EXERCISE 7

Geologic Maps and Structures

Earth is a dynamic planet. Its internal forces result in crustal movements that are continuously causing rocks to deform (Figure 7.1). If the magnitude of the force exceeds the strength of the rocks, the rocks will yield and folding or breaking may occur. In this exercise, you will investigate some of the common rock structures that are produced during crustal deformation and learn how Earth scientists map and analyze these geologic features to gain insights into the nature of the evolving Earth.

Objectives

After you have completed this exercise, you should be able to:

1. Explain how geologists describe the orientation of folded rocks and faults using the measurements strike and dip.
2. Draw and interpret a simple geologic block diagram.

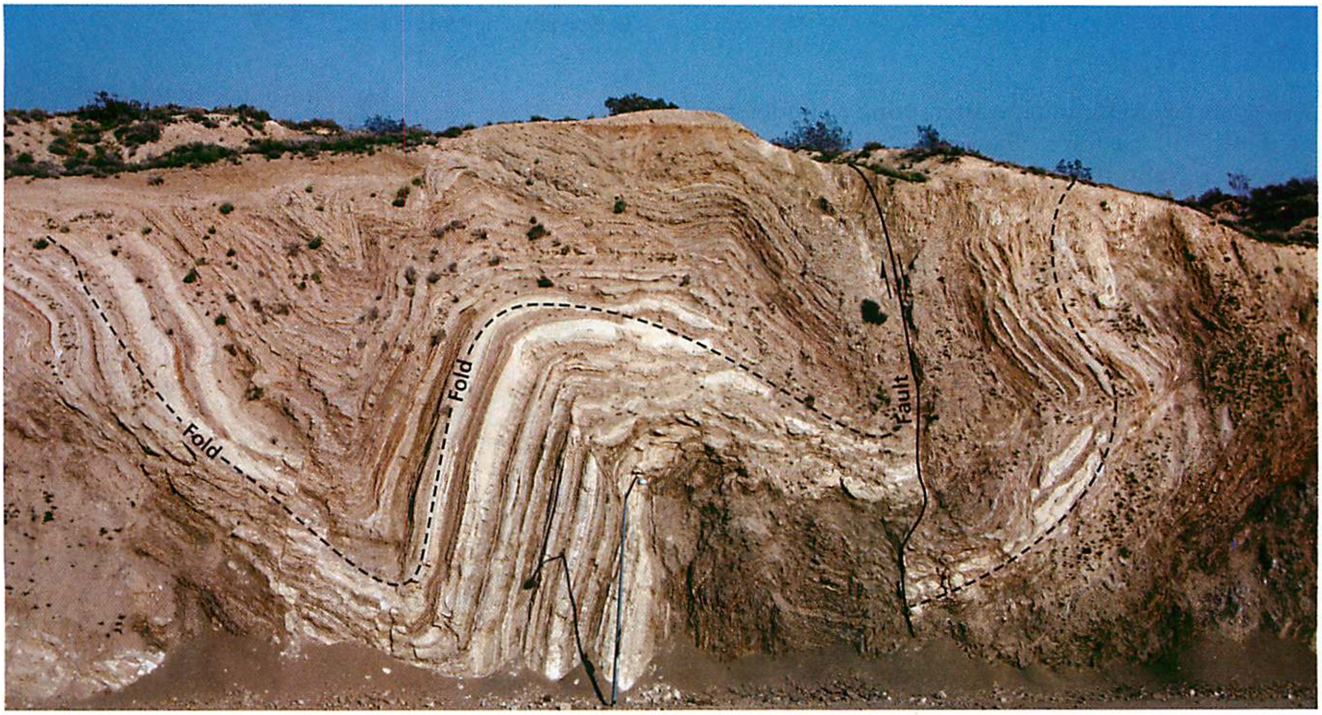


Figure 7.1 Deformed sedimentary strata. (Photo by E. J. Tarbuck)

3. Describe the various types of folds and how they form.
4. Recognize and diagram anticlines, synclines, domes, and basins in both geologic map and cross-sectional views.
5. Discuss the formation and types of dip-slip and strike-slip faults.
6. Recognize and diagram the various types of faults in both geologic map and cross-sectional views.
7. Interpret a simplified geologic map and use it to construct a geologic cross section.

Materials

ruler	hand lens
colored pencils	protractor

Terms

geologic map	joint	basin
stress	strike	dip-slip fault
compressional stress	dip	strike-slip fault
tensional stress	cross section	normal fault
shear stress	anticline	reverse fault
plastic deformation	syncline	right-lateral fault
fold	axial plane	
fault	dome	left-lateral fault

Introduction

Geologists are continuously attempting to understand the nature of the forces that cause rocks to deform. They often begin their study by preparing a **geologic map** that shows the types, ages, distribution, and orientation of rocks on the surface of Earth. Working from these maps, geologists can interpret the nature of the rocks below the surface and assess any forces that may have caused their deformation.

Stress is the term used to describe the force that acts on a rock unit to change its shape or volume. The forces that act to shorten a rock body are known as **compressional stresses,** whereas those that elongate or pull apart a rock unit are called **tensional stresses. Shear stresses** tend to bend or break a rock unit (Figure 7.2).

If the stress applied to a rock unit exceeds its strength, the rock may undergo plastic deformation or fracture. **Plastic deformation** takes place at high temperatures and pressures within Earth and results in permanent changes in the rock unit. A rock's size and shape may be altered through folding or flowing. Plastic deformation often produces wavelike undulations called **folds** (see Figure 7.1) in formerly flat-lying rocks. Under the lower temperature and pressure conditions found near the surface, most rocks behave like a brittle solid and fracture or break when stressed beyond their limit. If the rocks on either side of the fracture move, the geologic feature is called a **fault** (see Figure 7.1). A **joint** is a fracture or break in a rock along which there has been no displacement (Figure 7.3).

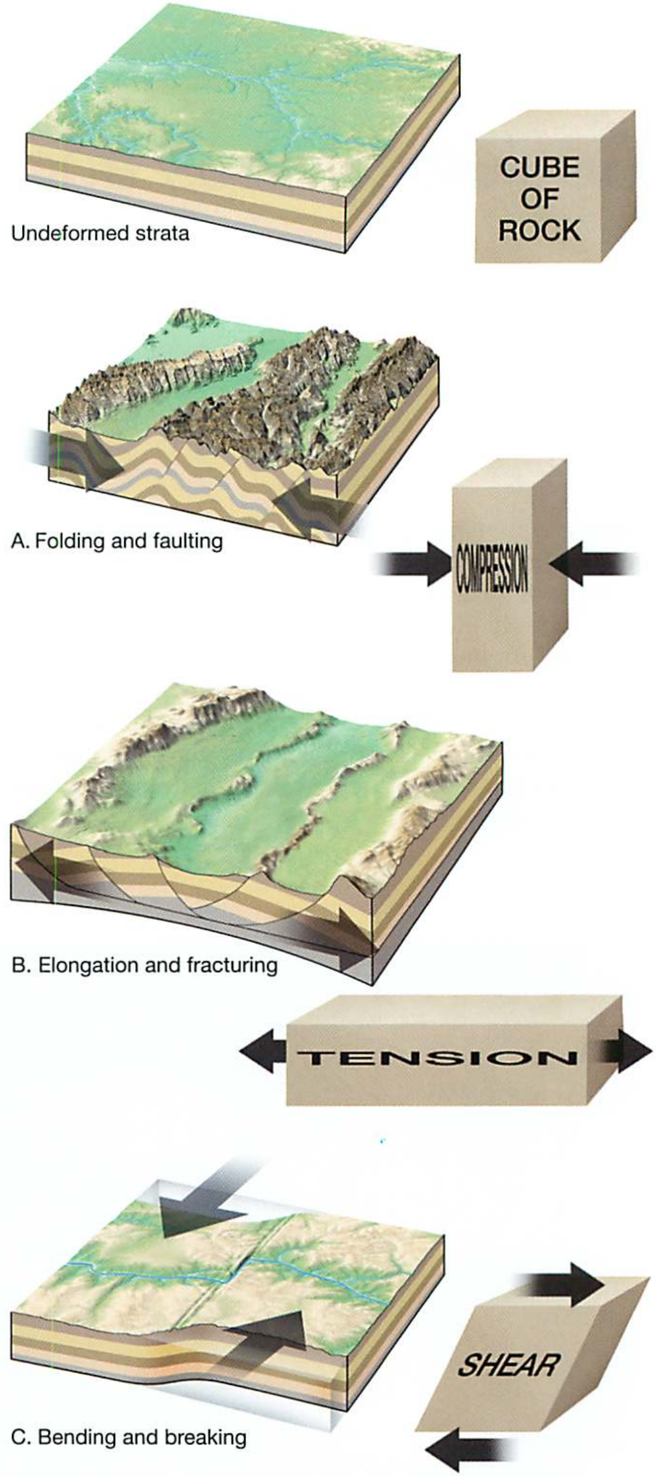


Figure 7.2 Simplified diagram showing the deformation of rock layers. **A.** Compressional stresses tend to shorten a rock body, often by folding. **B.** Tensional stresses act to elongate, or pull apart, a rock unit. **C.** Shear stresses act to bend or break a rock unit.

