GEOL.5220 – Structural Geology
Faults, Folds, Outcrop Patterns and Geologic Maps

I. Properties of Earth Materials

When rocks are subjected to differential stress the resulting build-up in strain can cause deformation. Depending on the material properties the result can either be elastic deformation which can ultimately lead to the breaking of the rock material (faults) or ductile deformation which can lead to the development of folds. In this exercise we will look at the various types of deformation and how geologists use geologic maps to understand this deformation.

II. Strike and Dip

Strike and dip refer to the orientation or attitude of a geologic feature. The *strike line* of a bed, fault, or other planar feature, is a line representing the intersection of that feature with a horizontal plane. On a geologic map, this is represented with a short straight line segment oriented parallel to the strike line. *Strike* (or strike angle) can be given as either a quadrant compass bearing of the strike line (N25°E for example) or in terms of east or west of true north or south, a single three digit number representing the azimuth, where the lower number is usually given (where the example of N25°E would simply be 025), or the azimuth number followed by the degree sign (example of N25°E would be 025°).

The *dip* gives the steepest angle of descent of a tilted bed or feature relative to a horizontal plane, and is given by the number (0°-90°) as well as a letter (N, S, E, W) with rough direction in which the bed is dipping. One technique is to always take the strike so the dip is 90° to the right of the strike, in which case the redundant letter following the dip angle is omitted. The map symbol is a short line attached and at right angles to the strike symbol pointing in the direction which the planar surface is dipping down. The angle of dip is generally included on a geologic map without the degree sign. Beds that are dipping vertically are shown with the dip symbol on both sides of the strike, and beds that are flat are shown like the vertical beds, but with a circle around them. Both vertical and flat beds do not have a number written with them.
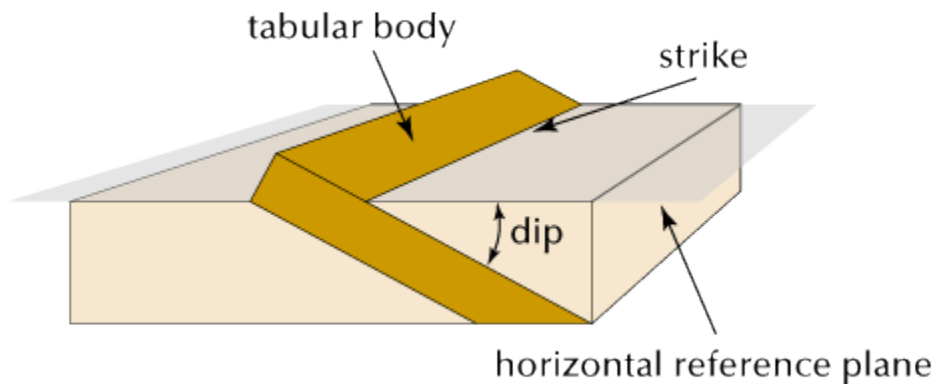

Figure 1. Illustration of stike and dip of a tabular body.

Geologists often measure the strike and dip of a surface using a Brunton compass. The strike is measured by leveling (with the bull's eye level) the compass along the plane being measured. Dip is taken by laying the side of the compass perpendicular to the strike measurement and rotating the horizontal level until the bubble is stable and the reading has been made. Strike and dip measurements are shown on a geologic map as illustrated in Figure 3.

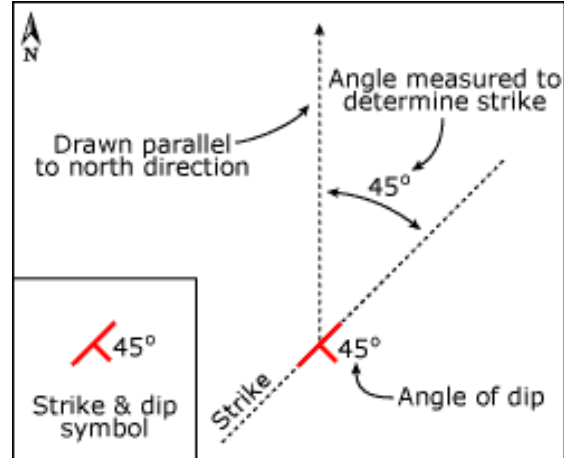**Figure 2. Brunton compass showing bulls eye and bubble levels.**

Figure 3. Plotting strike and dip on a geologic map.

Using the strike and dip board, measure two strikes and dips and report the results in Table 1. Set two different angles by moving the block, and in your table record the letter corresponding to the position of the block.

