Structural Geology

Unit-I

Structural Geology

Structural Geology

- Introduction, Causes of Development of Structures, Structural Elements - Folds, Faults, Joints, Unconformity, Dip, Strike, Outcrop Patterns, Outliers and Inliers.

Introduction

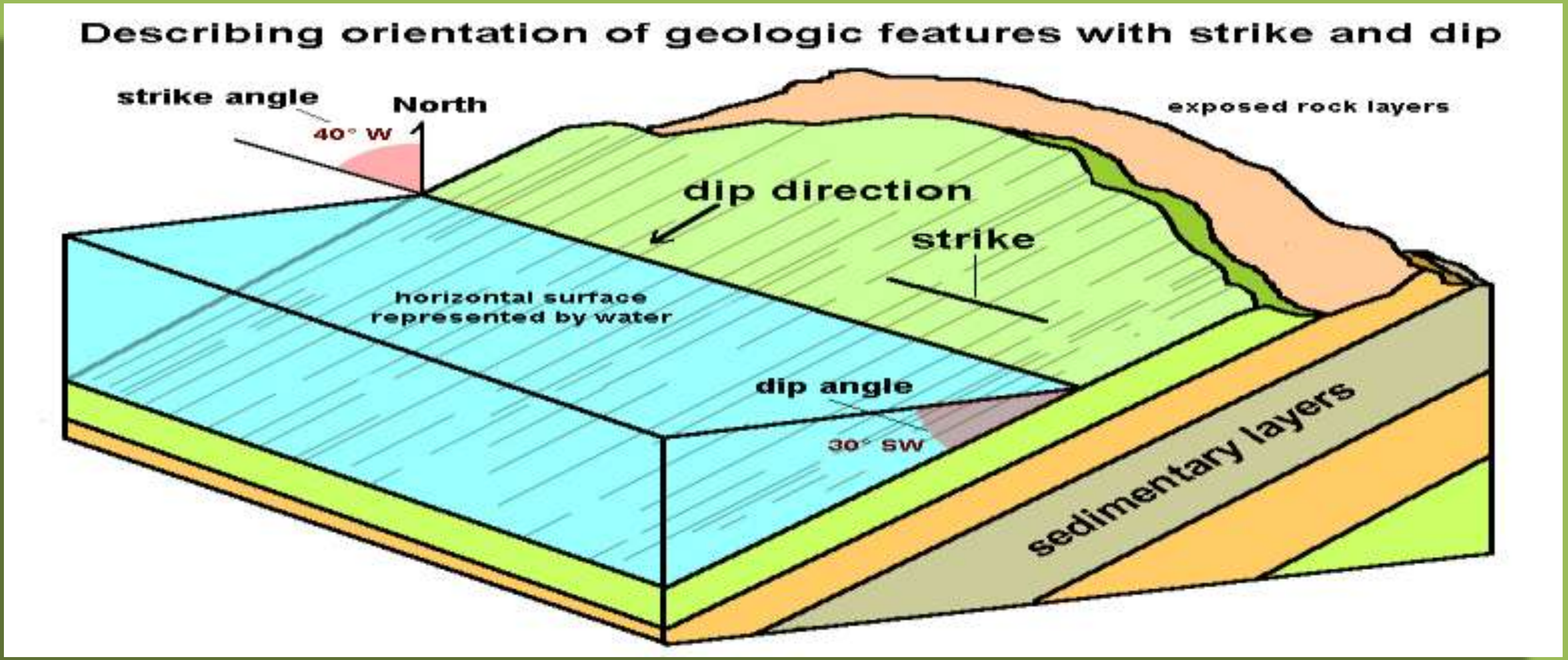
- Structural geology is **the study of factors such as origin, occurrence, classification, type and effects of various secondary structures like folds, faults, joints, rock cleavage** and are different from those primary structures such **as bedding and vesicular structure,** which develop in rocks at the time of their formation.

Outcrop

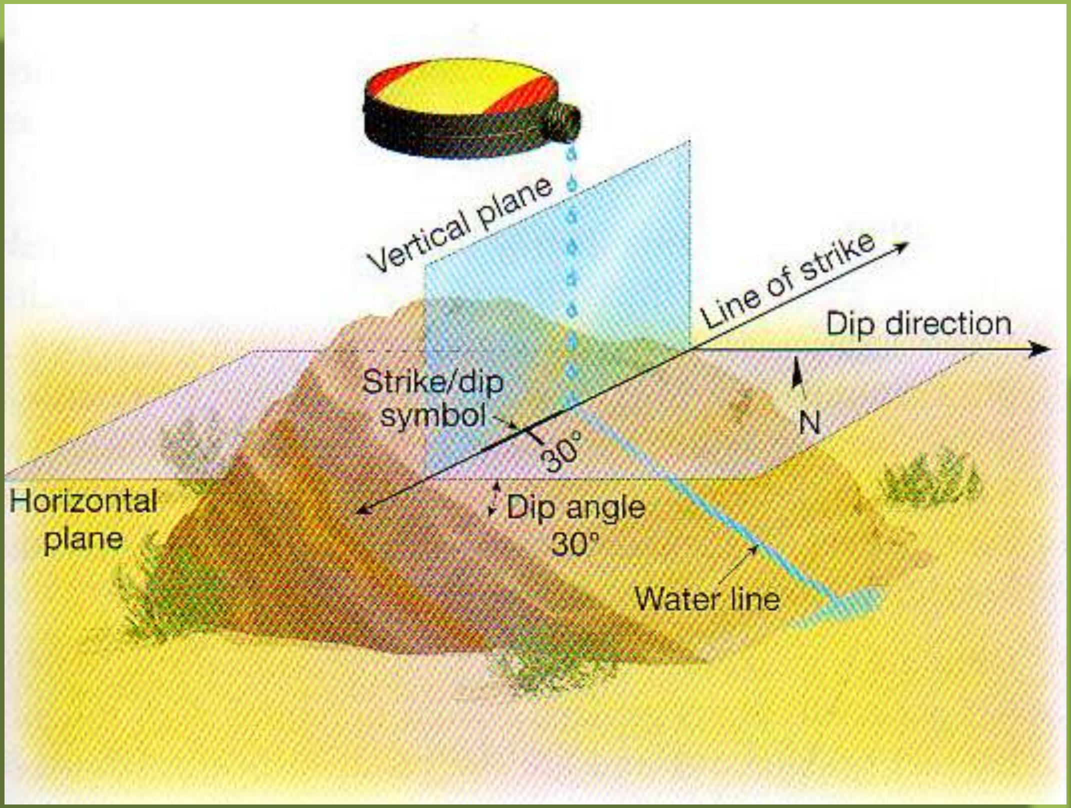
- Any Geological formation exposed on the surface is called an outcrop.

Strike and Dip

- **Strike** refers to the **direction in which a geological structure is present**. The strike direction may be defined as the **direction of the trace of the intersection between the bedding plane**

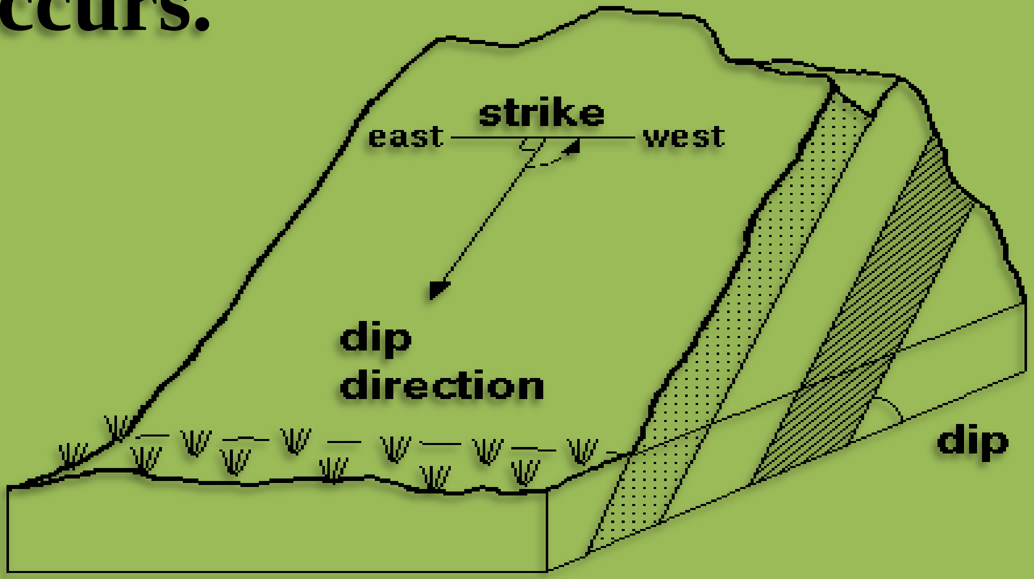


Strike and Dip

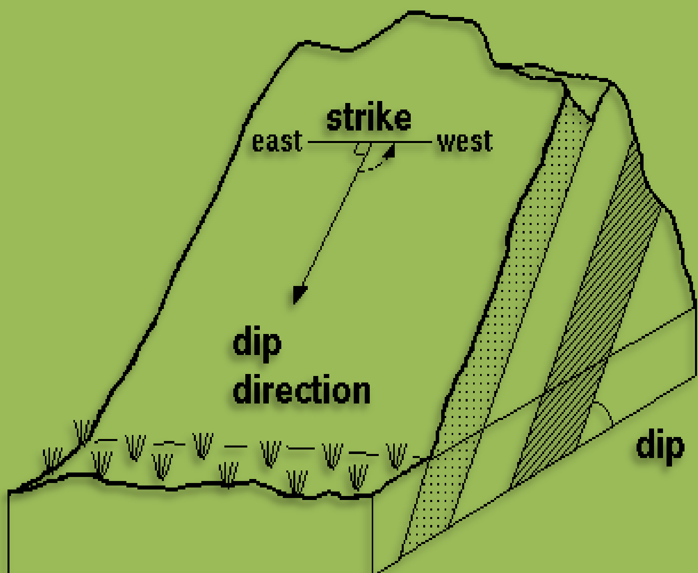


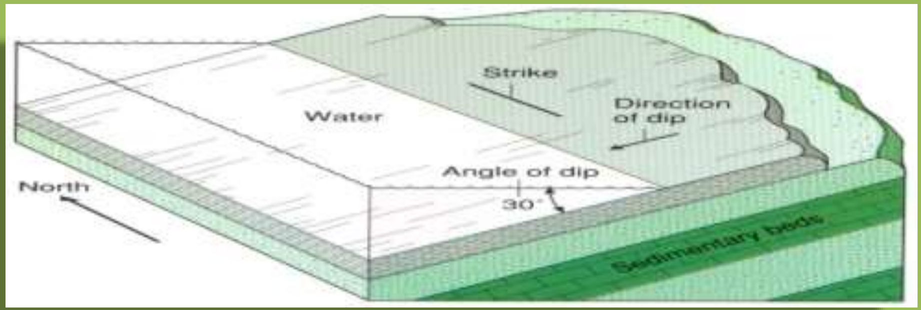
Strike and Dip

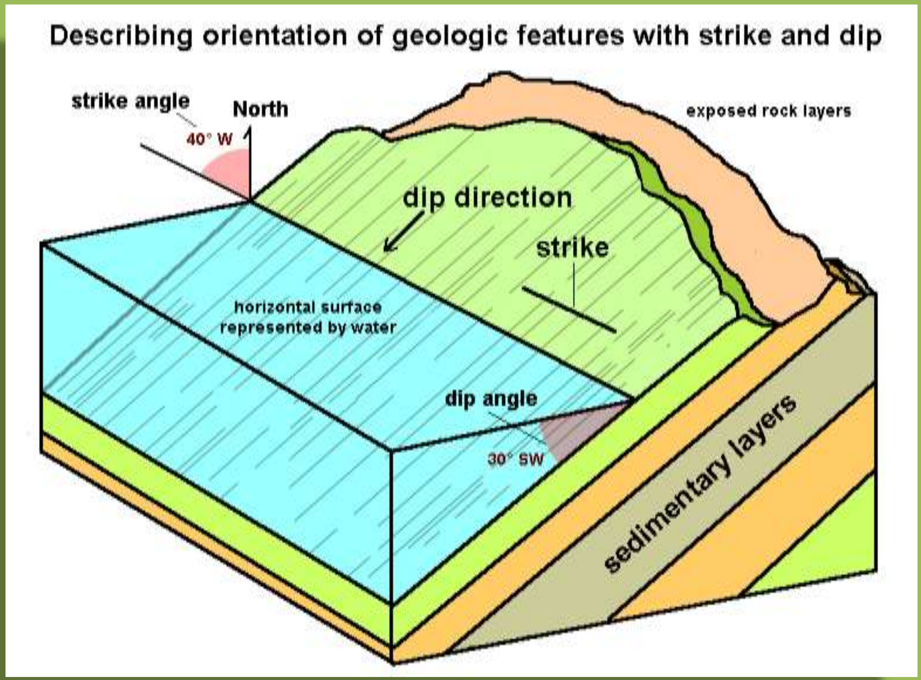
- **Dip** literally means **slope or inclination**. In structural geology dip is expressed both as direction and amount. **The dip direction is the direction along which the inclination of the bedding plane occurs.**



Strike and Dip





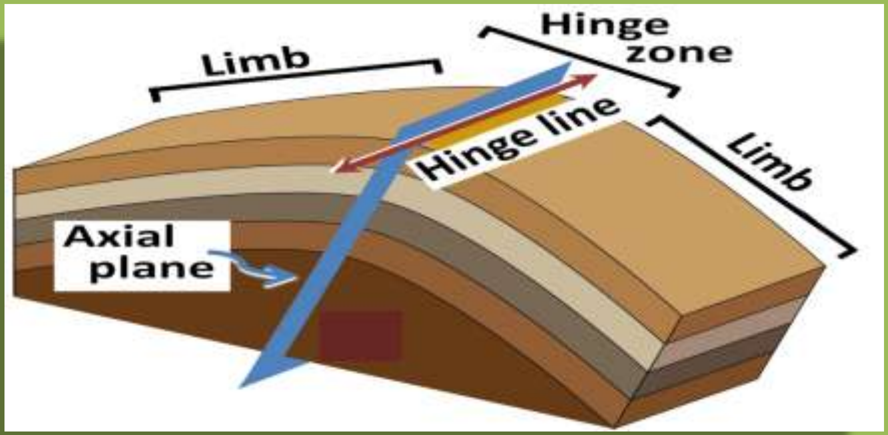


Folds

- Folds are one of the most common geological structures found in rocks. When a set of horizontal layers are **subjected to compressive forces, they bend either upward or downward.** The bend noticed in rocks are called folds.
- In terms of their nature too, folds may occur as single local bends or may occur repeatedly and intricately folded to the tectonic history of the region.

Folds

Folds



Classification and Types of Folds

Usually, folds are classified on the basis of

- Symmetrical Character
- Upward or Downward Bend
- Occurrence of Plunge
- Uniformity of Bed Thickness
- Behavior of the Fold Pattern with Depth.

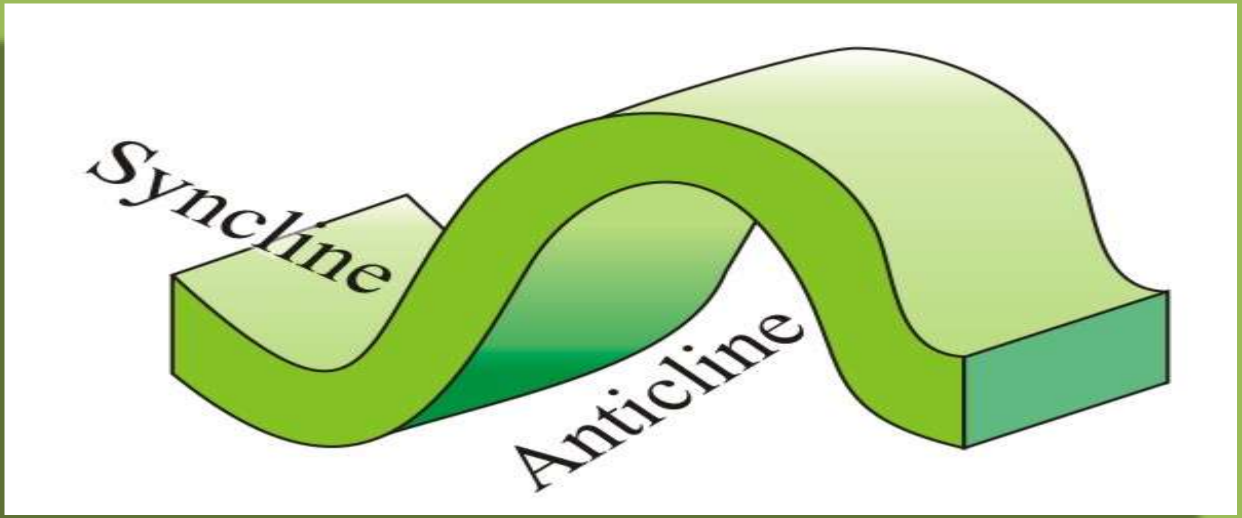
Classification and Types of Folds

Anticline and Syncline

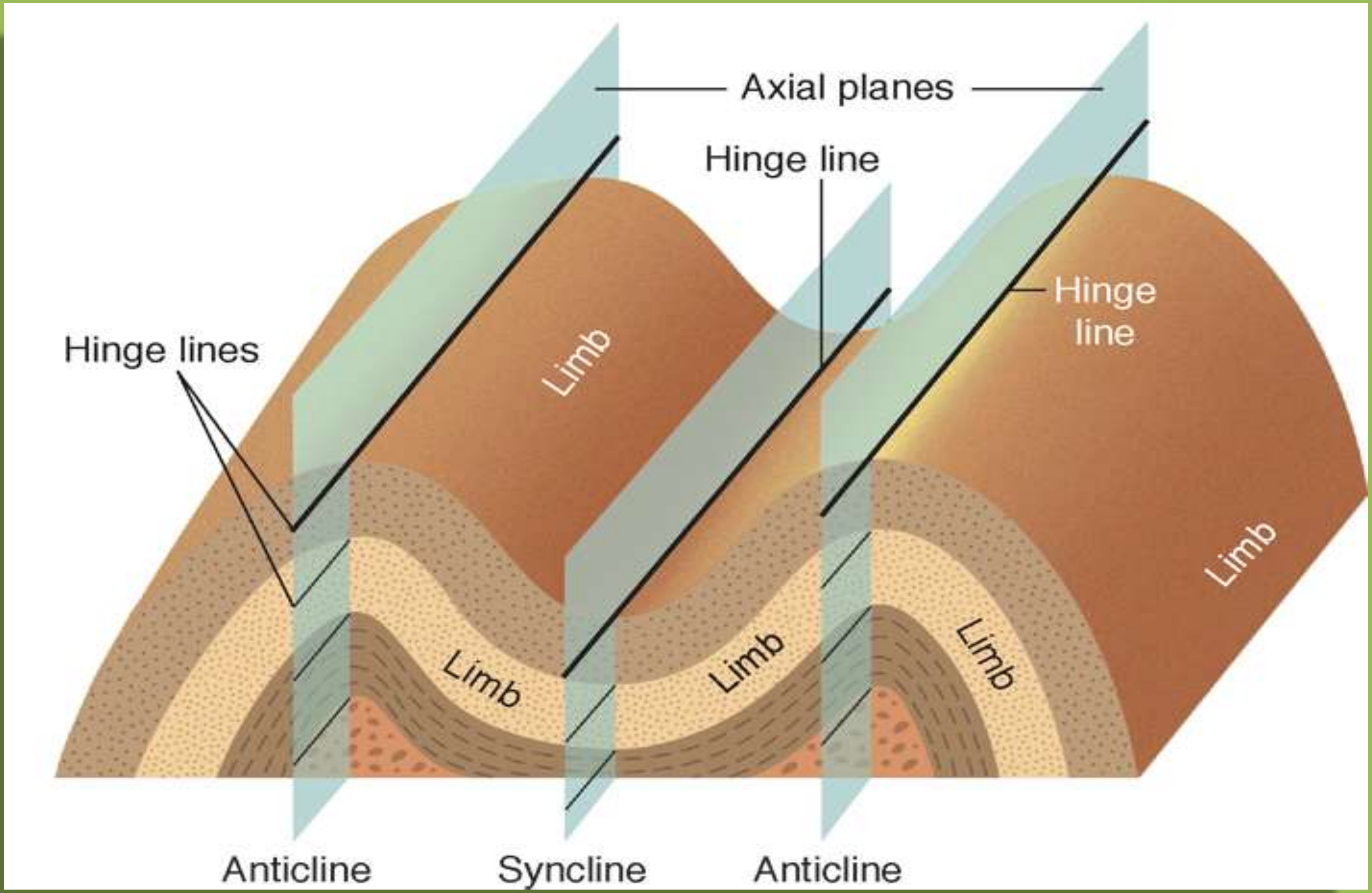
- When the beds are **bent upwards**, the resulting fold is called anticline. **This fold is convex upwards**. Naturally, in such a fold, the older beds occur towards the concave side, In a simple case, the limbs of anticline slope in opposite directions with reference to its axial plane. But when the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

