Chapter one
Introduction

Geology is the study of the Earth. Geology is the science of the Earth, its composition and structure, its history, and its past plant and animal life.
In a general, geology is divided into two major groups. The first, called *Physical Geology* deals with the materials that constitute the Earth (soils and rocks), the structures and surface features of the Earth, and the processes that created these structures. The second group called *Historical Geology* deals with the history of the Earth.

Geology is further divided into a number of branches according to the subject matter that is covered or to the industrial or commercial applications. Subject matters of possible interest to engineers include:
Petrology: systematic study of rocks and their origin. It consists of *Petrography* (identification, description, and classification of rocks) and *Petrogenesis* (study of origin of rocks);
Mineralogy: study of rock constituents or minerals;
Crystallography: deals with the atomic structure of minerals and their external appearance;
Geochemistry: study of the chemistry of rocks;
Geomorphology: study of landforms, their origin and development;
Stratigraphy: study of layered rocks, mostly those of sedimentary origin;
Structural Geology: deals with the position of rock bodies, their deformation, and fracturing;
Geophysics: application of principles of physics to the study of the Earth. It consists of *Geomagnetic* (study of Earth's magnetic field) and *Seismology* (study of earthquakes);
Geodesy: study of the form and size of the Earth;
Oceanography: study of oceans and basins;
Paleontology: study of life of past geologic periods and evolution of plants and animals;
Engineering Geology: geology and engineering;
Hydrogeology, Hydrology: study of underground and surface water

Engineering geology is an interdisciplinary field in which pertinent studies in geology and other geosciences areas are applied toward the solution of problems involved in engineering works and resources uses" engineering geology as "[The] application of geologic data, techniques, and principles to the study of naturally occurring rock and soil materials or subsurface fluids. The purpose is to assure that geologic factors affecting the planning, design, construction, operation, and maintenance of engineering structures and the development of groundwater resources are recognized, adequately interpreted, and presented for use in engineering practice".

Engineering geology provides a means to *appreciate* and *identify* geologic features that could have short and long term consequences to the overall performance of engineering structures and projects.
Examples of geologic problems associated with some areas of CEAE engineering practice are:
Foundations for bridges, towers, high-rise buildings, residences, dams, and offshore structures:
- Settlement (uniform or differential)
- Settlement due to soft layers and compressible soils
- Settlement due to fluid withdrawal
- Settlement due to uneven ground composition (landfills, cemeteries, sewers, etc.)
- Subsidence associated with underground mining
- Subsidence into natural caverns (caves, karsts, etc.)
- Dam movement due to unstable foundation and abutments
- Frost heave and solifluction (soil creep caused by waterlogged soil slowly moving downhill on top of an impermeable layer)
- Heaving and settling due to swelling ground
- Liquefaction
- Scouring (erosion) of bridge pier foundations
- Deterioration by acid waters

Slopes and surface excavations for canals, highways, railways, pipelines, penstocks, dam abutments, open pit mines, quarries and trenches, landfills.
- Landslides (including rock falls, flows, creep, both natural and man-induced)
- Block movement by sliding or toppling
- Block movement during blasting or earthquakes

Stability problems of earth and rockfill dams
- Drainage and dewatering problems
- Piping, liquefaction
- Piercing of landfill lining and ground contamination

Underground Excavations for tunnels, mines, underground chambers, hydroelectric plants, pump storage plants, gas and water storage chambers, subsurface space, and military shelters.
- Caving and collapse of a section
- Water problems
- Squeezing and swelling ground
- Rock bursts
- Leakages of stored material (toxic and non-toxic)
- Toxic gases (radon, methane, sulfur dioxide) and dusts (asbestos)
- Disposal of excavated ground

Chapter Two
Rocks and Minerals

Rocks

Engineering geology deals with two types of earth materials: *rocks* and *soils*. Both materials are used in themselves as raw sources for construction materials (aggregates, construction stones, decorative stones, etc.). They can also be used as foundation materials to support foundations for bridges, towers, high-rise buildings, residences, dams, and offshore structures. The behavior of those structures is partly determined by the proper selection and sizing of man-made materials such as concrete and steel, and partly determined by the geology and the properties of the underlying rock or soil on which the structures must rest. Rocks and soils become the engineering material in surface excavations (quarries, canals, highway and railroad cuts, surface mines, gravel pits, etc.) and underground excavations (tunnels, caverns, hydroelectric plants, pump storage plants, gas and water storage facilities, waste repositories, military shelters, etc.).

Here, the performance (short and long term) of the structures depends on the rock/soil type as well as the rock/soil quality, strength, deformability, permeability, etc. Rocks and soils are also critical factors in determining the extent of leakage and contaminant transport and in assessing the potential of environmental problems associated with the disposal of various types of waste (chemical, nuclear, etc.). Finally, rocks and soils are important in the investigation and development of surface and ground water resources.

From an engineering point of view, a *rock* is an aggregate of mineral grains that are connected by strong and permanent forces that cannot be separated by slight mechanical means. On the other hand, a *soil* is an aggregate of mineral grains that can be separated by slight mechanical means.

In general, soils are formed from the erosion or weathering (mechanical, chemical) of rocks. The weathering zone (i.e. the volume of weathered rock) can be a few feet thick in arid areas and several hundred feet thick in tropical (hot and humid) areas. A rock that is not weathered is called "fresh" (weathering grade I), whereas a fully weathered rock is called a soil (weathering grade VI). Obviously, there is a wide range of earth materials that fit in between those two extremes. Some of them have properties that are more rock dominant whereas others have properties that are more soil dominant; these materials are called *rock-like soils* or *soil-like rocks*.

As civil engineers, on a given project, we need to know the vertical and lateral extent of the weathering zone, the different grades of weathering, and how deep the fresh unweathered rock is located.

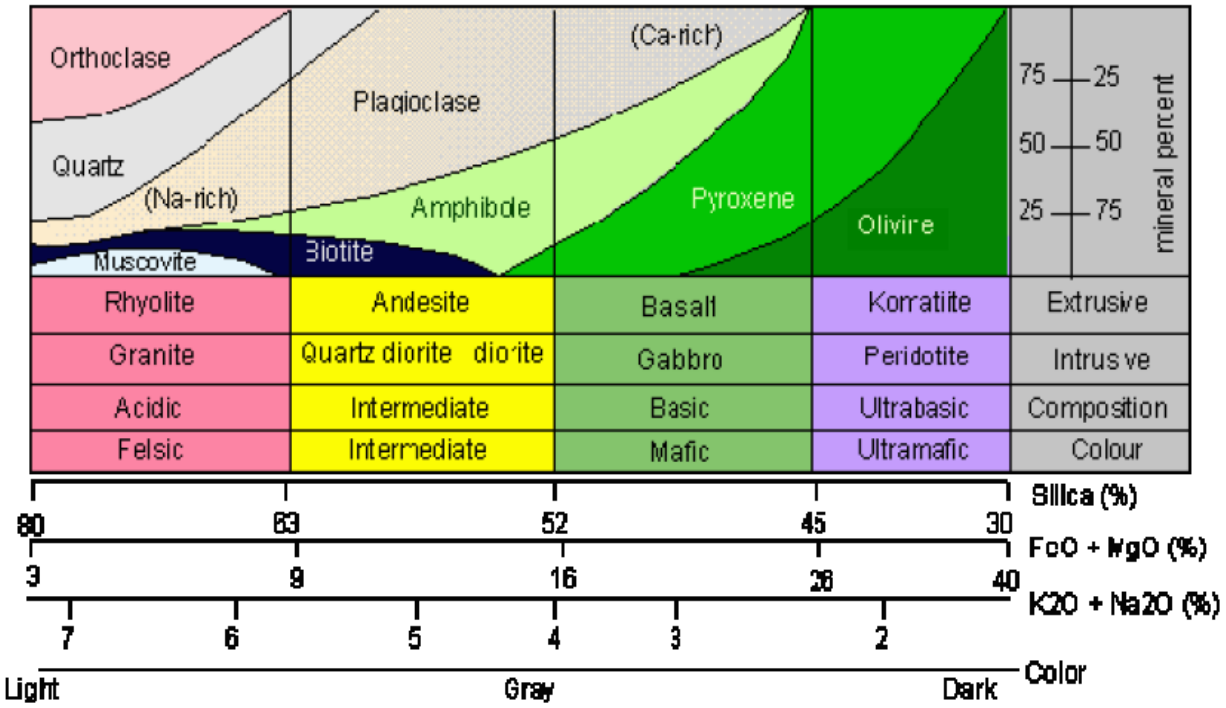
For a geologist, the term *rock* means all the material found in the Earth's crust regardless of the degree of bonding between the mineral grains, whereas the term *soil* is reserved for the upper part of the ground surface that is supporting the vegetation.

