CHAPTER 19

Engineering Geology

19.1 Introduction

- Geological Engineering is the application of geological knowledge to the siting, design, construction, operation and maintenance of civil engineering structures and facilities.
- It is one of the rapidly growing fields of engineering reflecting society's developing interest in the stewardship of the environment, managing risk, and creating a safer world.
- The field of Geological Engineering encompasses a wide range of activities including the geological characterization of complex foundations of major buildings and structures, development of natural resources (mining, water, hydroelectricity, forestry, oil and gas), investigation and assessment of groundwater movement and quality, the engineering safety of major infrastructure (dams, reservoirs, offshore drilling platforms, pipelines, roads and railways), and the assessment of geohazard risk (landslides, earthquakes, volcanoes, and the stability of natural dams).
- It also includes aspects of such fields as project finance and insurance, land-use planning, forensic geological engineering, and the application of geological knowledge to the repair and preservation of cultural heritage sites.
- As the name suggests, the field of engineering geology is actually a sup-topic or a sub branch of the field of geology. Geology essentially involves studying of different aspects of or different processes involving different parts of the earth.

19.2 Geologic Mapping and Remote Sensing

- Remote sensing is used as a tool to extract information about the land surface structure, composition or subsurface, but is often combined with other data sources providing complementary measurements.
- Remote sensing is not limited to direct geology applications - it is also used to support logistics, such as route planning for access into a mining area, reclamation monitoring, and generating base maps upon which geological data can be referenced or superimposed.

  Geological applications of remote sensing include the following:

  - surficial deposit / bedrock mapping
  - lithological mapping
  - structural mapping
  - sand and gravel (aggregate) exploration/ exploitation
  - mineral exploration
  - hydrocarbon exploration
  - environmental geology
  - geobotany
  - baseline infrastructure
  - sedimentation mapping and monitoring
  - event mapping and monitoring
  - geo-hazard mapping and planetary mapping
- Remote sensing adds considerably to this research by providing a wide variety of sensors operated from airborne and satellite platforms.
- The GARS Program of UNESCO and IUGS provides a means of continually investigating the geological applicability of remote-sensing techniques.

19.3 Minerology

- Mineralogy is a subject of geology specializing in the scientific study of chemistry, crystal structure, and physical (including optical) properties of minerals.
- Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.

Minerals:

- A naturally occurring, inorganic, solid, crystalline substance which has a fixed structure and a chemical composition which is either fixed or which may vary within certain defined limits.
- This excludes man-made substances (e.g. synthetic diamonds), organic substances (e.g. chitin), and substances without a fixed composition which are classified as mineraloids (e.g. volcanic glass [obsidian]).
- Some minerals have a definite fixed composition, e.g. quartz is always SiO_2, and calcite is always $CaCO_3$.
- However, other minerals exhibit a range of compositions between two or more compounds called end-members. For example, plagioclase feldspar has a composition that ranges between end-members anorthite ($CaAl_2Si_2O_8$) and albite ($NaAlSi_3O_8$), so its chemical formula is written as (Ca, Na)(Al, Si) $AlSi_2O_8$.

Rock :

- In geology, rock or stone is a naturally occurring solid aggregate of one or more minerals or mineraloids. For example, the common rock granite is a combination of the quartz, feldspar and biotite minerals. The Earth's outer solid layer, the lithosphere, is made of rock.
- Three major groups of rocks are defined: igneous, sedimentary, and metamorphic. The scientific study of rocks is called petrology, which is an essential component of geology.

Igneous Rocks:

- Igneous rocks are formed by the solidification of magma, a silicate liquid generated by partial melting of the upper mantle or the lower crust. Different environments of formation, and the cooling rates associated with these, create very different textures and define the two major groupings within igneous rocks:
- **Volcanic rocks (Extrusive Igneous Rocks):** Volcanic rocks form when magma rises to the surface and erupts, either as lava or pyroclastic material. The rate of cooling of the magma is rapid, and crystal growth is inhibited. Volcanic rocks are characteristically fine-grained. Volcanic rocks often exhibit structures caused by their eruption, e.g. flow banding (formed by shearing of the lava as it flows), and vesicles (open cavities that represent escaped gasses).
- **Plutonic rocks (Intrusive Igneous Rocks):** Plutonic rocks form when magma cools within the Earth's crust. The rate of cooling of the magma is slow, allowing large crystals to grow. Plutonic rocks are characteristically coarse-grained.

