TITLE: PHYSICAL AND STRUCTURAL GEOLOGY

COURSE CODE: 1GELTC0101

UNIT – 5

5.1: UNCONFORMITIES:DEFINITION, KINDS AND THEIR SIGNIFICANCE.

In the sedimentary rocks when the sediments are deposited without interruption they are said to be conformable. The unconformity represent major time gap in the sediments. These major gaps in the sedimentation record is called Unconformity. An **unconformity** represent a buried erosional or non-depositional surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous. In general, the older layer was exposed to erosion for an interval of time before deposition of the younger layer, but the term is used to describe any break in the sedimentary geologic record. An unconformity represents time during which no sediments were deposited in a region, that means it represents non-depositional period.

Under the normal conditions the rocks above an unconformity are younger than the rocks beneath (unless the sequence has been overturned). These unconformities represents time during which no sediments were preserved in a region. The local record for that time interval is missing and geologists must use other clues to discover that part of the geologic history of that area. The interval of geologic time not represented is called a hiatus. It is a kind of relative dating.

In the field these unconformities are marked on basis of certain evidences, such as;

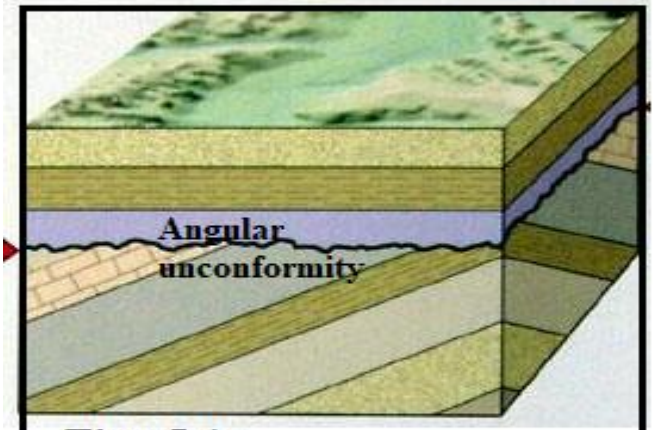
- The difference in the fossils record in the succession of rock beds.
- Presence of conglomerates at the base of upper series of rocks. Such conglomerates contain fragments of the underlying rock beds.
- Presence of structure discordance in the two rock units
- Based on difference in environment of deposition. Presence of such rock beds, which are formed under contrasting conditions.
- Difference in fossil records on both sides of unconformities in the lower and upper rock beds.
- Based on relationship with intrusive.

TYPES/KINDS OF UNCONFORMITIES

Depending upon the contact relationship between younger and older rock layers, unconformities are classified into four types.

ANGULAR UNCONFORMITIES

Angular Unconformity is a type of rock unconformity in which the beds shows angular relationship with each other. The horizontally parallel strata of sedimentary rocks are deposited on the eroded and tilted layers of sedimentary rocks. It takes hundreds of million years to produce Angular **Unconformities in** the rocks. The 3-d sketch of unconformity is shown in **Fig.51a**.



Fi.g: 5.1a

The photographs are shown in fig. **5.1b.**The formation of the angular unconformities in the rocks arebased on the following steps:

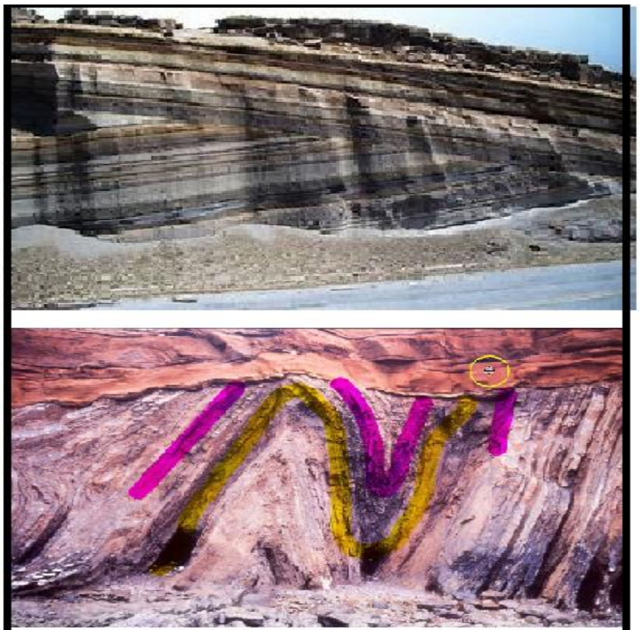


Fig.5.1b

1. The sediments gets weathered from land and moves into the sea where they get accumulated. These sediments takeover millions of years to get converted into layers of rock.
2. As the tectonic disturbances causes the earth's crust constantly shifted, lifted, folded and tilted. Thesedeposited sedimentary layers (beds) at sea beds also suffered such changes and get uplifted above the sea level. These uplifted bedsgets eroded or weathered again by natural agents.
3. Due to this erosion, the edges of the tilted layers become flat.
4. Finally, the sea level rises and the land sink in the sea which again deposited the new horizontal layers which shows angular relationship with the older rock beds.

Example: The angular unconformity exist between the Sargur and the Dharwar sequences of the South Indian Craton.

NONCONFORMITY

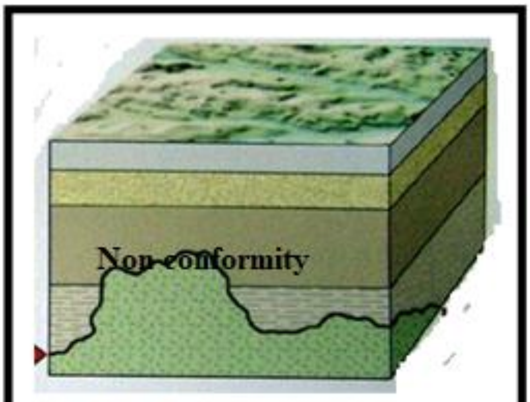


Fig.5.1c

It is easier to recognize nonconformity, if it occurs on igneous/metamorphic rocks. It exists between sedimentary rocks and metamorphic or igneous rocks. The sketch of nonconformity is shown in **Fig.5.1c.**The sedimentary rock lies above are younger and was deposited on the pre-existing and eroded metamorphic or igneous rock which is older one.The contact between them can be easily recognized in the field due to the difference in characters of both younger (sedimentary) rocks and older (metamorphic/igneous) rocks.**Fig.5.1d** shows the photographs of nonconformity.The minerals, rock texture and a closer examination of the structure of rocks will enable us to recognize nonconformity between.There is no layering in igneous rock whereas; the sedimentary rock is in layered form.

