Box 2-2. Elevation, Relief, Slope, and the Angle of Repose

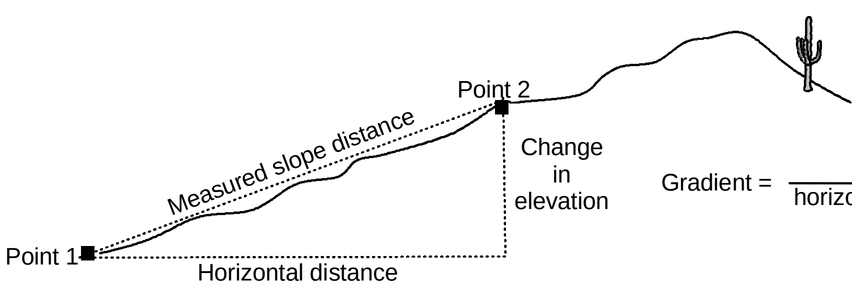
Elevation and Relief

In addition to wanting to know and measure directions horizontally, we may be interested in how rugged an area is and how much we would have to climb to reach the top of a hill. **Elevation** refers to the vertical height of a point above sea level. It is typically measured in feet or meters. When areas are surveyed during the construction of a topographic map, the precise elevations of several points are accurately measured. This procedure provides a reference system of known elevations for use by other surveyors and in drawing contour lines on the topographic map. Surveyed locations are called **benchmarks** and their positions are shown on most topographic maps with the letters "B.M." The number beside this symbol lists the surveyed elevation, generally in feet. The elevation of points that do not fall directly on contour lines on a topographic map may be estimated by *interpolating* between the two adjacent contours. For example, a point on the ground situated midway between 640' and 660' contour lines would likely have an elevation of approximately 650'. In contrast, a point located very near to the 660' contour line would more likely have an elevation of 658' or 659'.

Relief is the difference in elevation between two points. It is easily calculated by subtracting the lowest elevation from the highest elevation in an area. If a mountain, for example, has an elevation of 8,000 feet and an adjacent valley has an elevation of 3,000 feet, we would say the relief between the two is 5,000 feet. The maximum relief on a topographic map is the difference in elevation between the highest and lowest points on the map. Relief is most commonly calculated when you are trying to determine how much elevation you will have to gain on a hike to the top of a mountain.

Slopes, Gradients, and the Angle of Repose

We generally think of **slope** in the context of hillsides: a steep slope versus a gentle slope. The steepness of a slope controls many geologic processes, such as landsliding, and has major land-use implications, including slope stability and whether a slope efficiently drains rainfall or becomes a swamp. The steepness of a slope can be expressed as an angle, ranging from 0° for a horizontal surface to 90° for a vertical cliff; most natural slopes are 30° or less. Slope can also be expressed as a **gradient**, which is the ratio between the elevation change of the slope and the horizontal length over which the change occurs. In algebra terms, it is the *rise* over the *run*. For example, if a slope drops 10 meters over a distance of 100 meters, it has a gradient of 0.1 (i.e., 10/100). On highway signs, this number is multiplied by 100 to convert it to a percent, and written as "% grade". A road that drops 5 meters in a distance of 100 meters has a gradient of 0.05 (5/100), or a 5% grade (5/100 × 100%). Highway grades are rarely more than 8%.



$$\text{Gradient} = \frac{\text{change in elevation}}{\text{horizontal distance between points}}$$

Figure B-2. Calculation of gradient from a topographic profile. The profile above is an example profile drawn from a topographic map, which has designated the elevations of Points 1 and 2. To determine gradient, simply divide the change in elevation between the two points found on your topographic map by their horizontal distance. That's it!

Gradient is commonly also expressed as the ratio of two different units of measurement, such as feet/mile. In this case, the elevation difference of the slope (the rise) is measured in feet or meters, and the horizontal length of the slope (the run) is measured in kilometers or miles. For example, if a slope drops 30 meters vertically in one kilometer, it has a gradient of 30 meters/kilometer. This type of gradient is also used to convey how steep a stream or river is.

Gradient, for either a slope or river, can be calculated from a topographic map via the following:

- Say you are interested in the gradient between two points that are 4 centimeters apart on a 1:50,000 map, with an elevation difference of 300 meters.
- Convert the total number of centimeters on the map into meters on the ground. On a 1:50,000 map, one centimeter on the map equals 50,000 centimeters on the ground, so 4 centimeters equal 200,000 centimeters (4 cm x 50,000=200,000 cm).
- Since there are 100 cm in a meter, simply divide 200,000 cm by 100 to convert the centimeters into meters. This gives a result of 2,000 meters (or 2 kilometers, since there are 1,000 meters in a kilometer).
- The equation for gradient is:

$$\text{Gradient} = \frac{\text{change in elevation between points (m)}}{\text{horizontal distance between points (m)}} = \frac{300\text{ m}}{2{,}000\text{ m}} = 0.15$$

For a gradient of 0.15, this means that for each 1,000 meters (kilometer) traveled on the ground, the slope increases or drops 150 meters in elevation . Be careful when extending gradients too far from where you calculated it. If there is no observed change in the spacing of contours lines, then the gradient of the slope has not changed much. However, if the spacing between contour lines changes noticeably, this indicates that the gradient has also changed.

The importance of slopes and their angles is obvious when you see pictures of houses sliding into the ocean along the California coast. It's related to what happens when you try to walk up a sand dune. There is a maximum slope, or angle, at which a pile of loose material remains stable, called the **angle of repose**. The angle of repose of natural slopes is fairly constant, between 25º and 40º, but depends upon the size of the individual particles, their angularity, the degree of sorting, and whether they are wet or dry. Larger, more angular particles, such as gravel, tend to form slopes with steeper angles of repose than those of finer particles. If a slope is at its stable angle of repose, and some process removes material from the base of the slope, then the loose material up the slope will slump down to fill in the hole and reestablish the stable angle. If your house is built on this slope, it may come down the hill with the rest of the material. This is what happens in the California example, where waves undercut the base of a slope and the slope just doesn't like it! The angle of repose is expressed in **talus slopes**, where loose rocks and sand accumulate on a slope with a ~30° angle beneath cliffs, and also on the sides of cinder cones (e.g., SP Crater in Figure 2-1).