Anticline and Syncline

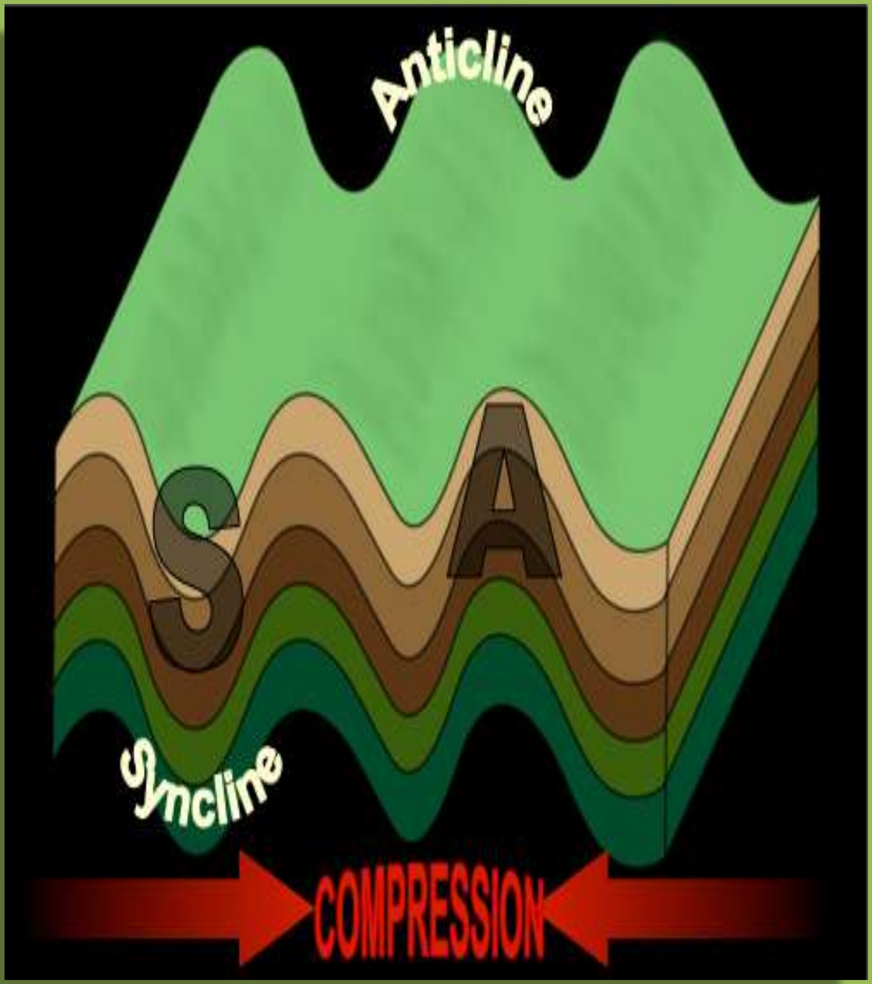
- **Syncline** is just opposite to **anticline in its nature, i.e. when the beds are bent downwards the resulting fold is called syncline.** This fold is **convex downwards.** In this the younger beds occur towards the concave side and, in a simple type of syncline, its limbs dip towards each other with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

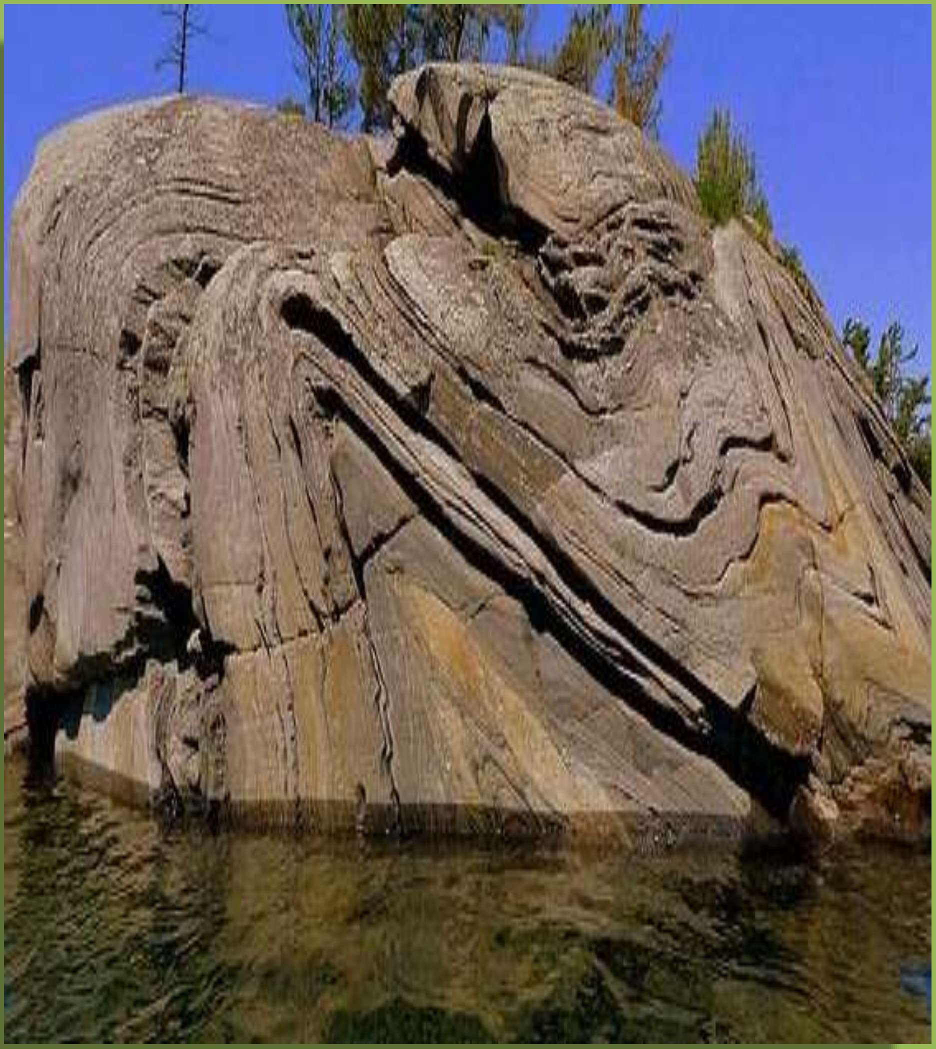


Anticline and Syncline



Anticline and Syncline



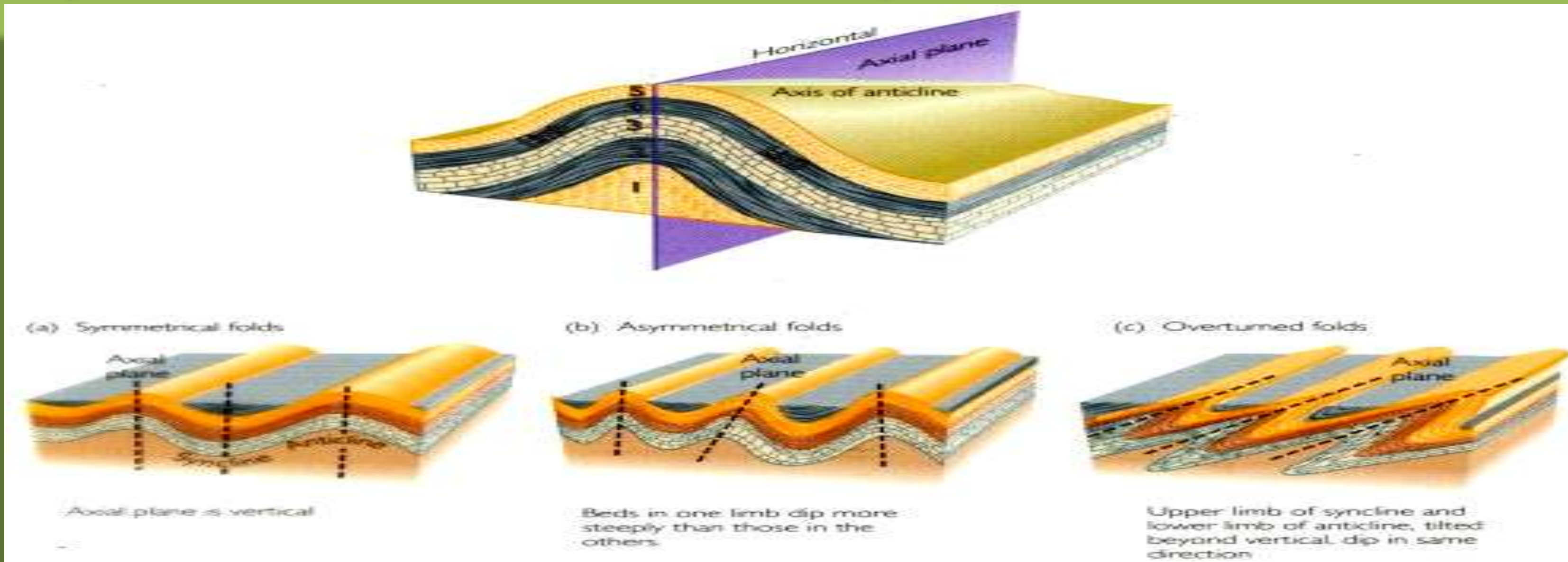


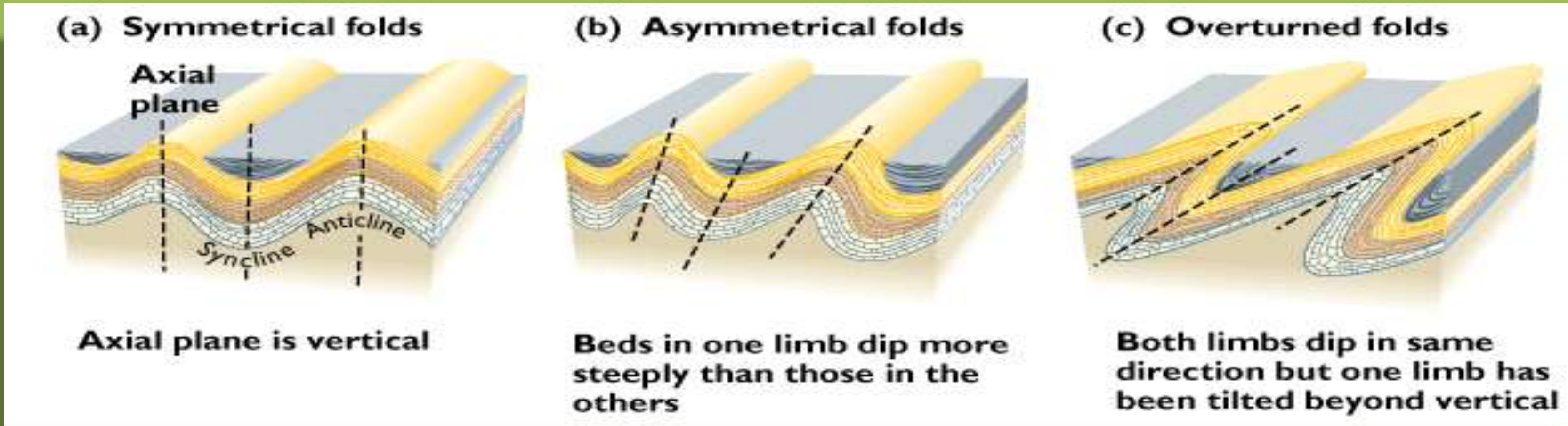
Classification and Types of Folds

Symmetrical and Asymmetrical Folds

- When the axial plane divides a fold into two equal halves in such a way that **one half is the mirror image, then the fold is called as symmetrical fold**. If the compressive forces responsible for folding are not of the **same magnitude, asymmetrical folds are formed.**

Symmetrical and Asymmetrical folds



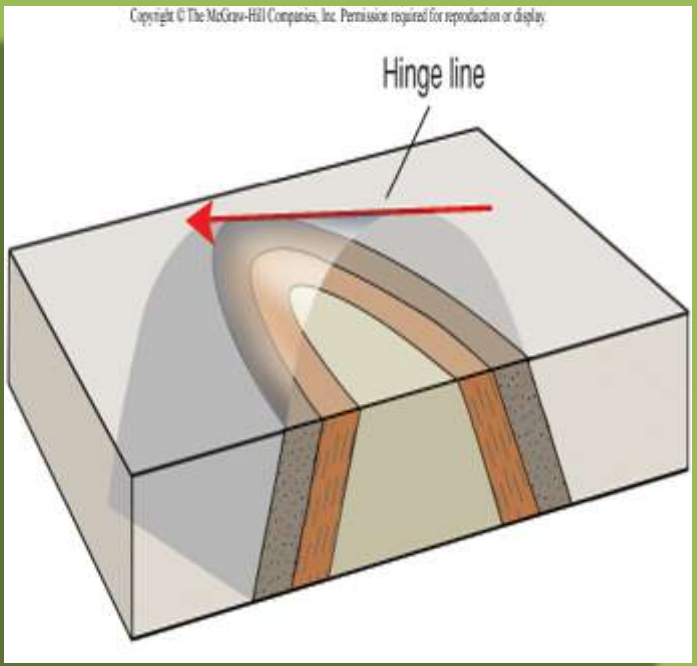


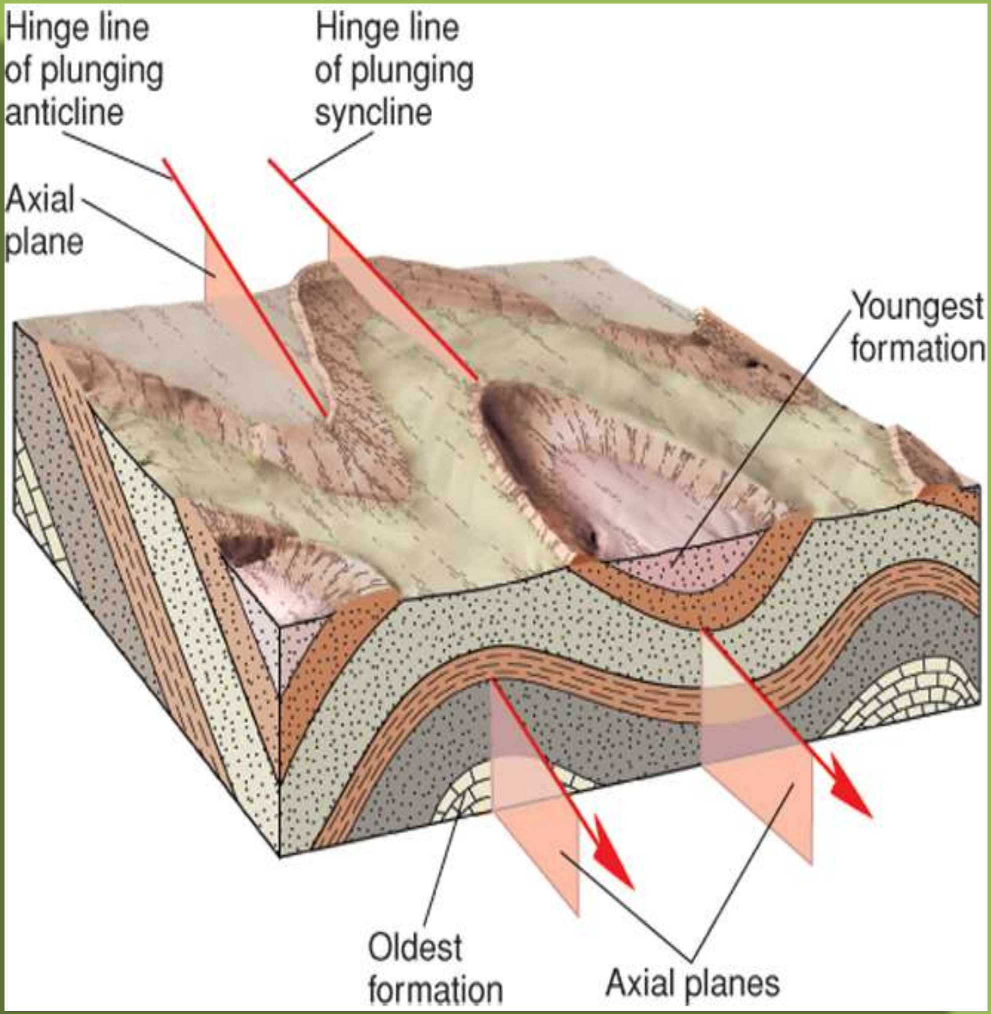
Classification and Types of Folds

Plunging and Non-Plunging Folds

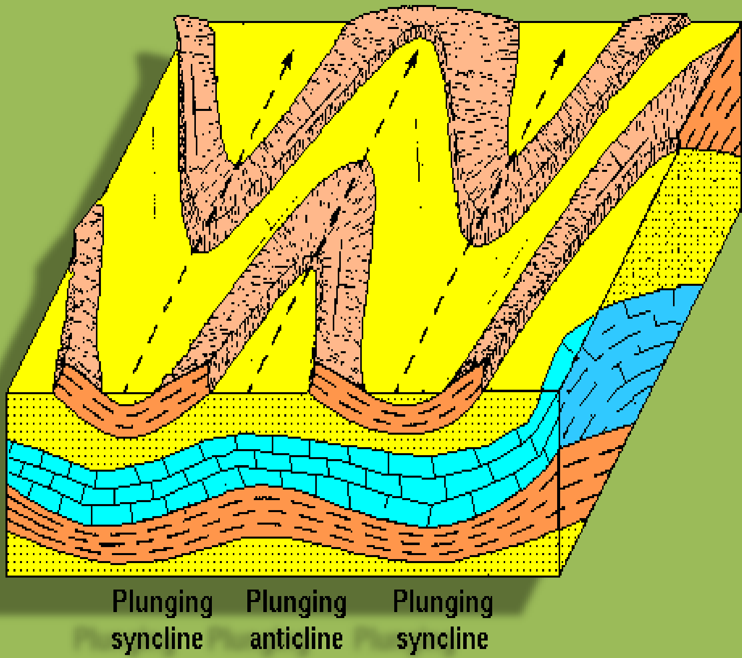
- The **plunge of a fold** has already been described as the inclination of the fold axis to the horizontal plane. **Based on this, i.e. whether the axis of a fold is inclined or horizontal, the folds are grouped as plunging folds or non-plunging folds**.
- In geological maps, when strike lines are drawn for both the limbs, for a **non-plunging fold, they will be mutually parallel and for a plunging fold they will be either converging or diverging but not parallel.**

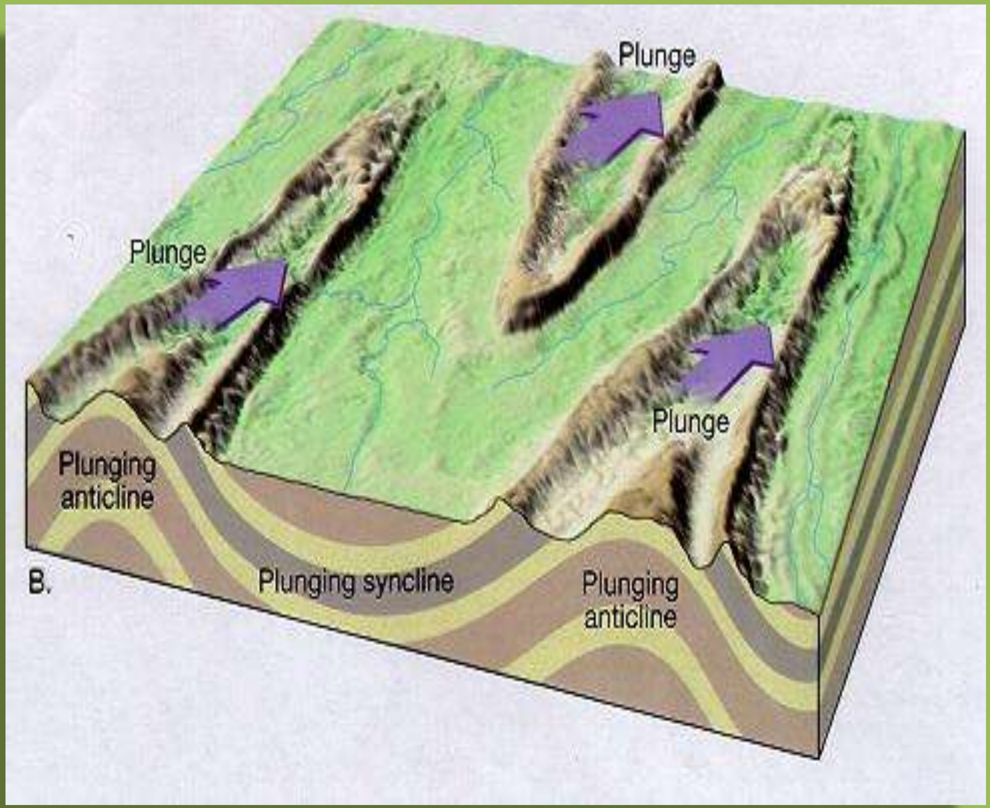
Classification and Types of Folds





Plunging and Non-Plunging Folds



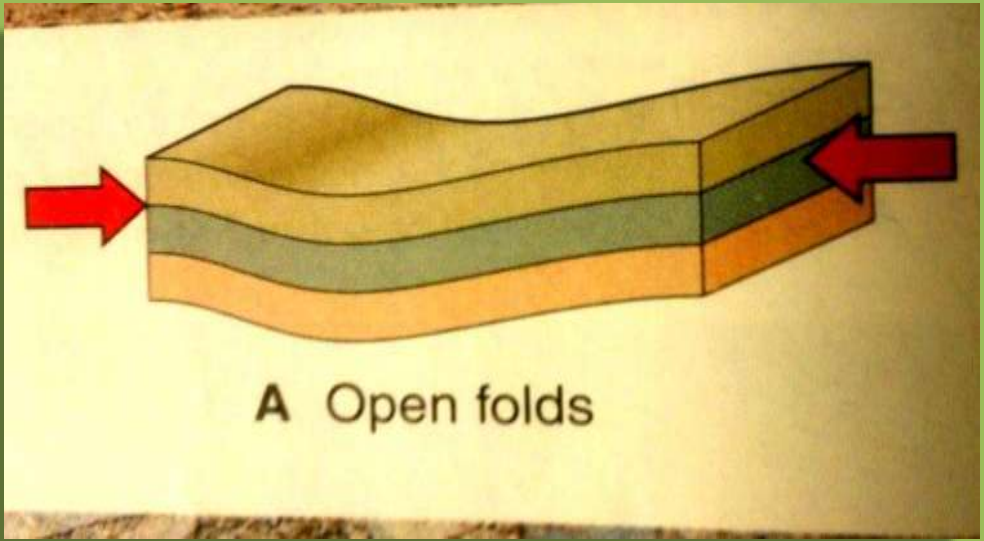


Classification and Types of Folds

Open and Closed Folds

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

Classification and Types of Folds



Classification and Types of Folds

Similar and Parallel Folds

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

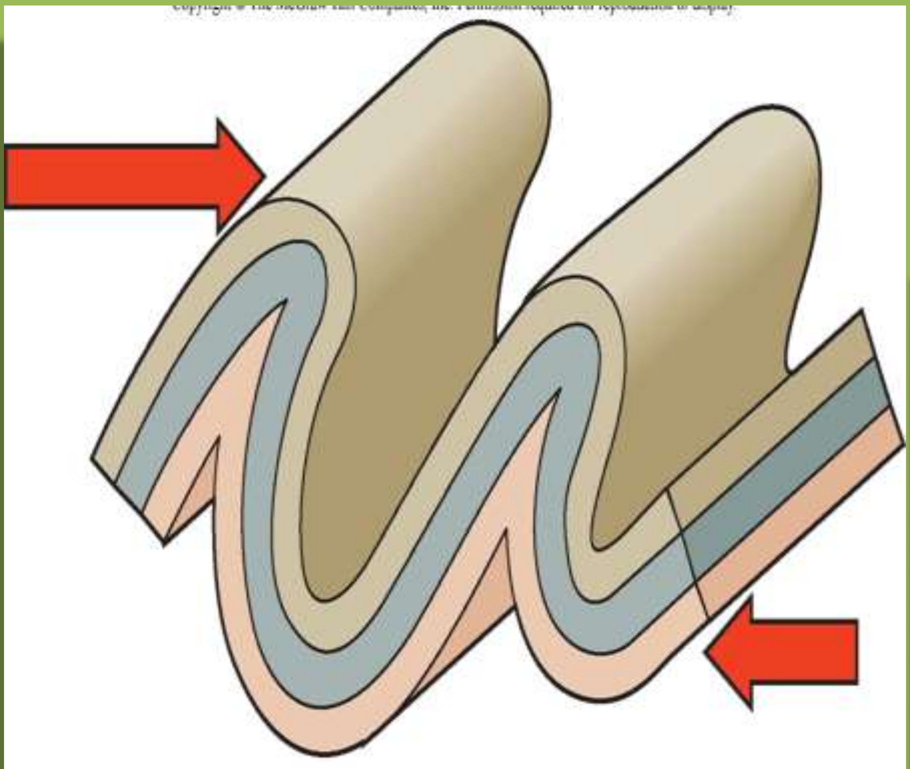
Classification and Types of Folds

Miscellaneous Folds

Overturned Fold

- Usually, in simple folds, the limbs show the order of superposition. **But when one of the limb is overturned, the order of superposition of beds in that limb will be in reverse order** and such a fold is called an **overturned fold.**

