Welcome

This is

CE181404
Engineering Geology

Crustal Deformation

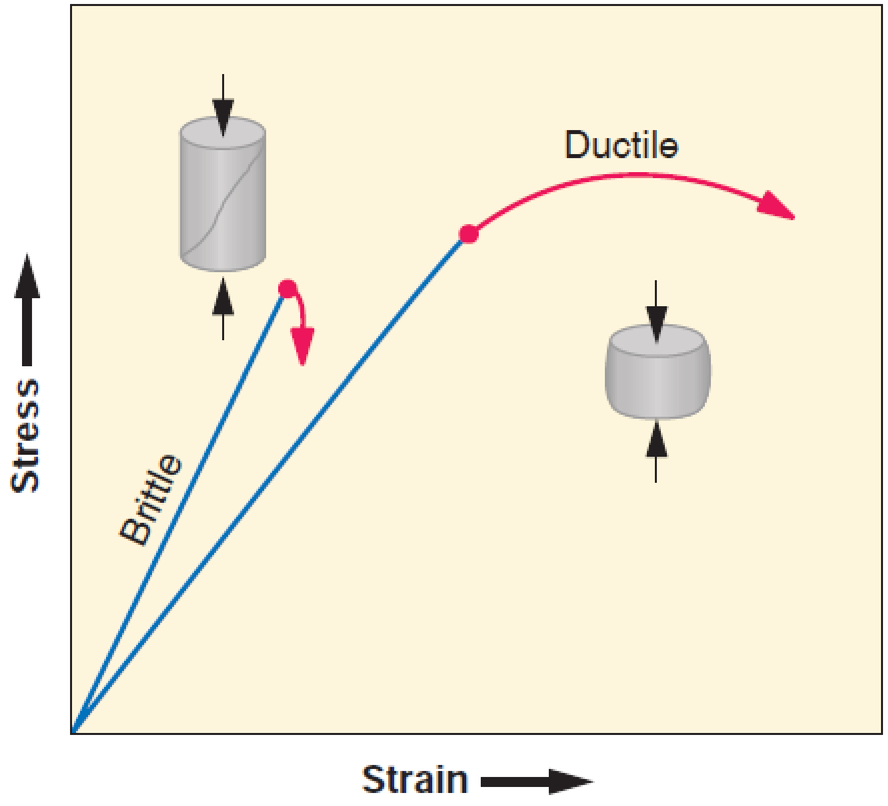
- Earth is a dynamic planet. Shifting lithospheric plates continually change the face of our planet by moving continents across the globe.
- Deformation is a general term that refers to all changes in the original shape, size (volume), or orientation of a rock body.
- Geologists use the term stress to describe the forces that deform rocks. Stress that squeezes and shortens a rock mass is called ***compressional stress***, whereas stress that pulls apart or elongates a rock body is known as ***tensional stress***. Stress can also cause a rock to ***shear.***

Elastic, Brittle, and Ductile Deformation

When stress is gradually applied, rocks first respond by deforming elastically. Changes that result from elastic deformation are recoverable. During elastic deformation the chemical bonds of the minerals within a rock are stretched but do not break.

Once the elastic limit (strength) of a rock is surpassed, it either flows or fractures. Rocks that break into smaller pieces exhibit brittle deformation. Brittle deformation occurs when stress causes the chemical bonds that hold a material together to break.

Ductile deformation, on the other hand, is a type of solid-state flow that produces a change in the shape of an object without fracturing.



DIP and STRIKE

According to the principle of *original horizontality,* sedimentary rocks and some lava flows and ashfalls are deposited as horizontal beds or strata. Where these originally horizontal rocks are found tilted, it indicates that tilting must have occurred after deposition and lithification.

Strike is the compass direction of a line formed by the intersection of an inclined plane with a horizontal plane.

Dip is the angle at which a rock layer is inclined from the horizontal. The direction of dip is at a right angle to the strike.

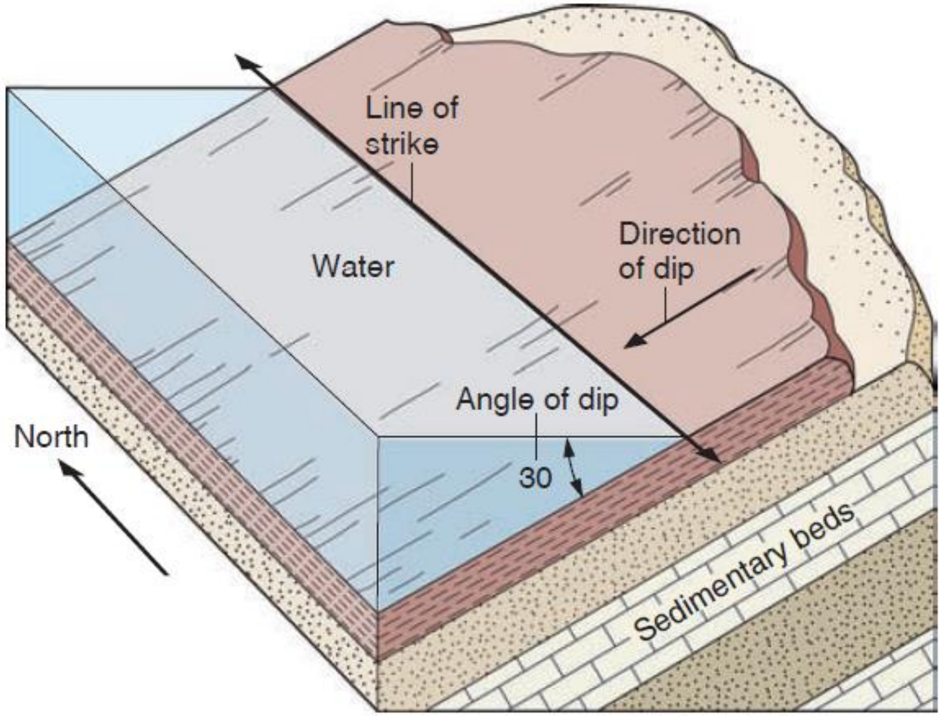


FIGURE 6.7

Strike, direction of dip, and angle of dip. The line of strike is found where an inclined bed intersects a horizontal plane (as shown here by the water). The dip direction is always perpendicular to the strike and in the direction the bed slopes (or a ball would roll down). The dip angle is the vertical angle of the inclined bed as measured from the horizontal.

DIP and STRIKE

the strike is the line formed by the intersection of the tilted sedimentary beds and the horizontal layer of sand in the foreground. The direction of dip is toward the left.

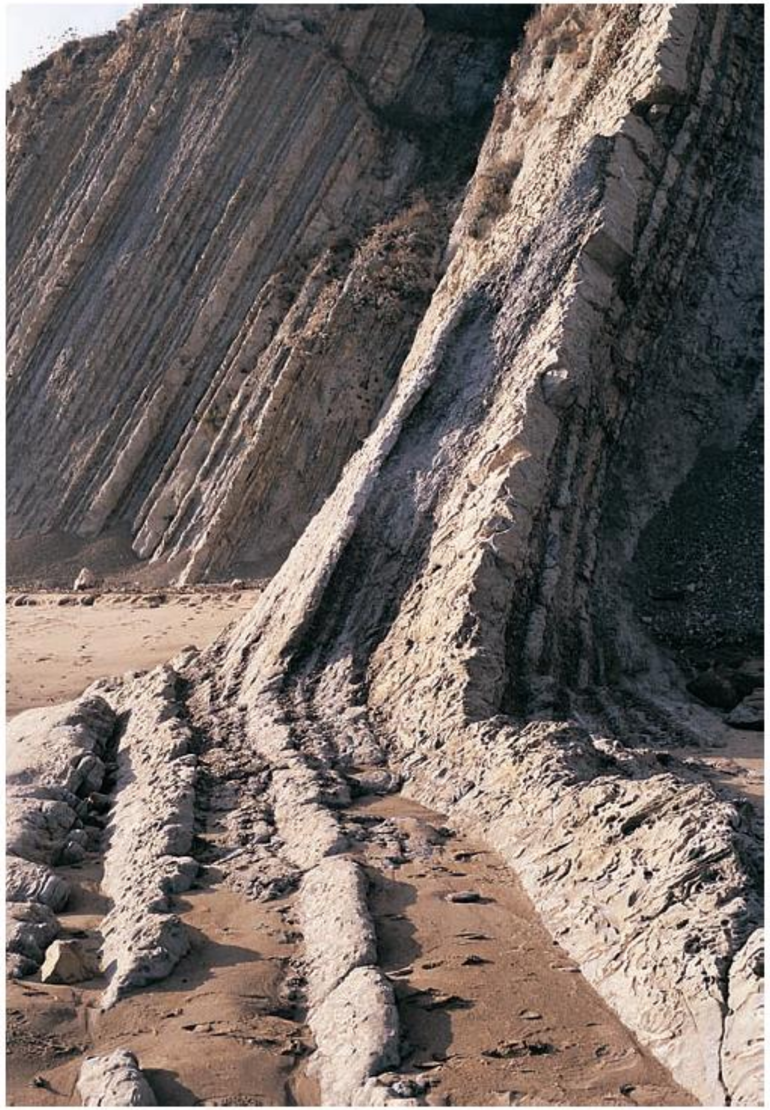


FIGURE 6.6

Tilted sedimentary beds along the coast of northern California near Point Arena. Here, the strike is the line formed by the intersection of the tilted sedimentary beds and the horizontal layer of sand in the foreground. The direction of dip is toward the left. *Photo by Diane Carlson*

Structures Formed by Ductile Deformation: FOLD

Rocks can bend without breaking.

