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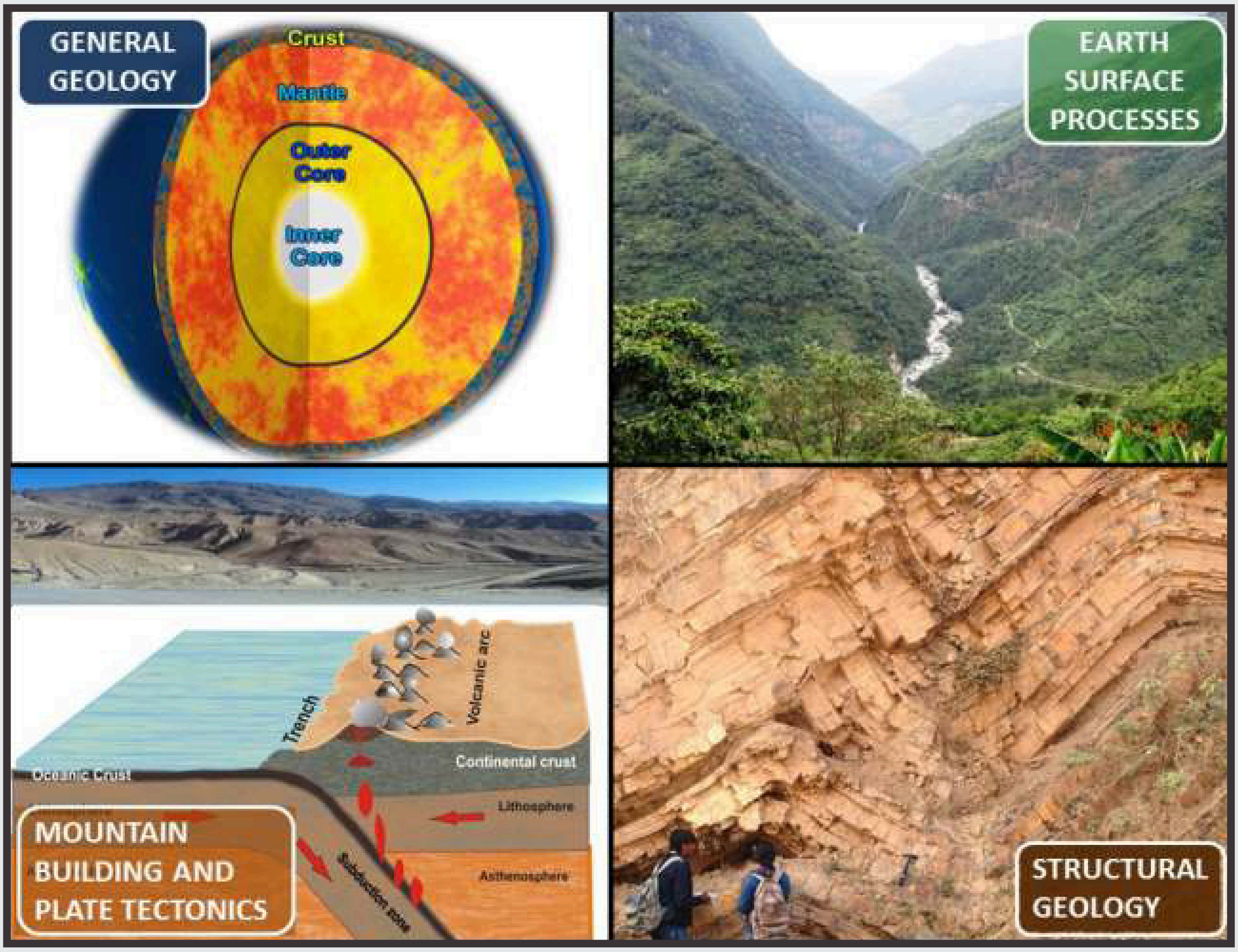
BGYCT – 131
PHYSICAL AND STRUCTURAL GEOLOGY



Structural Geology

3

“शिक्षा मानव को बन्धनों से मुक्त करती है और आज के युग में तो यह लोकतंत्र की भावना का आधार भी है। जन्म तथा अन्य कारणों से उत्पन्न जाति एवं वर्गगत विषमताओं को दूर करते हुए मनुष्य को इन सबसे ऊपर उठाती है।“

– इन्दिरा गांधी

“Education is a liberating force, and in our age it is also a democratising force, cutting across the barriers of caste and class, smoothing out inequalities imposed by birth and other circumstances.”

- Indira Gandhi

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Block

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STRUCTURAL GEOLOGY

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BGYCT-131: PHYSICAL AND STRUCTURAL GEOLOGY

List of audio / video materials related to this course

1. Earth System Science and Society -Part 1
   Link: https://www.youtube.com/watch?v=dVbjNn0ZHRg

2. Earth System Science and Society- Part 2
   Link : https://www.youtube.com/watch?v=0GMPIOrCdcE

3. Geoinformatics: An Introduction
   Link: https://youtu.be/vu7f5aFoox0

4. Applications of Geoinformatics
   Link: https://youtu.be/tfSDp2TO-Eg

5. Weathering, its types and Significance
   Link: https://www.youtube.com/watch?v=gBYijIPPVgc

6. Soil: Product of Weathering
   Link: https://www.youtube.com/watch?v=y-SENU4Abv8

7. Landslides: Its types and causes
   Link: https://youtu.be/cI73TU0hjQk

8. Landslides: Mitigation measures
   Link: https://www.youtu.be/BcUVeL43x7c

9. Deccan Volcanism-an Inside Story
   Link: https://www.youtube.com/watch?v=1a3glcg0oGs

10. Himalaya-an Overview
    Link: https://www.youtube.com/watch?v=vK5Cglisa1Y

11. Evolution of Himalaya
    Link: https://www.youtube.com/watch?v=gVGZKqrjVZY

Development of audio/video programmes is a continuous process. For recent materials pertaining to the course you may visit Youtube page of the School of Sciences, IGNOU.

Alternatively, you can visit eGyankosh website of IGNOU
Link : http://egyankosh.ac.in/handle/123456789/36575

BLOCK 3 : STRUCTURAL GEOLOGY

Structural geology is the branch of geology which deals with the recognition, representation, and genetic interpretation of rock-structures. The rocks after their formation may remain undisturbed or may be subjected to varying degrees of deformation. The geological structures like folds, faults, joints and fractures result from deformation of rocks due to forces acting from within the Earth. These geological structures not only record geological history but they also help us in understanding the Earth's processes, site selection of engineering projects such as dam, tunnel, power generation, etc., in addition to search for energy resources and valuable mineral deposits. These geological structures create beautiful landscapes which may enhance geotourism. In order to study these geological structures, one must go to the field and observe the Earth materials and processes in their natural setting. It is well-accepted principle in Geology that "*the present is the key to the past*" meaning Earth processes occurring today have operated throughout Earth's history. Careful data collection, examination and interpretation of all the details both in field and laboratory help to visualise the entire sequence of activities. The experience and knowledge helps in reconstructing the tectonic events. It is basically the field science that provides the ground truth for geologic concepts and theories of how the Earth works.

This block comprises five units, wherein we would learn the basic concepts of structural geology, geological structures like folds, faults, joints and unconformity and fundamentals of field geology.

Unit 9 is an introduction to the basic concepts and terminologies used in structural geology. We will discuss about the representation of topography, and learn how to measure dip and strike. This unit also elaborates on planar and linear structures.

In **Unit 10** we will study about the fold, discuss the significance of folds in geology and classify folds on the basis of geometry. We will identify the criteria of recognition of folds in the field and list causes of folding.

In **Unit 11**, we will learn about faults and discuss their significance to the geologists. We will read about geometric and genetic classifications of faults. In addition, we will identify the criteria of recognition of faults in the field and list the causes of faulting.

Unit 12 introduces us to joints and unconformity. It acquaints us with their geological significance and helps us decipher different kinds of unconformities.

Unit 13 is an introduction to the basic concepts of fieldwork in geology. It will familiarise us with the procedures to be followed while planning the fieldwork, field safety measures and field equipments. It will enable us to recognise and measure geologic features in the field and learn method to document field observations.

Expected Learning Outcomes:

After studying this block, you should be able to:

- discuss basic terminologies and concepts in structural geology;
- get familiar with clinometer and measure dip and strike;
- discuss the significance of folds and faults and classify them;
- identify the criteria of recognition of folds and faults in the field;
- list causes of folding and faulting;

- define and classify joints and unconformity;
- evaluate the geological significance of joints and unconformity;
- recognise the importance of geological fieldwork;
- list safety measures and field equipments needed for fieldwork; and
- discuss about planning and collection of field data and its documentation.

We hope that after studying this block you will acquire understanding of the basic concepts of structural geology and geological structures such as folds, faults, joints and unconformity and geological fieldwork.

Wishing you success and all the best in this endeavour!!

UNIT 9

INTRODUCTION TO GEOLOGY

Structure

9.1 INTRODUCTION

You are now well acquainted with the basic concepts of geology and the planet Earth, along with the external (exogenic) and internal (endogenic) processes operating and modifying the surface configuration of the Earth in Blocks 1 and 2. In this unit, we will be studying about the basic concepts of structural geology. Try to recall the definition of structural geology from Unit 1 of this course. It states that structural geology deals with the study of structures observed in the rocks which are formed in response to various stresses (forces) generally from within the body. **'Structural'** is derived from Latin word '*Struere*' which means 'to build'. It has been variously defined. Two definitions are given here.

Structural geology is the study of the architecture of rocks insofar as it has resulted from deformation (Billings, 1990).

Structural geology deals with the geometry, distribution and formation of structures (Fossen, 2010).

Geologic structure or architecture signifies form, symmetry, geometric configuration of rocks and the elegance of the components of the Earth's crust, on all scales. It incorporates the different geometries in the rocks, resulted from the deformation caused by the forces of the Earth and the extraterrestrial bodies. However, majority of the structures in the rock develop due to deformational forces of the Earth. These forces are endogenic (generated from within the Earth) in nature and are also called as **tectonic forces**. Tectonic forces (tectonic is derived from Greek word *'Tektos'* meaning 'builder') is the study of the forces and motion that result in rock deformation and structure.

Let us look at the relation between structural geology and tectonics. Generally, they go hand in hand. However, the subject of structural geology is primarily concerned with the geometry of the rocks whereas tectonics deals with the forces and movements that produced the structures. In other words, both structural geology and tectonics relate to the building and resultant structure of the rocks, and to the motions that change and shape the outer parts of our planet. You can say that tectonics is more closely connected to the underlying processes that cause the structures to form. It implies that while tectonics embraces the cause, generation and operation where as, a structural aspect deals only with the end geometry. The aim of structural geology is to determine and explain the architecture of rocks as observed in the field. Laboratory investigations supplement in the attainment of this objective. It pertains to the observation, description and interpretation of structures that can be mapped in the field. Geologic structures are dynamically produced patterns or arrangements of rock or sediment that result from forces acting within the Earth. These structures yield information about the tectonic forces. These structures range from hundreds of kilometres to microscopic scales. Fold, fault, joint and unconformity are names of some common structures that are studied under the domains of structural geology.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ define basic terminology used in structural geology;
- ❖ acquaint with the representation of topography;
- ❖ get familiar with clinometer and measure dip and strike; and
- ❖ list planar and linear structures and their combinations.

9.2 CONCEPTS OF STRUCTURAL GEOLOGY

You have read that the tectonic forces and movements in the Earth result in the development of various structures in the rocks viz. folds, faults, joints, unconformities. Before we study these structures let us study the basic concepts of structural geology.

You have read that structural geology is study of the architecture of rocks of Earth. This is primarily accomplished with the study of geometrical aspects of the geological structures which are formed at the time of origin of the rock formation itself or subsequently developed due to later deformation. A structural geologist tries to find answers of the following questions while observing a structure:

What is the structure?

How are the structures distributed in the region?

What were the conditions of rocks and stresses under which the structures developed?

What were the sequences of development of these structures?

Laboratory investigations help to achieve these objectives of structural geology. Thus, it would be realised that **Structural geologists** are concerned with the identification of the structure, their geometry and orientation in the Earth, the time and sequences of their development and assessing the physical conditions responsible for the development of these structures. Let us get acquainted with some of the common terminologies used to describe the geological structures.

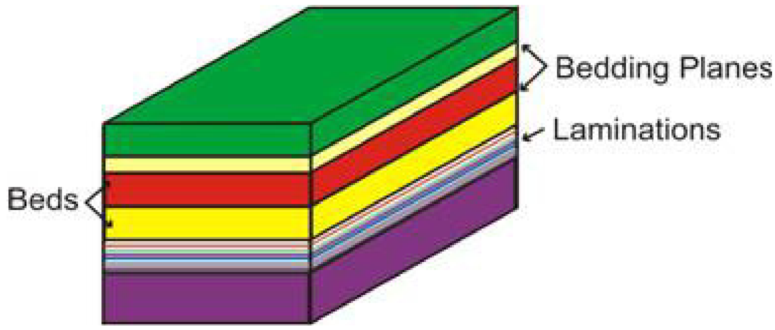
9.2.1 Layering

Layering is the linear deposition of constituent sediments - small fragments of parent minerals, rock materials or mineral grains in a rock. Sedimentary rocks are generally layered rocks because of the deposition of sediments one over another in a basin. Individual layer of a sedimentary rock is called **bed** (Figs. 9.1a and 9.4). Each bed is separated from the adjacent bed by a plane called **bedding plane**. If the individual layers are less than one cm thick they are called **lamination** (Figs. 9.1a and 9.1b). **Stratum** (Pl. strata) is a term which is used to cover both bed and lamination. Stacking up process of strata one over another is known as **stratification** (Fig. 9.1a)**.**

We observe bedding planes in sedimentary rocks. Bedding plane in sedimentary rock is formed at the time of origin of the rock itself and is also referred to as a kind of **primary structure** e.g. planar lamination (Fig.9.1b). The orientation of the bedding plane or any other planar structures is described in terms of their strike and dip, which has been discussed in subsection 9.2.3. However, volcanic rocks (igneous rocks) too develop layering because of lava flow. It is referred to as primary structures, as they are developed simultaneously with rock formation. The layers in metamorphic rocks are known as **secondary structures** because they develop later due to reorientation of the recrystallised newly formed mineral particles.

9.2.2 Outcrop

You might have observed that the surface of the Earth is generally covered with soil, water or ice and the rock exposures are not seen everywhere. When a portion of the rock appears at the surface it is termed as '**outcrop'** (Figs. 9.2a and b). Those parts of the rocks which are not exposed at the surface are referred to as **incrop.** The outcrops are generally exposed all along the mountains, valley walls, river valley (Fig. 9.2b), road/railway cuttings and tunnels. The term outcrop means 'what emerges out'. Thus, an outcrop denotes the area over which rock mass crops out and is visible on the surface. The line of intersection of the limiting surface of the rock mass with the surface of the ground marks the limit of it. The study of geological structures is generally done on the outcrops because they are the basic source of information for a geologist.



(a)

Fig. 9.1: a) Sketch showing stratification with numerous beds, bedding planes and laminations; and b) Field photograph showing planar laminations, parallel to cap of pen. (Photo credit: Ganga Prasad Bhartiya)

9.2.3 Dip and Strike

Most sedimentary rocks initially get deposited horizontally in a basin. However, you should bear in mind that beds are tilted by movements that occurred after their deposition. Now you will be introduced to terms like dip and strike.

Dip is the inclination of the bedding plane with respect to horizontal. It is measured in a vertical plane generally lying at right angles to the strike of the bedding plane.

Strike is the geographical direction of an extension line produced by intersection of inclined bed and a horizontal plane. Strike is measured on a horizontal plane (Fig. 9.4b and 9.5). Strike has only direction and no magnitude. The dip is a vector quantity. It has two components i.e. direction as well as magnitude.

Direction of dip indicates the geographical direction in which the bed is inclined.

Amount of dip is the angle of inclination of the bed from horizontal which may vary from 0° to 90°.

(a)

(b)

Fig. 9.2: a) An outcrop of quartzite rock at IGNOU headquarters, New Delhi; and b) Outcrop of marble rocks along Narmada river valley, Jabalpur. (Photo credit: Dr. Nishi Rani)

Obviously in horizontal beds the amount of dip would be 0° while inclined or tilted beds may have amounts of dip varying between 0° and 90° and vertical beds have 90° amount of dip (Figs. 9.3 and 9.4).

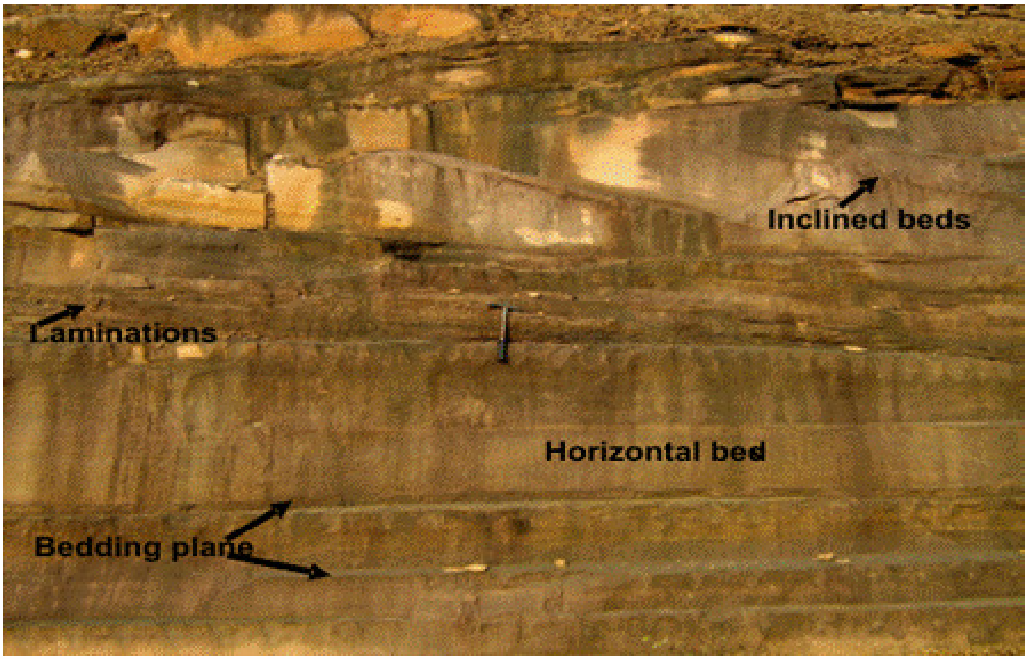


Fig. 9.3: Field photograph showing laminations, bedding plane, horizontal and inclined beds.

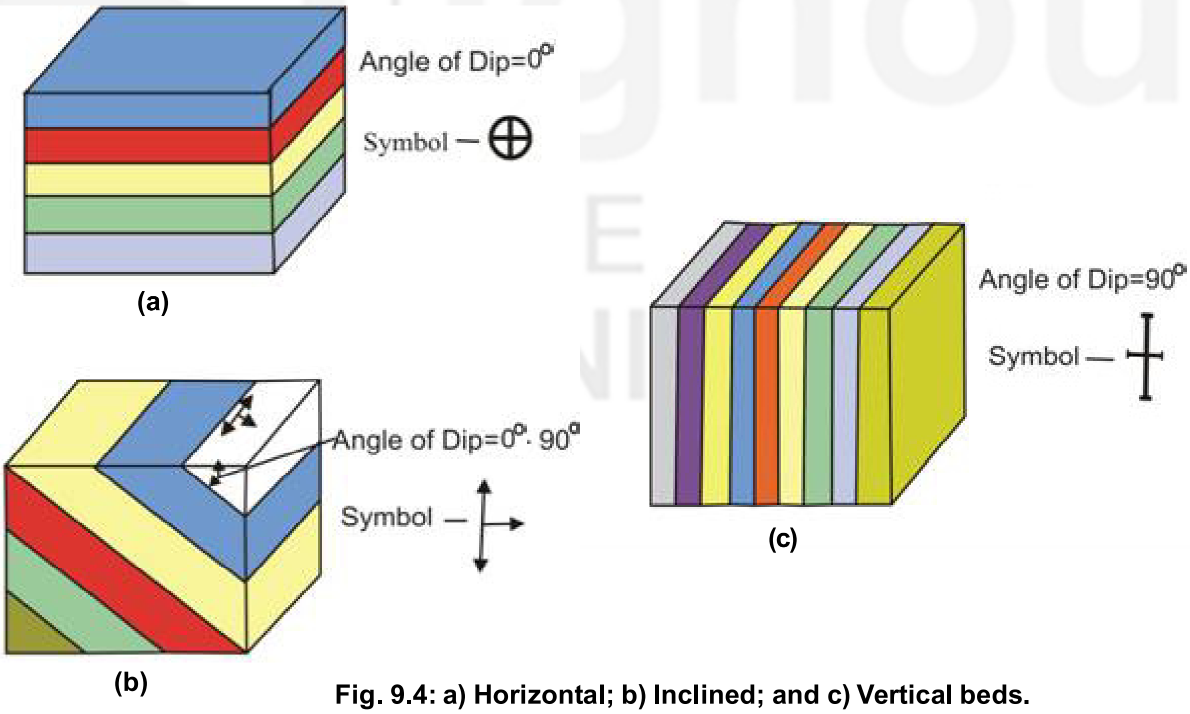


Fig. 9.4: a) Horizontal; b) Inclined; and c) Vertical beds.

Dips may be:

1. **True dip:** The maximum amount of dip of a bed is found along a line perpendicular to the strike, it is called **true dip.** The true dip direction and strike of a bedding plane are always perpendicular to each other (Figs. 9.3, 9.4 and 9.5).

2. **Apparent dip:** The dip of the bed measured in any other direction than that of true dip it is referred as **apparent dip**. The amount of apparent dip is always less than that of true dip. The apparent dip amount of a bed becomes zero if measured in the direction of strike even though in reality the bedding plane is tilted (Fig.9.5).

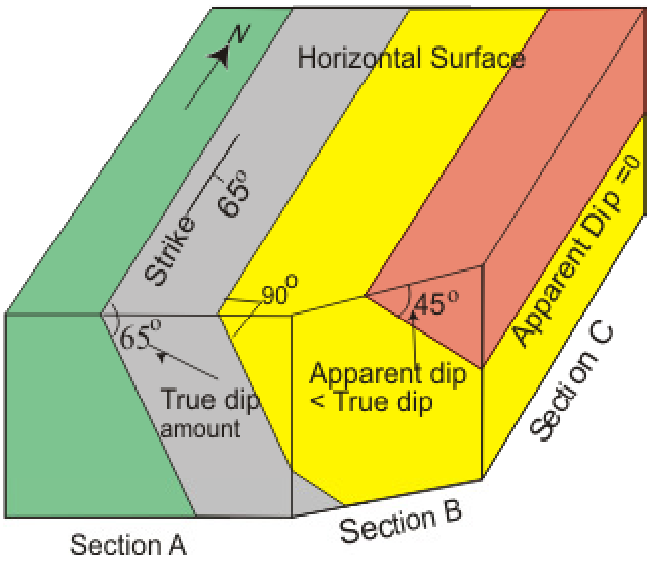


Fig. 9.5: True dip, apparent dip and relation between dip and strike directions. Strike is measured on horizontal plane, which in this case, is North - South. True dip direction is towards east. The true dip amount of the beds is 65° which is measured on a vertical plane perpendicular to strike (Section A). Note that on Section B which is not parallel or perpendicular to strike, the beds show less dip amount. This is apparent dip. On section C where the plane is parallel to strike, the apparent dip is zero.

Relation between dip and strike: The direction of true dip and strike of any inclined bedding plane is always at right angles to each other. True dip can only be measured in the direction perpendicular to strike. In specifying the attitude of any inclined bed, therefore, its amount and direction should be mentioned clearly.

SAQ 1

a) Define structural geology. What is its relation to tectonics?

b) What is the difference between bedding plane and layering?

c) Define outcrop.

d) Dip is a vector quantity. Why?

e) Distinguish between apparent and true dip.

9.2.4 Importance of Strike and Dip

In structural geology, strike and dip are quite important for following purposes:

- **Determination of the younger bed or formation**: If we go in the direction of dip we will observe beds of progressively younger age. Younger beds are always found in the direction of the dip. Conversely in the direction opposite to dip older beds are encountered. We will observe same bed if we move along the strike.

- **Identification and classification of geological structures**: Dip and strike data provides useful information in identifying and classifying the structures such as folds, faults, joints and unconformities.

9.2.5 Intrusion

The stratification or layering of the bed / foliation is generally seen in the rocks in their outcrops in which the individual layers are observed in parallelism. However, sometimes some igneous bodies cut across these beds of the **country rock** (also called **host rock**) because of their late entry into the system along some fractures or plane of weakness. These igneous rocks are called intrusive rocks and the phenomenon as **intrusion** (Fig. 9.6). Thus, the **intrusive rocks** are those igneous rocks which penetrate or intrude in a pre-existing host rock. Intrusive rocks are solidified underneath the surface of the Earth at higher pressure and temperature conditions than at the surface. The intrusion may be of different types, which you shall study later in this unit.

Fig. 9.6: A view of an intrusive igneous body in Sidhi district, M.P.

9.2.6 Deformation

Deformation is a general term that encompasses change in shape, size or both in a body. In geological studies deformation in the rocks is generally observed in the form of folding, faulting, and shearing. Deformation is change in the size and/or shape of rock due to tectonic forces. The forces or stresses which cause deformation in the rocks are derived from within the Earth and they may be compressional, tensional, and/or shearing types.

Let us discuss about the forces first.

- **Compressive forces** are directed towards each other from opposite directions (Fig. 9.7a).
- **Tensional forces** are directed away from the body away in opposite directions. They stretch and pull the body apart (Fig. 9.7b).

- **Shearing forces** act upon the opposite ends of the body in opposite directions and try to rotate it (Fig. 9.7c).

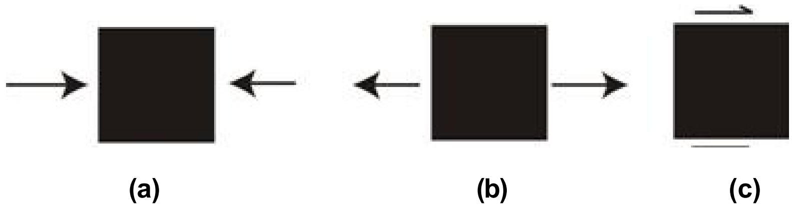


Fig. 9.7: a) Compressional forces; b) Tensional forces; and c) Shearing forces.

If a body is subjected to directed forces lasting over a period of time, it usually passes through following stages of **deformation**:

1. **Elastic**: Initially, the deformation is elastic; that is, if the stress is withdrawn, the body returns to its original shape and size.

   Elastic Limit is the bearing capacity of the rock mass. On increasing the stress continuously, a critical stage arrives that even if we withdraw the stresses the body does not return to original state. This critical stage is called **elastic limit** of the body.

2. **Plastic**: When the stress exceeds the elastic limit, the deformation is **plastic**; that is the body does not return to its original shape even after the stress is removed. Therefore, this kind of deformation is permanent.

3. **Rigid**: The continued stress may cause increased deformation beyond limit of elasticity and plasticity and the rock mass ultimately breaks down such rock mass are stated as rigid. Igneous and metamorphic rocks are generally rigid though many sedimentary rocks are also rigid.

The type of deformation in a rock body is a function of factors like:

- amount and type of stress;
- composition of the rock materials;
- temperature
- time

However, the **type of deformation** may be categorised broadly into:

- **Elastic deformation:** The rock deforms when the stresses are applied but returns back to original shape when stresses are removed (like a rubber).

- **Plastic deformation:** It is permanent deformation and the body does not return to its original shape. A rock body undergoes plastic deformation after a critical value of stress; **'yield point'** is crossed. The yield point is also the elastic limit of the body beyond which the deformation becomes plastic.

- **Brittle deformation**: It implies that the fracturing or rupture of the rock has occurred within the elastic limits. Plastic deformation or ductile deformation denotes bending, folding, stretching, thinning of rocks, and aligning of grains etc. in the form of structures in the rocks.

9.2.7 Importance of Structural Geology

Structural geologist is an individual practicing structural geology. The story revealed by structures in rocks is beautiful, fascinating and interesting, and it can be very useful to society.

It is of prime importance in geological studies. Let us discuss them.

1. The knowledge of structural geology helps to unveil very complicated Earth's primary /mega structures and unravel different tectonic episodes and processes through which the earth has passed i.e. Earth's history..
2. This helps in understanding the tectonic events and their implication in the formation of different natural sculptures on the Earth.
3. It helps us in planning for effective and sustainable mining activities.
4. This helps us in exploring and exploiting the natural resources like building stones, ores, groundwater, and oil and gas. There are many types of structures in which the mineral solutions get deposited. Therefore, the geometrical aspects of these structures are very important.
5. It facilitates in selecting suitable sites for major civil engineering projects like dams, tunnels, etc. Many project sites are changed or even rejected under adverse structural conditions.
6. The knowledge of structural geology helps in delineating sites for artificial groundwater recharge and rainwater harvesting.
7. It is very important for eco-societal linkage.

Now you must have become familiar with the various aspects of importance of structural geology.

9.3 REPRESENTATION OF ALTITUDE

You might have observed that surface of the Earth is not uniform everywhere. There are many elevations and depressions in the form of mountains, plateaus, valleys and plains. The highs and lows of the Earth's surface are sometimes represented by hachuring or shadings on the maps.

Let us discuss the method of representing the altitudes on a topographical map with help of contour lines. A **topographical map** is a map where surface features of a region are depicted on a certain scale with the help of contour lines. **Contour lines** are the imaginary lines on map which represent points of equal heights, with respect to the ground surface (Fig. 9.8). In other words, a contour line is a locus of all points which are at equal elevation on the given ground. Fig. 9.8a represents a hill of height more than 400m. On this hill the 100m, 200m, 300 and 400m height from mean sea level (msl) have been marked. If a horizontal plane at a height of 400m cuts the hill, it may have a trace of the intersection of plane and hill (Fig. 9.8c). If we look from the top, the projection of this trace will be seen on the ground surface (Fig. 9.8c). This imaginary line, which is representing projection of the trace of intersection of hill and 400m high horizontal surface, is the contour line of the hill at 400m height. Likewise the 100m, 200m, 300m and 400m heights of the hills may be represented by contour lines (Fig. 9.8b).

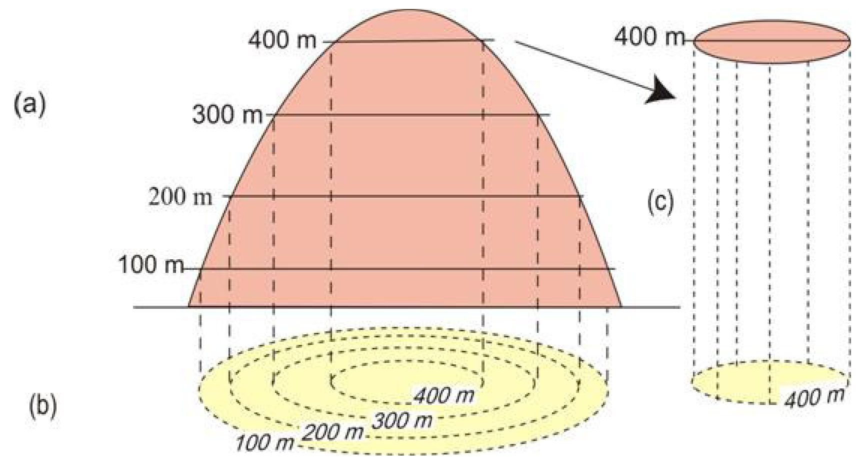


Fig. 9.8: a) Hill showing different heights; b) Contour lines for respective heights; and c) Projection of 400m on ground contour lines and slope.

The above also gives an idea of how you can find out slope of a ground from the contour lines. Slope of the ground for a given direction can be obtained by measuring the horizontal distance between two contour lines in that direction and height difference referred to as vertical interval between the contour lines. The slope gradient can obviously be determined on a topographical map by using equation:

$$\text{Slope} = \frac{\text{Vertical interval between contour lines}}{\text{Horizontal distance between contour lines}}$$

It is noticeable from the above that if the contour lines are closer, the slope (gradient) of the ground will be more. For a vertical slope, the distance between the contour lines will be zero. In other words, if several contour lines of different altitudes are observed in a topographical map one over another at a particular place, it represents a vertical slope of ground at that place. If the contour lines are placed at equal interval in a topographical map, it will represent a **planar slope** (Fig. 9.9a). In a concave slope (Fig. 9.9b), the contour lines of higher values are placed closer while those of lower values are placed farther. For **convex slopes** the contour lines of higher values are placed farther while those of lower values are placed closer (Fig. 9.9c).

