Module 1.

Introduction:
Application of Earth Science in Civil Engineering Practices, Understanding the earth, internal structure and composition.

Mineralogy:
Mineral properties, composition and their use in the manufacture of construction materials - Quartz Group (Glass); Feldspar Group (Ceramic wares and Flooring tiles); Kaolin (Paper, paint and textile); Asbestos (AC sheets); Carbonate Group (Cement); Gypsum (POP, gypsum sheets, cement); Mica Group (Electrical industries); Ore minerals - Iron ores (Steel); Chromite (Alloy); Bauxite (aluminum); Chalcopryte (copper).

Module 2.

Petrology:
Formation, Classification and Engineering Properties. Rock as construction material, concrete aggregate, railway ballast, roofing, flooring, cladding and foundation. Deformation of rocks, Development of Joints, Folds, Faults and Unconformities. Their impact in the selection of sites for Dams, Reservoirs, Tunnels, Highways and Bridges, Rock Quality Determination (RQD), Rock Structure Rating (RSR): Igneous Rocks - Granite, Gabbro, Dolerite, Basalt; Sedimentary rocks - Sandstone, Shale, Limestone, Laterite; Metamorphic rocks - Gneiss, Quartzite, Slate, Charnockite; Decorative stones - Porphyries, Marble and Quartzite.

Module 3.

Geomorphology and Seismology:
Landforms - Classification, Rock weathering, types and its effects on Civil Engineering Projects. Study of Geo-morphological aspects in the selection of sites for Dams, Reservoirs, Tunnels, Highways and Bridges. Watershed management, Floods and their control, River valley, Drainage pattern - parameters and development; Coastlines and their engineering considerations.
Earthquake - Causes and Effects,, Seismic waves, Engineering problems related to Earthquakes, Earthquake intensity, Richter Scale, Seismograph. Seismic zones- World and India, Tsunami - causes and effects. Early warning system. Reservoir Induced Seismicity; Landslides - causes and their control.

Module 4.
Hydrogeology:

Module 5.
Geodesy:
Study of Topographic maps and Contour maps; Remote Sensing - Concept, Application and its Limitations; Geographic Information System (GIS) and Global Positioning System (GPS) - Concept and their use resource mapping. LANDSAT Imagery - Definition and its use. Impact of Mining, Quarrying and Reservoirs on Environment. Natural Disasters and their mitigation.
Module 1.

Introduction:
In Greek word “Geo” means earth and “logy” means study”. It means the Geology is the scientific study of earth.

Geological Engineering is the application of science to problems and projects involving the Earth, its physical environment, earth materials, and natural resources. The curriculum is offered in a cooperative effort between the Department of Civil and Environmental Engineering and the Department of Geosciences and is specially designed for the student who wishes to build upon the freshman and sophomore mathematics and engineering courses as a basis for studies in the earth sciences.

Engineering geology is the application of the geology to engineering study for the purpose of assuring that the geological factors regarding the location, design, construction, operation and maintenance of engineering works are recognized and accounted for. Engineering geologists provide geological and geotechnical recommendations, analysis, and design associated with human development and various types of structures. The realm of the engineering geologist is essentially in the area of earth-structure interactions, or investigation of how the earth or earth processes impact human made structures and human activities.

Engineering geology studies may be performed during the planning, environmental impact analysis, civil or structural engineering design, value engineering and construction phases of public and private works projects, and during post-construction and forensic phases of projects.

Works completed by engineering geologists include: geological hazard assessments, geotechnical material properties, landslide and slope stability, erosion, flooding, dewatering, and seismic investigations, etc. Engineering geology studies are performed by a geologist or engineering geologist that is educated, trained and has obtained experience related to the recognition and interpretation of natural processes, the understanding of how these processes impact human made structures (and vice versa), and knowledge of methods by which to mitigate against hazards resulting from adverse natural or human made conditions. The principal objective of the engineering geologist is the protection of life and property against damage caused by various geological conditions.

Although the study of geology has been around for centuries, at least in its modern form, the science and practice of engineering geology only commenced as a recognized discipline until the late 19th and early 20th centuries. The first book titled Engineering Geology was published in 1880 by William Penning. In the early 20th century Charles Berkey, an American trained geologist who was considered the first American engineering geologist, worked on several water-supply projects for New York City, then later worked on the Hoover dam and a multitude of other engineering projects. The first American engineering geology textbook was written in 1914 by Ries and Watson. In 1921 Reginald W. Brock, the first Dean of Applied Science at the University of British Columbia, started the first undergraduate and graduate degree programs in Geological Engineering, noting that students with an engineering foundation made first-class practicing geologists. In 1925, Karl Terzaghi, an Austrian trained engineer and geologist, published the first text in Soil Mechanics (in German). Terzaghi is known as the parent of soil mechanics, but also had great interest in geology; Terzaghi considered soil mechanics to be a sub-discipline of engineering geology. In 1929, Terzaghi, along with Redlich and Kampe, published their own Engineering Geology text (also in German).
The need for geologists on engineering works gained worldwide attention in 1928 with the failure of the St. Francis Dam in California and the death of 426 people. More engineering failures which occurred the following years also prompted the requirement for engineering geologists to work on large engineering projects.

One of the most important roles as an engineering geologist is the interpretation of landforms and earth processes to identify potential geologic and related man-made hazards that may have a great impact on civil structures and human development. The background in geology provides the engineering geologist with an understanding of how the earth works, which is crucial in minimizing earth-related hazards. Most engineering geologists also have graduate degrees where they have gained specialized education and training in soil-mechanics, rock mechanics, geotechnics, groundwater, hydrology, and civil design. These two aspects of the engineering geologists’ education provide them with a unique ability to understand and mitigate for hazards associated with earth-structure interactions.

**Scope of study**

Engineering geology investigation and studies may be performed:

- for residential, commercial, and industrial developments;
- for governmental and military installations;
- for public works such as a storm water drainage system, power plant, wind turbine, transmission-line, sewage treatment plant, water treatment plant, pipeline (aqueduct, sewer, outfall), tunnel, trenchless construction, canal, dam, reservoir, building foundation, railroad, transit, highway, bridge, seismic retrofit, power generation facility, airport and park;
- for mine and quarry developments, mine tailing dam, mine reclamation and mine tunneling;
- for governmental, commercial, or industrial hazardous waste remediation sites;
- for coastal engineering, sand replenishment, bluff or sea cliff stability, harbor, pier and waterfront development;
- for offshore outfall, drilling platform and sub-sea pipeline, sub-sea cable; and
- for other types of facilities.

**Typical geologic hazards or other adverse conditions evaluated and mitigated by an engineering geologist include:**

- fault rupture on seismically active faults;
- seismic and earthquake hazards (ground shaking, liquefaction, lurching, lateral spreading, tsunami and seiche events);
- landslide, mudflow, rockfall, debris flow, and avalanche hazards;
- unstable slopes and slope stability; erosion;
- slaking and heave of geologic formations, such as frost heaving;
- ground subsidence (such as due to ground water withdrawal, sinkhole collapse, cave collapse, decomposition of organic soils, and tectonic movement);
- volcanic hazards (volcanic eruptions, hot springs, pyroclastic flows, debris flow, debris avalanche, gas emissions, volcanic earthquakes);
- non-rippable or marginally rippable rock requiring heavy ripping or blasting;
- weak and collapsible soils, foundation bearing failures;
shallow ground water/seepage; and
other types of geologic constraints.

An engineering geologist or geophysicist may be called upon to evaluate the excavatability (i.e. rippability) of earth (rock) materials to assess the need for pre-blasting during earthwork construction, as well as associated impacts due to vibration during blasting on projects.

Methods and reporting
The methods used by engineering geologists in their studies include
- geologic field mapping of geologic structures, geologic formations, soil units and hazards;
- the review of geologic literature, geologic maps, geotechnical reports, engineering plans, environmental reports, stereoscopic aerial photographs, remote sensing data, Global Positioning System (GPS) data, topographic maps and satellite imagery;
- the excavation, sampling and logging of earth/rock materials in drilled borings, backhoe test pits and trenches, fault trenching, and bulldozer pits;
- geophysical surveys (such as seismic refraction traverses, resistivity surveys, ground penetrating radar (GPR) surveys, magnetometer surveys, electromagnetic surveys, high-resolution sub-bottom profiling, and other geophysical methods);
- deformation monitoring as the systematic measurement and tracking of the alteration in the shape or dimensions of an object as a result of the application of stress to it manually or with an automatic deformation monitoring system; and
- other methods.

The fieldwork is typically culminated in analysis of the data and the preparation of an engineering geologic report, geotechnical report or design brief, fault hazard or seismic hazard report, geophysical report, ground water resource report or hydrogeologic report. The engineering geology report can also be prepared in conjunction with a geotechnical report, but commonly provides the same geotechnical analysis and design recommendations that would be presented in a geotechnical report. An engineering geology report describes the objectives, methodology, references cited, tests performed, findings and recommendations for development and detailed design of engineering works. Engineering geologists also provide geologic data on topographic maps, aerial photographs, geologic maps, Geographic Information System (GIS) maps, or other map bases.

Geological engineering track requirements provide a foundation in civil and environmental engineering as well as emphasize principles of earth systems, geophysical processes, geochemistry, and biogeochemistry. The engineering design courses are the same as in the environmental engineering track.

Application of Geology in Civil Engineering
1. Knowledge of engineering geology is crucial to detect potential earth science problems of a project and to identify their rational solutions.
2. Engineering geology contributes to the development activity of a country that necessitates construction of high dams, large reservoirs, long tunnels, railways, highways and several other engineering.
3. Engineering geology involved in selecting sites for engineering structures such as, dams, reservoirs, power houses, bridges and airports.
4. Engineering geology involved in fixing alignment for construction of tunnels, highways and railways especially in hilly and hazardous geological terrains.

5. Geologist assesses the conditions of the foundation for civil structured sites based on the mechanical properties and stability of the rocks or unconsolidated materials.

6. The success and economy of engineering constructions depend upon the understanding of the degree and extent of earth science problems and their solutions.

7. Engineering earth science strives to achieve, stability, safety, and economy in constructing civil engineering structures.

8. In the present set up engineering geology and civil engineering work as a team with mutual co-operation and the common goal of contributing their knowledge for the development work of the country.

One of the most important roles as an engineering geologist is the interpretation of landforms and earth processes to identify potential geologic and related man-made hazards that may have a great impact on civil structures and human development. The background in geology provides the engineering geologist with an understanding of how the earth works, which is crucial minimizing earth related hazards. Most engineering geologists also have graduate degrees where they have gained specialized education and training in soil mechanics, rock mechanics, geotechnics, groundwater, hydrology, and civil design. These two aspects of the engineering geologists’ education provide them with a unique ability to understand and mitigate for hazards associated with earth-structure interactions.

Understanding the Earth

The earth is a dynamic planet belonging to the system of the milky-way Galaxy, with a natural satellite the moon. It is the third planet from the sun. The planet on which we live is called the earth. There is a lot of disagreement between the scientists regarding the shape of the earth. The interior of the earth is shrinking day by day. This shrinkage may be either due to loss of heat or reorganization of molecules under enormous pressure and high temperature.

Geological processes are not random, but follow a well-worn pattern that is repeated in cycles, such as the tectonic cycle and the rock cycle. Since the Earth was formed about 4500 million years ago, nothing has been added to it apart from minor incursions of meteorite materials and yet the world is very different now because of the effects of these cycles. Ultimately, the engine of change in the cycles is the heat derived from the Earth’s interior, driven by the decay of natural radioactive mineral isotopes.

Understanding of the Earth System is not a dry academic exercise; knowledge of the behavior of our planet and the interactions between it and humanity are fundamentally important in providing the basis for the management of our environment and our ability to derive sustainable benefit from it. At the same time as we begin to understand more deeply the Earth as a system, it has become clear that recent human activities are having a profound impact on this system, pushing it into states whose consequences for the planet and for humanity are currently unknown. An unequivocal indicator of this is the atmospheric carbon-dioxide concentration, which, since the Industrial Revolution and the mass use of fossil fuels, has risen far beyond its natural limits. Our understanding of CO₂ as a greenhouse gas, and the strong link between CO₂ concentration and temperature, both point to human activity leading to a warming World, unlike anything seen over at least the last million years. The complexity and interweaving of the Earth System’s response to this human forcing has been clearly demonstrated by the measurements of atmospheric CO₂ performed at the Mauna Loa Observatory in Hawaii since 1958. The difference
between estimated global emissions from fossil-fuel burning and the actual observed increase in the atmosphere has to be attributed to flows of carbon between the atmosphere and the Earth’s land and oceans. It has been verified that on average the land and oceans together soak up roughly half of the emitted CO₂, and this ‘sink’ is increasing, but not keeping pace with emissions. Strong variations from year to year are symptoms of varying annual productivities of the land and ocean, with direct impacts on the resources (crops, forests and fish) available to humanity.

Global variations in the Earth System display very large regional differences. The human inputs to the system also show widely different patterns of change across the globe, be it deforestation, manipulation of hydrological resources, occurrence of fires, fossil-fuel burning, land-use management, etc. What seems clear is that these highly variable local and regional types of environmental management sum together to produce global changes with major influences on the Earth System. We are only just beginning to understand the related feedbacks and consequences for the Earth as a living planet, with humanity as one of its life-forms.

We stand at a critical moment in Earth's history, a time when humanity must choose its future. As the world becomes increasingly interdependent and fragile, the future at once holds great peril and great promise. To move forward we must recognize that in the midst of a magnificent diversity of cultures and life forms we are one human family and one Earth community with a common destiny. We must join together to bring forth a sustainable global society founded on respect for nature, universal human rights, economic justice, and a culture of peace. Towards this end, it is imperative that we, the peoples of Earth, declare our responsibility to one another, to the greater community of life, and to future generations.

**Earth, Our Home**

Humanity is part of a vast evolving universe. Earth, our home, is alive with a unique community of life. The forces of nature make existence a demanding and uncertain adventure, but Earth has provided the conditions essential to life’s evolution. The resilience of the community of life and the well-being of humanity depend upon preserving a healthy biosphere with all its ecological systems, a rich variety of plants and animals, fertile soils, pure waters, and clean air. The global environment with its finite resources is a common concern of all peoples. The protection of Earth's vitality, diversity, and beauty is a sacred trust.

**The Global Situation**

The dominant patterns of production and consumption are causing environmental devastation, the depletion of resources, and a massive extinction of species. Communities are being undermined. The benefits of development are not shared equitably and the gap between rich and poor is widening. Injustice, poverty, ignorance, and violent conflict are widespread and the cause of great suffering. An unprecedented rise in human population has overburdened ecological and social systems. The foundations of global security are threatened. These trends are perilous but not inevitable.

**The Challenges Ahead**

The choice is ours: form a global partnership to care for Earth and one another or risk the destruction of ourselves and the diversity of life. Fundamental changes are needed in our values, institutions, and ways of living. We must realize that when basic needs have been met, human
development is primarily about being more, not having more. We have the knowledge and technology to provide for all and to reduce our impacts on the environment. The emergence of a global civil society is creating new opportunities to build a democratic and humane world. Our environmental, economic, political, social, and spiritual challenges are interconnected, and together we can forge inclusive solutions.

**Universal Responsibility**
To realize these aspirations, we must decide to live with a sense of universal responsibility, identifying ourselves with the whole Earth community as well as our local communities. We are at once citizens of different nations and of one world in which the local and global are linked. Everyone shares responsibility for the present and future well-being of the human family and the larger living world. The spirit of human solidarity and kinship with all life is strengthened when we live with reverence for the mystery of being, gratitude for the gift of life, and humility regarding the human place in nature.

**Interior part of earth/ Different layers of earth system**
Rocks, metals, minerals, water etc., have something common in relation to earth, the third planet from the Sun in our Solar System. These are the components that largely form the earth and make it one of the known, densest rocky planet that was formed 4.5 billion years ago. Man has always wondered about the occurrence of phenomena like earthquakes, tsunamis, volcanoes etc. The answer to this lies in the study of the interior of the earth. The interior of this rocky planet differs completely in nature which becomes evident from the information obtained from the study of different sources. The earth comprises of three main realms - the lithosphere (the solid inorganic section), hydrosphere (the liquid section) and the atmosphere (the gaseous realm). The solid earth actually has a concentric layer structure comprising of the crust, the mantle and the core. The temperature within the earth increases with the depth at the rate of 10°C for every 32 meter depth. This makes the average temperature at the centre of the earth touch 5000°C.

**The Interior/Layers of the Earth**
The Crust: The outermost layer also known as lithosphere. It is the thinnest layer of the earth that is 5 - 40 km thick. It is the most significant part of the earth’s surface with its name lithosphere being derived from Latin word ‘lithos’ meaning ‘rocks’ or ‘stones’.

The crust is subdivided into two distinct parts according to its composition known as Sial and Sima.

Sial: The topmost layer consists of granite rocks which on an average forms first 25 km of the crust and is lighter. It consists of silicates and aluminium along with other lighter metals. This layer is thick over the continents but is thin or absent on the ocean floors. Sial - Silicon and aluminium - is the material of the continental crust.

Sima: It lies below the sial layer. A dense layer with an average thickness of 35 km, it consists predominantly of silicates of magnesium, iron and other denser metals. It is a zone of basaltic rocks forming the ocean floors. Sima - Silicon and magnesium - is the material of the oceanic crust and upper mantle. Though these two layers are in a solid state, the lighter sial is considered as floating on denser sima layer.

98.5% of the crust is comprised of just 8 elements. Oxygen is the most abundant element in the crust. This reflects the importance of silicate (SiO2-based) minerals. As a large atom, oxygen occupies ~93% of crustal volume.
2. The Mantle: Below the crust lies the mantle that extends up to a depth of about 2900 km. It is composed of mineral matter in a solid state, the chief constituents being silicates of iron and magnesium. Both the temperature and the density of the mantle increases with the increasing depth towards the centre of the earth. The zone of separation between the crust and the mantle is called Moho Discontinuity. (Moho, a simplification of the name of the Croatian seismologist Mohorovicic who discovered it). Moho marks the lower limit of the earth’s crust. It occurs at an average depth of 8km beneath the oceans and 32km beneath the continents.

The mantle has two parts:
(a) Upper Mantle: The thickness of the upper mantle is about 670 km. The top layer of the upper mantle is solid. Below this layer lies a soft mobile layer. This soft layer of the upper mantle is called asthenosphere (from the Greek word asthenes meaning weak). The lithosphere that consists of the crust and the hard uppermost part of the mantle floats over this asthenosphere.

(b) Lower Mantle: This is about 2200 km thick. This part of the mantle is a solid region starting at about 700 km. It is composed of rocks of uniform thickness.

