D.N.R.COLLEGE (AUTONOMOUS), BHIMAVARAM

II B.Sc., GEOLOGY (STRUCTURAL GEOLOGY)

Structural geology is the study of the architecture of rocks in so far as it has resulted from deformation. Tectonics and tectonic geology are terms many consider to be synonymous with structural geology. Tectonics deals with the forces and movements that produced the structure.

The aim of structural geology is to determine and explain the architecture of rocks as observed in the field; laboratory investigations are supplementary means to attain this primary objective.

Objectives of structural geology:

The structural geologist is concerned with three major problems (1) what is the structure? (2) When did it develop? (3) Under what physical conditions did it form?

I. What is the structure: it is very essential for geologist to determine the shape and size of the different types of rock bodies. In other words, he has to find out if these rock bodies are flat lying tabular masses covering large areas running into scores of square miles and if these rock bodies are tabular masses that have been thrown into folds with a wave-length of several miles and amplitude of thousands of feet. He has also to find out if these rock bodies are cylindrical bodies thousands of feet in diameter and a mile or two deep. The geologist tries to solve this problem with the help of topographic maps and by means of topography and drainage.

The geologist has to accumulate significant facts. At each outcrop he records whatever data are pertinent to his problem, and, ideally, he should never have to visit an out crop a second time. He must have a good knowledge of geological mapping and knowledge of what data are significant. In order to evaluate properly the vast number of facts gathered from thousands of outcrops, it is necessary that the geologist should have a fair experience and judgment.

II. When did it develop? : The second problem before the geologist is to relate the structure to some chronology. He has to determine the sequence in which the structural features developed. He has to ascertain their relative ages. It may be that the anticline may be the oldest and the dike may be the younger or vice versa. There may be other possibilities too.

The geologist has to keep himself interested not only in the sequences of the tectonic events in a particular area but he has also to integrate them with the geological history of the whole earth. He has to give an approximate data to a particular structure, i.e., to determine the geological period in which it had formed or developed.

III. Under what physical conditions did it form? : The geologist has to determine the physical processes that produced a particular geological structure. He has to ascertain the temperature and pressure at the time this structure formed or developed. He has also to determine its stress distribution. The geologist has to find answer to such problems before he tries to deduce the ultimate causes of the particular structure. Without first determining the stress distribution which existed at the time of the formation or development of the structure it is rather difficult to decide whether a particular fold came into existence as a result of contraction of the earth or due to some other cause. These causes may be sub crustal convection currents, or the forceful injection of magma.

STRESS & STRAIN

STRESS:

Stress is the intensity of force (pressure). It is defined as the force per unit area.

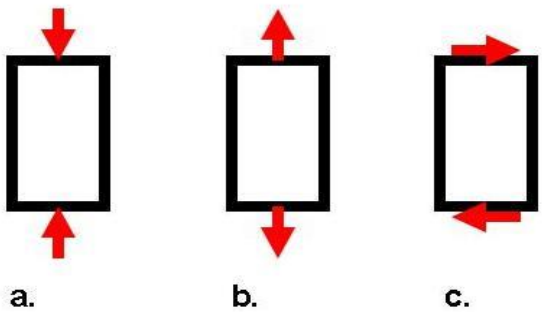
Types of stresses:

(a) Tension: a system of external forces tending to pull apart.

(b) Compression: a system of external forces tending to shorten, decrease or reduce the volume of a body.

Confining pressure, when the force acting on a rock body is uniform in all directions, similar to **hydrostatic pressure**, it is called uniform or confining or lithostatic pressure.

(c) Couple: a system of two equal and opposite forces that act along parallel lines in the same plane, but not along the same line.



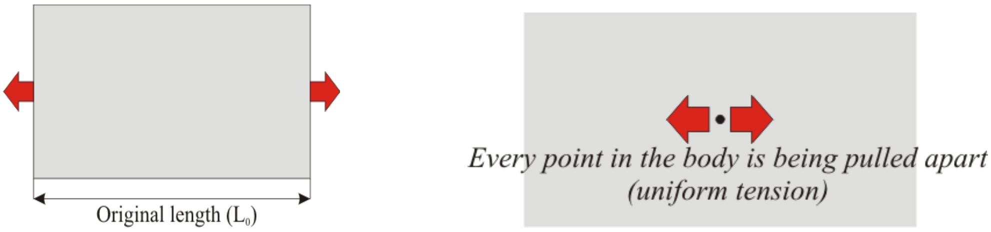
Stress components:

When force is applied by a vertical column of rock on a horizontal plane within the rock body it is directed vertically and the stress has a compressive tendency.

When force is applied on an inclined plane vertically it is resolved into two components.

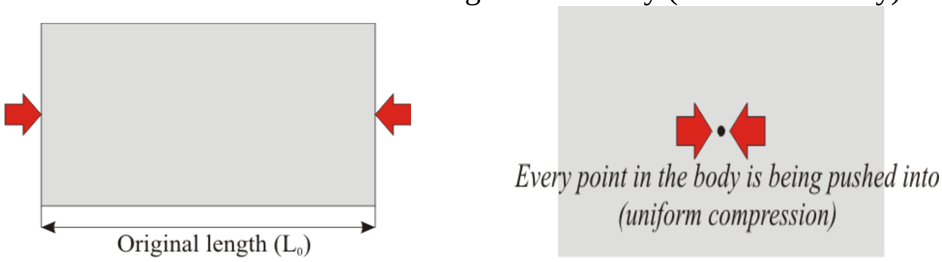
(1) Normal stress: acting perpendicularly to the plane, if this normal component tends to pull apart the material on opposite sides of the plane, it is called a tensile stress.
On the other hand if it tends to push together the material on opposite side of the plane, it is called a compressive stress.
(2) Tangential stress: acting tangential to the given plane.
Tangential stress is also called a shear stress as it represents forces tending to slide or shear the material in the plane.
The imaginary plane may be horizontal, vertical, or inclined.
The stress-difference at any point in a body is the algebraic difference between the greatest stress and the least stress at that point.

Tensile Stress
Uniaxial tensile stress tends to elongate the body



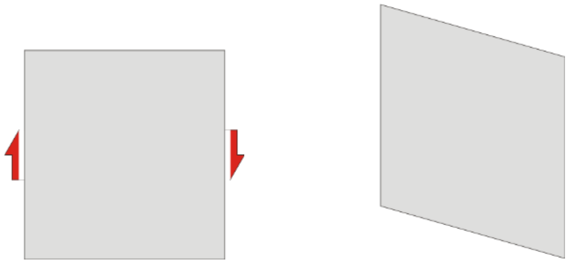
Compressive Stress

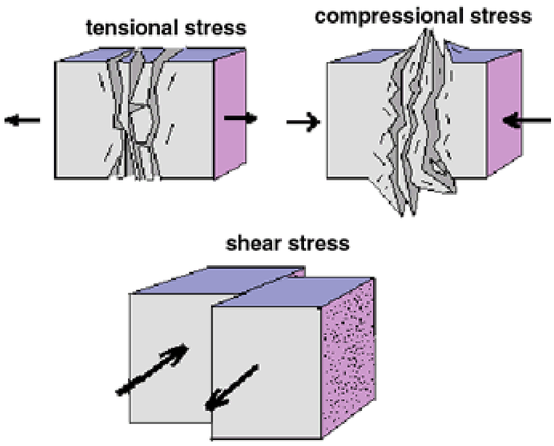
Uniaxial compressive stress tends to reduce the length of the body (shorten the body)



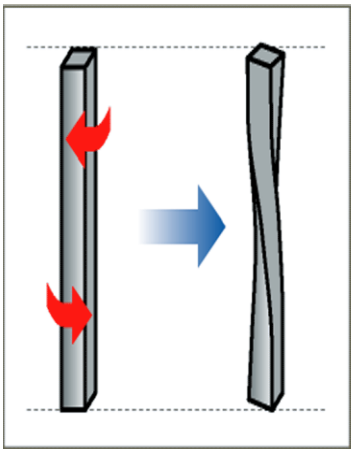
Shear Stress

Shear stress tends to change the shape of a body without changing its volume





Torsion



Torsion: Forces act in a curvilinear fashion, in opposite directions and opposite ends of the body is called torsion.

STRAIN:

Strain is the deformation caused by stress; strain may be **dilation**, which is a change in volume, or **distortion**, which is a change in form, or both.

All deformations of rock bodies are represented as a combination of these two types of strains.

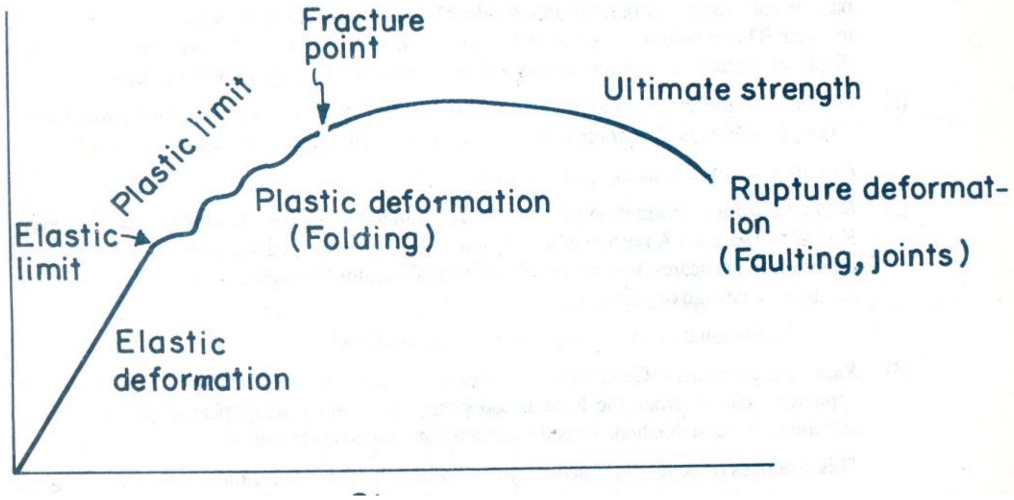
(1) Normal strain: that results in the displacement of particles along the line of force.

(2) Shear strain: right angle to the line of force.

Normal vs. Shear. Normal strain measures changes in length along a specific direction. It is also called extensional strain as well as dimensional strain. Shear strain measures changes in angles with respect to two specific directions.

Three stages of deformation

The relation existing between stress and strain is commonly expressed in graphs known as stress-strain diagram. The stress is plotted on the vertical axis, where as the strain is plotted on the horizontal axis.



If a body is subjected to directed forces lasting over a short period of time, it usually passes through three stages of deformation, except in brittle substances. **At first, the deformation is elastic** that is, if the stress is withdrawn, the body returns to its original shape and size. There is always a limiting stress, called the elastic limit; if this is exceeded, the body does not return to its original shape. Below the elastic limit, the deformation obeys **Hooks law, which states that strain is proportional to stress**.

If the **stress exceeds** the **elastic** limit, **the deformation is plastic**; that is, the specimen only partially returns to its original shape even if the stress is removed. The plastic deformation is change of shape of rock bodies without visible rupturing. (Due to intergranular movement, intra granular movement and recrystalization)

Inter granular: displacement between individual grains or particles of rocks

Intra granular: displacement in individual crystals or particles by movements along glide planes.

When there is a continued increase in the stress, one or more fractures develop, and the specimen eventually fails by rupture due to tension, compression, couple and shear.

Brittle substances are those that rupture before any significant plastic deformation takes place. **Ductile substances** are those that undergo a large plastic deformation before rupture. After the elastic limit has been exceeded, ductile substances undergo a long interval of plastic deformation, and in some instances they may never rupture.

Elastic limit: the point at which the rock loses its elasticity and becomes plastic is called the elastic limit.

The induction approach applied to structural geology is the observations of rock deformation:

folding: Ductile, or plastic deformation, a slow process, with relative hot and soft materials;

faulting: brittle, a rapid to instantaneous process, with relatively cold material, usually caused by compressive force.

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BED

Lamination: is typically represented by the finer grained sediments, such as argillaceous shales. As a rule they cohere only slightly, so that a rock of this kind is readily separated along the planes of lamination. The laminated structure being the result of successive depositions of fine sediment by periodical river-floods usually indicates accumulation in quiet water. Although lamination is very characteristic of argillaceous rocks, it is by no means confined to these. When laminae exceed an inch or so, however, they are often described as **layers.**

"**Bed"** or "**Stratum"** is the term applied to any sheet like mass which has a more or less definite petrographical character, and is separated by well-marked parallel division planes from overlying and underlying rocks. A bed may be homogeneous and without any apparent arrangement of its constituents, or it may consist of successive layers of laminae. It is well to point out, however, that "bed" or "stratum" and "layer" are purely relative. Sandstone consisting of a series of layers, for example, is often described as a thin-bedded rock. Again a thin sheet of limestone, or coal, intercalated in a series of shales, might be termed either a bed, a layer, or a "**seam".**

Beds of rocks are bounded by "bedding surfaces", which may be horizontal or tilted.

Each bedding surface is usually common to two beds of rock, being the top of one and the bottom of the one next above. In the simplest case these surfaces are planes: "**bedding planes".**

Outcrop: The area where rock-unit occurs at the surface of the earth. The place, strip of land or area, where a rock or rock body emerges at the surface, not concealed by soil, weathered material, building, etc. ***Outcrop*** is used for an exposure that is natural.

Exposure: A place where rocks can be seen in their natural position and are not covered by vegetation or buildings. Outcrops are natural, but exposures need not be. An outcrop should protrude (project) whereas an exposure may be flat or concave.

Geologic structures may be classified as (a) **planar** structures- consisting of some features in the form of planes, eg. Bedding; and (b) **linear** structures- those occurring in the form of lines, eg. Arrangement of minerals along parallel lines.

Features (structures) of the rock that are present before the onset of deformation are called "**Primary structures".** They are original features of sedimentary or igneous rocks, resulting from deposition or emplacement.

Structures reflecting subsequent deformation or metamorphism are "**secondary structures".**

Primary structures are important for the interpretation of the geometrical, as opposed to historical, aspects of the deformation.

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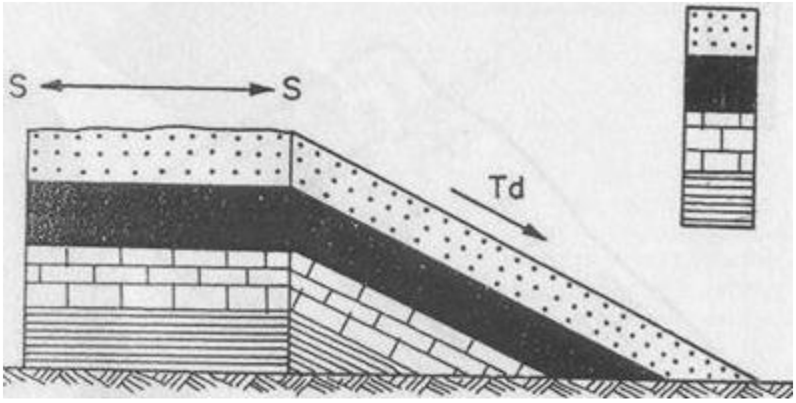
STRIKE AND DIP

Attitude of Beds: - The attitude of planar features is defined by their strike and dip.

The "**strike" of** a bed is its trend measured on a horizontal surface. More precisely, strike may be defined as the direction of a line formed by the intersection of the bedding and a horizontal plane. The strike direction is expressed in terms of full circle bearings or more commonly as quadrant bearings (the horizontal angle) in degrees like N15^{0}E-S15^{0}W, N 60^{0}W-S60^{0}E etc.,.

A vertical cut made parallel to the strike of the beds shows them as a horizontal series. Only a vertical section cut in the direction at right angles to the strike shows the maximum inclination which is the full or true dip of the beds. Sections cut obliquely show only apparent dips.



"**Dip"** is the downward inclination of the rock beds from the horizontal plane. It is the angle between the bedding and a horizontal plane; it is measured in a vertical plane that strikes at right angles to the strike of the bedding. The direction of the dip is perpendicular to the strike. Dip has two parameters i.e. direction of inclination and amount of inclination.

The direction of inclination: the geographic direction, i.e.the trend of the line in the direction of inclination represented by compass points expressed either in terms of

Full Circle bearings: by means of a 360^0 circle like 87^0,120^0,245^0 etc., or more commonly as

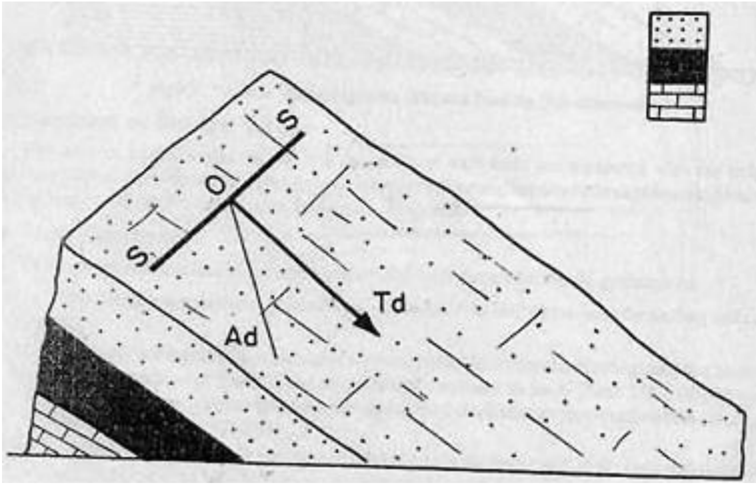
Quadrant bearings: like N15^{0}W, S25^{0}E etc.,

The amount of inclination: expressed as the vertical angle between the bedding plane of the strata and the horizontal surface (expressed in degrees like 25^0, 30^0,40^0, etc.,)

The maximum inclination of the strata in the plane of the dip i.e., the steepest angle made by the bedding plane with the horizontal is called its **"full dip or true dip".** The "**apparent dip"** is the dip in any direction other than true dip direction. It is always less than true dip. The strike and dip are measured by compasses, Viz. Clinometer, Brunton, Esray.

Dip is always specified by its direction and amount.

Example: A Sandstone formation in a hill side is dipping at 30^0 along N22^{0}E.



Measurement of Dip and Strike:

The amount and direction of dip and strike of rock beds are measured with the help of an instrument called Clinometer or with Brunton Compass.

The Clino-Compass

This instrument consists of a large circular dial with three concentric graduations.

The outermost peripheral graduation reads from 0^0 to 360^0 clock-wise for reading full circle bearings.

The innermost graduation indicates the geographic directions for reading quadrant bearings. In this the positions of E and W are reversed to the N for easy and direct reading as in sighting the instrument is turned about its compass needle which always points to North.

The third graduation is in between the above two in the lower half of the dial and is semicircular reading from 0^0 at E to 90^0 either side towards N and S indicating dip values in degrees.

A large magnetized compass needle with its N-end marked and a pendulum are pivoted at the centre co-axially which move freely on the graduations of the dial.

The whole assembly is enclosed in a circular non-magnetic aluminum brass box (that will not affect the magnetized compass needle) with a glass top mounted on a tilting stand with sight slits. The stand acts as a base for the clinometer and a sighting devise for the compass bearings. Outside the box there is an arresting pin to stop the movement of the compass needle.

Measurement of Strike Direction

A safe and suitable point (the observation point) is selected on or near the outcrop and the clino compass with its base brought over the dial is held in the hand at the eye level and sighted through the silts in the direction of the strike from the south end (Sometimes the edge of the bedding, joints etc., which are parallel to the strike direction and coincides with the line of sight).

In some cases the edge of the clino-compass base may be held firmly pressed against the bedding surface in the direction of strike and the compass levelled.

Next when the compass needle comes to rest it is arrested and reading taken from the N-point of the dial towards east or west and recorded as N25^0E,N40^0W etc.,. or commonly N 25^0 E-S 25^0 W, N 40^0 W-S 40^0 E etc .,.

Measurement of Dip

Direction of Dip: The direction of the dip of the beds is determined by holding the clino-compass length wise in the direction of dip. The direction should always be read from the N or S point of the dial towards east or west and recorded as N 30^0 E, S 70^0 W etc.,

Amount of Dip: At the same observation point or at a nearby edge of the dipping strata a clean even surface is selected and the clino-compass is placed on it and held firmly with its length in the direction of dip. (Sometimes the edges of the beds, joint planes etc.,. which are parallel to the dip direction, trend in this direction). Immediately the pendulum moves on from its rest position 0^0 and comes to rest on a point on the dip value scale. The reading is taken then from the position of the pendulum on the scale and recorded in degrees as 30^0, 25^0 etc,.

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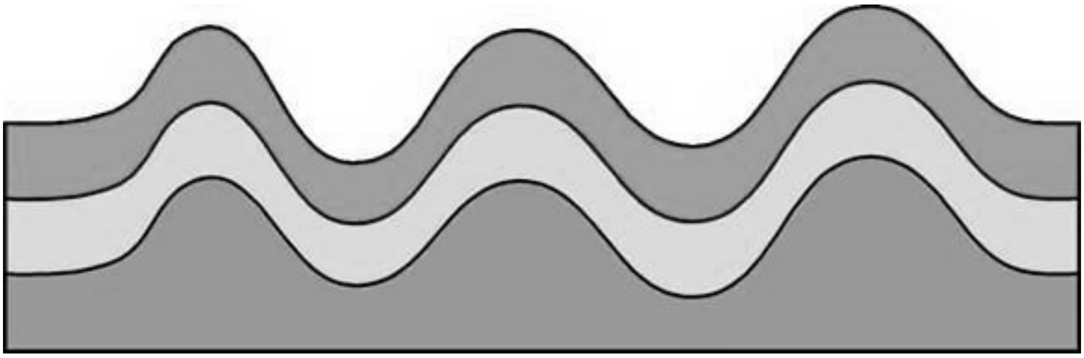
FOLDS

Folds are undulations or waves in the rocks of the earth.

Folds (Frontispiece) are best displayed by stratified formations. Some folds are a few miles across. The width of others is to be measured in feet or inches or even fractions of an inch.

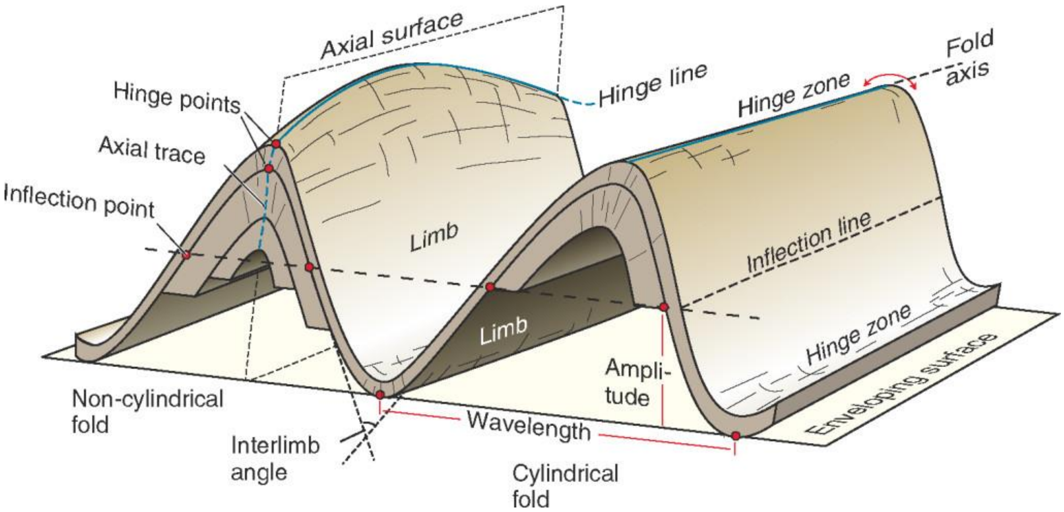


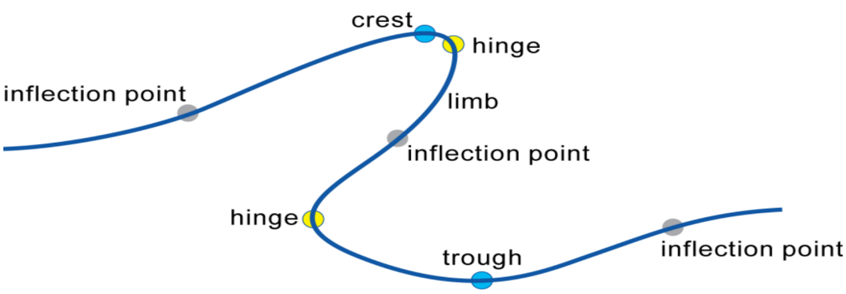
Parts of a Fold:-

The "**hinge"** of a fold is the line of maximum curvature in a folded bed. There is a hinge for each bed. The hinges may be horizontal, inclined, or vertical.

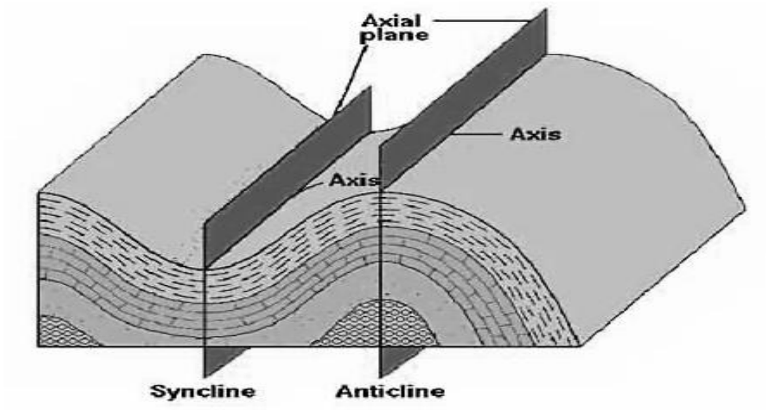
The "**axial plane"** is the surface connecting all the hinges. The attitude of the axial plane in defined by its strike and dip.

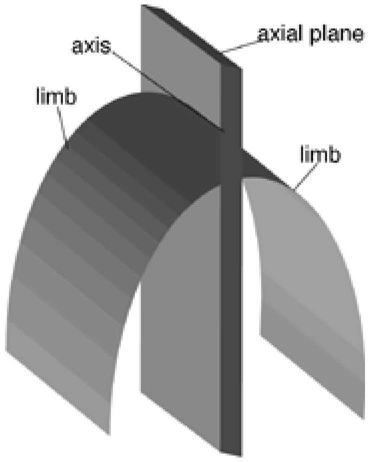
Inflection line = the line along a surface across which the sense of curvature changes from concave to convex, or vice versa

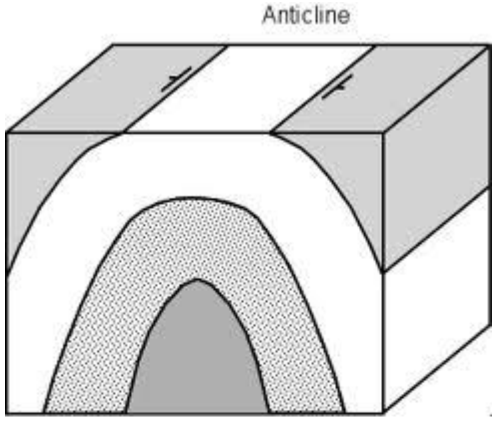


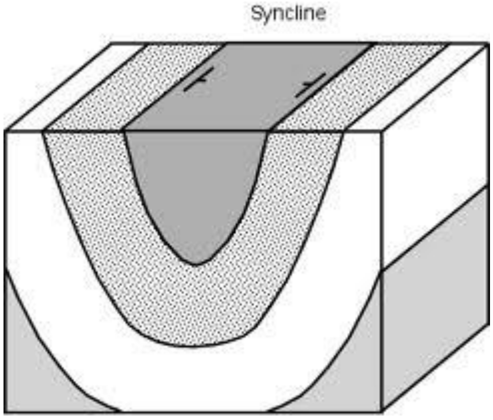


Basic terminology on a folded single surface

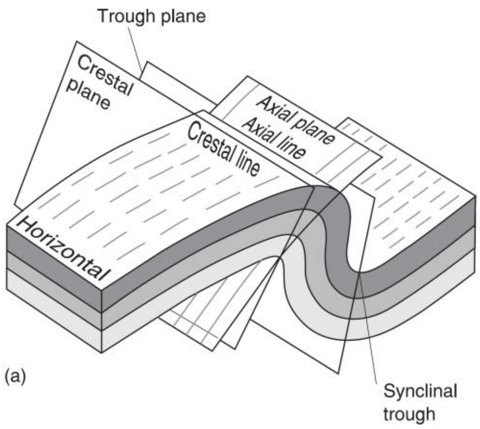


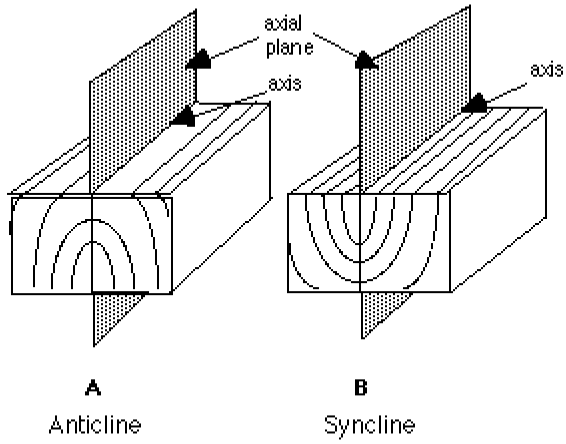






The axial surface is the surface defined by connecting al the hinge lines of stacked (pile) folding surfaces. If axial surface is a planar surface then it is called axial plane and can be described by strike and dip of the plane.



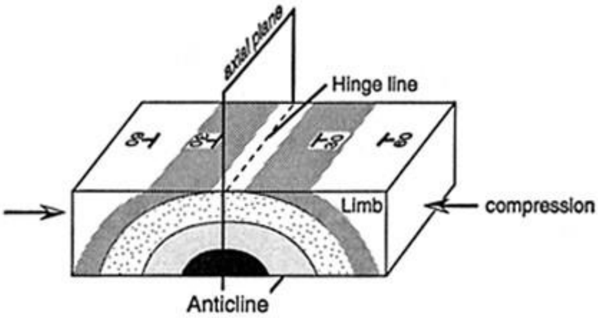


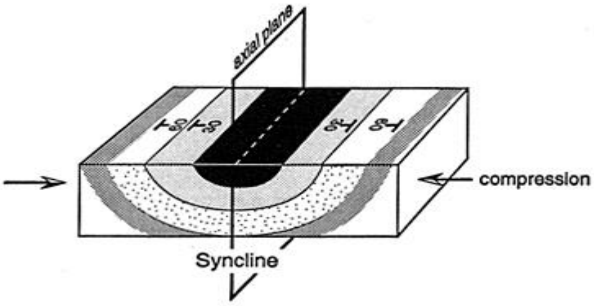
The "**axis"** is a line parallel to the hinges. It is that straight line moving parallel to itself that generates the fold. The term "fold axis" as thus used is an abstraction. The term axis has also been used as synonymous with hinge.

The sides of a fold are called the "limbs or flanks". A limb extends from the axial plane in one fold to the axial plane in the next. Every limb is mutually shared by two adjacent folds.

The '**crest'** is a line along the highest part of the fold, or, the line connecting the highest points on the same bed. There is a separate crest for each bed. The plane or surface formed by all the crests is called the "crestal plane".

The '**trough'** is the line occupying the lowest part of the fold, or, the line connecting the lowest parts on the same bed. The plane connecting such lines may be called the "trough plane".





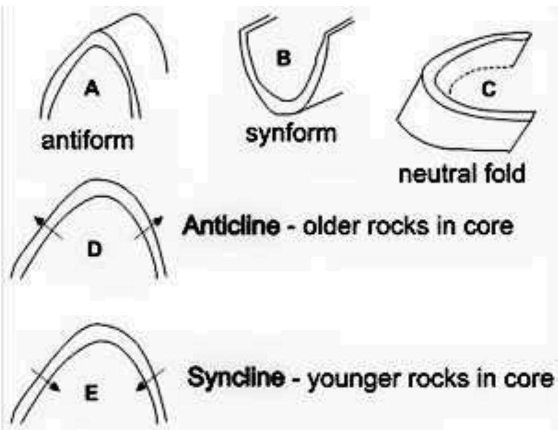
Nomenclature of Folds:-

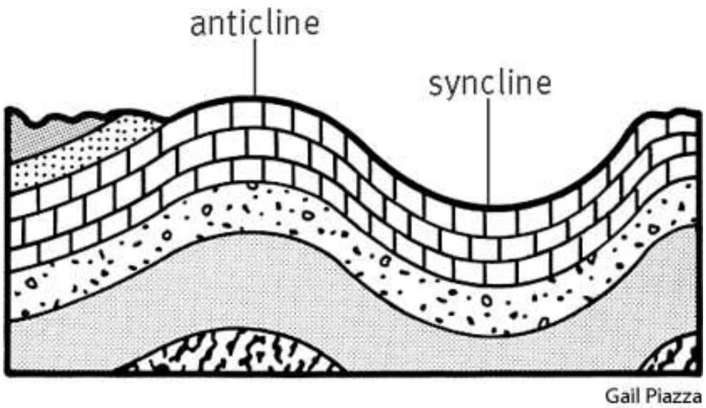
Closing and facing direction - Folds which close upwards, that is where the limbs dip away from the hinge, are termed antiforrns (figure 4A) and those which close downwards, where the limbs dip towards the hinge, are termed synforrns (figure 4B). Folds which close sideways are termed neutral folds (figure 4E).

Antiform - upward closing fold

Synform - downward closing fold   Stratigraphic succession is unknown.

Neutral - side ways closing fold

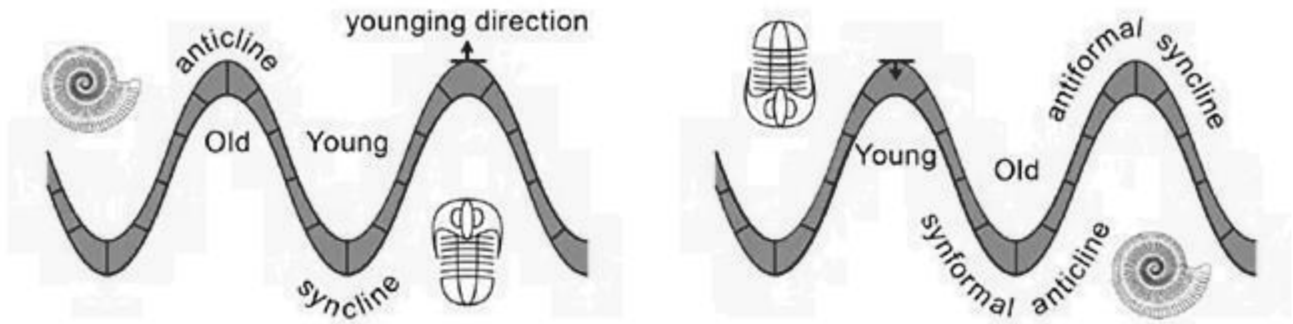




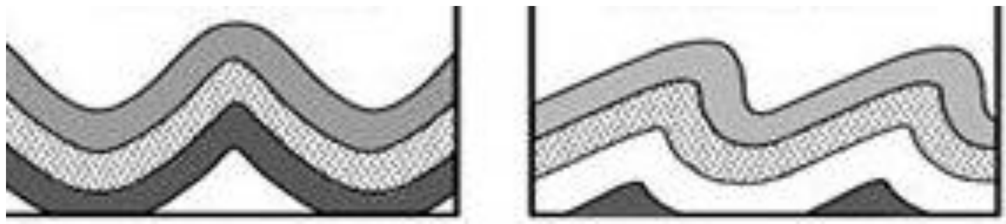
An "**Anticline"** may be defined as a fold that is convex upward; it may also be defined as a fold that has older rocks in the centre. In the simplest anticlines the two limbs dip away from each other. But the term has also been extended to folds, where the two limbs dip in same direction at different angles. The term has been extended to any fold where older rocks are in the centre.

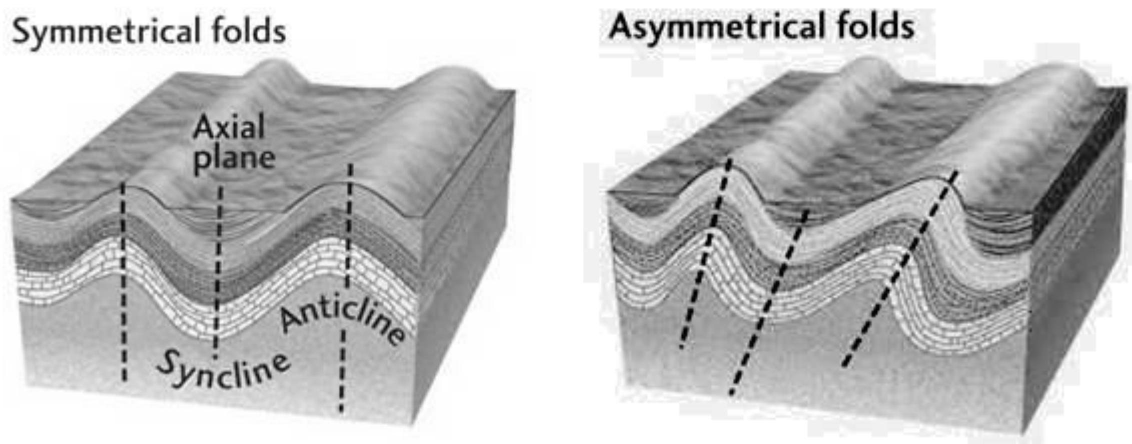
A "**Syncline"** may be defined as a fold that is convex downward. In the simplest synclines the two limbs dip toward each other. But the term has been extended to such folds, where the two limbs dip in the same direction at different angles. Normally this means that younger rocks are in the centre of the fold.

Anticline and syncline are terms with stratigraphic significance. Anticlines are **antiforms** in which the oldest strata are in the core of the fold. Synclines are **synforms** in which the youngest strata are in the core. But **antiformal synclines** and **synformal anticlines may** exist in regions of complex, polyphase deformation. In these regions it is important to determine the younging direction, which is the direction along the axial surface in which the strata become younger.

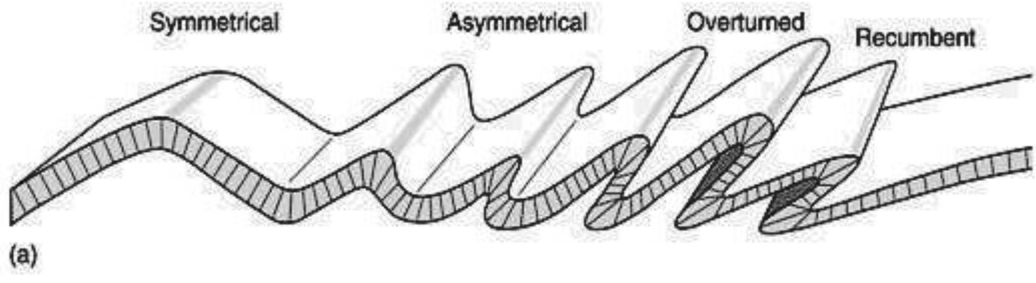


A "**Symmetrical fold"** is one in which the axial surface is essentially vertical.

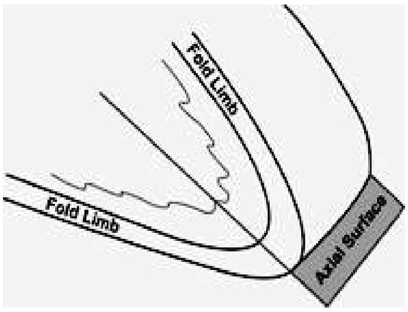


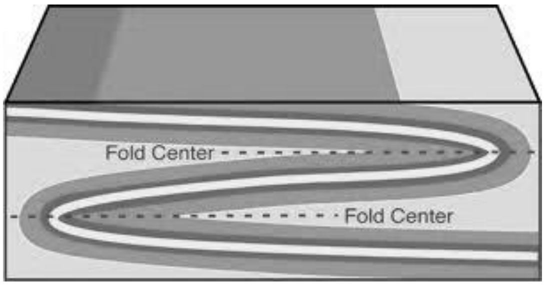


An “**Asymmetrical fold”** is defined as one in which the axial surface is inclined.



In the “**Overturned fold”** or “over fold” the axial plane is inclined, and both the limbs dip in the same direction, usually at different angles. The overturned or inverted or reversed limb is the one that has been rotated through more than 90^0 to attain its present attitude. In an overturned fold, axial surface and both fold limbs dip (tilt) in the same direction.

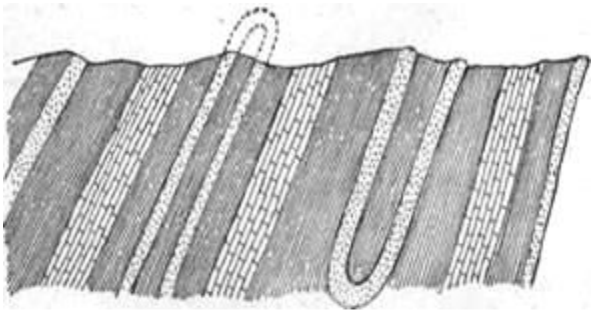


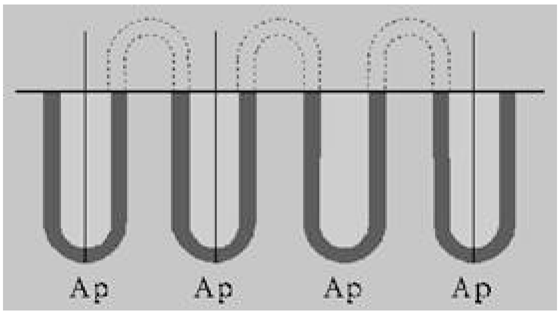


Overturned fold Recumbent fold

A"**Recumbent fold**" is one in which the axial plane is essentially horizontal.

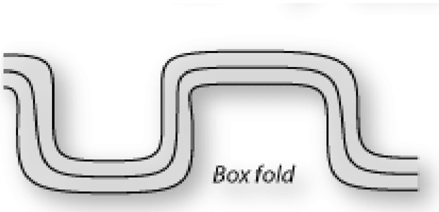
An "**Isoclinal fold"** refers to folds in which the two limbs dip at equal angles in the same direction.





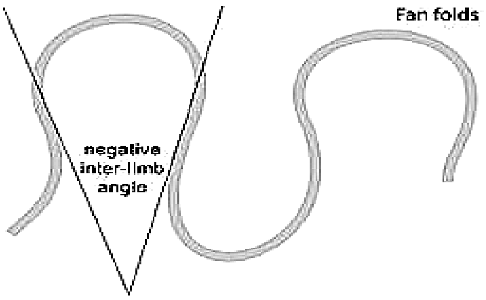
Isoclinal fold

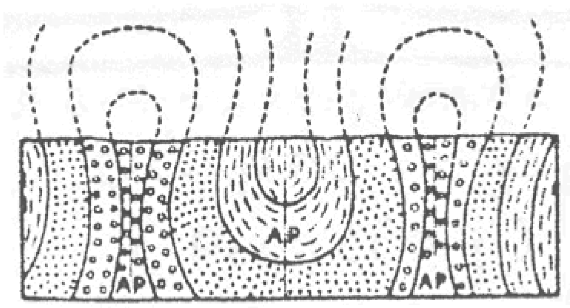
A "**Chevron fold"** is one in which the hinges are sharp and angular.



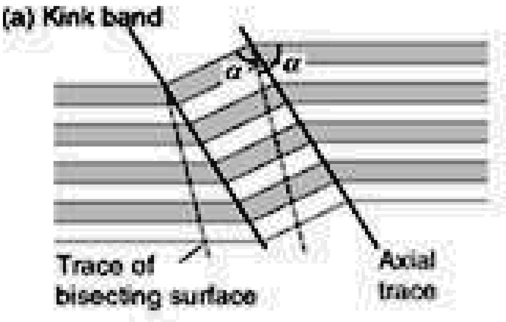
A "**Box fold"** is one in which the crest is broad and flat; two hinges are present, one on either side of the flat crest.

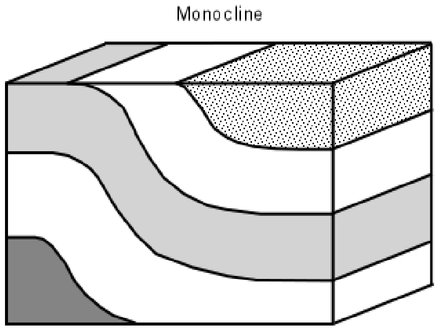
A "**Fan fold"** is one in which both limbs are overturned. Fan folds have negative interlimb angles.





