Chapter 3: Strike, Dip, and Map Notation

ABOUT THREE-QUARTERS of the continental surface area is covered with rocks of sedimentary origin. Although the sedimentary succession was originally deposited as horizontal beds, deformation processes may have translated, rotated, and distorted these beds over the course of tectonic history. Consequently, many tectonized sedimentary layers are no longer horizontal. The orientation of planar features, such as tilted layers, can be measured and expressed in terms of azimuth, strike, and dip, introduced in this chapter. The width of inclined layers in horizontal map view decreases with increasing dip. Even in vertical cuts, the dip and thickness of strata seen on such vertical surfaces, perhaps surprisingly, vary with the angle between the line of section and the strike line. In vertical cuts oblique to their strike line, layers appear thicker and with dips shallower than in sections normal to strike. Consequently, the dip and thickness of strata may be either true or only apparent.

Contents: True dip, plunge, strike and azimuth are introduced in section 3-1. The difference between true and apparent dip in oblique sections is explained in section 3-2. True and apparent thickness are discussed in section 3-3.

3-1 Dip, strike, and azimuth of strata

Dip and strike are two measures to describe the orientation of rock layers in the field. The *dip* is the inclination of the layer, measured as the angle between the horizontal plane and the layer itself (Fig. 3-1a & b). The *strike* of a layer is the geographical direction of a horizontal line or surface trace of that layer. The orientation of both the strike line and dip can be measured directly in the field, using a geological compass. The use of the compass for structural measurement itself can be best explained during the preparation for field mapping (see *Principles of Geological Mapping*). Alternatively, strike and dip can be inferred by graphical construction, using the intersection of an outcrop pattern with the topographic contours (see chapter five).

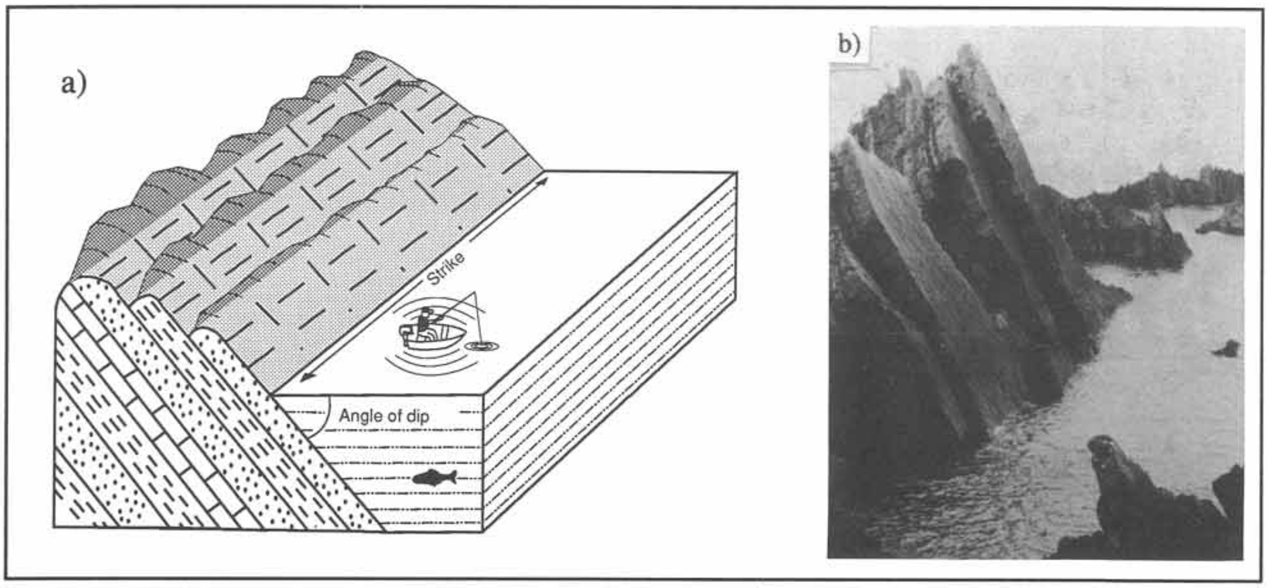


Figure 3-1: a) Sketch showing the strike and angle of dip for uniformly inclined beds. b) Sandstone beds, dipping into the sea, viewed nearly along their strike line due west.

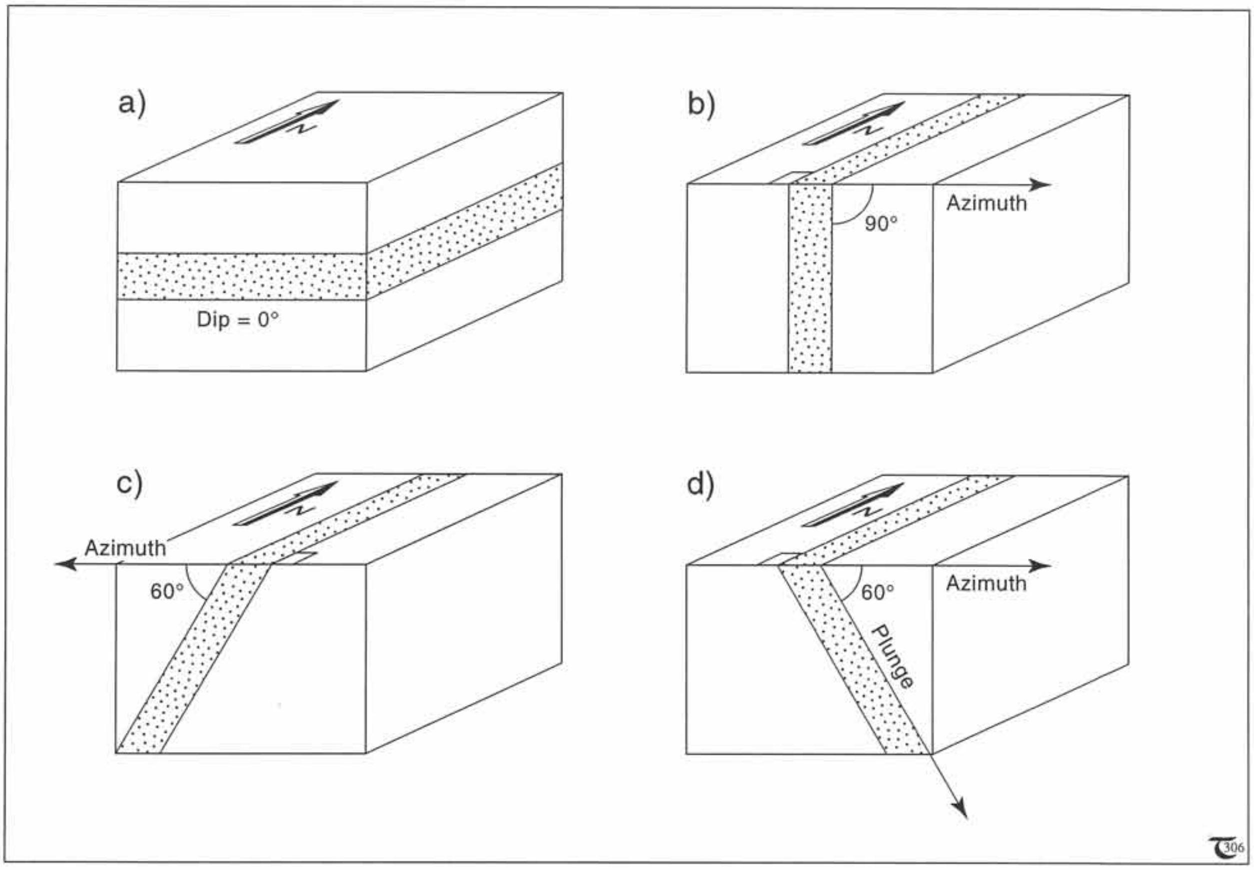


Figure 3-2: The layer dip is measured in an imaginary vertical plane normal to the strike line of a bed. Orientations shown are: (a) horizontal, (b) vertical, (c) dipping 60°west, and (d) dipping 60°east.