3. The Core: Scientists believe that as we go deep within the earth, there’s a huge ball of liquid and solid iron, which is the earth’s core. The thickness of the core is about 3500 km. It is the densest layer. When the earth was first formed, 4.6 billion years ago, it was a hot ball of molten rock and metal. And since it was mostly liquid, heavier elements like iron and nickel were able to sink down into the planet and accumulate at the core.

The core is believed to have two parts: a solid inner core, with a radius of 1,220 km, and a liquid outer core that extends to a radius of 3,400 km. The two most abundant elements found in the core are iron and nickel. This is why it is called as NIFE. The inner core is solid, but the outer core is a hot liquid. At the core of the earth, temperatures may be as high as 5000°C.

Mineralogy:
The scientific study of mineral is called as Mineralogy. Mineral is an element or chemical compound that is normally crystalline and that has been formed as a result of geological processes. Mineral is defined as a natural inorganic substance with characteristic physical properties and definite range of chemical composition.
Matter may exist in three states: solids, liquid and gaseous. Most minerals are solid, but some ‘minerals’ such as native mercury are normally liquid in their natural state, and others, such as natural gas, are gaseous. Gases and liquids are termed fluids; that is, they flow, unlike solids, under the action of gravity at atmospheric temperature (t) and pressure (p); solids may flow under the influence of gravity but at higher t and p. A gas will entirely fill the space containing it, whereas a liquid may not, but may be bounded by an upper, horizontal surface. Most pure substances can exist in all three states depending upon the combination of temperature and pressure acting on the mineral. At specific temperatures, called melting points, many minerals melt to form liquids, although some may actually be decomposed by the heat before reaching their melting points. A sublimate is formed by the direct condensation of a gas into a solid.

**Classification:**

Minerals are classified on the basis of chemical composition as follows.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Name</th>
<th>Examples</th>
<th>Che. Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Oxides</td>
<td>Quartz</td>
<td>SiO₂, Fe₂O₃</td>
</tr>
<tr>
<td>2.</td>
<td>Carbonates</td>
<td>Calcite</td>
<td>CaCO₃, MgCO₃</td>
</tr>
<tr>
<td>3.</td>
<td>Sulphates</td>
<td>Gypsum</td>
<td>CaSO₄, H₂O</td>
</tr>
<tr>
<td>4.</td>
<td>Sulphides</td>
<td>Iron Pyrites, Galena</td>
<td>Fe₂, PbS</td>
</tr>
<tr>
<td>5.</td>
<td>Silicates</td>
<td>Orthoclase, Hornblende</td>
<td>KAl₃Si₃O₈, Complex Hydrades</td>
</tr>
</tbody>
</table>

Minerals are also classified on the basis of their formations and uses.

1) **Rock Forming Minerals:** Rock forming minerals are those which are found abundance in the rocks of the earth crust. Most of the rock-forming minerals are silicates. Broadly speaking, the over 3,000 known mineral species can be subdivided into **Silicate** and **Non-silicate** minerals.

2) **Ore Minerals:** Ore minerals are those which are of economic values and which do not occur in abundance in rocks.

**Mineral properties**

All minerals possess certain physical properties. Rocks and minerals help us understand Earth’s historical development and its dynamics. They are important to us because of their availability and properties. The use and distribution of mineral resources and fossil fuels have important economic and environmental impacts. As limited resources, they must be used wisely. Minerals have physical properties determined by their chemical composition and crystal structure. Chemical composition and physical properties determine how minerals are used by humans. Minerals can be identified by well-defined physical and chemical properties, such as

1. Colour
2. Lustre
3. Streak
4. Form
5. Hardness
6. Specific gravity
7. Cleavage
8. Fracture
9. Tenacity
10. Transparency
11. Special properties- Magnetism, Striations, Feel and odour
1. **Colour**
The shade or the tint of the mineral surface, in reflected light or the colour shown by a mineral depends upon the absorption of some, and the reflection of others, of the coloured rays or vibration which constitute ordinary white light.

**Descriptive Terminology:**
1. **White**: Milk white, Chalk white, Snow white, Silver white, Grayish white, Dirty White
2. **Gray**: Steel gray, Dark gray, Grayish black, Grayish white.
3. **Green**: Greenish yellow, Olive green, Parrot green, greenish black.
4. **Yellow**: Yellowish brown, golden yellow, Brass yellow.
5. **Red**: Reddish brown, Brick red, Chocolate brown, Brownish black, Pink.
6. **Black**: Black, Jet black, Charcoal black, Velvet black, Dull black.
7. **Colourless**: For transparent minerals without any shade/tint.

2. **Lustre**
The brilliance of the mineral surface in reflected light or the quality and intensity of light reflected from the surface of a mineral, this property must be observed first hand and cannot be demonstrated in a photograph.

**Descriptive terminology of lustre**

<table>
<thead>
<tr>
<th>Lustre</th>
<th>Description</th>
<th>Mineral example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>Shining like polished metals</td>
<td>Galena, Haematite, Graphite</td>
</tr>
<tr>
<td>Submetallic</td>
<td>Feebly display of metallic lustre</td>
<td>Chromite, Cuprite</td>
</tr>
<tr>
<td>Vitreous</td>
<td>Shining like (a piece to broken) glass</td>
<td>Quartz, Orthoclase</td>
</tr>
<tr>
<td>Subvitreous</td>
<td>The partial shining like glass</td>
<td>Hornblende, amphiboles</td>
</tr>
<tr>
<td>Dull or Earthy</td>
<td>Not shining</td>
<td>Magnesite, Ochre</td>
</tr>
<tr>
<td>Silky</td>
<td>Shining like silk thread or cloth</td>
<td>Asbestose, Gypsum</td>
</tr>
<tr>
<td>Pearly</td>
<td>Shining like a pearl</td>
<td>Calcite, Muscovite, Talc</td>
</tr>
<tr>
<td>Resinous</td>
<td>Shining like wax (candle) thick oil or greese</td>
<td>Olivine, Chlorite, Serpentine</td>
</tr>
<tr>
<td>Adamantine</td>
<td>Shining like a diamond</td>
<td>Diamond</td>
</tr>
</tbody>
</table>

3. **Streak**
The colour of the fine powder of the mineral or the streak of a mineral is the colour of its powder and may be quite different from that of the mineral in mass. Streak is obtained by scratching or rubbing the mineral across a piece of fired but unglazed Porcelain, called a streak plate.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Mineral with Chem. Comp.</th>
<th>Colour</th>
<th>Streak</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Magnetite – Fe_{2}O_{4}</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>2.</td>
<td>Hematite – Fe_{2}O_{3}</td>
<td>Steel</td>
<td>Cherry red</td>
</tr>
<tr>
<td>3.</td>
<td>Galena – pb</td>
<td>Lead gray</td>
<td>Black</td>
</tr>
<tr>
<td>4.</td>
<td>Chromite – Fe_{2}Cr_{2}O_{3}</td>
<td>Dark gray</td>
<td>Brownish black</td>
</tr>
<tr>
<td>5.</td>
<td>Iron Pyrite – Fe_{2}S (Fools Gold)</td>
<td>Bright golden yellow</td>
<td>Black</td>
</tr>
</tbody>
</table>

4. **Form**
The characteristic natural internal shape of minerals or under favourable conditions the mineral assume a definite crystal form.
Crystallized: A term denoting that the mineral occurs’ as well developed crystals.

Crystalline: A term denoting that no definite crystals are developed, but that a confused aggregate of imperfect crystal grains have formed, interfering with one another during their growth.

Amorphous/Massive: A term used to describe the complete absence of crystalline structure.

5. Hardness
The degree of resistance of the mineral surface is to scratching or abrasion. Hardness may be tested by rubbing the specimen over a fine-cut file and noting the amount of powder and also the degree of noise, produced in the operation. The less the powder and the greater the noise, the harder is the mineral. A soft mineral yields much powder and little noise.

Determination of Hardness
1. Finger nail (Thumb nail) \(H=2.5\) max. 2. Steel knife \(H=6.5\) max. 3. Moh’s standard hardness minerals

<table>
<thead>
<tr>
<th>Grade of Moh’s Standard hardness</th>
<th>Hardness</th>
<th>Moh’s number/Hardness of mineral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talc</td>
<td>Soft Grade</td>
<td>1</td>
</tr>
<tr>
<td>Gypsum</td>
<td>Medium Grade</td>
<td>2</td>
</tr>
<tr>
<td>Calcite</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Fluorite</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Apatite</td>
<td>Hard Grade</td>
<td>5</td>
</tr>
<tr>
<td>Orthoclase</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Quartz</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Topaz</td>
<td>Hardest Grade</td>
<td>8</td>
</tr>
<tr>
<td>Corundum</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Diamond</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

6. Specific gravity
The relative weight of the mineral compared to that of equal volume of water.

\[\text{Sp. Gr}=\frac{\text{Wa}}{\text{Wa}-\text{Ww}}.\]

Where, \(\text{Wa}\) : Weight of mineral specimen in air

\(\text{Ww}\) : Weight of mineral specimen in water, & \(\text{Sp. Gr}\) : Specific Gravity.

The Specific gravity of minerals depends upon their chemical composition and the state of molecular aggregation.

<table>
<thead>
<tr>
<th>Weight</th>
<th>Specific Gravity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Low</td>
<td>(\text{Sp Gr }&lt; 2.5)</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>(\text{Sp Gr }&lt; 2.5 - 3.5)</td>
</tr>
<tr>
<td>Heavy</td>
<td>High</td>
<td>(\text{Sp Gr }&gt;3.5)</td>
</tr>
</tbody>
</table>
7. Cleavage
The tendency of many minerals to split along certain definite plains or the tendency of crystallized minerals to split or part repetitively in parallel planes along definite directions of least atomic or molecular cohesion yielding smooth planar surface. Cleavage is the tendency of crystallized minerals to split in a definite planes /directions. These directions are depends on the arrangement of the atoms in a mineral.

**Descriptive Terminology:** Cleavages are described according to the numbers, directions and intersection of sets of cleavage planes.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Cleavage pattern</th>
<th>No of sets</th>
<th>Description &amp; Terminology</th>
<th>Mineral Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td>One</td>
<td>Basal Cleavage</td>
<td>Mica, Beryl</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td>Two</td>
<td>Prismatic Cleavage Perpendicular intersection</td>
<td>Orthoclase, Augite, Hornblende, Gypsum</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td>Two</td>
<td>Oblique Cleavage Intersecting at an angle</td>
<td>Hornblende</td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td>Three</td>
<td>Rhombohedral Cleavage Intersecting at an angle parallel to rhombic face</td>
<td>Calcite, Dolomite</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td>Three</td>
<td>Cubical cleavage Mutually perpendicular and parallel to cubic faces</td>
<td>Galena, Pyrite, Fluorite</td>
</tr>
</tbody>
</table>

8. Fracture
The breakage of a mineral in a direction other than that of cleavages in crystalline mineral and in any direction in other minerals. The character of the fracture displayed on the broken or chipped surfaces of a mineral is an important property.

**Descriptive Terminology of fracture**

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
<th>Mineral Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even</td>
<td>Breaking with smooth, almost plane surface</td>
<td>Chert, Hornstone</td>
</tr>
<tr>
<td>Uneven</td>
<td>Breaking with rough irregular surface</td>
<td>Orthoclase, Hornblende, augite</td>
</tr>
<tr>
<td>Conchoidal</td>
<td>The mineral breaks with a curved, concave or convex shape in a mineral</td>
<td>Limestone, opal, flint</td>
</tr>
<tr>
<td>Hackly</td>
<td>Breaking with sharp or jagged surfaces like wood.</td>
<td>Castiron, Asbestose, Gypsum</td>
</tr>
<tr>
<td>Earthy</td>
<td>Breaking with curved or irregular surface yielding shapeless irregular lumps with smooth or rough surfaces.</td>
<td>Bauxite</td>
</tr>
</tbody>
</table>

9. Tenacity
This is a measure of how a mineral deforms when it is crushed or bent; that is subjected to some form of deformation.
### Descriptive Terminology of Tenacity

<table>
<thead>
<tr>
<th>Tenacity Terms</th>
<th>Description</th>
<th>Mineral Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sectile</td>
<td>The mineral can be cut with a knife and the resulting slice breaks up under a hammer.</td>
<td>Talc</td>
</tr>
<tr>
<td>Malleable</td>
<td>A slice cut from the mineral can be hammered out into the flat sheets</td>
<td>Native silver, Gold, Platinum</td>
</tr>
<tr>
<td>Flexible</td>
<td>The mineral or thin plates or laminate from it, can be bent but does not return to its original position, when the pressure is removed.</td>
<td>Chlorite, Selenite</td>
</tr>
<tr>
<td>Elastic</td>
<td>The mineral or thin plates of laminate from it, can be bent and returns to its original position after the pressure is removed.</td>
<td>Muscovite, Biotite</td>
</tr>
<tr>
<td>Brittle</td>
<td>The mineral crumbles or shatters easily.</td>
<td>Pyrite, Galena</td>
</tr>
</tbody>
</table>

#### 10. Transparency

A mineral is transparent when the outline of an object seen through it is sharp and distinct.

### Descriptive Terminology of Transparency

<table>
<thead>
<tr>
<th>Terms</th>
<th>Description</th>
<th>Mineral Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparent</td>
<td>When the outline of an object seen through it is sharp and distinct</td>
<td>Quartz crystal, Rose quartz</td>
</tr>
<tr>
<td>Translucent</td>
<td>A mineral which although capable of transmitting light, cannot be seen through.</td>
<td>Smoky quartz, Black flint</td>
</tr>
<tr>
<td>Opaque</td>
<td>If no light is transmitted the mineral</td>
<td>Magnetite, Illemenite</td>
</tr>
</tbody>
</table>

#### 11. Special Properties: Magnetism, Striations, Feel and Odour

**Magnetism:** To test the availability of magnetic mineral composition in the mineral.

**Descriptive terminology**

- Low magnetic
- Medium magnetic
- High magnetic
- Non magnetic

**Feel:** Feel to touch sensation of touch

**Descriptive terminology**

iii) Greesy- Soapy surface. Example- Talc, Gypsum.

**Odour:** Smell emitted when moistened, heated, acted upon, by acids or frictions.

**Descriptive Terminology**

i) Argillaceous- Smell of moistened clay. Example- Serpentine, Kaoline.ii) Sulphurous- Smell of burning sulphur. Example-Pyrite

**Test:** relish, savour.

**Descriptive Terminology**


**Acid Test:** Certain carbonate minerals react with hydrochloric acid. Example-Calcite.
Composition and Mineral’s Use in the manufacture of construction materials

Quartz Group (Glass);
Quartz is an essential constituent of acid igneous plutonic rocks such as granites, granodiorites and pegmatites. It may also be present in some diorites and gabbros, always occurring as shapeless interstitial grains. Quartz is a common gangue mineral in hydrothermal and other veins, accompanying the economic ore minerals. Quartz is detrital mineral because of its hardness, lack of cleavage and stability. Present days this mineral used as artificial sand for building material.

<table>
<thead>
<tr>
<th>Variety of Quartz</th>
<th>Milky quartz</th>
<th>Smoky Quartz</th>
<th>Rose Quartz</th>
<th>Citrine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>White, Milky white</td>
<td>Smoky white</td>
<td>Rosey brown/yellow</td>
<td></td>
</tr>
<tr>
<td>Streak</td>
<td>White</td>
<td>White</td>
<td>White</td>
<td>Pale</td>
</tr>
<tr>
<td>Lustre</td>
<td>Vitreous</td>
<td>Vitreous</td>
<td>Vitreous</td>
<td>Vitreous</td>
</tr>
<tr>
<td>Form</td>
<td>Crystalline/Massive</td>
<td>Crystalline</td>
<td>Crystalline</td>
<td>Crystalline</td>
</tr>
<tr>
<td>Hardness</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Cleavage</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Fracture</td>
<td>Conchoidal</td>
<td>Conchoidal</td>
<td>Conchoidal</td>
<td>Conchoidal</td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
<td>Brittle</td>
<td>Brittle</td>
<td>Brittle</td>
</tr>
<tr>
<td>Transparency</td>
<td>Transferent</td>
<td>Transferent</td>
<td>Transferent</td>
<td>Transferent</td>
</tr>
<tr>
<td>Chemical</td>
<td>SiO₂</td>
<td>SiO₂</td>
<td>Mn.SiO₂</td>
<td>Li.Na.Ti.SiO₂</td>
</tr>
<tr>
<td>Uses</td>
<td>Glass making, glass cuttings, electronic lenses, optical instruments, Prestressed concrete, Industrial and agro granules.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Feldspar Group (Ceramic wares and Flooring tiles);
The feldspars are the most important group of rock-forming silicate minerals occurring in igneous, sedimentary and metamorphic rocks. Their range of compositions has led to then being used as a means of classifying igneous rocks, since they are absence only from certain ultramafic and ultra-alkaline igneous rock types and carbonatites. In metamorphic rocks, feldspars are absent only from some low grade pelites, pure marbles, pure quartzites and most eclogites. Feldspars are common in arenaceous sedimentary rocks, but are less common in argillaceous types.

