LAB 8

Rock Structures

OBJECTIVES

- **To learn how to measure the orientation of planar geologic features such as bedding**
- **To learn some basics about geologic maps and cross sections**
- **To learn types of rock behavior and forces of deformation**
- **To learn types of folds and faults**
- **To understand different types of rock masses and learn their relationships to each other**

The three types of rocks you have learned about in previous labs combine to make up the crust of the Earth in various shapes and masses. Some are layers, some are massive bodies (non-layered bodies) that underlie large regions; others have more complex shapes. The features of a rock and the general arrangement or relative positions of rock masses at field and regional scales are known as geologic **structures.** Sometimes various processes in the Earth — especially major Earth movements (see plate tectonics, in Lab 12), and metamorphism — change the shape of rocks after they have formed. The general term for these changes is **deformation,** which leads to the formation of different structures. In this lab we will look at the different types of rock masses, their relationships to each other, and their deformation — in other words *rock structures*. Two ways to display these relationships are in geologic maps and cross sections.

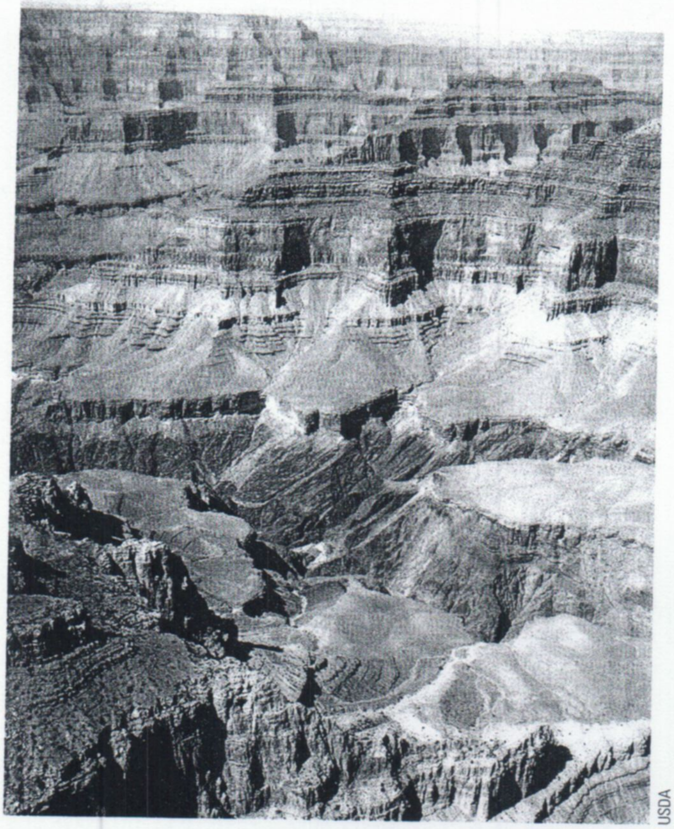
DEFORMATION OF ROCK MASSES

Rock type influences deformation of rock masses. We begin with sedimentary rock masses because — although they do not make up the largest volume of the Earth's crust — sedimentary rocks are the most widespread rocks at the surface. The most common and dominant form that large bodies of sedimentary rocks have is layering or bedding (■ Figure 8.1), and the space between layers is a **bedding plane**. (We'll say more about this topic and its close relation to geologic time in Lab 9.) Layers of sedimentary rock are especially useful in detecting deformation because they can easily become bent, folded, and broken or faulted. Igneous and metamorphic rocks also undergo deformation, and again it is the layered varieties such as lava flows, volcanic ash beds, and foliated metamorphic rocks that show deformational structures the best.

Measurement of Orientation of Bedding

Deformation often moves bedding planes or volcanic layers from their original horizontal position so that they are found tilted at various angles. The planes may then have many different orientations, such as vertical, horizontal, or anything in between. The orientation of a plane — also called its **attitude,** or its **strike** and **dip** — is described by three quantities: the strike, the dip direction, and the dip angle (■ Figure 8.2).

- The **strike** is the direction of any horizontal line on the plane. Geologists measure strike in one



USDA

Figure 8.1

Sedimentary bedding in the Grand Canyon. The Colorado River has cut a cross section through horizontally-layered sedimentary rocks at the Grand Canyon, Arizona. Foliated metamorphic rocks are visible in the deepest part of the canyon.

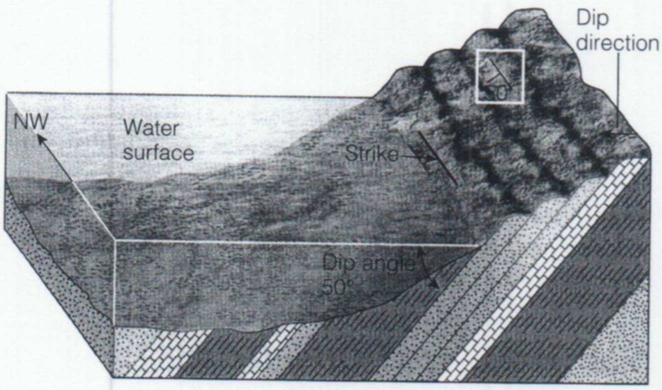


Figure 8.2

Strike and dip of tilted bedding. The strike is parallel to the waterline, and measured by one of the compass roses in Figure 8.3, which makes it 135°, 315°, N45°W or S45°E, depending on which end of the line you measure. The dip direction is perpendicular to the strike in the direction the beds tilt downward, in this case SW. The dip angle is measured from horizontal; in this case it is 50°.

of two ways: They measure it clockwise with respect to north, as indicated on the compass rose in ■ Figure 8.3a; or they measure it either clockwise or counterclockwise from north or south,

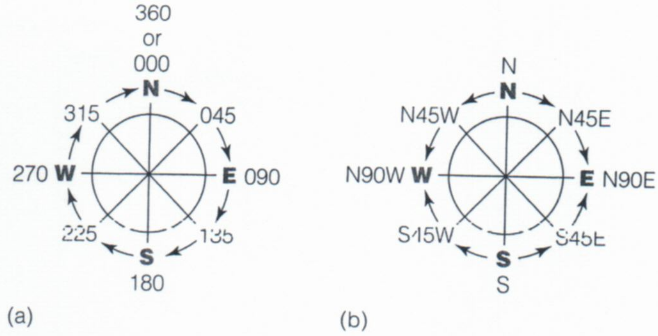


Figure 8.3

Strike angles corresponding to the different points of the compass for two styles of compass rose. (a) 360°-style compass rose. (b) Quadrant-style compass rose.

as shown on the compass rose in Figure 8.3b. Measuring a strike is similar to measuring a bearing, as practiced in Lab 6 (see Figure 6.10), as both are written in degrees from North. However, unlike taking a bearing, any single strike direction has two possible measurements, from either end of the strike line, so measurements with exactly 180° difference have the same strike. Because of the two different styles of compass rose, this usually gives four possible ways to write the strike. Your instructor will suggest which method for you to use. Here are some examples: Beds striking due east and west have a strike written 090°, 270°, N90°E, or N90°W. Strata striking due north also strike due south, written five ways: 000°, 360°, 180°, N or S. A northwest–southeast strike could be written four ways: 135°, 315°, N45°W, or S45°E.

- The **dip direction** is the direction of the downward slope of the plane, always exactly perpendicular to the strike (Figure 8.2), but expressed in general terms (such as NE, NW, and so on).
- The **dip angle** is the angle of tilt, or slope, of the plane measured with respect to the horizontal (Figure 8.2).

For the bedding in Figure 8.2, the strike is measured as degrees from north, or from south, from either end of the strike line, so it is 135° or 315°, or could be N45°W or S45°E. The strike and dip are written with strike first, then dip angle, then dip direction: the four ways to write the attitude are

- 315°, 50°SW;
- 135°, 50°SW;
- N45°W, 50°SW;
- or S45°E, 50°SW.

An instrument called a *compass clinometer* measures strike and dip. When looking at an inclined bed, decide which direction is the steepest slope of the bedding plane. This is the *dip direction* — the direction that water runs down the plane. Hold the compass clinometer level against the bed so the long edge of the compass is perpendicular to the dip direction. If you do this correctly, the long edge of the compass will be along a horizontal line on the plane, the strike. Your instructor will show you how to read the compass (the method varies with the type of compass). Write down the strike angle. While the compass is still in this position, note the dip direction (perpendicular and down the slope). Use the clinometer part of the compass or a separate clinometer to measure the dip angle. Again the procedure varies with the compass or clinometer so follow the directions given by your instructor.

Measuring Strikes and Dips

1. Models of dipping planes set up in the lab simulate tilted bedding planes in sedimentary rocks (or any other kind of planar feature) in the field. For these models, use a compass clinometer to determine the strike and dip of each model, and enter the measurements in ■ Table 8.1. Be careful not to move the models as this will change the results.

Table 8.1

Measurements of Strike-and-Dip Models

Model Number	Strike	Dip Direction	Dip Angle

Table 8.2

Planar Features in Rocks

Rock Number and Name	Type of Planar Structure	Rock Number and Name	Type of Planar Structure

The most common form of geological structure is a plane. Beds or strata are the most common type of plane, but other geologic features can also be planes: dikes, sills, foliation (slaty cleavage, schistosity, gneissic banding in metamorphic rocks), and faults are all planar features.

2. Examine the rock samples displaying various structures. Determine which samples have some sort of planar structure, determine the type and enter this information in ■ Table 8.2.

INTRODUCTION TO GEOLOGIC MAPS AND CROSS SECTIONS

A geologic map endeavors to explain the underlying geology of an area by showing the placement of rock *formations* and their *structures, contacts,* forms, and shapes.

- A **formation** is a continuous or once continuous layer of rock — sedimentary, igneous, or metamorphic — that can be easily recognized in geologic fieldwork and is the basic unit shown on geologic maps. The term is more commonly used with sedimentary rocks, but can be used for igneous and metamorphic rocks as well.
- **Contacts** are the boundaries between rock units or formations, where one formation gives way to the next, depicted as a solid black line (or dashed line where uncertainly located) on most maps. Contacts always separate two different rock formations, which are usually depicted as different colors on either side of the line.
- **Structures** are the physical arrangements of rock masses. They include intrusive bodies, unconformities, attitude of rock layers, and deformational features such as faults and folds. These structures will be discussed later in this lab and in Labs 9 and 10.

