Structural Geology

Lecture(3)

Deformation Rocks

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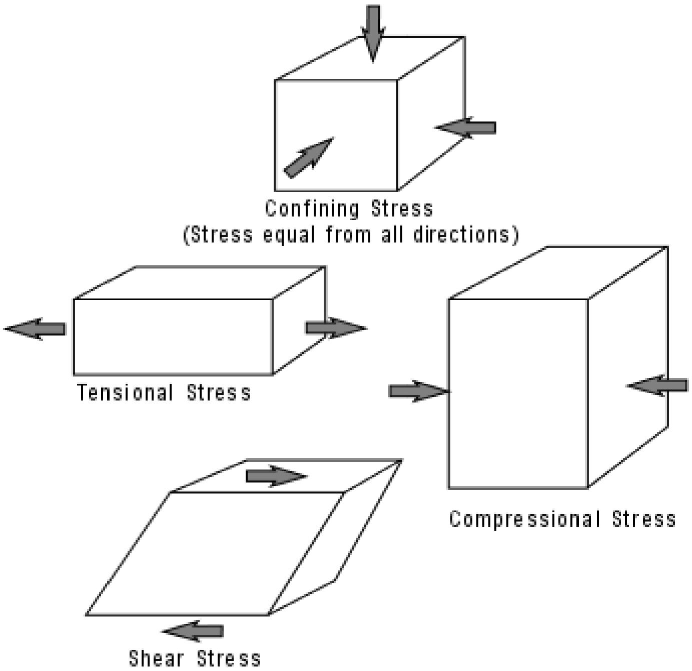
3-1:Stress and Strain

We start our discussion with a brief review of the concepts of stress and strain. Recall that stress is a force acting on a material that produces a strain. Stress is a force applied over an area and therefore has units of Force/area (like lb/in ^{2}). Pressure is a stress where the forces act equally from all directions.

If stress is not equal from all directions then we say that the stress is a differential stress. Three kinds of differential stress occur.

1. ***Tensional stress (or extensional stress)***, which stretches rock;
2. ***Compressional stress***, which squeezes rock; and
3. ***Shear stress***, which result in slippage and translation.



Fig(3-1):Kind of Stress

When rocks deform they are said to ***strain***. A strain is a change in size, shape, or volume of a material. We here modify that definition somewhat to say that a strain also includes any kind of movement of the material, including translation and tilting.

3-2: **Stages of Deformation**:

When a rock is subjected to increasing stress it passes through 3 successive stages of deformation.

- ***Elastic Deformation*** -- wherein the strain is reversible.
- ***Ductile Deformation*** -- wherein the strain is irreversible.
- ***Fracture*** - irreversible strain wherein the material breaks.