There are two main groups of feldspars:

i) Alkali Feldspars, which occupy a range of compositions between albite, NaAlSi₃O₈ and K-feldspar, KAlSi₃O₈.

ii) Plagioclase feldspar, which occupy a range of compositions between albite, NaAlSi₃O₈, and Anorthite, CaAl₂Si₂O₈. If pure anorthite is written Ab₀An₁₀₀, or more commonly An₁₀₀, then pure albite is written Ab₀. A complete range of plagioclase feldspars can be described with albite (Ab₀-An₁₀₀), oligoclase (Ab₁₀-An₃₀), andesine (Ab₃₀-An₅₀), labrodorite (Ab₅₀-An₇₀), bytonite (Ab₇₀-An₉₀), and anorthite (Ab₉₀-An₁₀₀).
<table>
<thead>
<tr>
<th>Types of Feldspars</th>
<th>Plagioclase</th>
<th>Orthoclase</th>
<th>Microcline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>White, Grey</td>
<td>Pink</td>
<td>Green/Pink</td>
</tr>
<tr>
<td>Streak</td>
<td>Colourless</td>
<td>Colourless</td>
<td>Colourless</td>
</tr>
<tr>
<td>Lustre</td>
<td>Sub-Vitreous</td>
<td>Vitreous</td>
<td>Sub-Vitreous</td>
</tr>
<tr>
<td>Form</td>
<td>Massive</td>
<td>Tabular</td>
<td>Crystalline</td>
</tr>
<tr>
<td>Hardness</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Medium, 2.6</td>
<td>Medium/2.6</td>
<td>Medium/2.6</td>
</tr>
<tr>
<td>Cleavage</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Fracture</td>
<td>Even</td>
<td>Even to Uneven</td>
<td>Even</td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
<td>Brittle</td>
<td>Brittle</td>
</tr>
<tr>
<td>Transparency</td>
<td>Translucent</td>
<td>Translucent</td>
<td>Translucent</td>
</tr>
<tr>
<td>Chemical Composition</td>
<td>NaAlSi$_3$O$_8$</td>
<td>KAlSi$_3$O$_8$</td>
<td>KaAlSi$_3$O$_8$</td>
</tr>
<tr>
<td>Uses</td>
<td>Used in ceramics and glazes, some show a milky translucence and occasionally used as gems. Used in the manufacture of high-class, colourless glass. Feldspar is also an important constituent for the preparation of white coloured enamels for metallic and ceramic surface.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Kaolin** (Paper, paint and textile);

Kaolin/Clay minerals are important products from the weathering of rocks. In particular, feldspars give rise to clays, with k-feldspar reacting in the presence of water to give illite, and plagioclase feldspar reacting in a similar manner to give montmorillonite. If excess water is present, both reactions will eventually produce kaolinite which is the final product. The weathered material either remains where it is and gives rise to residual clays, or is transported by various agencies (water, wind and ice) and deposited as beds of clay in the sea or in lakes, as a superficial deposit of boulder clay, or as loess or adobe deposits. Clays also become hard when heated to a suitable temperature. Certain other substances are also considered briefly, such as fuller’s earth and bentonite, which do not become plastic when wetted.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Kaolin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>White, Dull white</td>
</tr>
<tr>
<td>Streak</td>
<td>White</td>
</tr>
<tr>
<td>Lustre</td>
<td>Greasy to touch, Pearly</td>
</tr>
<tr>
<td>Form</td>
<td>Massive</td>
</tr>
<tr>
<td>Hardness</td>
<td>Equal to 1</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Medium, 2.6-2.65</td>
</tr>
<tr>
<td>Cleavage</td>
<td>Absent</td>
</tr>
<tr>
<td>Fracture</td>
<td>Earthy</td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
</tr>
<tr>
<td>Transparency</td>
<td>Opaque</td>
</tr>
<tr>
<td>Chemical Composition</td>
<td>H$_4$Al$_2$Si$<em>9$O$</em>{18}$</td>
</tr>
</tbody>
</table>

**Uses:** Kaolin clays are utilized in the production of refractory materials. Ceramics, porcelain, chinaware, bricks and glazed tiles filler, white cement stiffener.
Asbestos (AC sheets);
Asbestos includes the fibrous forms of amphibole. The fibres in general are very long, thin, flexible and easily separated by the fingers. The colour may vary from white to greenish and brownish. The ancients called similar material amianthus, undefiled, alluding to the ease with which cloth woven from it was cleaned by throwing it into a fire; but the name amianthus is now restricted to the more silky kinds. Mountain cork, mountain leather and mountain wood are varieties of asbestos which vary in compactness and the matting of their fibres. The term ‘asbestos’ is confined to the fibrous forms of actinolite, but common asbestos includes fibrous varieties of a number of different silicates.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Asbestos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Greyish, pale green, yellowish, Pale greyish White</td>
</tr>
<tr>
<td>Streak</td>
<td>Pale greyish White</td>
</tr>
<tr>
<td>Lustre</td>
<td>Silky, resinous</td>
</tr>
<tr>
<td>Form</td>
<td>Fibrous</td>
</tr>
<tr>
<td>Hardness</td>
<td>2-2.5</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Medium, 2.6-2.65</td>
</tr>
<tr>
<td>Cleavage</td>
<td>Absent</td>
</tr>
<tr>
<td>Fracture</td>
<td>Hackly</td>
</tr>
<tr>
<td>Tenacity</td>
<td>Flexible</td>
</tr>
<tr>
<td>Transparency</td>
<td>Opaque</td>
</tr>
<tr>
<td>Chemical</td>
<td>2H₂CaMg Siicate</td>
</tr>
</tbody>
</table>


Carbonate Group (Cement);
The term "carbonate" can refer both to carbonate minerals and carbonate rock (which is made of chiefly carbonate minerals), and both are dominated by the carbonate ion, CO₃²⁻. Carbonate minerals are extremely varied and ubiquitous in chemically precipitated sedimentary rock. The most common are calcite or calcium carbonate, CaCO₃, the chief constituent of limestone (as well as the main component of mollusc shells and coral skeletons); dolomite, a calciummagnesium carbonate CaMg(CO₃)₂; and siderite, or iron(II) carbonate, FeCO₃, an important iron ore. Sodium carbonate ("soda" or "natron") and potassium carbonate ("potash") have been used since antiquity for cleaning and preservation, as well as for the manufacture of glass. Carbonates are widely used in industry, e.g. in iron smelting, as a raw material for Portland cement and lime manufacture, in the composition of ceramic glazes, and more.

<table>
<thead>
<tr>
<th>Types of Feldspars</th>
<th>Calcite</th>
<th>Magnesite</th>
<th>Dolomite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>White, Grey, Pink, Chalk White</td>
<td>White, Gray, Black</td>
<td></td>
</tr>
<tr>
<td>Streak</td>
<td>White or Greyish</td>
<td>White</td>
<td></td>
</tr>
<tr>
<td>Lustre</td>
<td>Pearly</td>
<td>Dull-Earthy</td>
<td>Vitreous</td>
</tr>
<tr>
<td>Form</td>
<td>Crystallized</td>
<td>Massive</td>
<td>Crystalline</td>
</tr>
<tr>
<td>Hardness</td>
<td>3</td>
<td>3.5 to 4</td>
<td>3.5 to 4</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>High, 3</td>
<td>Medium/2.9-3.0</td>
<td>Medium/1.7-1.8</td>
</tr>
<tr>
<td>Cleavage</td>
<td>Present</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Fracture</td>
<td>Uneven</td>
<td>Uneven, conchoidal</td>
<td>Uneven</td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
<td>Brittle</td>
<td>Brittle</td>
</tr>
</tbody>
</table>
**Gypsum** (POP, gypsum sheets, cement);
Gypsum is a soft **sulfate mineral** composed of **calcium sulfate dihydrate**, with the **chemical formula** CaSO$_4$·2H$_2$O. It is widely mined and is used as a **fertilizer**, and as the main constituent in many forms of **plaster**, **blackboard** chalk and **wallboard**. **Mohs scale of mineral hardness**, based on **scratch Hardness comparison**, defines **hardness value** 2 as gypsum. It forms as an **evaporite** mineral and as a **hydration product of anhydrite**.

Gypsum is a common mineral, with thick and extensive **evaporite** beds in association with **sedimentary rocks**. Deposits are known to occur in **strata** from as far back as the **Archaean eon**. Gypsum is deposited from lake and sea water, as well as in **hot springs**, from **volcanic** vapors, and sulfate solutions in **veins**. **Hydrothermal anhydrite** in veins is commonly hydrated to gypsum by groundwater in near-surface exposures. It is often associated with the minerals **halite** and **sulfur**. Gypsum is the commonest sulfate mineral. Pure gypsum is white, but other substances found as impurities may give a wide range of colors to local deposits.

Gypsum is also formed as a by-product of **sulfide oxidation**, amongst others by **pyrite oxidation**, when the **sulfuric acid** generated reacts with **calcium carbonate**. Its presence indicates oxidizing conditions. Under reducing conditions, the sulfates it contains can be reduced back to sulfide by **sulfate-reducing bacteria**. Electric power stations burning coal with **flue gas desulfurization** produce large quantities of gypsum as a byproduct from the scrubbers.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Gypsum</th>
<th>Uses: Plaster of paris, Plaster casts. Fertilizer to naturalize alkali soils cement work sheets.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>White, snow white, gray</td>
<td></td>
</tr>
<tr>
<td>Streak</td>
<td>Peal White</td>
<td></td>
</tr>
<tr>
<td>Lustre</td>
<td>Resinous</td>
<td></td>
</tr>
<tr>
<td>Form</td>
<td>Crystalline</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Medium, 2.2-2.4</td>
<td></td>
</tr>
<tr>
<td>Cleavage</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td>Uneven</td>
<td></td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
<td></td>
</tr>
<tr>
<td>Transparency</td>
<td>Translucent to Opaque</td>
<td></td>
</tr>
<tr>
<td>Chemical Composition</td>
<td>CaSO$_4$.2H$_2$O</td>
<td></td>
</tr>
</tbody>
</table>
Mica Group (Electrical industries);
The mica group of sheet silicate (phyllosilicate) minerals includes several closely related materials having nearly perfect basal cleavage. All are monoclinic, with a tendency towards pseudohexagonal crystals, and are similar in chemical composition. The nearly perfect cleavage, which is the most prominent characteristic of mica, is explained by the hexagonal sheet-like arrangement of its atoms.

Mica is widely distributed and occurs in igneous, metamorphic and sedimentary regimes. Large crystals of mica used for various applications are typically mined from granitic pegmatites. The mica group represents 37 phyllosilicate minerals that have a layered or platy texture. The commercially important micas are muscovite and phlogopite, which are used in a variety of applications. Mica’s value is based on several of its unique physical properties. The crystalline structure of mica forms layers that can be split or delaminated into thin sheets usually causing foliation in rocks. These sheets are chemically inert, dielectric, elastic, flexible, hydrophilic, insulating, lightweight, platy, reflective, refractive, resilient, and range in opacity from transparent to opaque. Mica is stable when exposed to electricity, light, moisture, and extreme temperatures. It has superior electrical properties as an insulator and as a dielectric, and can support an electrostatic field while dissipating minimal energy in the form of heat; it can be split very thin (0.025 to 0.125 millimeters or thinner) while maintaining its electrical properties, has a high dielectric breakdown, is thermally stable to 500°C (932°F), and is resistant to corona discharge. Muscovite, the principal mica used by the electrical industry, is used in capacitors that are ideal for high frequency and radio frequency. Phlogopite mica remains stable at higher temperatures (to 900°C (1,650°F)) and used in sheet and ground forms. Technical grade sheet mica is used in electrical components, electronics, in atomic force microscopy and as window sheets. Other uses include diaphragms for oxygen-breathing equipment, marker dials for navigation compasses, optical filters, pyrometers, thermal regulators, stove and kerosene heater windows, radiation aperture covers for microwave ovens, and mica thermic heater elements. Mica is birefringent and is therefore commonly used to make quarter and half wave plates.

<table>
<thead>
<tr>
<th>Types of Feldspars</th>
<th>Muscovite</th>
<th>Biotite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Colourless, silver white</td>
<td>Dark brown, Black</td>
</tr>
<tr>
<td>Streak</td>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td>Lustre</td>
<td>Vitreous to Pearly</td>
<td>Vitreous to Pearly, sub-metallic</td>
</tr>
<tr>
<td>Form</td>
<td>Flaky</td>
<td>Flaky</td>
</tr>
<tr>
<td>Hardness</td>
<td>2-2.5</td>
<td>2-2.5</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Medium/2.7-3.0</td>
<td>Medium/2.8-3.2</td>
</tr>
<tr>
<td>Cleavage</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Fracture</td>
<td>Uneven</td>
<td>Uneven</td>
</tr>
<tr>
<td>Tenacity</td>
<td>Elastic, Flexible</td>
<td>Elastic, Flexible</td>
</tr>
<tr>
<td>Transparency</td>
<td>Translucent</td>
<td>Transparent to opaque</td>
</tr>
<tr>
<td>Chemical Composition</td>
<td>H₂KAl₃(SiO₄)₃</td>
<td>K(MgFe)(AlSiO₄)₂(OH)₂</td>
</tr>
</tbody>
</table>
Ore minerals

An ore is a type of rock that contains sufficient minerals with important elements including metals that can be economically extracted from the rock. The ores are extracted from the earth through mining; they are then refined (often via smelting) to extract the valuable element, or elements.

The grade or concentration of an ore mineral, or metal, as well as its form of occurrence, will directly affect the costs associated with mining the ore. The cost of extraction must thus be weighed against the metal value contained in the rock to determine what ore can be processed and what ore is of too low a grade to be worth mining. Metal ores are generally oxides, sulfides, silicates, or "native" metals (such as native copper) that are not commonly concentrated in the Earth's crust, or "noble" metals (not usually forming compounds) such as gold. The ores must be processed to extract the metals of interest from the waste rock and from the ore minerals. Ore bodies are formed by a variety of geological processes. The process of ore formation is called ore genesis.

Iron ores (Steel);

Banded iron formations (BIFs) are sedimentary rocks containing more than 15% iron composed predominantly of thinly bedded iron minerals and silica (as quartz). Banded iron formations occur exclusively in Precambrian rocks, and are commonly weakly to intensely metamorphosed. Banded iron formations may contain iron in carbonates ( siderite orankerite) or silicates (minnesotaite, greenalite, or grunerite), but in those mined as iron ores, oxides (magnetite or hematite) are the principal iron mineral.

The ores are usually rich in iron oxides and vary in colour from dark grey, bright yellow, or deep purple to rusty red. The iron itself is usually found in the form of magnetite ($\text{Fe}_3\text{O}_4$, 72.4% Fe), hematite ($\text{Fe}_2\text{O}_3$, 69.9% Fe), goethite ($\text{FeO(OH)}$, 62.9% Fe), limonite ($\text{FeO(OH)} \cdot n(\text{H}_2\text{O})$, 55% Fe) or siderite ($\text{FeCO}_3$, 48.2% Fe).

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Magnetite</th>
<th>Haematite</th>
<th>Goethite</th>
<th>Limonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Iron Black</td>
<td>Steel grey,reddish</td>
<td>Peakock green</td>
<td>Reddish brown</td>
</tr>
<tr>
<td>Streak</td>
<td>Black</td>
<td>Cherry red</td>
<td>Black</td>
<td>Yellowish brown</td>
</tr>
<tr>
<td>Lustre</td>
<td>Metallic</td>
<td>Metallic</td>
<td>Metallic</td>
<td>Metallic</td>
</tr>
<tr>
<td>Form</td>
<td>Crystalline</td>
<td>Massive</td>
<td>Massive</td>
<td>Massive</td>
</tr>
<tr>
<td>Hardness</td>
<td>5.5-6.5</td>
<td>5.5-6.5</td>
<td>5.5-6.0</td>
<td>1-5</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>High/5.5</td>
<td>High/5.5</td>
<td>High/4.5</td>
<td>Medium/2.7-4.3</td>
</tr>
<tr>
<td>Cleavage</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Fracture</td>
<td>Uneven</td>
<td>Uneven</td>
<td>Uneven</td>
<td>Uneven</td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
<td>Brittle</td>
<td>Brittle</td>
<td>Brittle</td>
</tr>
<tr>
<td>Transparency</td>
<td>Opaque</td>
<td>Opaque</td>
<td>Opaque</td>
<td>Opaque</td>
</tr>
<tr>
<td>Chemical Composition</td>
<td>$\text{Fe}_3\text{O}_4$</td>
<td>$\text{Fe}_2\text{O}_3$</td>
<td>$\text{FeO(OH)}$</td>
<td>$\text{FeO(OH)} \cdot n(\text{H}_2\text{O})$</td>
</tr>
<tr>
<td>Uses</td>
<td>It is an ore of iron</td>
<td>Important ore of iron dye stuff</td>
<td>Goethite is an important ore of iron</td>
<td>Limonite is an important ore of iron</td>
</tr>
</tbody>
</table>
**Chromite (Alloy);**
Chromite is found as orthocumulate lenses of chromitite in peridotite from the Earth's mantle. It also occurs in layered ultramafic intrusive rocks. In addition, it is found in metamorphic rocks such as some serpentinites. Ore deposits of chromite form as early magmatic differentiates. It is commonly associated with olivine, magnetite, serpentinite, and corundum. The vast Bushveld igneous complex of South Africa is a large layered mafic to ultramafic igneous body with some layers consisting of 90% chromite making the rare rock type, chromitite. The Stillwater igneous complex in Montana also contains significant chromite. The limited deposits occurs in Orissa and Karnataka state in India.

Chromite is an iron chromium oxide: FeCr$_2$O$_4$. It is an oxide mineral belonging to the spinel group. Magnesium can substitute for iron in variable amounts as it forms a solid solution with magnesiochromite (MgCr$_2$O$_4$); substitution of aluminium occurs leading to hercynite (FeAl$_2$O$_4$).

<table>
<thead>
<tr>
<th>Properties</th>
<th>Chromite</th>
<th>Uses: Chromite is the only ore of chromium, refractory materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Black</td>
<td></td>
</tr>
<tr>
<td>Streak</td>
<td>Brownish black</td>
<td></td>
</tr>
<tr>
<td>Lustre</td>
<td>Sub-metallic</td>
<td></td>
</tr>
<tr>
<td>Form</td>
<td>Crystalline</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>High/4.5-4.8</td>
<td></td>
</tr>
<tr>
<td>Cleavage</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td>Uneven</td>
<td></td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
<td></td>
</tr>
<tr>
<td>Transparency</td>
<td>Opaque</td>
<td></td>
</tr>
<tr>
<td>Chemical Composition</td>
<td>FeCr$_2$O$_4$</td>
<td></td>
</tr>
</tbody>
</table>

**Bauxite (aluminum);**
Lateritic bauxites (silicate bauxites) are distinguished from karst bauxite ores (carbonate bauxites). The carbonate bauxites occur predominantly above carbonate rocks (limestone and dolomite), where they were formed by lateritic weathering and residual accumulation of intercalated clay layers - dispersed clays which were concentrated as the enclosing limestones gradually dissolved during chemical weathering.

The lateritic bauxites are found mostly in the countries of the tropics. They were formed by lateritization of various silicate rocks such as granite, gneiss, basalt, syenite, and shale. In comparison with the iron-rich laterites, the formation of bauxites depends even more on intense weathering conditions in a location with very good drainage. This enables the dissolution of the kaolinite and the precipitation of the gibbsite. Zones with highest aluminium content are frequently located below a ferruginous surface layer. The aluminium hydroxide in the lateritic bauxite deposits is almost exclusively gibbsite.

