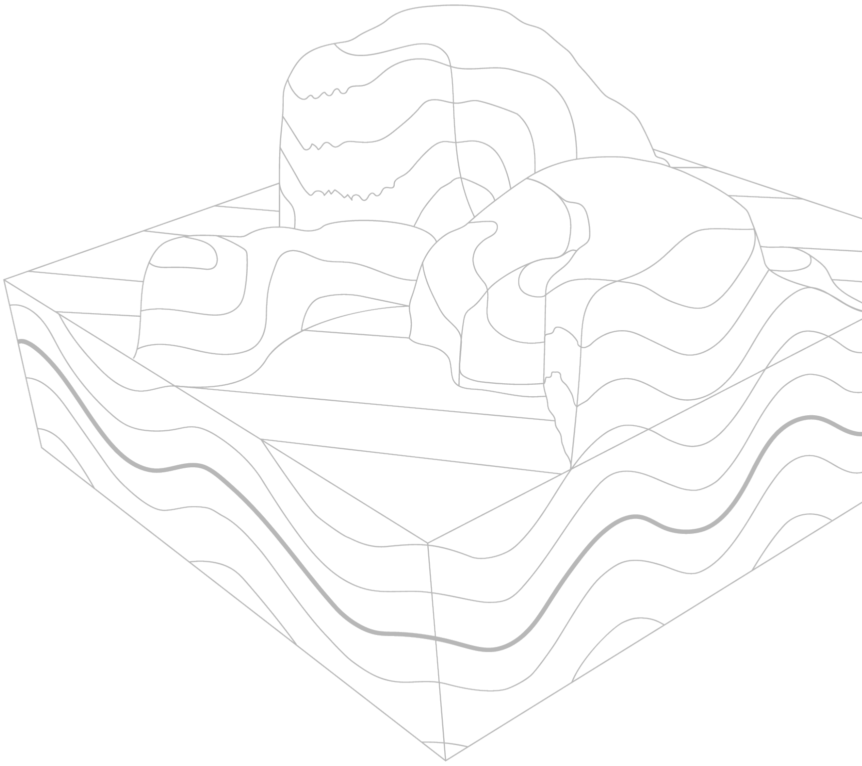
University of Canterbury
Te Whare Wānanga o Waitaha
Christchurch New Zealand

An initiative by SEEQUENT



Lesson plan

Folds 1:
limbs, hinges and planes

Learning objectives:

- Identify the limbs, axis and axial plane of a fold
- Distinguish anticlines from synclines based on how they outcrop at the surface
- Measure the amplitude and wavelength of a series of folds
- Identify if folds are symmetric or asymmetric
- Relate fold geometry to the tectonic history of an area

Key Visible Geology skills:

- Apply folds to layers
- Manipulate fold orientations

Timelines:

- Workflow 1 – 9: ~30 min
- Questions and exercise: ~30 min

Glossary:

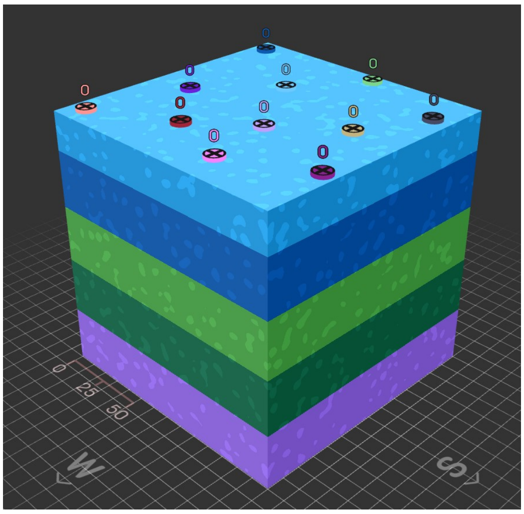
- See page 5

VisibleGeology

What are folds?