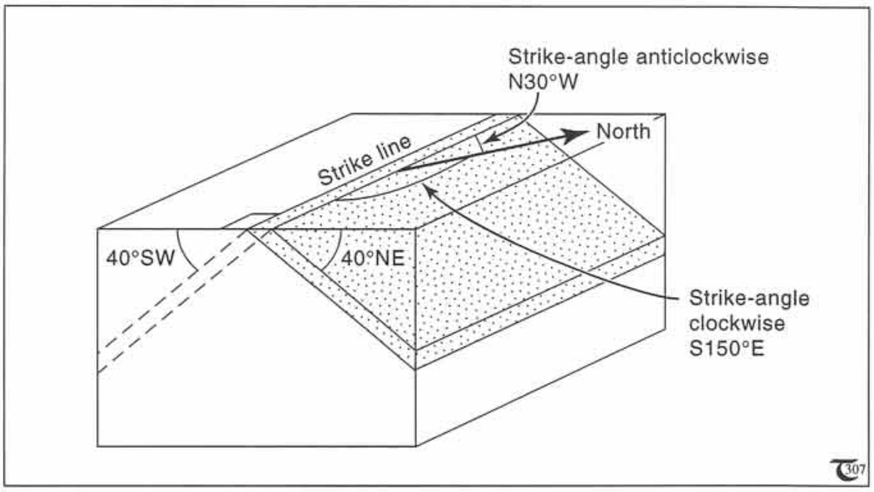


***Figure 3-3:** The geographical orientation of the strike line is measured as an angle away from the north, but may be measured either clockwise or anti-clockwise.*

True dip: The true dip of a layer is measured within an imaginary vertical plane, *normal* to its strike line (Fig. 3-2). The vertical plane of measurement intersects the dipping layer along an intersection line or *plunge line*. The vertical plane, also, transects the horizontal surface as a line perpendicular to the strike: the azimuth line. The true dip of any layer will be obtained only if measured between the azimuth and plunge lines (Fig. 3-2). If measured in sections oblique to the strike line, the dip is termed *apparent*, because, in such cuts, the layer appears to slope less than the true dip (see section 3-2). The true dip is an angle varying between 0° and 90°. A layer which dips 0° is effectively horizontal. If small local deviations in dip of several degrees occur, the sheet is termed subhorizontal, which means the layer is more or less horizontal. A layer which dips 90° is vertical. If a layer dips close to (but not exactly) 90°, it is said to be subvertical (meaning more or less vertical). The term *plunge* is usually reserved for the angle between lines (e.g. fold axes) and the horizontal surface, whereas the term *dip* is preferred to indicate the inclination of layers and other planar fabric elements in rocks.

Strike: To characterize the orientation of the layers in Figure 3-2, in addition to the dip, the geographical orientation of the strike line needs to be expressed according to some system. Physically, the strike line is outlined by the trace of inclined layers at the horizontal ground surface. The orientation of strike lines should not be confused by ways of measurement, and it is, therefore, useful to agree upon which convention you follow when exchanging data on strike angles. The strike of a strike line is always expressed as an angle, but there are several ways to express the compass direction of this angle. The geographical orientation of strike lines is measured as an angle away from the north but may be measured either clockwise or anti-clockwise. For example, one possible notation for the strike of the plane in Figure 3-3 is N30°W, measuring 30° in anti-clockwise direction away from N toward the W, so that the strike line trends NW. The angle can, also, be measured in clockwise direction away from the N and represents the same strike line by N150°E. The usual convention (USA) is that the first letter denotes the direction from which to measure the angle and the last letter denotes the direction to measure in. Other notations write NW30°, instead of N30°W. In strike/dip notation of a plane, it is important to add the geographical direction of dip, in order to eliminate one of the two opposite directions of dip possible (Fig. 3-3). Consequently, the orientation of the layer of Figure 3-3 can be written as: N30°W/40°NE or NW30°/40°NE or N150°E/40°NE. It is worth noting that, although the strike is strictly speaking a geographical angle, it is common practice to refer to "strike lines" as "strikes".

Azimuth: Perhaps more practical and straightforward is to represent a plane not by strike/dip notation, but by its azimuth/dip. The azimuth line

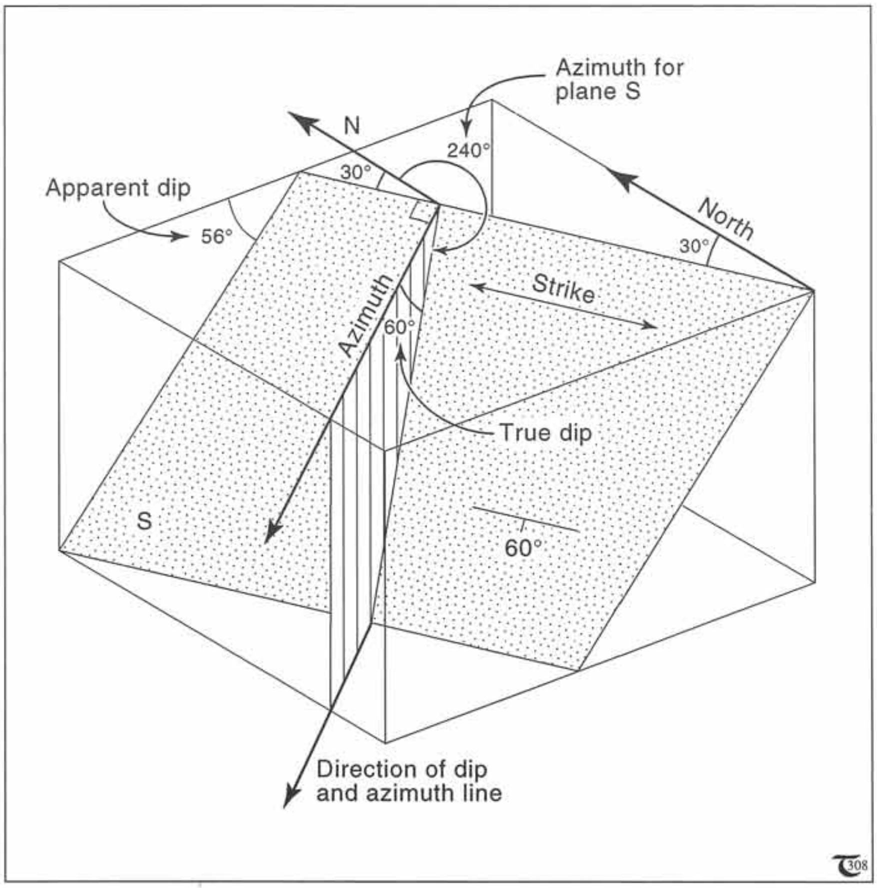


Figure 3-4: The azimuth line is always horizontal and normal to the strike line. The azimuth is always measured clockwise away from the north.

is normal to the strike line and lies within the horizontal plane; it is, also, part of a vertical plane, containing the line of greatest plunge on the bed. Conventionally measured clockwise, azimuth may vary between 0° and 360°. The representation of the plane in Figure 3-4 by the azimuth and dip of the unique line of greatest dip within that plane is 240°/60°. The latter method for representation of planar features is strongly recommended and will be adopted throughout this book. The azimuth/dip notation is shortest and, also, most practical for later manipulation of the directional data in stereonets (treated in *Principles of Geological Mapping*). However, the various strike/dip notations are employed by many geologists, and, therefore, one must be able to understand all systems used.