Bauxite, an aluminium ore, is the world's main source of aluminium. It consists mostly of the minerals gibbsite (Al(OH)$_3$), boehmite ($\gamma$-AlO(OH)) and diasporc ($\alpha$-AlO(OH)), mixed with the two iron oxides goethite and haematite, the clay mineral kaolinite and small amounts of anatase (TiO$_2$) and ilmenite (FeTiO$_3$ or FeO.TiO$_2$). In 1821 the French geologist Pierre Berthier discovered bauxite near the village of Les Baux in Provence, southern France. In 1861, French chemist Henri Sainte-Claire Deville named the mineral "bauxite"...
<table>
<thead>
<tr>
<th>Properties</th>
<th>Bauxite</th>
<th>Uses: Bauxite is an ore of aluminum refractory bricks, oil refining and bauxite cement, ceramics, porcelain cement, and chemicals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Dirty white, Reddish brown stained</td>
<td></td>
</tr>
<tr>
<td>Streak</td>
<td>White stained red</td>
<td></td>
</tr>
<tr>
<td>Lustre</td>
<td>Dull</td>
<td></td>
</tr>
<tr>
<td>Form</td>
<td>Massive</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>1-3</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Low to medium/2.3-2.5</td>
<td></td>
</tr>
<tr>
<td>Cleavage</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td>Earthy, Uneven</td>
<td></td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
<td></td>
</tr>
<tr>
<td>Transparency</td>
<td>Opaque</td>
<td></td>
</tr>
<tr>
<td>Chemical Composition</td>
<td>Al₂O₃.2H₂O</td>
<td></td>
</tr>
</tbody>
</table>

**Chalcopyrite (copper):**

Chalcopyrite is the most important copper ore. Chalcopyrite ore occurs in a variety of ore types, from huge masses formed in irregular veins and disseminations associated with granitic to dioritic intrusives as in the porphyry copper deposits.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Chalcopyrite</th>
<th>Uses: Chalcopyrite is the most important ore copper its by product &amp; comprise Silver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Bronze yellow, Golden yellow</td>
<td></td>
</tr>
<tr>
<td>Streak</td>
<td>Black</td>
<td></td>
</tr>
<tr>
<td>Lustre</td>
<td>Metallic</td>
<td></td>
</tr>
<tr>
<td>Form</td>
<td>Crystallize</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>3.5-4.0</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>High/4.1-4.3</td>
<td></td>
</tr>
<tr>
<td>Cleavage</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td>Uneven</td>
<td></td>
</tr>
<tr>
<td>Tenacity</td>
<td>Brittle</td>
<td></td>
</tr>
<tr>
<td>Transparency</td>
<td>Opaque</td>
<td></td>
</tr>
<tr>
<td>Chemical Composition</td>
<td>CuFeS₂</td>
<td></td>
</tr>
</tbody>
</table>

Chalcopyrite is a copper iron sulfide mineral that crystallizes in the tetragonal system. It has the chemical formula CuFeS₂. It has a brassy to golden yellow color and a hardness of 3.5 to 4 on the Mohs scale. Its streak is diagnostic as green tinged black. On exposure to air, chalcopyrite oxidises to a variety of oxides, hydroxides and sulfates. Associated copper minerals include the sulfides bornite (Cu₅FeS₄), chalcocite (Cu₂S), covellite (CuS), digenite (Cu₅S₅); carbonates such as malachite and azurite, and rarely oxides such as cuprite (Cu₂O). Chalcopyrite is rarely found in association with native copper.
MODULE 2.

PETROLOGY

The science of rock is called Petrology. Rock is a naturally occurring solid aggregates of minerals. But Petrology (from the Greek word petros, "rock" and logos, "subject matter") is the branch of geology that studies the origin, composition, distribution and structure of rocks.

Lithology was once approximately synonymous with petrography, but in current usage, lithology focuses on macroscopic hand-sample or outcrop-scale description of rocks while petrography is the speciality that deals with microscopic details. In the petroleum industry, lithology, or more specifically mud logging, is the graphic representation of geological formations being drilled through, and drawn on a log called a mud log. As the cuttings are circulated out of the borehole, they are sampled, examined (typically under a 10x microscope) and tested chemically when needed. Petrology utilizes the fields of mineralogy, petrography, optical mineralogy, and chemical analysis to describe the composition and texture of rocks.

Formation:

When debated of the universe, the dropping temperatures were essential for the organization of matter as we know it. First the subatomic particles (quarks, electrons, etc.) were able to form, when temperature dropped further quarks were able to organize into protons and neutrons, then these were able to form simple atomic nuclei, and finally neutral atoms of hydrogen and helium could form when temperatures had dropped even lower. The remaining elements of the periodic table were produced via successive nuclear fusion in stars (up to iron), and under the intense pressures and temperatures of supernova explosions (up to uranium).

When the Earth and other planets accreted around 4.5-4.6 billion years ago, they contained a mixture of all the elements, and the relative abundances probably reflected the cosmic abundances indicated by spectroscopic studies. What happened to that mixture once the Earth started to heat up and differentiate? Basically, whenever chemical elements (atoms) are brought together there is a tendency for them to react with each other and to form compounds. How this works exactly is the subject of thermodynamics or physical chemistry, a subdiscipline of chemistry. Thermodynamics allows us to calculate the outcome of chemical reactions and certain substances together. What kind of compounds form in a given mixture of elements depends in part on their relative abundance, and in part on whether a given combination produces an energy-releasing reaction (exothermic, for example when gasoline combines with oxygen and explodes), or whether it requires energy input to react (endothermic, for example the synthesis of ammonia from nitrogen and hydrogen). The material that was displaced into the mantle during formation of the iron core contained abundant oxygen, silica, magnesium, iron, aluminum, and calcium (plus smaller quantities of a range of other elements) and under the pressures and temperatures that prevail there, chemical reactions (following the laws of thermodynamics) produce compounds that are known as olivine and pyroxene. During formation of the crust, other compounds, in particular feldspars and quartz were common reaction products. The atoms and molecules in these compounds are present in compound-specific proportions, and they are not randomly distributed. Instead, they show very specific geometric arrangements. These compounds that make up the crust and mantle are commonly known to us as minerals.

Minerals, the building blocks of rocks, are inorganic solids with a specific internal structure and a definite chemical composition (varies only within a narrow range). They can form under a variety of conditions, such as:
during the cooling of molten materials (steel, from lavas, igneous rocks).
> during the evaporation of liquids (salt, sugar, reference to evaporites)
> the cooling of liquids (saturated solution) at high temperatures and pressures new crystals may grow in solid materials (diamonds from coal, metamorphism)

**THE RELATIVE ABUNDANCE OF MINERALS** in the earth's crust and mantle is governed by the relative abundance of the elements in these units. For example consider the eight fractions of elements in the crust, it is obvious that Oxygen is by far the most abundant, followed by Silica and Aluminum. The elements from Oxygen to Magnesium make up 98.5% of the crust and are called "major" elements. The elements that make up the remaining 1.5% are called the minor elements (abundance some tenth of a percent) and the trace elements (abundance measured in ppm).

<table>
<thead>
<tr>
<th>Element</th>
<th>Approximate Percentage by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen (O)</td>
<td>46.6</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>27.7</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>8.1</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>5.0</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>3.6</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>2.8</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>2.6</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>2.1</td>
</tr>
<tr>
<td>All others</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

**Minerals in the Earth's Crust**
There are more than 3000 known minerals (the number is still growing), but of these only about 20 are very common, and only 9 of these constitute 95% of the crust. These 9 minerals are all silicates, and are also called the rock forming minerals. They can be subdivided into two groups, the mafic and felsic minerals according to the principal rocks types they mainly occur in.

**Mafic Minerals:** The term mafic is used for silicate minerals, magmas, and rocks which are relatively high in the heavier elements (dominated by Fe, Mg, Ca, Al, SiO2; Ma stands for magnesium and F stands for iron). The minerals are:
1. **Biotite** (mica)
2. **Amphibole/hornblende**
3. **Pyroxenes/augite**
4. **Olivine**
5. **Ca-plagioclase** (feldspar)

**Felsic Minerals:** Felsic is a term used for silicate minerals, magmas, and rocks which have a lower percentage of the heavier elements, and are correspondingly enriched in the lighter elements, such as silica and oxygen, aluminum, and potassium. The term is a combination of FEL (for feldspar; in this case the potassium-rich variety) and SICS (indicating a higher percentage of silica). The minerals are:
1. **Quartz**
2. Muscovite (mica)  
3. Orthoclase (feldspar)  
4. Na-plagioclase/albite (feldspar)

Felsic minerals are light in color and felsic rocks are therefore typically of light color. The most common felsic rocks are granite and rhyolite, which (as we shall see later) represent the end product of the Earth's crustal differentiation process. Rocks that are intermediate in composition between these two groups are also called (surprise!) the intermediate rocks. All of these minerals form through crystallization from silicate melts in the crust and mantle.

**Silicate Minerals**

The composition of the 9 rock forming minerals, they all belong into the silicate group of minerals. The basic buildingstone of silicate minerals is the \( \text{SiO}_4^{4-} \) complex ion, the silica tetrahedron. Oxygen and Silica are the most abundant elements in the crust and mantle, and they form the strongly bonded \( \text{SiO}_4^{4-} \) complex over a wide range of conditions (from the P/T conditions of the mantle to the P/T conditions of the Earth surface). This complex is even stable in silicate melts, and because more than 90% of the Earth's crust is made of these two elements (more than 70% by weight), it is easy to understand why practically all the minerals in the crust (and mantle) are composed of silica tetrahedra with a variety of other elements sprinkled (not at random of course) among them.

**ROCK CLASSIFICATIONS**

There are three types of rocks, classified based on their origin of formation. Those are-

1. Igneous rock  
2. Sedimentary rock and  
3. Metamorphic rock

1. **IGNEOUS ROCKS**

Igneous Rocks are formed by the cooling and crystallization of a silicate melt i.e., dominated by oxygen and silicon, with a variety of other metals. The occurrence and distribution of igneous rocks and igneous rocks types can be related to the operation of plate tectonics. The molten rock material from which igneous rocks form is called magma. Magma is molten silicate material and may include already formed crystals and dissolved gases. The name magma applies to silicate melts within the Earth's crust, when magmas reach the surface they are referred to as lava. The principal constituent of a magma are O, Si, Al, Ca, Na, K, Fe, and Mg. The properties of a magma (viscosity, melting point) are largely controlled by the SiO\(_2\) (viscosity) and the H\(_2\)O content (melting point). SiO\(_2\) is the most abundant component and ranges in abundance from 35% in mafic rocks to 75% in felsic rocks. Two Dissolved gases, CO\(_2\) and H\(_2\)O, are important even though they are not the most abundant components.

**The Origin of Magmas**

The origin of magmas has been a subject for considerable scientific debate in the first half of this century, but today it is basically agreed that three principal magma families can distinguished, basaltic,
andesitic, and granitic, and that they are all the product of partial melting.

**Basaltic Magmas** have comparatively low silica contents (about 50%) and have temperatures between 900 and 1200 degrees Celsius. They are rich in iron and magnesium and form through partial melting of the upper mantle (from peridotite) in areas of mantle upwelling and high heat flow (mid-oceanic ridges; continental rifts).

**Andesitic Magmas** are intermediate in composition between basalts and granites. They form through partial melting of subducted ocean crust in areas of crustal convergence (subduction zones). In areas of island arc formation they are the dominant magma type. In areas of crustal compression and thickening (subduction near continent) they occur together with granitic magmas that originate in the lower crust.

**Granitic magmas** have high silica contents (60-70%) and usually have temperatures below 800 degrees Celsius. They originate in the lower crust in the deeply buried "root zones" of mountain belts. In these areas the temperatures of deeply buried rocks become high enough to allow partial melting. The melts that form under these conditions are granitic in composition.

**Formation of Igneous Rocks**
Igneous rocks are formed by solidification of magma either below or the earth’s surface. It is below the earth i.e., about a depth of 40 kilometers. The rocks are believed to be in a molten state, due to enormous temperature and pressure. This molten material always has a tendency to penetrate into the cracks and lines of weakness of the thin solid crust of the earth. Sometimes, the magma during its endeavor to come out on the earth’s surface is successful in coming out. But sometimes the magma is held up by strong and massive rock masses, below the earth’s surface during its upward journey. If the magma erupted on the earth surface through a weak zone with a great force is known as lava solidifies due to cool temperature of the atmosphere, but if the magma is held up below the earth’s surface during the upward movement, it is then unable to descend. This magma then slowly cools down and ultimately solidifies. The process of solidification of the magma or lava gives from to igneous rock.

**CLASSIFICATION OF IGNEOUS ROCK**
Igneous rocks are classified in two types based on its formation. Those are-

1. Intrusive Igneous rock
2. Extrusive Igneous rock

1. **INTRUSIVE ROCKS** are those that do not make it to the surface and cool down slowly inside the crust. Thus we see mainly phaneritic textures with minerals of coarse to intermediate grain size. These rocks divided into three types established on their depth beneath the crust.
   1) Plutonic Igneous rocks
   2) Hypabyssal Igneous rock and
   3) Ultrabasic Igneous rock

1) **Plutonic Igneous Rock:** If they form at considerable depth they are called plutonic rocks and the respective rock bodies may be called stocks, or batholiths, or plutons. For example- Granites, Porphyritic Granite.
2) **Hypabyssal Igneous rock:** If these rocks form at very shallow depths they may be called hypabyssal or subvolcanic rocks, and we may also see porphyritic textures. Example-dykes and sills

3) **Ultrabasic Igneous rock:** These rocks form from the earth’s mantle. These rocks includes igneous rocks with low silica content that may not be extremely enriched in Fe and Mg. Examples-Peridotite, Serpentinite.

2. **EXTRUSIVE ROCKS** are those that make it to the surface of the Earth in a molten state, tend to cool quickly, and have therefore typically had small crystals (fast cooling does not allow large crystals to grow). The resulting textures are called **aphanitic** (fine grained), **glassy** and **porphyritic** (if some crystals formed before extrusion). Thus these textures are typical for volcanic rocks. Gas bubbles (pressure drop at eruption) may give rise to **vesicular** and **frothy** textures. **Pyroclastic** textures are found in volcanic rocks that formed from ashfalls and ashflows.

**Volcanic rocks:**
Volcanic rocks are those, which are formed on the surface of the earth. This happen when the magma is forced out on the surface of the earth. Due to a sudden change of pressure and temperature on the ground rapidly cools, thus are fine grained rocks. Example-Basalt, vesicular Basalt, Rhyolite, Trachyte.

**Igneous Rocks and Mineral Composition:**
This diagram shows the main groups of igneous rocks, their main mineral constituents and their intrusive (cooling in the crust) and extrusive (cooling as lava flow) equivalents. For example: granitic magmas solidify to granite if they cool in the crust (intrusive), but are called rhyolites if they cool down after they reach the Earth's surface as lava flows (extrusive). Both, rhyolites and granites, are composed of K-feldspar, Quartz, Sodium Plagioclase, and Biotite. Peridotite is the name for rocks of the upper mantle, and Komatiite is the name for extrusive lavas that are essentially of Peridotite composition. The latter are found primarily in very old rocks (Archean) that formed soon after the formation of the first crust (crust was thin, very mobile, and convection was vigorous).

Different minerals crystallize at different temperatures (olivine at high temperatures, quartz at low temperatures), and therefore the mineral composition of an igneous rock can tell us something about the cooling history of that rock. The realization that types and modes of occurrences of igneous rocks can be tied to a common history of cooling, was formulated by the petrologist Bowen, who related laboratory experiments on mineral crystallization with petrographic observations in a theoretical scheme that is nowadays known as **BOWEN'S REACTION SERIES.**

**Forms of Igneous Rocks**
Bodies of igneous rocks come in a large variety of shapes and sizes, and geologists use a variety of terms to describe these. A small sample of these terms is shown in the figure below.
Rock bodies that cool beneath the surface are generally described as Plutons. A **batholith** is a large former magma chamber, often many miles across. A **sill** is a sheet like injection of magma between layers of sedimentary rock. A **dike** is a sheet like body that fills a fracture that cuts across other rocks. A **laccolith** is a small magma chamber at shallow depth (roughly lens shaped). **Volcanic cones** and **lava flows** are surface expressions (see volcanic landforms for pictures).

All of the subsurface igneous rock bodies will eventually be exhumed by erosion and can be seen at the surface. Erosion may reveal the solidified magma plug in the base of volcanoes, a so called **volcanic neck**.

**Texture of Igneous rocks**
The texture is defined as the mutual relationship of the constituent mineral grains their size, shape and etc.

**Descriptive Terminology:**
1. **Equigranular Texture:** Equigranular texture are those in which mineral constituents are more or less developed to the same size, megascopically mineral grains shows equal grain size. **Ex:** Plutonic igneous rocks like Granites, Gabbro
2. **Porphyritic Texture:** When a large crystals called phenocrysts is surrounded by a ground mass called matrix.  
Ex: Hypabyssal Igneous rocks - Porphyries of granite Syenite diorite, dolerite.
3. **Intergrowth / Graphics Texture:** Intergrowth texture is mainly formed due to simultaneously crystallization of two minerals more or less in equal proportions. Intergrowth of two minerals generally results in formation of a peculiar texture called graphic texture.
Ex:- Common Intergrowth in between Quartz & feldspar.
4. **Ophitic Texture:** Consists of small white grains of plagioclase enclosed wholly or partial in large dark gray irregular grains of Augite.
Ex:- Dolerite.
5. **Directive texture:** Directive Texture are formed due to flow of lava during crystallization. It produces bands of layers in which minerals are oriented in a particular direction.
Ex:- Volcanic Igneous rocks - Rhyolite. Trachite, Andesite.
6. **Glassy Texture:** Consists of an amorphous surface with or without vesicles some filled with mineral matter sometimes very fine grained.
Ex:- Volcanic Igneous rocks - Basalts.

**2. SEDIMENTARY ROCKS**
Sedimentary Rocks are a product of the surface processes of the earth i.e., by weathering, erosion, rain, stream-flow, wind, wave action, ocean circulation. The starting materials for sedimentary rocks are the rocks outcropping on the continents.

Processes of physical and chemical weathering break down these source materials into the following components: small fragments of the source rock of gravel, sand, or silt size, that may be identifiable rock fragments or individual minerals new minerals produced by weathering processes mainly clays are dissolved portions of the source rock. From accumulations of these
materials (fragmental material, clays, and dissolved salts) do all sediments on the earth's surface form. Sediments may form by: mere mechanical accumulation of wind, water such as gravel and sand deposits in a river or sand dunes in a desert chemical precipitation, such as salt and calcite precipitation in shallow seas and lakes activity of organisms, such as carbonate accumulation in coral reefs (organic precipitation), or accumulation of organic matter in swamps (coal precursor). Sedimentary rocks form when these initial sediments solidify by cementation and compaction. The probably most significant feature of sedimentary rocks is the fact that they are stratified, that means the sediments of any particular time period form a distinct layer that is underlain and overlain by equally distinct layers of respectively older and younger times. Therefore sediments are the preserved record of former climates and landscapes. The study of sedimentary rocks allows therefore looking back in time and to decipher the sequence of events that made today's Earth what it is. In addition, because the animals that lived during these time periods are found preserved in their respective sediment units, a record of the animal and plant life is kept throughout Earth history. This record allows seeing the changes of plant and animal communities through a time interval of more than 3 billion years (3.2 b.y. the oldest algae) and is therefore a prime piece as well as a prime source of evidence for the theory of evolution. Stratification is also observed in sedimentary rocks from other planets, such as Mars (sedimentary layers from Mars orbit, sedimentary layers at Mars surface).