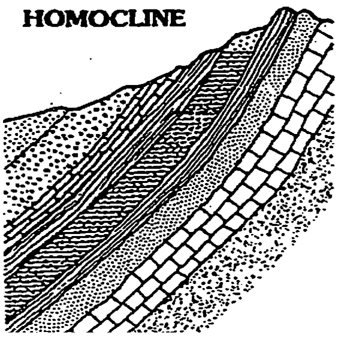
"Kink bands" are narrow bands in which the beds assume a dip that is steeper or gentler than that in the adjacent beds. Kinks are folds with straight, planar limbs (there is no inflexion point) and angular hinges (the hinge zone is reduced to a point). The short limb is referred to as a **kink band**.

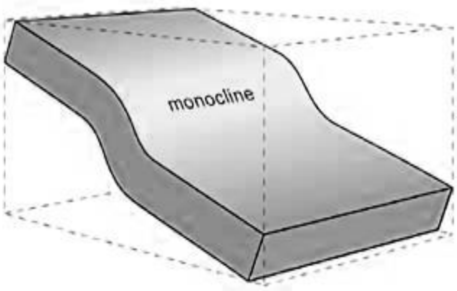


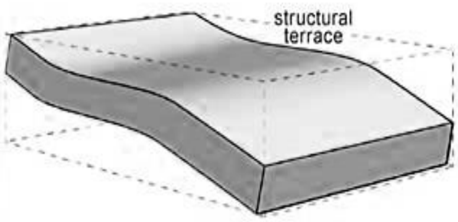


In plateau areas, where the bedding is relatively flat or gently inclined, the strata may locally assume a steeper dip (like knee bend). Such a fold is a "**monocline".**

The term "**homocline"** may be applied to strata that dip in one direction at a relatively uniform angle.







A succession of beds with uniform parallel attitudes over a large area forms a **homocline**.

An antiform and an adjacent synform delimit a single limb. Such a flexure pair involving a local increase in regional dip (i.e. only one tilted, step-like limb in an otherwise subhorizontal or gently dipping sequence) constitutes a **monocline**. Conversely, a local decrease in regional dip is a **structural terrace**.

Fold Tightness: Fold tightness is described in terms of interlimb angle (angle between the limbs of the folded surface).

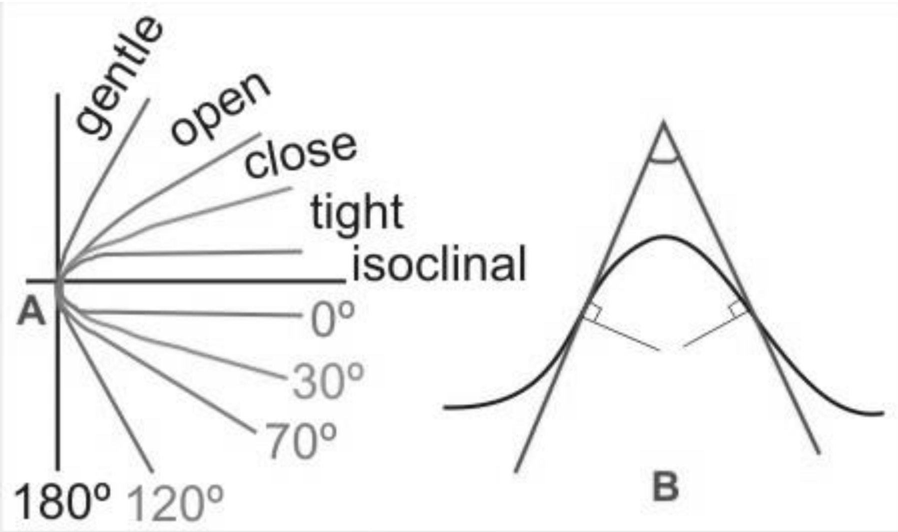
In areas where dipping strata locally assume a horizontal attitude, a "**Structural Terrace"** is formed.

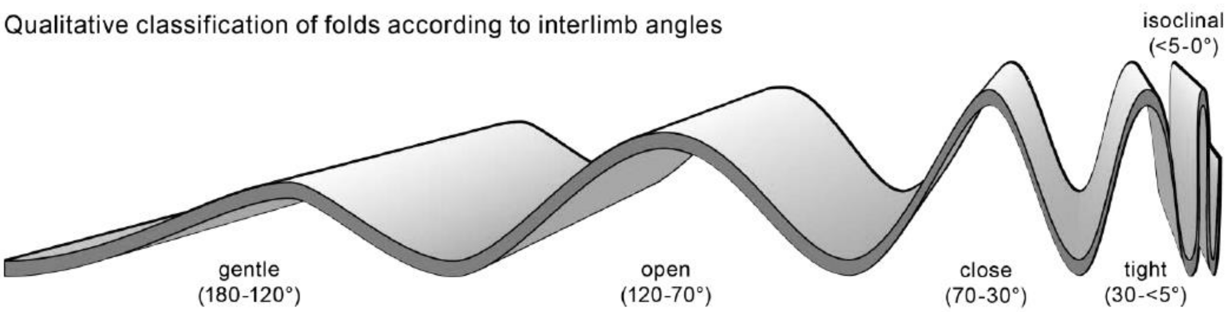
A “**Closed or tight fold”** is one in which the deformation has been sufficiently intense to cause flowage of the more mobile beds so that these beds thicken and thin.

$5^0 – 30^0 \rightarrow$ tight $\quad$ $70^0 – 120^0 \rightarrow$ open

30^0 -$70^0 \rightarrow$ closed $\quad$ $120^0 – 180^0 \rightarrow$gentle

An “**Open fold”** is one in which this flowage has not taken place.





“**Drag folds”** form when a competent bed slides past an incompetent bed. Drag folds form on the incompetent beds. Such minor folds may form on the limbs of larger folds because of the slipping of beds past each other. The axial planes of the drag folds are not perpendicular to the bedding of the competent strata, but are inclined at an angle.

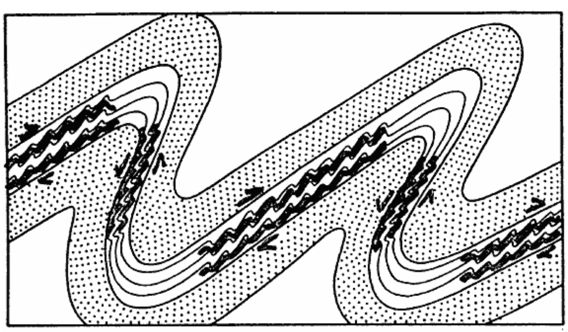


Fig. 4-22. Structure section of overturned folds showing relation of drag folds and direction of shearing.

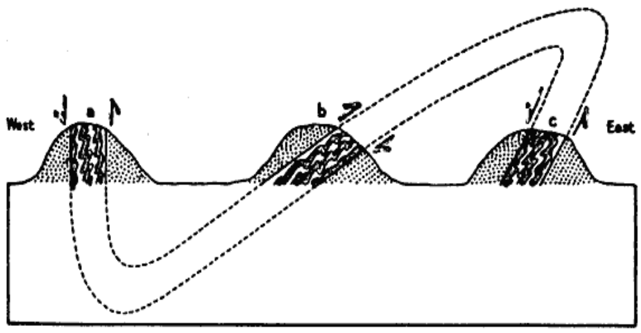
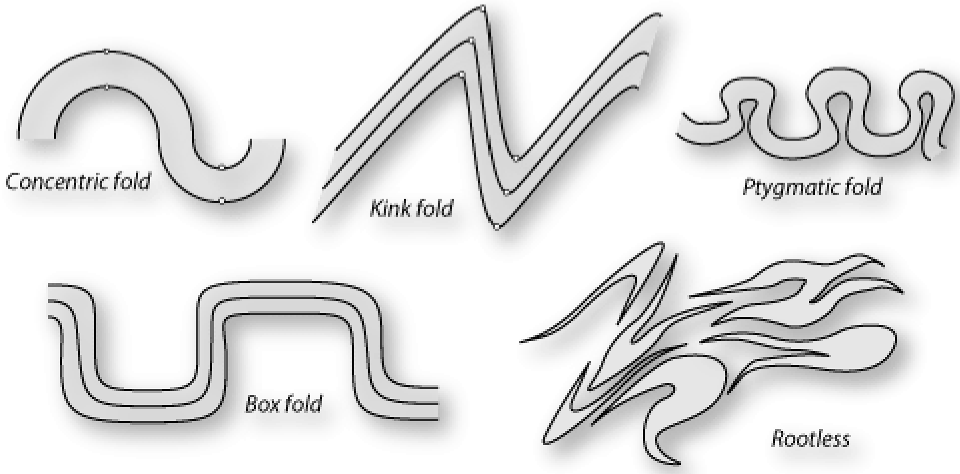


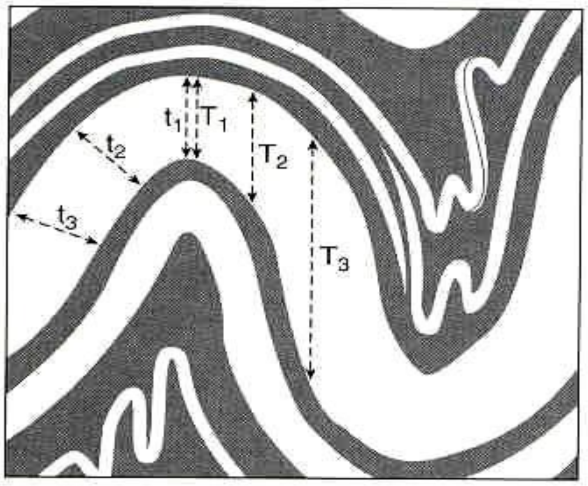
Fig. 4-23. Use of drag folds in determining major structure. Letters are referred to in text.



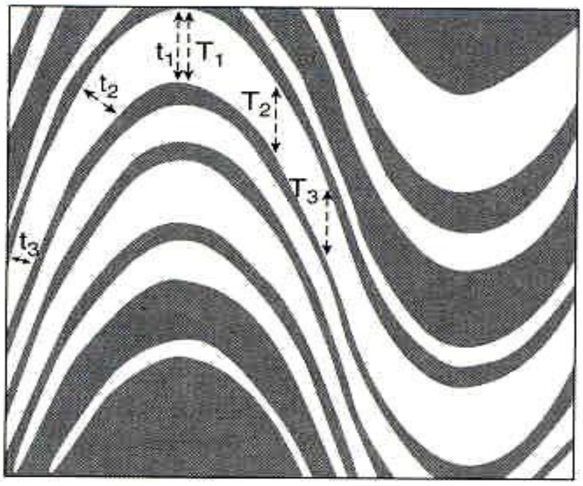
Ptymatic fold have short limbs relative to the their hingh.

Rootless folds have broken limbs due to shearing.

In **Parallel folding (concentric)** the rock layers maintain same thickness throughout deformation. **Similar folds** show variation in the thickness of layers. In similar fold hinges appear thickened relative to thinned limbs.

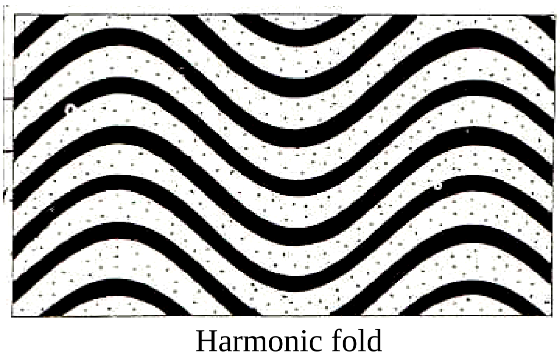


Parallel fold

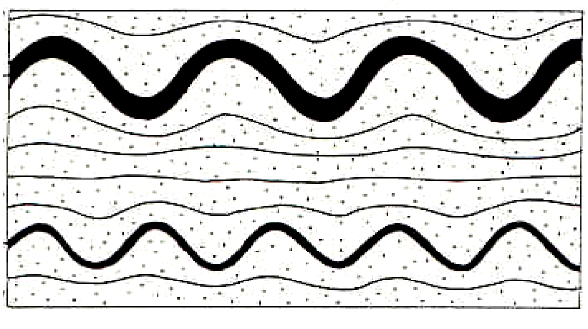


Similar fold

Folds in which axial planes are continuous across successive folded layers that show approximately the same wavelength and amplitude are **harmonic**. Typically, similar folds that ideally maintain their shape throughout a section are harmonic. Folds in which the amplitude, wavelength and style change along discontinuous axial surfaces from one layer to another are **disharmonic**. Disharmonic folds develop because of differing theology in the different layers.

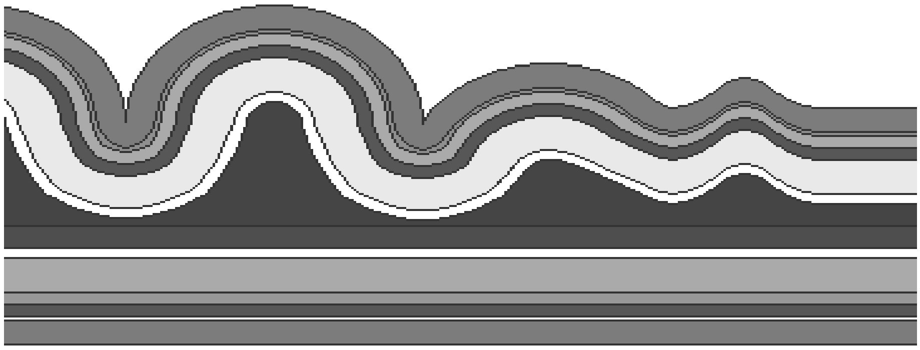


Harmonic fold



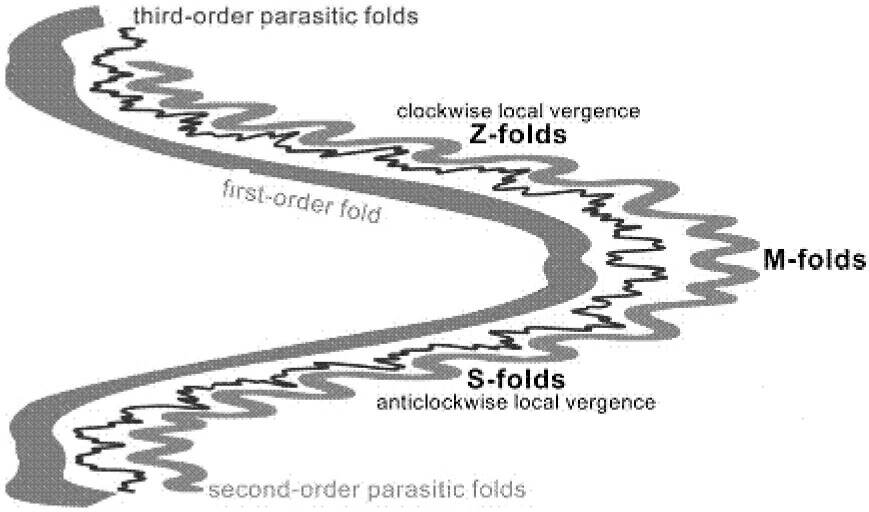
Disharmonic fold

“**Decollement”** is one in which the upper strata are thrown into folds that do not affect the underlying rocks.



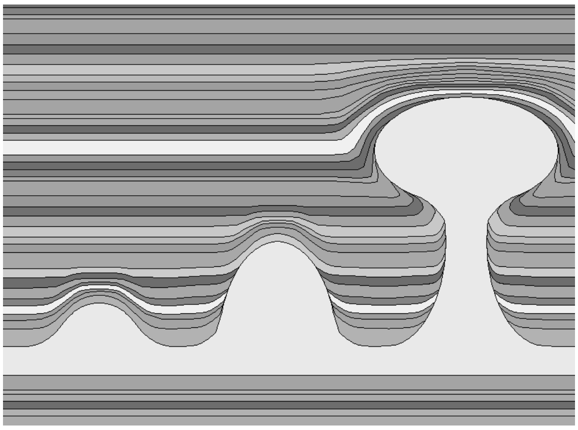
Parasitic folds

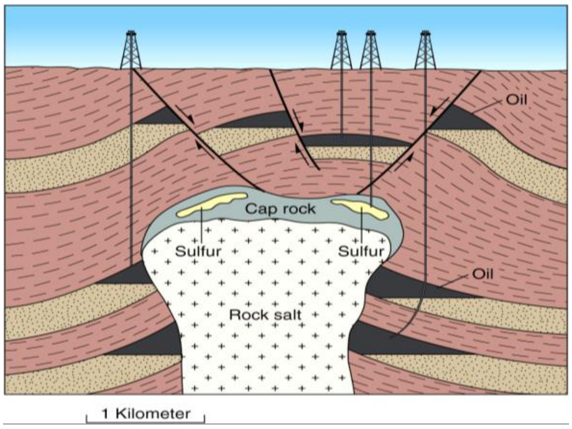
Hinge zones and limbs of large folds often display folds of smaller wavelength and amplitude: larger and smaller folds are together **polyharmonic**. The small folds are called **parasitic** or **subsidiary folds** with respect to the larger ones. The largest folds are termed **first-order folds**, the next largest are called **second-order folds** and so forth.



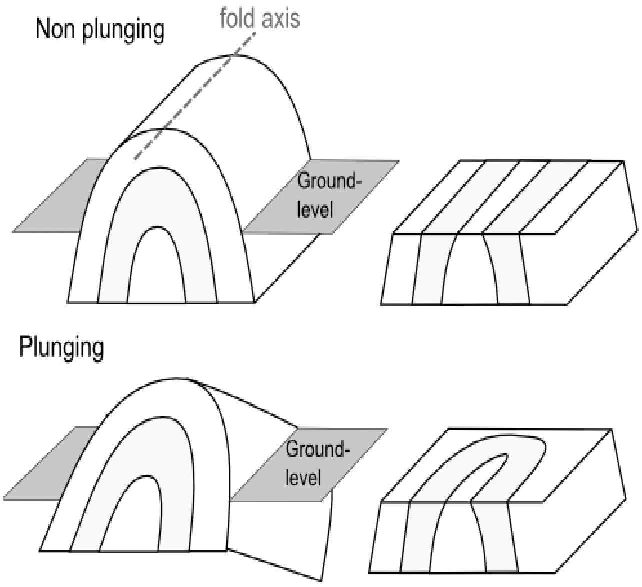
“**Piercing or diapir folds”** are anticlines in which a mobile core (rock salt) has broken through the more brittle overlying rocks. Pierced (penetrated) though the more brittle overlying rocks.

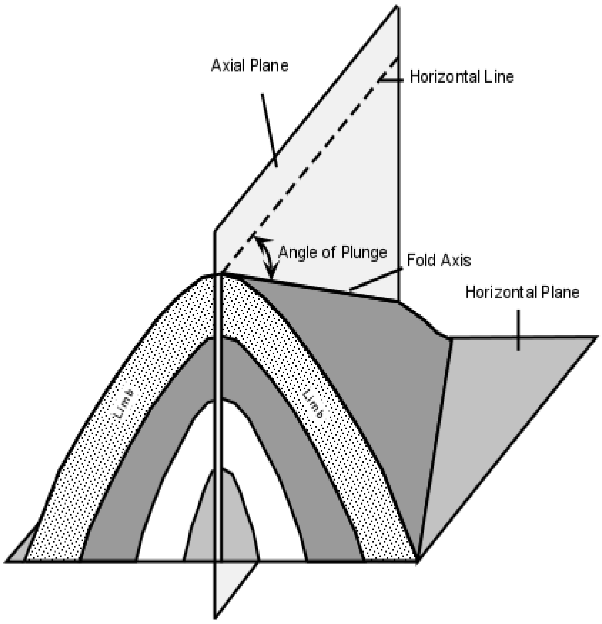
A fold or dome, such as an anticline, in which the upper strata of sediment or rock have been ruptured by the upward movement of more plastic rock, such as a body of salt, gypsum, or lava.

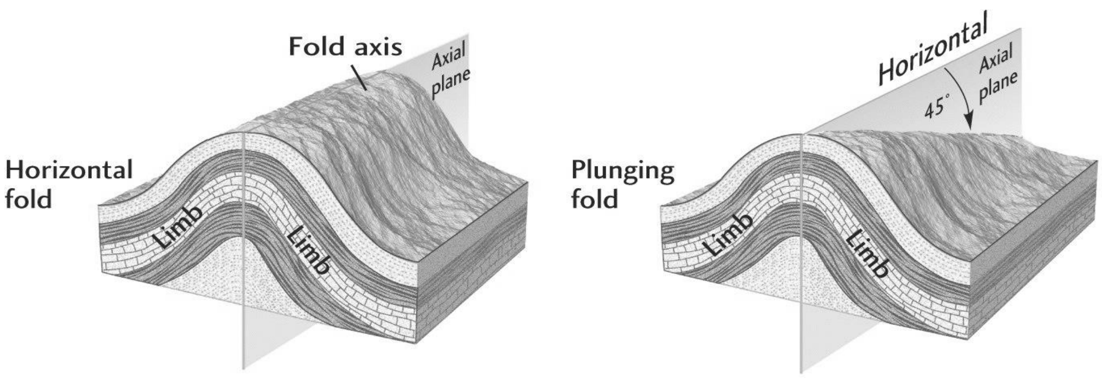




Plunge (Pitch) of Folds: *Plunge is a measure of inclination*. The angle of inclination of the fold axis from the horizontal is called the plunge or pitch. It is expressed in degrees.

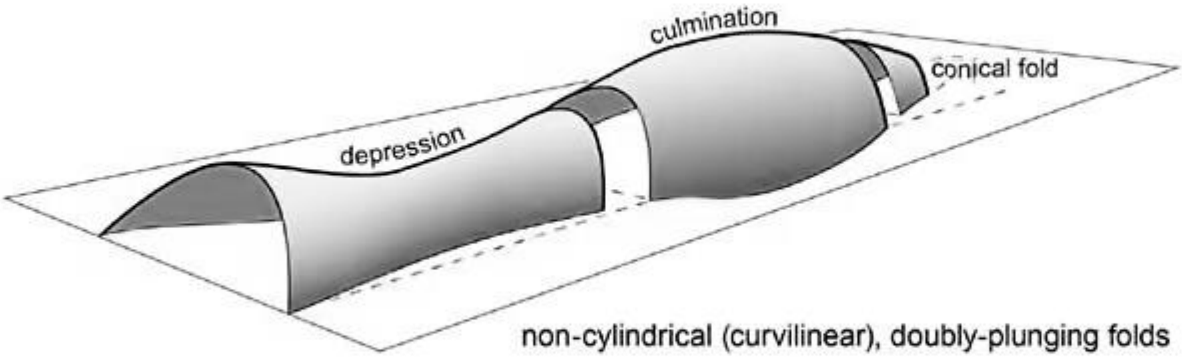






A “**Doubly plunging fold”** is one that reverses its direction of plunge within the limits of the area under discussion. The plunge of the hinge line reverses along a **doubly plunging** fold. If the hinge line plunges away from a high point (the axis is convex upward), the high point is a **culmination**; if it plunges toward a low point (the axis is concave upward) the low point is a **depression.**

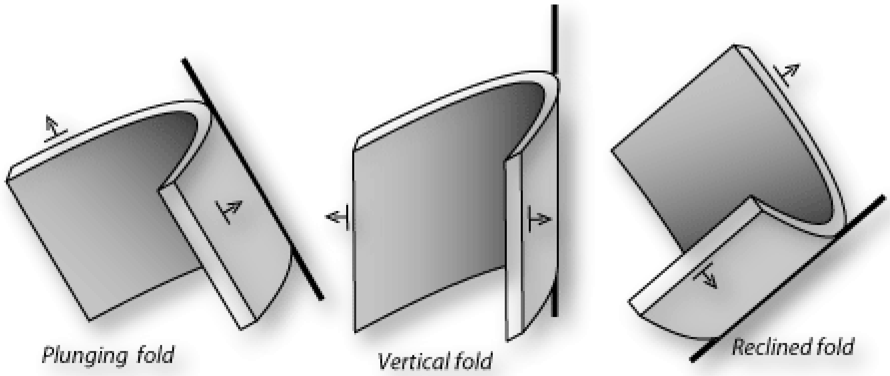
Sheath folds



A “**Dome”** is an anticlinal uplift that has no distinct trend.

A “**Basin”** is a synclinal depression that has no distinct trend.

A “**Reclined fold”** is one in which the axes plunge directly down the dip of the axial surface. Strike of the axial plane is perpendicular to the trend of the fold axis.



A fold with both plunging hinge and inclined axial surface. Reclined folds have fold axis plunging down the dip of the axial surface.

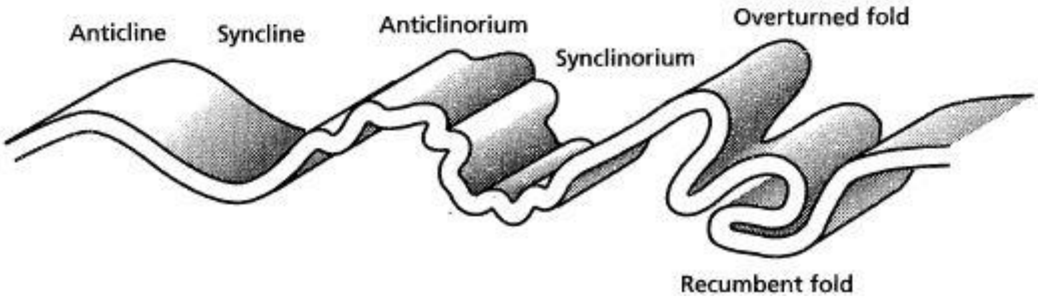
•Horizontal folds have horizontal fold axis.
•Vertical folds have vertical fold axis.
•Plunging folds have plunging fold axis.
•Reclined folds have a plunging fold axis AND dip pointing downward.

Fold systems:-

A major anticline that is composed of many smaller folds is called an ‘**Anticlinorium’.** A ‘**Synclinorium’** is a large syncline composed of many smaller folds.

“**Geosynclines”** literally means an “earth syncline”. It is a large depression, hundreds of miles long and tens of miles wide.

A “**Geoanticlines”** literally means an “earth anticline” is a broad uplift, comparable in size to a geosyncline. It is a large uplift, hundreds of miles long or tens of miles wide.

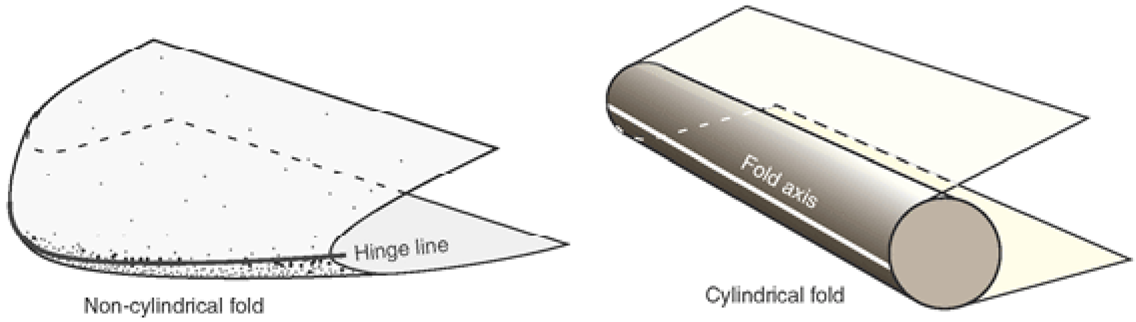


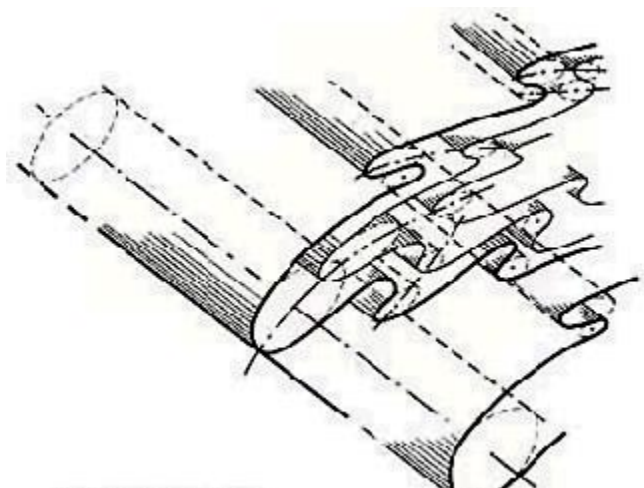
In some localities individual folds do not extend any great distance, but overlap one another. These are **“en echelon” folds.**

cylindrical folds

A cylindrically folded surface is a curved surface which shape can be generated by taking a straight line. It is characterized by a straight hinge line. Folds are often drawn as **cylindrical** structures, meaning that the fold axis is a straight line which, when moved parallel to itself, generates any single fold of the same generation.

Depending on the orientation of the axial surface, the folds can be divided in to cylindrical and non-cylindrical folds. This is expected since, the cylindricity is actually a mathematical model rather than a observational one. It is very difficult to observe perfect symmetry in nature.





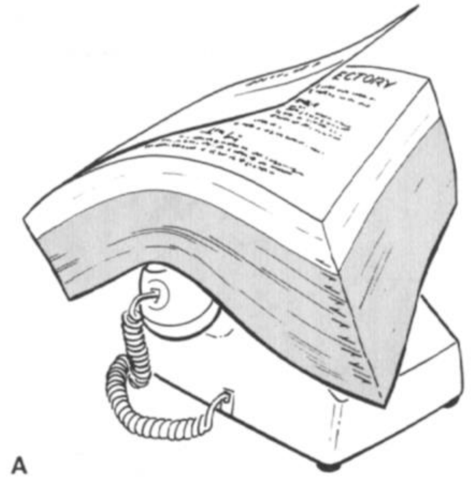
Cylindrical folds

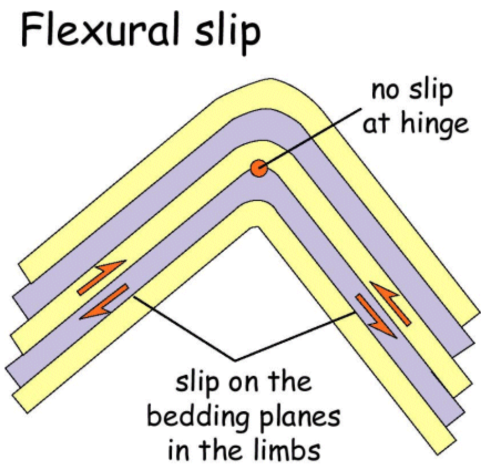
Folds can also be classified, depending on the causes of folding, as

(1) Flexure folds (2) Flow Folds (3) Shear Folds

1) Flexure folds (Flexural slip)

Flexural-slip folding accommodates buckling by layer-parallel slip between layers. Direction of relative slip is perpendicular to hinge. The layers actively participate in folding by bending and flexing. The several bed then may be sliding past each other under the influence of tension (top side of the fold), and the compression (underside of the fold). Occur in uppermost levels of earth crust. Therefore the top side of the fold experience stretching or thinning, while the underside experiences thickening or squeezing. So thinning stretching or thickening are the mechanisms of the flexure folding. As such wherever thinning, stretching or thickening has been observed, such folds are called as the "flexure folds" and where slipping has been observed, those are called as the "flexure slip folds".





2) Flow folding

Flow folding accommodates the buckling by layer parallel flow within the mechanically soft units sandwiched between stiff units. If the rocks be composed of thinly bedded, incompetent layers, then the entire unit yields plastically **without any slipping movement** along the bedding planes. Many minor folds are developed in the incompetent bed.

3) Shear Folds: These are also called as the **"slip folds"**.

Minute displacements along closely spaced fractutes. Original horizontal strata are broken into blocks by fractures that dip to the left. The blocks 1 and 11 remain undisturbed. Block 6 has moved upward the greatest amount; the blocks on either side of it have moved upward in amounts that decrease progressively. The resulting structure is a major fold. Slip of layers parallel to each Other.

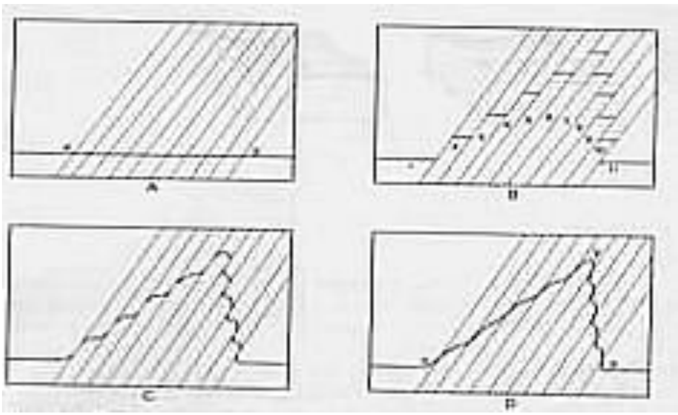
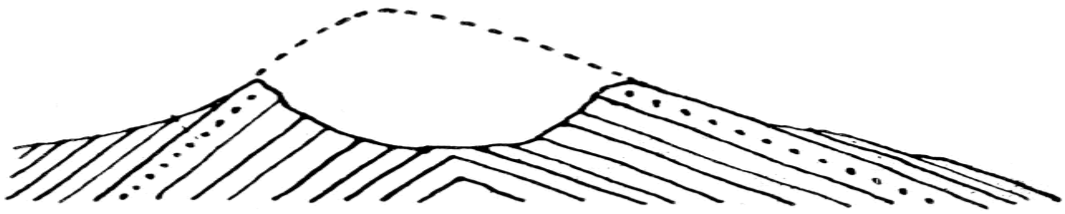


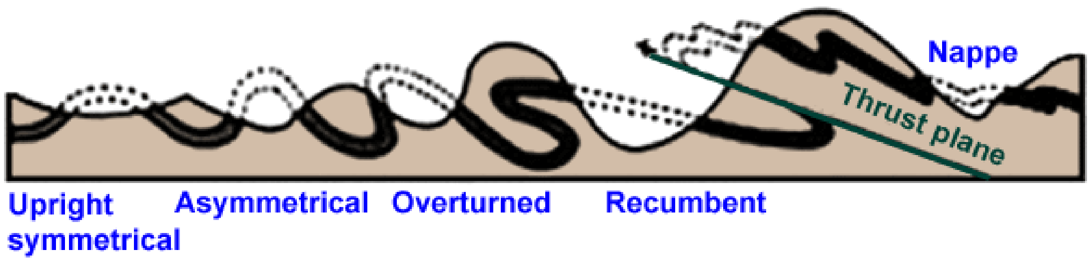
Fig: Heavy line, xz, is a bedding plane. Inclined light lines are fractures. (A) Before displacement on fractures. (B) After displacement. (B) Because of friction, beds tend to parallel the fractures. (D) Fold results if bed maintains continuity.

Recognition of folds: Folds may be recognized in many ways. The easiest and most satisfactory method is "**Direct observation"**; but this is possible in few regions.

Folds larger than an outcrop are based on "**inference".** In the case of simple folding the structure may either be a syncline or an anticline or it may be made up of a series of synclines and anticlines as well. In regions exhibiting folded structures therefore (a) a participant bed occurs more than once. (b) Along the repetition of beds and particular bed must dip towards opposite directions in any two of its successive outcrops. (c) Depending upon the exact dip-pattern, the nature of the folded structure can be duly interpreted.

Moreover, the part of the fold that was above the present surface of the earth has been removed by erosion. One or more of the following pieces of information are commonly used to deduce folds. (1) differences in attitude of some planar feature at different localities; (2) areal map pattern; (3) subsurface exploration by drilling, mining, and tunneling; and (4) subsurface studies by geophysical methods, Drag folds, Pi diagrams and Beta diagrams may also be employed.





Causes of Folding:

Tectonic Processes (due to forces operating within the earth) horizontal compression; contraction theory; plate tectonics (sea floor spreading & continental drift); vertical movements (uplifts); intrusion; gravity sliding.

Non-tectonic processes (Superficial process associated with erosion or deposition): hill side creep; collapse structures; cambers & bulges; glacial ice; differential solution; differential compaction of sediments.

Determination of Top of Beds in the case of overturned folds by Primary Features:

Paleontological methods; Ripple marks – Oscillation ripples – (sharp crests point upward and broad troughs are convex downward); Cross-bedding; graded bedding; sole markings; channeling; Pillow structures; Drag folds.

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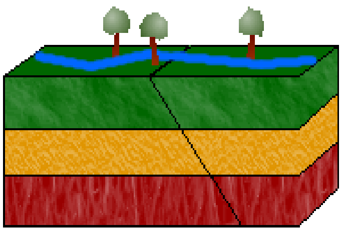
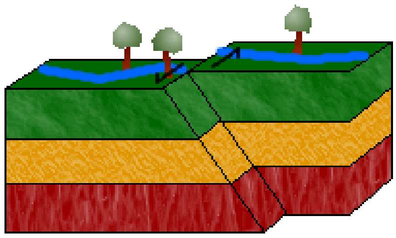
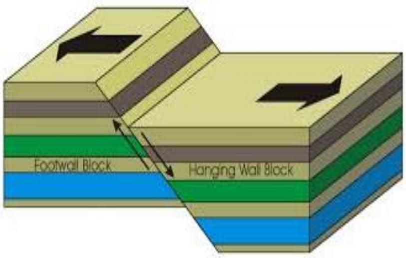
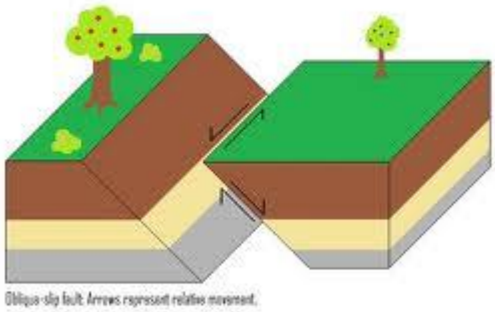
FAULTS

Faults are ruptures along which the opposite walls have moved past each other. The essential feature is differential movement parallel to the surface of the fracture.



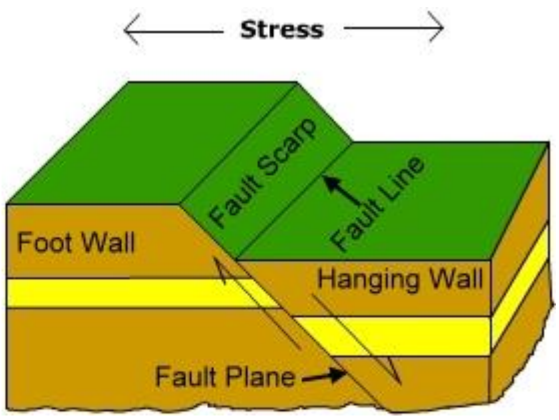


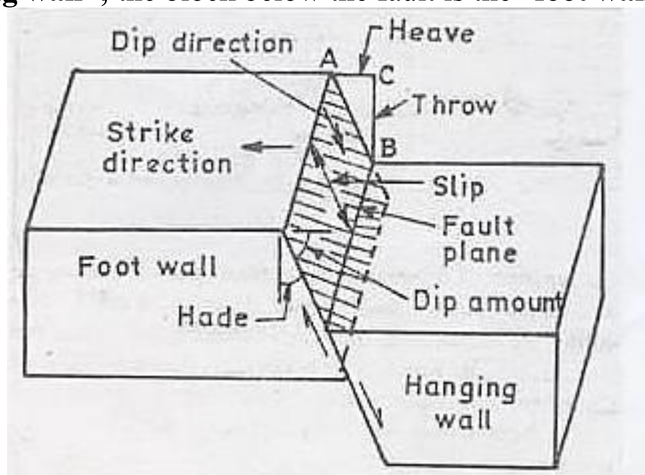




The strike and dip of a fault are measured in the same way as they are for bedding or jointing. The "**hade**" is the complement of the dip; i.e., 90^0 less the angle of dip. The hade may also be defined as the angle between the fault plane and a vertical plane that strikes parallel to the fault.

The block above the fault is called the "**hanging wall";** the block below the fault is the "**foot wall"**



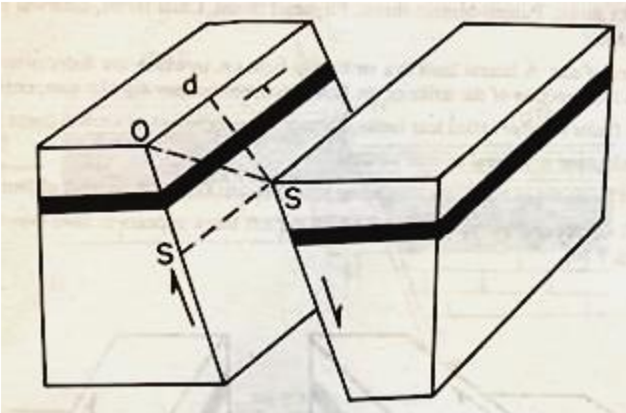


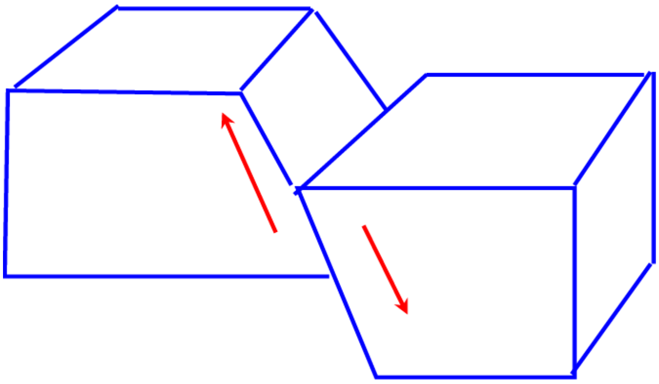
The fault zone may consist of numerous interweaving small faults.

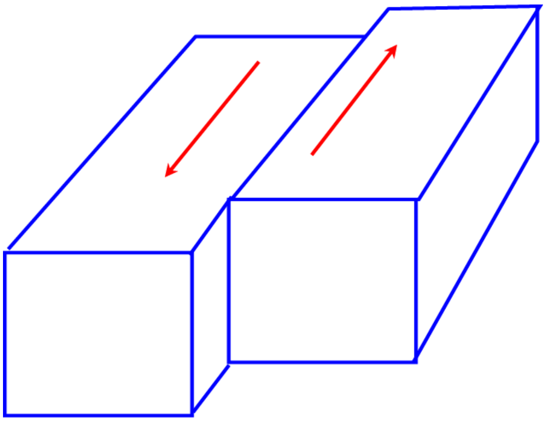
The intersection of the fault with the surface of the earth is known as the "**fault line",** fault trace or fault outcrop.

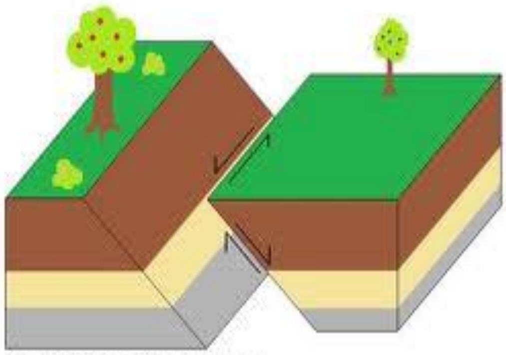
In translational movement there has been no rotation of the blocks relative to each other. Rotational movements are those in which straight lines on opposite sides of the fault, parallel before the displacement, are no longer parallel afterwards.

The term “**slip”** is used to indicate the relative displacement of formerly adjacent points on opposite sides of the fault, and it is measured in the fault surface. The “**net slip”** is the total displacement; it is the distance measured on the fault surface between two formerly adjacent points situated on opposite walls of the fault. The “**Strike slip”** is the component of net slip parallel to the strike of the fault. The “**dip slip”** is the component of the net slip measured parallel to the dip of the fault plane.



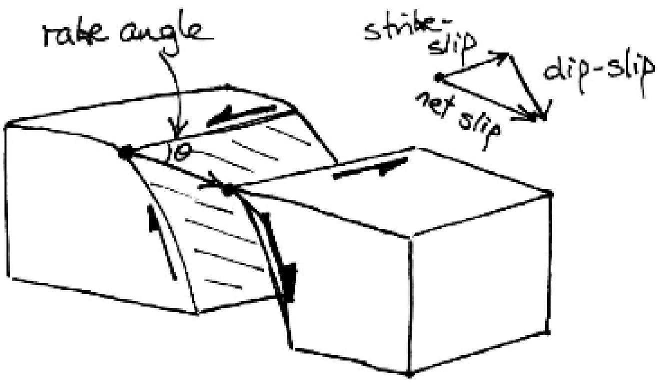


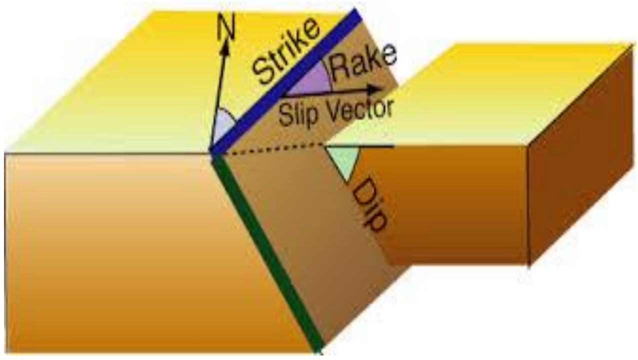




Oblique-slip fault. Arrows represent relative movement.