Overturned Fold



Classification and Types of Folds

Classification and Types of Folds

- **Cheveron folds:** Usually the crest and troughs of beds are smoothly curved. **But some folds have sharply bent, angular crest and troughs**, such folds are known as **“ Chevron folds”.**

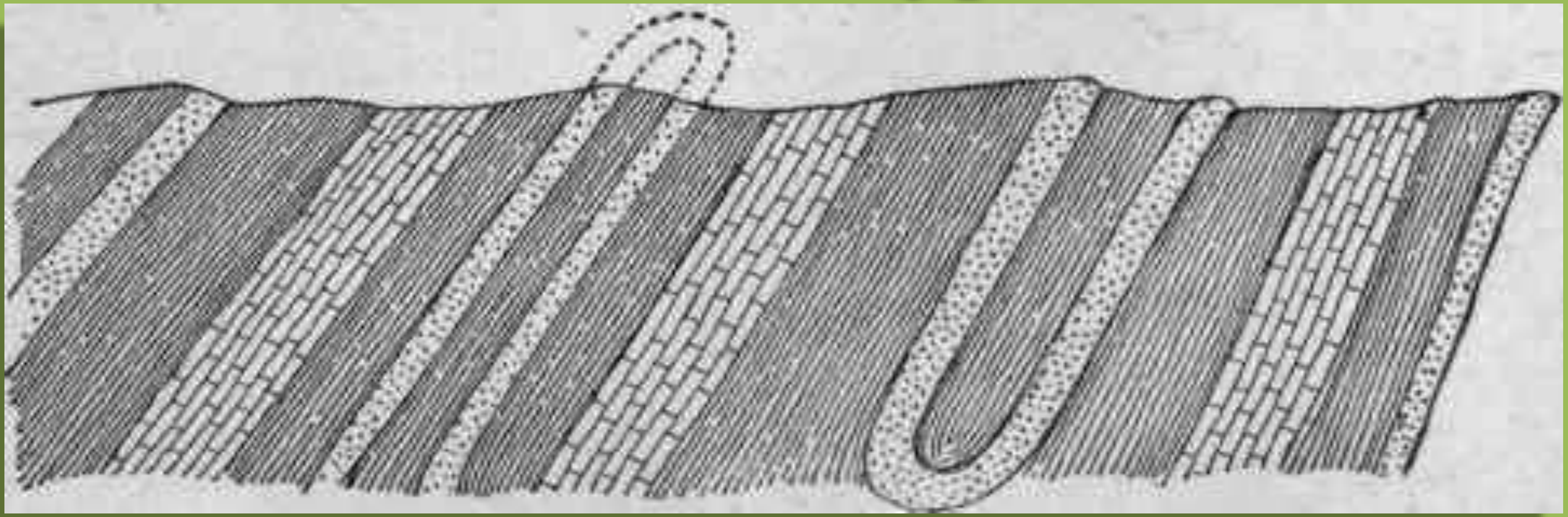
Cheveron Folds

Classification and Types of Folds

Isoclinal Folds

- Usually the **folds have inclined limbs**, i.e. the limbs will be mutually diverging or converging with reference to axial planes. But in some folds, the **limbs will be mutually parallel to a great extent**. Such folds are called isoclinals folds. These folds may be vertical inclined or horizontal.

Classification and Types of Folds

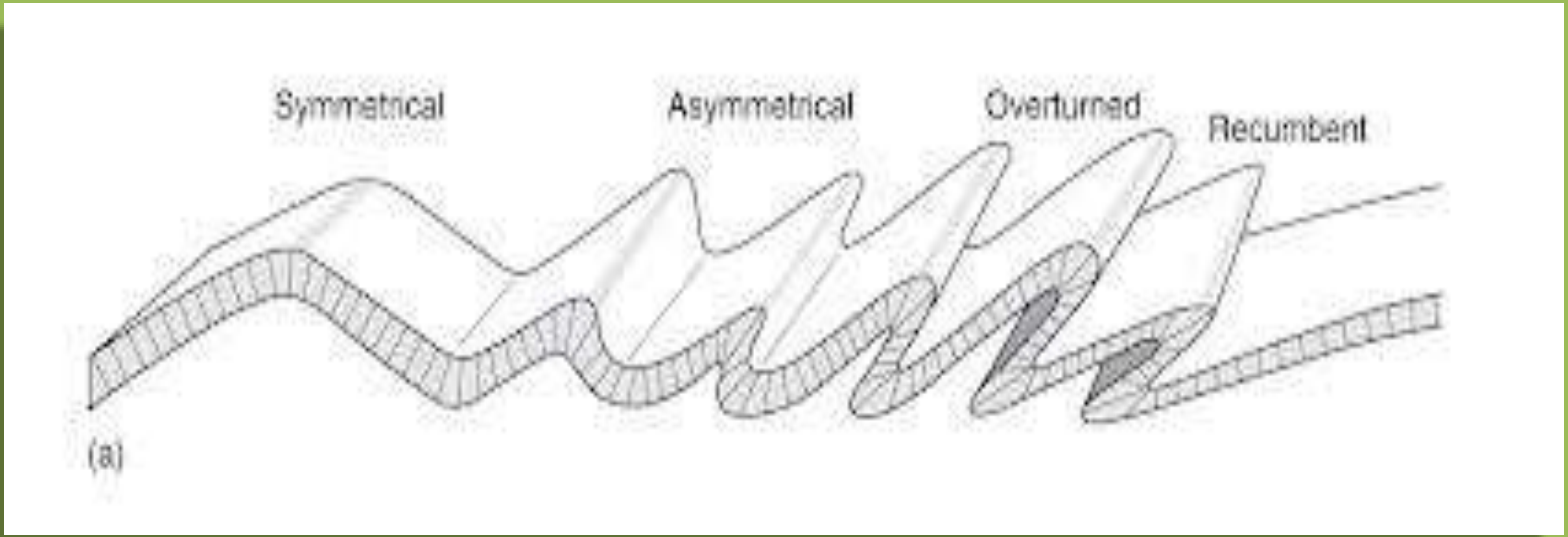


Classification and Types of Folds

Fan Folds

- Usually in simple anticlines, the limbs dip away from one another and in simple synclines they dip towards each other. But in the case of fan folds, this trend is just the opposite, i.e**. in anticlines of fan folds, the limbs dip towards each other with reference to their axial plane.** In **synclines of this kind, the limbs dip away from each other**. As the term suggests, these folds are fan shaped.

Classification and Types of Folds

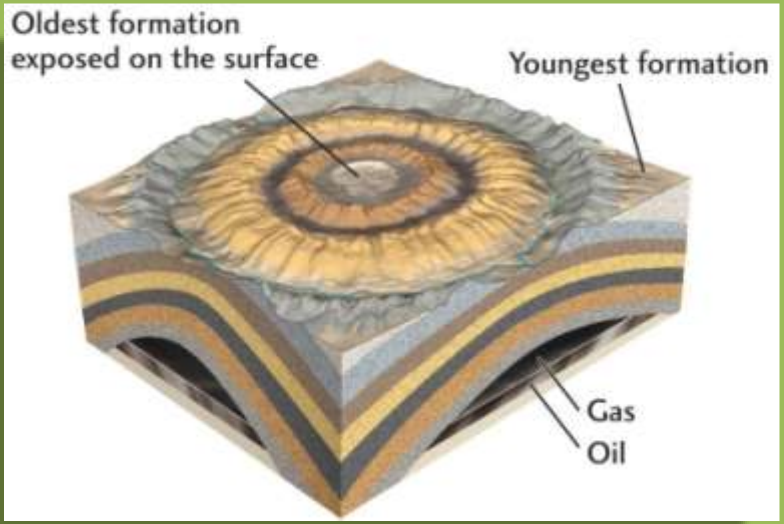


Classification and Types of Folds

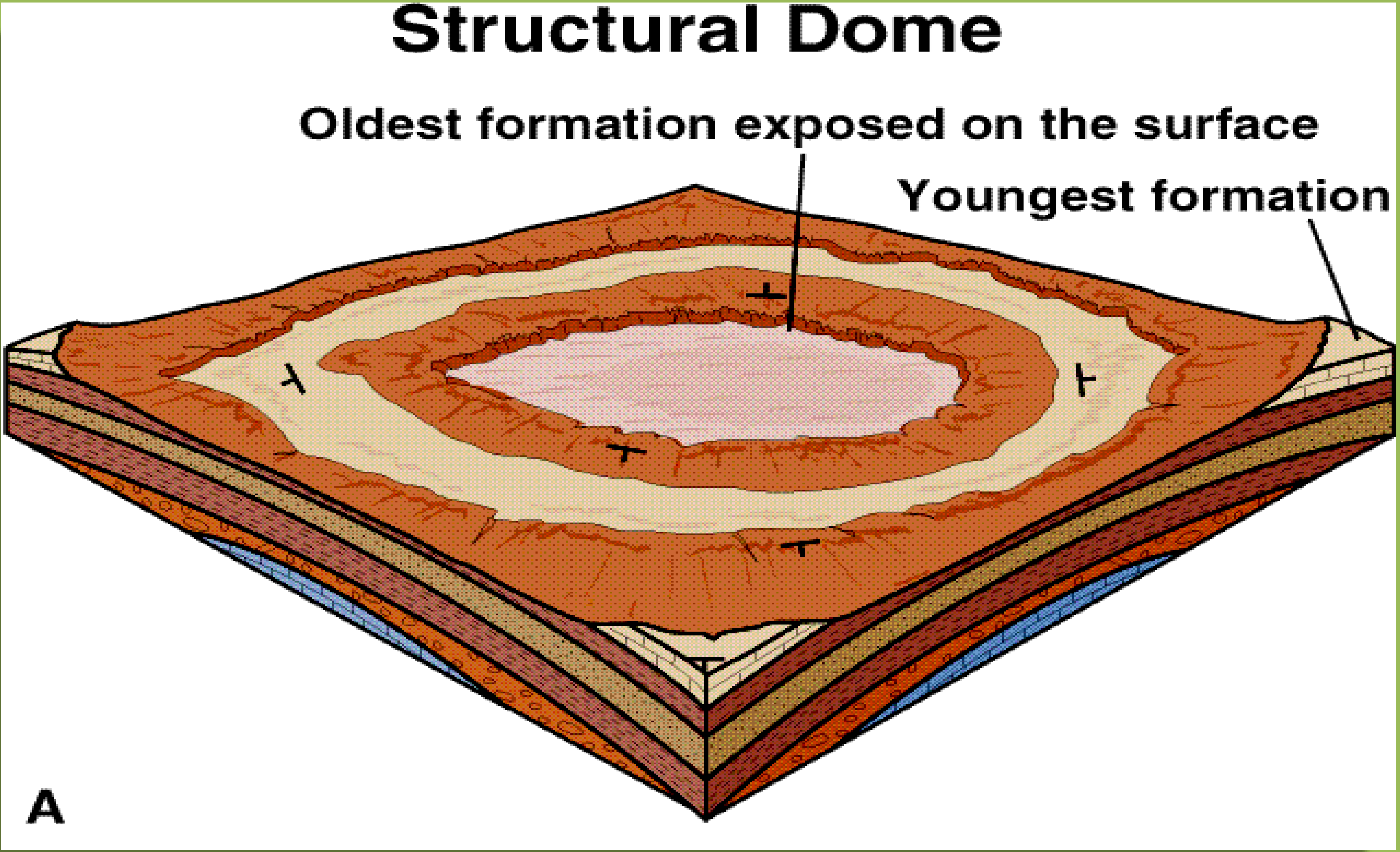
Domes and Basins

- Usually, a fold will have two distinct limbs. But some folds do not have any such specific **limbs and appear as beds locally pushed up or down**, i.e. their shapes appear as **dome or basin**. In a dome, which resembles an upper hemisphere, the dips are found in all sides from the common central top point. **Thus, this is a type of anticline. In the basin, which is like a bowl, the slopes are just opposite**

Domes and Basins

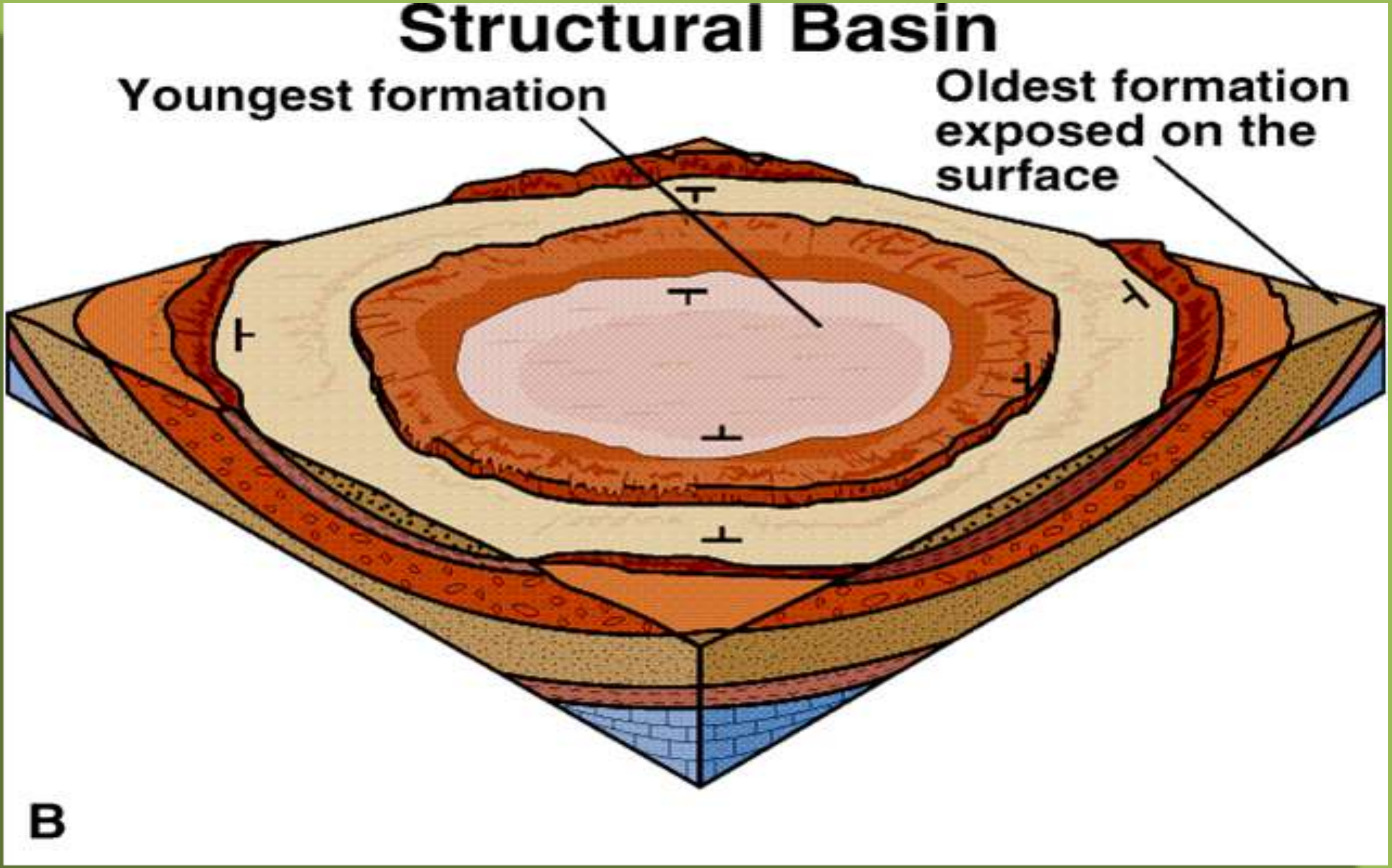


Domes



Structural Dome
Oldest formation exposed on the surface
Youngest formation
A

Basins

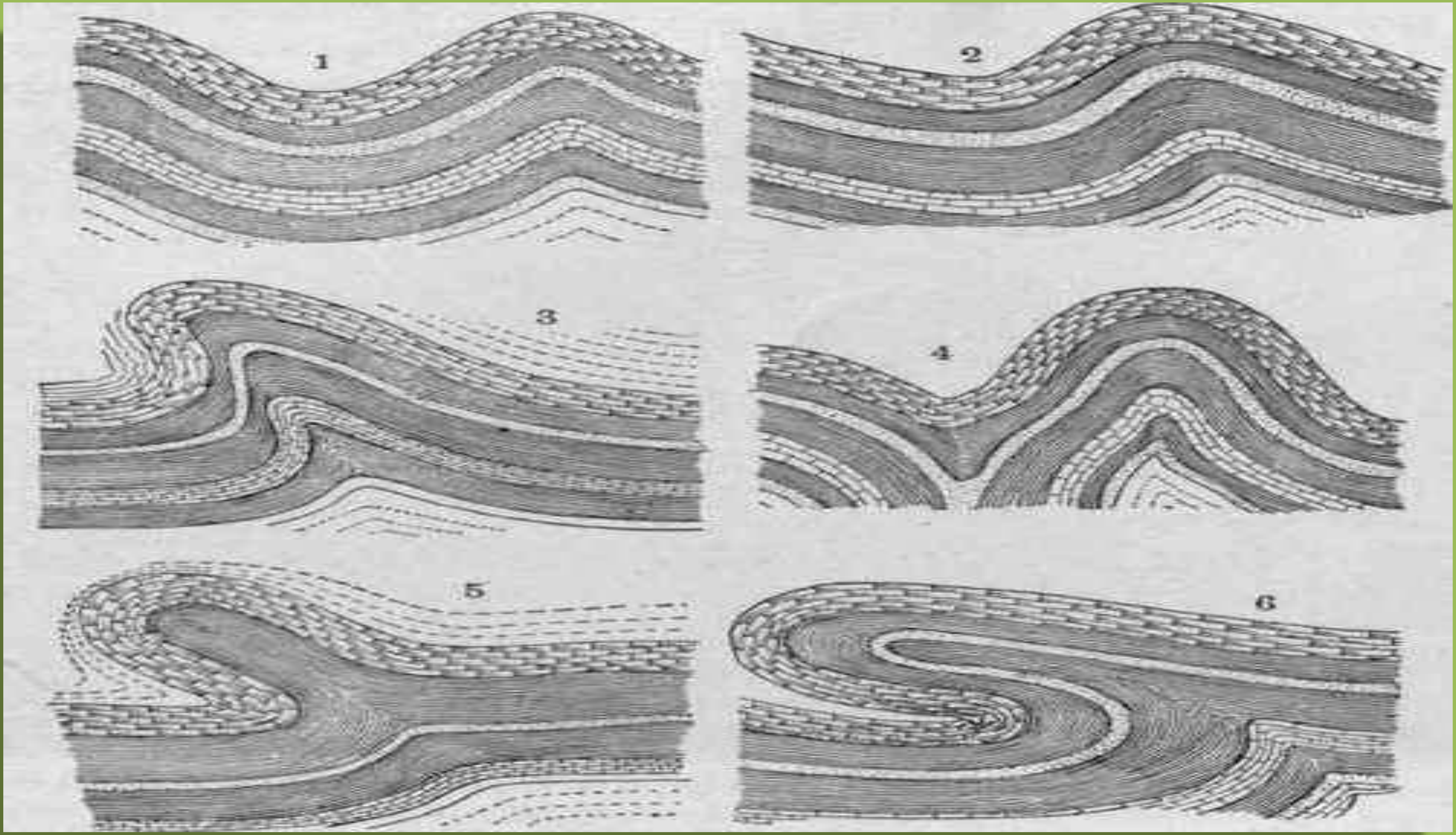

Structural Basin
Youngest formation
Oldest formation exposed on the surface
B

Classification and Types of Folds

Geanticlines and Geosynclines

- The anticlines and synclines with a normal shape but a **very large magnitude** are called Geanticlines and Geosynclines.

