GEOLOGIC STRUCTURES

Geologic structures are usually the result of the powerful **tectonic forces** that occur within the earth. These forces **fold** and **break rocks**, form deep faults, and build mountains. Most of these forces are related to plate tectonic activity. Some of the **natural resources** we depend on, such as **metallic ores** and **petroleum**, often form along or near geologic structures.

Structural geology is the study of the processes that result in the formation of geologic structures and how these structures affect rocks. Structural geology deals with a variety of structural features that can range in size from microscopic (such as traces of earlier folds after multiple events of deformation have occurred) to large enough to span the globe (such as mid-oceanic ridges).

Tectonic Forces

Rocks are under stress when they are subjected to a force at depth. When the rocks are exposed at the surface after uplift and erosion, the effects of the stress can be studied. **Stressed rocks** show varying degrees of strain the change in the volume and/or shape of the rock because of that stress. For example, volcanic agglomerate may be compacted and its pyroclastic fragments stretched (strained) in response to a tectonic stress, such as compression.

Stresses: Three kinds of stress can be applied to rocks: **tensional**, **compressive**, and **shear**. **Tensional stress** occurs when a rock is subjected to forces that tend to elongate it or pull it apart; a rock that has experienced tensional stress tends to be narrower and longer than its original shape, like a piece of gum or taffy that has been pulled. A **compressive stress** on a rock is applied from opposite sides and has a tendency to shorten (compress) the rock between the opposing stresses, which may also stretch it parallel to the stress-free direction. A **shear stress** results when forces from opposite directions create ashear plane in an area in which the forces run parallel to one another. The scale of shear stress can vary from a few centimeters to hundreds of meters (Fig.4-1).

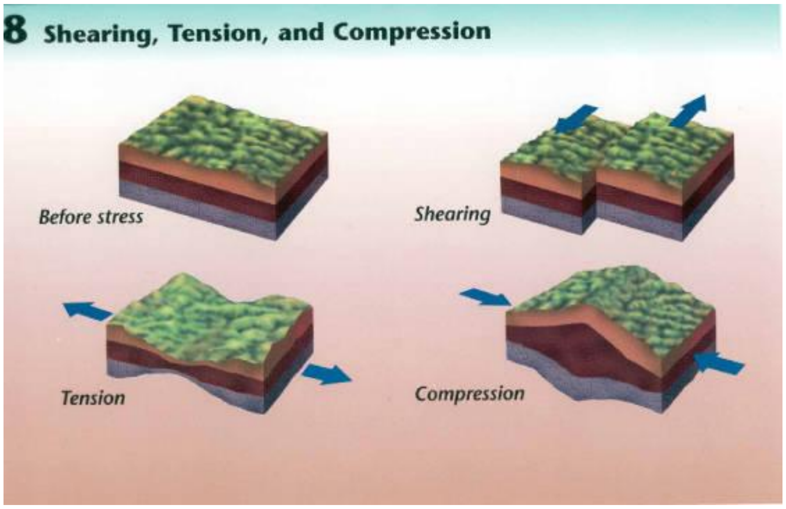


Fig. 4-1

Strains: When subjected to stress, a rock can undergo one of three kinds of deformation (strain): elastic, brittle, or plastic. Deformationis called **elastic strain** if the body of rock returns to its previous shape after the stress has been removed. A good example is the slow rebound of the North American crust after having been down warped by the great weight of the Pleistocene glaciers. **Brittle strain** occurs when the stress is great enough to break (fracture) the rock. **Plastic strain** results in a permanent change in the shape of the rock. A ductile rock is one that "flows plastically" in response to stress. Whether the strain is plastic or brittle depends on both the magnitude of the stress and how quickly the stress is applied. A great stress that is slowly applied often folds rocks into tight, convoluted patterns without breaking them.

Strike and Dip

One of the most useful measurements is the **strike and dip** of a tilted rock unit (Figure 4-2). The strike of the unit is the direction (compass bearing) of the line formed by the intersection of the tilted bedding plane with the horizontal plane. The dip angle is the angle between the horizontal plane and the tilted bedding plane. Compasses equipped with a device called an inclinometer can determine the dip angle. The direction of dip is always perpendicular to the strike direction. For example, in Figure (4-2) the rock strikes north-south and dips 30 degrees to the west. A rock that is perfectly flat-lying has no strike direction and no dip. A rock unit that has been tilted into a vertical position has a maximum dip of 90 degrees.