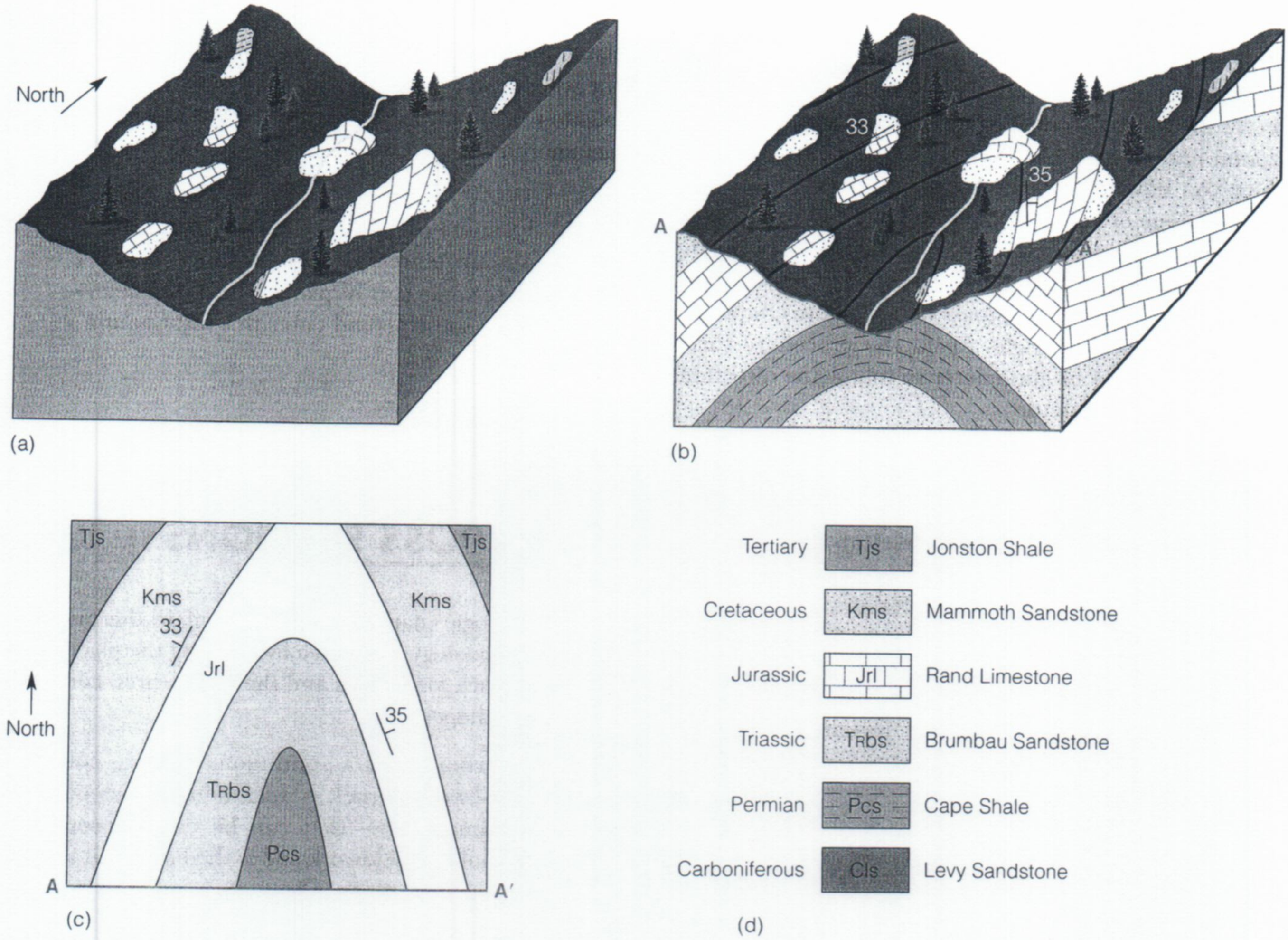


Figure 8.4

Making a map and cross section from outcrops. (a) A region with scattered outcrops of limestone, sandstone, and shale. (b) Outcrops help geologists determine what the rock structures are where structures are not visible at the surface, between outcrops. Contact lines and cross sections have been drawn in to show how the geologist interprets the underlying geology. A to A' is a cross section. (c) Map of the same region inferred from the outcrops. (d) Map explanation with names and periods of the formations. From *Physical Geology*, 5th ed., by J. Monroe and R. Wicander, p. 383. Copyright © 2005 Thomson Higher Education.

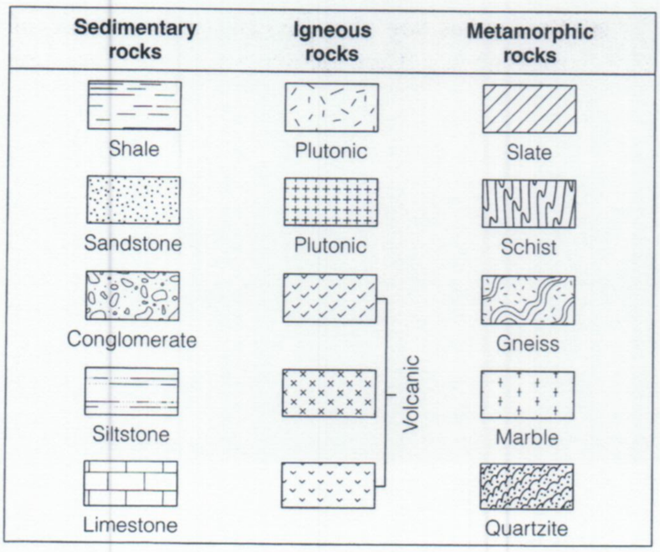


Figure 8.5

Some map patterns used for different types of rocks

What Is Shown on a Geologic Map

On each geologic map, you will find an explanation of the symbols used for the colors, patterns, and deformational structures on that particular map. The key or legend of the map is an explanation of rock formations in chronological order — with the youngest rocks at the top and the oldest rocks at the bottom (■ Figure 8.4) — and sometimes separated by rock type into igneous, sedimentary, and metamorphic groupings (Figure 10.8, pp. 214-215). Colors are usually used to differentiate different rock formations. On maps that are not printed in color, the cartographer uses different patterns and letter codes to indicate the different rock units. Some common examples of patterns for different rock types are shown in ■ Figure 8.5.

Cross sections, also known as *structure sections,* are included with many geologic maps to show the arrangement and history of the rocks, as in Figure 8.4b. These sections are like a slice through a layer cake —

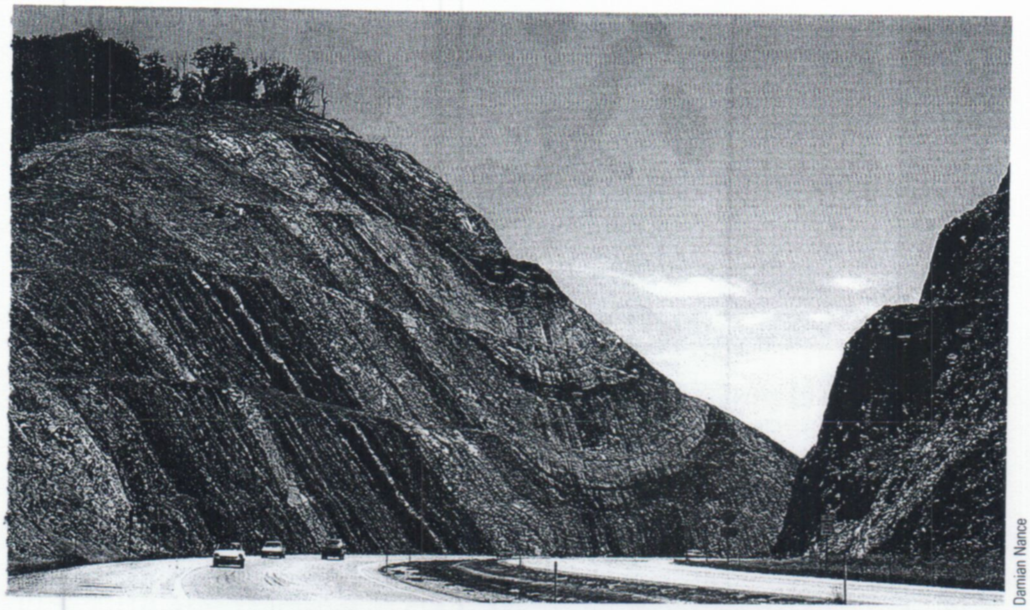


Figure 8.6

Road cut through a syncline along Interstate 68 at Sideling Hill, Maryland

they exhibit the arrangement and compositions of the interior from a side view, much as the Colorado River has cut through the rock layers forming the Grand Canyon (Figure 8.1). Mountainous areas may have road cuts where the terrain has been sliced through for highways, and these often are actual cross sections of the geology of the region (■ Figure 8.6). A cross section is in part a topographic profile, but it also shows the underground arrangement of the rock masses, how much they are tilted, and whether they are folded, faulted, or intruded. The line along which a cross section has been drawn is generally labeled on the accompanying map with letters such as A–A′ or B–B′ (Figures 8.4 and 10.2, pp. 202-203). Geologic cross sections are constructed from the information on the map.

3. Examine the geologic map in Figure 8.4c and its key in Figure 8.4d.

a. What type of rock does the symbol Jrl represent? ____________________

b. What does the J in Jrl stand for?

____

c. How about the rl in Jrl?

____

d. What do the colors represent? How do they aid a person reading this map?

____

____

____

e. Locate a contact in 8.4a and c and name the formations on either side of it.

____

____

Plotting Strikes and Dips on Maps

One of the chief benefits of being able to measure strike and dip is to be able to place information on a geologic map about the angle or tilting of planar geologic features such as sedimentary bedding, lava flows, volcanic ash beds, and faults. A geologist represents the strike and dip of bedding planes on a map using symbols such as those shown in ■ Figure 8.7 or of foliation using symbols such as those shown in p€bs and p€v on the map in Figure 10.2a, on p. 203.

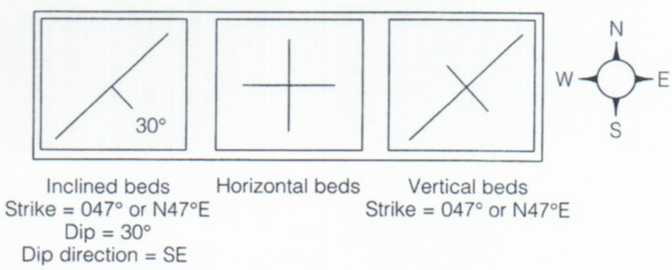


Figure 8.7

Strike and dip symbols. The strike is a long line positioned with the correct orientation measured from north. The dip direction is a short tick perpendicular to it, starting at the middle of the strike line and pointing in the dip direction. The dip angle is written next to the symbol. Horizontal beds are represented by a large plus sign, and vertical beds have a long strike line with a shorter line perpendicular to it.

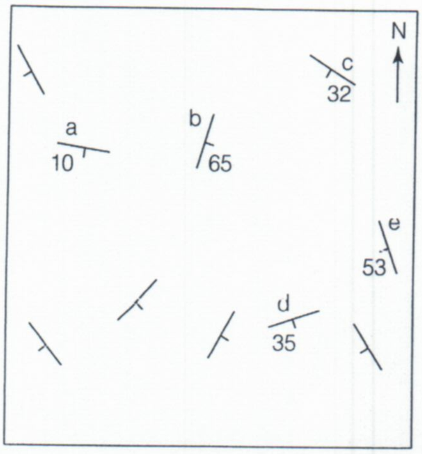


Figure 8.8

Map with strike and dip symbols (Exercise 4)

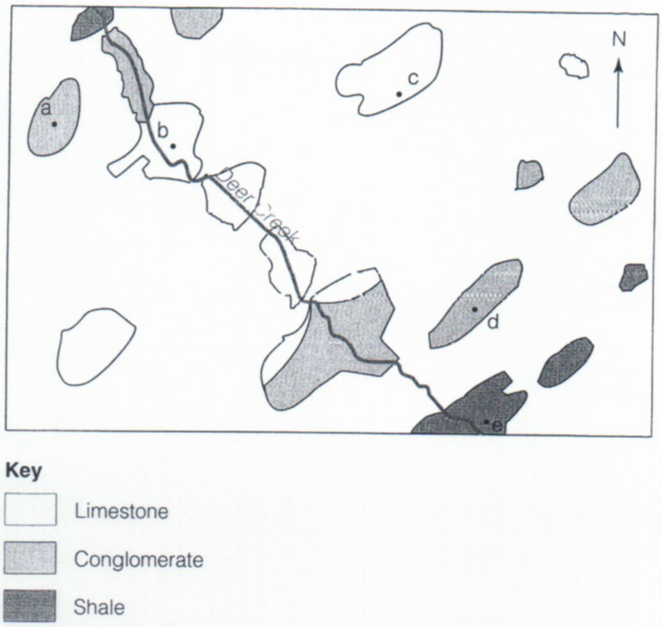


Figure 8.9

Outcrop map of a region of sedimentary rocks (Exercises 5, 6, and 15)

4. For each lettered strike and dip symbol on the map in ■ Figure 8.8, write out the approximate numeric strike and dip.

a. ______________________

b. ______________________

c. ______________________

d. ______________________

e. ______________________

5. Imagine that while mapping the area in ■ Figure 8.9 you measured five strikes and dips at the lettered locations on the map and recorded your measurements in your notebook. To continue making your geologic map in Figure 8.9, put the appropriate strike and dip symbol at each lettered location on the map. The measurements are given below, first using the 360° compass rose (Figure 8.3a) and then using the quadrant style (Figure 8.3b). Use the style preferred by your instructor.

a. 228°, 42°SE S48°W, 42°SE

b. 052°, 28°SE N52°E, 28°SE

c. horizontal horizontal

d. 230°, 20°NW S50°W, 20°NW

e. 049°, 32°NW N49°E, 32°NW

Plotting Contacts on Maps

Most geologic maps are constructed from natural outcroppings of rocks (Figure 8.4). **Outcrops** are areas of rocks exposed at the surface that are not obscured or covered by foliage, soil, sediment, or artificial structures such as buildings and roads (Figure 8.4a). Geologists infer the position and orientation of rock layers (formations) from the outcrops that are available, and decipher the unseen structures beneath. The resulting map is drawn as if the area were made entirely of outcrops (Figure 8.4b and c).

