization:

- Fossilization
  - Direct evidence
    - Actual remains
      - Unultered soft part e.g. woof. mammoth
      - Unultered hard parts
    - Altered hard part
      - Carbonized e.g. Jellyfish
      - Petrification
      - Recrystallized- e.g. Brachiopod shell
      - Dehydrated and crystallized e.g. Radiolarian test
      - Replaced
  - Indirect evidence or trace of organisms
    - Moulds and cast
    - Tracks and trails
    - Burrows and boring
    - Coprolites
    - Gastroliths
    - Pseudofossils

Petrifaction: Preservation of hard parts of many organisms by mineral bearing solution after burial in sediments.
Mould: The impression of fossil shell on encasing materials.
Cast: The mould was filled by mineral matter.
Coprolites: The fossilized faecal (excreted) matter.
Gastroliths: The highly polished and rounded stones from certain extinct reptiles.

Index fossils

Certain forms of extinct animals and plants were restricted to the beds of definite geological age beyond which they were not known to occur called the index fossils. The formations of index fossils are dependent on following parameters.

a. The short geological range i.e. limited interval of time.
b. The organisms are most abundant in quantity.
c. The organisms should in wide geographical distribution.
d. The organisms should have easy in identification.

Uses of index fossils:

- For the classification of stratigraphy.
- For the correlation of different rock strata in stratigraphic paleontology.
- It is the tools for the determination of the relative age of fossilliferous strata.

Limitation of index fossils:

- The organisms have own definite physio-chemical condition. The all species have the same geographical distribution.
- Some species have wide range of adapting ability and they widely distributed in the earth surface.
- Any organisms may reappear higher up in younger beds.

The organic evolution

A study of evolution indicates that our modern day plants and animals have attained their present degree of development as a result of gradual or orderly changes which taken place in the geologic past. The theories of organic evolution were given by Lamark, Darwin and Hogo de veries.

I. Lamark (1809):
   a. Theory of inheritance of acquired characters.
   b. Theory of use and disuse.
II. Darwin (1859):
   a. The struggle for existence.
   b. Variation.
   c. Natural selection.
   d. Sexual selection.
III. The mutation theory (Mutation-sudden change or variation in germ plasm of organisms). Inherited to the offspring and passed from one generation to another.

Evidences of evolution:

i. Evidences from comparative anatomy.
ii. Evidences from embryology.
iii. Evidences from classification.
iv. Evidences from genetics.
v. Evidences from geographic distribution.
vi. Evidences from paleontology.

Geological time scale

The earth has undergone multitudinous changes during its long history. These changes both physical and biological had a marked effect on the climate, geography, topography and life forms of prehistoric times. An arbitrary chronological arrangement of these geological events in a chart like form called the geological time scale. The Precambrian i.e. cryptozoic time may well represent as much as 85% of all earth history.

The geological time scale and the Himalayas (K. Kizaki)

Eon	**Era**	**Period**			**Mi. yrs**	**Geological events**
PHENEROZOIC	CAINOZOIC	Quaternary		Holocene	0.01	Uplift continues
				Pleistocene	1.7	Upheaval of siwaliks followed by Mahabharat range
		Tertiary	Neogene	Pliocene	5	Upheaval of whole Himalayas
				Miocene	24	Upheaval of Higher Himalaya, Metamorphism and nappe formation
			Paleogene	Oligocene	36	Uplift of Tibetan marginal Mountains
				Eocene	58	Collision of India with Eurasia, Tethys sea dry up
				Paleocene	66	
	MESOZOIC	Cretaceous		K1, K2, K3	144	India's northward drift initiated (Dinosaur disappear)
		Jurassic		J1, J2, J3	208	Break of Gondwana
		Triassic		T1, T2, T3	245	Dinosaur appear
	PALAEOZOIC	Permian		P1, P2	286	
		Carboniferous		C1, C2	360	
		Devonian		D1, D2, D3	406	
		Silurian		S1, S2	438	Formation of gondwana continent
		Ordovician		O1, O2, O3	505	
		Cambrian		Ca1, Ca2, Ca3	570	Tethys sea appear (Trilobites)
CRYPTOZOIC	PROTEROZOIC	Late proterozoic			1600	
		Early Proterozoic			2600	
	ARCHEOZOIC				4500	

Unit: 7
WEATHERING:
Weathering is the processes of disintegration and decomposition of rocks and minerals at or near the earth surface. It is the initial stage of denudation & the static part of the process of erosion. Weathering products are equilibrium in position with the new physio-chemical condition and tend to accumulate in insitu forming soft layer called regolith.

Controlling Factors on Weathering:
1. Structure, Texture & Mineral Composition of Rocks
   - Structures: Joints, Cracks, Fissures, Beddings, Foliations.
   - Textures: Fine grained rocks – More Susceptible to weathering than coarse grained
   - Mineral Composition: High Silica content – Less weathering, Low Silica content – More weathering

   It depends upon Bowen's reaction series. (Consult Book)
2. Climate: Sum total of Temperature, Moisture (Humidity, Precipitation), Atmospheric pressure, Wind etc
   - Tropical & arid climate – Physical weathering
   - Temperate & humid climate – Chemical weathering
   - Temperature: Diurnal & Seasonal temperature changes results contraction & expansion of rocks High temperature within humid condition effects rate of chemical weathering.
   - Rainfall: High precipitation saturate rocks increase pore pressure. H^+, OH^-, HCO_3^- ion with water react unstable minerals causes Chemical decomposition.
3. Topography: It is the gradient of area
   - Most effective weathering in average topography is due to percolation of water.
   - In high relief less effective weathering but high rate of erosion & transportation.
4. Vegetation:
   - Plants roots on joints & fissures cause the disintegration of rocks.
   - Organic acid from plant decay cause decomposition.
5. Time:
   - Longer the time period the degree of weathering is maximum and affects the greater rock volume.

Types of Weathering:
1. **Physical Weathering:** →
   - Insolation: Due to thermal expansion results exfoliation & granular disintegration.
   - Dilation: Due to pressure variation or unloading
   - Crystal Growth: Due to soluble constituents ($HaCl$, $CaCO_3$, $MgSO_4$ etc) on fractures & joint
   - Frost action: → Frost wedging (laterally)
     → Frost Heaving (Upwardly)
   - Colloidal Plucking: Soil colloids have power to Loosen rocks.
2. **Chemical Weathering**: Process of mineral alteration due to chemical reaction.

Depending upon size, composition of rocks, temperature and humidity the most important Chemical weathering are:

a. Hydration: Chemical union of water causing more stress.