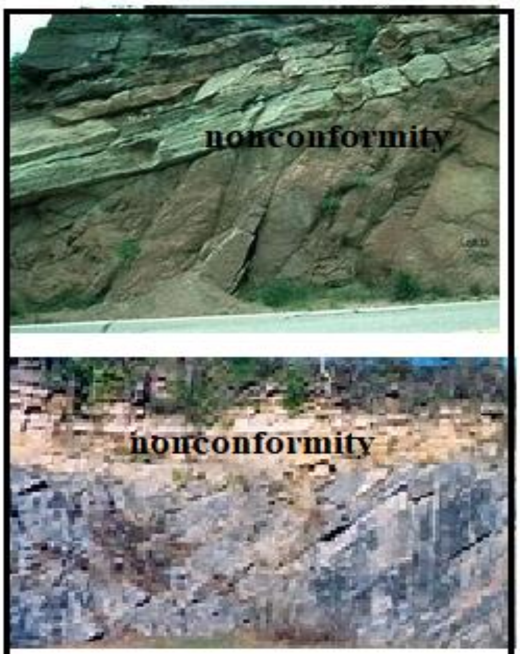


Fig.5.1d

In other words, suppose, we are studying two rocks: sedimentary and metamorphic. The lower rock is metamorphic which is 600 million years old and the upper rock is sedimentary which is 400 million years old. We cannot easily differentiate them in the filed on the basis of their relative ages. Some time we cannot differentiate them on the basis of their material and structure. In such cases the only difference we will see is the erosional contacts lying between both of them.The erosional contacts lying parallel to the surfaces of both the rocks are known as a nonconformity. The very thin layer of erosions between the younger and metamorphic rock makes them separate and it cannot be recognized easily. The erosional contacts lying parallel to the surfaces of both the rocks. We can recognize it only if there are fossils between the two rocks. The layer of fossils between them can differentiate the ages of the rocks and can draw a clear difference line between them. It indicates the period of uplift and erosion of rocks previously overlying the igneous/ metamorphic prior to the deposition of the younger sedimentary rock.

DISCONFORMITY

A disconformity occurs when two sedimentary rocks layers lying together in parallel position, but they have different ages. The **fig.5.1e** is the 3d sketch of disconformity. For example one rock will be 100 million years old and the other one is 300 million years old. The layers of sediments are uplifted without folding or tilting and are eroded. In the end the area subsides and deposition resumes. The rock layers on either side of the unconformity are nearly horizontal. Itlooks like the rock layers were deposited continuously but a time gap exist between the rock layers. In disconformity the difference between both the layers can be identify easily. The paleosol formation of the rocks shows a clear disconformity in them.Eparchaean unconformity demarcated in the Tirupati hills which is a major discontinuity of stratigraphic significance. The boundary is between sedimentary rocks of the CudappahSupergroup, (1600 million years old) and Archaean rocks that comprises granites, gneisses and dolerite dykes that are more than 2100 million years old. There is a 500 million year gap of deposition.

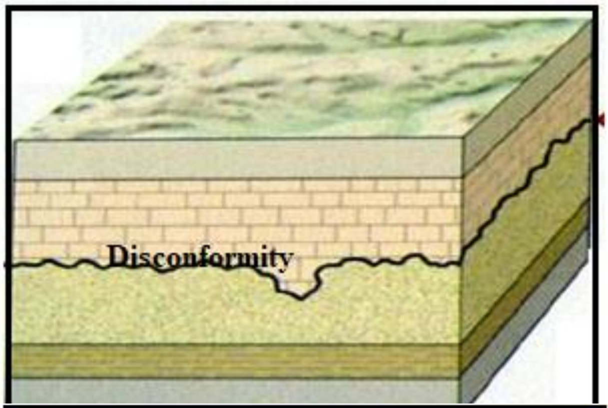


Fig.5.1f

PARACONFORMITY

A paraconformity is a type of unconformity in which strata are parallel; and the contact is simple bedding plane. It is also called non-depositional unconformity or pseudo-conformity. Short para-conformities are called diastems.**Fig.5.1g** shows the sketch of para-conformity

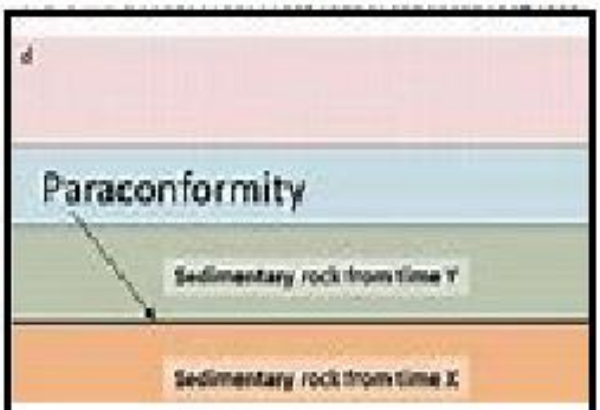


Fig.5.1g

DIASTEM

A diastem is a short interruption in sedimentation with little or no erosion. They can also be described as very short paraconformities. In 1917 Joseph barrel of USA estimated the rate of deposition of succession from the available radiometric age. His accumulation showed that the strata accumulation was at the rate of thousands of years per foot rather than hundreds. He stated that diastems are universal in sedimentary rocks and explain them as a product of fluctuation of base level.

BUTTRESS UNCONFORMITY

A buttress unconformity occurs when younger bedding is deposited against older strata thus influencing its bedding structure.

BLENDED UNCONFORMITY

A blended unconformity is a type of disconformity or nonconformity with no distinct separation plane or contact. It sometimes consists of soils, paleosols, or beds of pebbles derived from the underlying rock.

SIGNIFICANCE

James Hutton (1795) was first to interpret the significance of unconformities;

- Unconformity is a contact between two rock units in which under the normal condition upper unit is always younger than the lower unit. Unconformities represent a break in the geologic record of hundreds of millions of years or more.
- A disconformity which is an unconformity between parallel sedimentary rocks layers are marked by features of sub-aerial erosion. This type of erosion can leave channels and paleo-sols in the rock record.
- The significance of angular unconformity was shown by James Hutton in 1787. These Indicates that during the silent period there was period of deformation and erosion. The rocks above an unconformity are younger than the tilted rocks beneath.
- In the economic geology at some places these unconformities produces oil traps and act as good aquifers.
- Unconformity helps in visualizing paleogeography of a region.
- Unconformity is an important structure that affects site conditions for engineering work. These generally forms weak zone.