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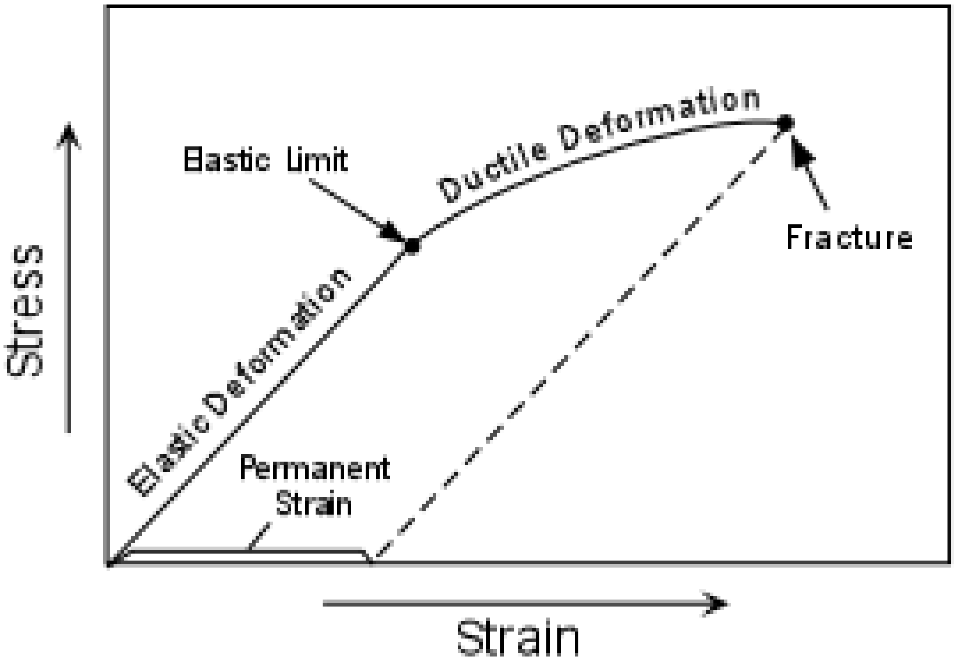
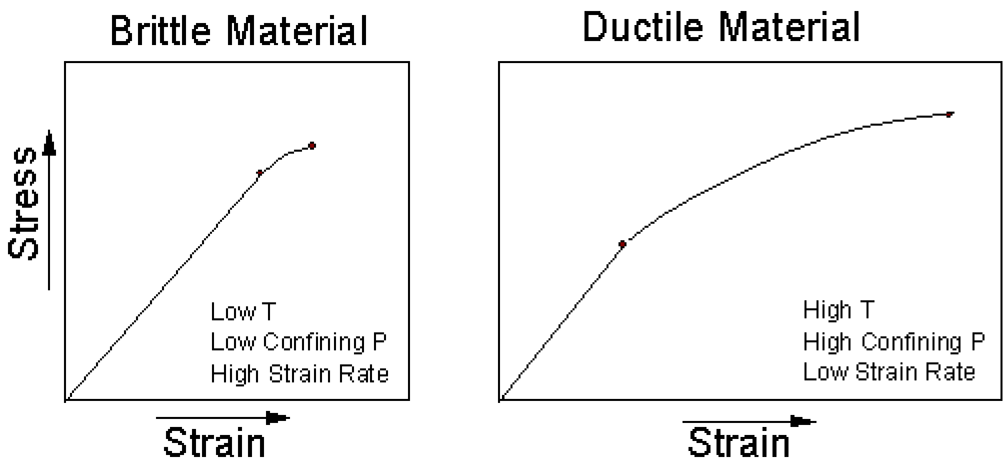


Fig(3-2):Stage of Deformation

We can divide materials into two classes that depend on their relative behavior under stress.

- Brittle materials have a small or large region of elastic behavior but only a small region of ductile behavior before they fracture.
- Ductile materials have a small region of elastic behavior and a large region of ductile behavior before they fracture.



Fig(3-3):Brittle and Ductile Material

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3-3: **How a material behaves will depend on several factors. Among them are:**

- Temperature - At high temperature molecules and their bonds can stretch and move, thus materials will behave in more ductile manner. At low Temperature, materials are brittle.

- Confining Pressure - At high confining pressure materials are less likely to fracture because the pressure of the surroundings tends to hinder the formation of fractures. At low confining stress, material will be brittle and tend to fracture sooner.

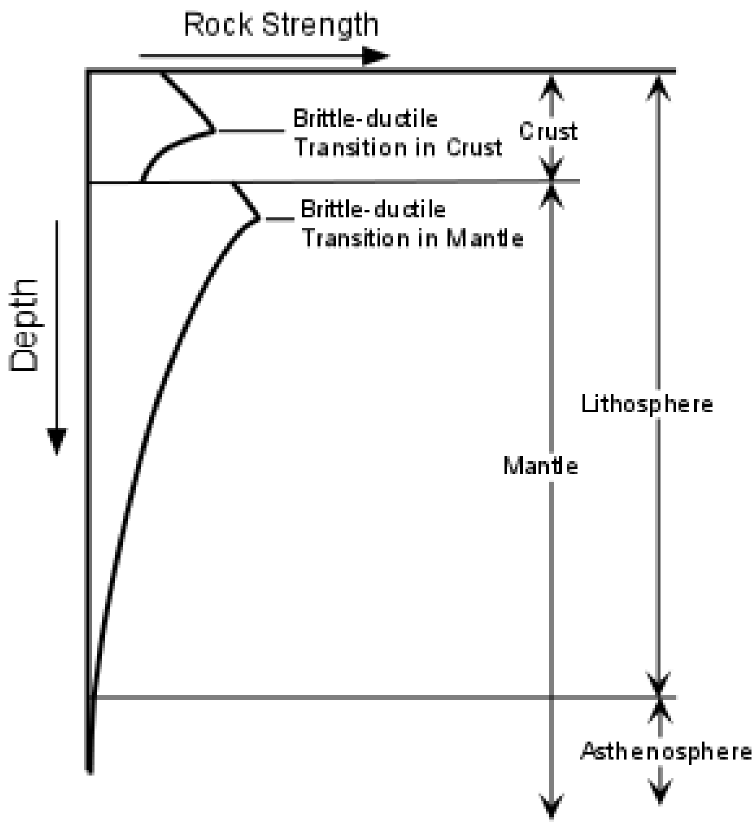
- Strain rate -- At high strain rates material tends to fracture. At low strain rates more time is available for individual atoms to move and therefore ductile behavior is favored.