E.g. $CaSO_4 + 2H_2O \longrightarrow CaSO_4.2H_2O$
(Anhydrite) → (Gypsum)

$Fe_2O_3 + nH_2O \longrightarrow Fe_2O_3.nH_2O$
(Hematite) (Limonite)
When the mineral is hydrated, OH^- ion builds new crystal lattice.

b. **Hydrolysis:** Chemical reaction between ions of minerals and H+ or OH- ions of water. H+ ion & OH- ions are measured by PH values.
When PH = 7 – $H^+ = OH^-$ (Neutral)
PH > 7 – $H^+ < OH^-$ (Basic)
PH < 7 – $H^+ > OH^-$ (Acidic)
Example:
$KAlSi_3O_8 + HOH \longrightarrow HAlSi_3O_8 + KOH$
(Orthoclase) (Unstable Colloidal Silica & Colloidal complex → Clay)
& $2KOH + H_2CO_3 \longrightarrow K_2CO_3 + 2H_2O$

$MgFeSiO_2 + 2HOH \longrightarrow Mg(OH)_2 + H_2SiO_3 + FeO$
(Olivine) (Silicic acid)

c. **Oxidation**: Chemical union of oxygen with metallic elements. It is active in Ferro-magnesium minerals (Pyroxene, Hornblende & Olivine).
Example:
$FeS_2 + nO_2 + mH_2O \longrightarrow Fe(SO_4)_3 \longrightarrow Fe_2O_3.nH_2O$
(Pyrite) (Limonite)
$PbS + 2O_2 \longrightarrow PbSO_4$ (Soluble)

d. **Reduction:** Opposite process of Oxidation.
Example:
$2FeO \longrightarrow 2Fe + O_2$
$Fe^{3+} + e^- \longrightarrow Fe^{2+}$
$S + H_2 \longrightarrow H_2S$

e. **Carbonation:** Addition of CO_2 in minerals.
$H_2O + CO_2 \leftrightarrow H_2CO_3$
$2KAlSi_3O_8 + H_2CO_3 \rightarrow K_2CO_3 + AlSi_2O_5(OH)_4$(Kalonite) $+ 4SiO_2$

f. **Solution:** mineral dissolved by water & removed in solution. Al_2O_3 have high ionic Potential tend to remain in insitu & these controlled by PH value.
The $CaCO_3$ is soluble in low PH & SiO_2 is soluble in high PH.
E.g. $CO_2 + H_2O \leftrightarrow H_2CO_3$
$CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2$

3. **Biological Weathering:** Disintegration and decomposition of rocks by the action of plants and animals. Biological weathering due to,

- Plants root on cracks results wedge.
- Activities of burrowing animals.
- Produce reducing gasses (H_2S) results chemical weathering.
- Organic acids i.e. humic acids in rain water increase its solvent power.
- Some bacteria are active in reducing condition and making Sulphide.
- Other bacteria can convert N_2 to NH_4 which affect the PH value.

Processes of Weathering

The most important following five processes are involved in weathering.

a. Dual effect of water molecules – freezing and expansion, electrical charge.
b. Disintegration
c. Decomposition
d. Weathering from organisms
e. Complex weathering

Significance of Weathering

i. As an aid to mass wasting and erosion.
ii. As a factor in the general lowering of land surface.
iii. It contributes to the creation and modification of land forms.
iv. As a major process involved in the formation of regolith or soil.
v. Facilitates soil nutrients within earth crust. Most of the plant nutrients are derived from weathering processes.
vi. Suitable site for plant growth and forest development.

Unit: 8

GEOMORPHIC PROCESSES & THEIR AGENTS:

Geomorphic Process: They are all those physical and chemical changes which effect a modification of earth's surfacial form.
Geomorphic agents: Any natural medium which is capable of securing and transporting earth materials. These are running water, wind, glacier, tides etc.

AN OUTLINE OF THE GEOMORPHIC PROCESSES

A. Exogenetic Processes:

1. Gradation (denudation):- It tends to bring surface of the lithosphere to a common level.
   - i. Degradation: Those level down.
     - Weathering
     - Mass wasting
     - Erosion
   - ii. Agradation: those levels up (deposition)

B. Endogenetic Processes:

- i. Diastrophism: Movement of earth's crust.
- ii. Volcanism
- iii. Earthquakes
- iv. Metamorphism

C. Extra-terrestrial Processes:

- i. Infall of Meteorites

GEOLOGICAL PROCESSES:

Geological processes have been playing dominant role in shaping the surface of the earth due to both constructive as well as destructive in nature. The following two major processes have been operating in earth's lithosphere.

1. Endogenous Processes:
2. Exogenous Processes

Endogenous Processes:

The processes were originated within/under the earth's crust. These processes are caused by thermal energy due to the decay and disintegration of radioactive elements and gravitational differentiation in the mantle. The most important end genetic processes are as given below.

a) **Earthquakes**: It is a form of energy as in wave motion transmitted through the surface layer of the earth and they produced due to underground dislocation of rocks. An Earthquake is a sudden and temporary vibration set up on the earth's surface due to the sudden release of energy stored in the rocks beneath the earth's surface.

- **Focus:** The point within the earth where earthquake waves originate is called Focus & from the focus the vibrations spread in all directions.
- **Epicenter:** The point found on surface above the focus where the earthquake waves reach first.
- **Seismic waves:** The waves of energy sent out through the earth are called Seismic waves. On the basis of amplitude, wavelength & nature of vibration, the seismic waves are classified into following 3 main types:

1. Primary or P-wave (Longitudinal wave): The rocks vibrate parallel to the direction of wave propagation i.e. in the same direction as the waves are moving. They travel in all media. This wave is fastest in all.
2. Secondary or S-waves (Transverse waves): The rocks vibrate perpendicular to the direction of wave propagation. These waves travel only in solid media. The transverse vibration causes a sacking of the earth surface.
   The P & S-waves are traveling through the earth interior and spread outward from the focus in all directions.
3. Surface or L-waves: These waves are transverse in nature and travel in the earth surface away from the epi-centre. They travel at low speed in comparison to P and S-waves. They produce more ground movement and are responsible for most of the destructive force of the earthquake.

Causes of Earthquake:

Earthquake originates due to following two major causes:

1. Non-Tectonic Causes:
   a. Surface Causes: Rock falls and avalanches, large landslides, underground explosion of bombs, working of heavy machinery etc.
   b. Volcanic Causes: Due to volcanic eruption and the hydraulic shock of magma.
   c. Collapse of Subterranean cavities: In the caverns of Horst areas.
2. Tectonic Causes: The structural changes of the earth crust due to deformation or displacement i.e. faulting or folding. An elastic rebound theory (Movement along a fault) is proposed to explain the origin of tectonic earthquake.