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5.2 RECOGNITION OF FOLDS IN THE FIELD

Folds are undulation or waves in the layered rocks of Earth's crust.. These layered rocks were originally formed from sediments that were deposited in flat horizontal sheets, but in a number of places the strata are no longer horizontal but have been folded due to pressure effects generated by tectonic forces. . The morphology of the fold is shown in **figure.5.2a and b**

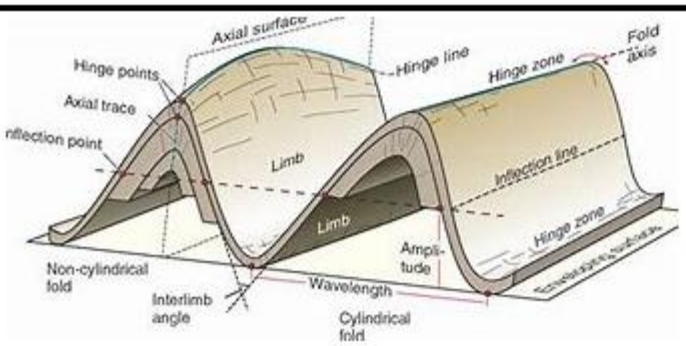


Fig.5.2a

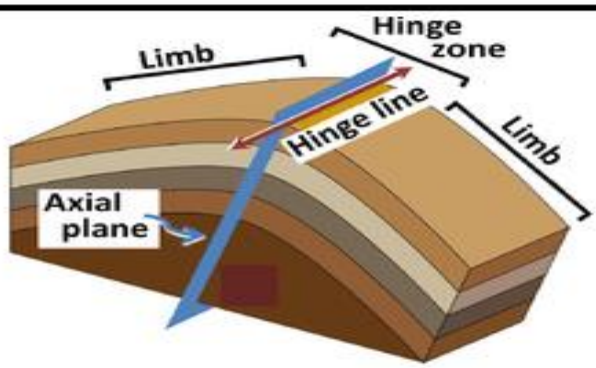


Fig.5.2b

The folds can recognise in the field with the help of different methods and criteria, these ares;

1. Direct observation:
2. Plotting the attitude of beds:
3. Map pattern
4. Topography
5. Drilling
6. Mining
7. Geophysical methods.

1. **Direct observation**: The most effective method for the identification of the fold is the field observation. The field observation of the fold is possible at few places only, where they are well exposed. These places may be mountain cliffs, large highway cuts **(Fig.5.2c),** road cutting along, natural exposures. In the visible exposures folds are studied by their relation with minor features associated with these folds, such as foliations. When small folds are recognised in the field, their attitude is recorded such as the magnitude of their axial plane and axis. In the field large fold cannot be observed in a single outcrop or in a series of closely

adjacent. In such cases the attitude of axial plane and the axis cannot be measured directly.

2. **Plotting the attitude of beds:** The plotting of dip and strike of the beds on the map is the common method to recognise the folds which are larger than an outcrop **(Fig.5.2d).** The suitability of this method depends up on the complexity of the structure. In case of the complex structures most exposures are necessary, where as for the simple structures few exposures are required.

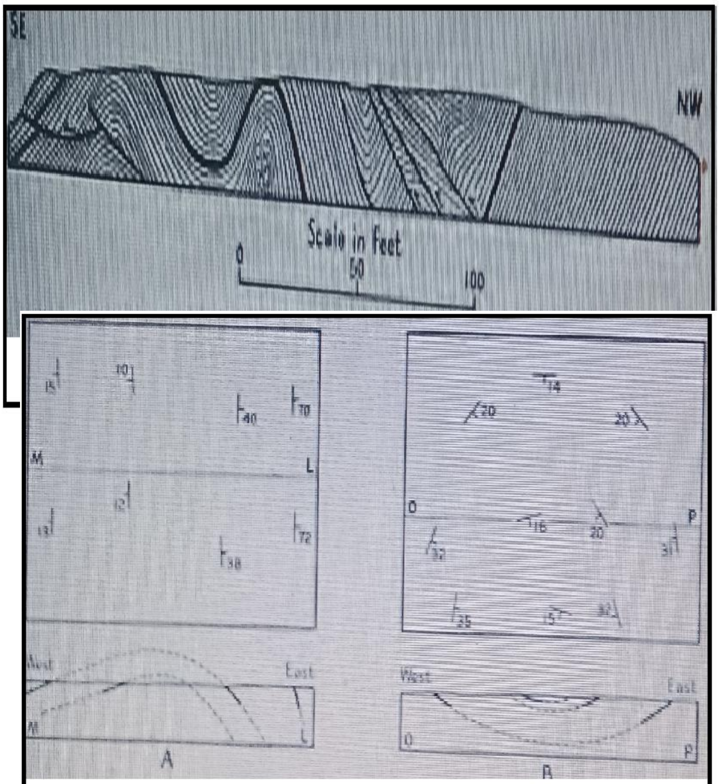
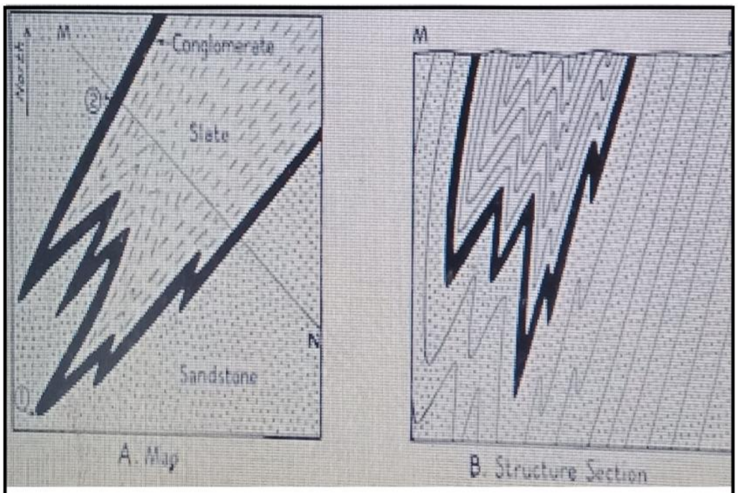


Fig.5.3d

3. **Map pattern**: In the geological map the pattern shown by the stratigraphic units are used for the study of geological structures.
4. **Topography:** For the study of folds topography is very important. By following the topography the important units can be trace for longer distance. The folds can be identify on the basis of outcrop pattern **(Fig. 5.2e).** The difference in the resistance of rock produces the different topography. By the erosion the less resistance rock forms the valleys and resistant rock forms the ridges. The attitude of the bed may be determined quantitatively from the relationship of the bedding plane to contours. If the contact between the formation is parallel to contour the strata is horizontal. If irrespective to the topography the contact maintains a uniform strike the strata are vertical. The dipping strata have outcrop pattern that is partially controlled by contours.