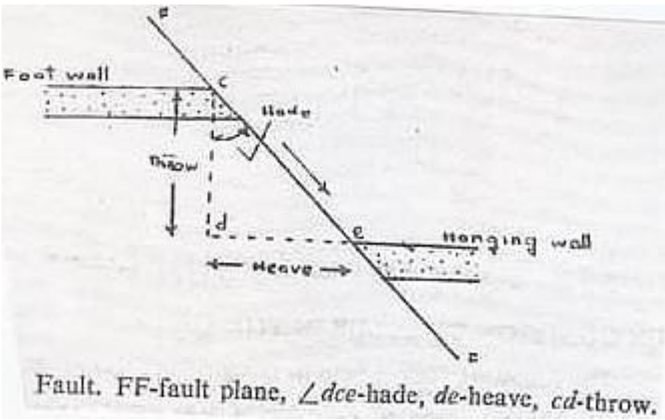
The “**rake”** is the angle that a line in a plane makes with a horizontal line in that plane. The acute angle between fault strike and the slip vector on the fault plane is termed rake.



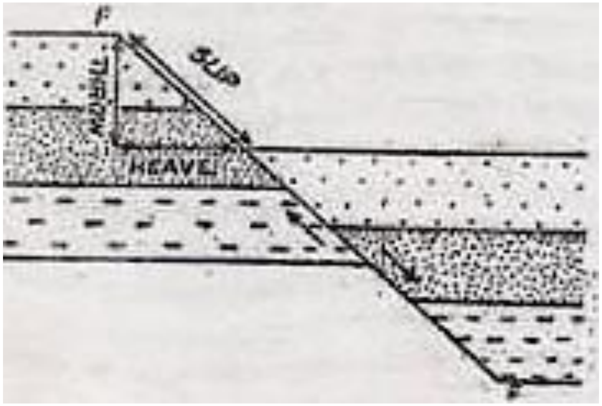


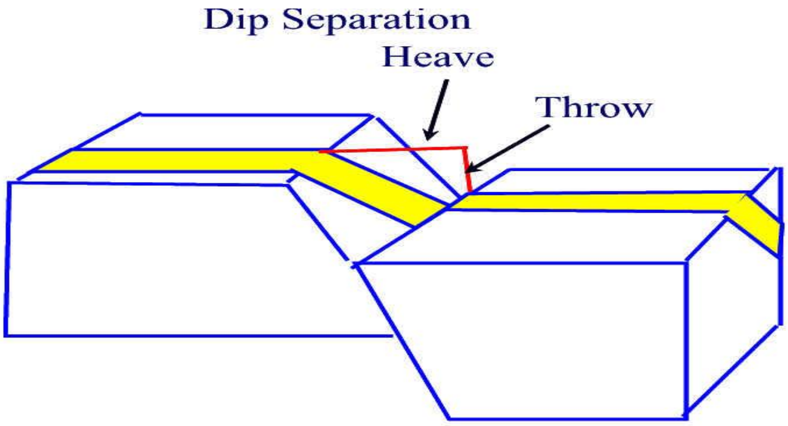
In structural geology rake (or pitch) is formally defined as "the angle between a line [or a feature] and the strike line of the plane in which it is found", measured on the plane.

A vertical plane perpendicular to the strike of the fault contains the dip slip. The “**vertical slip” (throw)** is the vertical component of the net slip and dip slip. The “**horizontal slip” (heave)** is the horizontal component of net slip. The ‘**horizontal dip slip’(heave)** is the horizontal component of the dip slip.



Fault. FF-fault plane, ∠dce-hade, de-heave, cd-throw.



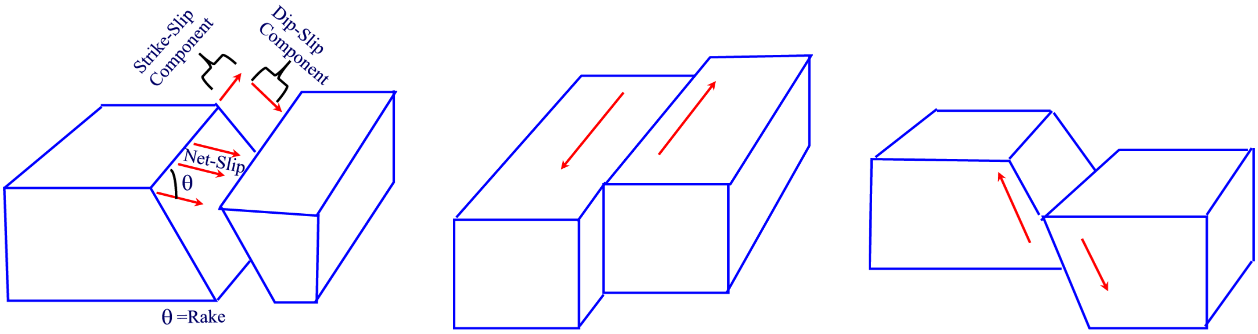


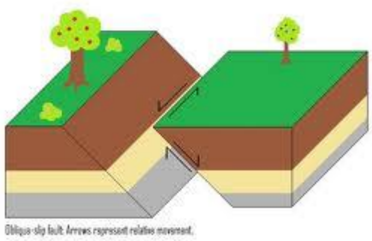
Classifications:

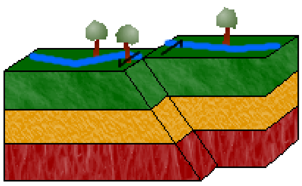
Geometrical :- (i) Based on rake of net slip: - A **"strike – slip fault" (also called wrench fault)** is one in which the net slip is parallel to the strike of the fault; that is, the strike equals the net slip and there is no dip-slip component. The rake of the net slip is therefore zero. **Transform fault** is a type of strike-slip fault, associated with oceanic ridges.

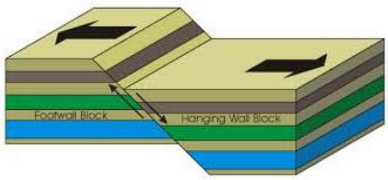
A **"Dip-slip fault"** is one in which the net slip is up or down the dip of the fault; that is, the dip slip equals the net slip and there is no strike-slip component. The rake of the net slip is therefore 90^0.

A "**Diagonal – slip fault"** is one in which the net slip is diagonally up or down the fault plane. There is both a strike-slip and dip-slip component; the rake of the net slip is greater than zero but less than 90^0.









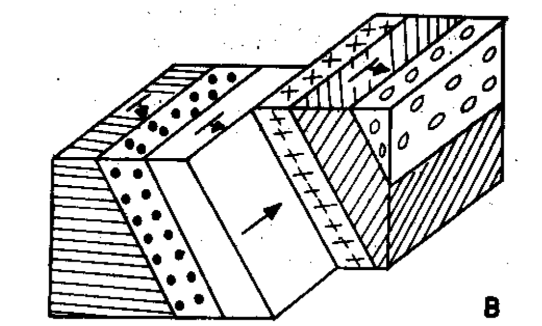
(ii) **Based on attitude of fault** relative to attitude of adjacent beds:-

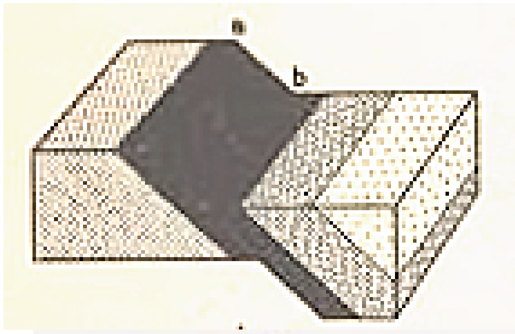
A "**strike fault"** is one that strikes essentially parallel to the strike of the adjacent rocks.

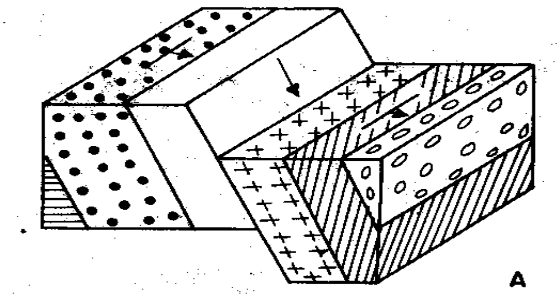
A **"bedding fault"** is a variety of strike fault that is parallel to the bedding

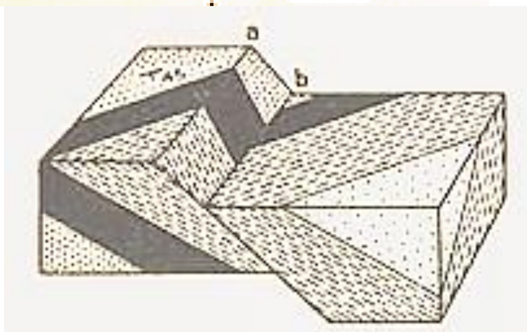
A “**dip-fault”** strikes essentially parallel to the direction of dip of the adjacent beds; that is, its strike is perpendicular to the strike of the adjacent beds.

An “**Oblique or diagonal fault”** is one that strikes obliquely or diagonally to the strike of the adjacent rocks.









A “**longitudinal fault”** strikes parallel to the strike of the regional structure.

A “**transverse fault”** strikes perpendicularly or diagonally to the strike of the regional structure.

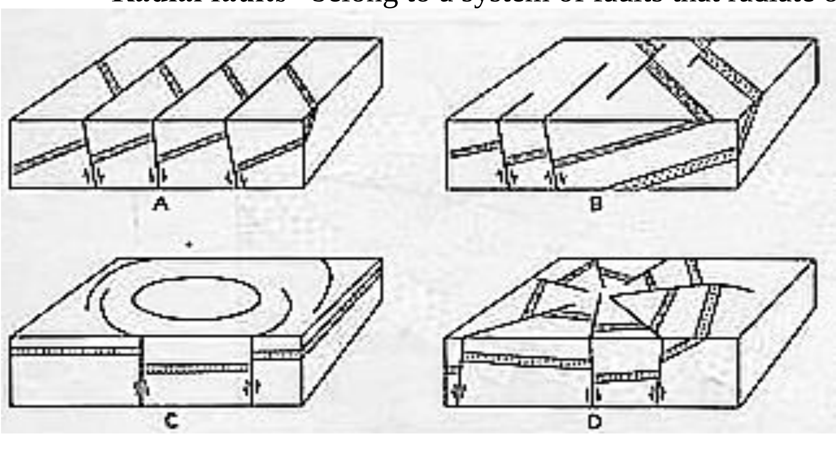
(iii) Based on fault-pattern:-

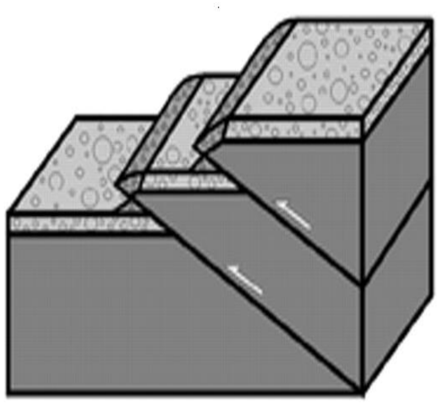
In some localities, the faults have essentially the same dip and strike; they thus belong to a set of “**parallel faults”.**

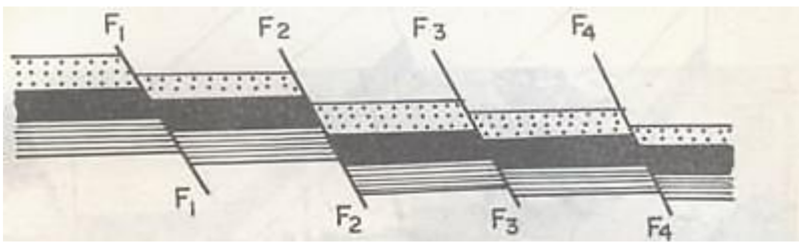
“**En Echelon faults”** are relatively short faults that overlap each other.

“**Peripheral faults”** are circular or arcuate faults that bound a circular area or part of a circular area.

“**Radial faults”** belong to a system of faults that radiate out from a point.

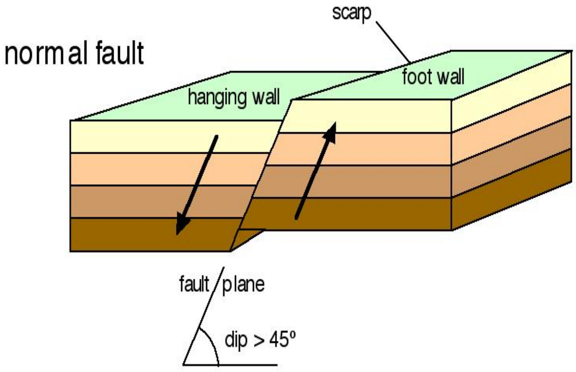


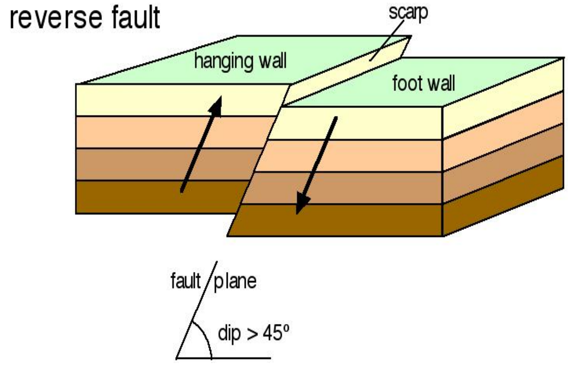


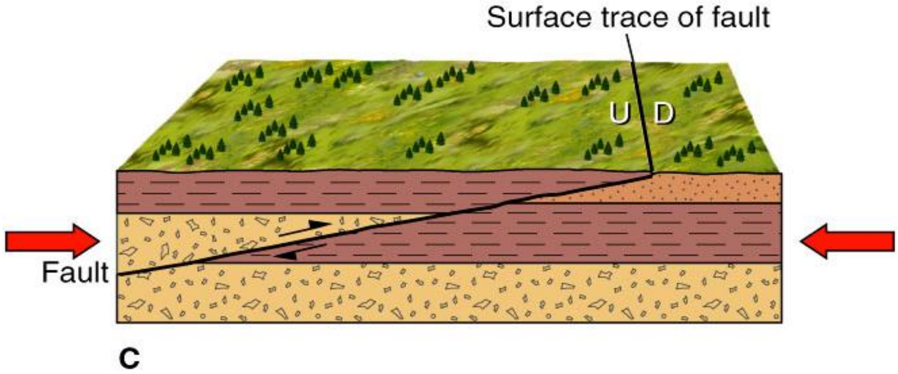


(iv) Based on value of Dip of fault:-

High- angle faults are those that dip greater than 45^0; **low-angle faults** are those that dip less than 45^0.

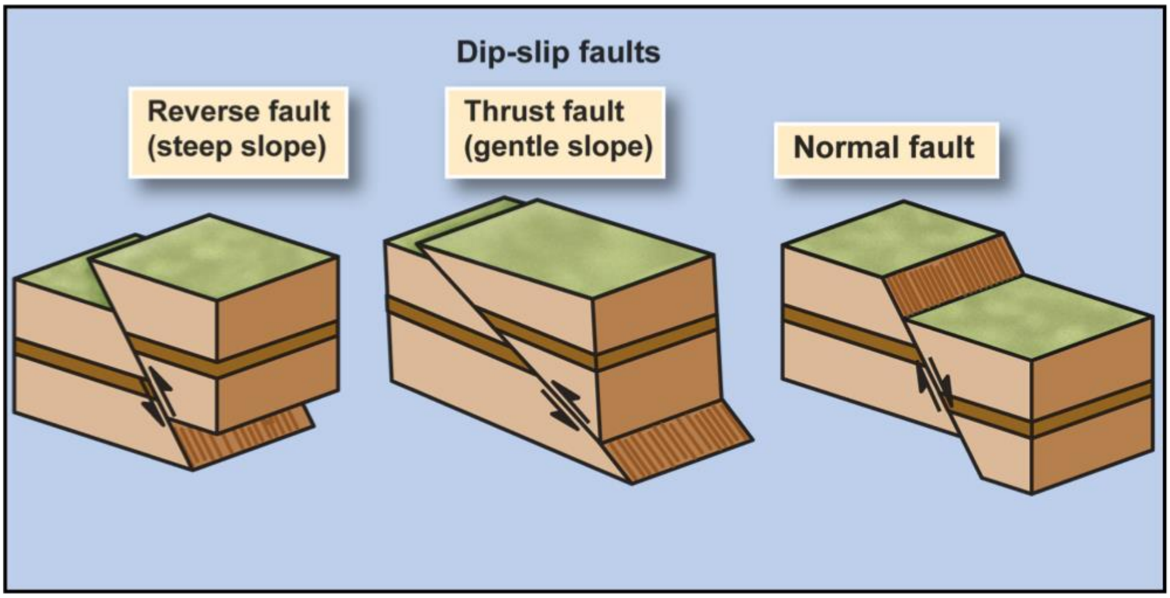






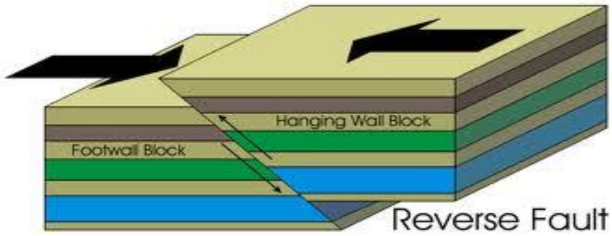
(v) Based upon apparent movement:-

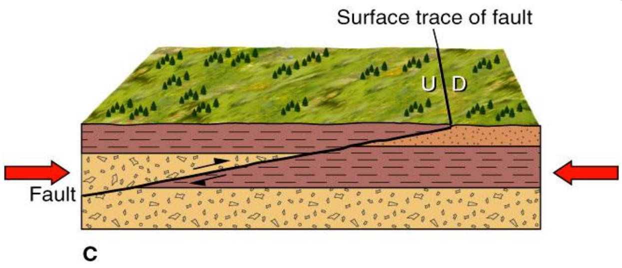
An "**apparent normal fault"** is one in which the hanging wall, in a vertical section at right angles to the strike of the fault, appears to have gone down relative to the footwall.
An "**apparent thrust fault"** [**reverse fault**] is one in which the hanging wall, in a vertical section at right angles to the strike of the fault, appears to have gone up relative to the footwall.



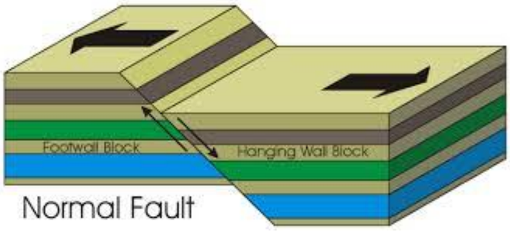
Genetic classification:-

A "**thrust fault"** or thrust is a fault along which the hanging wall has moved up relative to the footwall. **Three categories are usually recognized.** A "**reverse fault"** is a thrust that dips more than 45^0, the term **thrust** is one that dips less than 45^0, but **overthrust** is used for a fault that dips less than about 10^0 and has a large net slip.



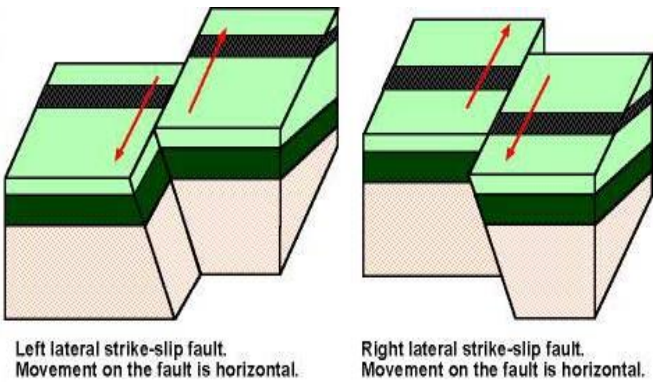


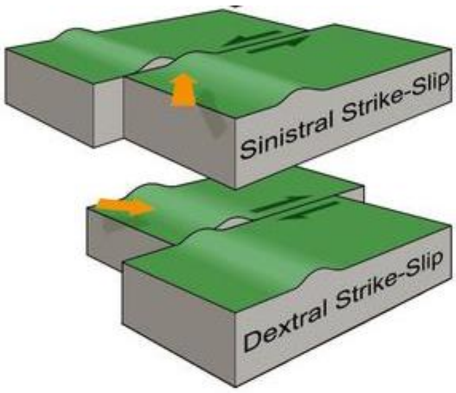
A “**normal fault”** is also known as gravity fault.



A “**detachment fault”** is a special category of low angle normal fault due to the downhill sliding of rocks from an uplifted region.

Strike-slip faults are also called **wrench faults (lateral fault or tear fault).** A “**right-slip fault”** is one in which the opposite wall moved relatively to the right (dextral). In which the right side block appears to have moved towards the observer. A “**left-slip fault”** is one in which the opposite wall moved relatively to the left (sinistral). In which the left block appears to have moved towads the abserver.

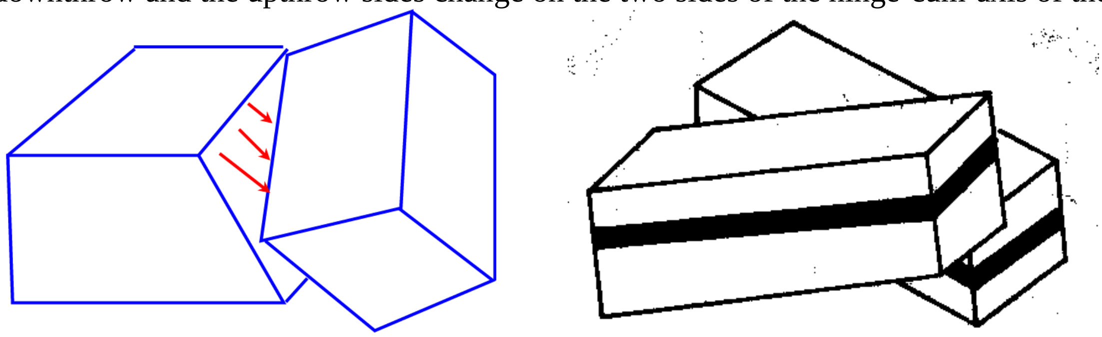




“**Upthrusts”** are high-angle faults along which the relatively uplifted block has been the active element.

“Under thrust” is used for those thrust faults in which the footwall has been the active element, whereas “overthrust” is used for those thrust faults in which the hanging wall has been the active element.

Rotational Faults: 1. "Hinge-Fault" is a fault with an angular or **rotational** displacement in which the wall rocks of one side have rotated along an axis normal to the fault plane with respect to the rocks of the other wall.Hinge fault is also called a **pivotal, rotational or scissors fault.** 2. "Axail Fault"is a fault the downthrow and the upthrow sides change on the two sides of the hinge-cum-axis of the fault.



Recognition of faults and field evidences in the field:

To locate a fault in the field is a bit difficult. If a bed occurs upon a surface and exhibiting a definite dip and strike of its own, terminates almost abruptly at some places, it is very likely that there exists a fault near about its point of termination. The same bed may, however, occur again somewhat off from the place where it terminated. Some discontinuous occurrence of rock beds in any region is definitely suggestive of the presence of a fault within them.

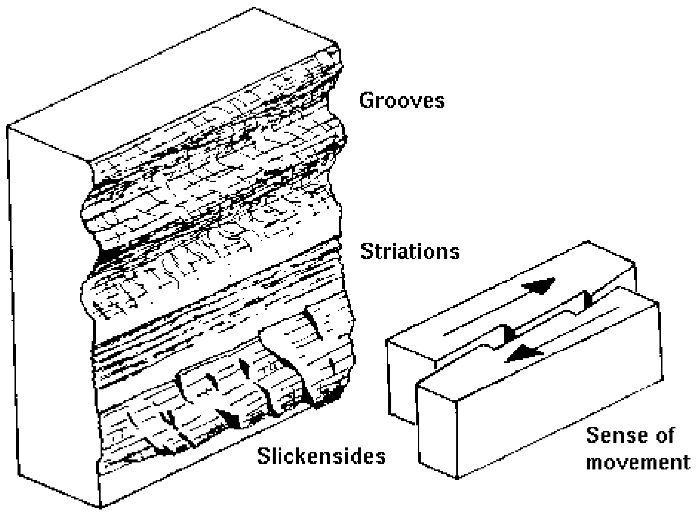
In any area affected by faulting, the rock beds forming the country rock are often found to be repeated and or omitted. This constitutes an important criterion for identification.

Faults sometimes give rise to "**Scarps"** which are rather steep and straight slopes formed along the strike of the fault plane due to relative displacement of the affected blocks along the vertical direction. Due to erosion these scarps are partially or totally destroyed. A real fault scarp always originates due to actual displacement of the faulted rock along the vertical direction.

The criteria for the recognition of faults may be considered according to (1) Discontinuity of structures; (2) Repetition or omission of strata; (3) features characteristic of fault planes-slickensides, drag, gouge, horses or slices, breccia, mylonite etc., (4) silicification and mineralization; (5) sudden changes in sedimentary facies; (6) physiographic data.

Grooves, Striations and Slickensides

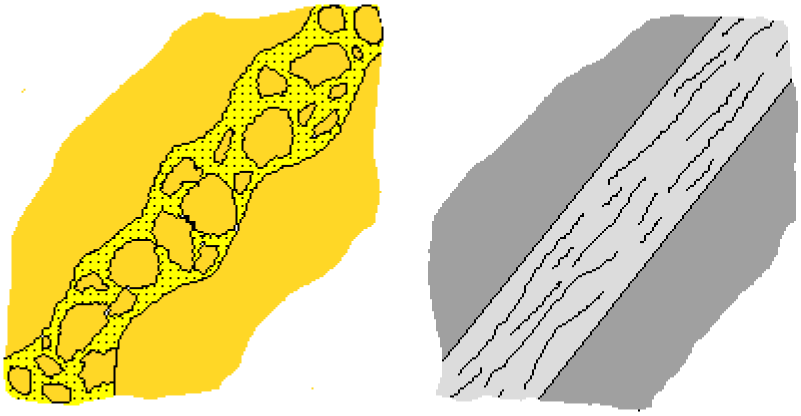
Fault surfaces often show grooves, straitions (scratches) and **asymmetric fracture patterns called slickensides.**



Only slickensides provide evidence of the movement of fault. The asymmetric surface roughness features are steepest downhill or down the shear direction. Slickensides refer to the smoothly polished surface caused by frictional movement between rocks on the two sides of a fault.

Breccia and Gouge

Faults are shear planes and commonly contain the debris from the frictional contact of the two surfaces. In strong rocks, material is fragmented to create a zone of crushed rock or fault breccia.



In weaker rocks, the material in the fault plane can be reduced to a very fine clay-size infill known as fault gouge. Gouge is very significant in engineering terms since the shear strength of the discontinuity is that of the weak gouge rather than the wall rock.

Horse is the geological technical term used for any block of rock completely separated from the surrounding rock

Lineament: - is a line, which serves to mark the location of fault traces.

(A **lineament** is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault.)

A "**scarp"** is a relatively steep, straight slope that may range in height.

A "**fault scarp"** owes its relief directly to the movement along the fault.

(A **fault scarp** is a small step on the ground surface where one side of a fault has moved vertically with respect to another)

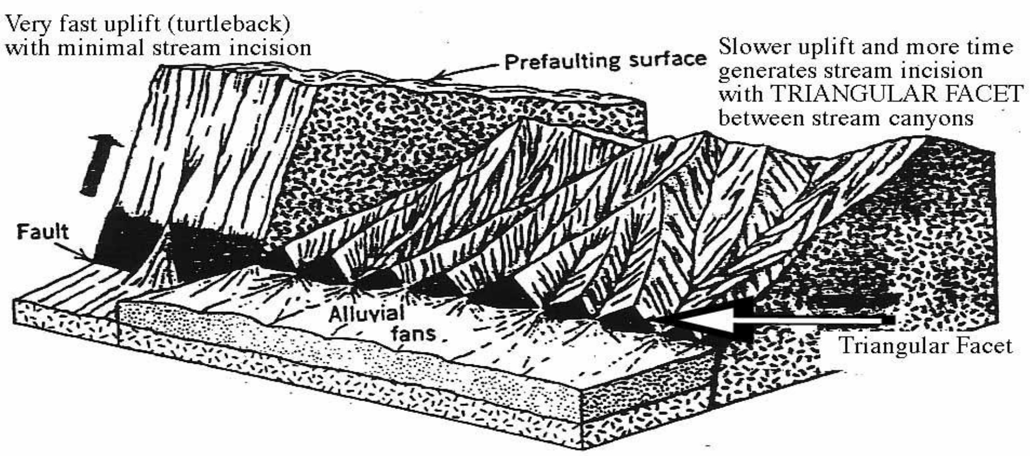
A "**fault-line scarp"** owes its relief to differential erosion along a fault line.

Piedmont scarps, sometimes called "**scarplets"** lie at or near the foot of mountain ranges.

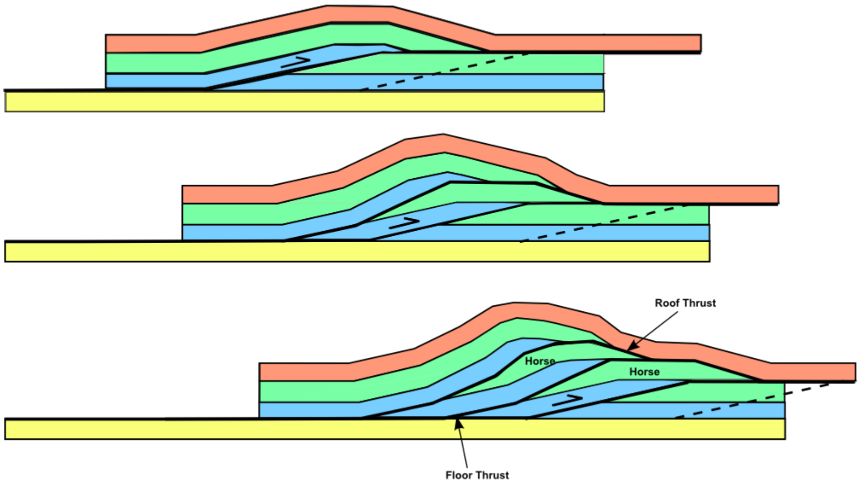
(A small, low cliff formed in alluvium on a piedmont slope at the foot of a steep mountain range; due to dislocation of the surface, especially by faulting. Also known as scarplet.)

"**Triangular facets"** are found on some scarps resulting from normal faulting.

(A triangular-shaped steep-sloped hill or cliff formed usually by the erosion of a fault-truncated hill.)



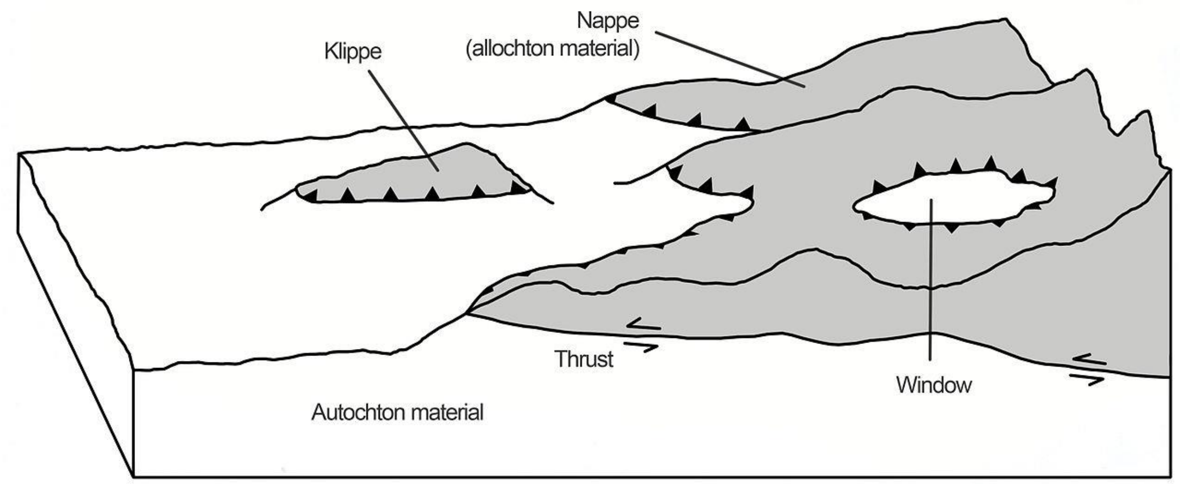
The term **"imbricate structure"** may be used for slabs that overlap one another. It is used for those cases in which several adjacent thrust planes dip in the same direction, as a result at which the intervening thrust sheets overlap one another.



A "**Nappe**"is a large thrust sheet or recumbent fold. It is best described as large body of solid rock that has moved over the underlying rocks a long distance by either recumbent folding or overthrusting. (A large recumbent fold or a low-angle thrust with large net-slip.)

A remnant of the overthrust sheet isolated by erosion from the main thrust sheet is known as "**Klippe**".

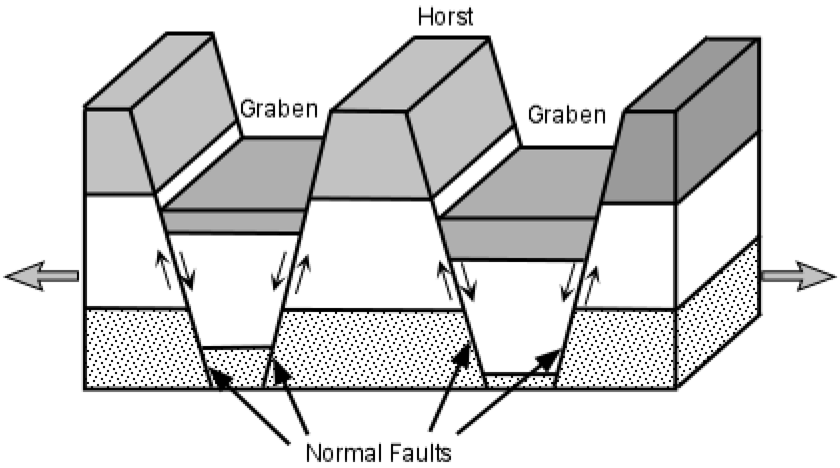
If erosion has broken through the upper sheet, exposing the rocks beneath the fault, the area is known as a "**fenster or window**" because it is possible to look through the upper sheet to the lower.



"**Step faulting**" is one in which the downthrown side is systematically on the same side of several parallel faults.

A "**horst**" is a block, generally long compared to its width, and has been raised relative to the blocks on either side. Generally, two, near parallel faults having a central upthrown block, produce such a fault. Morphologically, these give rise to hills or ridges.

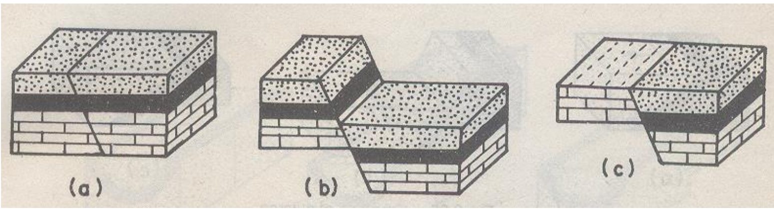
A "**Graben**" is a block, generally long compared to its width, which has been lowered relative to the block on either side. Such a fault is produced when two, near parallel faults have a central block thrown down. Morphologically such structures give rise to valleys which are very long. The faults bounding horsts and graben are usually steep normal faults.



General Effect of Faulting

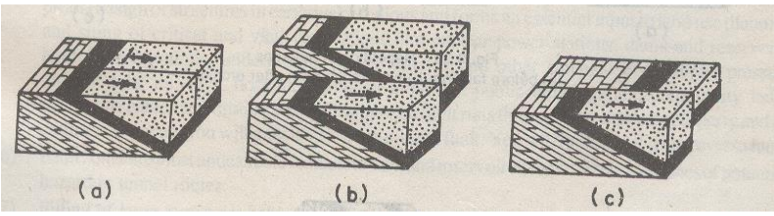
"Due to faulting younger beds of the down throw side will come in contact with older beds of the upthrow side along the fault plane".

1. **Effect on horizontal beds**: in case of horizontal beds due to faulting and erosion younger beds of the downthrow side will come into contact with the older beds of upthrow side along the fault plane and trace.

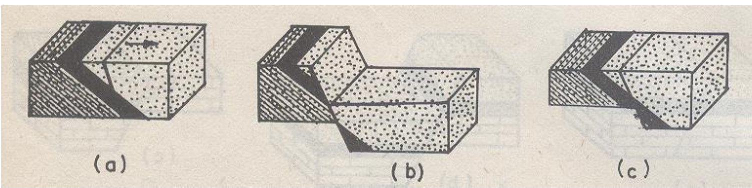


2. Effect on inclined beds:

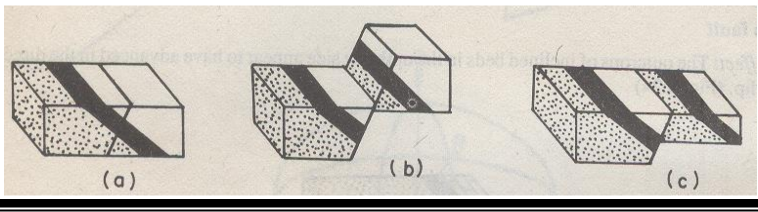
(a) Dip fault: Effect: the outcrop of inclined beds in the upthrow side appear to have advanced in the direction of the dip..



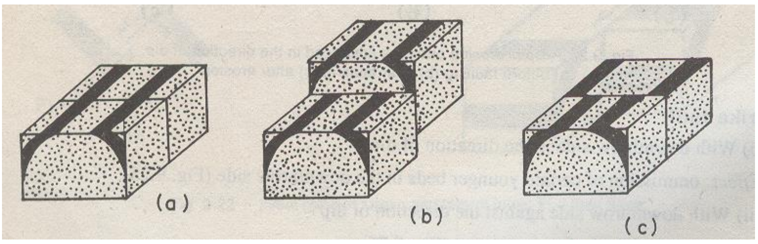
(b) Strke fault: (i) With downthrow side in the direction of dip – Effect: ommission of certain younger beds in the downthrow side.



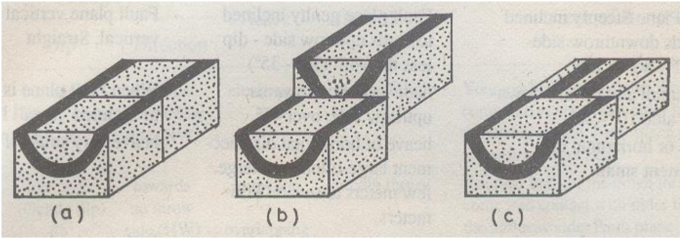
(ii) With downthrow side against the direction of dip – Effect: some of the beds are repeated.



3. Effects on folded beds:
(a) Dip fault on anticline: Effect: Outcrops of beds of the upthrow side become widened



(b) Dip fault on syncline: Effect: Outcrops of beds of the downthrow side become widened



Note: Reverse faults produce opposite effects. The effect of reverse or thrust faults is frequently to push older strata upon younger strata.

Causes of faulting: 1. Shearing stress (sliding action) 2. Convection currents (dragging)
3. Horizontal tension.

****

Shear zones: rock fractures along which some movement has occurred but not a great amount, at the level of a few centimeters. Usually, shear zone occurs in weak materials with rich of water, and in great depth.
Faults: fractures along which significant movement has occurs, much more than that associated with shear zones. The level of displacement is on the order of meters to kilometers, even to hundred kilometers.

****

JOINTS

Most rocks are broken by relatively smooth fractures known as “**Joints”.** The length of such fractures is measured in feet, tens of feet, or even hundreds of feet; the distance between them is likewise to be measured in feet or tens of feet. There has been no visible movement parallel to the surface of the joint; otherwise it would be classified as a fault.

Knowledge of joints is important in many kinds of geological studies. Quarry operations, especially those involved in obtaining blocks of certain dimension and sizes, are obviously greatly influenced by the joints. The orientation and concentration of joints is very significant in engineering projects. Closely spaced horizontal joints are obviously of great concern in tunneling. A large joint dipping into a highway cut is the site of a potential landslide. Wells drilled in granites for water supply will be more productive in highly jointed rocks than in less jointed rocks. Many studies of joints have been made in order to deduce the orientation of the stresses to which the rocks have been subjected.

Joints may have any attitude; some joints are vertical, others are horizontal, and many are inclined at various angles. The strike and dip of joints are measured in the same way as for bedding.

Classification of Joints:

Joints may be classified according to their

(a) The trend (strike) of joint trace relative to the attitude (dip and strike) of rock beds called geometric types.

(b) Mode of origin and forces responsible called genetic types.

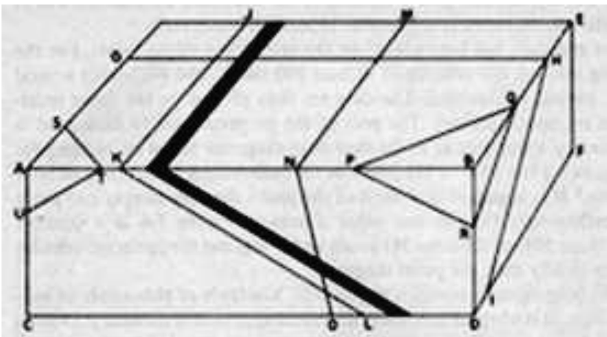
Geometric classification:

In a geometrical classification, the joints may be classified on the basis of their attitude relative to the bedding.

“**Strike Joints”** are those that strike parallel or essentially parallel to the strike of the bedding.

“**Dip Joints”** are those that strike parallel to the direction in which the bedding dips.

“**Oblique or diagonal”** joints are those striking in a direction that lies between the strike and direction of dip of the associated rocks.



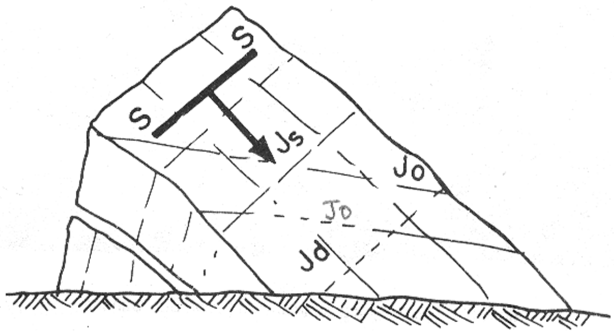


Fig.1. Heavy black layer is a bed. ABCD and GHI are dip joints; BDEF AND MNO are strike joints. JKL is bedding joint. PQR and STU are diagonal joints. Fig.2.Dip Joints(Jd), Strike Joint(Js) and Oblique Joint(Jo)

"**Bedding joints"** are parallel to the bedding of the associated sedimentary rocks.

A "**Joint set"** consists of a group of more or less parallel joints. A rock may be traversed profusely by joints but some of them may appear well developed and continuous for considerable length than the others. Such conspicuous joints are termed "master" or major joints.

A "**Joint System"** consists of two or more joint sets or any group of joints with a characteristic pattern.

Genetic Classification:

Basically two types of joints are recognised. They are Tension joints and Shear joints

(1) TENSION JOINTS: There are joints produced by tensional forces developed by increase or decrease of volume of rocks due to drying shrinkage while cooling or dehydration and stretching of the limbs of folded strata.

Tension joints in Igneous Rocks: As cooling and solidification progress magma or lava become increasingly rigid and ultimately rupture or crack producing tension joints. The different tension joints in igneous rocks are:

(a) Mural Joints: This system is typical of granites and related massive plutonic and certain hypabyssal rocks. Mural joints consist of three almost equally spaced mutually perpendicular joint sets dissecting the rock mass into cuboidal blocks. Mural joint system helps obtain easily intact cuboidal blocks of rock in quarries.

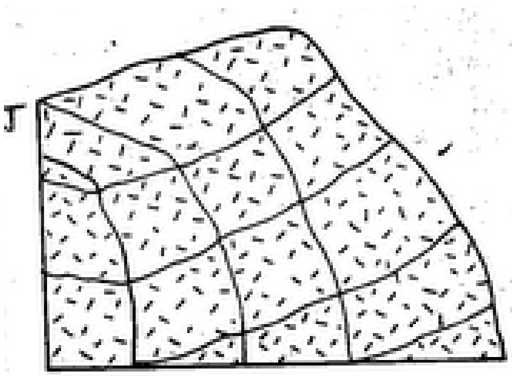


Fig.1. Mural Joints in Granite.