Table 1. Strike and dip measurements

Position (letter)	Strike	Dip

III. Flat lying beds

Sedimentary rocks are deposited and lithified in a nearly horizontal position and, even after uplift, maintain a relatively flat or only gently inclined attitude. In areas where relatively flatlying rocks occur the whole area may be underlain by one sedimentary formation and older rocks would be found only in stream valleys where erosion has cut down through the younger rocks (Fig. 4).
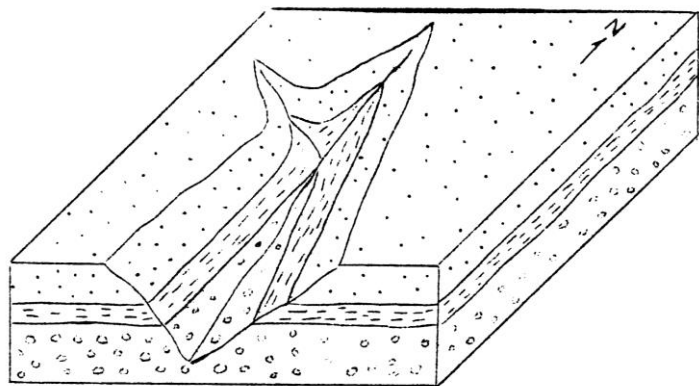

Figure 4

IV. Folded strata

During deformation rocks may break (faults and joints) or bend and form folds. When the strata are bent upwards the structure is an anticline and when the strata are bent downwards the structure is a syncline (Fig. 5). Note that in an anticline the oldest rocks are in the center of the fold while in a syncline the youngest rocks are in the center of the fold. The axial plane is the surface that bisects the fold and the hinge line marks the center of the fold. Folds may be symmetrical or asymmetrical (Fig. 6).
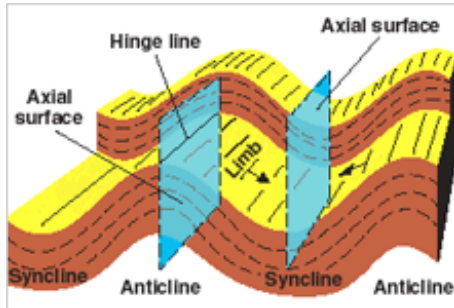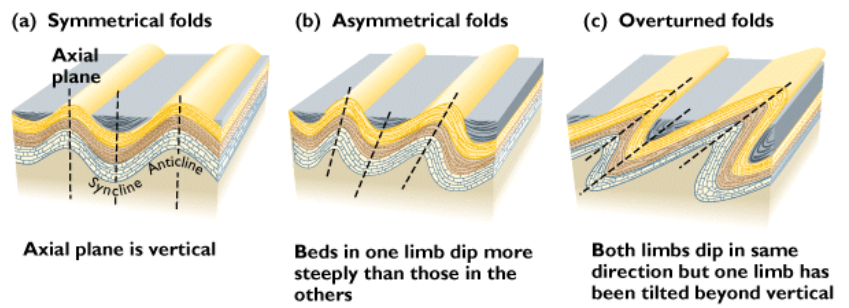

Figure 5. Fold nomenclature

Figure 6. Symmetrical and asymmetrical folds

The fold axis may be horizontal or it may plunge at some angle from horizontal (Fig. 7). Geologic maps show the rock units that are exposed at the surface. Folds can be very complex and form very complicated outcrop patterns on geologic maps. In subsequent parts of this exercise you will get a chance to explore these complexities.
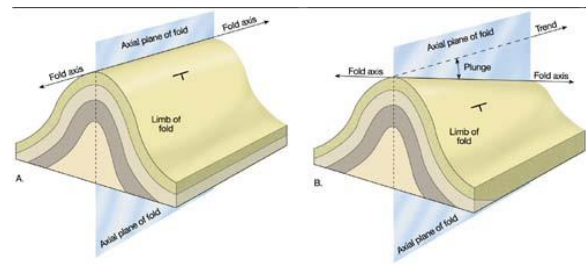

Figure 7. Horizontal and plunging folds.

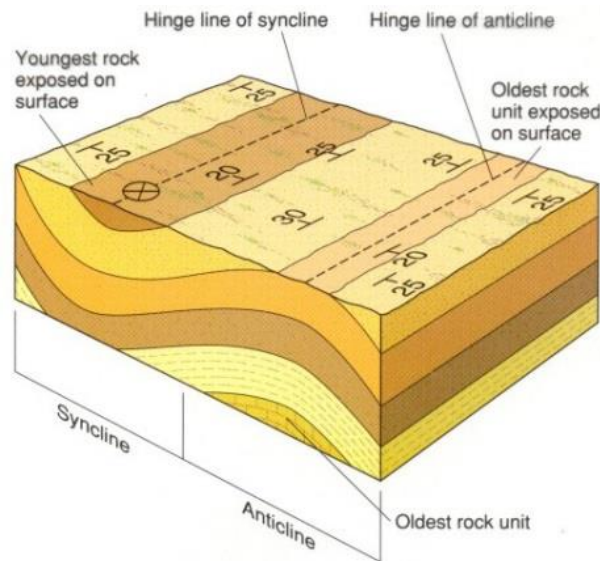The drawing of a geologic map is illustrated on Figure 8.