During mountain building, flat-lying sedimentary and volcanic rocks are often bent into a series of wavelike undulations called folds.

Folds are the result of *compressional stresses that result in a shortening and thickening of the crust.*

Folds are bends or wavelike features in layered rock.

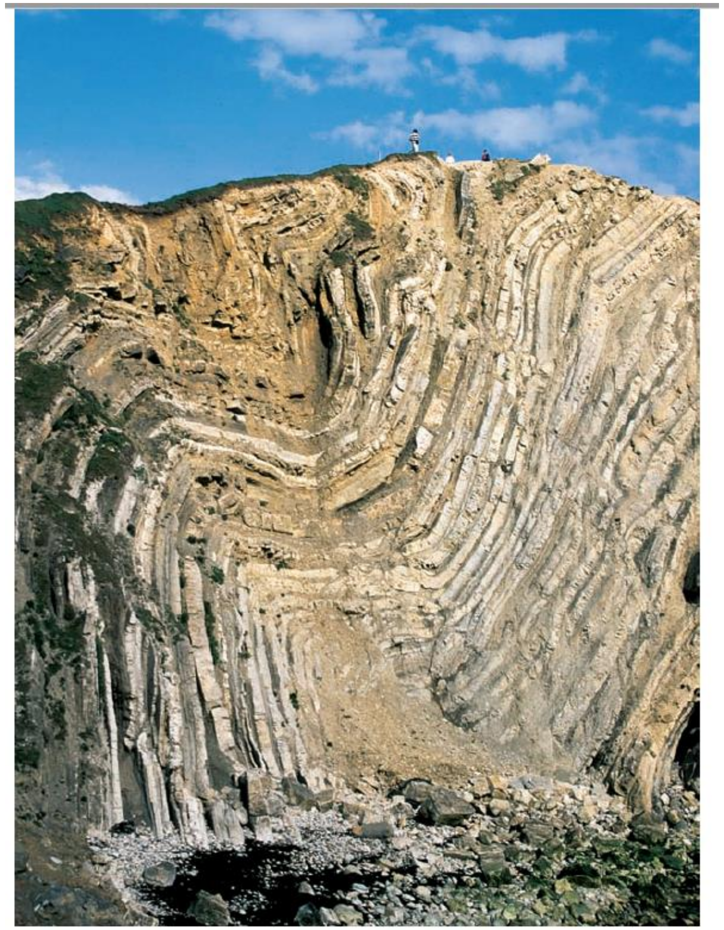


FIGURE 6.10

Folded sedimentary rock layers exposed at Lulworth Cove, Dorset, England. *Photo © Tom Bean*

FOLD

Anticlines and Synclines

The two most common types of folds are anticlines and synclines .

Anticlines usually arise by upfolding, or arching, of sedimentary layers.

Almost always found in association with anticlines are downfolds, or troughs, called *synclines* .

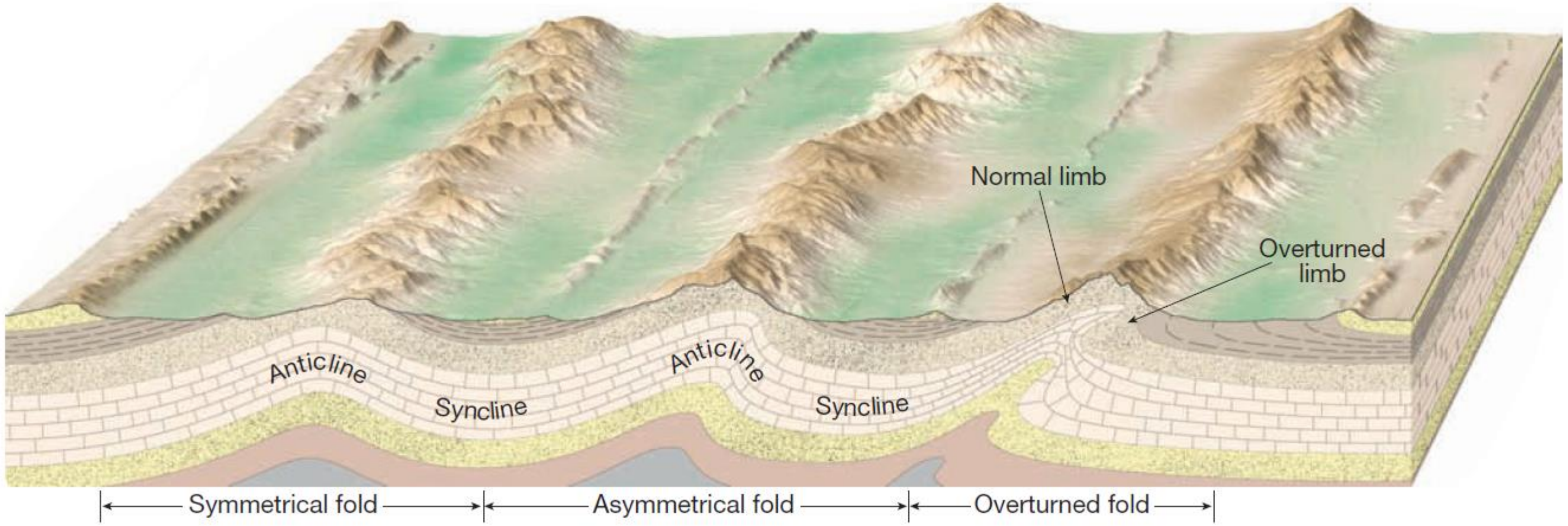


FIGURE 17.3 Block diagram of principal types of folded strata. The upfolded, or arched, structures are *anticlines*. The downfolds, or troughs, are *synclines*. Notice that the limb of an anticline is also the limb of the adjacent syncline.

FOLD

Anticlines and Synclines

Depending on their orientation, these basic folds are described as *symmetrical* when the limbs are mirror images of each other and *asymmetrical* when they are not.

A.

FIGURE 17.4 Anticline and syncline. **A.** An asymmetrical anticline in which one limb dips more steeply than the other. **B.** A nearly symmetrical syncline formed in limestone and siltstone strata. *(Photos by E. J. Tarbuck)*

B.

FOLD

Anticlines and Synclines

An asymmetrical fold is said to be *overturned* if one or both limbs are tilted beyond the vertical (FIGURE 17.5). An overturned fold can also “lie on its side” so a plane extending through the axis of the fold is horizontal. These *recumbent* folds are common in highly deformed mountainous regions such as the Alps.