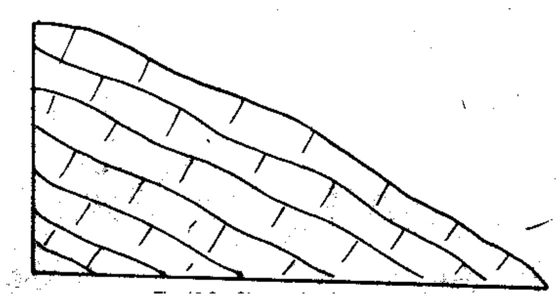
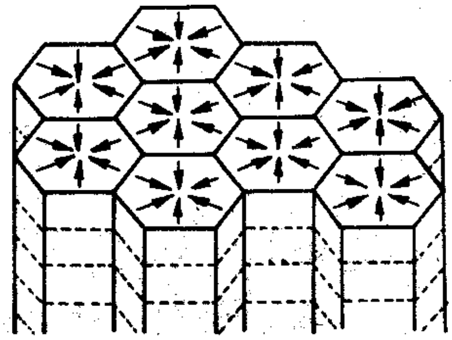


Fig. 2. Sheet Joints in Granite.

(b) Sheet joints: This system, also typical of granite and other plutonic rocks, consists of one set of prominent joints parallel to the ground surface with varying spacing usually increasing with depth, and the other less marked at right angles. Sheet joints dissect the rock mass into sheet like blocks. The layers of rocks generally are thinner near the surface and thicker at depth. These joints are produced by tensional forces due to relief from confining pressures (weathering of overburden causes the release of pressure) and consequent vertical expansion of the rock.

(c) Columnar joints: This system is typical of basalts and certain other volcanic igneous rocks, and consist of vertical and horizontal cross joints that dissect the rock mass into a number of vertical polygonal, usually hexagonal prismatic columns. They are produced by radial contraction during the cooling of lava flow. As a result vertical cracks develop perpendicular to this direction of contraction.



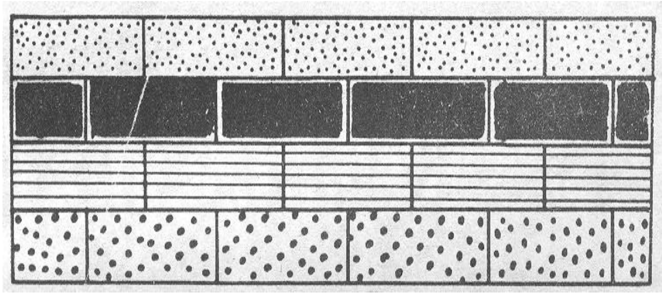


Fig. 1. Columnar Jointing in Granite. Fig. 2. Master Joints in Sedimentary rocks

Tension joints in sedimentary rocks:

(a) Master joints: This system is typical of sandstones and limestones and consists of three sets of mutually perpendicular joints of which one set parallels or coincides with the bedding planes. The other two sets traverses across the beds. Master joints dissect the rock mass into rectangular blocks.

(b) Extension and Release Joints: In case of folded strata tension joints are produced in the crestal region and extend either parallel or at right angles to the axial plane or in both the directions. Those that are parallel to the axial plane are called release joints (strike joints) and those at right angles are called extension joints (dip joints).

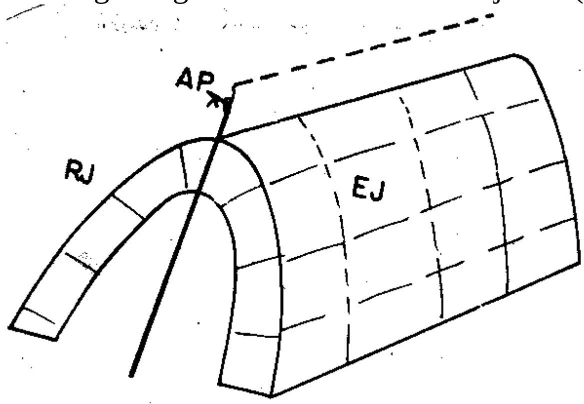


Fig. 1. Extention(EJ) and Release Joints(RJ), AP: Axial Plane

Tension joints in Metamorphic Rocks: Metamorphic rocks are the rocks which are derived from pre-existing rocks (ie. From igneous, sedimentary and even metamorphic rocks). So the joint pattern of the parent rock from which it was formed may be preserved wholly or partially or deformed or completely change over or destroyed. Thus massive rocks like gneiss show mural and sheet joints (like igneous rocks) where as marbles and quartizites show master joints (like sedimentary roks).

(2) SHEAR JOINTS: These are associated with the deformed rocks especially folded ones. Shear joints consists of intersecting or criss-cross sets, these are called **Conjugate Joint-System**. They are produced due to the shearing stresses involved in folding and faulting. This criss cross joint system consists of tow or three obliquely intersecting sets which dissects the rock mass into small rhombohedral or irregualr blocks, and fragments. They are mostly found in metamorphosed pegmatites and metamorphic rocks like quartizites, schists and amphibolites.

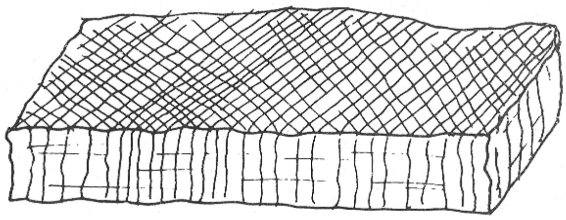


Fig. 1. Shear Joints(Conjugate Joint System)

Principles of failure by Rupture:

Most rocks are brittle and fail by rupture at the elastic limit.

Several factors are of concern: (1) the nature of the deformation preceding rupture; (2) the physical conditions at the time of rupture; (3) the stresses necessary to cause rupture; and (4) the orientation of the fractures relative to the causative stresses.

Joints may be classified genetically as either shear fractures or tension fractures. The ultimate causes may be several: (1) Tectonic stresses, (2) Residual stresses, (3) Contraction, and (4) Surficial movements.

***

Exfoliation domes are formed in some granitic areas.
"**Foliation"** is the property of rocks whereby they break along approximately parallel surfaces.
Lineation: is the result of the parallelism of some directional property in the rock.
"**Cleavage":** sometimes called "**rock cleavage"** to distinguish it from mineral cleavage, is the property of rocks whereby they break along parallel surfaces of secondary origin.
"**Schistosity"** is a term applied to the variety of rock cleavage found in rocks that are sufficiently recrystallized to be called schist or gneiss. Thus the secondary foliation of a slate would be called "cleavage", but a similar structure in mica schist would be termed "schistosity".

******

Rock Cleavage: Rock cleavage is a tendency of certain rocks to split into thin sheets along definite closely spaced parallel planes which may be inclined to the bedding planes. Rock cleavage is a secondary structure (to see in metamorphic rocks) confined to foliated rocks produced by directed pressure. Rock cleavage is characteristic of metamorphic rocks like schists and slate. Also found in limestones and shales (under low temp. and shearing stress). **It is the property of rocks whereby they break along parallel surfaces of secondary origin.**

Lineation: is the result of the parallelism of some directional property in the rock. Minerals that are acicular in habit or atleast are much more long than broad and thick (tabular crystals of feldspar or prismatic crystals of quartz) alone can produce lineation. The commonly occurring minerals in rocks showing lineation are hornblende, kyanite, actinolite and so on. Thus in general, the amphibolic minerals produce lineation more frequently. Followed by these are feldspar and quartz(Mineral lineation is commonly oriented parallel to local flow direction).

"**Foliation"** is the property of rocks whereby they break along approximately parallel surfaces.
A planar arrangement of textural or structural features in any type of rocks especially in gnessic rocks, i.e. metamorphic rocks.

"**Schistosity"** is a term applied to the variety of rock cleavage found in rocks that are sufficiently recrystallized to be called schist or gneiss. Thus the secondary foliation of a slate would be called "cleavage", but a similar structure in mica schist would be termed "schistosity".

The term cleavage is generally used slates in which this properety is best developed.

Schistosity for the schistose rocks, and Foliation for the gneissic rocks(alternative bands – light and dark minerals).

Rock cleavage caused by parallel arrangement of tabular lenticular or flaky constituents like micas, hornblende and chlorite – **Flow Cleavage.**

Flow cleavage is characteristic of slate and certain schists, and pervades the whole rock mass. It is also called slaty cleavage or schistosity.

The foliation in schist or other coarse grained, crystalline rock due to the parallel arrangement of minerals grains of the platy or prismatic types, usually mica. It is considered by some to be a type of cleavage.

Foliation is the result of the parallel arrangement of (micas, etc.) in a plane perpendicular to the maximum principal applied stress. A lineation is caused by a similar growth of elongate minerals (eg. hornblende) in this plane. **Slate, schist, and gneiss** are three common foliated metamorphic rocks. **Slate** is a hard, fine-grained rock with a well-developed rock cleavage or slaty cleavage caused by the incipient growth of platy (micaceous) minerals, due to metamorphism of fine-grained clastic sediments such as shale and siltstone and also volcanic tuffs. **Schist** is a still higher degree of metamorphism, characterized by coarse grained foliation and/or lineation, with mica crystals large enough to be easily identified with the unaided eye. **Gneiss** is a medium to coarse-grained, irregularly banded rock with only poorly developed cleavage. The light and dark bands ***(gneissic banding)*** are alternations of felsic vs. mafic layers.

****

Unconformities

(DATING OF STRUCTURAL EVENTS)

Unconformities are gaps in the geologic record that may indicate episodes of crustal deformation, erosion, and sea level variations as well as tectonic processes. They are a feature of stratified rocks, and are therefore usually found in sediments (but may also occur in stratified volcanics). Most important of all is the use of unconformities in dating orogenic and epiorogenic movements.

They are surfaces between two rock bodies that constitute a substantial break (hiatus) in the geologic record (sometimes people say inaccurately that "time" is missing). Unconformities represent times when deposition stopped, an interval of erosion removed some of the previously deposited rock, and finally deposition was resumed.

An “**unconformity”** is a surface of erosion or non-deposition-usually the former-that seperates younger strata from older rocks. The development of an unconformity involves several stages. The first stage is the formation of the older rock. Most commonly this is followed by uplift and subaerial erosion. Finally the younger strata are deposited.

An unconformity is a stratigraphic plane or contact that makes an important interruption of the stratigraphic record.

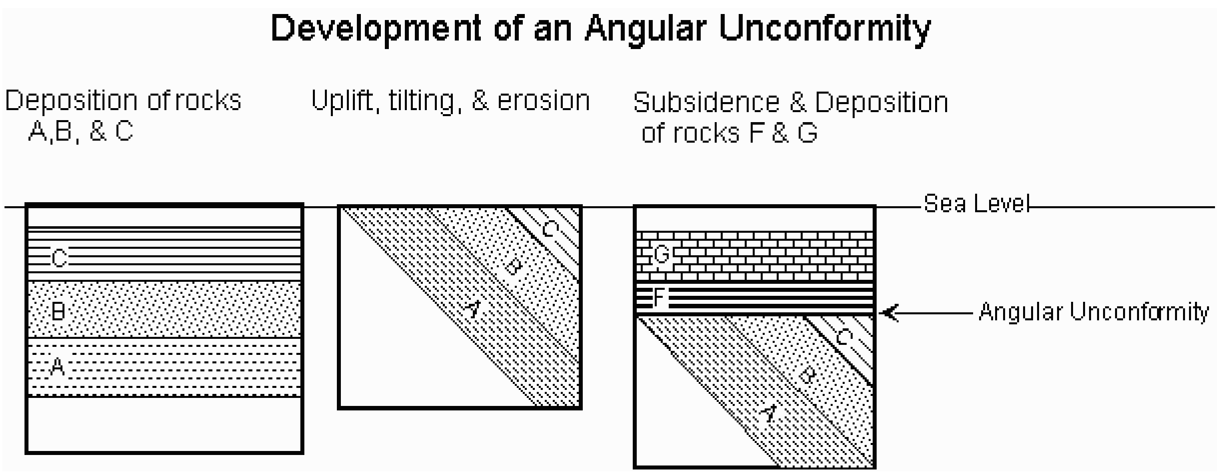
Rocks of various origins may participate in unconformities; sedimentary rocks, volcanic rocks, plutonic rocks, or metamorphic rocks may be involved.

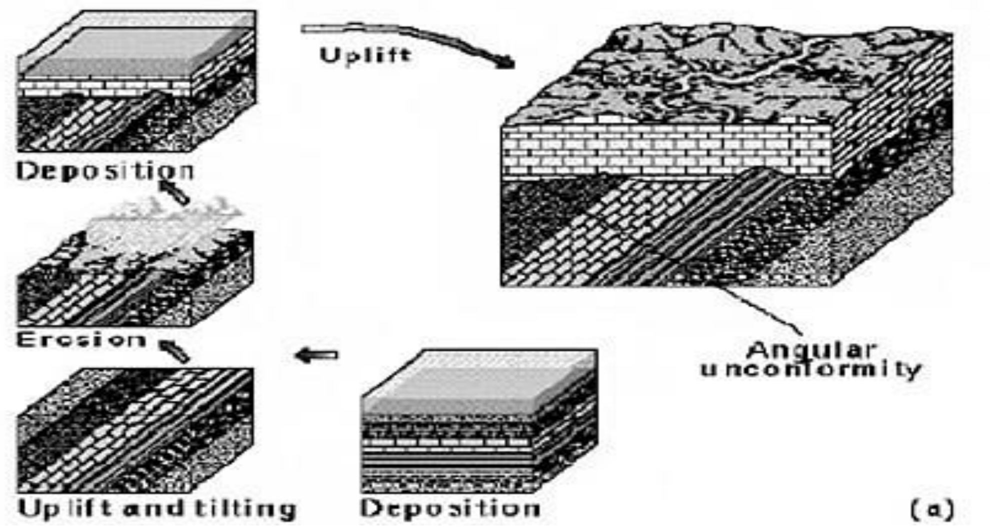
Commonly three types of unconformities are distinguished by geologists:

1. Angular unconformities 2. Disconformities 3. Nonconformities4. Local unconformity

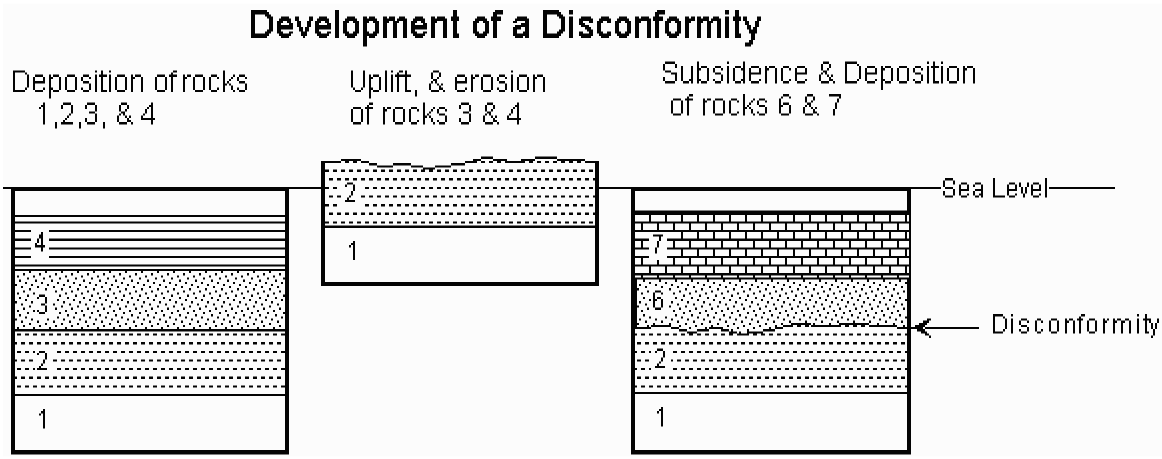
The rocks on opposite sides of an “angular unconformity” are not parallel.

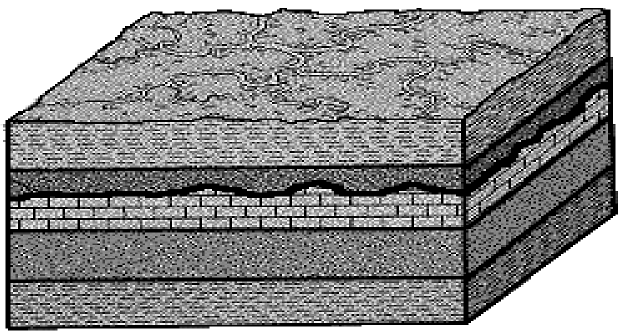
“Angular Unconformities” are those where an older package of sediments has been tilted, truncated by erosion, and than a younger package of sediments was deposited on this erosion surface. The sequence of events is summarized in the pictures at left. **First:** subsidence and sediment deposition occurs; **Second:** rocks are uplifted and tilted (deformation); **Third:** erosion removes the uplifted mountain range; **Fourth:** subsidence occurs, the sea covers the land surface, and new sediments deposition occurs on top the previous land surface. Then the cycle may repeat.



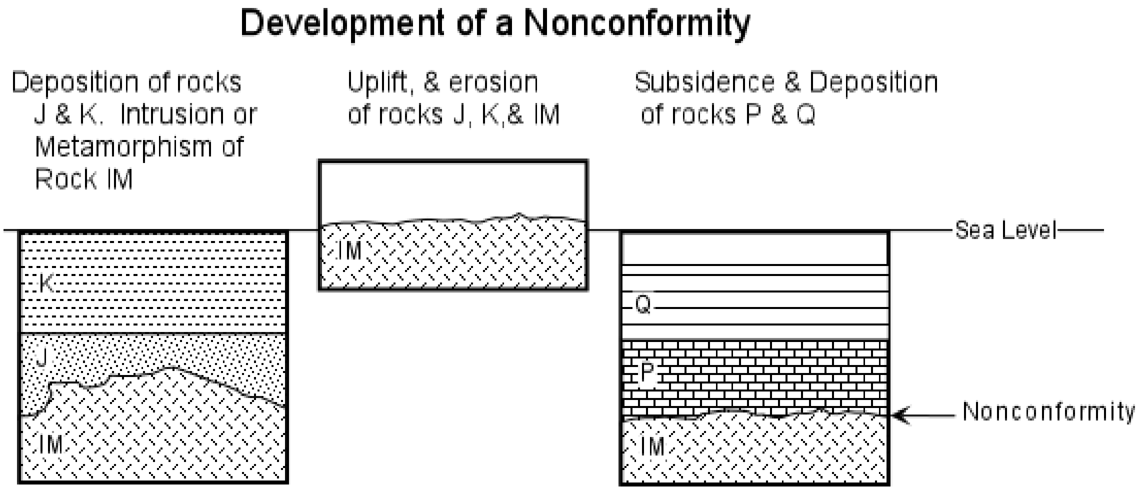


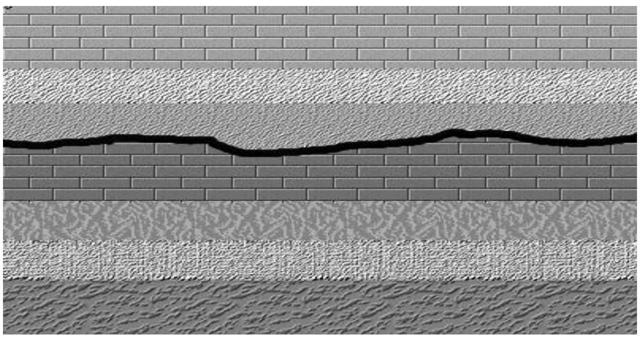
In a **"disconformity"** the formations on opposite sides of the unconformity are parallel. A disconformity covers a large area and represents a considerable interval of time. Disconformities are also an erosion surface between two packages of sediment, but the lower package of sediments was not tilted prior to deposition of the upper sediment package. The sequence of events is as follows: **First:** subsidence and sediment deposition; **Second:** uplift and erosion; **Third:** renewed subsidence and deposition. Because the beds below and above the disconformity are parallel, disconformities are more difficult to recognize in the sedimentary record. In the diagram at left, the disconformity is indicated by an irregular black line between the 3rd and 4th rock unit from the bottom.



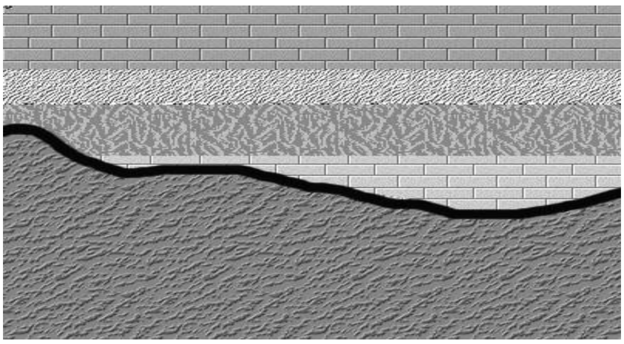


The term “**nonconformity”** is used for unconformities in which the older rock is of plutonic origin. Nonconformities are unconformities that separate igneous or metamorphic rocks from overlying sedimentary rocks. They usually indicate that a long period of erosion occurred prior to deposition of the sediments (several km of erosion necessary). In the diagram at left, the igneous/metamorphic rocks below the nonconformity are colored in red.

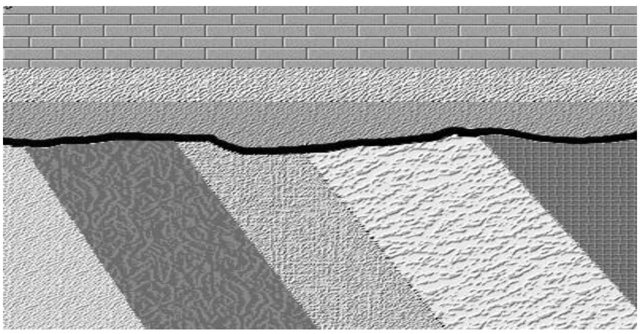




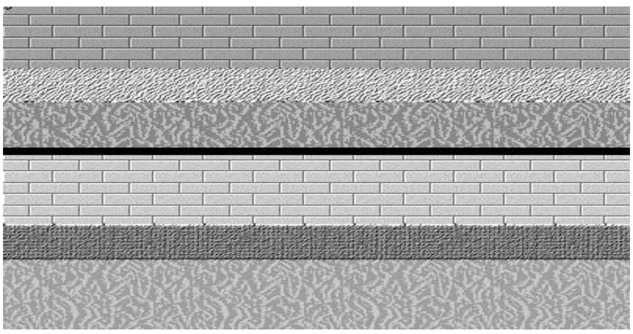
Disconformity



Nonconformity



Angular unconformity



Paraconformity

A **“paraconformity”** is a type of unconformity in which strata are parallel; there is little apparent erosion and the **unconformity surface resembles a simple bedding plane**. It is also called non depositional unconformity or pseudoconformity.

A “**local unconformity”** is similar to a disconformity, but, as the name implies, it is distinctly local in extent; the time involved is short.

Recognition of unconformities:-

The unconformable relation between two series of rocks may be exposed directly along river, road or railway cuttings. The vast majority of unconformities can be established successively only after a careful and detailed study of the nature and structure of the country rocks.

The beds belonging to the older formations commonly end abruptly against the lower surface of the bottom most bed belonging to the younger formations. In case of real **angular unconformity** the two participant formations must have dissimilar structure. Lack of parallelism of the beds on opposite sides of the contact. In case of **non-conformities** the older formations must be made up of plutonic rocks. In two unconformably related beds the bottom most horizon of the younger formations is commonly (but not necessarily) made up of "**conglomerate"** which is also called as **basal conglomerate,** suggests the existence of an unconformity. The pebbles of the conglomerate derived from the underlying formations.

The surface along which the two unconformably related groups of rocks lie in mutual contact is generally rough and rather uneven or wavy like nature.

There is a difference in the colour, lithological composition, thickness and order of superposition of the overlying strata with respect to underlying rocks. Abrupt changes in these characters may suggest the presence of an unconformity.

Difference in the grade of regional metamorphism of the underlying and overlying rocks. The less metamorphosed rocks were deposited unconformably upon the more metamorphosed rocks. Significant difference in the intensity of folding in both- younger and older set of beds.

The "palaeontology" may indicate an unconformity. Difference in age as indicated by the fossil assemblages of the overlying and underlying beds. Fossils of widely different ages either side of the **unconformity**. For example, if rocks with Triassic (230 – 195M.Y.) fossils is directly overlain by rocks with cretaceous (140 – 65 M.Y.) fossils, it is said to be an unconformity. i.e the Jurassic (195 - 140) rocks are missing.

Distinguishing faults from unconformities

Unconformities	Faults
An erosion surface	A shear fracture
Involves two or more series of different ages	One series of a period only
Offset of beds of one series along a line	Dislocation of beds along a line
Parallel or discordant contact of two different series of different ages along the both sides of eroded surface	Contact of outcrops of rocks of different ages of the same sequence along the both sides of the fault plane
Intrusive bodies in older series are not affected	Intrusive bodies like sills and dikes are affected by faulting
Sudden change in the fossil content	No changes of sequence and included fossils in the the footwall and hanging wall formations
Indicated by small ridges of the older rock may project into the younger rocks, and a basal conglomerate or sandstone, with fragments of the older rock, may lie above the contact,	Indicated by fault breccia or mylonite, slickensides, gouge, and breccia, would be absent from an unconformity

Hiatus:

An unconformity which represents a long geological period (during which break in sedimentation had occurred) is known as a “hiatus”. In our country we find such a hiatus in the peninsular region, where, after the formation of precambrian strata (i.e., the Cuddapah system and the Vindhyan system) there was no deposition of sediments for a long geological time (this time gap covers the cambrian period of 100 million years, the ordovician period of 60 million years, the silurian period of 35 million years and the Devonian period of 60 million years; i.e., total approximately 300 million years). After that, the sedimentation resumed there, and the Gondwana group of rocks was formed.

Diastem:

A short interruption in deposition with little or no erosion before resumption of sedimentation. Diastems are not an appropriate basis for establishing unconformity-bounded units.

Overlap:

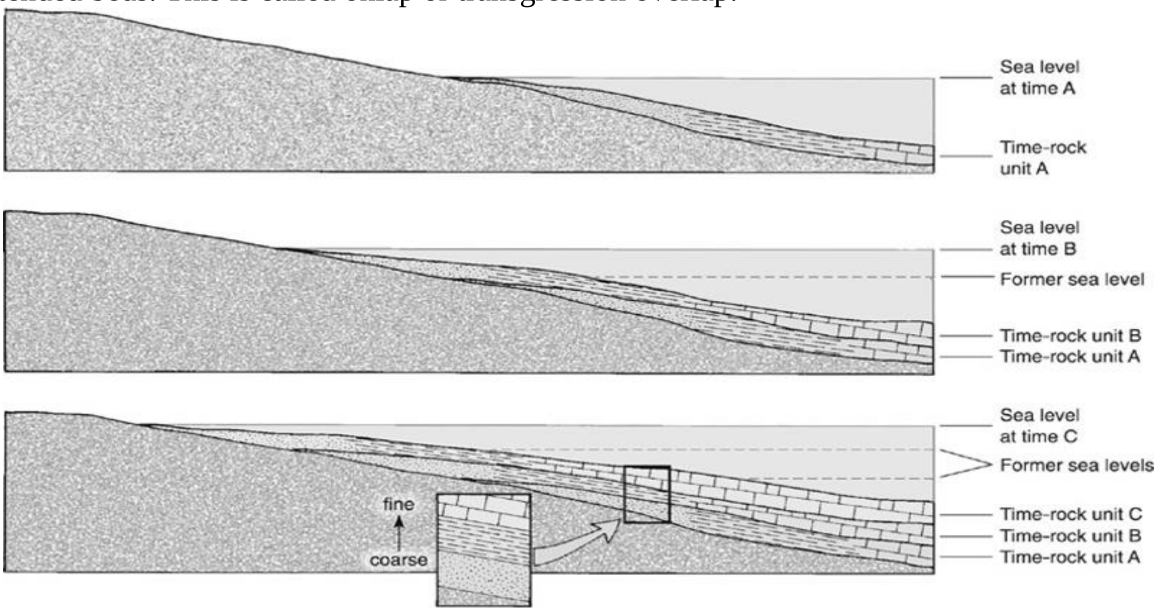
Overlap is an extension of an younger bed beyond the edge of the immediate older bed below in a unconformable sequence. Overlap is an important depositional feature associated with unconformity and formed commonly in shore regions as a consequence of marine transgression or regression. Overlap is of two kinds.

(a) **Onlap or transgression overlap**

(b) **Offlap or regression overlap**

(a) Onlap (transgression overlap)

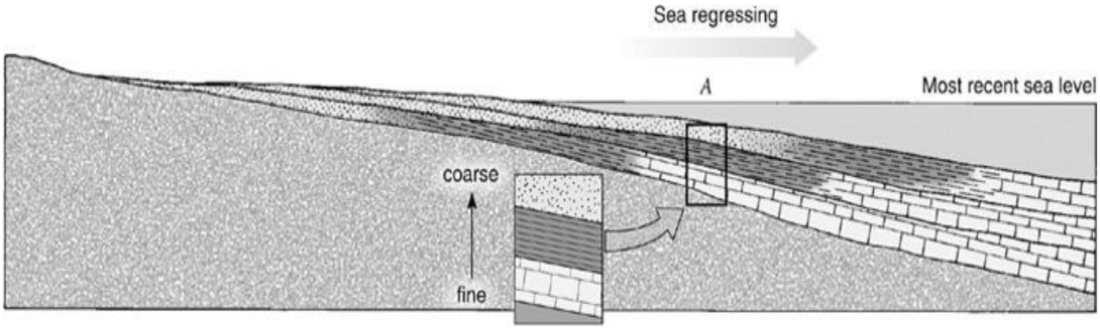
During marine transgression that is the encroach of a shallow sea on shore either due to rise of sea level or sinking of the land the area of deposition increases and extend inland. Sedimentation takes place over the existing beds below sea level and extend beyond their margins landward. By this the older beds in the sequence are completely concealed beneath the extended beds. This is called onlap or transgression overlap.



Onlap or transgression overlap

(b) Offlap (Regression overlap)

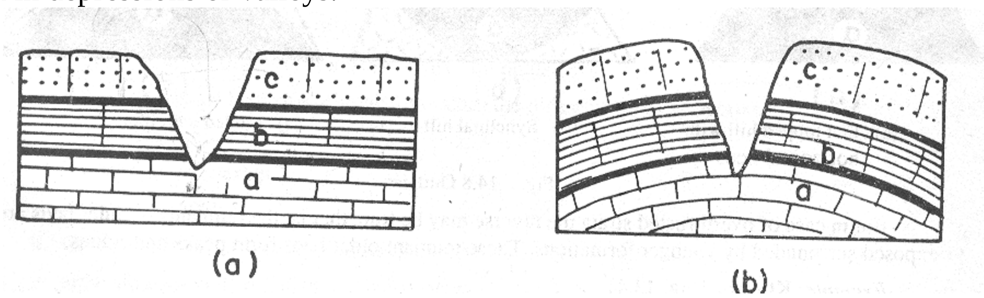
This is the reverse of the transgression overlap. During marine regression that is when a shallow sea recedes as a result of emergence of land or fall in sea level the area of deposition gets reduced as the shoreline receds seaward. Sedimentation taken place in such cases at succedingly lower levels on the existing older beds according to receding sea level.



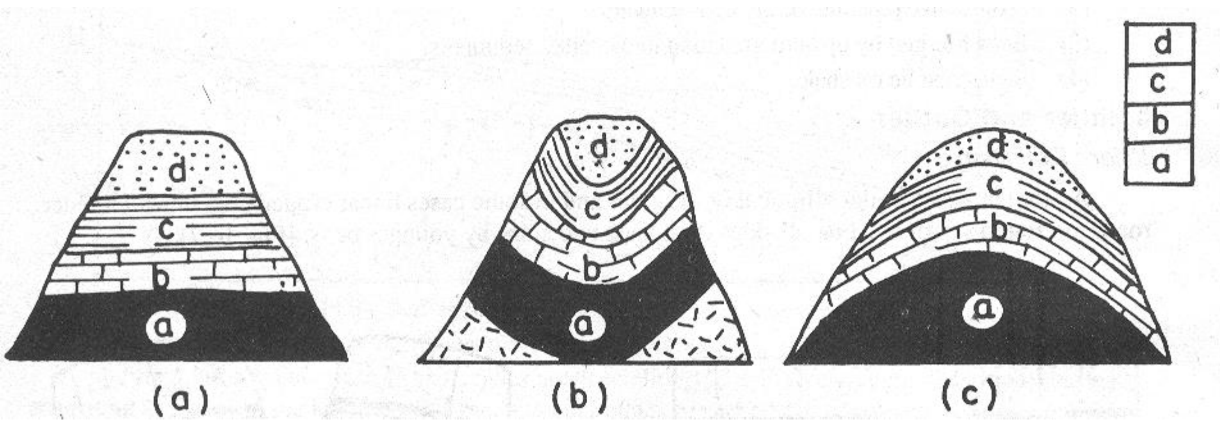
Onlap (transgression overlap)

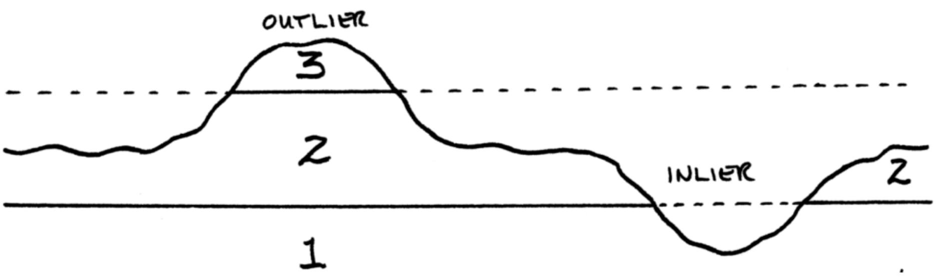
Inlier and Outlier:

Inlier: An **inlier** is an exposure of older strata surrounded by younger. A more or less circular elliptical or irregular and in some cases linear eroded area in which older rocks are found sorrounded on all sides or at least two sides by younger beds. Inliers are typical erosion structures and are commonly found in depressions or valleys.



Outlier: An **Outlier** is an exposure of Younger strata that are completely surrounded by older.
It is an isolated mass or detached remnant of younger rocks surrounded aerially by older formations. Outlier are typical erosional structures and the reverse of inliers. These are commonly found produced in horizontal strata or along the axes of synclines and standout prominently as hills with younger beds forming the summits.





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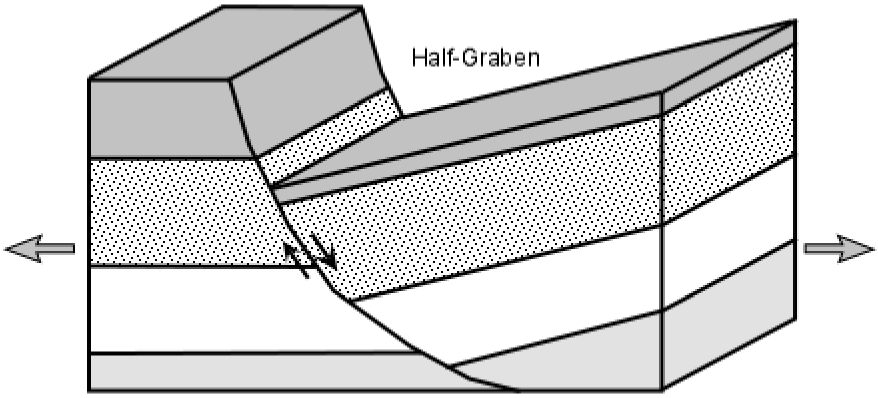


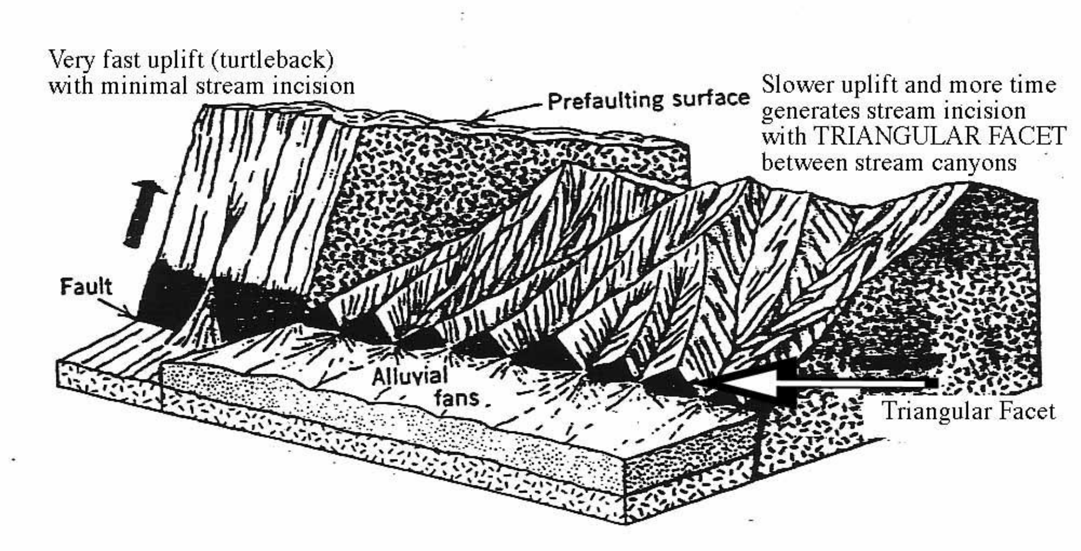
Half-Grabens **-** A normal fault that has a curved fault plane with the dip decreasing with depth can cause the down-dropped block to rotate. In such a case a half-graben is produced, called such because it is bounded by only one fault instead of the two that form a normal graben.

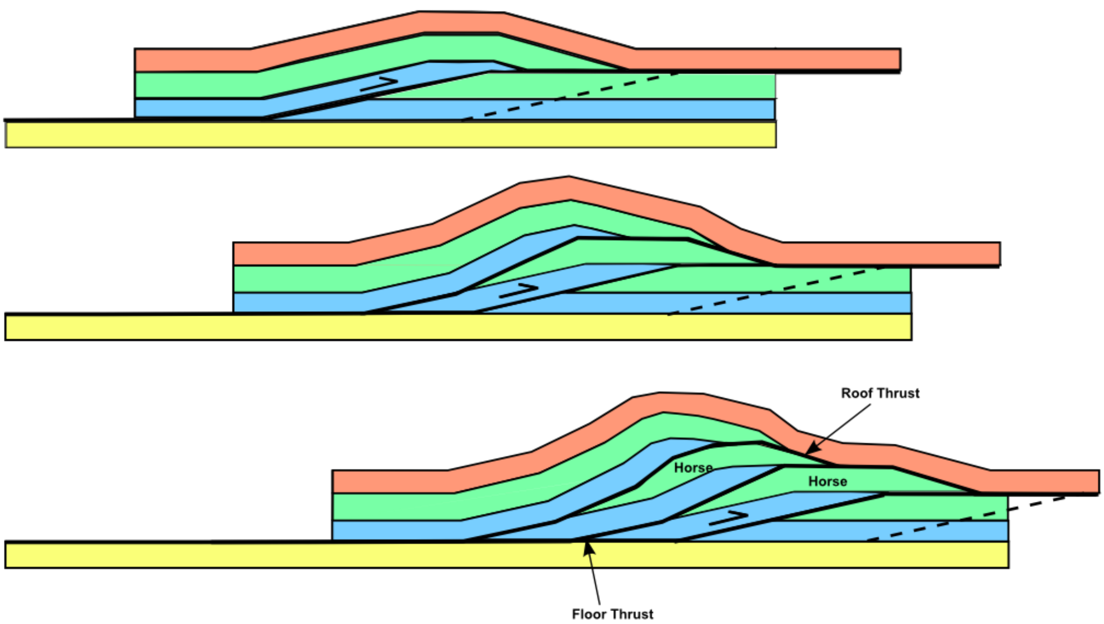
Transform-Faults are a special class of strike-slip faults. These are plate boundaries along which two plates slide past one another in a horizontal manner. The most common type of transform faults occur where oceanic ridges are offset. Note that the transform fault only occurs between the two segments of the ridge. Outside of this area there is no relative movement because blocks are moving in the same direction. These areas are called fracture zones. The San Andreas fault in California is also a transform fault.

******

Fault scarps are short-lived features in geologic terms, enduring no more than a few millennia at best; they are one of the purest tectonic landforms. But the movements that raise scarps leave a large area of land on one side of the fault higher than the other side, a persistent elevation difference that erosion can obscure but never erase. As fault displacement is repeated thousands of times over millions of years, larger escarpments and whole mountain ranges—like the high Sierra Nevada range beyond—can arise.

A small, low cliff formed in alluvium on a piedmont slope at the foot of a steep mountain range; due to dislocation of the surface, especially by faulting. Also known as **scarplet**.





326 - STRUCTURAL GEOLOGY
MORE ON FAULTS
Faults can be recognized by three basic criteria:
Features of faults themselves
· fault rocks (see chart in text)
· slickensides etc.

Effects on stratigraphic units
· break in continuous stratigraphic section; truncation of structures
· (don't confuse faults w/ unconformities--upper units usually parallel to contact)
· horses (fault slices) = blocks surrounded on all sides by faults--usually displaced a large distance from original position
· repetition of strata
· omission of strata
· drag folds (also reverse drag)

Effects on topography or geomorphology
· scarps
· offset ridges, valleys, streams
· springs, sag ponds
· nickpoints in streams
More terms
cutoff line = intersection of displaced bed w/ fault plane
hangingwall cutoff, footwall cutoff
fault ramps = connect segments of faults
frontal ramp, lateral ramp (sidewall ramp)
jog, bend (strike-slip faults)
fault duplex = multiple ramps that produce imbricate slices (or horses)
(see additional list of terms under "Activities" section of syllabus)

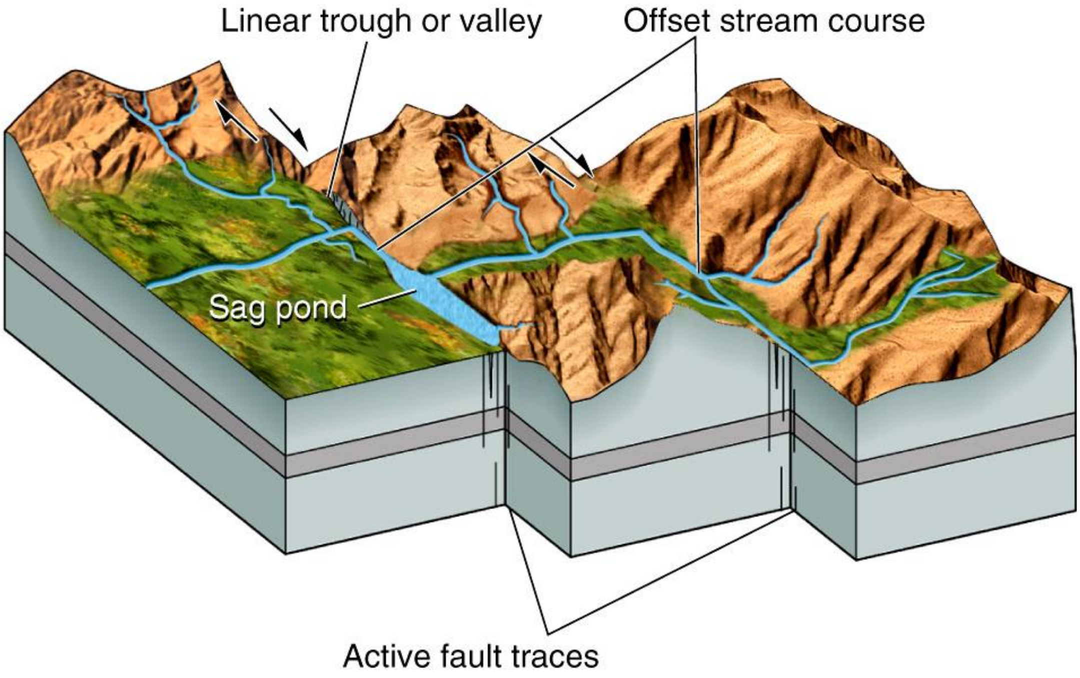
****

How do geologists recognize faults in the field?

In: **Earthquakes** [**Edit categories**]

Answer:

Fault scarp: A steep slope resulting from the movement of rock strata Slickensides and slickenlines: Slickensides refer to the smoothly polished surface caused by frictional movement between rocks on the two sides of a fault, while slickenlines are groove marks on fault surfaces, slickensides, produced by the rubbing forces of the two sides of the fault. Fault breccia: angular fragments of rock resulting from the frictional movement on fault zones. Straight rivers and a long line of green vegetated area: since faulting is accompanied by friction between the two sides of the fault, the rocks at the fault zone are commonly pulverized, fragmented and weakened. As a result, running water from streams and rivers would tend to flow along the fault zone because that is the place where rocks are weaker to erode. Moreover, groundwater usually finds its way to the surface along the openings created by faults. Hence in areas where there are fault lines we also see plants flourishing, because they are close to groundwater source. Thus, exceptionally straight flowing rivers and streamsor long lines of vegetated areas are evidence of the presence of a fault.



