

**JoVE: Science Education**  
**Making a Geologic Cross Section**  
--Manuscript Draft--

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## **Earth Science Education Title: Making a Geologic Cross Section**

### **Overview**

Geologic maps were first made and utilized in Europe, in the mid-to-late 18<sup>th</sup> century. Ever since, they have been an important part of geological investigations all around the world that strive to understand rock distributions on the surface of the earth, in the subsurface, and their modification through time. A modern geologic map is a data-rich representation of rocks and rock-structures in a two-dimensional plan view. The base for most geologic maps is a topographic map, onto which color variations have been placed to represent specific rock units. The boundaries between the rock units are called contacts. In addition to the contact lines, geologic maps contain symbols that represent key features, such as the dip and strike of the rock units, anticlines and synclines, and the traces of fault surfaces.

Although the two-dimensional map-view is useful, one of a geologist's key tasks is to infer the type and orientation of rocks in the subsurface. This is done using geologic rules, inferences, and projections downward from the surface. The result is a geologic cross section, a view that essentially provides a cutaway image, much like one would see on a canyon wall or in a roadcut.

This hypothetical slice into the earth, providing a third dimension (depth), is the key to a host of geological applications. Cross sections are used to assess temporal models of rock formation through time. In other words, the goal is to recreate a step-by-step sequence of which rocks and structures came first, last, and in between. They're also used to determine specific modes of deformation — whether rocks have undergone compressional, extensional, or other stresses.

Geologic cross sections help to identify regions of groundwater movement, evaluate potential sites for economic mineral deposits, and locate oil and gas reservoirs.

### **Principles**

Folds are evidence of plastic deformation—they typically form as a result of low-strain rates, high-confining pressures, and elevated temperature. In contrast, faults are indicative of brittle deformation—they typically result from high-strain rates, low-confining pressures, and overall lower temperatures.

Fold-type deformation that generates up-warped strata (*i.e.* analogous to an upside down bowl) are referred to as anticlines or antiforms; and those folds that involve down-warped strata are synclines or synforms. In many cases, a region that has undergone folding will show multiple sets of synclines and anticlines, like wrinkles on a carpet.

In both fold types (synclines and anticlines) the strata dip in opposite directions, either towards or away, from what is termed the fold axis. For example, with an anticline, the strata dip down and away from the fold axis, much like shingles on a roof dipping away from a ridge-line. The compass orientation of the fold axis is termed the “strike” direction of the fold.

The first step in constructing a geologic map is to take a topographic map and then color-code the regions that contain different rock types. Between each rock unit is a line, called the “contact” between identifiable units. Within each rock type (and sometimes on the contact itself) are given dip/strike symbols to show the surface outcrop orientation of the rock strata. (\*Note: strike and dip are defined in a previous video involving the use of the Brunton Compass. In brief, dip is simply the angle that the rock layers make with a horizontal plane, and strike is the resultant azimuth compass orientation of the line that represents the intersection of the rock unit with a horizontal plane.)

It is the extrapolation of these dips and strikes into the subsurface—through the use of the geologic cross section—that can be used to help infer the type of fold structure that is present. For example, beds dipping away from a central axis are indicative of anticlines, whereas beds that dip towards a central axis are indicative of synclines. Once the structure has been identified, the map will be marked with symbology that denotes the particular fold type that is present, and the strike of the fold axis.

It is worth noting that geologists can often infer these structures merely by looking at the plan-view geologic map, but the cross-section view provides a 3-D visual perspective that greatly enhances the ability to evaluate fold and fault structures, and locate them with great precision.

One of the primary uses of the geologic cross section is to reconstruct folds and faults that are somewhat cryptic, as a result of erosion removing their surface features. An anticline does not need to be a hill (an up-warpage of earth material) and a syncline does not need to manifest itself as a valley (a down-warpage of earth material). Earth’s surface topography does not always imply a particular kind of fold or fault structure at depth.