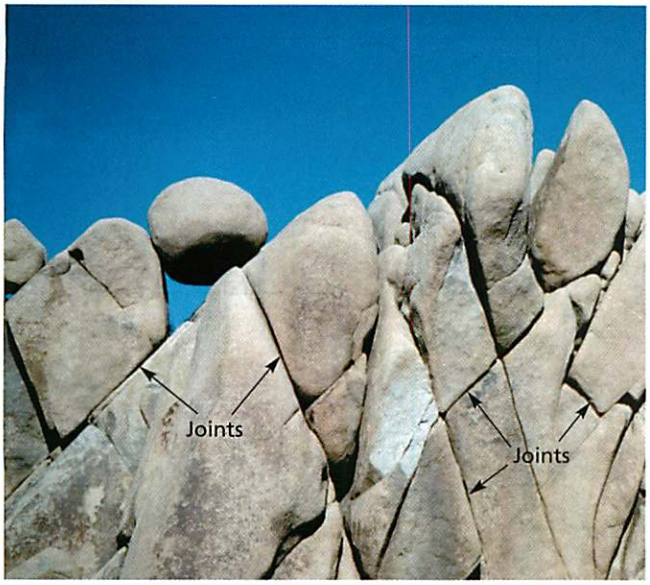


Figure 7.3 Joints are fractures along which no appreciable displacement has occurred. (Photo by E. J. Tarbuck)

Strike and Dip

Geologists use measurements called **strike** (trend) and **dip** (inclination) to help define the orientation or attitude of a rock layer or fault (Figure 7.4). By knowing the strike and dip of rocks at the surface, geologists can predict the nature and structure of rock units and faults that are hidden beneath the surface, beyond their view.

Strike is the compass direction of the line produced by the intersection of an inclined rock layer or fault with a horizontal plane at the surface (see Figure 7.4). The strike, or compass bearing, is generally expressed as an angle relative to north. For example, "north 10° east" (N10°E) means the line of strike is ten degrees to the east of north. The strike of the rock units illustrated in Figure 7.4 is approximately north 60° east (N60°E).

Dip is the angle of inclination of the surface of the rock unit or fault from the horizontal plane. Dip includes both an angle of inclination and a direction toward which the rock is inclined. In Figure 7.4 the dip angle of the rock layer is 30°. A good way to visualize dip is to imagine that a water line will always run down the rock surface parallel to the dip. The direction of dip will always be at a 90° angle to the strike. (To illustrate this fact, hold your closed textbook at an angle to the tabletop. The upper edge of your text represents the strike. Regardless of the way you point the text, the direction of dip of the book is always at 90°, or a right angle, to the strike.)

Typically, the strike and dip of rock units are shown on geologic maps. The standard map symbol for strike and dip is 20° . The long line shows the strike direction and the short line points in the direction of the dip. The number written at the end of the short dip line is the angle of dip. In Figure 7.4, the strike-dip symbol indicates that the rocks are dipping toward the southeast at a 30° angle from the horizontal plane (30°SE).

1. Figure 7.5 illustrates geologic map views (views from directly overhead) of two hypothetical areas showing a strike-dip symbol for a rock layer in each area. Complete the information requested below each map and draw a single large arrow on each map illustrating the direction of dip of the rock layer.

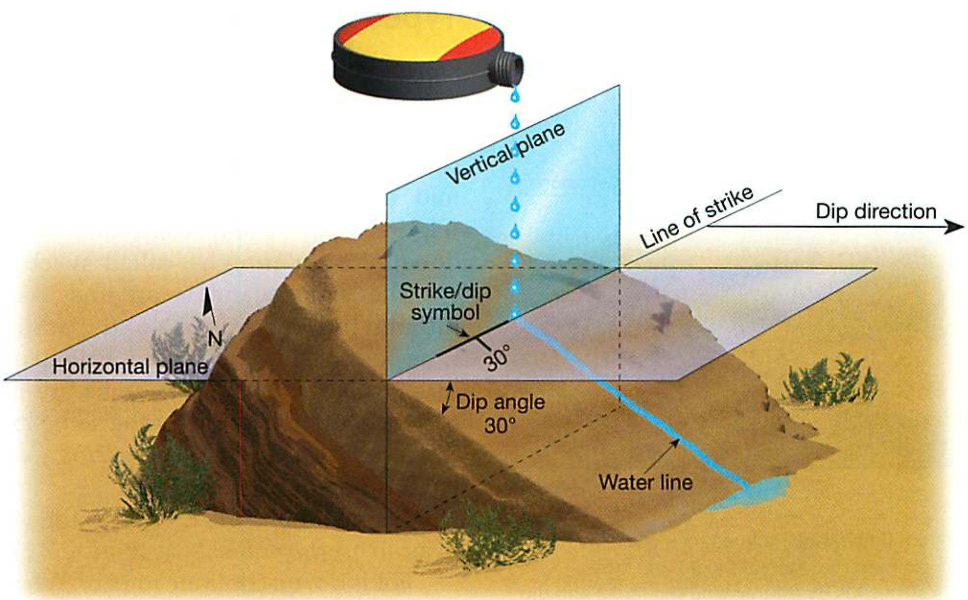


Figure 7.4 Determining the strike and dip of a rock layer.

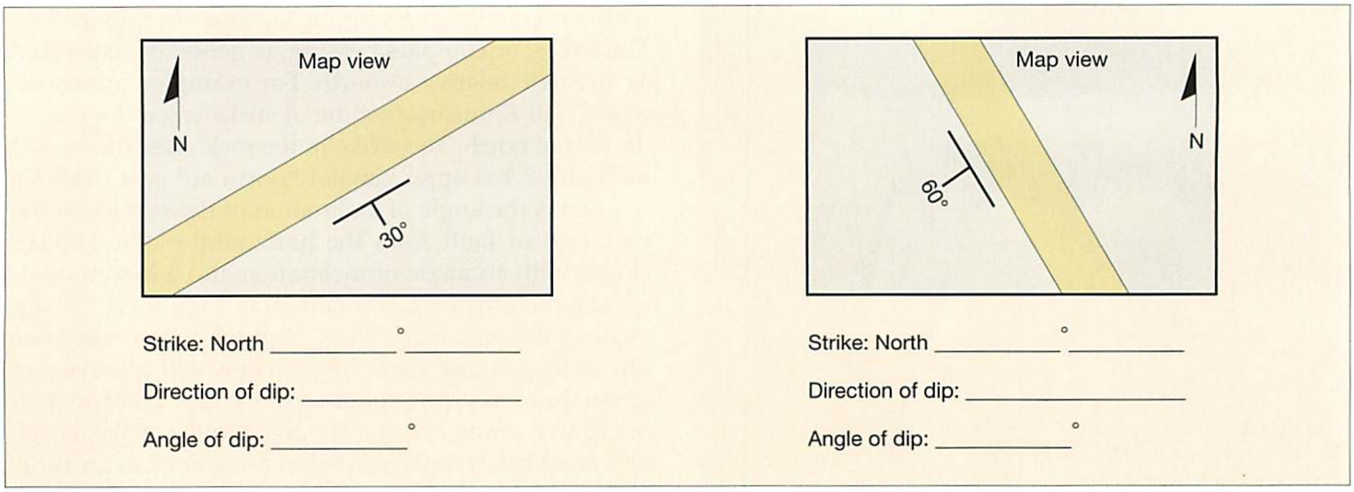


Figure 7.5 Geologic map views of two hypothetical areas.

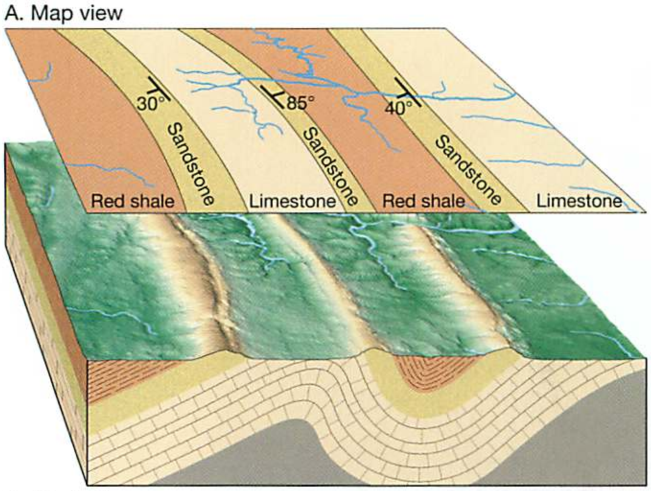
Block Diagrams

Block diagrams allow geologists to illustrate both the geologic map view and geologic **cross section** (view from the side or beneath the surface) of an area (Figure 7.6).

Use the block diagram as a guide while you answer questions 2, 3, and 4.

2. Use the information presented on the map view to complete the cross sections on the front and side of the block diagram illustrated in Figure 7.7.
3. Use the information supplied on the geologic map views to complete each of the block diagrams illustrated in Figures 7.8 and 7.9.

A. Map view



B. Block diagram

Figure 7.6 Block diagram illustrating inclined rock layers as they would appear in a geologic map view (top of block) and cross sections (front and side of block). By establishing the strike and dip of outcropping sedimentary beds on a map, geologists can infer the orientation of the structure below ground.

4. On Figure 7.10, use the following guidelines to sketch both a geologic map view and block diagram of an area.

Guidelines:

a. Four sedimentary layers of equal thickness exposed at the surface.
b. The strike of each layer is N45°W.
c. The direction of dip of each layer is to the northeast.
d. The angle of dip of each layer is 60°.

5. Show strike-dip symbols for each rock layer on both illustrations in Figure 7.10.

Types of Folds

During the process of mountain building, formerly flat-lying rocks are often compressed into a series of waves called *folds.* **Anticlines** and **synclines** are the two most common types of folds (Figure 7.11). Rock layers that fold upward forming an arch are called anticlines (Figure 7.12). Often associated with anticlines are downfolds, or troughs, called synclines (Figure 7.13).