Figure 8

In areas where the formations have been folded, the surface is underlain by successively younger rocks in the direction of the dip of the sedimentary strata. Because of the original attitude of the sedimentary rocks, it becomes obvious that a general rule can be applied to gently folded strata. The rule is the "older beds always dip toward and under younger beds (Fig. 9).
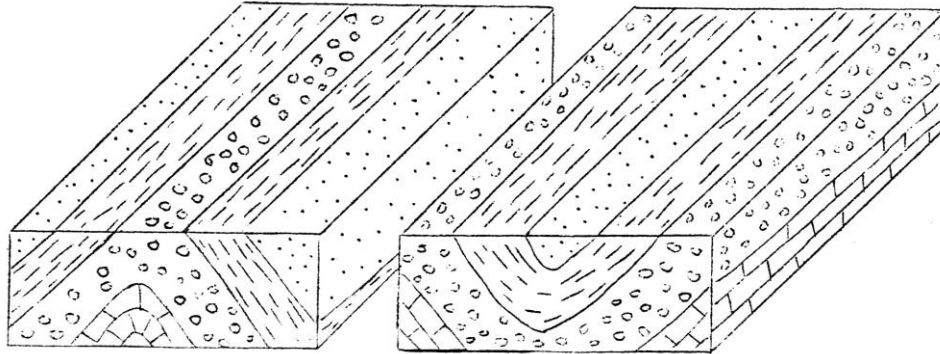

Figure 9

In areas where the rocks are moderately folded and all of the fold axes are horizontal, erosion usually carves out a surface of linear ridges and valleys due to the differences in strength of the various rock units (Fig. 10). Study the diagram and then draw a geologic map on Figure 11. Remember that a geologic map shows the rock units that intersect the surface. Put in the strike and dip symbols where needed and answer the questions (1-4).
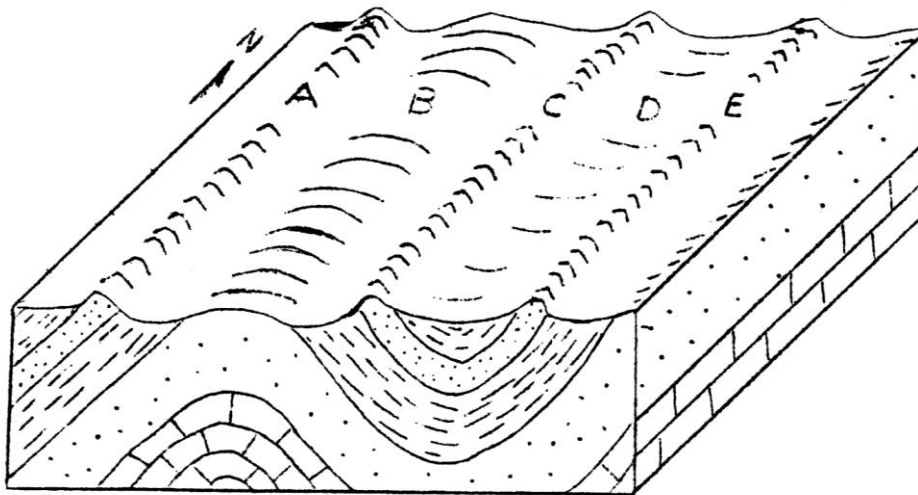

Figure 10

1. What structure would you cross in going from A to C in Figure 10?

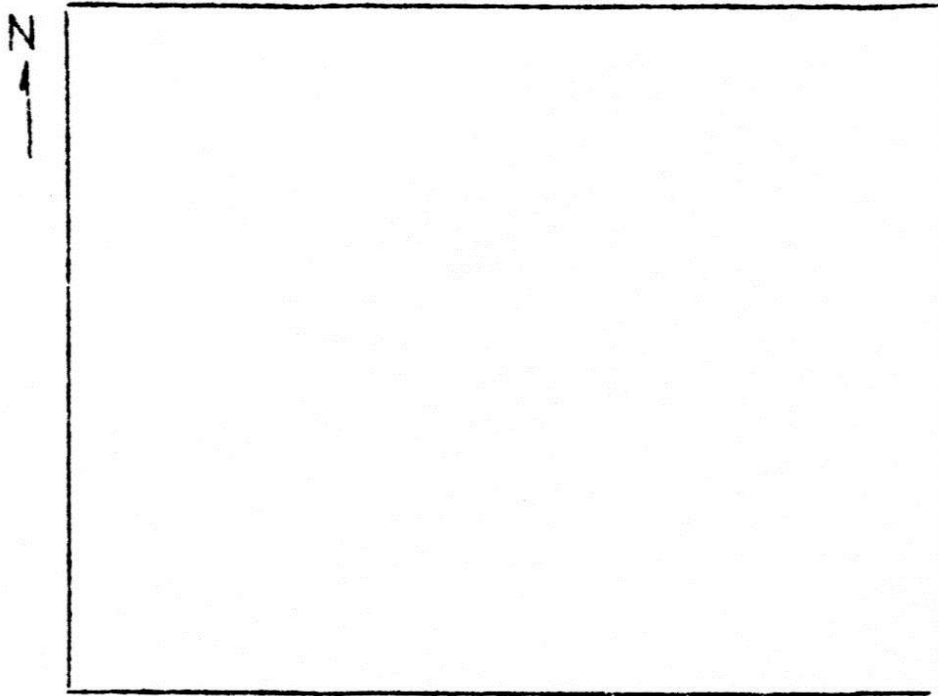2. What structure would you cross in going between C and E?

Figure 11

3. What is the approximate strike and dip of the sandstone unit at A?

4. Fold axes are indicated by a straight line, a little longer than the strike symbol with two arrows at right angles to it. The arrows point toward the axis if it is a synclinal axis and away from the axis if it is an anticilinal axis. Place the appropriate symbols on the map above.
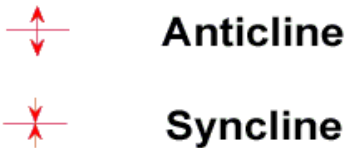
 Anticline

 Syncline

Figure 12 is a geologic map showing three fold axes and contacts between a limestone and a sandstone. Answer the following questions (5-7).