- Composition -- Some minerals, like quartz, olivine, and feldspars are very brittle. Others, like clay minerals, micas, and calcite are more ductile This is due to the chemical bond types that hold them together. Thus, the mineralogical composition of the rock will be a factor in determining the deformational behavior of the rock. Another aspect is presence or absence of water. Water appears to weaken the chemical bonds and forms films around mineral grains along which slippage can take place. Thus wet rock tends to behave in ductile manner, while dry rocks tend to behave in brittle manner.

3-4:Brittle-Ductile Properties of the Lithosphere

We all know that rocks near the surface of the Earth behave in a brittle manner. Crustal rocks are composed of minerals like quartz and feldspar which have high strength, particularly at low pressure and temperature. As we go deeper in the Earth the strength of these rocks initially increases.

At a depth of about 15 km we reach a point called the brittle-ductile transition zone. Below this point rock strength decreases because fractures become closed and the temperature is higher, making the rocks behave in a ductile manner. At the base of the crust the rock type changes to peridotite which is rich in olivine. Olivine is stronger than the minerals that make up most crustal rocks, so the upper part of the mantle is again strong. But, just as in the crust, increasing temperature eventually predominates and at a depth of about 40 km the brittle-ductile transition zone in the mantle occurs. Below this point rocks behave in an increasingly ductile manner.



Fig(3-4):Brittle-Ductile properties of the earth.

Deformation in Progress

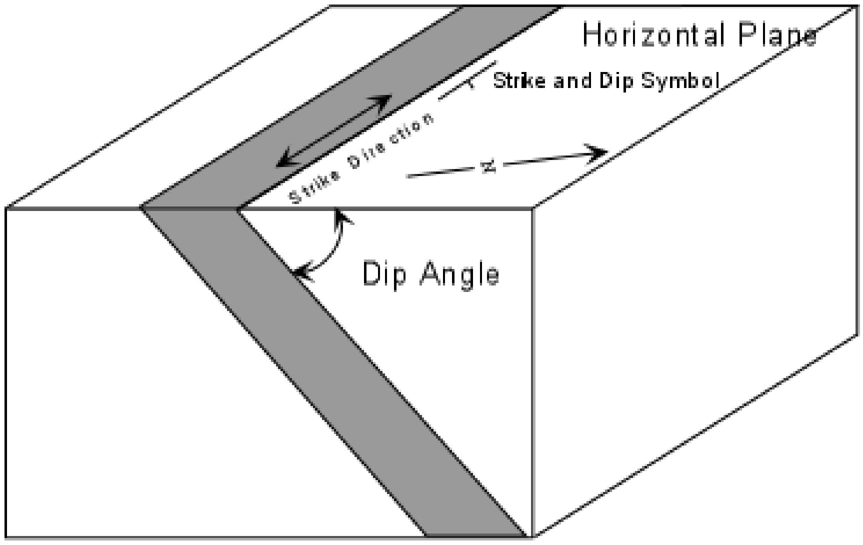
Only in a few cases does deformation of rocks occur at a rate that is observable on human time scales. Abrupt deformation along faults, usually associated with earthquakes occurs on a time scale of minutes or seconds. Gradual deformation along faults or in areas of uplift or subsidence can be measured over periods of months to years with sensitive measuring instruments.