Geanticlines and Geosynclines



Classification and Types of Folds

Drag Folds

- These are the **minor asymmetrical folds** within **major folds** but confined only to incompetent beds which are sandwiched between competent formations. **These develop because of the shearing/ dragging effect.**

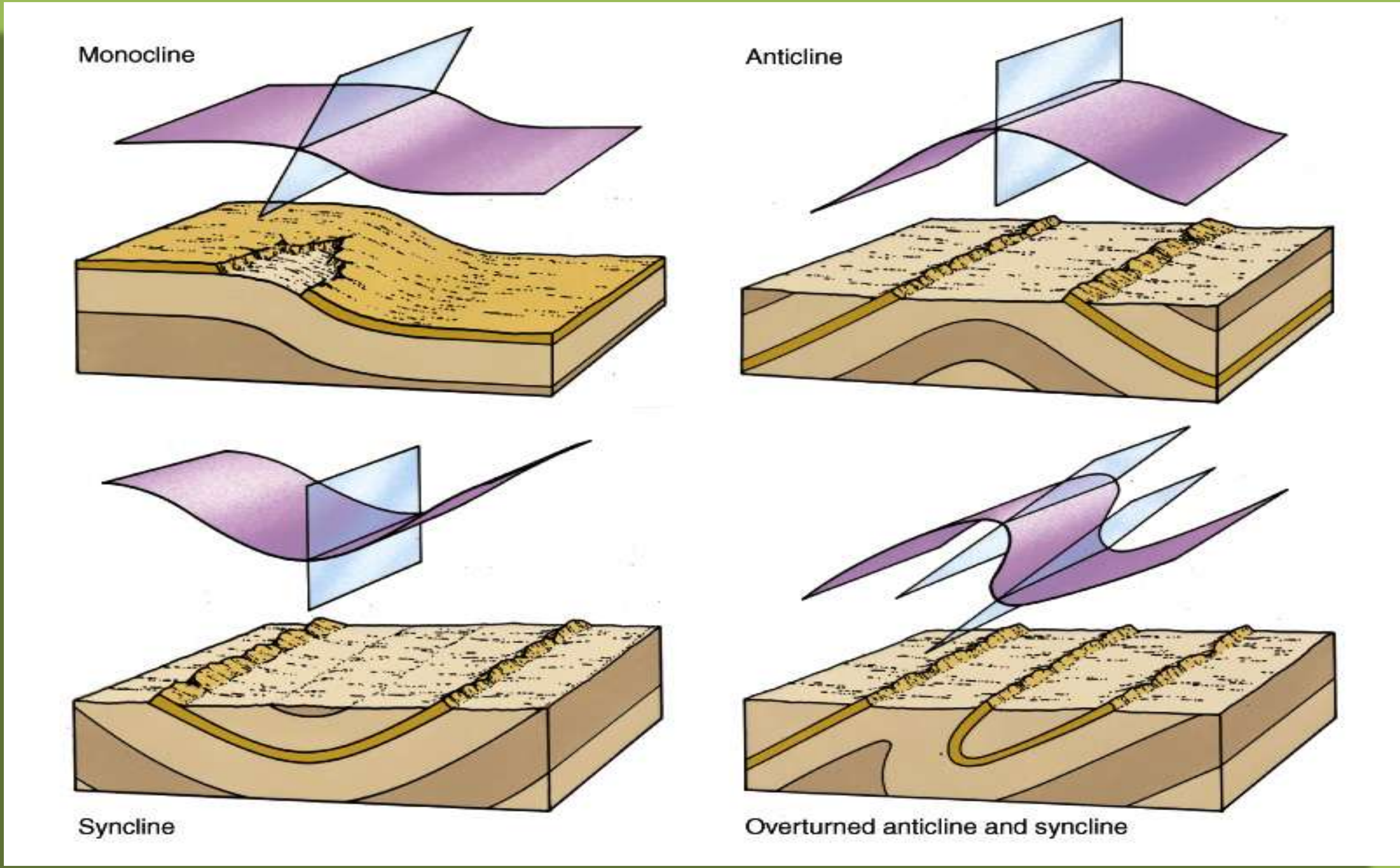
Drag Folds

Mechanisms of Folding

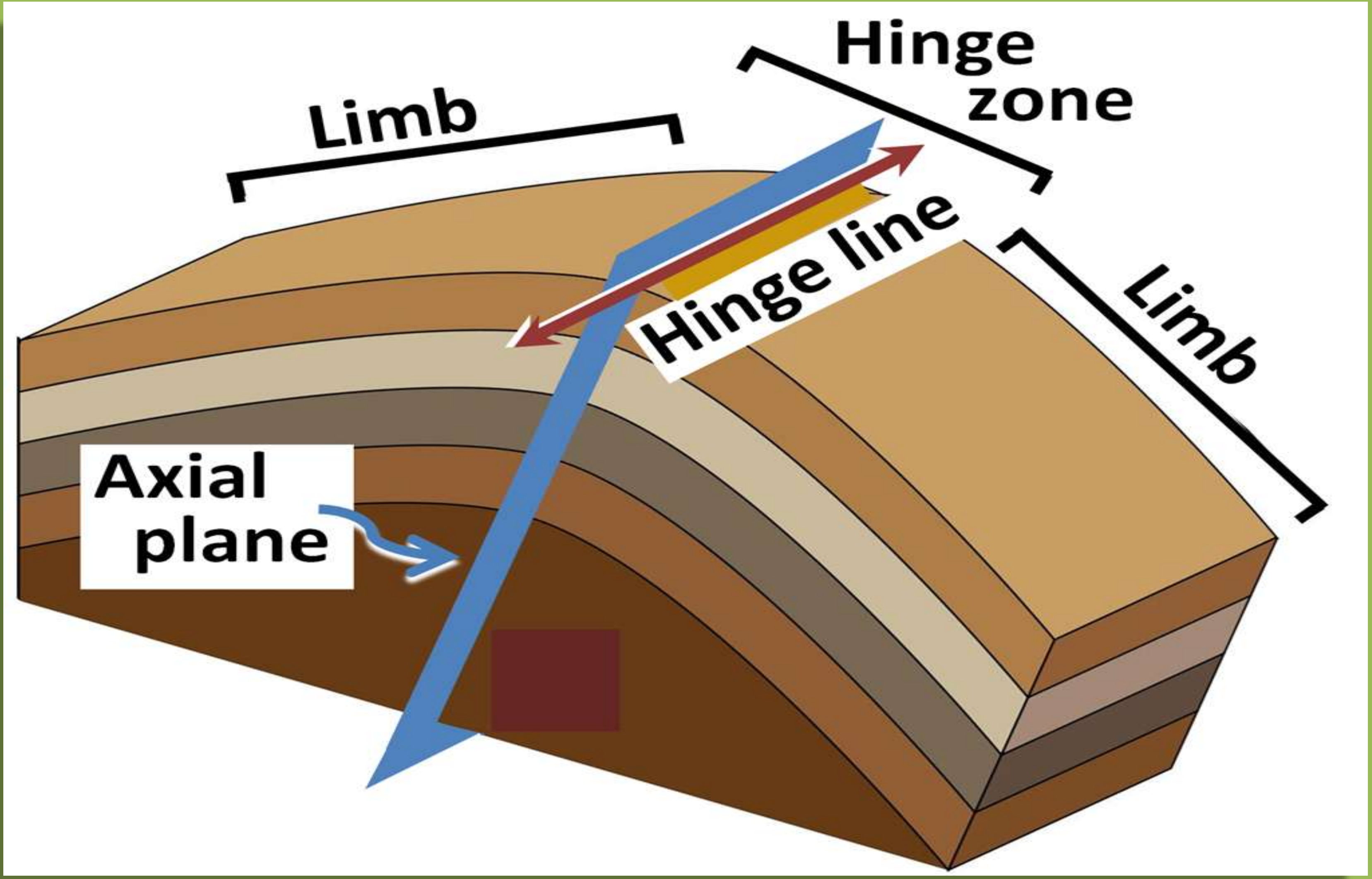
- Folding of rocks takes place by different ways of accommodation of stress. In many cases, slips or shear occur in between the beds.
- The process is similar to **slipping of cards** which occurs when the set is fold. If they are not allowed to slip over one another, folding of the set cannot take place.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

Mechanisms of Folding

Mechanisms of Folding



Mechanisms of Folding



Causes and Effects of Folding

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

Causes and Effects of Folding

Causes and Effects of Folding

- When a folded area is affected by weathering and erosion, interesting topographic features are produced as follows, **immediately after folding, anticlines by virtue of their upward bending appear as hills and synclines due to downward warping appear as valley.** During folding in the crest portions, the **geological formation are subjected to tensional forces and hence numerous fractures appear there**. Because of these fractures, crest portions are eroded quickly leading to conspicuous degradations locally.

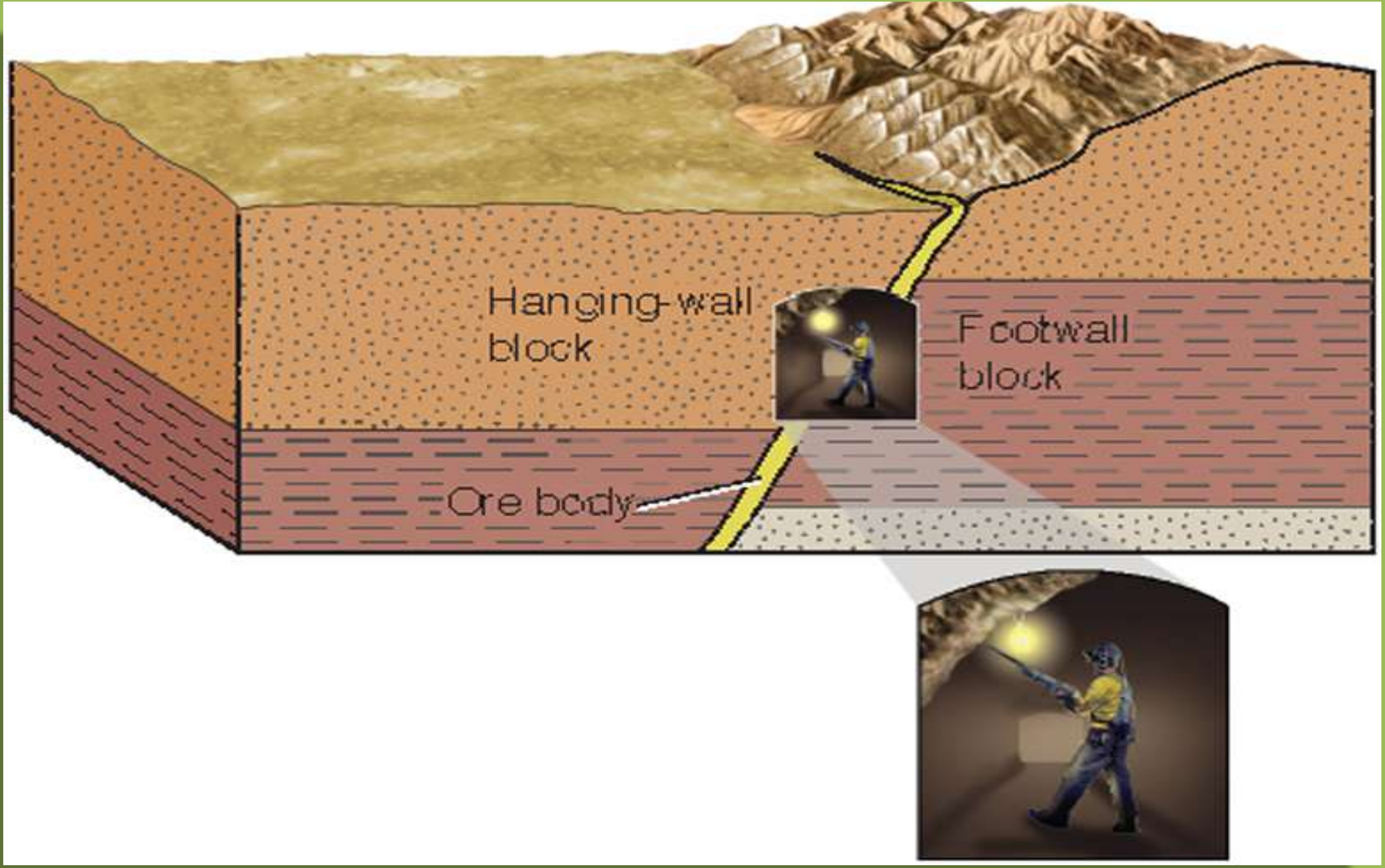
Causes and Effects of Folding

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

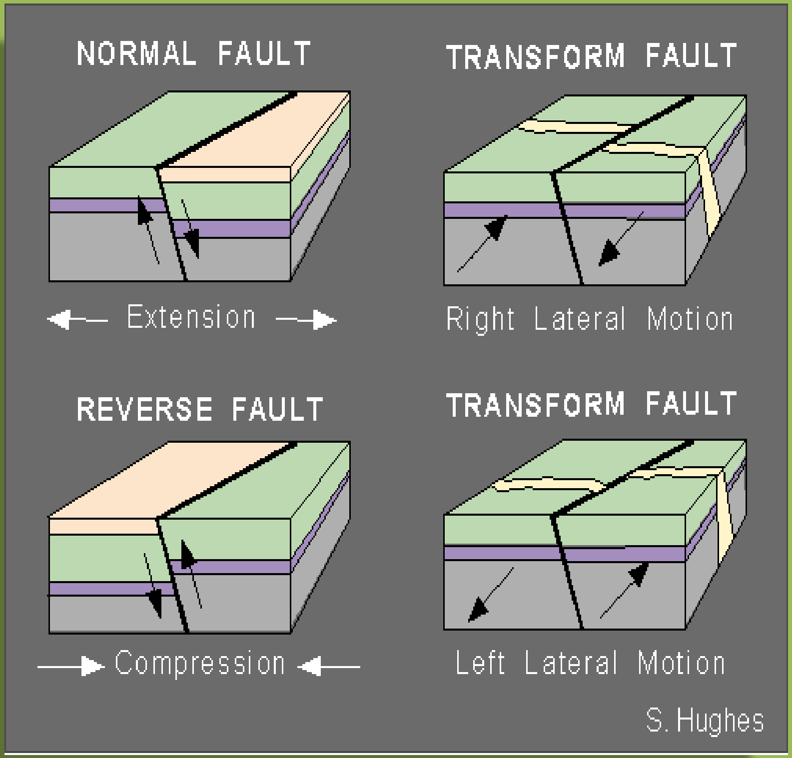
Faults

- From the Civil engineering point of view, faults are the most unfavorable and undesirable geological structures at the site for any given purpose, i.e. for location of reservoir; **as foundations site for construction of dams, importance bridges or huge buildings, for tunneling; for laying roads, railways tracks, etc.**
- This is because faults considerably **weaken the rocks and render the sites in which they occur** as unfavorable places for all constructional purposes.
- Further, as long as the faults are active, the site is unstable and **susceptible to upward, downward or sideward movement along the fault plane**, thereby making the places highly **hazardous for foundation purposes**. Thus, by virtue of the harm they are capable of causing, faults are necessarily investigated with special care in dealing with any major construction.

Faults



Faults


NORMAL FAULT
Extension
TRANSFORM FAULT
Right Lateral Motion
REVERSE FAULT
Compression
TRANSFORM FAULT
Left Lateral Motion
S. Hughes

Joints and Faults

- Structurally, faults may be described as fractures along which relative displacement of adjacent blocks has taken place.
- If such **relative displacement does not take place on either side of fracture plane**, it is **called a joint.** Thus both joint and faults are fractures in rocks but with difference in the kind of displacement. **Joints may be described as a set of aligned parallel cracks or openings in geological formations.**

Joints and Faults

Magnitude of Faults

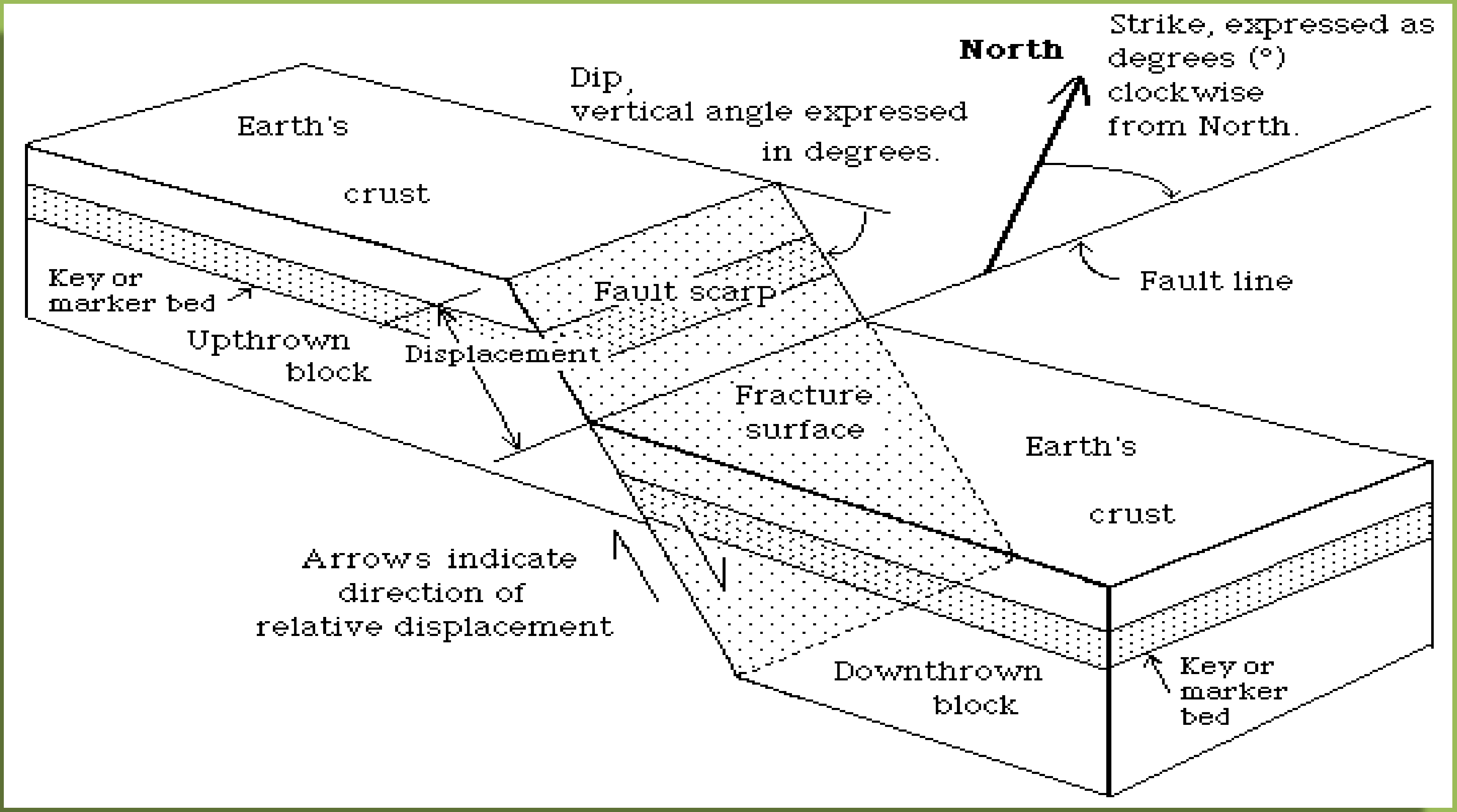
- Like folds, faults also have considerable range in their magnitude. Some occur for short distance, while other can be traced for very long distances. In some cases displacement **may be less than a centimeter while in other it may be many or even kilometers**. The magnitude of faulting obviously depend on the intensity and the nature of shearing stresses involved.

Magnitude of Faults

Nature of Fault Plane

- **Rarely the displacement during faulting occurs along a single fault plane**. In many cases, faulting takes place along a **number of parallel fractures,** Such a zone which contains a number of closely spaced sub-parallel fractures along which the relative displacement has taken place is called **shear zone or fault zone**.
- A **fault plane may be plain or straight** or may be **curved or irregular**, it may be horizontal or inclined or vertical.

Nature of Fault Plane



Recurrence of Faulting

- **Faulting occurs when shearing resistance of the geological formation is overcome by the tectonics forces**. Occurrence of faulting is often accompanied by earthquakes and it is an indication of subsurface instability of the region concerned.
- **Thus, faulting may be treated as an attempt to reach stability**. Because of the hard, rigid and solid nature of the rock masses involved, this stability is not achieved in one stroke but by repetition of the process. **Thus once if a faulting occur in a place, it shall remain active for some time,** i.e. subsequent recurring faulting takes place there only.