Because sedimentary processes shape the surface of the earth, the processes that form sediments are much more accessible to observation, and because about 75% of the earth's exposed land surface consists of sediments and sedimentary rocks.

Types of Sedimentary Rocks
Several different types of sedimentary rocks can be distinguished according to mineral composition, and origin of the sediment. The main groupings are:

1. Clastic Sedimentary Rocks, subdivided into conglomerates sandstones mudstones/shales

2. Chemical and Biochemical Sedimentary Rocks, subdivided into limestone/dolostone evaporites carbonaceous rocks

1. Clastic Sedimentary Rocks are those that are composed of fragments of other rocks of igneous, metamorphic, sedimentary. Depending on grain size they are subdivided into conglomerate (grain size larger than 2 mm), sandstone (size between 2 mm and 0.0625 mm), and shale (mudstone).

CONGLOMERATES (size of particles above 2 mm) are consolidated gravel deposits with variable amounts of sand and mud between the pebbles, and are the least abundant sediment type. They usually occur as lenticular bodies that are interbedded with sandstones and sometimes mudstones. Conglomerates accumulate in stream channels (mountain streams), along the margins of mountain ranges (brought out by streams), and may also accumulate on beaches. The basic conditions for formation are either closeness to a source area (usually high relief, fast flowing streams), and/or a high energy environment of deposition (beach, winnowing is the important ingredient). The source rock of a conglomerate can easily be determined by examining the lithology of the pebbles (granite pebbles, basalt pebbles, etc.).
SANDSTONES (particle size between 2 mm and 0.0625 mm) comprise about 30% of all sedimentary rocks. Because in many igneous and metamorphic source rocks the grain size of component minerals is larger than or equal to that of sandstones, it is much more difficult to determine the source rock of a sandstone (as compared to a conglomerate).

The most abundant mineral in sandstone is usually quartz, because it is the hardest one of the rock forming minerals and therefore the most resistant to abrasion during transport. The second most abundant mineral is feldspar (potassium feldspar), followed by micas. These minerals are also the chemically most stable (under conditions of the Earth’s surface) among the rock forming minerals.

SHALE OR MUDSTONE consists of consolidated mud (clay and other fine particles), and comprises about 60-70% of the sedimentary rocks on earth. Shale is not as conspicuous as sandstone because it is softer, and therefore tends to form smooth hills and slopes during weathering. Generally they require a relatively quiet environment of deposition (deep sea, lagoon, lake, tidal flat) because otherwise the fine material cannot settle out of the water (too much agitation). The color of a shale may indicate if deposition occurred in stagnant water (black, organic matter), or in an oxidizing environment (well aerated, usually higher energy level).

Chemical and Organic Sedimentary Rocks are the other main group of sediments besides clastic sediments. They usually form by inorganic or organically mediated mineral precipitation, and as the result of biological activity. Usually it takes some special conditions for these rocks to form, such as small or absent clastic sedimentation (would dilute chemical and organic input), high temperatures and high evaporation (cause super-saturation, and high organic activity (reefs, tropical swamps).

LIMESTONES are the most common type of chemical sediment. They consist predominantly of calcite (CaCO3), and may form by inorganic precipitation as well as by organic activity. If looked at in detail, however, organic activity contributed practically all of the limestones in the geologic record. Limestones may consist of gravel to mud sized particles, and thus classifications of limestones exist that are similar to those of clastic rocks.

The animal hardparts that contribute to limestone formation can be anywhere from meters (coral reef) to some thousands of a mm (from certain algae) in size.

The picture at left shows a large colonial coral from a Tertiary coral reef in the Taiwan Strait. Growing over each other, the corals form a solid framework of carbonate skeletons. Later the open spaces fill with carbonate cement and become solid bodies of limestone. Photomicrograph of ooid limestone. Grains are 0.5-1 mm in size. Large grain in center shows well developed concentric calcite layers.

DOLOSTONES/DOLOMITE consist of the carbonate mineral dolomite [CaMg(CO3)2], and occur in more or less the same settings as limestones. Even though dolomite can precipitate
theoretically from seawater, it only rarely does, and probably most of the dolostones in the sedimentary record are due to post-depositional replacement of calcite by dolomite (Mg for Ca exchange by Mg-rich pore waters).

**EVAPORITES** are true chemical sediments. They consist mostly of salt (table salt [NaCl] and various others) and/or gypsum (CaSO4). They usually form from evaporation of seawater. They require high evaporation rates (high temperatures) for their formation, and usually the sedimentation basin has to be partially or totally closed off (otherwise supersaturation not reached because of influx of new water). They usually indicate arid (dry) climate at their site of deposition.

**CARBONACEOUS SEDIMENTARY ROCKS** are those that contain abundant organic matter in various forms. Although they make only a small fraction of sedimentary rocks, they are important energy resources. Coal, for example is a carbonaceous rocks that consists of the altered (due to increased pressure and temperature) remains of trees and other plant material. It has used since the last century for energy production and chemical industry. Oil shales are black mudstones that contain abundant organic matter that has been altered into solid (keroogen) or very viscous hydrocarbons (bitumen) that can be extracted from the rock through heating. Tar sands are sandstones whose pore spaces are filled with heavy crude oil and bitumen. The hydrocarbons are usually extracted with steam. At current oil prices (2004-2005) oil shale and tar sands are attracting interest because some occurrences are are reaching the point where exploitation becomes economically viable. It is likely that these more unconventional energy sources become more important as as oil supplies dwindle over the coming decades.

**Sedimentary Structures** are another feature of sedimentary rocks that allows distinction between different rock units. Sedimentary structures are a consequence of the depositional process at a site of deposition. The investigation of these structures in ancient rocks allows us to reconstruct physical conditions in the past, such as velocity and direction of depositing currents, emergent or submerged conditions, frequency of depositing events (storms, tides), and in that way may allow reconstructions of climate and paleogeographic setting. Probably the most important sedimentary structures are:

1. **Stratifications**: The arrangement of sedimentary rock in strata / bedding. It may be indicated by difference in texture, cementation, colour or composition.
2. **Lamination**: A thin scale / the finest stratification layer in a sediments / sedimentary rocks differing from other layers in colour, composition or particle size. The finest stratification typically shown by shale and fine grained sand stone.
3. **Current bedding / Cross bedding**: Any bedding structure produced by current action, cross stratification resulting from water or air currents of variable direction. Ex: Sand Stone.
4. **Gradded Bedding**: A type of bedding in which each layer displays a gradual change in particle size, usually from coarse at the base to fine at the top. Ex: Conglomerate.
5. **Ripple Marks**: Any feature formed by the action of water current on a sedimentary surface. An irregular feature made by a tidal current in the beach zone, consisting of a small depression extending toward the shore from the side of an abstraction. Ex: Sandstone, Shale.
6. **Sun Cracks / Mud Cracks**: An irregular fracture in a crudly polygonal pattern formed by the shrinking of clay, silt or mud generally in the course of drying under surface conditions.
7. **Rain Prints**: Small depressions with characteristic rim formed by the impact of rain drop. Ex: Shale

**The Origin of Sedimentary Rocks**

A sedimentary rock that we can examine in an outcrop has a long history and has been subjected to modification by various processes. The first process, **WEATHERING**, produces the materials that a sedimentary rock is composed of by mechanical (freezing, thawing) and chemical (dissolution of minerals, formation of new minerals [clays]) interaction between atmosphere, hydrosphere and earth surface rocks. The second process, **TRANSPORT**, moves these materials to their final destination. Rivers are the main transporting agent of material to the oceans (glaciers are at times important). During transport the sediment particles will be sorted according to size and density (gold placers) and will be rounded by abrasion. Material that has been dissolved during weathering will be carried away in solution. Winds may also play a role (Sahara -- east/central Atlantic). The sorting during transport is important because it is the reason that we have distinct clastic rock types (conglomerates, sandstones, shales).

The third process, **DEPOSITION**, of a sediment, occurs at a site with a specific combination of physical, chemical and biological conditions, the sedimentary environment. An overview of sedimentary environments. Environments on land include (from left to right) Barrier Island, Tidal Flat, Delta, Beach, Fluvial Environment (Rivers), Glaciers, Lakes Alluvial Fans, Desert Dunes, and Lagoons. Marine environments include (from right to left) Organic Reef, Shallow Marine (Shelf), and Deep Marine (deep sea fans, abyssal plains). Each sedimentary environment is characterized by a distinctive set of features such as, type of sediment, sediment association, sediment texture, sedimentary structures, and animal communities, and is in this way (by using modern analogues) that we can go back and reconstruct ancient landscapes. Finally, after the sediment has come to rest, **COMPACTION** and **CEMENTATION** of the sediment occur and a sedimentary rock is formed. Compaction is effected by the burden of younger sediment that gets piled on top of older sediments (rearrangement of particles, packing, dewatering). Minerals precipitated from the pore waters in these sediments cement together adjacent sediment grains. Thus, a coherent solid rock is formed.

3. **METAMORPHIC ROCKS**

Metamorphic rocks are those whose original texture, composition and mineralogy have been changed by conditions of high pressure and temperature (higher than conditions of formation of starting material). The materials from which metamorphic rocks form are igneous rocks, sedimentary rocks, and previously existing metamorphic rocks. Mineralogical and textural changes during metamorphism occur essentially in the solid state. Metamorphic rocks form when the precursor
materials (igneous, sediment, etc.) are buried deeply and are consequently brought into an environment of high pressure and temperature. They are therefore most commonly encountered in the core zones of mountain belts (uplifted root zone), in old continental shields, and as the basement rock below the sediment veneer of stable continental platforms. Metamorphic rocks and associated igneous intrusions (from rock buried so deep that it melted) make up about 85% of the continental crust.

Picture of a metamorphosed conglomerate. The pebbles look "normal" on the right hand cut, but they are much longer than expected on the left hand cut (perpendicular). The pebbles were stretched during metamorphism because the rock was sufficiently hot to behave plastic and flow. The most strongly metamorphosed rocks often show evidence of extensive deformation without fracturing (in part detectable because of relict structures), and that observation indicates that these rocks behaved plastically (see conglomerate above) when they were hot and deeply buried. Usually, the older a portion of continental crust is, the more widespread are outcrops of metamorphic rocks (erosion to very deep crustal levels, isostasy finally exposes root zones of mountain ranges). In older metamorphic rocks oftentimes several successive episodes of metamorphism can be determined with modern methods of investigation (age determination on minerals of different stability, different isotopic systems). Thus, deformation of the earth's crust occurred repeatedly during geologic history. This is evidence for continued tectonic movements and readjustments of the earth's crust throughout documented geologic history.

Classification of Metamorphic rocks
Metamorphic rocks are generally classified on the basis of presence or absence of the structures indicating parallelism of the constituents. There are two types of rocks classification-

1. Foliated and
2. Non-foliated

1. Foliated Metamorphic Rock
These are metamorphic rocks showing development of conspicuous parallelism in their mineralogical constituents as indicated by structures like slaty cleavage, schistosity, gneissic structure etc. Ex: Slates, Phyllites and gneisses.

2. Non-Foliated Metamorphic Rock
These rocks are characterized by an absence of parallelism in its structural constitution. Ex: Quartzites, Marble, Soapstone etc.

Factors of Metamorphism
Metamorphic changes in the result of a number of factors that may operate singularly or in close cooperation with each other. The metamorphic effects are developed that result from the collective action among such factors are temperature, pressure and chemically active fluids may be named as most important.

Temperature
Two common sources of heat for metamorphism are the internal heat and the magmatic heat. As mentioned earlier the temperature of the Earth rises with depth. Such increase in the temperature may induce some changes in those rocks that are brought downwards after their formation.
Similarly, magmatic intrusions may cause partial or complete recrystallization of the invaded rocks.

**Pressure**
Many metamorphic changes are induced merely due to pressure factor whereas in great majority of cases pressure is a dominant factor assisted considerably by heat factor. Any given rock at a suitable depth below the surface of the Earth is subject to pressure from two sources; first, load of the overlying rocks and second crustal disturbances during the orogenic or mountain building activity.

**Chemical Environment**
Presence or absence of chemically active fluids beneath the surface is regarded as a very important consideration in the process of metamorphism. When present, the chemically active fluids exert a positive role in in bringing about metamorphic changes. In the vicinity of magmas in particular and in many other situations certain liquid and gases approach and act upon the rocks in a selective and persistent manner. Among such fluids, steam deserves first mention. Some water is supplied by the magmas; a part of water goes down from the surface as meteoric water. Chemically active water is invariably at high temperature. Carbon dioxide, hydrofluoric acid, bromine, fluorine and some other gases are also present and induce many important changes in some rocks during the process of metamorphism.

**Kinds of Metamorphism**
Three major kinds of metamorphism differentiated on the basis of dominant factors are: thermal metamorphism, dynamic metamorphism and dynamothermal metamorphism.

1. **Thermal Metamorphism**
   It is a general term including a variety of metamorphic processes in which the heat factor has played a predominant role. The pressure and chemically active fluids are attributed only secondary importance.

2. **Dynamic Metamorphism**
   It is also called clastic metamorphism, mechanical metamorphism or dislocation metamorphism and is brought about by pressure acting along zones of dislocation in the crust of the Earth.

3. **Dynamothermal Metamorphism**
   The term Dynamothermal or Regional metamorphism involves both the processes of changing temperature and pressure. The principal factor is temperature, which attains a maximum of around 800°C in regional metamorphism. Igneous intrusions are found within areas of regional metamorphism, but their influence is restricted. Regional metamorphism may be regarded as taking place when the confining pressures are in excess of 3 kilobars.

**Engineering Properties**

1) **Crushing Strength:** It is also termed as compressive strength of a stone and may be defined as maximum force expressed per unit area which a stone can withstand. Any force beyond the compressive strength will cause a failure of the stone. Mathematically, compressive strength is expressed by a simple relationship.

\[
C_o = \frac{P}{A}
\]

Where \(C_o\) = Compressive strength, \(P\) = Load at failure.
Area of cross-section of stone under P

2) **Transverse Strength:** It is defined as the capacity of the stones to withstand bending loads. Such loads are only rarely involved in situations where stones are commonly used.

3) **Porosity:** The shape, size and nature of packing of the grains of a rock give rise to the property of porosity or development of pore spaces within a rock. Porosity is an important engineering property in the sense that it accounts for the absorption value of the stones in most cases. Absorption value defines the capacity of a stone to absorb moisture when immersed in water for 72 hours or still saturation. It is generally expressed in percentage terms of original dry weight of the sample.

Absorption value = \( \frac{S - W}{W} \times 100 \)  

Where S=Saturated weight of the stone  
W=Dry weight of the stone

4) **Density:** It is defined as usual weight per unit volume of a substance, rocks being included. The rock may comprise of pores or open spaces which may be empty partly filled or wholly filled with water. Accordingly three types of density may be distinguished in rocks.
   a. **Dry density:** is the weight per unit volume of an absolutely dried rock specimen.
   b. **Bulk Density:** is the weight per unit volume of a rock sample with natural moisture content where pores are only partially filled with water.
   c. **Saturated density:** is the density of the saturated rock or weight per unit volume of a rock in which all the pores are completely filled with water.

5) **Abrasive Resistance:** It is more a qualitative than a quantitative properly and may be broadly defined as the resistance which a stone offers to rubbing action of one kind or another. For example- Stones used in paving along roads in flooring in buildings and as lining in tunnels or as facing stones in buildings of arid regions where strong sand laden winds are a rule rather than exception. Such situations demand stones with not only high abrasive resistance but also of essentially uniform composition so that wear is as uniform as possible.

6) **Resistance to Fire:** The ability of stone to resist the action of both heat as in case of a fire and also water without showing the signs of cracks or crumbling is known as fire resistance. Monomineralic rocks like quartzite, marbles, compact limestone and dolomites possess.

7) **Resistance to frost:** Frost action is common in cold and humid regions and is more pronounced in rocks having pores and fractures. Water held in the voids freeze and expands to 9% in volume in freezing temperatures. For example- Rocks with negligible porosity like granites and quartzites have greater frost resistance and some sandstone and limestones which are porous are less frost resistant.

**ROCKS AS A CONSTRUCTION MATERIAL**

Rock is a solid cumulative of minerals located in the earth’s lithosphere. They have been used by mankind through history as a basic construction material. There are huge variation within each type of rocks depending on their engineering properties rocks have been used in various construction works. Rocks are using for making bricks, fire places and kitchen counter of homes, dams, buildings, railway ballast, pavement material, road metal, concrete aggregates etc. Rocks are extremely important in terms of their stability and strength as a geological material on which construction foundation are made.

1. **Quality of building stone Strength:**- Strength of many building stones much higher than the loads they are often supposed to withstand in ordinary type of building construction.
2. **Quality of building stone Durability**: Stones should possess a natural durability to withstand the destructive effects of various agents continuously operating on them.

3. **Hardness**: The stone used in floors, pavements and aprons of bridges should be able to resist the abrasive forces caused due to wear and friction. Hardness of stones tested by Mohr’s scale of hardness in the laboratory and in the field by scratching the surface with a sharp knife. A hard stone will not show any scratches.

4. **Quality of building stone & Specific Gravity and Weight**: The stones used for the construction of dams, weirs, barrages, docks and harbours should be of a heavier variety. In case of dams and roof coverings, lighter varieties of stones are preferred. The specific gravity of good building stones should be between 2.4 and 2.8.

5. **Cost**: An important consideration in the selection of building stone is its cost. The cost of a stone depends upon the ease with which it can be quarried out, the proximity of the quarry to the place of use, and the transportation facilities available.

6. **Texture**: Good building stone should be homogeneous in structure.

7. **Quality of building stone Porosity and Absorption**: A good stone should not be porous. More porous building stones are unsuitable for use in construction especially for exposed surfaces of structures.

8. **Appearance**: Appearance is a primary factor of building stone used for face work, its color and ability to receive polish is an important factor.

9. **Toughness**: Building stones should also be tough enough to withstand stresses developed due to vibrations of machinery and moving loads over them.

**ROCK FOUNDATIONS**

Rock Foundations are always preferred because rocks offer a number of advantages compare with soil in terms of stability and durability. Even the weakest rock is better in strength and reliability compared to good soils. Rocks such as limestone, granite, sandstone, shale and hard solid chalk have a high bearing capacity which are extensively used for foundation

**RAILWAY BALLAST**

Railway Ballast is the foundation of railway track and provide just below the sleepers. The loads from the wheels of trains ultimately come on the ballast through rails and sleepers. The stone to be used as railway ballast should be hard, tough nonporous and should not decompose when exposed to air and light. Igneous rocks like quartzite and granite forms the excellent ballast materials.