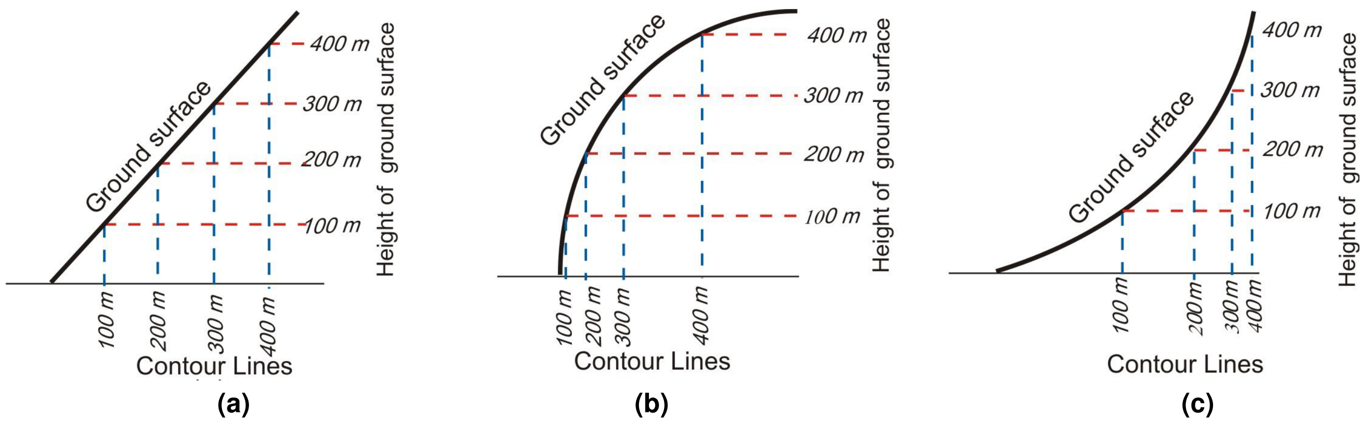


Fig. 9.9: Graphical representation of a) planar slope; b) concave slope; and c) convex slope.

The contour lines have following characteristics:

- They are always a closed curve. They do not terminate abruptly.
- They do not cross one another.
- The contour lines are closely placed it means slope of the ground is greater and vice versa.
- If they are placed at regular or irregular intervals this would mean that the ground is regular (uniformly sloping) or irregular, respectively.

9.4 CLASSIFICATION OF STRUCTURES

Now let us learn about the major structures found in rocks.

9.4.1 Planar Structures

Planar structures are those structures which are found as a plane or as a surface in the rocks and go hand in hand with linear structures.

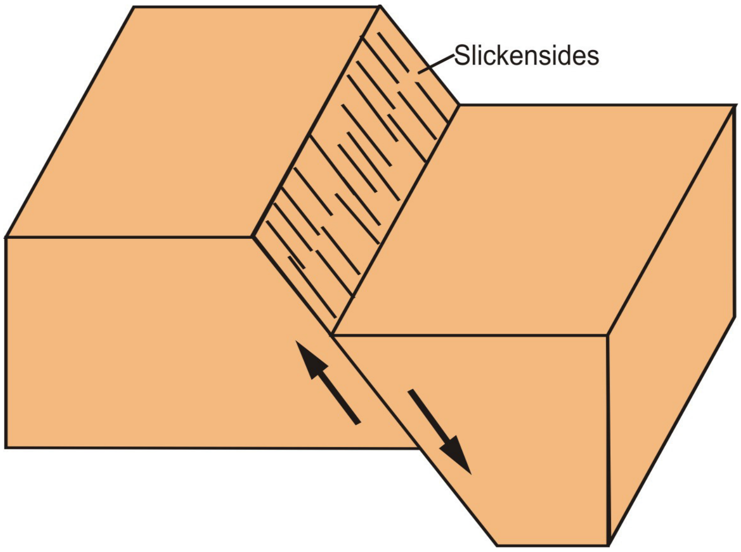
Let us discuss the following types of planar structures:

1. **Bedding plane**: You have read earlier in this unit the bedding planes are surfaces that bind sedimentary beds. Two beds are separated by a bedding plane in a sedimentary rock (Figs. 9.1 and 9.4). Bedding planes are also considered as a primary foliation because these planar features are formed at the time of formation of rocks.

2. **Joints**: Joints are the regular or irregular planar fracture that separates two adjacent blocks by a gap.

3. **Fault plane**: Fault planes are fractures along which the co-existing rock blocks have been displaced (Figs. 9.10a and b). Fault is a fracture along which measurable displacement has taken place between two blocks.

4. **Metamorphic foliation**: Metamorphic foliations are those planar structures which are formed after the formation of rock during its subsequent deformation and metamorphism. Hence they are the secondary foliations, as already discussed earlier in this unit. Metamorphic foliations or simply '**foliation'** are characteristically found in the metamorphic rocks (Fig. 9.11). Often the metamorphic rocks are recognised by the characteristic foliation found in them. The metamorphic foliations include **slaty cleavage**, **schistosity** and **gneissosity** which are found in the rocks known such as slate, schist and gneiss, respectively.



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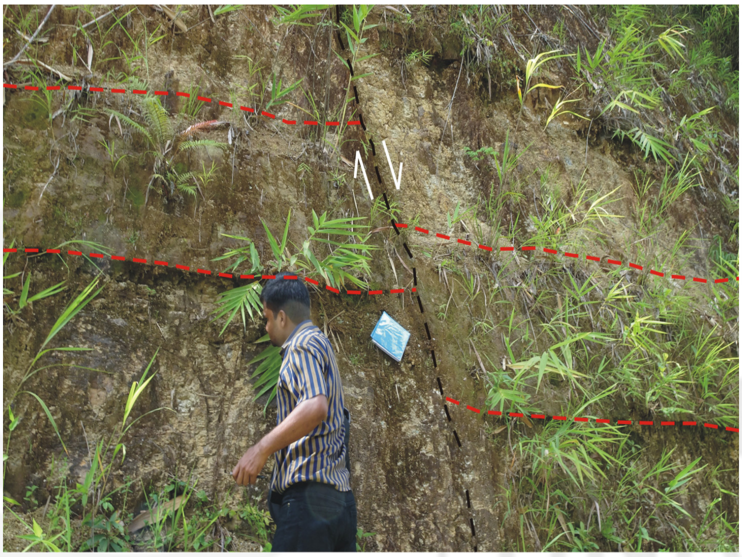


(b)

(c)

Fig. 9.10: a) Displacement has taken place along the fault plane. Direction of movement is marked by arrows; b) Field photograph of fault, notice the fault plane (Photo credit: Ganga Prasad Bhartiya); **and c) Field photograph of slickensides on a fault plane surface.**

Fig. 9.11: Foliation seen in metamorphic rock (phyllite) which is parallel to the pen.

9.4.2 Linear Structures

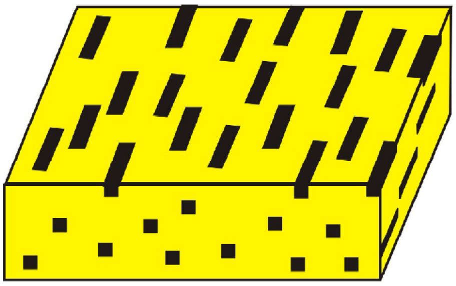
The linear structures are structures that are continuous and occur as a line, as the nomenclature indicates. They are mesoscopic (medium sized) structures and point in a specific direction and may be:

1. **Mineral lineation**: Some minerals have crystalline habit, such that their one dimension is appreciably longer than other two. The longer dimension of the minerals is aligned in a particular direction, or a deformed group of minerals have their orientation in such a way that their longer dimension is aligned in a particular direction parallel to each other and they give rise to mineral lineation (Fig. 9.12a).

2. **Crenulation lineation:** If any planar surface such as foliation is affected by folding of small or microscopic scale, the hinge lines of these folds are aligned in a particular direction which generates crenulations lineation (Figs. 9.12b and c).

3. **Slickensides**: They are usually polished surface with frictional lines developed on the fault plane caused by movements between two faulted blocks (Fig. 9.11c).

4. **Boudinage, pinch-and-swell, mullions and roddings**: They are the linear structures developed due to deformation in **competent** (stronger) layers lying between **incompetent** layers. Boudinage is a structure in which the layers have been stretched and separated into segments. Individual boudin is commonly much longer in one dimension than other two and thus depicts a lineation (Fig. 9.13a). In pinch and swell structure, the layer shows pinching and swelling but no segmentation (Figs. 9.13b and d). **Mullions** and **Rodding** describe linear corrugations in the rocks (Figs. 9.13c). If these corrugations are formed by the rock itself, it is called mullion and if it is formed by any particular mineral, generally quartz, the structure is called rodding.



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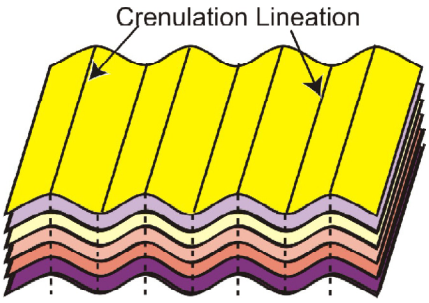

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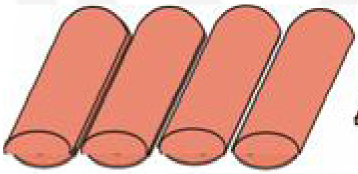
Fig.9.12: a) Mineral Lineation; b) Crenulation lineation; and c) Field photograph showing lineations. (Photo credit: Mr. Ganga Prasad Bhartiya)



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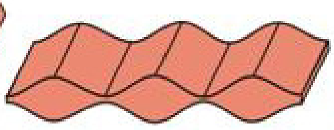

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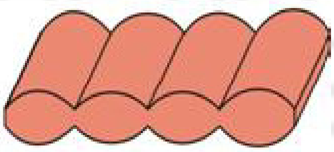

(c)

(d)

Fig. 9.13: a) Boudinage; b) Pinch and Swell structure; c) Mullion/Rodding structure; and d) Field photograph of pinch and swell structure. (Photo credit: Ganga Prasad Bhartiya)

9.4.3 Folds

Some structures have elements of both linear and planar structures developed together the example of this are the folds which are wavelike undulations over a planar structure, such as bedding plane or foliation. They comprise combination of planar and linear structures. We will read about fold in Unit 10.

9.5 MEASURING STRUCTURAL ELEMENTS

We have read earlier in this unit that many rocks show planar structures in the form of layering, bedding plane, foliation. Bedding plane or foliation in any outcrop is not always horizontal and they may show inclination of varying amounts. The strike and dip describe the orientation of a rock layer exposed at an outcrop. The strike is the compass direction of a line formed by the intersection of layer of rock layer's surface with the horizontal surface. The **dip** is measured at right angles to the strike. It is simply the amount of tilting on the angle at which the rock layer inclines from the horizontal. However, the amount of dip of a layer or bedding plane is variable if measured in different directions. In order to understand the orientation of the structures, it is necessary to measure their dip and strike on the outcrops during the fieldwork. In fact field is the true laboratory for a structural geologist. The measurement of dip and strike is done with the help of **Clinometer Compass** (Fig. 9.14).

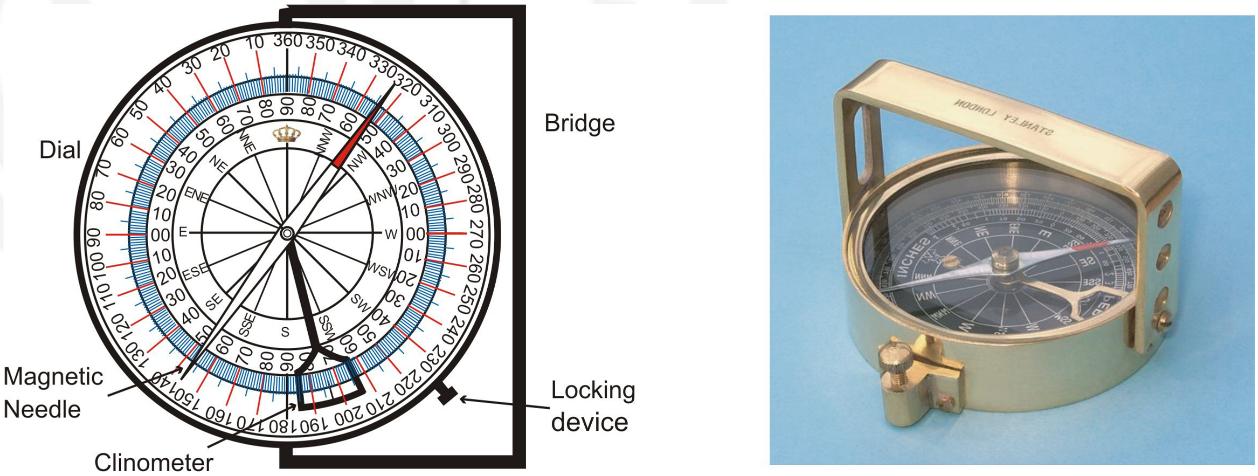

Fig. 9.14: Sketch and photograph of clinometer compass.

9.5.1 Clinometer Compass

Clinometer compass is comprised of a compass and clinometer. The compass has a circular **dial** graduated with 360 divisions anticlockwise in the outer most circle for reading the direction which is called **azimuthal circle** where 0 or 360 represents for North, 90 for East, 180 for South and 270 for West. It has a **magnetic needle** which rests in north- south direction of the Earth, when set free. The desired direction is read on the dial with help of N (north) marked end of this magnetic needle. One of the inner circles on the dial is also marked with directions such as E (East), NE (North East), NNE (North North East), W (West) in supplement to the outermost circle to read the direction directly.

The inclination of a line with respect to horizontal is read with the help of a clinometer fitted in compass (Fig. 9.14). The clinometer, which consists of

i) a magnetic needle with a graduated dial,

ii) a pendulum,

iii) both fitted on a frame referred to as **bridge**.

The open space within the clinometer's frame has a inner circle in the dial marked with 0 to 90^o graduation to facilitate some direct reading. A mark in the middle of the frame opening is used to take the reading of inclination (or dip amount). The reading of the inclination of the bed is done with the help of a bridge fitted outside the dial. This is a movable bridge which can rotate upto 90^o angles from a plane parallel to the dial up to a plane perpendicular to the dial. The bridge line is always parallel to the North-South line of the dial. There is a **locking device** outside the dial ring, which on pressing locks the magnetic needle as well as clinometer so that the reading may be taken even after removing the compass from the outcrop.

9.5.2 Measuring Strike and Dip of an Inclined Bed

You are instructed to adopt following procedure in order to measure the strike and dip of a bed:

i) **To measure the strike direction**

- Keep the compass on bedding plane in such a way that the bridge of the compass touches the bedding plane completely.
- Rotate the compass so that the bridge becomes horizontal and one end of the bridge still touches the bedding plane.
- On becoming horizontal the magnetic needle moves freely.
- Let the needle come to rest and then read both ends of the azimuthal circle. The two ends represent strike.

ii) **To measure the amount of dip of the bed**

- Draw a line on the bed perpendicular to strike line. For convenience let us call it as dip line.
- Now keep the bridge on the bedding plane along this line in such a way that the dial plane is vertical.
- Take the reading in frame of the clinometer, which gives the dip amount.

iii) **To measure the direction of the dip**

- Put the bridge along the dip line drawn on the bedding plane but this time the dial will face the sky.
- Now rotate the compass to horizontal in such a way that the bridge and N-S line of the dial both remain parallel to the dip line. Take care that the crown (often N is marked as a crown in many clinometer compasses) in the dial is towards the dip direction of the bed.

- On rotation to horizontal, the N marked end of the magnetic needle gives the dip direction.
- You can cross check your reading because strike and true dip directions are always perpendicular to each other.
- On a vertical plane if inclination of a linear structure with respect to horizontal is measured, it is called **plunge** of that structure. Thus, dip of a planar structure and plunge of linear structures both are analogous.

The geographical direction of plunge of a linear structure is referred to by the term **bearing.**

SAQ 2

a) Define contour and topographical map.

b) What is the difference between contour lines of planar, concave and convex slopes?.

c) List planar and linear structures.

d) Differentiate between extrusive and intrusive igneous rocks.

9.6 SUMMARY

Structural geology is study of the rock architecture of the solid Earth. Let us summarise what we have learnt in this unit.

- The geometry and sequence of development of the geological structures are studied in structural geology. Many kinds of planar and linear structures or their various combinations develop in the rocks due to tectonic forces.
- The outcrops and their patterns are expressions as developed on interaction between structures and topography of the ground surface. The study of the structures is primarily done on the outcrops where they are exposed.
- Measurements for their orientation are done by measuring strike and dips with the help of clinometer compass on the outcrops, to understand the geometry of these structures.
- Contour lines in a topographic map depict the highs and lows of the ground surface.
- The bedded rocks can be invaded by intrusive igneous rocks in concordant or discordant forms as sills and dikes. These intrusive igneous rocks can be observed in a variety of forms.

9.7 ACTIVITY

1. Try to find out a topographical map of your region or a region. Look at the contour lines and asses the highs and lows of selected area of your choice.

2. Try to observe the layers in the rocks exposed in your area. Determine the dip amount and dip direction of the layers. Also, try to find the strike of the inclined bed.

9.8 TERMINAL QUESTIONS

1. Elaborate the importance of structural geology.
2. Describe briefly how you would measure strike and dip of a bed in the field.
3. Discuss various planar and linear structures.

9.9 REFERENCES

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- Fossen, H. (2010) Structural Geology, Cambridge University Press, ISBN 978-0-521-51664-8, 463p.

9.10 FURTHER/SUGGESTED READINGS

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- Singh, P. (2009) Engineering and General Geology, S.K. Kataria and Sons, 600p.

9.11 ANSWERS

Self-Assessment Questions

1. a) Structural geology is the study of the architecture of rocks developed on deformation. Structural geology deals with the geometry, distribution and formation of structures. Structural geology and tectonics go hand in hand. However, the subject of structural geology is primarily concerned with the geometry of the rocks whereas tectonics deals with the forces and movements that produced the structures. In other words both structural geology and tectonics relate to the building and resulting structure of the Earth's lithosphere, and to the motions that change and shape the outer parts of our planet.

b) Both are planar structure and bedding plane are found in sedimentary rocks and layering in igneous rocks.

c) The rock exposed on the surface of the Earth is called as outcrop.

d) The dip of a bed has two components i.e. direction as well as magnitude, and therefore is a vector quantity.

e) The maximum amount of inclination of bed along a line perpendicular to the strike is called true dip. The dip of the bed measured in any direction other than that of true dip is called apparent dip. The amount of apparent dip is always less than amount of true dip, which is maximum and apparent dip amount of a bed becomes zero if measured in the direction of strike.

2. a) A topographical map is a map where surface features of any region are depicted on a certain scale. Contour lines are the imaginary lines on a topographical map which virtually represent points of equal heights on the ground.

b) If the contour lines are placed at equal interval in a topographical map, it will represent a planar slope. In a concave slope, the contour lines of higher values are closely spaced while those of lower values are placed farther. For convex slopes the contour lines of higher values are placed farther while those of lower values are placed closer.

c) Planar-bedding plane, metamorphic foliation, igneous foliation, joint and fault pane. Linear-Mineral lineation, crenulation lineation, slickensides, boudinage, mullions and roddings, and fold hinge lines.

d) When the magma reaches the Earth's surface it forms the extrusive igneous rock. Intrusive igneous rocks forms when magma intrudes into country rocks but consolidates beneath the surface of the Earth.

Terminal Questions

1. Please refer to the subsection 9.2.7.
2. Please refer to the section 9.5.
3. Please refer to the section 9.4.

UNIT 10

FOLDS

Structure

10.1 INTRODUCTION

In Unit 9 we learnt about the basics of structural geology. Now in next three units we will study about the geological structures like folds, faults, joints and fractures that result from deformation of rocks due to forces acting within the Earth. These geological structures not only record geological history but they also help us in understanding the Earth's processes such as mountain building. The knowledge of geological structures is essential in site selection of engineering projects such as dam, tunnel, power generation station, etc., in addition to search for energy resources and valuable mineral deposits.

In this unit we shall be discussing an important geological structure namely, fold. Folding is the most common form of deformation in the rocks that make up Earth's crust, apart from faulting about which we will discuss in Unit 11 Fault. Folds may range in size from a few millimetres to thousands of kilometres. Majestic mountain ranges whether it is Aravalli or Himalaya are actually a frame of folds series. The folds represent ductile or plastic deformation of the rock and the faults represent mainly the brittle nature of deformation. Folding of strata represents a shortening of Earth's crust and results from compressive forces. **Compressive force** is the force generated from compressing an object or substance. The object gets compacted, on its application. The geologist starts with the knowledge that the beds must originally have been horizontal and undeformed at the bottom of an ancient ocean. Careful data collection, examination, and interpretation of all the details help a geologist to visualise the entire sequence of activities. This experience and knowledge helps us to reconstruct the succeeding tectonic events of geological past.

In this unit, we shall define and discuss the classification of folds, causes and effects of folds on outcrop. We would also learn about the criteria of identification of folds in the field.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ define fold;
- ❖ discuss significance of folds in geology;
- ❖ classify folds on the basis on geometry;
- ❖ identify the criteria of recognition folds in the field; and
- ❖ list causes of folding.

10.2 FOLD

Folds are spectacular and noticeable structures that can form in practically any rock type; however they are best identified in layered rocks. They have been recognised, admired and explored by geologists and even non-geologists. They are some of our most important windows into local and regional deformation histories of the geological past.

Let us define fold.

10.2.1 Definition

Folds are wave-like undulations in strata/foliations. They are bending or arching in the bedding or foliation planes of the rock layers due to forces of the Earth. Folding is commonly observed in layered rocks. They are best displayed by stratified formations such as sedimentary, layered volcanic igneous rocks and most metamorphic rocks.

Folds in rocks are like folds in clothing. Just as when a piece of cloth is pushed together from opposite sides it buckles up in the form of folds. Similarly, the layers of rock when compressed by forces cause the development of folds, as they are capable of being crumpled or buckled into folds. Folding is the process of development of folds. However, they may develop in variety of ways. We will study about them later in this unit.

10.2.2 What do Geologists Infer from Folds?

Observations in the field seldom provide geologists with complete information; either bedrock is obscured by overlying soil or erosion has removed much of the evidences. So geologists search for clues which decipher the relation of one bed to another. Folds are significant in geological studies because of following reasons. They:

- bring the deep seated rocks upto the surface of the Earth.
- facilitate development of site for deposition of mineral bearing solution.
- serve as good host for oil and natural gas.
- create beautiful landscapes which may enhance geotourism.

10.3 ELEMENTS OF FOLDS

Now let us discuss the different parts or elements of a fold.

Fold morphology comprises of components/elements like:

- **Wavelength of fold**: We have already read that the folds are the wave like undulations found in the layered rocks. Wavelength of the fold is the minimum distance between its two successive points of same phase. It can also be defined as the distance between two alternating inflection points. For practical purposes the distance between two successive inflection points is considered as half wavelength of the fold (Fig 10.1).

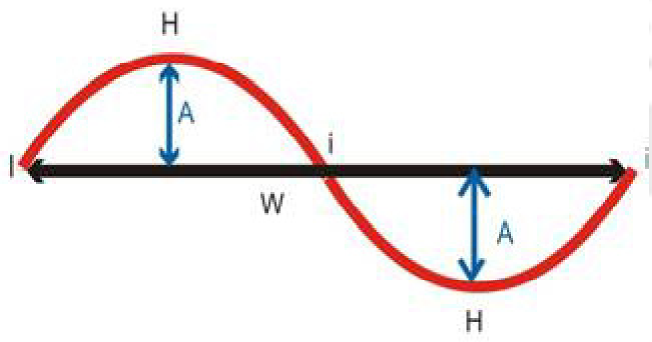
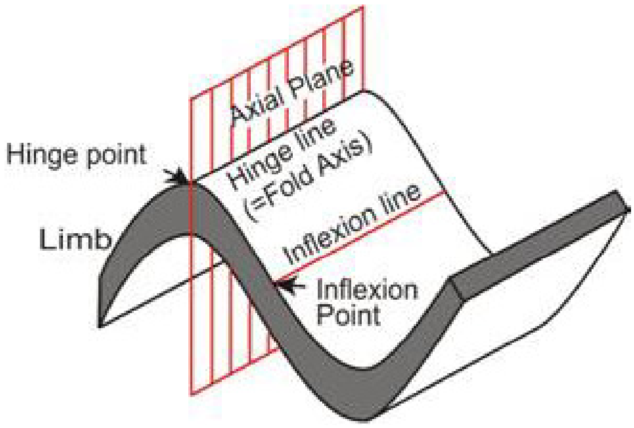


Fig. 10.1: Elements of fold (Abbreviations used: W-wavelength, A-amplitude, H-hinge point, i-inflexion point).

- **Amplitude of fold**: It is the length of perpendicular drawn from hinge point of the fold on the line joining the two successive inflection points of the fold.
- **Hinge point**: It is the point of maximum curvature on the profile section of a fold (Fig. 10.2). The profile of the fold is a cross section or transverse section across the hinge line of the fold.
- **Hinge zone**: Sometimes the maximum curvature of the fold is not at a point but in a zone called hinge zone. A hinge zone is a region where the dip of the folded surface changes over small distance. Such a region is also called a fold closure.
- **Hinge line**: It is the locus of hinge points of a particular bedding plane. Hinge line of a fold is the line of maximum curvature in the folded bed

(Fig. 10.2). In other words, we can say that hinge line is a line along which change in the direction of dip takes place, and on many folds this coincides with the amount of maximum curvature.



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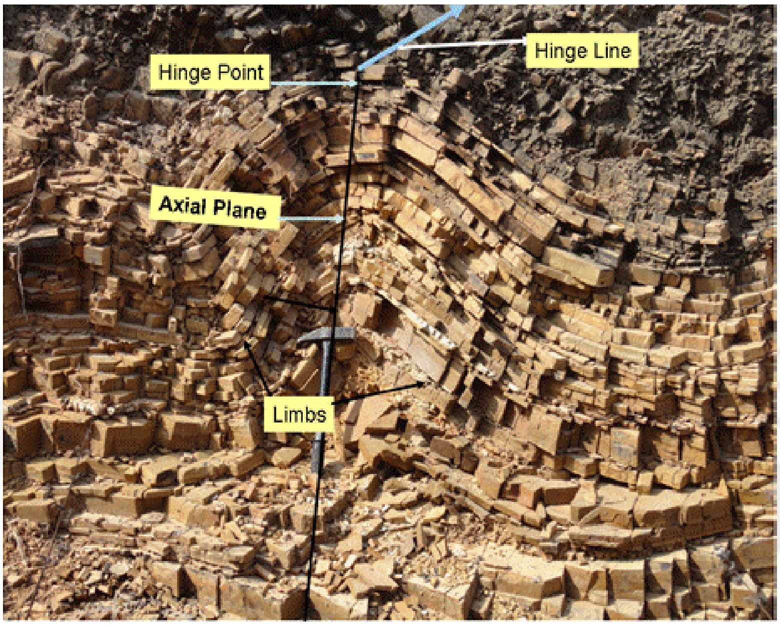


(b)

Fig. 10.2: a) Parts of a fold; and b) Field photograph of a fold.

- **Fold axis**: It is an imaginary line which by moving parallel to itself generates the fold. The hinge line of a fold is equivalent to '**fold axis**' if it is straight and the fold is cylindrical in nature (Fig. 10.2).
- **Inflexion point**: It is a point of the fold with zero curvature where its form changes. That is to say, it is the point where an antiform changes into synform on cross section of the fold or vice- versa (Figs. 10.1 and 10.2).
- **Inflexion line**: This line is obtained by joining the inflexion points of a folded layer. In other words, the inflexion line is that line from where an antiform changes into a synform or vice-versa (Fig. 10.2).
- **Limb**: It is a portion of a fold between inflexion point and hinge (Fig. 10.2).
- **Axial surface/ Plane**: It is a surface formed by joining of fold hinge lines of successive beds. When the axial surface forms a plane it is called axial plane (Fig. 10.2).

- **Crest**: It is that point which is located highest in the profile section of the fold (Fig. 10.3a).
- **Trough**: It is that point which is located lowest in the profile section of a fold. (Fig. 10.3b).
- **Crestal line:** This is located highest in the fold and is obtained by joining the crestal points of its layer (Fig. 10.4a).
- **Trough line:** This is located lowest in the fold and is obtained by joining the trough points its folded layer (Fig. 10.4b).

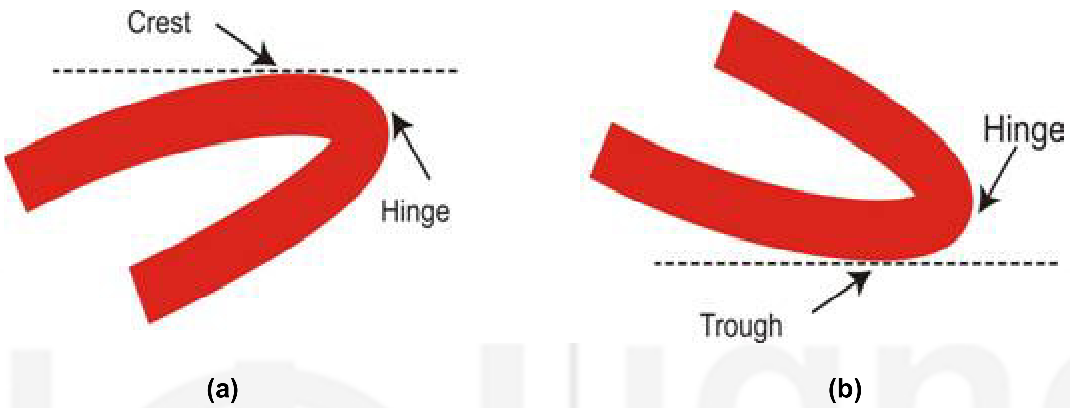


Fig. 10.3: a) Crest; and b) Trough of a fold.

- **Culmination** is the highest point located on the crest line (Fig. 10.4a).
- **Depression** is the lowest point located on the trough line (Fig. 10.4b).

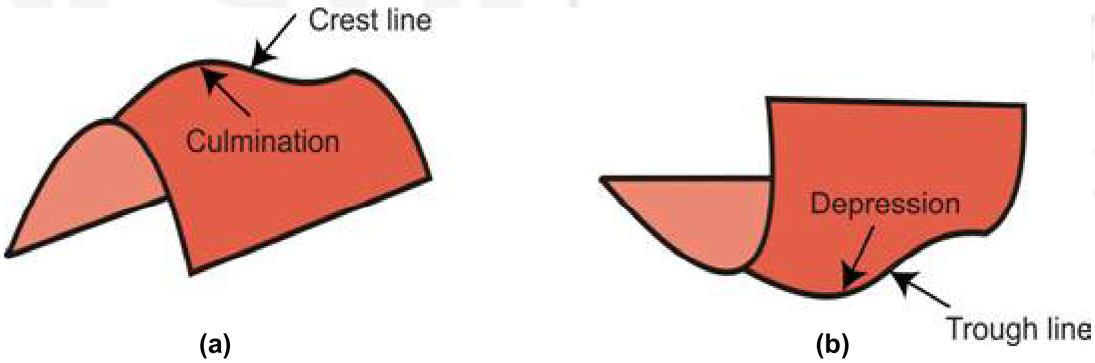


Fig. 10.4: a) Culmination; and b) Depression.

- **Fold closure** indicates the direction in which the limbs converge which is also referred sometimes by the terms like **arching** and **nose** of the fold. The shape of the fold closure depends on how the curvature of the folded surface changes around the hinge. The hinge may be very sharp and the limbs may be relatively straight, or can have curvature which is smoother around the fold.

10.4 GEOMETRICAL CLASSIFICATION OF FOLDS

Let us discuss the geometrical classification of folds.

