Map Patterns and Finding the Strike and Dip from a Mapped Outcrop of a Planar Surface

Topographic maps represent the complex curves of earth’s surface with contour lines that represent the intersection of those curves with (imaginary) horizontal surfaces at regular intervals. Planar geologic structures, such as bedding contacts and faults, also intersect the earth’s surface along lines. You have seen how folded beds intersecting a flat surface make curved lines showing the hinges and limbs of the folds, and can be interpreted to determine aspects of the 3D geometry such as the plunge direction of the folds. In this lab you will explore the intersection of planar features with complex topography – which creates “map patterns” – and how to use these patterns to interpret the 3rd dimension.

**Horizontal beds**

The simplest case is one of horizontal bedding intersecting a horizontal flat landscape. Only the uppermost bedding plane appears on the map:

![Block Diagram and Map](image)

Figure 1: Flat-lying bedding contacts and flat topography

In contrast, on a uniform slope, horizontal beds crop out as a series of parallel contacts in map view. The line of intersection of a geologic surface with topography is called the *trace* of the geologic surface. Figure 2 shows the trace of two contacts. Note that the slope governs the thickness of the units in map view, which is not the same thickness as the *true thickness* as seen in cross-section view, defined as the thickness measured perpendicular to the bedding contacts. On the map, one sees the *apparent thickness*. Shallow slopes increase the apparent thickness observed on the map. Steeper slopes show an apparent thickness closer to the true thickness (with the vertical cross-section on the side of the block showing the true thickness).

A valley (with a stream in it shown by dashed line in Figure 3) is the intersection of two
sloped surfaces at slightly different orientations. The trace of the bedding contacts intersects the two walls of the valley at slightly different angles, forming a V-shape in the trace on the map. For horizontal units, the V-shape that forms is parallel to the contour lines, and therefore the V points upstream. Also note the difference between true and apparent thickness of the units. From Figures 2 and 3 you should see that the trace of a horizontal geologic plane must always follow contours. *A horizontal geologic contact can never cross a contour line.*

**Uniformly dipping strata or planar surfaces**
Units with parallel strikes and dips (planar units) intersect flat topography as straight, parallel lines (Figure 4). The trace of the contacts is equal to the strike of the bedding surface. Why must this be true? Mentally picture the change in the map pattern if the top surface of the block diagram were eroded uniformly by 30%. What would the map look like?
The same pattern results from dipping beds on a uniform slope, but *the trace of a contact will not be the same as the strike of the contact!* In other words, the trace in this case is not a horizontal line in the contact plane. However, it can be used to determine the strike and dip of the plane, because it crosses the plane at an angle and therefore depends on the strike and dip.

**Rule of V’s**

A dipping surface that intersects a valley produces a V-shaped trace on a map, *unless the dip is vertical* (Figure 8). A vertically dipping surface always has a straight map trace, regardless of the topography.
Notice the map patterns in Figure 8. The direction the V points depends on both the direction of the dip of the beds, and also on the steepness of the dip relative to the slope of the valley floor (see the last example in Figure 8). Usually, the V points toward the direction of dip. The exception is when the dip is in the same direction of the valley slope, but the dip is shallower than the valley. Also notice that the shape of the V changes depending on the dip angle.

Also, notice that the V’s in Figure 8 are symmetric (i.e. the apparent bed thickness and
Figure 8: The Rule of V’s for different dipping surfaces crossing a valley.
Determining Strike and Dip Directions from Map Patterns

From the discussion above, it should be apparent that a rough approximation of the direction of dip can be made by noting whether a V points up or down the valley. What about strike? By definition, strike is always perpendicular to dip and is the line of intersection of a horizontal plane with the geologic plane. If a dipping surface crosses valleys and ridges we can construct strike lines (also called structure contours) to precisely determine the strike.

A strike line is a line connecting two or more points on a geologic surface that are at the same elevation (Figure 9). By drawing a line between two points on a surface that are at the same elevation, you can define the intersection of a horizontal plane with the surface in
question, and thus the strike of that geologic surface. Strike lines are labelled by elevation. For example, the 400’ strike line in Figure 9 connects the two exposed points on the contact between the white and grey units (the base of the gray unit) where that contact surface crosses the 400’ topographic contour. Because a planar surface can have only one strike, all the strike lines on a surface must be parallel if the surface is planar. Non-parallel strike lines on a surface indicate that the surface is not planar, such as folded beds and erosional unconformities. This condition can be used to differentiate between Vs formed by planar beds crossing V-shaped topography, versus folded beds.