**Functions of Ballast**

a) To provide firm and level bed for the sleepers to rest on
b) To allow for maintaining correct track level without disturbing the rail road bed
c) To drain off the water quickly and to keep the sleepers in dry conditions
d) To discourage the growth of vegetation
e) To protect the surface of formation and to form an elastic bed
f) To hold the sleepers in position during the passage of trains
g) To transmit and distribute the loads from the sleepers to the formation
h) To provide lateral stability to the track as a whole
Types of Railway Ballast

Sand ballast is used primarily for cast iron (CI) pots. It is also used with wooden and steel trough sleepers in areas where traffic density is very low. Coarse sand is preferred over fine sand. It has good drainage properties, but has the drawback of blowing off because of being light. It also causes excessive wear of the rail top and the moving parts of the rolling stock. Moorum ballast- The decomposition of laterite results in the formation of moorum. It is red, and sometimes yellow, in colour. The moorum ballast is normally used as the initial ballast in new constructions and also as sub-ballast. As it prevents water from percolating into the formation, it is also used as a blanketing material for black cotton soil.

Coal ash or cinder- This type of ballast is normally used in yards and sidings or as the initial ballast in new constructions since it is very cheap and easily available. It is harmful for steel sleepers and fittings because of its corrosive action.

Broken stone ballast- This type of ballast is used the most on Indian Railways. Good stone ballast is generally procured from hard stones such as granite, quartzite, and hard trap. The quality of stone should not be such that it is porous nor does it flake off due to the vagaries of weather. Good quality hard stone is normally used for high-speed tracks. This type of ballast works out to be economical in the long run.

ROCKS IN CONCRETE AGGREGATE

Concrete is made by mixing fine aggregate, coarse aggregate, cement and water. The raw material for making cement is also obtained by rocks. Aggregates are used in concrete for very specific purposes. The use of coarse and fine aggregates in concrete provides significant economic benefits for the final cost of concrete in place. Aggregates typically make up about 60 to 75 percent of the volume of a concrete mixture, and as they are the least expensive of the materials used in concrete, the economic impact is measurable.

ROAD METAL

The materials such as crushed rock, broken stone used to construct a road is known as Road metal. The greater part of the body of road is generally constituted by the aggregates which bear main stress of all the traffic, so it is essential to select the right type of aggregate material for ensuring stability and durability of road. Road metal should possess the following quality.

a) Sufficient hardness and toughness
b) Durability at the place of use
c) Cementation property
d) Hydrophobic property

Granites, Basalts, Sandstones, limestones etc. are the some important natural Rocks from which road aggregates are obtained.

FLOORING AND ROOFING

Slate is a foliated metamorphic rock that forms from the metamorphism of shale, it is popular for a wide variety of uses such as roofing, flooring. Slate is useful for roofing, pool tables and floor tile. Shale, Marble, mudstone, slate and well packed sandstone are all examples of impermeable rocks which are extensively used for flooring and roofing material. Stone are available in plenty across the entire stretch of the country. Many of these are suitable for providing floors in residential construction. Stones suited for the purpose should be strong and able to resist abrasion.
and impact besides giving a pleasing appearance. Some of the stones which are used for floor construction are given below. (a) Kota stone (b) Granite (c) Sand stone

DEFORMATION OF ROCK

Deformation of rocks in the Earth's crust can take many forms. Sedimentary and some igneous rocks are initially deposited in layers - usually very close to horizontal. When these layers are found tilted, folded, or broken they indicate that deformation has occurred.

Mount Everest is the highest peak on Earth at 29,028 feet above sea level. The rock at the top of the peak is a marine limestone, deposited on the sea floor about 450 million years ago. This is an amazing fact that due to deformation.

Stress and Strain
Stress is the force acting on a material that produces a strain. Stress is a force applied over an area and therefore has units of Force/area. Pressure is a stress where the forces act equally from all directions.

If stress is not equal from all directions then we say that the stress is a differential stress. Three kinds of differential stress occur.

1. **Tensional stress** (or **extensional stress**), which stretches rock;
2. **Compressional stress**, which squeezes rock; and
3. **Shear stress**, which result in slippage and translation.

Strain
A strain is a change in size, shape, or volume of a material. The modification that definition somewhat to say that a strain also includes any kind of movement of the material, including translation and tilting.

Stages/Types of Deformation
When a rock is subjected to increasing stress it passes through 3 successive stages of deformation.

1. **Elastic Deformation** - wherein the strain is reversible.
2. **Ductile Deformation** - wherein the strain is irreversible.
3. **Fracture/Brittle Deformation** - irreversible strain wherein the material breaks.
Material behaves will depend on several factors. Among them are:

**Temperature** - At high temperature molecules and their bonds can stretch and move, thus materials will behave in more ductile manner. At low Temperature, materials are brittle.

**Confining Pressure** - At high confining pressure materials are less likely to fracture because the pressure of the surroundings tends to hinder the formation of fractures. At low confining stress, material will be brittle and tend to fracture sooner.

**Strain rate** - At high strain rates material tends to fracture. At low strain rates more time is available for individual atoms to move and therefore ductile behavior is favored.

**Composition** - Some minerals, like quartz, olivine, and feldspars are very brittle. Others, like clay minerals, micas, and calcite are more ductile. This is due to the chemical bond types that hold them together. Thus, the mineralogical composition of the rock will be a factor in determining the deformational behavior of the rock. Another aspect is presence or absence of water. Water appears to weaken the chemical bonds and forms films around mineral grains along which slippage can take place. Thus wet rock tends to behave in ductile manner, while dry rocks tend to behave in brittle manner.

**Strike and Dip**

For an inclined plane the *strike* is the compass direction of any horizontal line on the plane. The *dip* is the angle between a horizontal plane and the inclined plane, measured perpendicular to the direction of strike.

In recording strike and dip measurements on a geologic map, a symbol is used that has a long line oriented parallel to the compass direction of the strike. A short tick mark is placed in the center of the line on the side to which the inclined plane dips, and the angle of dip is recorded next to the strike and dip symbol as shown above. For beds with a 90° dip (vertical) the short line crosses the strike line, and for beds with no dip (horizontal) a circle with a cross inside is used as shown below.

**Features of brittle deformation-Joints and faults**

When rocks break or rupture instead of flowing into folds cracks develop. If there is no slippage along these cracks (i.e., no differential movement on opposite sides of the crack) they are called JOINTS. If there is slippage or differential movement, they are called FAULTS.

**JOINTS**

A *joint* is a break (fracture) of natural origin in the continuity of either a layer or body of *rock* that lacks any visible or measurable movement parallel to the surface (plane) of the fracture.

**Formation**

Joints result from brittle fracture of a rock body or layer as the result of tensile stresses. These tensile stresses either were induced or imposed from outside, e.g. by the stretching of layers; the
rise of pore fluid pressure as the result of either external compression or fluid injection; or the result of internal stresses induced by the shrinkage caused by the cooling or desiccation of a rock body or layer whose outside boundaries remained fixed.

When tensional stresses stretch a body or layer of rock such that its tensile strength is exceeded, it breaks. The rock fractures in a plane parallel to the maximum principal stress and perpendicular to the minimum principal stress. This leads to the development of a single subparallel joint set. Continued deformation may lead to development of one or more additional joint sets. The presence of the first set strongly affects the stress orientation in the rock layer, often causing subsequent sets to form at a high angle, often 90°, to the first set.

**Classification of joints**

Joints are classified either by the processes responsible for their formation or their geometry.

**Geometry of Joints**

The geometry of joints refers to the orientation of joints as both plotted on stereonets and rose diagrams or observed in rock exposures. In terms of geometry, three major types of joints, nonsystematic joints, systematic joints, and columnar jointing are recognized.

**Nonsystematic joints** are joints that are so irregular in form, spacing, and orientation that they cannot be readily grouped into distinctive, through-going joint sets.

**Systematic joints** are planar, parallel, joints that can be traced for some distance, and occur at regularly, evenly spaced distances on the order centimeters, meters, tens of meters, or even hundreds of meters. As a result, they occur as families of joints that form recognizable joint sets. Typically, exposures or outcrops within a given area or region of study contains two or more sets of systematic joints, each with its own distinctive properties such as orientation and spacing, that intersect to form well-defined joint systems.

Based upon the angle at which joint sets of systematic joints intersect to form a joint system, systematic joints can be subdivided into conjugate and orthogonal joint sets. The angles at which joint sets within a joint system commonly intersect are called by structural geologists as the dihedral angles. When the dihedral angles are nearly 90° within a joint system, the joint sets are known as orthogonal joint sets. When the dihedral angles are from 30° to 60° within a joint system, the joint sets are known as conjugate joint sets.

Based upon their orientation to the axial planes and axes of folds, the types of systematic joints are:

**Longitudinal joints** - Joints which are roughly parallel to fold axes and often fan around the fold.

**Cross-joints** - Joints which are approximately perpendicular to fold axes and often fan around the fold.

**Diagonal joints** - Joints which typically occur as conjugate joint sets that trend oblique to the fold axes.

**Strike joints** - Joints which trend parallel to the strike of the axial plane of a fold.

**Cross-strike joints** - Joints which cut across the axial plane of a fold.

**Columnar jointing** is a distinctive type of joints that join together at triple junctions either at or about 120° angles. These joints split a rock body into long, prisms or columns. Typically, such columns are hexagonal, although 3-, 4-, 5- and 7-sided columns are relatively common. The diameter of these prismatic columns range from a few centimeters to several metres. They are often oriented perpendicular to either the upper surface and base of lava flows and the contact of the tabular igneous bodies with the surrounding rock. This type of jointing is typical of thick lava flows and shallow dikes and sills. Columnar jointing is also known as either columnar...
structure, prismatic joints, or prismatic jointing. Rare cases of columnar jointing have also been reported from sedimentary strata.

Types of joints with respect to formation
Joints can also be classified according to their origin. On the basis of their origin, joints have been divided into a number of different types that include tectonic, hydraulic, exfoliation, unloading (release), and cooling joints depending on the specific author and publication. Also, the origin of many joint sets often can be unclear and quite ambiguous. Often, different authors have proposed multiple and contradictory hypotheses for specific joint sets and types.

Tectonic joints are joints that formed when the relative displacement of the joint walls is normal to its plane as the result of brittle deformation of bedrock in response to regional or local tectonic deformation of bedrock. Such joints form when directed tectonic stress causes the tensile strength of bedrock to be exceeded as the result of the stretching of rock layers under conditions of elevated pore fluid pressure and directed tectonic stress. Tectonic joints often reflect local tectonic stresses associated with local folding and faulting.

Hydraulic joints are joints thought to have formed when pore fluid pressure became elevated as a result of vertical gravitational loading. In simple terms, the accumulation of either sediments, volcanic, or other material causes an increase in the pore pressure of groundwater and other fluids in the underlying rock when they cannot move either laterally or vertically in response to this pressure. This also causes an increase in pore pressure in preexisting cracks that increases the tensile stress on them perpendicular to the minimum principal stress. If the tensile stress exceeds the magnitude of the least principal compressive stress the rock will fail in a brittle manner and these cracks propagate in a process called hydraulic fracturing.

Exfoliation joints are sets of flat-lying, curved, and large joints that are restricted to massively exposed rock faces in a deeply eroded landscape. Exfoliation jointing consists of fan-shaped fractures varying from a few meters to tens of meters in size that lie sub-parallel to the topography. The vertical, gravitational load of the mass of a mountain-size bedrock mass drives longitudinal splitting and causes outward buckling toward the free air.

Unloading joints or release joints are joints formed near the surface during uplift and erosion. As bedded sedimentary rocks are brought closer to the surface during uplift and erosion, they cool, contract and become relaxed elastically. This causes stress buildup that eventually exceeds the tensile strength of the bedrock and results in the formation of jointing. Cooling joints are columnar joints that result from the cooling of either lava from the exposed surface of a lava lake or flood basalt flow or the sides of a tabular igneous, typically basaltic, intrusion. They exhibit a pattern of joints that join together at triple junctions either at or about 120° angles. They split a rock body into long, prisms or columns that are typically hexagonal, although 3-, 4-, 5- and 7-sided columns are relatively common.

FAULTS
Faults occur when brittle rocks fracture and there is an offset along the fracture. When the offset is small, the displacement can be easily measured, but sometimes the displacement is so large that it is difficult to measure. Or Fault is a displacement of two rock blocks either each other.
Types of Faults
Faults can be divided into several different types depending on the direction of relative displacement. Since faults are planar features, the concept of strike and dip also applies, and thus the strike and dip of a fault plane can be measured. Dip-slip faults, where the displacement is measured along the dip direction of the fault, and strike-slip faults where the displacement is horizontal, parallel to the strike of the fault. Follow the types of faults:

1. **Dip Slip Faults** - Dip slip faults are faults that have an inclined fault plane and along which the relative displacement or offset has occurred along the dip direction.

2. **Normal Faults** - are faults that result from horizontal tensional stresses in brittle rocks and where the hanging-wall block has moved **down** relative to the footwall block.

3. **Horsts & Grabens** - Due to the tensional stress responsible for normal faults, they often occur in a series, with adjacent faults dipping in opposite directions. In such a case the down-dropped blocks form **grabens** and the uplifted blocks form **horsts**.
   - In areas where tensional stress has recently affected the crust, the grabens may form **rift valleys** and the uplifted horst blocks may form linear mountain ranges.
   - The East African Rift Valley is an example of an area where continental extension has created such a rift.

4. **Half-Grabens** - A normal fault that has a curved fault plane with the dip decreasing with depth can cause the down-dropped block to rotate. In such a case a halfgraben is produced, called such because it is bounded by only one fault instead of the two that form a normal graben.

5. **Reverse Faults** - are faults that result from horizontal compressional stresses in brittle rocks, where the hanging-wall block has moved up relative the footwall block.

6. **A Thrust Fault** is a special case of a reverse fault where the dip of the fault is less than 45°.
   - Thrust faults can have considerable displacement, measuring hundreds of kilometers, and can result in older strata overlying younger strata.
7. **Strike Slip Faults** - are faults where the relative motion on the fault has taken place along a horizontal direction. Such faults result from shear stresses acting in the crust. Strike slip faults can be of two varieties, depending on the sense of displacement. To an observer standing on one side of the fault and looking across the fault, if the block on the other side has moved to the left, that the fault is a *left-lateral strike-slip fault*. If the block on the other side has moved to the right, that the fault is a *right-lateral strike-slip fault*.

The famous San Andreas Fault in California is an example of a right-lateral strike-slip fault. Displacements on the San Andreas fault are estimated at over 600 km.

**Evidence of Movement on Faults or Recognition of fault in the Field:**

Since movement on a fault involves rocks sliding past each other there may be left evidence of movement in the area of the fault plane.

1. **Fault Breccias** are crumbled up rocks consisting of angular fragments that were formed as a result of grinding and crushing movement along a fault. When the rock is broken into clay or silt size particles as a result of slippage on the fault, it is referred to as *fault gouge*.

2. **Slickensides** are scratch marks that are left on the fault plane as one block moves relative to the other. Slickensides can be used to determine the direction and sense of motion on a fault.

3. **Mylonite** - Along some faults rocks are sheared or drawn out by ductile deformation along the fault. This results in a type of localized metamorphism called dynamic metamorphism (also called cataclastic metamorphism). The resulting rock is a fine grained metamorphic rock show evidence of shear, called a mylonite. Faults that show such ductile shear are referred to as *shear zones*.

**DEFORMATION OF DUCTILE ROCKS**

**FOLD**

When rocks deform in a ductile manner, instead of fracturing to form faults or joints, they may bend or fold, and the resulting structures are called *folds*. Folds result from compressional stresses or shear stresses acting over considerable time. Because the strain rate is low and/or the temperature is high, rocks that we normally consider brittle can behave in a ductile manner resulting in such folds.

**Geometry of Folds** - Folds are described by their form and orientation. The sides of a fold are called *limbs*. The limbs intersect at the tightest part of the fold, called the *hinge*. A line connecting all points on the hinge is called the *fold axis*. An imaginary plane that includes the fold axis and divides the fold as symmetrically as possible is called the *axial plane* of the fold.
Types of Folds

1. **Monoclines** are the simplest types of folds. Monoclines occur when horizontal strata are bent upward so that the two limbs of the fold are still horizontal.

2. **Anticlines** are folds where the originally horizontal strata has been folded upward, and the two limbs of the fold dip away from the hinge of the fold.

3. **Synclines** are folds where the originally horizontal strata have been folded downward, and the two limbs of the fold dip inward toward the hinge of the fold. Synclines and anticlines usually occur together such that the limb of a syncline is also the limb of an anticline.

4. **Plunging fold**: if the fold axis is not horizontal the fold is called a *plunging fold* and the angle that the fold axis makes with a horizontal line is called the *plunge* of the fold.

5. **Domes** and **Basins** are formed as a result of vertical crustal motion. Domes look like an overturned bowl and result from crustal upwarping. Basins look like a bowl and result from subsidence.

6. **Symmetrical fold**: If the two limbs of the fold dip away from the axis with the same angle, the fold is said to be a *symmetrical fold*.

7. **Asymmetrical folds**: If the limbs dip at different angles, the folds are said to be *asymmetrical folds*.

8. **Isoclinal fold**: If the compressional stresses that cause the folding are intense, the fold can close up and have limbs that are parallel to each other. Such a fold is called an *isoclinal fold* (iso means same, and cline means angle, so isoclinal means the limbs have the same angle).

9. **Overturned fold**: If the folding is so intense that the strata on one limb of the fold becomes nearly upside down, the
fold is called an **overturned fold**.

10. **Recumbant fold;** An overturned fold with an axial plane that is nearly horizontal is called a **recumbent fold**.

11. **Chevron fold;** A fold that has no curvature in its hinge and straight-sided limbs that form a zigzag pattern is called a **chevron fold**.

**Folds and Topography**

Since different rocks have different resistance to erosion and weathering, erosion of folded areas can lead to a topography that reflects the folding. Resistant strata would form ridges that have the same form as the folds, while less resistant strata will form valleys.

**How Folds Form**

Folds develop in two ways:

1. **Flexural folds** form when layers slip as stratified rocks are bent. This results in the layers maintaining their thickness as they bend and slide over one another. These are generally formed due to compressional stresses acting from either side.