Classification of Earthquake:

The earthquakes are classified mostly by the following criteria.

a. Cause of Origin:
   Tectonic Earthquake
   Volcanic Earthquake
b. Depth of Focus:
   Surface Earthquakes (depth <10000m)
   Shallow focus Earthquakes (depth in between 10-50kms)
   Intermediate focus Earthquakes (depth in between 50-300kms)
   Deep focus Earthquakes (depth >300kms)

Intensity & Magnitude of Earthquakes:

The strength of an earthquake can be measured either by its intensity or by its magnitude. Intensity of an earthquake is a measure of a degree of damage and destruction. It can be measured without any sensitive instrument. The line of equal intensity is known as isoseismic line. The magnitude of an earthquake can be measured from Richter scale. The Richter scale is Logarithmic. The most of the destructive earthquakes originate within following two zones.

i. The Circum-Pacific belt: About 80% of all the terrestrial earthquake.
ii. The Mediterranean: Himalayan Seismic belt

b) **Tectonic Movements:** It results faulting, folding and creation of new landforms.
   i. Orogeny: Mountain building activities with deformation of earth's crust.
   ii. Epi-orogeny: Regional upliftment with marked deformation.
   E.g. Mountains – Subsidence
   Subsidence – Up
   iii. Lateral Movements/Displacement: Displacement of the crustal blocks by continental drift, ocean floor spreading etc.

c) **Volcanism:** The processes of effusion/intrusion of magmatic materials on the surface of the earth, thus forming carious volcanic structures and/or flowing over the surface called Volcanism.
d) **Metamorphism:** It is the transformation of pre-existing rocks into new rock types by the action of temperature, hydrostatic as well as directive pressure and chemically active fluids.

Exogenous Processes:

The processes of external origin (i.e. from outside the surface) are due to the effect of sun energy, wind blow, moisture, the force of gravity, the activities of organisms etc. The exogenous processes are closely linked with the role of geomorphic agents such as running water, underground water, glaciers, wind etc on the surface of the earth. The exogenous processes are divisible into two major categories viz. (i) Degradation (ii) Aggradations.
Degradation: The processes of level down (materials from high land are removed by the geomorphic agents). The degradation of the earth's surface is mainly carried out through,

a) Weathering
b) Mass-Wasting
c) Erosion

Mass-Wasting: It is the processes of downward movement of soil/regolith and rock due to the influence of gravity. C.F.S Sharpe (1938) classified mass movement on the basis of movement involved are given below.

movement i.Slow-Flowage:
- Soil Creep: in unconsolidated mass, on < 35^{o} slope
- Talus Creep: Coarse & fragments of rocks in downhill
- Rock Creep: Movement of jointed block
- Rock Glacier Creep: Creep of boulder with stream of ice.
- Solifluction: Water saturated regolith in down hill.

ii.Rapid Flowage:
- Earth flow: Water saturated soil move down from steep slope.
- Mud flow: Fluid mass of fine soil in stream channel.
- Debris avalanche: Saturated material with natural disturbance

iii. Landslides:
- Slump: Movement of bed rock mass down from curved surface
- Debris Slide: Rapid down slope movement of coarser materials through rolling & sliding process.
- Debris fall: Materials fall from a vertical cliff.
- Rock Slide: Rocks move down usually from weak surface.
- Rock fall: Free falling or rolling from steep cliff.

iv. Subsidence:

EROSION

The wearing away of any part of the earth's surfaces are due to the natural agencies. The major processes of erosion are given below.

a. Abrasion or Corrasion: wearing down the surface and crave out due to the processes of rubbing, rolling, scratching and grinding.
b. Attrition: Mechanical wears and tears of the transported materials by collision themselves.
c. Corrosion: Chemical processes of rock erosion mainly from solution in Calcareous rocks.
d. Cavitations: River with high pressure create hollow. E.g. Pot holes
e. Hydraulic action: materials move out due to Turbulence flow of water in river channel.

Aggradations:
The levels up of the land are due to the processes of sediment deposition. When transporting agents loose their carrying power, the transported materials get deposited in low lying tracts. The deposition of sediments creates new land of various types.

Thus the processes of gradation are considered as three-fold processes because of the following processes.

- The earth surface is first decayed and eroded.
- The product of the decay and erosion are transported, and
- The transported materials are deposited in low lying areas

So the geological processes have been playing significant role in changing the surface of the earth.

Unit: 9

GLACIERS:

Snow: The frozen vapor falling from the sky in soft and white flakes in the ground.
Ice: The frozen water which makes water solid by cold.
Glacier: It is a moving mass of ice with rock debris and air under the influence of gravity.
Snow Line: The lower limit of snow is known as snow line. The snow line is divided broadly into two categories.

a. Permanent: The snow line appears through out the year.
b. Temporary: The snow line appears only in the winter season.
    - The snow line is determined largely by latitude.
    - Snow line falls in the lower altitude (sea level) as latitude increases (at latitude 90^o North or North Pole.)
    - In the equatorial zone or latitude 0, the snow line appear above 6000m from sea level.

Snow field: The massive accumulation of snow above snow line.
Nave or Firn: When the snow freezes and compacts, they are changes into granular ice particles called Nave or firn. The neve undergoes changes which transform the entire mass into glacier ice.

TYPES OF GLACIERS:
The glaciers are divided into three major groups on the basis of their stages of development, size, shape and the relationships between the supply & flow areas.

a. Mountain or Valley Glacier:
    - Simple Glacier
    - Complex Glacier
    - Cirque Glacier
    - Transaction Glacier: They spill over dividing ridges & join with other glacier in adjoining areas.

b. Continental Glacier:
c. Piedmont Glacier:

Valley Glacier: It is originated at the head of mountain valley. It occurs particularly in Alps &Himalayas.

Continental Glacier or Ice Sheet: The broad ice masses in large land areas. The smaller ice sheet called ice caps. Glaciers spread outward from the centre of the land mass as a radial drainage pattern. They are mostly found in polar region. E.g. ice sheet in Antartica.

Piedmont Glacier: Two or more valley glacier emerges from adjacent mountain valleys on to the plain below. The lower end of glaciers unites to form a broad rounded mass of ice called Piedmont Glacier. E.g. Malaspina glacier of Alaska.

CAUSES OF GLACIATION:
Glaciations: The covering and alternation of the earth's surface by glacier and ice sheet. The major causes of glaciations are given below:

a. Variation in the intensity of solar radiation.
b. Changes in the atmospheric composition – increase in CO_2 causes green house effect and increase temperature & vice versa.

c. Increase of dust in the atmosphere absorbs solar heat causing decrease of temperature at the surface.
d. Shifting of continent with respect to poles.
e. Elevation of continental masses by tectonic movement.

Movement of Glaciers:

Factors which affect the rate of movements are given below.
a. Size of the glacier (i.e. thicker-faster).
b. Slope & topography of the land.
c. Temperature of the area (Higher temperature-Faster move.)
d. The amount of unfrozen water in the glacier.

Depositional Features of Glaciers:

Three distinct types of depositional features are developed by glacier.
1. Unstratified Deposit
2. Stratified Deposit
3. Glacio-Lacustrine Deposit

Unstratified Deposit: Deposited by valley glacier. A heterogeneous mass of boulder to clay sized particles in the form of unstratified deposit is called till. The land forms are developed by till called Moraines. Moraines are found either on the body of existing glacier or in the ancient glaciated valleys.

- Moraines
  - Moving Moraines
    - Surface Moraine: i. Lateral
      ii. Medial
    - Ground Moraine
      (In Stream valley floor)
    - Englacial Moraine (in crevasses)
  - Stationary Moraines
    - End Moraine
      (At the end of Glacier)
    - Recessional Moraine
      (Several end moraine in the form of concentric fashion)

Erratic blocks: Deposition of different large block. A group of erratic block spread out fan wise called Boulder Train.