## **Procedure**

1. Identify two points that define a cross-section profile, *e.g.* A-A'. These points are chosen such that the line between them is approximately perpendicular to the strike directions of the intervening rock units.
2. A topographic profile is drawn between the two points, A-A'. Directions for how to generate a topographic profile are provided in a different video.
3. Take a strip of paper and align it along the line, carefully marking the contacts between the different rock units.
4. Transfer the contacts onto the topographic profile.
5. At each contact, the dip of the adjoining layers is used to project this boundary into the subsurface. As long as the topographical profile has no vertical exaggeration, the dips from the map can be directly used. For example, if the dip at a limestone/sandstone boundary (contact) is  $20^\circ$ , then that contact can be drawn as extending into the subsurface at an angle of  $20^\circ$ .
6. Utilize this projection and knowledge of the local geology to infer the folds or faults in the subsurface. For example, rock layers that dip away from the central axis (again, like shingles on a peaked-roof) may indicate the presence of an anticline or antiform. In addition, if the rock layers along the central axis are older than those that are successively further from the axis, then this is further confirmation of an anticlinal structure.
7. Extend the rock layers into the above ground region using dotted lines; this shows the inferred presence of rocks prior to erosion.

As discussed in the Principles section, the dotted lines above the surface are effectively a representation of a geologic structure that once existed, but has been removed by erosion.

## Results

For this demonstration, a portion of the Carter Lake, Colorado, USGS 7.5-minute Quadrangle Map was used. This notation means that 7.5 minutes of longitude and 7.5 minutes of latitude define the E-W and N-S boundaries on the map. On the east side of the cross section line A-A', the rock layers dip to the west; in contrast, on the west side, the

layers dip to the east. It can be inferred that these layers meet in the subsurface to form a bowl-shaped fold-structure, known as syncline. Ultimately, all folds (whether down-warps, such as synclines, or up-warps, such as anticlines) are a product of compression-style deformation. When rocks have been squeezed, they show plastic deformation features (folding), especially if deformation has occurred relatively rapidly, with high-confining pressures and elevated temperatures in Earth's upper crust. In contrast, rapid application of stress, low-confining pressure, and low temperatures are more likely to produce brittle deformation, known as faulting.

## Applications

Cross-sections provide a means to analyze and assess the subsurface orientation of rock units. Geologists use the relative dating rules of cross-cutting and superposition to determine the timing of deposition and deformation. For example, when one layer sits above another, it can be inferred that the top layer is most likely younger than the layer below. Furthermore, if a fault cuts across a particular rock unit, then the fault is most likely younger than the rock unit it offsets.

Some specific applications include the determination of geologic history, groundwater flow analysis, mineral deposits, and oil and gas reservoirs. Relative dating techniques permit an assessment of a sequence of geologic events, including deposition, intrusion, and deformation (folds and faults). Geologists seek to understand the earth in not only the three spatial dimensions, but also within the context of a temporal dimension- the idea being to reconstruct geological change through time.

Cross sections are a key to evaluating fluid flow in the subsurface. Understanding the orientation of flow-enhancing layers (aquifers) versus flow-preventing layers (aquicludes) is the key to evaluating the motion of groundwater. This also provides an application for determining where wells are best to be drilled. It allows for analysis of aqueous pollutant movement and possible mitigation strategies. In general, rock types that contain considerable pore space (e.g. sandstone or highly fractured igneous/metamorphic rocks) will be aquifers. In contrast, rock types that contain limited pore space (or pores that lack inter-connectivity) will more likely be aquicludes.

Most economic mineral deposits (*e.g.*, Au, Ag, Cu, Mo, etc.) are associated with igneous rocks. If igneous rocks outcrop on the surface, and their surface contacts can be assessed, then one can determine where possible ores can be found in the subsurface. Most oil and gas reservoirs are associated with sedimentary rocks, because these are the rock types that contain hydrocarbon sources (decayed organics, both terrestrial and marine). Here, cross

section analysis is absolutely critical to determining where fold or fault traps are likely to exist, and if they contain petroleum resources. For example, up-warps (anticlines) are a classic location for oil and gas drilling. This is because mobile hydrocarbons tend to flow upward, within permeable layers, until they reach the peak (or axis) of an anticline. If the permeable layer is capped by an impermeable layer, then a hydrocarbon reservoir accumulates and pools at the apex of the fold.