According to their origin, rocks are divided into three groups, namely, the igneous, metamorphic and sedimentary rocks.

Igneous Rocks

Igneous rocks are formed when hot molten rock material called magma solidifies. Magmas are developed when melting occurs either within or beneath the Earth's crust, that is, in the upper mantle. They comprise hot solutions of several liquid phases, the most conspicuous of which is a complex silicate phase. Thus, igneous rocks are composed principally of silicate minerals. Furthermore, of the silicate minerals, six families – the olivines [(Mg,Fe)2SiO4], the pyroxenes [e.g. augite, (Ca, Mg, Fe, Al)2(Al,Si)2O6], the amphiboles [e.g. hornblende, (Ca,Na,Mg,Fe,Al)7 8(Al,Si)8O22(OH)2], the micas [e.g. muscovite, KAl2(AlSi2)10(O,F)2; and biotite, K(Mg,Fe)2(AlSi3)O10(OH,F)2], the feldspars (e.g. orthoclase, KAlSi3O8; albite, NaAlSi3O8; and anorthite, CaAl2Si2O8) and the silica minerals (e.g. quartz, SiO2) – are quantitatively by far the most important constituents. Figure 1.1 shows the approximate distribution of these minerals in the commonest igneous rocks.
Igneous rocks may be divided into intrusive and extrusive types, according to their mode of occurrence. In the former type, the magma crystallizes within the Earth's crust, whereas in the latter, it solidifies at the surface, having erupted as lavas and/or pyroclasts from a volcano. The intrusions have been exposed at the surface by erosion. They have been further subdivided on the basis of their size, that is, into major (plutonic) and minor (hypabyssal) categories.

The Identification Chart of the Igneous Rocks



Engineering Aspects of Igneous Rocks

The plutonic igneous rocks are characterized by granular texture, massive structure and relatively homogeneous composition. In their unaltered state, they are essentially sound and durable with adequate strength for any engineering requirement. In some instances, however, intrusive rocks may be highly altered by weathering or hydrothermal attack; furthermore, fissure zones are by no means uncommon. The rock mass may be fragmented along such zones; indeed, it may be reduced to sand-size material, or it may have undergone varying degrees of kaolinization

Generally speaking, the older volcanic deposits do not prove a problem in foundation engineering, ancient lavas having strengths frequently in excess of 200 MPa. But volcanic deposits of geologically recent age prove treacherous at times, particularly if they have to carry heavy loads. This is because they often represent markedly anisotropic sequences in which lavas, pyroclasts and mudflows are interbedded. In addition, weathering during periods of volcanic inactivity may have produced fossil soils, these being of much lower strength. The individual lava flows may be thin and transected by a polygonal pattern of cooling joints. They also may be vesicular or contain pipes, cavities or even tunnels

Normally, the geomechanical properties of fresh basalts and dolerites are satisfactory for engineering purposes. Certain basalts and dolerites are susceptible to rapid weathering. This rapid breakdown phenomenon is referred to as slaking. Certain factors are responsible for causing and/or enhancing breakdown of basalts and dolerites. These include swelling and shrinking of smectitic clays upon hydration and dehydration, respectively.

Pyroclasts usually give rise to extremely variable ground conditions due to wide variations in strength, durability and permeability. Their behaviour very much depends on their degree of induration, for example, many agglomerates have enough strength to support heavy loads and also have a low permeability. By contrast, ashes are weak and often highly permeable. They also may be metastable and exhibit a significant decrease in their void ratio on saturation. Ashes are frequently prone to sliding.

Sedimentary rocks

Most sedimentary rocks are of secondary origin, in that they consist of detrital material derived by the breakdown of pre-existing rocks. Indeed, it has been variously estimated that shales and sandstones, both of mechanical derivation, account for between 75 and 95% of all sedimentary rocks. However, certain sedimentary rocks are the products of chemical or biochemical precipitation whereas others are of organic origin. Thus, the sedimentary rocks can be divided into two principal groups, namely, the clastic (detrital) or exogenetic, and the non-clastic or endogenetic types. Nevertheless, one factor that all sedimentary rocks have in common is that they are deposited, and this gives rise to their most noteworthy characteristic, that is, they are bedded or stratified.
The particles of which most sedimentary rocks are composed have undergone varying amounts of transportation. The amount of transport together with the agent responsible, be it water, wind or ice, play an important role in determining the character of a sediment. For instance, transport over short distances usually means that the sediment is unsorted (the exception being beach sands), as does transportation by ice. With lengthier transport by water or wind, not only does the material become better sorted but it is further reduced in size.

Types of Sedimentary rocks
Limestone is produced from the mineral calcite (calcium carbonate) and sediment. The main source of limestone is the limy ooze formed in the ocean.
Sandstone is a sedimentary rock that formed from the cementing together of sand sized grains forming a solid rock. Quartz is the most abundant mineral that forms sandstone. Calcium carbonate, silica, or iron has been added to the water that is in contact with the sand grains.
Chert is a very hard sedimentary rock that is usually found in nodules in limestone. It probably formed from the remains of ancient sea sponges or other ocean animals that have been fossilized. Silica has replaced the tissue forming the sedimentary rock.
Conglomerate is a sedimentary rock that forms from the cementing of rounded cobble and pebble sized rock fragments. It is formed by river movement or ocean wave action.

The cementing agents that fill the spaces to form the solid rock are silica, calcite, or iron oxides

Engineering Aspects of Sedimentary rocks

Sandstones

Sandstones may vary from thinly laminated micaceous types to very thickly bedded varieties.
Moreover, they may be cross-bedded and are jointed. With the exception of shaley sandstone, sandstone is not subject to rapid surface deterioration on exposure.
Sandstones are composed chiefly of quartz grains that are highly resistant to weathering, but other minerals present in lesser amounts may be suspect, for example, feldspars may become kaolinized. Calcareous cements are vulnerable to attack by weak acids

Limestone

carbonate rocks are susceptible to dissolution, which commonly removes shell fragments. An important effect of dissolution in limestone is enlargement of the pores that enhances water circulation, thereby encouraging further dissolution. This brings about an increase in stress within the remaining rock framework that reduces the strength of the rock mass and leads to increasing stress corrosion. On loading, the volume of the voids is reduced by fracture of the weakened cement between the particles and by the reorientation of the intact aggregations of rock that become separated by loss of bonding. Most of the resultant settlement takes place rapidly within a few days of the application of load.
Dissolution of limestone is a very slow process. Nevertheless, it may be accelerated by man-made changes in groundwater conditions or by a change in the character of the surface water that drains into limestone . Generally limestone develop caves (dissolution cavity) when interacts with water.





Metamorphic Rocks

Metamorphic rocks are derived from pre-existing rock types and have undergone mineralogical, textural and structural changes. These changes have been brought about by changes that have taken place in the physical and chemical environments in which the rocks existed. The processes responsible for change give rise to progressive transformation in rock that takes place in the solid state. The changing conditions of temperature and/or pressure are the primary agents causing metamorphic reactions in rocks. Some minerals are stable over limited temperature–pressure conditions, which mean that when these limits are exceeded mineralogical adjustment has to be made to establish equilibrium with the new environment.

Most deformed metamorphic rocks possess some kind of preferred orientation. Preferred orientations may be exhibited as mesoscopic linear or planar structures that allow the rocks to split more easily in one direction than in others. One of the most familiar examples is cleavage in slate; a similar type of structure in metamorphic rocks of higher grade is schistosity. Foliation comprises a segregation of particular minerals into inconstant bands or contiguous lenticles that exhibit a common parallel orientation.