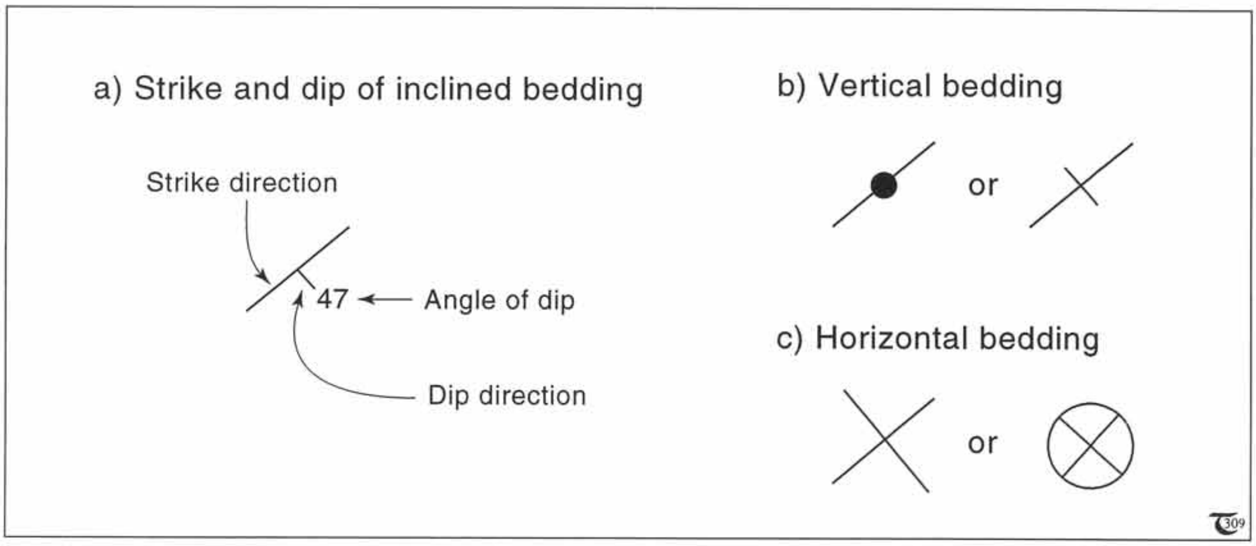


Figure 3-5: Conventional symbols used to indicate the orientation of strata on geological maps.

Map symbols: The strike line and dip direction of a layer are represented on the geological map by structural symbols, as indicated in Figure 3-5. The strike-dip symbol for bedding is a long line along strike with a shorter, normal tick mark pointing down the direction of dip. The number near the symbol represents the angle of dip. The strike line orientation need not be written separately on the map, because its orientation is fixed by its angle with the north arrow. It, therefore, is absolutely essential that the geographical north arrow be included in the geological map. Figure 3-6 illustrates a geological map which allows geologists to infer the structure of the subsurface.

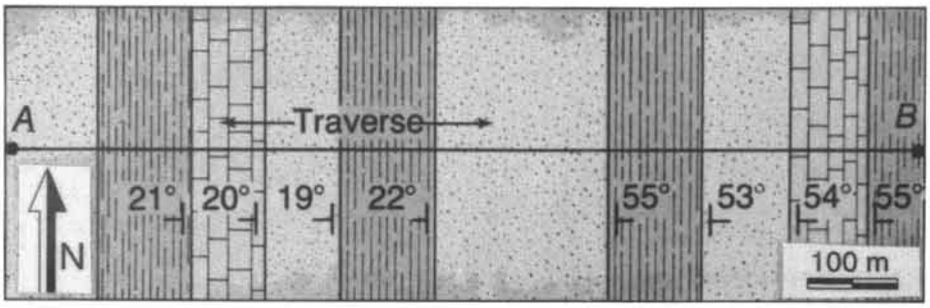
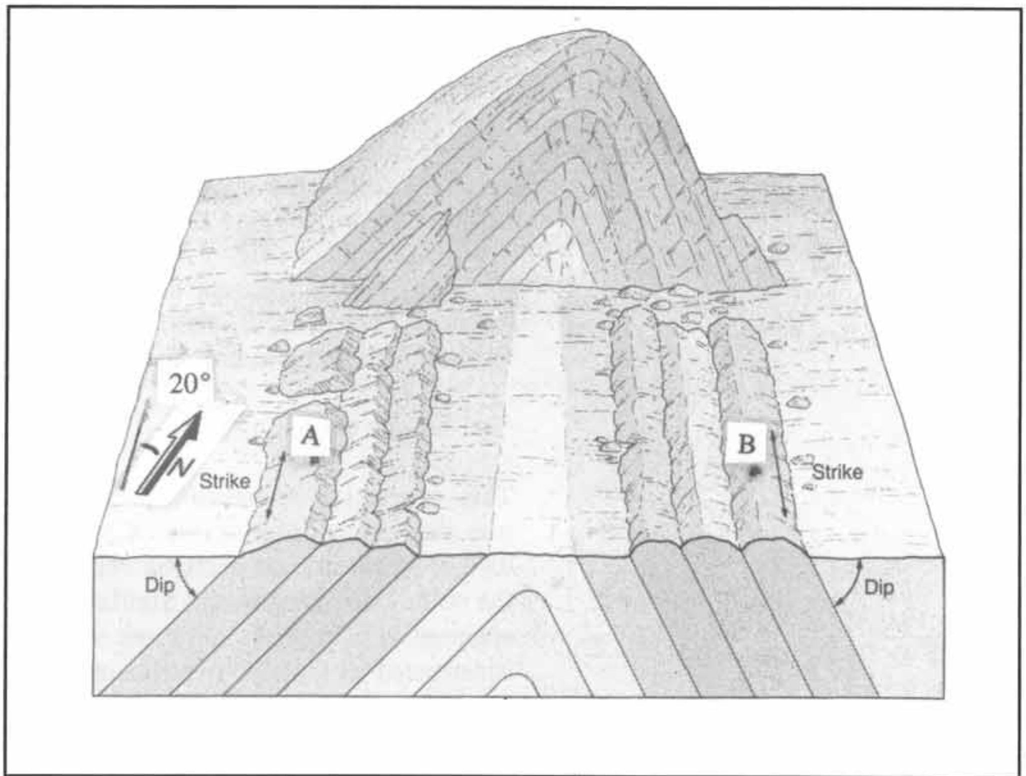


Figure 3-6: *Geological map with lithologic and strike-dip symbols. Amount of dip is indicated.*

□Exercise 3-1: Refer to Figure 3-7, and consider the layer attitude in the locations marked A and B. Give for both locations: (a) clockwise strike/dip, (b) anticlockwise strike/dip, and (c) azimuth/dip.



□Exercise 3-2: Sketch a geological map of the area displayed in Figure 3-7. Indicate the orientation of the strata with structural symbols.

Figure 3-7: *Perspective view of upright horizontal antiform. See exercises 3-1 & 3-2.*

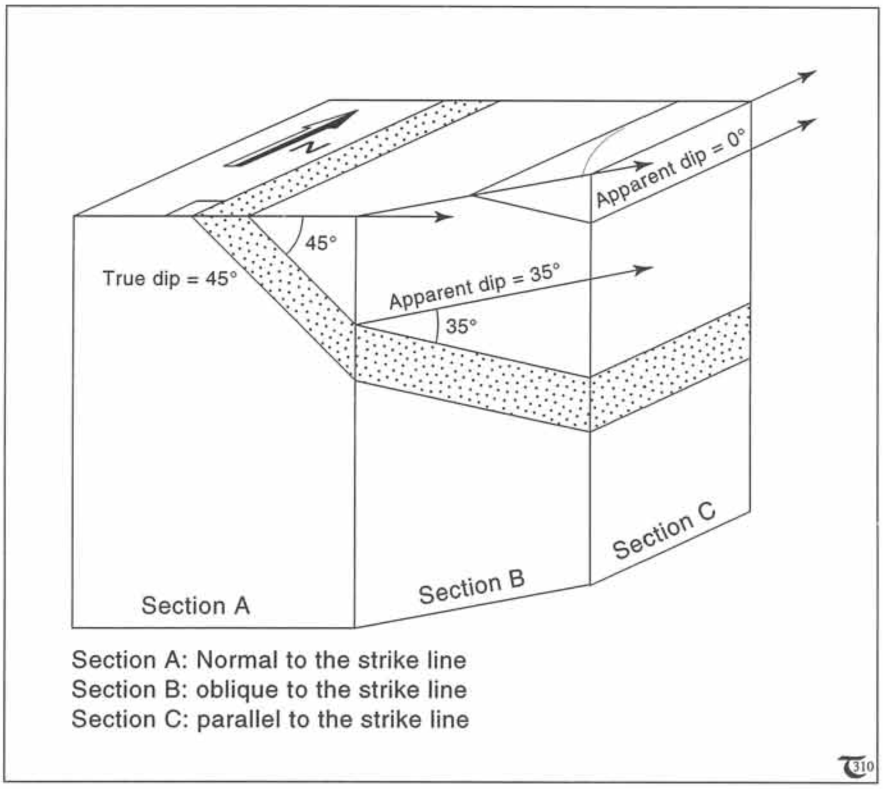


Figure 3-8: The true dip of a layer dipping 45° eastward is seen in a section normal to the strike line. Any oblique sections give apparent dips, less than the true dip angle.