Recurrence of Faulting

- This is so because this fault plane offers the least resistance for the readjustment of the blocks concerned and for the release of accumulated energy in the rock. **Once the stability is attained, faulting may not recur or, even if faulting takes place**, it would be of mild intensity. Such faults which have not been affected in the known histgory are called **dead faults.**

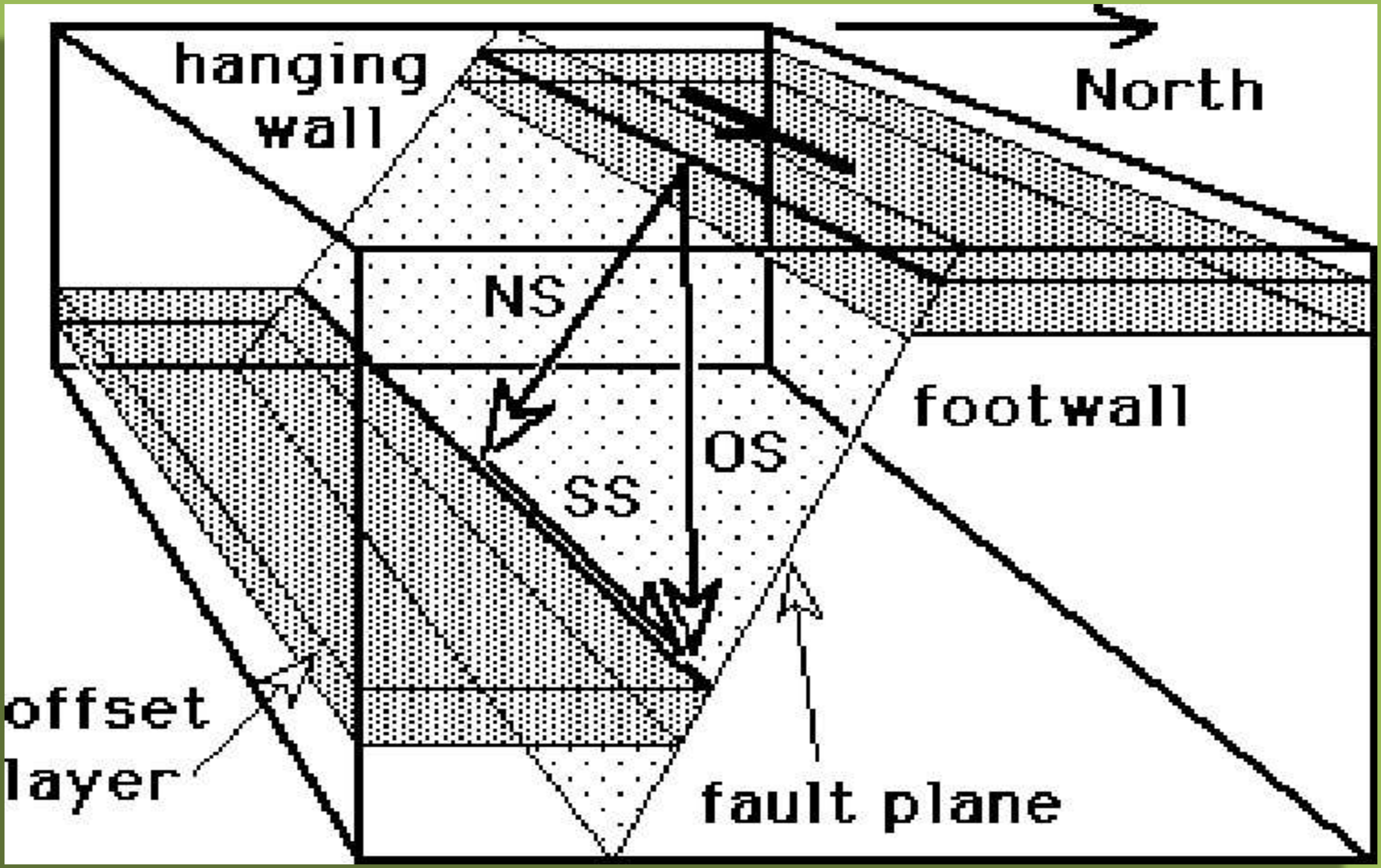
Parts of a Fault

- The different parts of a fault are

Fault Plane

- This is the plane along which the adjacent blocks were relatively displaced. In other words, this is **the fracture surface on either side of which the rocks had moved past one another.** Its intersection with the horizontal plane gives the strike direction of the fault. **The direction along which the fault plane has the maximum slope is its true dip direction.**

Parts of a Fault

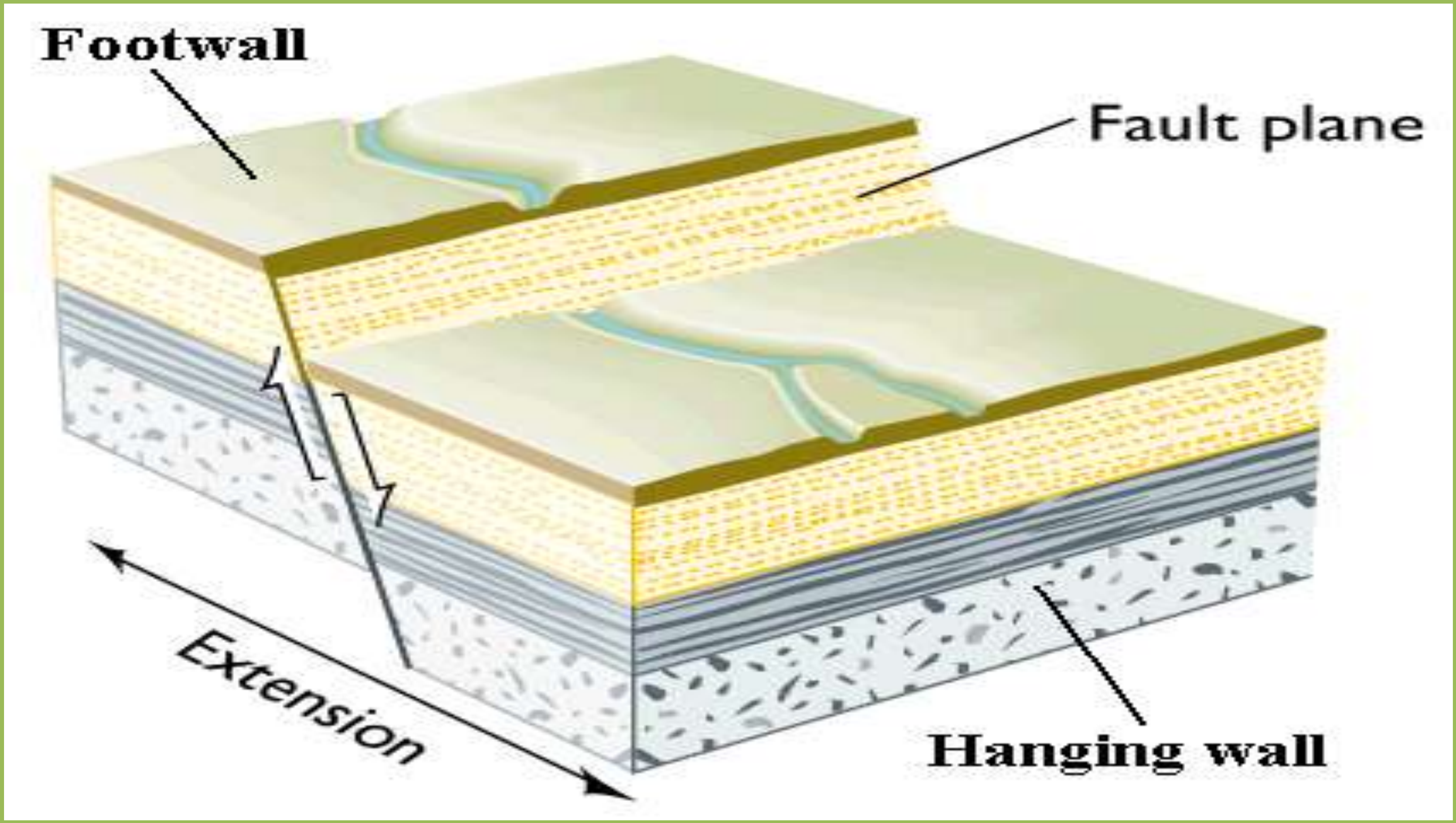


Parts of a Fault

Foot Wall and Hanging Wall

- When the fault plane is inclined, the faulted block which lies below the fault plane is called the **"foot wall"** and the other block which rests above the fault plane is called **"hanging wall".** In this case of vertical faults, naturally the faulted blocks cannot be described as foot wall or hanging wall.

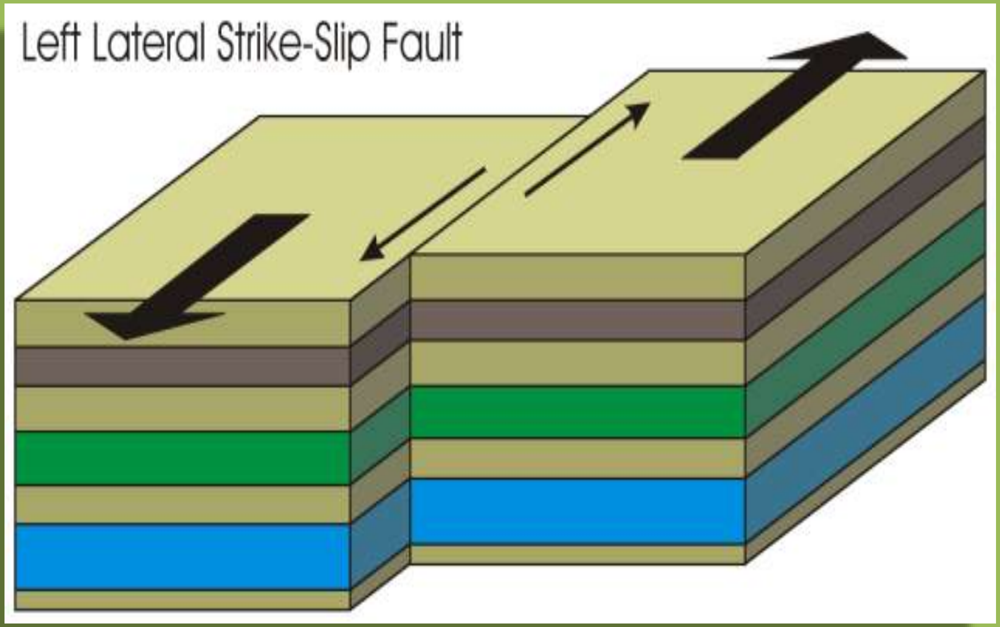
Foot Wall and Hanging Wall

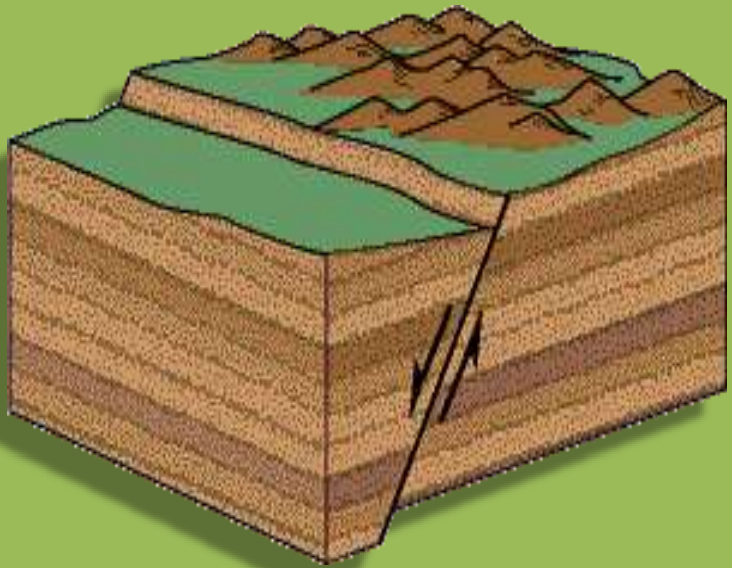


Parts of a Fault

Slip

- The **displacement that occurs during faulting is called the slip**. The total displacement is known as the next slip. This may be along the strike direction or the dip direction or along both.



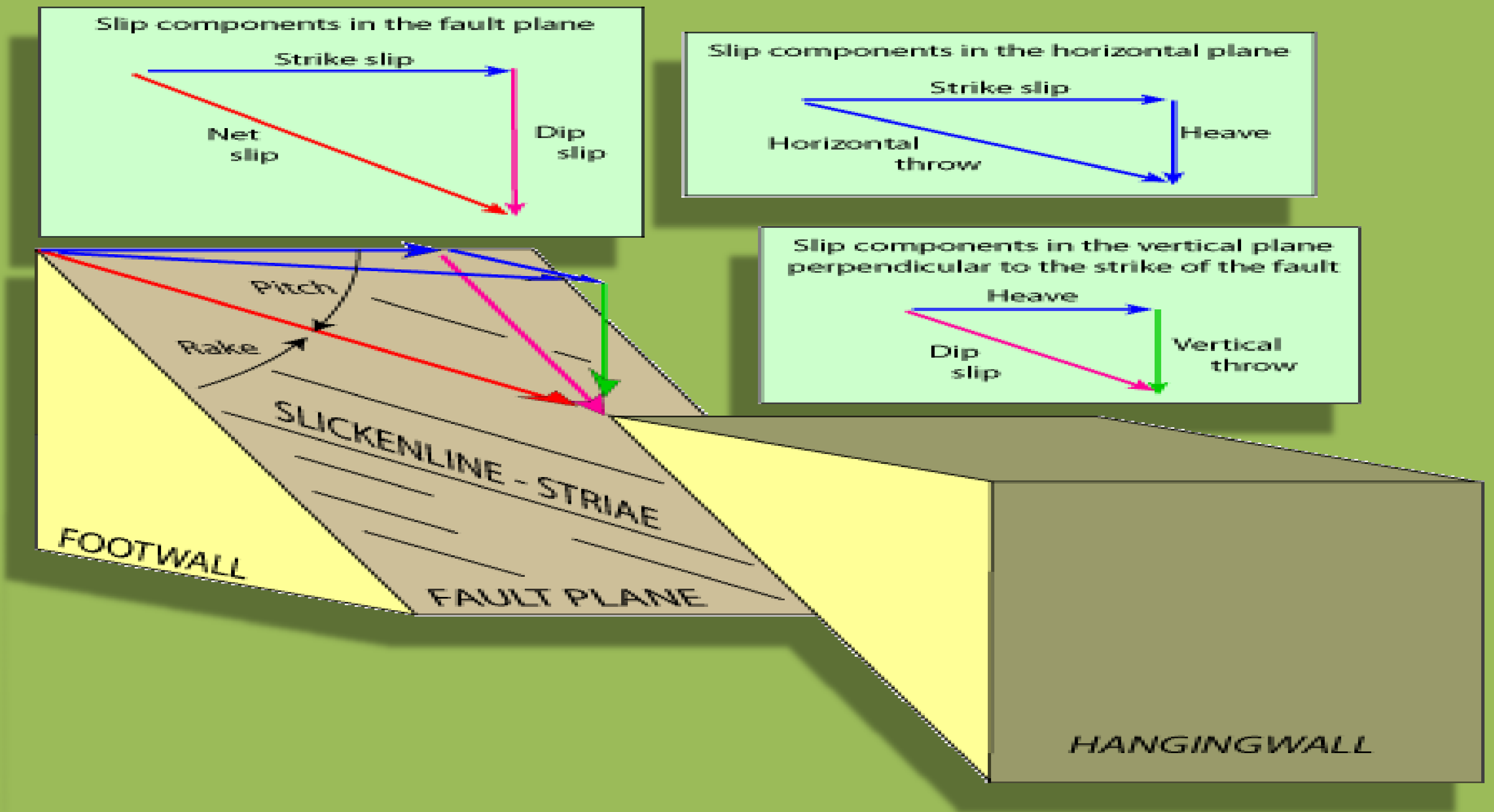


Parts of a Fault

Heave and Throw

- The **horizontal component of displacement** is called **"heave"** and **the vertical component of displacement** is called **"throw"**
- In vertical faults, there is only throw, but no heave. In horizontal faults, there is only heave, but no throw.

Heave and Throw



Classification and Types of Faults

- Like folds, faults also have been classified on the basis of different principles as
- Types of displacement along the plane.
- Relative movement of foot wall and hanging wall.
- Types of slip involved.
- Mode of occurrence of faults

Classification and Types of Faults

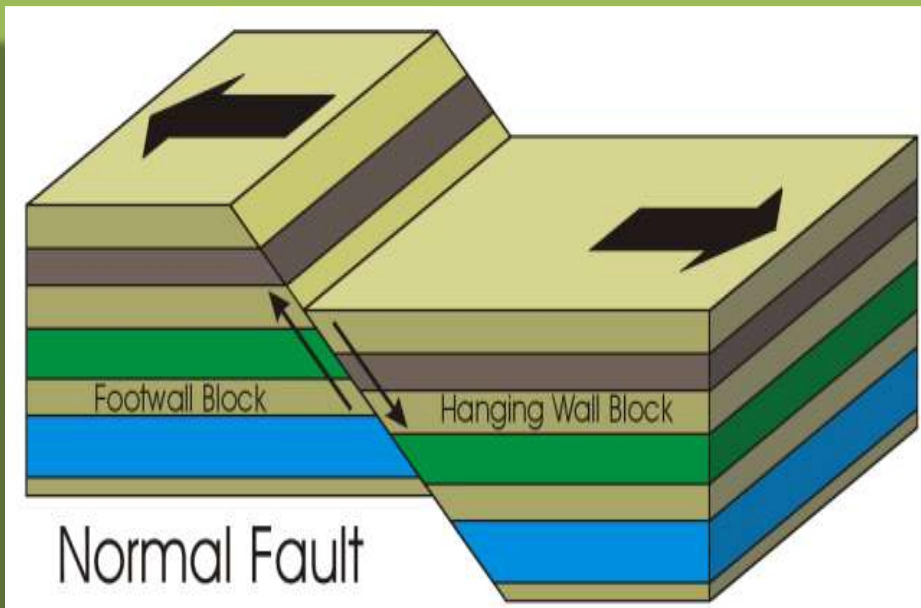
Types of displacement along the plane

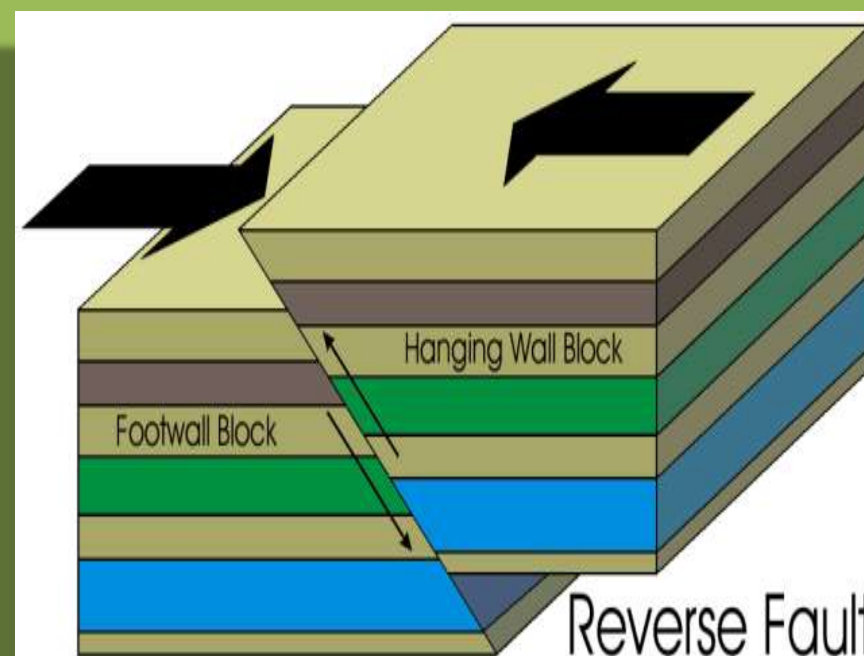
- Based on this principle, faults are divisible into **transitional faults and rotational faults**.
- In the case of **transitional faults**, the type of displacement of the foot wall with reference to the hanging wall is uniform along the fault plane.
- In the case of the **rotational fault** the displacement varies from place to place.

Classification and Types of Faults

- **Relative movement of the footwall and the Hanging Wall.**
- In the case of inclined faults, if the hanging wall goes down with reference to the footwall, it is called **normal fault or Gravity fault**. These terms are very appropriate because of the hanging wall is normally expected to move down along the slope of the fault plane under the influence of gravity.

Classification and Types of Faults

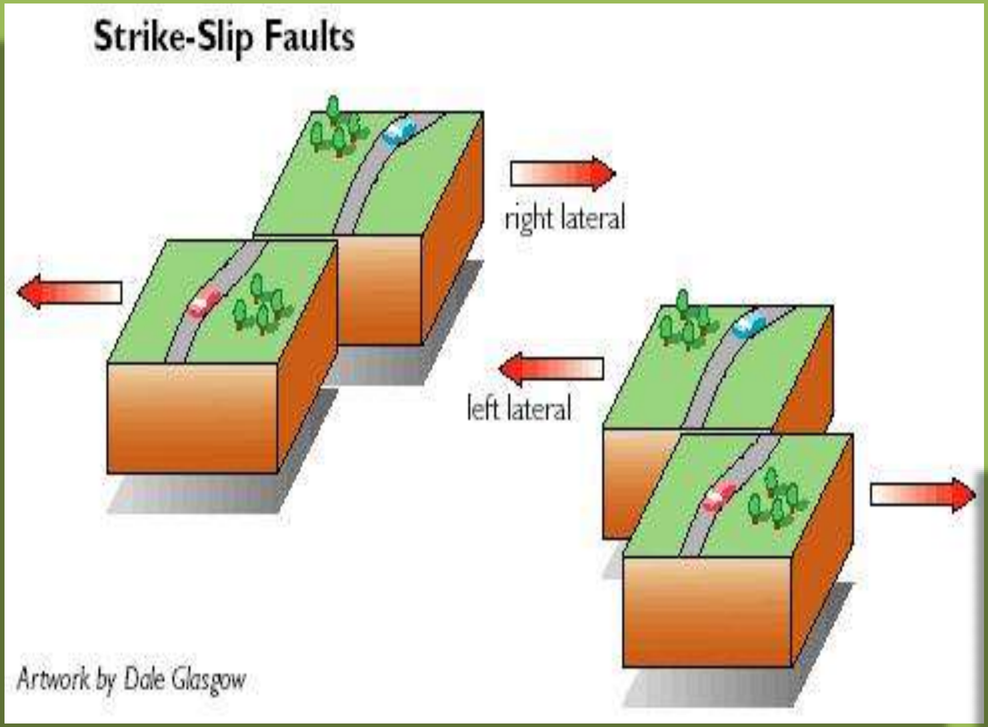




Classification and Types of Faults

- If the kind of displacement of the hanging wall is opposite to this, the fault is called R**everse faults** or thrust fault. These terms also are appropriate because in such fault plane and, therefore the type of displacement is the reverse of the normally expected downward movement of the hanging wall under such a condition.
- If the relative displacement of the hanging wall is neither upwards nor downwards with reference to the inclined fault plane, but sidewards, then such faults are described as S**instral Faults**.