2. Stratified or Glacio-Fluvial Deposits:
The landforms are developed due to the deposition earth materials by the stream which is formed by the melting of glaciers.
- Deposits are sorted and stratified.
- The important depositional features are given below.

Outwash Plain:
Materials carried out by melt water, deposited in gentler slope as a broad fan shaped deposits. These are composed of sand and gravel. Outwash deposits in valley floor forming terrace like feature called Valley trains.

Esker:
A long, narrow, sinuous or straight ridges are formed due to melt water deposits. Ridge appears in the direction of the movement of glacier. These are resulted due to Recession and evaporation of melt water.

Kame and Kame terrace:
Small, rather steep sided, flat topped hills of stratified deposits due to collection of sediments in circular depressions. Layered deposits of sand and gravel formed in between the side of wasting glacier and the adjoining valley wall called Kame terrace.

Kettles:
Kettles are depressions developed on the surface of glacial deposits. These hollows are formed by the melting of ice blocks that might have been enclosed or buried within the glacial drift during time of deposition.

3. Glacio-Lacustrine Deposits: The deposition in glacial lakes.
Varves: Layering of fine clays and silts accumulated in Lake Bottom forming stratified layer when the lake drain away. The fine sediments carried in lakes in suspension with the melt water.

Unit: 10

EROSION & DEPOSITION

Erosion: The wearing away and removal of soil and rock fragments by the natural agencies like as running water, wind, glacier, tides etc from the earth surface.

Deposition: The processes of sediment laid down (i.e. rock and soil materials) in low lying areas under suitable condition.
All the geomorphic agents (river, wind, glacier & sea-waves) basically serve three geological functions. These are given below.

a. Erosion
b. Transportation
c. Deposition

Geologic Work of River:

Geologic Work of River

- Erosion
  - Corrasion
  - Hydraulic action
  - Attrition
  - Cavitation
  - Corrosion
- Transportation
  - Bed Load-with coarser materials.
  - Suspended load sand, silt, clay.
  - Dissolved load in solution
- Deposition
  - Alluvial fan
  - Deltas
  - Flood Plains
  - River Terraces
  - Natural Levees

The deposition of the transported materials was taken place when the capacity of the river is decreased. The velocity of the river decreased due to the following causes.

I. Reduction in stream gradient or slope.
II. Decrease in volume of water i.e. discharge.
III. Decrease in velocity of the transporting medium.
IV. Obstacles in the stream channel.
V. Change in channel.
VI. Widening of the stream bed.
VII. Overloading
VIII. Freezing &
IX. Chemical precipitation.

All of the above factors reduce the velocity of the river and results the deposition of sediment. Such deposits are called fluvial deposits. Materials thus deposited called Alluvium. Alluvial materials are usually composed of rock fragments which have been smoothed or rounded by stream abrasion and attrition.

Depositional Features:

1. **Alluvial Fan:**

An outspread fan shaped masses of alluvium deposited by following water where it carry out from a steep, narrow canyon onto the plane or valley floor. The slope of the alluvial fan is up to 10^o. When the slope of that deposits ranges from 10 to 50^o represents the alluvial cone. The materials constituting in a fan includes coarse, boulders, cobbles and pebbles at its head and finer materials down its slope. A number of alluvial fans join each other at the foot of mountain range to form Piedmont alluvial plains. E.g. Terai

2. **Deltas:** When a river flows into a large body of water such as sea or lakes, its velocity is suddenly decreased and much of its load is dropped. Approximately triangular shape deposits formed under this condition are called Deltas. E.g. Ganges Delta of India **(Figure)**
   - Bottom-shaped Bed – Gentle seaward slope of finer materials
   - Foreset Bed – A steep slope deposit of silt and clay towards the sea.
   - Topset Bed – Thin layer sediment lying on the top of foreset bed.
   -
3. **Flood Plain:** Flood plains are formed when a river in flood (overflow of river from its banks). The velocity is reduced when the stream or river leaves its channel and much of the load deposited on the valley floor.

4. **Natural Levees:** When stream flows over its banks onto the flood plain, the greatest loss of coarse materials taken place along the bank of the channel and this process trend to build up a ridge or embankment called a Natural levee. They may afford protection to the adjacent low lands during time of flood.

5. **River Terraces:** The remnants of ancient flood plain that has undergone erosion are known as river terraces. Such terraces are topographically higher than the surrounding flood plain.

Agents & Processes of Erosion

Types of Erosion	**Active Agents**	**Agent Alone**		**Agent armed with detritus**	**Detritus alone**
		Solvent & Chemical Action	Mechanical loosening & removal of Materials passed over	Wearing of surfaces by transported materials	Mutual wear of materials transported
Rain Erosion	Rain Water	Corrosion	Splashing rainwater sheetwash	Localized Corrosion	Attrition Slight; if any
River Erosion	Rivers	Corrosion	Hydraulic lifting and scoring Cavitation	Corrasion	Attrition
Glacial Erosion	Glaciers, ice-sheets	Corrosion limited to sub-glacial streams	Exaration (Plucking & Quarrying)	Abrasion (e.g. Striated surfaces)	Attrition
Wind (or Aeolian) Erosion	Wind	-	Deflation (Blowing away)	Wind Corrasion (Sand Blasting)	Attrition
Marine Erosion	Sea & Ocean waves, tides & current	Corrosion	Various hydraulic processes	Marine Abrasion	Attrition.

Definition:

- Abrasion: Wearing away of surfaces by mechanical processes such as rubbing, cutting, scratching, grinding, and polishing.
- Attrition: Reduction in size of detrital fragments by friction and impact during transport.

- Cavitations: Collapse of bubbles of water vapor in highly turbulent eddies of water; such collapse is like a negative explosion and sets of powerful shock-waves which tend to disintegrate any adjacent rocks.
- Corrasion: Cumulative effects of mechanical erosion by running water or wind when charged with detritus and so provided with 'tools' or abrasives.
- Corrosion: Wearing away of surfaces and of detrital particles and fragment by the solvent and chemical action of natural water.
- Deflation: Lifting and removal of dust and sand by wind.
- Exaration: A term now little used, for modes of erosion by glacial ice, a kin to 'plucking' and ‘quarrying’.

UNIT: 11

GEOLOGY OF NEPAL

Geological framework of Nepal

Introduction:
Nepal is situated in the central part of the Himalayan arc i.e. Karakoram Himalayan range or Hindu Kush Himalayan range. It is tectonically sandwiched between the Tibetan plateau in the north and Indian shield in the south. The Karakoram Himalayan belt extends for about 2400 Km from the Punjab Himalaya in the west to the NEFA Himalaya in the east. Out of 2400 Km length, the middle strip about 800 Km belongs to Nepal.