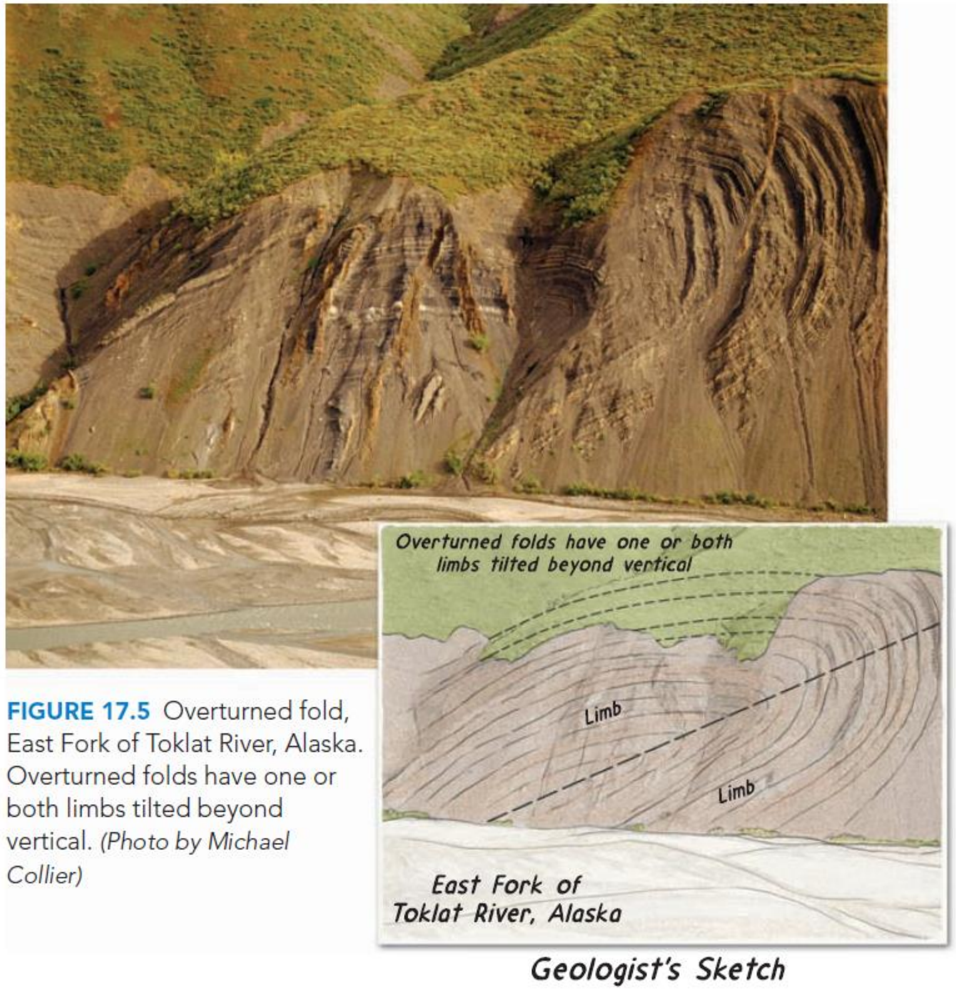


FIGURE 17.5 Overturned fold, East Fork of Toklat River, Alaska. Overturned folds have one or both limbs tilted beyond vertical. *(Photo by Michael Collier)*

FOLD

Anticlines and Synclines

Some folds *plunge* because the axis of the fold penetrates the ground. FIGURE 17.6 shows an example of a plunging anticline and the pattern produced when erosion removes the upper layers of the structure and exposes its interior.

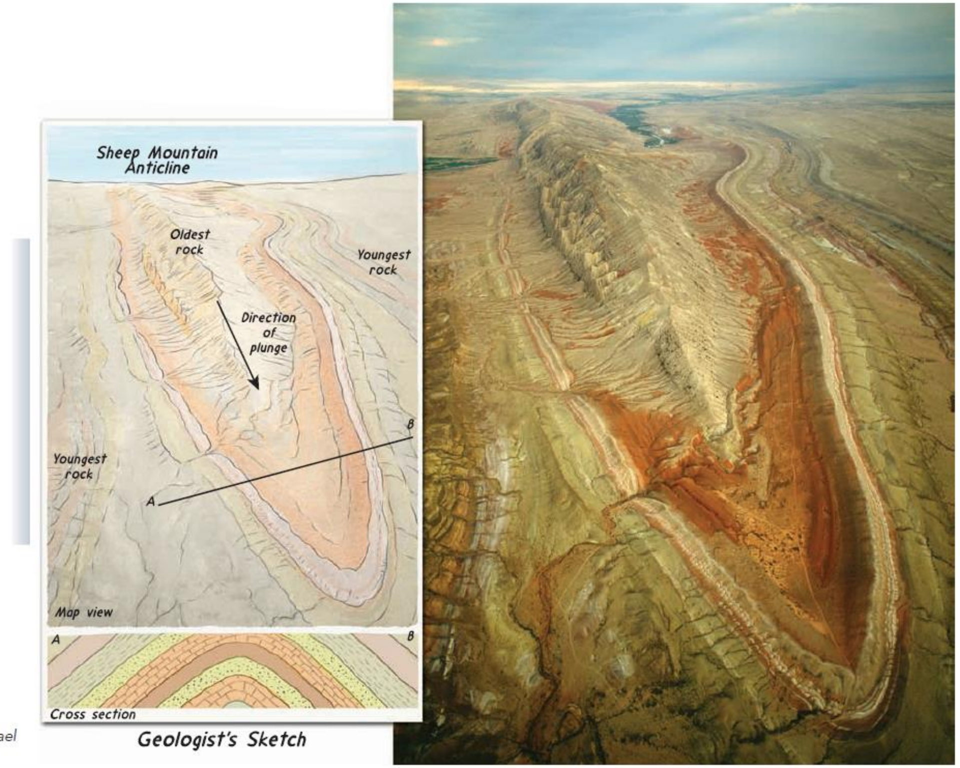


FIGURE 17.6 Plunging anticline, Sheep Mountain, Wyoming. In a plunging anticline the outcrop pattern "points" in the direction of plunge, the opposite is true of plunging synclines. *(Photo by Michael Collier)*

FOLD
Domes and Basins

Broad upwarps in basement rock may deform the overlying cover of sedimentary strata and generate large folds.

When this upwarping produces a circular or slightly elongated structure, the feature is called a dome**.**

Downwarped structures having a similar shape are termed basins**.**

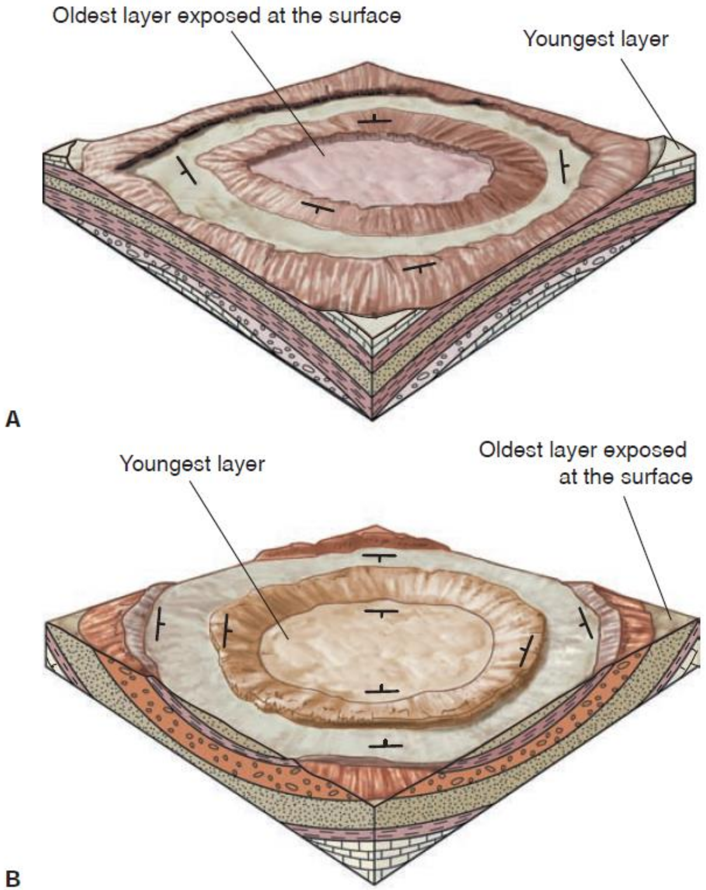
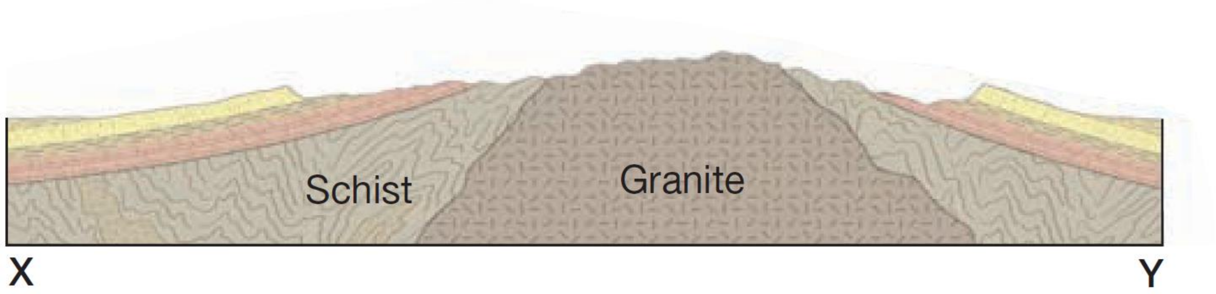


FIGURE 6.15
(A) Structural dome. (B) Structural basin.

