3 TWO DIMENSIONAL PRESENTATION OF 3-D GEOLOGY

A highly artificial and simplified model will initially be used to demonstrate the fundamental principles of this chapter. A layer-cake sequence of rocks allows us to concentrate on the basics and branch out later to more realistic stratigraphies. In a layer-cake, each distinct layer (in this case of rock) has constant thickness though this may vary from layer to layer (Figure 3.1). We are not much concerned at the moment with the choice of particular boundaries, that is, lithostratigraphy (see Chapter 6). Two main factors influence this selection process. A mappable unit or **formation** is normally of sufficiently distinct characteristics (grain size, colour, composition, texture) to allow it to be readily distinguished from its neighbours. More difficult situations arise with gradational boundaries where arbitrary lines are drawn but then hopefully kept to. Another influence is scale of representation. A unit of conglomerate beds 30 m thick is easily represented on a 1:10 000 map but at 1:50 000 the same unit may only occupy a width of 0.6 mm in its least favourable attitude. A formation at one scale is not necessarily a formation at a smaller scale.

3.1 ATTITUDES OF PLANAR SURFACES

Mappable units may be sedimentary rocks, sequences of lava flows or perhaps complexes of metamorphic or intrusive material. Our first steps will consider concepts applicable to sedimentary rocks as these are the simplest to deal with. Many sedimentary layers are deposited horizontally with approximately planar bounding surfaces, particularly when viewed at mapping scales less than 1:10 000. If subsequent deformation tilts the layer-cake then we need a system to accurately describe its new attitude. **Structural contours** fulfil this need by using an approach that is very similar to that of topographic contours. The main difference is that,

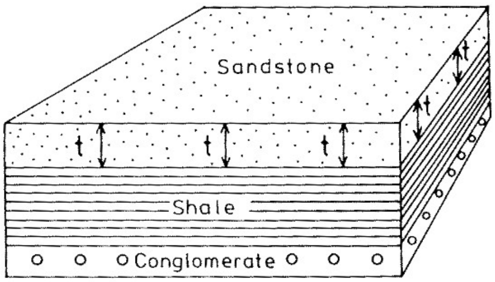

Fig. 3.1 The layer-cake, a simple starting-point. Layers are of constant thickness (*t*) measured perpendicular to the bounding surfaces — also known as stratigraphic thickness

instead of the land surface, we contour geological surfaces of any kind (sedimentological, intrusive igneous, or fracture). A structure contour is a line of equal elevation drawn on a geological surface (Figure 3.2a). A graphic illustration of a structure contour is the intersection of a bedding surface and a body of water (Figure 3.3). Though we are here applying the method to sedimentary formations, it is equally useful in describing the shape of an intrusive body or a fracture surface. For this reason the old term stratum contour is best replaced by the more general term structural contour.

Figure 3.2a shows the top surface of an inclined bed of sandstone where several structure contours have been drawn in. Again, as with topography, it is wise to consider a regular vertical interval to be represented by the contours; here it is 100 m and each 100 m rise or fall of the surface has a structure contour. Because our layer-cake has planar bounding surfaces to the formations, it follows that the structure contours will be straight lines. An important step in understanding the nature of structure contours comes from appreciating that their appearance on the map is a function of vertical projection (Figure 3.2) as is the case with topographic contours.It is the process of projection that allows 2-D representation of 3-D shape. For the tilted layer-cake the structure contours on one surface will be parallel and evenly spaced when projected on to the map. To cut down on verbiage the projected nature of the structure contours will not usually be mentioned though it always has to be borne in mind. Structure contours, which are horizontal lines, may trend along any bearing of the compass and hence their orientation should be specified. In Figure 3.2b the bearing is N75° W, E15° S, 285° or 105°, depending on what system you use to specify compass bearings. By definition the bearing of a structure contour is called the **strike** (Figures 3.2 and 3.3). Note that each end of any straight horizontal line such as a structure contour has a bearing and that these are 180° apart; methods will be given later that will allow us to uniquely specify just one end. The sandstone surface we are examining (Figure 3.2) has a maximum inclination from the horizontal, this angle being known as the **true dip** (or dip for short). The spacing of the structure contours on the MAP (the horizontal equivalent) is directly related to the angle of the dip of the surface in the same way that the spacing of topographic contours relates to the slope of the land surface. Widely spaced contours mean a gentle dip and a closer spacing means a steeper dip.