Evidence of Past Deformation

Evidence of deformation that has occurred in the past is very evident in crustal rocks. For example, sedimentary strata and lava flows generally follow the law of original horizontality. Thus, when we see such strata inclined instead of horizontal, evidence of an episode of deformation.

Since many geologic features are planar in nature, we a way to uniquely define the orientation of a planar feature we first need to define two terms - strike and dip.

For an inclined plane the ***strike*** is the compass direction of any horizontal line on the plane. The ***dip*** is the angle between a horizontal plane and the inclined plane, measured perpendicular to the direction of strike.



Fig(3-5): strike and dip of folds ore Faults.

In recording strike and dip measurements on a geologic map, a symbol is used that has a long line oriented parallel to the compass direction of the strike. A short tick mark is placed in the center of the line on the side to which the inclined plane dips, and the angle of dip is recorded next to the strike and dip symbol as shown above. For beds with a 90^0 dip (vertical) the short line crosses the strike line, and for beds with no dip (horizontal) a circle with a cross inside is used as shown below.

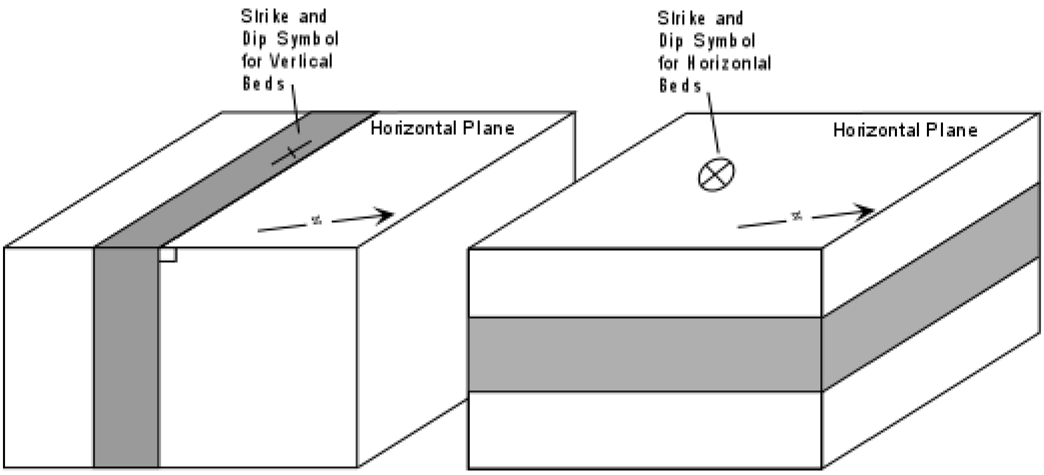


Fig.(3-6): Vertical and Horizontal Strata.

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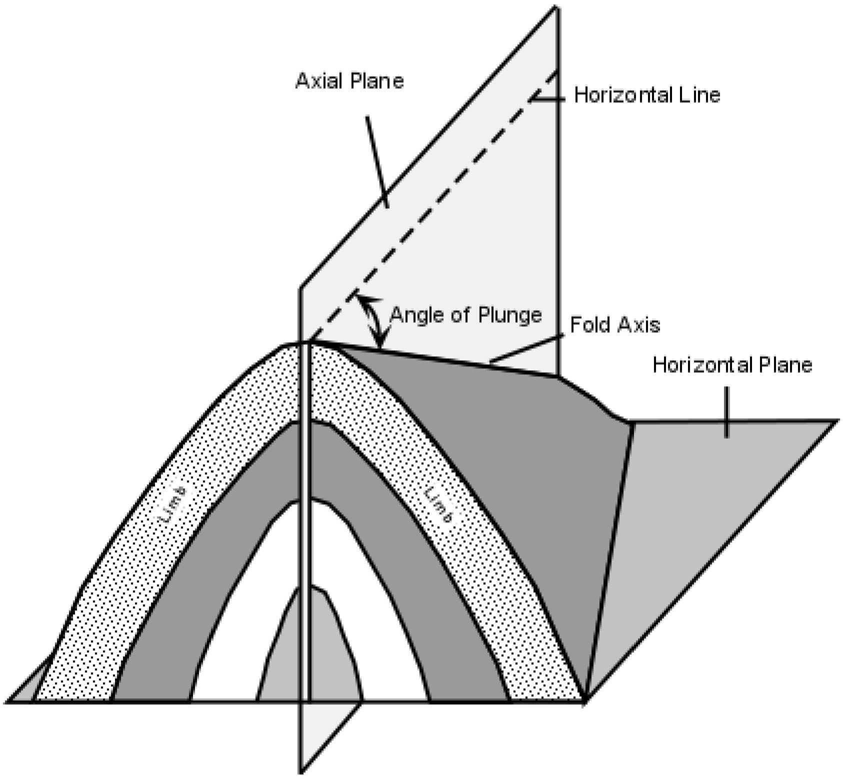
For linear structures, a similar method is used, the strike or bearing is the compass direction and angle the line makes with a horizontal surface is called the plunge angle.