Sedimentary Rocks:

- Sedimentary rocks are the product of the erosion of existing rocks. Eroded material accumulates as sediment, either in the sea or on land, and is then buried, compacted and cemented to produce sedimentary rock (a process known as diagenesis).

There are two major groupings of sedimentary rocks:

- **Clastic sedimentary rocks:** The fragments of pre-existing rocks or minerals that make up a sedimentary rock are called clasts. Sedimentary rocks made up of clasts are called clastic (clastic indicates that particles have been broken and transported).
- Clast shape, or the degree of rounding of clasts, is important in differentiating some sedimentary rocks. Clasts vary in shape from rounded to angular, depending on the distance they have been transported and / or the environment of deposition, e.g. rounded clasts are generally the product of long transportation distances and / or deposition in high energy environments (beaches, rivers).
- **Non-clastic sedimentary rocks:** These sedimentary rocks occur when minerals / mineraloids are precipitated directly from water, or are concentrated by organic matter / life. Components have not been transported prior to deposition. No clasts are present.

Metamorphic Rocks:

- Metamorphism is the alteration of pre-existing rocks in the solid state due to changes in temperature and pressure. Under increasing temperature and / or pressure existing minerals become unstable and break down to form new minerals. In the case of regional metamorphism the rocks are subjected to tectonic forces which provide the necessary mechanisms for metamorphism. Products include schist and slate. Contact metamorphism involves metamorphosis through heating by an intruding plutonic body. Hornfels is the result of this type of metamorphism.

Metamorphic textures:

The two distinctive metamorphic textures are:

- **Foliation:** This represents a distinct plane of weakness in the rock. Foliation is caused by the re-alignment of minerals when they are subjected to high pressure and temperature. Individual minerals align themselves perpendicular to the stress field such that their long axes are in the direction of these planes (which may look like the cleavage planes of minerals). Usually, a series of foliation planes can be seen parallel to each other in the rock. Well developed foliation is characteristic of most metamorphic rocks. Metamorphic rocks often break easily along foliation planes.
- **Granular:** This describes a metamorphic rock consisting of interlocking equant crystals (granules), almost entirely of one mineral. A granular texture is developed if a rock's chemical composition is close to that of a particular mineral. This mineral will crystallise if the rock is subjected to high pressure and temperature. A granular texture is characteristic of some metamorphic rocks.
- Each of these rock groups contains many different types of rock, and each can be identified from its physical features.

Features of Rocks:

Important features to look for when writing descriptions and identifying rocks are:

- **Texture:** Refers to the shape, arrangement and distribution of minerals or grains / clasts within the rock - the texture in a geological sense does NOT refer to the roughness of the surface of the rock;
- **Structure:** Refers to broader features of a rock which may extend beyond the hand specimen into the outcrop; examples are bedding (in sedimentary rocks), foliation (in metamorphic rocks);

  Note: Texture and structure, collectively referred to as fabric, are of primary importance in determining which major rock group a particular rock specimen belongs to.
- **Grain size:** Refers to the size of individual mineral crystals or clasts (pieces of pre-existing rock) in a rock. Grain size is useful for determining various rock types within the three major rock groups;
- **Mineralogy:** Refers to the minerals present within the rock, and also their relative proportions (especially important in the case of igneous rocks);
- **Other features:** Features such as colour, hardness / strength and specific gravity can also provide useful information, and should be included in a complete petrographic description. If a rock appears to be weathered this is an important feature to note as weathering can change physical characteristics markedly. The size of the sample should also be noted.

19.4 Geological Agents

- The surface features of the earth are the result of the action of various geological agents.
- The structure of land surface like mountains, hills, valleys, plains etc. are the result of exogenous (outer) as well as endogenous (inner) processes.
- **The exogenous processes** are those which derive their energy from external sources and ultimately from the sun.
- These processes are mainly caused by geological agents such as Blowing-wind, running water, Glacier, Sea-Waves etc.
- Since these agents originate upon the earth's surface, they are known as Epigone-geological agents and their activities include processes like gradation, degradation, aggradations and weathering.
  - **Gradation:** It is the three fold process, first the surface is decayed and eroded, secondly the products of their decay and erosion are transported; finally they are deposited usually at lower levels. Thus gradation is the process by which the original irregularities of the earth's surface are removed and levelled surface is created. All gradation processes are directed by gravity.
  - **Degradation:** It is the process in which materials from a high relief (height, altitude) features is removed by external processes.