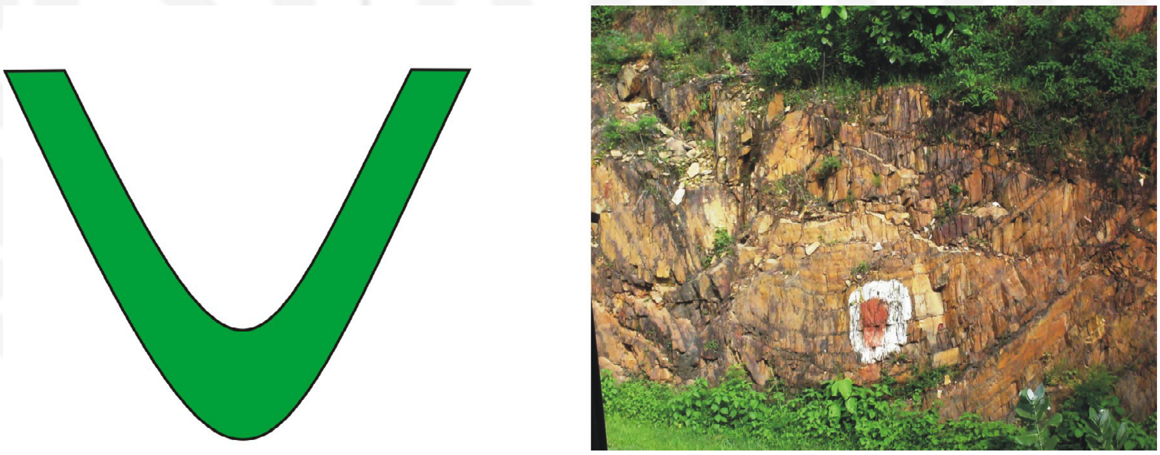
Folds have been classified geometrically on the basis of many parameters about which we shall discuss in following sections.

10.4.1 Based on Arching Direction

- **Antiform** is a fold which arches upward (Fig. 10.5a and b).
- **Synform** is fold which arches downward (Fig. 10.6a and b).
- **Neutral fold** arches neither up nor down but sideways (Fig. 10.7a and b).

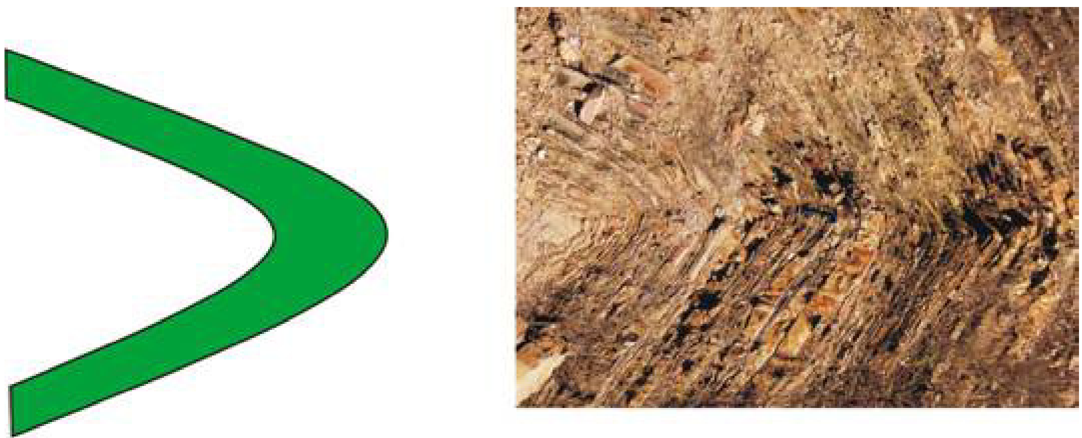
(a) (b)

Fig. 10.5: Antiform: a) Sketch; and b) Field photograph.



(a) (b)

Fig. 10.6: Synform: a) Sketch; and b) Field photograph.

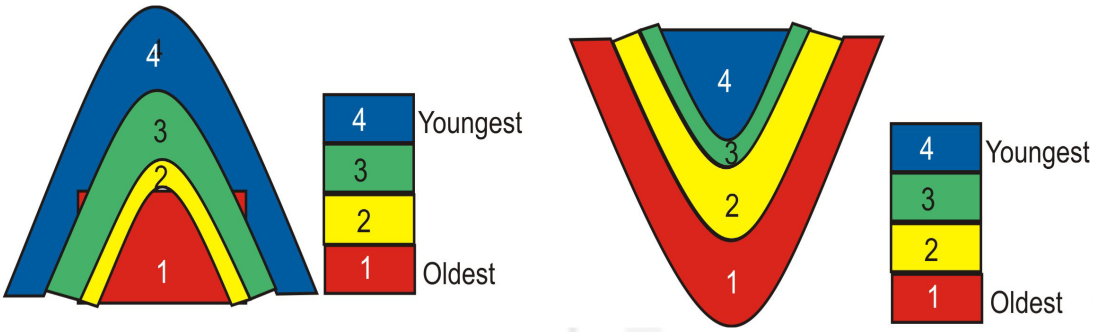


(a) (b)

Fig. 10.7: Neutral Folds: a) Sketch; and b) Field photograph.

10.4.2 Based on Relative Age of Beds

- **Anticline:** It is a fold in which older rocks occur in the core (Fig. 10.8a).
- **Syncline:** It is a fold in which the core is occupied by younger rock. (Fig. 10.8b).
- **Antiformal Anticline:** In this case, the fold arches upward and the core of the fold comprises of older rocks (Fig. 10.8a).
- **Synformal Syncline:** It is that fold which has downward arching and the younger beds occupy the core (Fig. 10.8b).



(a) (b)

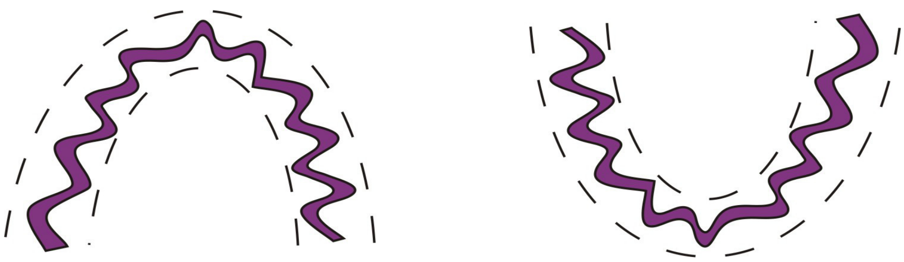
Fig. 10.8: a) Anticline/Antiformal anticline; and b) Syncline/Synformal syncline.

- **Antiformal Syncline:** Antiformal syncline is a fold which arches upward and the core of the fold comprises of younger rocks (Fig. 10.9a).
- **Synformal Anticline:** In the synformal anticline, the fold arches downward with core comprised of the older rocks (Fig. 10.9b).

(a) (b)

Fig. 10.9: a) Antiformal syncline; and b) Synformal anticline.

- **Anticlinorium:** It is a large anticline comprised of numerous smaller anticlines and synclines (Fig. 10.10a).
- **Synclinorium:** A large syncline comprising of numerous smaller anticlines and synclines (Fig. 10.10b).



(a) (b)

Fig. 10.10: a) Anticlinorium; and b) Synclinorium.

10.4.3 Based on Symmetry

- **Symmetrical fold:** In a symmetrical fold, the axial plane divides it into two parts which are mirror images of each other (Figs. 10.11a and 10.11b).
- **Asymmetrical fold:** In an asymmetrical fold, the axial plane divides it into two parts which are somewhat skewed so that one is not the mirror image of the other (Fig. 10.11c).

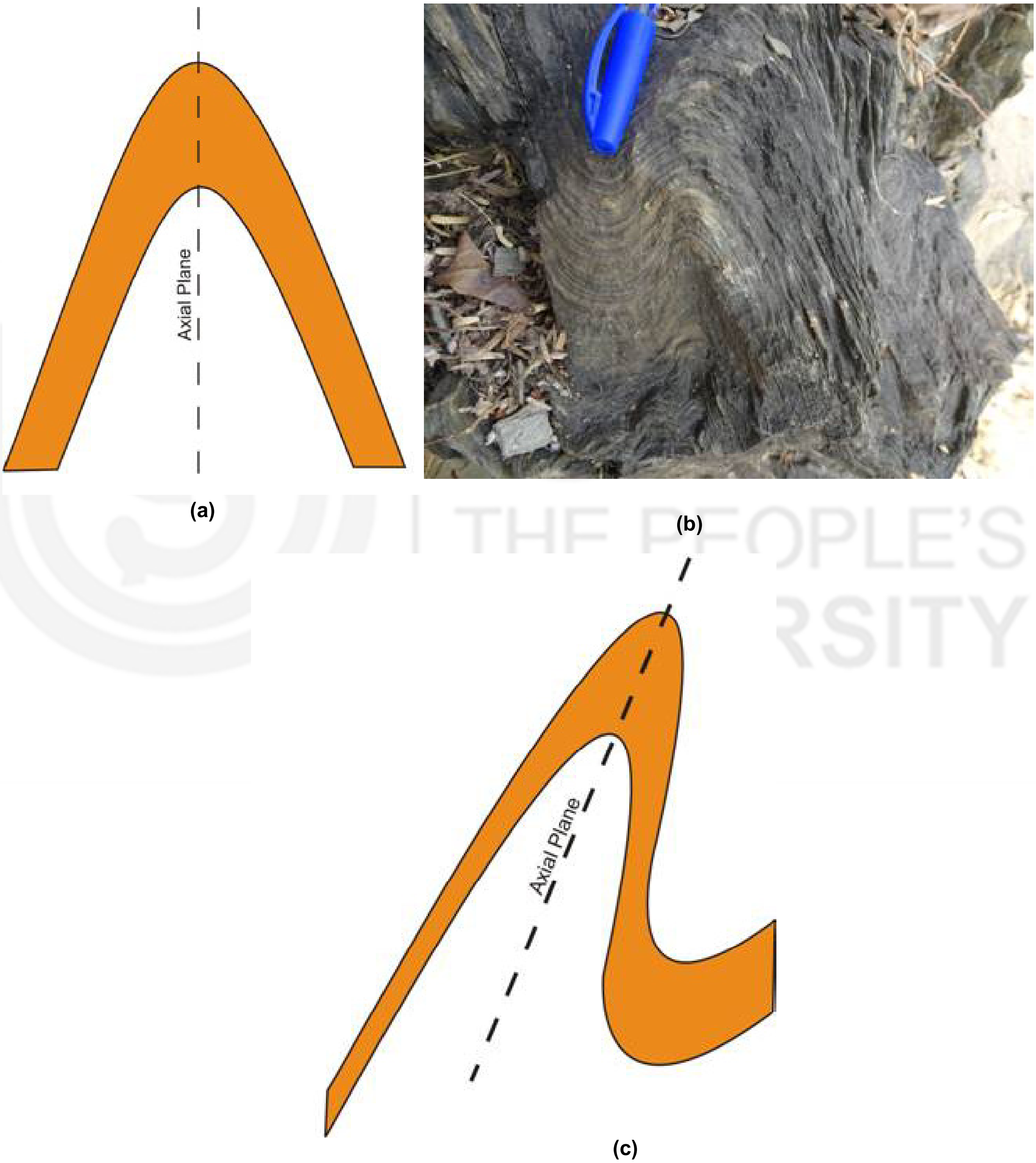


Fig. 10.11: a) Sketch of symmetrical fold; b) Field photograph of symmetrical fold in phyllite (Photo credit: Ganga Prasad Bhartiya); **and c) Asymmetrical fold.**

10.4.4 Based on Dip of Axial Plane

- **Recumbent fold:** In this fold axial plane is more or less horizontal. The dip of axial plane varies between 0 to 10° (Fig. 10.12a) in such folds.
- **Inclined fold:** When the axial plane dips more than 10° (Fig. 10.12b), it is referred to as inclined fold.

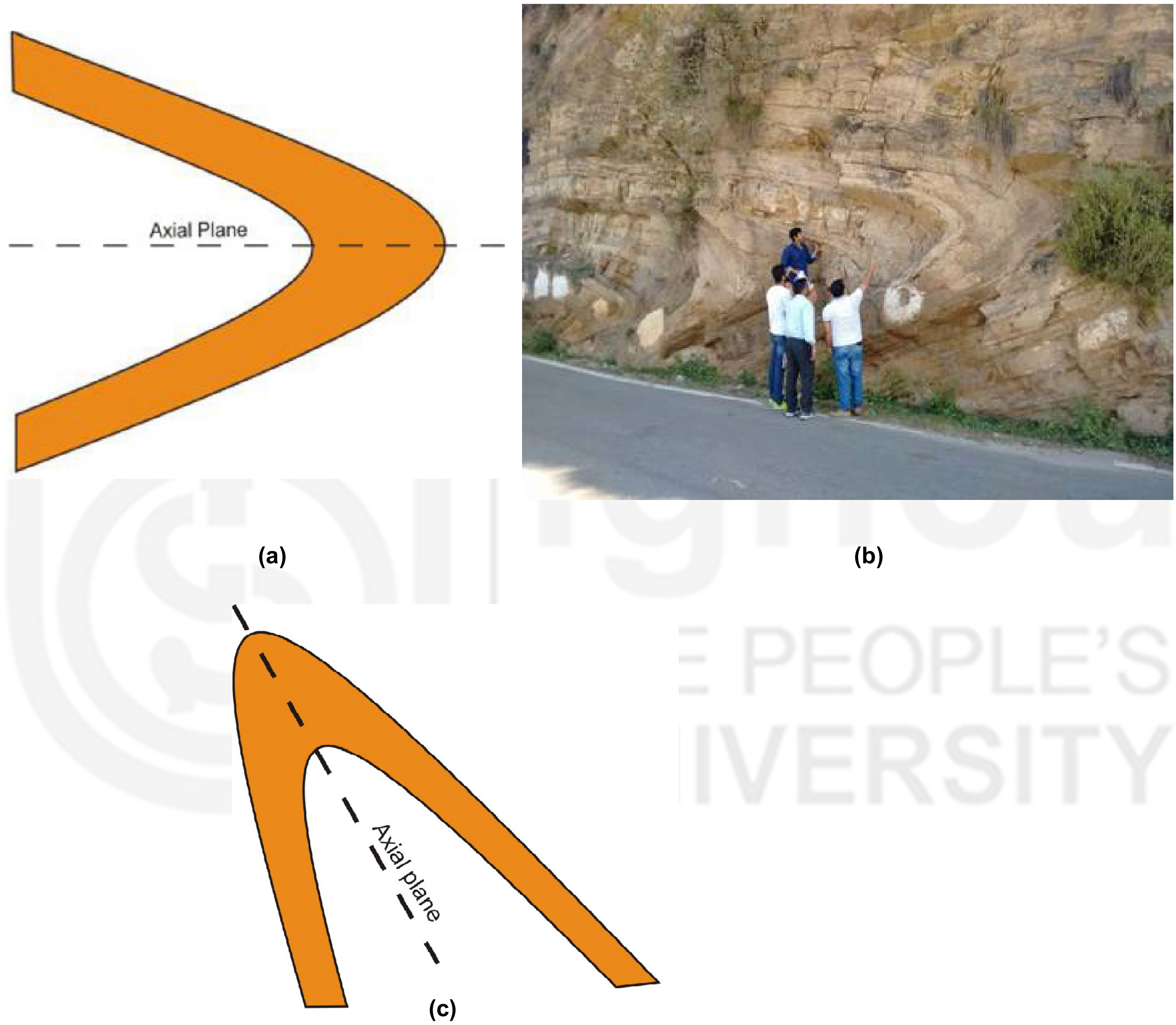


Fig. 10.12: a) Recumbent fold; b) Field photograph of recumbent fold in gneisses (Photo credit: Dr. Dinesh Sati)**; and c) Inclined fold.**

10.4.5 Based on the Plunge of Fold Hinge Line

The plunge as we know is the inclination of a line or lineation with respect to horizontal. Plunge of any line is always measured in vertical plane. The angle of inclination of the axis, as measured from the horizontal, is called the **plunge**. Folds have been classified on the basis of plunge of its hinge line or fold axis as follows:

- **Non-plunging fold:** The plunge of the fold hinge line is zero (Fig. 10.13a).
- **Plunging fold:** Fold hinge line has amount of plunge greater than zero (Fig. 10.13b).

- **Doubly plunging fold:** It is a structure where the fold hinge line plunges in two opposite directions from the culmination (Fig. 10.13c). In a doubly plunging anticline, the plunge is away from culmination whereas in a doubly plunging syncline, the plunge is toward depression.

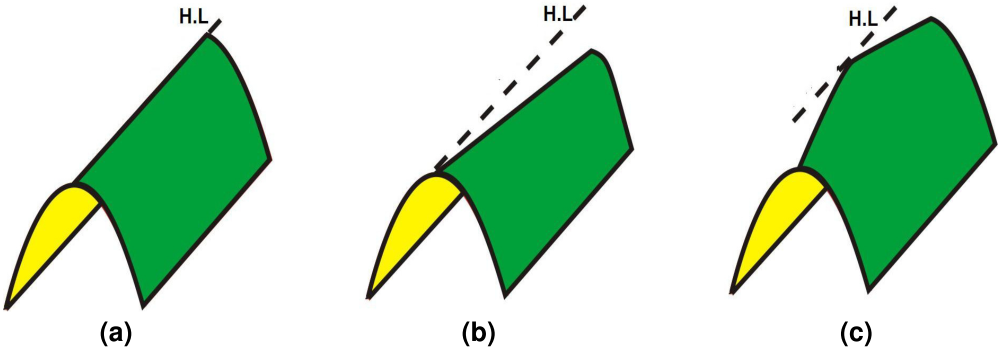


Fig. 10.13: a) Non plunging fold; b) Plunging fold; and c) Doubly plunging fold; H.L. = Horizontal Line.

- **Dome:** A dome is quaquaversal dipping antiformal structure, a broad circular upward bulge of rock layers which means the fold plunges in all direction from the culmination. **Quaquaversal** refers to the structures that dip outward in all directions from a central point.
- A dome has a circular outline on plan and the whole structure is like inverted bowl. The flanking beds of a dome encircle a central point and dip radially away from it (Fig. 10.14a). Domal structure assume greater importance in petroleum exploration.
- **Basin:** It is a special type of fold which is synformal in nature having circular outline on plan. It has a centripetal dip meaning dipping towards a common point from all directions. It appears like a bowl (Fig. 10.14b).

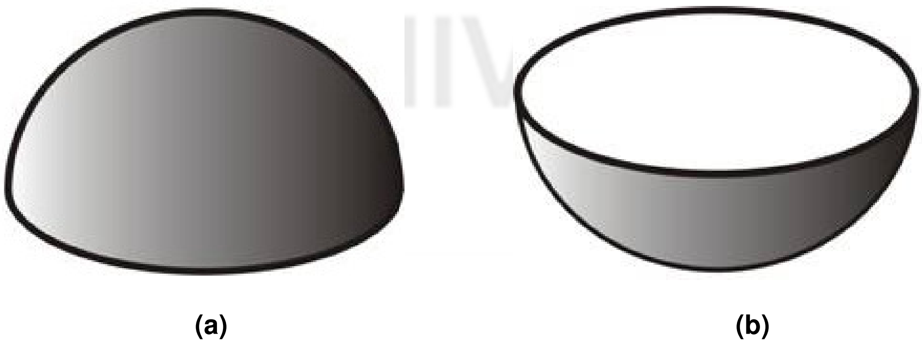


Fig. 10.14: a) Dome; and b) Basin.

Before reading more about geometrical classification of folds let us check our progress.

SAQ 1

a) Define hinge line and fold axis.

b) Differentiate between antiformal syncline and synformal anticline.

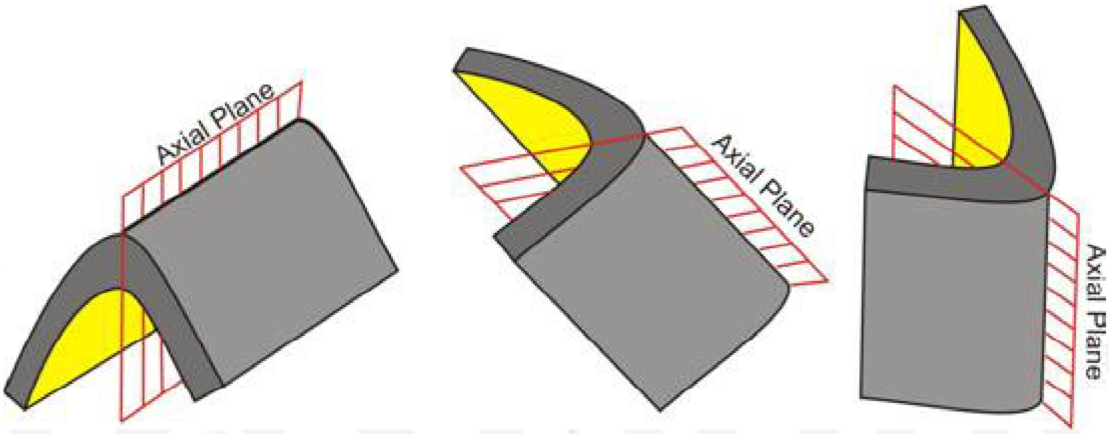
c) Classify folds on the basis of dip of the axial plane.

d) Differentiate between dome and basin.

Now let us go through some more criteria of geometrical classification of folds.

10.4.6 Based on Relation of Dip of Axial Plane and Plunge of Fold Hinge Line

- **Upright fold:** It is a fold where axial plane is vertical and plunge of the fold hinge line is zero (Fig. 10.15a and 10.15d).
- **Reclined fold:** Fold which has same amount and directions of dip of axial plane and plunge of fold hinge line (Fig. 10.15b).
- **Vertical fold:** In this fold dip of axial plane as well as plunge of fold hinge line are 90° (Fig. 10.15c). This is a special variety of reclined fold.



(a) (b) (c)

(d)

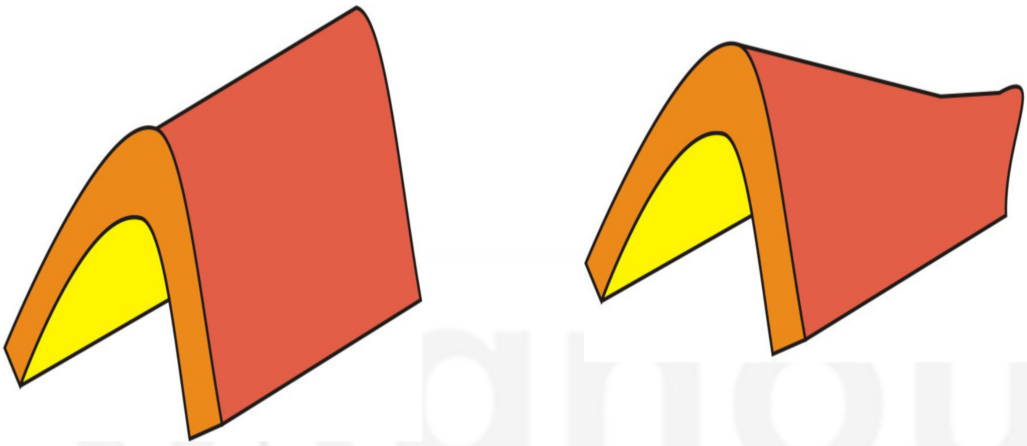
Fig. 10.15: a) Upright fold; b) Reclined fold; and c) Vertical fold; and d) Field photograph of upright fold. (Photo credit: Ganga Prasad Bhartiya)

10.4.7 Based on Cylindricity

- **Cylindrical fold:** This is a kind of fold which can be generated by moving the fold axis parallel to itself (Fig. 10.16a). Folds are often drawn as cylindrical structures which means that the fold axis is a straight line which, when moved parallel to itself, generates any single fold of the

same generation. The axis of cylindricity is parallel to the fold axis.
The cylindricity of a fold is a qualitative expression of the degree to which the fold approximates cylinder.

- A cylindrical fold appears as a straight line in a section parallel to its axis, while in any other section the trace of the folded surface has a wavy shape approximate to a cylinder.
- **Non-cylindrical Fold:** This fold cannot be generated on moving the fold axis parallel to itself (Fig. 10.16b).



(a) (b)

Fig. 10.16: a) Cylindrical fold; and b) Non-cylindrical fold.

10.4.8 Based on Thickness of Folded Layer

The thickness of a folded layer is generally measured on **profile section** of the fold. Profile section of a fold is that vertical plane which is perpendicular to fold axis. As such based on the thicknesses measured on profile section, the folds may be categorised as follows:

- **Parallel or Concentric Fold:** A parallel fold is that in which the thickness measured perpendicular to the layer (called orthogonal thickness) remains same throughout the layer (Fig 10.17a). The beds of each fold are approximately concentric, i.e. successive beds are bent into arcs having the same centre of curvature. Beds retain their constituent thickness round the curves and there is little thinning or attenuation of beds in the limbs of the fold.
- **Similar Fold:** It is a fold in which the thickness of the bed when measured parallel to axial surface is same throughout the layer. The orthogonal thickness of the folded bed in hinge zone may be more than that in the limb zone (Fig 10.17b). Thinning of the beds takes place in the limbs of the folds and a strong axial plane cleavage is usually developed.
- **Suprataneous fold:** In this fold the orthogonal thickness of the layer in the axial zone is less than that of the limb zone (Fig 10.17c).

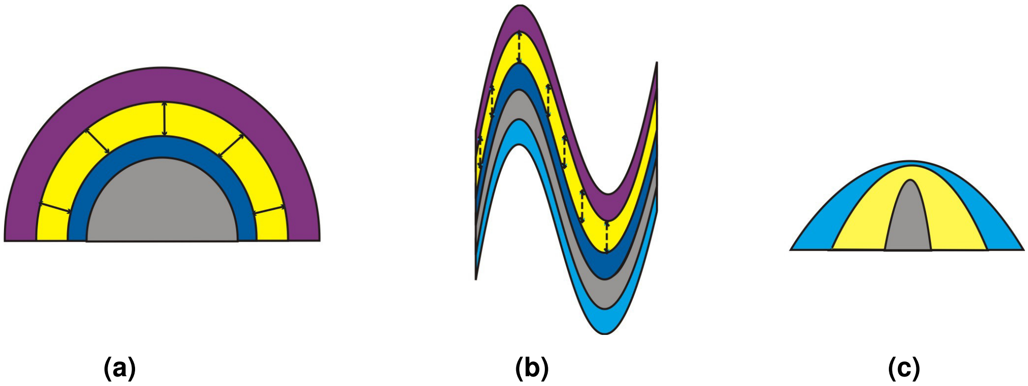


Fig. 10.17: a) Parallel fold; b) Similar fold; and c) Suprataneous fold.

10.4.9 Based on the Interlimb Angle

Fold tightness is defined by the size of the angle between the fold's limbs, called the **interlimb angle. Gentle folds** have an interlimb angle of between 180° and 120°.

Interlimb angle is the angle between two limbs of a fold measured on profile section. On the basis of interlimb angles the folds are of following types:

	Fold Type	**Interlimb Angle**
1.	Isoclinal Fold	0-10° (Fig. 10.18a)
2.	Tight Fold	10-30° (Fig. 10.18b)
3.	Close Fold	30-70° (Fig. 10.18c)
4.	Open Fold	70-120° (Fig. 10.18d)
5.	Gentle Fold	>120° (Fig. 10.18e)
6.	Fan Fold/Elastics Fold	(Negative interlimb angle <0°; Fig. 10.18 f)

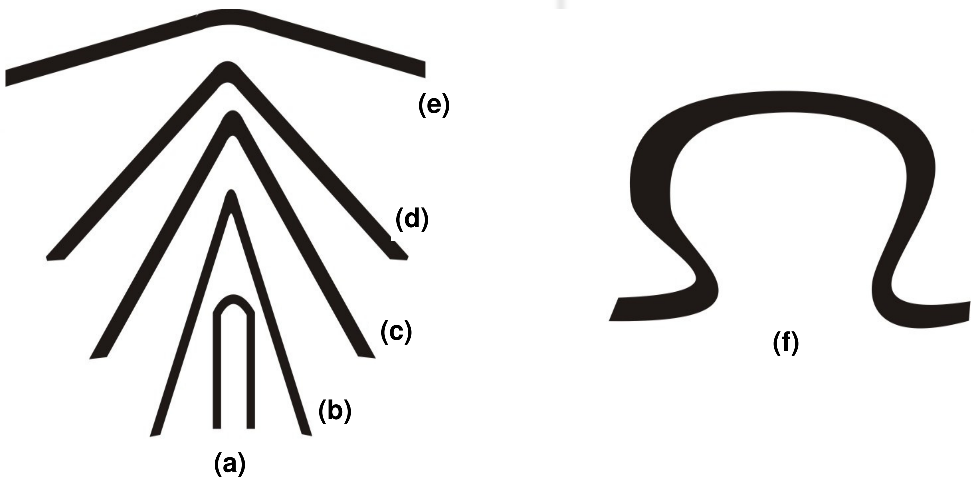


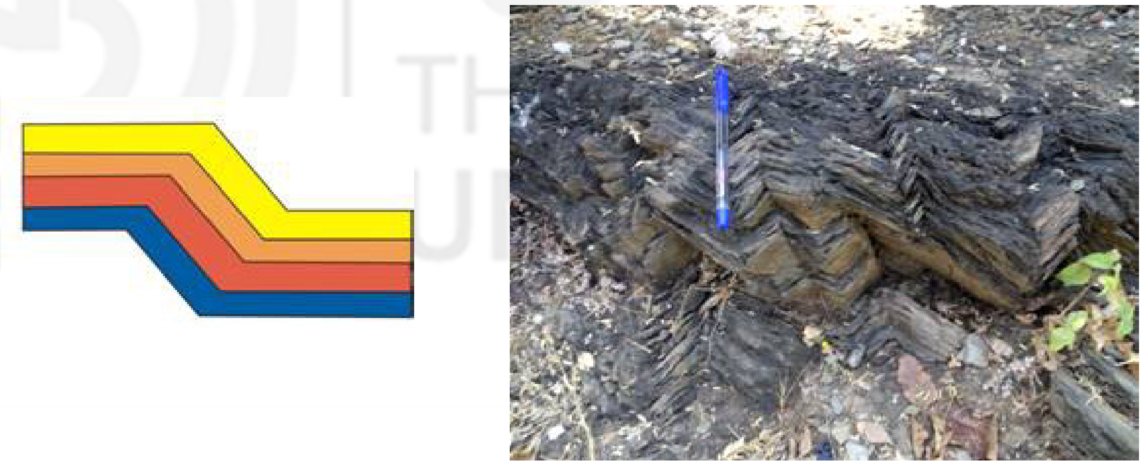
Fig. 10.18: a) Isoclinal fold; b) Tight fold; c) Close fold; d) Open fold; e) Gentle fold; and f) Fan fold.

Isoclinal folds are special case of overfolding in which both the limbs of a fold have equal dip amounts and same direction of dip (*isos*=equal; *clino*=slope) as the name suggests.

10.4.10 Based on Special Properties of Folds

- **Box Fold:** It is a special fold which has two hinges (Fig. 10.19a).
- **Kink fold:** It is a special type of asymmetrical fold which has sharp hinge and straight limbs. Kink folds are found in narrow bands where the bed locally acquires a steeper or gentler dip. This strip or band, in which kink folds are observed, is known as **kink band.** The kink fold or kink bands are found in thinly laminated or foliated rock and they are of the dimensions of few inches to a meter only (Fig. 10.19b).

(a)



(b)

(c)

Fig. 10.19: a) Sketch and field photograph of box fold; b) Sketch and field photograph of kink fold; and c) Chevron fold. *(*Photo credit: Ganga Prasad Bhartiya)

- **Chevron fold:** It is a special type of fold which has sharp hinge and straight limbs. They are also known as **concertina or accordion folds**. The two limbs of a chevron folds are usually equal in size and symmetrical (form mirror image) across the axial plane.

- **En-echelon Folds:** These are a group of folds in which individual folds do not extend to great distances but partially overlap one-another (Fig. 10.20). The term 'en-echelon' refers to closely-spaced, parallel or subparallel, overlapping or step-like minor structural features in rock (faults and tension fractures), which lie oblique to the overall structural trend.