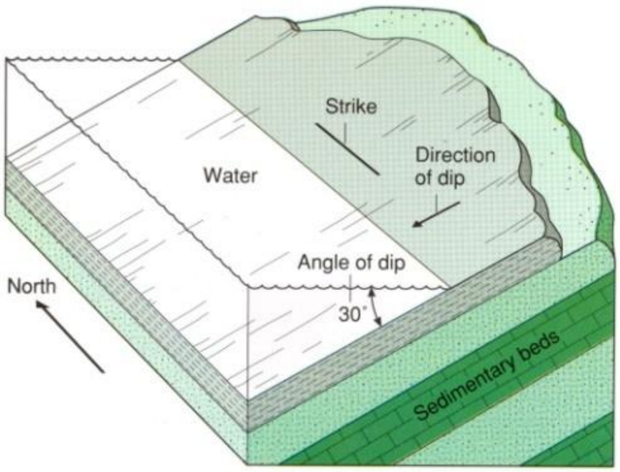


Fig. 4-2

A **plan** (two-dimensional) geologic map shows the locations and shapes of the outcrops at an appropriate scale and indicates, through a variety of geologic symbols, features such as folds, faults, contacts between different rock units, and strike and dip. A **geologic cross section**, a vertical slice across the map area, can be constructed from the structural information on a geologic map. It depicts the spatial relationships of the rock units and structures beneath the surface (Figure 4-3). A cross section supplies a third dimension to the plan geologic map. A good geologic map is critical to understanding and interpreting structures, when they formed, and how they fit into the overall geologic picture.

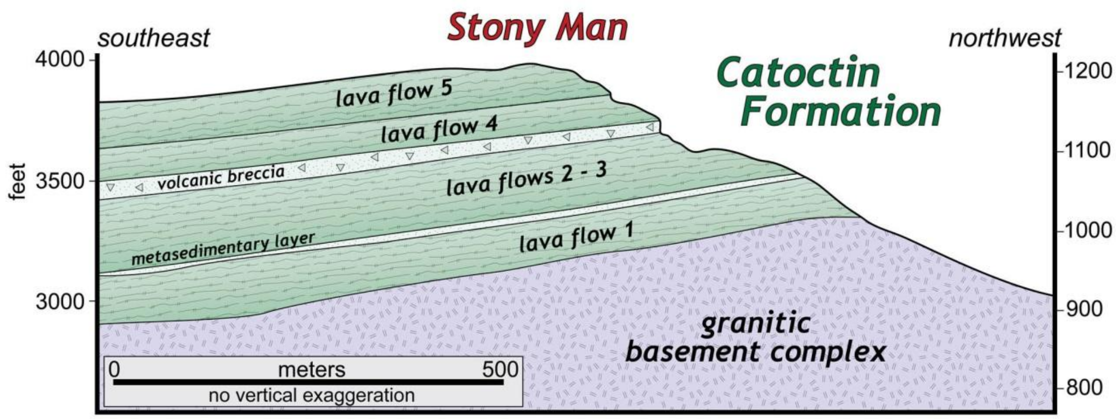


Fig. 4-3

Folding

A layered rock that exhibits bends is said to be **folded**. The layered rock was at one time uniformly straight but was stressed to develop a series of arches and troughs. A compressive stress compacts horizontal rock layers and forces them to bend vertically, forming fold patterns.

Anticlines and synclines: An **anticline** is a fold that is arched upward to form a **ridge**; a **syncline** is a fold that arches downward to form a **trough** (Figure 4-4). Anticlines and synclines are usually made up of many rock units that are folded in the same pattern.