The **axial plane** is an imaginary plane drawn through the long axis of a fold that divides it as equally as possible into two halves called *limbs* (Figure 7.14). In a *symmetrical fold,* the limbs are mirror images of each other and diverge at the same angle (see Figures 7.11 and 7.13). In an *asymmetrical fold* the limbs each have different angles of dip (see Figure 7.12). A fold where one limb is tilted beyond the vertical is referred to as an *overturned fold* (see Figure 7.11).

Folds do not continue forever. Where folds "die out" and end, the axis is no longer horizontal and the fold is said to be plunging (Figure 7.14B and Figure 7.15).

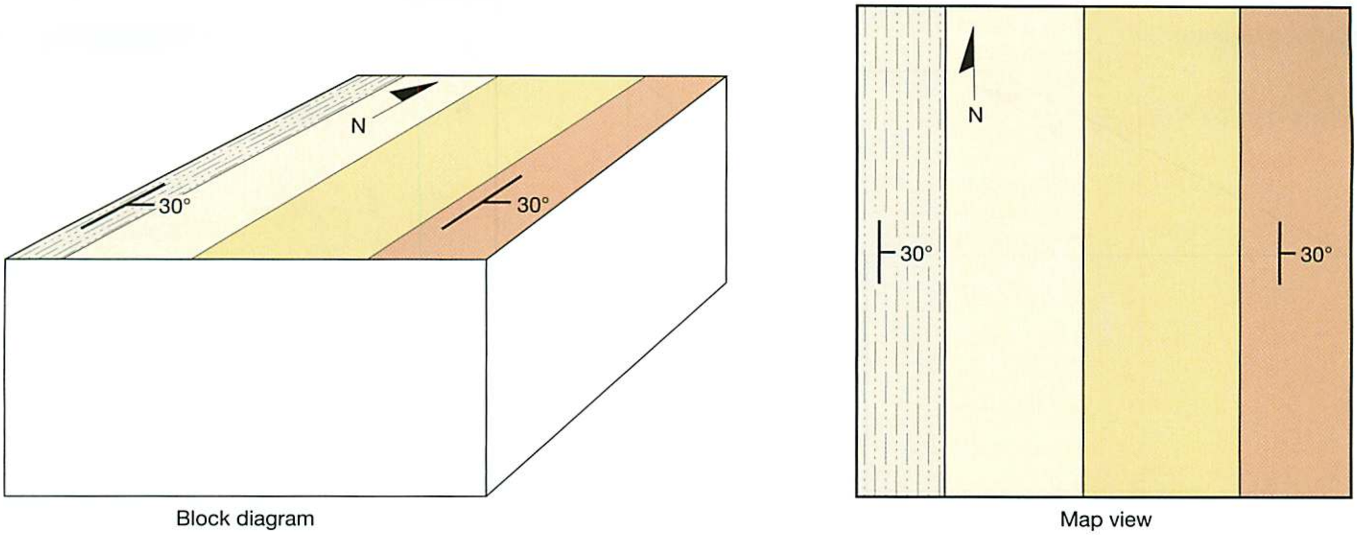


Figure 7.7 Block diagram and map view of a hypothetical area.

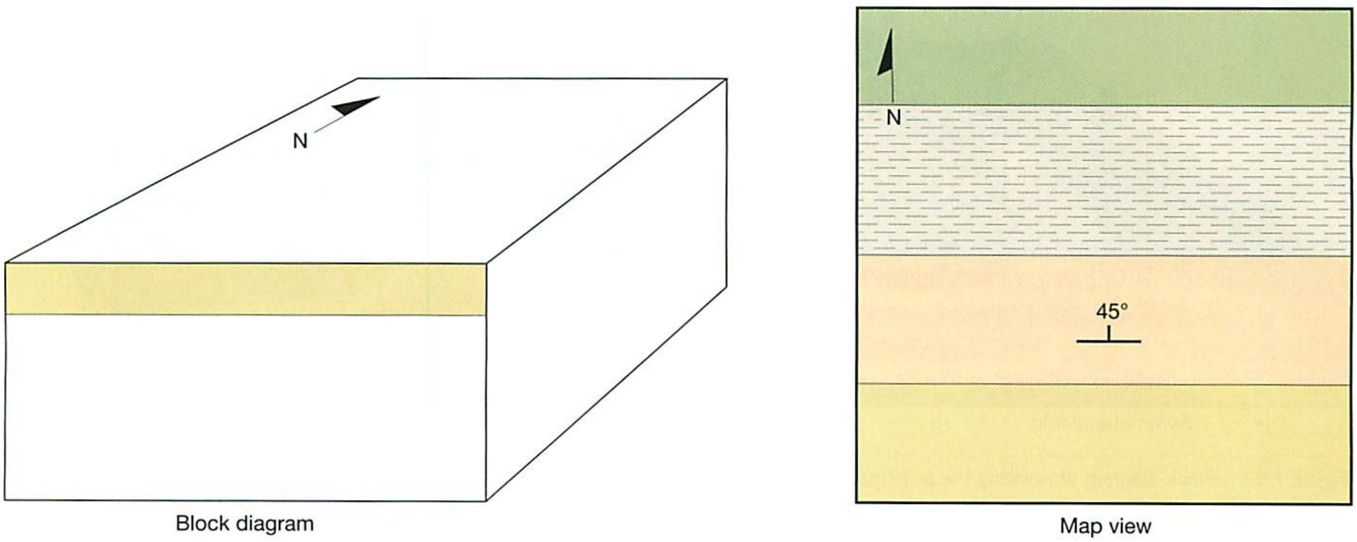


Figure 7.8 Block diagram and map view of a hypothetical area.

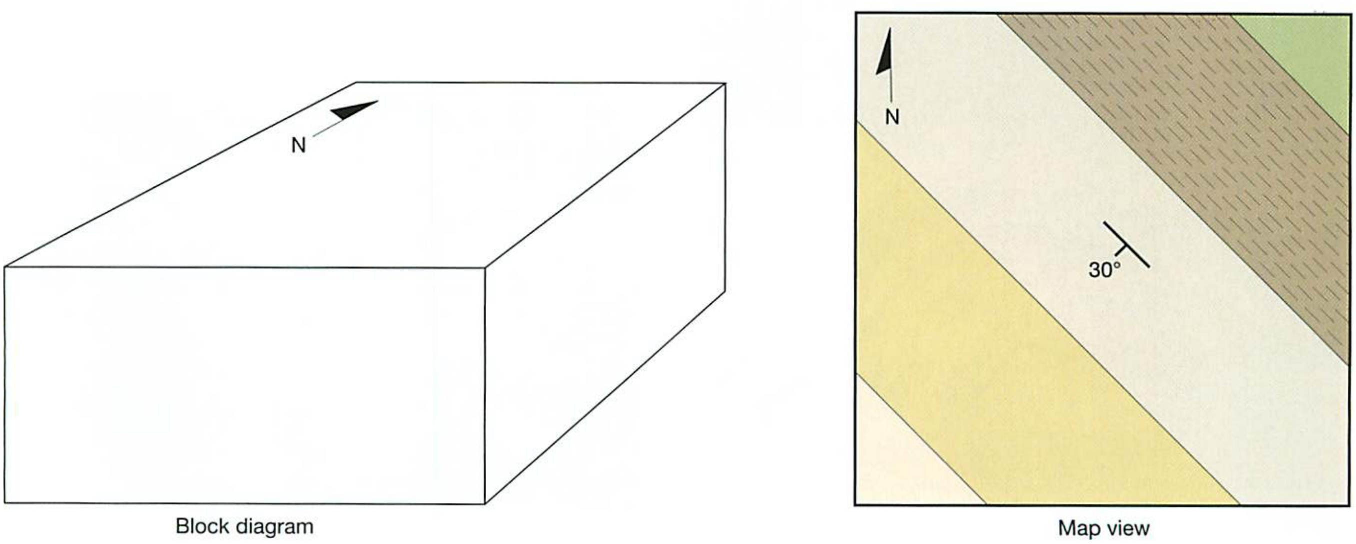


Figure 7.9 Block diagram and map view of a hypothetical area.

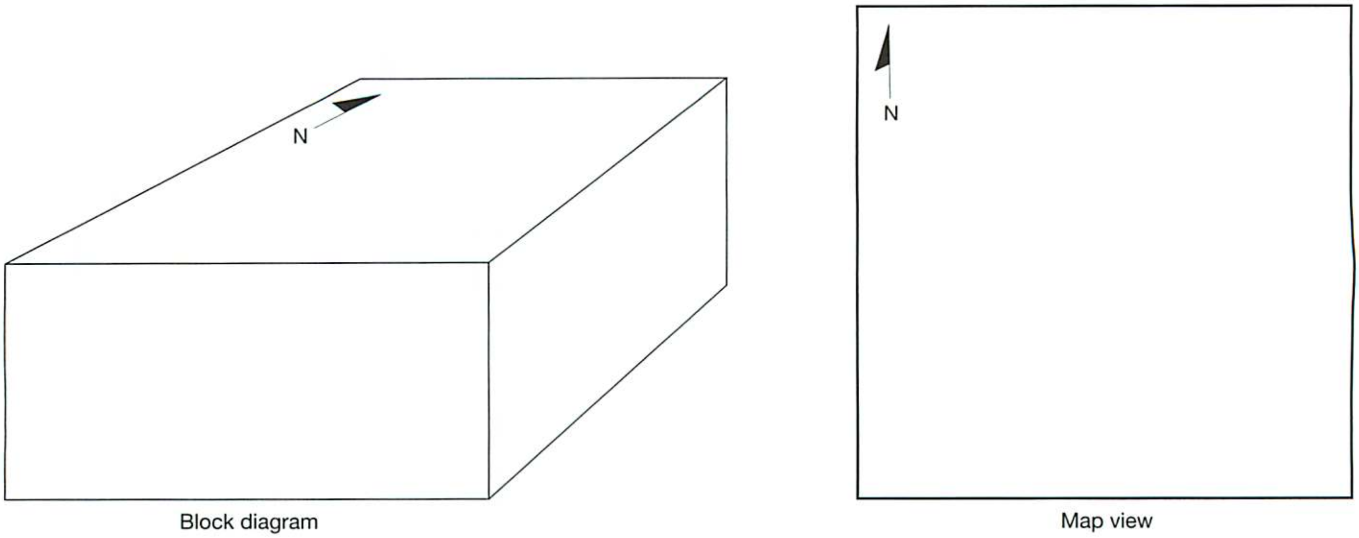


Figure 7.10 Block diagram and map view of a hypothetical area.