3-2 True and apparent dip of strata

The relevant or true dip of the layer in Figure 3-8 is 45°. If the dip angle were to be measured on a vertical surface that is not normal to the strike line, the dip angle would appear to be less than 45°. The difference between the true and any apparent dip is the consequence of simple goniometric principles. The apparent dip can vary anywhere between 45° and 0° for the example shown in Figure 3-8. The dip of a planar layer in cross-section may vary from an apparent dip of 0° to its true or real dip, depending upon whether the profile line is parallel, oblique, or perpendicular to the strike of that layer (Fig. 3-8).

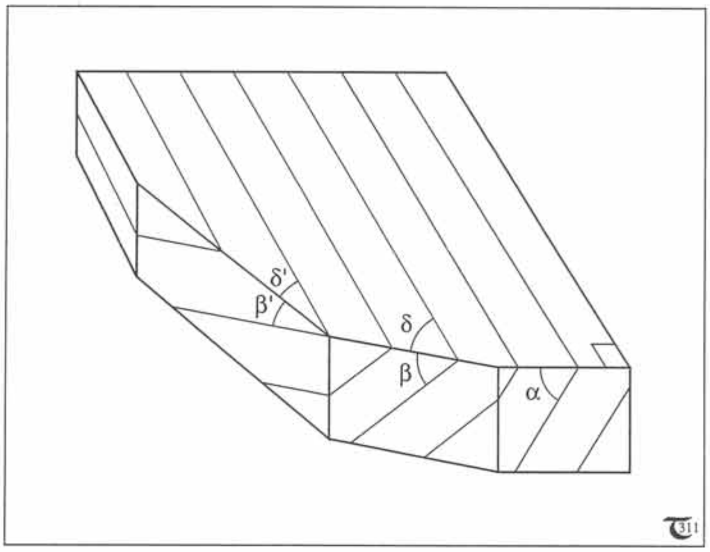


Figure 3-9: Definition of the three angles, α, β, and δ, used to relate the true dip, α, apparent dip, β, and the angle, δ, between the strike and section of apparent dip. See equation (3-1).

True and apparent dips are simply related through the angle, δ, measured between the section line and the strike of the strata studied (Fig. 3-9). If the true dip is α and the apparent dip is β, then the three angles, α, β, and δ are related by the following goniometric expression:

$$\tan \beta = \tan \alpha \sin \delta \qquad (3\text{-}1)$$

This expression is useful to determine true dips from observations of apparent dips of strata in road sections oblique to the strike line of the strata. Similarly, the apparent dip as seen on cross-sections constructed obliquely to strike may be calculated from the true dip measured on field outcrops.

Instead of calculating equation (3-1), it may be faster to use a nomogram to obtain one of the unknown angles from the other two. Such nomograms aim to transform true dips from maps to apparent dips in oblique profiles and vice versa. Figure 3-10 shows an example of such a nomogram, as used by the United States Geological Survey. Many different conversion tables are available to find the true dip from the apparent dip and vice versa. Such tables are all based on equation (3-1) and give the same answer to your particular problem if properly used. To use the nomogram of Figure 3-10, draw a straight line between any two of the known angles. The third, unknown angle is found at the intersection of the straight line with the corresponding vertical scale. In the example shown, the apparent dip seen in a vertical section is 8°, and the angle between the strike line and the line of section is 15°. It follows that the true dip of the layers must be 30°. Table 3-1 gives the angles in table format.

Cross-sections should preferably be drawn normal to the regional trend of geological structures for the following reasons. If the section is constructed obliquely through the map strike of such structures, all dips in the cross-sections are apparent and may give a misleading view of the subsurface structure. The conversion from the map data to the line of section is, also, more elaborate than in normal profiles. However, there are situations where oblique sections are needed for engineering purposes. For example, sometimes trenches have to be dug for sinking pipelines or a tunnel has to be constructed obliquely to the strike of geological structures.

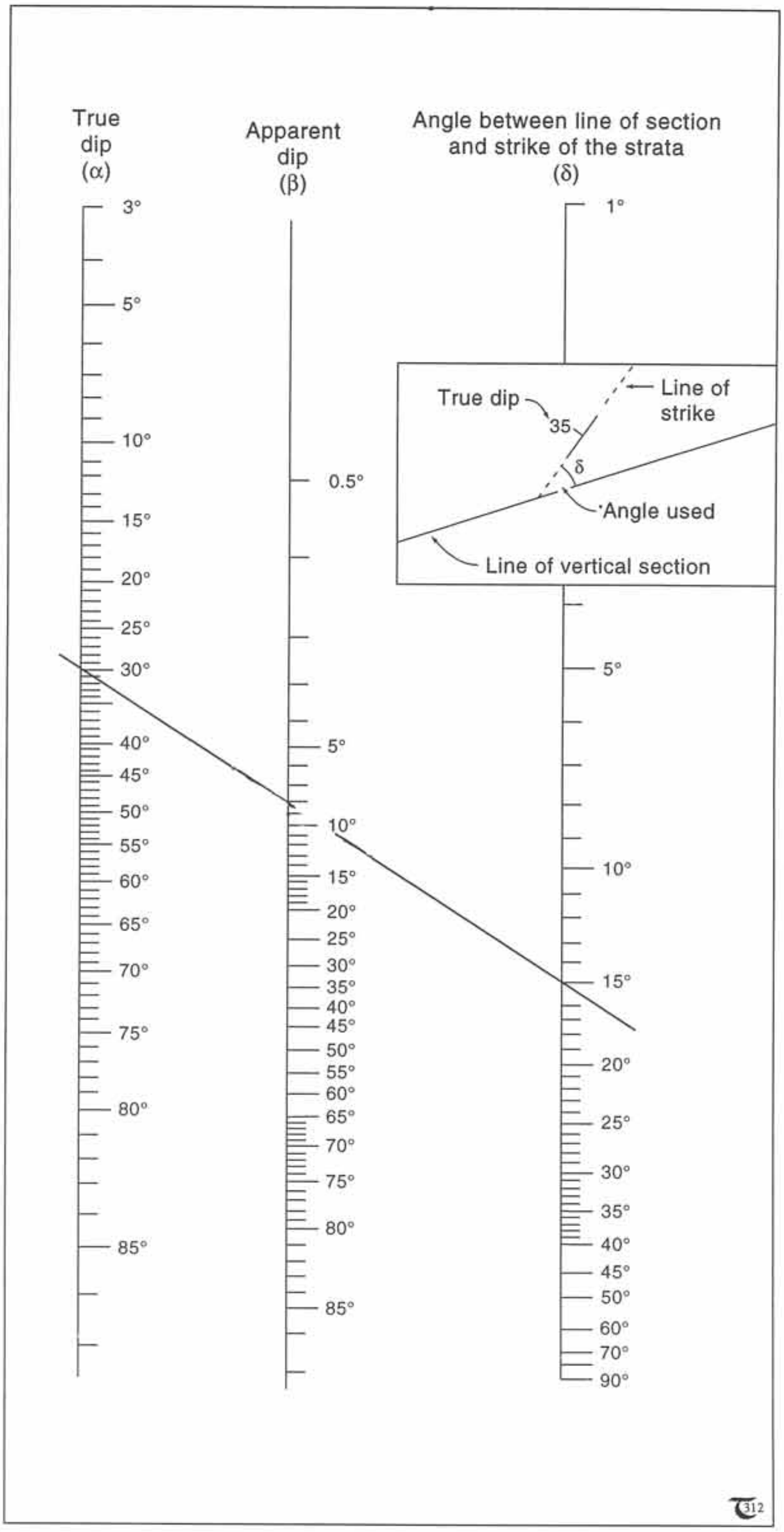


Figure 3-10: *Nomogram relating true dip, α, apparent dip, β, and section orientation, δ (see inset for definition of angles). Any straight line connects solutions of equation (3-1).*