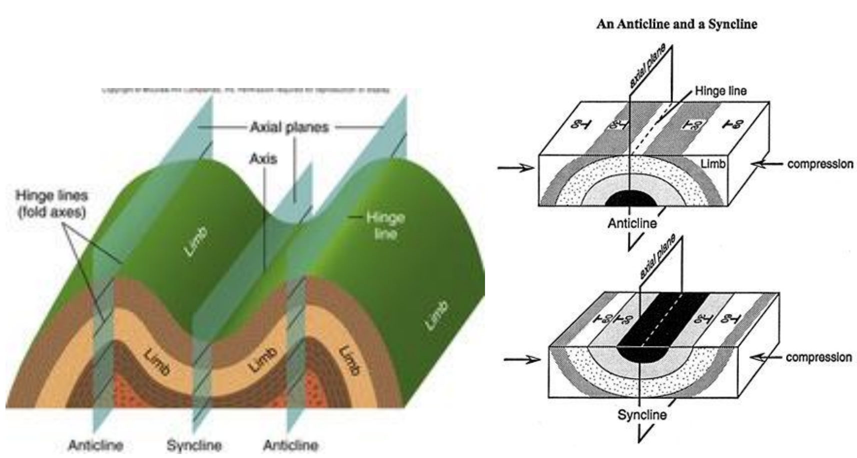
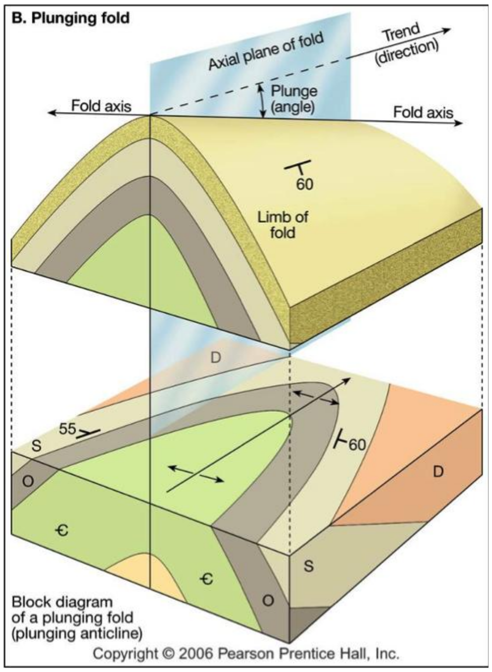


Fig. 4-4

Plunging folds: Plunging folds have been tipped by tectonic forces and have a hinge line not horizontal in the axial plane. The angle between the horizontal and the hinge line is called the **plunge** and, like dip, varies from less than 1 degree to 90 degrees. Plunging folds characteristically show a series of V patterns on a bed rock surface (Figure 4-5).



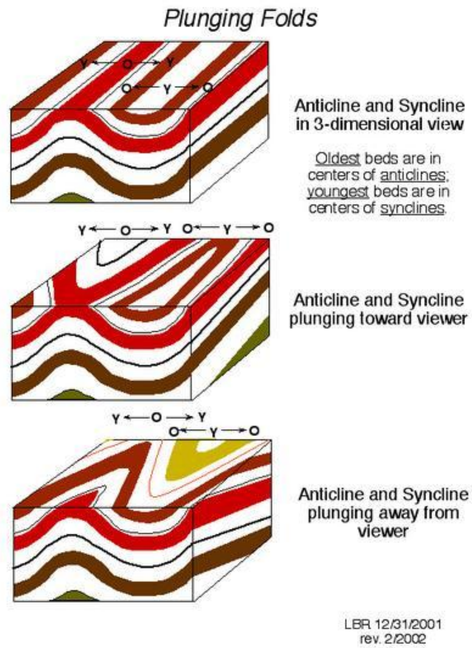


Fig. 4-5 shows symmetrical folds, and plunging folds.

Structural domes and basins: A **structural dome**, a variety of anticline, is a feature in which the central area has been warped and uplifted and all the surrounding rock units dip away from the center (Fig. 4-6 A).

Similarly, a **structural basin** is a variation of syncline in which all the beds dip inward toward the center of the basin. Basins and domes can be as large as 100 kilometers across (Fig. 4-6 B).