Folded geological layers are no longer flat and horizontal but now undulate due to tectonic forces squeezing them together (the same way a piece of papers bends as you slide the two ends towards each other!). We can understand what has happened to the layers by studying the orientation, size and frequency of the folds within them. In this workflow, we're going to identify the key features of a fold within a geological layer and use these to understand how the layers were deformed! Ready? Let's get started!

Workflow



1. First, add some layers to your block model

<u>Layers</u> -> Add -> add several layers until your block is full -> apply

2. Then, add some bedding readings (known as 'decals' in VG) so we can follow how the dip of our layers changes as we progress.

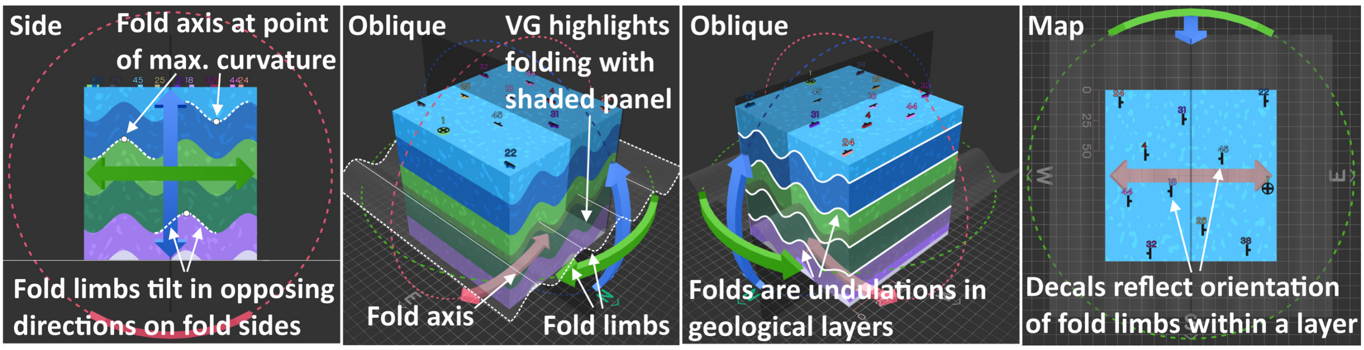
<u>Decals</u> -> New strike & dip decal -> add at least 10 evenly across the top surface of your block

3. Now, let's fold the layers!

<u>Events</u> -> Fold -> strike = 000, dip = 90, plunge = 0, amplitude = 8, wavelength = 8 (Don't click apply! We want to explore the model first)

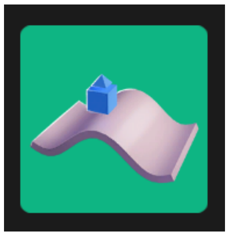
ⓘ Learning observation!

The folds in the layers can be seen in the end-on panels. Visible Geology highlights the folds by including a wavy shaded surface that cuts through the block. The peak of each of these folds/waves is called the **fold axis** (a.k.a. **fold hinge line**). This marks the point where the curvature of the folded layer is greatest. The sides of the fold are called the **fold limbs**.



The bedding readings (i.e., decals) show the strike and dip of the layers at the surface (for more on strike and dip, see the Dipping Layers module). Notice how the bedding readings reflect the tilt angle of the fold limb, being steepest in the middle of the limb and becoming shallower as you approach a fold axis.