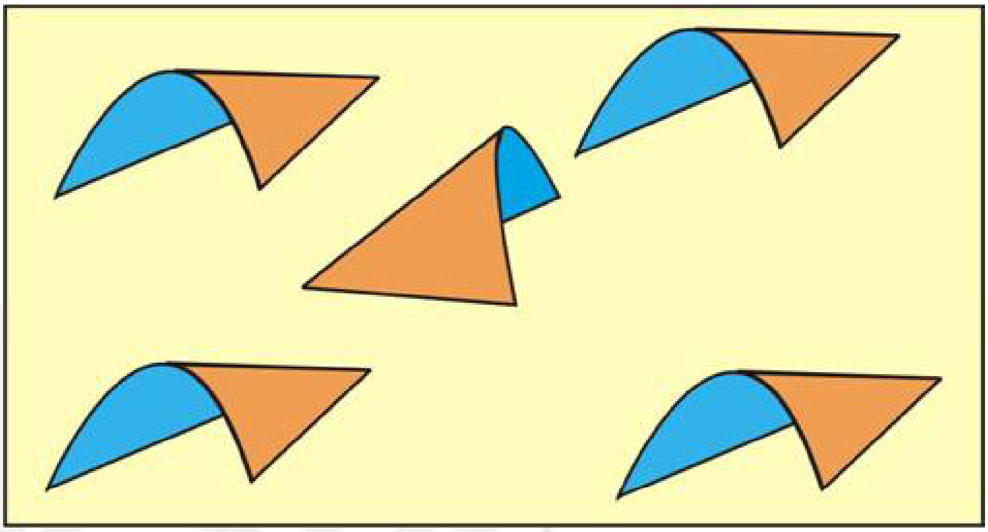
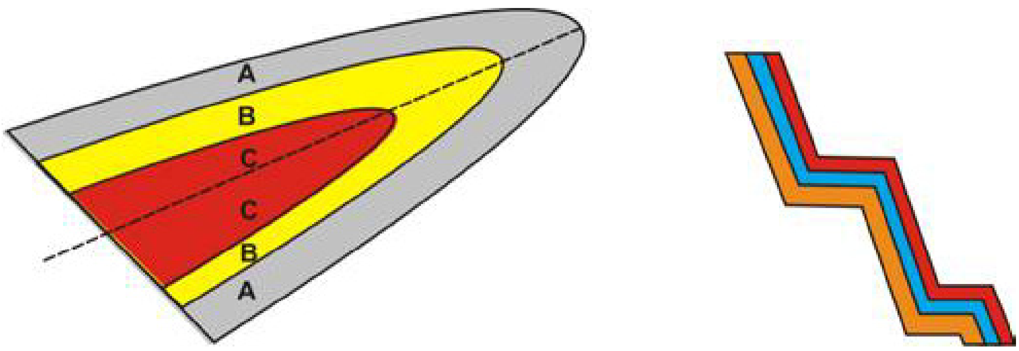


Fig. 10.20: En echelon folds.

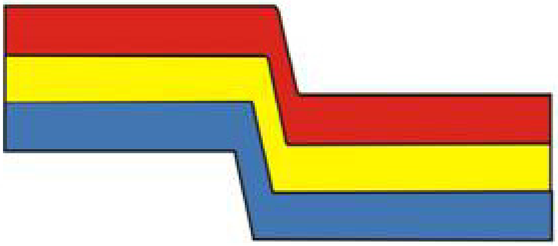
- **Overturned fold or overfold**: In this, beds of the opposite limbs of the fold dip in same direction with same or differing amounts. In this situation, the beds of one limb have normal but that of the other limb have inverted stratigraphic sequence (Fig. 10.21a). It represents a fold in which if we draw a vertical line across the axial plane of the fold, we may find that there is reversal of stratigraphic sequence, that is to say the older (A, B) and younger layers (B, C) sequences lie one above the other in reversed order. An overturned fold, or overfold, has the axial plane inclined to such an extent that the strata on one limb are overturned.



(a) (b)

Fig. 10.21: a) Overturned fold; and b) Structural Terrace.

- **Structural terrace**: In a region of moderately or steeply dipping rocks, when the beds locally assume a horizontal dip, the structure is called structural terrace or structural bench (Fig. 10.21b).
- **Monocline**: In a region of horizontally bedded rocks, when a local steepening of beds occurs, it is called monocline. The monocline is sometimes also called as anticlinal bend (Fig. 10.22a and b).

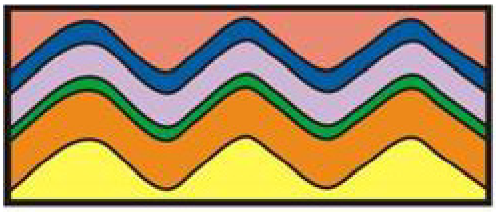


(a)

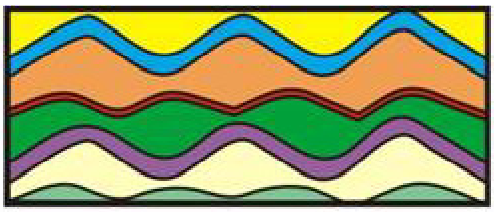
(b)

Fig. 10.22: Monocline: a) Sketch; and b) Field photograph.

- **Geanticline**: It is very large elevated area adjacent to a geosyncline.
- **Geosyncline**: This is a very large depression or basin which is found in the oceans and can accumulate large thickness of sediments.
- **Orocline**: Sometimes the entire orogenic belt comprising of many fold mountain ranges, may show a sharp bend, which is called orocline.
- **Piercing or diapiric fold**: Diapiric folds are local antiformal structure formed due to flowage of rock-salt or gypsum from an underlying bed causing local arching at places where they accumulate. This fold are formed because of non-tectonic reasons.
- **Harmonic fold**: This is that multilayer fold in which all the layers have same wavelength and amplitudes (Fig. 10.23a).
- **Disharmonic fold**: In these folds the different layers constituting a multilayer fold have different wavelengths and amplitudes (Fig. 10.23b).



(a)



(b)

Fig. 10.23: a) Harmonic fold; and b) Disharmonic fold.

10.5 CRITERIA FOR RECOGNITION OF FOLDS

We have read in Unit 5 Rock Weathering that geological agencies like wind, river, glacier, underground water, etc. causes weathering and erosion resulting in the lowering of uplifted surfaces. The effect of erosion on folded strata is to produce outcrops such that the succession of beds of one limb is repeated (though of course in the reverse order) in the other limb. In an eroded anticline, the oldest bed outcrops in the centre of the fold and as we move outwards, successively younger beds are found in the outcrop. In the eroded syncline, conversely, the youngest bed outcrops at the centre of the structure, with successively older beds outcropping to the either side. Folds are often visible on the surface and can be recognised with naked eye but at times it is not possible to recognise folds. There are certain other deformations which alter the surface, making it difficult to directly recognise the fold.

The following criteria may be used to recognise or detect folds in the field:

- **Direct observation**: Folds may be recognised by direct observations on the outcrops exposed along the valley walls, stream, road or railway cuttings, quarries or tunnels.
- **By measuring the attitudes of beds**: If the folds are larger than outcrops they are recognised by measurements of dip and strike data of bedding planes.
- **By repetition patterns of beds**: A symmetric repetition of beds helps in recognising the fold in the field. For example, on a linear path if the repetition occurs in the pattern DCBCD, this would mean that the fold axis is located in bed B which divides the rock sequence into 2 halves which are mirror image to each other (Fig. 10.24).
- **By variation in thickness**: If the thickness of the bed is gradually increasing or decreasing, there might be fold.
- **By cleavage- bedding relationship**: The cleavage bedding relation criteria can be used to find the fold. The top bottom of bed can also be used to identify the folds.

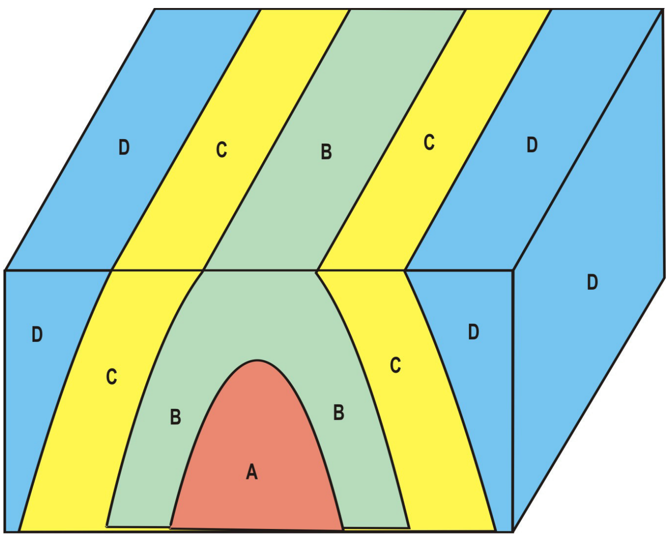


Fig. 10.24: Repetition patterns of beds in fold.

SAQ 2

a) Distinguish between cylindrical and non- cylindrical folds.

b) Define isoclinal fold.

c) What is kink fold?

d) Differentiate between geanticline and geosyncline.

10.6 CAUSES OF FOLDING

We may classify the causes of folding and faulting into tectonic and non tectonic categories. Let us read about them.

- **Tectonic Causes**: The tectonic reasons developed due to compressive forces may include orogenic (mountain building) forces and endogentic forces which are generated from within the Earth. We will read more about tectonic causes in Block 4 Mountain Building and Plate Tectonics of this course.
- **Non-tectonic causes**: The non-tectonic reasons which may cause local folding may be due to hill side creep, collapse or gravity sliding, erosion of certain bed, glacial ice push, solution, differential compaction and contemporaneous or synsedimentary deformation (deformation occurring at the time of sedimentation).

10.7 SUMMARY

In this unit, we have learnt about an important geological structures namely fold. Let us summarise what we have learnt in this unit:

- The prime reasons for development of geological structures are the Earth's forces which operate upon the rock bodies and deform them.
- Folds are wave-like undulations in the rocks easily visible in layered rocks.
- Folds represent the ductile nature of deformation.
- The folds may occur in a variety of geometric forms and are accordingly identified by different names.
- Folds have been classified geometrically based on: (1) arching direction, (2) relative ages of the beds in fold, (3) dip of the axial plane, (4) relation of dip of axial plane and plunge of fold hinge line, (5) cylindricity, (6) thickness of folded layer, (7) interlimb angle, and (8) special properties of folds.
- There are several criteria for recognition of folds in field. It can be (1) by direct observation, (2) by repetition patterns of beds, (3) by measuring the attitudes of beds, (4) by cleavage- bedding relationship, and (5) by variation in thickness.

- The fold is usually developed by compressive forces which may be caused due to non tectonic and tectonic reasons.

10.8 ACTIVITY

Take few (3-5) papers of different colours and put them one over another to represent layered rocks. Try to visualise different geometric forms of folds as discussed by folding these papers.

10.9 TERMINAL QUESTIONS

1. Describe with neat diagrams different parts of a fold.
2. Elaborate the basis of geometrical classification of folds. Draw neat well labelled diagrams wherever required.
3. Discuss criteria of recognition of fold in the field.
4. Mention the causes of folding.

10.10 REFERENCES

- Hatcher, R.D. Jr. (1990) Structural Geology, Principles, concepts, and problems, Merrill Publishing Company, London, 533p
- Twiss, R.J., and Moores, E.M. (1992) Structural Geology. W.H. Freeman and Company, New York, 532p.

10.11 FURTHER/SUGGESTED READINGS

- Mukherjee, P.K. (2000) A Text Book of Geology, The World Press, Kolkata, 638p.
- Singh, P. (2009) Engineering and General Geology, S.K. Kataria and Sons, 600p.

10.12 ANSWERS

Self-Assessment Questions

1. a) Hinge line is the locus of hinge points of a particular folded bedding plane. In a fold, hinge line is the actual line of maximum curvature in the folded bed. Fold axis is an imaginary line which by moving parallel to itself generates the fold. The hinge line of a fold is equivalent to 'fold axis' if it is straight and the fold is cylindrical in nature.

   b) Antiformal syncline is an upward arching fold wherein beds dip away from each other and the core of the fold comprises of younger rocks. In the synformal anticline the fold arches downwards with core comprised of the older rocks.

c) Hint: recumbent and inclined fold.

d) A dome is an antiformal structure, a broad circular upward bulge of rock layers. It has quaquaversal dip. Basin is a fold having circular outline on plan and a centripetal dip. Here the fold is like a bowl where beds have dip from all direction towards common point or depression.

2. a) Cylindrical fold is a kind of fold which can be generated by moving the fold axis parallel to itself whereas non-cylindrical fold cannot be generated on moving the fold axis parallel to itself.

   b) Isoclinal folds are special case of overfolding in which both the limbs of a fold dip in same direction are same angle .

   c) Kink folds are narrow band or region where the bed locally acquires a steeper or gentler dip.

   d) Geanticline is very large elevated area adjacent to a geosyncline while geosyncline is a very large depression or basin which is formed in the oceans and can accumulate large thickness of sediments.

Terminal Questions

a) Please refer to the sections 10.2 and 10.3.

b) Please refer section 10.4, discuss in brief eight types of classification. Folds have been classified geometrically based on: (1) arching direction, (2) relative ages of the beds in fold, (3) dip of the axial plane, (4) relation of dip of axial plane and plunge of fold hinge line, (5) cylindricity, (6) thickness of folded layer, (7) interlimb angle, and (8) special properties of folds.

c) Please refer to the section 10.5. There are several criteria for recognition of folds in field. It can be (1) direct observation, (2) by repetition of patterns of beds, (3) by measuring the attitudes of beds, (4) by cleavage- bedding relationship, and (5) by variation in thickness.

d) Please refer to the section 10.6. The folding is caused by compressive forces which can be exerted due to non-tectonic and tectonic causes.

UNIT 11

FAULTS

Structure

11.1 INTRODUCTION

We discussed about the study domains of structural geology in Unit 9 and an important structure namely, fold in Unit 10. We also learned that folding and faulting are the most common forms of deformation in rocks that are observed in the Earth's crust. In this unit we shall discuss about faults which cause displacement of rock bodies. Fault is one of the important factors which bring complexities in the geology of a region. In this unit, we shall define and discuss classification of faults and also learn about the causes of faulting and different criteria of identification of faults in the field.

Expected Learning Outcomes

After reading this unit you should be able to:

- define faults;
- discuss the significance of faults in geology;
- classify faults on the basis on geometry;
- elaborate on the genetic classification of faults;
- identify the criteria of recognition of faults in the field; and
- list the causes of faulting.

11.2 FAULT

Now let us study the faults. They are described as natural ruptures along which the opposite walls have moved with respect to each other. Fault severes rock sequences, thus introducing "faults" or "defects" in stratigraphic framework. They pose challenges to geologists while mapping rocks in the field. We know much more about faults today, than a few decades ago because of their importance in petroleum industry. Faults also create problems to site selection for civil engineering considerations.

11.2.1 Definition

Fault is a fracture along which there is an observable displacement of the two blocks of rock (Figs. 11.1 and 11.2). It displaces the rock on either side of it. The displacements of these rock blocks are essentially parallel to the fracture surface. Like folds, faults also occur in all sizes, in many mountain belts, continents and oceans. The development of fault in rock is often due to tectonic stresses which may be of tensional, compressional or tangential type alone or in combination.

11.2.2 Importance of Faults in Geological Studies

Faults are significant in geological studies because:

1. Faults may bring material from the deeper level to or near the surface of the Earth, and thus they provide us knowledge of the subsurface.
2. Many mineralised solution or petroleum rise up along the fault. Faults sometime trap petroleum from migration and loss.
3. Faults may develop beautiful landscapes which enhance geotourism.
4. They may cause earthquakes.
5. Fault locations are very important in mining.

11.3 ELEMENTS OF FAULTS

Let us get acquainted with different components or parts of a fault. You are advised to refer Fig. 11.1 and 11.2 for reference.

11.3.1 Basic Terminology

- **Fault surface/ Fault plane**: It is a surface or plane along which the dislocation has taken place (Fig. 11.1a).
- **Fault zone**: A fault zone is a zone of numerous small scale dislocated fractures which constitute the fault (Fig. 11.1b).

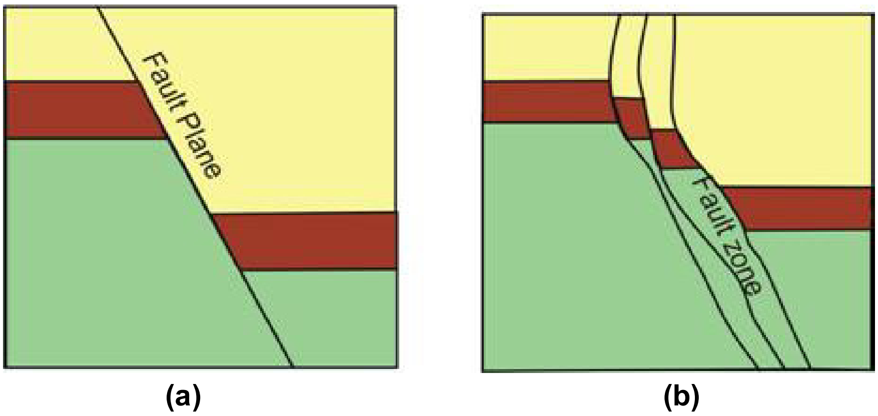
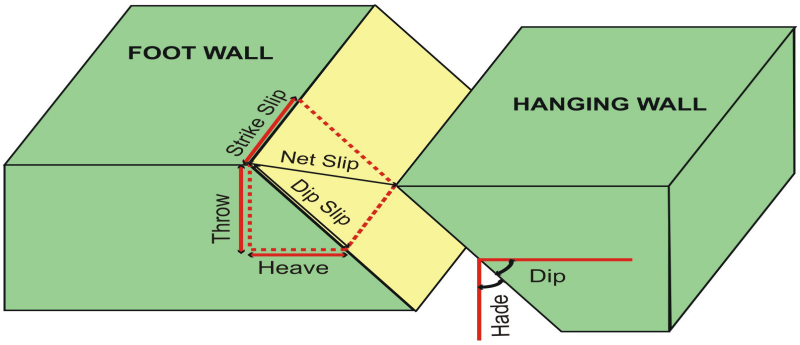
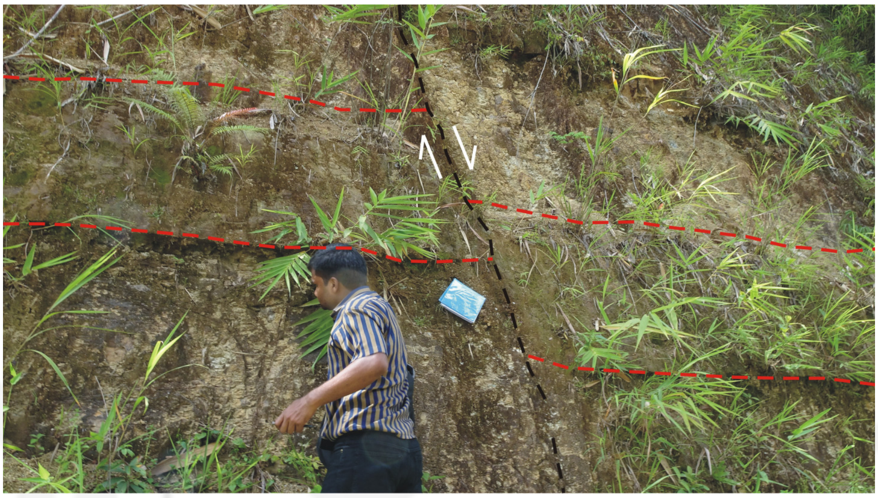


Fig. 11.1: a) Fault plane; and b) Fault zone.

- **Fault line/ fault trace**: The line formed by intersection of a fault with surface of the Earth or any given surface.
- **Strike of the fault plane**: It is the direction in which the fault plane cuts the horizontal ground.
- **Dip of the fault plane**: The angle of inclination of the fault plane with respect to horizontal is called dip of the fault. The true dip is measured on a vertical section perpendicular to the strike.
- **Hade of the fault plane**: The angle made by fault plane with respect to a vertical line. Hade is complementary to the dip amount which together add upto 90^o.
- **Hanging wall**: If the fault plane is not vertical, the rock mass resting above the fault plane is known as hanging wall.
- **Foot wall**: The rock mass resting below the inclined fault plane is known as foot wall.
- **Slip**: Slip refers to actual displacement parallel to fault plane in a given direction.
- **Net-slip**: Net slip is the total amount of displacement measured parallel to fault plane.
- **Dip-slip**: It is the displacement or movement parallel to dip of the fault plane.
- **Strike-slip**: It is the displacement or movement parallel to strike of the fault plane.
- **Oblique-slip**: The net slip is neither entirely parallel to dip nor strike of the fault plane. Fig. 11.2 represents an oblique slip fault where net slip contain both strike-slip and dip slip components
- **Heave**: It is the horizontal component of the dip slip (Fig. 11.2).
- **Throw**: This is the vertical component of the dip slip (Fig. 11.2).



(a)



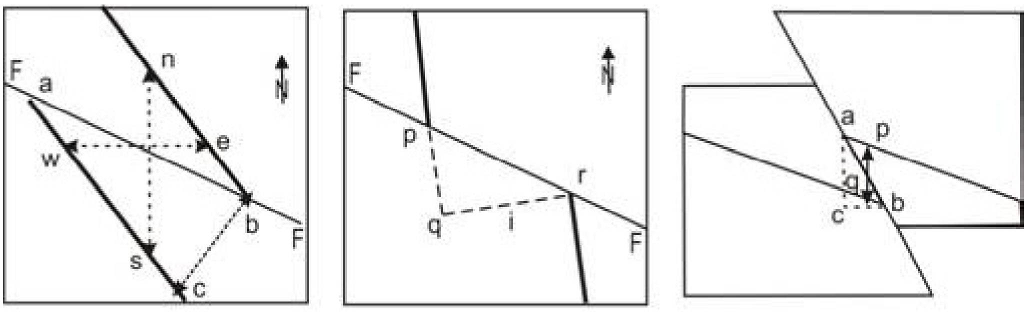
(b)

Fig. 11.2: a) Diagram showing parts of the fault; and b) Field photograph of fault. (Photo credit: Ganga Prasad Bhartiya)

11.3.2 Separation

Separation indicates the distance between the two parts of the disrupted horizon (bed) measured in any given direction.

- **Horizontal separation**: It is measured in any horizontal direction. Look at the Fig. 11.3a where **ew** and **ns** distances represent horizontal separation in east-west and north-south directions, respectively. Horizontal separation also means the separation perpendicular to strike of the fault plane if otherwise the direction is not specified. In this case, it is the horizontal component of the dip separation.
- **Strike separation**: It is the horizontal separation parallel to the strike of the fault (**ab** in Fig. 11.3a and **pr** in Fig. 11.3b)
- **Dip separation**: It is the separation measured directly down the dip of the fault (**ab** in Fig. 11.3c)
- **Normal separation or Offset or Perpendicular separation**: It is measured perpendicular to the disrupted horizon. (**bc** in Fig. 11.3a and **qr** in Fig. 11.3b)
- **Overlap**: It is the portion of the disrupted bed which overlaps due to faulting (**ac** in Fig. 11.3a).
- **Gap**: It is the portion of the disrupted bed which is missing due to faulting (**pq** in Fig. 11.3b).



(a) (b) (c)

Fig. 11.3: (a) Overlap, (b) Gap and (c) Vertical separation

- **Right separation**: This term is used when walking in the strike direction of bed one finds the disrupted bed in right hand side direction (Fig 11.3a)
- **Left separation**: This term is used when walking in the strike direction of bed one finds the disrupted bed in left direction (Fig. 11.3b)
- **Vertical separation**: Vertical separation is measured along vertical line. It is the vertical component of dip separation as well as stratigraphic separation (**pq** in Fig.11.3c)
- **Stratigraphic separation or stratigraphic throw**: The thickness of intervening strata is the stratigraphic separation or stratigraphic throw:

11.4 GEOMETRICAL CLASSIFICATION OF FAULTS

Now let us discuss about the geometric classification of the faults. This includes:

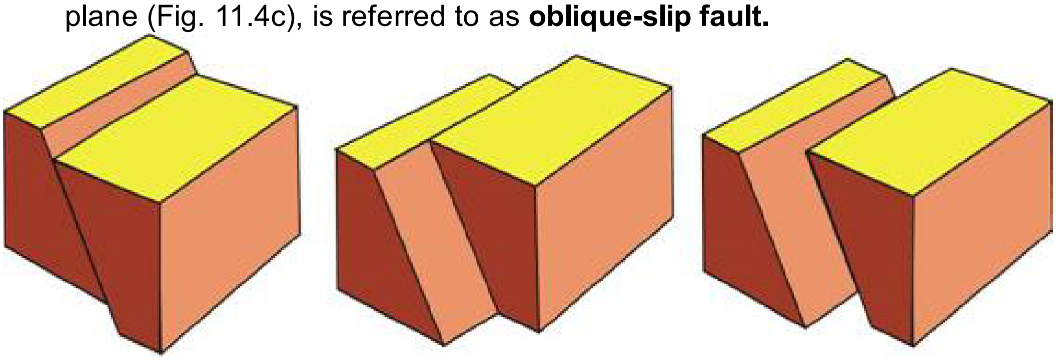
11.4 .1 Based on the Direction of Net-Slip

As we have already read that net slip is the actual displacement of the blocks along the fault plane. In other words, it is the actual displacement of two points on the fault surface which were adjacent before faulting. They may be of the following three types:

i. Fault in which the net-slip is parallel to the dip direction of fault plane (Fig. 11.4a), is called **dip-slip fault.**

ii. Fault in which the net-slip is parallel to the strike of the fault (Fig. 11.4b), is termed **strike-slip fault**.

iii. Fault in which the net slip is neither parallel to dip nor strike of the fault plane (Fig. 11.4c), is referred to as **oblique-slip fault.**



(a) (b) (c)

Fig. 11.4: a) Dip Slip Fault; b) Strike Slip Fault; and c) Oblique faults.

11.4 .2 Based on Relationship with Bedding Plane

In the previous section we notice that the dip-slip, strike-slip and oblique slip faults are only based on relation of the net slip with dip and strike of the fault plane. However in relation to dip and strike of the bedding plane the faults are categorised as follows:

- **Dip Fault**: In this the strike of the fault plane is parallel to dip direction of the beds. In other words the strike of fault plane and bedding plane are mutually perpendicular to each other (Fig. 11.5a).
- **Strike Fault**: In this the strike of the fault plane and the bedding plane are parallel (Fig. 11.5b).
- **Oblique Fault**: Here the strike of the fault and beds are neither parallel nor perpendicular but are oblique to each other (Fig. 11.5c).
- **Bedding Fault**: A bedding fault is that fault in which the dip and strike of the fault plane is parallel to those of the bedding planes (Fig. 11.5d).

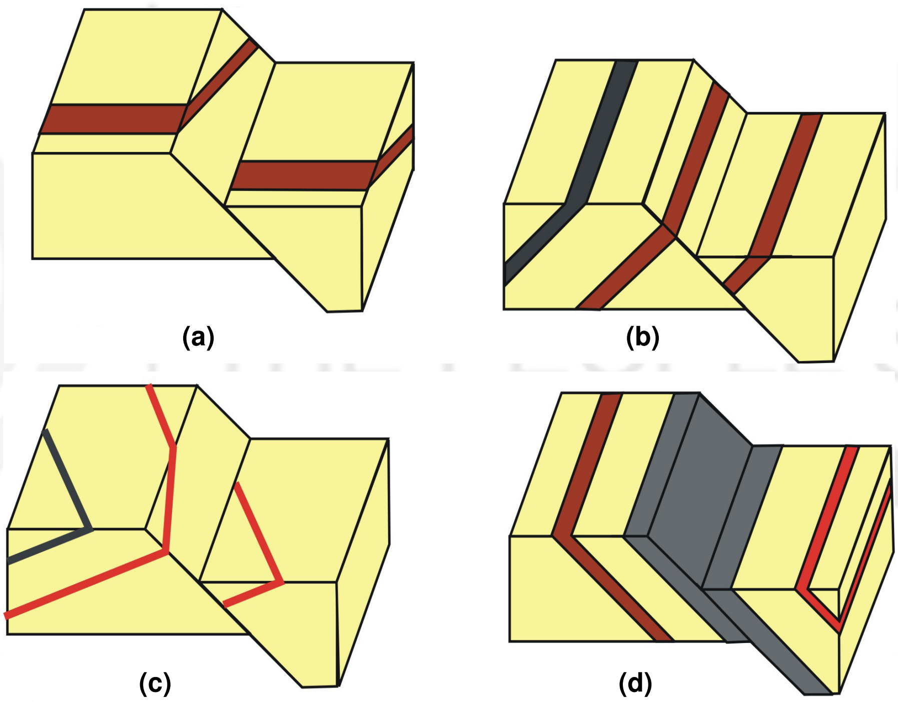


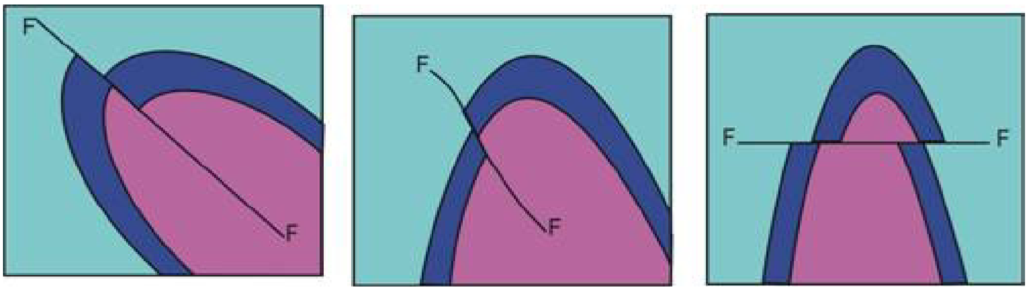
Fig. 11.5: a) Dip fault; b) Strike fault; c) Oblique fault; and d) Bedding fault.

11.4.3 Based on the Relation with Major Structures

Many a times the beds are not simple and straight but may exhibit folding which may cause variation in dip and strike over a region. In folded regions the following terms are used to describe the faults:

- **Longitudinal Fault**: In this the fault plane is parallel to the axial trace of the major folds (Fig. 11.6a).
- **Transverse Fault**: This fault disrupts the major structures such as major folds, in a direction which is not parallel to axial trace of that fold (Fig. 11.6b).

- **Tear Faults**: They are those large scale faults which cut across the regional structures such as major fold or nappes. Tear faults are large scale strike-slip fault because of which, the structure seems to be torn apart (Fig. 11.6c).



(a) (b) (c)

Fig. 11.6: a) Longitudinal fault; b) Transverse fault; and c) Tear fault.

There are some other major structures related to faults. Therefore you need to know about them also.

- **Nappe**: A portion of a region of intensely folded strata may be displaced to several kilometers because of overthrusting. Low angle dipping thrust faults are often called overthrust. The displaced block which lies above another rock unit is termed as **'nappe'** (pl. Nappes) (Fig. 11.7). Nappes are allochthonous rock units that have been displaced from some distant places to rest upon autochthonous rock units. **Allochthonous** is term applied for rock units which have been transported from their original location. Similarly the term autochthonous is used for rock units which have not been transported but rest at their place of origin. **Alloch** refers to moved away from the parent rock body and autoch refers to in situ or at the site of origin.
- **Window**: Sometimes a nappe may be eroded deeply through which the rocks below become visible giving an idea of subsurface geology. Such structure is termed as **'window'** and is also known as ***fenster*** (German word for window) and **fault inlier** (Fig. 11.7).
- **Klippe** (pl. Klippen): A ***klippe*** (Danish word for cliff or crag) is the remnant portion which has been detached and isolated from the main

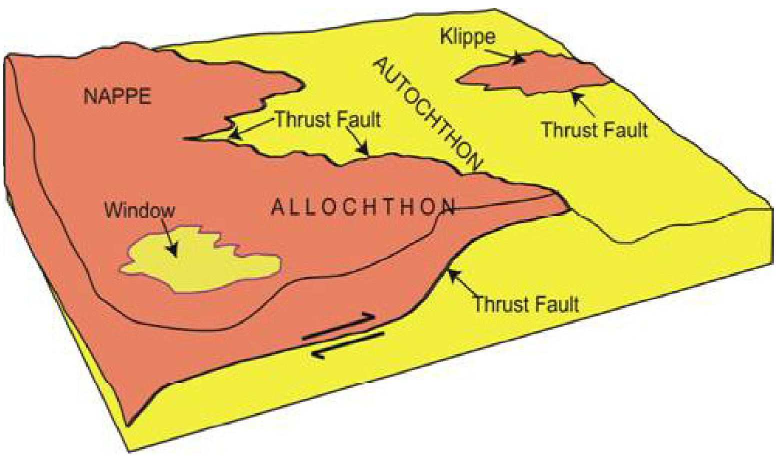


Fig. 11.7: Nappe, window and klippe.

body of the nappe mainly due to erosion of the nappe rocks lying between them. Klippe is thus surrounded by rocks of the autochthon when seen in a map (Fig. 11.7).

11.4.4 Based on Patterns of Faults

Fault may occur singly or in a group with or without definite pattern. If any definite pattern is observed in a group of faults, they may be called as:

- **Parallel faults**: When a series of faults have same dip and strike as that of the fault planes (Fig. 11.8a).
- **Peripheral fault**: It is an arcuate fault which generally occurs on the periphery of elevated or depressed areas such as domes or basins (Fig. 11.8b).
- **Radial Fault**: They are group of faults which radiate from a central point (Fig. 11.8c).
- **En echelon Fault**: They are group of small parallel faults which partially overlap (Fig. 11.8d).