5. What is the approximate strike of the sandstone?

6. Is the strike of the limestone the same?

7. In the space to the right of the map, draw a structure cross section of the map from A to B showing the two formations and their structural relations.
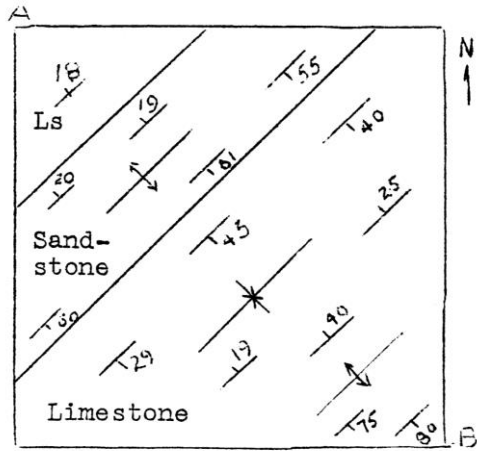

Figure 12

Figure 13 illustrates a level surface cut by a stream valley. A basalt dike cuts across the valley with an east-west strike. In the map view show what the outcrop pattern of the dike would look like if it dipped the amount and direction indicated under each map.
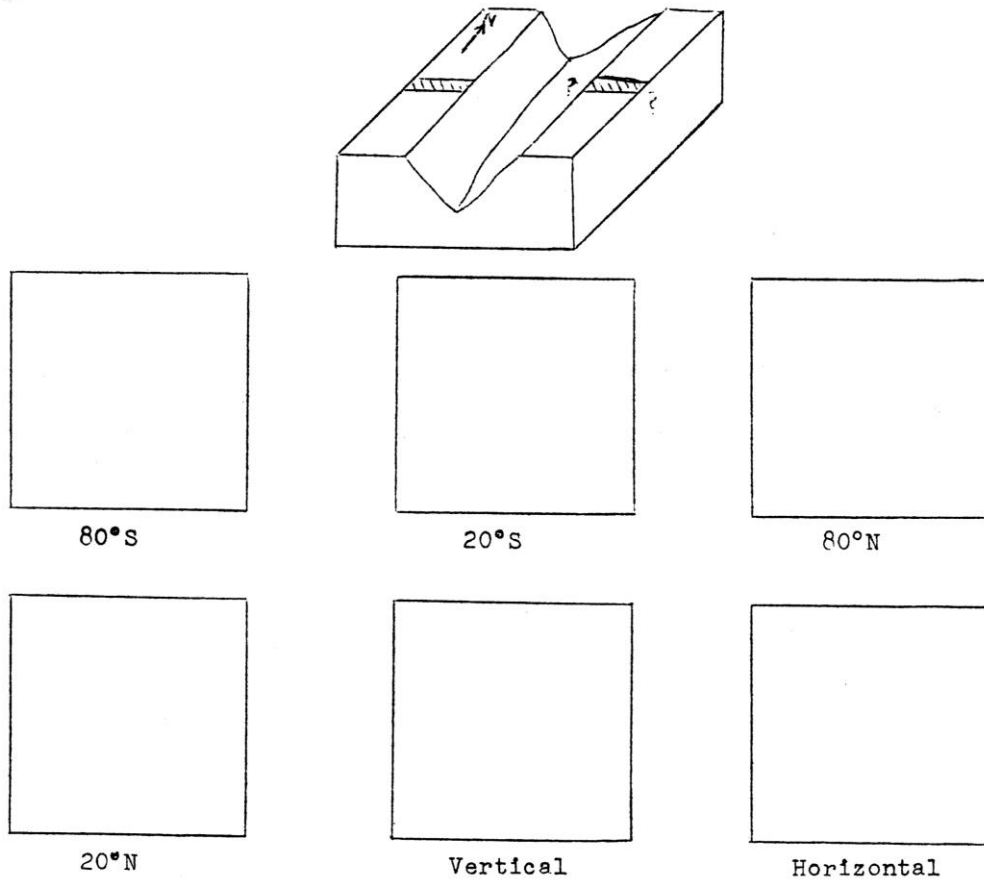

80°S	20°S	80°N

20°N	Vertical	Horizontal

Figure 13

8. As you can see a consistent relation exists between the direction of dip and the direction in which the V of the outcrop points. State this relationship, known as the "Rule of the V's".

9. Can you think of any possible exceptions to this rule?

A valuable clue to the structure of the rocks is the width of the outcrop of a formation. Note in Figure 14 that the sandstone bed is of uniform thickness but its outcrop width varies considerably. As the dip of a bed becomes more gentle the outcrop width becomes greater. The width of an outcrop is equal to the true thickness of the bed only when the dip is vertical.
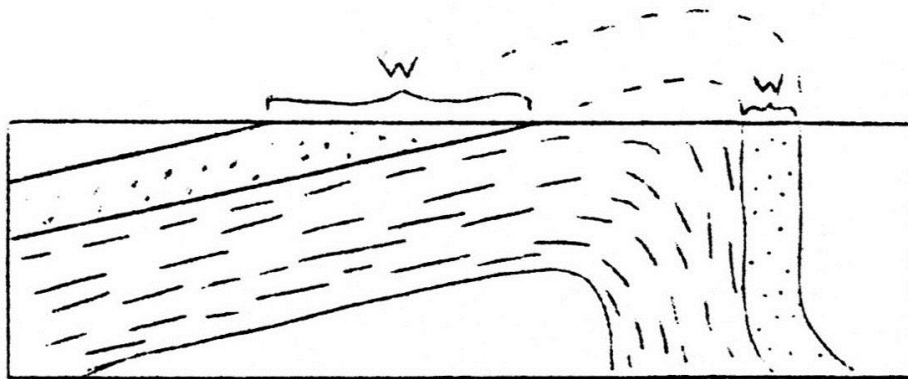

