Engineering Geology CE1301

Lecture #7 Structural Geology

Muayad A. Al-Sharrad
Ph.D. Geotechnical Engineering
Assist Prof.- Department of Civil Engineering
University of Anbar
Room 012
Civil Engineering Building
Ramadi 31001
Iraq
Email: muayad.alsharrad@uoanbar.edu.iq

Image Source:
https://blogs.agu.org/georneys/2011/11/20/geology-word-of-the-week-s-is-for-syncline/

STRUCTURAL GEOLOGY

- Involves the study of rocks that have been deformed by earth stresses and includes a description of their position in space which occurs as a consequence of the deformation.
- Sedimentary rocks that show tilting or folding indicate deformation by compression or extension and uplift of the strata.
- Foliation in metamorphic rocks, flow banding in extrusive igneous rocks and bedding in sedimentary rocks are examples of structures that can be observed with the unaided eye.

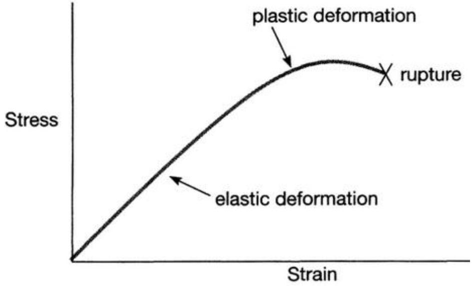
Foliated Gneiss
Image Source: https://study.com/academy/lesson/foliated-rock-definition-examples.html

Flow-banding in rhyolite.
Image Source: https://en.wikipedia.org/wiki/Flow_banding

Rock Deformation

- Rock deformation occurs slowly under high confining pressures and elevated temperature.
- This causes the rocks to be less brittle so that plastic deformation can occur.
- During elastic deformation, such as that cause by small earthquake, the rock returns to its original shape when the load is removed.
- During elastic deformation, such as that cause by small earthquake, the rock returns to its original shape when the load is removed.
- Folding in rocks occurs in the plastic range of the curve. Compressive forces slowly deform the rock but after removal of this load by uplift and erosion, the rock still retains the folded shape.
- Faulting occurs when the rocks rupture (plastic deformation).

Folding in rocks



Folds in rock

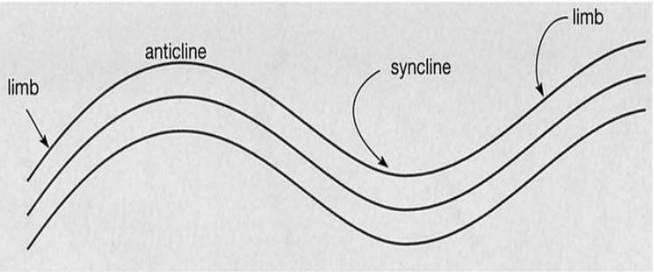


Image Source: https://blogs.agu.org/georneys/2011/11/20/geology-word-of-the-week-s-is-for-syncline/

- Commonly, folds are caused by compressional forces which buckle rock units.
- Anticline: is the crest portion of the fold.
- Syncline: is the trough portion of the fold.
- Limb: is the sloping portion of a fold that connects the crests and troughs.
- The axial plane: is an imaginary plane used to divide the fold into two nearly equal portions. It is used to describe the degree of symmetry of the fold system.
- The axis: represents the intersection of the axial plane with the bedding surface.

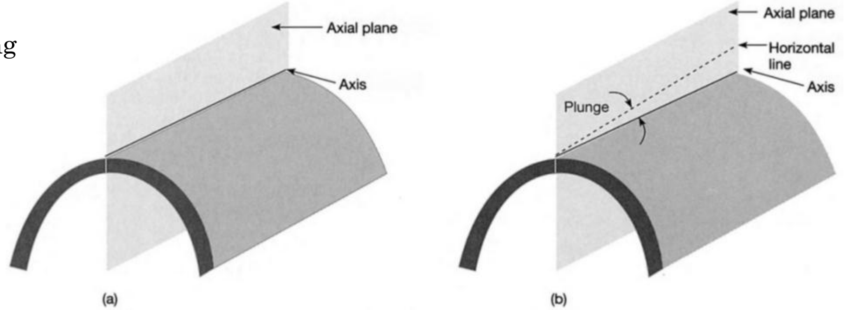


FIGURE 10.3 Anticline, with axial plane and axis. (a) Nonplunging. (b) Fold plunging to the rear.