The dip angle may be calculated by using simple trigonometry; of the SOCATOA mnemonic (sine is opposite over hypotenuse, etc.) you only have to remember tangent is opposite side divided by adjacent. The true dip is found in a direction at right angles to the strike (AC in Figure 3.2b and XZ in Figure 3.2b and the inclination measured in any other direction (e.g. AB in Figure 3.2b and XY in Figure 3.2c) is a lower value known as an apparent dip (Figure 3.4). In the direction of true dip (towards 195°) the sandstone surface (Figure 3.2b) is seen to fall 200 m from C to A in a ground (horizontal) distance of 500 m and therefore each 100 m structure contour has a ground spacing (horizontal equivalent) of 250 m. Tangent of the dip angle is $200 \div 500$, making the dip 22°. To claim a precision better than to the nearest degree is a pointless exercise and geological realities often continue to give several degrees of uncertainty. Because we are dealing with a planar surface the 250 m ground spacing of the structure contours on Figure 3.2b is constant.

Several shorthand notations have been established to describe the attitude of planar surfaces. The most direct is to quote the dip amount and the direction that the surface dips towards, which for Figure 3.2a/b gives $22 \rightarrow 195$. By giving the direction of the fall of slope a unique specification of attitude is produced. Other systems quote dip and strike but, because strike is double ended, confusion may arise. One group of methods records the general quadrant of the dip direction and the strike by various