- Fault scarp: A steep slope resulting from the movement of rock

Slickensides refer to the smoothly polished

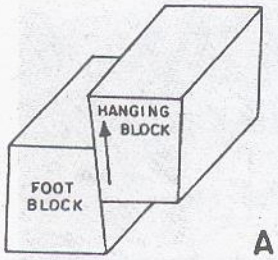
- surface caused by frictional movement between rocks on the two sides of a fault,
- while slickenlines are groove marks on fault surfaces, slickensides, produced by
- the rubbing forces of the two sides of the fault. Fault breccia: angular
- fragments of rock resulting from the frictional movement on fault zones.
- Straight rivers and a long line of green vegetated area: since faulting is
- accompanied by friction between the two sides of the fault, the rocks at the
-
- fault zone are commonly pulverized, fragmented and weakened. As a result,
- running water from streams and rivers would tend to flow along the fault zone
- because that is the place where rocks are weaker to erode. Moreover, groundwater
- usually finds its way to the surface along the openings created by faults. Hence
- in areas where there are fault lines we also see plants flourishing, because
- they are close to groundwater source. Thus, exceptionally straight flowing
- rivers and streams or long lines of vegetated areas are evidence of the presence

of a fault.

What are the different parts of Faults?

SHYAM SONI

Description: Faults are well-defined cracks along which the rock-masses on either side have relative displacement. The attitudes of faults are defined in terms of their strike and dip. The strike and dip of a fault are measured in the same way as they are for bedding.



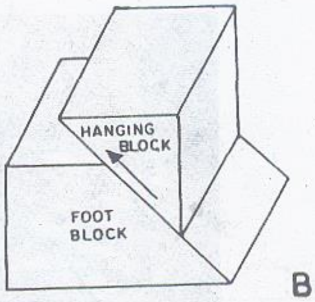
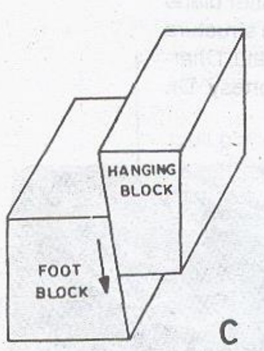


Fig. 63A Upthrust.
Note that the fault plane is nearly vertical. The hanging block has moved up and against gravity, and therefore against the direction of dip of the fault plane.

Fig. 63B Upthrust
Note that the fault plane has moderate inclination and the hanging block has moved up and against the gravity. It is therefore against the direction of dip of the fault plane.



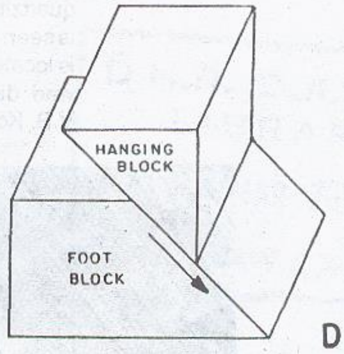
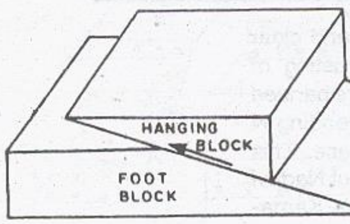


Fig. 63C. Downthrust
Note that the fault plane is nearly vertical and the foot block has moved down and in the direction of gravity. It is therefore down the dip direction of the fault plane.

Fig. 63D. Downthrust
Note that the fault plane has a moderate inclination. The foot block has moved down and in the direction of gravity. It is therefore down the dip direction of the fault plane.



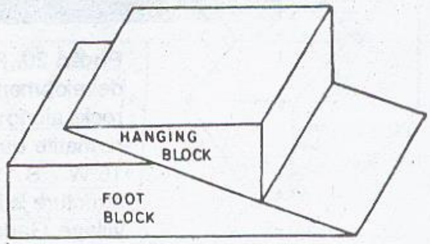


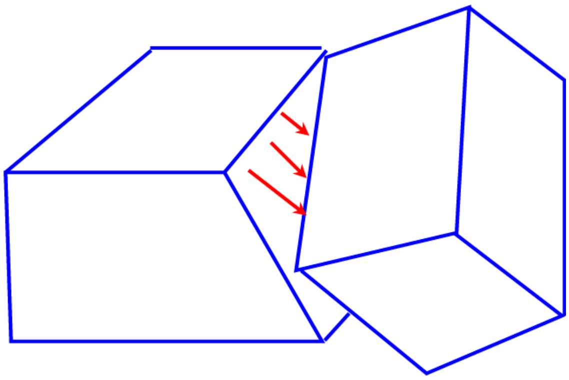
Fig. 64. Overthrust
Note that the fault plane has a low dip, and the hanging block has moved up and against the direction of dip of the fault plane. On comparing it with Figures 63 A,B, it is clearly seen that the hanging block "rides over" the foot block. It is hence called an "overthrust fault".

Fig. 65 Underthrust.
Note that the fault plane has a low dip, and the foot block has moved down and in the direction of dip of the fault plane. On comparing Figures 63 C,D with the present one, it is observed that the foot block is "thrust under" the hanging block. It is hence called an "underthrust" fault.

Hybrid-Faults

Scissors Faults- (rotational) -

Amount of slip changes along the strike of the fault



The followings are the parts of a fault:

(i) Footwall and hanging-wall:

Of the two blocks lying on either side of the fault-plane, one appears to rest on the other. The former is known as hanging-wall side whiles the latter which supports the hanging-wall is known as the footwall side.

(ii) Fault scrap:

The relative displacement on either side of the fault line results in an upstanding structure with a steep side which is called 'fault scrap'.

Fault-line scrap:

It owes its relief due to differential erosion along a fault-line.

(iii) Down thrown side and up-thrown side:

In case of a fault, one of the dislocated blocks appears to have been shifted downwards in comparison with the adjoining block lying on the other side of the fault-plane. The former, therefore is known as the down-thrown side while the latter is described as the up-thrown side.

Terminologies associated with faults:

1. Strike:

Strike of the fault is the trend of a horizontal line in the plane of the fault.

2. Dip:

Dip is the angle between a horizontal surface and the plane of the fault and is measured in a vertical plane that strikes at right angles to the fault.

3. Hade:

It is the complement angle of dip, i.e., the angle which the fault plane makes with the vertical plane or (90°-Dip -Hade).

4. Throw and heave:

The throw of a fault is the vertical component of the apparent displacement of abed, measured along direction of dip of the fault.

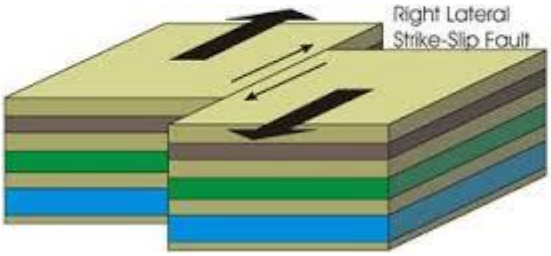
The heave of a fault, in a like manner, is the horizontal component of the apparent displacement. It is also known as gape.

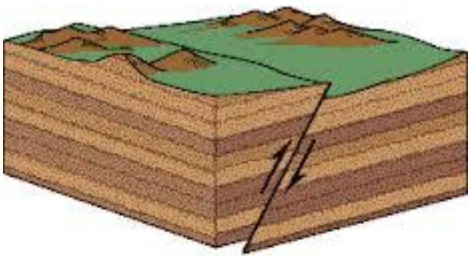
5. Stratigraphic throw:

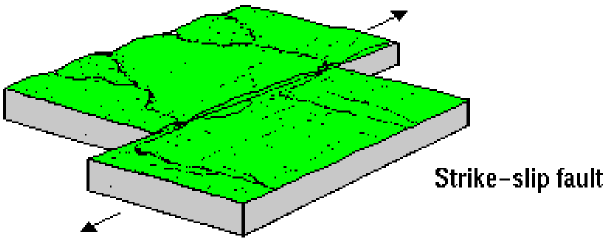
If the same bed occurs twice because of faulting, the perpendicular distance between them measured along a vertical section at right angles to the strike of the fault, is known, as stratigraphic throw.

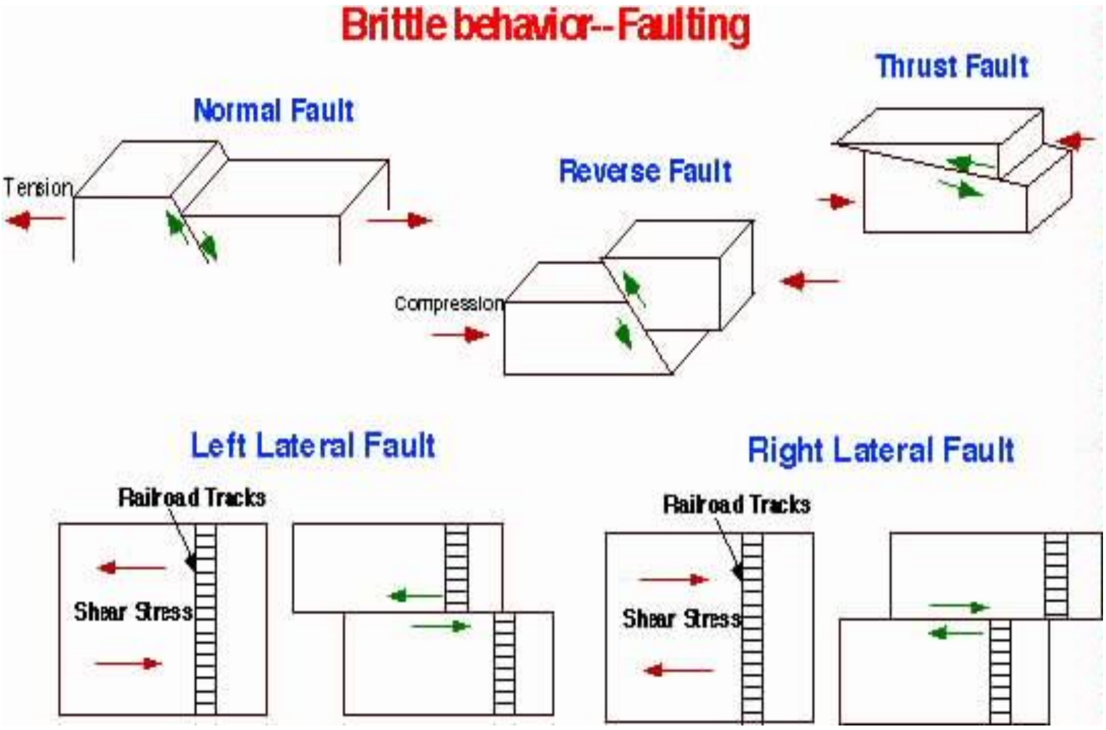
6. Net-slip:

The total displacement due to a fault is described as its net-slip.









JOINTS

Most rocks are broken by relatively smooth fractures known as "**Joints".** The length of such fractures is measured in feet, tens of feet, or even hundreds of feet; the distance between them is likewise to be measured in feet or tens of feet. There has been no visible movement parallel to the surface of the joint; otherwise it would be classified as a fault.

Knowledge of joints is important in many kinds of geological studies. Quarry operations, especially those involved in obtaining blocks of certain dimension and sizes, are obviously greatly influenced by the joints. The orientation and concentration of joints is very significant in engineering projects. Closely spaced horizontal joints are obviously of great concern in tunneling. A large joint dipping into a highway cut is the site of a potential landslide. Wells drilled in granites for water supply will be more productive in highly jointed rocks than in less jointed rocks. Many studies of joints have been made in order to deduce the orientation of the stresses to which the rocks have been subjected.

Joints may have any attitude; some joints are vertical, others are horizontal, and many are inclined at various angles. The strike and dip of joints are measured in the same way as for bedding.

Classification of Joints:

Joints may be classified according to their

The trend (strike) of joint trace relative to the attitude (dip and strike) of rock beds called geometric types.

Mode of origin and forces responsible called genetic types.

Geometric classification:

In a geometrical classification, the joints may be classified on the basis of their attitude relative to the bedding.

"**Strike Joints"** are those that strike parallel or essentially parallel to the strike of the bedding.

"**Dip Joints"** are those that strike parallel to the direction in which the bedding dips.

"**Oblique or diagonal"** joints are those striking in a direction that lies between the strike and direction of dip of the associated rocks.

"**Bedding joints"** are parallel to the bedding of the associated sedimentary rocks.

A "**Joint set"** consists of a group of more or less parallel joints. A rock may be traversed profusely by joints but some of them may appear well developed and continuous for considerable length than the others. Such conspicuous joints are termed "master" or major joints.

A "**Joint System"** consists of two or more joint sets or any group of joints with a characteristic pattern.

Genetic Classification:

Basically two types of joints are recognised. They are Tension joints and Shear joints

TENSION JOINTS: There are joints produced by tensional forces developed by increase or decrease of volume of rocks due to drying shrinkage while cooling or dehydration and stretching of the limbs of folded strata.

Tension joints in Igneous Rocks: As cooling and solidification progress magma or lava become increasingly rigid and ultimately rupture or crack producing tension joints. The different tension joints in igneous rocks are:

Mural Joints: This system is typical of granites and related massive plutonic and certain hypabyssal rocks. Mural joints consist of three almost equally spaced mutually perpendicular joint sets dissecting the rock mass into cuboidal blocks. Mural joint system helps obtain easily intact cuboidal blocks of rock in quarries.

Sheet joints: This system, also typical of granite and other plutonic rocks, consists of one set of prominent joints parallel to the ground surface with varying spacing usually increasing with depth, and the other less marked at right angles. Sheet joints dissect the rock mass into sheet like blocks. The layers of rocks generally are thinner near the surface and thicker at depth. These joints are produced by tensional forces due to relief from confining pressures (weathering of overburden causes the release of pressure) and consequent vertical expansion of the rock.

Columnar joints: This system is typical of basalts and certain other volcanic igneous rocks, and consist of vertical and horizontal cross joints that dissect the rock mass into a number of vertical polygonal, usually hexagonal prismatic columns. They are produced by radial contraction during the cooling of lava flow. As a result vertical cracks develop perpendicular to this direction of contraction.

Tension joints in sedimentary rocks:

Master joints: This system is typical of sandstones and limestones and consists of three sets of mutually perpendicular joints of which one set parallels or coincides with the bedding planes. The other two sets traverses across the beds. Master joints dissect the rock mass into rectangular blocks.

Extension and Release Joints: In case of folded strata tension joints are produced in the crestal region and extend either parallel or at right angles to the axial plane or in both the directions. Those that are parallel to the axial plane are called release joints (strike joints) and those at right angles are called extension joints (dip joints).

Tension joints in Metamorphic Rocks: Metamorphic rocks are the rocks which are derived from pre-existing rocks (ie. From igneous, sedimentary and even metamorphic rocks). So the joint pattern of the parent rock from which it was formed may be preserved wholly or partially or deformed or completely change over or destroyed. Thus massive rocks like gneiss show mural and sheet joints (like igneous rocks) where as marbles and quartizites show master joints (like sedimentary roks).

SHEAR JOINTS: These are associated with the deformed rocks especially folded ones. Shear joints consists of intersecting or criss-cross sets, these are called **Conjugate Joint-System**. They are produced due to the shearing stresses involved in folding and faulting. This criss cross joint system consists of tow or three obliquely intersecting sets which dissects the rock mass into small rhombohedral or irregualr blocks, and fragments. They are mostly found in metamorphosed pegmatites and metamorphic rocks like quartizites, schists and amphibolites.

Principles of failure by Rupture:

Most rocks are brittle and fail by rupture at the elastic limit.

Several factors are of concern: (1) the nature of the deformation preceding rupture; (2) the physical conditions at the time of rupture; (3) the stresses necessary to cause rupture; and (4) the orientation of the fractures relative to the causative stresses.

Joints may be classified genetically as either shear fractures or tension fractures. The ultimate causes may be several: (1) Tectonic stresses, (2) Residual stresses, (3) Contraction, and (4) Surficial movements.
***

Exfoliation domes are formed in some granitic areas.

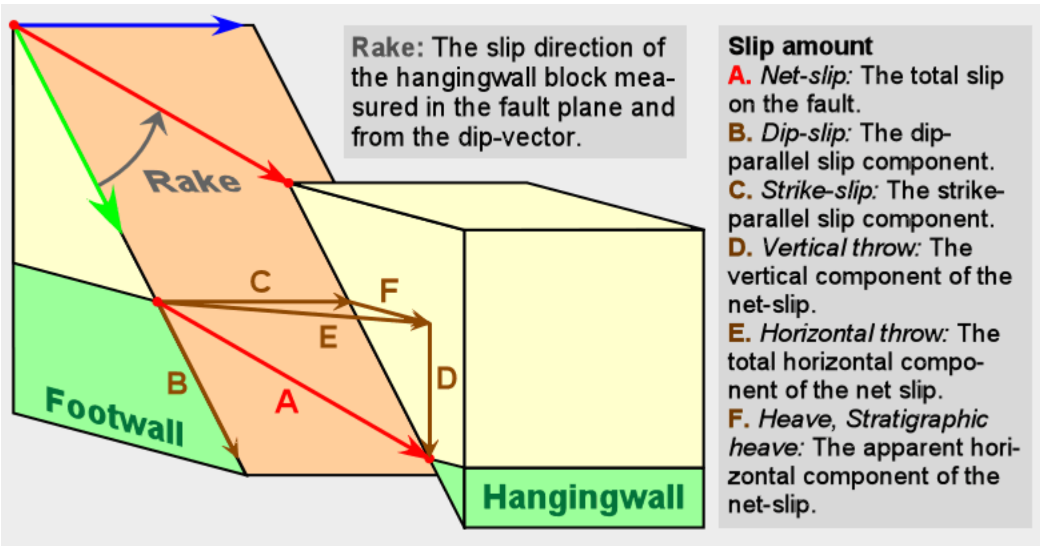
"**Foliation"** is the property of rocks whereby they break along approximately parallel surfaces.

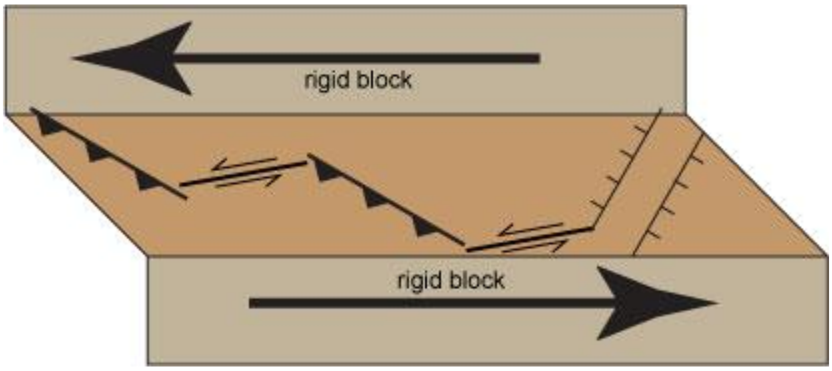
Lineation: is the result of the parallelism of some directional property in the rock.

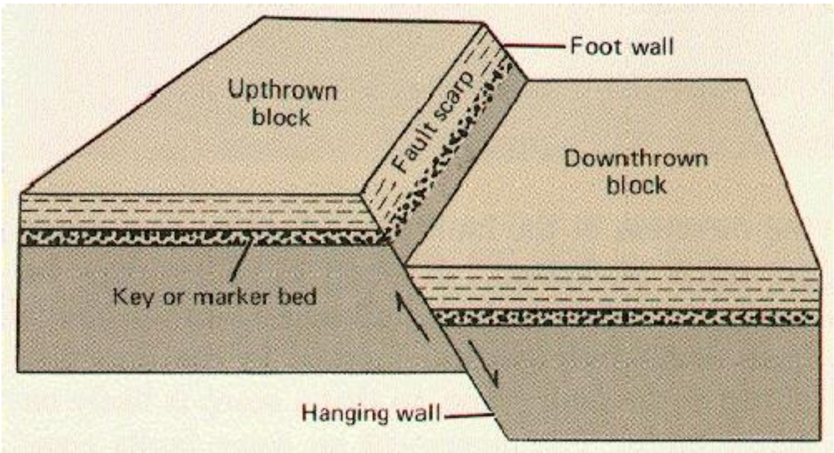
"**Cleavage":** sometimes called "**rock cleavage"** to distinguish it from mineral cleavage, is the property of rocks whereby they break along parallel surfaces of secondary origin.

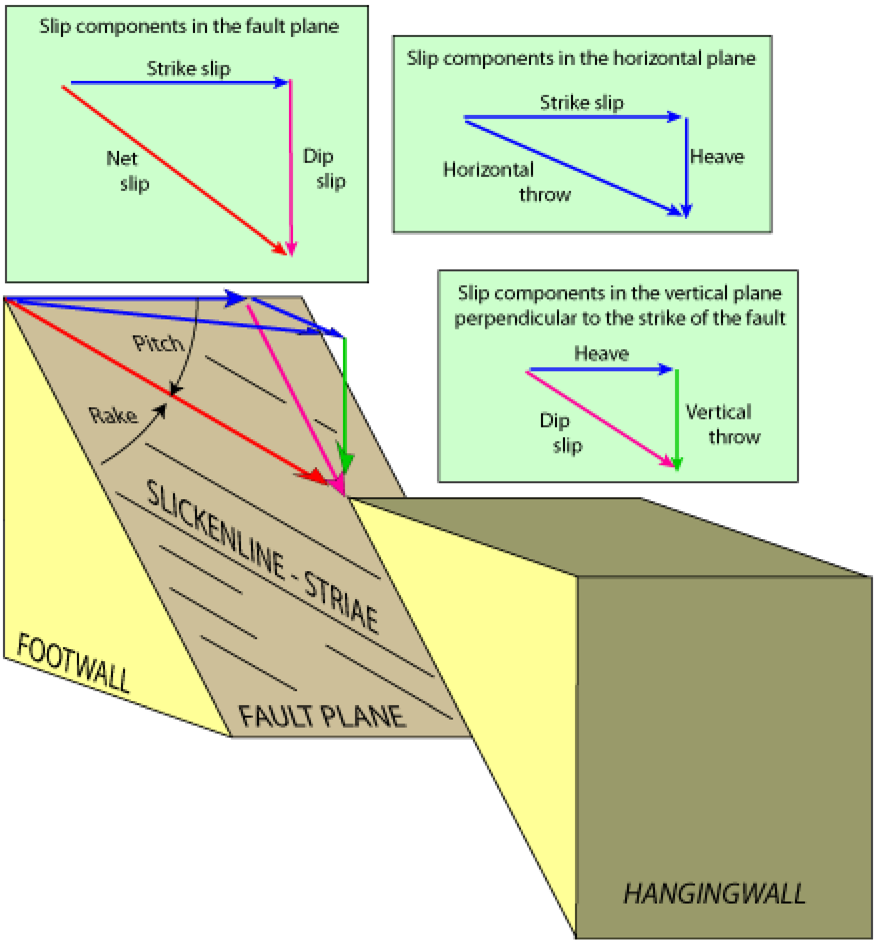
"**Schistosity"** is a term applied to the variety of rock cleavage found in rocks that are sufficiently recrystallized to be called schist or gneiss. Thus the secondary foliation of a slate would be called "cleavage", but a similar structure in mica schist would be termed "schistosity".

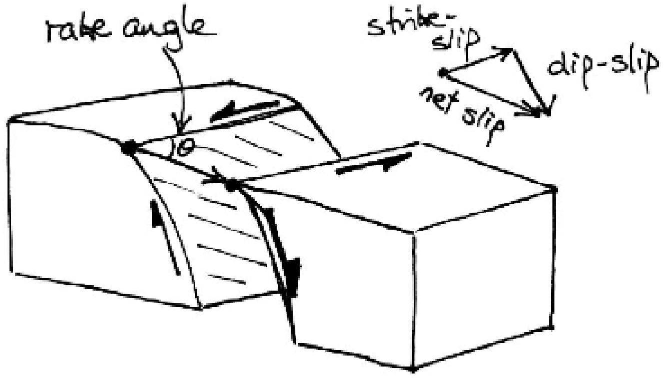
******

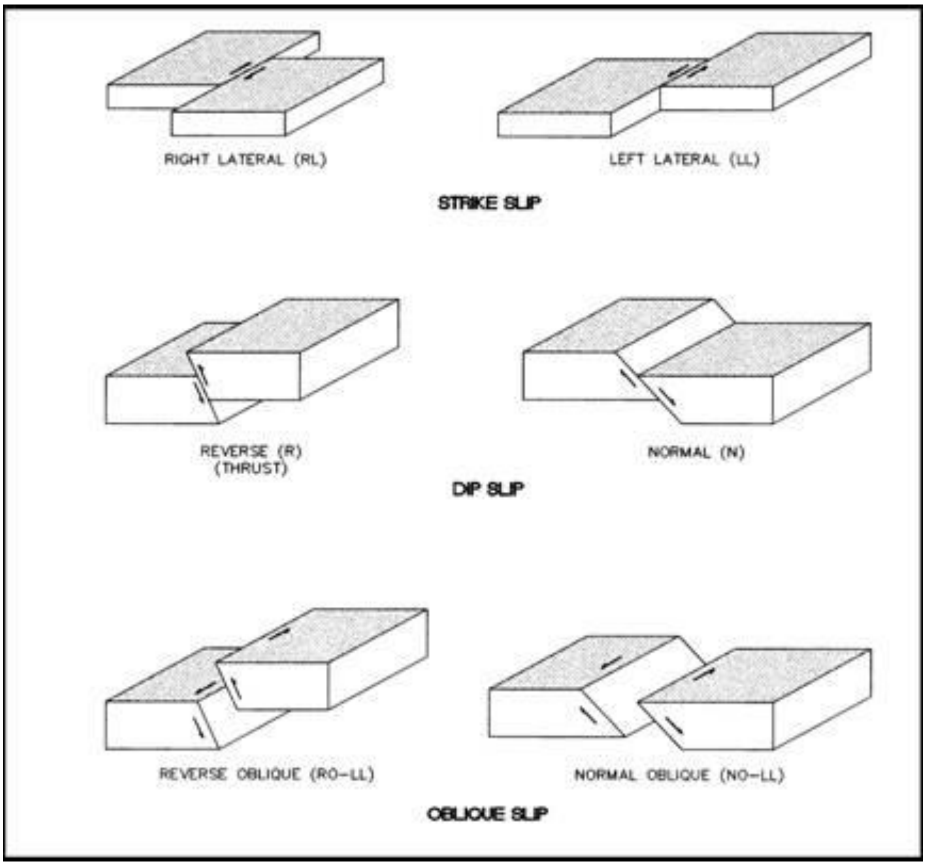


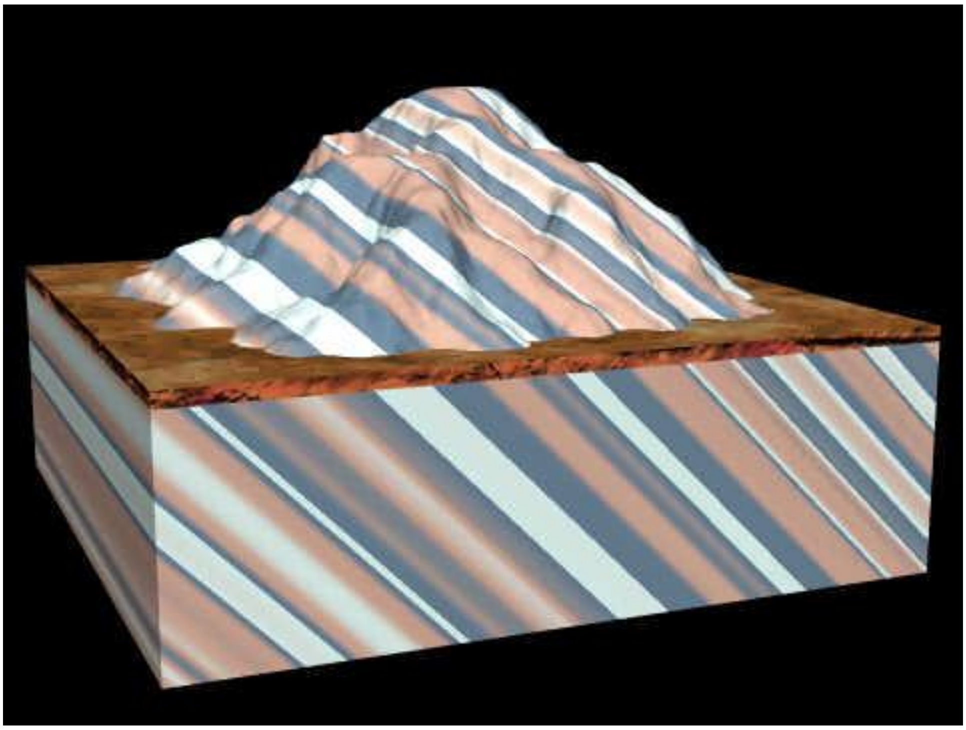

rigid block
rigid block

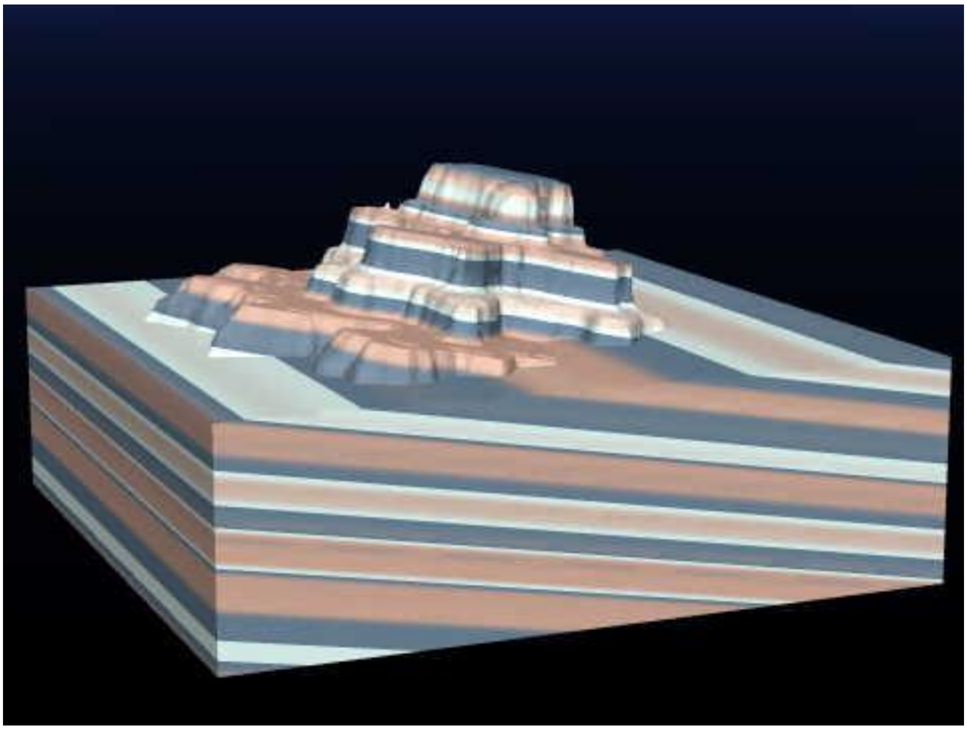

Foot wall
Upthrown block
Fault scarp
Downthrown block
Key or marker bed
Hanging wall

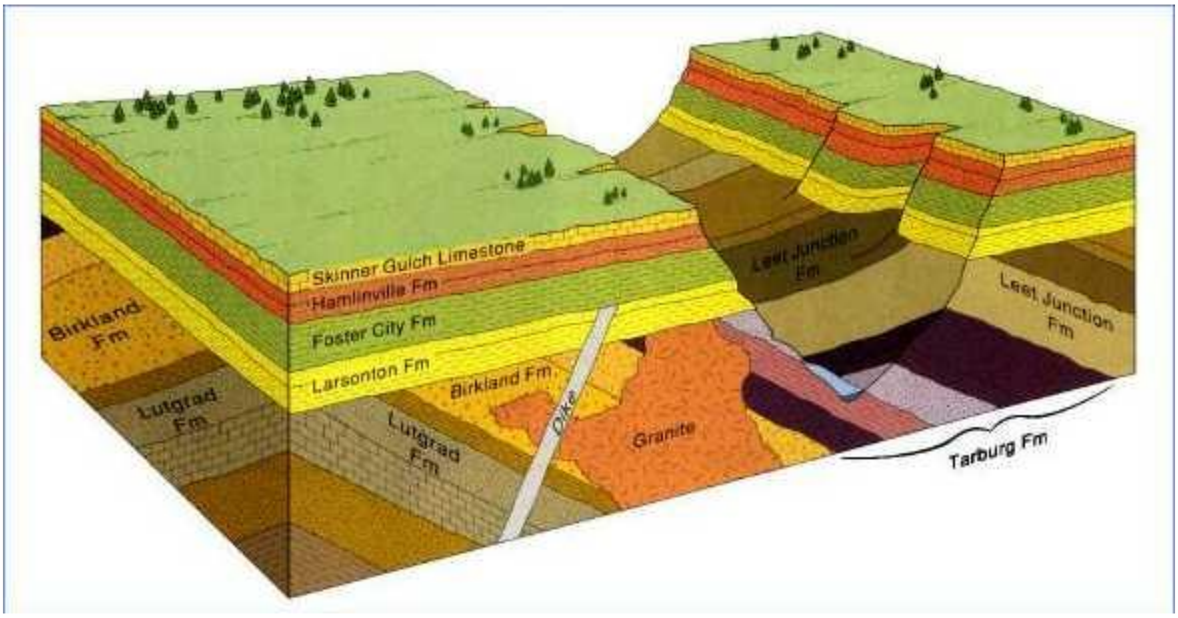

Slip components in the fault plane
Strike slip
Net slip
Dip slip
Slip components in the horizontal plane
Strike slip
Horizontal throw
Heave
Slip components in the vertical plane perpendicular to the strike of the fault
Heave
Dip slip
Vertical throw
Pitch
Rake
SLICKENLINE - STRIAE
FOOTWALL
FAULT PLANE
HANGINGWALL

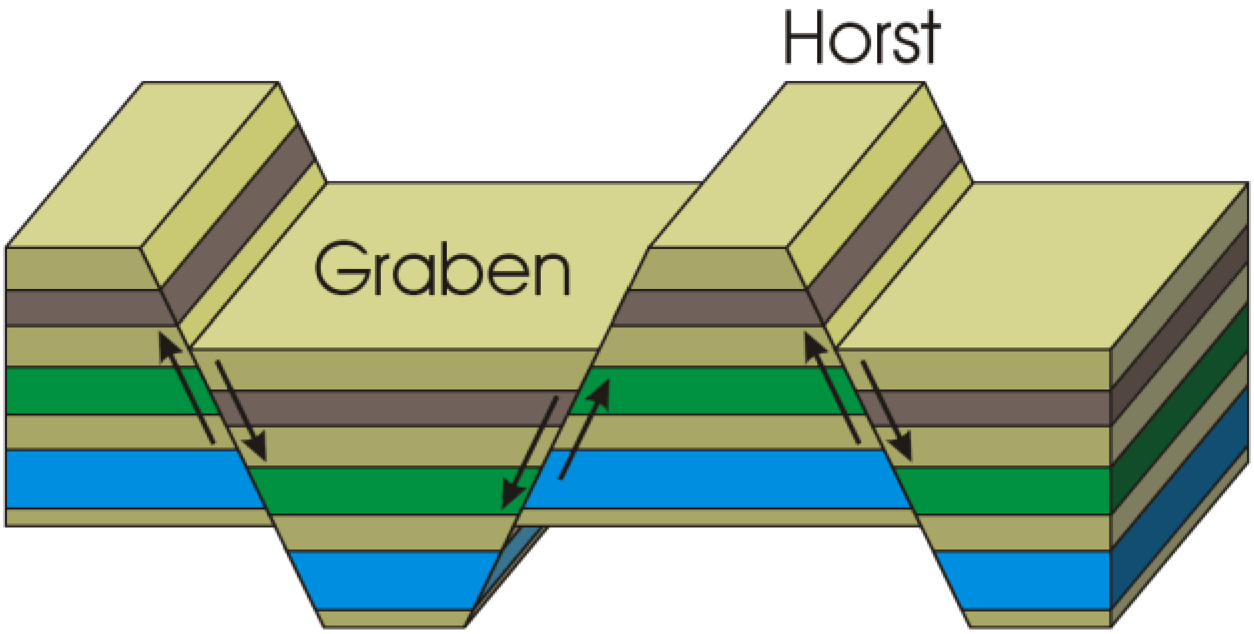

rake angle
θ
strike-slip
dip-slip
net slip

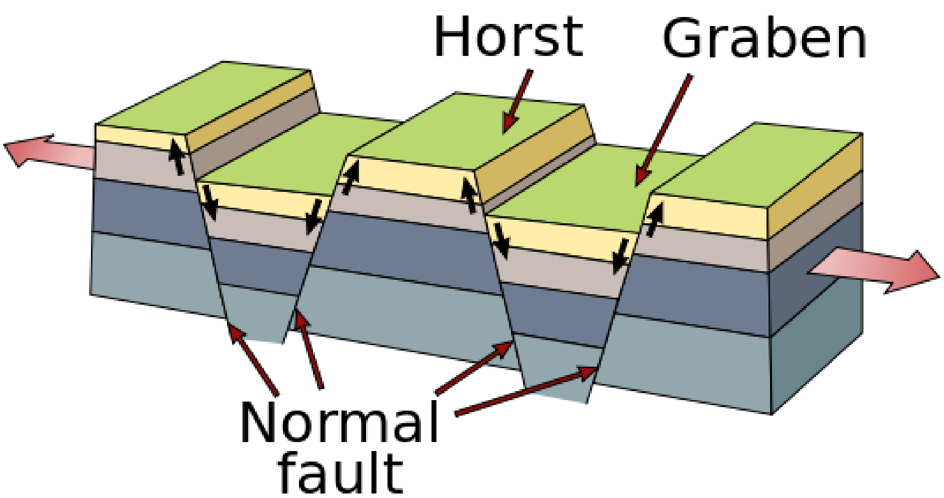

RIGHT LATERAL (RL)
LEFT LATERAL (LL)
STRIKE SLIP
REVERSE (R)
(THRUST)
NORMAL (N)
DIP SLIP
REVERSE OBLIQUE (RO-LL)
NORMAL OBLIQUE (NO-LL)
OBLIQUE SLIP

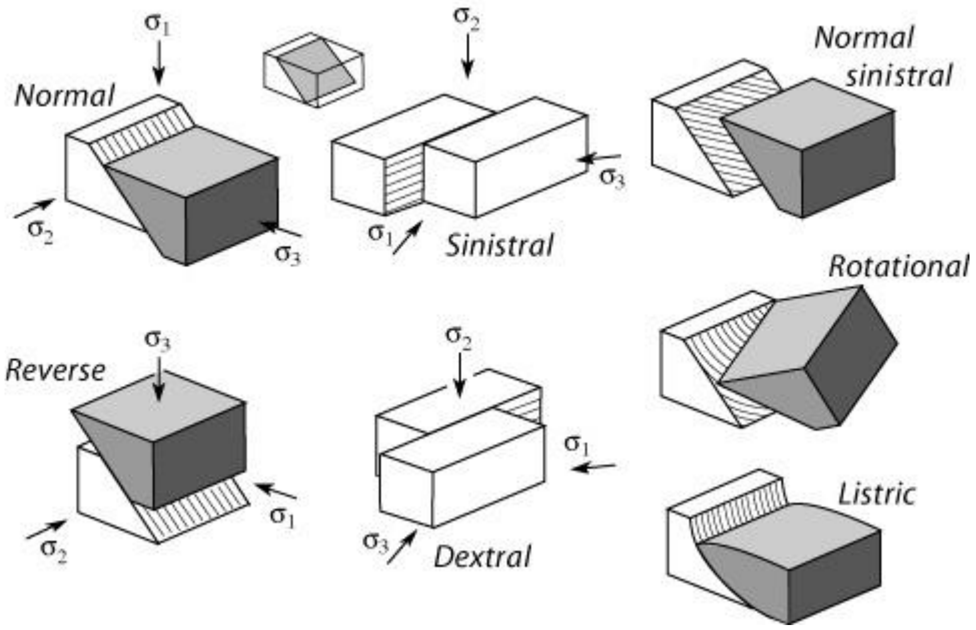


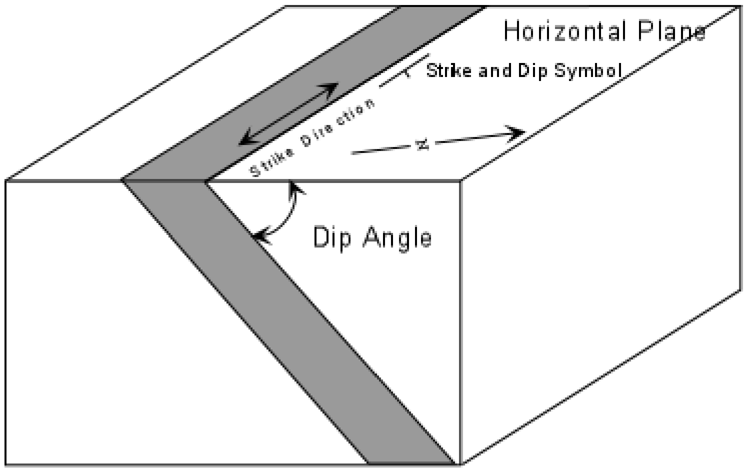



Skinner Gulch Limestone
Hamlinville Fm
Foster City Fm
Larsonton Fm
Birkland Fm
Birkland Fm
Lutgrad Fm
Lutgrad Fm
Dike
Granite
Leet Junction Fm
Leet Junction Fm
Tarburg Fm


Horst
Graben

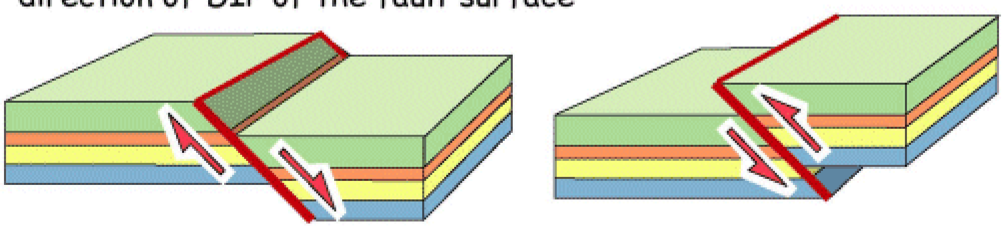

Horst
Graben
Normal fault





Dip-slip faults

where the fault slip is along the direction of DIP of the fault surface



Normal Fault

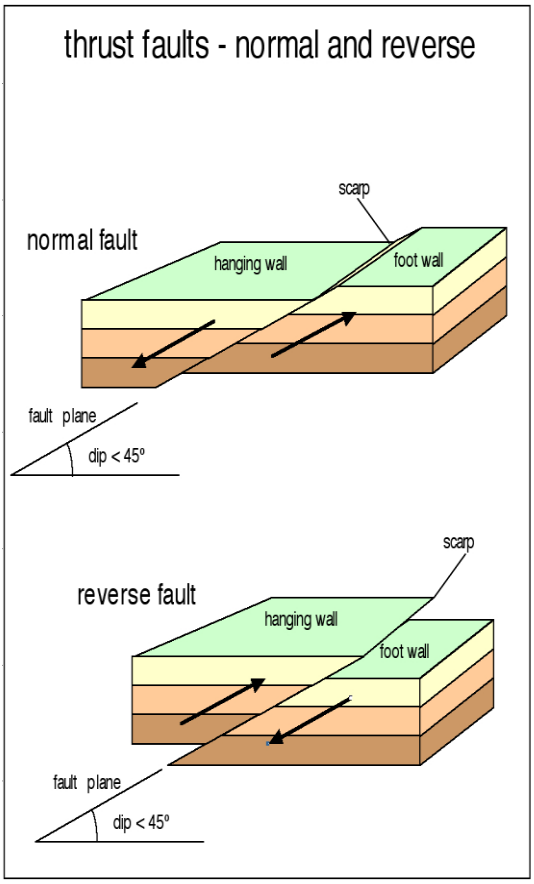
hanging-wall moves down relative to the footwall