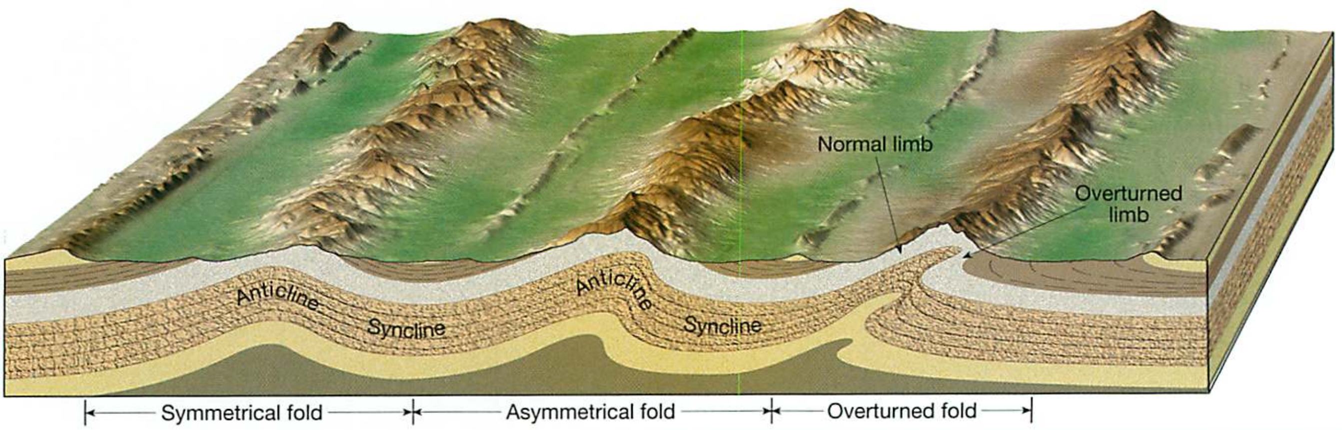


Figure 7.11 Block diagram illustrating the principal types of folded geologic structures.

Figure 7.12 An asymmetrical anticline. (Photo by P. Jay Fleisher)

Figure 7.13 A nearly symmetrical syncline. (Photo by E. J. Tarbuck)

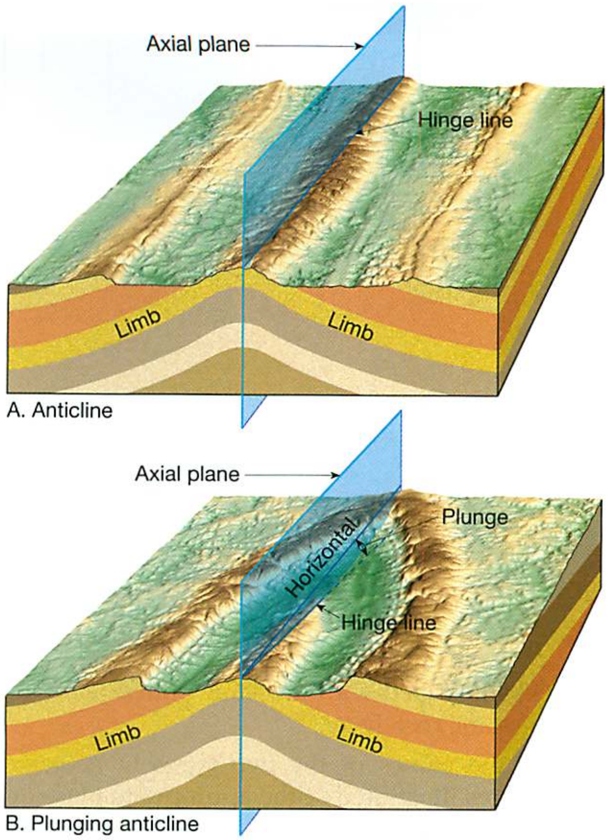


Figure 7.14 Features of simple folds.

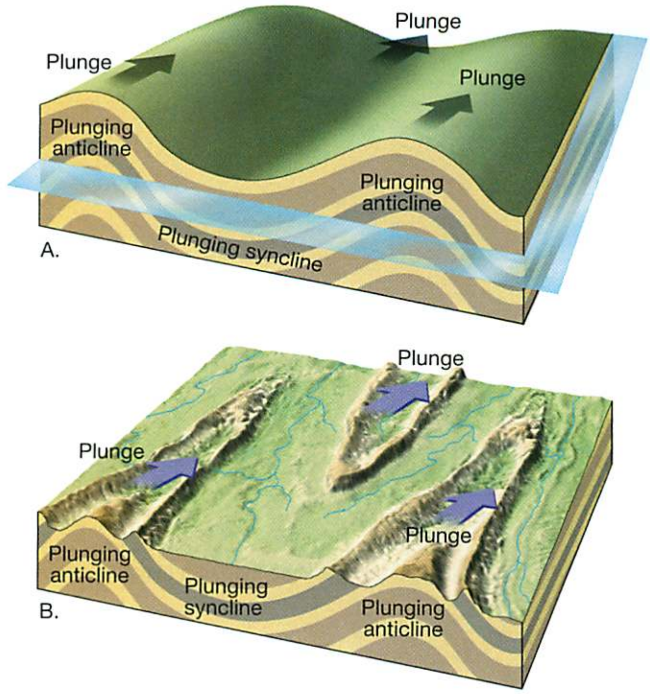


Figure 7.15 Plunging folds. **A.** Idealized view. **B.** View after extensive erosion.

In an anticline, rock layers dip away from the axial plane. If erosion levels an anticline, then the formerly deepest, and hence oldest, rock layers will be exposed on the surface at the axial plane (see Figures 7.11 and 7.15). In an eroded syncline, the layers dip toward the axial plane where the youngest, most recently deposited rock layer occurs (see Figures 7.11 and 7.15).

Figure 7.16 illustrates an eroded anticline and an eroded syncline. Use the figure to answer questions 6–15.

6. On each block diagram, label the type of fold, anticline or syncline, illustrated.
7. The *law of superposition* (see Exercise 6) states that, in most situations concerning layered rocks, the oldest rocks are at the bottom. With this in mind, list by number the rock layers in each block diagram from oldest to youngest.

   Anticline:

   Oldest ______________________ Youngest

   Syncline:

   Oldest ______________________ Youngest

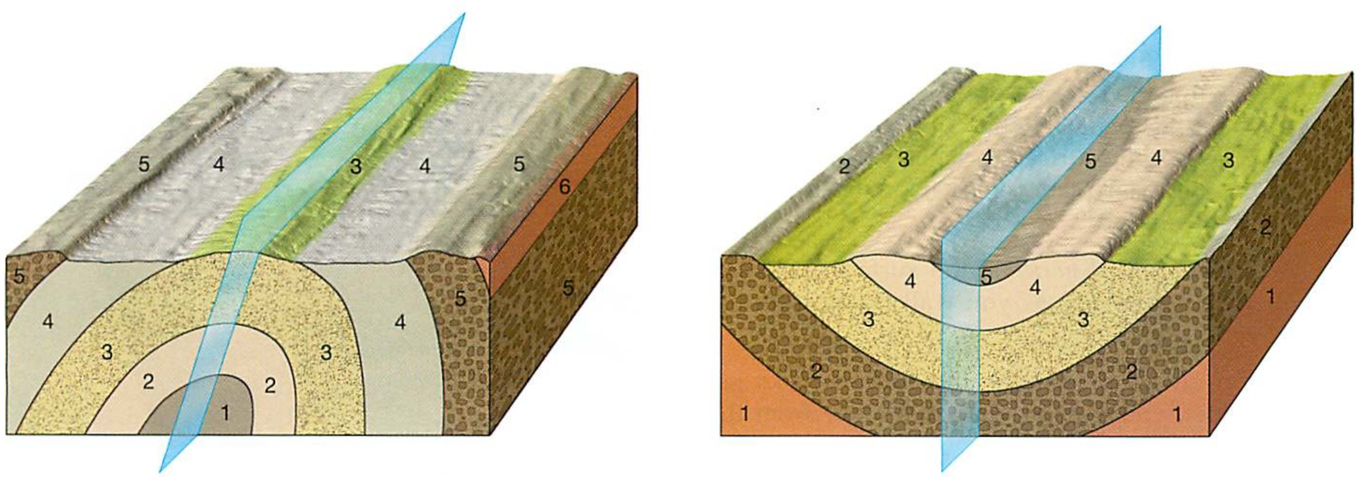
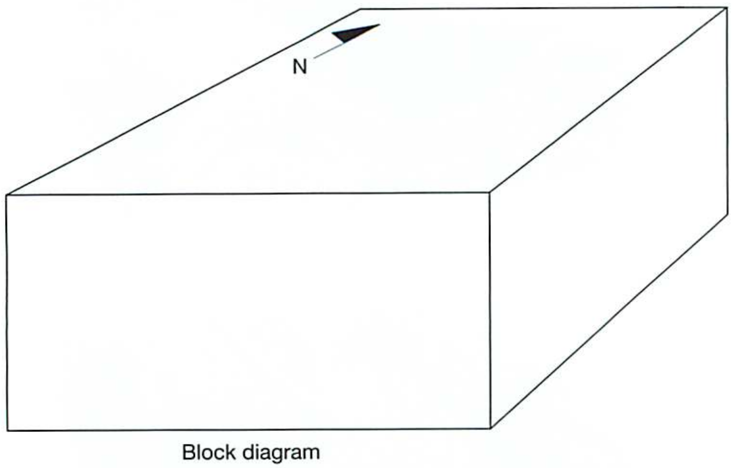


Figure 7.16 Idealized eroded folds.