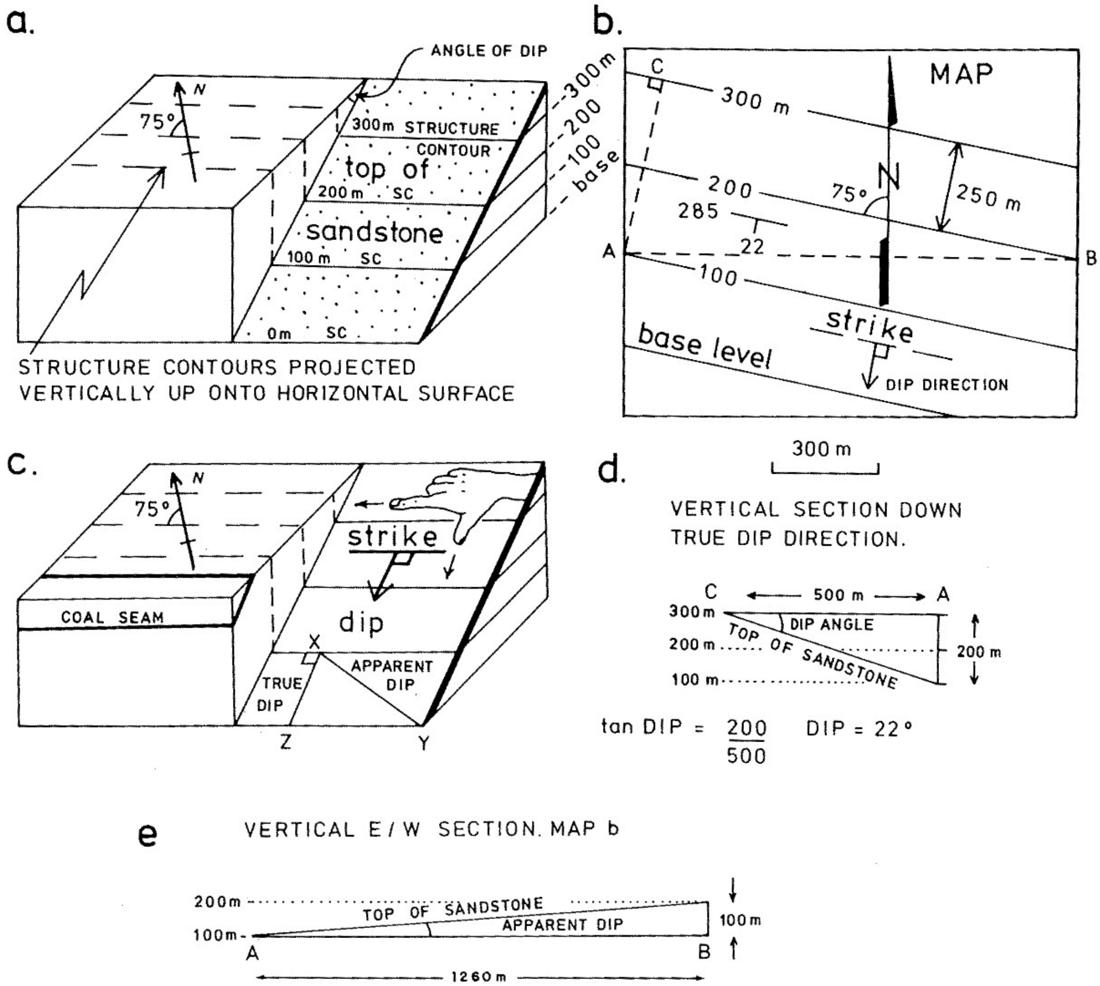

Fig. 3.2 (a) Structure contours drawn on the exposed surface of a sandstone layer dipping towards the south-south-west. When the structure contours are vertically projected on to a horizontal surface, a map view is created. (b) Map view of (a). Because the sandstone has planar bounding surfaces the structure contours have a constant horizontal equivalent of 250 m. The slope in the direction AC is the maximum on the surface — the **true dip**. Any other direction is a lower slope known as an apparent dip, e.g. AB. The orientation of the structure contours is the **strike**. (c) Horizontal structure contours have two bearings one at either end. The right-hand rule uniquely specifies one of these for a dip and strike reading. With the palm of the right hand on the surface and the thumb down the dip, the strike to choose is pointed to by the index finger. The front face of the block is a strike section and the coal seam parallel to the sandstone has a horizontal trace in this view, i.e. zero apparent dip. XY is an apparent dip direction between the strike section and the true dip direction (XZ). (d) A vertical section along AC (b) to show the true dip of the sandstone. Tangent of the dip is the 200 m fall from C to A of the surface divided by the horizontal distance (500 m). (e) A vertical east – west section along AB (b) to show the apparent dip of the sandstone in this direction. Tangent^{-1} (200/500) $\gg$ tangent^{-1} (100/1260). Apparent dips are always less than the true dip

means, e.g. 22°SW, N75°W or 22° SW, 105; the part before the comma is the dip and the quadrant of the dip direction, and that after the comma is the strike. A more reliable approach establishes a convention which consistently gives the bearing of one end of the structure contour. Both the right-hand rule or the clockwise convention achieve the same result. Following the right-hand rule, imagine that you have placed your right hand palm down on the surface with your thumb pointing down the dip, you then record the strike bearing your index finger is pointing to