FOLD

Domes

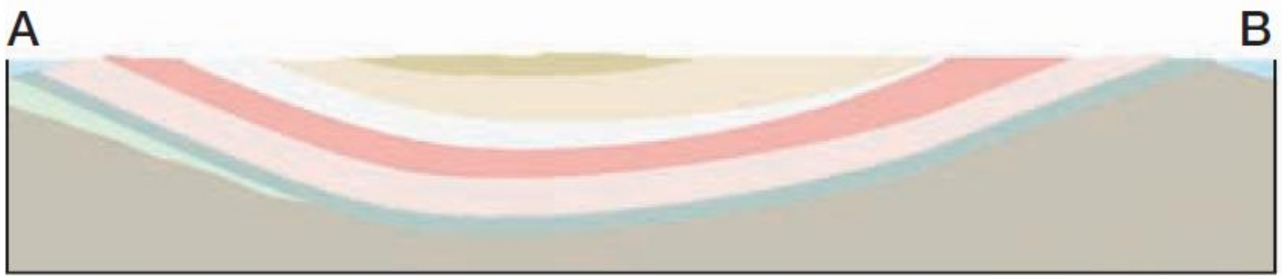
Broad upwarps in basement rock may deform the overlying cover of sedimentary strata and generate large folds. When this upwarping produces a circular or slightly elongated structure, the feature is called a dome.



FOLD

Basins

Downwarped structures having a similar shape as domes are termed basins.



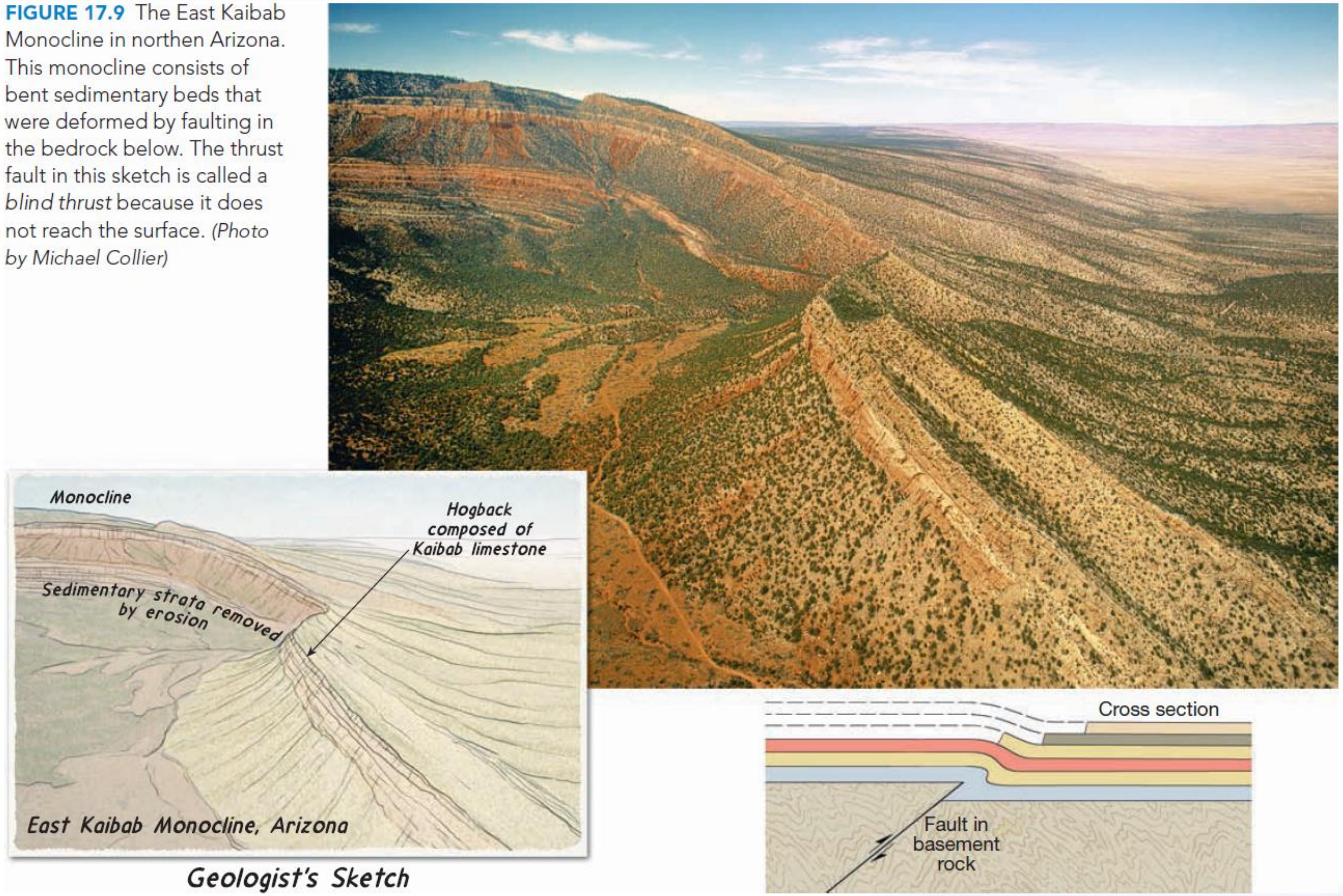
FOLD

Monoclines

Folds can be intimately coupled with faults. Examples of this close association are broad, regional features called *monoclines*.

Monoclines are large, step like folds in otherwise horizontal sedimentary strata.

FIGURE 17.9 The East Kaibab Monocline in northen Arizona. This monocline consists of bent sedimentary beds that were deformed by faulting in the bedrock below. The thrust fault in this sketch is called a *blind thrust* because it does not reach the surface. *(Photo by Michael Collier)*



FOLD

Open folds

Open folds (figure 6.17*A*) have limbs

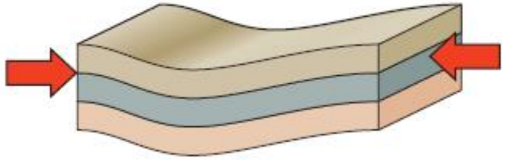
that dip gently, and the angle between the limbs is large. All

other factors being equal, the more open the fold, the less it

has been strained by shortening. By contrast, if the angle

between the limbs of the fold is small, then the fold is a **tight**

fold.



A Open folds

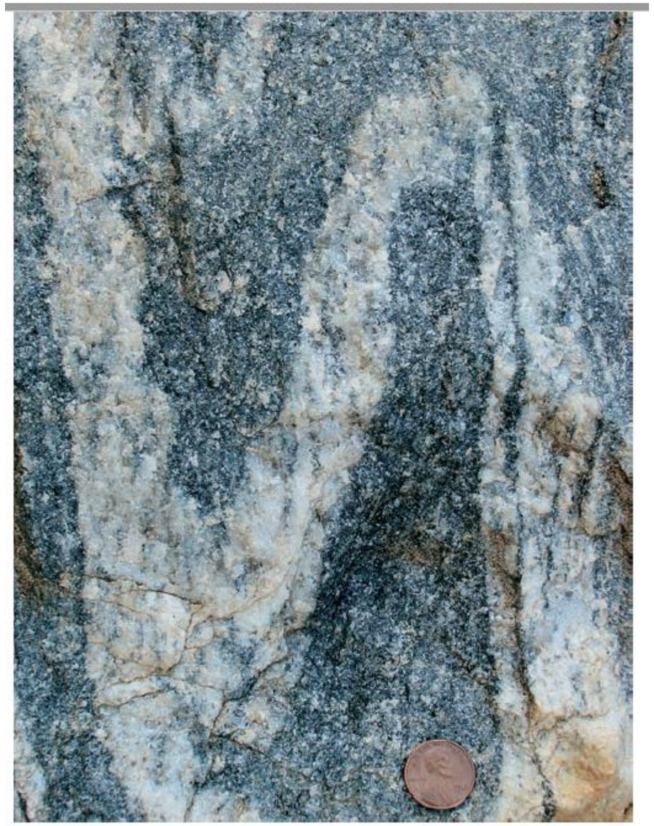
FOLD

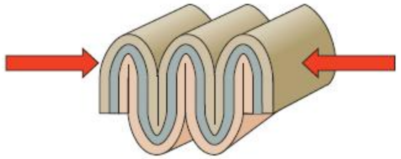
Isoclinal fold

An **isoclinal fold,** one in which limbs are nearly parallel

to one another, implies even larger shortening strain or shear

strain (figure 6.17*B*).