Table 3-1: *Conversion of true dip, α, and apparent dip, β, rounded to the nearest 0.5°.*

True dip, α	Acute angle between strike and line of section, δ: 0	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	80	90
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0.0	0.5	1.0	1.5	2.0	2.0	2.5	3.0	3.0	3.5	4.0	4.0	4.5	4.5	5.0	5.0	5
10	0	0.5	1.0	2.0	2.5	3.5	4.0	5.0	6.0	6.5	7.0	8.0	8.0	8.5	9.0	9.5	10.0	10
15	0	1.0	1.5	3.0	4.0	5.0	6.5	8.0	9.0	10.0	11.0	11.5	12.5	13.0	13.5	14.0	15.0	15
20	0	1.0	2.0	3.5	5.5	7.0	9.0	10.0	12.0	13.0	14.5	15.5	16.5	17.5	18.0	19.0	20.0	20
25	0	1.0	2.0	4.5	7.0	9.0	11.0	13.0	15.0	17.0	18.0	20.0	21.0	22.0	23.0	24.0	25.0	25
30	0	1.5	3.0	6.0	8.0	11.0	14.0	16.0	18.5	20.5	22.0	24.0	25.0	26.5	27.5	28.5	29.5	30
35	0	2.0	3.5	7.0	10.5	13.5	16.5	19.5	22.0	24.0	26.5	28.0	30.0	31.0	32.5	33.5	35.5	35
40	0	2.0	4.0	8.0	12.0	16.0	19.5	23.0	26.0	28.5	30.5	33.0	34.0	36.0	37.0	38.5	39.5	40
45	0	2.5	5.0	10.0	14.5	19.0	23.0	26.5	30.0	33.0	35.0	37.0	39.0	41.0	42.0	43.0	44.5	45
50	0	3.0	6.0	11.5	17.0	22.0	27.0	31.0	34.5	37.5	40.0	42.5	44.0	46.0	47.0	48.0	49.5	50
55	0	4.0	7.0	14.0	20.0	26.0	31.0	35.5	39.5	42.5	45.0	47.5	49.5	51.0	52.5	53.5	54.5	55
60	0	4.5	8.5	16.5	24.0	30.5	36.0	41.0	45.0	48.0	51.0	53.0	55.0	56.0	57.5	58.5	59.5	60
65	0	5.5	10.5	20.5	29.0	36.0	42.0	47.0	51.0	54.0	56.5	58.5	60.0	62.0	63.0	63.5	64.5	65
70	0	6.5	13.0	25.5	35.0	43.0	49.0	54.0	57.5	60.5	63.0	64.5	66.0	67.0	68.0	69.0	69.5	70
75	0	9.0	18.0	33.0	44.0	52.0	57.5	62.0	65.5	67.5	69.0	70.5	72.0	73.0	73.5	74.0	75.0	75
80	0	13.5	26.5	44.5	56.0	63.0	67.5	70.5	73.0	74.5	76.0	77.0	78.0	78.5	79.0	79.5	80.0	80
85	0	26.0	45.0	63.5	71.5	75.5	78.0	80.0	81.5	82.0	83.0	83.5	84.0	84.0	84.5	84.5	85.0	85
90	-	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90

□Exercise 3-3: Figure 3-11a shows a map, and the true dip of the layer is constructed in a section normal to its line of strike. Figure 3-11b shows a map of a layer of similar thickness and dip but striking obliquely to the required section line. The dip of this unit in cross-section will not be the same as the true dip. Use the nomogram in Figure 3-10 to infer the apparent dip, and complete the cross-section of Figure 3-11b.

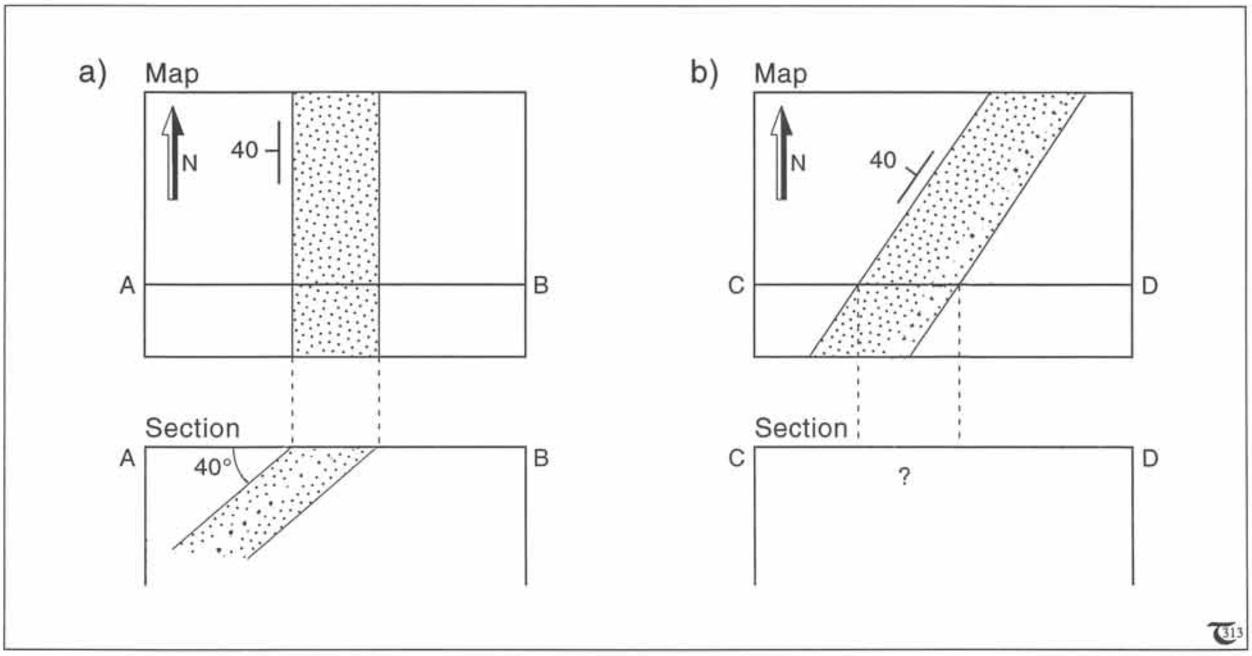


Figure 3-11: *a) Map view and section of a bed dipping westward. b) Map view and section oblique to the strike of the bed. See exercise 3-3.*

☐**Exercise 3-4: Figure 3-12 is a geological map with stratigraphic units labelled A to D. a) Construct five different cross-sections: along lines P-Q, P-R, P-S, P-T, and P-U. Use the nomogram of Figure 3-10 to find apparent dips where necessary. Arrange all five sections on one sheet, such that their left-hand scales are vertically aligned. b) Which section gives the best view of the subsurface structure? c) Which is the least representative?**