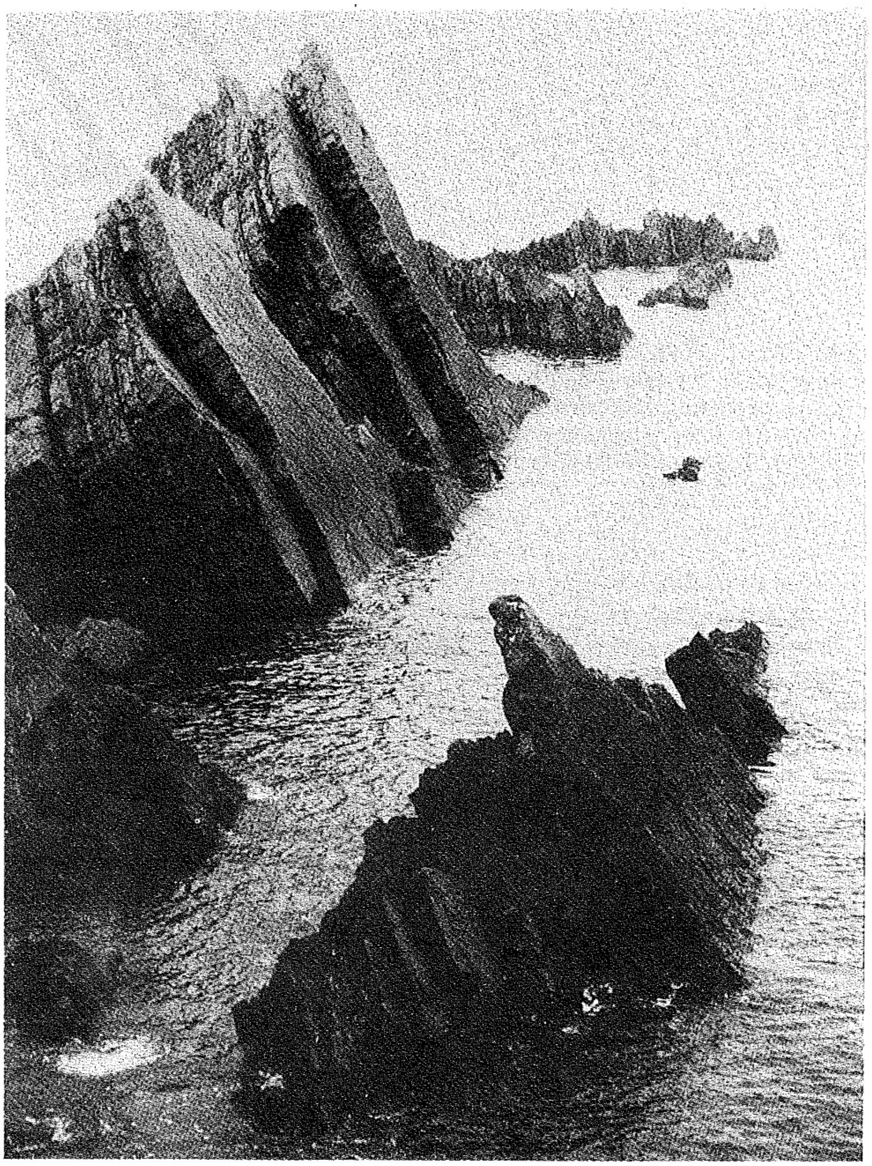

Fig. 3.3 Sandstone bedding surfaces dipping steeply into the sea (on a calm day a horizontal planar surface). The intersection of these two planes defines the 0 m structure contour and the bearing of this intersection is the strike

(Figure 3.2c and 3.5). The clockwise convention records the strike bearing that is clockwise from the dip direction. With either style, Figure 3.2a/b would be recorded as 22/285. If two digits are used for the dip and three for the strike there can be no confusion between strikes less than 090° and dips. A surface dipping 5° to the north-west and striking N30° E would be recorded as 05/030. Mistakes can arise when using these conventions and a dip direction 180° in error may be recorded either by carelessness or unfamiliarity. A not so well oriented person may also make mistakes with dip and dip direction though this is impossible with compasses specifically adapted for this system. When structures become more variable I believe that dip and strike symbols (Figures 1.1b, c, 3.2b) are more graphic than dip and dip direction in highlighting changing trends, and for this reason prefer to record dip and strike.

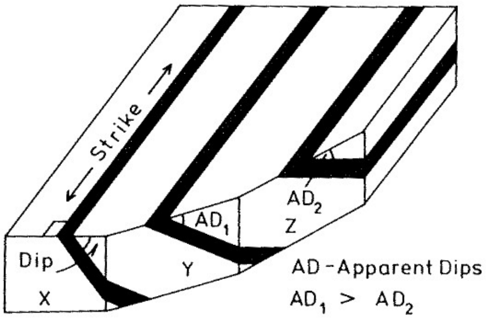

Fig. 3.4 Three beds of constant dip and strike and thickness seen in differently orientated vertical sections (X, Y and Z). X is at right angles to the strike and down the true dip (commonly abbreviated to dip). The orientations of Y and Z progressively move away from the dip direction towards that of strike sections and hence the apparent dip on Z (AD_2) is less than that on Y (AD_1)