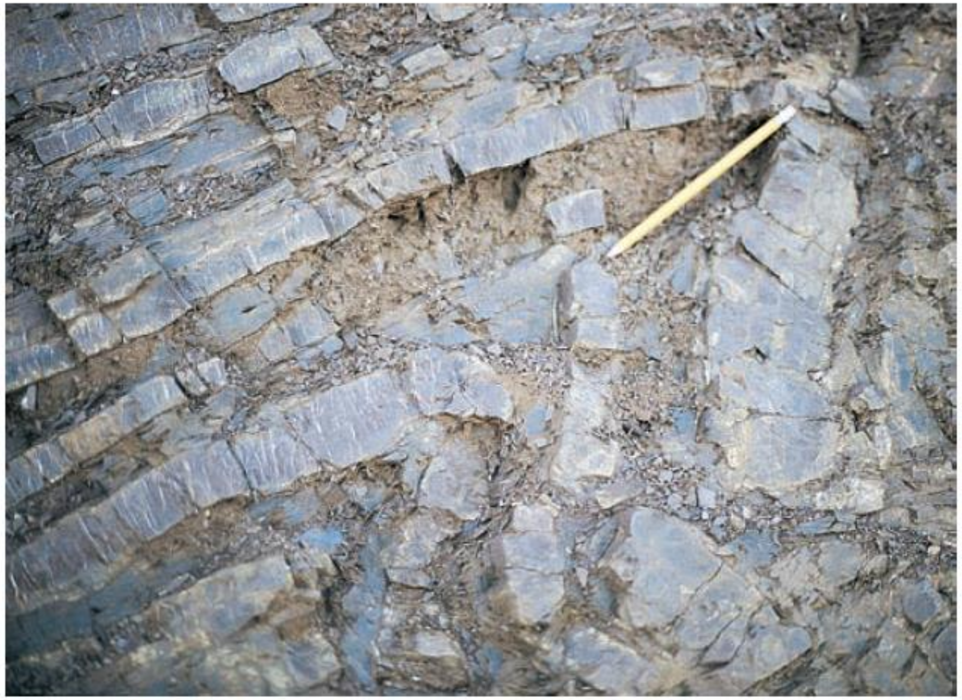


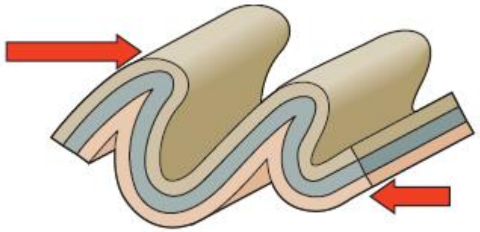
B Isoclinal folds

FOLD

Overturned fold

If the axial plane is inclined to such a degree that the fold limbs dip in the same direction, the fold is classified as an **overturned fold** (figure 6.17*C*).



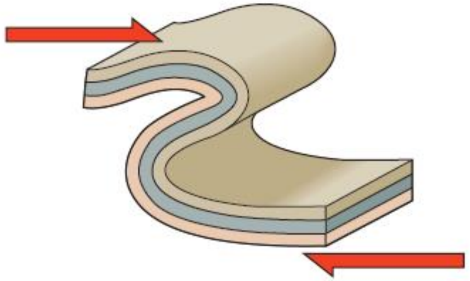


C Overturned folds

FOLD

Recumbent folds

Recumbent folds (figure 6.17*D*) are overturned to such an extent that the limbs are essentially horizontal. Recumbent folds are found in the cores of mountain ranges such as the Canadian Rockies, Alps, and Himalayas and record extreme shortening and shearing of the crust typically associated with plate convergence.



D Recumbent folds

UNCONFORMITY

- In many places one series of strata is seen to lie upon an older series with a surface of separation between them. Junctions of this kind are called unconformities.
- The older strata were originally deposited in horizontal layers but often they are now seen to be tilted and covered by beds that lie across them.
- The upper beds are said to be unconformable on the lower, and there is often a discordance in dip between the younger and older strata. The unconformity represents an interval of time when deposition ceased and denudation took place during an uplift of the area.
- An unconformity represents a long period during which deposition ceased, erosion removed previously formed rocks, and then deposition resumed. In each case, uplift and erosion are followed by subsidence and renewed sedimentation.

Structures Formed by Brittle Deformation

Fractures in Rock

- If a rock is brittle, it will fracture. Commonly, there is some movement or displacement.
- If essentially no shear displacement occurs, a fracture or crack in bedrock is called a **joint.**
- If the rock on either side of a fracture moves parallel to the fracture plane, the fracture is a *fault.*

Joints

Joints are one of the most commonly observed structures in rocks (figure 6.18). A joint is a fracture or crack in a rock body along which essentially no displacement has occurred. Joints form at shallow depths in the crust where rock breaks in a brittle way and is pulled apart slightly by tensional stresses caused by bending or regional uplift. Where joints are oriented approximately parallel to one another, a **joint set** can be defined.

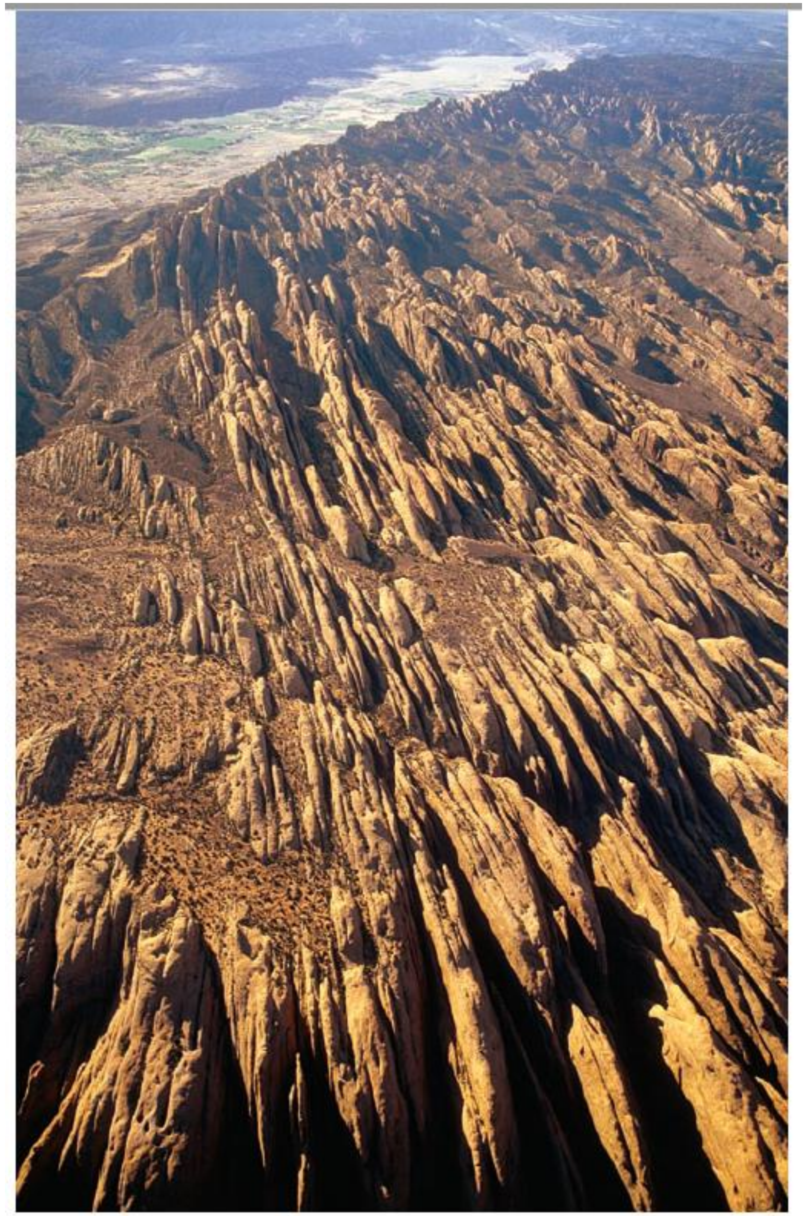


FIGURE 6.18

Vertical joints in sedimentary rock at Moab, Utah, formed in response to tectonic uplift of the region. *Photo © Michael Collier*

JOINTS

Unlike faults, joints are fractures along which no appreciable displacement has occurred.

Although some joints have a random orientation, most occur in roughly parallel groups.

Most joints are produced when rocks in the outermost crust are deformed as tensional stresses cause the rock to fail by brittle fracture.

Highly jointed rocks present a risk to the construction of engineering projects, including highways and dams.

Faults

Faults are fractures in bedrock along which sliding has taken place. The displacement may be only several centimeters or may involve hundreds of kilometers.

In some faults, the contact between the two displaced sides is very narrow. In others, the rock has been broken or ground to a fractured or pulverized mass sandwiched between the displaced sides (figure 6.20).