Fig(3-7): The plunging Fold.

Fracture of Brittle Rocks

As we have discussed previously, brittle rocks tend to fracture when placed under a high enough stress. Such fracturing, while it does produce irregular cracks in the rock, sometimes produces planar features that provide evidence of the stresses acting at the time of formation of the cracks. Two major types of more or less planar fractures can occur: joints and faults.

Joints

As we learned in our discussion of physical weathering, joints are fractures in rock that show no slippage or offset along the fracture. Joints are usually planar features, so their orientation can be described as a strike and dip. They form from as a result of extensional stress acting on brittle rock. Such stresses can be induced by cooling of rock (volume decreases as temperature decreases) or by relief of pressure as rock is eroded above thus removing weight.

Joints provide pathways for water and thus pathways for chemical weathering attack on rocks. If new minerals are precipitated from water flowing in the joints, this will form a vein. Many veins observed in rock are mostly either quartz or calcite, but can contain rare minerals like gold and silver. These aspects will be discussed in more detail when we talk about valuable minerals from the earth in a couple of weeks.

Because joints provide access of water to rock, rates of weathering and/or erosion are usually higher along joints and this can lead to differential erosion.

From an engineering point of view, joints are important structures to understand. Since they are zones of weakness, their presence is critical when building anything from dams to highways. For dams, the water could leak out through the joints leading to dam failure. For highways the joints may separate and cause rock falls and landslides.

Faults

Faults occur when brittle rocks fracture and there is an offset along the fracture. When the offset is small, the displacement can be easily measured, but sometimes the displacement is so large that it is difficult to measure.

3-5:Types of Faults

As we found out in our discussion of earthquakes, faults can be divided into several different types depending on the direction of relative displacement. Since faults are planar features, the concept of strike and dip also applies, and thus the strike and dip of a fault plane can be measured. One division of faults is between dip-slip faults, where the displacement is measured along the dip direction of the fault, and strike-slip faults where the displacement is horizontal, parallel to the strike of the fault. Recall the following types of faults:

- Dip Slip Faults - Dip slip faults are faults that have an inclined fault plane and along which the relative displacement or offset has occurred along the dip direction. Note that in looking at the displacement on any fault we don't know which side actually moved or if both sides moved, all we can determine is the relative sense of motion.

  ■:Normal Faults - are faults that result from horizontal tensional stresses in brittle rocks and where the hanging-wall block has moved down relative to the footwall block.