☐**Exercise 3-5: Assume a contractor asks you to plan the cheapest way to construct a narrow, five-meter-deep trench between locations P and S. The cost per horizontal meter is $100 for trench-cuts through the soft units A, B, and D, but the cost of cutting through unit C is three times higher. a) Sketch in red pencil, on the map of Figure 3-12, the cheapest pathway of the trench. b) Calculate how much is saved by the cheaper transection as compared to a straight ditch from P to S.**

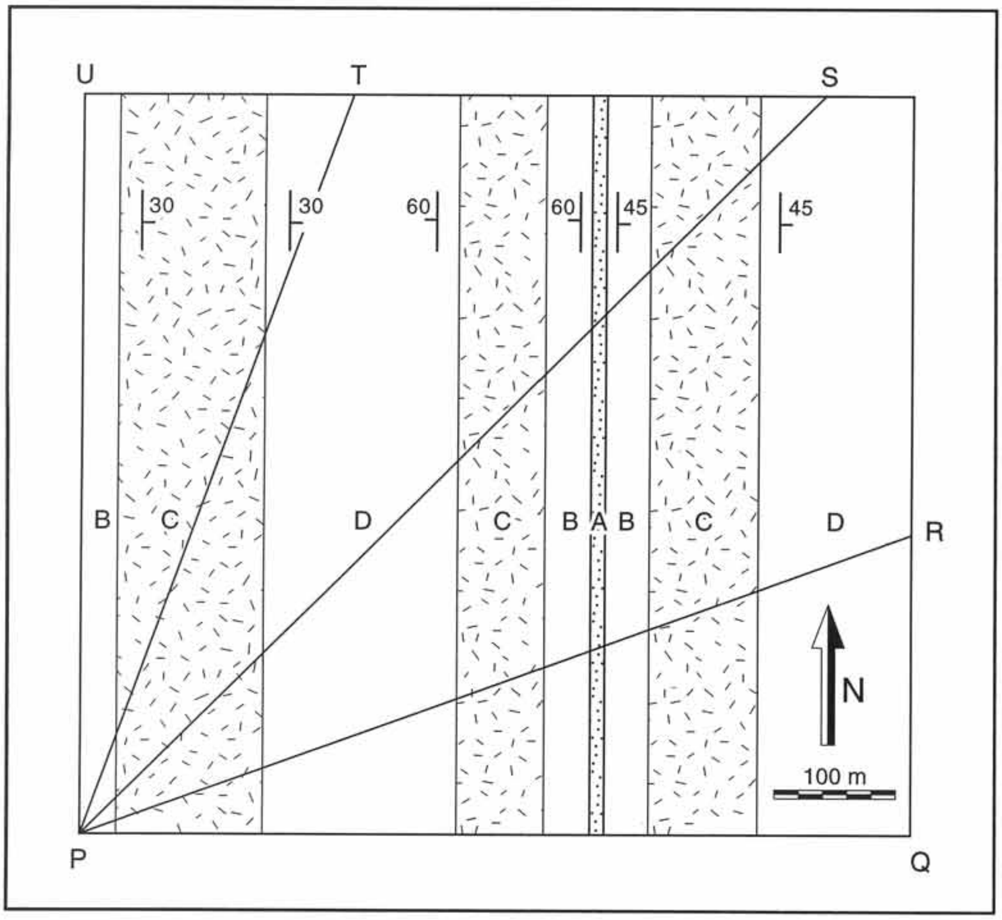


Figure 3-12: *Geological map of a stratigraphic sequence with units A to D. Exercises 3-4 and 3-5 call for five different sections to be completed along the traverses P-Q, P-R, etc.*

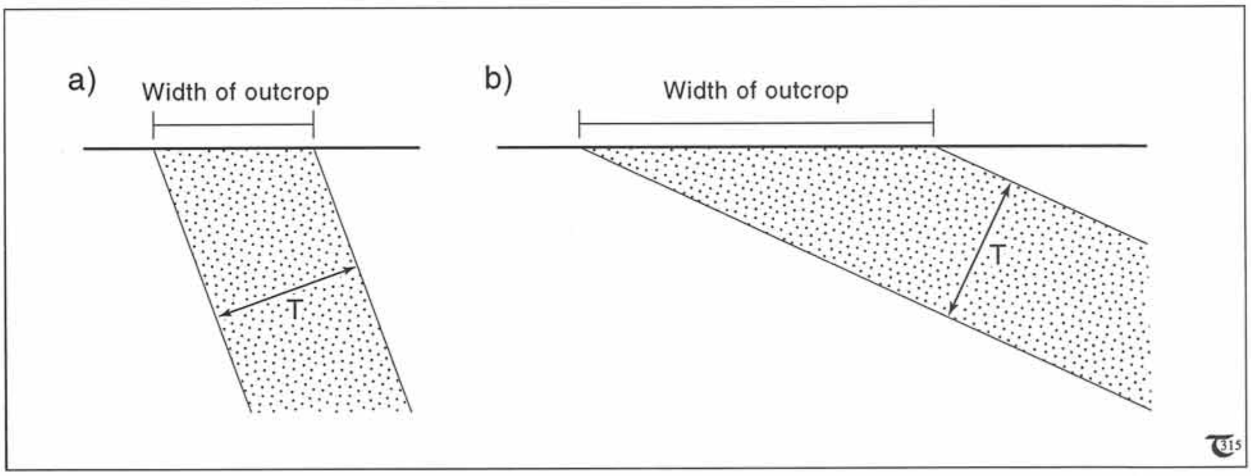


***Figure 3-13:** a) & b) The width of an outcrop seen at the ground surface in flat terrains always overestimates the true thickness of the beds, unless the dip is vertical so that the true width is exposed.*

Only sections oblique to the regional structures and parallel to the trace of the planned trenches and tunnels can show what rock units will be encountered and where (see exercises 3-4 & 3-5).

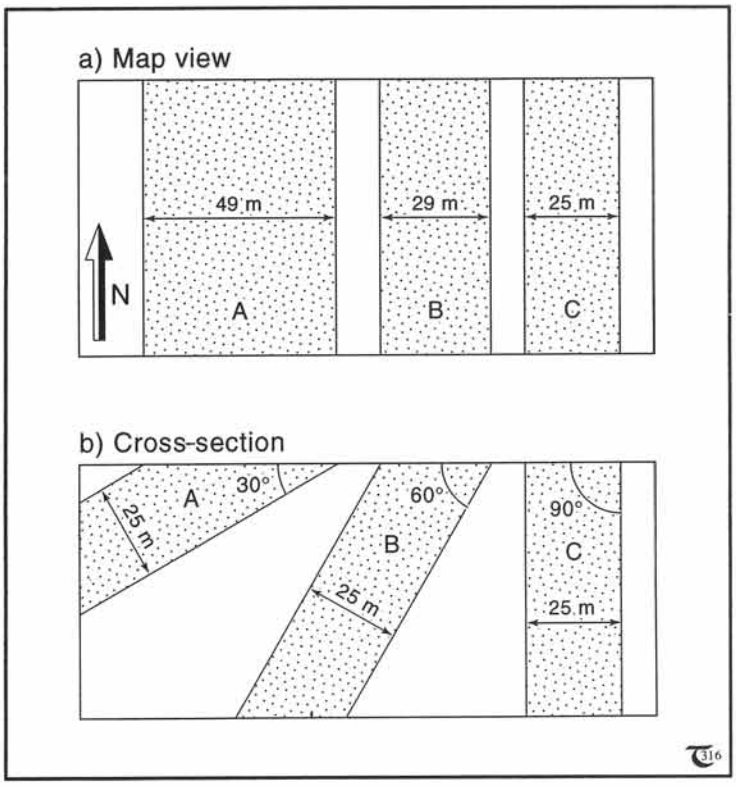


***Figure 3-14:** Map view (a) and cross-section (b) of three igneous dikes of identical thickness (A, B, and C). The steepest dike appears with an outcrop-width smaller than that of dikes with shallower dips.*

Moreover, strikes of all units are not always parallel. For example, straight sections through plunging folds cannot show all true dips (see, also, exercise 4-10).