In the field cuestas indicate gently dipping formations. A concentric series of ridges with steep inner slope but with gentler inner slopes indicare domal structure.

5. **Drilling :** Drilling may provide the vital information where the exposures are limited or absent. The drill cores are used for the determining the dip of the bedding plane. The under stand the more comples folding the more drill cores per unit area are used.



A-Geological Map. B. Infered structure (Fig.5.2 e

6. **Mining**: Mining operation especially the coal mining provides the valuable data as the mining may exposed large area and folds may expose for study. This method give complete information of the geological structure in the area.
7. **Geophysical methods**: Geophysical methods have been applied to determine of the geological structures. These methods are gravimeter, seismic, magnetic, and electrical.

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Note; All the figures for sub unit-5.2 is taken from Book: Structure geology By Billings)

5.3. RECOGNITION OF THE FAULTS IN THE FIELD.

Faults are fractures in which there is relative displacement of the two blocks along the fault plane. Faults can be recognised on the basis of certain criteria.

1. Discontinuities' in the structures.
2. Repetition and omission of the strata.
3. Characteristic features present on fault planes
4. Silicification and mineralization
5. Sudden changes in the sedimentary facies
6. And Physiographic criteria.

Some features are similar to the unconformities therefore it becomes very difficult to distinguish between fault and unconformities in the field.

1. **Discontinuities' in the structures**. If strata suddenly end against the different beds, fault may appear. At mountain cliff, on map, the discontinuity may appear as line. The disrupted data may appear on the same outcrops, nearby exposures. Dykes, veins may ends along a line and displaced rocks may appear elsewhere.

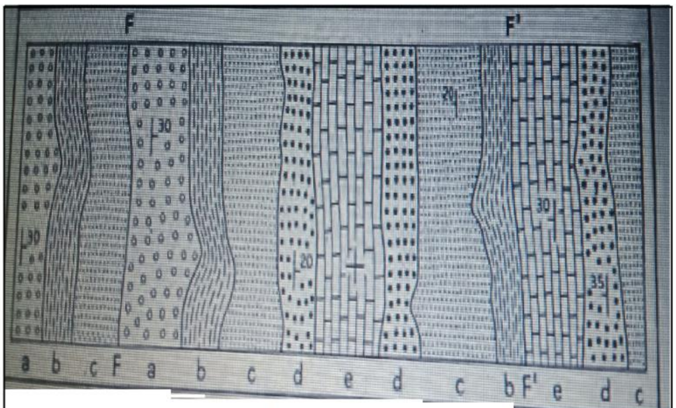


Fig.5.3a

2. **Repetition and omission of the strata.** Due to faulting there is repetition and omission of the beds. This because the rock beds gets displaced along the fault plane. In case of reverse faults. Thrust faults there is repetitions of the belts. These repetitions can be easily seen in the field **(Fig.5.3a).**
3. **Features on fault planes:** Slickensides, gouges, mullions, breccias, mylonites are important features seen on the fault planes. Along the fault planes due to frictions, marking and polished surfaces are produced along the movement of the blocks called slickensides (**fig.5.3b).** Mullions structures are large groves and furrows which are produces along the

direction of displacements. Due to frictions along the fault planes some rocks gets pulverised to form the gouges

Some angular and Sub-angular rock fragments of different sizes are formed with the fine grained matrix along the fault planes these are called breccias.

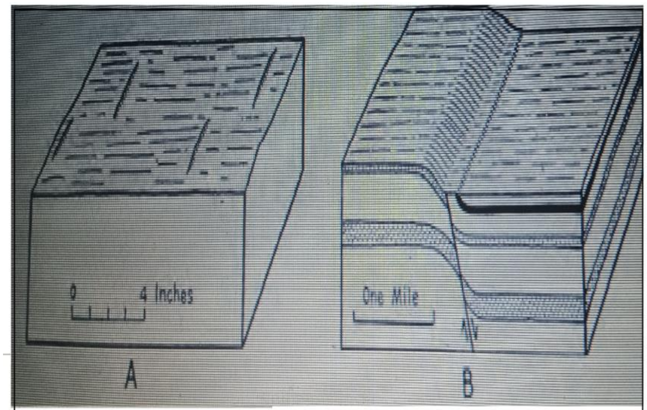


Fig.5.3b(A-Slickensides B-Drag along faults)

4. **Silicification and Mineralization:** As faults provide the channels for the movements of hydrothermal solutions. This solution during their movement altered the surrounding rocks. Silicification is a type of alteration in which silica content in the altered zone increases due to alteration of the rocks and deposition by the hydrothermal solutions. The fault plane becomes the suitable sites for the deposition of the ore minerals from the hydrothermal solutions.

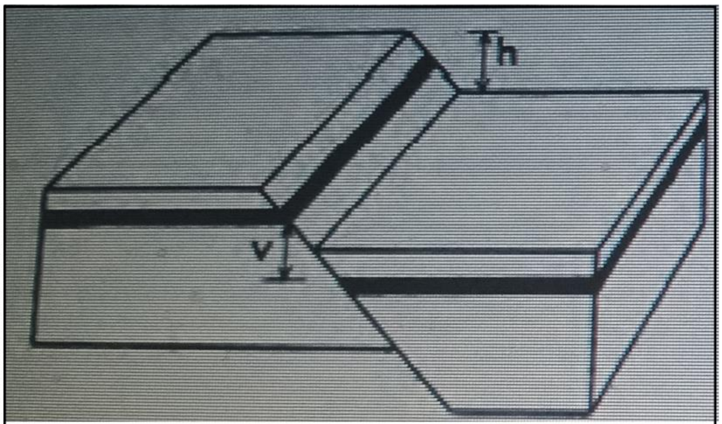


Fig.5:3c

5. **Sudden changes in the sedimentary facies:** when there is a long horizontal displacement of the rocks due to folding which is called overthrusting there is contiguous strata of exactly the same age show very different sedimentary facies. If contemporaneous strata are represented in the same area by the different sedimentary facies, then a fault of large displacement occurs .
6. **Physiographic criteria:** If the down through block of the fault is completely buried under the alluvium, there is no direct evidence of faulting. In such cases some physiographic features are helpful for identifying the faults. These features are offset ridges, scarps, scarplets, triangular facets, truncation of the sediments by a mountain fronts, modified drainage patterns and springs. Steep straight slope of any height is called fault scarps(**Fig.5.3d)**. It may be ten or thousand feet high. A fault line scarps is a scarps whose relief is due to differential erosion along the fault line **(Fig.5.3d).** A composite fault scraps is one whose relief is due to erosion and movement along the fault plane. Scraps and Scraplets are the indicators of active faulting. These lie at or near the foot of mountains.

