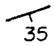
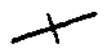
Geological Map Symbols



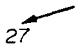
inclined strata, dip in degrees


horizontal strata

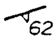

vertical strata


axial surface trace of antiform


axial surface trace of synform



fold hinge line, fold axis or other linear structure, plunge in degrees



inclined cleavage, dip in degrees

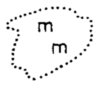

horizontal cleavage


vertical cleavage


geological boundary


fault line, mark on downthrow side


younging direction of beds



metamorphic aureole

1
Geological Maps

1.1 What are geological maps?

A geological map shows the distribution of various types of bedrock in an area. It usually consists of a topographic map (a map giving information about the form of the earth's surface) which is shaded, or coloured to show where different rock units occur at or just below the ground surface. Figure 1.1 shows a geological map of an area in the Cotswolds. It tells us for instance that clays form the bedrock at Childswickham and Broadway but if we move eastwards up the Cotswold escarpment to Broadway Hill we can find oolitic limestones. Lines on the map are drawn to show the boundaries between each of the rock units.

1.2 How is such a geological map made?

The geologist in the field firstly records the nature of rock where it is visible at the surface. Rock outcrops are examined and characteristics such as rock composition, internal structure and fossil content are recorded. By using these details, different units can be distinguished and shown separately on the base map. Of course, rocks are not everywhere exposed at the surface. In fact, over much of the area in Fig. 1.1 rocks are covered by soil and by alluvial deposits laid down by recent rivers. Deducing the rock unit which underlies the areas of unexposed rock involves making use of additional data such as the type of soil, the land's surface forms (geomorphology) and information from boreholes. Geophysical methods allow certain physical properties of rocks (such as their magnetism and density) to be measured remotely, and are therefore useful for mapping rocks in poorly exposed regions. This additional information is taken into account when the geologist decides on the position of the boundaries of rock units to be drawn on the map. Nevertheless, there are always parts of the map where more uncertainty exists about the nature of the bedrock, and it is important for the reader of the map to realize that a good deal of interpretation is used in the map-making process.

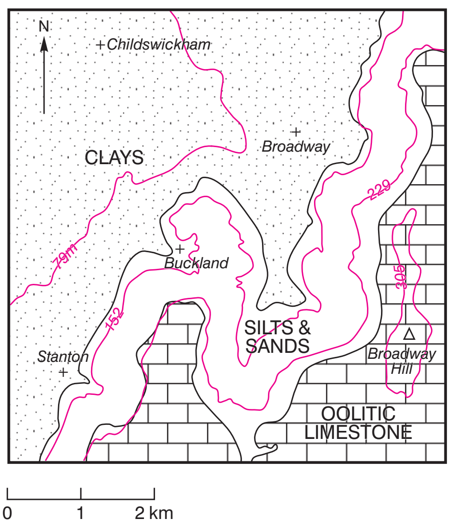


Fig. 1.1 A geological map of the Broadway area in the Cotswolds.

1.3 What is a geological map used for?

The most obvious use of a geological map is to indicate the nature of the near-surface bedrock. This is clearly of great importance to civil engineers who, for example, have to advise on the excavation of road cuttings or on the siting of bridges; to geographers studying the use of land and to companies exploiting minerals. The experienced geologist can, however, extract more from the geological map. To the trained observer the features on a geological map reveal vital clues about the geological history of an area. Furthermore, the bands of colour on a geological map are the expression on the ground surface of layers or sheets of rock which extend and slant downwards into the crust of the earth. The often intricate pattern on a map, like the graininess of a polished wooden table top, provides tell-tale evidence of the structure of the layers beneath the surface. To make these deductions first requires knowledge of the characteristic form of common geological structures such as faults and folds.

This book provides a course in geological map reading. It familiarizes students with the important types of geological structures and enables them to recognize these as they would appear on a map or cross-section.

2
Uniformly Dipping Beds

2.1 Introduction

Those who have observed the scenery in Western movies filmed on the Colorado Plateau will have been impressed by the layered nature of the rock displayed in the mountainsides. The layered structure results from the deposition of sediments in sheets or beds which have large areal extent compared to their thickness. When more beds of sediment are laid down on top the structures comes to resemble a sandwich or a pile of pages in a book (Fig. 2.1A & B). This stratified structure is known as *bedding*.