6. The map in Figure 8.9 shows the locations of outcrops of three formations. Imagine you are the geologist who made this map.

a. Turn this into a geologic map by inferring the location and pattern of the contacts. The strikes and dips you plotted can assist you. In areas of low relief and where no faults occur, the contacts are nearly parallel to the strike of the beds.

b. Where the position of a contact is precisely known, draw it in as a *solid black line*. Where it is approximately located or uncertain, draw it in as a *dashed line*.

c. Add the symbols you used for the contacts to the map key in Figure 8.9.

d. After you sketch in the contacts, color or label the remaining areas with the formations inferred to be at those locations.

STRUCTURES AND DEFORMATION

Deformation, including folding and faulting, produces structures in rocks. Some of these structures are planar features, others are not. Different styles and forces of deformation produce different structures.

Now you can measure strike and dip and read strike and dip symbols on a map, but what do they signify? From the principle of original horizontality from Lab 4, we would expect sedimentary bedding to be horizontal, yet observations show that it is not always so (Figure 8.6). Deformation can tilt and change the position and orientation of bedding. One reason we bother to measure and map strike and dip is so that we can better observe the results of deformation, especially over areas larger than an outcrop.

Rocks deform in two different ways when forces are applied to them. **Brittle** deformation breaks rocks. This *style* of deformation occurs when rocks are cold and (usually) near the surface. **Ductile** deformation occurs when rocks bend, flex, and/or flow, and generally when the rocks are deep and possibly warm. Rapid movement is also more likely to produce brittle deformation, and conversely, ductile behavior is more likely when the deformation is slow. Rocks are difficult to deform in a laboratory, so we will use other substances in our experiments.

Three different *forces* result in deformation, as shown in ■ Figure 8.10. **Compression** squeezes things together or has forces pushing toward each other (Figure 8.10a). **Tension** pulls them apart or has forces moving away from each other (Figure 8.10b). **Shear** is a scissor-like motion causing one rock mass to slide past another (Figure 8.10c).

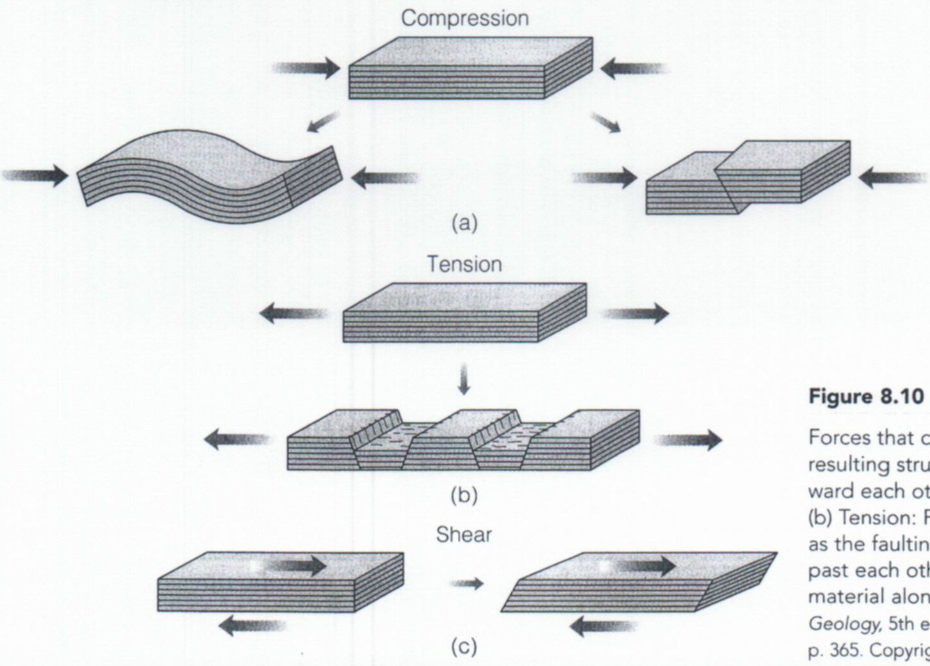


Figure 8.10

Forces that cause deformation (blue arrows) and the resulting structures. (a) Compression: Forces push toward each other, causing either folding or faulting. (b) Tension: Forces pulling apart cause extension such as the faulting shown. (c) Shear: Forces push sideways past each other and cause shearing (movement of material along closely-spaced planes). From *Physical Geology*, 5th ed., by J. Monroe and R. Wicander, Fig. 13.3, p. 365. Copyright © 2005 Thomson Higher Education.

Deformation Experiments

Take one piece of Silly Putty® and place it on the table while you do your next experiment.

7. Take a second piece of Silly Putty, and — without warming it in your hands — roll it into an elongated shape about as thick as your finger. Hold onto the two ends and pull them apart suddenly. (Note that some brands of putty require cooling on ice for this experiment.)

a. What happened?

____

____

b. What *style* of deformation occurred?

____

c. What type of *force* of deformation did you apply? ______________________

8. Put the pieces back together again. Warm the Silly Putty slightly in your hands and roll it into the same shape as before. Hold on to the two ends and pull them apart gradually.

a. What happened?

____

____

b. What *style* of deformation occurred?

____

c. What force of deformation did you apply? ____________________

9. Observe the Silly Putty you left on the table.

a. What happened to it?

____

____

b. What style of deformation occurred?

____

10. Consider the Silly Putty further.

a. How does heating the Silly Putty change the results of the experiment?

____

____

b. What influence does the speed of deformation have on the style of deformation?

____

____

____

____

c. Rocks, of course, are very different from Silly Putty, but the putty is similar to rock in the way it reacts in this experiment. What are these similarities?

____

____

____

____

____

Take a piece of wax and hold it in your hand to warm it for about two minutes while you do the next experiment.

11. Place another piece of wax in a small vise (or a C-clamp), and crank the vise together until you see significant deformation in the wax.

a. What happened?

____

____

b. What style of deformation occurred?

____

c. Name the type of force of deformation you applied. ____________________

d. Sketch the deformed wax in the space below. Draw an approximate north arrow on the top of each piece of wax, and notice the orientation and arrangement of your deformed wax so that you can reposition it after removing it from the vise. Keep these for a later exercise.

12. Place the warmed piece of wax in the vise (or C-clamp), and crank the vise together until you see significant deformation in the wax.

a. What happened?

____

____

b. What style of deformation occurred?

____

c. Did you apply compression, tension, or shear? ____________________

d. Before you remove your piece of deformed wax, mark a north arrow on the top so you know the orientation it had in the vise for some later questions.

Folded Layers: Anticlines and Synclines

Folds are formed whenever layered rocks are *compressed* parallel to their layering, and the beds are buried deeply enough that they behave in a *ductile* manner (that is, they bend rather than break). The beds may form an upward arch called an *anticline* (■ Figure 8.11a) or may

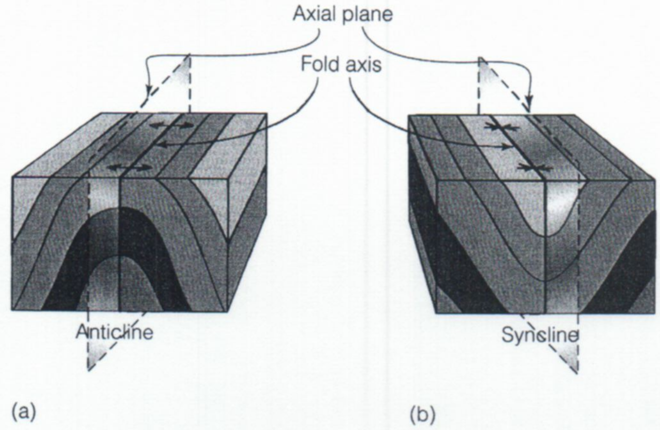


Figure 8.11

Ductile deformation may produce folds. (a) Non-plunging anticline. (b) Non-plunging syncline.

bow downward in the middle and form a *syncline* (Figure 8.11b). Figure 8.6 shows a road cut through a syncline. Note that anticlines and synclines are bends in rock layers beneath the land surface and are not necessarily directly related to topography. In the photograph in Figure 8.6, for example, the syncline is a hill. In Figure 8.16, the surface above anticline is nearly flat in the foreground and a hill is in the distance. If multiple folds occur in an area and the beds are not broken (faulted), anticlines and synclines must alternate. In the foreground in Figure 8.16, notice a syncline is present to the left of the anticline.

The line around which bending takes place (similar to the crease in a folded sheet of paper) is called the fold **axis.** The fold axes (plural of axis) are represented on maps by symbols shown in ■ Figure 8.12. Fold axes lie in a plane that cuts through the bent part of the fold, called the **axial plane.** The central bent part of the fold is known as the **hinge zone,** which is flanked on both sides by **limbs.**

Folds are often too large to be seen in their entirety at one locality. Their presence, therefore, has to be deduced from observation of strikes and dips of individual beds. When you plot strikes and dips on a map, the presence of folds becomes immediately apparent. Beds *dipping away* from an axis define an **anticline;** beds *dipping toward* an axis define a **syncline.**

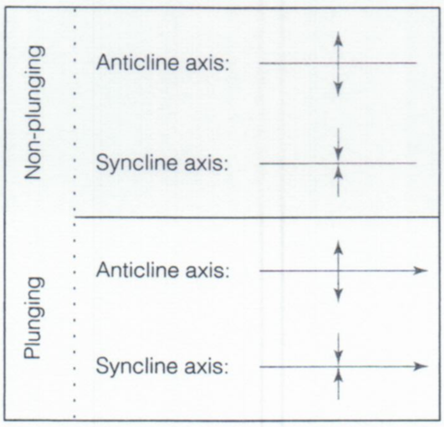


Figure 8.12

Fold axis symbols for non-plunging and plunging folds. These symbols should be used on maps (not on cross sections).

Non-plunging Folds

Non-plunging folds are anticlines and synclines that have horizontal fold axes (Figure 8.11). The strikes of sedimentary beds in a non-plunging fold are parallel to each other on opposite sides of the axis (■ Figures 8.13 and ■ 8.14).

13. Examine a block or clay model of a non-plunging anticline and syncline.

a. Try to visualize how the rock layers would penetrate through the block. Locate the axis of the fold. If you place the model on the table, is the axis horizontal? ________

b. Look at the top of the model (map view) and describe the pattern (zig-zags, wiggly, parallel stripes, circular, oval, or whatever), the rock layers make on this surface.

____

____

Making a Model of a Map Area (Figure 8.14)

Sometimes students have a little trouble visualizing strike and dip and anticlines and synclines from symbols on a map. The next exercise is intended to help you with this.

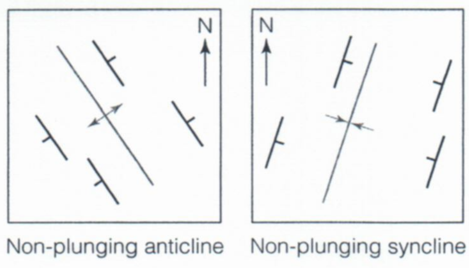
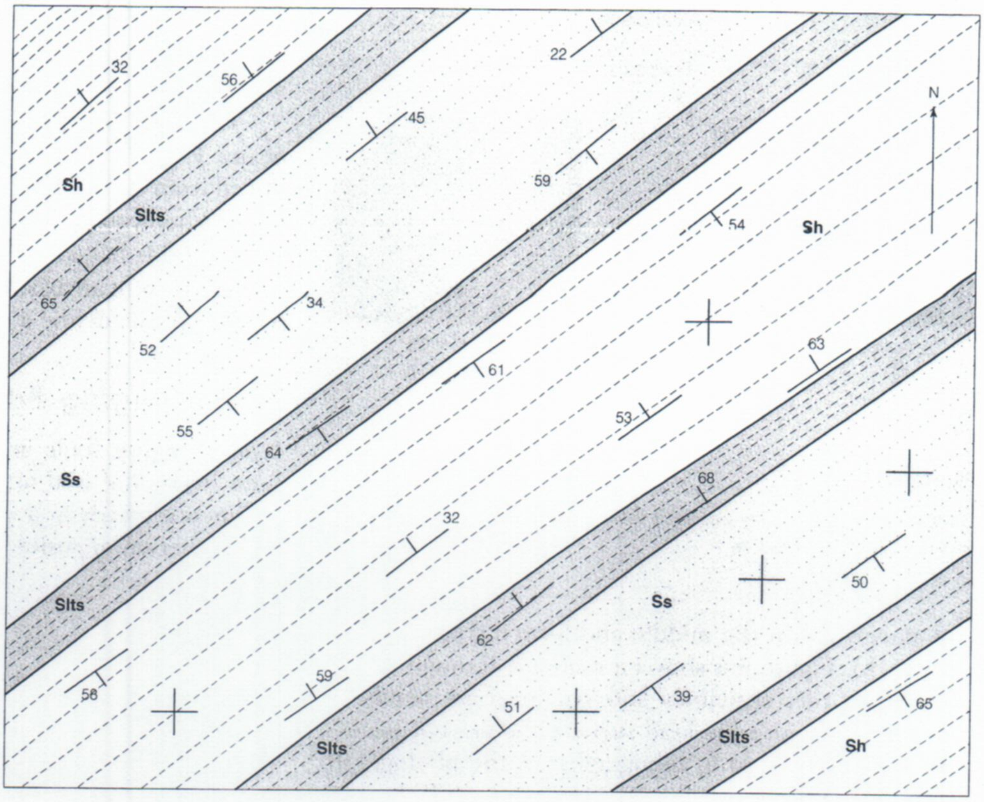


Figure 8.13

Strike and dip of beds in non-plunging folds.