- If the axial plane is vertical, the fold is **symmetrical**, otherwise it is not symmetrical.
- If the axial plane is tilted with the limbs dipping at not the same angle, the fold is **asymmetrical**.
- If the axial plane is tilted with the limbs dipping at the same angle, the fold is **overturned**.
- If the axial plane essentially horizontal , the fold is **recumbent**.

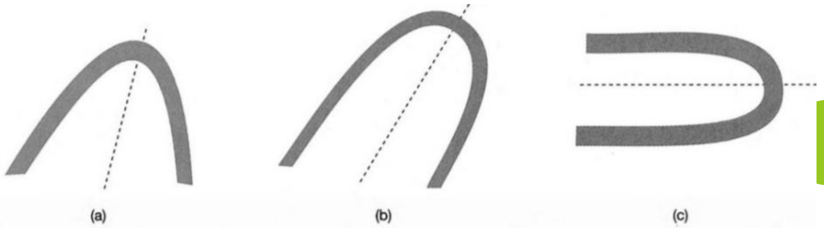


FIGURE 10.4 Attitudes of asymmetrical anticlines: (a) asymmetrical, (b) overturned, and (c) recumbent.

1) Strike and dip

- Dip: is the angle measured at the maximum inclination between inclined bed and a horizontal plane.
- Strike: is the compass direction (measured from true north) of the line of intersection between the horizontal plane and the inclined plane.
- Strike and dip directions are mutually perpendicular. For example, a bed dipping to the east will have a north-south strike.
- The strike and dip symbol looks similar to a T, with the stem indicating the dip direction and the cross bar indicating the strike. The lower numbered bed is always the oldest in these diagrams.
- Trend: is the compass direction of the line formed by the intersection of the planar geologic structure with the ground surface. It is similar to strike when the ground surface is parallel to the horizontal plane.

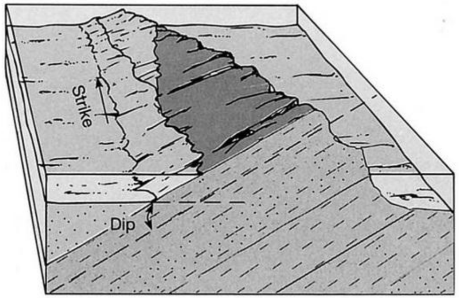


FIGURE 10.5 Dip and strike of inclined bed.

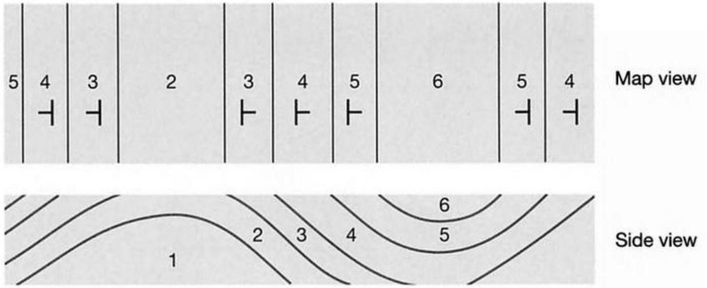


FIGURE 10.6 Anticlines and synclines, with strike and dip symbols.

First rule of anticlines

- The rule states that for the map view of an anticline, the oldest beds are in the center and the beds become progressively younger in each direction.
- Conversely, for synclines the youngest bed is in the center and the beds get progressively older in each direction.
- Viewing the top portion of the fold system alone, the inclination of the axial planes indicated the extend of symmetry of either the anticline or syncline.
- Also the age of the beds indicates whether an anticline or syncline is present.

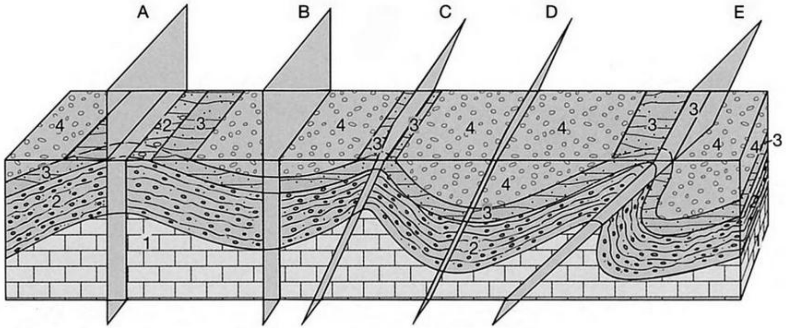


FIGURE 10.7 Diagram of anticlines and synclines.

