Structural geology is the study of the orientation and relationship of rock units. A rock unit is a lithologically similar layer or body of rock, and different rock units are given names referred to as formations.

As you have seen from the “Dating Methods” lab, most geological processes take place over thousands or millions of years and so have very little direct effect on our lives. In future labs, you will explore the more sudden (and catastrophic) geological events, such as earthquakes and landslides. In this lab, you will see how to use the results (hidden in the rock record) of many sudden events to reconstruct geologic history. Part of this analysis is structural geology.

Stress and Strain

Tectonic forces move and deform the Earth’s lithosphere. These movements create stress in the lithosphere, which is measured in units of force (such as Newtons, or N). In turn, the rocks accommodate the stress by changing the space they occupy. This change in size is called strain, which is measured in units of volume (such as meters-cubed, or m³).

There are three basic types of stress: compression, extension, and shear.

- **Compression** results in rocks (as small as a layer and as large as a plate) being pushed together
- **Extension** (or tension) results in rocks being pulled apart
- **Shear** results in rocks sliding past one another

Regardless of the type of stress, the amount of stress can result in different strain response by the rocks: elastic deformation, plastic deformation and brittle failure.

- With a small amount of stress, the deformed rock returns to its original shape after the stress is removed. This is elastic deformation. A good example of this is isostatic rebound, when an area, which had been under a thick continental ice sheet, returns to its original elevation after the ice sheet has melted.

- With a bit more stress, the deformed rock rebounds somewhat when the stress is removed, but some permanent strain remains. This is plastic strain (the word “plastic” refers to the moldable property of the rock—hardly an everyday experience!). Folds are examples of plastic strain in a large volume of rock.

- After a lot of stress, the deformed rock will fracture or break, and the rock’s volume does not return at all to its original size. This is brittle failure. A fault is an example of brittle failure in a large volume of rock.
How geologists measure geological structures

Clearly, a horizontally-bedded set of rocks will tell a different geological story than a tilted set of rocks. To convey the data that would allow geologists to formulate an interpretation, a set of standard symbols and measurements was developed.

The two principal measurements of any geological structure (for instance, a fault or a layer of rocks) is the **strike** and the **dip** of a layer of bedded rocks. Both measurements can be made with a Brunton compass; both measurements have a compass orientation (i.e., such as N 30 W (or NW 30) which means “30 degrees west of due north”). In addition, the dip requires the measurement of an angle (reported in degrees off of horizontal). But what are they?

The strike of a structure is the compass orientation of any horizontal line on a planar surface. The dip is the angle of slope at right angles to the strike. Note that the strike orientation will always be 90° (perpendicular) off of the dip orientation.

A way to think about strike and dip is to consider how water behaves. Imagine a boat ramp sloping toward a lake. The water dripping off the ramp into the lake will be going in the direction of the dip; the slope angle of the boat ramp is the magnitude of the dip. The water level of the lake, which makes a horizontal line across the planar surface of the boat ramp, is the strike (once you measure its direction).

“**Attitude**” is the term used to describe a feature’s strike and dip at a particular point. An attitude symbol looks like a short-legged “T” with the arms of the T representing the direction of the strike and the short leg of the T pointing in the direction of the dip (towards lower elevation). A number is written next to the short leg of the T, which represents the magnitude of the dip in degrees.

1. a. What sort of rocks will structural geology be most effective on (recall the emphasis on layers)? Indicate your answer by circling the most appropriate rock types.

   Intrusive igneous  Extrusive igneous  Clastic sedimentary
   “Other sedimentary”  Foliated metamorphic  Non-foliated metam.

b. Examine the foamboard model of a tilted layer set up on the back table. Using the Brunton compasses provided, record the strike and dip of the board.

   Strike ___ (compass orientation)  Dip ___ (angle in degrees)  (simplified compass orientation)

   c. Given the north arrow shown, draw the attitude symbol for the board.
Folds and faults

Folds are warped or bent layers of rock, usually consisting of two limbs dipping (tilting) in opposite directions. In simple folds, the axial plane is the surface that passes through the points of maximum curvature of the fold. The expression of the axial plane on the surface of the land is the fold axis (or hinge line), which is usually a straight line. See the diagram below.

There are two fold types: **anticlines**, in which the strata (layers) dip away from the fold axis; and **synclines**, in which the strata dip towards the fold axis. Note the terms anticline and syncline do not necessarily refer to landforms such as hills and valleys; rather, the terms describe the cross-sectional appearance of the rock layers (remember that erosion will alter the topography at the surface!). Thus, geologists can recognize an eroded syncline or anticline, even if the surface is eroded flat, by observing the orientation and relative ages of the strata.
2. a. Put **attitude symbols** (don’t worry about the exact dip angle) on the two block diagrams below.

![Block Diagrams](image)

b. Which numbered layer corresponds to the oldest rock unit of the anticline?

c. Which numbered layer corresponds to the youngest rock unit of the anticline?

d. Which numbered layer corresponds to the oldest rock unit of the syncline?

e. Which numbered layer corresponds to the youngest rock unit of the syncline?

The fold axis can also be tilted, leading to **plunging** folds. When planed off by erosion, as shown in the diagram, the fold pattern on the ground can look odd, but still allow the reconstruction of the eroded fold.

![Fold Diagram](image)

3. Complete the blank side of each of the two block diagrams by filling in the layers that should be visible; use the existing patterns to indicate layer types.
A local use of structural geology

Below is a geologic map of Cougar Mountain, near Renton.

Note the circled attitude symbols.
This will be a cross-section of the same area (along the line A-A’ on the geological map). The top of the cross-section is called the topographic profile and represents the elevations of the surface of the land along the cross-section line.
4. Complete the cross-section of Cougar Mountain. Make sure to shade in the different formations with different colors or patterns.