Thrust Fault

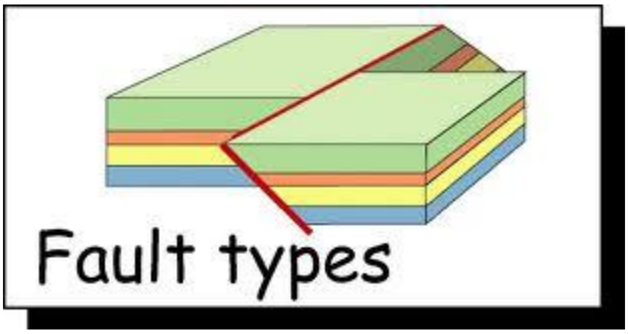
hanging-wall moves up relative to the footwall

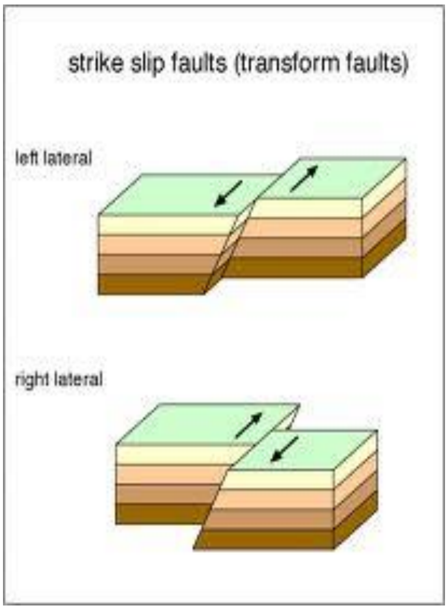
return to menu

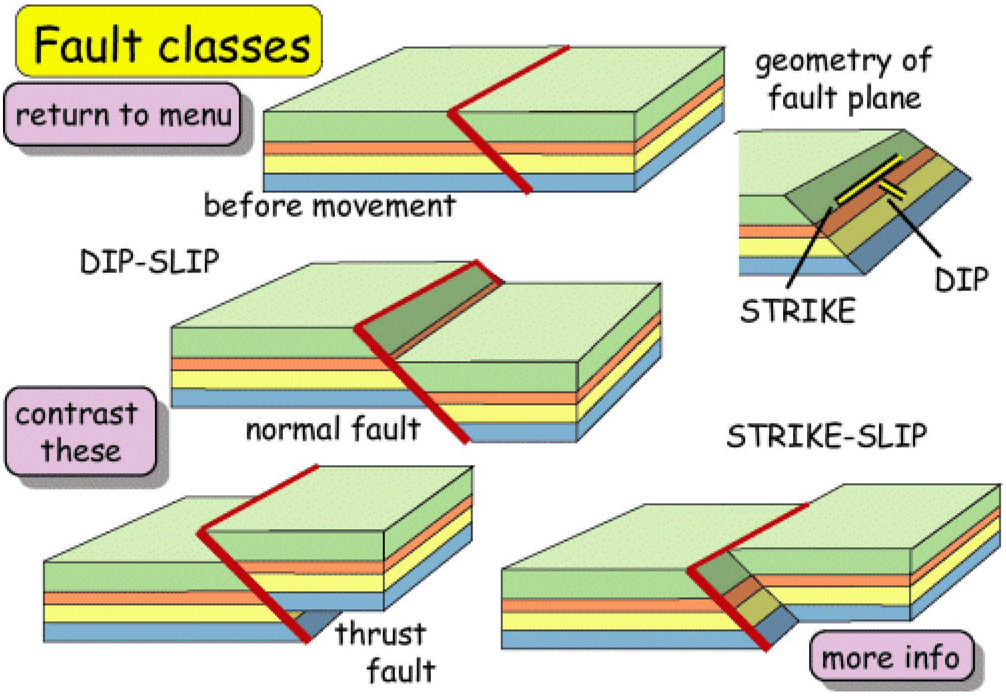
compare attributes

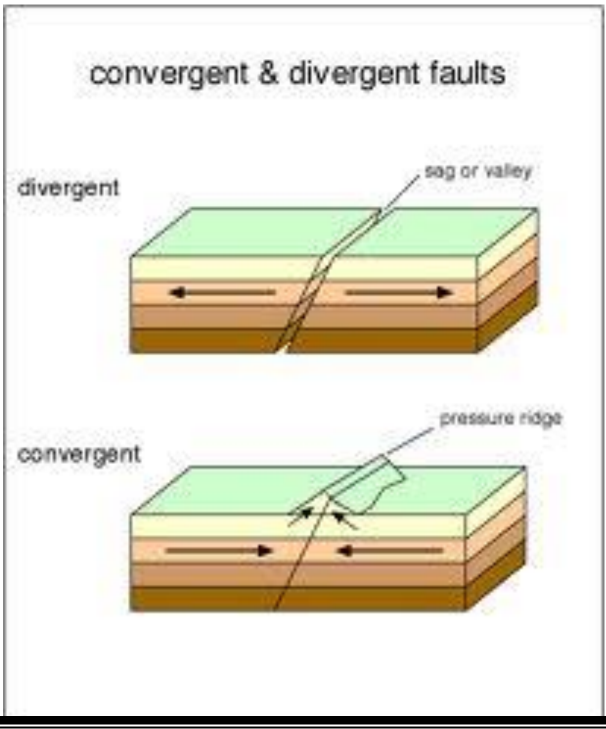


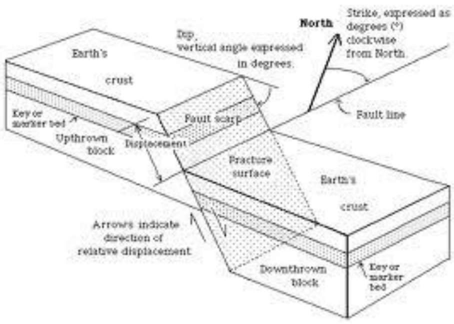
http://www.sanandreasfault.org/Information.html

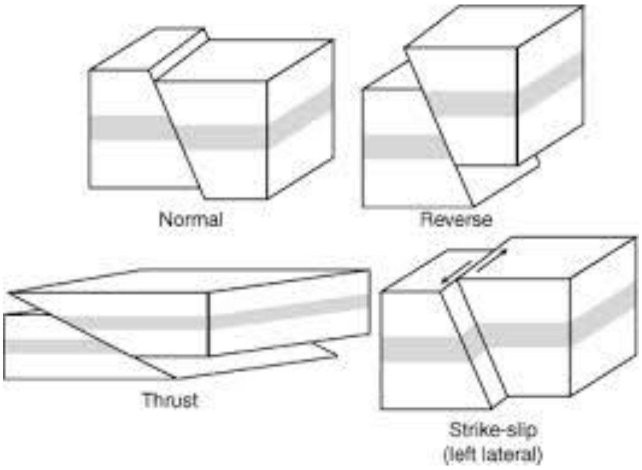


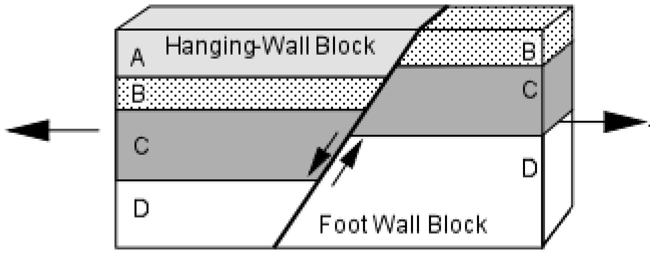

strike slip faults (transform faults)
left lateral
right lateral


Fault classes
return to menu
before movement
geometry of fault plane
STRIKE
DIP
DIP-SLIP
normal fault
contrast these
STRIKE-SLIP
thrust fault
more info

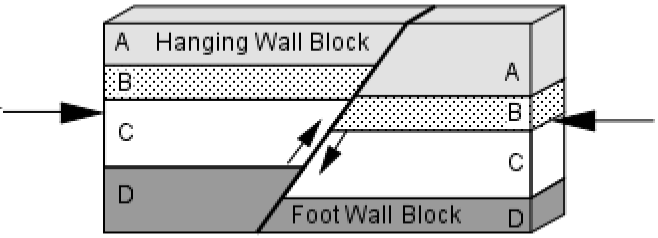

convergent & divergent faults
divergent
sag or valley
convergent
pressure ridge



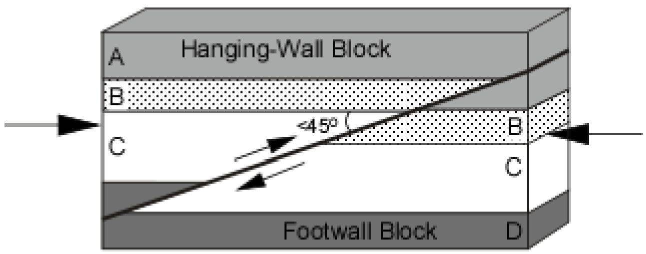




Normal Fault
Extensional Stress

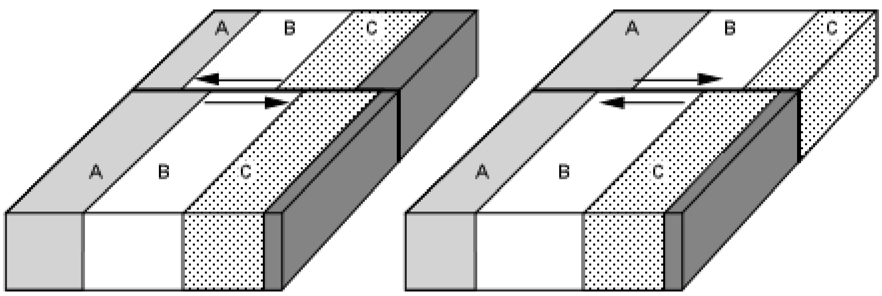


Reverse Fault
Compressional Stress



Thrust Fault
Compressional Stress

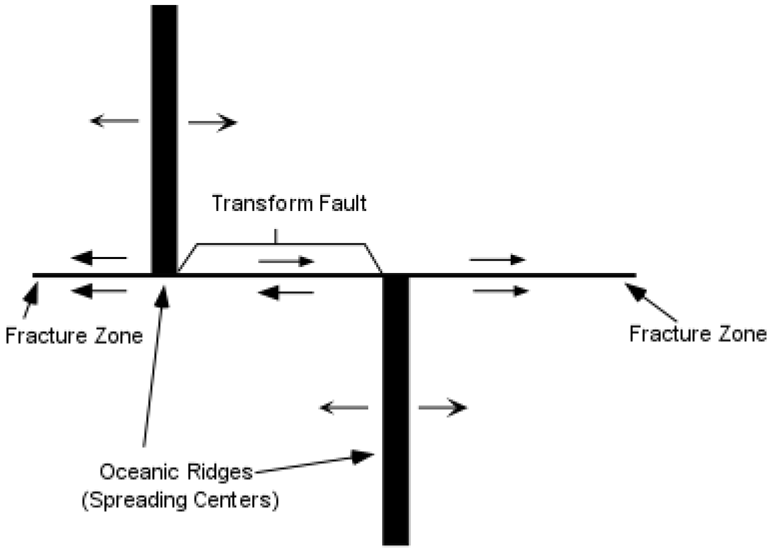
http://www.tulane.edu/~sanelson/geol111/deform.htm

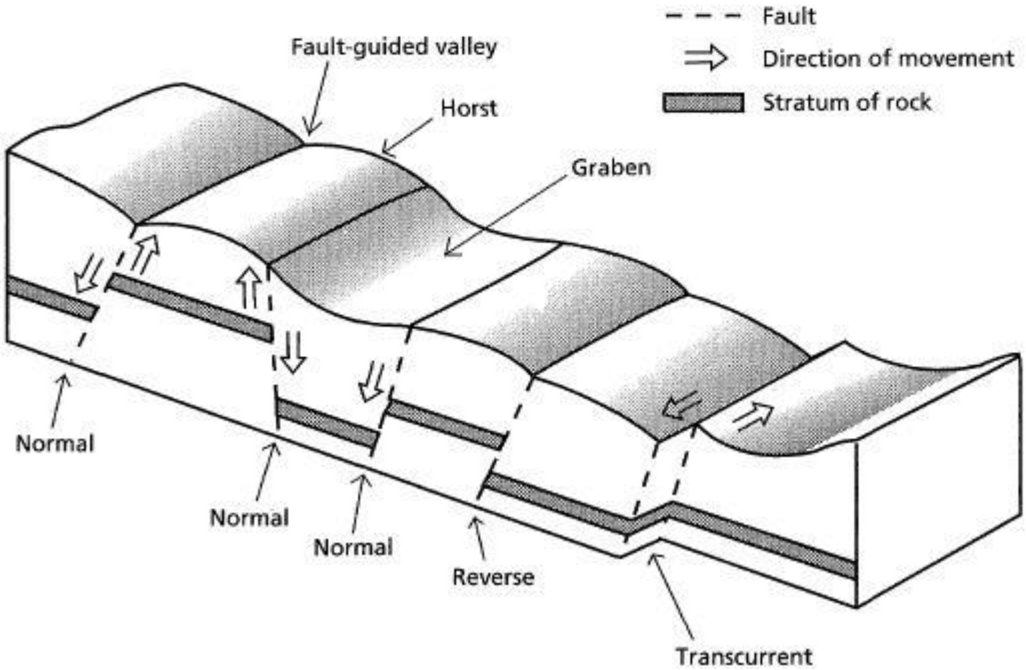


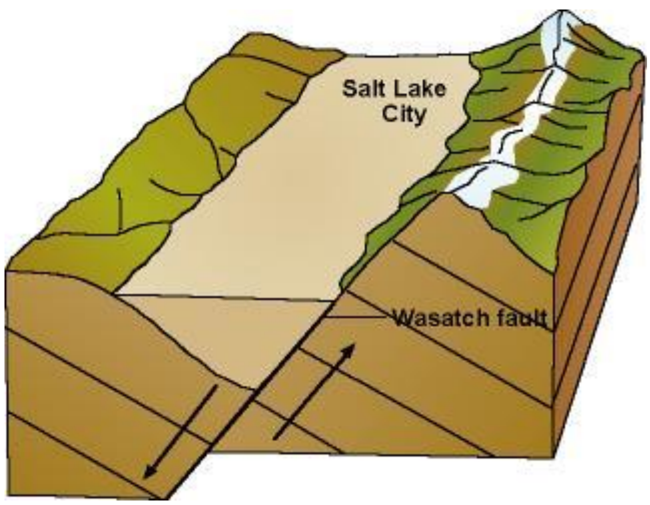
Left-Lateral Strike-Slip Fault

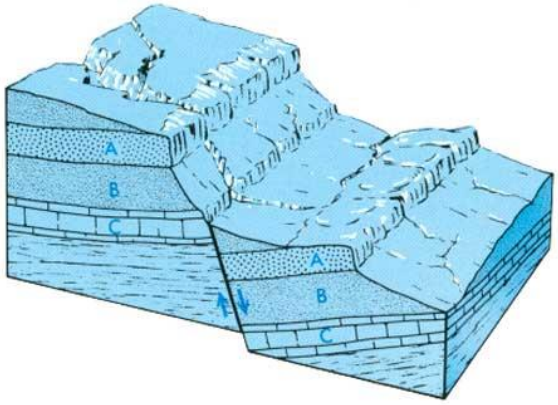
Right-Lateral Strike-Slip Fault

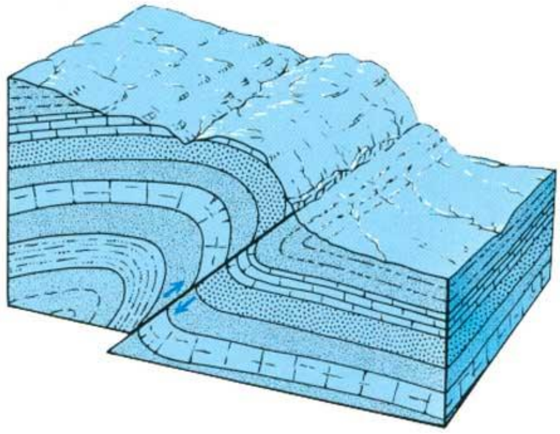
Shear Stress

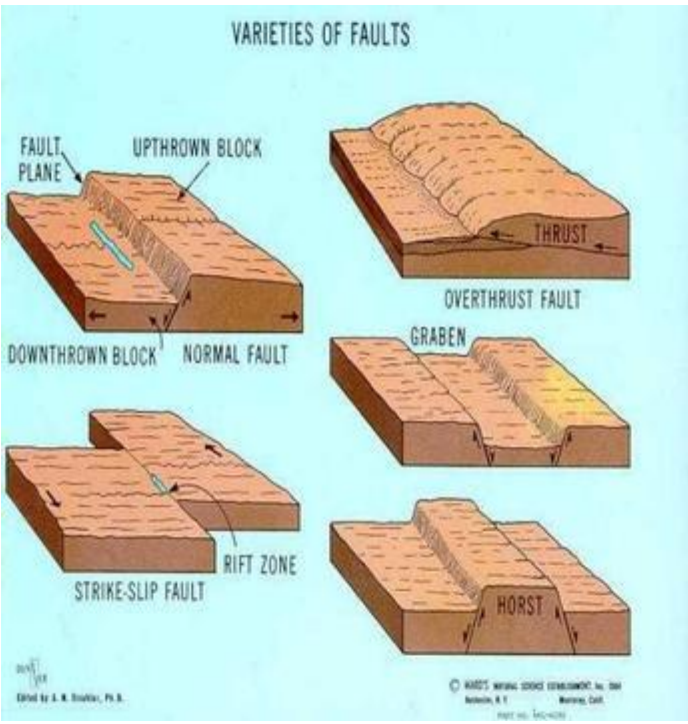

Transform Fault
Fracture Zone
Fracture Zone
Oceanic Ridges
(Spreading Centers)

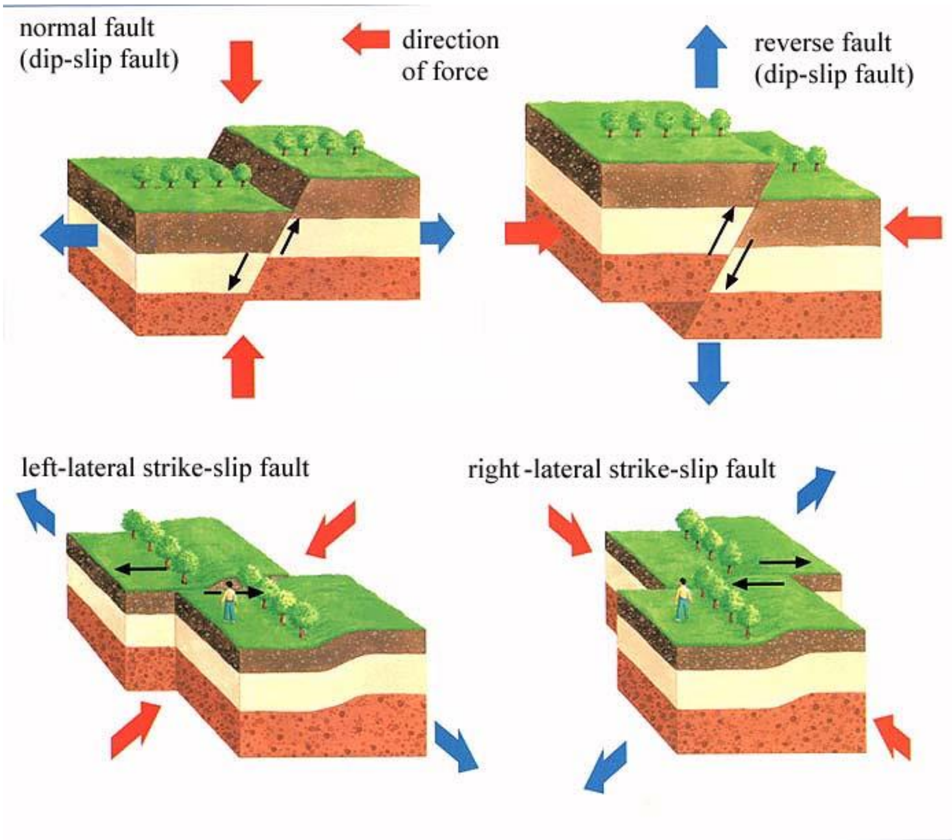

Fault
Direction of movement
Stratum of rock
Fault-guided valley
Horst
Graben
Normal
Normal
Normal
Reverse
Transcurrent

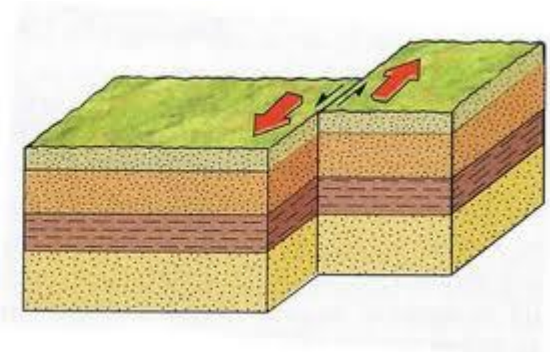

Salt Lake City
Wasatch fault

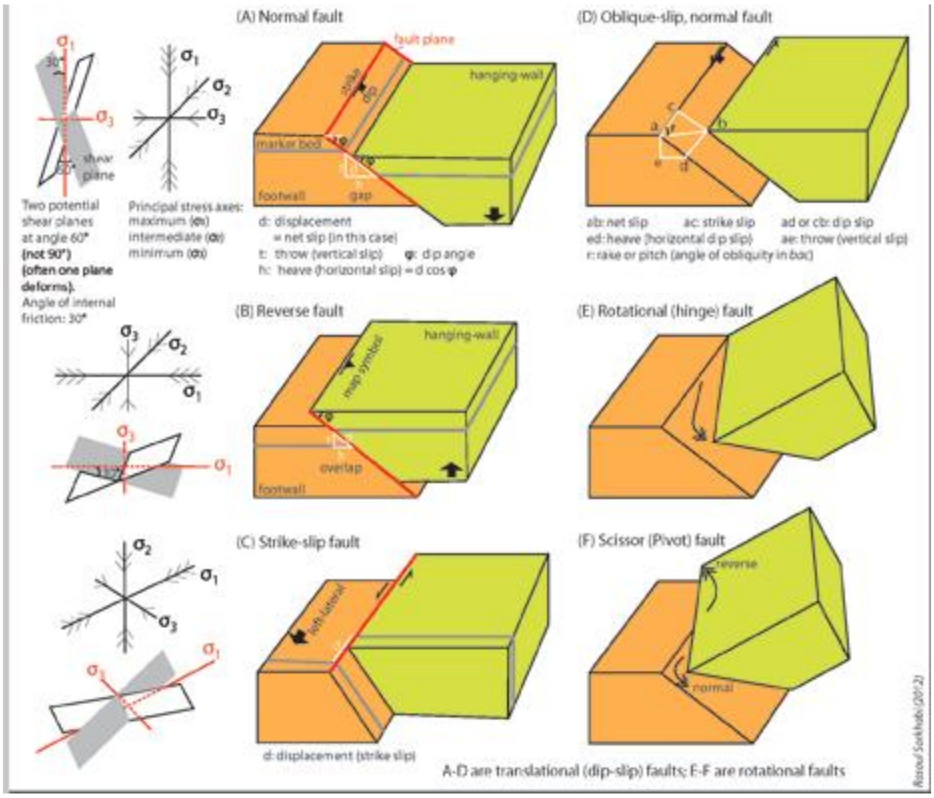

A
B
C
A
B
C

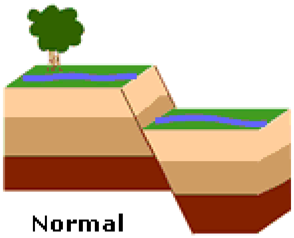



VARIETIES OF FAULTS
FAULT PLANE
UPTHROWN BLOCK
DOWNTHROWN BLOCK
NORMAL FAULT
THRUST
OVERTHRUST FAULT
GRABEN
RIFT ZONE
STRIKE-SLIP FAULT
HORST

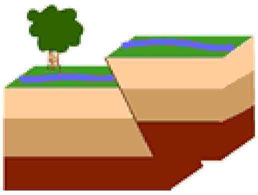

normal fault
(dip-slip fault)
direction
of force
reverse fault
(dip-slip fault)
left-lateral strike-slip fault
right-lateral strike-slip fault



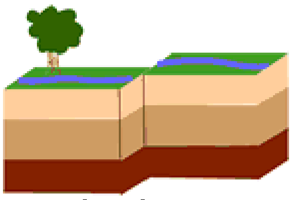




Normal



Reverse



Strike-slip

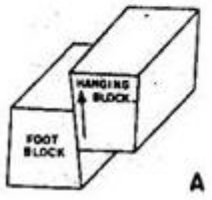


Fig. 63A Upthrust.
Note that the fault plane is nearly vertical. The hanging block has moved up and against gravity, and therefore against the direction of dip of the fault plane.

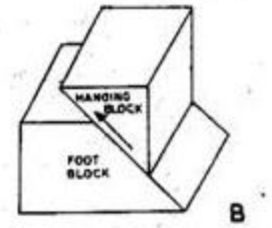


Fig. 63B Upthrust
Note that the fault plane has moderate inclination and the hanging block has moved up and against the gravity. It is therefore against the direction of dip of the fault plane.

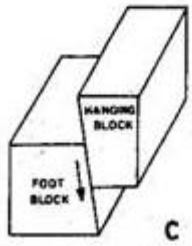


Fig. 63C. Downthrust
Note that the fault plane is nearly vertical and the foot block has moved down and in the direction of gravity. It is therefore down the dip direction of the fault plane.

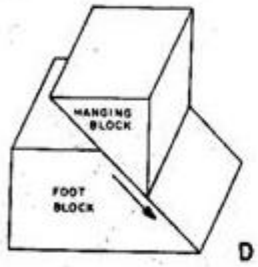


Fig. 63D. Downthrust
Note that the fault plane has a moderate inclination. The foot block has moved down and in the direction of gravity. It is therefore down the dip direction of the fault plane.

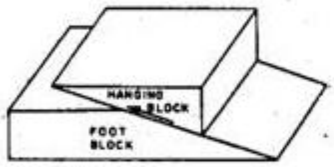


Fig. 64. Overthrust
Note that the fault plane has a low dip, and the hanging block has moved up and against the direction of dip of the fault plane. On comparing it with Figures 63 A,B, it is clearly seen that the hanging block "rides over" the foot block. It is hence called an "overthrust fault".

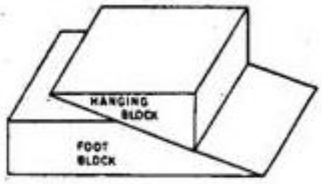


Fig. 65 Underthrust.
Note that the fault plane has a low dip, and the foot block has moved down and in the direction of dip of the fault plane. On comparing Figures 63 C,D with the present one, it is observed that the foot block is "thrust under" the hanging block. It is hence called an "underthrust" fault.

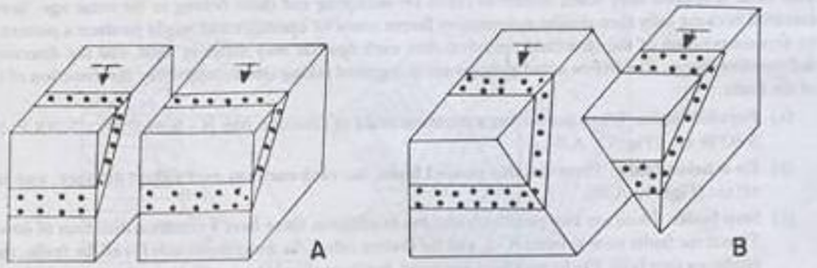


Fig. 67A. fault plane is vertical. It has an "oblique slip" component.

Fig. 67B. fault plane is inclined. It has an "oblique slip" component.

Figs. 67 A,B. Varieties of dip faults.

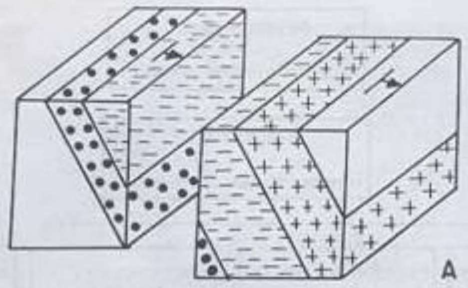


Fig. 68A. fault plane is vertical. It has an "oblique slip" component

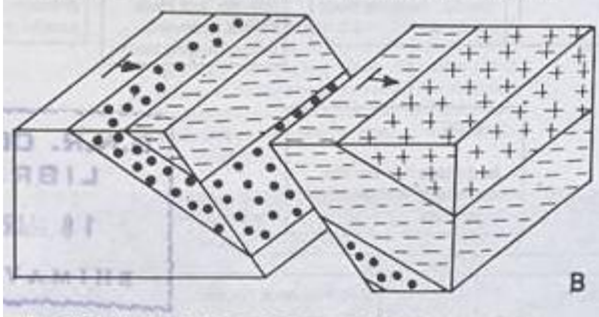


Fig. 68B fault plane is inclined. It has an "oblique slip "component

Figs. 68 A,B. Varieties of strike faults

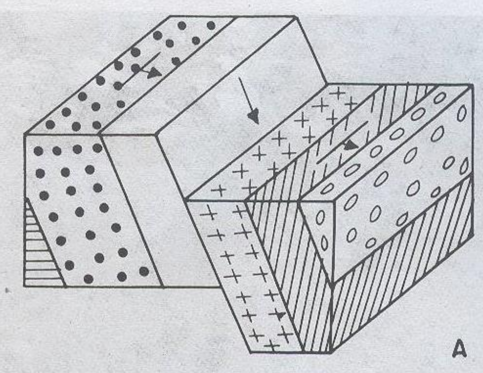


Fig. 69A. it has dip slip component

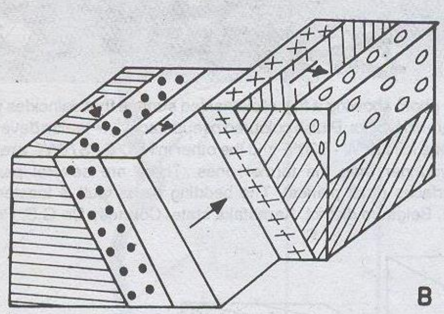


Fig. 69B. it has strike slip component

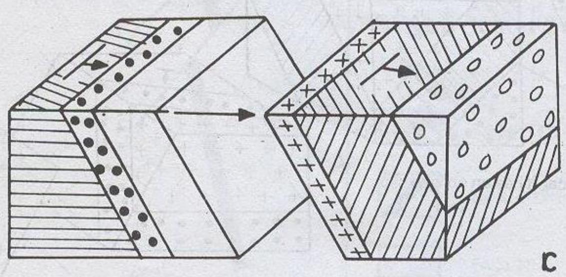
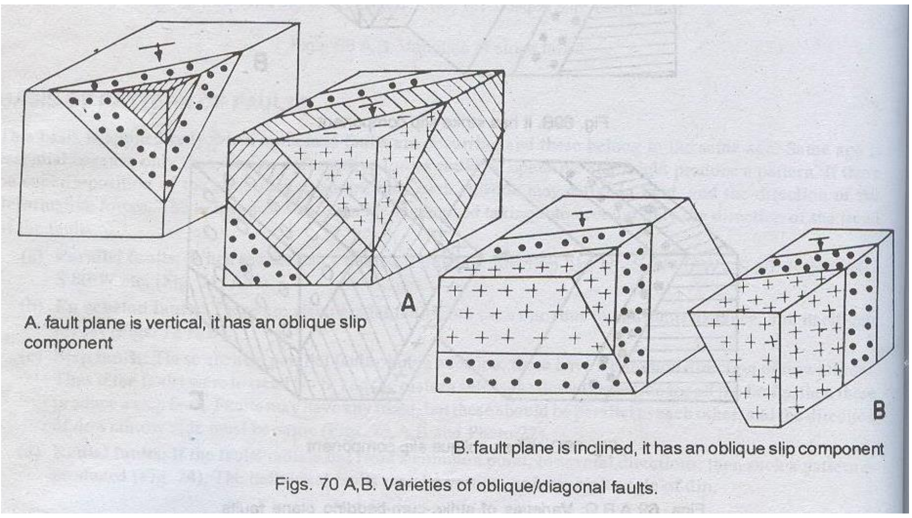
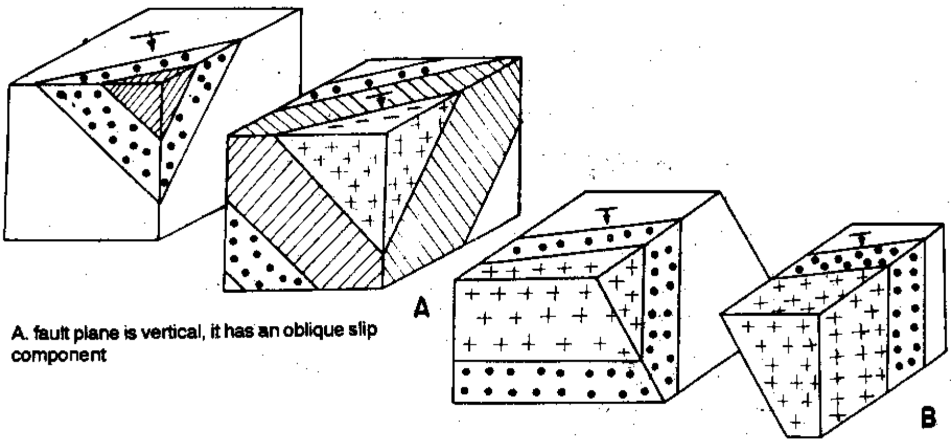


Fig. 69C. it has oblique slip component

Figs. 69 A,B,C. Varieties of strike-cum-bedding plane faults

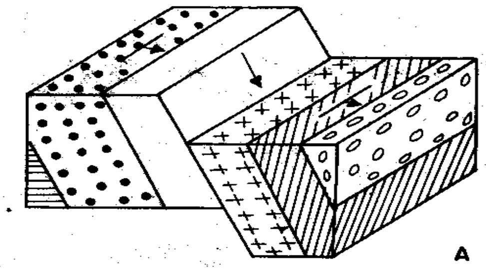




A. fault plane is vertical, it has an oblique slip component

B. fault plane is inclined, it has an oblique slip component

Figs. 70 A,B. Varieties of oblique/diagonal faults.



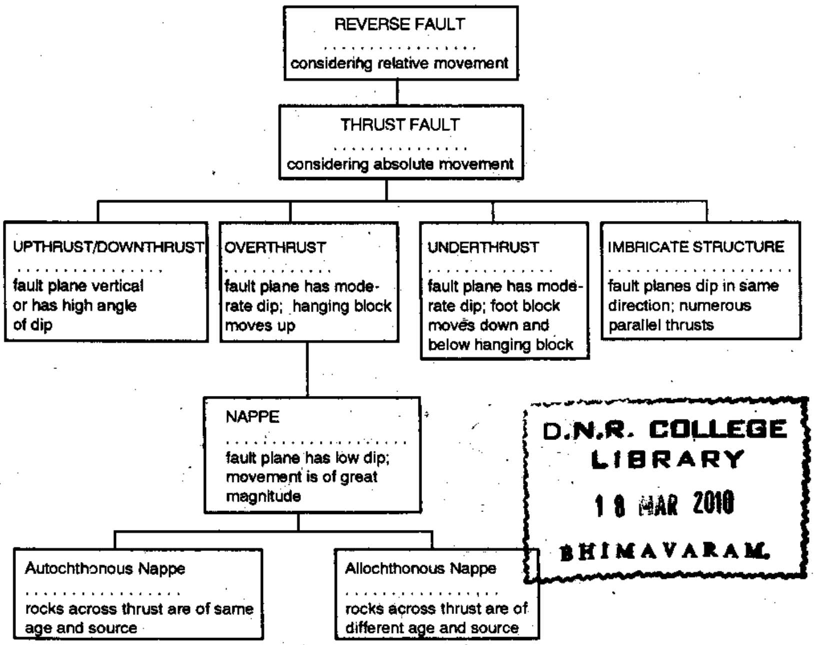


Fig. 66 Schematic Classification of Thrusts

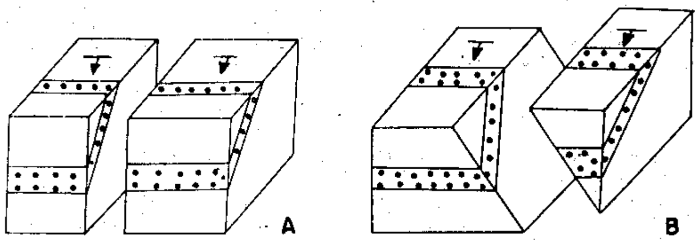


Fig. 67A. fault plane is vertical. It has an "oblique slip "component.

Fig. 67B. fault plane is inclined. It has an "oblique slip" component.

Figs. 67 A,B. Varieties of dip faults.

er has a very high
d up, while in the
en the inclination
ible. In the case
ot block (Fig, 64,
d in the direction
the hanging block

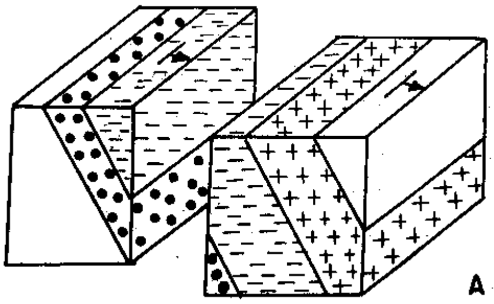


Fig. 68A. fault plane is vertical. It has an "oblique slip" component

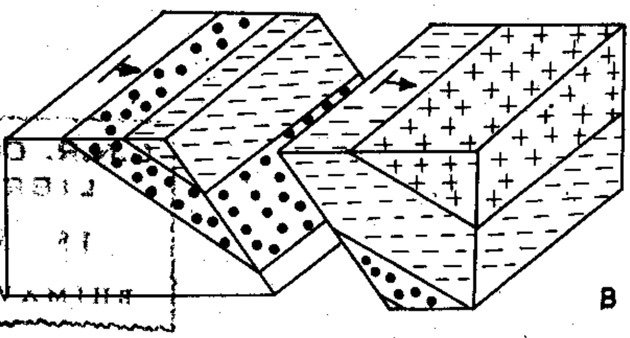


Fig. 68B fault plane is inclined. It has an "oblique slip "component

Figs. 68 A,B. Varieties of strike faults

BASIS OF PATTERN OF FAULTS

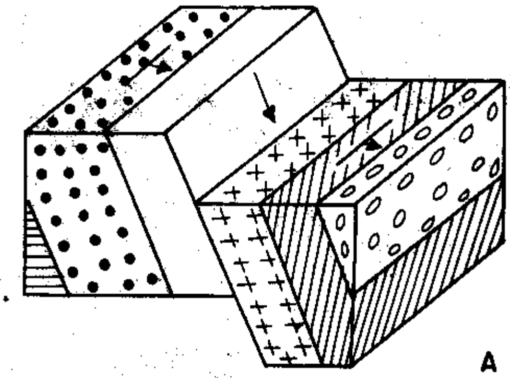
This basis is applied only when numerous faults are occurring and these belong to the same age. Same age is essential because only then similar deformative forces could be operative and might produce a pattern. If there be superimposition of the structural episodes, then each episode may differ in kind, and the direction of the deformative forces. The below noted patterns are recognised taking into account only the direction of the trend of the faults.

(a) **Parallel faults:** When the set has a common trend or direction like N - S, N 20°W - S 20° E, N 80°E - S 80°W etc. (Fig. 71, A,B).

(b) **En echelon faults:** These are also parallel faults, but each one runs over a short distance, and itself gets off set (Figs. 72 A,B).

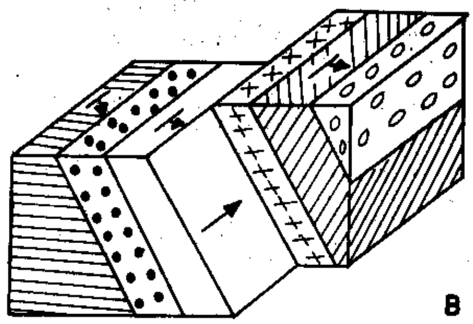
(c) **Step faults:** These are also parallel faults, but in addition, these have a common direction of downthrow. Thus if the faults were to trend N - S, and the eastern side is the downthrow side for all the faults, then these produce a step fault. Faults may have any trend, but these should be parallel to each other, and the direction of downthrow side must be same (Figs. 73 A,B and Photo 22).

(d) **Radial faults:** If the faults radiate out from a common point, in several directions, then such a pattern is produced (Fig. 74). The individual faults may be vertical or have high angle of dip.