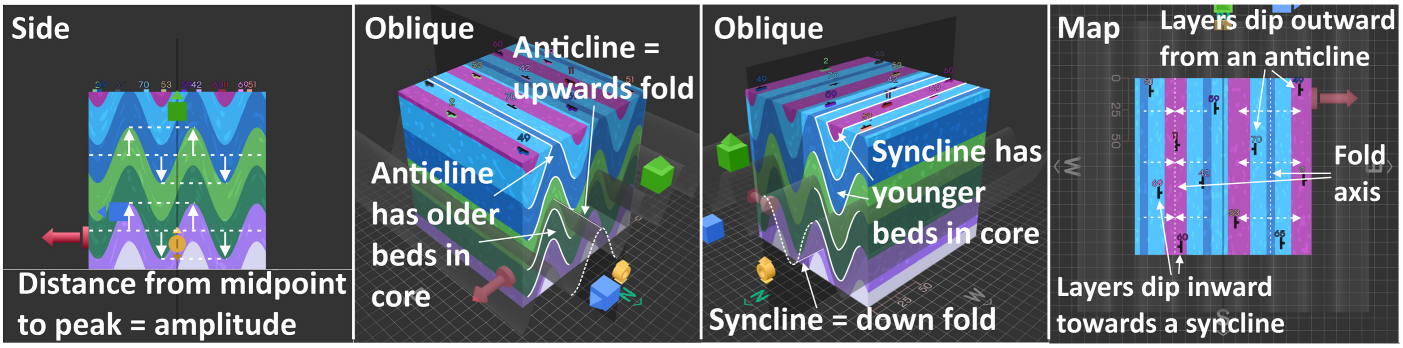
4. What happens if we change the size of the folds? In Visible Geology, this means increasing the amplitude.



Enter Amplitude = 22, or click and drag on the green cube when in the second editing tab

ⓘ Learning observation!

In Visible Geology, the height of the folds is called the **amplitude**. This is the distance of the fold axis from the centre of the fold, or from where the layer would run if it was still flat! The greater the amplitude of the fold, the larger the folds, and therefore the more the layer has been deformed.



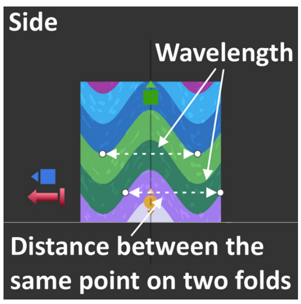
Notice how, as you increase the fold amplitude, new layers become visible on the top of the block! You now have the top of one fold exposed next to the bottom of the next fold. We call the top of a fold (the convex side) an **anticline**, where *the older layers are in the middle of the fold* and layers become younger as you move outwards. We call the bottom of a fold (the concave side) a **syncline**, and here *the younger layers are in the middle of the fold* and layers become older as you move outwards. Understanding this means that on the surface, we can distinguish anticlines from synclines both from bedding readings and the age relationships between layers!

5. We can also adjust the tightness of the folds. In Visible Geology, this can be done by changing the wavelength! How do the bedding markers react as you do this?

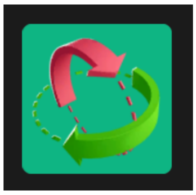
Enter Wavelength = 15 or click and drag the blue cube back and forth!

ⓘ Learning observation!

The **wavelength** of a series of folds is the distance between the same point (e.g., the peak/fold axis) of adjacent folds. Larger wavelengths mean the distance between folds is greater. *If the fold amplitude is the same*, folds with larger wavelengths have less steeply tilted limbs than for folds with smaller wavelengths. Notice how this change in limb tilt angle is reflected in the bedding markers at the surface as you change the wavelength.



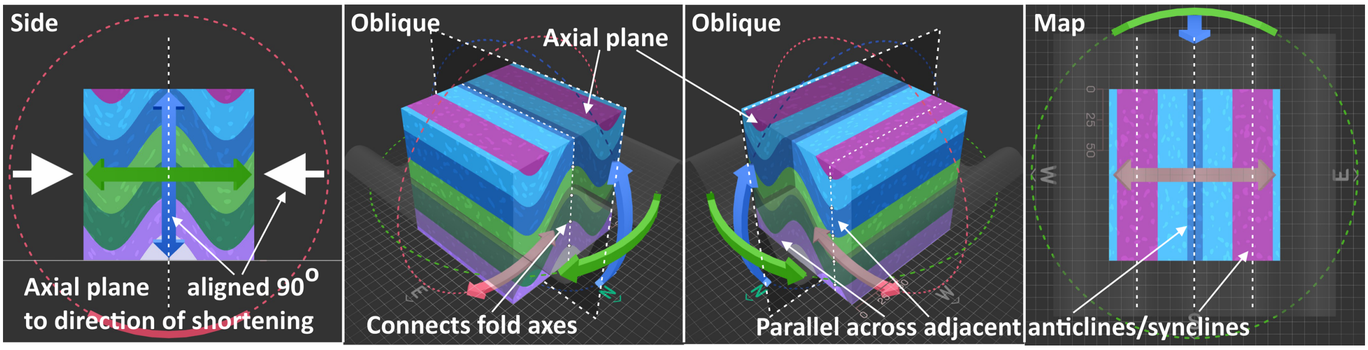
6. Nice work! By now, you might have noticed that Visible Geology also shows a shaded vertical surface within the block. This is called the **axial plane**, and its orientation is controlled in Visible Geology by the strike and dip in the control panel on the right. Let's explore this next!