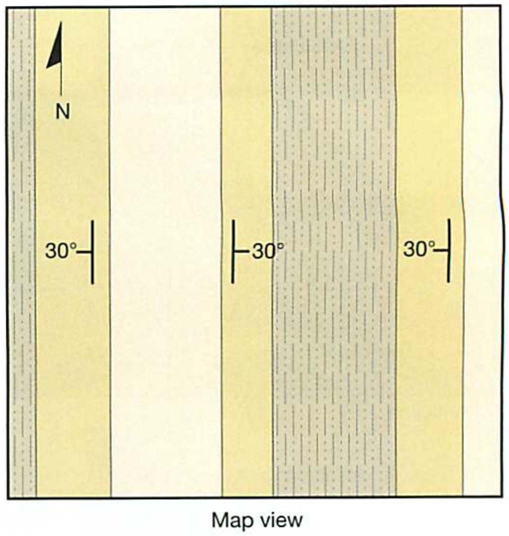


Figure 7.17 Block diagram and geologic map of a hypothetical area.

8. The near-vertical plane through each block diagram represents each fold's ________________ ________________________________.
9. Draw appropriate strike and dip symbols on the surface of each block diagram for a rock layer on both sides of the axial plane.
10. In the anticline, all the rock layers are dipping (toward, away from) the axial plane. Circle your answer.
11. In the syncline, all the rock layers are dipping (toward, away from) the axial plane. Circle your answer.
12. The anticline is (symmetrical, asymmetrical), and the syncline is (symmetrical, asymmetrical). Circle your answers.
13. Both folds are (plunging, nonplunging) folds. Circle your answer.
14. Using the word "old," label the area(s) of the oldest rocks exposed on the surface of the map view portion of both block diagrams.
15. By circling the correct response, complete the following statements that describe what happens to the ages of the surface rocks as you walk away from the axial plane of each of the following structures.
    a. On an *eroded anticline* the surface rocks get (older, younger) as you walk away from the axial plane.
    b. On an *eroded syncline* the surface rocks get (older, younger) as you walk away from the axial plane.
16. On Figure 7.17, complete the block diagram using the information provided on the map view. Rocks illustrated with the same pattern are part of the same rock layer.
17. Write the names of the two types of geologic structures illustrated at the appropriate place on the block diagram in Figure 7.17.

Anticlines and synclines are linear features caused by compressional forces. Two other types of folds, **domes** (Figure 7.18) and **basins,** are often nearly circular features that result from vertical displacement. Upwarping of sedimentary rocks produces a dome, whereas a basin is a downwarped structure.

18. Draw several appropriate strike and dip symbols on Figure 7.18.

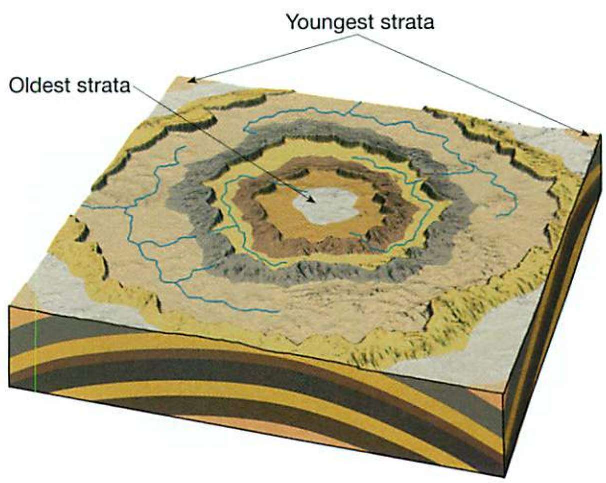


Figure 7.18 A typical eroded dome results in an outcrop pattern that is roughly circular with the rocks dipping away from the center.

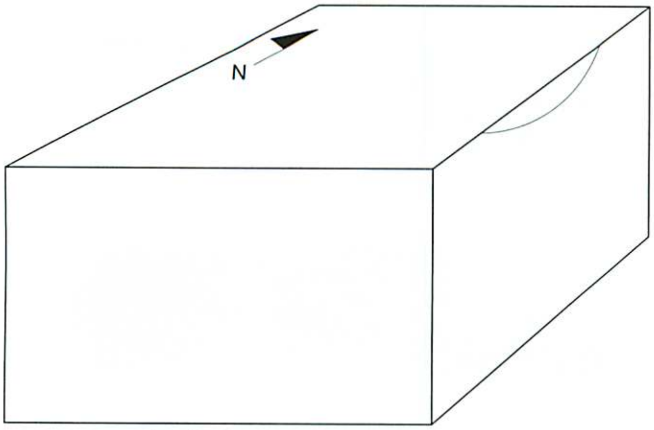


Figure 7.19 Block diagram of an eroded basin.

19. On Figure 7.19, complete the geologic block diagram for the indicated feature. Draw a minimum of four rock layers with appropriate strike and dip symbols on the diagram and label the oldest and youngest rocks.
20. Describe the directions of dip and map view locations of the oldest and youngest surface rocks that comprise the feature.

____

____

____

____

Types of Faults

Faults are fractures or breaks in rocks along which movement has occurred. As with folds, geologists also use strike and dip to describe the attitude of faults. Faults in which the relative movement of rock units is primarily vertical (along the dip of the fault plane) are called **dip-slip faults** (Figure 7.20). When the dominant motion of rock units is horizontal (in the direction of the strike), the faults are called **strike-slip faults**. Although most faults exhibit both vertical and horizontal displacement, this investigation will only consider the two fundamental motions.

Dip-Slip Faults

Since very few faults have a vertical dip, geologists describe the different types of dip-slip faults by noting the relative motion of the blocks on top and below the fault. If the hanging wall (the top of the fault, where miners who may be extracting minerals deposited in

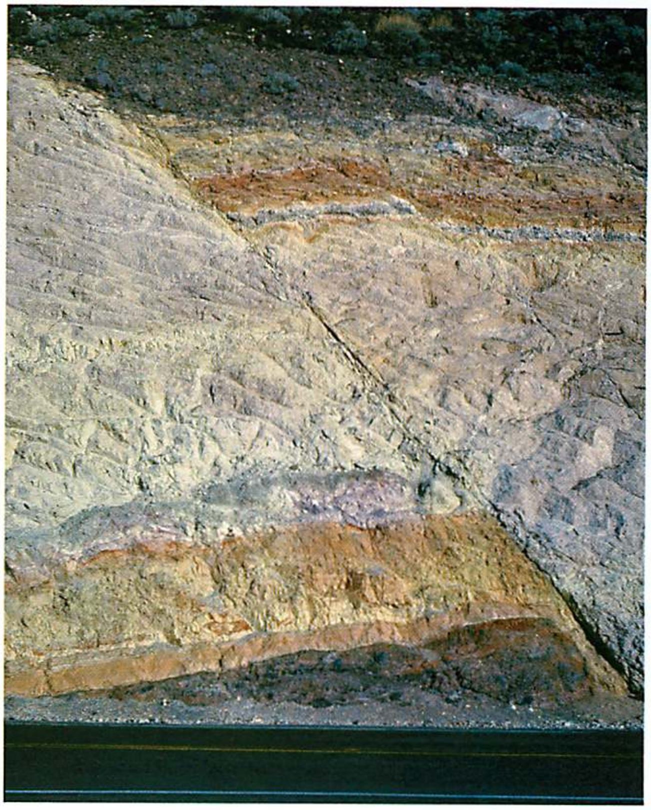


Figure 7.20 A typical dip-slip fault where the relative movement of the rock units is primarily vertical. (Photo by E. J. Tarbuck)

the fault would hang their tools) moves down relative to the footwall (the bottom of the fault, where the miner stands), the fault is classified as a **normal fault** (Figure 7.21A). Normal faults result from tensional forces. Compressional forces will often result in a **reverse fault**, where the hanging wall moves up relative to the footwall (see Figure 7.21B).

Use Figure 7.21 to answer questions 21 and 22.