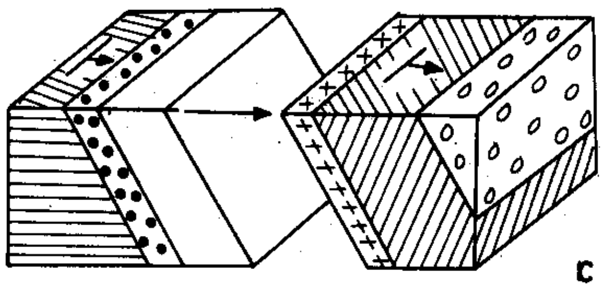
A

Fig. 69A. It has dip slip component



B

Fig. 69B. It has strike slip component



C

Fig. 69C. it has oblique slip component

Figs. 69 A,B,C. Varieties of strike-cum-bedding plane faults

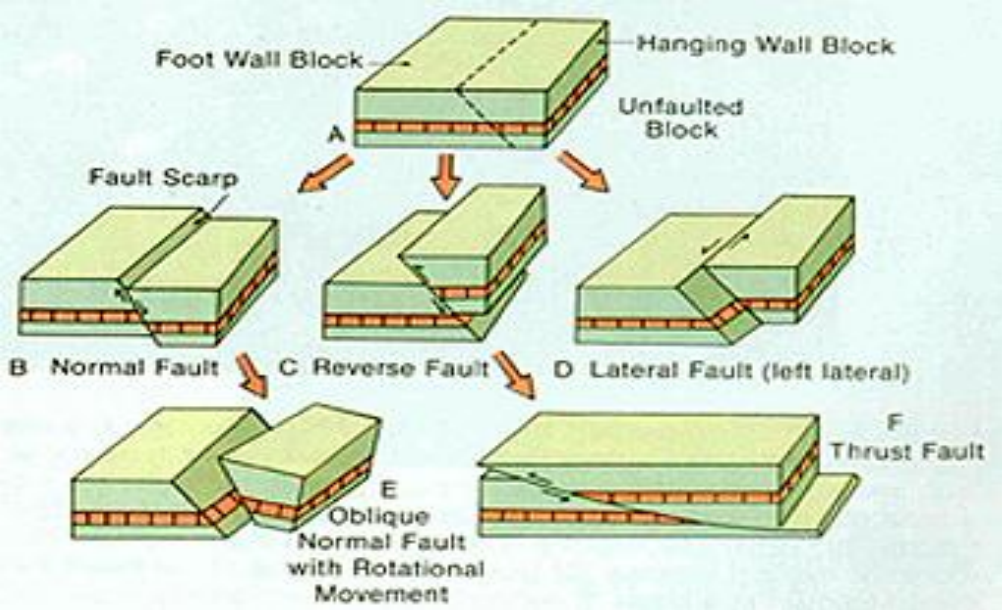
e age. Same age is
a pattern. If there
e direction of the
ection of the trend

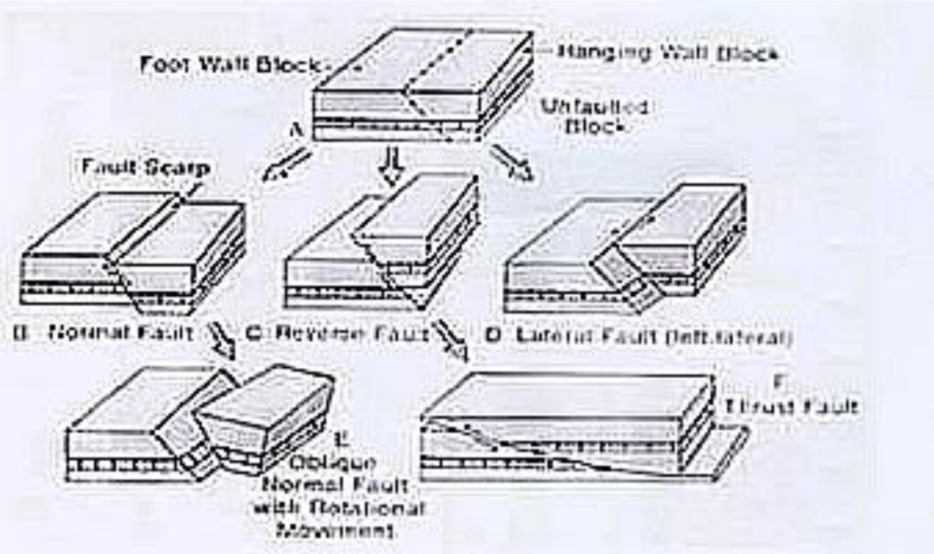
, S 20° E, N 80°E -

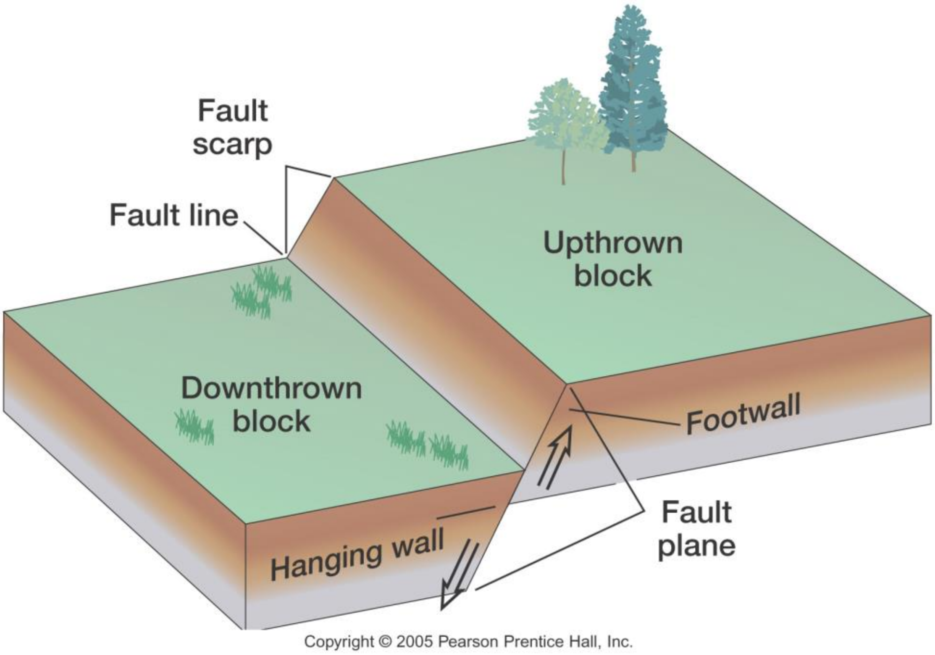
nce, and itself gets

tion of downthrow.
e faults, then these
r, and the direction

en such a pattern is



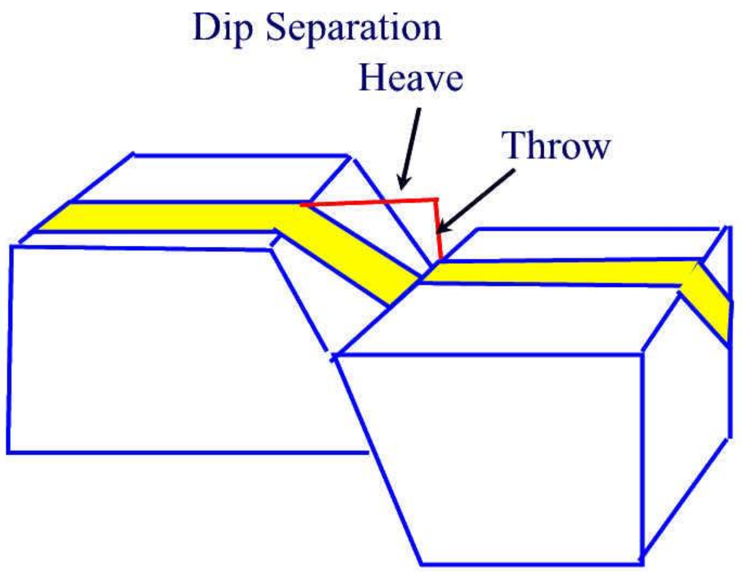




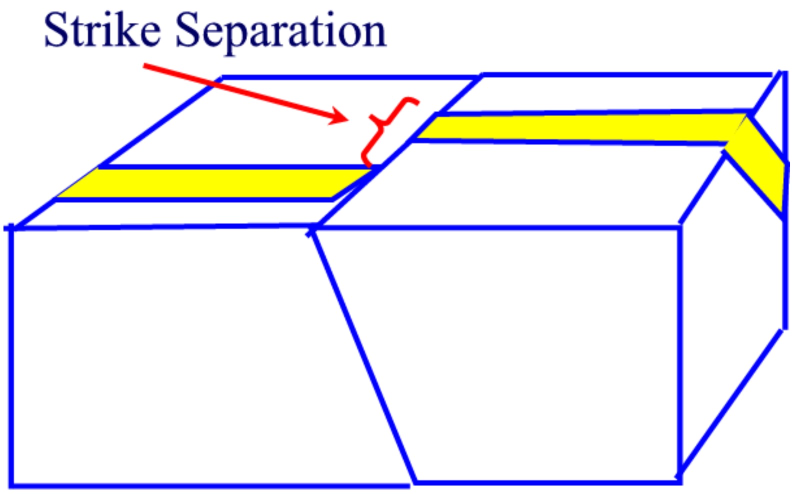
Dip separation- offset distance measured parallel to dip of the fault

Heave- horizontal component of dip separation

Throw- vertical component of dip separation

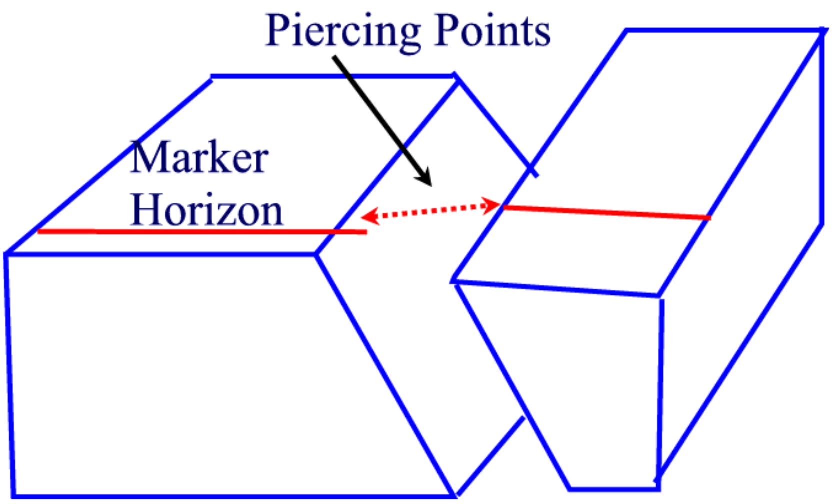


Strike separation- offset measured parallel to strike of fault



Piercing Points-

Displacement of two originally contiguous points across a fault



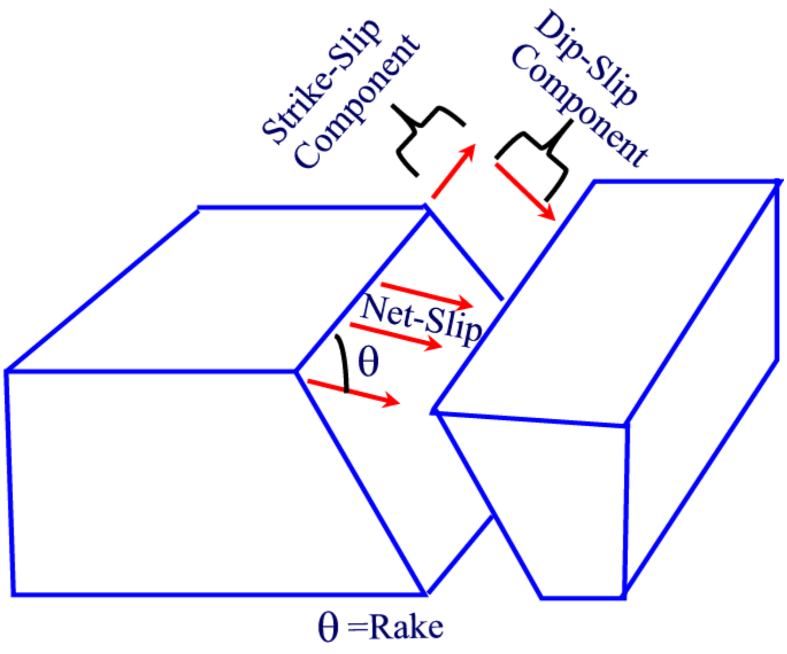
Fault Displacement Terms-

Net Slip-

distance between 2 originally contiguous points, offset by faulting.

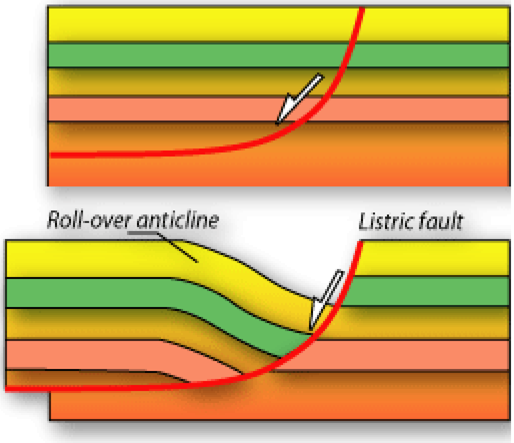
Dip slip component

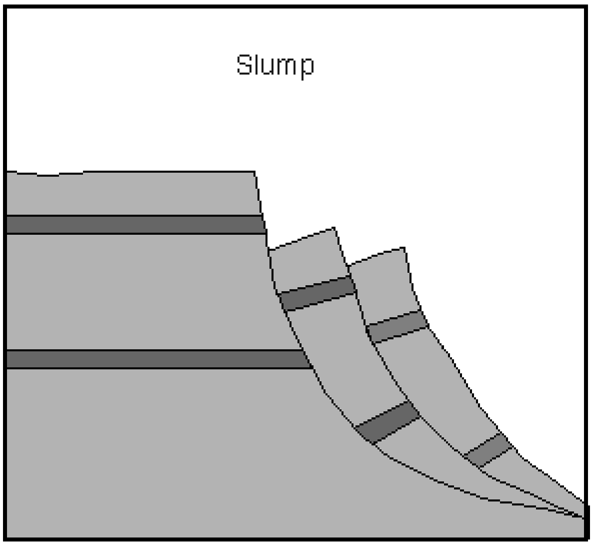
Strike slip component

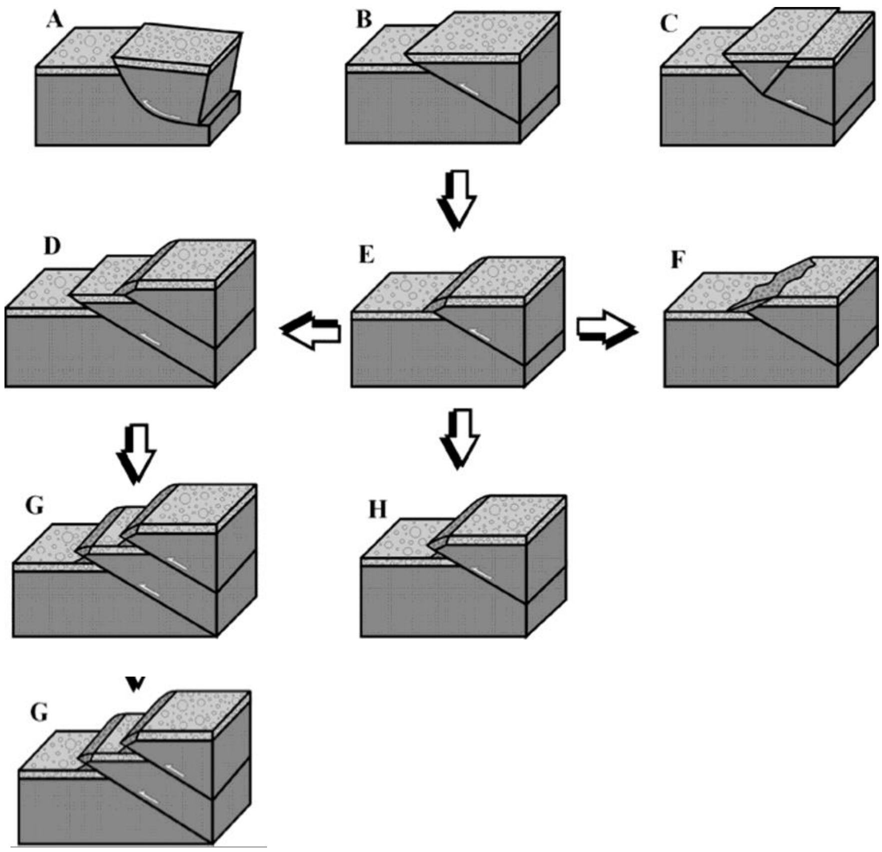


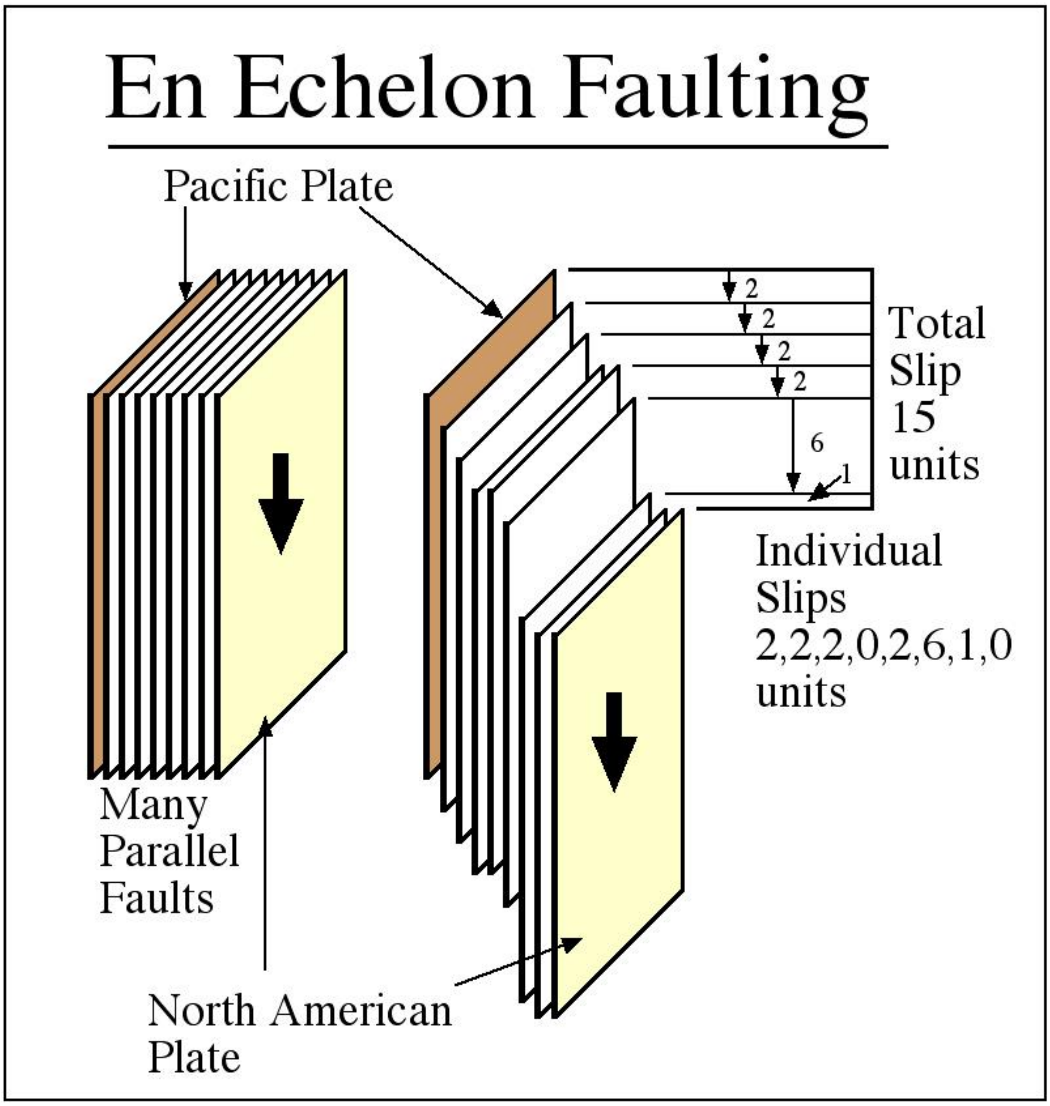
Listric fault[edit]

A listric fault is a type of fault in which the fault plane is curved. The dip of the fault plane becomes shallower with increased depth and may flatten into a sub-horizontal décollement.


Roll-over anticline
Listric fault


Slump


A
B
C
D
E
F
G
H
G



a) Parallel fault

A series of faults running more or less parallel to one another and all handing in the same direction, are called "parallel faults"

b) Step fault

It is consists of those parallel faults where down throw of all are in the same direction and it gives a step like arrangement

c) Graben or Rift fault

When two normal faults fade towards each other and the beds between them are thrown down in the from of a wedge, the structure is called graben or rift fault

d) Horst

A horst consists of a central block on the both sides of which adjacent beds appear to have been faulted down

e) Radial faults

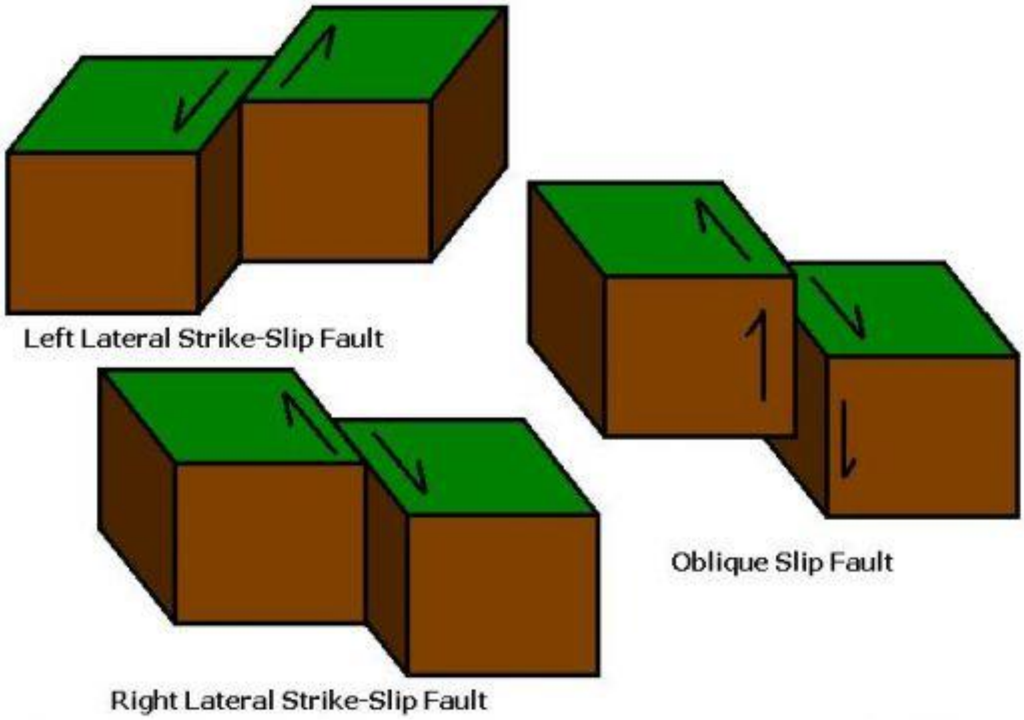
A number of faults exhibiting a radial pattern are descried as radial faults

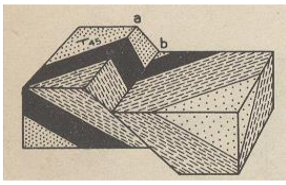
f) Peripheral faults

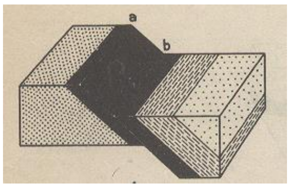
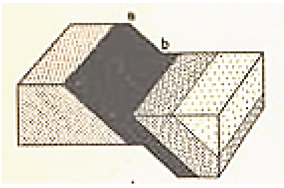
Curved faults of more or less circular, or are like outcrops on level surface are called peripheral faults

g) Enechelon Faults

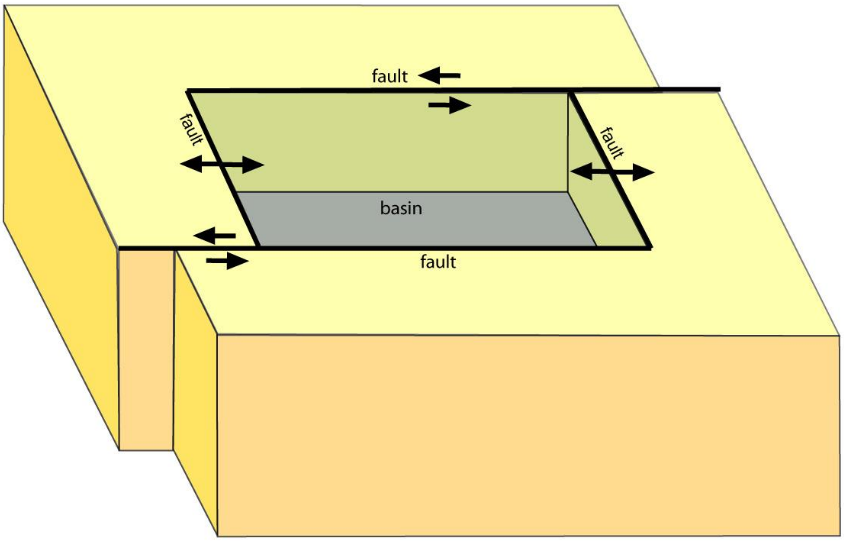
Enechelon fault are comparatively short faults which overlap each other



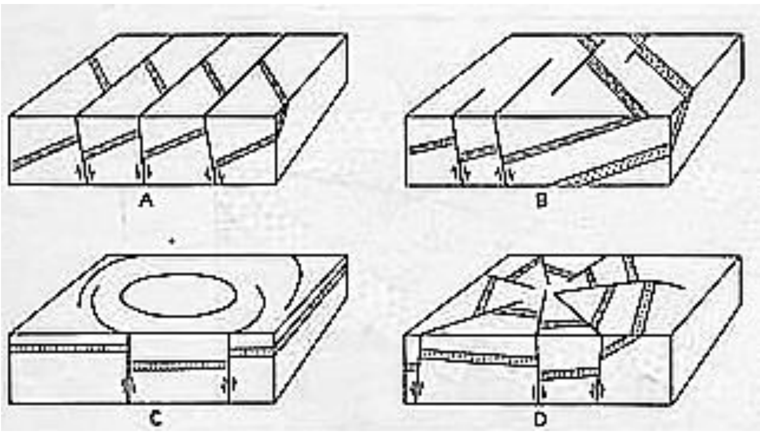


Idealized model of a pull-apart basin as a result of a transform fault. Arrows indicate motion along each fault segment.



Strike Slip Faults



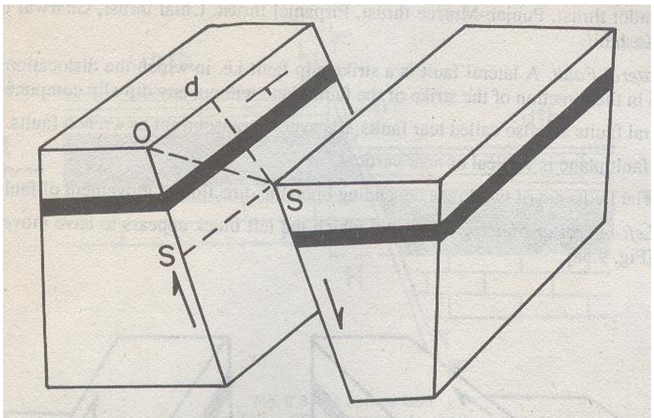


Fig. 9.6 Diagonal-slip fault
ds= dip slip, ss = strike slip, os = oblique slip

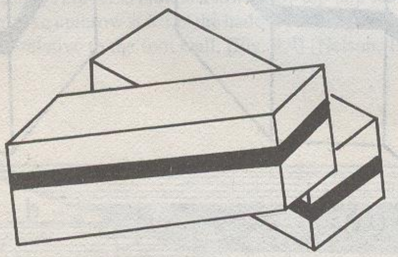
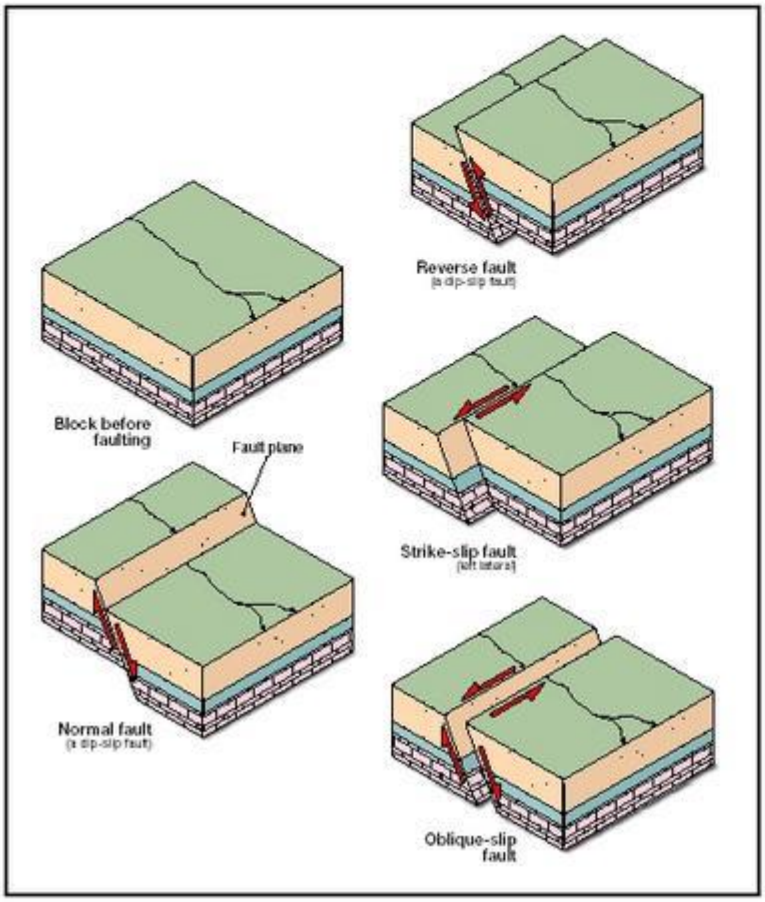
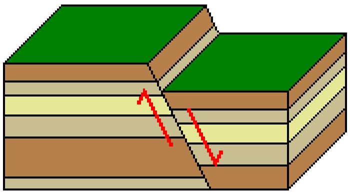


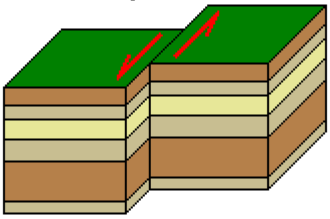
Fig. 9.7 A Hinge Fault



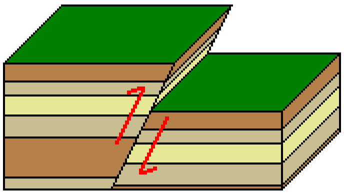
A normal fault



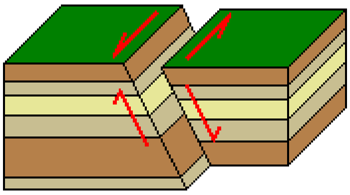
A strike-slip fault



A reverse fault

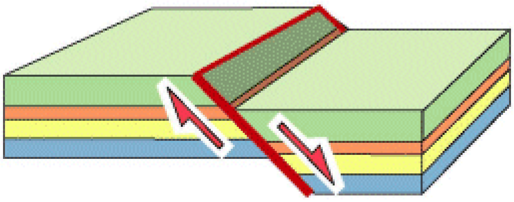


An oblique fault



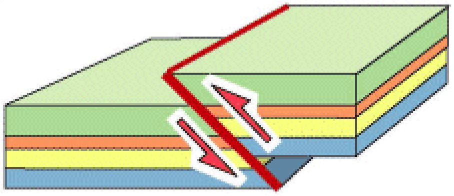
Dip-slip faults

where the fault slip is along the direction of DIP of the fault surface



Normal Fault

hanging-wall moves down relative to the footwall

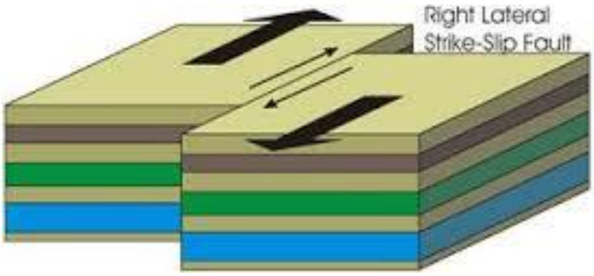


Thrust Fault

hanging-wall moves up relative to the footwall

return to menu

compare attributes



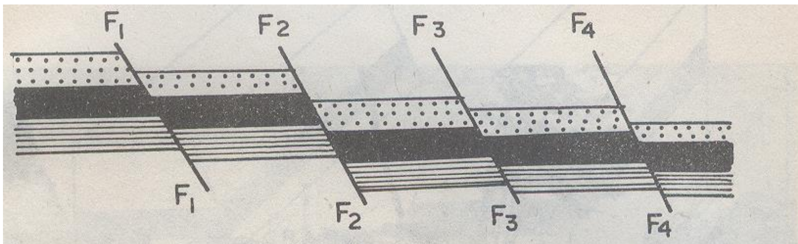


Fig. 9.12 A Step fault system
F_1 F_2 F_3....Fault planes

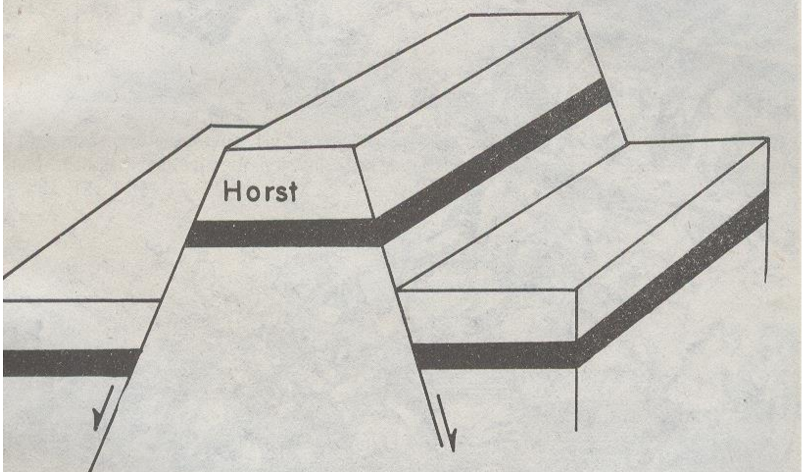
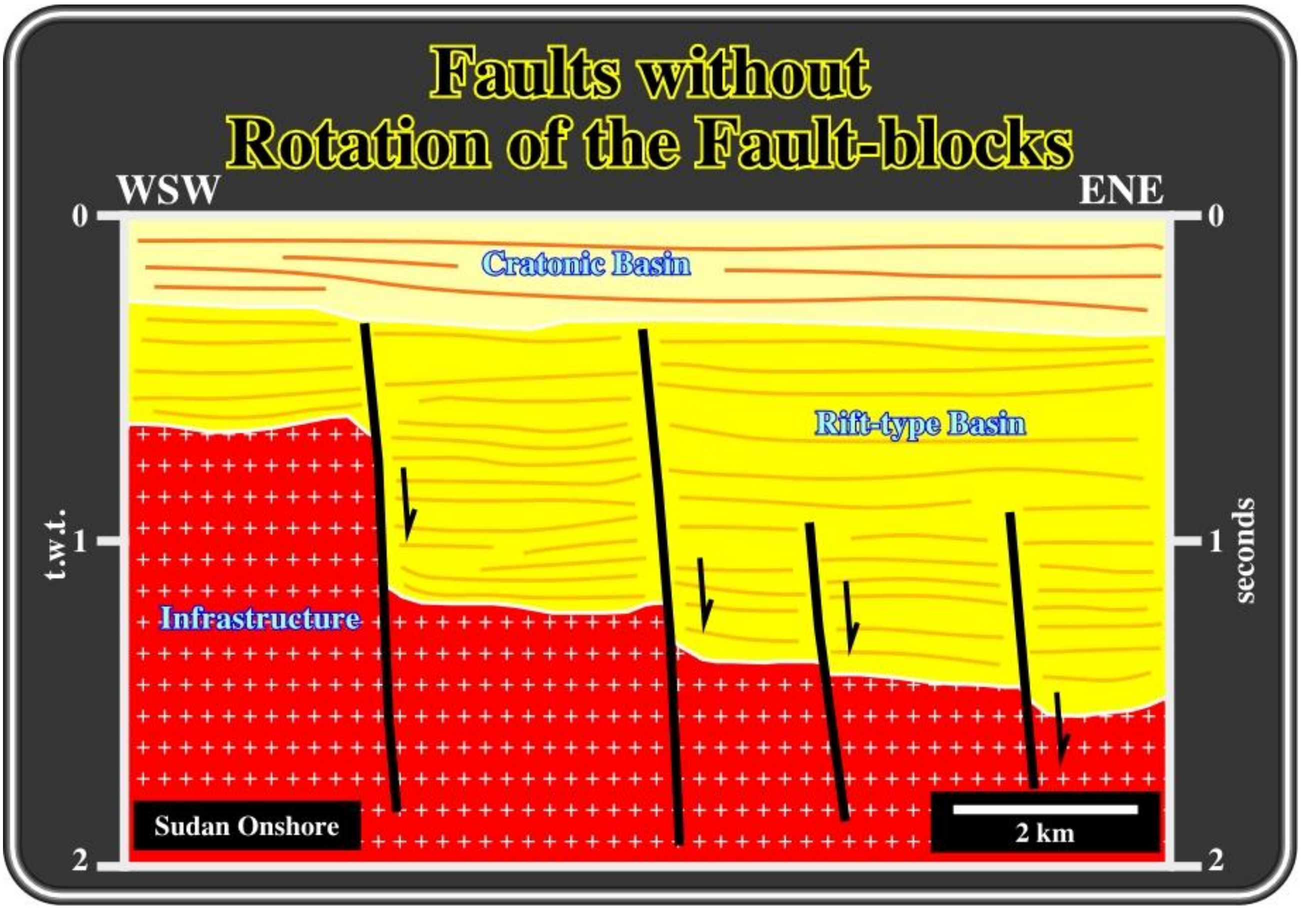


Fig. 9.13 A ridge fault system



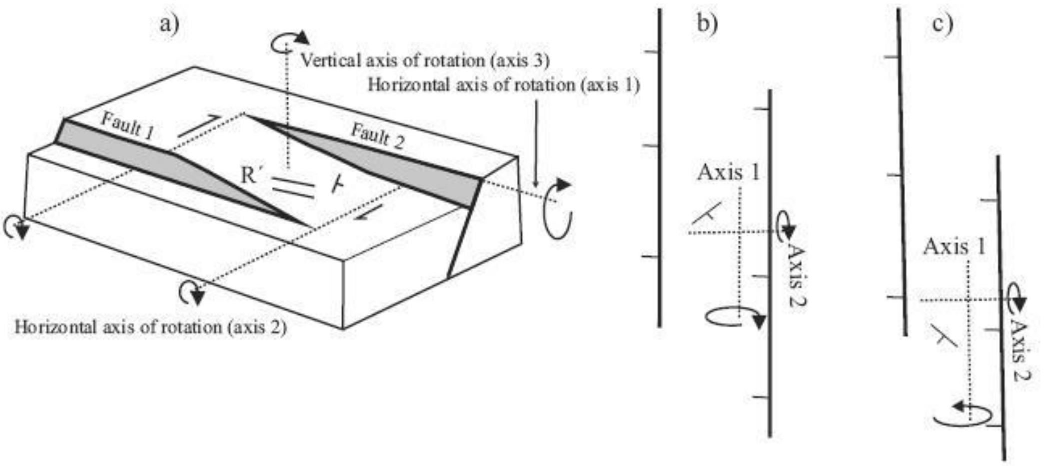
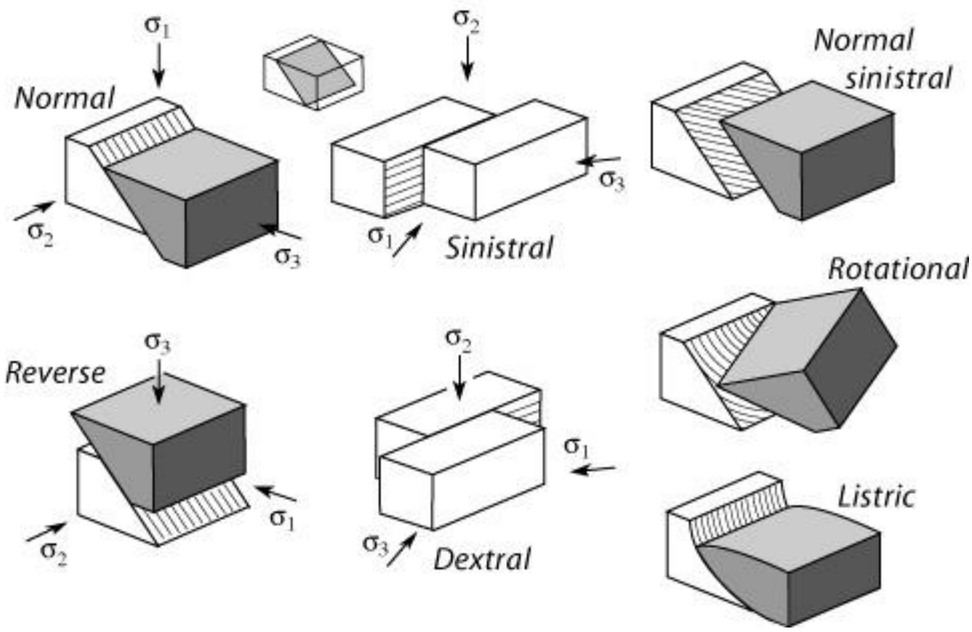
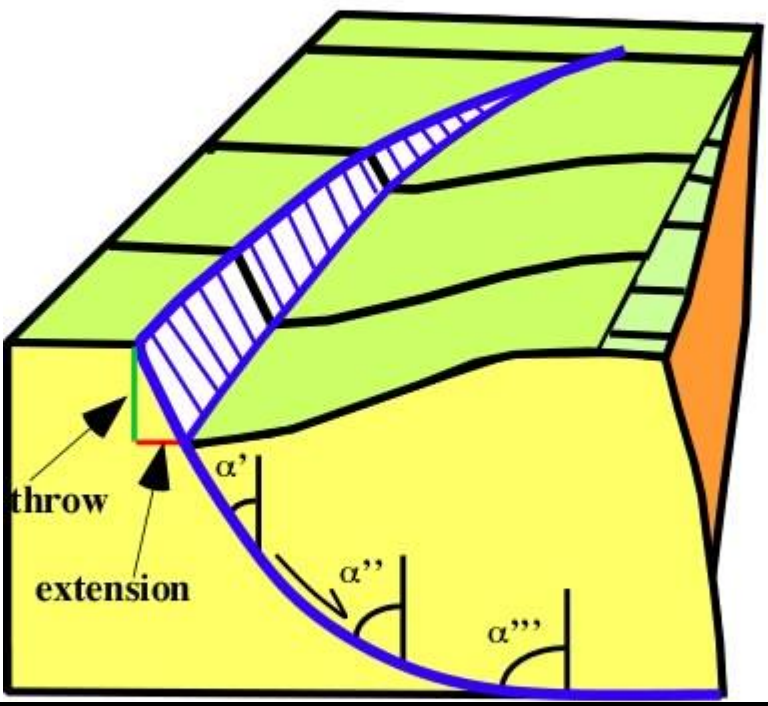
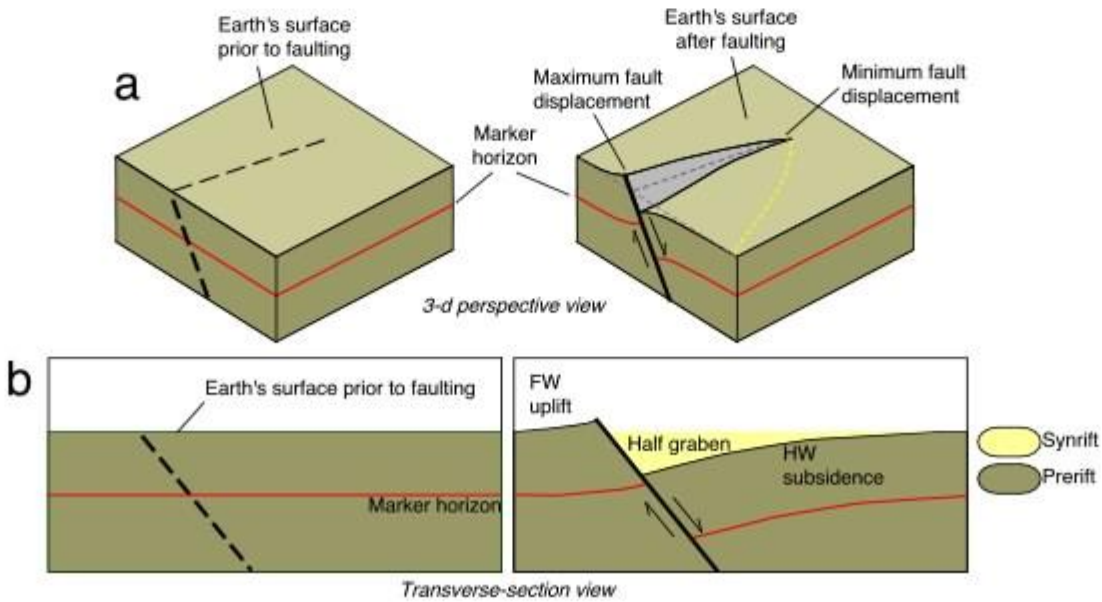


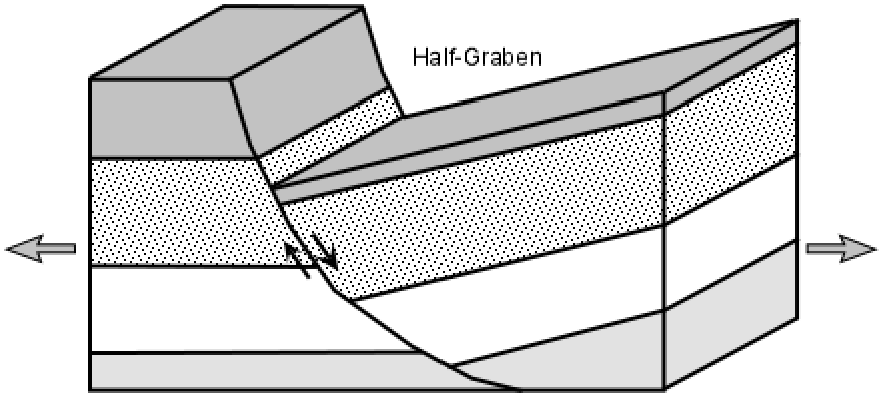
Figure 6. a) Three dimensional sketch showing the structure in a relay zone. Three axes of rotation are shown (modified from Ferrill and Morris, 2001). R´: Riedel fractures due to rotation of the vertical axis. b) and c) are two dimensional sketches showing two combinations of rotation around axis 1 and axis 2, which cause different orientations of bedding in the relay zone.