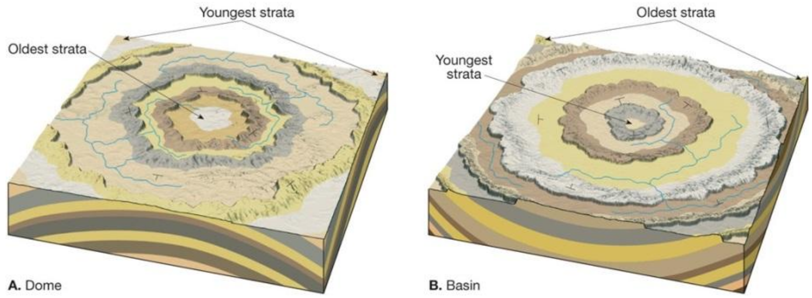


Fig. 4-6

Classification of fold according to limbs and axial plane inclination.

Symmetrical, asymmetrical, overturned, and recumbent, isoclinal folds: A variety of kinds of folds generally reflects increasing amounts of tectonic stress (Figure 4-7). An **open** or **symmetrical fold** is a broad feature in which the limbs dip at a gentle angle away from the crest of the fold. A special case is the upright symmetrical fold, wherein the axial plane is vertical and the dip angles of beds in both limbs are equal. Conversely, the limbs of **asymmetrical folds** have dip angles that are un equal. Thus, an asymmetrical fold has a steeply dipping limb and a shallowly dipping limb, and the axial plane is inclined. As the dip angle of the axial plane decreases, the steeply dipping limb reaches a vertical orientation. Continued deformation past this point produces an **overturned fold**. Structures of this type are recognized by the "turned-over" nature of the steeply dipping limb. In this case, both limbs and the axial plane dip in the same direction. If deformation is sufficiently intense, the axial plane of the fold will be pushed over to a horizontal position. In this extreme situation, both limbs of the fold and the axial plane are parallel. These very tightly folded structures are common in intensely deformed mountain ranges such as the Alps and are known as **recumbent fold**. When the two limbs and the axial surface are parallel and vertical the fold is **isoclinals (Figure 4-8, B).**

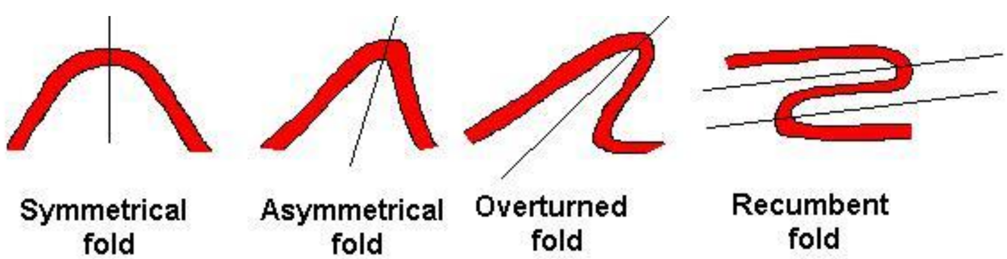


Fig. 4-7

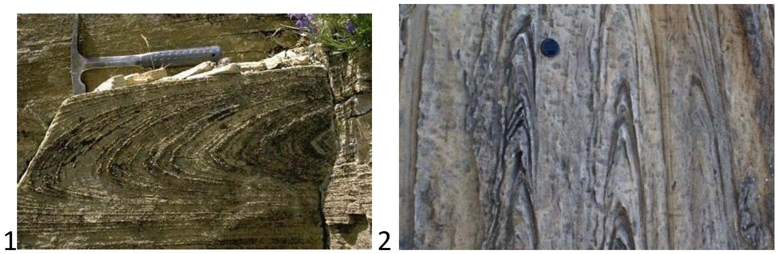


Fig. 4-8, shows A- recumbent fold, B- isoclinal folds

Fracturing

A rock fractures if it is hard and brittle and subjected to sudden strain that overcomes its internal crystalline bonds. If the rock has been displaced along a fracture, such as having one side that is moved up or down, the fracture is called a **fault**, and if there is no displacement along the crack, the fracture is called a **joint (Figure 4-9)**.