- **Agradation:** It is the process of deposition there by elevating the low lying area.
- **Weathering:** It is the combined actions of all processes to cause rocks disintegrate physically and decomposed chemically.

- **The endogenous processes** are those processes which originates within the earth's crust . The geological agents, which are associated with these processes and have their origin underneath the surface of the earth, are known as 'Hypogene'-Geological agents.
- Earthquake, Volcanic eruptions as well as other earth- movements are the results of the hypogene-processes.
- Although they originate within, they do affect the earth's surface in a spectacular way.
- The two main endogenous processes are: volcanism and diastrophism.
- The geomorphic features produced by them provide the setting for the operation of the exogenous processes.
- Mountains, plateaus and volcanoes are some of the striking features produced by hypogene agents.

19.5 Structural Geology

- Structural geology is the study of factors such as origin, occurrence, classification, type and effects of various secondary structures like folds, faults, joints, rock cleavage and are different from those primary structures such as bedding and vesicular structure, which develop in rocks at the time of their formation.
- **Structural Elements:** Folds, Faults, Joints, Unconformity, Dip, Strike, Outcrop Patterns, Outliers and Inliers.
- **Strike** refers to the direction in which a geological structure is present. The strike direction may be defined as the direction of the trace of the intersection between the bedding plane
- **Dip** literally means slope or inclination. In structural geology dip is expressed both as direction and amount. The dip direction is the direction along which the inclination of the bedding plane occurs.

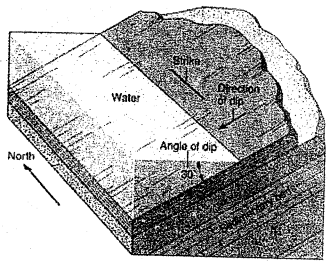


Fig. 19.1 *Dip and strike*

Unconformity:

- An **unconformity** is the contact between sedimentary rocks that are significantly different in age, or between sedimentary rocks and older, eroded igneous or metamorphic rocks. **Unconformities** represent gaps in the **geologic** record; periods of time that are not represented by any rocks.

Hiatus:

- An unconformity which represents a long geological period (during which break in sedimentation had occurred) is known as a "hiatus". In our country we find such a hiatus in the peninsular region, where, after the formation of Precambrian strata (i.e., the Cuddaphah system and the Vindhyan system) there was no deposition of sediments for a long geological time (approximately 300 million years). After that, the sedimentation resumed there, and the Gondwana group of rocks was formed.

Joints:

- A joint is a fracture dividing rock into two sections that have not moved away from each other. A joint sees little or no displacement. In other kinds of fracturing, like in a fault, the rock is parted by a visible crack that forms a gap in the rock.
- The presence of joints divides the rock into number of parts or blocks. In simple terms, through the joints may be described as mere cracks in rocks, they differ mutually.
- Joints, like cleavage of minerals, occur oriented in a definite direction and as a set. The cracks, on the other hand, like the fracture of minerals are random or irregular in their mode of occurrence.

Folds:

- Folds are one of the most common geological structures found in rocks.
- When a set of horizontal layers are subjected to compressive forces, they bend either upward or downward.
- The bend noticed in rocks are called folds.
- In terms of their nature too, folds may occur as single local bends or may occur repeatedly and intricately folded to the tectonic history of the region.
- Folds are classified on the basis of:
  - **Symmetrical Character:** When the axial plane divides a fold into two equal halves in such a way that one half is the mirror image, then the fold is called as symmetrical fold. If the compressive forces responsible for folding are not of the same magnitude, asymmetrical folds are formed.

Fig. 19.2

  - **Upward or Downward Bend:** When the beds are bent upwards, the resulting fold is called **Anticline**. This fold is convex upwards. Naturally, in such a fold, the older beds occur towards the concave side. In a simple case, the limbs of anticline slope in opposite directions with reference to its axial plane. But when the anticline is refolded, the inclined character of limbs will be complicated.