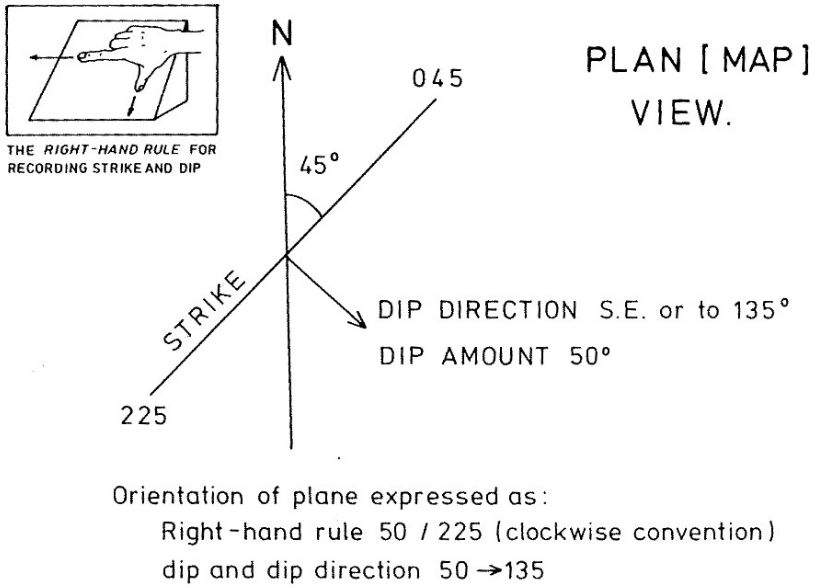

Fig. 3.5 Another example of the right-hand rule and dip plus dip direction specification of attitude for a plane. The plane dips at 50° towards 135°. Its strike is either 045 or 225. According to the right-hand rule (clockwise convention) 225° is quoted and full specification is 50/225

3.2 ATTITUDES OF LINEAR STRUCTURES

Without necessarily realizing it we have already considered, at least in part, the attitude of lines. Structure contours are linear features and many other linear structures, both real and constructed, will be met as we progress through the book. A line inclined to the horizontal is said to **plunge** (Figure 3.6). It is helpful to have a different nomenclature to that of planes such that the important difference between

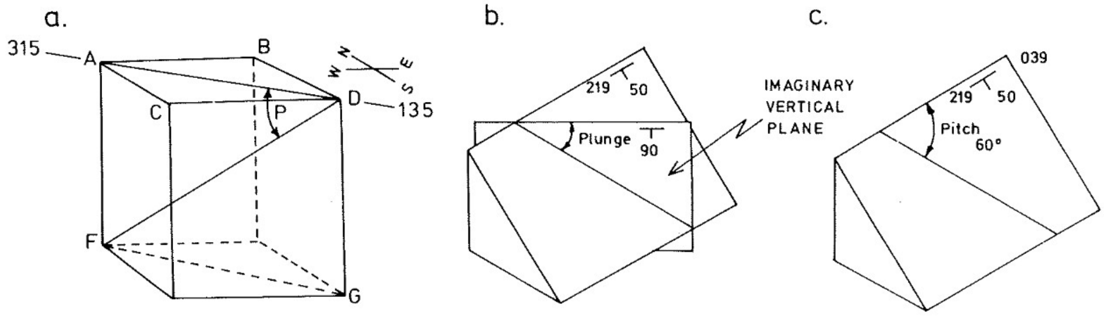

Fig. 3.6 (a) The line DF is plunging at $P°$ towards 315°. Its bearing is angle BDA. (b) The bearing of a linear structure is the strike of an imaginary vertical plane that contains the linear. The plunge is also measured in this plane as the angle between the linear and the horizontal. (c) A linear structure resting on a plane could have its orientation specified either by plunge and bearing (b) or by the angle between the linear and the strike of the plane measured on the plane, i.e. the pitch. Here the pitch is 60° from 039° on 50/219.