They are usually confined to unconsolidated rock, alluvial fans, glacial moraines, lake terraces. Triangular facets **(Fig.5.3e)** are developed along some sacrps in the fault. Triangular facets may also develop along fault line scraps.

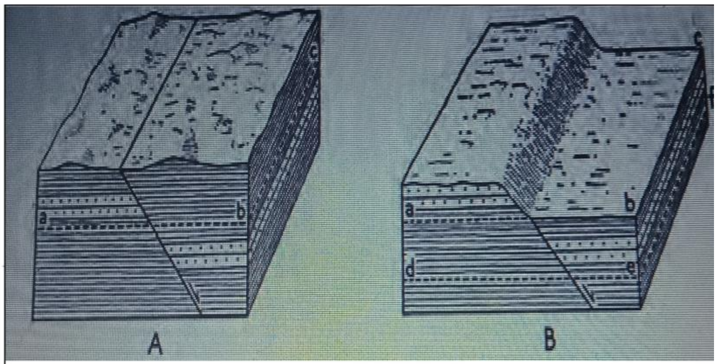


Fig.5.3d(A-Fault line, B-Fault Scrap line)

A break in stream profile or offset streams may occur at fault line. Whenever movement is dominantly horizontal and essentially parallel to the strike of high angle faults, a map of streams may show distinct offsets. The truncations of internal structure of the range at mountain front can be identified as fault. The alignment of the spring along the foot of the mountain range indicates the faulting. This alignment of the spring indicates the numerous weak planes. The hot spring indicates the deep fractures where there is circulation of the water .

Note; All the figures for sthe ub unit-5.3 is taken from Book: Structure geology By Billings)

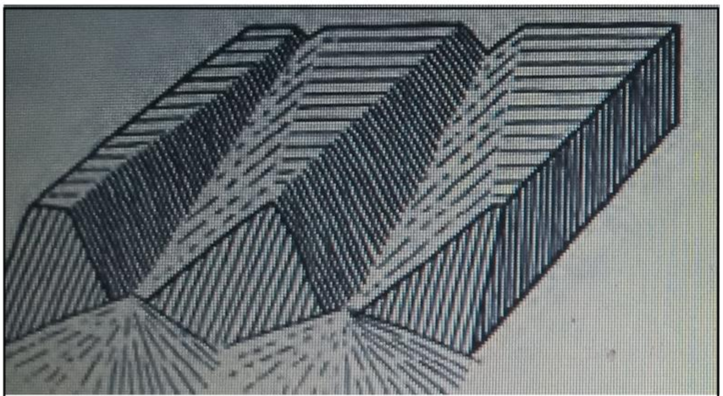


Fig.5.3e

5.4 Uses of sedimentary structures to determine the top and bottom of beds in deformed rocks.

Some structures tell us about the top and the bottom of a sedimentary layer at the time that it was laid down, and hence indicates the direction in which the rocks get younger. This can be very valuable information in the interpretation of an area; it may lead to recognition of folds that are otherwise difficult to recognize as in Figure 1a or may lead to the recognition of a complex structure in what is otherwise an apparently simple situation, as in Figure 1b. Some of the more reliable and commonly occurring structures, from the point of view of younging criteria are discussed here:

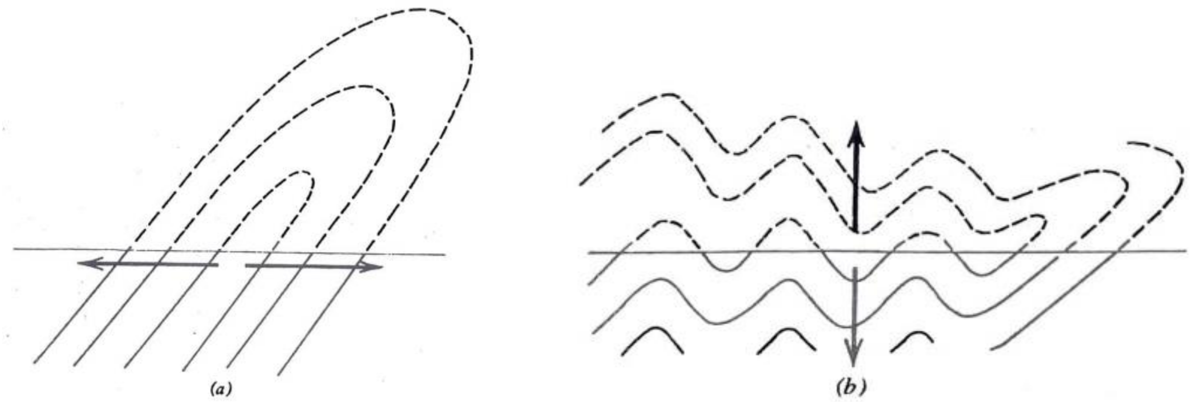


Figure 1: Hypothetical geological sections. Horizontal line represents ground surface and the arrows represent directions of younging.

1. CROSS BEDDING

Cross bedding is a structure confined to a single sedimentation unit and characterized by internal bedding or lamination, called foreset bedding, inclined to the principal surface of accumulation. The terms *current bedding* and *cross lamination* are commonly used for the same structure. This structure is found in a variety of water and wind-deposited clastic sediments and can often be used to determine the direction of younging of the sequence.

As deposited it may be a symmetrical structure (as in Fig. 2a and b) in that angles between the foreset lamination and the bed boundaries are the same at the top and at the bottom. This type of cross bedding is of no value as a younging criterion. However, cross-laminated units commonly suffer erosion prior to the deposition of the next bed, so that if the structure was originally sigmoidal (as in Fig. 2b) the resulting structure is asymmetrical as shown in Figure 2c. It is this asymmetry that is used to determine the direction of younging and, in general, it is very reliable. Cross bedding may survive quite intense deformation and metamorphism so that it is a very useful younging criterion in deformed metamorphic rocks.