    Syncline is just opposite to anticline in its nature, i.e. when the beds are bent downwards the resulting fold is called syncline. This fold is convex downwards. In this the younger beds occur towards the concave side and, in a simple type of syncline, its limbs dip towards each other with reference to the axial plane.

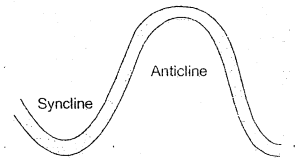


Fig. 19.3

  - **Occurrence of Plunge:** The plunge of a fold is described as the inclination of the fold axis to the horizontal plane. Based on this, i.e. whether the axis of a fold is inclined or horizontal, the folds are grouped as plunging folds or non-plunging folds.

    In geological maps, when strike lines are drawn for both the limbs, for a non-plunging fold, they will be mutually parallel and for a plunging fold they will be either converging or diverging but not parallel.

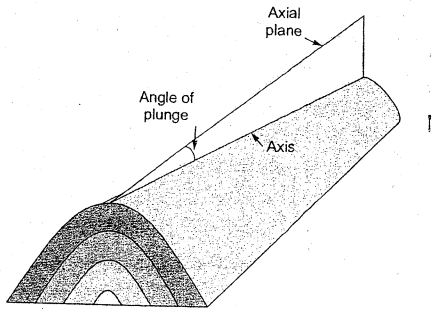


Fig. 19.4

- **Uniformity of Bed Thickness:** Depending on the intensity of deformation, the beds of the fold may or may not have uniform thickness. If the thickness of beds is uniform throughout the folds, it is called an **open fold**. On the other hand, in a fold, if the beds are thinner in the limb portions and thicker at crest and trough, such a fold is called **closed fold**.

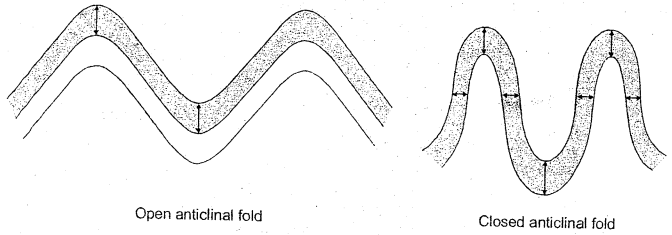


Fig. 19.5 Open and Closed anticlinal folds

- **Behavior** of the Fold Pattern with Depth- Based on whether the shape of folds remain the same or altered with depth, folds are grouped as similar or parallel folds. In the case of similar folds, the shape or pattern of folds remain the same at depths also. But in the case of parallel folds, the crest and trough become pointed or angular

Fig. 19.6 Similar and parallel fold

Miscellaneous folds:

- In addition to the preceding types, a few more folds with some peculiarities are as follows:
- **Overturned fold:** Usually, in simple folds, the limbs show the order of superposition. But when one of the limbs is overturned, the order of superposition (order of superposition means successively younger beds overlie the older beds) of beds in that limb will be in reverse order and such a fold is called an overturned fold.
- **Chevron folds:** Usually, the crests and troughs of beds are smoothly curved. But some folds have sharply bent, angular crests and troughs. Such folds are known as "chevron folds".
- **Isoclinal folds:** Usually, the folds have inclined limbs, i.e., the limbs will be mutually diverging of converging with reference to axial planes. But in some folds, the limbs will be mutually parallel to a great extent. Such folds are called isoclinal folds. These folds may be vertical, inclined or horizontal. The horizontal isoclinal folds are called **recumbent folds**.
- **Fan folds:** Usually, in simple anticlines, the limbs dip away from one another and in simple synclines they (limbs) dip towards each other. But in the case of fan folds, this trend is just the opposite, i.e., in anticlines of fan folds, the limbs dip towards each other with reference to their axial plane. In synclines of this kind, the limbs dip away from each other. As the term suggests, these folds are fan shaped.
- **Domes and basins:** Usually, a fold will have two distinct limbs. But some folds do not have any such specific limbs and appear as beds locally pushed up or down, i.e., their shapes appear as domes or basins. In a dome, which resembles an upper hemisphere, the dips are found in all sides from the common central top point. Thus, this is a type of anticline. In the basin, which is like a bowl, the slopes are just opposite, i.e., the dips are found towards a common central bottom point from all sides. This is a type of syncline.
- **Monocline (mono = one; cline = inclination or slope):** As already mentioned, usually, every fold has two limbs, each one of which is common to the adjacent folds. But when beds show a simple bend with similar attitude on either side of it, such a fold (bend) appears to have only one limb. This is called monocline.
- **Geanticlines and geosynclines:** The anticlines and synclines with a normal shape but a very large magnitude are called "geanticlines" (giant anticlines) and "geosynclines" Geosynclines are of special importance from the physiography point of view because these are the places accompanied by long periods of sedimentation and are the potential places which can become great mountain ranges in future. The Appalachian geosyncline, the Cordilleran geosyncline, and the Ouachita geosyncline (all of North America) are a few examples which have become sites of present mountain ranges.
- **Anticlioriums and synclinoriums:** When the limbs of folds are not plain but characterized by the appearance of other minor folds on them, the major folds are called anticlinoriums and synclinoriums.