Figure 14

In Figure 9 it is apparent that when erosion truncates folds with horizontal fold axes it produces an outcrop pattern of parallel bands of rock units. In observing the diagram two general rules are apparent.

a. Oldest beds are in the center of anticlines

b. Youngest beds are in the center of synclines

In the following diagrams the age of the beds will be indicated by letters representing the various geologic periods. The geologic column that will be used is as follows (from youngest to oldest):

K	Cretaceous	D	Devonian
J	Jurassic	S	Silurian
Tr	Triassic	O	Ordovician
P	Permian	C	Cambrian
C	Carboniferous		

Complete the block diagram (Fig. 15). Place strike and dip and appropriate fold axis symbols on the map surface.
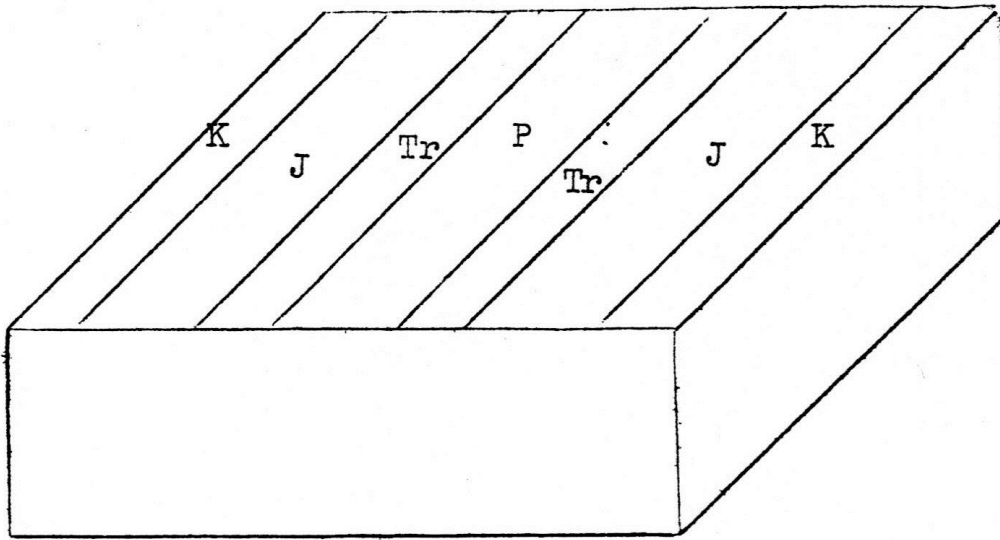

Figure 15

On Figure 16 draw an asymmetric syncline striking N-S with its gently dipping limb on the west side. Place strike and dip symbols on the map. Make sure that the widths of the outcrop patterns reflect the asymmetry of the fold.
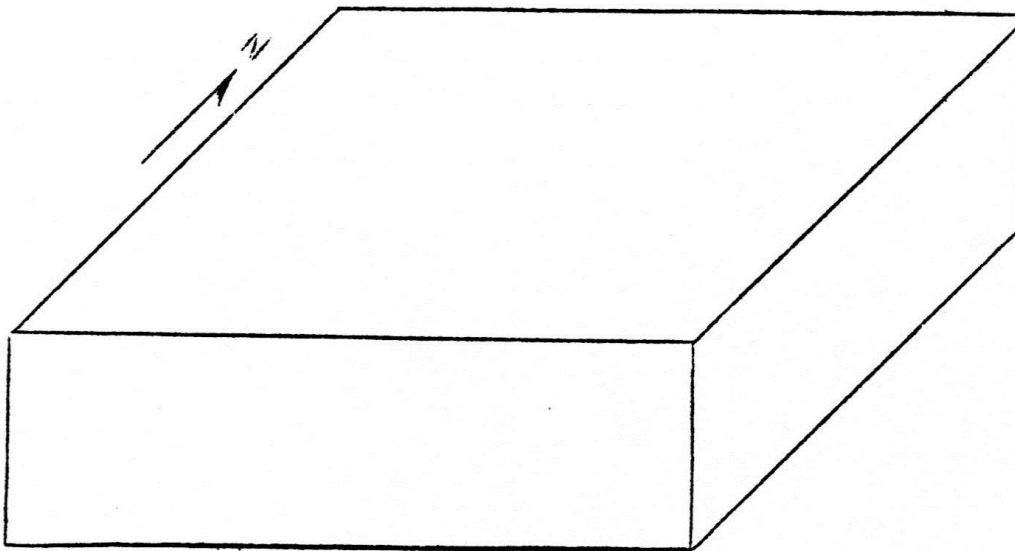