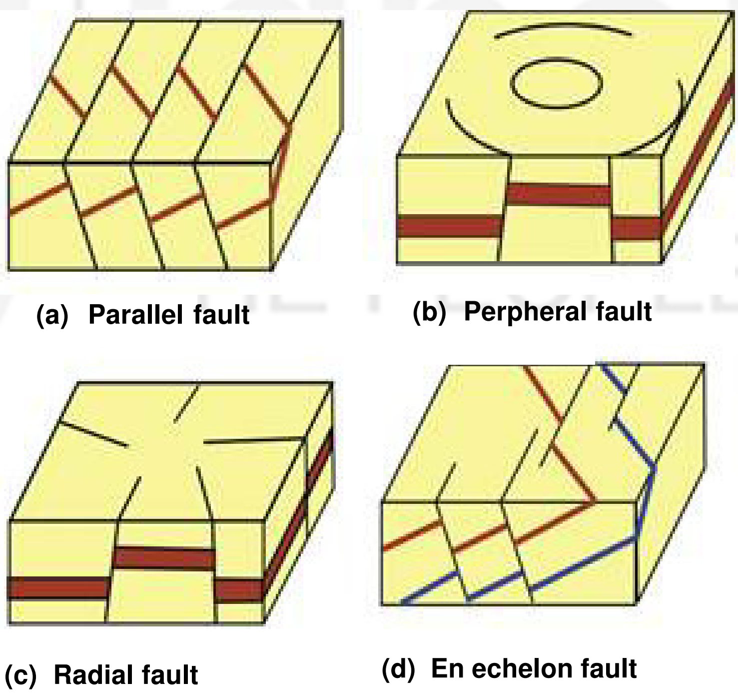


Fig. 11.8: a) Parallel fault; b) Perpheral fault; c) Radial fault; and d) En echelon fault.

- **Auxilliary or Branch Fault**: They are minor faults ending against the main fault.
- **Multiple Faults**: When several faults are parallel and close together and the intervening fault slab or slices are not distorted, the group may be termed as a multiple fault.
- **Step Fault** or **Distributive Fault**: A multiple fault, in which the down thrown blocks are on the same general side of each component faults, it is known as a distributive fault. These closely spaced faults are also called as step faults (Fig. 11.9).

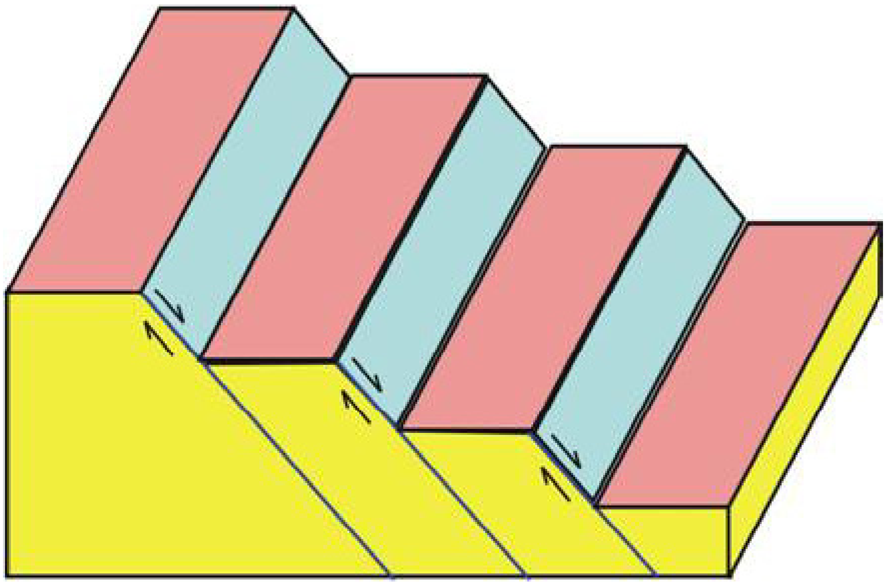


Fig. 11.9: Step Faults.

- **Intersecting faults**: This develops when the faults cross one another.
- **Fault Complex**: It is an intricate system of intersecting faults of the same or different ages.
- **Imbricate Structure**: This refers a multiple fault system wherein many thrust faults occur. It may divide the major blocks in regional overthrusting into minor slices.
- **Horst**: A horst is an uplifted block which is bounded between two parallel sets of normal faults dipping in opposite directions (Fig. 11.10).
- **Graben**: A graben is a downthrown block which is bounded between sets of two parallel but opposite dipping normal faults with same strike (Fig. 11.10).

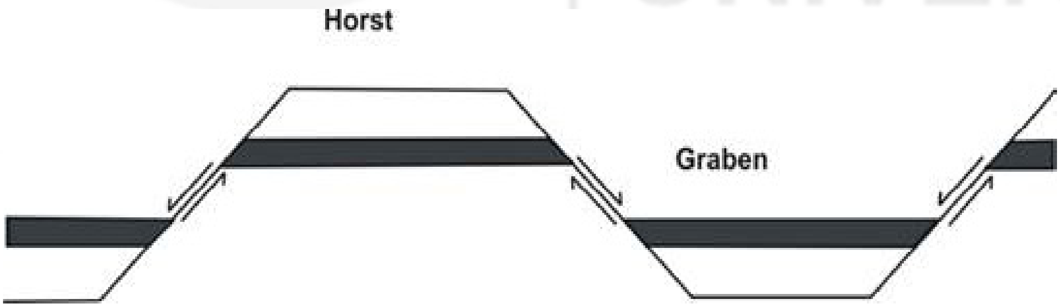


Fig. 11.10: Horst and Graben.

11.4.5 Based on Types of Movement

As we know that faults are developed because of displacement between two adjacent rock blocks. However, this displacement may in straight line (translational) or angular (rotational). Accordingly, the faults are known as:

- **Translational Fault** : It is one in which there is translational movement with no rotational component. In this case the dip of beds in hanging wall and foot walls remain the same (Fig. 11.11a).

- **Rotational Fault** : In this fault the blocks rotate during dislocation. They are also known as hinge fault, pivotal fault or scissor fault. In this case the dips of the beds of the two fault blocks do not remain the same (Fig. 11.11b).

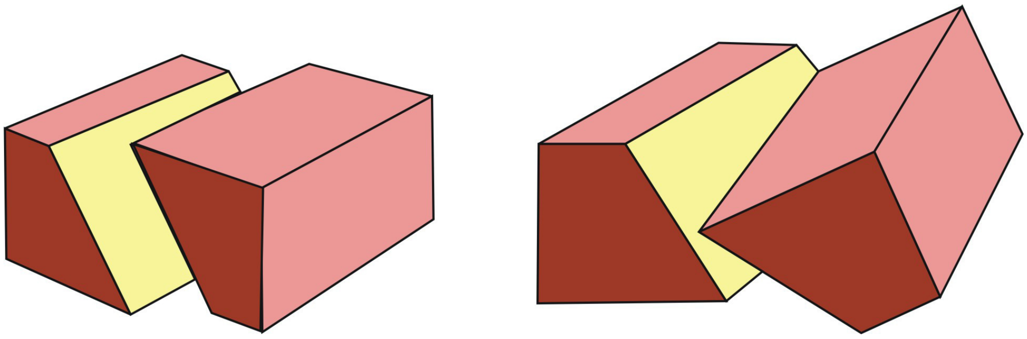


Fig. 11.11: a) Translational fault; and b) Rotational fault.

SAQ 1

a) List the types of faults based on the direction of net-slip.

b) Distinguish between longitudinal and transverse fault.

c) Define 'window' and 'klippe'.

d) Distinguish between horst and graben.

11.5 GENETIC CLASSIFICATION OF FAULTS

We have read about geometric classification of fault. Let us now learn about genetic classification.

The genetic classification of fault is related to the orientation of stresses which are responsible for their development. One such obvious force is the gravitational force which is always vertical. But there may be other directions of operating stresses. Let us consider any stress system along the three mutually perpendicular axes- in which two are horizontal and one vertical. For the convenience of study, any stress acting upon the rock body may be resolved into three components in three dimensional spaces. Out of these three resolved component of stresses, one which is maximum in amount is called as maximum principal stress axis and conventionally referred as σ_1. The least stress axis is represented by σ_3 and the intermediate as σ_2 (Fig. 11.12). The orientation of these stresses develops some geometric and genetic relationship to cause genesis of different fault types as described herein in their genetic classification.

On the basis of genesis, the faults can be classified as follows:

- **Normal Fault**: A normal fault is that fault in which the hanging wall has apparently moved down with respect to foot wall (Fig. 11.12a). The normal faults are created under a stress system in which the 'maximum principal stress axis (σ_1)' is vertical and the other two namely 'intermediate principal stress axis (σ_2)' and the 'least principal stress axis (σ_3)' are horizontal. Space is gained or widened when normal faulting occurs. The normal faults are and also called as **gravity fault** because the gravity of the Earth plays a major role in formation of these faults.

- **Reverse Fault**: In reverse fault, the hanging wall apparently moves upward relative to foot wall (Fig. 11.12b). The least principal stress axis (σ_3) in this case is vertical while the other two namely σ_1 and σ_2 are horizontal. Some space is lost in this faulting or we can say crustal shortening occurs. The low dipping reverse faults where the fault plane dips less than 45^o are called as **thrust faults.**

- **Strike- slip Fault**: Strike-slip fault is that fault in which the two blocks do not move up or down, rather they are displaced horizontally relative to each other (Fig.11.12c,d). The strike-slip fault may be further categorised as left lateral or sinistral and right lateral or dextral types**.** On standing over one block if an observer faces the other block and finds that the other block has moved to right hand side, the fault will be called as right lateral or **dextral strike-slip fault** (Fig. 11.12c). If the other block has moved to left hand side of the observer, it is a left lateral or **sinistral strike-slip fault** (Fig. 11.12d). The strike-slip faults are formed when the intermediated stress axis (σ_2) is vertical while the other two (σ_1) and (σ_3) are horizontal (Fig.11.12c). Wrench fault, transcurrent fault and transform faults are types of strike-slip fault.

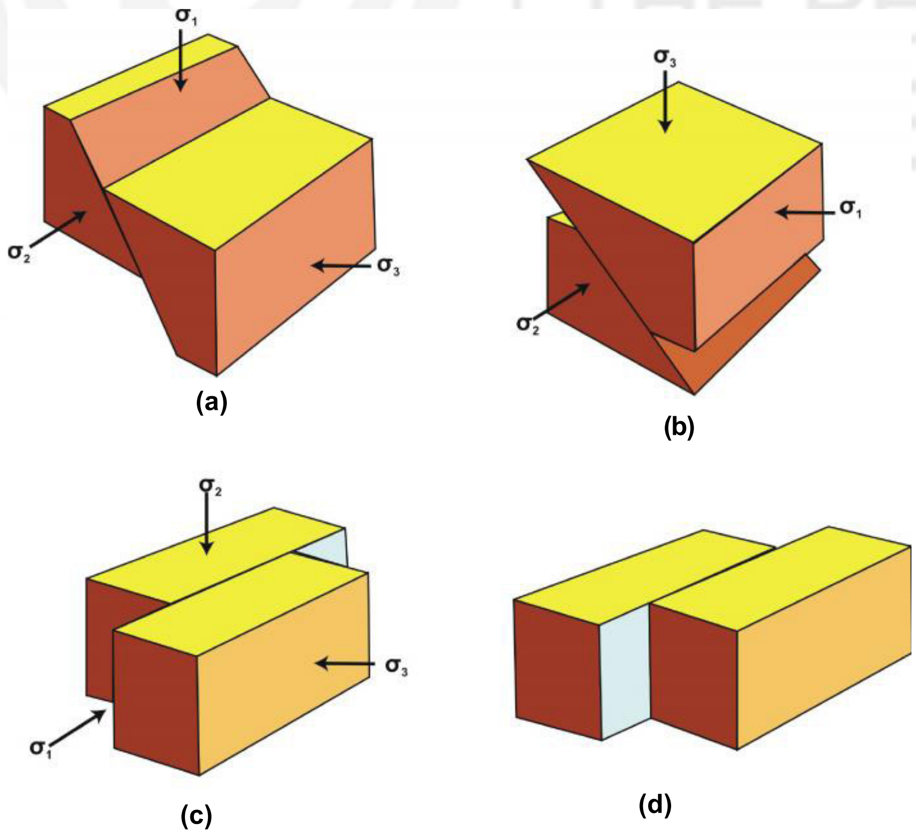


Fig. 11.12: a) Normal fault; b) Reverse fault; c) Strike- slip fault (right lateral); and d) Strike-Slip fault (left lateral).

11.6 CRITERIA FOR RECOGNITION OF FAULTS IN FIELD

Many features are characteristically related to faulting, consequently, when found in field, they are indicative of fault. These features are:

- **Visible displacement**: If visible displacements of veins, dikes, strata, etc. are seen in field , they are best evidence of faulting. Such faults are often small scale. For larger scale faulting generally indirect evidences are available.
- **Slickensides**: The polished and striated surfaces along a fault plane are called slickensides and are developed on the fault plane due to friction between the two faulted blocks (Figs. 11.12 and 11.13).

Fig. 11.13: Field photograph showing slickensides. (Photo credit: Ganga Prasad Bhartiya)

- **Fault breccia**: It is a rock which occurs generally found along the fault plane and which contains numerous angular fragments of the adjacent country rocks.
- **Dragging of strata**: In field when we observe that some flexure or bending of beds is present along a plane. This plane may be a fault plane.
- **Crushing, shearing and pulverisation**: Because of faulting of the blocks, the parent rocks are fragmented into smaller chunks or pulverised due to friction between two blocks.
- **Presence of mylonites**: Mylonites are in fact fault breccias where the fragments are of microscopic dimensions. Sometime they look like glassy matter which are called 'ultramylonites' or 'pseudotachylites'.
- **Silicification and Mineralisation**: Faults can be good sites for passage of solutions and other liquids and their deposition. If the solution is quartz rich, it may replace the country rock with fine grained quartz

known as silicification. Replacement by mineral rich solutions causes mineralization.

- **Difference in sedimentary or metamorphic conditions**: Such sedimentary or metamorphic conditions which are usually found at distant places, if they are juxtaposed together, presence of a fault may be indicated.
- **Abrupt change in topography**: There is often abrupt change in the topography because of faulting, which can be seen in the form of valley, cliff, triangular facets on mountains. A sharp change in altitudes of the mountains may also be indicator of large faulting.
- **Abrupt change in river profile**: A river may show an abrupt change in its flow direction or generate a waterfall. This could be indication of a fault!
- **Spring line**: Many times, springs are found on the mountains. If the springs are found along a line then fault may be present.

However, one has to keep in mind that though topographic or physiographic criteria are the indicators of faulting but they are not fool proof evidences of faulting. These topographic features may also develop due to certain other reasons.

SAQ 2

a) What do the notations σ_1, σ_2 and σ_3 represent?

b) List three genetic types of faults.

c) What are the relative movements of hanging wall with respect to foot wall in case of normal and reverse faults?

d) List the criteria for recognition of faults in field.

11.7 CAUSES OF FAULTING

We may categorise the causes of folding and faulting into tectonic and non tectonic categories.

- **Tectonic causes**: The tectonic reasons developed due to compressive forces that may include orogenic (mountain building) forces and endogentic forces which are generated from within the Earth.
- **Non tectonic causes**: The non-tectonic reasons which may cause local faulting may be due to hillside creep, collapse or gravity sliding, erosion of certain bed, glacial ice push, solution, differential compaction and contemporaneous or synsedimentary deformations.

11.8 SUMMARY

In this unit we have learnt about important geological structure namely fault. Let us summarise what we have learnt in this unit:

- The prime reasons for development of geologic structures are the Earth's forces which operate upon the rock bodies and deform them.
- A fault is a fracture that displaces the rock on either side of it.
- In contrast to folds which generally represent the ductile nature of deformation faults generally develop under brittle conditions.
- The faults may occur in a variety of geometric forms. Each geometric form is known by a characteristic name.
- Genetic classifications of faults are based on orientation of principal stresses ($\sigma_{1,}$ σ_2 and σ_3) responsible for their development.
- Faults have been classified geometrically based on: (a) direction of net-slip (2) relationship with bedding plane (3) relation with major structures (4) patterns of fault and (5) types of movement.
- There are several criteria for recognition of faults in field.

11.9 ACTIVITY

1. With your clay block, slice an inclined fault plane. With this fault plane, make either a normal or reverse fault scenario. Draw and color a block diagram of the faulted clay block, and label the hanging wall and the footwall. Be sure to use the colors you defined in your legend above, indicate the sense of movement with arrows, and title your design "normal fault" or "reverse fault".
2. Try to know the names of major thrusts in Himalaya.

11.10 TERMINAL QUESTIONS

1. Discuss with neat diagram the different parts of a fault.
2. Elaborate the bases of geometrical classification of fault. Draw neat well labelled diagrams in support.
3. Discuss in brief the genetic classification of faults.
4. Mention the causes of faulting.

11.11 REFERENCES

- Hatcher, R.D. Jr. (1990) Structural Geology Principles, concepts, and problems, Merrill Publishing Company, London, 533p.
- Twiss, R.J., and Moores, E.M. (1992) Structural Geology, W.H. Freeman and Company, New York, 532p.

11.12 FURTHER/SUGGESTED READINGS

- Billings, M.P. (1990) Structural Geology, Prentice Hall of India Pvt Ltd., 601p.

- Mukherjee, P.K. (2000) A Text Book of Geology, The World Press, Kolkata, 638p.
- Singh, P. (2009) Engineering and General Geology, S.K. Kataria and Sons, 600p.

11.13 ANSWERS

Self-Assessment Questions

1. a) Hint: Dip-slip Fault, Strike-slip Fault, Oblique-slip faults

   b) Longitudinal fault is parallel to the axial trace of the major folds. Transverse fault are those faults which disrupt structures such as major folds, in a direction which is not parallel to axial trace of that fold.

   c) When a nappe is eroded and the rock lying below it can be seen in a limited area. This area is called window or fenster. In a geological map window is surrounded by nappe or allochthonous rocks. Klippe is remnant of the upper thrust block (nappe) separated by erosion from the main area of nappe and surrounded by the rocks of the lower blocks. In a geological map klippe is surrounded by autochthonous rocks.

   d) Horst is an uplifted block which is bounded between two opposite dipping normal faults having same strike. Graben is a downthrown block bounded between two opposite dipping normal faults having same strike.

2. a) Refer to section 11.5. Maximum, Intermediate and Least principal stresses

   b) Normal fault, Reverse fault and Strike-slip fault.

   c) In normal fault hanging wall goes downwards while in reverse fault hanging wall goes upwards relative to foot wall.

   d) Mention about -visible displacement, fault breccia, dragging of strata, crushing, shearing and pulverization, presence of mylonites, spring line, difference in sedimentary or metamorphic conditions, abrupt change in topography, abrupt change in river profile, silicification and mineralization.

Terminal Questions

1. Refer to the section 11.3.
2. Refer to the section 11.4.
3. Refer to the section 11.5.
4. Refer to the section 11.7.

UNIT 12

JOINTS AND UNCONFORMITIES

Structure

12.1 INTRODUCTION

We have learnt about geological structures like folds in Unit 10 and faults in Unit 11. Now in this unit we will discuss about some other geological structures, viz. joints and unconformity. Most rocks on the surface of the Earth are broken by fractures known as **joints**. The term joint is said to have originated in the British coalfields because the miners thought that the rocks were "joined" along the fractures, just as bricks are put together in the wall (Billings, 1990). The fact is that the term joint is misnomer because these surfaces represent fractures in the intact rock blocks. They represent a deformation which is brittle in nature. Knowledge of joints is important for geological studies, *e.g.* site selection in engineering projects, identification of natural hazards like landslide, drilling well for water supply *etc.* Like joint, unconformity is another type of planar surface which represents a kind of discontinuity in the depositional sequence of rocks. We will discuss about them in this unit.

Expected Learning Outcomes

After reading this unit you should be able to:

- ❖ define joints and acquaint with their geological significance;
- ❖ classify joints on the basis of their geometry and origin;
- ❖ define unconformity;
- ❖ identify different kinds of unconformities; and
- ❖ discuss the significance of unconformity.

12.2 JOINTS

Joints are one of the most commonly occurring geological structures on the surface of the Earth. You will find in the field that hardly any outcrop exists that does not have any fracture or joint. A joint separates two adjacent blocks of rock without any relative displacement. The regional forces viz. compressive, tensional, or shearing may leave their imprint in the form of joints. You have read about these forces in Unit 9 of this block. These forces deform the rocks forming the crust of the Earth and are often responsible for the development of regular or irregular cracks. Most joints are, at least initially, tight fractures. Howerver, the joint may be enlarged into open fissure because of weathering.

Joints can also form as a result of nontectonic expansion and contraction of rocks when erosion has stripped away surface layers. They may also occur in lava as a result of contraction as it cools. When a rock fractures, this leads to the development of joints. These are usually the beginning of a series of changes that eventually alter the rocks significantly. For example, joints provide channels through which water and air can reach deep into the rocks and speed the weathering process and weaken them.

Definition

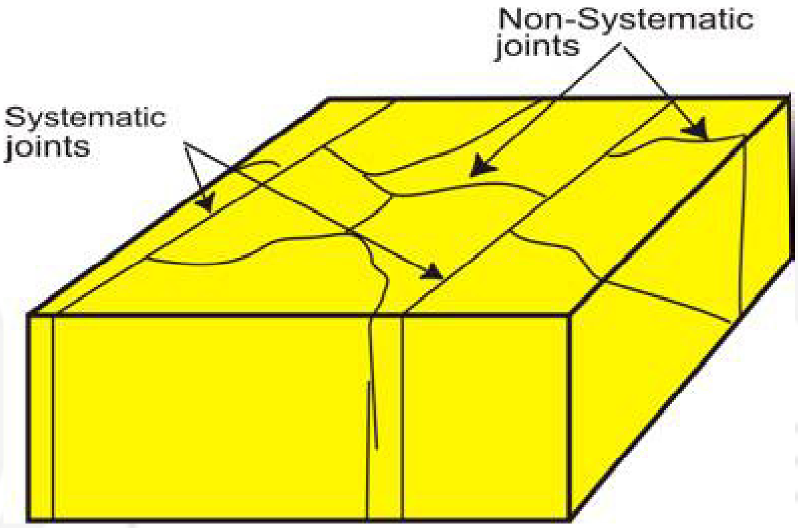
Joints are defined as fracture surfaces along which the movement is negligible or not observable. There may be, however, small movement of blocks perpendicular to fracture surface usually of the order of millimetres to a few centimeters. Joints are among the most common of all geological features. You will find that joints are ubiquitous and occur in all kinds of rocks, whether igneous, sedimentary or metamorphic. In coal, the joints are called **'cleat'**.

Study of joints in an area reveals the sequence and timing of fracture formation and provides information of both pure and applied scientific values. From the view point of hydrology, engineering, mining, *etc*., fracture and joints are among the most important geological structures.

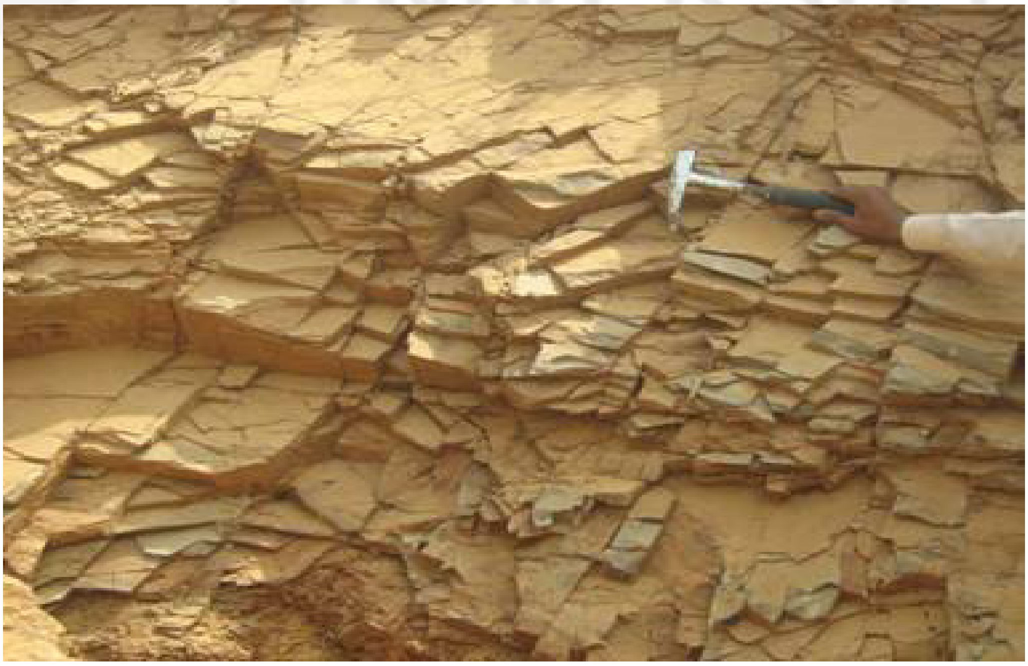
12.2.1 Description of Joints

You have read in Unit 9 Introduction to Structural Geology, that single joint is planar fracture plane, which like any other planar structure, can be described in terms of dip and strike. Joints may have different attitudes; some joints are vertical, others horizontal or may be inclined. The strike or dip of joints is measured in the same way as for bedding planes. The strike is the direction of horizontal line on the surface of joint; dip is measured in vertical plane at right angle to strike of the joint.

You may observe that in nature, joints generally occur in multiplicity in the rocks which may occur in systematic and non-systematic manner. The **non-systematic joints** or **irregular joints** are irregular in their orientation, while the **systematic joints** are found parallel to each other and show a regular pattern (Fig. 12.1a and b). An array of parallel joints having same dip and strike constitute a **'joint set'** (Fig. 12.2a and b). Two or more joint-sets that intersect can form a **'joint-system'.** In a joint system the different joint-sets may or may not be of same age. However, **conjugate joints** are two sets of joints of same age which intersect each other making 60° to 90 angles between the joint planes. When three sets of joints are mutually perpendicular, it gives rise to cubical rock mass, these types of joints are called **mural joints.** In a joint system if one of the joint sets is dominant, it is called **'primary joint set'** and the other set or sets of joints are termed as **secondary joint set(s)**. A **joint zone** is a quasicontinuous fracture that is composed of a series of closely associated parallel fractures and that extends much beyond than any individual fracture (Fig. 12.3a and b).

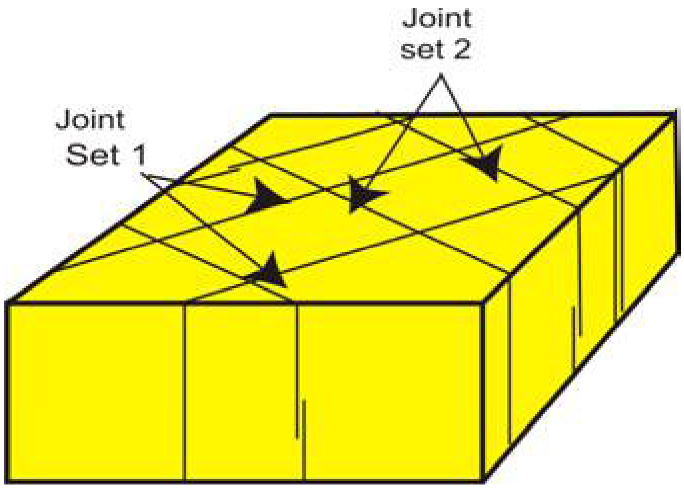


(a)



(b)

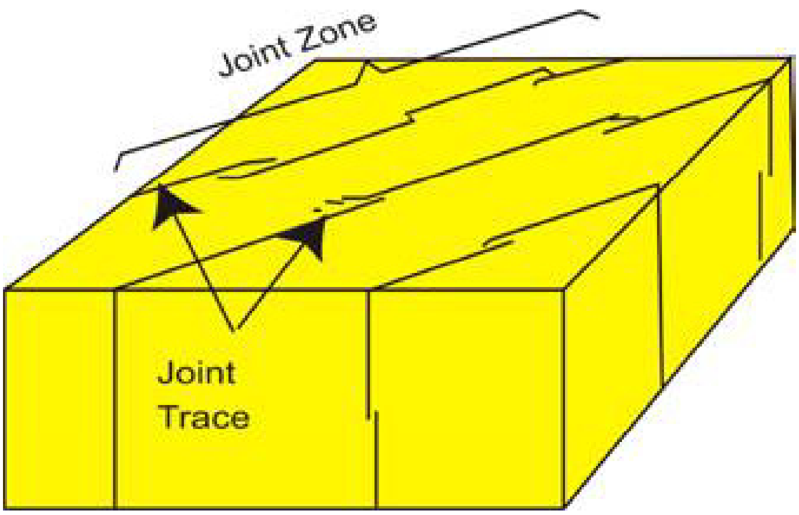
Fig. 12.1: Systematic and Non-systematic joints: a) Sketch; and b) Field photograph.



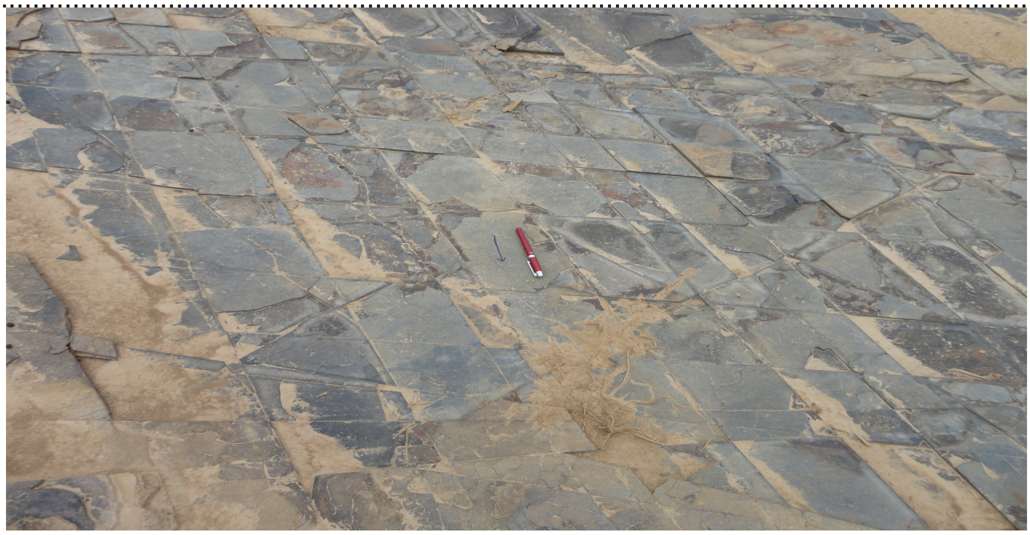
(a)

(b)

Fig. 12.2: Joint sets and joint system: a) Sketch; and b) Field photograph.



(a)



(b)

Fig. 12.3: Joint trace and joint zone, a) Sketch; and b) Field photograph.

Joint face is a two dimensional surface of the joint block which may be planar, curviplanar and generally featureless. The **aperture** of a joint is the perpendicular distance between two faces of same joint. Joint trace is a line feature which is formed by the intersection of joint surface and outcrop surface or any given surface (Fig.12.3a and b). **Plumose marks** are found on some joint faces which are characterised by presence of a series of tiny ridges and troughs in curvilinear patterns (Fig. 12.4).

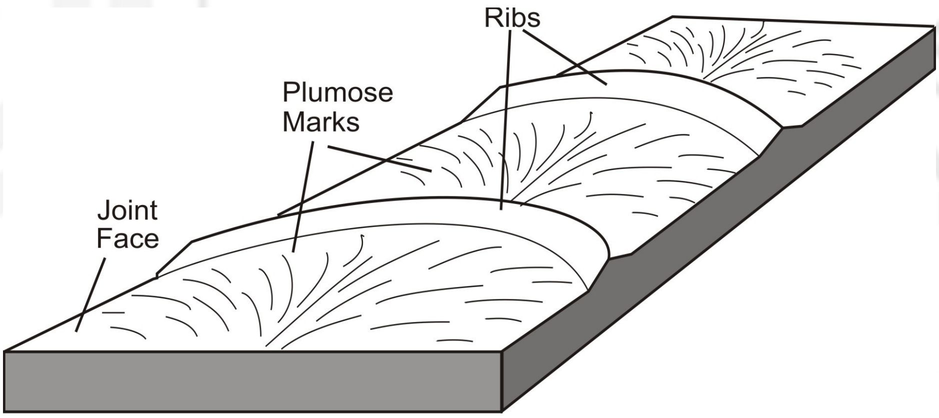


Fig. 12.4: Plumose marks on a joint face.