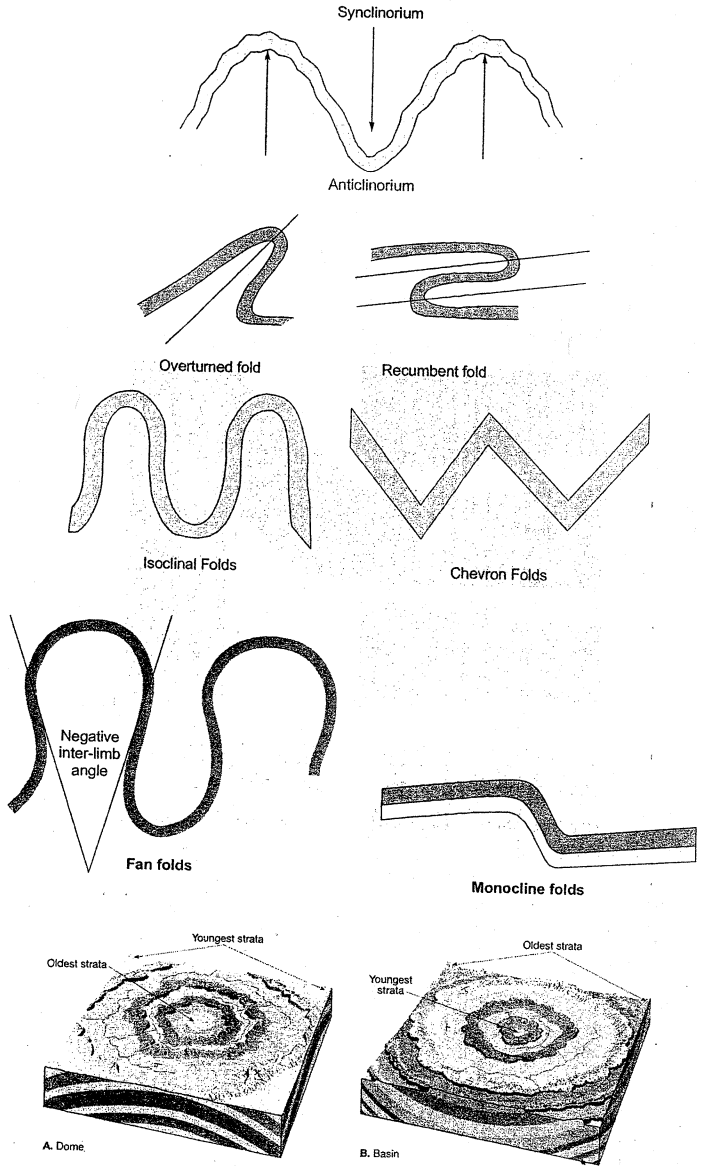


Fig. 19.7

Mechanism of Folding:

- Folding of rocks takes place by different ways of accommodation of stress. In many cases, slips or shear occur in between the beds.
- The process is similar to slipping of cards which occurs when the set is fold. If they are not allowed to slip over one another, folding of the set cannot take place.
- This is the way in which folding generally occur in the case of hard and competent rock like quartzites.
- In another kind of folding, folds are characterized by thinning of the limbs and thickening of crest and troughs. This takes place commonly in weak and incompetent rocks like shales.