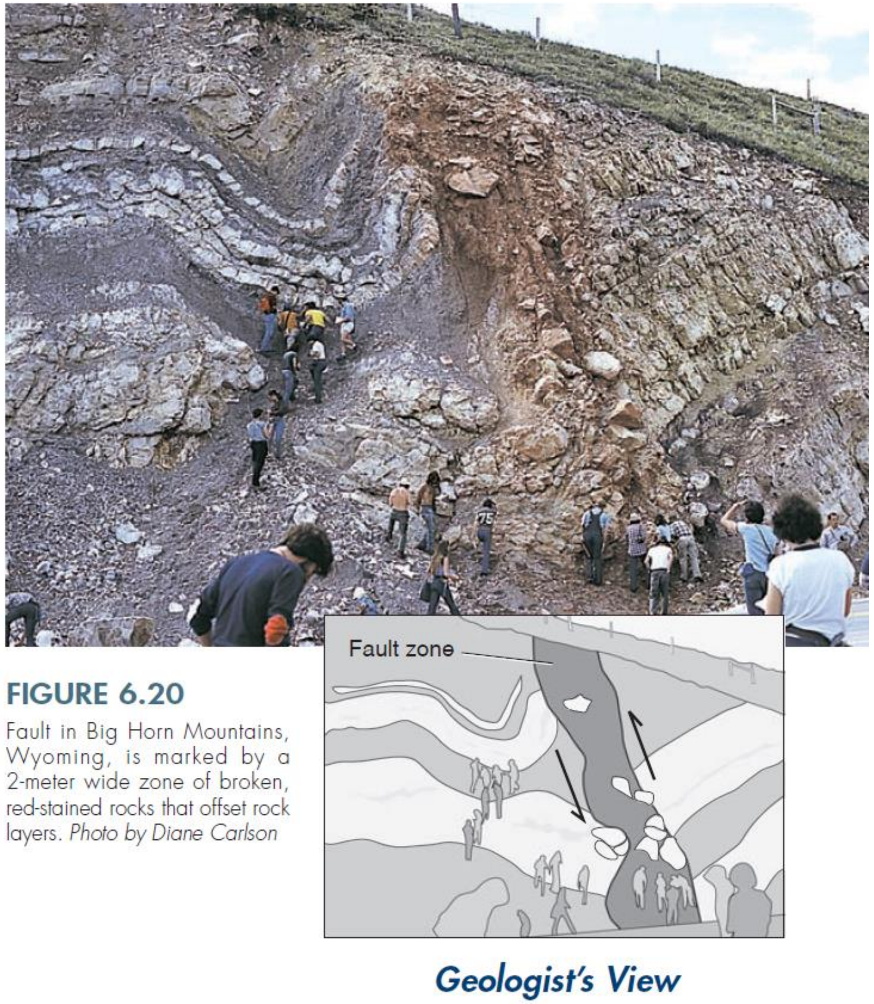


FIGURE 6.20

Fault in Big Horn Mountains, Wyoming, is marked by a 2-meter wide zone of broken, red-stained rocks that offset rock layers. *Photo by Diane Carlson*

Faults

Geologists describe fault movement in terms of direction of slippage: dip-slip, strike-slip, or oblique-slip (figure 6.21).

In a **dip-slip fault,** movement is parallel to the dip of the fault surface.

A **strike-slip fault** indicates *horizontal* motion parallel to the strike of the fault surface.

An **oblique-slip fault** has both strike-slip and dip-slip components.

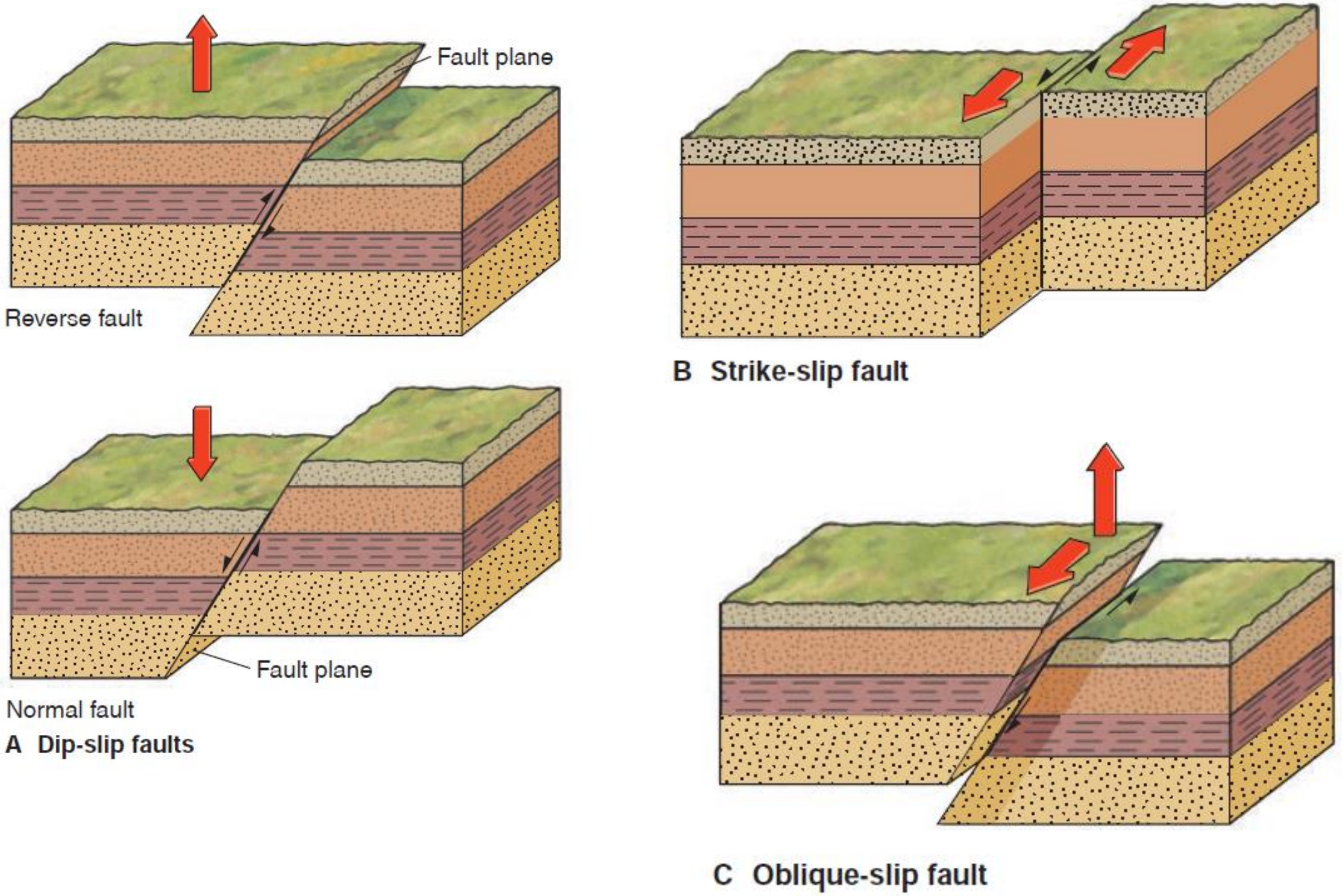


FIGURE 6.21

Three types of faults illustrated by displaced blocks. Although both blocks probably move when the fault slips, the heavier arrows show only the direction of movement on the left. (A) Dip-slip movement. (B) Strike-slip movement. (C) Oblique-slip movement. Black arrows show dip-slip and strike-slip components of movement.

Faults

Dip-slip Faults

In a dip-slip fault, the movement is up or down parallel to the dip of the inclined fault surface. The side of the fault above the inclined fault surface is called the **hanging wall,** whereas the side below the fault is called the **footwall** (figure 6.22).