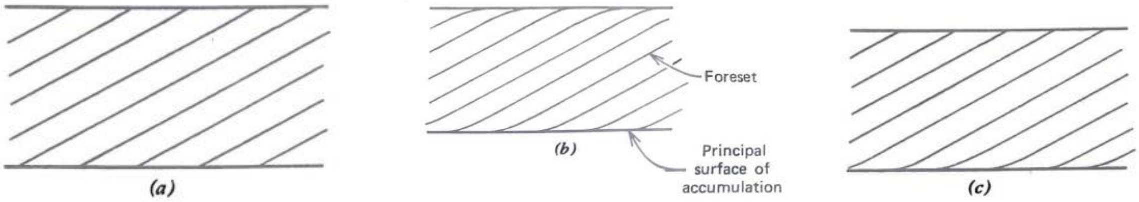


Figure 2: Various types of cross bedding as seen in the plane perpendicular to the line of intersection of the foreset beds and the principal surface of accumulation.

2. RIPPLE MARKS

Ripple is the name given to a group of wavelike depositional structures that may form in water or in air. Structures of this type vary in amplitude from a few millimetres to mega ripples, such as sand dunes, which have an amplitude measurable in meters or tens of meters. They can be divided into two groups: *oscillation ripples* and *current ripples.*

Oscillation ripples, in profile, are commonly seen to comprise angular ridges separated by arcuate troughs (Fig. 3a). This difference between the shape of the ridge and that of the trough, often makes it possible to tell the direction of younging of an oscillation ripple-marked sediment.

It is sometimes more difficult to determine the direction of younging from current ripples. They are asymmetrical in profile but both the ridges and the troughs have the same shape (Fig. 3b), so that when the structure is inverted their appearance is unchanged. Thus the direction of younging cannot be determined from the shape of the structure alone. However, in many cases, heavy minerals or organic matter accumulates in the ripple troughs so that the latter can be distinguished from the crests of the ridges, and the direction of younging can therefore be determined. Similarly, grains larger than the bulk of the sediment, but of the same composition, also accumulate in the troughs of water-formed ripples, thus making identification of the troughs possible. However, this fact must be used with care because if the sediment is wind deposited the coarse material tends to accumulate at the crest of the ridges.

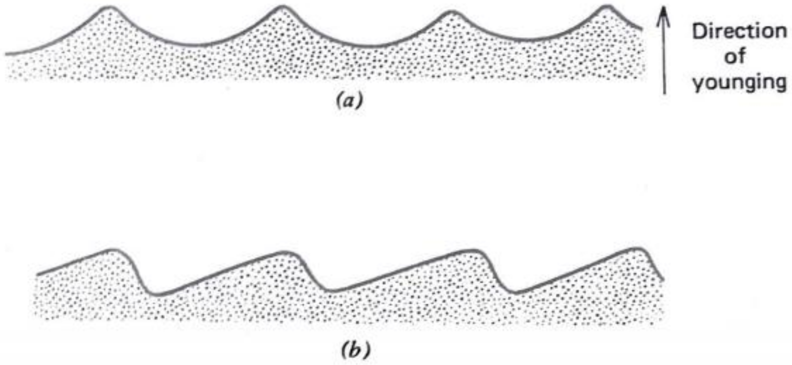


Figure 3: Ripple marks: *(a)* Oscillation type; *(b)* Current type.

3. GRADED BEDDING

Some sandstone beds show a concentration of the coarsest material at the bottom, a gradual reduction of grain size as we go upward and with the finest grains occurring at the top of the bed. The structure resulting from this graded succession of grain size is known as *graded bedding* (Fig. 4). The occurrence of such graded beds indicates the stratigraphic order. Graded beds often occur in succession, one above the other. Although graded bedding has been reported from different types of rocks, it is most common in deep sea sandstones known to have been emplaced by turbidity current. Although inverse grading with upward coarsening of grain size within a bed, is known to occur, it is rather rare.

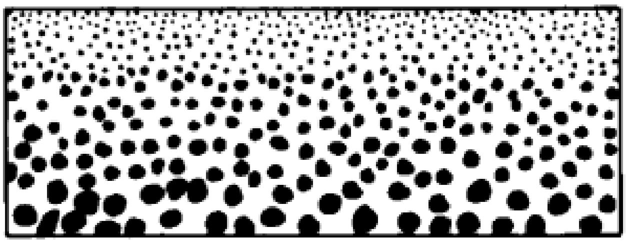


Figure 4: Graded Bedding

4. Sole Marks

Sole marks are produced as elongate depressions on the firm surface of mud and which is later covered by sand. The sole mark therefore appears as casts on the under surface of the sandy bed. The younging direction is obtained from our knowledge that these structures develop only on the bottom surface of a sandy bed. There are two main types of sole marks, the *flute casts* and the *groove casts* (Fig. 5 a, b). The flute casts are elongate and somewhat triangular in shape, with a bulging nose pointing up-current and which widen and flatten out in the direction of current flow. Flute casts are therefore often used to determine the direction of palaeocurrent. Flute casts are produced by the scouring action of eddies on a surface of mud. The groove casts are elongate structures which are parallel to the direction of current flow, although the sense of flow is not indicated by them. The groove cast (Fig. 2.4b) is thought to be one type of *tool mark*, i.e. a mark produced by the down-current movement of a relatively coarse object along a muddy surface.