2. **Flow folds** form when rocks are very ductile and flow like a fluid. Different parts of the fold are drawn out by this flow to different extents resulting in layers becoming thinner in some places and thicker in outer places. The flow results in shear stresses that smear out the layers.

**Folds and Metamorphic Foliation**

 Foliation is a planar fabric that develops in rocks subject to compressional stress during metamorphism. It may be present as flattened or elongated grains, with the flattening occurring perpendicular to the direction of compressional stress. It also results from the reorientation, recrystallization, or growth of sheet silicate minerals so that their sheets become oriented perpendicular to the compressional stress direction. Thus, we commonly see a foliation that is parallel to the axial plane of the fold.

 Shearing of rock during metamorphism can also draw out grains in the direction of shear.

**UNCONFIRMITY**

An unconformity is defined as a surface of erosion or non-deposition occurring within a sequence of rocks. Or Unconfirmity is the discontinuity of two different formations.

**Types of Unconfirmity;**

1. **Angular Unconfirmity:** It is characterized by different inclination and structural features above and below the surface of unconformity. The sequence below the unconformity may be steeply inclined and even intensity folded and faulted.

2. **Disconfirmity:** The beds lying below and above the surface of erosion (or no-deposition) are almost parallel. There is no angular variation in the disposition of the entire sequence. No fold or faulting or tilting of the strata.
3. **Non Conformity:** It is the term used for unconformity in a sequence of rocks composed of plutonic igneous rocks (like Granite) as older or underlying rocks and sedimentary or volcanic rocks as the overlying younger or newer rocks.

4. **Local Unconformity:** The unconformity is traceable only in a small area or in a few rock formation of a given area; the term is a local unconformity.

5. **Regional Unconformity:** The unconformity is traceable over a large area, extending for hundreds of kilometers; it is conveniently called a regional unconformity.

**MOUNTAINS AND MOUNTAIN BUILDING PROCESSES**

One of the most spectacular results of deformation acting within the crust of the Earth is the formation of mountain ranges. Mountains frequently occur in elongate, linear belts. They are constructed by tectonic plate interactions in a process called orogenesis.

Mountain building (orogenesis) involves
- Structural deformation.
- Faulting.
- Folding.
- Igneous Processes.
- Metamorphism.
- Glaciation.
- Erosion.
- Sedimentation

Constructive processes, like deformation, folding, faulting, igneous processes and sedimentation build mountains up; destructive processes like erosion and glaciation, tear them back down again. Mountains are born and have a finite life span. Young mountains are high, steep, and growing upward. Middle-aged mountains are cut by erosion. Old mountains are deeply eroded and often buried. Ancient orogenic belts are found in continental interiors, now far away from plate boundaries, but provide information on ancient tectonic processes. Since orogenic continental crust generally has a low density and thus is too buoyant to subduct, if it escapes erosion it is usually preserved.

**Uplift and Isostasy**

The fact that marine limestones occur at the top of Mt. Everest, indicates that deformation can cause considerable vertical movement of the crust. Such vertical movement of the crust is called **uplift.** Uplift is caused by deformation which also involves thickening of the low density crust and, because the crust “floats” on the higher density mantle, involves another process that controls the height of mountains. The discovery of this process and its consequences involved measurements of gravity. Gravity is measured with a device known as a gravimeter. A gravimeter can measure differences in the pull of gravity to as little as 1 part in 100 million. Measurements of gravity can detect areas where
there is a deficiency or excess of mass beneath the surface of the Earth. These deficiencies or excesses of mass are called **gravity anomalies**.

A positive gravity anomaly indicates that an excess of mass exits beneath the area. A negative gravity anomaly indicates that there is less mass beneath an area.

Negative anomalies exist beneath mountain ranges, and mirror the topography and crustal thickness as determined by seismic studies. Thus, the low density continents appear to be floating on higher density mantle. The protrusions of the crust into the mantle are referred to as crustal roots. Normal crustal thickness, measured from the surface to the Moho is 35 to 40 km. But under mountain belts crustal thicknesses of 50 to 70 km are common. In general, the higher the mountains, the thicker the crust.

What causes this is the principal of **isostasy**. The principal can be demonstrated by floating various sizes of low density wood blocks in your bathtub or sink. The larger blocks will both float higher and extend to deeper levels in the water and mimic the how the continents float on the mantle (see figure 11.26 in your text).

It must be kept in mind, however that it's not just the crust that floats, it's the entire lithosphere. So, the lithospheric mantle beneath continents also extends to deeper levels and is thicker under mountain ranges than normal. Because the lithosphere is floating in the asthenosphere which is more ductile than the brittle lithosphere, the soft asthenosphere can flow to compensate for any change in thickness of the crust caused by erosion or deformation.

The Principle of isostasy states that there is a flotational balance between low density rocks and high density rocks. i.e. low density crustal rocks float on higher density mantle rocks. The height at which the low density rocks float is dependent on the thickness of the low density rocks.

Continents stand high because they are composed of low density rocks (granitic composition). Ocean basins stand low, because they are composed of higher density basaltic and gabbroic rocks.

Isostasy is best illustrated by effects of glaciation. During an ice age crustal rocks that are covered with ice are depressed by the weight of the overlying ice. When the ice melts, the areas previously covered with ice undergo uplift. Mountains only grow so long as there are forces causing the uplift. As mountains rise, they are eroded. Initially the erosion will cause the mountains to rise higher as a result of isostatic compensation. But, eventually, the weight of the mountain starts to depress the lower crust and sub-continental lithosphere to levels where they start to heat up and become more ductile. This hotter lithosphere will then begin to flow outward away from the excess weight and the above will start to collapse.

The hotter rocks could eventually partially melt, resulting in igneous intrusions as the magmas move to higher levels, or the entire hotter lower crust could begin to rise as a result of their lower density. These processes combined with erosion on the surface result in **exhumation**, which causes rocks from the deep crust to eventually become exposed at the surface.

**Causes of Mountain Building**

There are three primary causes of mountain building.

1. Convergence at convergent plate boundaries.
2. Continental Collisions.

3. Rifting

1. **Convergent Plate Margins;**
When oceanic lithosphere subducts beneath continental lithosphere magmas generated above the subduction zone rise, intrude, and erupt to form *volcanic mountains*. The compressional stresses generated between the trench and the volcanic arc create *fold-thrust mountain belts*, and similar compression behind the arc create a fold-thrust belt resulting in mountains. Mountains along the margins of western North and South America, like the Andes and the Cascade range formed in this fashion.
Island arcs off the coast of continents can get pushed against the continent. Because of their low density, they don't subduct, but instead get accreted to the edge of the continent. Mountain ranges along the west coast of North America formed in this fashion (see figure 11.20 in your text).

2. **Continental Collisions;**
Plate tectonics can cause continental crustal blocks to collide. When this occurs the rocks between the two continental blocks become folded and faulted under compressional stresses and are pushed upward to form *fold-thrust mountains*. The Himalayan Mountains (currently the highest on Earth) are mountains of this type and were formed as a result of the Indian Plate colliding with the Eurasian plate. Similarly the Appalachian Mountains of North America and the Alps of Europe were formed by such processes.

3. **Rifting;**
Continental Rifting occurs where continental crust is undergoing extensional deformation. This results in thinning of the lithosphere and upwelling of the asthenosphere which results in uplift. The brittle lithosphere responds by producing normal faults where blocks of continental lithosphere are uplifted to form grabens or half grabens. The uplifted blocks are referred to as *fault-block Mountains*. The Basin and Range province in the western United States formed in this manner, including the Sierra Nevada on its western edge and the Grand Tetons in Wyoming.

**Cratons and Orogens**
The continents can be divided into two kinds of structural units

*Cratons* form the cores of the continents. These are portions of continental crust that have attained isostatic and tectonic stability and have cooled substantially since their formation. They were formed and were deformed more than a billion years ago and are the oldest parts of the continents. The represent the deep roots of former mountains and consist of metamorphic and plutonic igneous rocks, all showing extensive evidence of deformation.

*Orogens* are broad elongated belts of deformed rocks that are draped around the cratons. They appear to be the eroded roots of former mountain belts that formed by continent - continent collisions. Only the youngest of these orogens still form mountain ranges.
The observation that the orogens are generally younger towards the outside of any continent suggests that the continents were built by collisions of plates that added younger material to the outside edges of the continents, and is further evidence that plate tectonics has operated for at least the last 2 billion years.
Rocks and Structural impact in the selection of sites for Dams, Reservoirs, Tunnels, Highways and Bridges

SELECTION OF SITES FOR DAMS;

✔ The Success of a dam is not only related to its own safety and stability but also to the success of associated reservoirs. If a dam stands firmly but if its reservoirs leaks profusely then such a dam is to be treated only as a failure because the purpose for which it was constructed was not served.

✔ Careful geological studies bring out the inherent advantage or disadvantage of a site and such studies go a long way either in reducing or in increasing the cost of a dam considerably.

✔ The Important Geological requirements which should be considered in the selection of a dam are as follows: Narrow River Valleys, Occurrence of the bedrock at a shallow depth, Competent rocks to offer a stable foundation, Proper Geological Structures.

✔ Narrow River Valley- At the proposed dam site, if the river valley is narrow, only a small dam is required, which means the cost of dam construction will be less. On the other hand, if the valley is wide, a bigger dam is necessary which means the construction cost will be very high.

✔ Dam Sites Bedrock at Shallow Depths- To ensure its safety and stability a dam has to necessarily rest on (Physically) very strong and (Structurally) very stable (i.e. bedrocks). If such competent bedrocks occur near the surface or at shallow depths, the foundation cost of the dam will naturally be less. On the other hand, if competent bedrocks occur at great depths, the cost of the foundation will be very high because it involves extensive work of excavation of loose overburden and concrete refilling. The general occurrence of material like clay, silt, sand and gravel along the river bed, naturally makes it difficult to assess the thickness of loose overburden by mere surfacial studies. Therefore to know the bedrock profile, geophysical investigations such as “Electrical Resistivity studies” or “Seismic refraction Studies” are carried out carefully. The data recorded in the field during investigations are interpreted and the required bedrock profile is visualized.

✔ Dam Sites Competent Rocks for Safe Foundation- If Igneous rock occurs at the selected dam site, they will offer a safe basis, and weak sedimentary rocks, particularly shale's, poorly cemented sandstones and limestone's shall naturally be undesirable to serve as foundation rocks.

The suitability or otherwise of a site to serve as a foundation for major dams depends on factors such as : The existing rock type at the dam site, The extent of weathering it has undergone, The occurrence of intrusions, The extent of fracturing, The extent of geological structures, the mode and number of rock types concerned.

✔ Dam Sites Suitability of Igneous Rocks- Among the rock types, the occurrence of massive plutonic and (or) hypa-byssal igneous rocks is the most desirable at the dam site because they are very strong and durable due to their dense character. Interlocking texture, hard silicate mineral composition, occurrence of negligible porosity and permeability, absence of any inherent weak planes, resistance of weathering and their tendency to occur over wide areas. Thus all plutonic rocks like Granites, Syenites, diorites and gabbros are very competent and desirable rocks. However, volcanic rocks which are vesicular or amygdaloidal, are not equally desirable, obviously because these character contributes to porosity, permeability and hollowness which, in turn, reflect the strength of the rocks. It is necessary that such rocks
should not have been affected by any intense weathering or fracture or dykes or adverse
geological structures like shearing, faulting and jointing.

**Dam Sites Suitability of Sedimentary Rocks** - In this case of sedimentary rocks, the
bedding and its orientation, thickness of beds, nature and extent of compaction and
cementation, grain size, leaching of soluble matter, porosity and permeability, associated
geological structures and composition of constituents (i.e. Sediments, cementing material,
etc.) influence the strength and durability of different sedimentation rocks.

**Dam Sites Suitability of Metamorphic Rocks** - Among the metamorphic rocks:
“Gneisses” are generally competent like granites, unless they possess a very high degree of
foliations and are richly accompanied by mica-like minerals. Quartzites are very hard and
highly resistant to weathering. They are neither porous nor permeable. Marbles, like quartzite,
are compact, bear a granulose structure, are not porous, nor permeable and reasonably strong
too. But by virtue of their chemical composition and minerals they are unsuitable at dam sites.
Slates bear a typical slaty cleavage. Hence this rock is soft and weak and undesirable at dam
sites.

**Dam Sites Effects of Associated Geological Structures** - For the stability of a dam, the
occurrence of favorable geological structure is a very important requirement. Under structural
geology we have learnt that those rocks bear certain inherent or original physical properties,
such characters get modified either advantageously or disadvantageously when geological structure
occurs in those rocks.

**Dam Sites Cases of Undisturbed i.e. Horizontal Strata** - This geological situation is
good at the dam site because the load of the dam acts perpendicular to the bedding planes,
which means that the beds are in an advantageous position to bear the loads with full
competence. Further, the seepage of reservoir water that may take place beneath the dam is
effectively prevented by the weight of the dam which acts vertically downwards. Thus the
possible uplift pressure which is dangerous to the stability of the dam is effectively reduced.

**Cases where Beds lie Perpendicular to the length of the valleys** - (a) Tilted Beds-Beds
with 10⁰ to 30⁰ inclination in the upstream directions. Such a situation is ideal because the resultant
force acts more or less perpendicular to the bedding plane which are dipping in the upstream side.

**Dam Sites Beds with Steep Upstream Dip** - Such a situation is not bad but not as
advantageous as that of the previous situations, for obvious reasons, i.e. in this case, there
shall be no uplift on the dam site and no leakage of water from the reservoir, but due to steep
dip the bedding planes are not perpendicular to the resultant force, this means the rock will not be as
compatible as in previous case.

**Dam Sites Beds with Steep Downstream Dip** - For obvious reasons this situations has all the
disadvantages of the previous case. Further, here the resultant force and bedding planes are nearly
parallel, which means that the beds will be even less competent.

**Dam Sites Beds which are Folded** - Folding of beds, which occurs on a relatively large scale,
is generally less dangerous than faulting. Unless the folds are of a complex nature. However, it
should be borne in mind that unlike simply tilted strata, the folded rocks are not only under strain but
also physically fractured along the crests. Hence grouting & other precautions may have to be
considered, depending on the context, to improve the stability and competence of rocks at the site.

**Dam Sites Beds Which are Faulted** - Occurrence of faulting irrespective of its attitude
(i.e.. Strike and Dip), right at the dam site is most undesirable. If the faults are active, under
no circumstances, can dam construction be taken up there. This is not only because of the fear of possible relative displacement of the site itself but also due to the possible occurrence of earthquakes. Further, if the fault zone is crushed or intensely fractured, it becomes physically incompetent to withstand the forces of the dam. Thus locations of the dam sites on a fault zone is undesirable for different reasons.

**Dam Sites Beds Which Have Joints**- Among the different geological structures, joints are the most common and are found to occur in all kinds of rocks, almost everywhere. But since the rocks with these joints are not under any strain, and also because of the scope to overcome their effects easily by simple treatment, they are not considered as serious defects. Grouting is generally capable of overcoming the adverse effects of joints because it fills the gaps of joints, increase compactness and competency of the rocks & reduce porosity & permeability.

**SELECTION OF SITES FOR RESERVOIR**

From the Geological point of view, a reservoir can be claimed to be successful if it is watertight (i.e., if it does not suffer from any serious leakage of water) and if it has a long life due to very slow rate of silting in the reservoir basin. The reservoir, when filled, gives chances for reactivation of underlying inactive faults. This in turn, gives scope for the occurrence of seismicity and landslides in that region.

**Reservoir Capacity of the Reservoir Effect of Evaporation**- The natural process of evaporation reduces the quantity of water in the reservoir. Through unwanted, this process is unavoidable. Since reservoirs are open and extended over larger areas. The magnitude of evaporation will be extensive. Of course, such loss shall be less if the topography is such that a reservoir covers a small area but has a great depth to provide adequate capacity.

**Reservoir Water-** Tightness and Influencing factors that, when a river flows over such loose soil or fractured ground, it is natural that some water of the river percolates (or leaks) underground. Before the construction of the dam, this leakage shall be less and limited only to the extent over which the river flow occurs. But when the dam is constructed, the impounding water accumulates in large quantity in a reservoir which covers a very large area.

**Reservoir Influence of Rock Types**- Water-tightness of a reservoir basin is also very much influenced by the kind of rocks that occur at the reservoir site. If the rocks are porous and permeable, they will cause the leakage of water and hence such rock are undesirable at the reservoir site.

**Reservoir Igneous Rocks**- Intrusive igneous rocks like granite, by virtue of their composition, texture and mode of formation is neither porous nor permeable. Hence their occurs at the reservoir site will not cause leakage of water unless they have other defects like joints, faults, or shear zones. But the extrusive (i.e., Volcanic) igneous rocks like basalt are not desirable because they are often vesicular.

**Sedimentary Rocks**- The next common sedimentary rock i.e., sandstone is an aquifer and hence it has a tendency to cause leakage. However, careful examination is needed to know whether it causes severe leakage or not, if present at the reservoir site. This is so because the porosity and
permeability of different sandstone differ depending on a degree of cementation and composition of the cementing materials of sandstones. The Occurrence of limestone, the third most common rock of the sedimentary group at the reservoir site is, in general, undesirable. Of course, it may not only have negligible porosity but also possess reasonable hardness and durability. Thus through the compact of massive limestone superficially seem to be water proof, they may be internally cavernous and cause profuse leakage.

Metamorphic Rocks- Gneisses, which are one of the most common metamorphic rocks, behave like granite, i.e., they are neither porous nor permeable. The schists, on the other hand, by virtue of their excellent foliation and soft and cleavage-bearing mineral content and a source of weakness and leakage problems. The quartzite which are compact, by virtue of their quartz content and granulose structure, are neither porous nor permeable. Therefore, their occurrence at reservoir sites contributes to water-tightness. Marbles, through compact, by virtue of their calcium carbonate composition and calcite content are not reliable in terms of their water tightness. Slates due to their characteristic slaty cleavage may tend to cause leakage but their very fine grained nature helps in checking such leakage considerably.

Selection of sites for Tunnel and similar for Highways and Bridges
Tunnels are underground passages or routes (or passages through hills or mountains) used for different purposes. They are made by excavation of rocks below the surface or through the hills or mountains. Like dams, bridges and reservoirs, tunnels are also very important civil engineering projects, but with some differences. Unlike other civil engineering constructions which lie on the surface, generally, tunnels lie underground (i.e., within the rocks). For this reason, the needs for their safety and stability is much more important.

Tunnels Effects of Tunneling on the Ground- The tunneling process deteriorates the physical conditions of the ground. This happens because due to heavy and repeated blasting excavation, the rocks gets shattered to great extent and develop numerous cracks and fractures. This reduces the cohesiveness and compactness of rocks. In other words, rocks become loose and more fractured and porous. This naturally adversely affects the competence of the rocks concerned.