Slaty cleavage is probably the most familiar type of preferred orientation and occurs in rocks of low metamorphic grade. It is characteristic of slates and phyllites. It is independent of bedding, which it commonly intersects at high angles; and it reflects a highly developed preferred orientation of minerals, particularly of those belonging to the mica family.

Foliation in a metamorphic rock is a very conspicuous feature, consisting of parallel bands or tabular lenticles formed of contrasting mineral assemblages such as quartz–feldspar and biotite–hornblende. It is characteristic of gneisses. This parallel orientation agrees with the direction of schistosity, if any is present in nearby rocks.

Types of Metamorphic Rocks

- Slate & Mica schist : from mudstone (shale)
- Green schist : from basalt and gabbro
- Quartzite :Qtz arenite
- Marble : limestone

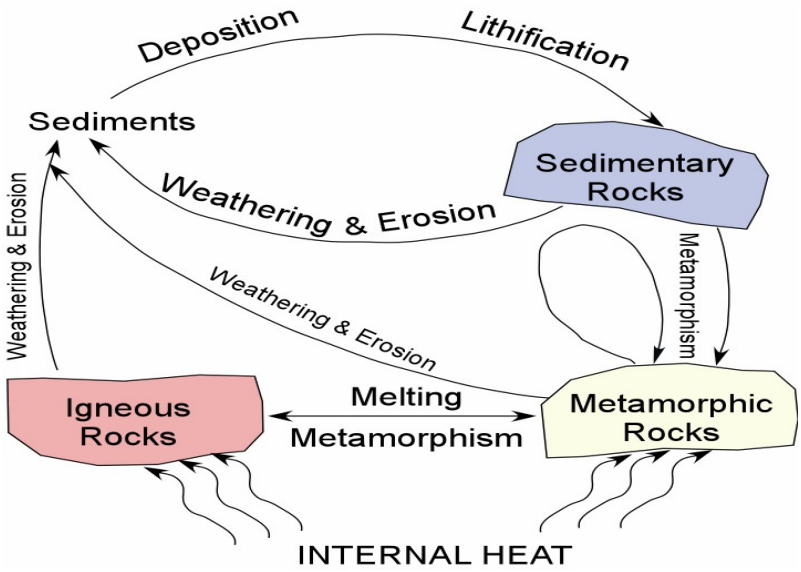
Engineering character of Metamorphic Rocks

Slates, phyllites and schists are characterized by textures that have a marked preferred orientation.

This preferred alignment of platey minerals accounts for cleavage and schistosity that typify these metamorphic rocks and means that slate, in particular, is notably fissile. Obviously, such rocks are appreciably stronger across than along the lineation.

Not only does cleavage and schistosity adversely affect the strength of metamorphic rocks, it also makes them more susceptible to decay. Generally speaking, however, slates, phyllites and schists weather slowly but the areas of regional metamorphism in which they occur have suffered extensive folding so that rocks may be fractured and deformed in places.
The engineering performance of gneiss usually is similar to that of granite. However, some gneisses are strongly foliated, which means that they possess a texture with a preferred orientation.
Fresh, thermally metamorphosed rocks such as quartzite and hornfels are very strong and afford good ground conditions. Marble generally has the same advantages and disadvantages as other carbonate rocks.

Rock Cycles


Deposition
Lithification
Sediments
Sedimentary Rocks
Weathering & Erosion
Weathering & Erosion
Weathering & Erosion
Metamorphism
Igneous Rocks
Melting
Metamorphism
Metamorphic Rocks
INTERNAL HEAT

Chapter Three

Geologic Structures

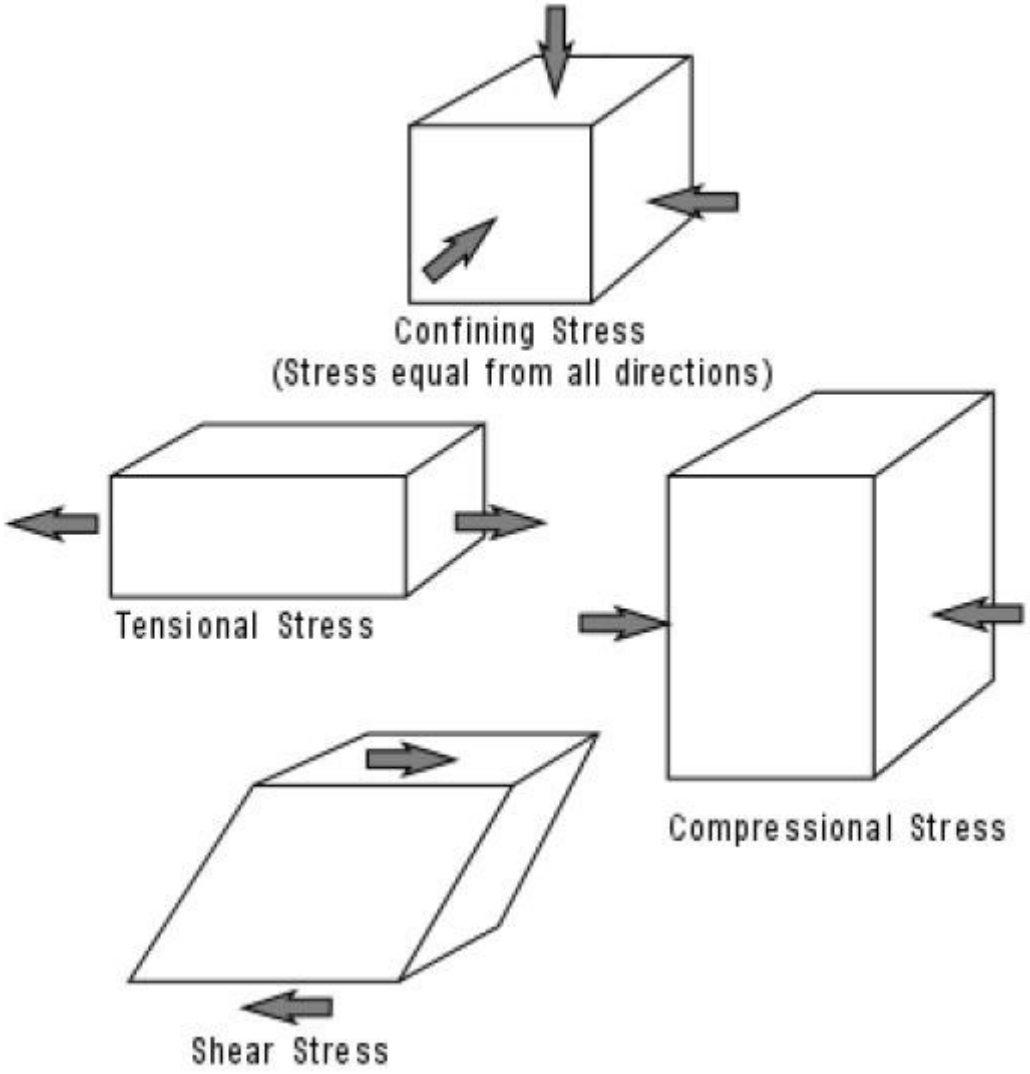
The rocks of the earth's crust are generally unstable, and are subjected to a number of forces operating within the earth's body. Due to these forces, which may operate either during or after the formation of rocks, the rocks may undergo deformation to varying degrees, depending upon the intensity and type of the forces, and rigidity of the rocks.
Only in a few cases does deformation of rocks occur at a rate that is observable on human time scales. Abrupt deformation along faults, usually associated with earthquakes caused by the fracture of rocks occurs on a time scale of minutes or seconds. Gradual deformation along faults or in areas of uplift or subsidence can be measured over periods of months to years

Causes for deformities or development of structures:
1. Constant mould and remould of the crust by exogenous geological agents (Weathering).
2. Instability of earth's interior resulting in plate tectonics or movements i.e orogenic and epeirogenic movements. The orogenic movements are mainly lateral and involve crustal deformations leading to the formation of mountains. The epeirogenic movements are primarily vertical and involve continental formation.

In the Earth the pressure due to the weight of overlying rocks is a uniform stress, and is sometimes referred to as confining stress.
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.