12.2.2 Genetic Classification of Joints

Joints may originate due to:

- stresses causing fracturing essentially contemporaneous with the tectonic activity;
- residual stresses, due to the tectonic event that had happened long before the fracturing;
- contraction due to shrinkage because of cooling; and
- downhill movement of rocks or mountain glaciers on surface movement.

Thus, the forces responsible for development may be tectonic and / or non tectonic in nature.

In the following section we will discuss about tectonic and non tectonic joints.

A) **Tectonic Joints**

It has been observed that majority of the joints generally develop when the rock is subjected to tectonic stresses that cause deformation under brittle conditions at the upper levels of the rock surface. The tectonic joints may be further recognised as follows:

1. **Tension joints**: These joints are formed due to pulling apart or tensional stresses. Tension joints exhibit minor circular grooves or ridges known as 'plumose marks' (Fig. 12.4).

2. **Shear Joints**: They are formed due to compressional stresses. In this case joints develop in conjugate sets dipping opposite to each other (Fig. 12.5).

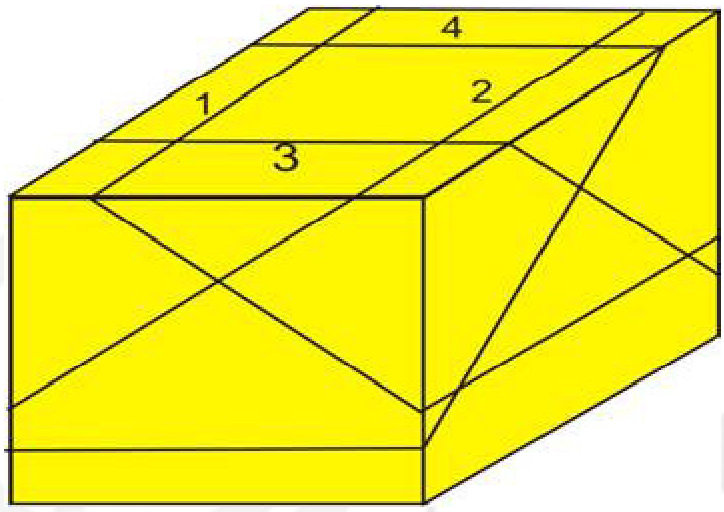


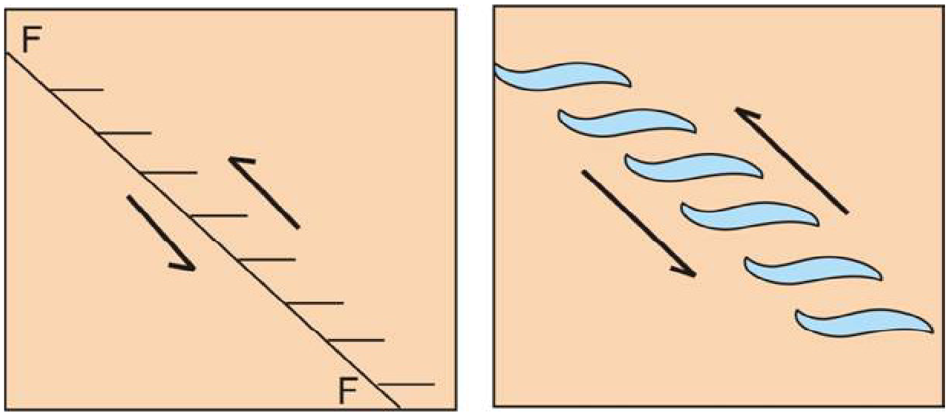
Fig. 12.5: Shear joints - 1 and 2 sets are conjugate sets, which have same strike but opposite dips. Similarly sets 3 and 4 are the other conjugate sets.

3. **Extension Joints**: Joints having their strike perpendicular to the axis of folds are commonly termed as extension joints. They are so called as it was thought that because of them the structure (fold) is further extended.

4. **Release joints**: Joints formed parallel to the axis of the folds are called release joints. These joints develop due to release of load by removal of overlying over burden.

5. **Feather Joints**: A group of small en echelon (partially overlapping) joints which originate due to brittle deformation near fault zones are called feather joints (Fig. 12.6a). These are a kind of extension joints and are also known as **pinnate joints.**

6. **Hybrid joints**: The hybrid joints are formed because of involvement of more than one type of force such as tensional, compressional or rotational. These joints are not observed as a single plane but they have rotational features. Tensional gash veins or en echelon joints are example of hybrid joints (Fig. 12.6b). The pinnate or feather joints acquire a shape of English alphabet 'S' or 'Z' Because of the rotation during the deformation.



(a) (b)

Fig. 12.6: a) Feather joints; and b) Hybrid joints.

B) **Non Tectonic Joints**

Non tectonic joints are obviously independent of the tectonic forces. The non-tectonic causes may be hillside creep, landslides or even anthropogenic activities such as impacts, explosion, etc. They have only a local or limited extent.

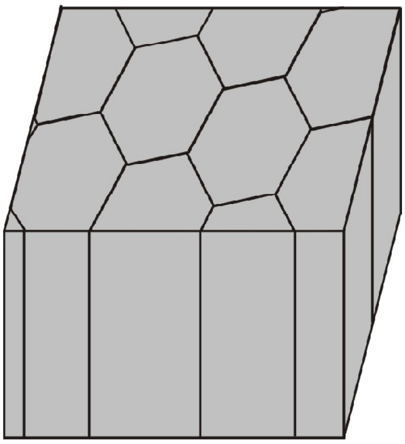
1. **Columnar Joints:** These joints exhibit columnar structure at depth and a polygonal (usually hexagonal) outline at surface (Fig. 12.7a). The columns are generally few to many meters in diameter and several meters in length. However, the columnar joints which develop because of non tectonic reasons may have a regular pattern.These joints develop during the cooling of lava over the surface of the Earth hence they are also called as **primary** or **shrinkage joints**. Shrinkage joints result due to cooling. Basaltic lava develops polygonal columns because of columnar joints (Fig. 12.7). Some of the columns are hexagonal, some are four or five sided.
2. **Mural Joints:** When three mutually perpendicular joint sets intersect with more or less equal spacing, **mural joints** are developed. In granite mural joints are advantageously utilized in producing cubical blocks while quarrying.
3. **Sheet joints:** They develop in sets and are more or less parallel to the ground surface, especially in plutonic igneous intrusions such as granite. They may be caused by expansion and contraction in response to solar heating and cooling or rocks during day and night.

12.2.3 Geometrical Classification of Joints

In the above section we have discussed the genetic classification of joints. Let us examine their geometry and the geometric classification based thereon.

A) **Attitude of Joints and Bedding Planes**

- **Strike Joints**: In this the strike of joint plane is parallel to the strike of the bedding plane, (Fig. 12.8)
- **Dip Joints**: When strike of joint plane is parallel to the dip direction of the bedding plane, the joints are called dip joints. In other words, strike of joint and bedding plane are mutually perpendicular in case of dip joints (Fig. 12.8).



(a)

(b)

Fig. 12.7: a) Sketch of polygonal joints; and b) Field photograph of columnar joints in Deccan Basalt.

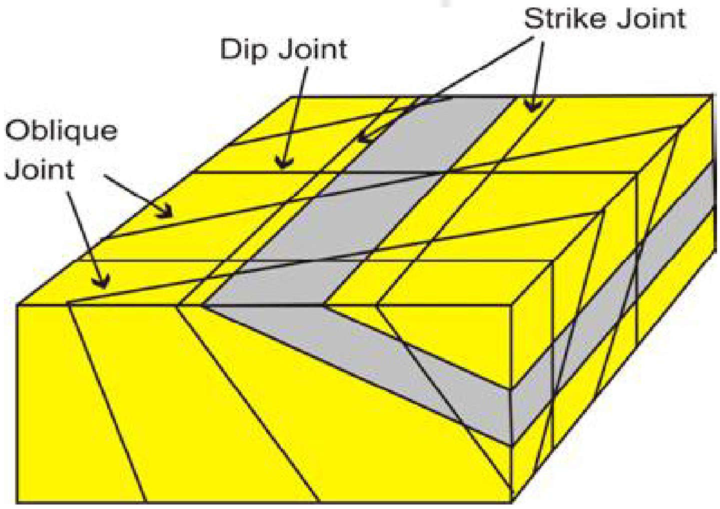


Fig. 12.8: Dip joints, strike joints and oblique joint.

- **Oblique Joints**: When strike of joint plane is neither parallel to the strike nor dip direction of the bedding plane, the joints are called oblique joints (Fig. 12.8).

- **Bedding Joints**: When dip and strike of the joints are parallel to the dip and strike of the bedding planes, the joint is called as bedding joint.

B) Size of Joint

Joints may range in dimension from microscopic to hundreds of meters. On the basis of their sizes, the joints can be classified as:

- **Master Joint**: It is the joint plane is of greater dimension than the average extent. It may affect several rock horizons and persist for hundreds of meters.
- **Major Joints**: Major joints are smaller than master joint but they are the prominent joint in the region.
- **Minor Joints**: Minor Joints are those which are confined within a bed and do not extend beyond the bedding planes.
- **Micro Joints**: The micro joints are very small in size and may be only of few millimeters in size.

C) **Relation to Major Structures of the Region**

i) Geometrical relation with folds

Joints display different relation to the folds:

- **Cross joints** are joints which are normal to the fold axis;
- **Longitudinal joints** are those which are parallel to axial plane of the fold;
- **Diagonal joints** are neither parallel nor perpendicular to the axial plane of the fold.
- **Radial joints** typically occur in folded competent layers and are perpendicular to local orientation of the layer. They strike parallel to the fold axis (Fig. 12.9). **Extension joints** are generally called cross joints and radial joints.

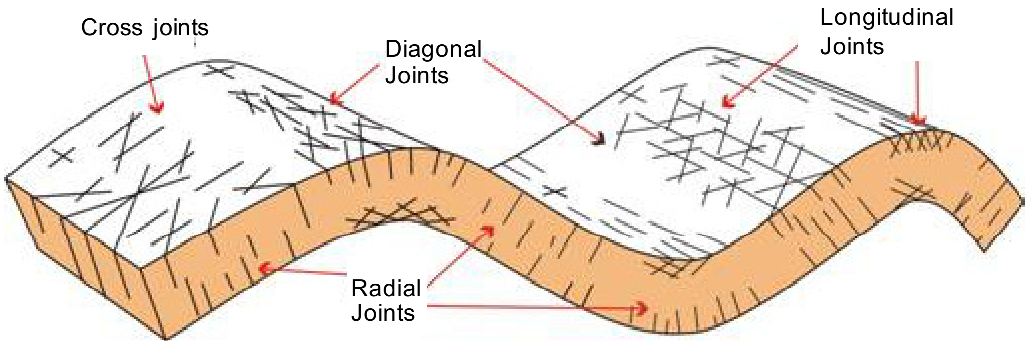


Fig. 12.9: Sketch showing cross joints, diagonal joints, radial joints and longitudinal joints.

ii) **Geometrical relation with faults**

As mentioned earlier, near the fault, many small joints may develop roughly at an angle of 45° with respect to the fault plane. These joints look like a feather and therefore they are also called as **feather joints** or **pinnate joints** (Fig. 12.6a). In some cases, they can be used to determine the directions of movement of the fault. You have read about them. **Gash fractures** (Fig.12.6b) are S or Z shaped extension fractures usually filled with mineral, formed along the shear zone. They are also known as **hybrid joint**, about which we have discussed earlier.

12.2.4 Significance of Joints

Joints are generally recognised in the field as 'faults without displacement'. Their dimension varies within wide limits. Sometimes they are very short, but in certain cases they are found to extend for kilometres. You might be questioning yourselves about the need of studying joints and their effects on outcrop. Here is the answer:

1. Joints occur at the outcrop scale in virtually all the rocks and thus comprise one of the most abundant geological structures on the crust of the Earth.

2. Joints in rock bodies permit infinitesimal adjustments to take place *i.e.* change in size and/or shape during tectonic movements *viz.* subsidence, uplift, thrusting, contraction, expansion and folding.

3. Many scenic landscapes are formed by joints and weathering and erosion along joints.

4. Drainage pattern of an area may follow joints. They also provide a conduit for the passage of water and accumulation of sub-surface water. It may also allow a means of weathering by the action of water flow.

5. Presence of joints invites circulation of fluid including rain water and ground water, hydrothermal mineralising fluids solution and oil and natural gas. Joints can serve as sites of deposition of metallic or non metallic minerals formed through hydrothermal deposition.

6. Joints add up the bulk porosity and permeability in the rock notably that of the latter. They are so important that in petroleum production, it is a common practice to fracture the shallow sedimentary rocks artificially so that petroleum could be recovered from depth.

7. Natural circulation of fluid through joints in hot rocks at depth constitutes important aspect of tapping the geothermal energy.

8. The systematic abundance of joints causes easy quarrying of the rocks. We have discussed this in non tectonic joints.

SAQ 1

a) What is columnar joint?

b) Differentiate between strike joint and dip joint.

c) What are the different kinds of joints associated with the fold?

d) Distinguish between joints and faults. List the joints associated with faults.

12.3 UNCONFORMITY

Unconformity is a common geological feature found in rocks or in rock successions. It is different from all other geological structures *viz.* the fold, joints and faults. Unconformity is related due to tectonism in the form of uplift or/and subsidence of land and is referred to a period of non-deposition. '*Un*' means not and '*con*' means similar and '*formity*' means formed.

Unconformity is defined as a plane of non deposition in the rock sequence. It marks the *hiatus* or break in deposition.

The fundamental "laws" of stratigraphy, was formulated in the 17^{th} century by Nicolas Steno, is known as **law of Original Horizontality**. This implies that initially deposition takes place totally in horizontal fashion. Later during non-depositional period due to some disturbances tectonic or non tectonic the layers or beds are tilted and exposed to weathering and erosional processes. Subsequently the exposed rocks may sink down and the depressed area (basin) may start receiving the deposition of sediments again to give birth to a new sequence. Thus the unconformity represents the time gap when the basin did not receive any sediment.

12.3.1 Types of Unconformities

The unconformities may be of the following types:

1. **Angular Unconformity**: In an angular unconformity the older and younger sequences across the unconformity surface have an angular relationship (Fig. 12.10 and 12.11). This develops due to the deposition of younger rock sediments on older rock formations which had already tilted before the initiation of deposition of younger sequence. Fig. 12.10 depicts the stages of development of an angular unconformity.

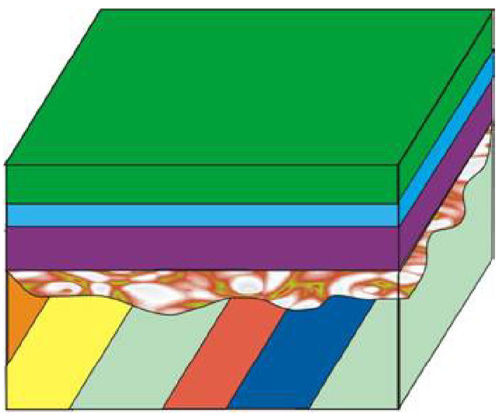


Fig. 12.10: Block diagram of an angular unconformity.

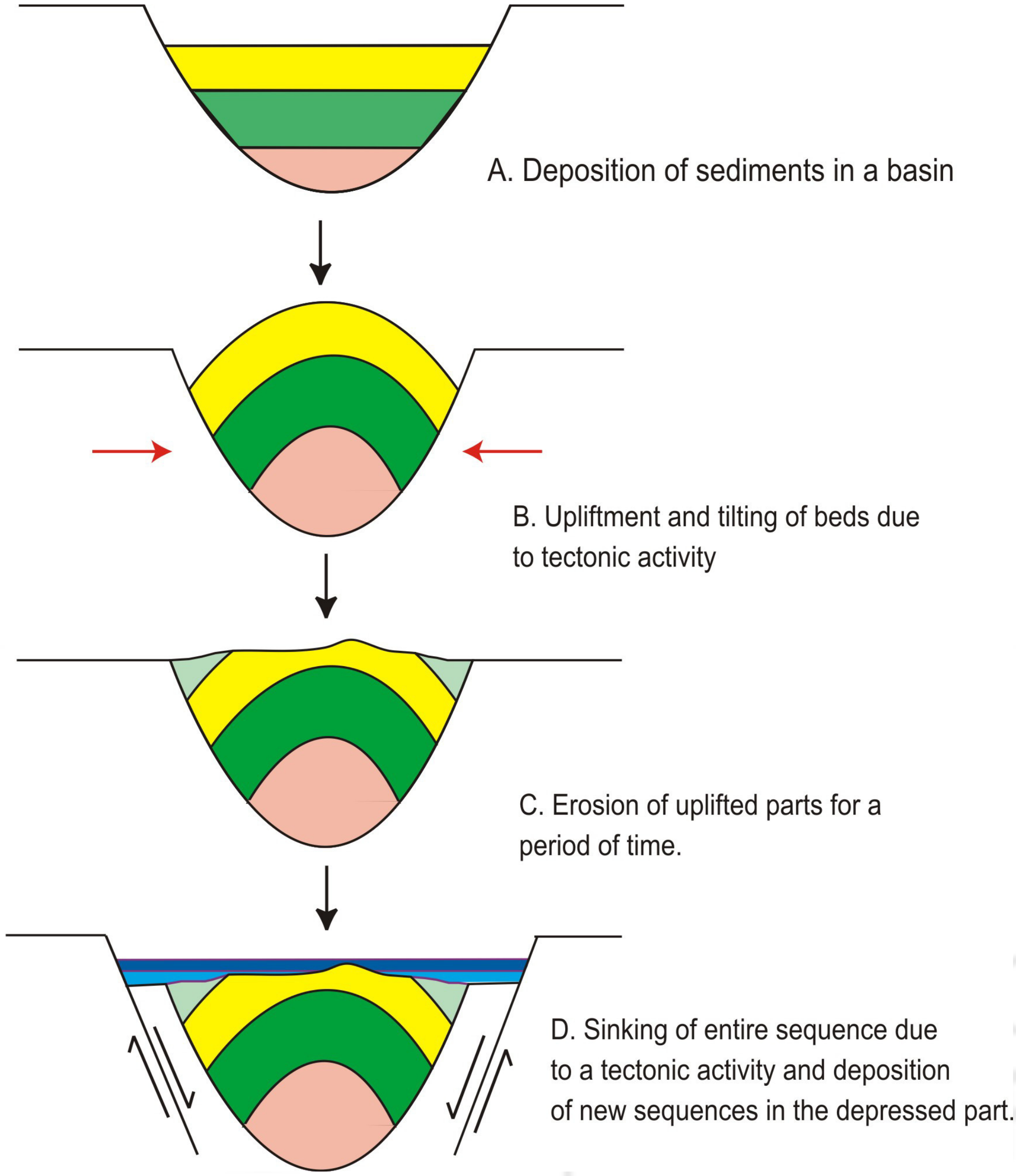
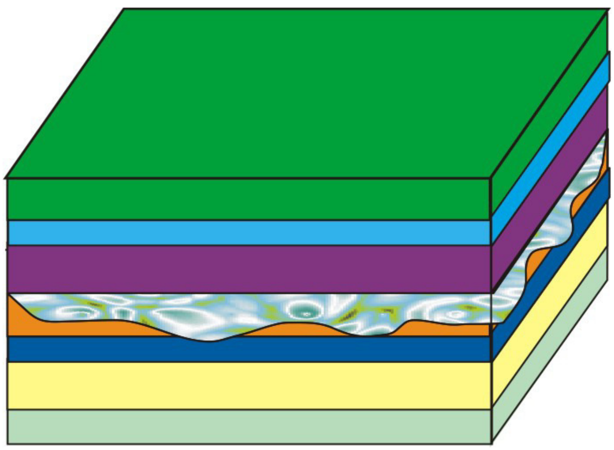
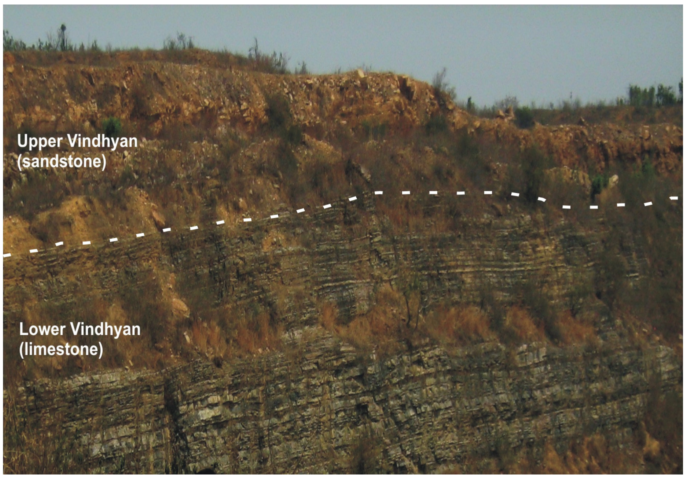


Fig. 12.11: Stages of development of an angular unconformity.

2. **Disconformity**: In this type beds of both the older and younger sequence are parallel (Fig. 12.12 a and b). Therefore, disconformity is also known as parallel unconformity.



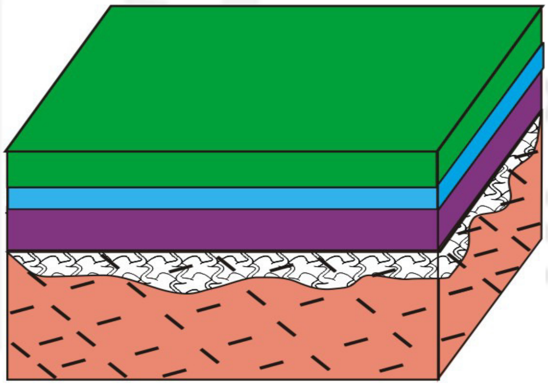
(a)



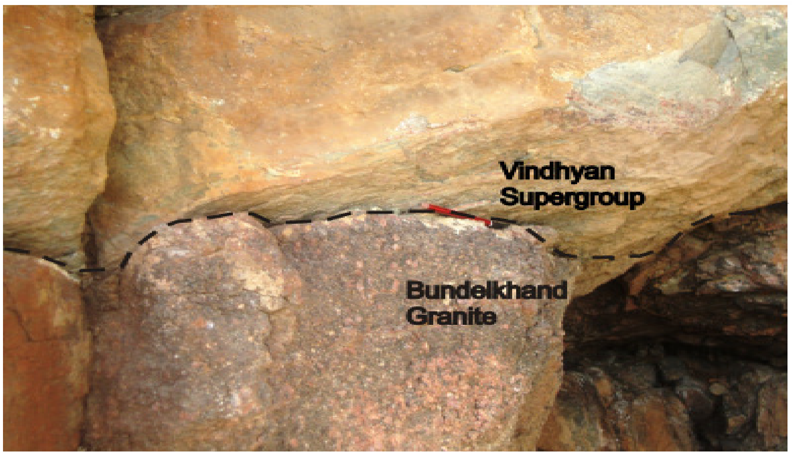
(b)

Fig. 12.12: a) Disconformity; and b) Field photograph showing younger sandstone of Upper Vindhyan resting over limestone of Lower Vindhyan of the older sequence in a parallel manner in Son valley.

3. **Nonconformity**: Nonconformity is the type of unconformity in which the older sequence is made up of plutonic igneous rock while the younger sequence is of sedimentary rocks. Here the sedimentary rocks get deposited directly over the plutonic igneous rock (Figs. 12.13a and b), which was earlier exposed to erosion prior to the new depositional sequence. It is also called as **heterolithic unconformity**.



(a)



(b)

Fig. 12.13: Nonconformity: a) Sketch; and b) Field photograph showing unconformable contact between sandstone of Vindhyan deposited on plutonic rock namely Bundelkhand Granite, Chitrakoot.

4. **Local Unconformity**: The unconformity which is of local extent is called local unconformity. It represents a small period of non-deposition within the sequence. This is similar to disconformities but the time and area involved are very short.

5. **Blended Unconformity**: Generally, the unconformities show sharp contact between the older and younger sequence but sometimes this contact is not sharp because a thick sequence of residual soil lies between them. The younger sequences sometimes incorporate these residual materials (soil and/or pebbles) and thus they may show a mixing or blending of two sequences. A blended unconformity is also a type of disconformity or nonconformity with no distinct separation plane or contact, sometimes consisting of ancient soils or beds of pebbles derived from the underlying rock (Fig. 12.14).

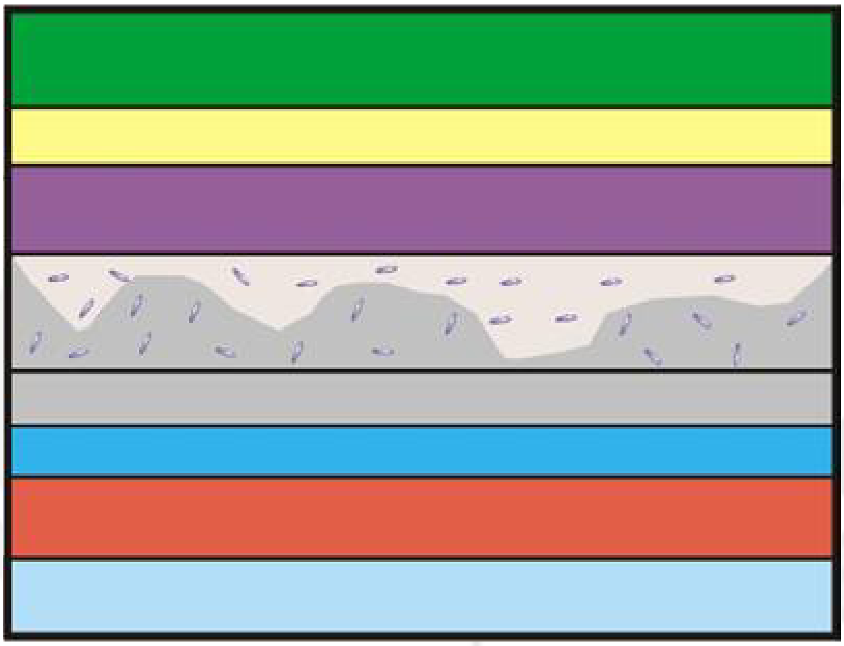


Fig. 12.14: Sketch of blended unconformity.

Besides the above types there are some special features, which indicate relationship between the older and younger sequences of the beds. **Marine transgression** is that phenomenon when sea encroach the land due to sea level rise. Similarly when sea level falls it gets away and away from land areas. This phenomenon is called **marine regression**.

1) **Overlap**: The term overlap is used to describe the relationship of beds in an unconformity where progressively younger member of an upper series rests upon an older series by overlapping it and extends beyond the previous one just below (Fig. 12.15a). This occurs because of marine transgression.

   In Fig. 12.15a bed B which is younger than bed A completely overlaps bed A and extends further and then makes a contact with beds of older series. The same kind of relationship called overlap can be seen for other beds C, D and E also. If you look from top the overlap shows a relation where successively younger bed covers more and more area of the older series.

2) **Offlap**: Offlap shows reverse relation of older and younger beds. Here the successively younger beds of the younger series get deposited short of the older sequence of beds. In case of offlap the lowest bed of an upper series extends further over the older series than the younger one of the same series (Fig.12.15b). This phenomenon occurs because of marine regression (i.e. receding of sea).

   Fig. 12.15b describes the relationship in an offlap. If you look from top the overlap shows a relation where successively younger beds cover lesser and lesser areas of the older series. That is to say we may find that the on surface distance between older series and beds of younger series increases with younging of beds. You can observe that the distance between older series and bed C is more than that of Bed D or E.

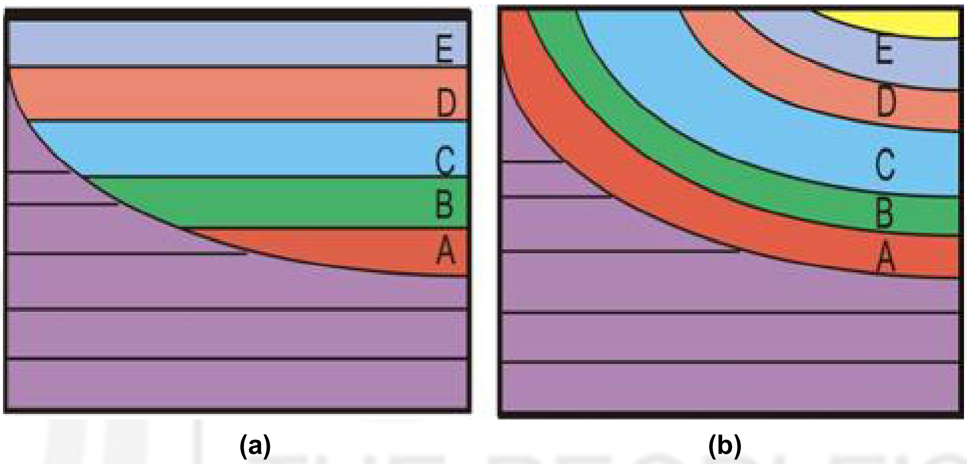


Fig. 12.15 : a) Overlap; and b) Offlap.

3) **Overstep**: The term overstep is used to describe the relationship of beds in an unconformable sequence where the younger series rests upon progressively older members of the underlying series. (Fig. 12.15a). This occurs because of marine transgression (*i.e.* extends of sea over land). Fig.12.16a describes the relationship in overstep. You can notice that bed A which is oldest of the younger series is in direct contact with younger beds S,T and U of older series; while the bed B (younger than A) is in a direct contact with beds R and S (older than T and U) of older series.

4) **Onlap**: Sometimes overstep is also called as onlap. The term onlap is applied for a relationship which exhibits characters of overlap and overstep (Fig. 12.16b).

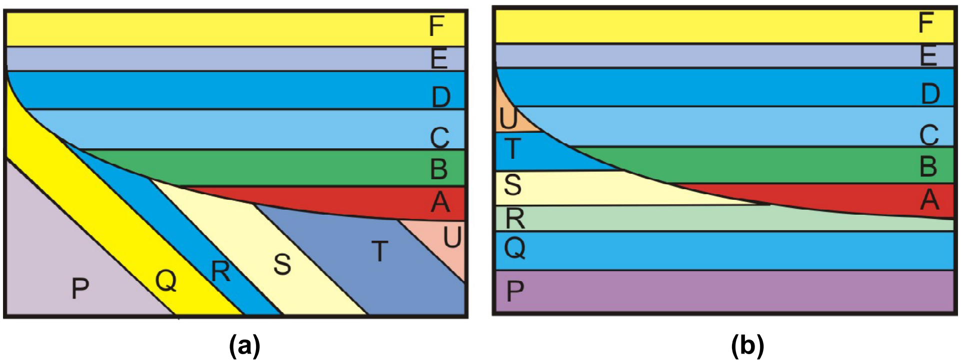
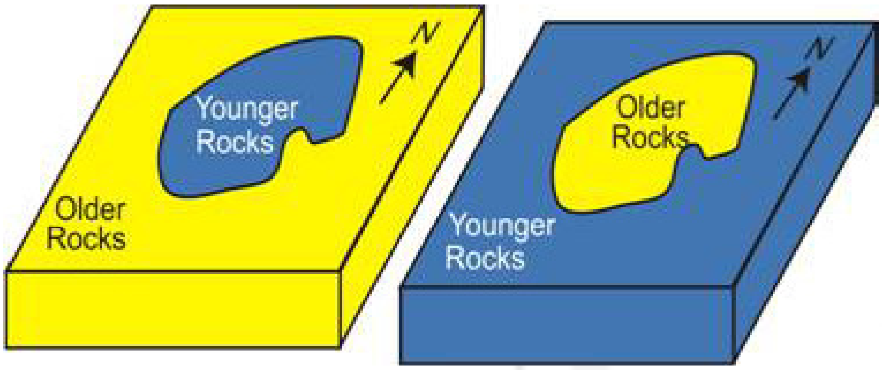


Fig. 12.16: a) Overstep; and b) Onlap.

5) **Outlier and Inliers**: Outlier refers to 'older bed outside' and inlier refers 'to older bed inside'. The terms indicate special relation between older and younger rocks. In the field or on a geological map when a limited area of younger rock is completely surrounded by older rocks, the structure is called as outlier (Fig. 12.17a). But when the older rock is completely surrounded by younger rocks it is known as inlier (Fig. 12.17b). Outlier and inliers may be produced by erosion, folding, faulting or combination of more than one of these phenomena.



(a) (b)

Fig. 12.17: Sketches : a) Outlier; and b) Inlier.