Classification and Types of Faults

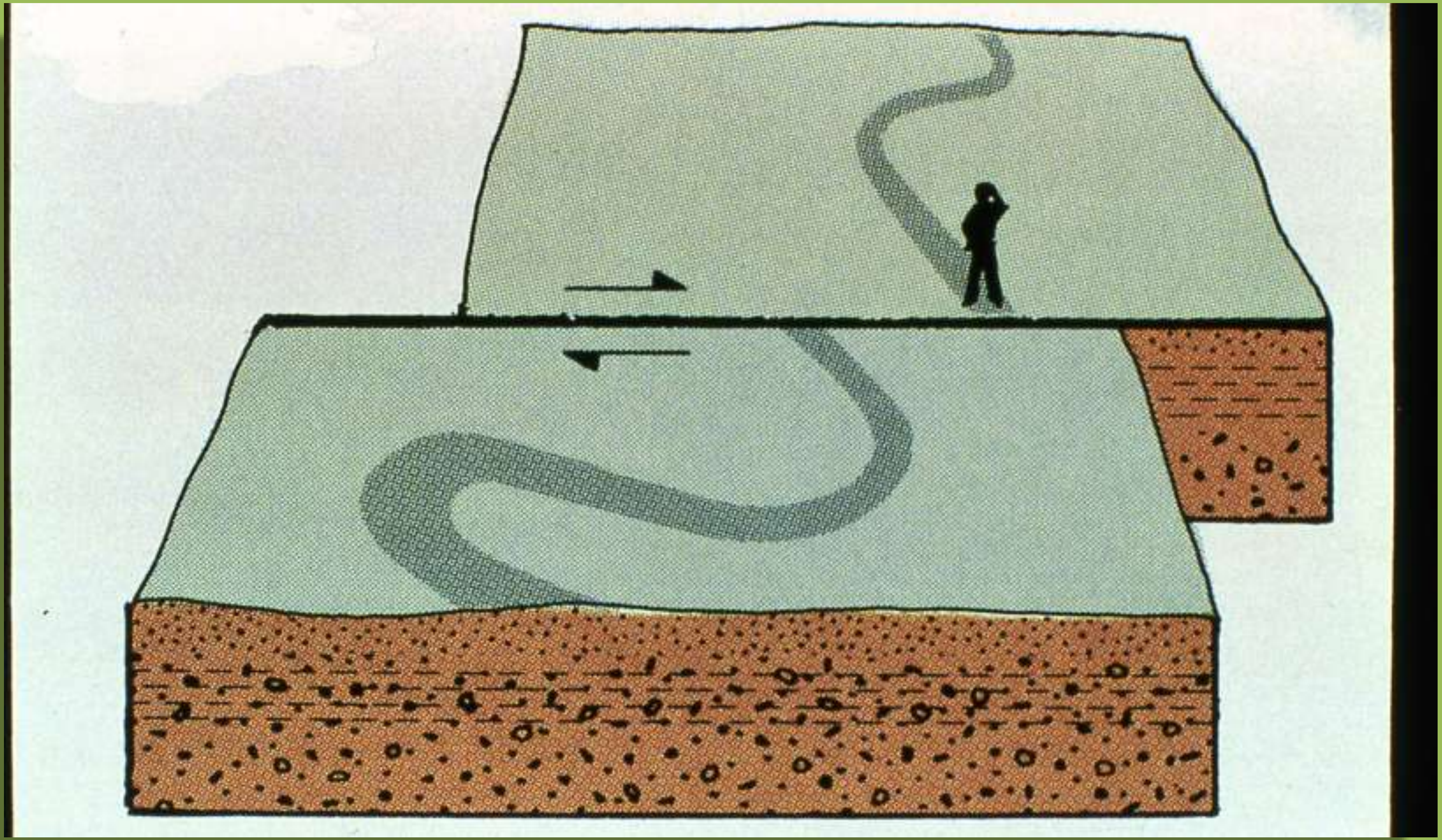


Classification and Types of Faults

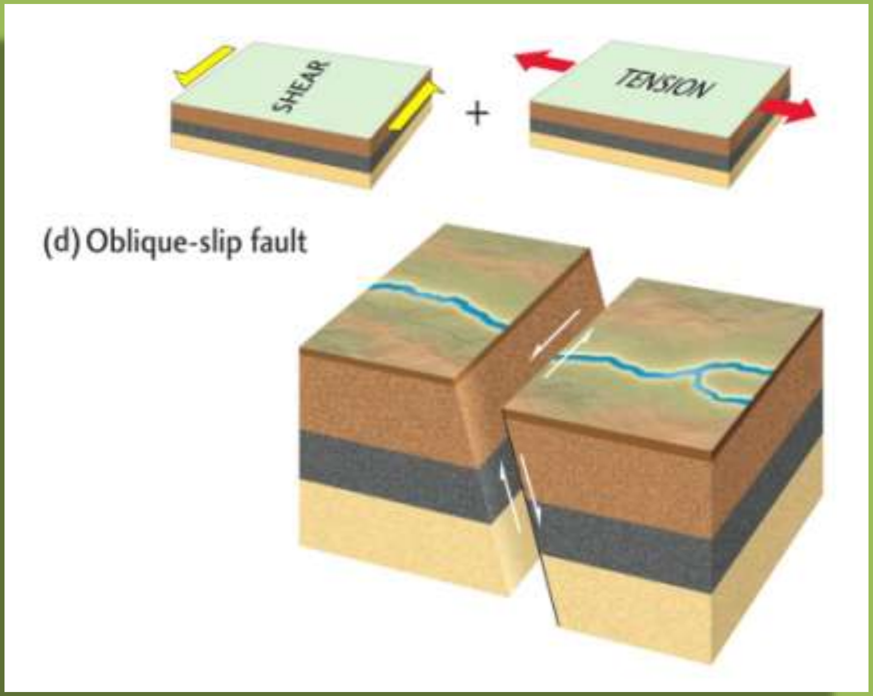
Types of Slip Involved

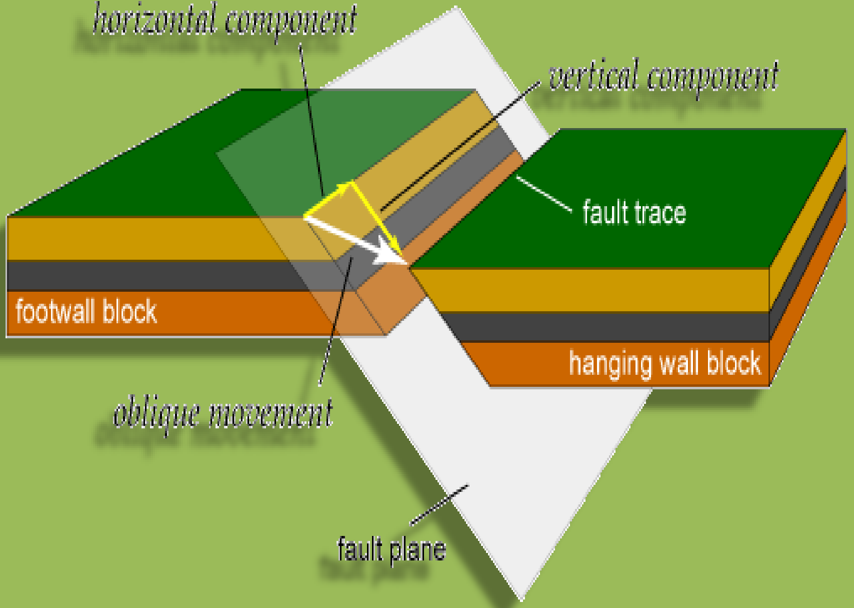
- Slip has been already described as the displacement along the fault plane. If the displacement is along the **strike direction** of the fault plane, such a fault is described as **strike slip fault.** On the other hand. If the displacement occurs partly **along the strike direction of the fault plane**, such a fault is called an **oblique slip fault.**

Strike Slip Fault

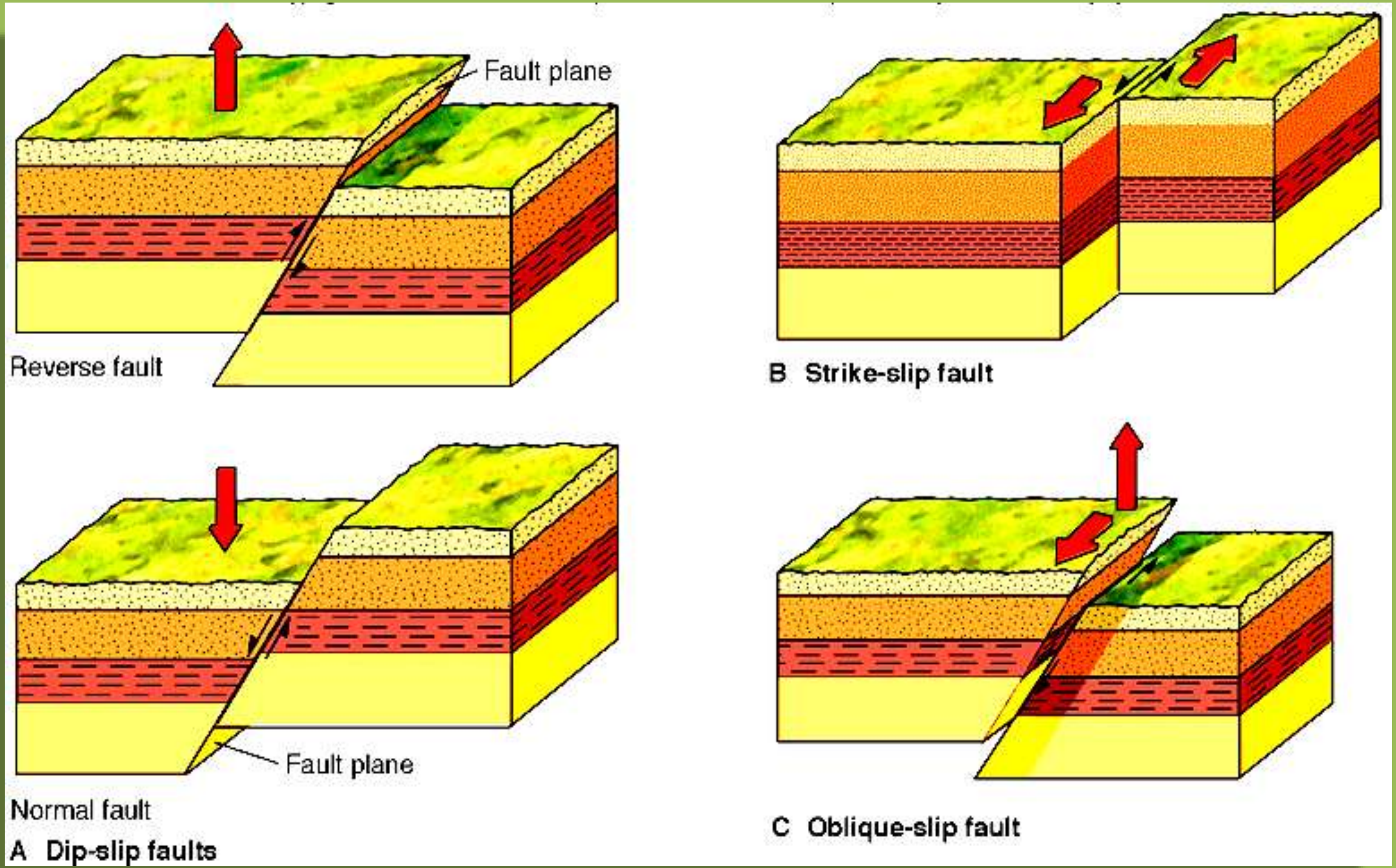


Oblique Slip Fault





Classification and Types of Faults



Classification and Types of Faults

Mode of Occurrence

Radial Faults

- When a set of faults occur on the surface and appears to be **radiating from a common point,** they are called **radial faults.**

Enechelon Faults

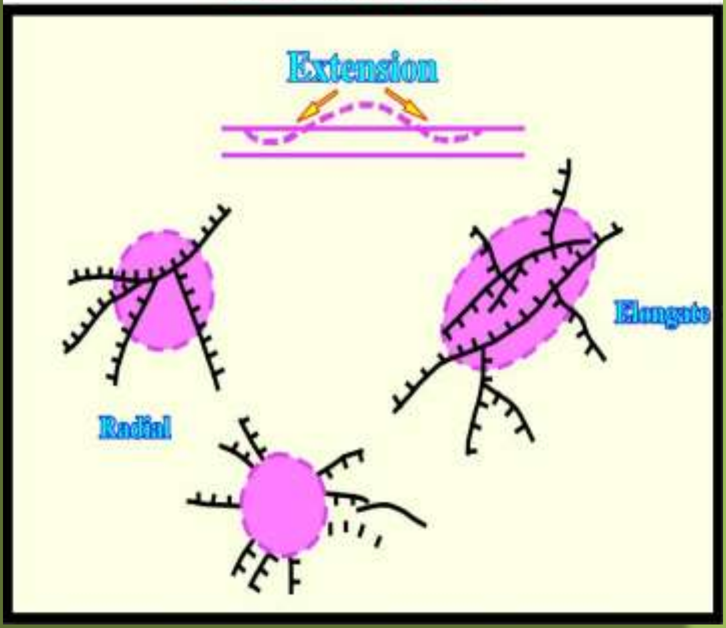
- These refer to a series of **minor faults which appear to be overlapping one another.**

Arculate or Peripheral Faults

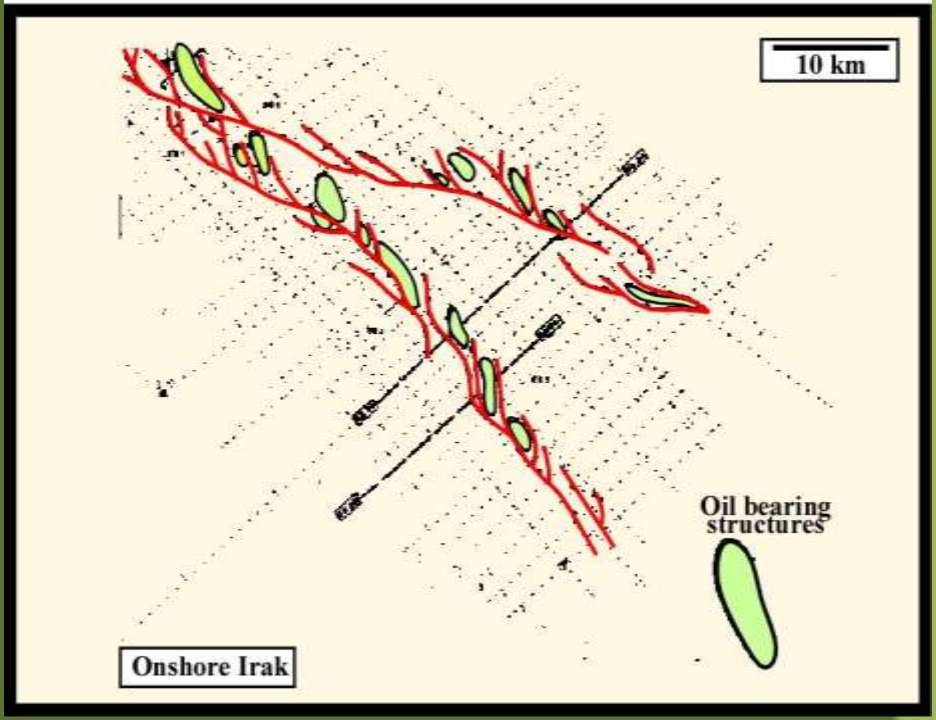
- These also refers to a set of **relatively minor faults which have curved outcrop** and are arranged in a peripheral manner, enclosing more or less a circular area.

Classification and Types of Faults

Radial Faults



En Echelon Folds



Classification and Types of Faults

Miscellaneous

Step Faults

- When a set of parallel normal faults occur at a regular interval, they give a step-like appearance and are called step faults.

Parallel Faults

- As the name indicates, these are a set of parallel normal faults with the same strike and dip. They are like step faults but may or may not have a regular interval.

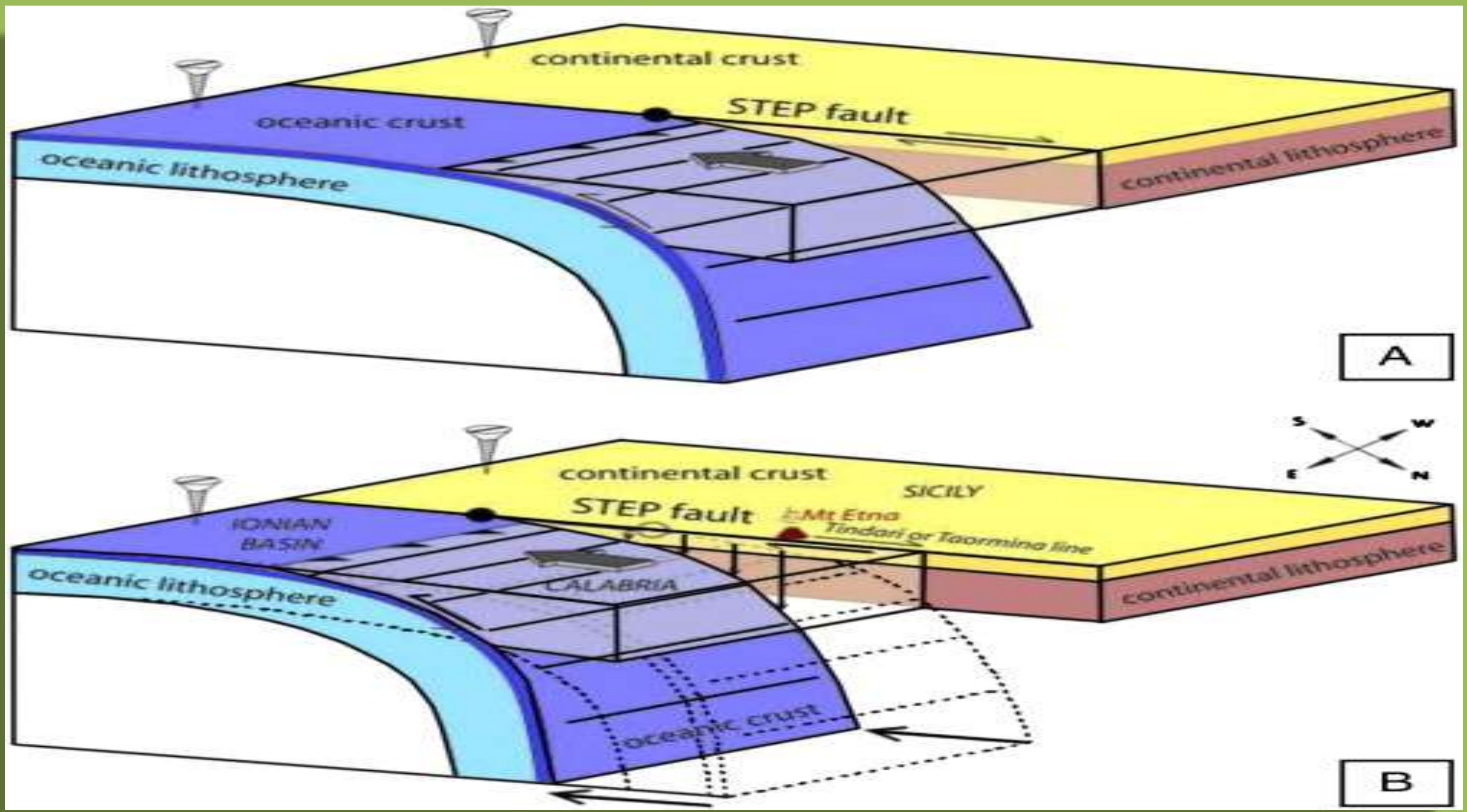
Classification and Types of Faults

Horst and Grabens

- When normal faults with mutually diverging or converging fault plane occurs, then a few wedge-shaped blocks called “horst” are displaced upwards and a few other called “grabens” are displaced downwards.

  Horst and Grabens of large magnitude are called block mountain and rift valleys.

Step Faults


continental crust
STEP fault
oceanic crust
oceanic lithosphere
continental lithosphere
A
S
W
E
N
continental crust
SICILY
STEP fault
Mt Etna
Tindari or Taormina line
IONIAN
BASIN
oceanic lithosphere
CALABRIA
continental lithosphere
oceanic crust
B