Figure 8.14

Map of a region with sandstone (Ss), siltstone (Slts) and shale (Sh) formations showing the strike and dip of bedding (Exericise 14)



14. Work together in a group. You will need a tray (or stream table) with sand and a quantity of three types or colors of small planar items to use as markers, such as streak plates, glass plates, or small rectangles cut out of colored index cards.

a. Carefully study the map in Figure 8.14. Draw, in the sand, the outline of the map and the contacts between the shale, siltstone, and sandstone layers.

b. Decide which type or color of plate, card, or marker will correspond to each rock type in Figure 8.14. Your instructor may have a preference as to how you do this. If using colored index card pieces, try to match the color of the formation on the map.

c. Next, examine the strike and dip symbols on the map. Starting with one strike and dip symbol, locate the appropriate position in your sand model, and position a planar marker well into the sand so that it has the same strike and dip as represented by the symbol. Remember that the *dip* is *down* into the ground. Take turns placing markers for the majority of strike and dip symbols on the map. Help each other out if necessary, and ask for help from your instructor if you get stuck. Have your instructor check your model.

d. Carefully study your model and the map in Figure 8.14. Determine where all anticlines and synclines are on the map, and draw in the axes for these folds in the sand and on the map using the symbols in Figure 8.12.

e. Are the folds non-plunging, with horizontal fold axes? That is, do the fold axes pass through horizontal beds (or dipping beds)? ____________________

f. Notice that for non-plunging folds all the beds strike in the same direction. Is the strike of the beds parallel to or at an angle to the fold axes?

____

g. Make a *key* in the margin by drawing three boxes one below the other.

- Decide which rock is at the top, which is in the middle, and which is on the bottom. You will have to visualize how the rocks continue down into the ground.

- In each box in your key write the letter symbol for the rock so that the order in the key is the same as their position in the ground. This will also put them in chronological order from oldest at the bottom to youngest at the top. (We will cover this subject in more detail in Lab 9.)
- Also in the box, sketch in the pattern used for each rock.
- Use colored pencils to shade each box the approximate color on the map for that rock.

h. What was the direction (in general terms, N–S, NW–SE, or whatever) of compression that affected the area?

____

The relationships observed in **e** and **f** will help you to recognize non-plunging folds in the future. Non-plunging folds show parallel stripes in map view and have beds that strike parallel to each other and parallel to the fold axes.

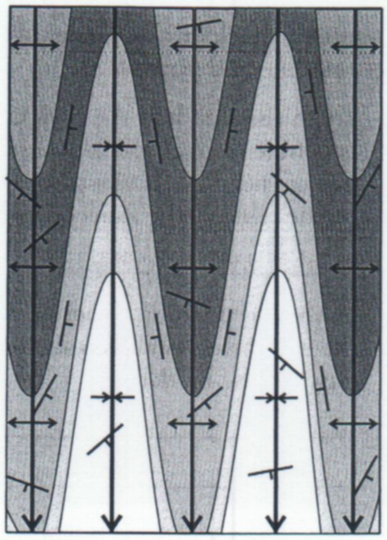
15. Examine the map you made in Figure 8.9. What structure(s) do you detect?

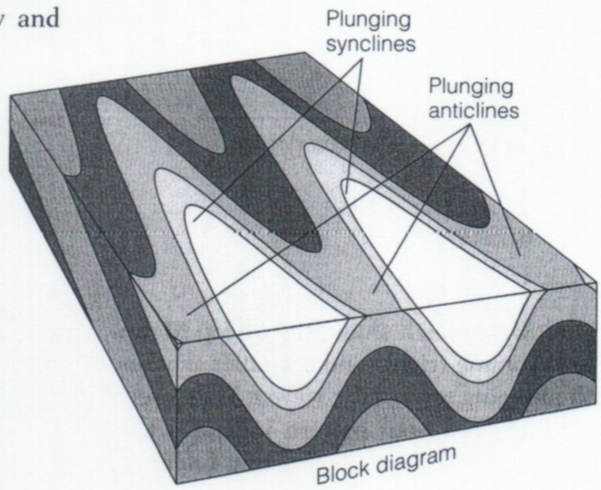
____

Finish the map by drawing in the appropriate fold axis symbol(s).

Plunging Folds

Most folds have axes that are not horizontal because the compression causing the beds to fold and the beds themselves are irregular. Such folds are called **plunging folds** because their axes plunge into the Earth at an angle (see the lower block diagram in ■ Figure 8.15). As Figure 8.15 shows, where plunging anticlines and synclines occur, erosion will expose the formations as a series of zigzag patterns. This type of pattern is also





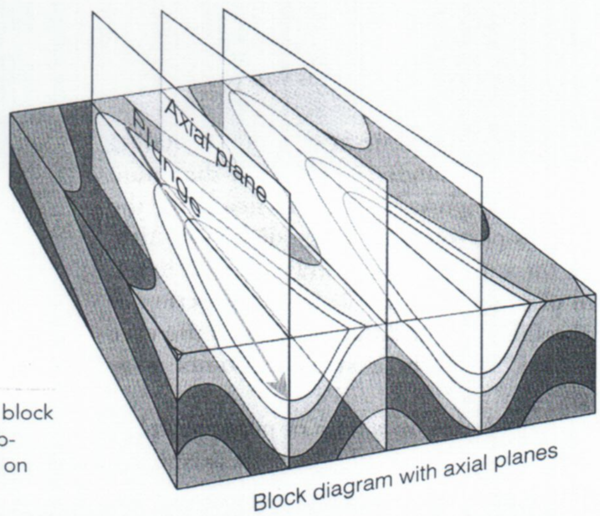


Figure 8.15

Plunging anticlines and synclines. The red arrow on the lower block diagram is the fold axis and shows the plunge of the folds. Observe the arrow heads on the map at the end of the fold axes on the downward (plunging) end.

Figure 8.16

Sheep Mountain anticline in Wyoming. This end of the anticline is plunging down toward the viewer. A syncline is visible in the foreground to the left of the anticline, which is also plunging toward the viewer.

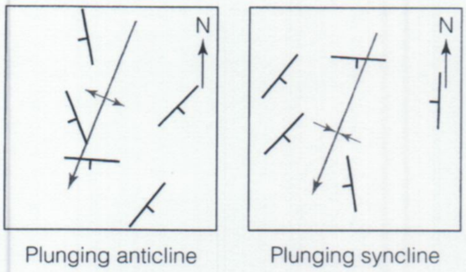


Figure 8.17

Strike and dip of beds in plunging folds.

visible in ■ Figure 8.16, which shows the Sheep Mountain anticline in Wyoming (right) and a smaller syncline on the left, both plunging toward the viewer. When seen on geologic maps, such a map pattern indicates that plunging folds are present. Beds in plunging folds still dip away from the axis of an anticline and toward the axis of a syncline, but the strikes are not parallel (Figures 8.15 and ■ 8.17) as they were for non-plunging folds. The dip of beds near the fold axes will point in the general direction of the plunge.

Plunging folds tend to occur in sets of alternating anticlines and synclines plunging in the same direction. Look more closely at Figure 8.15. Arrowheads on the ends of the fold axes portray the plunge direction. Also, you can see that for anticlines the bend or "nose" in the outcrop pattern of rock layers points in the direction of the plunge of the fold axis, and the opposite is the case for synclines — the "nose" of a syncline points away from the plunge.

When drawing fold axes on a map of plunging folds, as for non-plunging folds, you should draw the axis where a plane would be inserted to produce a mirror image of rock layers on either side. For plunging folds the axial plane (mirror) also connects the "kinks," bends, or "noses" of the folds. The axial planes in Figure 8.15 correspond to the position of the mirror planes for the folds shown in the block diagram. Of course, in nature, multiple folds rarely have such perfectly aligned symmetry. On a map, the fold axis coincides with the trace of the axial plane.

16. Examine a block or clay model of a *plunging* anticline and syncline.

a. Try to visualize how the rock layers would penetrate through the block. Locate the axis of each fold. If you place the model on the table, is the axis horizontal?

____

b. In your own words, describe the pattern the rock layers make on the top (map view) of the model.

____

____

____

17. ■ Figure 8.18 shows strikes and dips of beds in an area of folding. Fold axis traces are drawn on the figure for you (without the arrows).

a. Determine the type of folds, non-plunging or plunging.

____

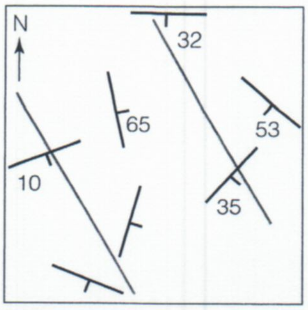


Figure 8.18

Folds marked by strike and dip symbols. The fold axes need appropriate arrows added (Exercise 17).

b. Also determine which is an anticline or a syncline, and finish drawing the fold axis symbols on the map.

c. If the folds are plunging, what is the direction of the plunge?

____

18. Look at the following figures from earlier in this lab, and decide whether the folds are non-plunging or plunging:

- Figure 8.4 ______________________
  Draw a fold axis on the map.
- Figure 8.8 ______________________

19. Draw complete fold axes for each map in ■ Figure 8.19. Also, fill in the information requested in ■ Table 8.3.

20. Examine the deformation in the warmed wax experiment. What type of structure(s) did you make?

____

Table 8.3

Practice with Folds (Exercise 19)

Fold	Map 8.19	8.19	8.19
Non-plunging or plunging?			
Plunge compass direction			
Compression compass directions			

Faults

Faults form by brittle deformation in the upper part of the Earth's crust (the upper 10 km) and are fractures across which displacement has taken place so that the two sides remain in contact (■ Figure 8.20). The displacement can be from a few centimeters to hundreds of kilometers. Geologic maps usually show faults as thick lines, but you can also easily recognize faults because they abruptly displace formation contacts. Faults are planes so they, too, have strikes and dips. If movement of the rocks on either side of the fault is parallel to the dip of the fault plane, the fault is said to be a **dip-slip fault.** The faults in Figure 8.20a, b, and c are dip-slip faults. **Strike-slip faults** are ones that do not have a component of up or down motion, but have slipped horizontally—that is, parallel to the strike (Figure 8.20d, e). An **oblique-slip fault** has movement between the strike and dip of the fault plane (Figure 8.20f).