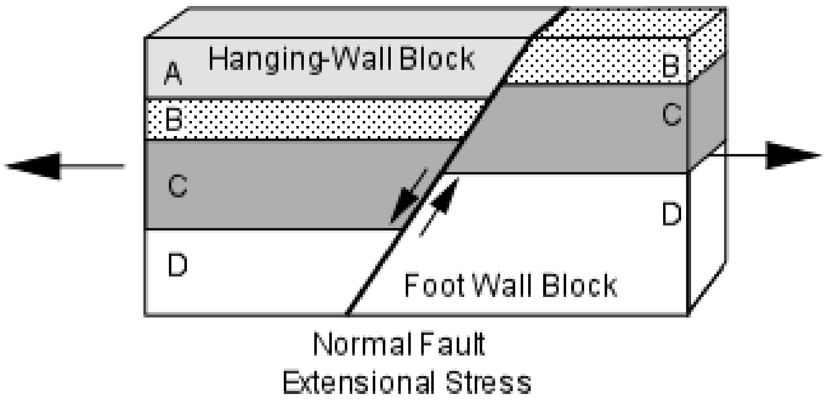


Fig.(3-8):Normal Fault

♦***: Horsts & Grabens -*** Due to the tensional stress responsible for normal faults, they often occur in a series, with adjacent faults dipping in opposite directions. In such a case the down-dropped blocks form ***grabens*** and the uplifted blocks form ***horsts***. In areas where tensional stress has recently affected the crust, the grabens may form ***rift valleys*** and the uplifted horst blocks may form linear mountain ranges. The East African Rift Valley is an example of an area where continental extension has created such a rift. The basin and range province of the western U.S. (Nevada, Utah, and Idaho) is also an area that has recently undergone crustal extension. In the basin and range, the basins are elongated grabens that now form valleys, and the ranges are uplifted horst blocks.

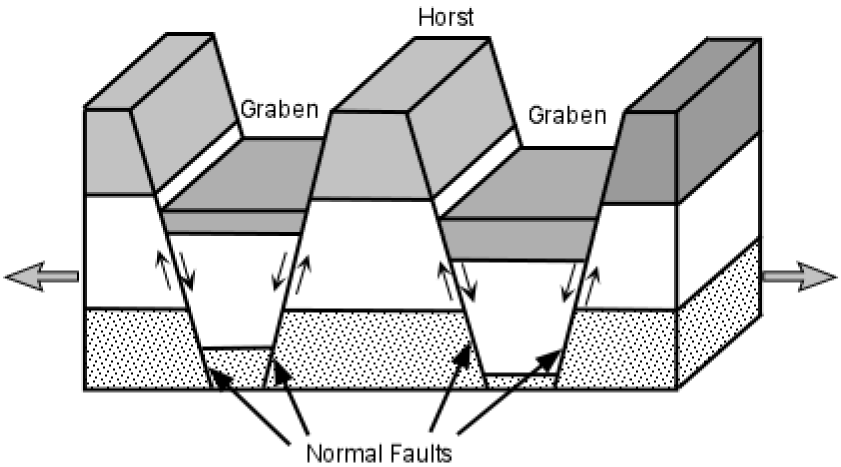


Fig.(3-9): Horse and Graben

♦ 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.

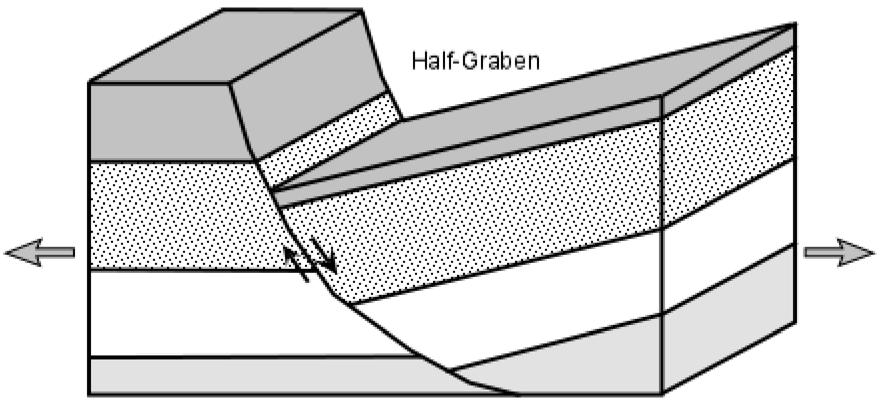


Fig:(3-9): Half graben

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- ■:***Reverse Faults*** - are faults that result from horizontal compressional stresses in brittle rocks, where the hanging-wall block has moved up relative the footwall block.