The Himalayan range with its NW-SE general trend was formed by the collision of the Indian plate with Eurasian plate about 40 millions years ago. Due to that collision the sediment of Tethys Sea was uplifted and the rocks and sediments of Indian shield to be folded and faulted into lofty peaks. The Himalayan belt is divided geologically and geographically into Punjab Himalaya, Kumaon Himalaya, Nepal Himalaya, Sikkim/Bhutan Himalaya and NEFA Himalayas. Each of these Himalayan Mountains is divided morpho-tectonically from north to south into following five major zones where they separated by clear and well defined boundaries like as thrusts and faults.

Tibetan Tethys Zone
-----------South Tibetan Detachment Fault System (STDFS) -----------
Higher Himalayan Zone
-----------Main Central Thrust (MCT) --------------------------------------
Lesser Himalayan Zone
- Lesser Himalayan Crystalline Zone
- ----Mahabharat Thrust (MT) ------
- Lesser Himalayan Metasedimentary Zone

---------Main Boundary Thrust (MBT) -------------------------------------
Siwalik Zone (also called Churia, Outer Himalayan or Sub Himalayan Zone)
---------Himalayan Frontal Thrust (HFT) or Main Frontal Thrust (MFT)—
Terai Zone
Each of these above mention zones is characterized by their own lithology, tectonics, structures and geologic history.

Nepal is also divided into following four transverse zones from east to west by the north to south flowing major rivers.
Eastern Nepal (Mechi to Koshi River)
Central Nepal (Koshi to Trishuli River)
Western Nepal (Trishuli to Karnali River)
Far western Nepal (Karnali to Mahakali River)
Each of the transverse zones is quite distinct in their stratigraphy, structures and tectonics.

Terai Zone:

It is the southernmost tectonic division of Nepal and represents the northern edges of the Indo-Gangetic alluvial basin. It is also bounded by the Main Frontal Thrust (MFT) in the north. The Terai zone represents the great alluvial tract of the Himalayan Rivers. The Terai plain is made up by the alluvium i.e. gravels, sand, silt and clays of Pleistocene to recent age

(1.8 million years to present) with an average thickness of about 1500m. The varying width of the Terai plain is 10 to 50 Km and forms the continuous belt from east to west exceptions along the Chitwan (70 Km) and Rapti (80 Km) valleys. The topography below the alluvium is not uniform; the depth to the basement beneath alluvial sediments also varies greatly (Valdiya, 1988).

Stratigraphy:
On the basis of lithological variation the Terai plain is divided into three parallel strips from north to south as given below.

a. Bhabar zone (Upper Terai): The coarser Terai sediments lie close to the Mountain front which is known as Bhabar zone. It consists near about 100m thick sediment of boulder, cobble, and pebble and with or without clays. It is made up of alluvial fan deposits sloping to the south, with its southern margin marked by the spring line that give rise to many streams.
b. Middle Terai: The middle Terai is an undulating terrain with isolated pocket of waterlogged and marshy conditions towards the southern part of the Bhabar zone. It consists of about 454mthick sediments of gravel, sand, silt and clay.
c. Southern Terai (Lower Terai): The southern Terai stretches along the Nepal-India boarder, with an altitude of less than 90m. It consists of about 450m thick sediments of sand, silt and clay.

Structure and tectonics:
Structurally the Terai plain is synclinal basin i.e. Himalayas to the north and Indian Peninsula in the south. The rocks under the alluvium far south of the Mountain front are experiencing tectonic activity and a number of thrusts and thrust propagated folds have been recognized (Bashyal,1998, Mugnier et.al..1999) due to the shearing of a significant proportion of Himalayan stress accumulation.

Degradation and aggradations:
The land system in The Terai is divided into recent flood plains of the rivers and older river terraces. Generally gravel and boulder soil prevail in the foothills and sand silt and clay soils are found in most of the remaining areas. The region often suffers from devastating flood and droughts.
The Terai has experienced massive deforestation since the control of malaria except for the ‘protected forests’, almost the entire Terai is cultivated.

Main Frontal Thrust (MFT):

A thrust plane passing through the northern part of the Terai plain and at the foothills of the Siwalik range is called MFT. The lower Siwalik rocks override the recent alluvium of Terai plain. It is active and enechelon (relatively short faults that are parallel and overlap each other) in pattern.

Siwalik Zone:

The Siwalik Zone consists of fluvial sedimentary rocks of Neogene to Quaternary age (14 to 1 million years ago). This Zone is bounded to the north By MBT and to the south by MFT. It is the southernmost hill range of Nepal. The Lesser Himalayan metasedimentary rocks have been thrust southward over the Siwalik Zone rocks along the MBT due to that the large part of the northern Siwalik Zone buried beneath them.

Stratigraphy:
The Siwalik Zone of Nepal has been divided from top to bottom into three informal stratigraphic formations as Upper Siwalik, Middle Siwalik and Lower Siwalik.
Upper Siwalik: The upper Siwalik is characterized by the presence of very coarse sediments such as boulder conglomerate with minor proportion of mudstone intercalation.
Middle Siwalik: The middle Siwalik beds are marked by the first appearance of thick bedded salt and peppery sandstone due to the abundance of dark colored biotite and light colored quartz and feldspar minerals with alternating subordinate beds of mudstone. An occurrence of paleosols (i.e. clay layer) with fossils of plants and freshwater mollusks is in the upper part that shows fining upward sequence.
Lower Siwalik: The lower Siwalik is characterized by the presence of alternation of fine grained sedimentary rocks as variegated mudstone, siltstone and shale with subordinate amount of fine grained sandstone.
The lithostratigraphy of the Siwalik zone has been studied by many authors. The lithostratigraphy of Siwalik zone of central west Nepal (by Tokuoka et.al. 1986) from bottom to top is given in the following table.

Unit	Main lithology	Approx. thickness (m)	Fossil records
Arung Khola Formation (Lower Siwalik)	Variegated mudstone and fine grained sandstone	2100	Shivapithecus
Binai Khola Formation (Middle Siwalik)	Medium to coarse grained sandstone, shale and mudstone	2800	Hiparian, Rhinoceras, Stegoden, several bivalve fossils.
Chitwan Formation (upper Siwalik)	Pebbly conglomerate with few coarse grained sandstone and shale	700	
Deorali Formation (Upper Siwalik)	Poorly sorted angular to sub angular conglomerate and rare shale.	450	

The dun valley within the Siwalik consists of quaternary fluvial sediments. The Siwalik succession is 4 to 6 Km in thickness and fluviatile in origin. The Siwalik succession is also contains invertebrate, vertebrate and plant fossils.

Structures and tectonics:
The Siwalik represents coarsening upward sequence with individual fining up cycles. The coarsening upward sequence is indicating the intense upheaval of the Himalayas in the geologic past. The Siwalik zone is tectonically less complicated than overlying Lesser Himalayan zone. Siwalik rocks are faulted, thrusted and folded to the south over the recent alluvium of the Terai zone. Intra-churia thrust called the central churia thrust (CCT) was developed due to thrusting. These are confirmed by the repetition of the Formations. The thrust propagated broad asymmetric folds have given rise to many wide valleys in the churia zone of Nepal i.e. dun valleys which were generally filled with recent sediments.