Dip-slip faults consist of **normal, reverse faults,** or **thrust faults**. Dip-slip faults are often defined in terms of a hanging wall and a footwall. The hanging wall is the block of rock physically above the fault plane, whereas the footwall is below the fault plane. You can

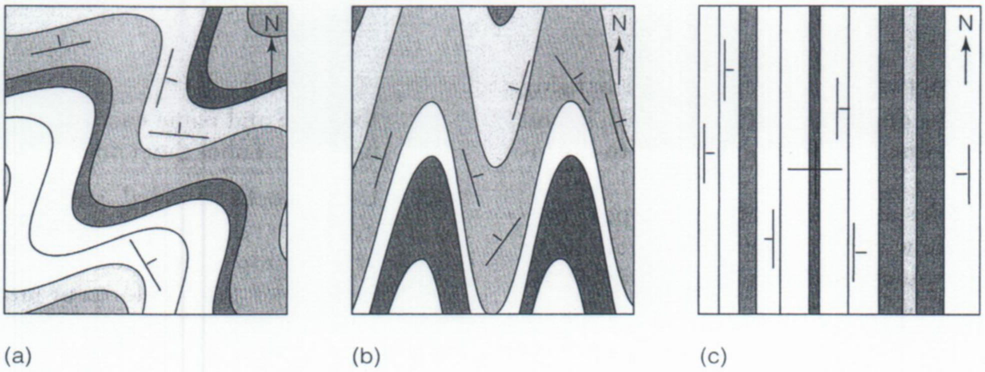
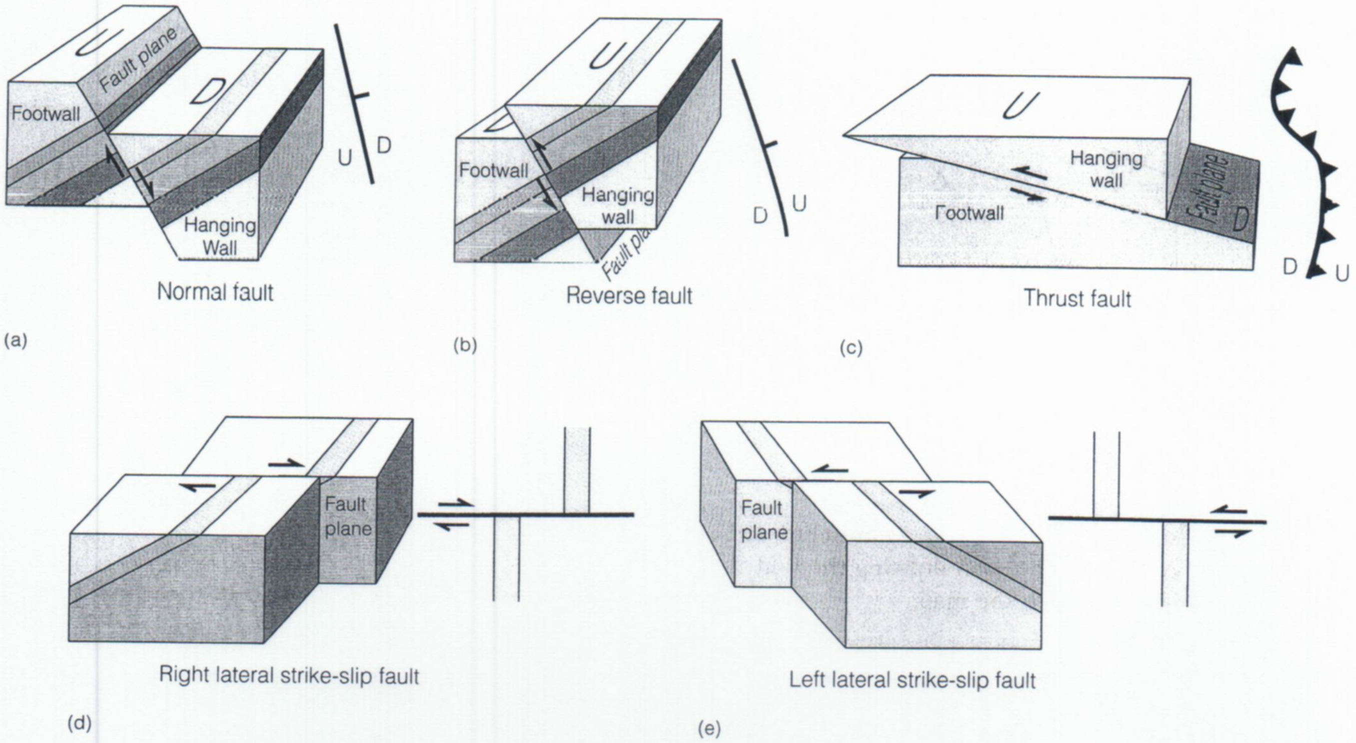


Figure 8.19

Simplified geologic maps of folds (Exercise 19)



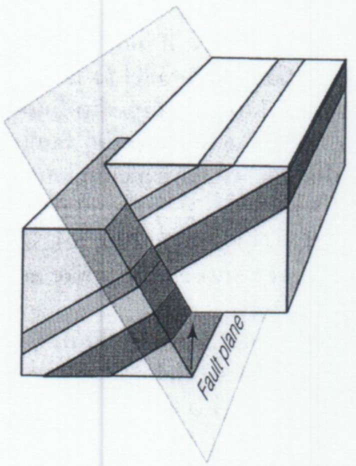


Figure 8.20

Types of faults and their map symbols (to the right). (a) **Normal faults** are *dip-slip faults* for which the hanging wall has slipped down the dip of the fault plane and/or the footwall moved up. *The block moved down the ramp.* On geologic maps, a small tick or arrow shows the down-dip side of the fault trace. The up-thrown side may also be marked with a U and the down-thrown side with a D symbol. The down-drop side (D) is in the direction of dip of the fault plane. (b) **Reverse faults** are also *dip-slip faults*, but with a dip greater than 45° and movement in the opposite direction of normal faults. The slip of the hanging wall is up the dip of the fault plane and/or the footwall moved down. *The block slid up the ramp.* For reverse fault symbols, the small tick in the down-dip direction will occur on the same side as the U. (c) **Thrust faults** are low-angle dip-slip faults with movement similar to reverse faults. The angle of dip is less than 45°. As for reverse faults, the slip of the hanging wall (or upper plate) of a thrust fault is up the dip of the fault plane. In the map symbol, the up-thrown side of the fault (hanging wall) is decorated with triangular, teeth-like symbols pointing toward the upper plate. (d) A **right lateral strike-slip fault** is one where the *opposite side of the fault moved horizontally to the right.* (e) For a **left lateral strike-slip fault**, the *opposite side moved horizontally to the left.* (f) If movement along the fault combines both strike and dip slip, it is an **oblique-slip fault**.

also think of the footwall as a ramp and the hanging wall as a block sitting on the ramp. Figure 8.20a, b, and c and its caption define these faults and how to distinguish them.

Strike–slip faults also have different types. Figure 8.20d and e show the two possible directions of slip. Imagine that you are standing on one side of the fault and you are looking across to the other side. If the block on the *other* side has moved to your right, then the slip is **right–lateral** (Figure 8.20d); if the block has moved to the left, then it is **left–lateral** (Figure 8.19e).

21. Examine and name each fault in ■ Figure 8.21. Label them on the diagram.

22. Using blocks provided, arrange the blocks into each type of fault. You may need books to help prop up the blocks so they will sit in the correct position for your fault.

a. For each type of fault, sketch on a separate piece of paper both a map view and a cross section of the fault.

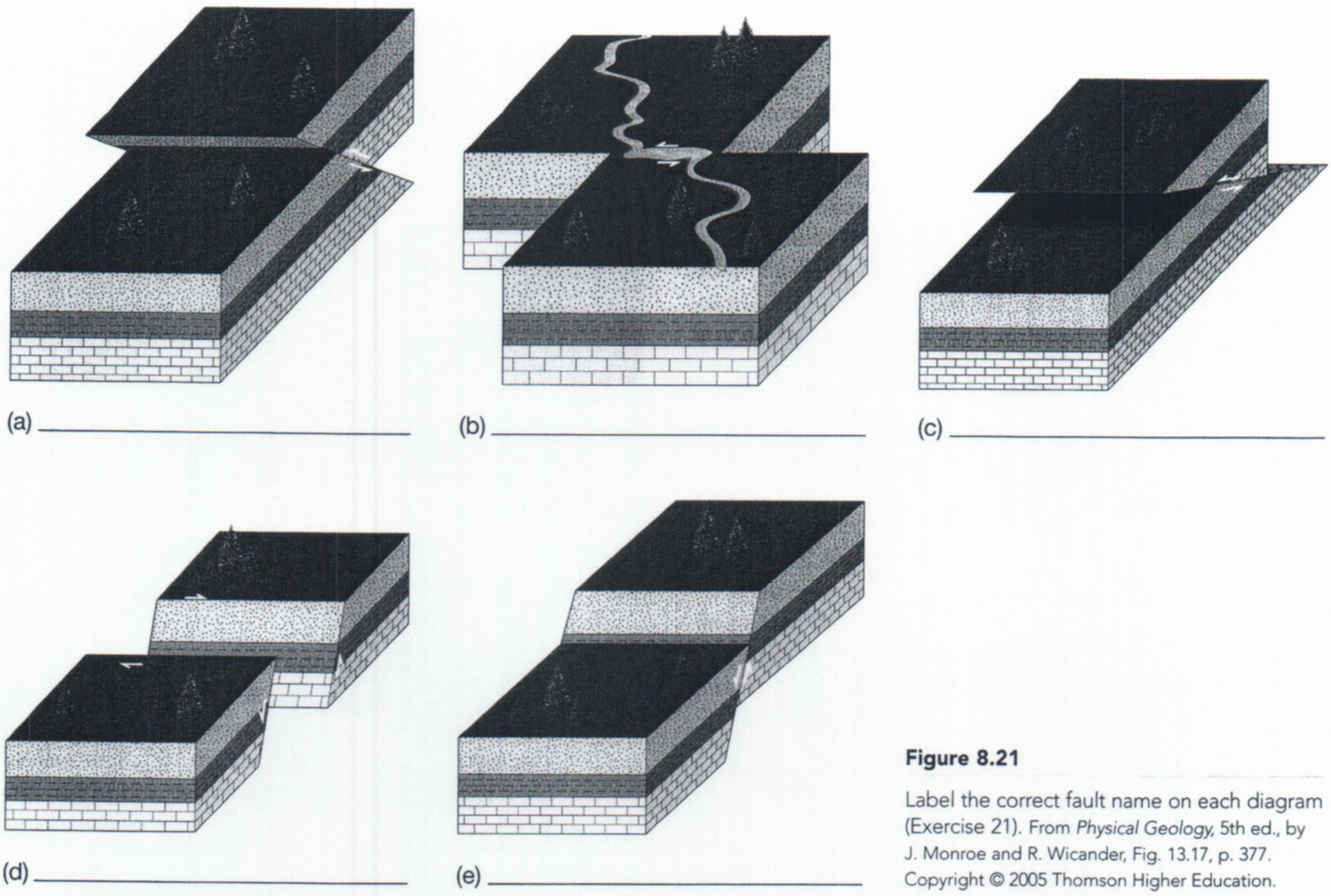


Figure 8.21

Label the correct fault name on each diagram (Exercise 21). From *Physical Geology*, 5th ed., by J. Monroe and R. Wicander, Fig. 13.17, p. 377. Copyright © 2005 Thomson Higher Education.

b. On each sketch, label the type of fault, which group it belongs to (dip-slip or strike-slip, if any) and place arrows on each block next to the fault showing the direction of movement (if visible from that view).

c. For which types of faults are the cross sections of little use in seeing the offset of the blocks?

____

d. For which types of faults does the map view fail to show the fault offset?

____

____

In some places along faults, the slipping of rocks past each other leaves smooth, slick ridges and grooves on the rocks known as **slickensides** (Figure 5.9f) that show whether the movement was strike-slip, dip-slip, or oblique-slip.

23. Look at the deformed wax and your sketch from Exercise 11.

a. What type of fault did you produce?

____

____

b. Also, observe the surface of the break you created and write your observations in the spaces below. Describe what it looks like.

____

____

c. Is there any indication from this surface of the direction of movement of the two pieces of wax? If so, name the feature

____

and describe it.

____

____

TYPES OF ROCK MASSES

In many cases deformational structures are most visible in sedimentary rocks because of sedimentary bedding — the most common sedimentary rock masses. Because bedding is laid down horizontally with one layer on top of another, sedimentary rock masses lend themselves to the interpretation of geologic time and the history of the Earth. We will discuss sedimentary rock masses in more detail in Lab 9, Geologic Time and Geologic History.

Deformational structures, such as faults and folds, can also be found in other rock types. Some igneous rocks form broad flat masses such as lava flows and volcanic ash layers, which are similar in form to sedimentary layers. Foliation in metamorphic rocks is also a layered or planar form, although generally not horizontal. Such bodies will fold and fault in similar ways to sedimentary rocks. Other bodies of igneous and metamorphic rocks, however, have different characteristics and shapes. For igneous rocks these depend on whether they were extruded or intruded.