lines and planes is emphasized. To specify a line's plunge and bearing involves the somewhat awkward step of imagining a vertical plane containing the line (Figure 3.6b). The strike of this plane is the bearing of the line and of the two ends of the strike we quote the direction the line is plunging towards. It is also within this vertical plane that the maximum inclination of the line—the plunge—may be measured. For Figure 3.6a the plunge and bearing is 45→315 (two digits→three digits). The arrow between the plunge and the bearing is to make the distinction (in field notebooks, reports, etc.) between lines, and planes which have an oblique between dip and strike. The non-plunging structure contours of Figure 3.2 would be written as 00→285 or 00→105 because these are identical. If the linear feature is resting on a plane (e.g. ripples on a sandstone surface) or striations on a fault surface) its attitude may be specified using the **pitch**. This quotes the angle between the line itself and the horizontal direction within the plane (the strike) and in the field would typically be measured by placing a protractor (or Silva-type compass) on the planar surface. The smaller of the two pitch angles is conventionally quoted (60° not 120° in Figure 3.6c) but in some circumstances the larger angle may be useful. In Figure 3.6c the 60° pitch may have been from the south-west end of the strike (219°) instead of the north-east end (039°) of the strike and the true orientation must be clearly stated. One means of achieving this is to quote the strike bearing that encloses the measured pitch angle, 039° in the case being discussed. A line's attitude is only properly specified by pitch if the plane's dip and strike is also quoted. The full statement for Figure 3.6c is a pitch of 60° from 039 on 50/219, though 120° from 219 on 50/219 would be equally clear and valid. The linear features in Figure 3.6b and c have the same plunge and bearing (42→087) but are represented differently to show the basis of attitude specification by both plunge and bearing, and pitch.

A common but rather unsatisfactory means of quoting pitch is to say, for example, a line pitches 80° to the south-east on a particular plane. In the case of Figure 3.6c pitches of 80° from 039 and 80° from 219 both pitch to the south-east and quoting the general quadrant of the pitch does not differentiate lines with 30° between their bearings. Rake has been used as a synonym for pitch but this practice is no longer favoured. At this point I should mention another example of the transatlantic separation of English-speaking peoples by a common language. In the United States rake is often used instead of pitch for the angle between a line and the strike of the containing plane. Part of the problem is that they sometimes use pitch in the place of plunge.

3.3 APPARENT DIPS

If Figure 3.2b were to be sectioned down the dip of the beds then the maximum inclination of the surface would be seen as in Figure 3.2d. A vertical slice in any other direction would give an apparent dip which is a linear feature with plunge and bearing but where the plunge is always less than the true dip. On an exposed portion of the sandstone bed, a walk from west to east (A to B of Figure 3.2b) would be up a 5° slope significantly less than the 22° true dip. As a linear feature the attitude of this apparent dip is quoted as 05→270 which can be readily calculated knowing the height and position of two points on the line. A vertical slice parallel to the strike (**a strike section**) shows no inclination of the surface for any value of true dip (except 90°). Such an apparent zero dip is shown by the coal seam on the front face of Figure 3.2c. Simple trigonometry shows the relationship between apparent and true dip. On Figure 3.2b, a fall of 100 m down the true dip of the sandstone is achieved in a ground distance of 250 m. The same fall of 100 m in an east – west section occurs along a ground distance of 1260 m giving a much lower dip (compare Figures 3.2d and e). Following the same procedure it is a simple matter to calculate the apparent dip in any direction with any surface dip and strike. Rather than use a construction in every case the following relationship links true and apparent dips:

$$\tan A = \tan B \sin C$$

where angle A is the apparent dip, angle B is the true dip and angle C is the difference in bearing between the strike and the apparent dip direction. For the east – west section of Figure 3.2b, the angle C would be 15°. In regions where strike varies, a single vertical section cannot always show the true dip of the beds and apparent dips have to be calculated or constructed. It is also advisable to have a feeling for how apparent dips change as the section direction moves away from the true dip. For example with a true dip of 80°, a vertical section on a bearing 45° from the dip direction would show an apparent dip of 76°; 80° from the dip direction the apparent dip has reduced to 45°.