Magmatism:
Hypabyssal basic magmatic sills and dykes of late Tertiary age have been reported from the middle and lower Siwalik sequence of the central Nepal i.e. Dolerite in Marine khola section (Herail et.al., 1986), small basic bodies along Dawar khola section (Kaphle and Pant, 1988).

Degradation:
The Siwalik zone is generally covered with thick forests and comprises the youngest sedimentary rocks. The soft, loose and easily erodible rocks represented by sandstone, siltstone, mudstone, shale and conglomerate. Due to the combination of geologic, anthropogenic and climatic (Rainfall 1500-2000mm per year) conditions has made the Siwalik range highly susceptible to the common types of mass movement and erosion like as gulley erosion, mudflow, and slumping, toppling and rock fall. The frequency of sliding increases considerably in the rainy season due to saturation of soft rocks. The water penetrates into the colluviums and than into the rocks along the fractures and joints. They exert enormous water pressure causing huge slumps and mudflows. The mass movement can also been activated due to the fast toe cutting by river which are flowing through upstream land i.e. lesser Himalayan zone and road construction. Due to the land's inherent week geologic characteristics, slope stabilization and erosion control is very difficult.

Main Boundary Thrust (MBT):

A thrust plane passing from the northern part of the Siwalik range and from the lower part of the Mahabharat range called the MBT. The MBT is an active fault. The outcrop of the MBT is very well exposed in the field.

a. The MBT is a low angle fault that has brought very older lesser Himalayan metamorphic units over the Siwalik Zone.
b. MBT has sharply separates the outer metasedimentary belt of Lesser Himalayan zone from the Siwalik zone.
c. The MBT follows mostly E-W trends of minor as well as major rivers.
d. The evidence of thrusting, the sedimentary structures in Siwalik rock adjacent to MBT invariably show that the top of the beds are facing north and bottom of the beds are facing south.
e. It has imbricate structures (Nearly parallel thrust faults that are overlap each other and oriented in the same direction) with metamorphic areas.
f. It appears vertical in many places and in other places it becomes 30^o to 45^o dipping north.
g. The age of the MBT is Pliocene or Pleistocene that shows the evolution of the Himalayas was late event.
h. The MBT area is highly susceptible to mass wasting due to tectonic activities.

Lesser Himalayan Zone:

The lesser Himalayan zone is bordered to the south by MBT and to the north by MCT. These are reaching the altitudes of 4000m. Morphologically it can be divided into the southernmost part called the Mahabharat range and more depressed part called the midland zone further north. Both zones are 60 to 100Km wide and consist of more than 30 Km thick sequence. These sequence are unfossiliferous sedimentary, metasedimentary and low- grade metamorphic rocks such as shale, slate, phyllite, quartzite, limestone, dolomite etc. called the lesser Himalayan metasedimentary zone. The age of these rocks are ranging from Precambrian i.e. 1800 million years to Eocene i.e. 40 million years. The rocks in this zone are highly folded and faulted, and have developed complicated structures. The high grade metamorphic rocks such as marble, quartzite, schist, gneiss etc. with granite intrusion in the lesser Himalayan zone are called the lesser Himalayan crystalline zone. These are rooted in the higher Himalayan zone.

Stratigraphy and age:

Stratigraphically, The lesser Himalayan zone is complicated in comparison to other zones due to nappe formation. The simplified stratigraphy is given below.

1. The lesser Himalayan Metasedimentary zone:
   - The rock sequences are exposed in two distinct belts i.e. inner and outer belt.
   - The age of inner belt is mostly Precambrian to early Paleozoic and the age of the outer belt in restricted area is Permo- Carboniferous to early Tertiary. The middle Paleozoic gap is in the lesser Himalayan zone.
   - The simplified stratigraphic scheme of lesser Himalayan metasedimentary zone is as given below.

Inner belt
- Kuncha group (Precambrian)
- ----Unconformity--------------
- Nawakot group (Precambrian to early Paleozoic)

-----------------Unconformity---

Outer belt i.e. Tansen group
- Permo-Carboniferous series (Sisne Formation, W. Nepal)
- ------Unconformity--
- Mesozoic series (Gondwanaland of Taltung and Amile Formation, W. Nepal)
- Tertiary series (Gondwanaland of Bhainskati and Dumri Formation, W. Nepal)

2. Lesser Himalayan Crystalline Zone:
   - The lesser Himalayan crystalline zone of Nepal is broadly divided into two stratigraphic groups on the basis of lithological, metamorphic and structural characters.
     a. Bhimphedi group (Proterzoic to Precambrian)
     b. Phulchoki group (Precambrian to lower Paleozoic
   - The lesser Himalayan crystalline zone are comprise the metamorphosed rock sequence with an occasional fossiliferous sedimentary cover overlie the lesser Himalayan metasedimentary rocks as klippen (remnants of overlying rocks due to long period of erosion).
   - The lesser Himalayan zone consist of phyllite, marble, quartzite, schist and gneiss.

The lesser Himalayan zone of Nepal is complete in central Nepal. The stratigraphy of lesser Himalayan zone of central Nepal (Stoklin and Bhattrai, 1977) is given in the following table.

Unit	Main lithology	Approx. thickness (m)	Age
--------------------------	---------------------MCT----	-------------	----------------------------
Phulchoki group			
Godavari limestone	Limestone, Dolomite	300	Devonian
Chitlang Formation	Slate	1000	Silurian
Chandragiri limestone	Limestone	2000	Cambro-Ordovician
Sopang Formation	Slate, calcareous Phyllite	200	? Cambrian
-------------------------	--------Transitional contact-	-------------	----------------------------
Bhimphedi group			
Tistung Formation	Metasandstone, Phyllite	3000	Precambrian/E.Cambrian
Markhu Formation	Marble, Schist	1000	Precambrian
Kulekhani Formation	Quartzite, Schist	2000	Precambrian
Chisapani quartzite	White Quartzite	400	Precambrian
Kalitar Formation	Schist, Quartzite, Dolomite, Conglomerate	2000	Precambrian
Bhainsedovan marble	Marble	800	Precambrian
Radhuwa Formation	Garnetiferous Schist	1000	Precambrian
-------------------------	--Mahabharat thrust (MT)--	-------------	----------------------------
Upper Nawakot group			
Robang Phyllite with dunga quartzite	Phyllite, Quartzite	200-1000?	Paleozoic
Malekhu limestone	Limestone, Dolomite	800	Paleozoic
Benighat slate with Jhikhu carbonate bed	Slate, argillaceous Dolomite	500?- 3000?	Paleozoic
------------------------	---------Unconformity-------	-------------	----------------------------
Lower Nawakot group			
Dhading dolomite	Stromatolitic Dolomite	500-1000	Late Precambrian
Norpul Formation	Phyllite, Quartzite, Dolomite	800	Late Precambrian
Dandagaon pyllite	Phyllite	1000	Late Precambrian
Fagfog quartzite	White Quartzite	400	Late Precambrian
Kuncha Formation	Phyllite, Quartzite	3000	Late Precambrian
------------------------	-----------MBT--------------	-------------	----------------------------

Magmatism:
Acidic rocks: Granitoid rocks such as Palung Granite, Dadeldhura Granite, Ulleri augen Gneiss (source rock is granite) etc.
Basic rocks: Small sill like lenses and dykes of basic rocks are occurring in Manohari Khola of Kuncha group, Tansen area, Barahchhetra etc.