Extrusive Rocks

Molten lava solidifies into lava flows, lava domes, or pyroclastic material depending on how it erupts.

- **Lava flows** are extruded magma that has solidified in tongue shapes and as sheets. Fluid lava will tend to flow farther, forming long tongues or occasionally spread out in wide flat lava sheets of great aerial extent called **flood basalts.** More *viscous* lava will make thick short tongues covering smaller areas.
- Sometimes lava is so viscous that it does not spread out, but domes up instead. When this happens it creates a **lava dome** (Figure 8.25b, in Mt. St. Helen's crater).
- When volcanic eruptions are explosive, a spray of magma and particles of rock spew out of the volcano, producing **volcanic ash** and other pyroclastic deposits (Figure 3.16, p. 47) that may lithify into tuff (Figures 3.18 and 3.19, pp. 47 and 48). Volcanic ash is a layered deposit (Figure 3.16b, p. 47) that may extend over a wide region and become buried within volcanic or sedimentary sequences. Volcanic ash, or tuff, deposits may be interlayered with lava flows depending on the sequence and type of eruption.

  Where a **volcanic vent** (the opening where volcanic eruptions occur) erupts frequently or repeatedly, a hill or mountain known as a **volcano** can build up. A volcano may be built entirely of lava flows, entirely of pyroclastic deposits, or a mixture of both.

Bernard Pipkin

Figure 8.22

The shield volcano in the distance is Fernandina in the Galápagos Islands.

- A **shield volcano** is one made up of basaltic lava flows and very little ash (■ Figure 8.22). Shield volcanoes can be very massive and are gently sloping with an angle of about 10°. The tallest (not highest) and most extensive mountain on Earth, Mauna Loa in Hawaii, is a shield volcano with its base at the bottom of the sea.
- A **cinder cone** is a small volcano made up of pyroclastic material, ash, and cinders (■ Figure 8.23). Associated lava flows may issue from their flanks.
- A **stratovolcano,** also called a **composite volcano,** is made of intermediate to felsic interlayered pyroclastic deposits and lava flows (■ Fig-

Courtesy of Geological Survey of Canada

Figure 8.23

Eldfell cinder cone, Heimaey, Iceland, formed in 1973, growing 100 m in two days. A second cinder cone, Helgafell, is visible to the right.

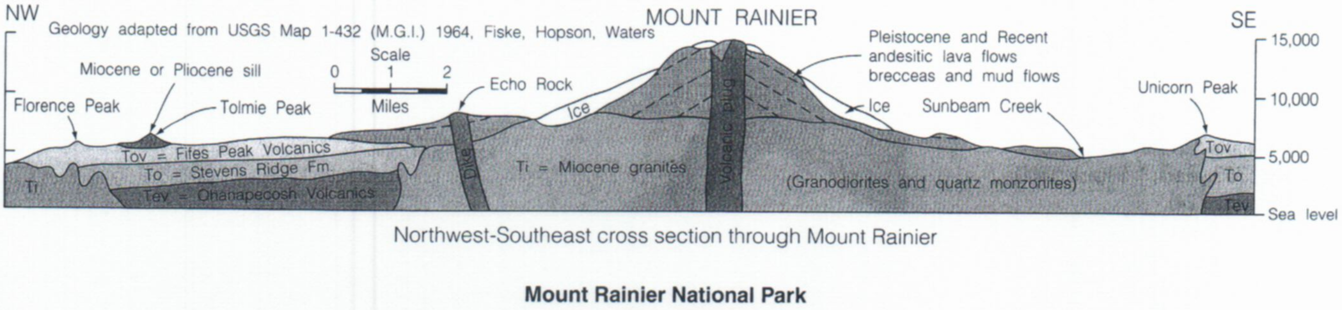
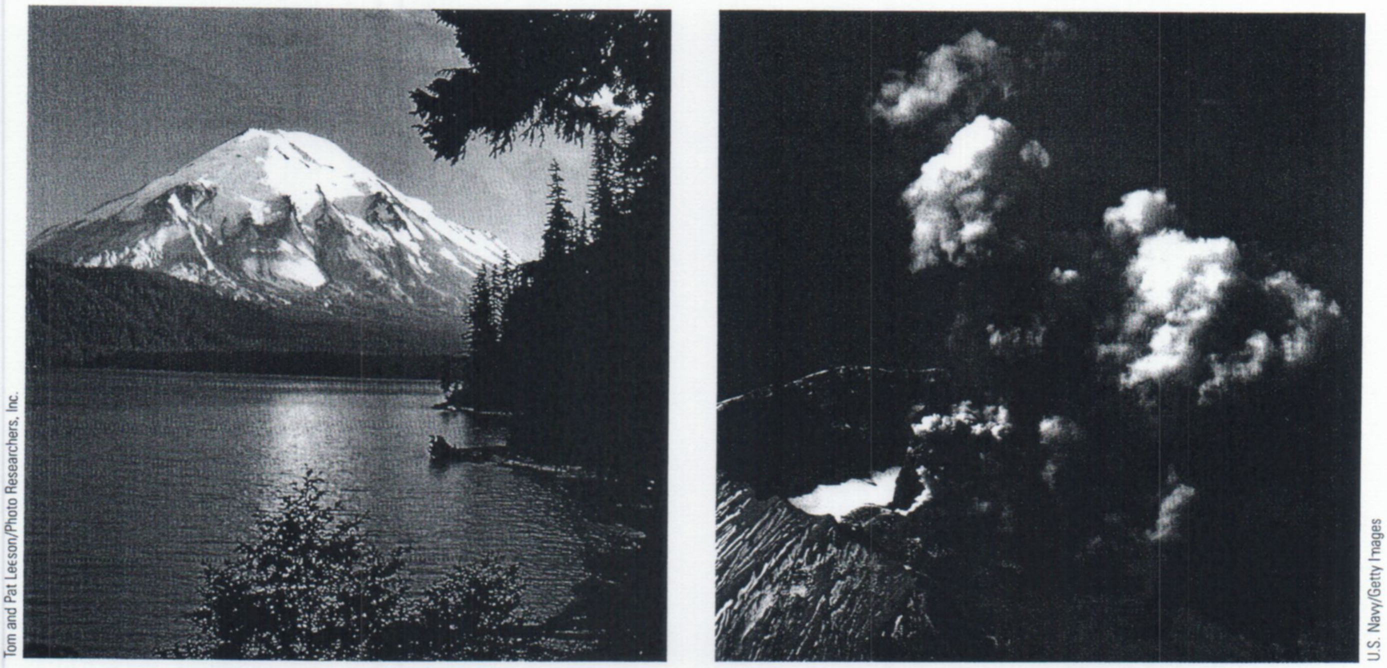


Figure 8.24

Northwest–southeast cross section through the Mount Rainier stratovolcano.



(a) (b)

Figure 8.25

Stratovolcano: Mount St. Helens, Washington, (a) before it erupted in 1980. This view is from the shores of Spirit Lake. (b) View of the older (1980s) and newer (2004) lava domes in Mount St. Helens' crater. The older dome is in front of the new dome, with steam rising between the two.

ures 8.24 and 3.16a, p. 47). Stratovolcanoes make impressive snow-capped volcanic peaks with steep (about 30°) slopes (■ Figure 8.25), but are generally much smaller in volume than shield volcanoes.

24. Examine the Geologic Map of Mauna Loa in ■ Figure 8.26.

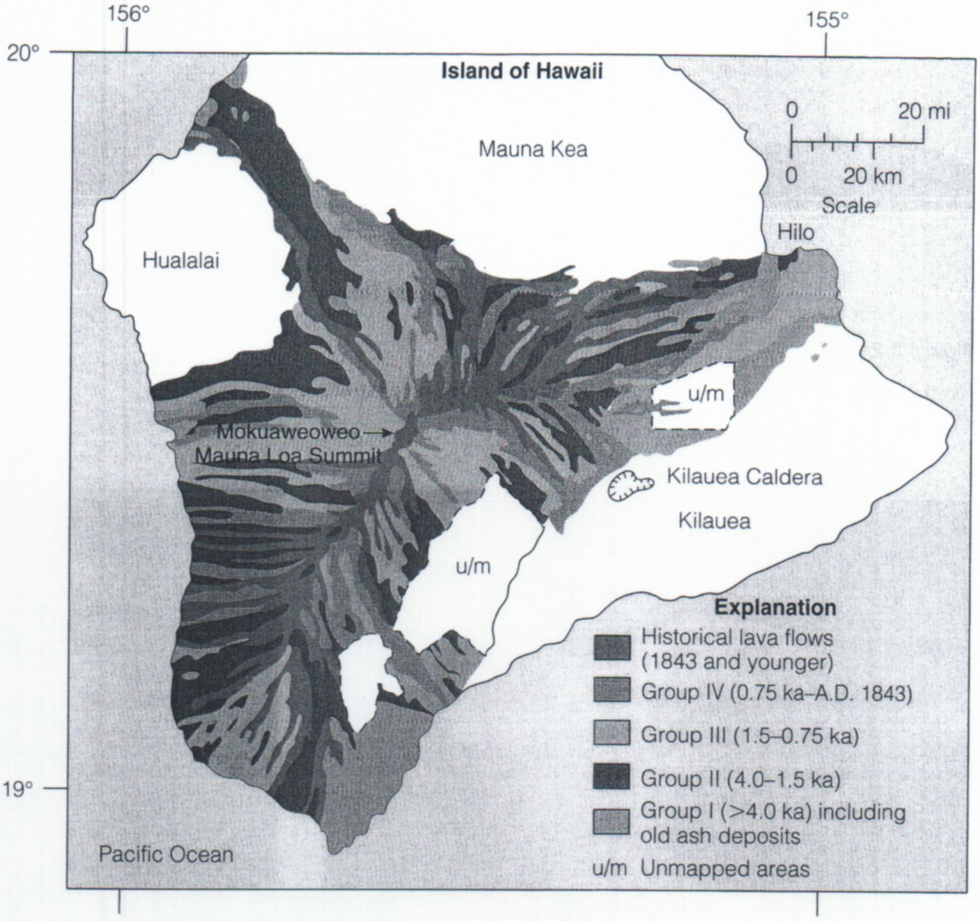
a. What types of rock masses make up the area? ______________________________

b. Identify the youngest rock masses. Of these, find a single one that is one of the longest. Choose a location where this one continuous rock mass is clearly separated from others. What is the approximate length of the one continuous rock mass? ________________________

c. Do you think this lava was fluid or viscous? ___________________________

Figure 8.26

Geologic map of Mauna Loa. Mokuaweoweo is the summit caldera of Mauna Loa. The age unit ka means thousands of years. 0.75 ka = 750 years; 1.5 ka = 1500 years (Exercise 24).



d. Why do you think this?