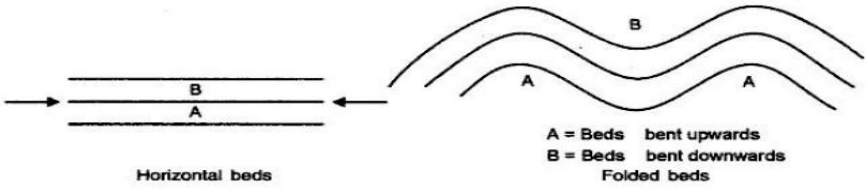
When rocks deform they are said to strain. A strain is a change in size, shape, or volume of a material.



Stages of Deformation

Folds, faults, joints are the most commonly found geological structures in nature.

Folds:
The term fold is used in geology when one or a stack of originally flat and planar surfaces, such as sedimentary strata, are bent or curved as a result of permanent deformation.

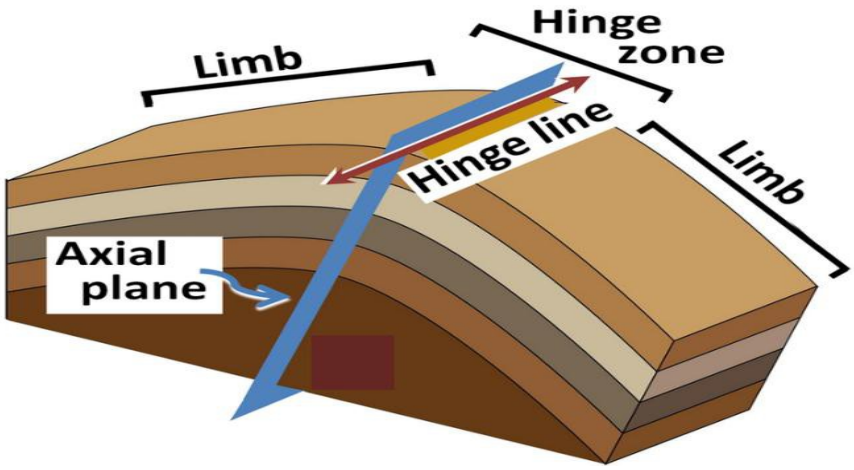


Folds are commonly formed by shortening of existing layers, but may also be formed as a result of displacement on a non-planar fault (fault bend fold), at the tip of a propagating fault (fault propagation fold), by differential compaction or due to the effects of a high-level igneous intrusion e.g. above a laccolith.

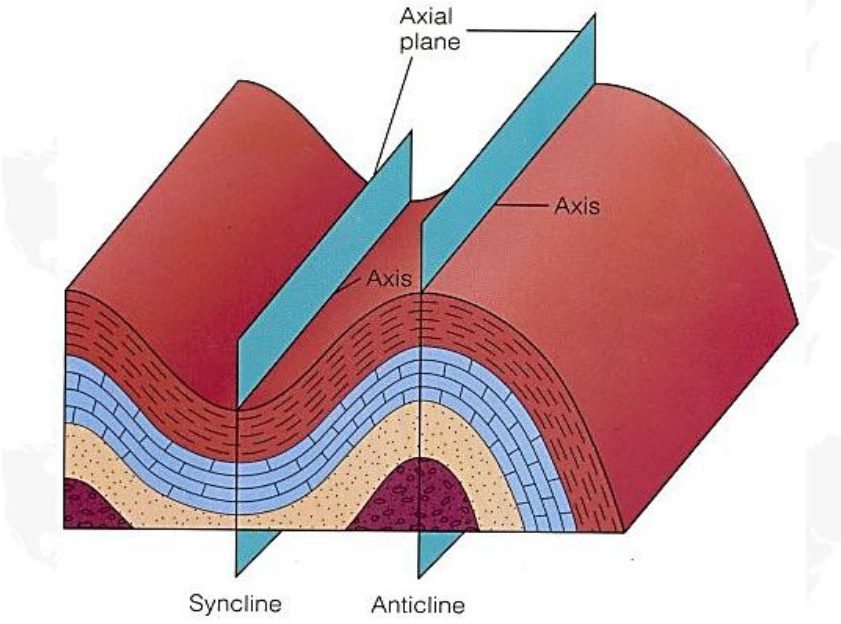


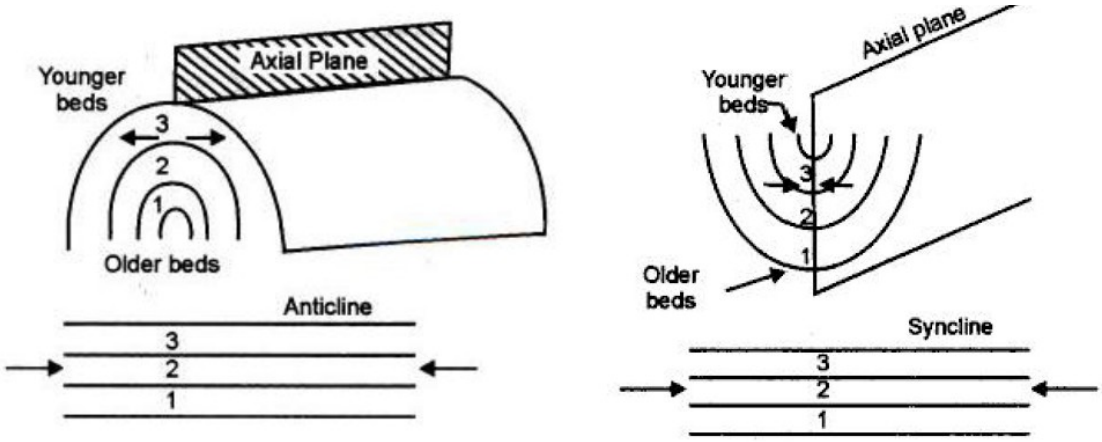
Folds are classified by their size, fold shape, tightness, and dip of the axial plane.

Fold terminology in two dimensions
Looking at a fold surface in profile the fold can be divided into hinge and limb portions. The limbs are the flanks of the fold and the hinge is where the flanks join together. The hinge point is the point of maximum radius of curvature for a fold. The crest of the fold is the highest point of the fold surface, and the trough is the lowest point. The inflection point of a fold is the point on a limb at which the concavity reverses; on regular folds, this is the midpoint of the limb.



Simple folds are divided into two types, that is, anticlines and synclines When the beds are bent upwards, the resulting fold is called anticline. When the beds are bent downwards, the resulting fold is syncline.
In the anticline, the fold will be convex upwards and the younger beds occur towards convex side. In the syncline, the fold will be convex downwards and the younger beds occur towards the concave side.



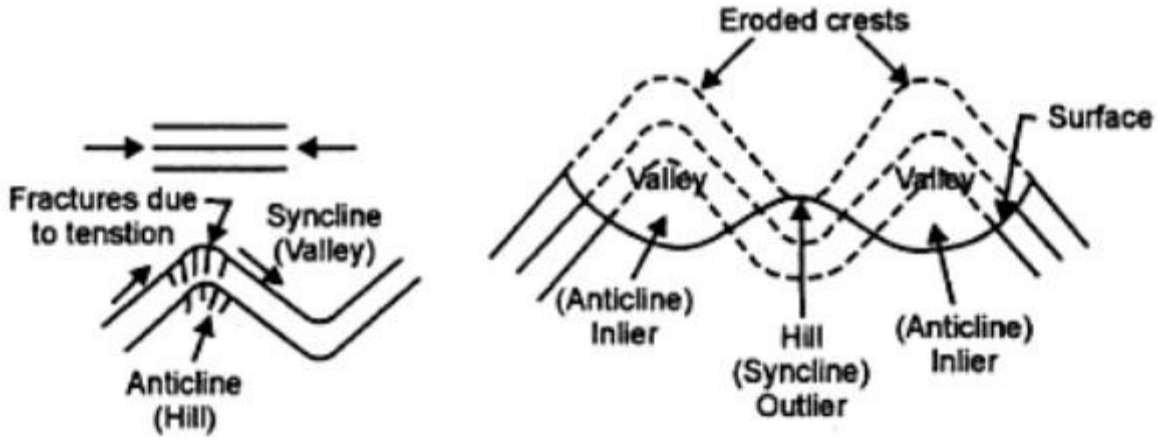


Effects of folding:

When a folded area is affected by weathering and erosion, interesting topographic features are produced as follows:

- Immediately after folding, anticlines by virtue of their upward bending appear as hills and synclines due to downward wrapping appear as valleys.