Figure 16

Two maps (Figure 17) of entirely different areas are submitted for geologic interpretation. In the space below the figure, draw structure sections of each one from NW to SE to help explain the difference.
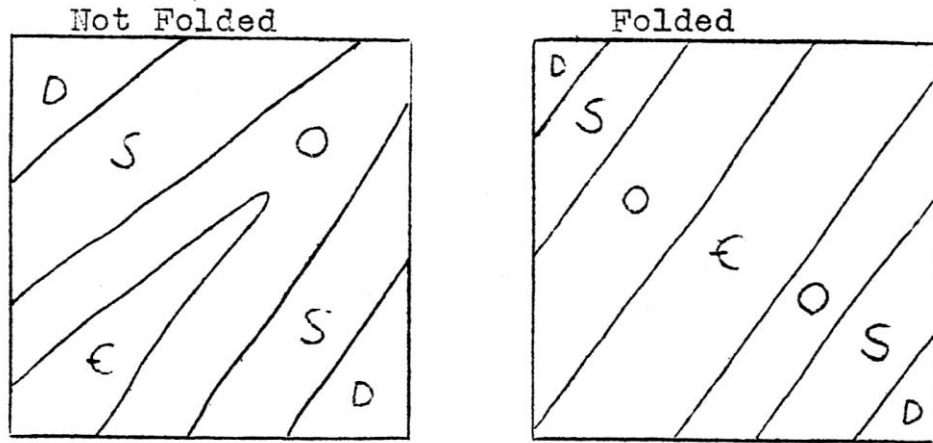

Figure 17

It is obvious from the preceding exercises that if the fold axes are horizontal, erosion causes the various formations to crop out in parallel linear bands. However, folds commonly have tilted axes. When the axes are tilted erosion causes a typical horseshoe shaped or hairpin-like outcrop pattern. The degree of deviation of the folds axis from the horizontal is called the plunge of the fold.

The symbols for plunging fold axes are shown below. The direction of plunge is indicated by an arrow. The degree of plunge may be shown as a number at the end of the arrow.

The folds shown in Figure 18 plunge along their axes. The angle of plunge is the same as the angle of dip of a bed measured along the axis of a fold. The following rules may be helpful in interpreting folded strata.

1. Older beds plunge toward and under younger beds along the axis of a fold.

2. Anticlines close in the direction of plunge.

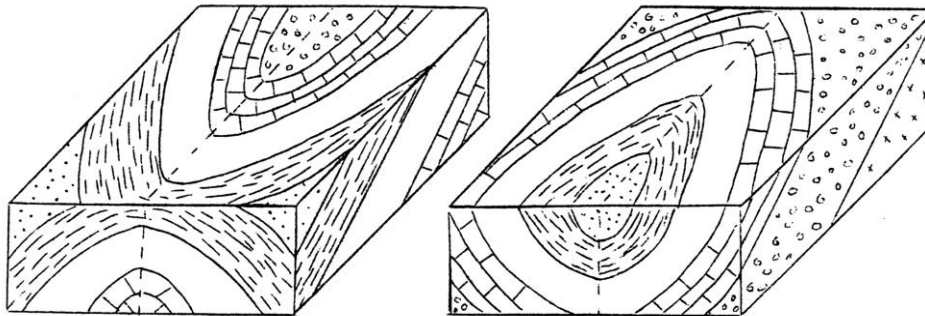3. Synclines open in the direction of plunge.

Figure 18

On the block diagram (Fig. 19) sketch in the outcrop pattern and structure section of the folded strata shown on the cross profile.
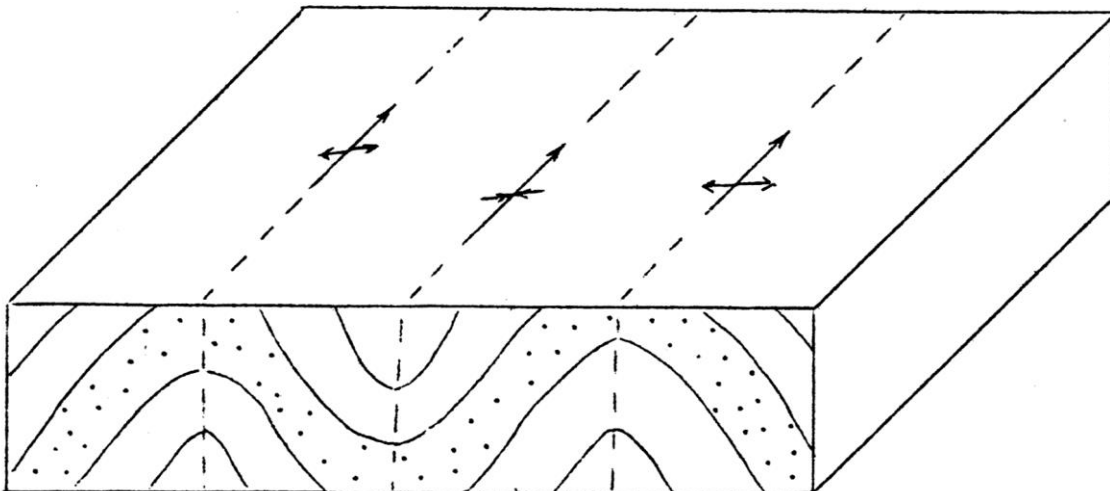

Figure 19

V. Faults

Faults are fractures in the rocks of the earth's crust along which there has been some displacement. They are formed when the rocks are subjected to strong forces of compression, tension, or twisting.