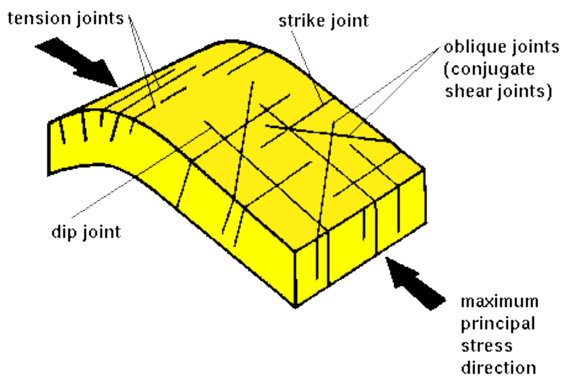


Fig. 4-9, shows strike, dip, and oblique joints.

Faults: Horizontal or vertical displacement along the fault plane can range from a few centimeters to hundreds of kilometers.The fault can be merely a crack between the two sides of rock, or it can be a fault zone hundreds of meters wide that consists of rock that has been very fractured, brecciated, and pulverized from repeated grinding movements along the fault plane (Figure 4-10). The broken material within a fault is called fault **gouge.**

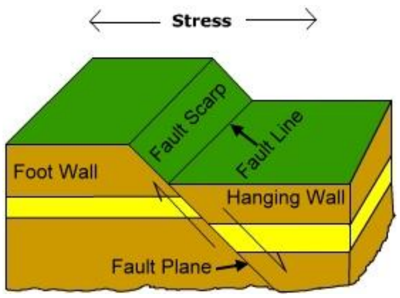


Fig. 4-10

Fault movements: Three kinds of fault movements are recognized: **dip-slip, strike-slip**, and **oblique-slip**. Movement in a dip-slip fault is parallel to the dip of the fault plane in an "up" or "down" direction between the two blocks. The block that underlies an inclined dip-slip fault is called the **foot wall**; the block that rests on top of the inclined fault plane is called the **hanging wall**. A **normal dip-slip** fault, or **normal fault**, is one in which the hanging wall block has slipped down the fault plane relative to the footwall block. A **reverse dip-slip** fault is just the opposite: the hanging wall block has moved upward relative to the footwall block (Figure 4-11).

The blocks on either side of a **strike-slip fault** move horizontally in relation to each other, parallel to the strike of the fault. If aperson is standing at the fault and looks across to see that a featurehas been displaced to the left, it is called a left-lateral strike-slip fault. A **right-lateral strike-slip fault** is one in which the displacement appears to the right when looking across the fault (Figure 4-11).

Thrust faults are reverse dip-slip faults in which the hanging wall block has overridden the footwall block at a very shallow angle for tens of kilometers. The hanging wall block and footwall block of a thrust fault are typically called the upper plate and lower plate, respectively (Figure 4-11).

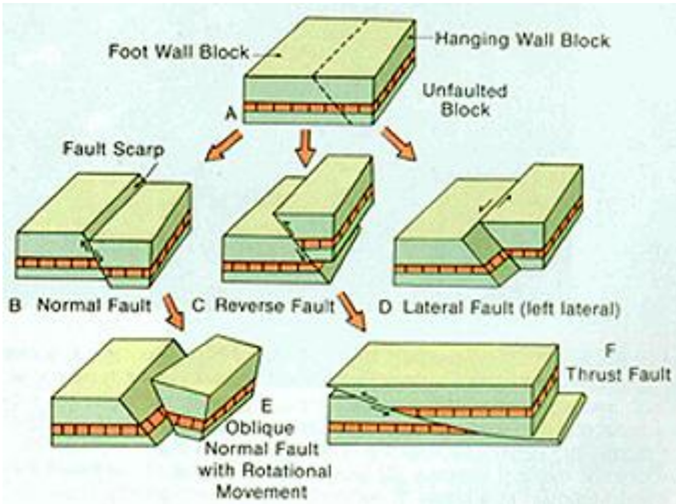


Fig. 4-11

Horst and Graben

The **horst** and **graben** are bounded on both sides by steeply dipping normal faults, along which movement has been essentially equal, resulting in blocks that are scarcely tilted. The faults forming **horsts** generally dip away from each other and those forming **grabens** generally dip toward each other. Two or more horsts and grabens may occur adjacently (Figure 4-12). They are thought to be due to lateral tension possibly produced by regional uplift or salt dome formation.