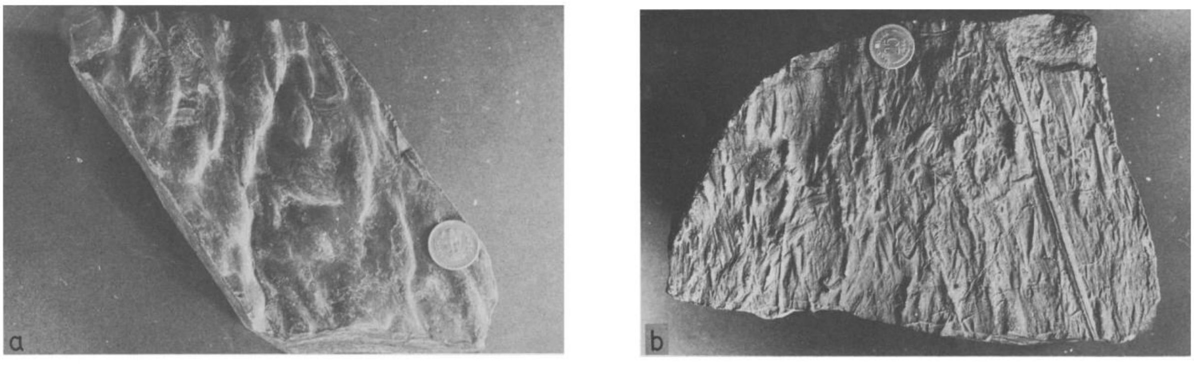


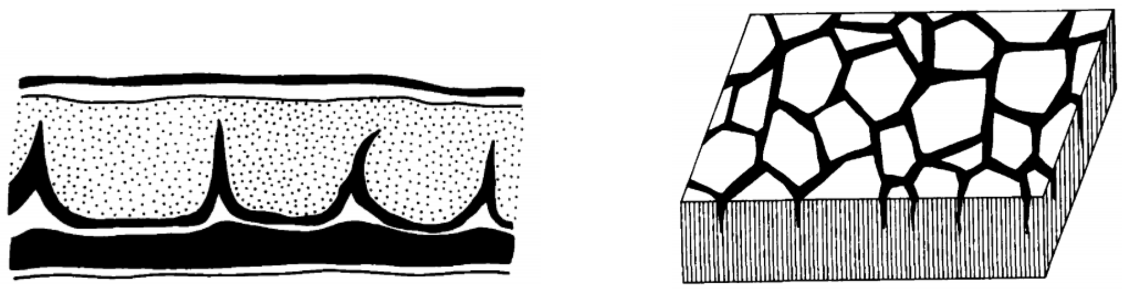
Figure 5: (a) Flute cast in siltstone. (b) Tool marks in fine-grained sandstone. The continuous mark on the right-hand side in (b) is a groove cast. The observed surfaces of both specimens are bottom surfaces.

5. Load Casts

Unlike flutes and groove casts, *load casts* are produced by the sinking of a freshly deposited bed of sand as a series of pockets into a soft mud. The downward closures of the pockets are generally broad or rounded, while the upward closures are narrow and sometimes flame-shaped (Fig. 6a). Unlike the flutes and grooves which cut through the bedding of the underlying shale, the bedding in both the sandy and the shaly units are deformed during the formation of the load structure. The load casts give us the younging direction because they form at the basal part of sandstone beds. In certain cases the shape of the load cast, with its broad or rounded downward projection into the shale and the narrow or sharp upward projections, can also be used to determine the direction of facing.

6. *Mud Cracks* or *Sun Cracks*

In comparison with the sedimentary structures described above, *mud cracks* or *sun cracks* (Fig. 6b) are rather rare. When a clay-rich surface of deposition is exposed to the air, a polygonal network of cracks appears due to shrinking of the clay during drying. If the surface is once again submerged and is covered by sand, the cracks are filled up by the sand. The shape of the mud cracks is then preserved as casts on the under surface of the bed of sandstone. In sections normal to the depositional surface, the mud cracks taper downward. The direction of younging can be determined from this feature.



a b

Figure 6: (a) Load cast of sandstone in shale. The load casts have sharp upward-pointed crests and lobate troughs, (b) Mud cracks. In vertical section the cracks taper downward.

7. Stromatolite

Stromatolite, an organo-sedimentary structure, occurs in certain late Precambrian carbonate rocks. A common variety of stromatolite grows as columns normal to the bedding and has upward convex fine laminations which indicate the direction of younging. In folded terrains the angle between the columns and the general bedding does not remain a right angle. The change in the right angle can then give us both the magnitude and the sense of bedding-parallel shear strain. The stromatolitic structure is often very well preserved even when the rocks are metamorphosed.

5.5 Vertical and Horizontal tectonics: origin of Nappe, Klippe, Horst, Graben and Window.

Vertical and Horizontal tectonics are the terms used to represent the extensional and compressional tectonic regimes respectively. Extensional tectonics is prevalent near the mid oceanic ridges where the plates are moving away from each other, in such areas Horst and Graben like structures form. In extensional regimes, the vertical movement is comparatively large as compared to the horizontal movement along the discontinuity surface. Compressional regimes are found where the lithospheric plates are moving towards each other. The structures like Nappe, Klippe and Window are present in compressional regimes, particularly in orogenic belts. In such areas horizontal transport is comparatively large to the vertical movement.

Origin of Nappe, Klippe and Window:

Reverse faults are those which have dominant dip-slip components with a relative upward movement of the hanging wall. Reverse faults with a low angle of dip (less than 45°) are called **thrusts** or **thrust faults**. Thrust faults may show large horizontal displacements in the scale of a few kilometres or tens of kilometres. If the foot wall stays in position and the hanging wall is transported, the fault is called an **overthrust.** If the foot wall moves instead of the hanging wall, the thrust is called an **underthrust**. The hanging-wall sheet of rocks which travelled to some distance over a thrust fault is described as a **thrust sheet**.

If a tectonic unit has moved far over rocks in front of it, it is called an **allochthonous** unit. A rock mass which has not moved over other rocks is described as **autochthonous**. **Parautochthonous** rocks are those which have moved over other rocks to a small extent.

A **thrust nappe** is an allochthonous tectonic sheet which has moved over a thrust fault (Figure 1a). A **fold nappe** is an allochthonous tectonic unit which exhibits large-scale stratigraphic inversion and may have initiated from large recumbent folds. The underlying limbs of these folds may be sheared out into thrust faults. Thus, a fold nappe might or might not have a fault at its base (Figure 1b, c).

Nappes exposed at the surface can be discontinuous because erosion has selectively removed some parts while others have been spared. An erosional remnant of a nappe is called a **klippe** (Figure 2). Similarly, an erosional "hole" through a nappe that exposes the underlying rock unit or nappe is called a **fenster** or **window** or **tectonic window** (Figure 3).