Intermediate alkaline rocks: A massif of Nepheline Syenite and alkaline Gneisses in the Gorkha district at Ampipal and Dhorandi Khola.

Tectonics and Structures:
The tectonics and structures of lesser Himalayan zone of Nepal are more complicated in comparison to other morpho-tectonic division. The tectonics of lesser Himalayan zone of Nepal has been seen great variety from east to west. In eastern Nepal, the tectonics are characterized by the development of an extensive crystalline thrust sheet i.e. nappe that has traveled southward for at least 100Km to reach close to the outcrop of the MBT. The lesser Himalayan rocks are exposed only in few large tectonic windows i.e. Taplejung, Arun and Chautara-Okhaldhunga windows. The lesser Himalayan zone in central Nepal is similarly occupied by the Kathmandu nappe. The outcrop of that nappe covered wide area around Kathmandu and extends in narrow arm (south-eastward) along the Mahabharat range ti join the great thrust sheet of eastern Nepal. The west of Kathmandu, the crystalline rocks are restricted to the higher Himalayan zone north of MCT except for outcrops in a narrow klippe in Jajarkot area and most of the areas have covered by the metasedimentary rocks. The lesser Himalayan zone consist many major thrust as well as other types of faults and, several types of anticline and syncline folds.

Degradation:
The lesser Himalayan zone is highly susceptible to mass movement due to the combination of climatic factors, week geologic conditions, very steep slope, improper land use, intense deforestation etc. The most common types of degradation and aggradations processes are wedge failure, rock slide, rock fall, rock toppling, debris avalanche, deep gulley erosion, debris flow, slump and several alluvial fans.

Main Central Thrust (MCT):

The thrust plane boundary between northern part of the lesser Himalayan zone and southern part of the higher Himalayan zone is called the MCT. The thrust plane is a continuous plane which separates two types of rocks such as low grade metamorphic rocks as Phyllite, Quartzite, Slate etc. and high grade metamorphic rocks as Schist, Marble, Gneiss, Migmatite etc. from east to west of Himalayas including Nepal. The MCT have divided into MCT1 and MCT2 (Arita et.al., 1973).

- MCT1 lie in between the high grade gneisses and low grade metasediments.
- MCT2 is a contact between the low grade metamorphic rocks and very low grade metasediments.
- The rocks between MCT1 and MCT2 have been recognized as the MCT zone sequence.
- The tectonic zone of regional significance involve in breaking the stratigraphic continuity between the rocks of different zones, the MCT1 is regarded as the real MCT in the map and in the several literatures.
- The age of MCT is Miocene and later period.
- The rocks in MCT zone are highly metamorphosed like as migmatization due to selective metamorphism by magma injection and their higher tectonic levels.
- Several geothermal springs are found in the MCT zone e.g. hot spring of Dana area of Myagdi district in Kaligandaki River, West Nepal.
- Largely across the MCT, the metamorphic reversal is seen due to the hot iron model.
- The MCT zone is highly susceptible to magma intrusion and mass movement.

Higher Himalayan Zone:

The higher Himalayan zone is bordered to the south by MCT and to the north by STDFS. Geologically, the higher Himalayan zone includes the rocks lying north of the MCT and south of the fossiliferous rocks of Tibetan Tethys zone within the altitudinal range up to 8000m and more. The crystalline rock units of the higher Himalaya extend continuously along the entire length of the country, its width (5 to 15Km) varies from place to place with more than 10Km thickness. This zone is distinctive zone comprising of high grade metamorphic rocks such as gneiss, schist, quartzite, marble and migmatites.

Stratigraphy:
The higher Himalayan zone is less complicated in comparison to lesser Himalaya. The stratigraphy of higher Himalaya (informally) is given below from top to bottom.
Topmost sequence: It is represented by augen gneiss, granitic gneiss, granite and migmatites e.g. Makalu granite i.e. Leucogranite.
Middle sequence: It is represented by calcareous gneiss with smaller interbanding of argillites at various stages of gneissification.
Lower sequence: It is represented by the appearance of kyanite-sllimanite gneiss with dominant argillo-arenaceous fraction i.e. quartzite.

The age of higher Himalayan zone is Precambrian (i.e. in basement rocks) and Tertiary (The rock resulting from magmatic intrusion and thrusting).

Magmatism:
- The igneous rocks i.e. leucogranite, granitic gneiss, pegmatites are resulted from acid magmatism in topmost sequence (Le Fort, 1982).
- The sills and dykes of amphibolites occur invariably in the lower and middle sequence.

Structures and Tectonics:
- The presence of diversely oriented micro-structures related to the multiple deformational stages suggest their involvements in the orogenic movements prior to the last Himalayan orogenesis.
- The higher Himalayan zone constitutes a moderately NNE dipping homoclinal structures.
- Hagen (1969), Le Fort (1975) and Pecher (1977) divided the gneissic complex into a series of thrust sheets which is thrusted over the rocks of lesser Himalaya.

Mass movement:
The rocks found in higher Himalaya have undergone metamorphism at very high temperatures and pressures. They are comparatively strong and can support very steep slopes with very little soil cover. Due to that the resulting erosion and mass movements are sheet erosion, rock fall, debris fall and sudden glacier lake outbursts.

South Tibetan Detachment Fault System (STDFS):
Between higher Himalayan zone and Tibetan Tethys zone there is a north dipping normal fault plane called the STDFS. The fault is a continuous plane separating high- grade metamorphic rock with granitic intrusion and fossiliferous sedimentary rocks in the north.

Tibetan Tethys Zone:

The Tibetan Tethys zone lies in between the STDFS in the south and extends to the north in Tibet. In Nepal, the fossiliferous rocks of the Tibetan Tethys zone are well exposed in Thak Khola (Mustang) and uncomplicated succession in Manang and Dolpa districts which is the most complete succession of the Karakoram Himalayan range. Most of the great Himalayan peaks of Nepal including Mount Everest, Manaslu, Annapurna and Dhaulagiri are belong to the Tibetan Tethys zone. This zone is composed of marine sedimentary rocks like as shale, limestone and sandstone with young granite intrusion. The age is ranging from Cambro-Ordovician (570 million years) to late cretaceous- lower Tertiary (70 million years). This zone is largely made up of sedimentary rocks exceeding more than 10 Km in thickness.

Stratigraphy:
The biostratigraphic division is adopted in Tibetan Tethys zone from younger to older are given below.