Causes and effects of Folding:

- Most of the important folds, as already pointed out, are due to tectonic causes. But a few folds of a minor type are due to non-tectonic causes.
- Mainly, the compressive and shear type of tectonic forces are responsible for the folding phenomenon. Igneous intrusion of viscous magmas such as laccoliths and lopoliths also contribute to folding.
- Non-tectonic causes like landslides, creeping, differential compaction, isostatic setting and glaciations too are responsible for some folds. These are minor in terms of frequency of occurrence and magnitude.

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 warping appear as valley. During folding in the crest portions, the geological formation is subjected to tensional forces and hence numerous fractures appear there. Because of these fractures, crest portions are eroded quickly leading to conspicuous degradations locally.

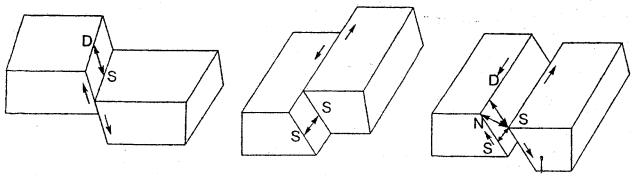
On the other hand, trough portion are highly compressed and hence offer a greater resistance to erosion. Thus, they stand out in the long run at a greater elevation, while the adjacent parts degrade fast. The net result of this response to erosion is that the anticlines will change over to valleys, while synclines change 'over to hills.. This paradoxical phenomenon is popularly expressed as "anticlinal valleys and Synclinal hills" The anticlinal valley are the typical example of inliers and the synclinal hill are example of outlier.

Faults:

- A fault is a surface or narrow zone along which one side has moved relative to the other in a direction parallel to the surface or zone. Most faults are brittle shear fractures or zones of closely spaced shear fractures, but some are narrow shear zones of ductile deformation where movement took place without loss of cohesion at the outcrop scale.
- We generally use the term fault for shear fractures or zones that extend over distances of meters or larger.
- They affect blocks of the Earth's crust thousands or millions of square kilometers in area, and they include major plate boundaries hundreds or even thousands of kilometers long.

Parts of Faults:

1. Fault Plane: It is the plane or surface along which the blocks move that are separated on the fault.
2. Fault Blocks: They are the two portions of rock separated by the fault plane. If the "fault plane" is tilted, the block above the fault plane is the "hanging wall" or "upper block" and beneath the fault plane is called "footwall block".
3. Slip: It is the displacement that occurs during faulting. It may occur along the stike direction (strike slip) or the dip direction (dip slip) or along both.



Net slip (NS) = dip slip (DS) and strike slip is zero | Net slip (NS) = strike slip (SS) and dip slip is zero | Net slip (NS) = strike slip (SS) and dip slip (DS)

Fig. 19.8 Relation of net slip, dip slip and strike slip

The horizontal component of displacement is called "heave" and the vertical component of displacement is called "throw".

- The fault block above the fault plane is the hanging wall bock and the block below the fault is the footwall block. For a vertical fault, these distinctions do not apply, and the sides of the fault are named in accordance with geographic direction e.g., the northwest side and the southeast side.
- Faults are classified in terms of the attitude of the fault surface. If a fault dip is more than 45°, it is a high angle fault; if less than 45°, it is a low-angle fault.

Types of Faults:

- **Strike-slip fault:** A fault in which rock strata are displaced mainly in a horizontal direction, parallel to the line of the fault.
- **Dip-slip faults:** They are inclined fractures where the blocks have mostly shifted vertically. They are further classified as **Normal Faults** when the hanging wall drops down in relation to the footwall and **Reverse Faults** when the hanging wall moves up in relation to the footwall.

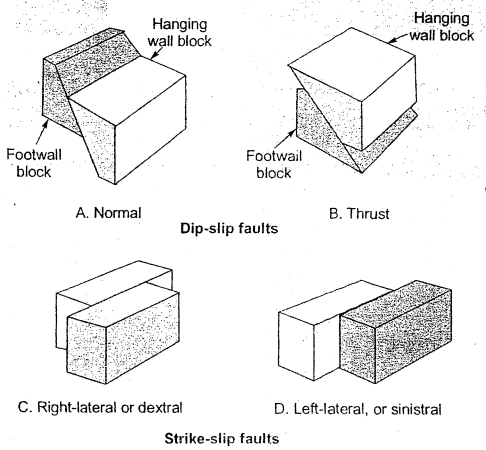


Fig. 19.9

Strike-slip faults are usually vertical, while normal and reverse faults are often at an angle to the surface of the Earth.