If the rocks of the crust are subjected to tension and pulled apart, one rock mass will slide down over the adjacent rock mass. Faults of this type are called **normal faults**.

If the rocks are subjected to compression and pushed together, one rock mass will be shoved up over the adjacent rock mass. Faults of this type are called **reverse faults** (dip of the fault plane greater than 30°) or **thrust faults** (dip of the fault plane less than 30°).

Classification of the various kinds of faults is made easier by referring to the upthrow (hanging wall) and downthrow (footwall) sides of the faults. The upthrow side of the fault may be determined by observing on which side the older beds occur because the processes of erosion are more active on the upthrow side and the younger beds have been eroded away.

The following rules are useful in interpreting faults:

1. Older beds indicate the upthrow side of a fault.

2. For normal faults the hanging wall is on the downthrow side of the fault.

3. For reverse (or thrust) faults the hanging wall is on the upthrow side of the fault.

8. What is the approximate strike and dip of the fault shown in Figure 20?
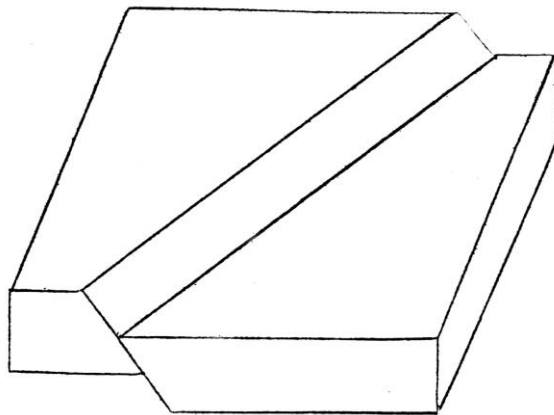
9. What kind of fault is it?

Figure 20

10. The line F-F' represents a fault prior to (block on the left) and after (block on the right) actual faulting (Fig. 21).

    a. What is the strike of the fault surface?

    b. What is the dip of the fault surface?

    c. What is the strike of the sandstone bed?

    d. What is the dip of the sandstone bed?

    e. What is the true displacement along the fault F-F'?

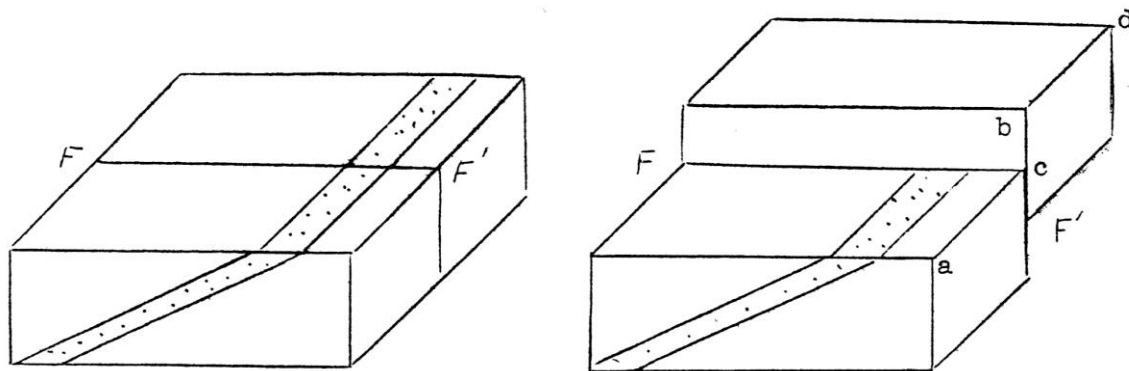   f. Complete the outcrop pattern of the sandstone in the displaced block.

Figure 21

A rule that always works is: Outcrop patterns "move" in the direction of the dipping bed on the upthrow side of a fault. The displaced block in Figure 21 has been eroded so that the surface is flat again. Complete the outcrop pattern of the sandstone on Figure 22. In which direction has the outcrop pattern "moved" as the result of erosion?
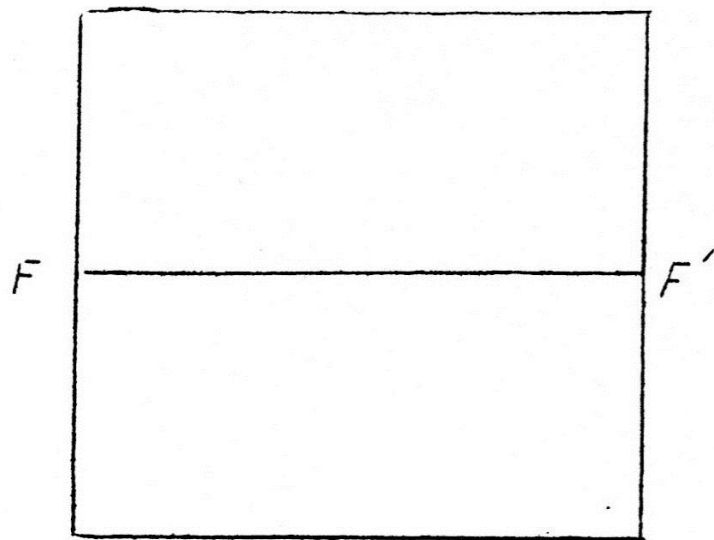