During folding in crest portions, the geological formation is subjected to tensional forces and hence numerous fractures appear there. Because of the fractures, crest portions are eroded quickly leading to conspicuous degradations locally. On the other hand trough portions are highly compressed and hence offer a greater resistance to erosion.



Fault:

A fault is a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement along the fractures as a result of earth movement. Large faults within the Earth's crust result from the action of plate tectonic forces. Energy release associated with rapid movement on active faults is the cause of most earthquakes

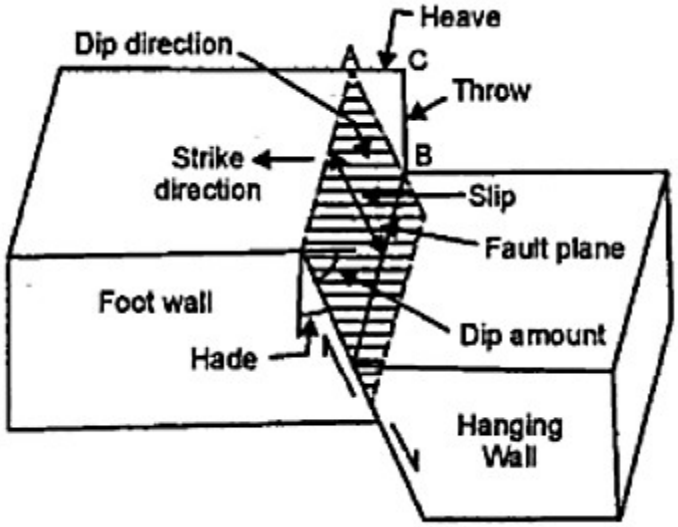
A fault line is the surface trace of a fault, the line of intersection between the fault plane and the Earth's surface. Since faults do not usually consist of

a single, clean fracture, geologists use the term fault zone when referring to the zone of complex deformation associated with the fault plane.

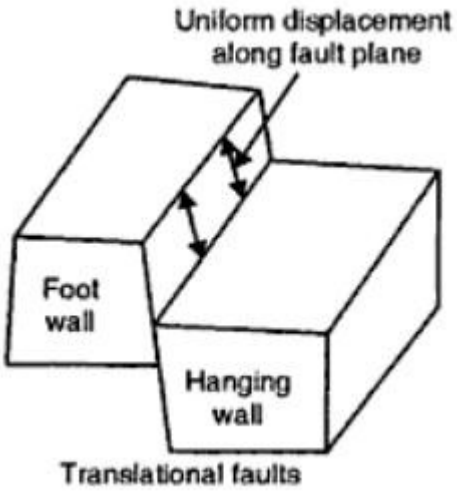
Technical words:

Slip:
Slip is defined as the relative movement of geological features present on either side of a fault plane, and is a displacement vector.
Sense of slip:
Sense of slip is defined as the relative motion of the rock on each side of the fault with respect to the other side.

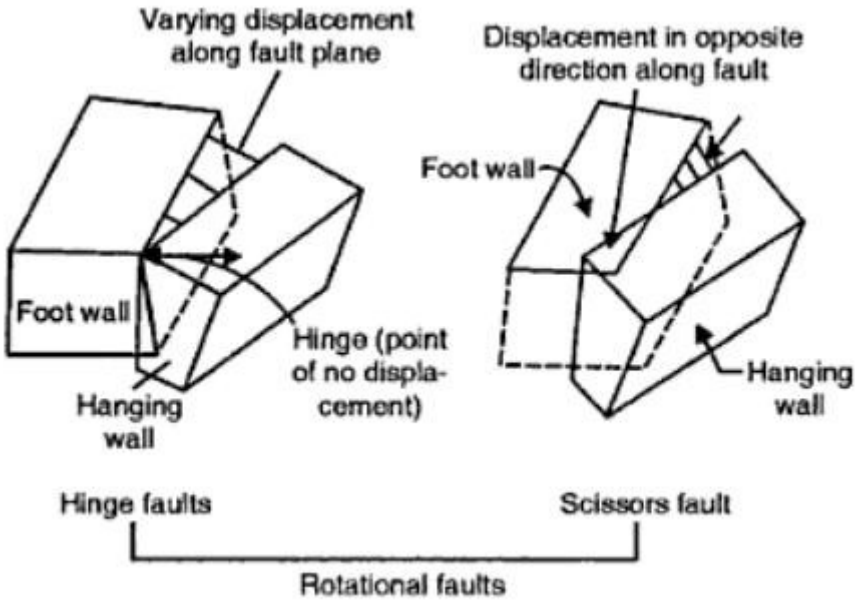
Throw:
Throw of the fault is the vertical component of the dip separation
Heave:
Heave of the fault is the horizontal component.
Fault Plane:
The plane along which the adjacent blocks are relatively displaced is fault plane.
Foot wall & Hanging Wall:
The two sides of a non-vertical fault are known as the hanging wall and footwall. By definition, the hanging wall occurs above the fault plane and the footwall occurs below the fault. This terminology comes from mining: when working a tabular ore body, the miner stood with the footwall under his feet and with the hanging wall hanging above him.



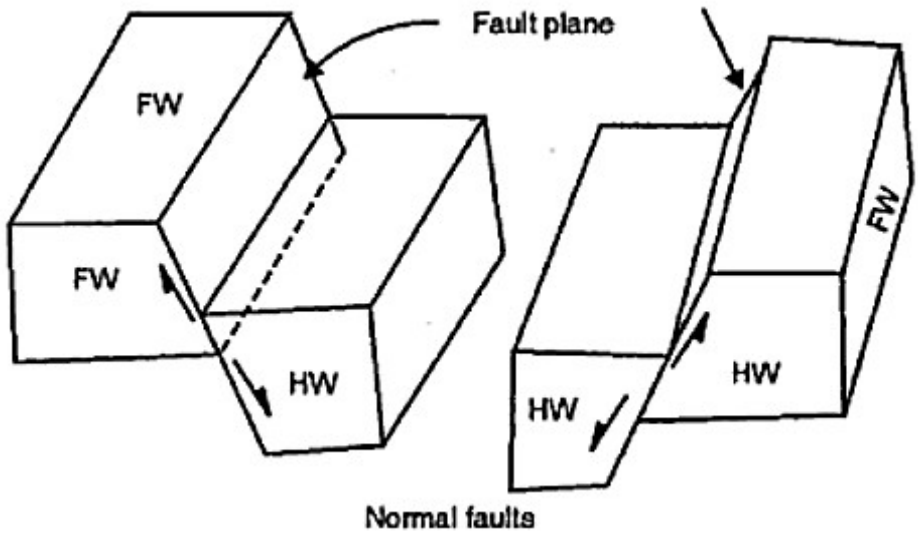
Types of faults:
Translational fault:
If the displacement of the footwall with reference to the hanging wall is uniform along the fault plane, it is translational fault.



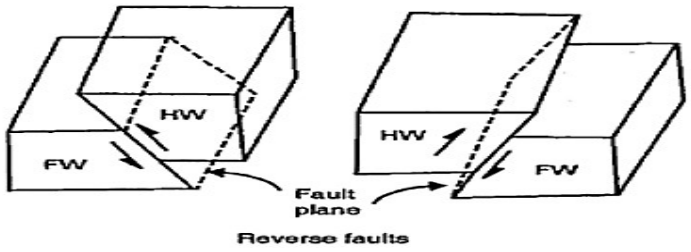
Rotational fault:
If the displacement of footwall gradually increases or decreases with reference to hanging wall, it is said to be rotational fault.