Plio- Pleistocene Series

---------------Unconformity---

- Tibetan Tethys Zone
  - Mesozoic series
    - Cretaceous Succession
    - Jurassic Succession
    - Triassic Succession
  - Paleozoic Series
    - Upper Paleozoic Succession (Permian-Carboniferous)
    - Middle Paleozoic Succession (Silurian- Devonian)
    - Lower Paleozoic Succession (Cambrian- Ordovician)

----------------------------------STDFS--

The Tibetan Tethys zone of Nepal has complete succession in Thak Khola area of Mustang. The simplified lithostratigraphic successions from older to younger are as given below in the table.

Units	Main lithology	Thicknes (m)	Age	Fossils
Larjung Formation	Limestone	900	Early Cambrian	Brachiopods, Aporthophylla sp.
Nilgiri Limestone	Limestone, Dolomite, Marble			
North Face Quartzite	Calc. Schist, Sandstone, Siltstone	560	Ordovician	Orthoceras, Orthambonites
Dark Band Formation	Limestone, Dolomite	300-600	Devonian	Landovarian graptolites, Orthoceras
Tilichopass Formation	Quartzite, Limestone	900	Devonian	Corals, Gastropods
Tilicho Lake Formation	Coral bearing Limestone	300-500	Carbonifero us	Brachiopods, Pelecypods
Thinchu Formation	Slate, Sandstone, Dolomite, Limestone	700-1000	Permian	Trilobites fenesleuids, Brachiopods
Thinigaon Formation	Limestone, Shale	1000	Triassic	Rhynchonellida, Terebratulla
Quartzite Formation	Quartzite, sandstone, Shale			

Jomsom Limestone	Dolomitic Limestone, Shale	300	Early Jurassic	Corals, Pelecypods, Brachiopods
Lumachelle Formation	Limestone, Shale, few Sandstone	110	Jurassic	Pelecypods
Saligram Formation	Shale with sandstone lenses	150-550	Jurassic	Ammonites, Haplophyloceras
Kagbeni Series	Sandstone, Shale, Siltstone	900?	Cretaceous	Ptilophyllum pectin, Ammonites

Structures and Tectonics:
The Tibetan Tethys zone is resulted from the collision of Indian plate with Eurassian plate in the upper Cretaceous age. The Thakkhola is a graben which is resulted from transverse normal faults (Fort et. al., 1982). The northward recumbent folds (horizontal fold) characterize the southern margin sediments.

Magmatism:
- The acid volcanic tuffs have been reported from Cambro-Ordovician sequences of central Nepal (Colchen et. al., 1986).
- The leucogranites with two micaceous minerals and tourmaline minerals (Le Fort, 1975 and Hamet et. al., 1976).
- The banded Amphibolites probably of basic volcanic origin in the lower Paleozoic succession.
- The mafic volcanic elements in the sandstone beds of the lower Cretaceous (Colchen et. al., 1986).

Degradation:
The Tibetan Tethys zone is the rain shadow of the Nepalese Himalaya with an average annual rainfall of less than 250mm; these valleys experience less frequent landslides than other areas. The dominant mass movement of this zone is slump, rock fall and debris slides due to the causes of toe cutting by rivers and steep slopes.

Igneous Rocks of Nepal Himalaya:

The magmatic rocks of Nepal are broadly divided into following three categories.

1. Basic types: They are reported from various part of Nepal.
   a. Epidiorite and Amphibolite: Localized in Kuncha, Norpul and Robang formation of lesser Himalayan Precambrian rocks of Central Nepal.
   b. Basic rocks: Aulis Basalt in Amile and Taltung formation of Tansen group, Western Nepal of the age late Cretaceous to Pleistocene.
   c. Gabbro diabase: Manohari Khola, Central Nepal (C.K. Sharma)
   d. Nepheline syenite: Ampipal, Gorkha, Western Nepal.
   e. Alkali basalt: In the Siwalik of Sindhuli district (K.P. Kafle).
2. Granitic rocks: Granitic rocks are scattered in several parts of Nepal but authors like Ganser (1969) and Le Fort (1965) have divided into two distinct regions.
   a. Higher Himalayan Granite: Reported in central crystalline rocks of higher Himalayan zone and Tibetan Tethys zone.
   - Central crystalline Granite rocks: In the form of large concordant sheet and slab e.g. Makalu Granite (Leucogranite) of Tertiary age.
   - Three massive plutons were reported in Tibetan Tethys sediments. They were resulted from movement in MCT due to magma rising. E.g. Manaslu Granite, Mustang Granite, Mugu Granite etc.

   b. Granite in crystalline klippe: It is found in several lesser Himalayan nappe e.g. Agra and Palung Granite of Kathmandu nappe.

3. Granitic Gneiss: These are mostly found in lesser Himalayan crystalline zone and higher Himalayan zone of Nepal. They were resulted due to the metamorphism of Granitic rocks under pressure, temperature and thrusting e.g. Augen gneiss.

Metallogenic development in Nepal

1. Siwalik zone: Uranium- Vanadium deposits.
2. Lesser Himalayan zone: Copper- Lead- Zinc province.
3. Higher Himalayan zone: Mica-Beryl, Precious- semi precious stones and Sn-W-Sb mineralization associated with Granite and Pegmatite.
4. Tibetan Tethys zone: Gypsum salt, Phosphorites and gas province.

History of Geological work of Nepal

Systematic geological investigation in Nepal started very late in comparison to the Himalayas of the adjoining countries. The earliest report of geology of Nepal was given by Hooker who visited Tamur valley of eastern Nepal in 1848. Subsequently Medlicott (1875) took a traverse from Amlekhgunj- Kathmandu- Nuwakot. This was followed by a number of geologists who visited in Nepal.

The systematic geological investigation in Nepal was started by Auden (1935) who visited some part of eastern and central Nepal and gave a fairly a good account of the geology of these part of the Himalaya. Heim and Ganser (1939) visited north- western part of Nepal and described the geology of remote areas.

The first important and extensive work on the geology of Nepal was conducted by Tony Hagen (1950) and these works were summarized in their book (published in 1969). He worked a decade in Nepal almost covering every part of the Nepal and identifies many nappes in Nepal. Bordet, P with his colleagues also undertook pioneering work in Nepal. His works (in 1955, 1961, 1964 and 1972) related to eastern, central and central western Nepal and described about Kathmandu complex and other results. Ganser (1964) published the first book on the geology of Nepal Himalaya which was covering the entire range accompanied by regional geological map. Fuch (1967) has contributed significant geological studies in central western and far western Nepal with higher and Tethys Himalaya.
Hasimoto started geological investigations in Nepal the late fifties of 19th century and continued the work for well over a decade and summarized the work of his team in their book (Hasimoto. 1973). Talalov (1972) did extensive work in Nepal and interpreted geology of Nepal Himalaya quite differently than the previous workers. Sharma (1975, 1980) extensively worked in Nepal for over three decades and contributed in various fields of the geological investigations.

In addition to the above large numbers of published and unpublished literatures by both Nepalese and foreigner’s has been contributed. The Nepalese Himalayas have been a great place of research from the last few decades.