FOLDS & FAULTS – Tutorial Script

When we observe rocks around the Earth, we can often see surfaces along which rocks have broken and moved, surfaces we call fault planes. Or we can see layers of rock that have folded. What kind of pressures cause these faults and folds? Why? Where? And what causes one set of rocks to break and another to fold? In this video tutorial we will explore the causes and consequences of pressure applied to rocks, a term known as **stress**.

First let's examine more closely the three types of pressure or stress that can be applied to a rock: **compression, tension, and shear**. When rocks are compressed, they are squeezed. Compression happens at convergent plate boundaries where plates are pushed toward each other, and the crust and plates get thicker. When rocks undergo tension, they are pulled apart. Tension happens at divergent plate boundaries where plates spread apart, and the crust and plates get thinner. When rocks are sheared, they experience what happens when you push on the top of a deck of cards while friction holds the bottom – one side moves in one direction while the other side remains fixed or moves in the opposite direction. Shear happens at transform plate boundaries, where plates slide past one another. *(Review the Plate Tectonics video tutorials for more information on plate movements and boundaries).*

All of these different types of stresses will eventually lead to changes in the shape or form of a rock, a process known as **deformation – de"forming"**. Rocks that are undergoing deformation are experiencing **strain**. In some cases, strain or deformation of a rock leads to breaking the rock, which we call **brittle deformation**. In some cases, strain or deformation leads to a rock bending or folding, which we call **ductile or plastic deformation**. And in some cases, strain or deformation of a rock isn't permanent. When the stress is eventually released, the rocks go back to their original shape. We call that type of strain or deformation **elastic deformation**. Here I will demonstrate all three types of deformation with a wood skewer. Apply some pressure, deform the skewer, release the pressure, and the skewer returns to its original shape: elastic deformation. Apply some pressure, deform the skewer, release the pressure, and it's permanently bent. That's plastic deformation. Apply some pressure and break the skewer: brittle deformation.

How did we get one type of deformation over another? Let's return to the skewer. To get elastic deformation, we have to apply only a very little pressure – too much and it will break or permanently bend. Each substance or rock has its own **elastic limit** – the amount of pressure that if reached means that deformation will be permanent. There is another limit, the **yield point** of the rock. The yield point is the amount of pressure required to cause a rock to break. It of course will depend on the rock material and its strength. Now how about plastic vs brittle? As you can see in my demonstration, breaking the skewer happens when the stress is applied quickly. The bending required that the pressure be applied slowly over a long period of time. In addition, if I use my fingers to warm up the skewer, it's more likely to deform plastically. Colder rocks and materials are more likely to break. Warmer ones, bend or fold.

Applying these principles, where would we normally expect to see each deformation happening on our planet? Let's go to the plate boundaries, where we have stresses applied daily. At the surface of the plate boundary, rocks are cool; as we descend below the surface, rocks get warmer. So we're most likely to see brittle deformation at the surface and plastic deformation at depth. Faults at the top; folds below; which we can see in this illustration of a continental collision zone creating massive mountain systems like the Himalayas, with faulting at the surface and folding at depth. Note: if folds happen at depth, but we see those folded rocks at the surface, what does that mean? It means that all the rocks that were above the fold when it was forming have now been eroded away; the land has uplifted; and the older folded rocks are now exposed. We will come back to the topic of mountain building and erosion in later video tutorials.

What about elastic vs brittle deformation? Elastic primarily happens along active fault lines at the surface where stresses build just a little before overcoming friction on the fault, and the fault slips. Any strain experienced by the rock during the initial stress build up is then released, and the rocks go back to their original shape. We will discuss elastic deformation and rebound further in the video tutorials on Earthquakes.

For the rest of this video, we will explore the different types of faults and folds created by the different types of stresses that can be applied to rocks.

As previously mentioned, when rocks undergo brittle deformation, they break. The plane along which they have broken is called a **Fault.** After a fault has formed, successive application of stress can either cause continual movement of the rocks along each side of the fault or if friction is too high cause another break or fault for form elsewhere.

Faults can be classified by the type of movement that happens along them. Faults that have near vertical fault planes and have horizontal slip along strike are called **strike-slip faults**. (Strike is the orientation of the line that a fault plane makes when it intersects a horizontal surface. For example, the strike of this fault is due north. The strike of this fault is north 45 degrees west.) Faults that have planes that dip at an angle between horizontal and vertical and thus have vertical slip are called **dip-slip faults**. Faults that experience movement along strike and along dip – the combination of the two – are called **oblique-slip faults**.

For dip-slip faults, the top surface of the fault is the **hanging wall**. (Think of this as the block of rock that is hanging over the fault surface.) The bottom surface of the fault is the **footwall**. Draw a vertical line anywhere along the cross-section of a fault plane, and the hanging wall rocks will be sitting on top of the footwall rocks. If you draw a person standing upright, their head is in the hanging wall, and their feet in the footwall.

Faults are further classified by the stresses applied and the motion of rocks on one side of the fault relative to the other.

Normal faults are dip-slip faults caused by tension. As tension stress pulls the rocks apart, gravity pulls down the hanging block. Therefore, normal faulting gets its name because it is a normal response to gravity. If the hanging wall has moved downward in relation to the footwall, then the fault is a normal fault.

Reverse faults are dip-slip faults caused by compression. As stress pushes rocks together, one rock block rides up atop another. If the hanging wall has moved upward relative to the footwall, the fault is a reverse fault. **Thrust** faults are reverse faults that develop at very low angles nearly horizontal and thus may be difficult to recognize.