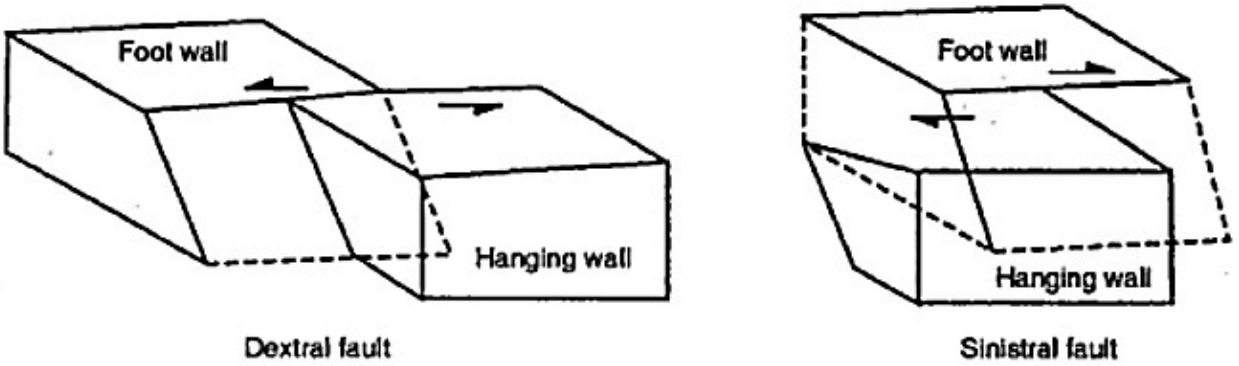
Normal fault:
If the hanging wall goes down with reference to the foot wall, it is called normal fault or gravity fault.



Reverse fault:
If the relative displacement of the hanging wall is upwards with reference to the foot wall, it is reverse fault or thrust fault.



Dextral faults:
If the relative displacement of the hanging wall is neither upwards nor downwards with the reference to the inclined fault plane, but side wards, then the faults are described as dextral faults. These are also called sinistral faults. If the relative displacement is towards right hand side, it is dextral and if it is towards left hand side, it is sinistral.



Effect of faults

- Collapsed Structure, Oakland, California
- Faults generate earthquakes
- Bound the tectonic plates of the Earth
- Deform the Earth's surface
- Fluid transport in the Earth's crus
    a. Water
    b. Magma
    c. Hydrocarbons
    d. Hydrothermal fluids
- Faults are zones of weakness to account for in engineering projects



Joints:

Joint is a fracture in rock where the displacement associated with the opening of the fracture is greater than the displacement due to lateral movement in the plane of the fracture (up, down or sideways) of one side relative to the other. Typically, there is little to no lateral movement across joints. This makes joints different from a fault which is defined as a fracture in rock in which one side slides laterally past the other with a displacement that is greater than the separation between the blocks on either side of the fracture. Joints normally have a regular spacing related to either the mechanical properties of the individual rock or the thickness of the layer involved. Joints generally occur as sets, with each set consisting of joints sub-parallel to each other.

Effects of joints:

From the civil engineering point of view, joints are important because they split the rocks into a number of pieces which, in turn, reduce the competence of rock mass, increase the porosity and permeability and make them susceptible to quick decay and weathering. Joints become avenues for the leakage of water in case of reservoirs. If they are closely spaced in the upstream side, silting problems also arise in reservoirs. Joints may pose ground water problems in tunnelling. The incompetence, leakage and other effects introduced by joints in rocks may create foundation problems at dam sites. Depending on the relation of the dip of joints in rocks with reference to the surface slope, they may pose problems in laying roads and railways along hill slopes. But a few advantages that accompany joints are: their occurrence increases the ground water potentiality in any place. Suitably spaced joints not only facilitate the quarrying process or tunnelling process but also reduce the cost by decreasing the use of explosives.

Chapter Four

Geologic Surface Processes

WEATHERING

When exposed to atmospheric conditions, rocks slowly break down. This process is called weathering and can be separated into mechanical (also called physical) weathering and chemical weathering.

Mechanical Weathering

Mechanical weathering causes disintegration of rocks into smaller pieces by exfoliation or decrepitation (slaking). The chemical composition of the parent rock is not or is only slightly altered. Mechanical weathering can result from the action of agents such as frost action, salt crystallization, temperature changes (freezing and thawing), moisture changes (cycles of wetting and drying), wind, glaciers, streams, unloading of rock masses (sheet jointing), and biogenic processes (plants, animals, etc.).

For instance, mechanical weathering is very active in high mountains with cold climates. The 9% increase in volume associated with the transformation of water into ice as the temperature drops below 0°C can create pressures large enough to crack rocks.

Another example is the weathering associated with the natural unloading of massive granitic or sandstone rock masses associated with removal of overburden. As unloading takes place, discontinuities called sheet joints (also called exfoliation joints or lift joints) may develop parallel to the surface of rock outcrops. The rock outcrops appear to be spalling off like layers of a giant onion. The rock mass is divided onto blocks or sheets, a few centimeters thick near the ground surface and becoming thicker with depth until it fades out completely at depth of about 50 m.

Stability problems can arise if these joints dip toward excavations with a potential for detachment of sheets.

A last example of mechanical weathering is the one associated with the rapid cooling and heating of rocks in desert areas. Temperature gradients are large enough to crack rocks

Chemical Weathering

This type of weathering creates new minerals in place of the ones it destroys in the parent rock.

As rocks are exposed to atmospheric conditions at or near the ground surface, they react with components of the atmosphere to form new minerals. The most important atmospheric reactants are oxygen, carbon dioxide, and water. In polluted air, other reactants are available (acid rain problems associated with the release of sulfuric acid from coal-fired power plants, sulfur dioxide and smoke emissions, nitrogen oxides from vehicle exhaust). In general, chemical weathering reaction are exothermic and cause volume increases.

Solution is a reaction whereby a mineral completely dissolves during weathering. This type of reaction depends on the solubility of the rock minerals. For instance, evaporite minerals (salt, gypsum) dissolve quickly in water, whereas carbonate minerals are somewhat less soluble.
Limestone dissolves by meteoric water which contains dissolved carbon dioxide. This results in the formation of cavities called *dolines* or *karsts* and geologic hazards called *sink holes*.
Because of impurities in the limestone, a red residual soil remains at the limestone surface called *terra rossa*

Hydrolysis is the reaction between acidic weathering solutions and many of the silicate minerals.
Feldspars are transformed by hydrolysis as they react with hydrogen ions to form various products including clay minerals. This phenomenon is responsible for the degradation of granite and other plutonic rocks to a material that resembles more of a dense soil than a rock. The disintegrated granite called *grus*, *saprolite*, or *spheroidal granite* consists of rounded blocks surrounded by a mixture of detrital clays and resistant grains of quartz.

Hydration corresponds to the penetration of water into the lattice structure of minerals. A good example is the hydration of anhydrite into gypsum which is often accompanied with large volume increases and substantial swelling pressures

Oxidation corresponds to the reaction of free oxygen with metallic elements. This reaction is familiar to everyone as rust. In an oxidation reaction, the iron atoms contained in the minerals lose one or more electrons each and then precipitate as different minerals or amorphous substances. An example of oxidation reaction is the transformation of pyrite (FeS_2) into iron hydroxides that liberates sulfuric acid. The sulfuric acid can also attack calcium carbonate to produce gypsum. This production of gypsum creates a local volume increase and possible attack of concrete. Oxidation of pyrite in mudstone can transform chlorite into smectite along the oxidation front. The increase in smectite is expected to be closely related to landslides.

Effect of Weathering in Engineering

The degree and pattern of weathering are among the most important factors to be determined in an on-site exploration. In general, as weathering takes place, the engineering properties of a rock change. Its porosity, permeability and deformability increase whereas its strength decreases. This detrimental changes can be critical to the suitability of a site for structures such as dams which require maximum strength and elasticity.

Also, geologic hazards can be created in weathered areas such as block movement, or landslides

Most engineering works involve rocks in various levels within the weathered zone.

Engineers need to know the elevations and locations of structures, selecting the types of foundations and locating the materials with which to build them. Weathering controls the depth to the bedrock and the uniformity of this contact.

Chapter Five

Earth Quake

The plates that make up the earth's lithosphere are constantly in motion. The rate of motion is a few centimetres per year, or approximately 0.1 mm per day (about as fast as your fingernails grow). This does not mean, however, that the rocks present at the places where plates meet (e.g., convergent boundaries and transform faults) are constantly sliding past each other. Under some circumstances they do, but in most cases, particularly in the upper part of the crust, the friction between rocks at a boundary is great enough so that the two plates are locked together. As the plates themselves continue to move, deformation takes place in the rocks close to the locked boundary and strain builds up in the deformed rocks. This strain, or elastic deformation, represents potential energy stored within the rocks in the vicinity of the boundary between two plates. Eventually the strain will become so great that the friction and rock-strength that is preventing movement between the plates will be overcome, the rocks will break and the plates will suddenly slide past each other - producing an earthquake

A huge amount of energy will suddenly be released, and will radiate away from the location of the earthquake in the form of deformation waves within the surrounding rock. S-waves (shear waves), and P-waves (compression waves) are known as body waves as they travel through the rock. As soon as this happens, much of the strain that had built up along the fault zone will be released.