Bed outcrop width relative to dip

- The width of bed is not the same on the opposite side of the axial plane.
- W=t/sinθ where W is the bed width of the outcrop, t is the thickness of the bed and θ is the angle of dip.
- For vertical beds W=t (minimum width) but for horizontal beds, W becomes infinite. Symmetrical folds have equal bed width on opposite sides of the axial plane because the opposing dip angles are the same.

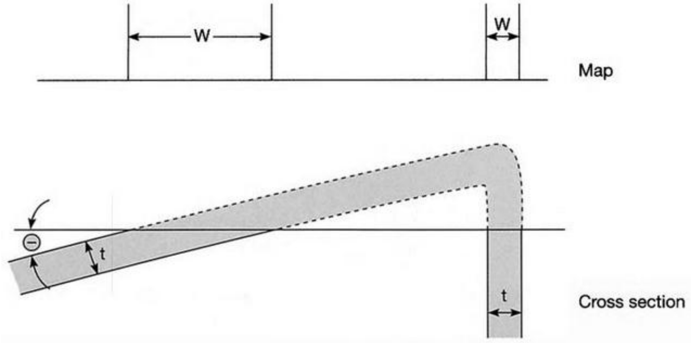


FIGURE 10.8 Outcrop bed width as related to dip.

Plunge folds

- The figure shows the intersection of a plunging syncline and in turn of a plunging anticline with a horizontal plane.
- The shape and direction of the intersection is of importance.
- In Figure (a): the syncline is plunging (lose elevation) to the right. The nose shape, formed by the intersection with the horizontal plane, points to the left; that is, it points in the direction opposite to the plunge.
- In figure (b): conversely, the nose for anticline points in the same direction as the direction of plunge.

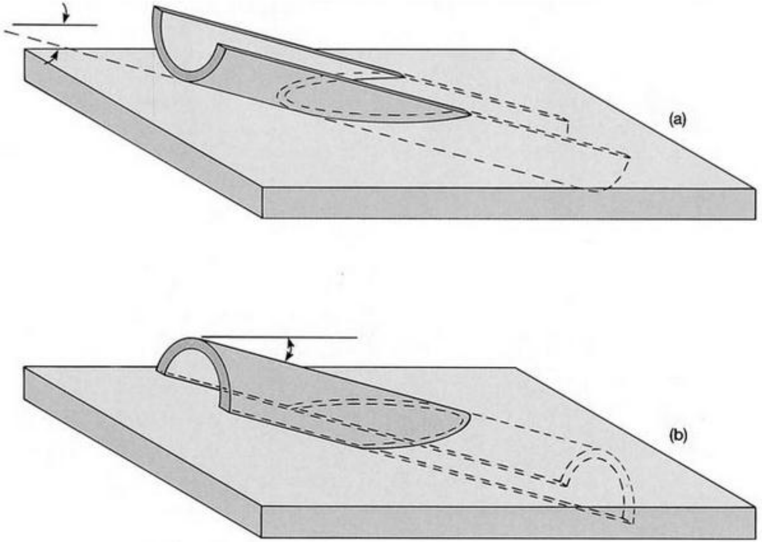
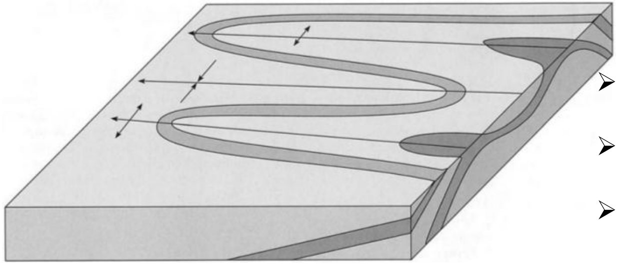


FIGURE 10.9 (a) Plunging synclines and (b) anticlines.