12.3.2 Recognition of Unconformity in the Field

Under favourable conditions unconformities are well recognised in the field. However, in the majority of field conditions unconformities are not directly traceable. In such conditions, indirect observation of associated rock structures, soil types, rock types, fossil assemblages, *etc.* are the tools to identify unconformities. In the field, the unconformities can be recognised by various ways such as:

a) **Observation in single outcrop**: The unconformities can be best recognised in the field by observation on a outcrop exposed along mountain, quarries, road and rail cuttings.

b) **Presence of conglomerate**: Conglomerate rock often marks the unconformity surface below it. This is generally based on the presumption that in a basin, first deposition of conglomerate of pre-existing rocks will take place. Disconformities are often recognised by presence of conglomerates.

c) **Abrupt truncation of beds**: If the beds are suddenly truncated against rocks of the other sequences, there might be unconformity. It must be noted that because of faulting also the beds get truncated along fault surface. In case of truncation by the fault, the beds are repeated again across the surface but in case of unconformity however, the same beds are not repeated across the discontinuity surface.

d) **Abrupt change in ages of the rocks**: When two rock sequences of different ages are juxtaposed together leaving a gap of sufficient time interval, there may be an unconformity. The ages can be confirmed by radiometric dating, palaeontological and stratigraphical records.

e) **Abrupt change is metamorphic grades**: Abrupt change in the metamorphic grade between the overlying and underlying rock units may be due to presence of unconformity between them.

f) **Difference in intensity of deformation**: The difference in the intensity of folding or deformation in overlying and underlying rock formations may indicate the presence of an unconformity between the two rock units. The older formation would be more deformed.

12.3.3 Significance of Unconformity

The unconformities are significant geological structures because of following reasons:

1. They reveal tectonic history of the rock sequence and their break in deposition.
2. Some unconformities have great importance since they mark a significant stratigraphic break at a particular level on a regional scale.
3. They are important and need considerable attention in engineering projects.
4. Unconformities have significance in petroleum exploration as petroleum may be trapped along them.
5. Many a times unconformities contain valuable minerals like diamond and uranium.

SAQ 2

a) Define unconformity.

b) Draw a neat well labelled diagram of nonconformity and angular unconformity.

c) Differentiate between outlier and inlier.

d) Mention two points giving significance of unconformity to mankind.

12.4 SUMMARY

In this unit you have learnt about two geological structures namely joints and unconformities. Let us summarise what we have learnt in this unit:

- Joints are quite common and important structures found in the rocks. Joint is in fact, a kind of fracture without any observable movement along it.
- Different terms are used to describe joints based on its pattern, size and prominence. Joints may be tectonic or non tectonic. Most joints originate because of tectonics but there are non tectonic reasons also.
- Joints have been classified differently on the basis of their attitude, size and relation with major structures.

- An unconformity is a planar structure between two rock sequences of different ages. It records the gap in the process of sedimentation.
- Based on the relationship between older and younger sequences, the unconformities are identified by different names.
- Overlap, offlap, overstep, outlier and inlier are also some of the terms which describe special relationship of older and younger rock sequences.

12.5 ACTIVITY

1. Visit nearby areas where solid rocks/outcrops are exposed. Try to observe joints in them. Also try to classify the joints on the basis of criteria you have studied here.
2. Try to observe date wise stacking of daily newspapers at your home or in a library. The missing number of days (such as holidays *etc.*) between the regular days will tell you the time gap of non availability of newspapers. This is analogous to the time gap in deposition of rock sequences and hence indicative of presence of unconformity.

12.6 TERMINAL QUESTIONS

1. What is joint? Give the geometrical classification of joints. Draw well labelled diagrams to illustrate them.
2. What are the different kinds of unconformity?
3. Discuss the significance of joints.
4. How would you recognise unconformity in the field?

12.7 REFERENCES

- Billings, M.P. (1990) Structural Geology, Prentice Hall of India Pvt Ltd., 606p.

12.8 FURTHER/SUGGESTED READINGS

- Mukherjee, P.K. (2000) A Text Book of Geology, The World Press, Kolkata, 638p.
- Singh, P. (2009) Engineering and General Geology, S.K. Kataria and Sons, 600p.

12.9 ANSWERS

Self-Assessment Questions

1. a) Columnar joints occur in mafic volcanic igneous rocks. These joints develop during the cooling of lava over the surface of the Earth; hence they are also called as shrinkage joints.

b) Strike Joints are those joints in which strikes of joint plane and bedding planes are parallel. Dip Joints are those joints in which strikes of joints are parallel to the dip direction of the bedding plane. In other words, strikes of joint and bedding plane are mutually perpendicular in case of dip joints.

c) Joints display different relation to the folds. Cross joints are those which strike normal to the fold axis and longitudinal joints are parallel to axial plane of the fold. The strike of a diagonal joint is neither parallel nor perpendicular to the axial plane of the fold. Radial joints are perpendicular to local orientation of the layer and they strike parallel to the fold axis. The cross joints and radial joints are generally called extension joints.

d) For difference between faults and joints refer to Unit 11 and Unit 12. feather joint or pinnate joint, gash fractures or hybrid joint.

2. a) Unconformity is defined as a plane of non deposition in the rock sequence. It represents a field of erosion.

b) Draw figures 12.13 and 12.15.

c) In the field or on a geological map when a limited area of younger rock is completely surrounded by older rocks, the structure is called as outlier. But when the older rock is completely surrounded by younger rocks it is known as inlier. Outlier and inliers may be produced by erosion, folding, faulting or combination of more than one of these phenomena.

d) Petroleum may be trapped along unconformities. Many times unconformities contain valuable minerals like diamond and uranium. Thus unconformities are of significance to the mankind.

Terminal Questions

1. Please refer to section 12.2 and subsection 12.2.3.
2. Please refer to subsection 12.3.1.
3. Please refer to subsection 12.2.4.
4. Please refer to subsection 12.3.2.

UNIT 13

FIELD GEOLOGY

Structure

13.1 INTRODUCTION

You have already read in Unit 1 Introduction to Geology of this course that fieldwork is a vital component of geology. Fieldwork involves the collection of reliable geological data that is essential for understanding the causative processes and evolved environments of the Earth. Thus, acquiring nuances for carrying fieldwork is one of the most essential activities that you should learn as a student of geology. In this unit, we shall discuss the importance of fieldwork in geological studies, planning for fieldwork, field equipments required for fieldwork, field safety measures and basic field techniques. We shall also discuss recognition and measurements of geologic features in the field and systematic documentation of field observations.

Expected Learning Outcomes

After reading this unit you should be able to:

- ❖ analyse importance of fieldwork in geology;
- ❖ discuss the procedures to be followed while planning for fieldwork;

- list field safety measures and equipment required for fieldwork;
- recognise and measure geological features in the field; and
- document field observations in the field diary.

13.2 GEOLOGICAL FIELDWORK

Let us discuss the importance of fieldwork in geological studies before we read about planning and other aspects of fieldwork.

Geologists try to probe Earth's long history by reading what has been "written on rocks". Fieldwork is an integral part of geology as Earth is the natural laboratory for geologists. They can directly observe the features and the operational surface processes of the Earth. The fieldwork initiates with the collection of samples and information pertaining to the rocks and geological structures, followed by analysis of the collected field data in the laboratory. This integrated approach by geologists helps them to unravel the geological history of the Earth: its origin, evolution, composition, structure, palaeogeography, palaeoclimate and past life. Palaeogeography generally refers to land and water distribution of the past. Palaeoclimate is a climate prevalent at a particular time in the geological past.

In addition to this, fieldwork plays an important role in exploring and exploiting the mineral resources, underground water, building materials, coal and petroleum resources and identifying suitable sites for engineering projects such as dams, bridges, roads and railway lines, etc. Now-a-days, geologists are playing an important role in the management and utilisation of natural resources, natural hazards zonation and their mitigation, which enables them in evaluating, assessing various environment related problems, and the impact of Earth processes on life systems.

The above explanation elucidates the importance of fieldwork in geology.

You have read earlier in this section that to study the Earth, geologists must go in the field and observe the Earth materials (minerals, rocks, sediment and soil) and processes in their natural setting. It is well accepted principle in geology that "**the present is the key to the past**" meaning Earth processes occurring today have operated throughout Earth's history. Therefore, it is only through field studies, geologists can record the scale of Earth processes and gain understanding of the Earth's history through space and time. These field investigations constitute the **Field Geology,** which is an essential component of geology. Geological fieldwork provides the ground truth for geologic concepts, theories and related hypothesis of how the Earth works. It is well said that geological studies are never complete without field geology or fieldwork, which forms a heart or core of geology. In fact, field geology makes a geologist a complete geologist.

13.3 BASICS OF FIELD GEOLOGY

The primary objective of the field geology is to observe, record and collect structural or geological data and samples of the rocks, minerals, sediments, soil and fossils occurring in their natural environments, and interpret their field relationships. It is important to recognise that actual relationship between Earth processes and geologic features is better understood in their natural environments. Now let us acquaint ourselves with some basic terminology that will facilitate us in comprehending field geology.

Field: It is an area from where field data and samples are collected in their natural setting.

Outcrop: It is the portion of the rock exposed on the Earth's surface. The outcrops are mostly exposed along the mountains, valley walls, nala section, road/rail cuttings and tunnels. The term **outcrop** means 'what emerges out' thus, an outcrop denotes the area on Earth's surface over which rock mass crops out and is visible on the surface, which provides the basic source of information for a geologist.

Fieldwork: It involves visiting field and observing outcrops, exposed in quarries or mines and road cutting and making careful observations and measurements of the geological features. During the fieldwork, we carefully observe and record different rock types and the contact relationship of one rock unit or lithology to another. It also involves the collection and precise recording of the location of samples for laboratory investigations. In Geology, "There's room for those who love field work and there's room for those who don't" Eric Calais in Perkins (2011).

Field Geology: When rocks and rock materials are examined in their natural environment and in their natural relations to one another, the study is called field geology (Lahee, 1987). Field geology also involves the integration of descriptive, structural, petrological, spatial and temporal data in order to know the geological setup and history of the concerned area. Rock/mineral/soil/sediment/fossil samples, geologic maps, cross-sections, structural data and samples are the main products of geological field work.

Traverse: This refers to the path taken by a geologist during the fieldwork in any area or terrain. A planned route or direction connects two points and passes through a number of locations or outcrops, where you can see and study them during the fieldwork. It is preferable to choose the traverse along or across true dip. The traverse along the strike of the beds should be avoided because in that case you will encounter the same lithology.

Sampling: It refers to the collection of fresh, homogenous rock pieces of a considerable dimension like 7cm to10cm×10cm to15cm×2.5cm to 5 cm from the outcrop. The size of the sample depends on the purpose for which it is collected. We use geological hammer and chisel for this purpose. Sampling is a crucial aspect of a field programme because only samples, field notes and photographs one has on returning from the field.

13.4 PLANNING FOR FIELDWORK

We have learnt about the significance of fieldwork now it is quite imperative to discuss the planning of geological fieldwork. We have read in the earlier section, fieldwork forms the basis for a geological study, as it is a source of primary data. It provides an opportunity to explore virgin terrains and provides a satisfying adventurous feeling. Geologists are people imagined as often trekking to far-flung regions to hammer rocks. Fieldwork provides many opportunities to work outdoor under a range of conditions in order to explore the natural world. It also provides a chance to travel and visit sites more than a tourist. Fieldwork is a serious exercise and requires systematic planning.

India is a vast country and its terrain has diverse natural features like snow-clad Himalayan mountain system and Indo-Gangetic plains towards the north, Deccan Plateau and Dharwar in the south, Satpura range in the Central India, Eastern Ghats and Western Ghats along the coastal regions and Aravallis and the Great Thar Desert in the northwest. Therefore planning for fieldwork in any of these areas is largely controlled by the terrain chosen for fieldwork. These areas have different climatic conditions, physiography, accessibility and logistics support. Hence, each area requires a separate strategy for planning of the fieldwork, which equivocally depends on the objectives of the fieldwork.

13.4.1 Objectives

The main skills of the geologist in the field are systematic observation and accurate recording of field data. No matter what ever be the purpose of fieldwork the advice is the same; **collect as much information as possible in the field and document it clearly and neatly**. *Y*ou may not know while collecting field data, which observations could be useful for interpretation or report.

Let us summarise these into three broad objectives which may sometimes be interconnected (Fig. 13.1).

- Academic purpose
- Exploring natural resources
- Government mandate.

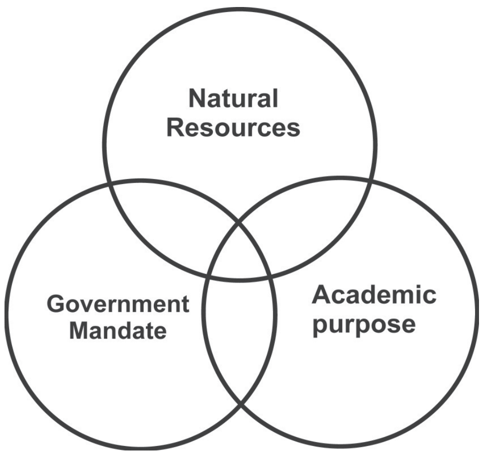


Fig. 13.1: Broad objectives of geological field work (Njue, 2010)

Let us read some common objectives of fieldwork (Table 13.1) that would guide fieldwork planning.

Table 13.1: Common objectives for conducting geological fieldwork (simplified after Coe, 2010)

S.N.	Objectives	What to observe, record and collect in the field
1.	To document general geology of an area	Lithology, structural features and rock samples
2.	To produce a geological map of an area	Lithology and structural data
3.	To construct the geological history of an area	Rock samples and to get basic geological information of all rock units in the area and their relationship to each other
4.	To construct biostratigraphy of an area	Collect fossils
5.	To determine sedimentary depositional environment	Collect samples from all lithounits and observe their textures and structures
6.	To locate mineral resources	Geologic mapping and lithology, collection of rock samples for analysis
7.	To determine nature of igneous rocks	Lithology and rock texture, structure and relationships

Here our broad objective for fieldwork is purely academic while the specific objective is to study general geology of the area. In later case, your focus during the fieldwork will be on careful observation of lithology/rock units, their relationships to one another, and documenting and measuring of structural features and collecting rock sample from the outcrop.

13.4.2 Preparation

Now you might be eager to know about the preparations made during the fieldwork. They are discussed below:

- **Collection of literature and maps:** Initially the preparation for fieldwork begins with the compilation of all the existing data. This includes topographical and geological maps as well as books, published or unpublished research papers and reports. These maps will help us in locating outcrops in the field and planning traverses. Literature will provide the existing knowledge about geology of the area and the work carried out by previous researchers. Systematic review would help you in developing an initial understanding of the geology such as lithology and their interrelationships and geological structures of the study area.

- **Planning of traverses during fieldwork**: Reconnaissance survey of the study area is conducted to have initial idea for the fieldwork. **Reconnaissance survey** is the preliminary survey usually executed rapidly and at relatively low cost, prior to detail mapping. The review of available existing geologic data will help you in planning the traverses. You can also use Google Earth (https://earth.google.com/) and Wikimapia (http://wikimapia.org/) websites to assess the availability of the rock outcrops in the area and plan the traverses. In the restricted area necessary permission from concerned authority is required prior to visiting, camping and collecting samples. **Restricted area** is an area under military jurisdiction in which special security measures are taken to prevent unauthorised entry. You should also be aware about the potential dangers, e.g. wildlife, acute weather conditions, etc., which you may encounter while doing fieldwork.

- **Field schedule and budget estimates**: It is necessary to prepare a field schedule and estimated expenditure based on accessibility, weather conditions, duration of fieldwork, field logistics, field equipments and mode of transportation (foot, jeep, truck, boat, horse) and get it approved from the concerned authority before conducting the fieldwork. The summer season is good for undertaking fieldwork in mountainous terrain like Himalaya while winter season is favourable for conducting fieldwork in the peninsular part of India. Fieldwork during rainy season for various reasons is not encouraged. The booking of tickets via air, rail or road journey along with the logistics arrangements are done before proceeding for fieldwork.

- **List of equipments**: You are required to prepare the list equipment in advance, pack them in field kit.

We will discuss in detail about field equipments in following section.

13.5 FIELD EQUIPMENTS

The field equipments required also depend on the objective of the fieldwork. Before going to the field ensure that you have all of the equipments that may be required during the fieldwork.

Let us list of common field equipments.

1. **Maps**: You will have to carry topographical map, geological, physical, relief, road and political maps to the field (Fig. 13.2, 13.3) which would enable you to gather all the relevant details in the field. Most importantly for geological fieldwork, a geological and topographical map is required. You can locate yourself and find the area covered by an outcrop in the field. Topographical maps are required for plotting geological observations in the field. Now-a-days satellite images are also useful for conducting fieldwork.

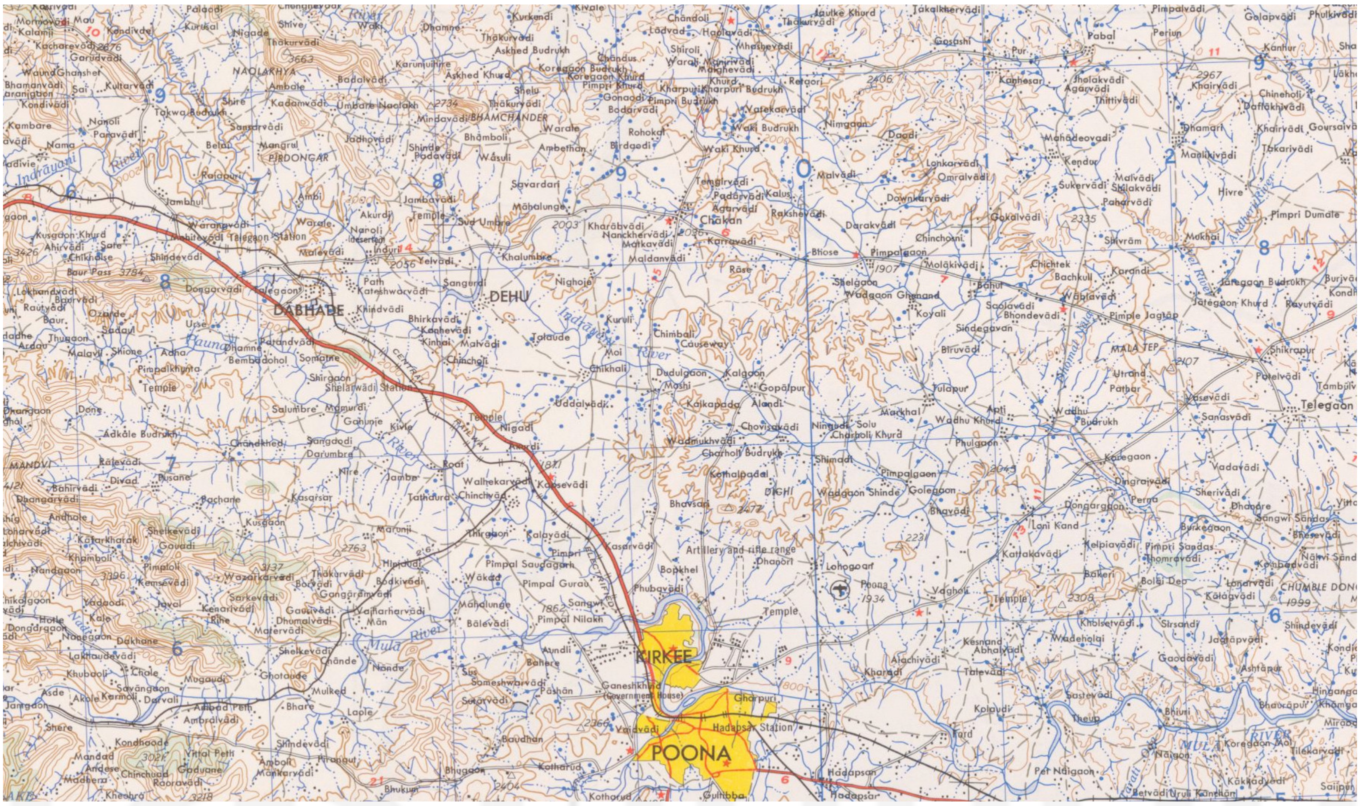


Fig. 13.2: A part of topographical map of an area in Pune, Maharashtra with scale 1:250,000.
(Source: http://www.lib.utexas.edu/maps/ams/india/)

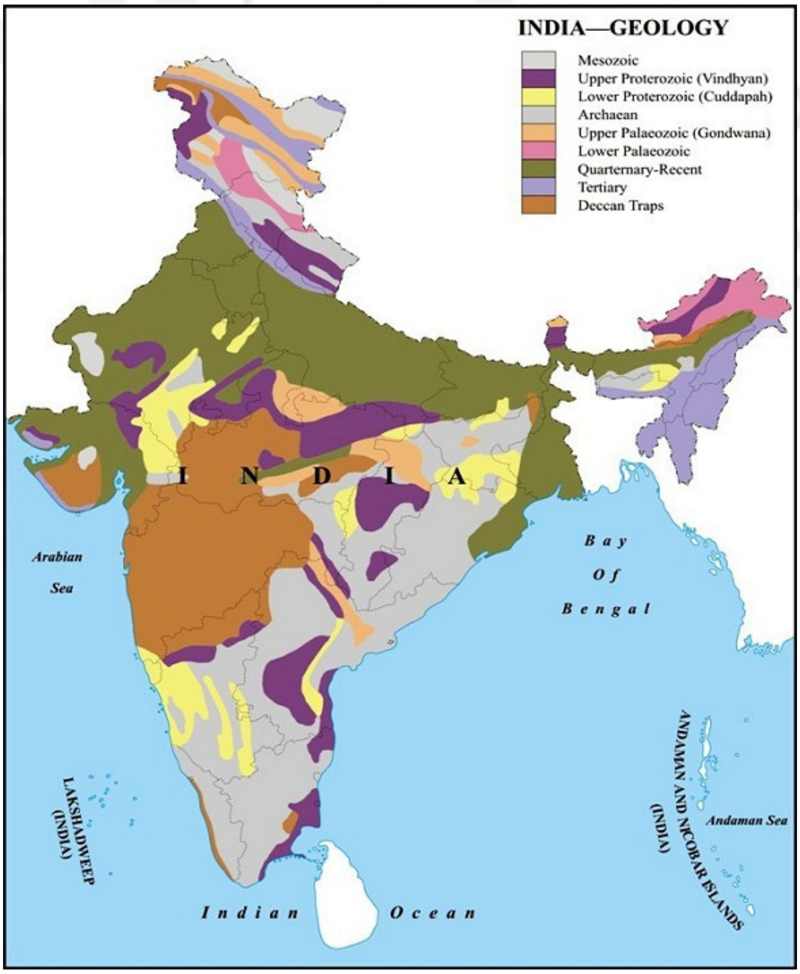


Fig. 13.3: Geological map of India
(Source: www.indiamapssite.com/india/india-geological-map.html)

2. **Geological hammer and chisel:** They are basic equipments used by geologists for collecting samples. Hammer with a chisel head made of hardened steel and a rubber coated shock reduction handle (Fig. 13.4a) is considered to be the best geological hammer. We use hammer to break the rocks, observe their fresh surfaces, and take fresh samples. Generally, a hammer is around 1 kg in weight.

3. **Hand lenses**: They are used for *prima facie* (derived from Latin word meaning 'first encounter' or 'at first sight') observation of the rocks in the field. There are hand lenses with 10x, 15x and 20x magnification (Fig. 13.4b). You can select the required magnification depending on the grain-size of rock to be studied. Hand lenses facilitate us to decipher the rock type, grain-size, colour, texture and identifiable minerals or fossils in the field.

4. **Clinometer compass**: We have discussed earlier about clinometer compass in Unit 9 Introduction to Structural Geology (Fig. 13.4c). It is useful to take basic geological information in the field such as orientation of geological map with respect to the north, dip and strike of rock beds, recording geometry of the geological structures like fold, fault or joint. We can orientate the map in field and locate our position on it. A compass is an instrument used for determining direction and has recently been supplemented by modern devices such as the Global Positioning System (GPS). But you may note that in areas with thick/dense forest cover, GPS at times may not be able to locate satellites.

Fig. 13.4: Field equipment (a) hammer and chisel, (b) hand lens, (c) clinometer, (d) GPS, (e) haversack, (f) measuring tape, (g) field notebook, (h) digital camera, and (i) first aid box

5. **GPS**: A multi-satellite based navigation system, allows you to locate yourself in any part of Earth, if you have a ground receiver or a hand-held GPS (Fig. 13.4d). GPS provides three dimensions locational information such as latitude, longitude and altitude or height. This is used in geological field mapping for finding your position, mapping lithologies, tracking structures, measuring elevation, storing data of the sampling points. GPS functions and capabilities are improving rapidly with advancement in technology. Before using GPS, one should ensure that you have set-up the GPS correctly as per the datum of your country.
6. **Haversack or rucksack and sample bags**: A strong, good quality partitioned, haversack or rucksack is required to carry all your essential items such as field equipment, drinking water, food, first-aid box and spare clothing into the field (Fig. 13.4e). The sample bags required to keep geological samples are made of canvas fabric and have a label tag for the sample number and location point. If the samples are soft, disintegrated or wet then plastic bags are used.
7. **Measuring tape**: A 30 meter long steel or cloth tape and 15 cm plastic scale are used to measure all geological features ranging from the thickness of a bed to the size of an individual grain in the field (Fig. 13.4f).
8. **Field notebook, masking tape, marker pens, pencils and erasers**: A good-quality, hard bound field diary with water resistant and waterproof paper of 12 x 20 cm size is an essential item of the field kit (Fig. 13.4g). It is required to document the field observations in a concise, orderly and legible manner. Masking tape and marker pens are used for labelling samples before they are put into the sample bags. Apart from this you must keep pens, pencils, sharpener, coloured pencils, eraser, marker pens which are needed for writing notes, making sketches and labelling the samples in the field.
9. **Camera**: A high-resolution digital camera is required in the field for taking high-quality field photographs of outcrops, important geologic structures and fossils (Fig. 13.4h); video clips can be used. You should remember to note GPS reading of each photograph taken in the field. Photographs or video clips can be used for report writing and making presentations.
10. **Acid bottle**: A small bottle containing of 10% dilute hydrochloric acid is useful in the field while working on carbonate (limestone) rocks. The rock will produce effervescence on pouring a drop of acid on the carbonate rock such as limestone or dolomite. Please ensure that acid bottle is properly labelled.
11. **Miscellaneous items**: These may include streak plate, pocket knife, sleeping bag, pocket calculator, torch, battery charger for camera and GPS, rock classification chart, grain-size scale, etc.
12. **Safety clothing**: These include sturdy shoes and clothes with tough fabric preferably jeans or *khaki.* Hat and sunglasses are required for protection from the Sun. Do not forget to carry raincoat and gum boots in rainy season. Safety glasses and gloves will protect you while hammering rock samples.
13. **First aid kit**: Safety in the field is always a priority, so carry a first aid kit (Fig. 13.4i).
14. **Geologist experience and imagination**: It is the most expensive equipment of all. Most of the Earth processes have never been witnessed in an actual sense. It is the experience and knowledge which can helps a geologist to interpret field observations.

SAQ 1

Dear learners before proceeding further, let us have a very short study break. Read the following exercises and try to solve/answer them.

a) Define geologic fieldwork?

b) List objectives for geologic fieldwork.

c) List the uses of topographic map in the field.

d) Why clinometer compass is an important field equipment?

13.6 FIELD SAFETY MEASURES

We have read that geological fieldwork is an enjoyable and challenging outdoor task as it involves hard work both physically and mentally. You may have to carry fieldwork in the inhospitable terrains, inaccessible or remote areas and work under extreme weather conditions. You may encounter a number of risks or hazards during the fieldwork. Therefore, following safety measures have been recommended:

- Concerned people should have detailed information about your field plan in advance so that they can contact you in case of any emergency.
- Submit your day-to-day plan to the incharge of your base camp so that they can contact you any time.
- Avoid conducting fieldwork alone in inhospitable terrains. It is preferred that fieldwork is carried in a group.
- If you are going in a virgin area consult the senior persons or people who visited the area, in order to assess and avoid the possible hazards.
- Avoid or be very careful while doing fieldwork in dangerous areas such as cliffs, steep slopes, quarry edges, mudslide and snow avalanche zones, slippery and loose rocks or surfaces covered by boulders.
- Always wear a helmet for safety while doing fieldwork in mine, quarry, cave, cliff or in an area with a risk of falling rocks (Fig. 13.5).
- Always wear impact resistant safety goggles while hammering tough or splintery rocks or using chisels for breaking rocks.
- Be aware about the dangerous animals and insects of the field area.
- Carry basic emergency equipment like first aid-box, whistle, torch, matches, drinking water, mobile phone, food and contact information of the nearby emergency services.
- Be positive, carry your identity proof and behave politely with local people. If possible, hire one or two local people who will accompany you during the fieldwork.

Fig. 13.5: Field photograph showing geologists wearing safety helmets.

- Do not hammer the beautifully preserved rocks, minerals, fossils and geologic structures as well as preserved material of geosites, geoparks and geological heritage.
- Follow all safety instructions given by the group leader, if you are working in a group.

The points mentioned above give an idea about the problems one may encounter during the fieldwork and the ways to tackle them.

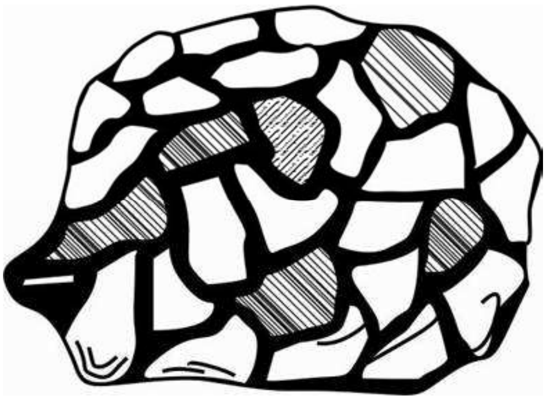
13.7 RECOGNITION OF LITHOLOGY

We have discussed the planning for fieldwork, field equipments and safety measures taken in the field. Now in this section, we will discuss the important characteristics of different rock types and their identification in the field.

13.7.1 Igneous Rocks

If you are in an igneous terrain the main objective would be to find out the type and extent of igneous body, heterogeneities, if present in the outcrops and contact relationships between the lithounits. If you examine igneous rock with hand lens you will find interlocking texture (Fig. 13.6). If rock is fine grained or coarse grained you can higher or lower magnification lens, respectively. The igneous rocks formed by the solidification of molten magma can be grouped into:

- **Plutonic or Intrusive Rocks**: These rocks are formed by cooling of deep-seated magma and they usually show concordant (sills) and discordant relationships (dykes) with adjacent rocks. You can identify plutonic rocks in field by observing their medium to coarse grain-size.
- **Volcanic or Extrusive Rocks**: These rocks are formed by extrusion of lava at or near the surface of the Earth. These rocks in the field can be recognised by their fine grained or glassy nature.



(a)

(b)

Fig. 13.6: (a) Interlocking texture observed in igneous rocks when examined rock under hand lens, and (b) Granite in handspecimen

You can also identify various igneous rocks in the field by observing their colour, texture, structure and mineralogy. For example, granite which is a plutonic rock can be identified by its light colour, coarse-grained texture and mineralogy comprising quartz, feldspar and mica (Fig. 13.6b). Pegmatite is a hypabyssal rock of granitic composition, but it has very large grains/crystals more than 3 cm. Basalt is a dark coloured, fine grained volcanic rock. Lava flows and contraction joints (like rhomboidal or columnar, please see Fig. 13.7 are some of the common features, which will help you to identify the volcanic rocks in the field.

Fig. 13.7: Columnar joints in the Deccan traps.

13.7.2 Sedimentary Rocks

We have read in Unit 5 Rock Weathering that sedimentary rocks are formed by the decomposition and disintegration of the pre-existing rocks like igneous, metamorphic or even earlier formed sedimentary rocks. Sediments are produced by the process of weathering (physical, chemical and biological) by geological agents such as wind, river, glaciers, oceans and groundwater.