The severity of earthquakes generated in any area will depend primarily on the degree to which the two plates are locked together along the boundary zone. The degree of locking will depend on several factors, including the rock types, the level of water saturation along the boundary, and the temperature.
The presence of weak or poorly consolidated rocks will prevent a fault zone from becoming locked. The presence of certain minerals, such as clays or graphite will lubricate a fault zone and also reduce the locking tendency.
Water will lubricate a fault zone, and thus will reduce the tendency for locking to take place. This is particularly significant if the rocks have clay minerals.
Temperature, which increases systematically with depth, will affect the tendency for locking. The higher the temperature the greater will be the tendency for the rocks to behave plastically, and hence the degree of locking will be reduced.
The actual location of an earthquake within the earth, is called its "focus" The point on the surface directly above the focus is known as the "epicentre". The location of an earthquake is determined from seismic

records, specifically by measuring the time interval between the first P wave and the first S wave. The distance from the seismic station to the focus of the earthquake can be determined from the time interval between the P and S events (As a rule of thumb, the distance in km is roughly equal to 10 times the interval in seconds.) By comparing distances from several seismic stations it is possible to determine the location of the epicentre If enough accurate data are available from seismic stations relatively close to the epicentre, it is also possible to determine the depth of the earthquake, that is the location of the focus

The Richter Scale—more appropriately called the magnitude scale—is one means of expressing the magnitude of an earthquake (i.e., the amount of energy released). A difference of 1 magnitude unit is equivalent a 10-fold difference in the amplitude of the waves on a seismograph, but to a 32-fold difference in the amount of energy released. Each year there are about 20 earthquakes over magnitude 7, and more than 100 over magnitude 6. An earthquake over magnitude 3 can only be felt in the area immediately around the epicenter

The amount of damage likely to be caused by an earthquake - or earthquake intensity - is measured on the Mercalli Scale, which ranges from I to XII [pages 268-269 and Table 10.1]. The intensity assigned to any earthquake is based on observations of witnesses and assessment of damages in the area around the epicentre, and for tens to hundreds of kilometres away. Intensities close to the epicentre will be different from those farther away. Where the intensity is around VI there will be minor damage to buildings. If the intensity is X or more many buildings will be destroyed, and there will be serious damage to dams and bridges and triggering of landslides. Variations in intensity with respect to distance from the epicentre will be affected by regional geology.

Where the underlying rocks are generally old and hard and strong, the effects of an earthquake are felt over a much wider area than is the case for the younger, softer and more variable rocks.

The amount of damage caused by an earthquake will also be related to the type of foundations on which buildings are built. Buildings on solid rock tend to be damaged less severely than those on unconsolidated sediments. *The explanation behind this is that different geological materials and structures have different harmonic frequencies.* Masses of solid rock normally have frequencies of significantly less than one second, while unconsolidated sediments have frequencies in the 1 to 3 second range. Many buildings also have harmonic frequencies of around 2 seconds. The high-energy vibrations from an earthquake are at the slower frequencies (longer than 1 second) and when these waves are transmitted into unconsolidated sediments they can set up vibrations in the sediments with much higher amplitudes than those of the waves themselves - in some cases the amplitudes are several tens of centimetres. These vibrations are then transmitted to the buildings, many of which vibrate at similar frequencies - causing them to collapse. Particularly severe damage can also occur in

areas where sediments are saturated with water, since the shaking can cause the sediments behave like a fluid so that they can no longer support buildings.

Chapter Six

Geological Site Investigation

The general objective of a site investigation is to assess the suitability of a site for the proposed purpose. As such, it involves exploring the ground conditions at and below the surface. It is a prerequisite for the successful and economic design of engineering structures and earthworks. Accordingly, a site investigation also should attempt to foresee and provide against difficulties that may arise during construction because of ground and/or other local conditions. Indeed, investigation should not cease once construction begins. It is essential that the prediction of ground conditions that constitute the basic design assumption be checked as construction proceeds and designs modified accordingly if conditions are revealed to be different from those predicted. The investigation of a site for an important structure requires exploration and sampling of strata likely to be significantly affected by the structural load. Data appertaining to groundwater conditions, extent of weathering, and discontinuity pattern in rock masses are also important. In some areas there are special problems that need investigating, for example, potential subsidence in areas of shallow abandoned mine workings and contaminated ground.
The complexity of a site investigation depends upon the nature of the ground conditions and the type of engineering structure. More complicated ground conditions and sensitive large engineering structures require more rigorous investigation of the ground conditions.
A site investigation usually consists of three stages, namely a desk study, a preliminary reconnaissance and a site exploration.

Desk Study

A desk study is undertaken as the first stage of a site investigation in order to make an initial assessment of the ground conditions and to identify, if possible, any potential geotechnical problems. In other words, the objective of a desk study is to examine available archival records, literature, maps, imagery and photographs relevant to the area or site concerned to ascertain a general picture of the existing geological conditions prior to a field investigation.
On large projects, literature and map surveys may save time and thereby reduce the cost of the site investigation programme. The data obtained during such searches should help the planning of the subsequent site exploration and prevent duplication of effort.

Preliminary Reconnaissance

The preliminary reconnaissance involves a walk over the site. The factors that should be taken into account depend on the nature of the site and the project but, where possible, note can be taken of the distribution of the soil and rock types present, the relief of the ground, the surface drainage and

associated features, any actual or likely landslip areas, ground cover and obstructions, earlier uses of the site such as tipping or evidence of underground workings etc. The inspection should not be restricted to the site but should examine adjacent areas to see how they affect or will be affected by construction on the site in question.
The importance of the preliminary investigation is that it should assess the suitability of the site for the proposed works, and if it is suitable, it will form the basis upon which the site exploration is planned. The preliminary reconnaissance also allows a check to be made on any conclusions reached in the desk study.

Site Exploration – Direct Methods
The aim of a site exploration is to try to determine and thereby understand the nature of the ground conditions on site and those of its surroundings. The extent to which this stage of a site investigation is carried depends, to some extent, upon the size and importance of the construction operation. The site exploration must be concluded by a report embodying the findings, which can be used for design purposes. This should contain geological plans of the site with accompanying sections, thereby conveying a 3D picture of the subsurface strata.

Geophysical Methods: Indirect Site Exploration
A geophysical exploration may be included in a site investigation for an important engineering project in order to provide subsurface information over a large area at reasonable cost.
A geophysical survey not only helps to locate the position of boreholes or drillholes but also detects variations in subsurface conditions between them.
Boreholes and drillholes provide information about the strata where they are sunk but provide no information about the ground in between
Geophysical methods are used to determine the geological sequence and structure of subsurface rocks by the measurement of certain physical properties or forces. The properties that are made most use of in geophysical exploration are density, elasticity, electrical conductivity, magnetic susceptibility and gravitational attraction. In other words, seismic and resistivity methods record the artificial fields of force applied to the area under investigation, while magnetic and gravitational methods measure natural fields of force. The former techniques have the advantage over the latter in that the depth to which the forces are applied can be controlled. By contrast, the natural fields of force are fixed and can only be observed and not controlled. Seismic and resistivity methods are more applicable to the determination of horizontal or near horizontal changes or contacts, whereas magnetic and gravimetric methods generally are used to delineate lateral changes or vertical structures.

Geology of Dam Sites

Of the various natural factors that directly influence the design of dams, none is more important than the geological, not only do to they control the character of the foundation but they also govern the materials available for construction. The major questions that need answering include the depth at which adequate foundations exist, the strengths of the rock masses involved, the likelihood of water loss and any special features that have a bearing on excavation. The character of the foundations upon which dams are built and their reaction to the new conditions of stress and strain, of hydrostatic pressure and of exposure to weathering must be ascertained so that the proper factors of safety may be adopted to ensure against subsequent failure. Excluding the weaker types of compaction shales, mudstones, marls, pyrolasts and certain very friable types of sandstone, there are few foundation materials deserving the name rock that are incapable of resisting the bearing loads even of high dams.