3-3 True and apparent thickness of strata

The thickness of inclined strata as seen on maps may appear much thicker than on sections orthogonal to the bedding (Fig. 3-13a & b). The true or normal thickness, T, is seen on a map only if the layers are exactly vertical (Fig. 3-14a & b, dike C). The smaller the dip of such inclined layers, the greater their apparent thickness or width, W, as seen on maps cutting obliquely through them (Fig. 3-14a).

The true thickness (T) and the outcrop width (W) in relatively flat areas are simply related by the true dip, α (Fig. 3-15a):

$$T = W \sin \alpha \qquad (3\text{-}2)$$

The true thickness of horizontal layers seen with width, W, in road cuts, mine pits, or canyon walls of slope, γ, is given by (Fig. 3-15b):

$$T = W \sin \gamma \qquad (3\text{-}3)$$

The true thickness of inclined layers cut parallel to their strike by inclined walls is given by (Fig. 3-15c):

$$T = W \sin (\gamma - \alpha) \qquad (3\text{-}4)$$

In vertical drill holes, the true thickness, T, can be inferred from the vertical thickness, T_V, and the layer dip, α:

$$T = T_V \cos \alpha \qquad (3\text{-}5)$$

In terrains of rugged relief, the width of inclined layers may vary greatly, according to the rock unit's resistance to erosion. Less resistant rocks erode with outcrop patterns wider than those of rock units more resistant to erosion (Figs. 3-16a & b). Field evidence indicates that units of limestone and sandstone are commonly very resistant to erosion and, therefore, form steeper outcrops. In contrast, shales, marls, and claystones are less resistant to erosion. These form gently sloping outcrops, and even very thin layers may appear on geological maps as bands of broad width, falsely suggesting a large thickness for such soft units. For example, in Figure 3-16b, the shale of true thickness T_4 is thinner than the underlying sandstone unit of true thickness T_3, but their outcrop width suggests the opposite.

The previous section emphasized that geological cross-sections, aiming to show the subsurface structure accurately, should be oriented normal

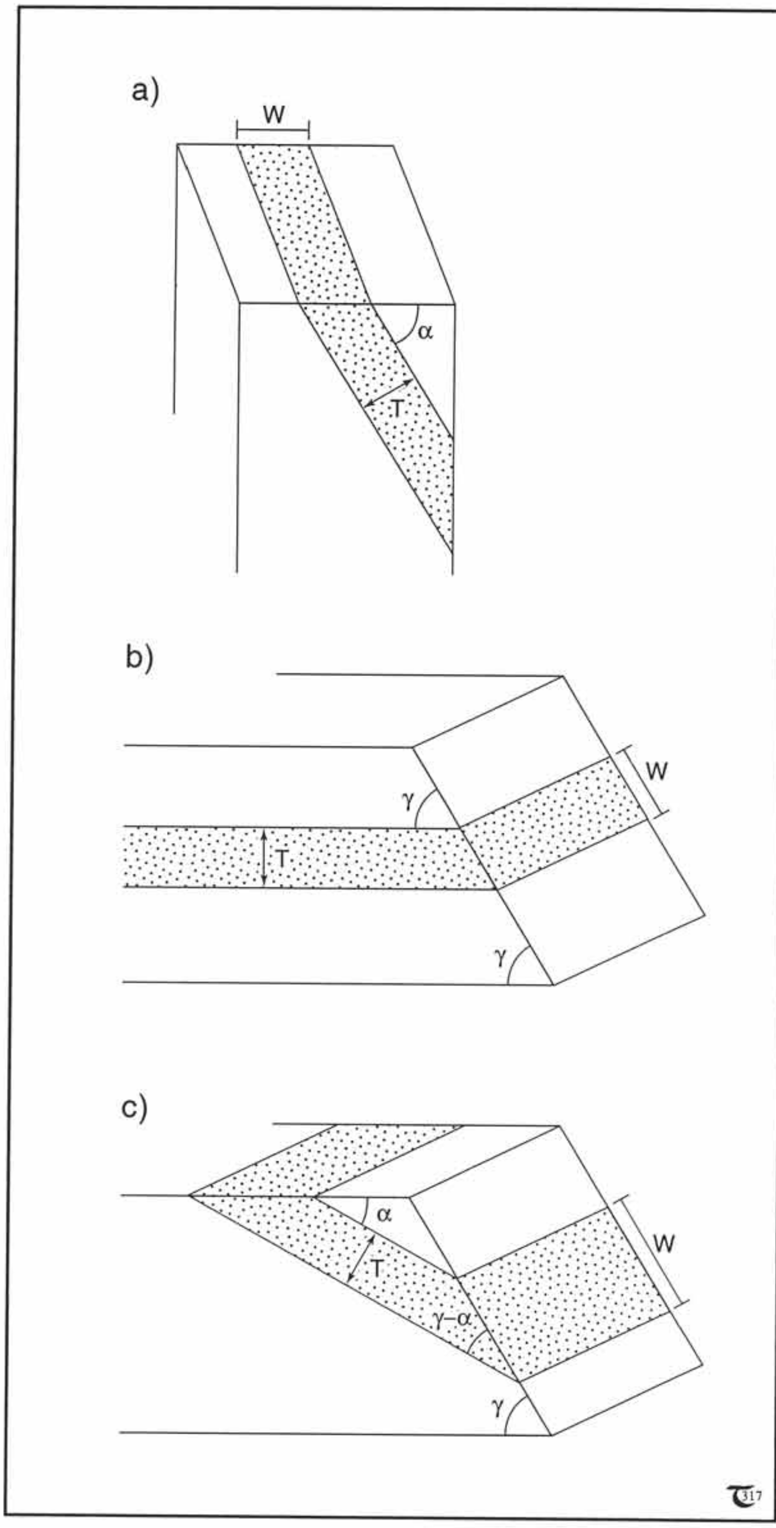


Figure 3-15: *Outcrop width for: (a) inclined layers in flat terrain, (b) horizontal beds in the walls of road cuts and trenches, and (c) inclined beds in the walls of trenches.*

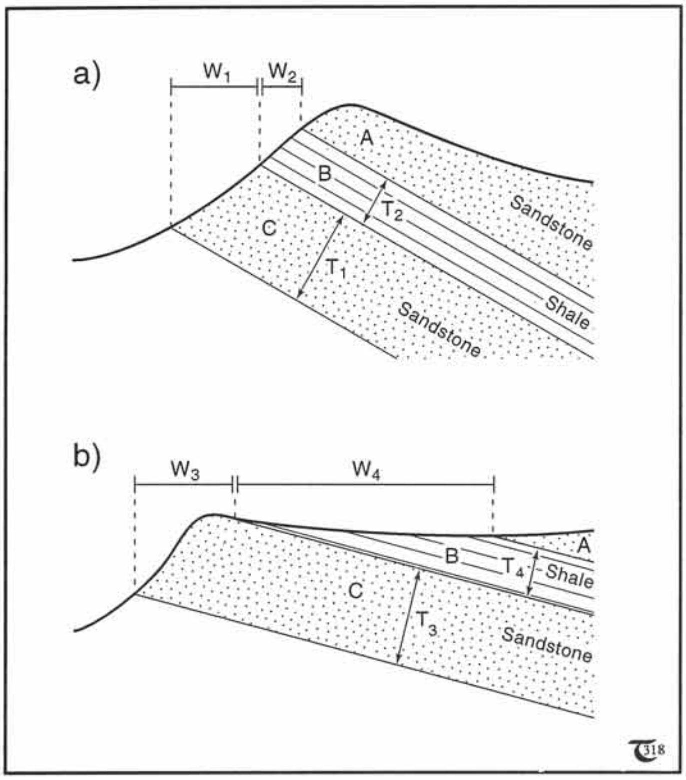


Figure 3-16: a) & b) The width, W, of beds as seen on orthographic map projections is dependent on the topographic relief of the terrain. The topography itself is partly controlled by the erosional resistance of each rock unit.