Constructing strike lines in this way is the easiest way to determine the attitude of contacts and faults, and provides a quick check on whether surfaces are planar. This is also a powerful predictor of where a contact should intersect topography when mapping, if the strike and dip of the contact are known. Finally, the spacing between the strike lines of different elevations is a function of dip. Steeper dips have more closely spaced strike lines (for the same reason that contours are closer together in steeper topography.)

To determine the strike, measure the angle between your constructed strike lines and the North direction on the map. In Figure 9, the strike is north-south (= 000° = 180°).

Calculating Dip

By definition, dip is perpendicular to strike, and by using the Rule of V’s (Figure 7) you can determine the direction of dip. To determine the angle of dip, you must use strike lines at different elevations.

In Figure 9, the difference in elevation between the 300’ and 400’ strike lines is 100’. To determine the structural gradient or dip, we must know the map distance (horizontal distance) over which that geologic surface drops 100’ in elevation. Measure the distance between the strike lines on the map, and using the map scale, convert your measurement (say, 10 mm) to a map distance (say, 225’). So the gradient can be calculated by the change in elevation divided by the map distance.

\[
\text{Gradient} = \frac{100'}{225'} = 0.44
\]

The dip angle is the inverse tangent of the gradient:

\[
\tan^{-1}(0.44) = 24°
\]

Therefore, the orientation of the bedding planes in Figure 9 is fully defined: (000/24W).

Apparent Dip

Imagine that you are on a uniformly sloping surface (such as a roof). If you walk directly down that surface, then that is the steepest slope along which you can walk (the path water would take if poured on the surface). Alternatively, by walking at an angle, the slope of your path will not be as steep.

Now consider the same idea, but in relation to the dip of geologic planar surfaces. If you take a cross section line perpendicular to strike, then the bed seen dipping in that cross
Figure 10: Two possible lines in a dipping plane (or paths to walk down a steep roof). The steepest one is the true dip. The other one will always be shallower slope (smaller apparent dip).

Figure 11: A: Plane is seen in a cross section which is cut perpendicular to the strike of the plane (parallel to, or containing, the line of true dip). B: Plane is seen in a cross section which is at some random angle to the strike of the plane (does not contain the line of true dip, but crosses the plane at some path of lesser, apparent dip).

section will be inclined at the true dip angle, that is, at the dip equal to the steepest slope in the plane. Remember that dip is defined as perpendicular to strike, and strike lines are horizontal.

However, suppose that the line of cross section takes a different slice through the Earth (not perpendicular to strike) and that it shows the inclined layers as if they had a lesser dip – this is the apparent dip.

Luckily there is a method that allows you to calculate apparent dip from true dip if the strike and bearing of the cross section line are known. The apparent dip depends on the angle between cross section and strike, $\beta$. As you saw above, if this angle is $90^\circ$ (perpendicular) then the dip you see is the true dip. If the angle $\beta$ between the strike line and the cross section line is anything other than $90^\circ$, then the apparent dip will be some value less than the true dip.
Naturally occurring or man-made cross sections through the earth (e.g. cliffs, quarry faces, road cuts, etc.) are very unlikely to be parallel to the true dip of the geological surfaces you are interested in. What is observed in these cross sections is the apparent dip of the surfaces in the direction of the cliff wall or road cut. If the cross section you are viewing is not perpendicular to strike, but you know the strike and can observe the apparent dip, you can determine the true dip.

In Figure 12, the line of section is at an angle $\beta$ to strike. To determine the apparent dip of the bed in the cross section, we must know two things: the true orientation of the plane (strike, dip and direction) and the angle between strike and the cross section line. In Figure 12, strike is E-W (090) and the dip is:

$$\tan^{-1}\left(\frac{100'}{500'}\right) = 11.3^\circ$$

Let’s say you measure $\beta = 30^\circ$ off the map. Use the formula:

$$\tan(\alpha) = \tan(\delta) \times \cos(\beta)$$

Where $\alpha =$ apparent dip, $\delta =$ true dip, and $\beta =$ angle between strike and cross section line. You can rearrange this equation to solve for the value that you need. In the above example where you know $\beta$ and $\delta$ and want to solve for $\alpha$ so that you can show that bedding plane accurately in the cross section you are drawing, use:

$$\alpha = \tan^{-1}\left[\tan(\delta) \times \tan(\beta)\right]$$

So in our case (Figure 12):

$$\alpha = \tan^{-1}\left[\tan(11.3^\circ) \times \tan(30^\circ)\right]$$

$$\alpha = 9.8^\circ$$

This is the dip you plot in your cross section.