In their unaltered state, plutonic igneous rocks essentially are sound and durable, with adequate strength for any engineering requirement. In some instances, however, intrusives may be highly altered by weathering or hydrothermal attack. Generally, the weathered product of plutonic rocks has a large clay content, although that of granitic rocks is sometimes porous with a permeability comparable to that of medium-grained sand, so that it requires some type of cut-off or special treatment of the upstream surface.

A major problem of dam sites located in sandstones results from the fact that they normally are transected by joints, which reduce resistance to sliding. The sandstones in a valley floor may contain many open joints that wedge out with depth, and these often are caused by rebound of interbedded shales. Conditions of this kind in the abutments and foundations of dams greatly increase the construction costs for several reasons. They have a marked influence on the depth of stripping, especially in the abutments. They must be cut off by pressure grouting and drainage, for the combined purposes of preventing excessive leakage and reducing the undesirable uplift effects of the hydrostatic pressure of reservoir water on the base of the dam or on the base of some bedding contact within the dam foundation.

Thick-bedded, horizontally lying limestones, relatively free from solution cavities, afford excellent dam sites. Also, limestone requires no special treatment to ensure a good bond with concrete. On the other hand, thin-bedded, highly folded or cavernous limestones are likely to present serious foundation or abutment problems involving bearing capacity or watertightness or both. Beds separated by layers of clay or shale, especially those inclined downstream, may serve as sliding planes under certain conditions.

Fresh metamorphosed rocks such as quartzite and hornfels are very strong and afford excellent dam sites. Marble has the same advantages and disadvantages as other carbonate rocks. Generally, gneiss has proved a good foundation rock for dams.

Cleavage, schistosity and, to a lesser extent, foliation in regional metamorphic rocks may adversely affect their strength and make them more susceptible to decay. Moreover areas of regional metamorphism usually have suffered extensive folding so that rocks may be fractured and deformed.

Joints and shear zones are responsible for the unsound rock encountered at dam sites on plutonic and metamorphic rocks. Unless they are sealed, they may permit leakage through foundations and abutments. Slight opening of joints on excavation leads to imperceptible rotations and sliding of rock blocks, large enough to appreciably reduce the strength and stiffness of the rock mass.

Geology of Tunnel

Geology is the most important factor that determines the nature, form and cost of a tunnel. For example, the route, design and construction of a tunnel are largely dependent on geological considerations.

Large planar surfaces form most of the roof in a formation that is not inclined at a high angle and strikes more or less parallel to the axis of a tunnel. In tunnels in which jointed strata dip into the side at 30° or more, the up-dip side may be unstable. Joints that are parallel to the axis of a tunnel and that dip at more than 45° may prove especially treacherous, leading to slabbing of the walls and fallouts from the roof.

The presence of flat-lying joints may also lead to blocks becoming dislodged from the roof. When the tunnel alignment is normal to the strike of jointed rocks and the dips are less than 15o, large blocks are again likely to fall from the roof. The sides, however, tend to be reasonably stable. When a tunnel is driven perpendicular to the strike in steeply dipping or vertical strata, each stratum acts as a beam with a span equal to the width of the cross section. However, in such a situation, blasting operations are generally less efficient. If the axis of a tunnel runs parallel to the strike of vertically dipping rocks, then the mass of rock above the roof is held by the friction along the bedding planes.

Problems of tunnel excavation and tunnel stability in areas of karstic limestone may be associated with weathered rock, abrupt changes in

lithology, rock weakened by dissolution or containing discontinuites opened by dissolution, as well as with the presence of voids and caverns with or without infill. Furthermore, a large cavern in the path of a tunnel presents a difficult problem and may delay excavation or, in extreme cases, may mean that the tunnel has to be diverted around it or relocated.

Construction of a tunnel may alter the groundwater regime of the locality, as a tunnel usually acts as a drain. This can lead to dewatering, leading to sinkhole development/reactivation, which may be manifested in the form of surface subsidence. Isolated heavy flows of groundwater may occur in association with solution pipes and cavities or fault zones, especially those in which the limestone has been crushed and subjected to dissolution. When water is under appreciable pressure it may break into the tunnel as a gusher.

Faults generally mean non-uniform rock pressures on a tunnel and hence necessitate special treatment at times, such as the construction of box sections with invert arches. Generally, problems increase as the strike of a fault becomes more parallel to the tunnel opening.

Geology of Highways and bridge

As highways are linear structures, they often traverse a wide variety of ground conditions along their length. In addition, the construction of a highway requires the excavation of soils and rocks, and stable foundations for the highway, as well as construction materials. The ground beneath roads and, more particularly, embankments, must have sufficient bearing capacity to prevent foundation failure and also be capable of preventing excess settlements due to the imposed load. Very weak and compressible ground may need to be entirely removed before construction takes place, although this will depend on the quantity of material involved.

The ground beneath bridge piers has to support not only the dead load of the bridge but also the live load of the traffic that the bridge will carry, in addition to accommodating the horizontal thrust of the river water when bridges cross rivers. The choice of foundations usually is influenced by a number of factors. For example, the existence of sound rock near the surface allows spread foundations to be used without the need for widespread piling, whereas piled foundations are adopted for flood plains and rivers where alluvial deposits overlie bedrock. Because of the strong currents and the high tidal range in an estuary, precast concrete open-bottom caissons, which are floated out and put in place by specially adapted barges, may be used for piers. Such caissons provide permanent formwork shells for the concrete infill. Alternatively, piers can be designed as cellular structures supported by cylindrical caissons.

When a bridge is constructed across a river, the effective cross-sectional area of the river is reduced by the piers, which leads to an increase in its velocity of flow. This and the occurrence of eddies around the piers enhances scouring action. Less scouring generally takes place where a river bed is formed of cobbles and gravels than where it is formed of sand or finer-grained material. Scouring of river bed materials around bridge piers has caused some bridges to fail. During floods, damage is caused by very high peak flows, by build-up of debris at the bridge and by excessive scour around supporting caissons/piers.

Geology of Buildings site

Footings distribute the load to the ground over an area sufficient to suit the pressures to the properties of the soil or rock. Their size therefore is governed by the strength of the foundation materials.
The amount and rate of settlement of a footing due to a given load per unit area of its base is a function of the dimensions of the base, and of the compressibility and permeability of the foundation materials located between the base and a depth that is at least one and a half times the width of the base.
The ultimate bearing capacity of foundations on coarse soils depends on the width and depth of placement of the foundation structure as well as the angle of shearing resistance. The position of the water table in relation to the foundation structure has an important influence on the ultimate bearing capacity. High groundwater levels lower the effective stresses in the ground, so that the ultimate bearing capacity is reduced by anything up to 50%. Generally speaking, gravels and dense sands afford good foundations. It is possible to estimate the bearing capacity of such soils from plate load tests or penetration tests. However, loosely packed sands are likely to undergo settlement when loaded.
The ultimate bearing capacity of foundations on clay soils depends on the shear strength of the soil and the shape and depth at which the foundation structure is placed. The shear strength of clay is, in turn, influenced by its consistency. Saturated clays in relation to applied stress behave as cohesive materials provided that no change of moisture content occurs. Thus, when a load is applied to saturated clay, it produces excess pore water pressures that are not dissipated quickly. In other words, the angle of shearing resistance is equal to zero. Therefore for all types of foundation structures on clays, the factors of safety must be adequate against bearing capacity failure.

If a rock mass contains few defects, the allowable contact pressure at the surface may be taken conservatively as the unconfined compressive strength of the intact rock. Most rock masses, however, are affected by joints or weathering that may significantly alter their strength and engineering behaviour. The great variation in the physical properties of

weathered rock and the non-uniformity of the extent of weathering, even at a single site, permit few generalizations concerning the design and construction of foundation structures. The depth to bedrock and the degree of weathering must be determined. If the weathered residuum plays the major role in the regolith, rock fragments being of minor consequence, then the design of rafts or footings should be according to the matrix material. Piles can provide Support at depth.