Enter strike = 045, or click and drag on the green arrow when in the first editing tab

ⓘ Learning observation!

The **axial plane** is the conceptual surface that is formed by connecting the fold axes of multiple layers within a fold. This means it cuts down through the centre of the fold. Its orientation is parallel to folds and perpendicular to the direction of compression. Changing the strike of your axial plane *does not affect the orientation of the layers*, only the folds! Identifying the axial plane of a fold is useful as it tells us about the deformation that happened to that rock.

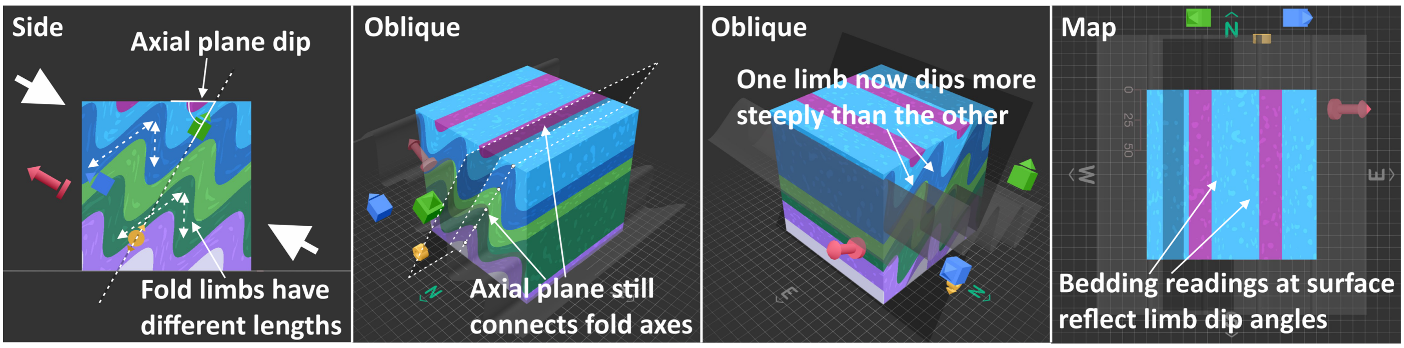


7. The dip of the axial plane is currently 90º, so the plane is vertical in our block model and perpendicular to the layers within the block. This means our folds are **symmetrical**: the limbs on both sides of a fold are equal in length. What happens if we tilt our axial plane? (Bear in mind we are *not* changing the orientation of our geological layers!)

Enter strike = 000, wavelength = 8, dip = 60 or click and drag on the red arrow

ⓘ Learning observation!

When the axial plane is tilted *relative to the orientation of the layers*, the folds are no longer symmetrical. We call these **asymmetric** folds, where one limb is shorter than the other. Notice how the bedding readings change depending on what side of the fold they are on!