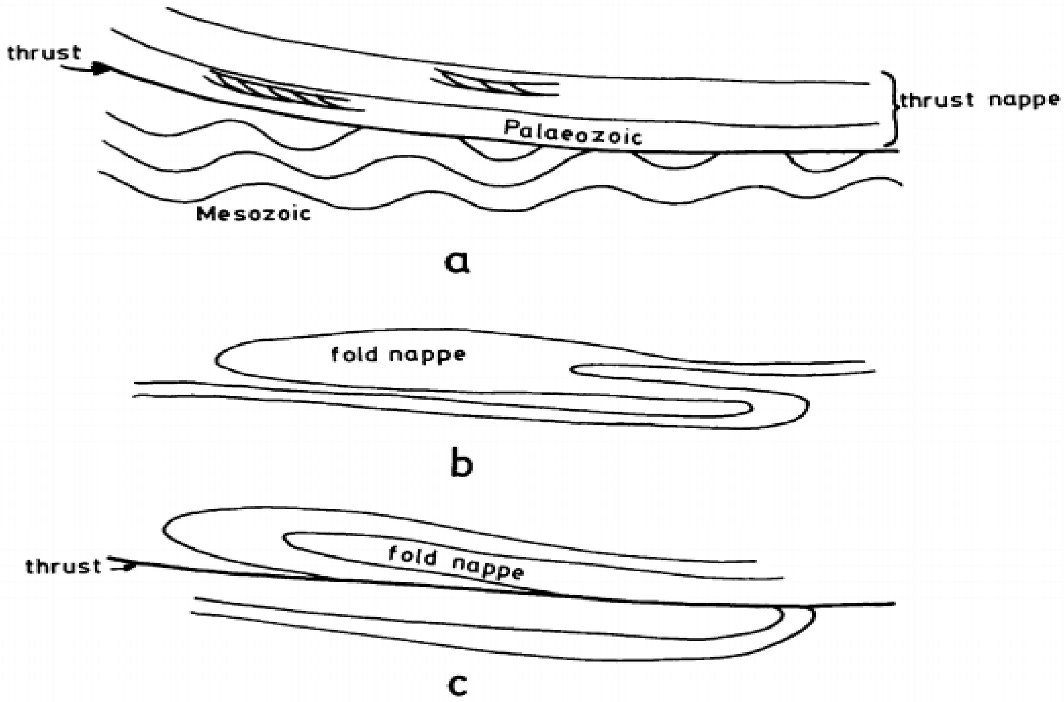


Figure 1: (a) Thrust nappe, (b) Fold nappe, (c) Fold nappe with middle limb sheared out into a thrust fault.

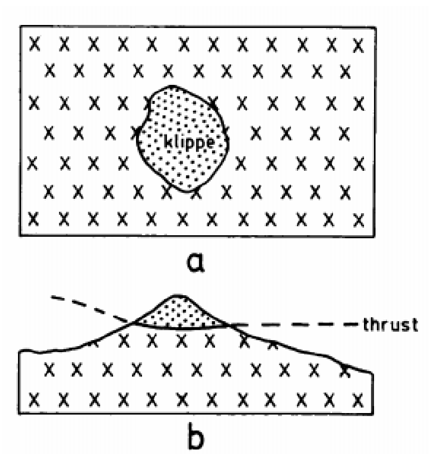


Figure 2: (a) Map and (b) section of a klippe..

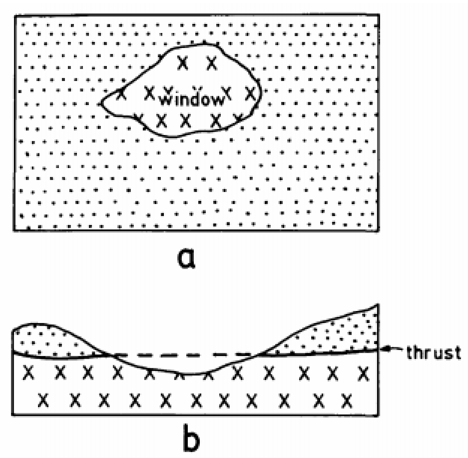


Figure 3: (a) Map and (b) section of a tectonic window.

<u>Origin of Horst and Graben:</u>

Normal faults have dominant dip-slip components, with the hanging wall moving down relative to the foot wall. The sense of movement of the fault blocks is such that there is an overall horizontal extension perpendicular to the fault strike. For this reason normal faults may also be described as **extension faults**.

In areas of extension the normal faults may occur as a set of parallel faults with the same sense of throw in all the fault blocks or they may occur in conjugate sets with opposed dips but with parallel strikes. The block which goes down between two oppositely dipping normal faults forms a fault trough or **graben**. A linear uplifted block between normal faults constitutes a **horst** (Figure 4a). Fault troughs may also form because of the downthrow on a single fault or a single set of faults. Such troughs are known as **halfgrabens** (Figure 4b).

Sediment-filled ancient grabens and half grabens have been identified in many areas. The large modern grabens, such as the Rhine graben, the East African rift valleys along the string of lakes from Lake Albert to Lake Nyasa and the graben system of the Red Sea, are associated with volcanism and have a complex tectonothermal history.

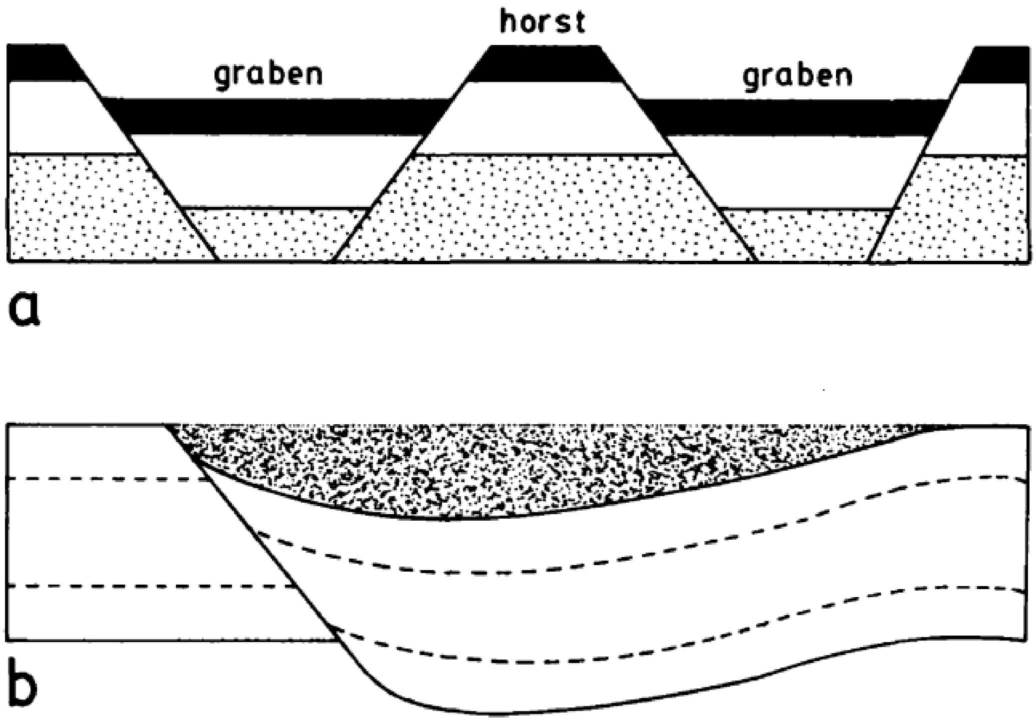


Figure 4: (a) Horst and Graben Structure. (b) A Half Graben.