Parallel Faults

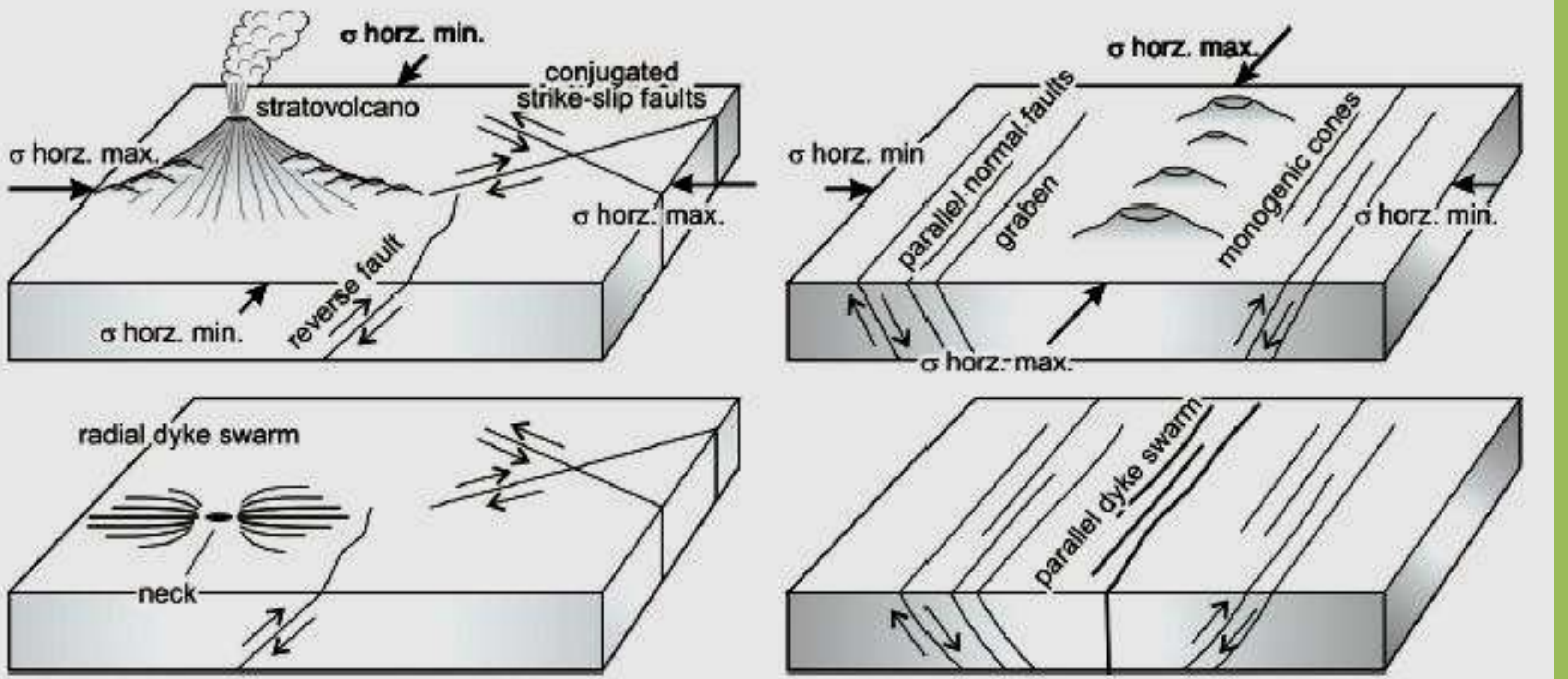
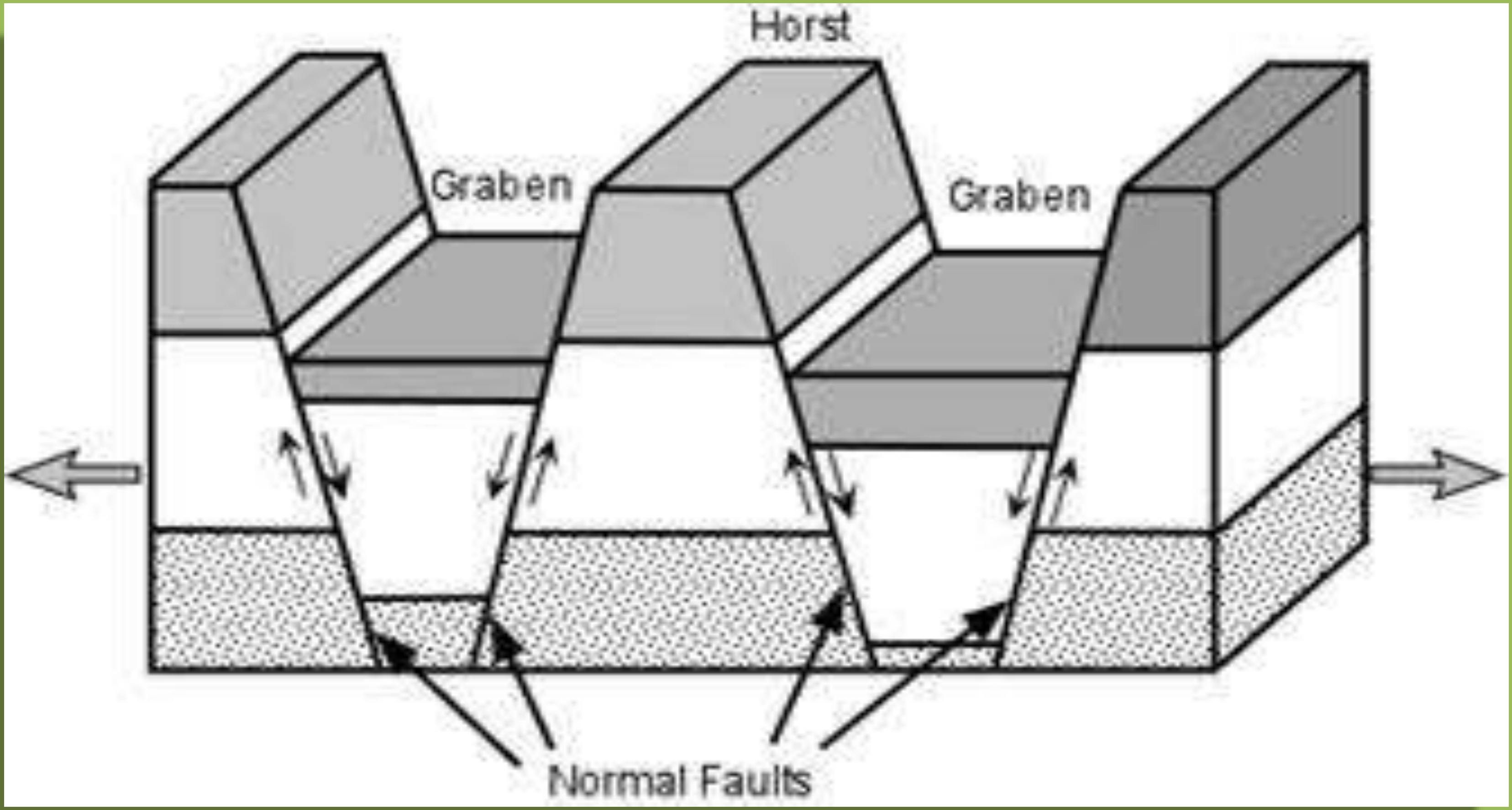


Fig. 8. Mode of occurrence of volcanoes, dykes, and fault systems according to hydraulic fracturing theory proposed by Nakamura (1977) and Nakamura et al. (1977): a) compressive tectonic stress field; b) extensional tectonic field.

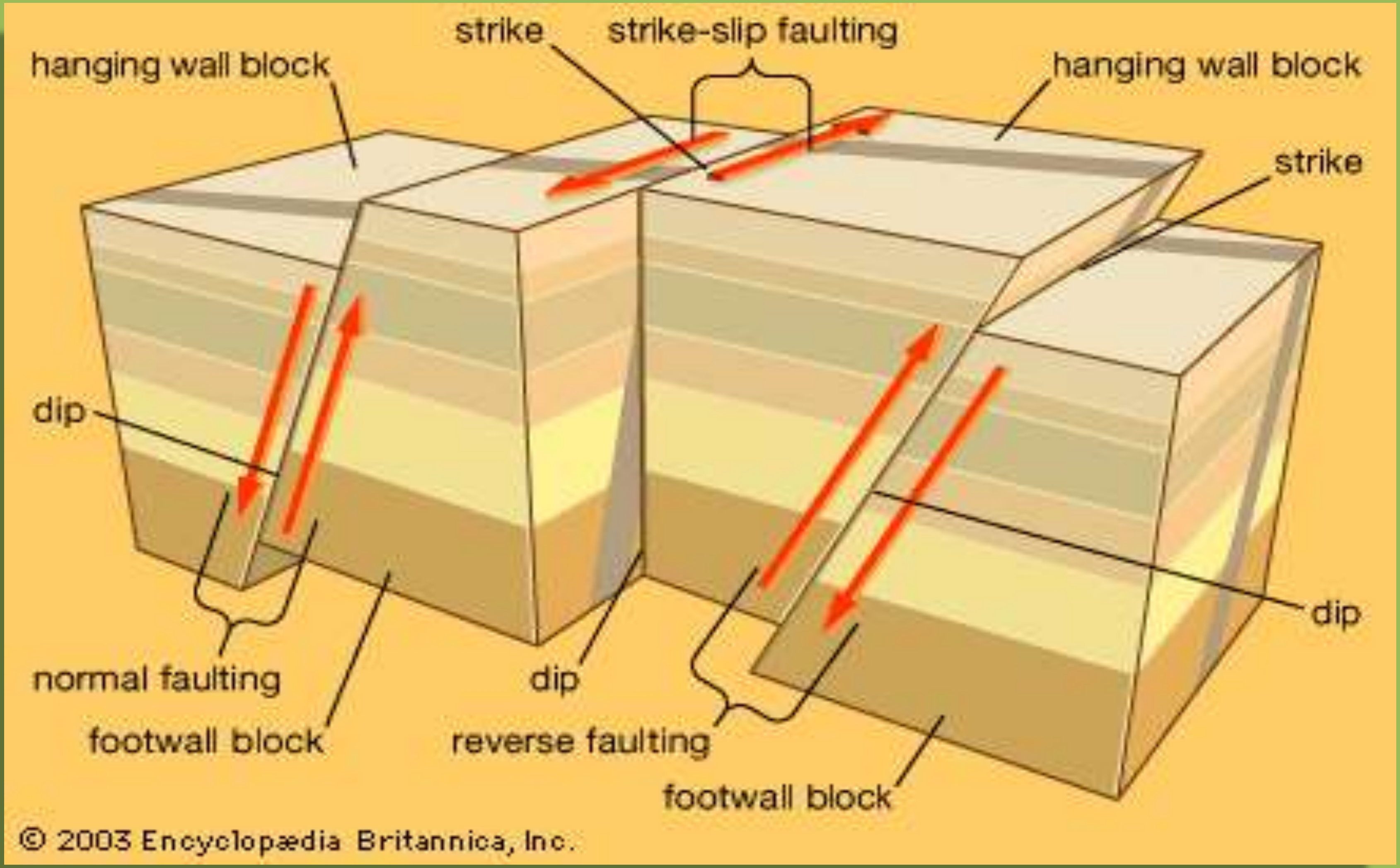
Classification and Types of Faults



Causes of Faulting

- Faults may occur due to various causes, among them **tectonic causes are responsible** not only for most of the faults but also for faults of grater magnitude.
- It may be recollected that faults develop mainly due to **shear and sliding failures** resulting from tectonic forces. It is natural that compression and tensional forces be mutually interlinked because if in one part of the crust there is compression, in the adjacent part there will be tension.
- In addition to these main causes, sometimes, the formation of **magmatic intrusions such as bysmaliths**, may also contribute to faulting, though on a very small scale. Occasionally, **local settlement under the influence of gravity may also cause minor faulting**.

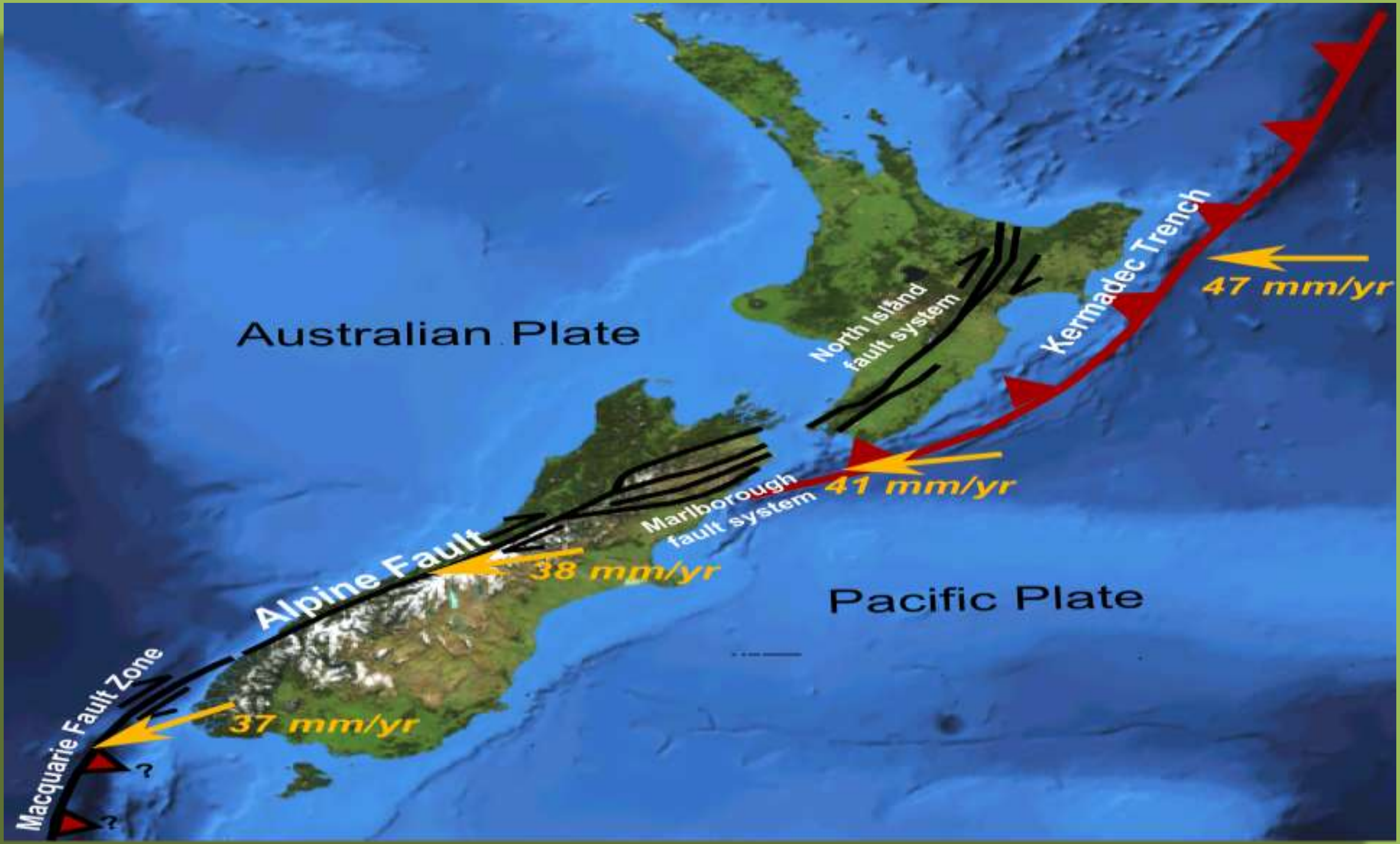
Causes of Faulting



Effects of Faulting

- The faulting phenomenon produces **dislocation in lithology and topography.** Hence, they offer evidences to recognize faults in the field. **Proper geological investigation followed by geological mapping enables one to detect the occurrence of faults in any area.**
- Slickness, **fault drags**, brecciation, **mineralization zones**, **repetition and omission of strata** and offsets of beds are some of the lithological evidences of Faulting.
- Topographical evidences include various surface features like, **offset ridges, parallel deflection of valley**, reversal of drainage, straight reverse courses, and a straight and steep coastal lines.

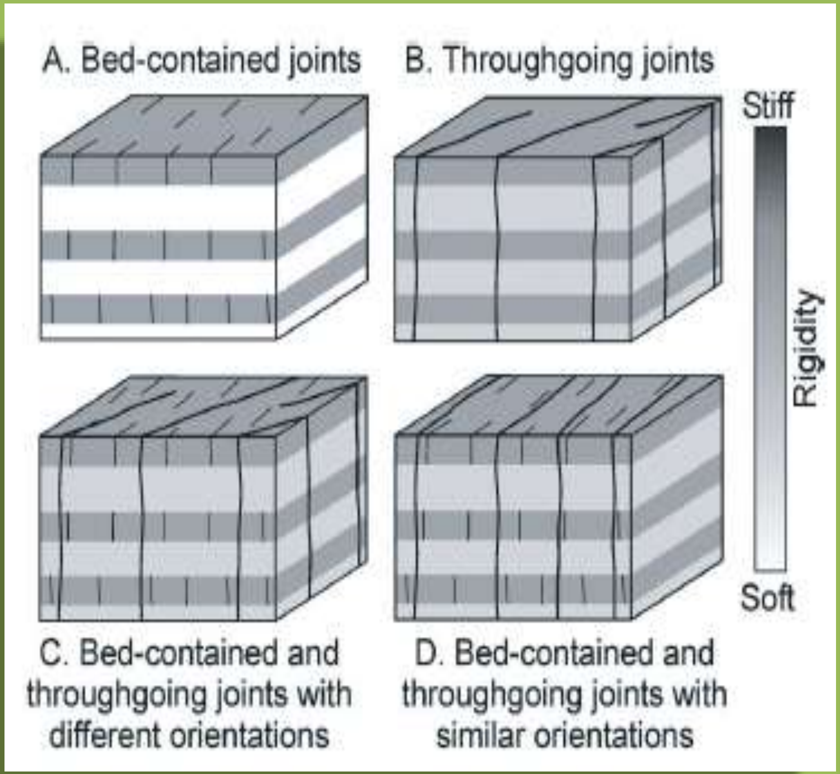
Effects of Faulting



Joints

- Joints are **fractures found in all types of rocks.** They are **cracks or openings formed due to various reasons**. Naturally, the presence of joints divides the rock into number of parts or blocks. **In simple terms, through the joints may be described as mere cracks in rocks**, they differ mutually. Joints, like cleavages of minerals, occur oriented in a definite direction and as a set.

Joints


A. Bed-contained joints
B. Throughgoing joints
Stiff
Rigidity
Soft
C. Bed-contained and throughgoing joints with different orientations
D. Bed-contained and throughgoing joints with similar orientations

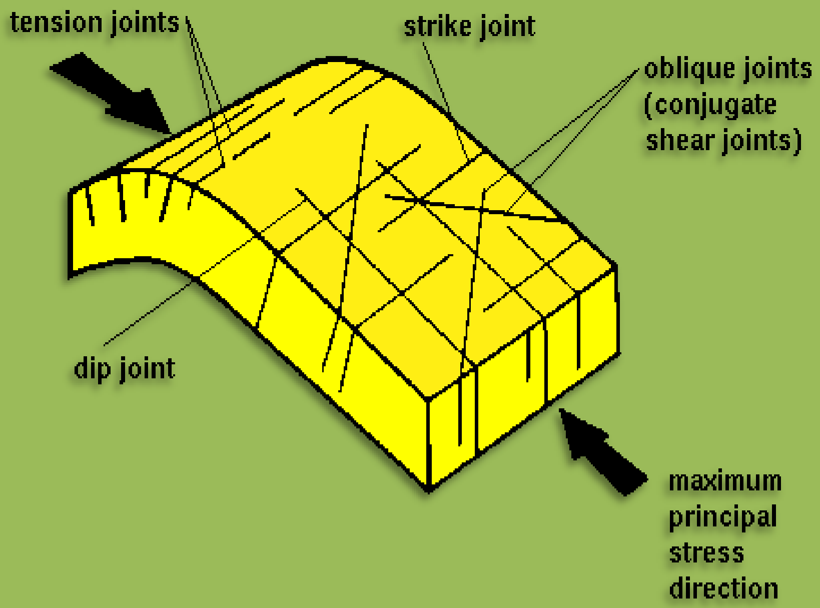
Joints

Joints

Effects of Joints

- From the civil engineering point of view, joints are important because they **split the rocks into a number of pieces which, in turn, reduce the competence of rock mass**, increase the porosity and permeability and make them susceptible to **quick decay and weathering**.
- Joints But a few advantages that accompany joints are; their occurrence increases the ground water potential in any place.

Joints


tension joints
strike joint
oblique joints
(conjugate
shear joints)
dip joint
maximum
principal
stress
direction

Joints

- Joints, though they resembles faults by appearing as fractures in rocks, are **not as dangerous as faults.** This is so primarily because the region affected by joint are **not liable to recurrence of joints in future as happens in the case of faults**. Thus places where joints occur are **not very unstable for foundation purpose.** Also the area affected by joints can be easily improved by methods such as suitable **cement grouting or plugging.**

Joints

Parts of a Joint

- Joints like faults, refer to the fracture in rocks. Hence, like faults, inclined and vertical joints also can be described by their attitude.
- However, in joints the fracturing blocks are not named as footwall or hanging wall.

Joints

Classification of Joints

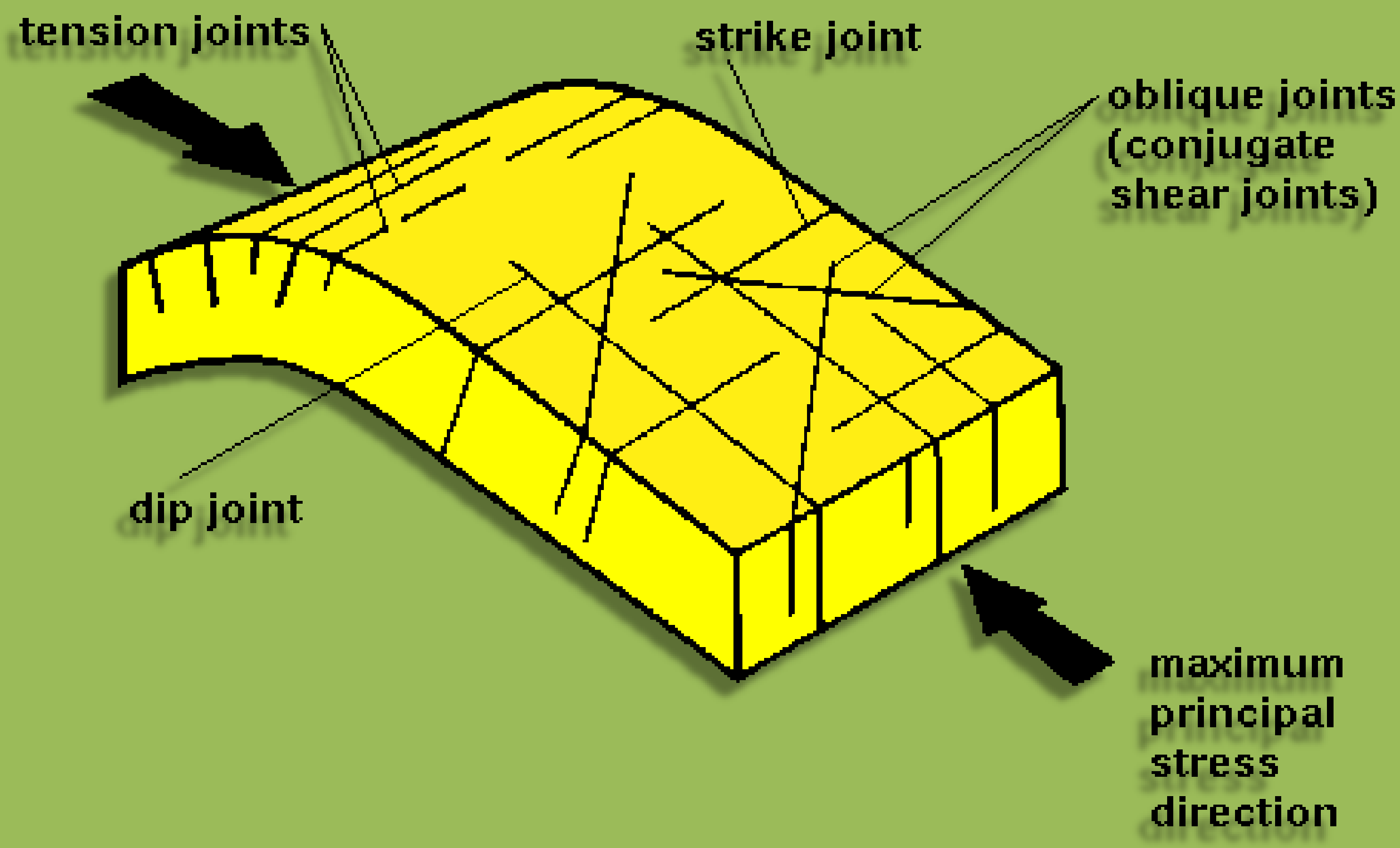
- Classification based on the relative attitude of joints
- When the joints **are parallel to the strike and dip of adjacent beds,** they are called **Strike Joints** or **Dip Joints**, respectively.
- If the strike direction of joints is **parallel neither to the strike nor dip direction of adjacent beds, then such joints are called Oblique Joints**.
- If the strike direction, dip direction and dip amount) coincides completely with the attitude of adjacent beds, they are called bedding joints.