19.6 Importance of Engineering Geology

- The selection of sites affected by the various engineering structures are very large presence of faults and folds, as they affect the safety of facilities, and pose a significant risk. The presence of faults or breaks, reduces the resistance of the rocks of the jurisprudence, and introduced the facilities provided by them to collapse.
- The folds are also a problem, since the existence of structures concave folds it with a great ability to collect ground water, causing water problems at large Construction of buildings or tunnels located in areas where this kind of folds are present. So we justify the importance of geological studies and their role in avoiding collapse of structures and buildings in the regions illustrated by the geological maps based on these studies as well as to avoid the high costs that may be borne by the the concerned authorities in the event that set up these projects on the areas of joints and faults and folds, as well as the lives that may be at risk.

19.7 Geological Hazards

- A **geologic hazard** is one of several types of adverse geologic conditions capable of causing damage or loss of property and life.

Geologic Event	Hazards They Cause
Earthquake	A. Ground shaking B. Surface faulting C. Landslides and liquefaction 1. Rock avalanches 2. Rapid soil flows 3. Rock falls D. Tsunamis
Volcanic Eruption	A. Tephra falls and ballistic projectiles B. Pyroclastic phenomena C. Lahars (mud flows) and floods D. Lava flows and domes E. Poisonous gases

Objective Brain Teasers

Q.1 Minerals
(a) can form by life-processes
(b) are crystalline solids
(c) have a unique chemical composition
(d) can be any state (solid, liquid, or gas) as long as that state occurs naturally

Q.2 Metamorphic rocks are changed rocks. Which of the following rock types could be the "parent" of a metamorphic rock?
(a) sedimentary (b) igneous
(c) metamorphic (d) all of the above

Q.3 Which of the following best defines a mineral and a rock?
(a) A rock has an orderly, repetitive, geometrical, internal arrangement of minerals; a mineral is a lithified or consolidated aggregate of rocks.
(b) A mineral consists of its constituent atoms arranged in a geometrically repetitive

structure; in a rock, the atoms are randomly bonded without any geometric pattern.

(c) In a mineral the constituent atoms are bonded in a regular, repetitive, internal structure; a rock is a lithified or consolidated aggregate of different mineral grains.

(d) A rock consists of atoms bonded in a regular, geometrically predictable arrangement; a mineral is a consolidated aggregate of different rock particles.

Q.4 Which of the following is not a mineral?
(a) olivine (b) limestone
(c) calcite (d) quartz

Q.5 In correct order from the center outward, Earth includes which layers?
(a) core, inner mantle, outer mantle, crust
(b) inner core, outer core, mantle, crust
(c) inner core, crust, mantle, hydrosphere
(d) core, crust, mantle, hydrosphere

Q.6 The tectonic plates
(a) are the outermost shell of the solid Earth.
(b) are a rigid, solid layer about 100 km thick
(c) includes the crust and the uppermost mantle
(d) all of the above

Q.7 What are the two most abundant elements in the Earth's crust?
(a) iron and magnesium
(b) oxygen and silicon
(c) nitrogen and oxygen
(d) silicon and calcium

Q.8 Normal fault takes place when crust is
(a) pushed towards (b) pulled apart
(c) vibrated (d) expanded

Q.9 If further pushed, overfold becomes a/an
(a) recumbent fold (b) precumbent fold
(c) procumbent fold (d) deceptive fold

Q.10 Reverse fault is caused due to
(a) compression (b) tension
(c) expansion (d) collision

Q.11 A fold mountain is a type of landform that is created when two crustal plates
(a) converge (b) collide
(c) diverge (d) DE collide

Q.12 Tremendous compressional forces exerted on rock layers by geological movements causes rock layers to
(a) crack (b) bend
(c) heat up (d) vibrate

Q.13 Reverse fault is similar to normal fault, except for the
(a) force (b) types of plates
(c) mass (d) movement of layers

Q.14 A rift valley forms when central block is moved
(a) upwards
(b) downwards
(c) into the side blocks
(d) away from the side blocks

Q.15 A clastic rock is:
(a) a rock formed from the cementation of transported grains
(b) a rock formed from evaporation of sea water
(c) transformed by heat into limestone
(d) transformed by pressure into limestone

Q.16 A crystalline or glassy rock formed when magma or lava cools down and solidifies is called
(a) sedimentary rocks (b) metamorphic rocks
(c) igneous rocks (d) morphic rocks

Q.17 Geochemical prospecting is concerned primarily with the examination of the
(a) Rocks and waters
(b) Waters and gases.
(c) Rocks only
(d) Rocks, waters & gases.