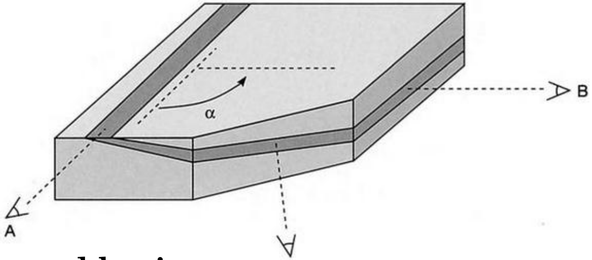
Second rule of anticline

- For a plunging anticline, the nose formed by the intersection of the fold system with a horizontal plane points in the same direction as the plunge.
- Conversely, for a plunging syncline, the nose points in the direction opposite to that of the plunge.
- The 3D view of the fold system is shown in the figure.



Apparent and true dip

- For line of sight A, a true dip (θ_{true}) of the bed is observed.
- For line of sight B, the apparent dip of the bed is zero.
- As the line of sight moves from A towards B, the apparent dip decreases and can be obtained from: $\theta_{apparent} = \theta_{true} \cos \alpha$



Standard structural symbols used on geological maps

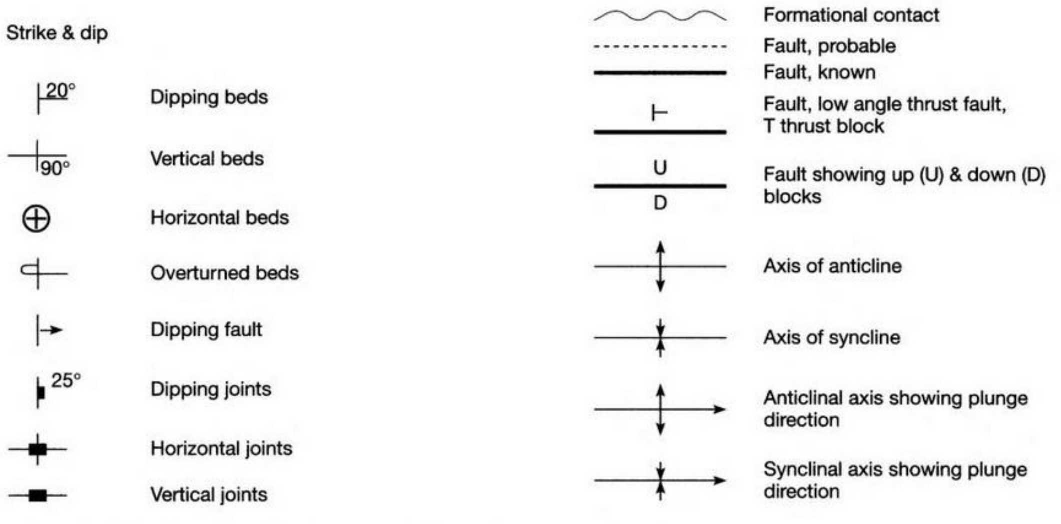
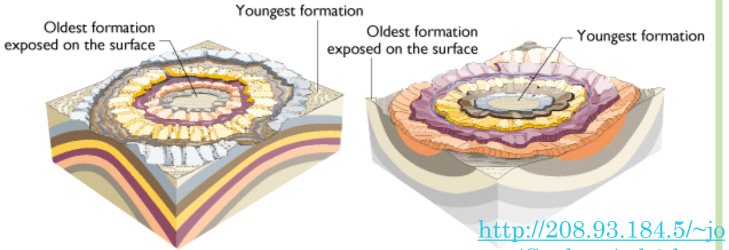


FIGURE 10.11 Standard structural symbols used on geologic maps.

Domes and basins

- 3D fold features also occur in nature.
- A structural dome (represents 3D anticline) is a fold in which the beds slope away from the center in all directions.
- A structural basin (represents 3D syncline) has bed that slopes inward in all directions.



(a) Dome (b) Basin

http://208.93.184.5/~jones/Geology/mb2.htm

2) Crustal Rock Fractures

Fractures in rock are narrow openings along which the rock mass has lost grain-to-grain contact.

Types of fractures

There are three types of fractures based on the relative movement of the rock blocks on opposite sides of the fracture:

A) Joints

- Joints are rock fractures along which no movement has occurred parallel to the joint surface.
- Some displacement perpendicular to the joint may develop because of frost wedging or gravity effects.
- There is a tendency for joints to occur in sets of parallel fractures rather than as a single isolated plane.
- Release of confining pressure forms joints in some rocks, for example, along steep exposures of rock.
- Even horizontal sedimentary rock exhibit joint sets, usually parallel to the slight regional dip or perpendicular to it.