21. Draw the appropriate strike-dip symbol for each fault on the surface of the large block diagrams in Figure 7.21.
22. On each large block diagram in Figure 7.21, write the word "older" or "younger" to indicate the relative ages of the surface rocks on both sides of the fault trace. Then complete the following statements by circling the correct response.
    a. On an eroded normal fault, the rocks at the surface on the direction of dip side of the fault are the (youngest, oldest) surface rocks.
    b. On an eroded reverse fault, the rocks at the surface on the direction of dip side of the fault are the (youngest, oldest) surface rocks.
23. Complete Figure 7.22 by illustrating an eroded reverse fault on the right-hand diagram. On diagram B, draw an appropriate strike-dip symbol

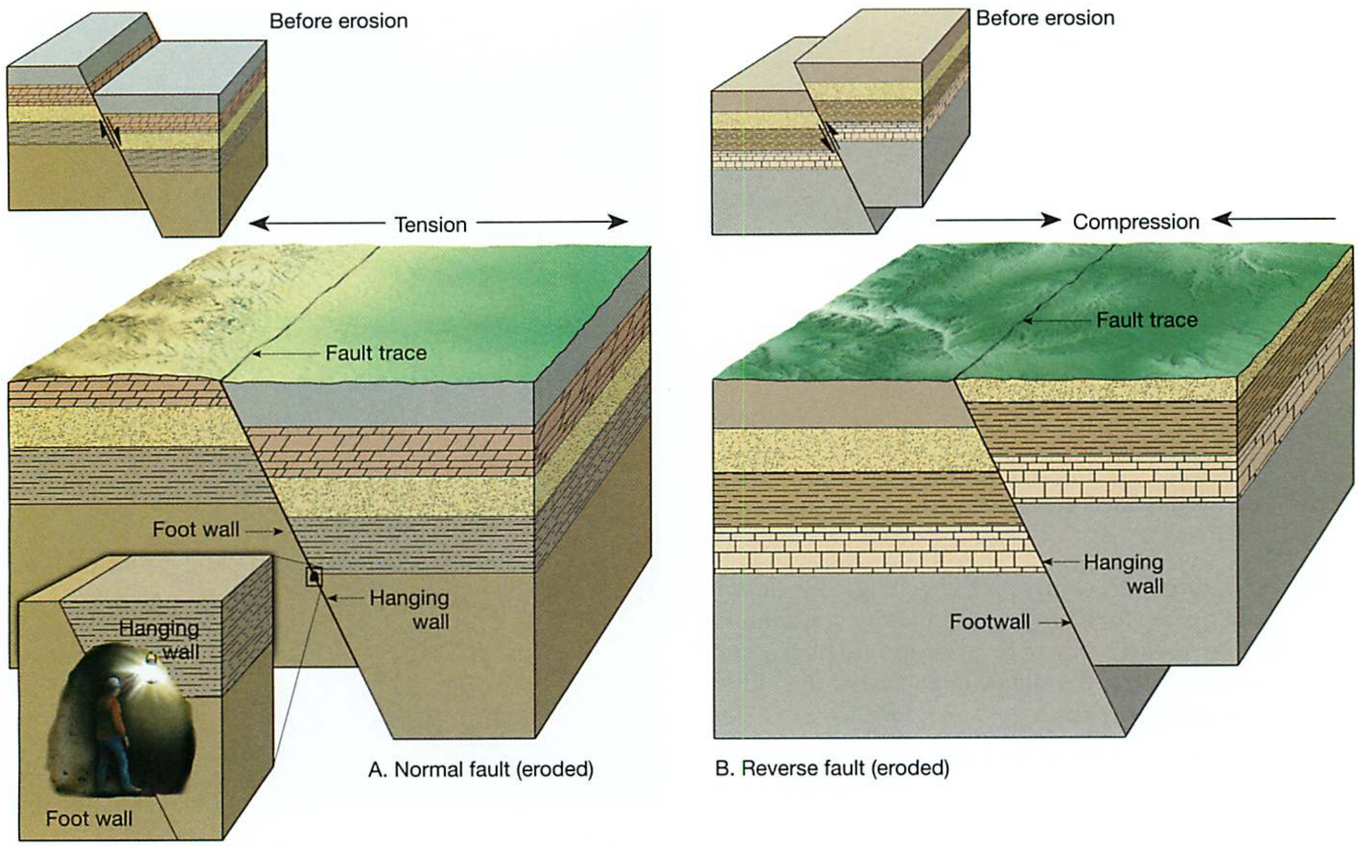


Figure 7.21 Block diagrams illustrating simplified eroded versions of the two common types of dip-slip faults. **A.** Normal fault. **B.** Reverse fault. The arrows by each fault show the relative motions of the blocks on both sides of the fault.

for the fault and arrows on both sides of the fault to illustrate the relative motion of the blocks.

Strike-Slip Faults

Strike-slip faults result from horizontal displacement of rock units along the strike or trend of a fault (Figure 7.23). Many strike-slip faults, such as the famous San Andreas fault system in California, are near-vertical faults that exhibit tens or hundreds of kilometers of displacement along their boundaries.

A strike-slip fault is described as being either a **right-lateral fault** or a **left-lateral fault** depending on the relative motion of the blocks on either side of the

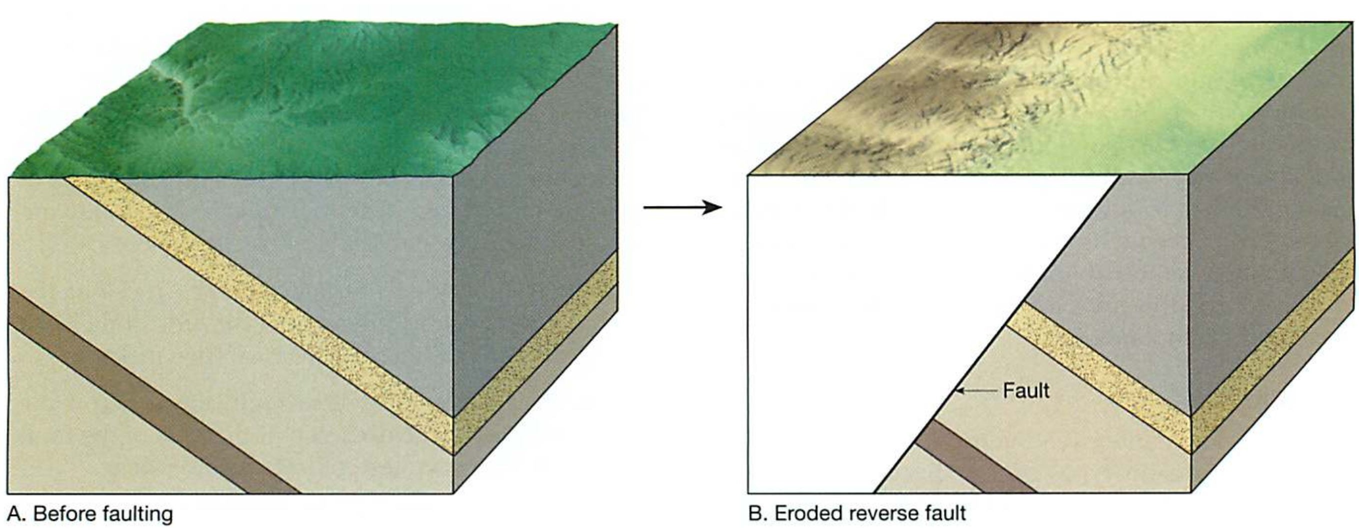


Figure 7.22 Block diagram of an eroded reverse fault. **A.** Before faulting, **B.** after faulting and erosion.

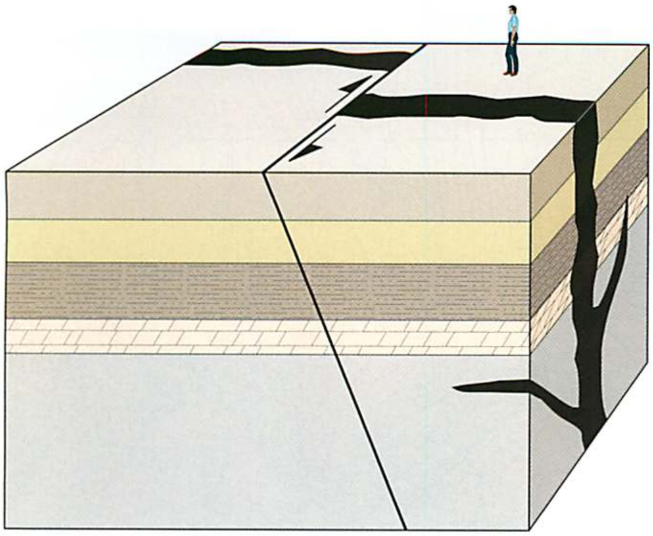


Figure 7.23 Block diagram illustrating a simplified eroded version of a strike-slip fault. The arrows on the surface show the relative motions of the blocks on both sides of the fault.

fault. If you are standing on one side of the fault, looking across the fault to the other side, and the opposite side has been displaced to your right, the fault is called a right-lateral fault. On the other hand, if the side opposite the fault has moved to the left, the fault is a left-lateral fault.

24. The fault illustrated in Figure 7.23 is a (right, left)-lateral fault. Circle your answer.
25. On Figure 7.24, complete the right-hand block diagram by illustrating a left-lateral fault. Draw arrows on both sides of the fault on the surface to illustrate the relative motion of each block.

Examining a Geologic Map

Figure 7.25 is a portion of the Devils Fence, Montana, geologic map with an abbreviated "Explanation" for the map shown in Figure 7.26. Examine the map and explanation, then answer questions 26–34. (*Note:* You may find the geologic time scale, Figure 6.14 in Exercise 6, helpful.)

26. What is the scale of the Devils Fence map?

    Scale: ____________ : ____________, which means one inch on the map equals inches, or approximately _____ mile(s).

27. What are the names and approximate age in years of the youngest and oldest *sedimentary* rock units shown in the map "Explanation"?