Q.18 Metamorphism is a:
(a) Solid - State reconstitution
(b) Solid -liquid state reconstitution
(c) Solid -liquid - gas - stare reconstitution.
(d) Liquid - state reconstitution.

Answers

1.	(b)	2. (d)	3. (c)	4. (b)	5. (b)
6.	(d)	7. (b)	8. (d)	9. (a)	10. (a)
11.	(b)	12. (b)	13. (d)	14. (b)	15. (a)
16.	(c)	17. (d)	18. (a)		

APPENDIX

Appendix-A: Instruments Used in Surveying

- **Tape:** For linear measurement on ground etc.
- **Chain:** It is used for linear measurements
- **Tripod:** It is used for setting up the instrument on ground
- **Staff:** For taking reading for determination of ground levels
- **Clinometer:** For vertical angle measurement
- **Pantograph:** Used for enlarging the plan
- **Ghat tracer:** Used for determination of gradients
- **Sextant:** For measuring angles from a boat
- **Fathometer:** For measuring depth of water bodies like oceans
- **Theodolite:** For measuring horizontal and vertical angles and taking staff readings
- **Substance bar:** For horizontal distt. measurement
- **Cross-staff Range finder:** To establish right angles
- **Parallax bar:** For displacement measurement from photograph
- **Tacheometer:** For horizontal and vertical distance computation
- **Planimeter:** Used for area measurement

Appendix-B: Electro-Magnetic Distance Measurement (EDM)

- There are three methods of measuring distance between any two given points:
  - Direct distance measurement (DDM), such as the one by chaining or taping.
  - Optical distance measurement (ODM), such as the one of tacheometry, horizontal subtence method or telemetric method using
  - Electro-magnetic distance measurement (EDM) such as the one by geodiameter, tellurometer or distomat etc.

Electromagnetic Waves:

- The EDM method is based on generation, propagation, reflection and subsequent reception of electromagnetic waves. The type of electromagnetic waves generated depends on many factors but principally, on the nature of the electrical signal used to generate the waves.

Types of EDM Instruments:

- Depending upon the type of carrier wave employed, EDM instruments can be classified under the following three heads:

- Microwave instruments
- Visible light instruments
- Infrared instruments
- **Microwave instruments:** These instruments come under the category of long range instruments, where in the carrier frequencies of the range of 3 to 30 GHz (1 GHz = 10^9) enable distance measurement upto 100 km range. Tellurometer come under this category.
- **Visible light instruments:** These instruments use visible light as carrier wave, with a higher frequency, of the order of 5×10^{14} Hz. Since the transmitting power of carrier wave of such high frequency falls off rapidly with the distance, the range of such EDM instruments is lesser than those of microwave units. A geodiameter comes under this category of EDM instruments.
- **Infrared instruments:** The EDM instruments in this group use near infrared radiation band of wavelength about 0.9 μm as carrier wave which is easily obtained from gallium arsenide (Ga As) infrared emitting diode. These diodes can be very easily directly amplitude modulated at high frequencies. Thus, modulated carrier wave is obtained by an inexpensive method. Due to this reason, there is predominance of infrared instruments in EDM. Wind distormats fall under this category of EDM instruments.

Total Station:

- A total station is a combination of an electronic theodolite and an electronic distance meter (EDM). This combination makes it possible to determine the coordinates of a reflector by aligning the instruments cross-hairs on the reflector and simultaneously measuring the vertical and horizontal angles and slope distances. A microprocessor in the instrument takes care of recording, readings and the necessary computations. The data is easily transferred to a computer where it can be used to generate a map.

Fundamental Measurements:

- When aimed at an appropriate target, a total station measures three parameters.
  - The rotation of the instrument's optical axis from the instrument north in a horizontal plane i.e. horizontal angle.
  - The inclination of the optical axis from the local vertical i.e., vertical angle
  - The distance between the instrument and the target i.e., slope distance