Now let's return to strike-slip faults. Strike-slip faults can be further sub-classified into right lateral and left lateral. Along a **right-lateral strike-slip fault**, one side of the fault appears to have slipped right relative to the other. Along a **left-lateral strike-slip** fault, one side appears to have slipped left.

How can you identify the type of fault just by looking at it? Let's try a few examples. If we're trying to classify a strike-slip fault, we can see relative motion only from a map view. We must look from above. First find an object like a fence or rock layer or river bed that was split apart by the fault movement. Draw relative motion arrows along and parallel to the strike of the fault plane, showing the motion of each side relative to the other. Now imagine standing on one side of the fault and looking across to the other side. Which direction did the other portion of your fence or rock layer or river bed move? To your right or left? If right, it's a right-lateral strike-slip. If left, it's a left-lateral strike-slip. *(*Notice that you should get the same answer no matter which side of the fault you are looking from as long as you answer it relative to where you're standing and whether the other side is moving to your right or your left.**)*

If we're classifying a dip-slip fault, we can see relative motion only from a cross-section (from the side). Find a rock layer that has been split by motion of the fault. Draw relative motion arrows along and parallel to the dip of the fault plane showing the motion of each side relative to the other. Which direction did each portion of the rock layer move relative to the other? Use the arrows to determine stress type. Line your hands up with the fault plane and move them in the direction of the arrows you showed. Are you pulling the rocks apart or pushing them together? If pulling apart, it's tension, and the fault is called a normal fault. If pushing the rocks together, it's compression, and the fault is called a reverse fault. Of course you can also look at the hanging wall and foot wall. Remember the hanging wall moves down in a normal fault and up in a reverse fault. That's a second check to ensure you named them correctly.

Now let's move on to folds. Folds occur in layers of rocks that were originally laid down horizontally but have since been deformed plastically. We classify folds based on their shape relative to the surface of the Earth. To classify these folds correctly, we have to see the fold from the surface and from the side (both a map view and cross-sectional view; to see both of those in the same picture, we call it an oblique view). First check to see if your fold has a hinge axis, an imaginary plane that bisects the fold and along which the fold drapes or hangs like blankets over a fence or wall. If the fold has a hinge axis, you can classify it by looking at its cross-section that cuts perpendicularly through the hinge axis. When you look from the side, **synclines** have a U-shape in cross section. **Anticlines** are the opposite: an upside down U, or an A-shape. If the axial plane is vertical then the fold is simple and upright. However, sometimes the axial plane can dip itself. In such cases we're going to call the fold a tilted fold and give the actual dip angle of the axial plane. For example, in this image, the anticline on the left is untilted and upright, but on the right, both the syncline and anticline have axial planes dipping eastward. The angle looks to be roughly 60°E, 90° would be vertical, 0° would be horizontal, so we call the right-most folds a syncline and anticline with hinge axes dipping 60°E. The direction, east, is the direction water would run along the surface, towards the east, if it ran down the surface of the hinge axis.

A hinge axis can also **plunge** into the ground, which means that the strike line stays the same, but the plane dips forward or backward into the ground. Plunge is the angle between the hinge line and a horizontal line. For example, an anticline with a hingeline plunging 20°N and a trend of due north would be lined up N-S, and the entire structure would plunge into the ground towards the north.

Plunging and nonplunging synclines and anticlines have similar cross-sectional shapes. However, their map views look quite different. Imagine folding all these pieces of paper into a syncline or anticline and then eroding the surface flat. From the map view, when we look down at the patterns of rock beds outcropping on the surface, we see parallel lines where the beds are coming out. These lines are symmetrical mirror images across the hinge axis. Notice that for synclines, the older rocks (the bottom rocks in the original horizontal deposits) appear furthest from the hinge axis and the youngest rocks are in the center. For anticlines, it's the opposite, the oldest rocks are pushed up in the center and the youngest rocks are furthest away.

Plunging synclines and **anticlines** show horseshoe-shaped outcrop patterns on eroded surfaces because we're not looking exactly perpendicular to the hinge axis. Effectively it's like seeing a combination of a cross-section and map view at the same time. For plunging anticlines, the horseshoe bends in the plunge direction. For synclines, the open side of the horseshoe is in the plunge direction.

Domes and **basins** are folds caused by pressure underground pushing up (a dome) or above ground pushing down (a basin) in a single spot, like a point. These folds have no hinge axes. Take a cross-section anywhere through the center and a basin will look like a syncline and a dome like anticline no matter where you cut it. However, in map view, after erosion, the outcrop pattern for both are concentric circles. Like with anticlines, in domes, the oldest rocks are pushed up at the center, while in basins, like synclines, the youngest rocks are preserved at the center.

So why does all this matter? Why does it help to identify the direction that beds are dipping or folding underground? Why does it matter where the oldest rocks are or the youngest or what the outcrop pattern looks like on the surface? Well, what if we're looking for mineral resources, or water resources, or we're simply trying to build our houses or communities on rocks and trying to see what type of fault movements might be happening, where the faults are, and where the folds are, where the beds that might be the strongest for building appear again in the neighborhoods. It's for that reason that we use the rocks that appear on the surface. We study them. We measure their dip. And based on the direction that the beds are dipping and the outcrop patterns, we can piece together a three-dimensional image of what's happening in the crust. Geologists use these 3-D images to answer all kinds of questions and search for all kinds of resources.

For more information about gathering the strikes and the dips and building the maps that tell us what's happening underground, continue on to the next video tutorial in this series.

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