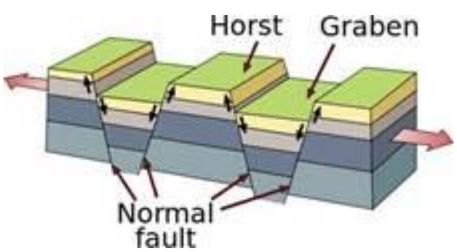


Fig. 4-12

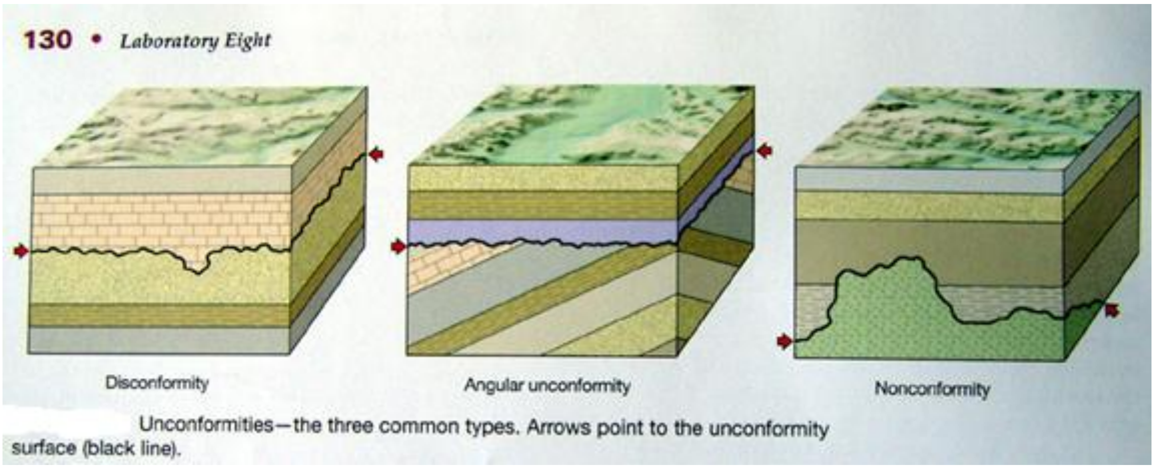
Unconformities

An **unconformity** is a contact between two rock units in which the upper unit is usually much younger than the lower unit. Unconformities are typically buried erosional surfaces that can represent a break in the geologic record of hundreds of millions of years or more. For example, the contact between a 400-million-year-old sandstone that was deposited by a rising sea on a weathered bed rock surface that is 600 million years old is an unconformity that represents a time **hiatus** of 200 million years. The sediment and/or rock that were deposited directly on the bed rock during that 200-million-year span were eroded away, leaving the "basement" surface exposed. There are three kinds of unconformities: **disconformities**, **nonconformities,** and **angular unconformities**.

Disconformities: Disconformities (Figure 4-13) are usually erosional contacts that are parallel to the bedding planes of the upper and lower rock units. Since disconformities are hard to recognize in a layered sedimentary rock sequence, they are often discovered when the **fossils** in the upper and lower rock units are studied. A **gap** in the fossil record indicates a gap in the depositional record, and the length oftime the disconformity represents can be calculated. **Disconformities** are usually a result of erosion but can occasionally represent periods of non deposition (Fig. 4-14, 2).

Nonconformities: A nonconformity (Figure 4-13) is the contact that separates a younger sedimentary rock unit from an igneous intrusive rock or metamorphic rock unit. A nonconformity suggests that a period of long-term uplift, weathering, and erosion occurred to expose the older, deeper rock at the surface before it was finally buried by the younger rocks above it. A nonconformity is the old erosional surface on the underlying rock (Fig. 4-14, 3).

Angular unconformities: An angular unconformity (Figure 4-13) is the contact that separates a younger, gently dipping rock unit from older underlying rocks that are tilted or deformed layered rock. The contact is more obvious than a disconformity because the rock units are not parallel and at first appear cross-cutting. Angular unconformities generally represent a longer time hiatus than do disconformities because the underlying rock had usually been metamorphosed, uplifted, and eroded before the upper rock unit was deposited (Fig. 4-14, 2).



Unconformities—the three common types. Arrows point to the unconformity surface (black line).

Fig. 4-13

Fig. 4-14, Shows 1-disconformity, 2- angular unconformity, 3- nonconformity.