    Youngest sedimentary rock unit shown in the "Explanation":

    Name: ______________________________

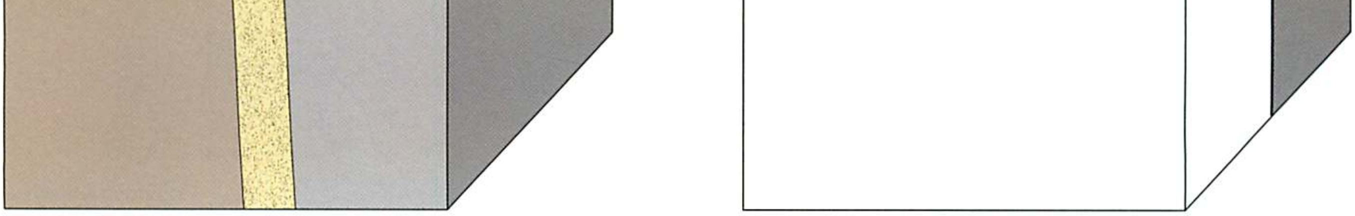
    Age in years: ________________ million

    Oldest sedimentary rock unit shown in the "Explanation":

    Name: ______________________________

    Age in years: ________________ million

28. On the geologic structure shown on the eastern half of the map, write the word "oldest" where the oldest sedimentary rock unit is exposed at the surface and the word "youngest" where the youngest sedimentary rocks occur.
29. The igneous intrusive rocks near the center of the structure shown on the eastern half of the map are (younger, older) than the youngest sedimentary rocks. Circle your answer.



A. Before faulting

B. After (left-lateral) faulting

Figure 7.24 Block diagram of an eroded left-lateral fault. **A.** before faulting, **B.** after left-lateral faulting.

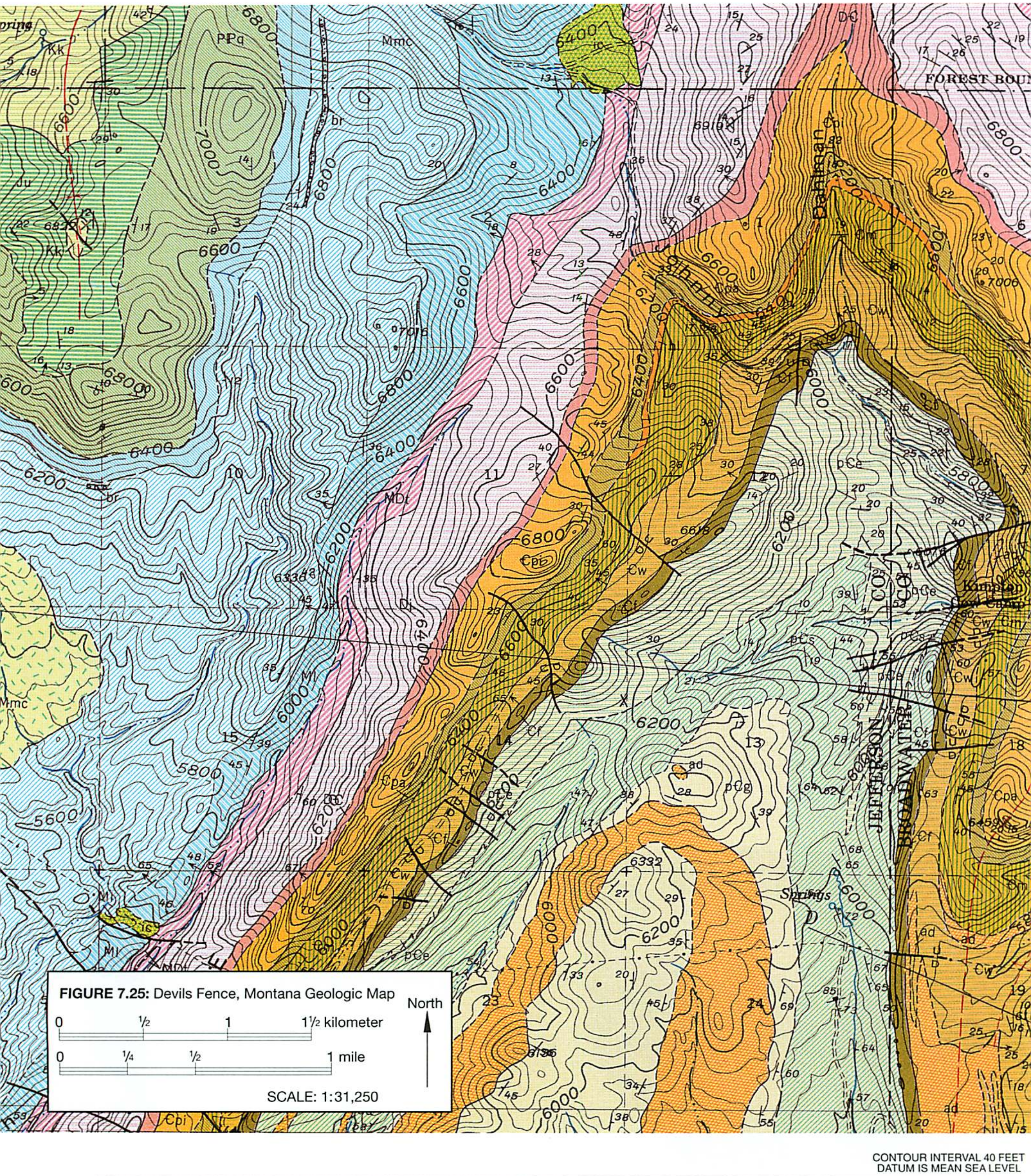


Figure 7.25 Geologic map—Devils Fence, Montana. (Source: U.S. Geologic Survey, Professional Paper 292)

EROSIONAL UNCONFORMITY

PERMIAN

Pp / PPq

Phosphoria formation
Brown and gray chert and sandstone, in part phosphatic; may locally contain one or two thin beds of phosphate rock, Pp. In places mapped with the Quadrant formation, PPq

CARBONIFEROUS — PENNSYLVANIAN

Pq

Quadrant formation
Light-colored quartzitic sandstone and interbedded light-gray sugary-textured sandy dolomite

PMa

Amsden formation
Red to grayish-red mudstone, shale, and subordinate amounts of carbonate rock with interbeds of gray, brown, or yellow argillaceous sandstone in upper and lower parts; middle part of medium- to dark-gray thick-bedded dolomite

EROSIONAL UNCONFORMITY(?)

MISSISSIPPIAN — *Madison group*

br Mmc

Mission Canyon limestone
Medium-gray to light-gray medium-grained thickly and indistinctly bedded limestone, with a few thin siliceous layers in lower 200 ft and sparse gray chert nodules and lentils in upper half. A breccia unit, br, about 200 ft below top of formation has been mapped locally

Ml

Lodgepole limestone
Upper part of medium-gray fine- to medium-grained limestone in distinct beds as much as 3 ft thick alternating with zones of much thinner beds containing rare mudstone partings; lower part of medium-gray limestone in beds 1 in. to 1 ft thick with partings and interbeds of yellow to red calcareous mudstone; grades into Mission Canyon limestone through a 150- to 200-ft zone

DEVONIAN AND MISSISSIPPIAN — *Upper Devonian and Mississippian*

li MDt

Three Forks shale
Predominantly greenish-gray and brown shale with subordinate amounts of interbedded sandstone and limestone. Dolomitic siltstone at top. Locally a 10- to 25-ft fossiliferous limestone unit, li, has been mapped

DEVONIAN — *Upper Devonian*

Dj

Jefferson dolomite
Dark-gray granular-weathering fetid well-bedded dolomite with subordinate amounts of dark-gray limestone and light-gray dolomite

Upper Cambrian and Upper Devonian

EROSIONAL — — — DC — — — UNCONFORMITY

Maywood and Red Lion formations undifferentiated,
Varicolored, generally in shades of red and yellowish-brown, argillaceous, dolomitic, and calcareous rocks; poorly exposed

CAMBRIAN — *Upper Cambrian*

Cpi

Pilgrim dolomite
Comprises three units. Upper unit is light-gray thick-bedded dolomite commonly mottled medium-gray near base. Middle unit is light- to medium-gray crystalline limestone irregularly ribboned with yellowish-gray silty dolomite. Lower unit is mottled light- and dark-gray dolomite with sparse intraformational conglomerate; locally, basal 8 to 10 ft is bluish-gray limestone

Middle Cambrian

Cpa

Park shale
Olive-gray, gray, and light-brown shale with minor amounts of argillaceous limestone, siltstone, and sandstone

Cm

Meagher limestone
Comprises three units. Upper and lower units are medium-gray limestone irregularly ribboned or mottled with yellowish-orange, yellowish-brown, and yellowish-gray dolomite. Middle unit is thickly and indistinctly bedded medium-gray limestone, commonly with oolitic beds

CAMBRIAN — *Middle Cambrian*

Cw

Wolsey shale
Upper half is interbedded gray argillaceous limestone and greenish- and yellowish-gray calcareous mudstone and shale. Lower half is greenish-gray and drab shale with some interbeds of sandstone and limestone; many beds are micaceous, some are glauconitic

Cf

Flathead quartzite
White to pale shades of gray, pink, brown, and purple medium- to thick-bedded homogenous even-grained quartz sandstone; most beds are cemented to vitreous quartzite; thin, discontinuous sparse pebble zones in lower part; crossbedding common

UNCONFORMITY

PRECAMBRIAN — *Upper Precambrian, Belt series*

pCe

Empire shale
Gray, greenish-gray, and brown, siliceous mudstone or argillite with interbeds of quartzite sandstone and shale. Intertongues with Spokane shale

pCs

Spokane shale
Grayish-red mudstone, shale, and sandstone, with a few thin beds of limestone near base

pCg

Greyson shale
Gray and brown mudstone or shale alternating with sandstone or quartzite. Base not exposed. Grades into Spokane shale

INTRUSIVE ROCKS

YOUNGER INTRUSIVE ROCKS

TERTIARY(?) — *Lower Tertiary(?)*

gd

Granodiorite and quartz diorite
In Sagebrush Park stock

ic

Composite or hybrid intrusives
Small plutons containing diverse and unusual rocks including olivine-rich and quartz-rich types

OLDER INTRUSIVE ROCKS

CRETACEOUS — *Upper Cretaceous*

ba

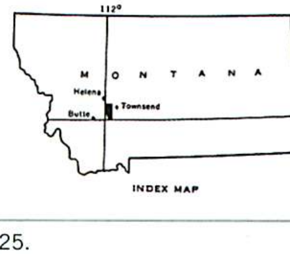
Basalt and related rocks
Dark-gray to greenish-black fine- to medium-grained rocks, mainly as sills

ad

Andesite porphyry, diorite porphyry, and related rocks
Greenish-gray to dark-gray porphyritic rocks with phenocrysts of plagioclase and hornblende or augite; mainly as sills

hl

Hornblende lamprophyre
Very fine grained gray rock with conspicuous hornblende phenocrysts



INDEX MAP

Figure 7.26 "Explanation" for the geologic map of Devils Fence, Montana, Figure 7.25.