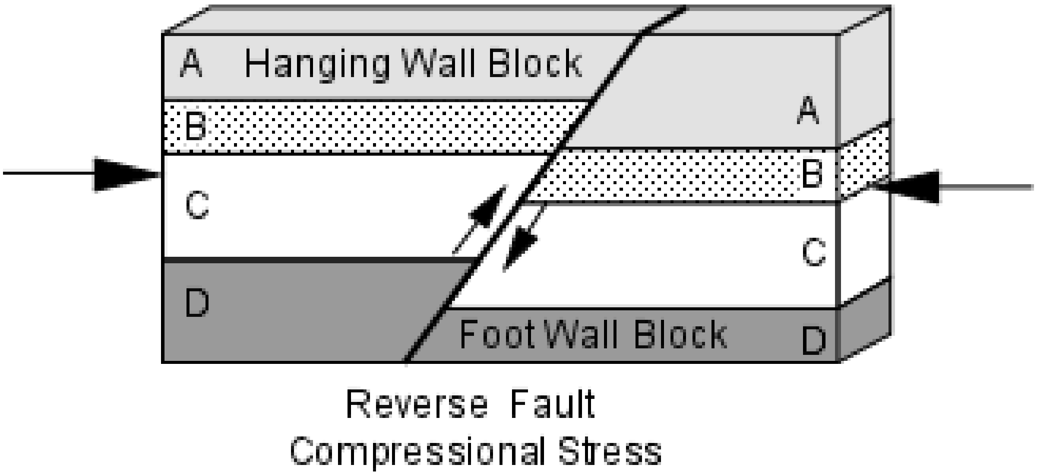
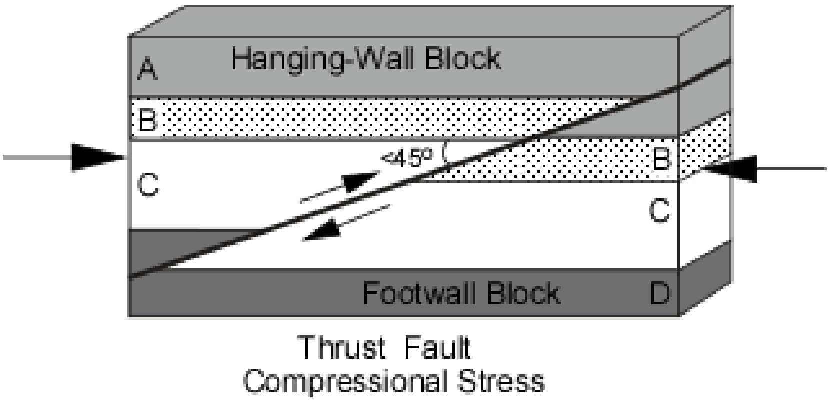


Fig:(3-10): Reverse Fault.

A ***Thrust Fault*** is a special case of a reverse fault where the dip of the fault is less than 45^{o}. Thrust faults can have considerable displacement, measuring hundreds of kilometers, and can result in older strata overlying younger strata.



Fig(3-11): Thrust Fault

●***trike Slip Faults*** - are faults where the relative motion on the fault has taken place along a horizontal direction. Such faults result from shear stresses acting in the crust. Strike slip faults can be of two varieties, depending on the sense of displacement. To an observer standing on one side of the fault and looking across the fault, if the block on the other side has moved to the left, we say that the fault is a ***left-lateral strike-slip fault***. If the block on the other side has moved to the right, we say that the fault is a ***right-lateral strike-slip fault***. The famous San Andreas Fault in California is an example of a right-lateral strike-slip fault. Displacements on the San Andreas fault are estimated at over 600 km.

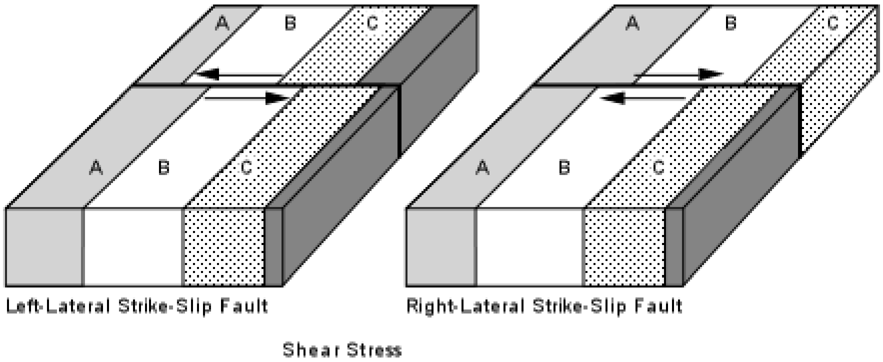


Fig.(3-12):Lateral Fault