B) Shear zones

- Shear zones are fractures in rock along which some movement has occurred but not a great amount.
- Most movements are due to slippage of the rock to compensate for distortions caused by folding.
- Rocks with shear zones are typically weak and have low strength. Ground water flows through these zones. Therefore they are not desirable areas for tunnelling, slope excavation and foundations for engineering works.

C)Faults

- Faults are fractures along which significant movement has occurred (minimum of 1 m but it can be up to kilometers).

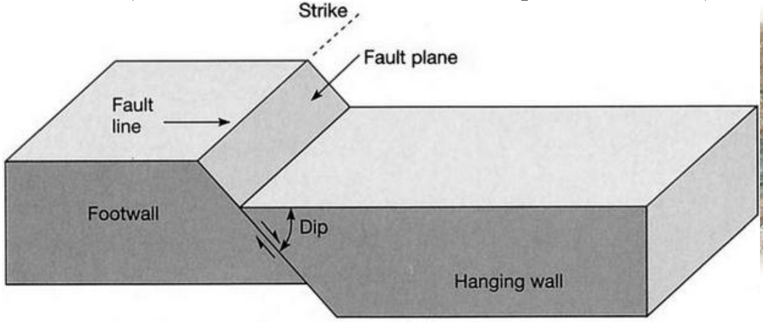
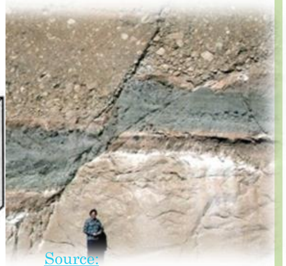


FIGURE 10.13 Fault terminology.



Source: geomaps.wr.usgs.gov640 × 420Search by image
Photograph of faulted sedimentary rock layers exposed in a road cut in Guatemala

- The block above the fault plane is called the hanging wall while the block below is called the foot wall.
- The fault line is the intersection of the fault plane with the surface of the earth.

Types of movement along the fault plane:

[Please click here to watch this video]

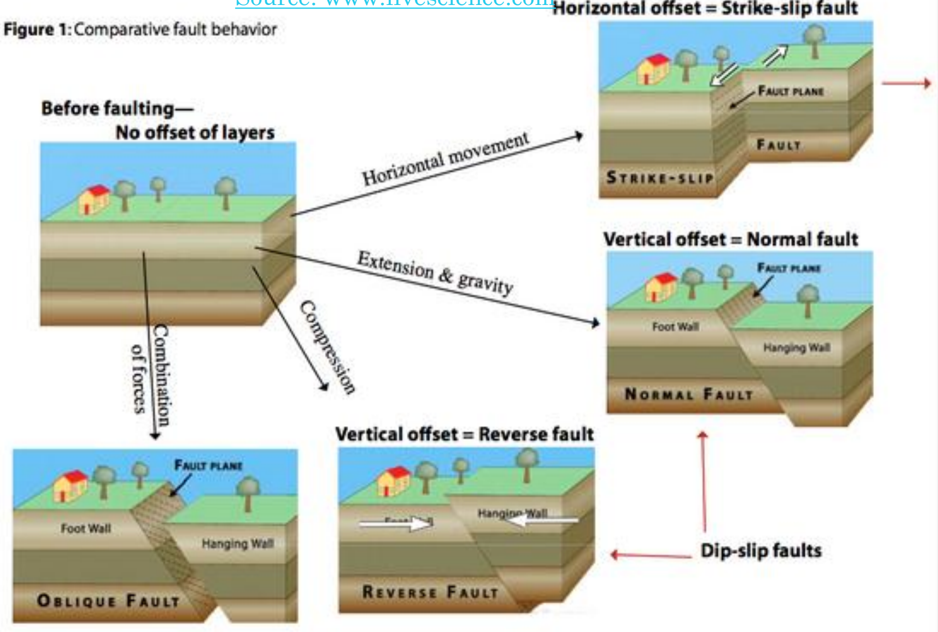
1- Dip-slip faults:

a) Normal fault: the hanging wall moves down relative the foot wall and caused by vertical compressive force or by a horizontal tensile force.

b) Reverse fault: the hanging wall moves up relative to the relative wall and caused by horizontal compressive force or by a vertical tensile force.