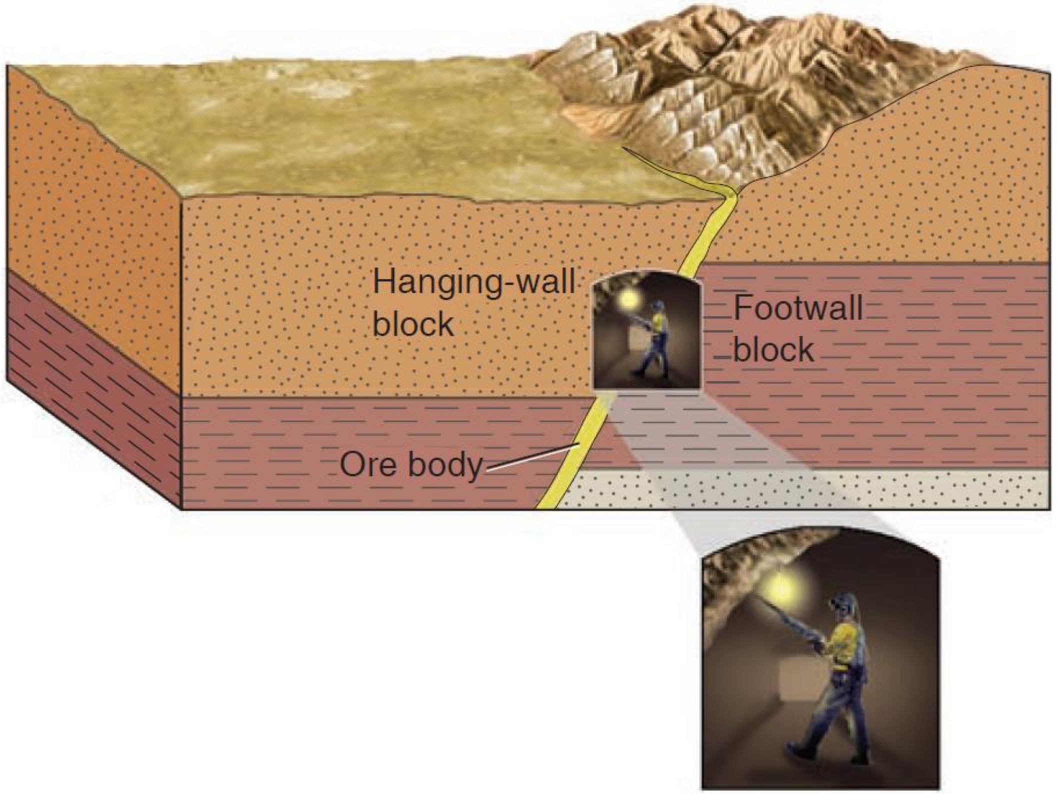


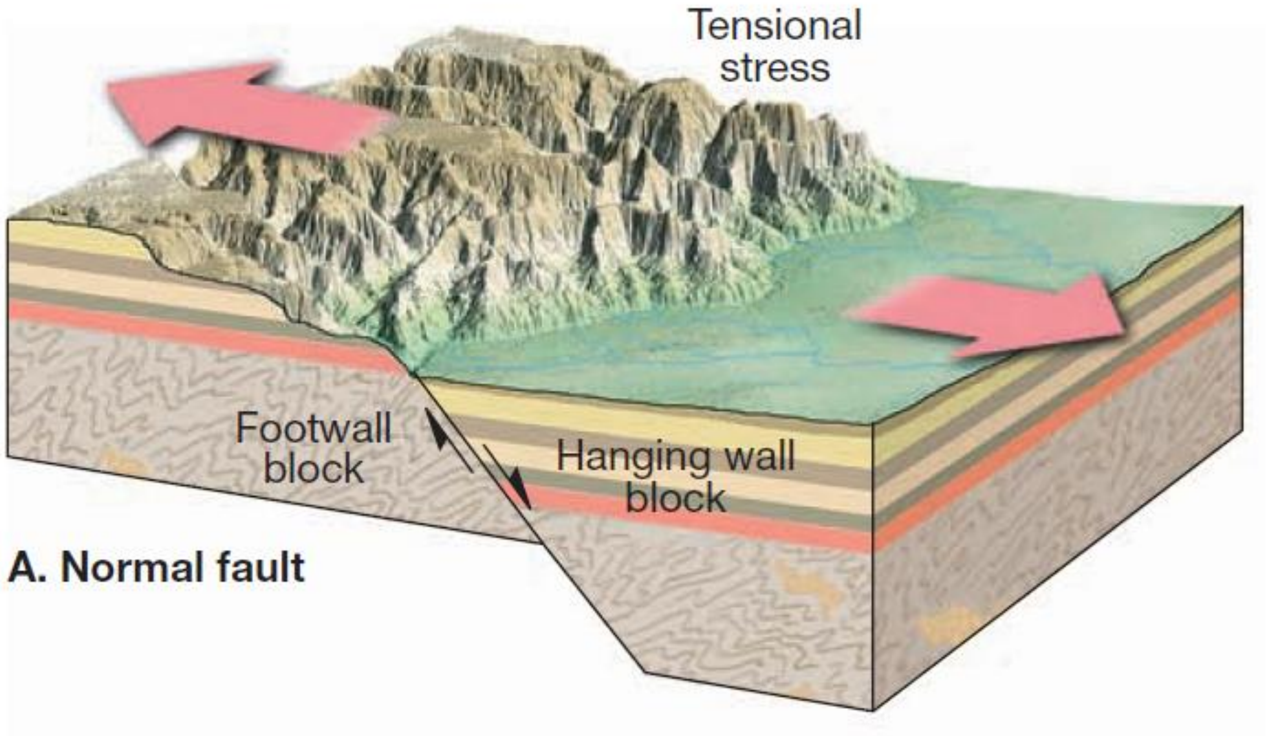
FIGURE 6.22

Relationship between the hanging-wall block and footwall block of a fault. The upper surface where a miner can hang a lantern is the hanging wall. The lower surface below the fault is the footwall.

Dip-slip Faults
Normal Faults

Dip-slip faults are classified as normal faults when the hanging wall block moves down relative to the footwall block.

Because of the downward motion of the hanging wall block, normal faults accommodate lengthening, or extension, of the crust.



Dip-slip Faults
Normal Faults

Sometimes a block bounded by normal faults will drop down, creating a *graben,* as shown in figure 6.23*C.* (*Graben* is the German word for “ditch.”)

If a block bounded by normal faults is uplifted sufficiently, it becomes a fault-block mountain range. (This is also called a *horst,* the opposite of a graben.)