Figure 22

12

The strike of the beds in Figure 23 is E-W. The axis of the fold is horizontal. Complete the outcrop pattern on the block to show how the formations will crop out on the fault surface and on the fault plane. Indicate by a dashed line the position of the axial plane of the fold.
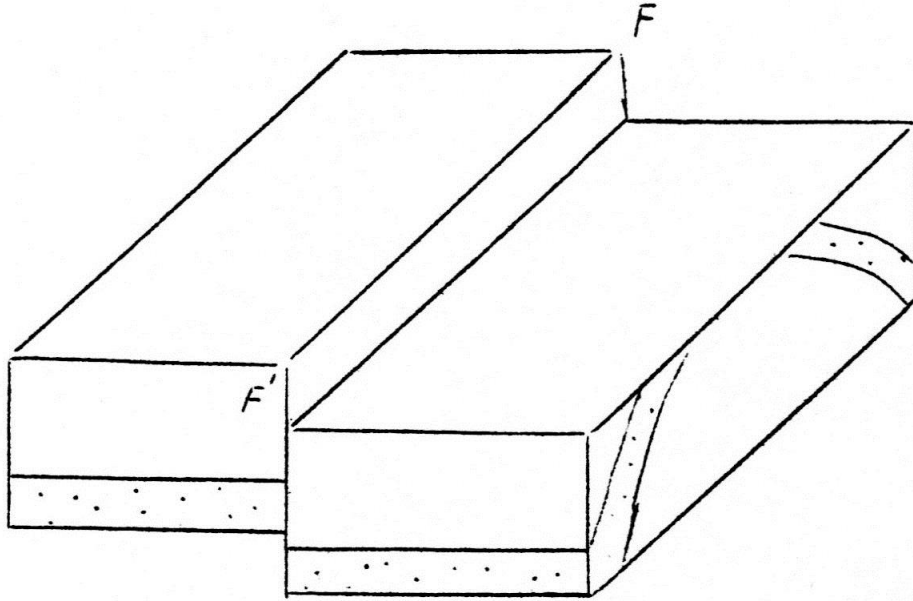

Figure 23

Complete the outcrop pattern on Figure 24 for the block shown in Figure 23 after it has been eroded to a peneplain (flat surface). Place some strike and dip symbols on the map.
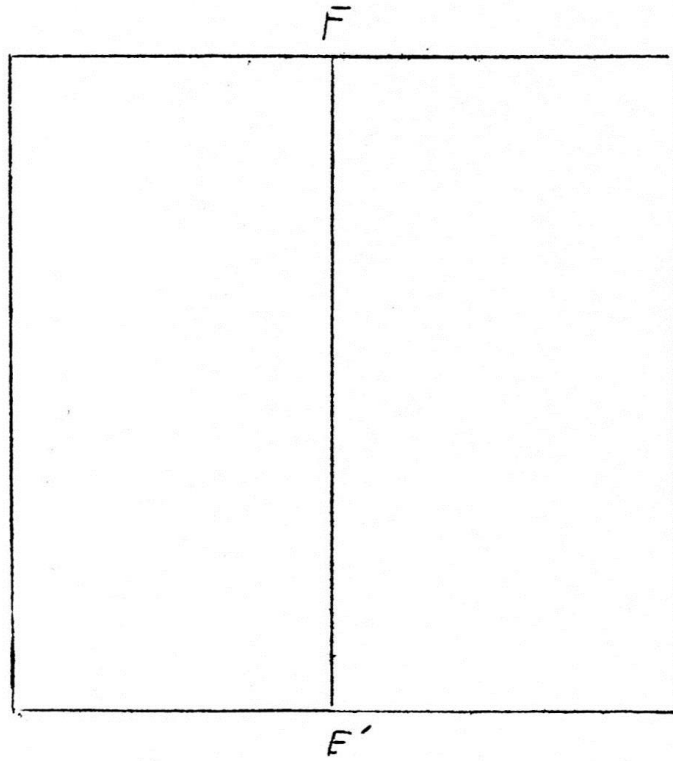

Figure 24

VI. Geologic Maps

A **geologic map** is used to show rock units or geologic strata that are exposed at the surface. Bedding planes and structural features such as faults, folds, foliations, and lineations are shown with strike and dip or trend and plunge symbols which give these features' three-dimensional orientations.

1. Bright Angel Quadrangle, Arizona

    a.   Locate the map with respect to latitude and longitude.

    b.   What is the attitude of the Paleozoic formations on this map?

    c.   Is there any relationship between structure, topography, and outcrop pattern on this map? If so, what?

    d.   When was the Pipe Fault formed?

2. Williamsville Quadrangle, Virginia

    a.   What structure lies between Little Mountain and Jack Mountain? How do you know?

b. The Clinton formation has an outcrop width southeast of Jack Mountain which is almost three times the outcrop width of the same formation at Little Mountain. Explain

c. What kind of fault lies on the NW side of Tower Hill Mountain?

d. In what direction do the folds of Chestnut Ridge plunge? The Chestnut Ridge referred to in this question is located in the southeast corner of the map.