Source: www.livescience.com

Figure 1: Comparative fault behavior



2- Strike-slip faults:

- Occurs when the relative movement is horizontal so that the blocks are displaced along the strike direction.
- Two types: right lateral and left lateral strike-slip fault.

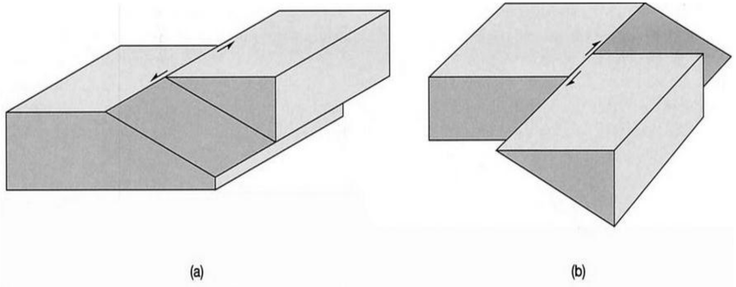


FIGURE 10.15 Strike-slip faults: (a) left lateral and (b) right lateral.

3- Translation fault:

- Occurs when the fault movement has both a strike-slipe and dip-slip component. The net movement is the net slip.

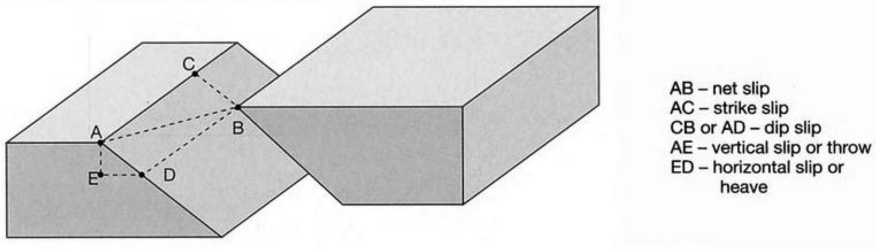


FIGURE 10.16 Translation fault.

Other considerations

- For strike-slip faults it is rather easy to determine the relative movement involved if a marker bed is present in the fault block.
- In dip-slip faults the uppermost block is typically eroded much faster than the lower block, yielding a horizontal surface across them.
- Block faulting sometimes occurs and involves the movement of 3D blocks of rock upward and downward along steeply dipping fault plane.

Field recognition of faulting

- The existence of fault should be considered early in the site selection investigation.
- Some details helping in the detection of faults:
- * **landform features associated with the fault line**, such as the offset of geological structures and marked change in elevation
- * **abnormal stratigraphic sequences** caused by faulting which usually involves the repetition or the omission of the normal beds within that sequence. For instance, the figure shows a series of rocks with a normal sequence of folded sedimentary rocks, which has been disrupted at two locations by faulting (note the F designations). A repetition of beds is shown on the left side of the diagram and an omission of beds on the right side.
- * **features of the fault plane**, seen in plan view or in cross section, can be used to establish the existence of the fault.

FIGURE 10.17 Strike-slip movement and marker beds: (a) left lateral and (b) right lateral.

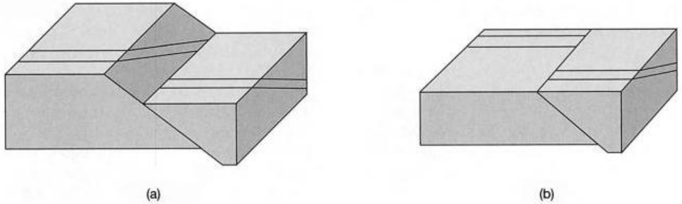


FIGURE 10.18 Dip-slip fault related to erosion: (a) before erosion and (b) after erosion.

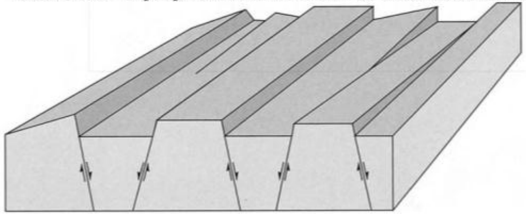


FIGURE 10.19 Block faulting.