30. Examine the strike and dip of the rock units on the Devils Fence geologic map. Draw several large arrows on the map pointing in the direction of dip of several of the rock units. Make sure you examine the entire map. Then answer questions 30a and 30b.

   a. Near the center of the map, in sections 11 and 14, the rocks are dipping to the (northwest, southeast). Circle your answer.

   b. The same rocks that occur in the southeast of section 14 are dipping to the (south, east) in the southeast area of the map, in the eastern halves of sections 13 and 24.

31. What is the approximate angle of dip of the rock units in section 15?

   Angle of dip = ________°

32. Draw a dashed line representing the hinge line of the large geologic structure illustrated in the eastern half of the map. Label the line "hinge line."

33. The geologic structure present over the majority of the eastern half of the map is a plunging (anticline, syncline). Circle your answer and give two lines of evidence that support your choice.

   ____

   ____

Examine the faults marked with bold black lines that occur in section 14 on the northwest limb of the fold. The relative motion of the faults is shown with a "U" on the side of the fault that has moved up and a "D" on the downward side. Although strike and dip of the faults is not given on the map, assume the direction of dip is to the southwest.

34. Label an example of a normal fault and a reverse fault in section 14 on the geologic map.

Geologic Maps and Structures on the Internet

Use the concepts presented in this exercise to investigate geologic structures and maps by completing the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

Geologic Maps and Structures

Date Due: ______________________

Name: ______________________

Date: ______________________

Class: ______________________

After you have finished Exercise 7, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. Figure 7.27 is a simplified geologic map. In the spaces provided, describe the strike and dip of the igneous intrusion illustrated on the map.

   Strike: North ______° ______

   Angle of dip: ______°

   Direction of dip: ______

2. In the center and upper-left of Figure 7.27, draw a map view of an eroded plunging syncline. Show at least three different sedimentary beds and indicate the dip and strike of each bed with the proper symbol.

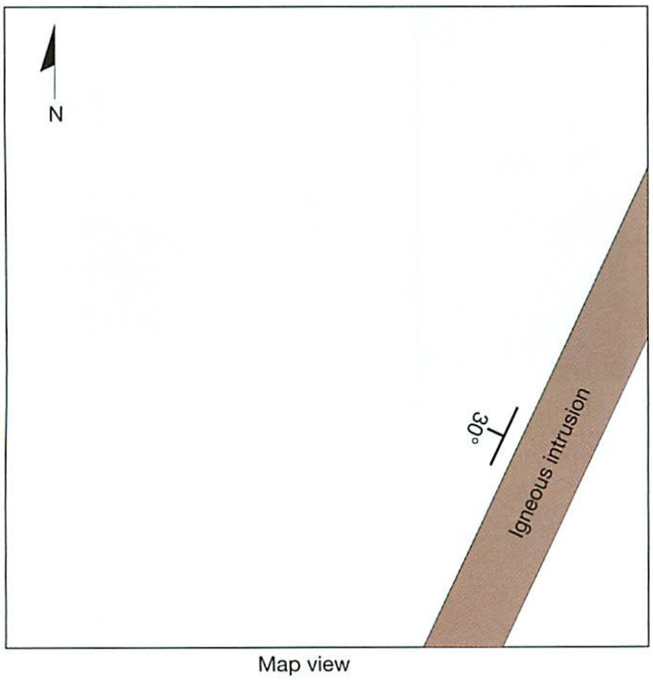


Figure 7.27 Simplified geologic map.

3. What type of geologic structure is illustrated in the eastern half of the Devils Fence geologic map, Figure 7.25? List two lines of evidence in support of your choice.

   ____

   ____

4. Describe the geologic structures that are illustrated in Figure 7.6. What force(s) caused their formation?

   ____

   ____

   ____

5. (Compression, Tension) was the type of stress most likely responsible for producing the geologic structures in Figure 7.25. Circle your answer.

6. Define the following terms.

   Strike: ______________________

   Dip: ______________________

   Symmetrical anticline: ______________________

   Normal fault: ______________________

   Left-lateral fault: ______________________

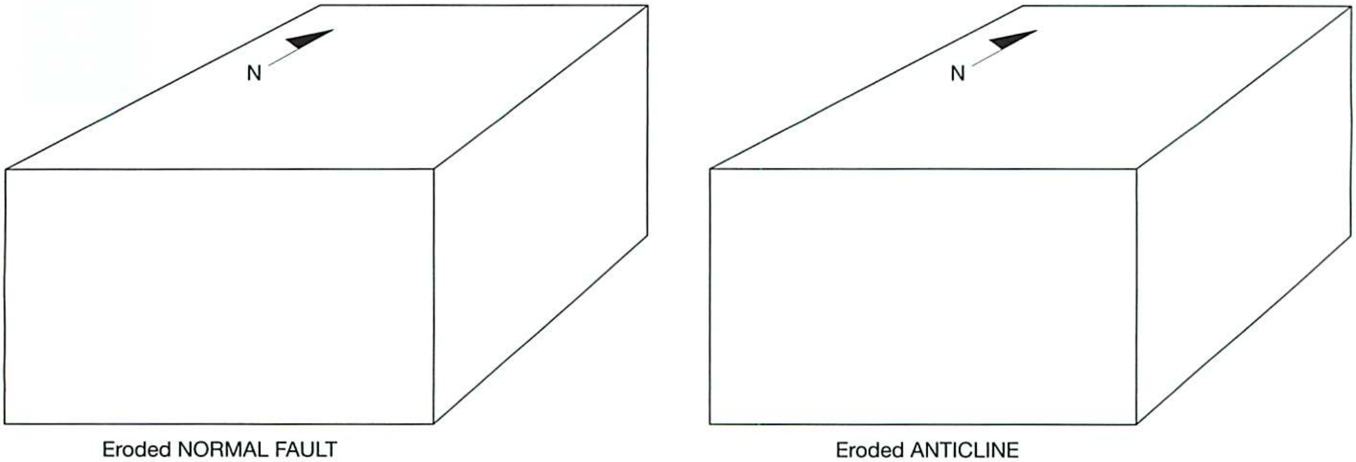


Figure 7.28 Block diagrams of an eroded normal fault and an eroded anticline.

7. On Figure 7.28, complete each of the block diagrams by illustrating the indicated geologic structure. Show a minimum of four rock layers and draw the appropriate strike-dip symbols on the surface of each block diagram.

8. With reference to the axial plane, where are the youngest rocks located in an eroded syncline?

____

9. Label the hanging wall and footwall on each of the two faults illustrated in Figure 7.29. On each photo, draw arrows showing the relative movement on both sides of the fault. Name the type of fault illustrated on each photo and describe the forces that most likely produced it.

A. _______________________________________

____

B. _______________________________________

____

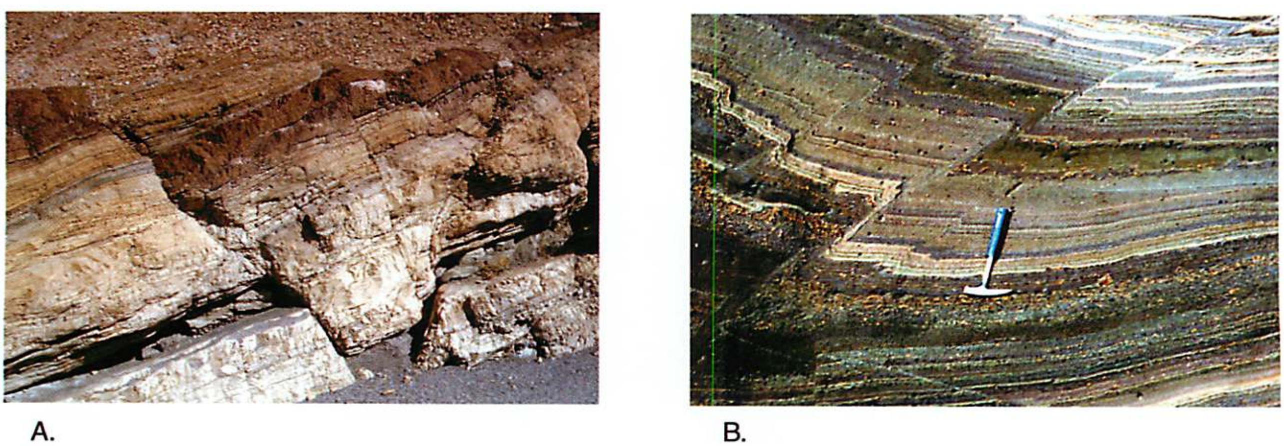


Figure 7.29 Photographs of two faults to be used with question 9. (Photos by Marli Miller)