5. a. Using the map and cross-section, what is the oldest formation in the Cougar Mountain area?

b. What is the youngest formation in the Cougar Mountain area?

6. Between what two formations does a significant unconformity lie? What type of unconformity is it? (Hint: look at the south side of the cross-section)

Faults
Faults are breaks or fractures in rocks along which movement of one side relative to the other has occurred. Breaks or fractures in rocks which exhibit no relative motion are called joints. While the expression of a fault (such as the San Andreas Fault in California or the Straight Creek Fault near Marblemount) on the surface is usually linear, the actual break or fracture is a planar surface, called (not shockingly) a fault plane.

The hanging wall of a fault rests on or lies above the fault plane; the footwall supports the hanging wall and is therefore underneath the fault plane. Note that this terminology does not necessarily make sense for every type of fault.

The upthrown block (or overriding plate) is the side that moves upward relative to the other side and the downthrown block is the side that moves downward. Once again, this terminology does not necessarily make sense for every type of fault. Note also that the footwall is not always the upthrown block, as shown in the diagram.

The slip is the distance measured along the fault plane that one side of the fault has moved relative to the other. There can be vertical and horizontal components to the slip. The slip rate is the slip divided by the time interval.
Faults are classified according to their relative movement, which can be up/down, right/left or a combination.

- In normal faults, the hanging wall moves down relative to the footwall. It is called “normal” because the superposition rule is preserved: younger rocks remain above older rocks.
- In reverse faults, the footwall moves down relative to the hanging wall. It is called “reverse” because the superposition rule is reversed: older rocks end up above younger rocks.
- In strike-slip faults, the fault plane is nearly perpendicular (at right angles) to the surface and any slip along the fault is parallel to the orientation (strike) of the fault plane. The strike-slip fault shown in the accompanying diagram is called a left-lateral strike-slip fault because the motion on the opposite side of the fault (from your perspective) is to the left. The opposite motion would be called right-lateral.

7. Fill in the table below (recall that the types of plate boundaries are convergent, divergent and transform):

<table>
<thead>
<tr>
<th>Fault type</th>
<th>Associated type of stress</th>
<th>Associated type of plate boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strike-slip</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8. For the cross-section below, draw the map view of the area above. Don't forget to indicate where the fault is and label each side of the fault "U" or "D" to indicate up and down directions of motion.

![Cross-section and map view](image1)

9. For the map view of the strike-slip fault below, draw the cross-section that corresponds to a slice taken along the line A-A'.

![Map view and cross-section](image2)

Examples of stress on rocks

10. a. Examine ST-1, which is a rhyolitic tuff (light-colored layers) sandwiched in obsidian (this rock was found in Monida Pass, Idaho). What event generates a tuff?

b. Does tuff therefore follow the law of original horizontality?

11. a. So, what kind of stress (compressive, extensive or shearing) is evident in the rock?

b. Was this a sudden or gradual stress? How can you tell?
12. How can you tell that this rock was solid when the stress was applied? In other words, if the rock were even partially molten, what differences would you notice?

13. a. Examine ST-2, which is from Matillija Canyon near Ojai, California. The smooth surface is called a slickenside. Is this the result of compressive, extensive or shearing stress (hint: more than one answer is possible)?

b. Along what type of structure (fault or fold) would a slickenside be found?

14. a. Examine the marked side of ST-3, which is a siltstone from Knappton, Washington. What type of structure is evident on that side?

b. Stratigraphic “up” is marked by the arrow on the rock. Sketch the face oriented vertically, and indicate any motion recorded in the rock by arrows.

c. These type of structures are called listric, because they flatten out as they go down. These structures exist under the Los Angeles Basin and are responsible for many of the non-San Andreas Fault earthquakes. Please classify this structure using one of the words in the left column of the table in question 7.

Needed: Geologic Map of the Centralia-Chehalis District, Washington

15. Find an attitude symbol in the Skookumchuck Formation near the town of Chehalis Hint: the Tono No. 1 coal seam should be nearby. What is the dip direction and dip angle of the rocks at that point?
16. Note that there is a road that hugs the outcrop of Skookumchuck Formation in this area; sketch what a roadcut would expose of the layers within the Skookumchuck along this road between circled points “26” and “53”.

17. What structure allows the Mendota, Upper Thompson and Tono No. 1 coal seams make a “U-turn” in the vicinity of Chehalis. Hint: are coal seams subject to the Law of Original Horizontality? Of course! Further hint: This is a two-word answer.

18. a. Notice there are a lot of parallel structures, such as the Centralia Syncline, the Meridian Hill Anticline and the Snyder Creek Syncline. What kind of tectonic stress (compression, extension or shearing) are related to these structures? Along what compass direction (e.g., north-south, east-west) is the stress oriented?

b. Some other structures (such as the Kopiah Fault and the Scammon Creek Fault) are parallel to the structures in question 18a; what type of faults (reverse, normal or strike-slip) are these?

19. a. Find another set of parallel structures, including the Salzer Creek Fault and the Chehalis Fault. These are the same type of faults as the ones in question 18b. Along what compass direction was the tectonic stress that generated these faults oriented?

b. Are these faults older or younger than the faults in question 18b? How can you tell?
20. a. Has the direction of tectonic stress remained the same throughout the Tertiary Period? What does this imply about the uniformity of subduction through the Tertiary?

b. What is the oldest epoch within the Tertiary period that the synclinal and anticlinal structures could have developed? Hint: Do the rocks of Qlh dip? Do the rocks of Tnm dip?