Geological Considerations for successful Tunneling- As already stated, the safety success and economy of tunneling depend on the various geological conditions prevailing at the site. As usual, the important geological factors which interfere with this civil engineering project (i.e. tunneling) are also lithological, structural and ground water conditions.

Importance of Rock Types- Since tunnels through underground rock masses, obviously the nature of rock types which are encountered along the tunnel alignment is very important for the safety and stability of the tunnel.

Suitability of Igneous Rocks at the Tunnel- Site Massive igneous rocks, i.e., the plutonic and hypabyssal varieties, is very competent but difficult to work. They do not need any lining or any special maintenance. This is so because they are very strong, tough, hard, rigid, durable, impervious and tunneling, do not succumb to collapse, floor bumps, side bulges or to any other
deformation. The volcanic rocks, too in spite of their vesicular or amygdaloidal character are competent and suitable for tunneling. Further, by virtue of frequently present vesicular or amygdaloidal structure, they are more easily workable than intrusive rocks.

**Sedimentary Rocks at the Tunnel Site** - In general, sedimentary rocks are less competent than igneous rocks. Thick bedded, well-cemented and siliceous or ferruginous sandstones are more competent and better suited for tunneling. They will be strong, easily workable and, moreover, do not require any lining. Thus they possess all the desirable qualities for tunneling, provided they are not affected adversely by any geological structures and ground water conditions. Shales, by virtue of their inherent weakness and lamination, may get badly shattered during blasting. But being soft, they can be easily excavated and hence tunneling progresses faster through shale formations. Limestones, dolomitic limestone are harder and more durable. They are better than other varieties. On the other hand, calcareous limestones or porous limestones are naturally weaker and softer.

**Metamorphic Rocks at the Tunnel Site** - Among different metamorphic rocks, gneisses are nearly similar to granites in terms of their competence, durability and workability. Hence, they are capable of withstanding the tunneling process without requiring any lining. The gneissose structure may be advantageous in the excavation process. Schists, phyllites, etc., which are highly foliated and generally soft, are easily workable but necessarily require good lining. Quartzite are very hard and hence very difficult to work they are more brittle too. They are competent and need no lining.

**Importance of Geological Structures**

**Effects of Joints at the Tunnel Site** - Most of the rocks in nature possess irregular cracks and regular joints, which are plane of complete separation in rock masses, and clearly represent weakness in them. There will be more qualitively and quantitatively nearer the surface but generally disappear with depth.

Closely spaced joints in all kind of rocks are harmful. However, in general, in igneous rocks, which are exceptionally strong, the presence may not harm their self-supporting character. In Sedimentary rocks, the occurrence of joints is undesirable because these rocks, which are originally weak and incompetent, become still weaker. As in the case of other rocks, the presence of joints in these rocks also depends on the past tectonic history of the concerned region.

In Metamorphic rocks also, joints are not characteristic, but are frequently present. Granite gneisses and quartzites, being very competent, can remain suitable for tunneling even if some joints occur in them. But schists and slates with joints will become very incompetent and necessarily requires lining. Marbles, which possess joints, are unsuitable for tunneling because, in them, joints are root causes for the occurrence of sink holes, solution cavities and channels.

**Fault at the Tunnel Site** - As in other civil engineering projects, in tunnels too, faults are harmful and undesirable because they create a variety of problems. The active fault are places where there is scope for further recurrence of faulting, which will be accompanied by the physical displacement of litho units. Hence, such faults lead to dislocation and discontinuity in the tunnel alignment.

**Fault at the Tunnel Site** - The fault zone even if inactive, are places of intense fracturing, which means that they are zones of great physical weakness. Such a remedial measures of lining (with
concrete) also becomes necessary fault zones, being highly porous, permeable and decomposed, are the potential zones to create ground water problems.

**Folds at the Tunnel Site** - Folds represent the deformation of rocks under the influence of tectonic forces. Hence the folded rocks will be under considerable strain. When excavations for tunnels are made in folded rocks, such rocks get the opportunity to release this strain (i.e., stored energy). Such a release may occur in the form of rock bursts or rock falls or bulging of the sides or the floor or the roof. Thus complications of such a kind are likely to occur when tunneling is made in folded regions. In folded regions, the tunnel alignment may be parallel or perpendicular or oblique to the axis of folds. Further the tunnel may run along the crests or troughs or limbs.

**Effects of Undisturbed or Tilted Strata at The Tunnel Site**

1. **Horizontal Beds** - In cases of horizontal or gently inclined beds, conditions will be favorable for tunneling. But it is desirable that the bed concerned be thick so that the tunnel passes through the same formation. This is preferable because thicker formations are more competent and hence tunnels through them will be safe and stable.

2. **Inclined Beds** - The forgoing advantage also occur when the tunnels are made parallel to the strike of massive, thick, inclined beds or when inclined tunnels are made following the directions of the slope.

3. **Tunnels i.e., Parallel to the dip** - In the latter case, an inclined tunnel driven along the dip of beds must run through the same bed or beds all along its course. The stability of the tunnel in all these cases depends on the nature of the beds which forms the roof. It is relevant to say in this context that the dip and strike galleries in coal mines are driven in this way, i.e. along the true dip and strike, respectively, of the coal seams. These tunnels, therefore, always run along the coal seams and have nearly similar conditions all along their length.

**ROCK QUALITY DESIGNATION (RQD)**

The Rock Quality Designation (RQD) was developed by Deere (Deere et al 1967) to provide a quantitative estimate of rock mass quality from drill core logs. RQD is defined as the percentage of intact core pieces longer than 100 mm (4 inches) in the total length of core. The core should be at least NW size (54.7 mm or 2.15 inches in diameter) and should be drilled with a double-tube core barrel. The correct procedures for measurement of the length of core pieces and the calculation of RQD are summarised in following figure. RQD is a directionally dependent parameter and its value may change significantly, depending upon the
borehole orientation. The use of the volumetric joint count can be quite useful in reducing this directional dependence.

*RQD* is intended to represent the rock mass quality in situ. When using diamond drill core, care must be taken to ensure that fractures, which have been caused by handling or the drilling process, are identified and ignored when determining the value of *RQD*.

**ROCK STRUCTURE RATING (RSR)**

Rock Structure Rating (RSR) is a quantitative method for describing quality of a rock mass and appropriate ground support. The RSR concept introduced a rating system for rock masses. It was the sum of weighted values in this classification system. There are considered two general categories:

- **Geotechnical** parameters: Rock type; joint pattern; joint orientations; type of discontinuities; major faults; shears and folds; rock material properties; weathering or alteration. And
- **Construction** parameters: Size of tunnel; direction of drive; method of excavation.

The RSR value of any tunnel section is obtained by summing the weighted numerical values determined for each parameter. The RSR concept is a very useful method for selecting steel rib support for rock tunnels. As with any empirical approach one should not apply the concept beyond the range of the sufficient and reliable data used for developing it. For this reason the RSR concept is not recommended for selection of rock bolts and concrete support.

**IGNEOUS ROCKS**

**Granite:** Granite is a light-colored igneous rock with grains large enough to be visible with the unaided eye. It forms from the slow crystallization of magma below Earth's surface. Granite is composed mainly of quartz and feldspar with minor amounts of mica, amphiboles, and other minerals. This mineral composition usually gives granite a red, pink, gray, or white color with dark mineral grains visible throughout the rock.

**Gabbro:** Gabbro is a coarse-grained, dark-colored, intrusive igneous rock. It is usually black or dark green in color and composed mainly of the minerals plagioclase and augite. It is the most abundant rock in the deep oceanic crust. Gabbro has a variety of uses in the construction industry. It is used for everything from crushed stone base materials at construction sites to polished stone counter tops and floor tiles.

**Dolerite:** Dolerite is composed of Plagioclase and Pyroxene. As the result, it is three times as stiff as Granite. It is a mafic rock, containing magnesium and iron, often in form of olivine. Like other mafic rocks, it is relatively low in silica content. It is a medium grained igneous rock, and can be dark grey or black with greenish shades in colour. Minerals in this rock include olivine, plagioclase feldspar, pyroxene, quartz and sometimes ilmenite, biotite, hornblende and magnetite.
Basalt: Basalt is a dark-colored, fine-grained, igneous rock composed mainly of plagioclase and pyroxene minerals. It most commonly forms as an extrusive rock, such as a lava flow, but can also form in small intrusive bodies, such as an igneous dike or a thin sill. It has a composition similar to gabbro. The difference between basalt and gabbro is that basalt is a fine-grained rock while gabbro is a coarse-grained rock.

SEDIMENTARY ROCKS

Sandstone: Sandstone is a sedimentary rock formed from cemented sand-sized clasts. The cement that binds the clasts can vary from clay minerals to calcite, silica or iron oxides. Sandstone can be further divided according to: Clast size - fine (0.06-0.2mm), medium (0.2-0.6mm), coarse (0.6-2mm); Sorting - a sandstone comprising a mixture of clast sizes is poorly sorted, while one comprising mostly clasts of the same size is well sorted; a sandstone containing very little silt and / or clay is termed arenaceous; a sandstone containing a significant amount of silt and / or clay is termed argillaceous or a "wacke" (see greywacke for more information);

Mineral content - a sandstone consisting of more than 25% feldspar clasts is termed arkose; a sandstone consisting of more than 90% quartz clasts is called quartzose;

Texture - clastic (only noticeable with a microscope).

Grain size - 0.06 - 2mm; clasts visible to the naked eye, often identifiable.

Hardness - variable, soft to hard, dependent on clast and cement composition.

Colour - variable through grey, yellow, red to white reflecting the variation in mineral content and cement.

Clasts - dominantly quartz and feldspar (orthoclase, plagioclase) with lithic clasts and varying minor amounts of other minerals.

Other features - gritty to touch (like sandpaper).

Uses - if soft then generally of no use; if hard then can be used as aggregate, fill etc. in the construction and roading industries; dimension stone for buildings, paving, etc.

Shale: Shale is a fine-grained sedimentary rock that forms from the compaction of silt and clay-size mineral particles that we commonly call "mud." This composition places shale in a category of sedimentary rocks known as "mudstones." Shale is distinguished from other mudstones because it is fissile and laminated. "Laminated" means that the rock is made up of many thin layers. "Fissile" means that the rock readily splits into thin pieces along the laminations.

Uses of Shale: Some shales have special properties that make
them important resources. Black shales contain organic material that sometimes breaks down to form natural gas or oil. Other shales can be crushed and mixed with water to produce clays that can be made into a variety of useful objects.

Limestone: Limestone is a sedimentary rock composed primarily of calcium carbonate (CaCO₃) in the form of the mineral calcite. It most commonly forms in clear, warm, shallow marine waters. It is usually an organic sedimentary rock that forms from the accumulation of shell, coral, algal, and fecal debris. It can also be a chemical sedimentary rock formed by the precipitation of calcium carbonate from lake or ocean water.

Limestone-Forming Environment: Marine

Most limestones form in shallow, calm, warm marine waters. That type of environment is where organisms capable of forming calcium carbonate shells and skeletons can easily extract the needed ingredients from ocean water. When these animals die, their shell and skeletal debris accumulate as a sediment that might be lithified into limestone. Their waste products can also contribute to the sediment mass. Limestones formed from this type of sediment are biological sedimentary rocks. Their biological origin is often revealed in the rock by the presence of fossils. Some limestones can form by direct precipitation of calcium carbonate from marine or fresh water. Limestones formed this way are chemical sedimentary rocks. They are thought to be less abundant than biological limestones.

Composition of Limestone

Limestone is by definition a rock that contains at least 50% calcium carbonate in the form of calcite by weight. All limestones contain at least a few percent other materials. These can be small particles of quartz, feldspar, clay minerals, pyrite, siderite, and other minerals. It can also contain large nodules of chert, pyrite, or siderite.

Uses of Limestone

Limestone is a rock with an enormous diversity of uses. It could be the one rock that is used in more ways than any other. Most limestone is made into crushed stone and used as a construction material. It is used as a crushed stone for road base and railroad ballast. It is used as an aggregate in concrete. It is fired in a kiln with crushed shale to make cement.

Some additional but also important uses of limestone include:

Dimension Stone: Limestone is often cut into blocks and slabs of specific dimensions for use in construction and in architecture. It is used for facing stone, floor tiles, stair treads, window sills, and many other purposes.

Roofing Granules: Crushed to a fine particle size, crushed limestone is used as weather and heat-resistant coating on asphalt-impregnated shingles and roofing. It is also used as a top coat on built-up roofs.

Flux Stone: Crushed limestone is used in smelting and other metal refining processes. In the heat of smelting, limestone combines with impurities and can be removed from the process as a slag.

Portland Cement: Limestone is heated in a kiln with shale, sand, and other materials and ground to a powder that will harden after being mixed with water.
**AgLime**: Calcium carbonate is one of the most cost-effective acid-neutralizing agents. When crushed to sand-size or smaller particles, limestone becomes an effective material for treating acidic soils. It is widely used on farms throughout the world.

**Lime**: If calcium carbonate (CaCO₃) is heated to high temperature in a kiln, the products will be a release of carbon dioxide gas (CO₂) and calcium oxide (CaO). The calcium oxide is a powerful acid-neutralization agent. It is widely used as a soil treatment agent (faster acting than aglime) in agriculture and as an acid-neutralization agent by the chemical industry.

**Animal Feed Filler**: Chickens need calcium carbonate to produce strong egg shells, so calcium carbonate is often offered to them as a dietary supplement in the form of "chicken grits." It is also added to the feed of some dairy cattle who must replace large amounts of calcium lost when the animal is milked.

**Mine Safety Dust**: Also known as "rock dust." Pulverized limestone is a white powder that can be sprayed onto exposed coal surfaces in an underground mine. This coating improves illumination and reduces the amount of coal dust that activity stirs up and releases into the air. This improves the air for breathing, and it also reduces the explosion hazard produced by suspended particles of flammable coal dust in the air.

**Laterite**: Laterite is a soil and rock type rich in iron and aluminium, and is commonly considered to have formed in hot and wet tropical areas. Nearly all laterites are of rusty-red coloration, because of high iron oxide content. They develop by intensive and prolonged weathering of the underlying parent rock. Tropical weathering (laterization) is a prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils. The majority of the land area containing laterites is between the tropics of Cancer and Capricorn.

**METAMORPHIC ROCKS**

**Gneiss**: Gneiss is a foliated metamorphic rock identified by its bands and lenses of varying composition, while other bands contain granular minerals with an interlocking texture. Other bands contain platy or elongate minerals with evidence of preferred orientation. It is this banded appearance and texture - rather than composition - that define a gneiss. Although gneiss is not defined by its composition, most specimens have bands of feldspar and quartz grains in an interlocking texture. These bands are usually light in color and alternate with bands of darker-colored minerals with platy or elongate habits. The dark minerals sometimes exhibit an orientation determined by the pressures of metamorphism.

**Uses of Gneiss**: Gneiss usually does not split along planes of weakness like most other metamorphic rocks. This allows contractors to use gneiss as a crushed stone in road construction, building site preparation, and landscaping projects.
Some gneiss is durable enough to perform well as a dimension stone. These rocks are sawn or sheared into blocks and slabs used in a variety of building, paving, and curbing projects.

Quartzite: Quartzite is a nonfoliated metamorphic rock composed almost entirely of quartz. It forms when a quartz-rich sandstone is altered by the heat, pressure, and chemical activity of metamorphism. These conditions recrystallize the sand grains and the silica cement that binds them together. The result is a network of interlocking quartz grains of incredible strength. The interlocking crystalline structure of quartzite makes it a hard, tough, durable rock. It is so tough that it breaks through the quartz grains rather than breaking along the boundaries between them. This is a characteristic that separates true quartzite from sandstone.

Uses of Quartzite
Quartzite has a diversity of uses in construction, manufacturing, architecture, and decorative arts. Although its properties are superior to many currently used materials, its consumption has always been low for various reasons. The uses of quartzite and some reasons that it is avoided are summarized below.

Slate: Slate is a fine-grained, foliated metamorphic rock that is created by the alteration of shale or mudstone by low-grade regional metamorphism. It is popular for a wide variety of uses such as roofing, flooring, and flagging because of its durability and attractive appearance. Slate is composed mainly of clay minerals or micas, depending upon the degree of metamorphism to which it has been subjected. The original clay minerals in shale alter to micas with increasing levels of heat and pressure. Slate can also contain abundant quartz and small amounts of feldspar, calcite, pyrite, hematite, and other minerals.

Uses of Slate
Most of the slate mined throughout the world is used to produce roofing slates. Slate performs well in this application because it can be cut into thin sheets, absorbs minimal moisture, and stands up well in contact with freezing water. A disadvantage is the cost of the slate and its installation in comparison with other roofing materials. As a result, in new construction slate is mainly confined to high-end projects and prestige architecture.

DECORATIVE STONES

Porphyries: Porphyry is a reddish-brown to purple igneous rock containing large phenocrysts of various minerals embedded in a fine-grained matrix.
1. a very hard rock, anciently quarried in Egypt, having a dark, purplish red groundmass containing small crystals of feldspar
2. any igneous rock containing coarse crystals, as phenocrysts, in a finer-grained groundmass.

**Marble:** Marble is a **metamorphic rock** that forms when **limestone** is subjected to the heat and pressure of metamorphism. It is composed primarily of the mineral **calcite** (CaCO$_3$) and usually contains other minerals, such as clay minerals, micas, **quartz**, **pyrite**, iron oxides, and **graphite**. Under the conditions of metamorphism, the calcite in the limestone recrystallizes to form a rock that is a mass of interlocking calcite crystals. A related rock, dolomitic marble, is produced when **dolostone** is subjected to heat and pressure.

**Quartzite:** In architecture, **marble** and **granite** have been the favorite materials for thousands of years. Quartzite, with a **Mohs hardness** of seven along with greater toughness, is superior to both in many uses. It stands up better to abrasion in stair treads, floor tiles, and countertops. It is more resistant to most chemicals and environmental conditions. It is available in a range of neutral colors that many people prefer. The use of quartzite in these uses is growing slowly as more people learn about it.

**Decorative Use**

Quartzite can be a very attractive stone when it is colored by inclusions. Inclusions of **fuchsite** (a green chromium-rich variety of **muscovite** mica) can give quartzite a pleasing green color. If the quartzite is semitransparent to translucent, the flat flakes of mica can reflect light to produce a glittering luster known as adventurine. Material that displays this property is known as "**aventurine**" a popular material used to produce beads, cabochons, **tumbled stones**, and small ornaments. Aventurine can be pink or red when stained with iron. Included dumortierite produces a blue color. Other inclusions produce white, gray, orange, or yellow aventurine.