____

____

25. Compare the scales and slopes of Mount St. Helens, Capulin Mountain, and Mauna Loa in ■ Figure 8.27.

a. On Figure 8.27c roughly sketch Mount St. Helens and Capulin Mountain profiles next to and at the same scale as Mauna Loa. Only the part of

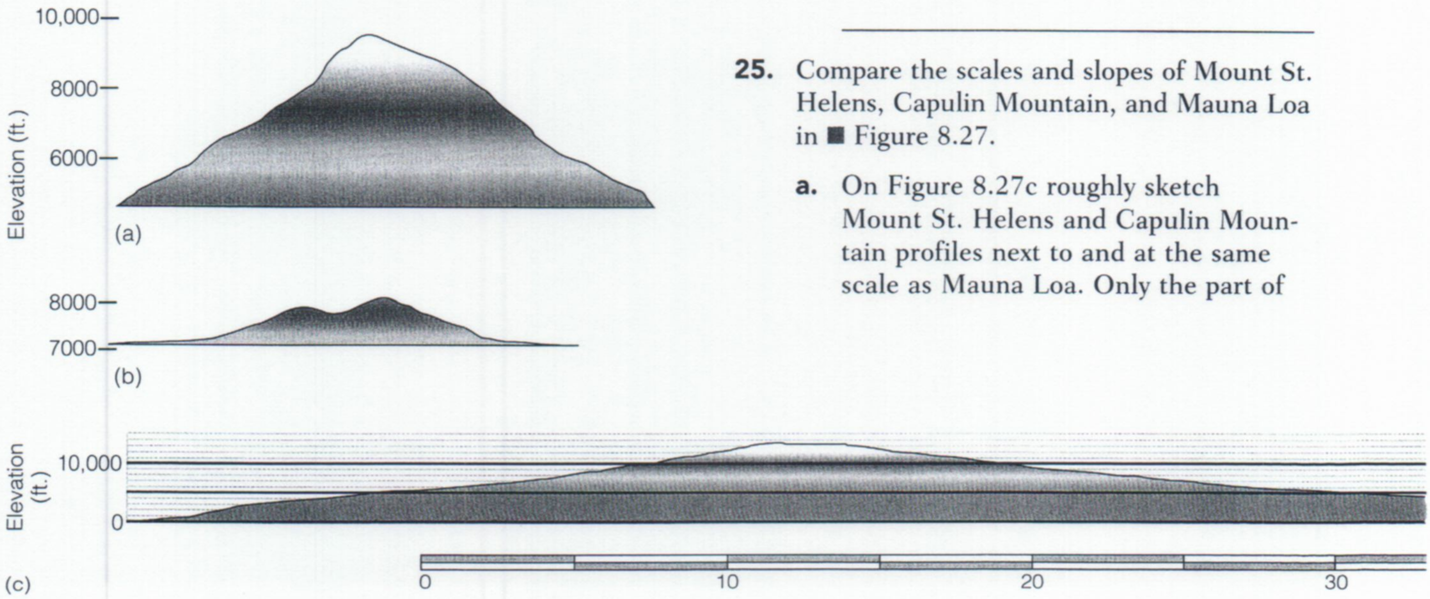


Figure 8.27

Side views or unexaggerated (vertical scale = horizontal scale) topographic profiles of three volcanoes: (a) Mount St. Helens before its eruption in 1980; (b) Capulin Mountain; (c) Mauna Loa. The three volcanoes are drawn at three different scales, as indicated by the elevation information on the left (Exercise 25).

Mauna Loa above sea level is shown in Figure 8.27c!

b. What type of volcano is each?

Mount St. Helens is a

________________________________,

Capulin Mountain is a

________________________________,

and Mauna Loa is a

________________________________.

c. How do you know?

____

____

____

____

Intrusive Rocks

Intrusive igneous rock masses have a variety of shapes and sizes and are classified based on these characteristics, as shown in ■ Figure 8.28. Some intrusives, such as dikes and sills, are planar in form, in other words, sheet shaped, or tabular.

- **Dikes** are planar bodies that cut across layers or through unlayered rocks (Figure 9.7, p. 175).
- **Sills** are planar bodies that intrude parallel to layers (■ Figure 8.29) Unlike lava flows, which have contact metamorphism only below them, a sill will cook the rocks both above and below, as seen as the lighter-colored areas both above and below the sill in the cover photo.
- **Laccoliths** also intrude parallel to layers but they bulge upward to make a dome-shaped, rather than planar body, often doming the layers above them (Figure 8.28).

40

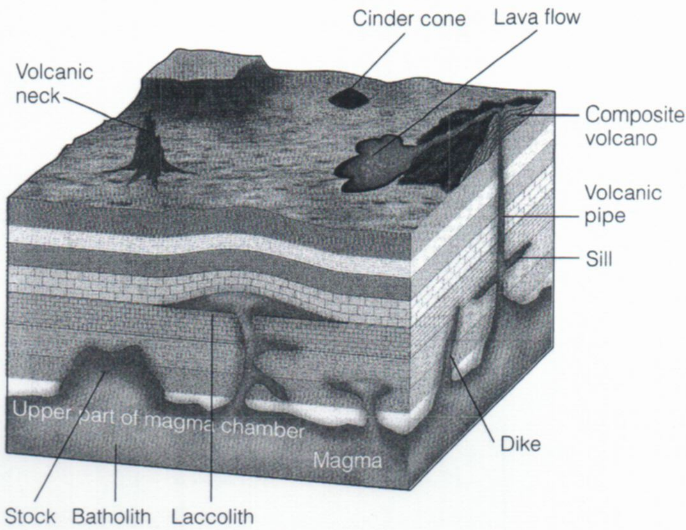


Figure 8.28

Block diagram of igneous bodies in the process of forming. Volcanic neck, cinder cone, lava flow, and composite volcano (or stratovolcano) are volcanic features. Stock, batholith, laccolith, dike, sill, and volcanic pipe are plutonic. A volcanic neck is an erosional remnant of a volcanic pipe. Some plutons are **discordant** and cut across layers, while others are **concordant**, intruding parallel to layers. From *Physical Geology*, 5th ed., by J. Monroe and R. Wicander, p. 78. Copyright © 2005 Thomson Higher Education.

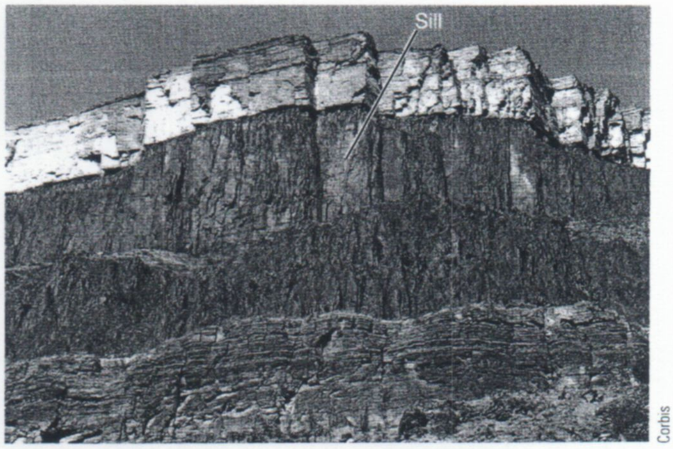


Figure 8.29

Basaltic sill intruded between sedimentary beds in Big Bend, Texas.

Some intrusive bodies are more similar in all three dimensions:

- **Stocks** are roughly equidimensional intrusions of small size (Figure 8.28), with an outcrop area less than 100 km^2 (or 40 mi^2).
- **Batholiths** are rough equidimensional intrusions of large size, with an outcrop area greater than 100 km^2 (or 40 mi^2). Batholiths in western North America (■ Figure 8.30) are quite extensive. One example occurs in the Sierra Nevada, California, including the granite batholith in Yosemite National Park (■ Figure 8.31).

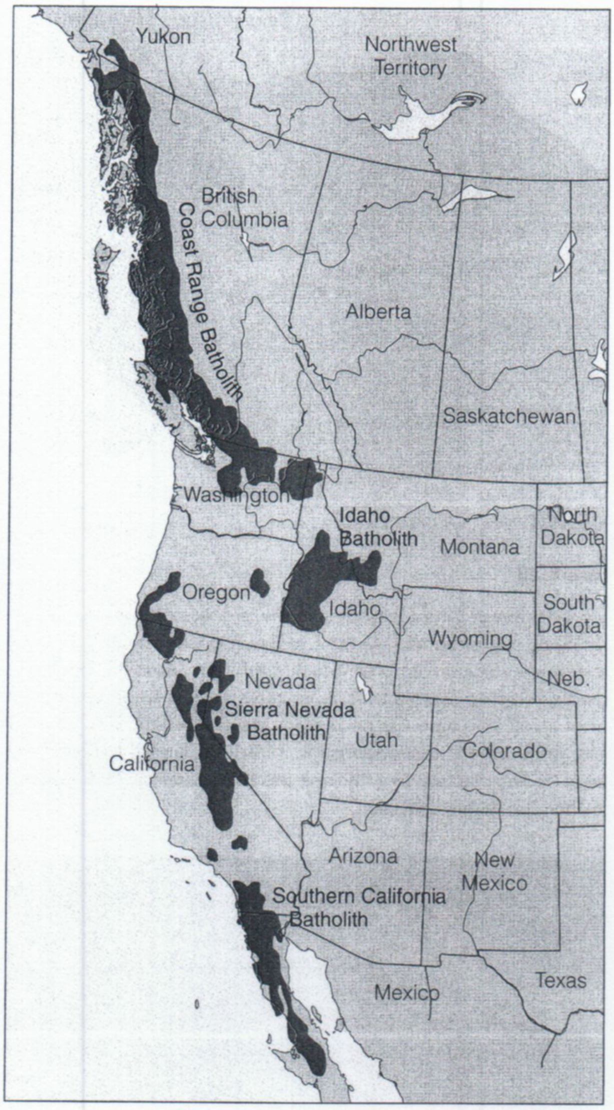


Figure 8.30

Map showing the extent of batholiths (red) in Western North America

Where intrusions come in contact with the **country rock** (the rock they intrude), the edges are cooled more quickly than the centers, producing generally finer-grained igneous rock along the margin of the intrusion, called **chilled margins.** The country rocks are metamorphosed to hornfels where they come in contact with an intrusion (Figure 5.4, p. 87). The intrusion sometimes envelops pieces of the country rock or brings up rock pieces from deeper within or below the Earth's crust. These bits of foreign rock, embedded in igneous rock, are known as **xenoliths** (Figure 3.10b, p. 42).

26. Examine the geologic map of the area near Chico, California, in ■ Figure 8.32.

a. Identify the pink rocks, Kjqd, on this map.

____

Figure 8.31

Batholith at Yosemite National Park, California. Virtually all the rocks visible from this viewpoint are part of the Sierra Nevada Batholith.

b. Judging by the size and shape of the bodies of Kjqd, what types of plutons are they? (Refer to Figure 8.28.)

____

c. How many periods of intrusive activity are visible on the part of the map shown? __________________ Extrusive activity? __________________

d. Do you think KJtr intruded KJqd or the other way around?

____

e. What is the name of the brown rocks, Tl?

____

Are they intrusive or extrusive?

____

What type of igneous body are they?

____

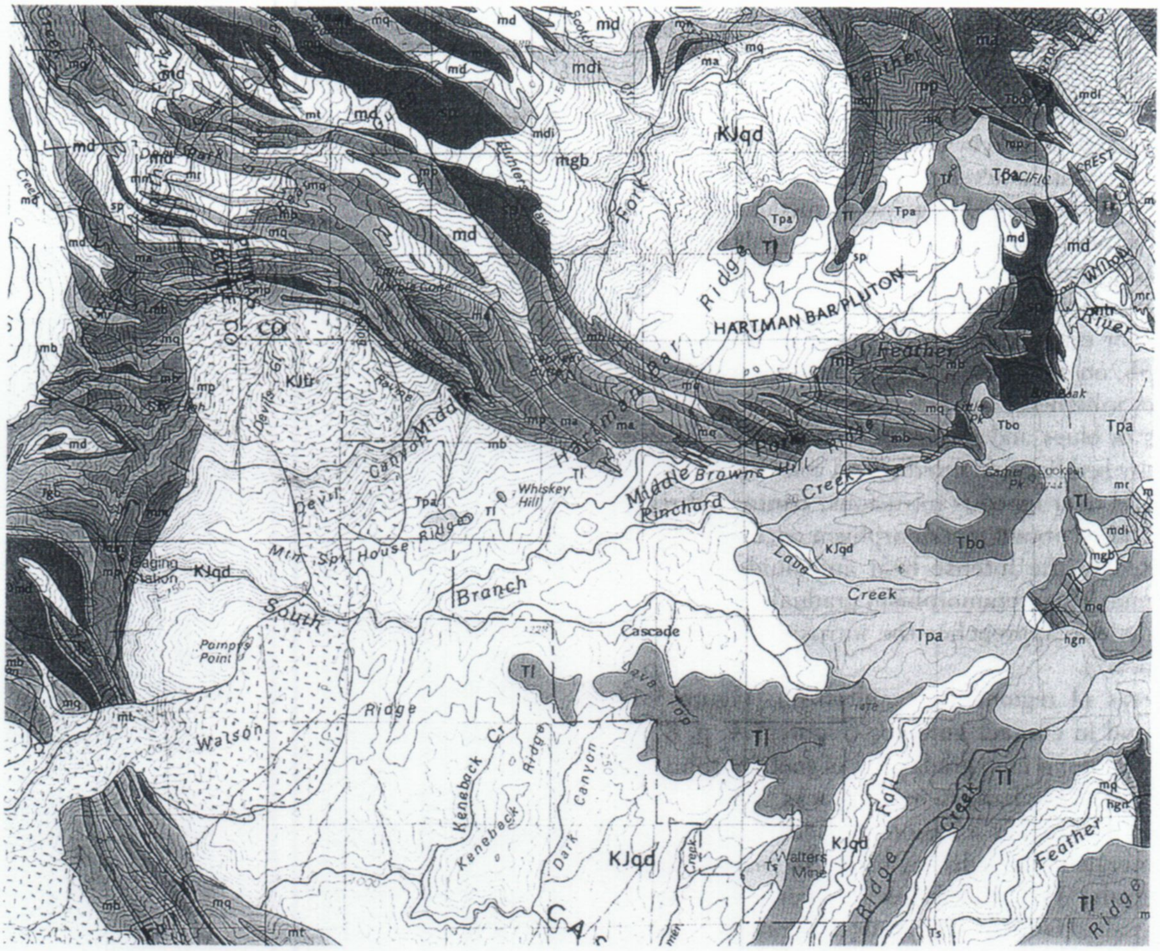
f. Topographically, are these rocks found mainly in valleys, peaks, ridges or slopes? __________________

g. Name each of the other types of volcanic material present in the area shown.