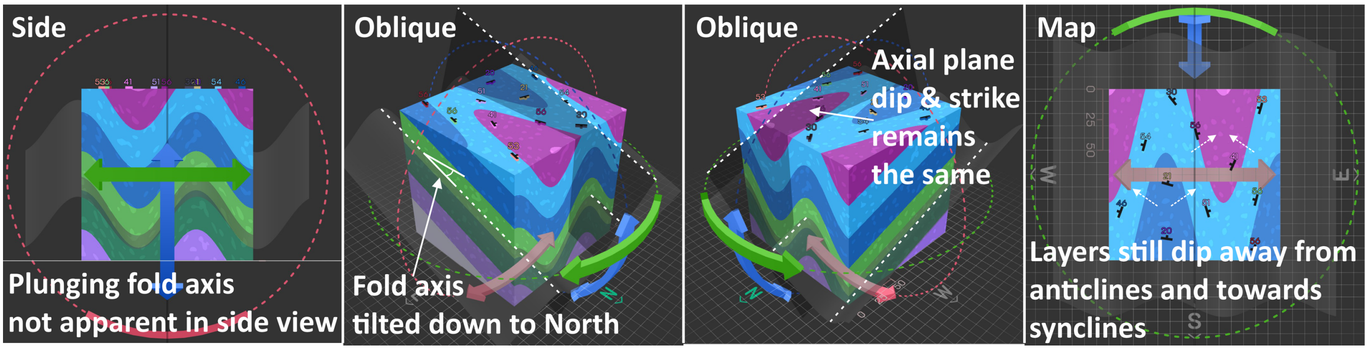
8. So far, our fold axes have been horizontal. Often in the real world, this is not the case! We can change the plunge of the fold axis in Visible Geology with the plunge value or the blue arrow. Let's try changing this and see what happens!

Enter dip = 90, wavelength = 15, plunge = 20, or click and drag on the blue arrow

ⓘ Learning observation!

Changing the **plunge** of the fold axis tilts the angle of the fold *along the axial plane*. As the fold axis is a linear feature, it has a trend (orientation) and plunge (tilt angle) rather than a strike and dip like a planar feature. Click and drag on the blue arrow to change your plunge up and down. Notice how the layers visible at the surface change as you do so, and the orientation of the bedding markers – can you still identify where the anticlines and synclines are?

[Important: unlike with the axial plane where changing its dip is independent of layer orientation, changing the plunge in Visible Geology also changes the dip of the layers! How can you tell this?]



Questions

- If the axial plane of the folds and the orientation of the geological layers were tilted by the same amount in the same direction, would the folds become asymmetrical or stay symmetrical?
- What geological forces might create folds in geological layers?
- Why might understanding the orientation of the axial plane of a fold be useful?
- Are there any commercial uses you can think of for understanding fold geometry?

9. Ok! Now we understand how to classify folds and what they represent, let's apply our knowledge! Below are some images of folds. Annotate on the figure the location of the fold axis, the axial plane, and the direction of shortening/compression that's been applied to the beds. Then, recreate it in Visible Geology!

Real-world examples

Folded carbonates. Basque country, France. Photo by Thibault Cavailhes.

Folded sedimentary beds. Apoplystra, Greece. Photo credit: G. Shuttleworth.

Glossary:

Fold: an undulation in a geological layer due to compression

Fold hinge: the location of maximum curvature on a folded layer.

Fold limb: The sides of the fold connecting the fold hinges

Plunge: The tilt angle of a linear feature, e.g., the fold axis, measured downwards from horizontal.

Anticline: The upwardly convex part of a fold sequence where the older beds are pushed up in the centre and younger beds lie over and around them.

Syncline: The upwardly concave part of a fold sequence where the younger beds are found in the middle and the older layers lie below and around them.

Amplitude: The distance from the middle of a fold to the fold axis.

Wavelength: The distance between the fault axes of two adjacent folds.

Axial plane: A conceptual surface connecting the fold axis of multiple layers within a fold. It is orientated perpendicular to the direction of shortening.

Symmetrical folds: Folds where the limbs on either side of a fold axis are the same length

Asymmetrical folds: Folds where the limbs on either side of a fold axis are unequal lengths. Usually caused by the direction of shortening being oblique to the geological layer orientation.