Amount of Extension

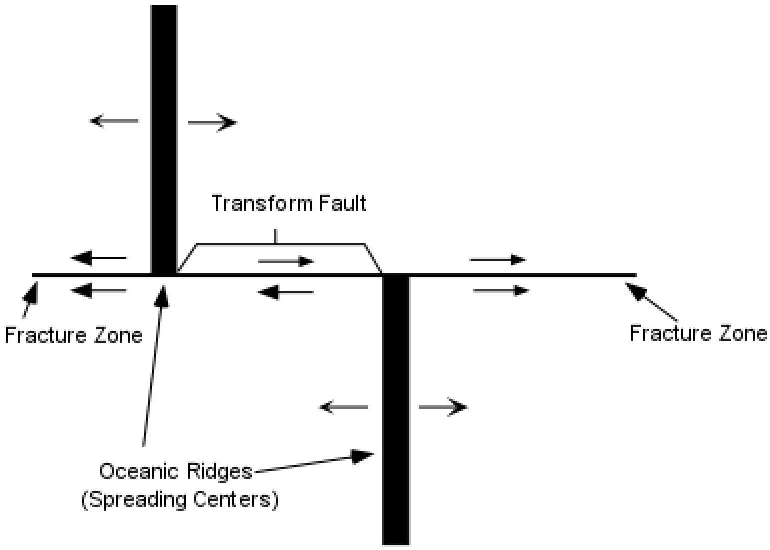


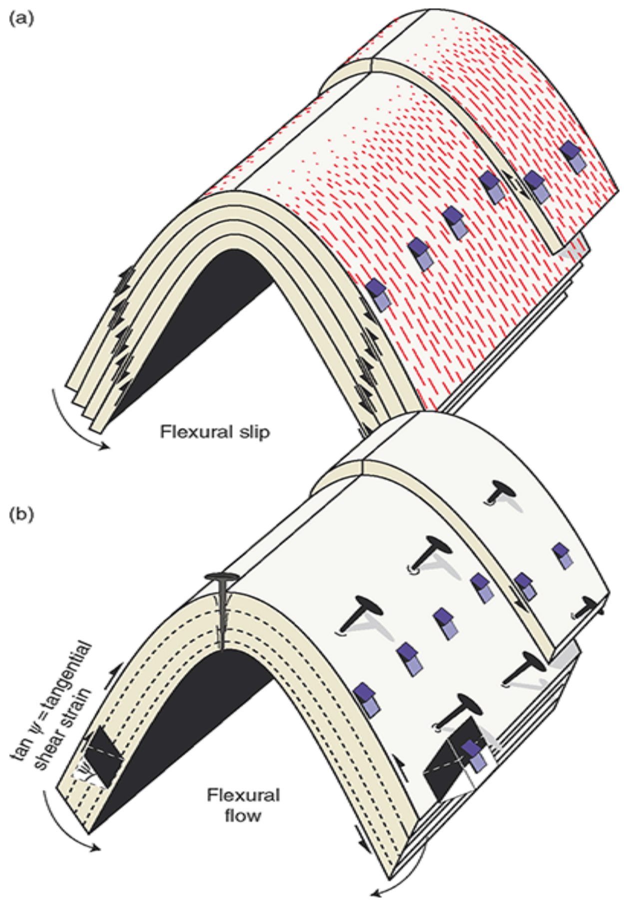




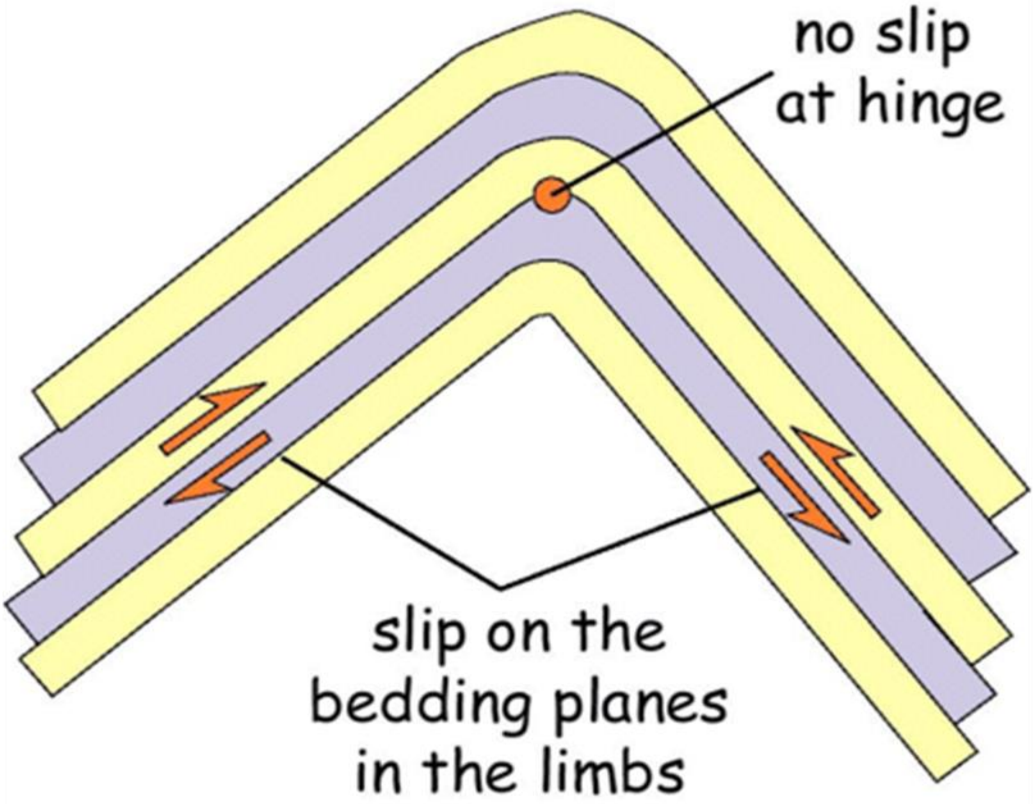
Half-Grabens - A normal fault that has a curved fault plane with the dip decreasing with depth can cause the down-dropped block to rotate. In such a case a half-graben is produced, called such because it is bounded by only one fault instead of the two that form a normal graben.

Transform-Faults are a special class of strike-slip faults. These are plate boundaries along which two plates slide past one another in a horizontal manner. The most common type of transform faults occur where oceanic ridges are offset. Note that the transform fault only occurs between the two segments of the ridge. Outside of this area there is no relative movement because blocks are moving in the same direction. These areas are called fracture zones. The San Andreas fault in California is also a transform fault.

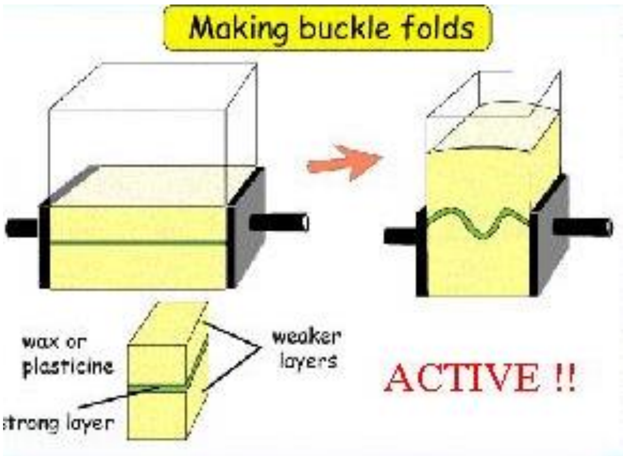

Transform Fault
Fracture Zone
Fracture Zone
Oceanic Ridges
(Spreading Centers)


(a)
Flexural slip
(b)
tan ψ = tangential
shear strain
Flexural
flow

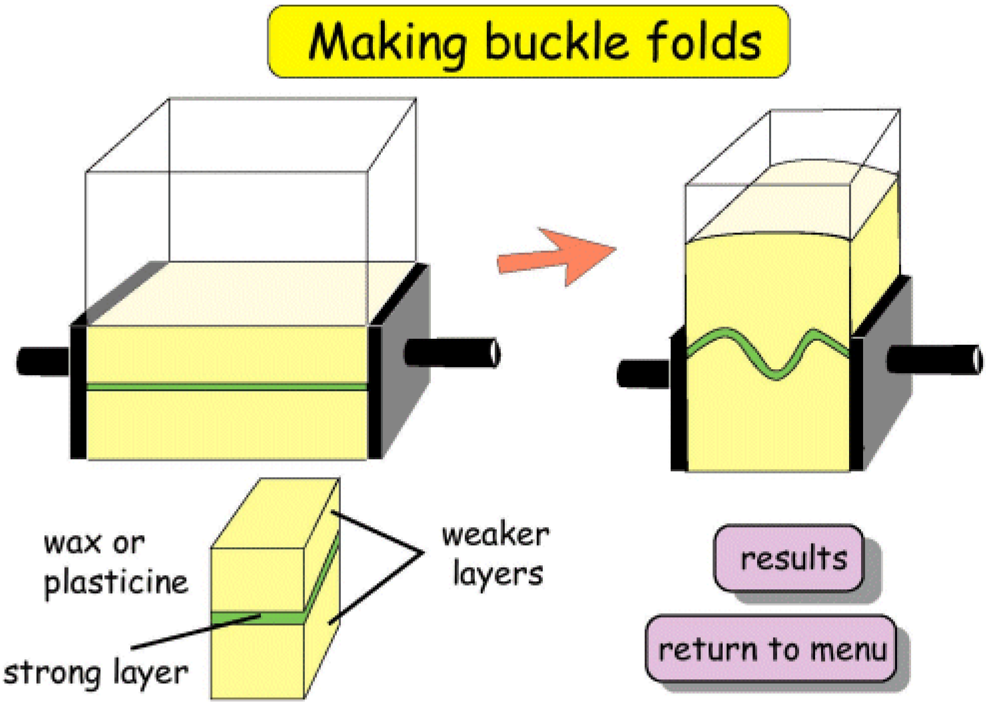
[redacted]

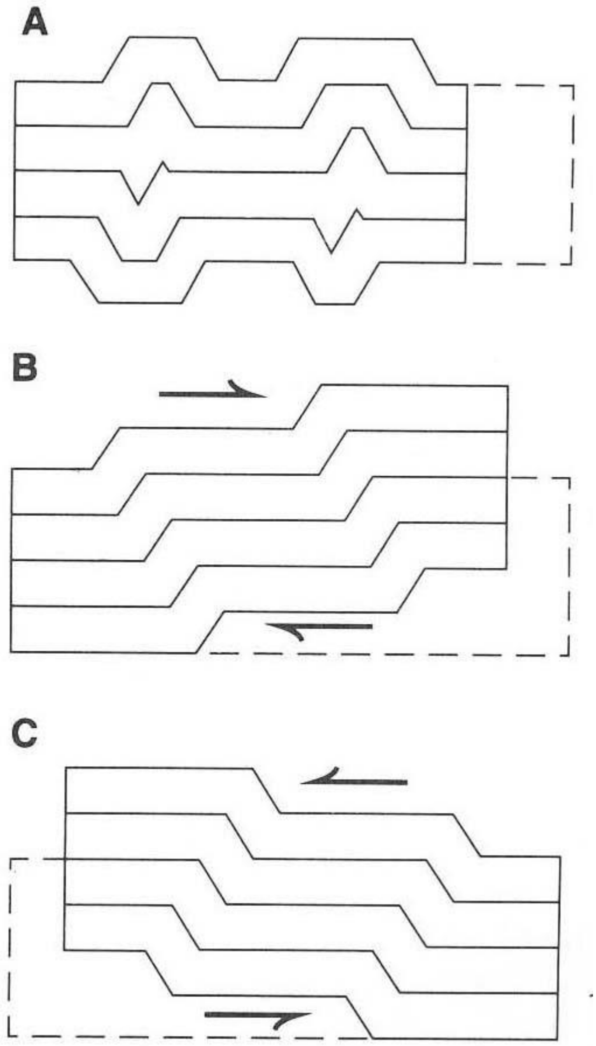


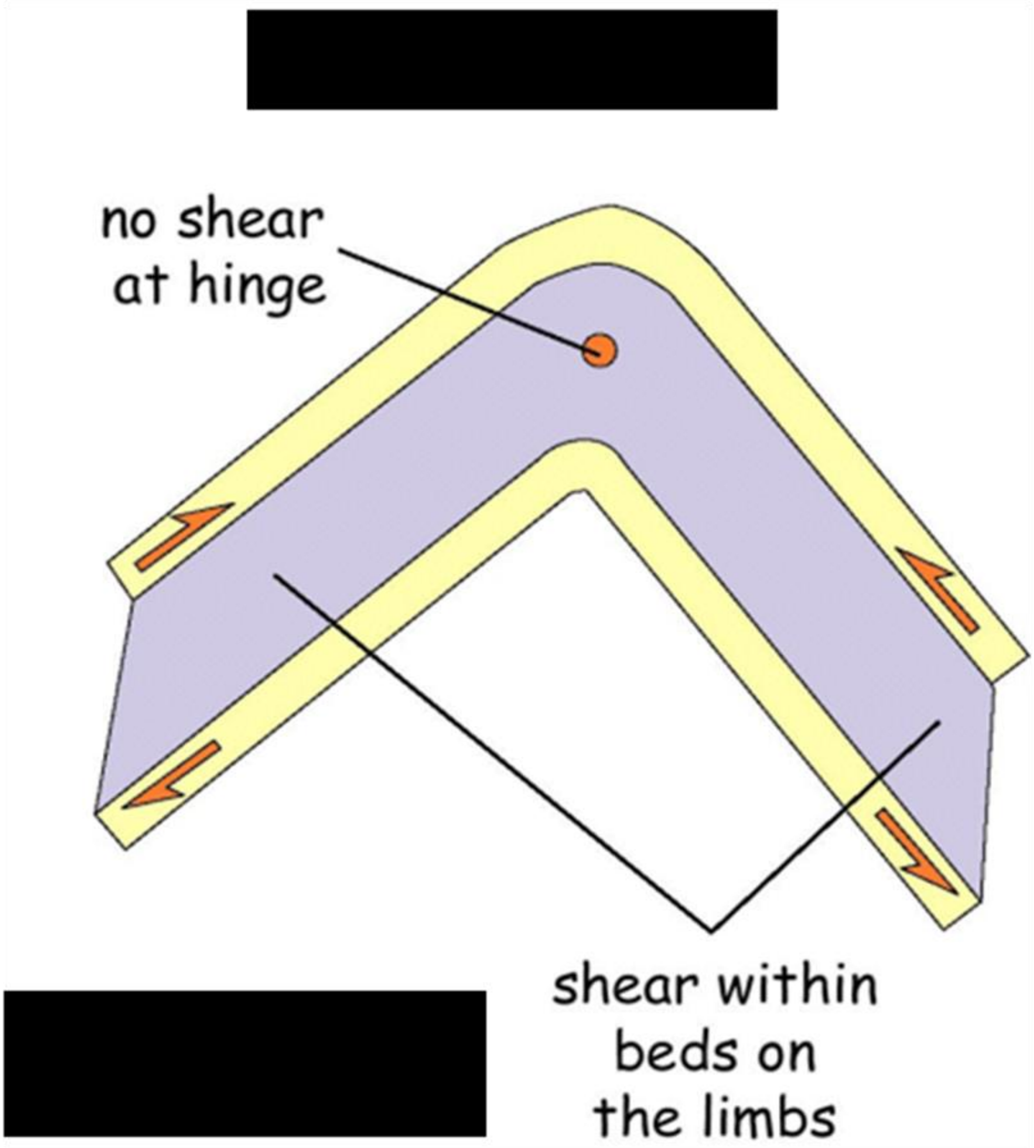
[redacted]

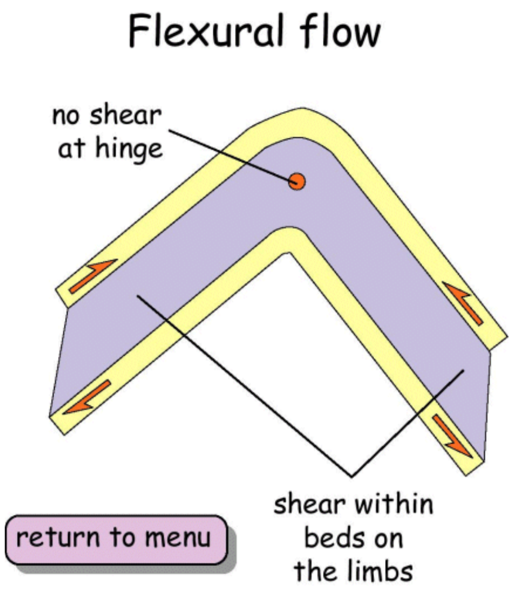

Making buckle folds
wax or
plasticine
weaker
layers
strong layer
ACTIVE !!

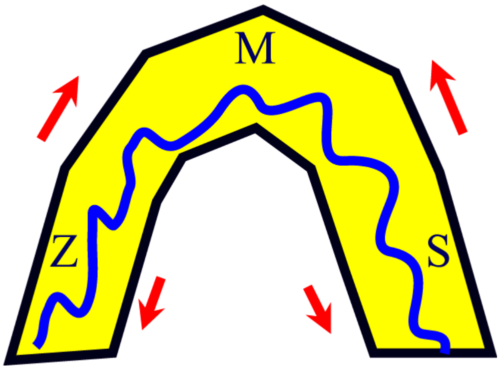
B

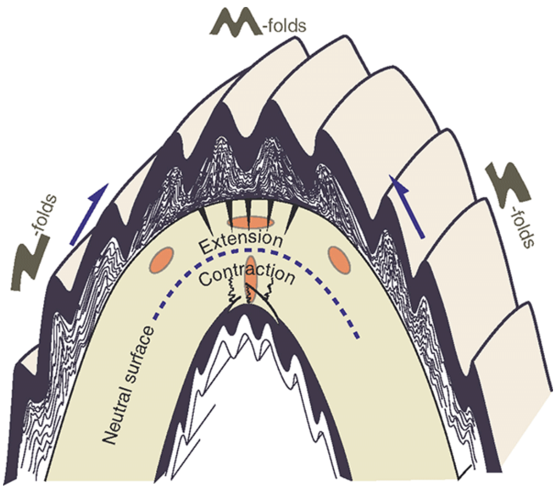

Making buckle folds
wax or
plasticine
weaker
layers
strong layer
results
return to menu

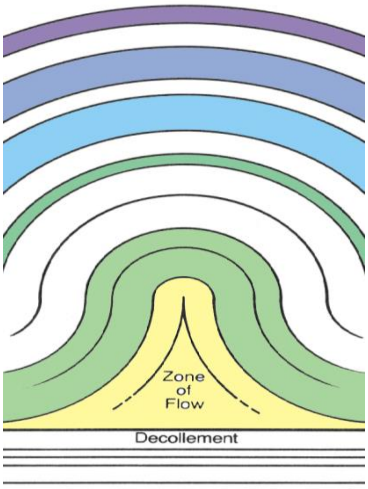

A
B
C

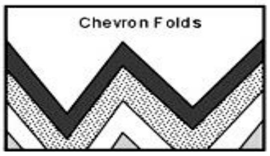

[redacted]
no shear
at hinge
[redacted]
shear within
beds on
the limbs

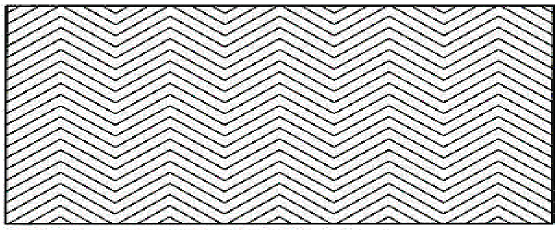

Flexural flow
no shear
at hinge
shear within
beds on
the limbs
return to menu


M
Z
S

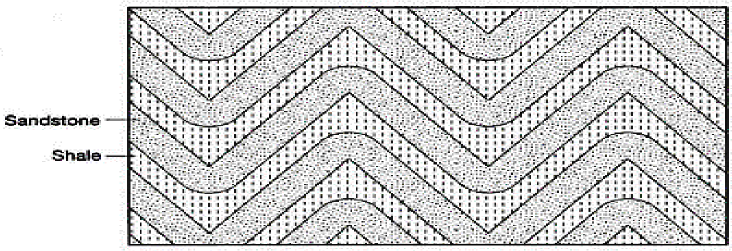

-folds
-folds
-folds
Extension
Contraction
Neutral surface



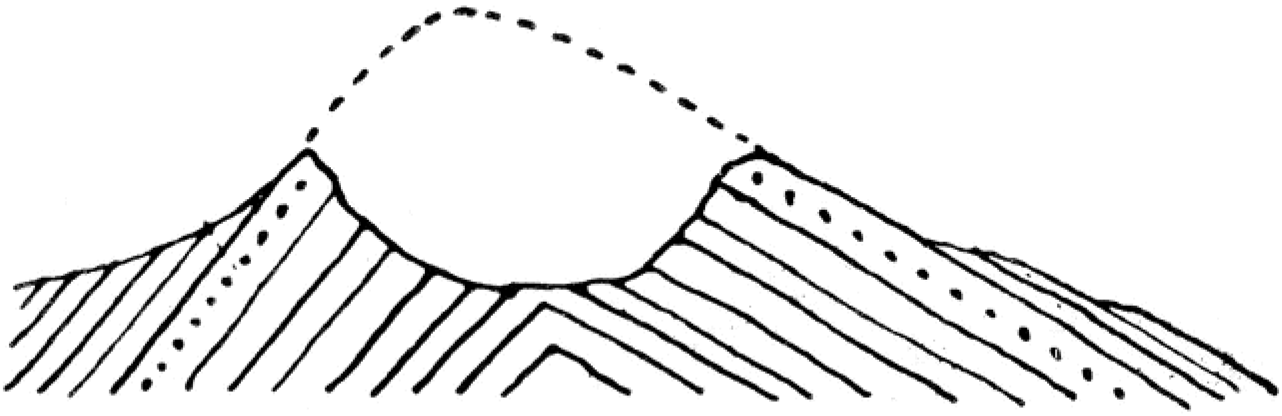


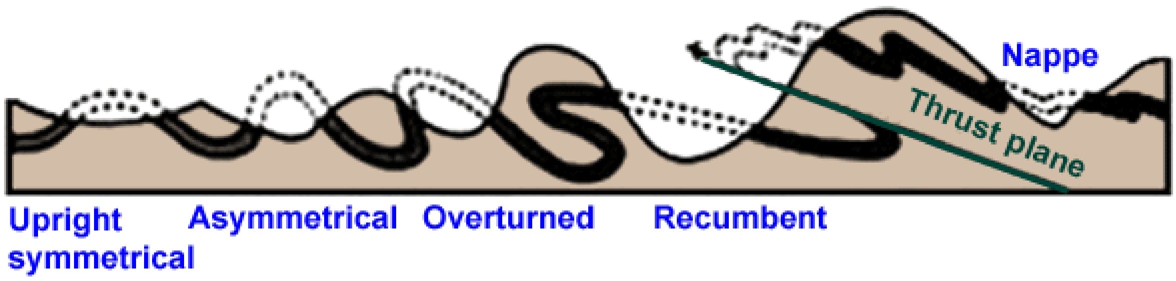

A.


B.



C.





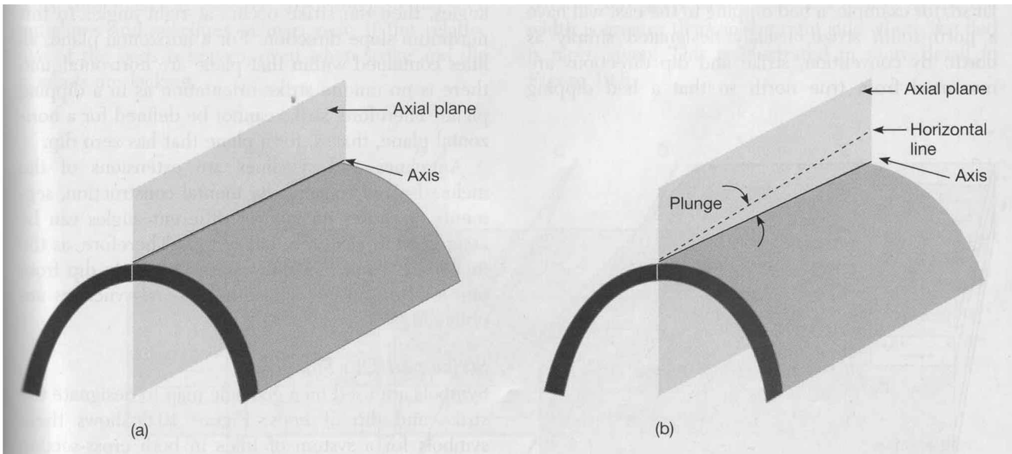
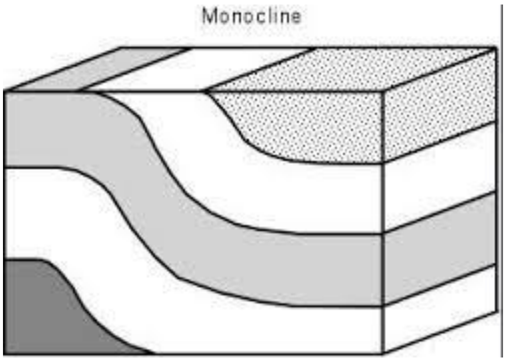
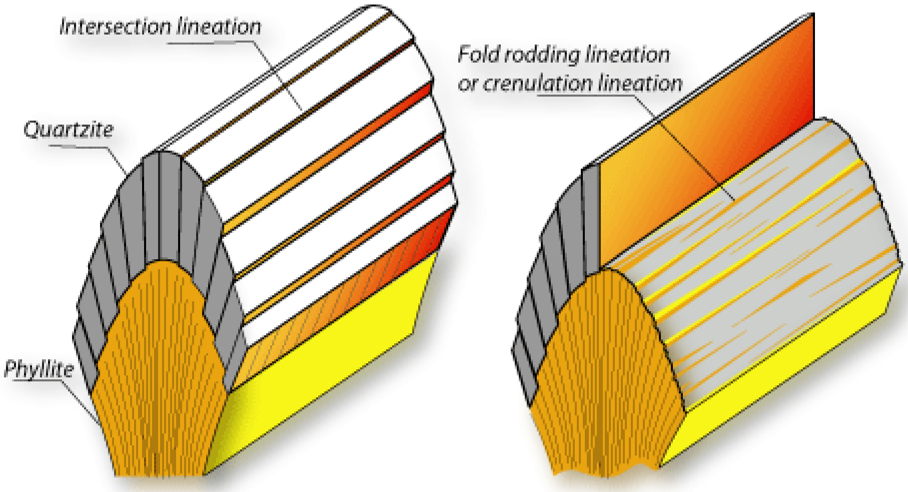
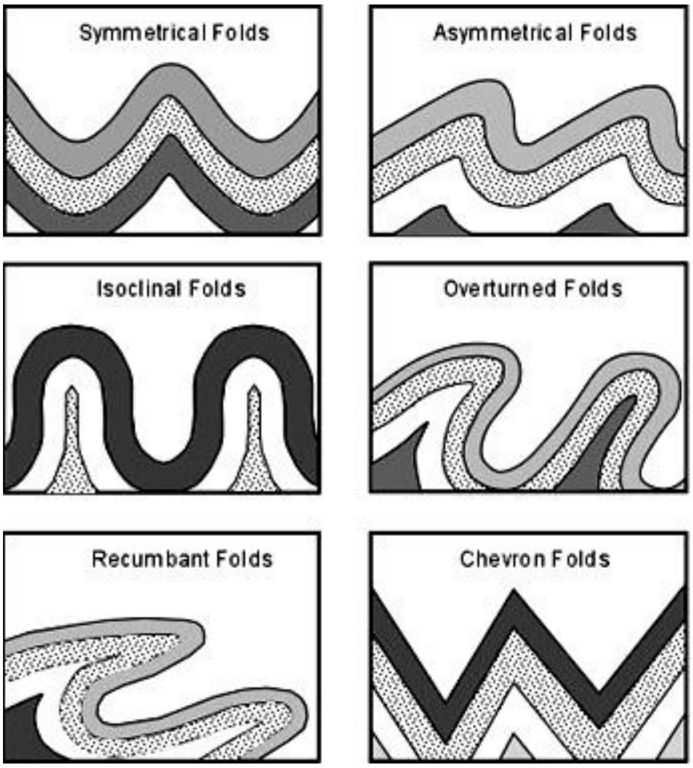


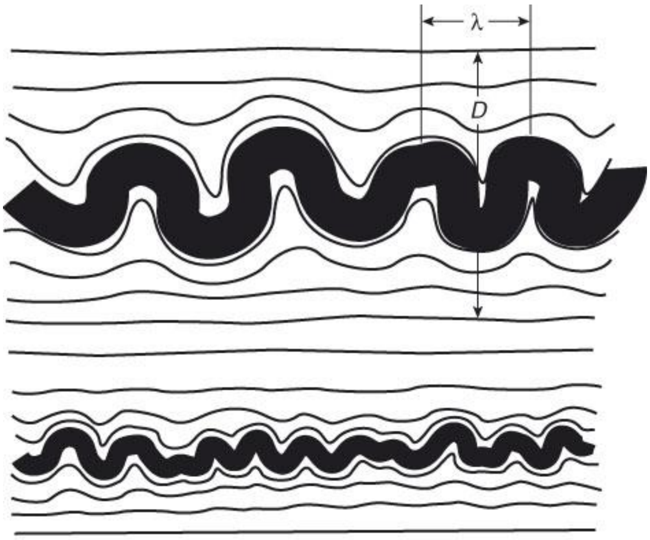
FIGURE 10.3 Anticline, with axial plane and axis. (a) Nonplunging. (b) Fold plunging to the rear.


Monocline

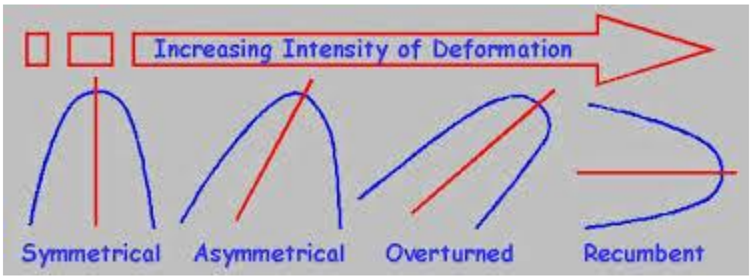

Intersection lineation
Quartzite
Phyllite
Fold rodding lineation
or crenulation lineation

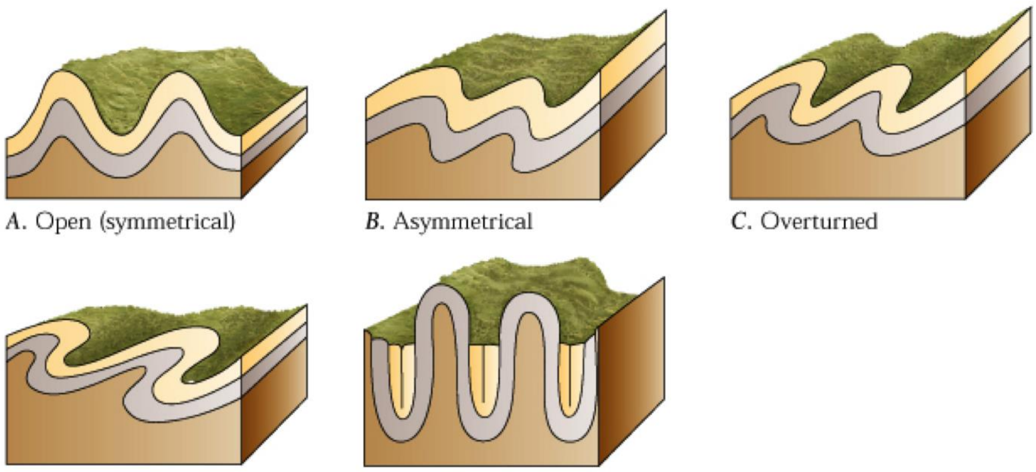

Symmetrical Folds
Asymmetrical Folds
Isoclinal Folds
Overturned Folds
Recumbant Folds
Chevron Folds

Disharmonic Folds



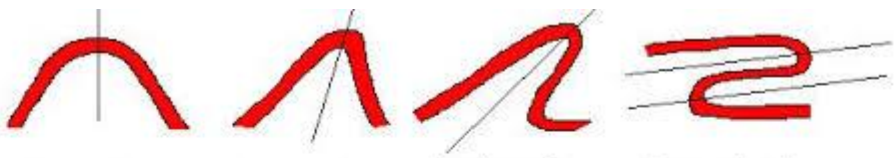
B.

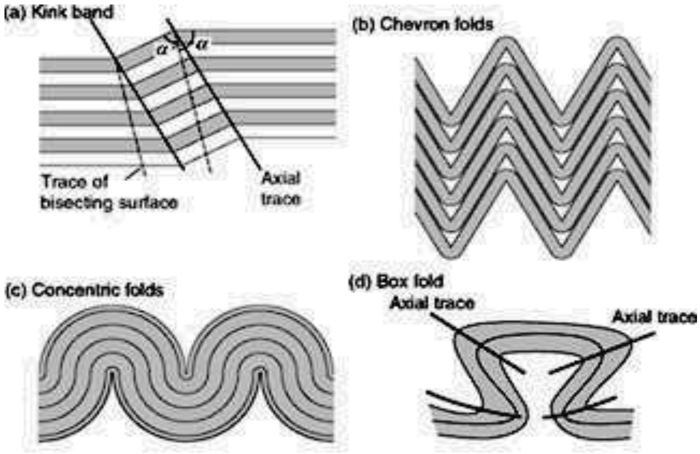


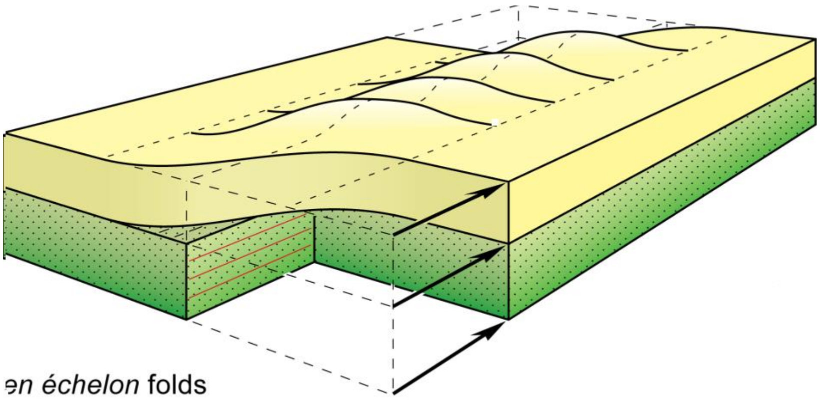


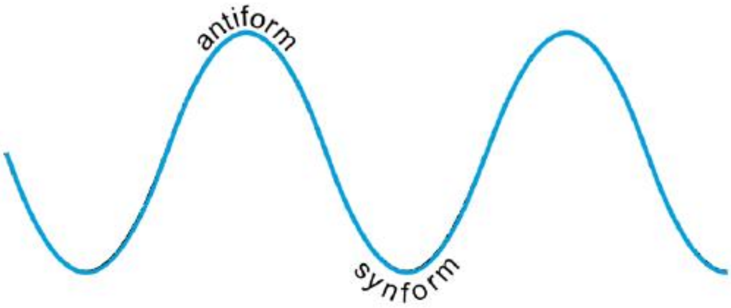
A. Open (symmetrical) B. Asymmetrical C. Overturned

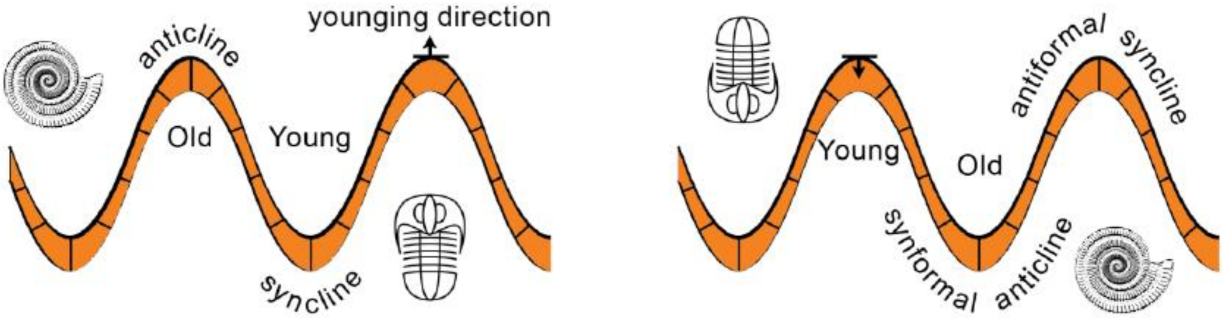
D. Recumbent E. Isoclinal





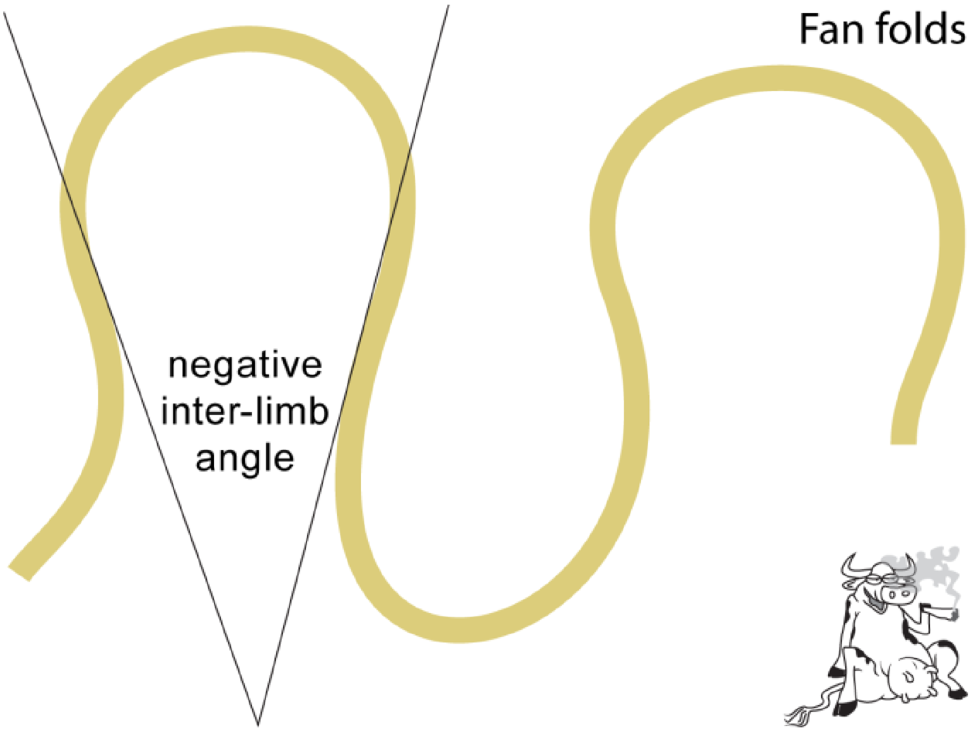


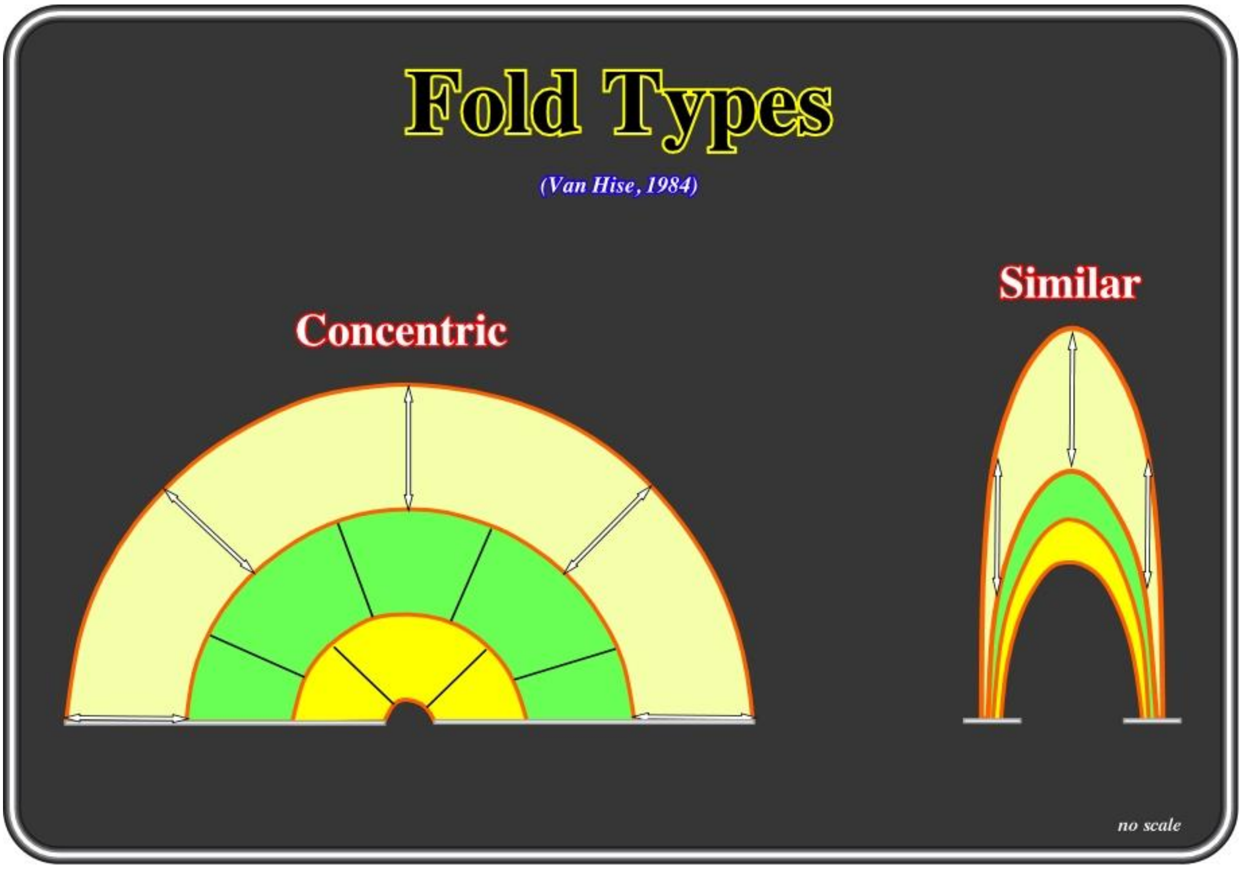




Anticline and syncline

Anticline and **syncline** are terms with stratigraphic significance. Anticlines are antiforms in which the oldest strata are in the core of the fold. Synclines are synforms in which the youngest strata are in the core. But **antiformal syncline**s and **synformal anticlines** may exist in regions of complex, polyphase deformation. In these regions it is important to determine the **younging direction**, which is the direction along the axial surface in which the strata become younger.





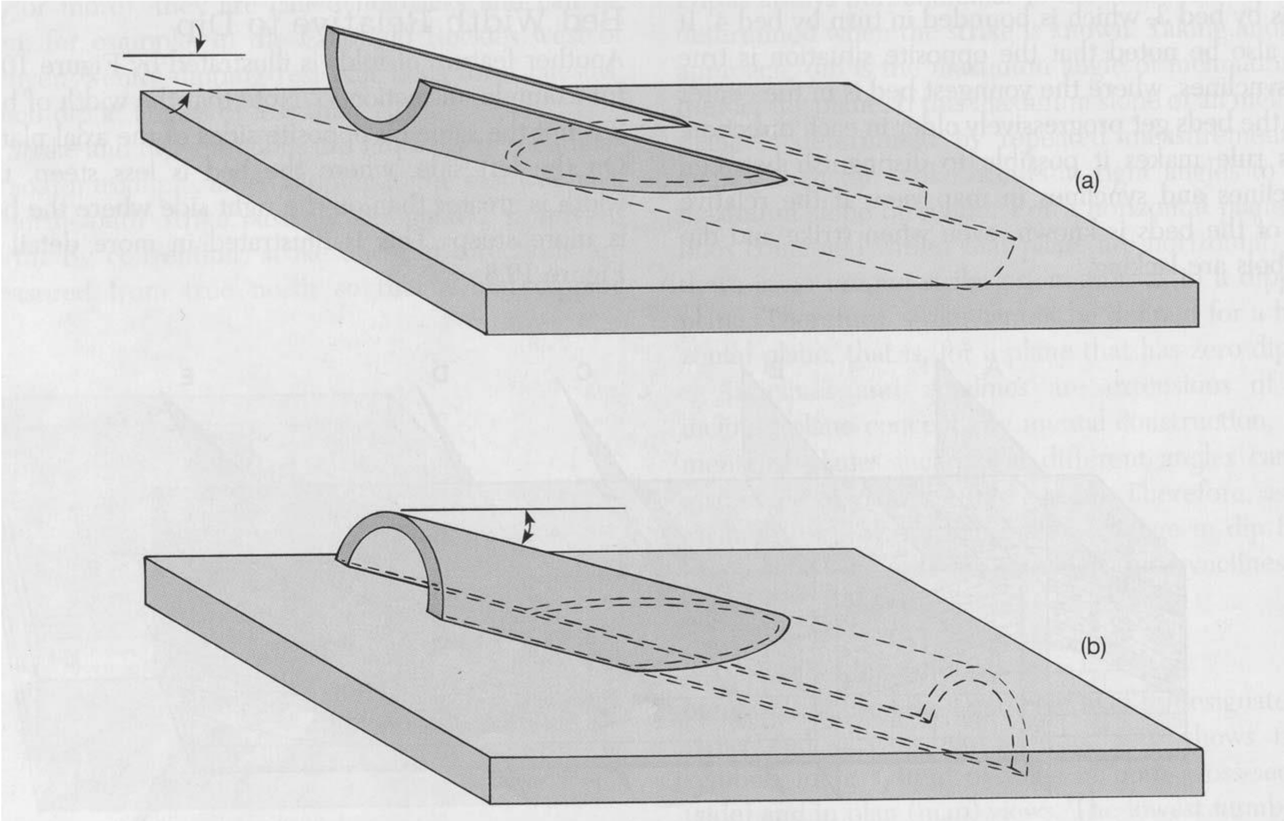


FIGURE 10.9 (a) Plunging synclines and (b) anticlines.