____

____

____



(a)

SURFICIAL DEPOSITS

- Qgr — Gravel deposits

EXTRUSIVE ROCKS

- Tbo — Olivine basalt
- Ta — Pyroxene andesite
- Tpa — Pyroclastic andesite
- Tl — Lovejoy basalt

PLUTONIC ROCKS

- KJtr — Trondhjemite
- KJqd — Quartz diorite/tonalite
- KJhd — Hornblende-biotite quartz diorite
- KJpd — Pyroxene diorite
- Jgb — Gabbro

(b)

FORMATIONS

- FRANKLIN CANYON FORMATION
- BLOOMER HILL FORMATION
- DUFFEY DOME FORMATION

METAMORPHIC INTRUSIVES

- sp — Serpentinite-talc schist
- mtr — Metatrondhjemite
- mdi — Metadiorite
- mgb — Metagabbro
- mqp — Metaquartz porphyry
- hgn — Hornblende gneiss

METAMORPHIC ROCKS

- mb — Metabasalt
- ma — Meta-andesite
- md — Metadacite
- mr — Metarhyolite
- mt — Metatuff
- mm — Marble
- mq — Quartzite-metachert
- mp — Phyllite

— FAULT

0 2 miles

Figure 8.32

(a) Geologic map of an area near Chico, California. (b) Map explanation (Exercises 26 and 28). a, b: From *Exercises in Physical Geology,* 11th ed., by W. Hamblin, Kenneth Howard, and D. James. © 2002. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

METAMORPHIC ROCK MASSES

Recall that some metamorphic rocks have **foliation,** or a layered structure caused by the arrangement of minerals in the rock, which often develops perpendicular to the direction of compression. In addition, some metamorphic rocks retain original structures from their protoliths (parent rocks). Bedding in a sedimentary parent rock may be preserved even after metamorphism and is known as **relict bedding.** For example, the color bands in the marble in Figure 5.9b, on p. 93, most likely resulted from chemical differences inherited from sedimentary bedding. Alternating colors of blues and greens in Figure 8.32 were once sedimentary bedding and interbedded volcanic rocks.

In areas near igneous intrusions, **contact aureoles** develop where contact metamorphism occurs. This area is subjected to the intense heat and fluids associated with magma. The metamorphism gradually increases in intensity as one approaches the intrusive contact (Figure 5.4, p. 87).

In areas of regional metamorphism (Figure 5.11, p. 101), and in contact aureoles (Figure 5.4, p. 87), it may be possible to map gradations of metamorphism by the mineralogical changes in the rocks. Recall that a **metamorphic zone** is a region marked by a particular set of minerals usually distinguished by one or two **index minerals.** The boundaries between metamorphic zones are called **isograds.** Isograds are drawn as lines on a geologic map, similar to contacts.

On geologic maps of metamorphic rocks, sometimes the aspects of metamorphism are emphasized — showing metamorphic zones, for example (■ Figure 8.33) — and sometimes the parent rock that was metamorphosed is mapped without showing details of the temperature or pressure of metamorphism (Figure 8.32).

27. Examine the metamorphic zone map of northwestern Michigan in Figure 8.33.

a. In general, what do colors represent on this map?

____

b. What is an easy way to distinguish regional metamorphism (influencing a general region) from contact metamorphism (caused by magma) on a geologic map of an area? That is, what body(ies) of rock would you expect to find next to the metamorphic rocks in an area where contact metamorphism occurred?

____

c. Do you find it/them in Figure 8.33?

_______ So, what type of metamorphism does this suggest occurred there?

____

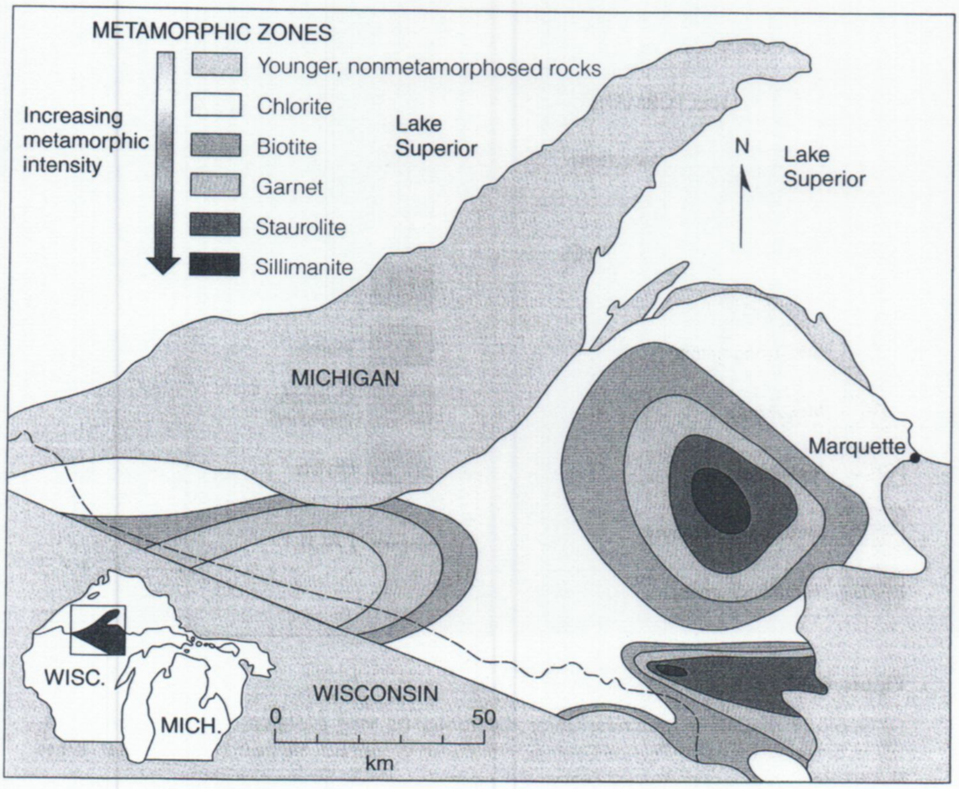


Figure 8.33

Map of the metamorphic zones in Upper Peninsular Michigan. Metamorphosed shales in this region best delineate the isograds, shown as black lines separating the colored metamorphic zones. Metamorphism here took place about 1.5 billion years ago (Exercise 27). From H. L. James, *G.S.A. Bulletin*, Vol. 66, Plate 1, p. 1454. Reprinted by permission of Geological Society of America.

d. Where would you expect to find garnets in this region? Refer to Figure 5.11 and Table 5.6, on pp. 101 and 102 to assist you with this answer.

____

____

e. The line separating yellow from light brown is called what?

____

f. Where did the highest temperature of metamorphism occur?

____

28. Examine the metamorphic rocks in the geologic map of the area near Chico, California, in Figure 8.32.

a. Before metamorphism, what rock type were most of the green rocks?

____

Most of the blue rocks?

____

b. Both of these rock types tend to form in layers. What happened to the layers during metamorphism?

____

c. Assuming compression caused this, what direction was the compression?

____

ROCKS IN A CROSS SECTION

29. Your instructor will provide rock samples that correspond to parts of the cross section in ■ Figure 8.34.

a. Use Figure 8.5 to identify the rock symbols in the cross section and then match them to the samples. To complete this properly, you will also need to think about which rocks are equivalent in some way. For example, decide which of the igneous rocks have equivalent composition so they could have formed from the same magma. Refer to Table 3.1, on p. 36, if you need to. List them:

____

____

b. Similarly, decide which of the metamorphic rocks would match unmetamor-

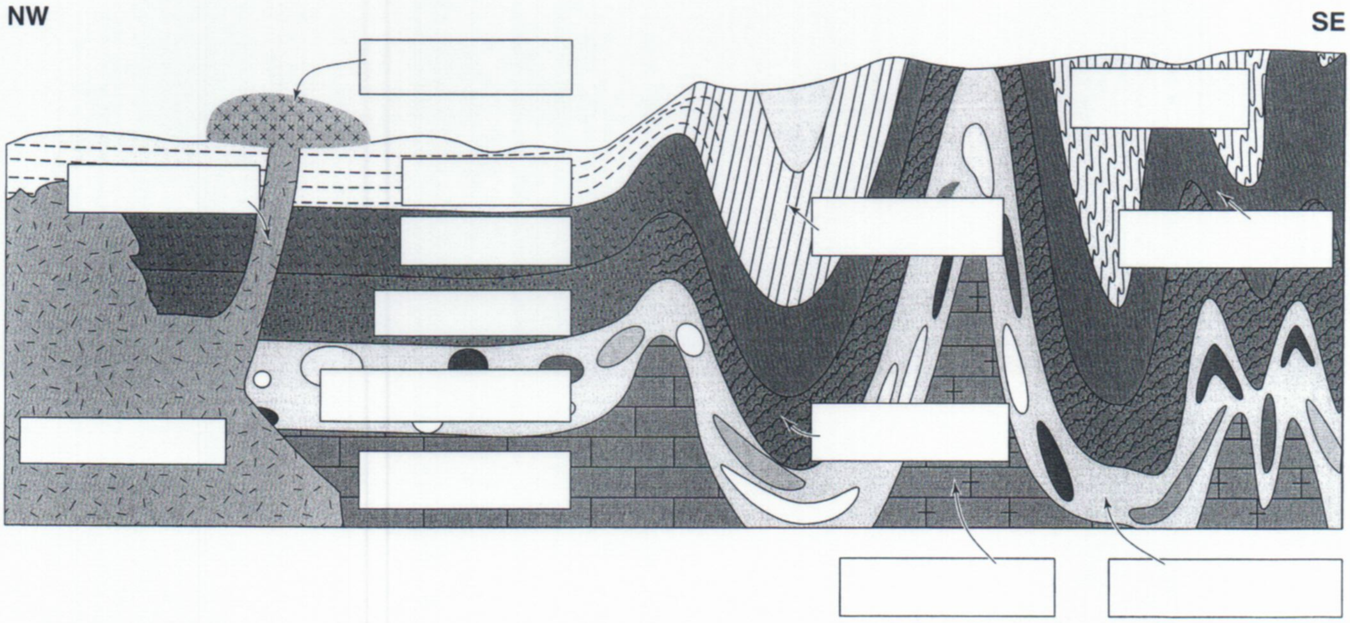


Figure 8.34

Hypothetical cross section of a region with corresponding rock samples (Exercises 29 and 30) phosed sedimentary and volcanic rocks along the same layer. To help with this, list the parent rock samples with their equivalent metamorphic rocks in Table 8.4. Notice that for the uppermost layer (light green), this one parent rock has two metamorphic equivalents. List these in Table 8.4 in the row that has three spaces. Refer back to Tables 5.3 and 5.4, on pp. 96 and 97, if needed.

c. Now that you have matched the rocks, write each sample name and number on the cross section (Figure 8.34) in the appropriate box.

d. Also enter the rock type for each sample using the following abbreviations: I = igneous, S = sedimentary, and M = metamorphic.

30. a. What structures are present in this cross section?

____

____

Table 8.4

Pairs of Parent and Metamorphic Rocks for the Cross Section in Figure 8.34 (Exercise 29)

Parent Rock	Metamorphic Equivalent	

b. Igneous features?

____

____