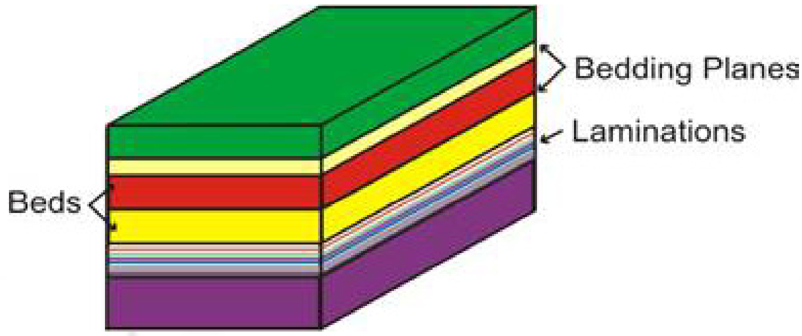
Similarly, the field study of sedimentary rocks is also very interesting. Sedimentary rocks may contain remains of past life in the form of fossils. Their studies also help to know the depositional environment of these rocks. The sedimentary rocks may be:

- **Clastic Sedimentary Rocks:** They comprise siliciclastic sediments, made up of physically deposited particles such as grains of quartz, and feldspar derived from weathering of the pre-existing rocks. These sediments are deposited by geological action of water, wind and ice. The most abundant silicate minerals in siliciclastics sedimentary rocks e.g., conglomerates, sandstones, siltstones and claystones are quartz, feldspar and clay minerals. Sediments are produced by the process of weathering (physical, chemical and biological) by geological agents such as wind, river, glaciers, oceans and groundwater.
- **Non-Clastic Sedimentary Rocks:** They comprise the biological and chemical group of sediments that are formed by the process of precipitation with or without organic materials, e.g. limestone, evaporites, chert, ironstones, phosphorites.

In the field, you can easily identity sedimentary rocks by observing following aspects: mineralogy, texture, grain-size, structure, colour and fossils. You can identify non-clastic rocks like carbonate rock like limestone or dolomite by performing acid test. A drop of dilute HCl can cause effervescence in carbonate rock.

Fig. 13.8: Medium grained sandstone overlain by very coarse grained sandstone. Quartz mineral can be identified in very coarse grained sandstone with naked eye.

Layering, bedding and lamination are the characteristic features of sedimentary rocks and recording their thickness, geometry, nature of boundaries, contacts, planes, dip and strike in the field important to decipher them. Stratum (Plural strata) is an umbrella term, which is used to cover both bed and lamination. Stacking up process of strata over one another is known as stratification (Fig. 13.9). A bed is the layer of sedimentary rocks, which is separated from adjacent beds by break called bedding planes. Based on thickness, a bed is said to be laminae when it is less than 1 cm thick and a bed when, it is more than 1 cm thick.



(a)

(b)

Fig. 13.9: (a) Sketch showing stratification with numerous beds, bedding planes and lamination and (b) Horizontal beds of shale and siltstone.
(Photo credit: Mr. Ganga Prasad Bhartiya)

13.7.3 Metamorphic Rocks

Metamorphic rocks are a product of alteration or recrystallisation of pre-existing rocks such as igneous, sedimentary and metamorphic, in response to a change in pressure and temperature conditions. Metamorphic rocks may preserve some primary features of their parent rock. In field, you can identity metamorphic rocks by at looking their texture, structure, mineralogy and grain-size. For example, slate can be recognised in the field by its very fine grained texture, well-developed cleavage and presence of mica. You can identity phyllite by its layered structure (Fig. 13.10). Schist exhibits foliation

Fig. 13.10: Layered structure in phyllite.

and **schistosity**. Schistosity is the layering present in a coarse grained, crystalline rock due to the parallel arrangement of platy mineral grains such as muscovite and biotite. Gneiss is medium to coarse grained mainly composed of quartz and feldspar and exhibits **gneissosity**. Gneissosity is the layering in a rock in which bands or lenses of granular minerals (quartz and feldspar) alternate with bands or lenses in which platy (mica).

13.8 MEASUREMENTS OF STRUCTURAL FEATURES

You have read about structural elements in Unit 9 Introduction to Structural Geology. Geologic structural features play an important role in the geological mapping of the area. These structural features comprise planar (bedding plane, metamorphic foliation, igneous foliation, joints, faults and unconformities), and linear (mineral and crenulation lineation, slickensides, boudinage, pinch and swell) as well as folds (Fig. 13.11). The documentation of these features involves the measurements of strike and dip of bedding, foliation and joints as well as thickness of beds and preparation of stratigraphic column.

Fig. 13.11: Geologists studying fold at an outcrop

13.8.1 Locating Your Position

Before you take structural measurements in the field, it is important to locate yourself on map. This can also be done with help of GPS, after adjusting coordinates of hand-held GPS according to the datum of topographical map.

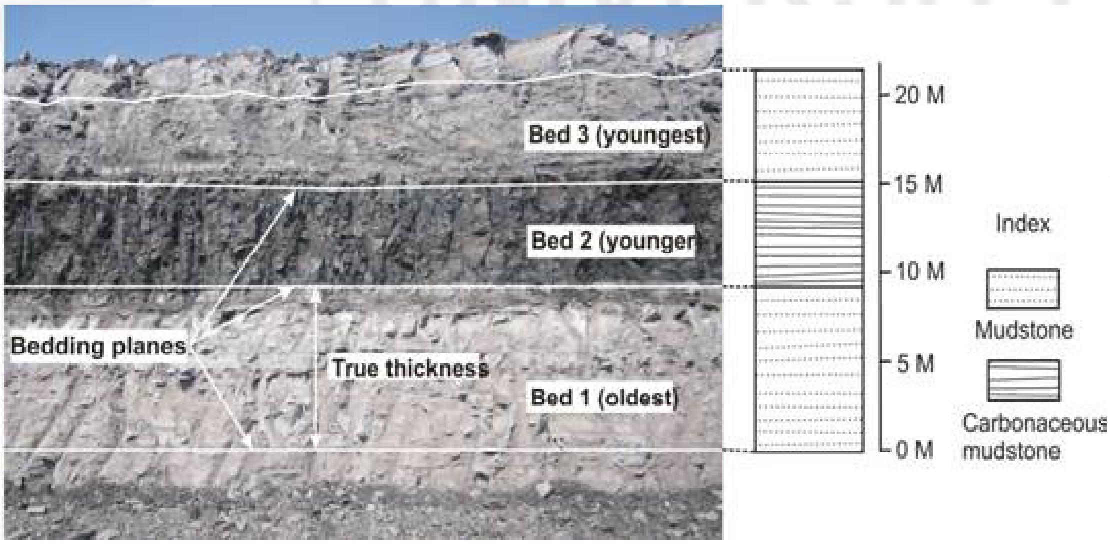
Using a clinometer compass for locating one's position on topographical map is one of the oldest and reliable method for which following the steps have to be followed:

1. Orient your map correctly that is by aligning compass and map in North direction and ensure that the features shown on the map correspond to features seen on the ground.
2. Find and select two features (e.g., a building, a tower, a pond, a hill or any other feature), which are visible both on your map and on ground.
3. Point the direction of your compass towards one selected feature; rotate the compass dial until its needle points to N (north) on the dial and note the bearing relative to the north. Draw a line connecting the centre of compass and selected features on the map.
4. Now turn the compass towards the second selected feature and repeat the process. The point where two lines intersect is our location.

You should also note that compass needle reflects the magnetic north and both geographic as well as magnetic north are close to each other. Therefore, to find exact location on map, the bearings needs to be corrected by magnetic declination. **Bearing** is an angle measured east ward or west wards either from north or south.

13.8.2 Measuring Thickness of Beds

An important step to perform in field is to measure the thickness of the individual beds.



(a) (b)

Fig. 13.12: (a) Field photograph showing the true thickness of bottom most bed and bedding planes in a rock sequence containing three beds (bed 1 to 3) and (b) is the litholog of rock sequence. The vertical scale as shown in (b) represents height of exposure whereas horizontal thickness of the column can be chosen as per your choice, but it is normally not more than 2 cm.

This could be measured directly by placing the measuring tape at right angles to the bedding plane that will give the true thickness of the bed (Fig. 13.12). You can prepare a litholog of lithologies encountered along a traverse. It has to be made to the scale based on the thickness of the individual beds as shown in Fig.13.12.

13.8.3 Measuring Structural Elements

This involves the recording of attitude of the beds, which means measuring their dip and strike. You have read about dip and strike in Unit 9 Introduction to Structural Geology. **Dip** is the orientation of a rock layer exposed at an outcrop, whereas **strike** is the compass direction of a line formed by the intersection of a rock layer's surface with horizontal surface. The dip is measured at right angles to the strike. The dip amount is the amount of tilting/inclination or the angle at which the rock layer inclines from the horizontal.

Let us measure strike and dip of an inclined bed. Here, we reproduce the method of measuring dip and strike of inclined beds from Unit 9 for your convenience. You are instructed to adopt following procedure in order to measure the strike and dip of a bed:

1. To measure the strike, keep the compass on bedding plane in such a way that the bridge of the compass touches the bedding plane completely.

2. Rotate the compass so that the bridge becomes horizontal and one end of the bridge still touches the bedding plane. On becoming horizontal the magnetic needle moves freely. Let the needle come to rest and then read both ends of the azimuthal circle. The two ends represent strike.

3. To measure the amount of dip of the bed, draw a line on the bed perpendicular to strike. Now keep the bridge on the bedding plane along this line in such a way that the dial plane is vertical. Take the reading in the clinometer, which gives the dip amount.

4. To measure the direction of the dip, again put the bridge along the line drawn on the bedding plane, but this time the dial will face the sky.

5. Now rotate the compass to horizontal in such a way the bridge and N-S line of the dial both remain parallel to the line. Take care the crown (often N is marked as a crown in many clinometers compass) in the dial is towards the dip direction of the bed.

6. On rotation to horizontal, the N marked end of the magnetic needle gives the dip direction. The reading can be cross-checked because strike and true dip directions are always perpendicular to each other.

7. On a vertical plane if inclination of a linear structure with respect to horizontal is measured, it is called **plunge** of that structure. Thus, dip of a planar structure and plunge of linear structures both are analogous. The term bearing refers to the geographical direction of plunge of a linear structure.

13.8.4 Plotting Attitude of Beds

For making geologic maps, it is important to plot attitude (dip and strike) of the bed on map once you have determined it at the outcrop. There are two methods of plotting the attitude of beds.

- **Quadrant or bearing method:** In this method, readings are in four quadrants or bearing of a compass. A bearing is an angle measured eastward or westward either from north or south, whichever is closer. The method employs a circle divided into four quadrants: northeast (NE), northwest (NW), southeast (SE), and southwest (SW) (Fig. 13.13a). Each of the four quadrants is divided into 90°, beginning with 0° at the north and south poles and ending with 90° at east and west. So, bearing is always less than 90° measured eastward or westward from either the north pole or the south pole. A bearing direction can be specified by stating (first) the pole-north or south-from which the angle is measured; (second) the magnitude of the angle measured; and (third) the direction-east or west toward which the angle is measured. For example if the dip direction measured at an outcrop is N135° and dip amount is 30° you will plot as shown in (Fig. 13.13b).

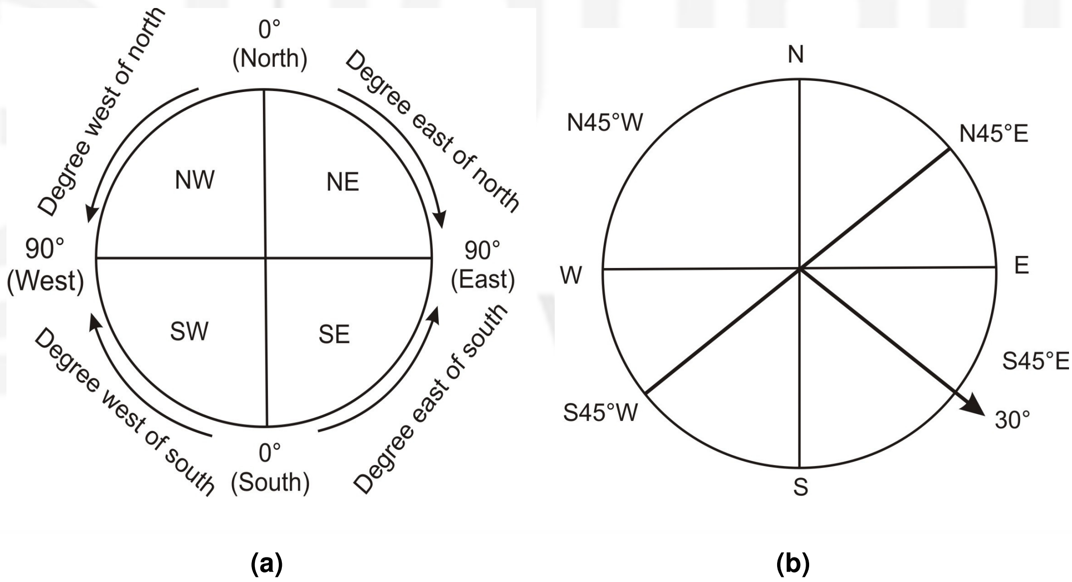


Fig. 13.13: Quadrant or bearing method of stating direction; (a) Four quadrants-NE, SE,SW,NW-are east or west of north or south and (b) Dip direction, strike direction and dip amount plotted in quadrant method

- **Azimuth method**: This method of stating direction employs that a circle is divided into 360°, beginning with 0° at the north pole and increasing clockwise to 360° at the north pole (Fig. 13.14). An azimuth circle is graduated in a manner analogous to that of the face of a clock. Only instead of being a clockwise sweep of 60 minutes, an azimuth circle is a clockwise sweep of 360°. The four directions illustrated in (Fig. 13.13a) are the same as those illustrated in (Fig. 13.14) which serves to contrast one method with the other. For example, if the dip direction measured at an outcrop is N135° and dip amount is 30° you will plot as shown in Fig. 13.13b.

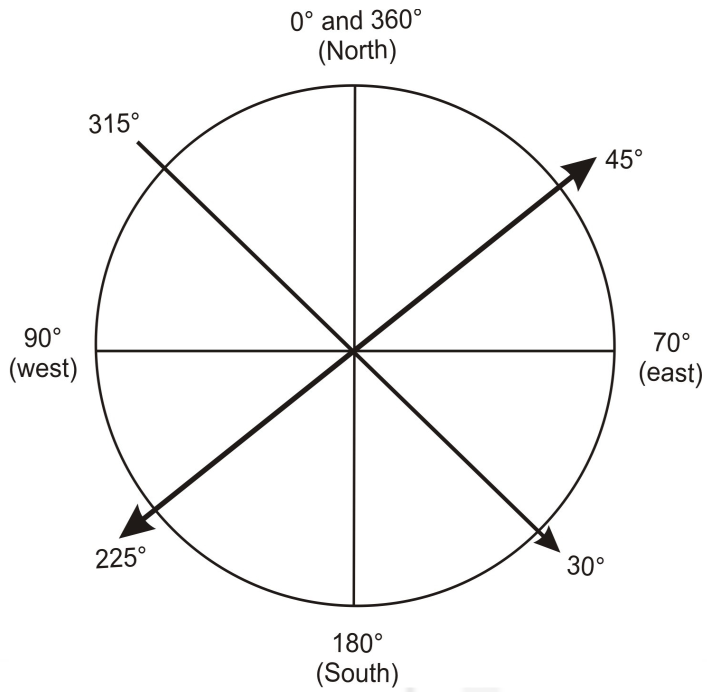


Fig. 13.14: The azimuth method of stating direction

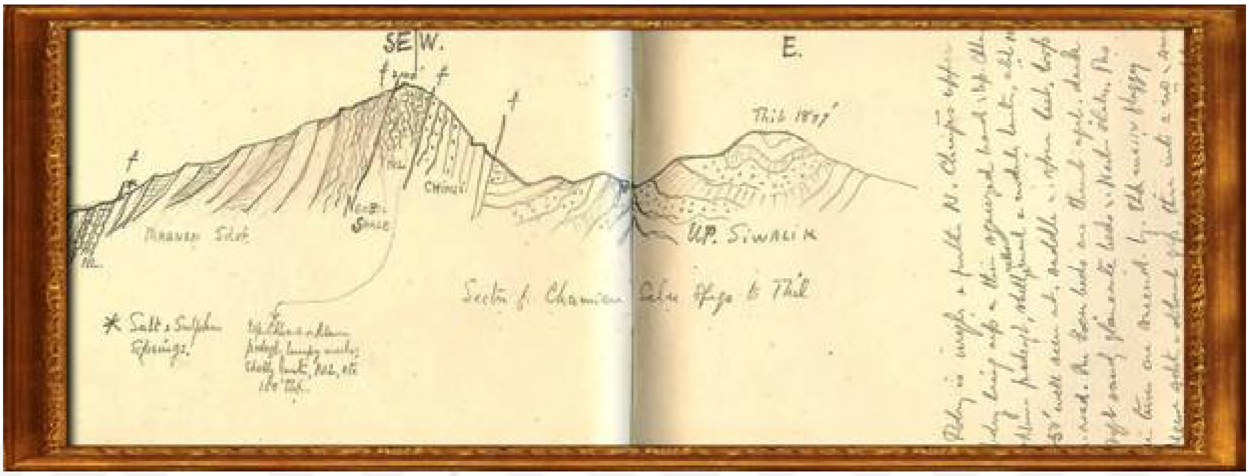
13.9 SPECIMENS AND SAMPLES

Specimens and samples is an important part of the fieldwork. **Specimens** are pieces of rocks, minerals, ores or fossils, collected from the outcrops for megascopic study at laboratory or display at museum. **Samples** on the other hand, are systematically collected pieces of rock, mineral or ore for carrying out further study or analysis in the laboratory. The laboratory study helps to identify collected samples as correctly as possible by performing various analysis such as petrological or chemical. The results of laboratory studies are useful to correlate the field data with laboratory findings.

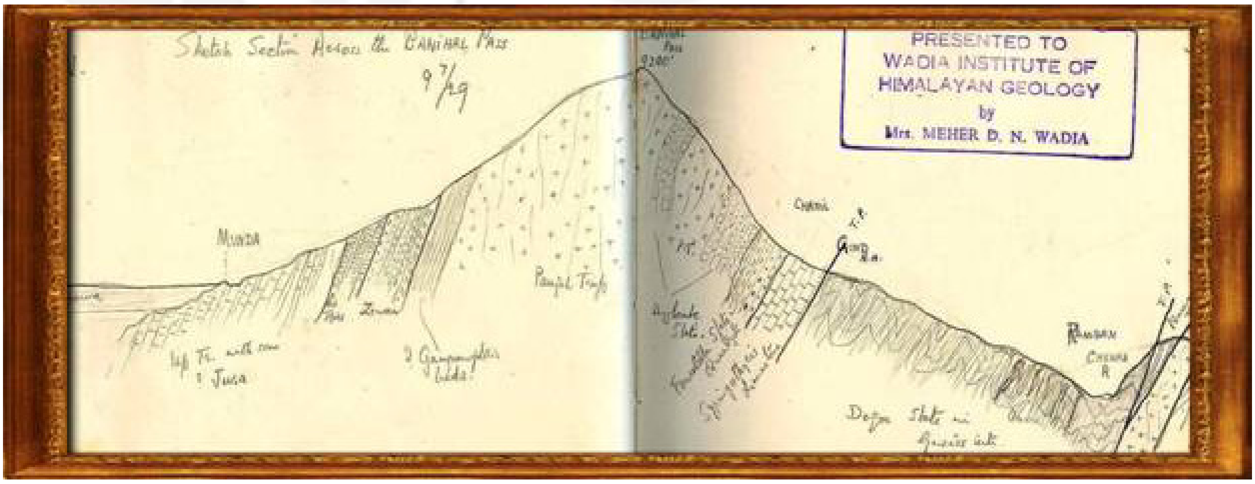
The amount and size of specimens and samples depend upon the objectives of the study. Specimens having 7cm to 10cm×10cm to15cm×2.5cm to 5 cm size are usually considered useful for many purposes. For most of the geological analysis, the rock samples of 0.5 kg to 2 kg weight are recommended. The collected specimens and samples should be carefully packed in sampling bags without any breakage, labelled with location information and the same information should be carefully recorded on the field diary. You can also write the sample name on the map. Finally, the packed specimens and samples are safely transported to the laboratory. It is always desirable to take field photographs of those outcrops or rock bodies, which show well-developed geological structures. In addition, you should take the photographs of those outcrops from where the specimens and samples are collected.

13.10 FIELD SKETCHES AND PHOTOGRAPHS

Sketches comprise a vital part of all geological field notebooks. It is one of the best way of recording and conveying geological information. Sketches can be of outcrops, rock formations, fossil, mineral, geological structure like fold or fault or sedimentary structure (Fig. 13.15) and cross-sections. They provide a shorthand means of conveying information in an communicable form. Drawing sketch involves careful observations of the features, units and the relationship between all of them. Photographs provide indispensable evidences of observations recorded during geological fieldwork. Photographs are not a replacement for sketches because they are neither selective nor deductive and you cannot add labels and cross references. Professional geologists regularly use a combination of photographs and sketches. You may have read 'A picture is worth thousand words'.



(a)



(b)

Fig. 13.15: Two field sketches from the field dairy of first National Professor Late Prof. D.N. Wadia, first Indian to receive the honour of Fellow of Royal Society of London (FRS) (Courtesy: Museum, Wadia Institute of Himalayan Geology, Dehradun)

SAQ 1

Dear learners before proceeding further, let us have another very short study break. Read the following exercises and try to solve/answer them.

a) Let us suppose that you visit a 20 m high outcrop consisting of four layers such as limestone at the bottom or base followed by conglomerate, sandstone and claystone lies at the top. From where i.e., at the base or top would you start measuring the thickness of the outcrop?

b) How would you differentiate sedimentary rocks from igneous rocks in the field?

c) List the name of basic structural measurements you should take in the field?

d) Differentiate between specimens and samples.

13.11 DOCUMENTATION OF FIELD OBSERVATIONS

You have read that a careful documentation of field information is an essential part of field geology, which forms the only permanent source of the field record. Field notebook is the single most important field tool and it constitutes the foundation for all your conclusions, reports and any other future work that you wish to undertake in the same field area. You can consider it is as an 'academic' diary, i.e. a record of all of your observations, ideas, interpretations and questions during the fieldwork. The field notebook contains notes on lithology; relationships between various rock types; textural, structural and compositional characteristics of rocks; fossil contents; sketches of outcrops; measurements of structural elements and stratigraphic columns. It also contains details on sampling sites. It is always considered as a good habit to record information like weather conditions, someone you met, lodging. This will help you while planning your future fieldtrips. The recording in the field notebook should be clear and concise. Write your name, address, e-mail and other contact information on the cover or first page of your field notebook. You must complete your field notebook on the outcrop/spot of data collection before proceeding further. Table 13.4 provides the checklist for recording observations and data in field notebook.

Table 13.4: Checklist for recording observations and data in field notebook.

S.No.	Observations Recorded
1.	**Date and time:** Record date, day and time
2.	**Base Camp:** Name of the place where you stayed
3.	**Traverse taken**: Path taken for fieldwork
4.	**Location:** Geographic location of the outcrop
5.	**Lithology:** **Colour**: What is the colour of the rock? Is there a difference between the colours of the weathered and fresh surfaces? **Grain sizes**: Record the range of sizes present. **Minerals present**: Identify the minerals present in the rock. **Rock type**: Identify the rock type or types present. If a sample is collected, it should be numbered and the same should be recorded in the field notebook. Describe any peculiarities or characteristics of the rocks.

S.No.	Observations Recorded
6.	**Sedimentary structures:** **Record the dip and strike of the beddingBedding**: Are the bedding planes evenly spaced or not? Is the rock thinly or thickly bedded? Are the bedding surfaces planar or undulating or irregular? **Other sedimentary structures**: e.g., cross-bedding, channels, ripples, sole-markings, concretions, etc., which may be present. Sketch these features.
7.	**Geological structures:** **Bedding plane**: Record the dip and strike of planar structures such as bedding plane. **Cleavage**: Record the dip and strike of slaty or fracture cleavage. **Joints and fractures**: Record the dips and strike. **Faults**: Record dip and strike and direction and amount of movement. **Folds**: Sketch the folding and record the trend and plunge of fold axes. **Lineation**: Record the trend and plunge of lineations such as cleavage- bedding intersections or preferred orientation of elongate minerals.
8.	**Fossils**: Note whether they are abundant or rare; body or trace fossils. Make a preliminary identification, if possible. Sketch and collect numbered specimens for further laboratory investigation.
9.	**Note any other obvious features,** e.g. mineralisation, relationships of different rock types to each other, etc.
10.	**Samples collected:** Note the sample number and the location, may be with help of GPS.
11.	**Sketches:** Sketches illustrating the structure of the rocks in relation to topography are necessary. All sketches must have a scale, direction and should be labelled. **Photographs also can be taken.** The subject of each photograph should be noted in the field notebook

13.12 ACTIVITY

You might have been living near the Himalayan mountains and Indo-Gangetic plain of northern India, coal-yielding Gondwana rocks and the Deccan traps of peninsular India, Rajmahal hills of eastern India, eastern and western Ghats of southern India or small hilly areas of western India. Visit the surrounding hilly areas near to you as mentioned above and try to find some outcrops. Observe carefully and focus your eyes on the outcrops, you may find igneous, sedimentary or metamorphic rocks alongwith some beautifully developed structural features such as layering, faults, folds, joints, unconformities, sills, dykes or lineation. Try to identify various rock types and structural features, determine the grain-size of rocks, find whether rocks contain fossils and make your own observations and interpretations and also record the same on the field notebook.

13.13 SUMMARY

Fieldwork is a vital component for a geology curriculum. Let us quickly summarise what you have read in this unit.

- Field geology involves investigations of rocks and rock materials in their natural environment and in their natural relationship with one another.
- Fieldwork requires systematic planning which depends on objectives and the area of study. The review of literature, preparation of field schedule and its cost estimates as well as list of equipments are important aspects of the planning for field work.
- Geological hammer, chisel, hand lens, clinometer compass, field diary/ notebook, measuring tape and scale, maps and relevant literature, GPS, altimeter, acid bottle, haversack or rucksack and digital camera are main field equipment used in geological fieldwork.
- Field safety measures help us to encounter various risks or hazards that may arise during the fieldwork.
- Igneous rocks in field can be identified with help of their colour, texture, structure and mineralogy. Lithology, texture, structure, colour, bedding, mineralogy and fossils are important criteria to recognise sedimentary rocks in the field. Texture, structure, mineralogy and grain-size are useful to identity metamorphic rocks.
- Measurements of dip and strike of the planar and linear structural features as well as folds are important data for understanding the geologic history of the area under study.
- Specimens and samples collected during the field are used for display at the museum and study in laboratory, respectively. Systematic documentation of field observations involve careful recording of all field information and data on the field notebook.

13.14 TERMINAL QUESTIONS

1. What is field geology? Elaborate the planning needed before conducting a geologic fieldwork.
2. What are the equipment you should carry while going for geologic fieldwork?
3. Describe field safety measures required for fieldwork.
4. Discuss the plotting of structural elements by quadrant and azimuth techniques.
5. Enumerate the documentation of field observations in the field notebook.

13.15 REFERENCES

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13.16 FURTHER/SUGGESTED READINGS

- Coe, A.L. (2010) Geological Field Techniques, Blackwell Publishing Ltd., United Kingdom, 336p.
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13.17 ANSWERS

Self-Assessment Questions

1. a) Geologic fieldwork involves visiting natural outcrops that are exposed in quarries or mines, valley walls, and road cutting and making careful observations and measurements of the geological features in the field. In fieldwork, we carefully examine and record different rock types and their relationship to another apart from collecting samples and specimens for laboratory studies.

   b) The main objectives of geologic fieldwork are:

- To document general geology of an area
- To produce a geological map of an area
- To construct the geological history of an area
- To construct the biostratigraphy of an area
- To determine sedimentary depositional environment
- To locate mineral resources
- To determine nature of igneous rocks

c) Topographical maps help us in the field to find actual locations of the outcrops and plan traverses to study the same.

d) Clinometer compass is one of the important equipments in a geological fieldwork. It is used to take basic geological information in the field such as measurement of the orientation of geological planes with respect to the north, dip and strike of rock beds, recording geometry of the geological structures and orientation the map in field as well as to locate your position on it.

2. a) A section or outcrop is always measured in a geologic succession from the bottom. In this case, we first measure the thickness of limestone layer or bed by keeping one end of measuring tape at bottom of bed at right angle to its bedding plane. This will follow the measuring of other three such as conglomerate, sandstone and claystone, successively, in the same manner as we did for limestone.

b) Sedimentary rocks can be distinguished from igneous rocks based on following characteristics:

Igneous rocks	Sedimentary rocks
• Formed by solidification of molten magma. • Do not contain fossils. • Layering, bedding and lamination are not present. • Plutonic rocks are characterised by medium to coarse grain-size. • Volcanic rocks are characterised by fine grained or glassy texture.	• Formed on decomposition and disintegration of the pre-existing rocks. • They contain remains of past life in the form of fossils. • Layering, bedding and lamination are its characteristic features. • Clastics rocks are characterised by the presence of siliciclastic sediments like cobbles, pebbles, sand grains and clay particles. • Non-clastic rocks are formed by the process of precipitation with or without organic materials and rich are in calcium carbonate and/or silica.

c) Dip and strike of beds are the basic structural measurements recorded in the field.

d) The main differences between specimens and samples are listed below:

Specimens	Samples
• These are pieces of rocks, minerals, ores or fossils, collected from the outcrops for megascopic study at laboratory or display at museum. • 7-10×10-15×2.5-5 cm is an average size for a specimen.	• These are systematically collected fractions from the body of rock, mineral or ore for carrying out further analysis in the laboratory. • Samples of 0.5 kg to 2 kg are useful for many laboratory studies.

Terminal Questions

1. Please refer to sections 13.3 and 13.4.
2. Please refer to section 13.5.
3. Plesssase refer to section 13.6.
4. Please refer to subsection 13.8.4.
5. Please refer to section 13.11.

GLOSSARY

Active fault : A fault which is characterized by recurrent movement time to time due to the displacements

Active fault : A fault which is characterized by recurrent movement time to time due to the displacements or seismic activity

Attitude : The position of a structural surface relative to the horizontal ones. It has strike and dip measurements.

Block diagrams : They are a combination of geologic maps and cross sections. They are three-dimensional representations of a block of the earth that can aid in the exploration for mineral resources and the interpretation of the cause or meaning of geological features.

Block faulting : A type of normal faulting in which the rockmass is divided into faulted blocks of different dimensions.

Cross sections : are vertical "slices" into the earth that are used to interpret the geology at depth. The geological data (contacts, dips of formations, etc.) are projected from the surface into the cross section to predict what might be down there. Often, data from drilling projects or seismic surveys are used to construct cross sections.

Deformation : A term used for the folding, faulting, shearing, compression, or extension processes of rocks due to the effects of tectonic forces.

Diastrophism or **tectonism** : A general term used for all movements of the crust formed by tectonic processes, inclusive of the ocean basins, continents, plateaus, and mountain ranges.

Dike : An igneous intrusion that cuts across the bedding or foliation of the country rocks.

Fault gouge : Highly crushed claylike mineral materials associated with fault breccias along faults or between the fault walls occupying a fault zone.

Fault scarp : A cliff developed on movement along a fault. It represents the exposed surface of the fault prior to modification by weathering and erosion.

Fracture : A break in a rock, produced due to mechanical failure by stress. It includes cracks and joints.

Geologic structures : They are dynamically produced patterns or arrangements of rock or sediment that result from forces acting within the Earth. The structures yield some insights about these forces.

Half-graben : A titled fault block in which the higher side is associated with mountainous topography and the lower side is a basin filled with sediment.

Lineament : A regional linear feature such as straight river courses that could be reflecting underlying geological structure e.g. a fault.

Lineation : A nongenetic term for any linear structure in a rock such as slickensides and axes of folds.

Mineral : It is a naturally occurring inorganic solid, which possess a definite internal atomic structure, and a specific chemical composition.

Plate tectonics : According to it the lithosphere is divided into a number of plates whose pattern of horizontal movement is that of torsionally rigid bodies intersecting one another at their boundaries, causing seismic and tectonic activity.

Rock : It is an aggregate of one or more minerals, i.e. mineral crystals are bound together or lithfied into an aggregate or rock.

Structural Petrology : Study of rock fabric on micro scale. It includes relationships of (microstructure) and the preferred orientations of minerals and their deformation. Crystal structures are also studied under electron microscope.

Tear fault : A type of strike slip fault which is vertical but associated with a low-angle overthrust fault towards the hanging wall. The displacement of over thrust side is horizontal.

Tectonic framework : The set up of subsiding, stable, and rising tectonic elements on a regional scale.

Tectonic map : A map which depicts the structural architecture such as folds, faults and regional dips. It also depicts the history of the varying ages of the structures and rocks.

Tectonics : It is one of the branches of geology dealing with the broad architecture of the deformational features, It also deals with mutual relations, origin, and historical evolution of structures.

Trend : is compass bearing in the direction of the plunge of the linear geological feature.

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