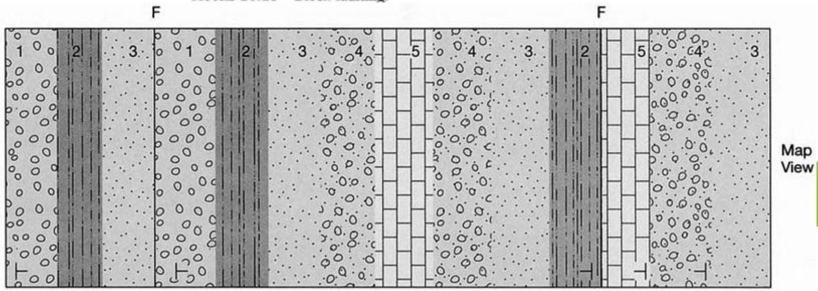


FIGURE 10.21 Faulting indicated by repetition and omission of beds.

3) Folds and faults combined

- **The first figure** is an example of a non-plunging syncline and it completes the details for combinations of folds and dip-slip faults.
- Note that the beds of the syncline converge with depth. Therefore, because the beds are closer together in the front block, that block had to have originated at a lower depth
- Consequently, the front block has moved upward relative to the rear block, yielding a reverse fault.

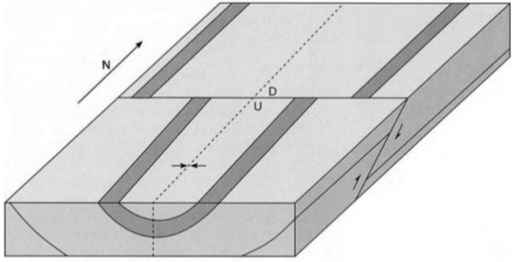


FIGURE 10.25 Symmetrical syncline cut by an east–west striking reverse fault dippi southward.

- **In The subsequent figures**, for the anticline, observe that as you proceed lower in the cross section, the outcrop of the dipping bed will move further apart (diverges).
- Therefore, the bed had to have originated at a higher elevation, and consequently the back block has moved downward.

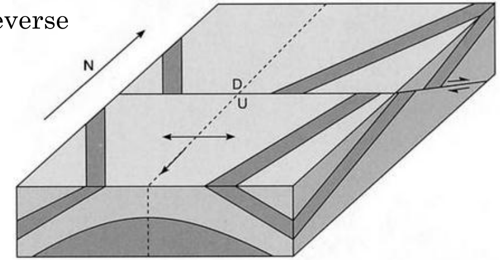


FIGURE 10.23 South plunging symmetrical anticline cut by an east–west striking normal fault dipping northward.

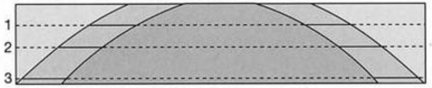


FIGURE 10.24 Front view of anticline from Figure 10.23.

Direction of stress and fault orientation

- When rocks are anisotropic, the orientation of the weakness planes (known as ***s* planes**) can influence the direction of breakage or faulting.
- Shear planes examples are noticeable bedding in sedimentary rocks, foliation in metamorphic rock or flow banding in extrusive igneous rocks.

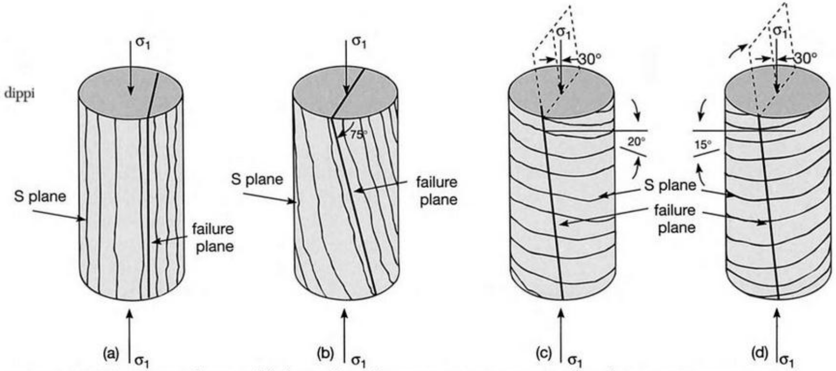


FIGURE 10.27 Dependence of failure plane location on orientation of *s* planes in test specimens.

- The figure above shows that if σ_1 is oriented within 60º of the *s plane*, failure will occur along or be controlled to some extent by the weakness plane. Otherwise, *s plane* will have little influence on the direction of failure.
- Major forces from engineering constructions should not be transferred to layered rocks in a direction parallel to the bedding planes to avoid risk of failure by slippage along these planes.