In some areas the sediments exposed on the surface of the earth still show their unmodified sedimentary structure; that is, the bedding is still approximately horizontal. In other parts of the world, especially those in ancient mountain belts, the structure of the layering is dominated by the buckling of the strata into corrugations or folds so that the slope of the bedding varies from place to place. Folds, which are these crumples of the crust's layering, together with faults where the beds are broken and shifted, are examples of geological structures to be dealt with in later chapters. In this chapter we consider the structure consisting of planar beds with a uniform slope brought about by the tilting of originally horizontal sedimentary rocks.

2.2 Dip

Bedding and other geological layers and planes that are not horizontal are said to dip. Figure 2.2 shows field examples of dipping beds. The *dip* is the slope of a geological surface. There are two aspects to the dip of a plane:

(a) the *direction of dip*, which is the compass direction towards which the plane slopes; and
(b) the *angle of dip*, which is the angle that the plane makes with a horizontal plane (Fig. 2.3).

The direction of dip can be visualized as the direction in which water would flow if poured onto the plane. The angle of dip is an angle between 0° (for horizontal planes) and 90° (for vertical planes). To record the dip of a plane all that is needed are two numbers; the direction of dip followed by the angle of dip, e.g. 138/74 is a plane which dips 74° in the direction 138°N (this is a direction which is SE, 138°

Fig. 2.1A Horizontal bedding: Lower Jurassic, near Cardiff, South Wales.

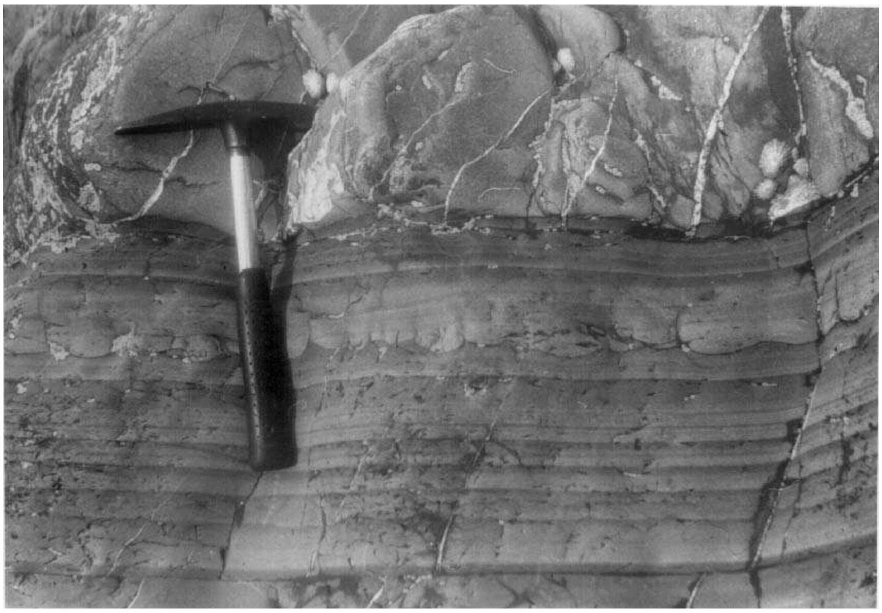
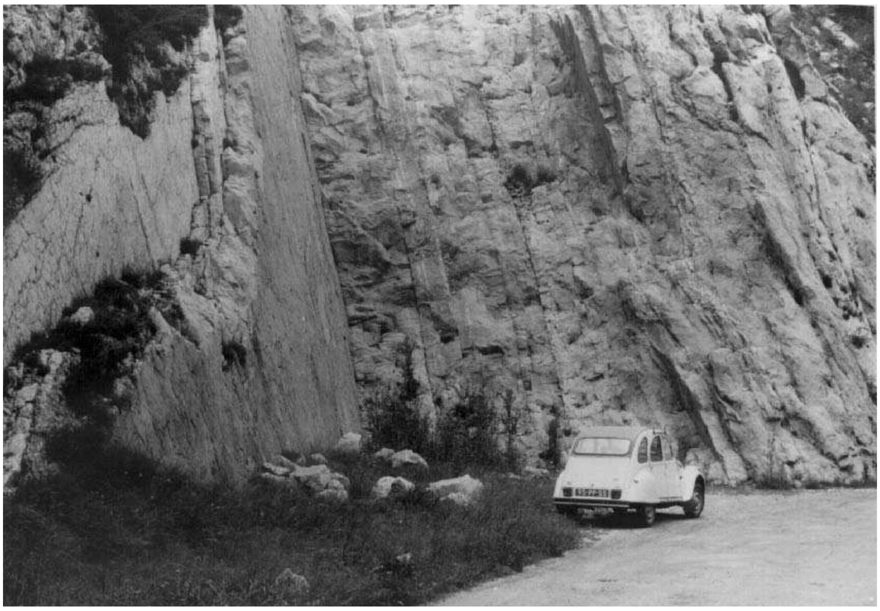
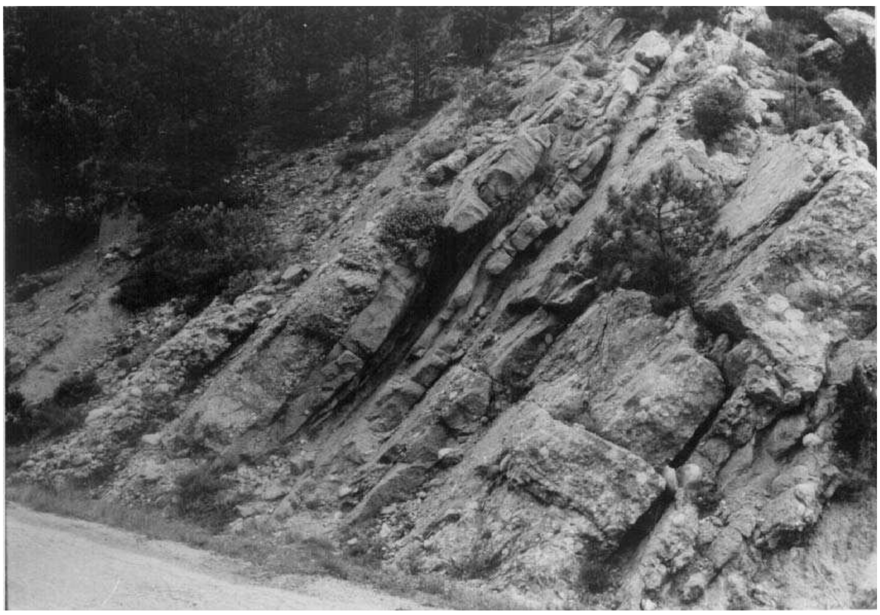