Several situations arise where two apparent dips on a plane are known and we need to calculate the attitude (dip and strike) of the plane. The method depends upon drawing the 'horizontal equivalent' for a 100 m drop of the surface for each apparent dip. (Note that stereographic projection — see Appendix 1 — is a quicker solution.) **Method** (Figure 3.7): Apparent dips 20→330 and 24→053 both rest on a plane. What is the dip and strike of the plane?

1. From a single point (O) draw two lines representing the bearings of the two apparent dips.
2. Along the 330° bearing measure off (using any reasonable scale) the distance OA = 100 ÷ tan 20° and along the 053° bearing mark off OB = 100 ÷ tan 24°. From O to A and O to B the surface has fallen 100 m (compare with parts d and e of Figure 3.2).
3. A line joining A and B is the strike (measure orientation on map) and is the projection of a structure contour 100 m lower than that running through O. (Note only relative heights are important.) Draw a line parallel to AB through O to define the horizontal equivalent of the structure contours. Use a protractor to measure the strike (110°/290°).

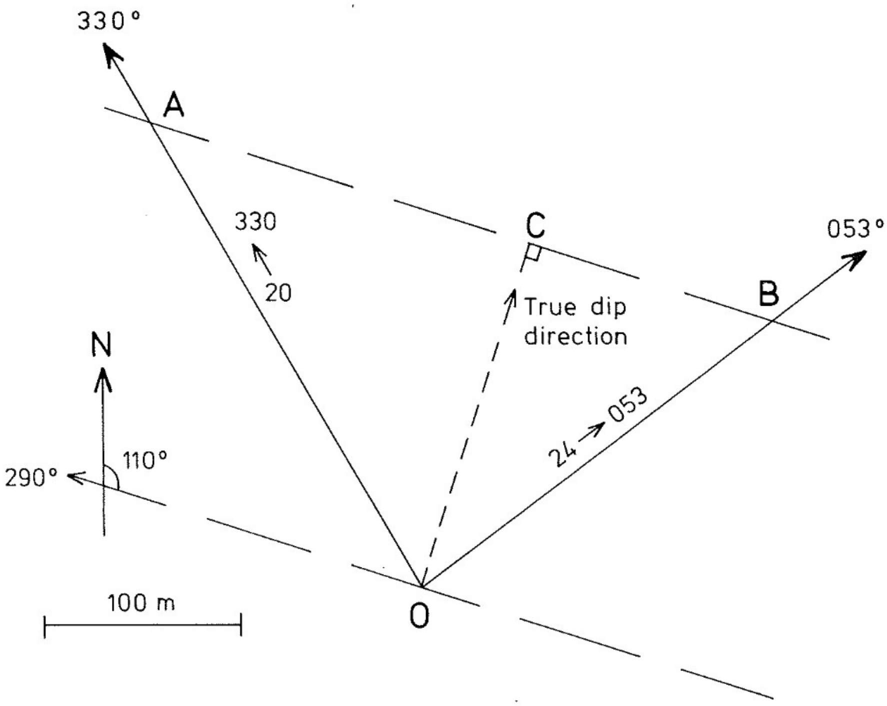

Fig. 3.7 Calculation of true dip and strike from two apparent dips (20→330 and 24→053). Select any convenient scale and choose a point to represent O. Draw OB and OA to represent 100 m falls of the surface along the apparent dip directions. The line AB is the strike and OC is the horizontal equivalent which allows calculation of the true dip

4. The perpendicular distance between the two structure contours gives the true dip = $\tan^{-1}$ (100 ÷ OC) which in this case is 30°.

∴ Surface dip and strike is 30/110 (right-hand rule).

All of the examples described in this chapter relate to planar surfaces. More complex shapes are also interpreted by constructing structure contours as will be discussed in later chapters.