Joints

Classification based on the Origin of Joints

- Most of the joints are formed due to either tensional forces or shearing forces. Accordingly they are described as **Tension or Shear Joint.**

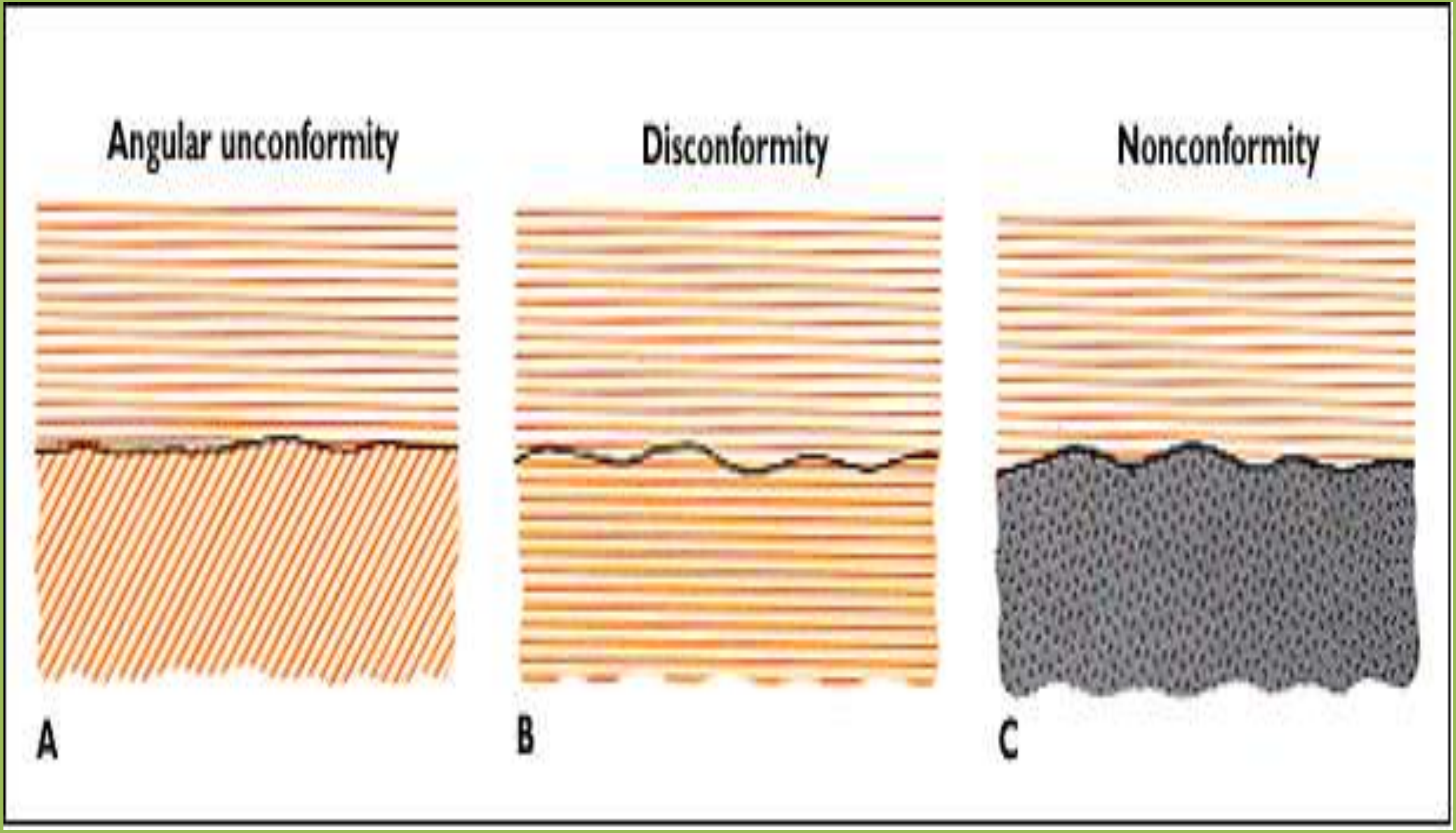
Classification of Joints



Unconformities

- Unconformity is one of the common geological structure found in rocks. It is somewhat different from other structures like folds, faults and joints in which the rock are distorted, deformed or dislocated at a particular place. Still, **unconformity is a product of diastorphism and involve tectonic activity in the form of upliftment and subsidence of land mass.**

Unconformities



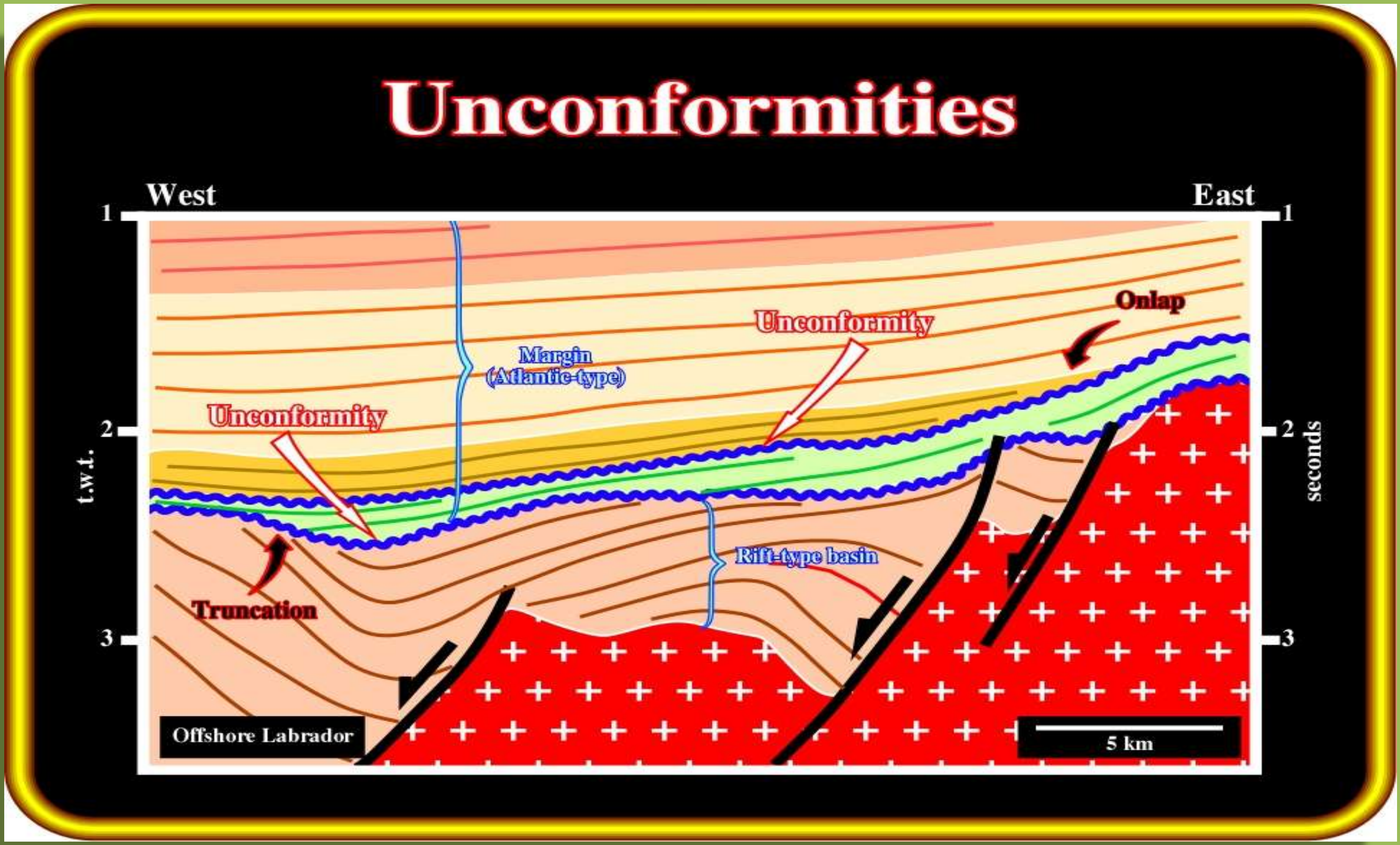
Unconformities

- When a **sedimentary rocks are formed continuously or regularly one after another without any major brake, they are said to be conformable beds**, and this phenomenon is called **conformity.** All the beds belonging to conformable set **shall possess the shame strike direction, dip direction and dip amount**.
- On the other hand, **if a major break occurs in sedimentation in between two sets of conformable beds, it is called an unconformity.**

Parts of an Unconformity

- There are different types of unconformities, all the types have two different ages, i.e. one set is older and the other set is younger having a depositional break in between)

Unconformity

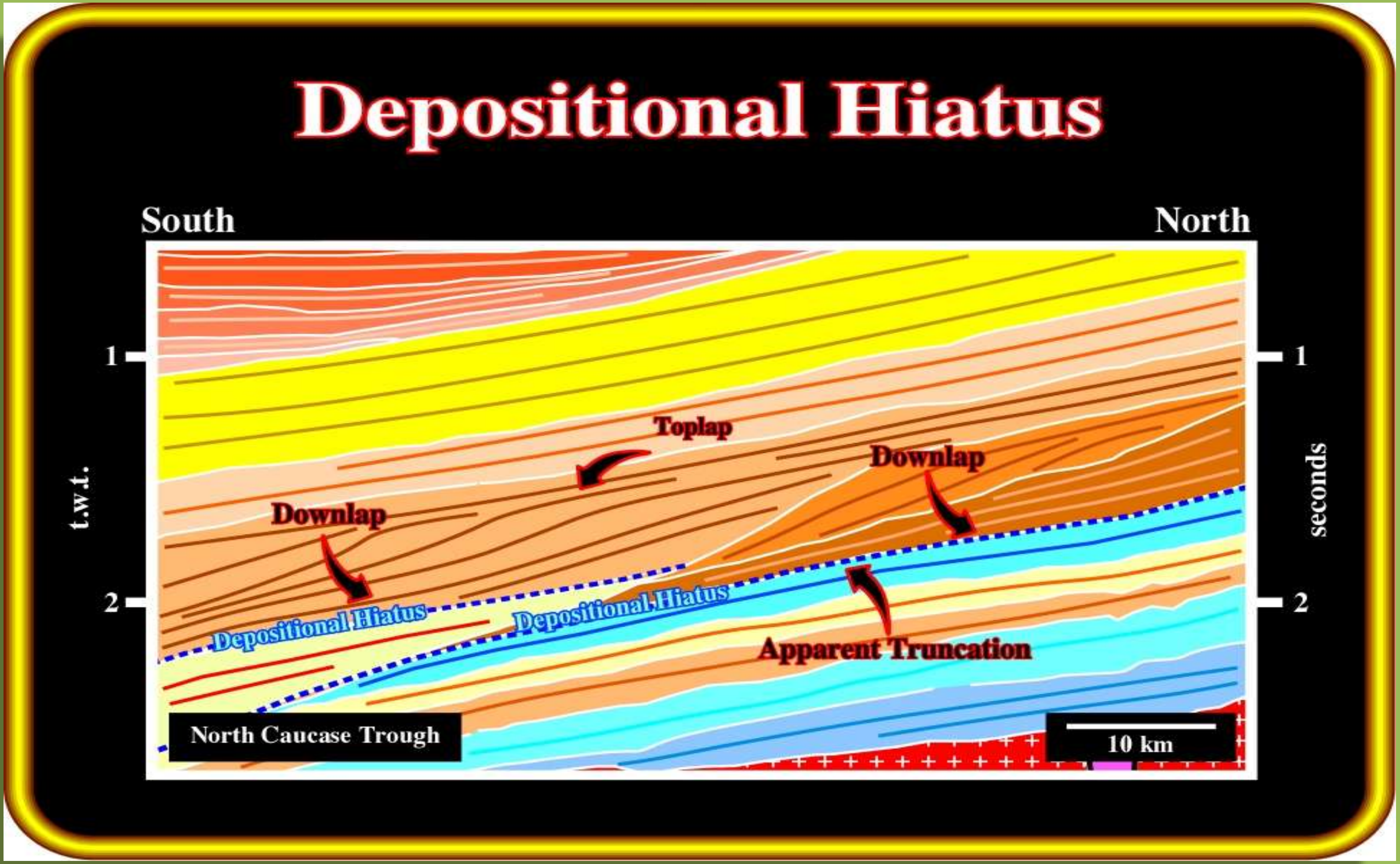


Unconformity

Hiatus

- An unconformity which represent a long geological period during which break in sedimentation had occurred) is known as a “hiatus”.

Hiatus


Depositional Hiatus
South
North
1
1
2
2
t.w.t.
seconds
Toplap
Downlap
Downlap
Depositional Hiatus
Depositional Hiatus
Apparent Truncation
North Caucase Trough
10 km

Types of an Unconformity

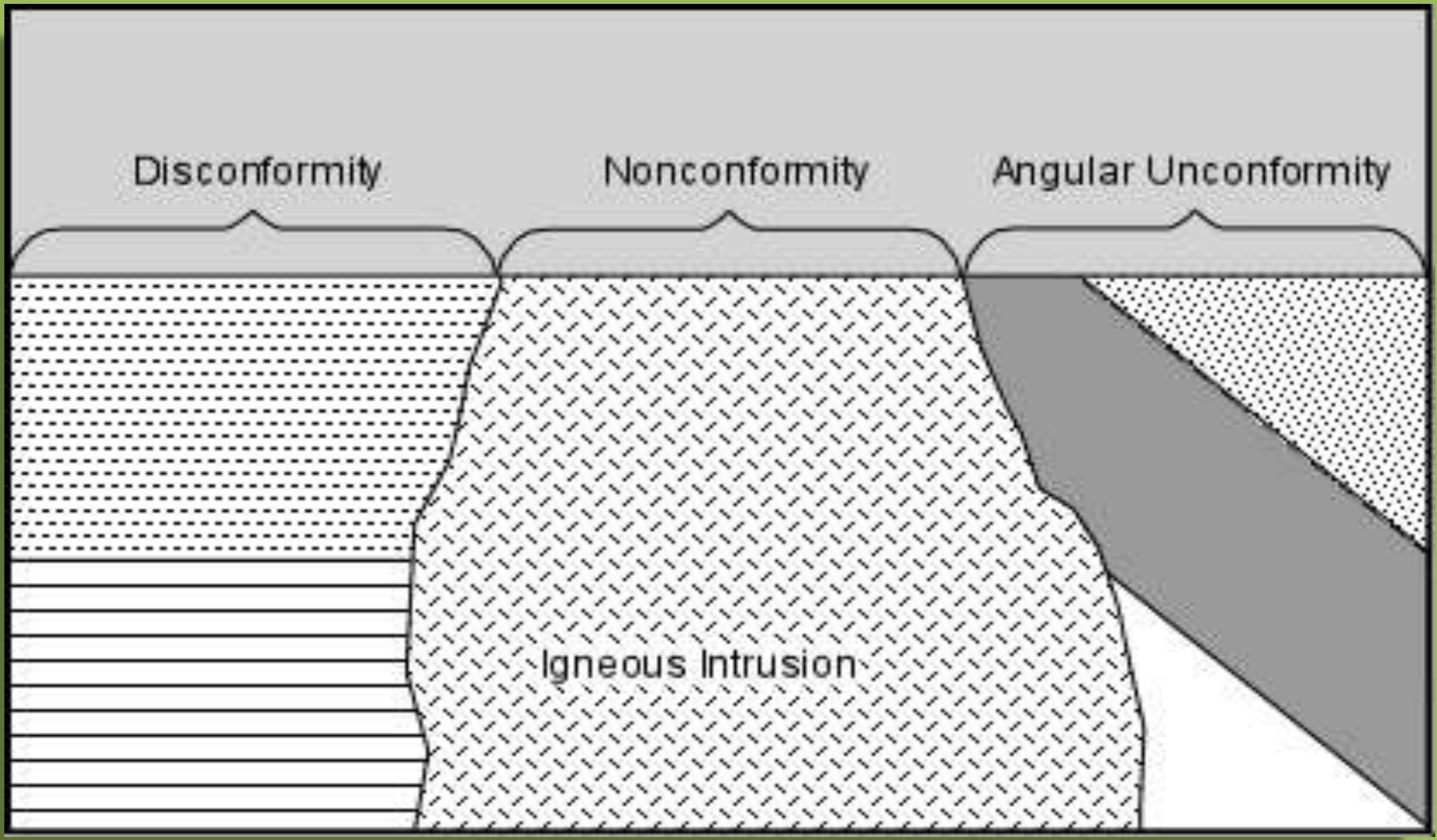
Types of Unconformities

- Based on factors such as type of rocks, relative attitude of sets involved and their extent of occurrence, the different types of unconformities are named as

Non-Conformity

- When the **underlying older formation** are represented **by igneous or metamorphic rocks** and the **overlying younger formation are sedimentary rocks**, the unconformity is called "non-conformity"

Types of an Unconformity



Types of an Unconformity

Angular Unconformity

- When the **younger bed and older set of strata are not mutually parallel**, then the unconformity is called **“angular unconformity”.** In such a case, beds of one set occur with a **greater tilt or folding.**

Types of an Unconformity

Disconformities

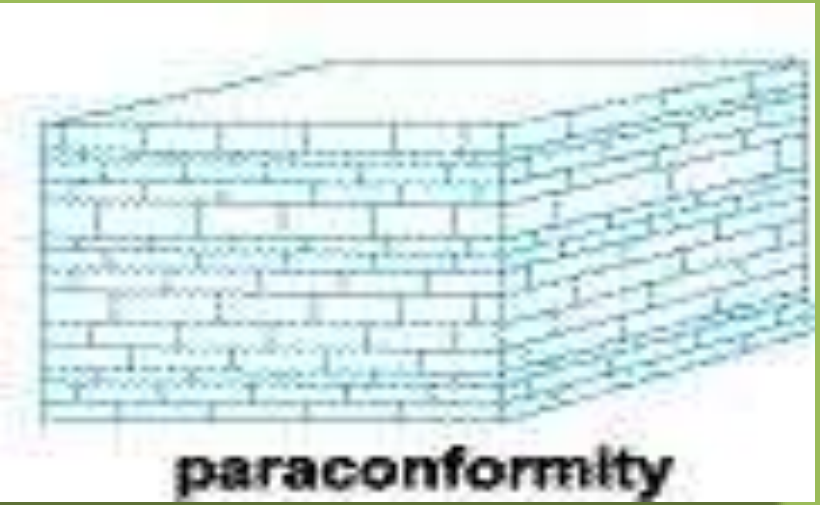
- On the other hand, if the bed of the **younger and older set are mutually parallel** and the contact plane of two sets is **only an erosion surface, then the unconformity is called "disconformities" i**n this case, the lower set of beds have undergone denudation before the deposition of the overlying strata commenced.

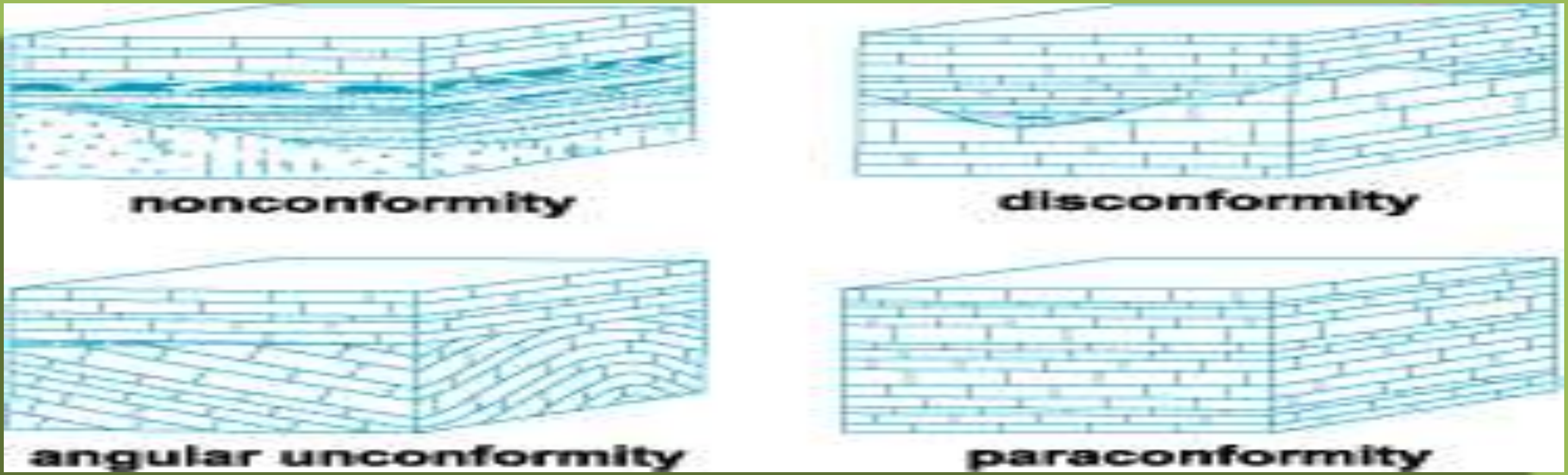
Types of an Unconformity

Paraconformity

- When the **two sets of beds are parallel and the contact is a simple bedding plane**, the unconformity is called **"paraconformity".** In such cases, **the unconformities is inferred by features like sudden change in fossil content or in lithological nature.**

Types of an Unconformity





Types of an Unconformity

Regional and Local Unconformities

- When an unconformity extends over a **larger or over a greater area,** it if called regional unconformity. **On the otherhand, if an unconformity occur over a relatively small area it is called local unconformity**.

Unconformity

Recognition of Unconformities

- Some of the evidences which helps in the recognition of unconformity are:
- Difference in attitude of **two adjacent sets of beds**
- **Remarkable difference in nature, age and types of beds**.
- **Occurrence of residual soil/ laterite/bauxite** along the unconformity surface.
- Considerable difference in the **degree of metamorphism of two adjacent sets of beds.**
- **Stratification correlation and lithological pecularities**.
- All of these and other evidences are inherently linked up with the processes of unconformity formation

Recognition of Unconformities

References

- Engineering and General Geology : By Parbin Singh
- Textbook of Engineering Geology : N.Chenna Kesavullu
- http://geology.com/

Thanks !

GHT