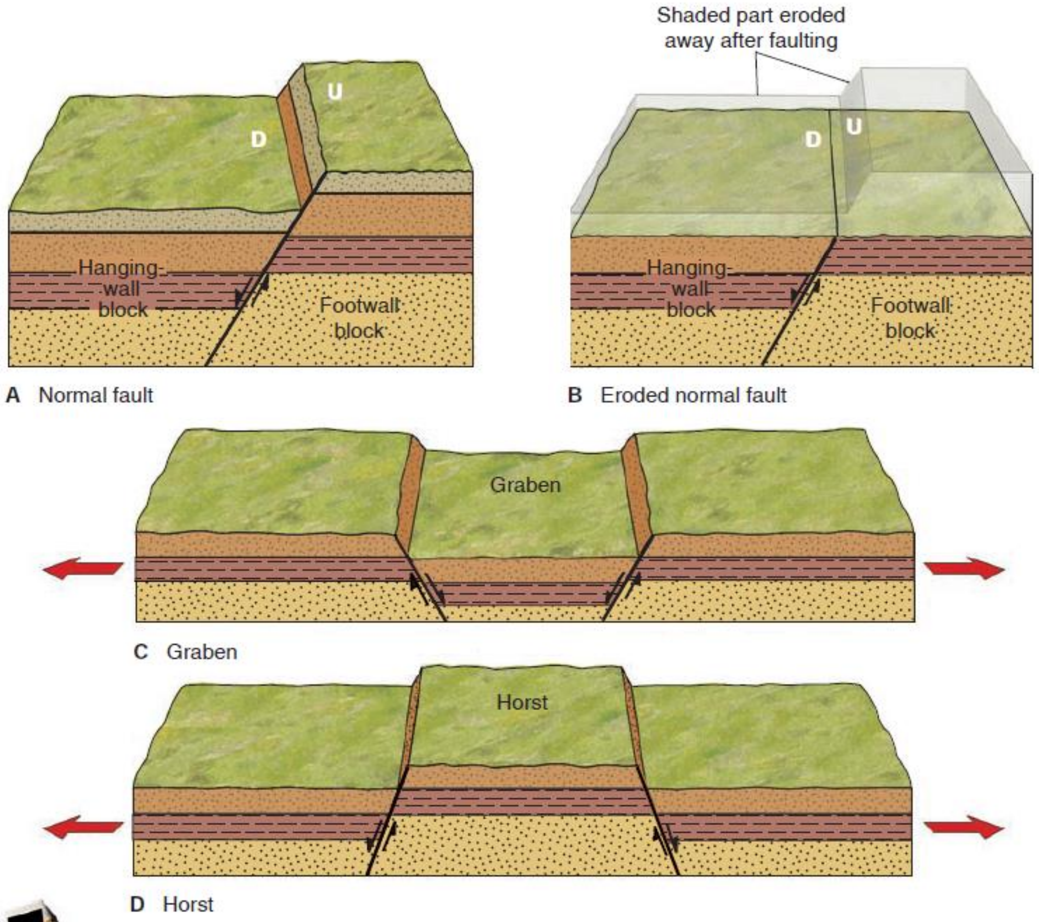


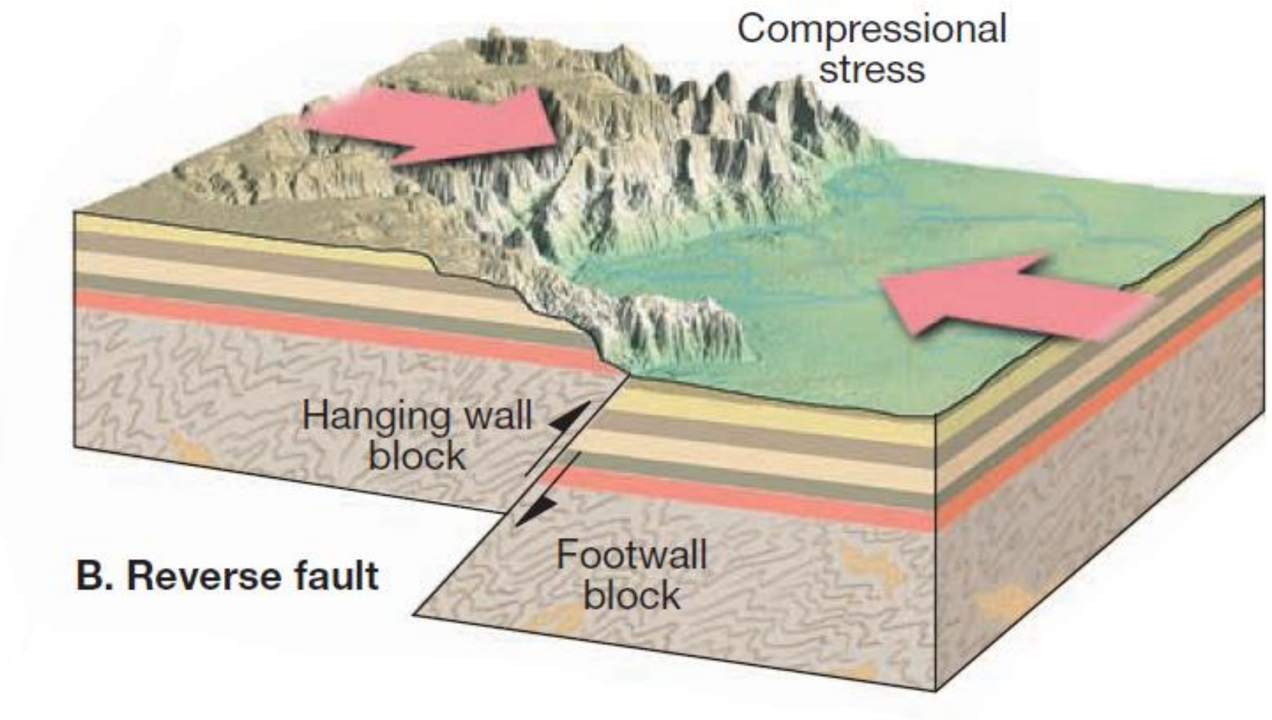
FIGURE 6.23

Normal faults. (*A*) Diagram shows the fault before erosion and the geometric relationships of the fault. (*B*) The same area after erosion. (*C*) A graben. (*D*) A horst. Arrows in *C* and *D* indicate horizontal extension of the crust.

Dip-slip Faults
Reverse Faults

Reverse faults are dip-slip faults in which the hanging wall block moves up relative to the footwall block.

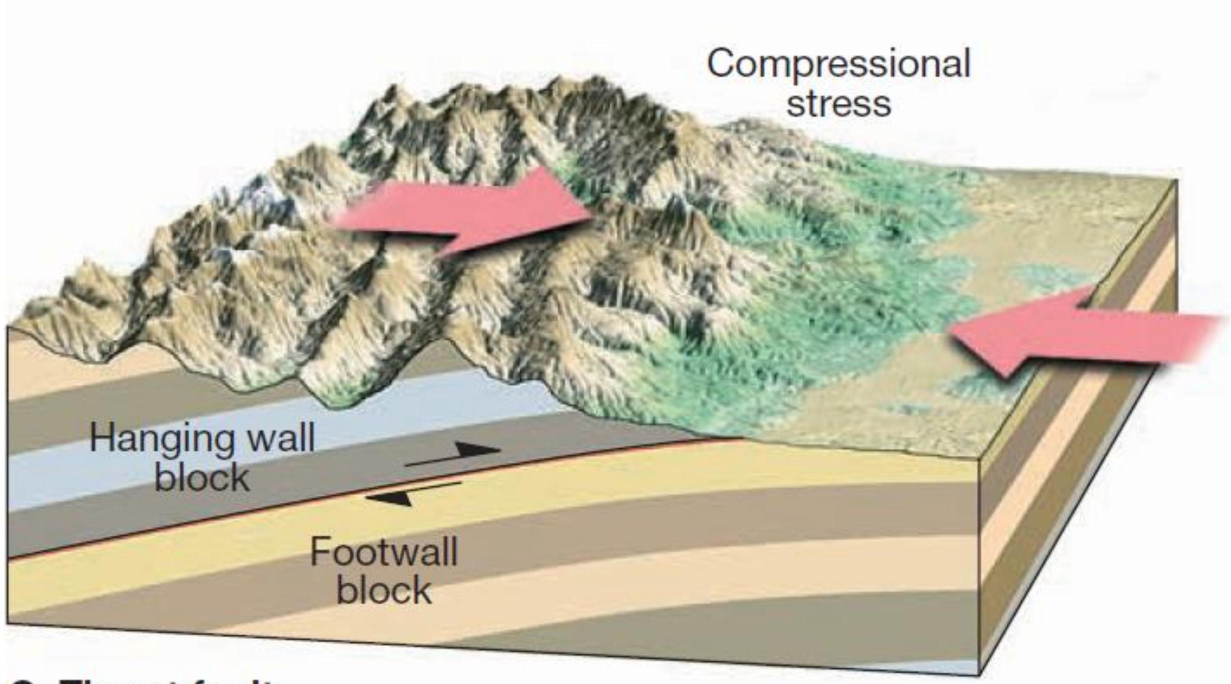
Reverse faults tend to shorten the crust.



Dip-slip Faults
Thrust Faults

Thrust faults are reverse faults having dips less than 45 degrees, so the overlying block moves nearly horizontally over the underlying block.

Because the hanging wall block moves up and over the footwall block, reverse and thrust faults accommodate horizontal shortening of the crust.

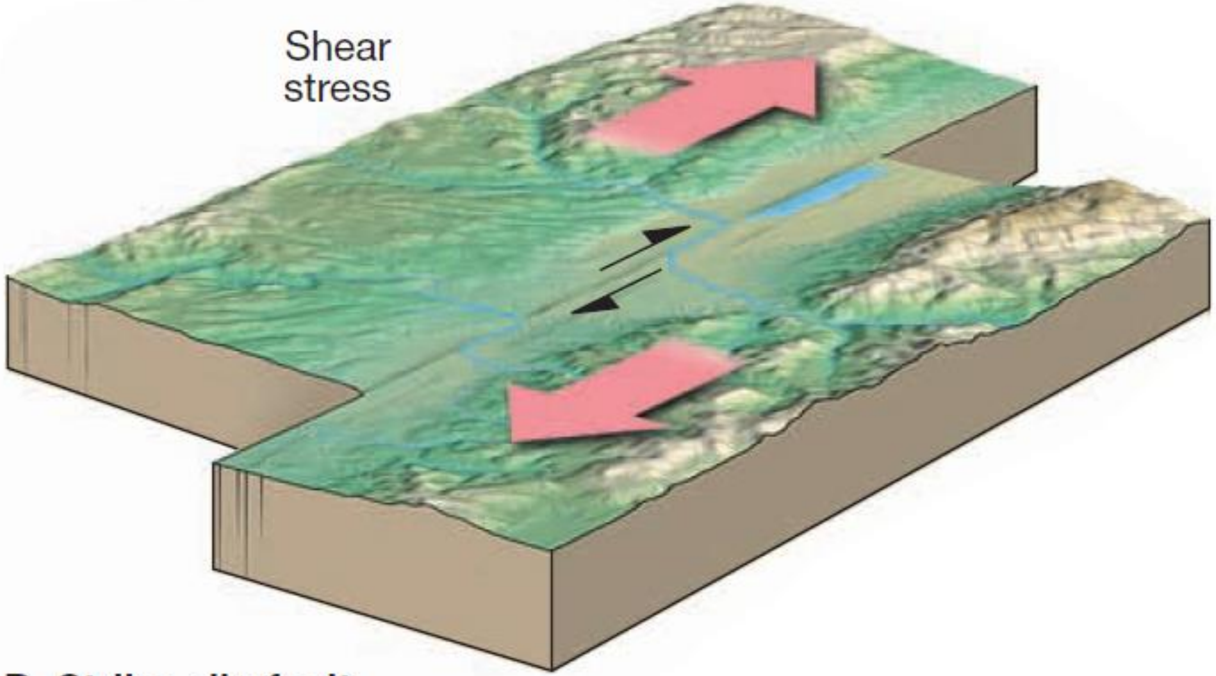


C. Thrust fault

Faults

Strike-slip Faults

A fault where the movement (or *slip*) is predominantly horizontal and therefore parallel to the strike of the fault is called a **strike-slip fault.**



D. Strike-slip fault