□Exercise 3-6: The map of Figure 3-17a shows the outcrop pattern of a uniformly inclined layer in a flat terrain. The cross-section of Figure 3-17b shows that the same map pattern (W=100 m) may arise for layers of different thickness if their dip angle is fixed correspondingly. a) Calculate the true thickness of each layer, using equation (3-2). b) Construct a vertical cross-section at 45° to the strike of the layers A, B, and C.

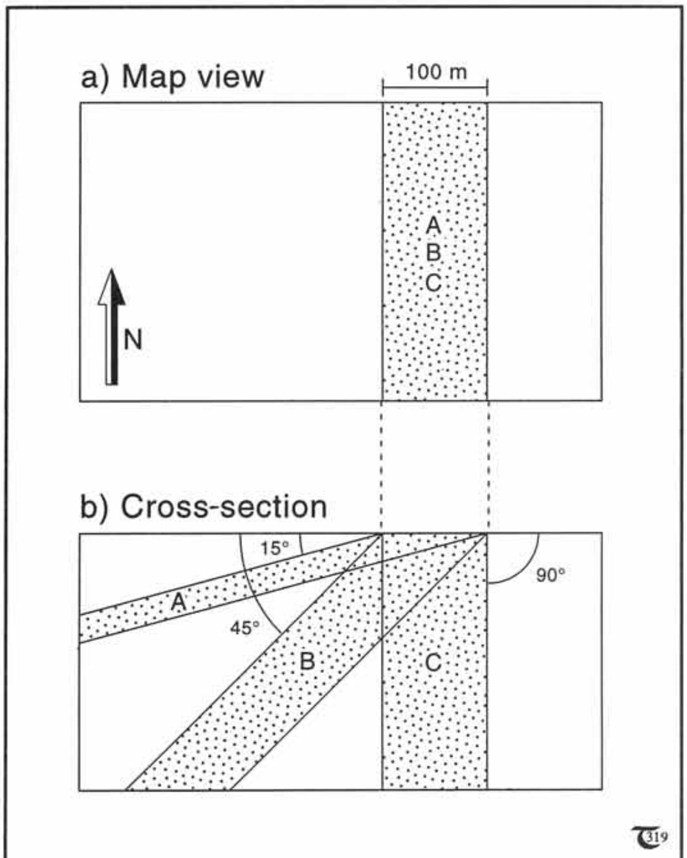


Figure 3-17: a) & b) Similar outcrop patterns arise for beds A, B, and C, shown in the carefully scaled cross-section (b). See exercise 3-6.

□Exercise 3-7: Construct a cross-section along line A-B on the map of Figure 3-18a. The topography along the line of section has been constructed for convenience in Figure 3-18b. a) Complete the cross-section of Figure 3-18b by showing the geological strata. Use the symbols of Figure 2-16. b) Make a stratigraphic column showing the true thicknesses of each layer. c) Compare the true thickness of the rock units seen in the column with the apparent thickness seen in the map. Explain the difference.

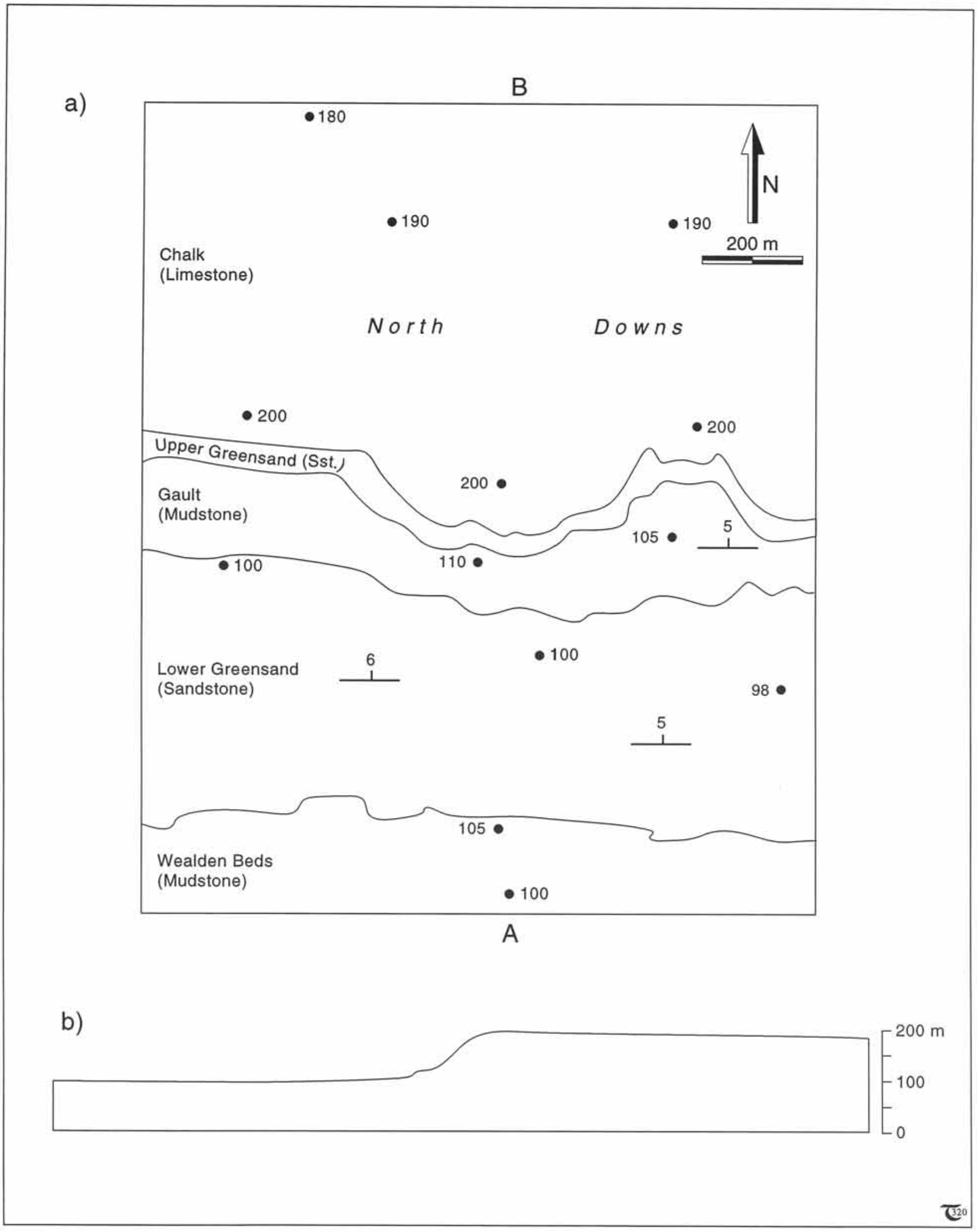


Figure 3-18: a) Geological map of part of the English basin. Spot elevations (dots) are in meters. b) Complete the cross-section along traverse A-B, as in exercise 3-7.

to the strike of rock strata. If the section is oblique to the strike, the true dip is obscured by an apparent dip. Another important reason for orienting profile lines normal to the regional strike of sedimentary layers is that their thick nesses appear as true thicknesses, unlike those in oblique sections. This assumes equal horizontal and vertical scales. If these two scales are unequal, both the dip and thickness of layers will be only apparent and not true, as explained in detail in the next chapter.

□Exercise 3-8: A sandstone aquifer strikes N90°E and dips 42°S. The width of its outcrop, measured due north, is 425 meters. There is no topographic relief in the region. Determine the true thickness of the aquifer: (a) by construction of a sketch map and a cross-section, and (b) by using equation (3-2).