Fig. 2.1B Horizontal bedding: Upper Carboniferous, Cornwall, England



A



B

Fig. 2.2 Dipping beds in Teruel Province, Spain. **A**: Cretaceous Limestones dipping at about 80°. **B**: Tertiary conglomerates and sandstones dipping at about 50°.

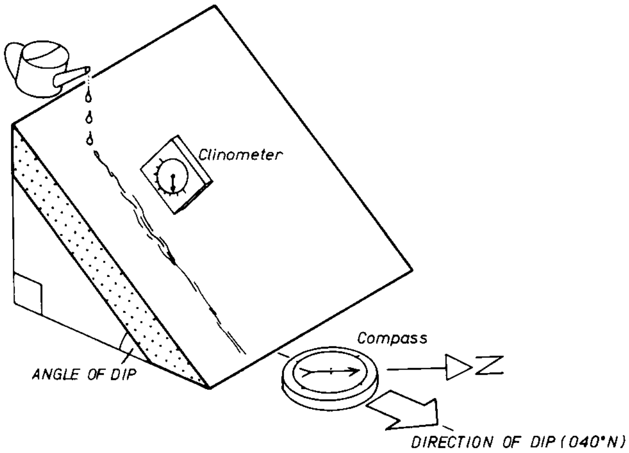


Fig. 2.3 The concepts of direction of dip and angle of dip.

clockwise from north). In the field the direction of dip is usually measured with a magnetic compass which incorporates a device called a clinometer, based on a plumbline or spirit level principle, for the measurement of dip angles.

2.3 Plunge of lines

With the help of Fig. 2.4 imagine a dipping plane with a number of straight lines drawn on it in different directions. All these lines are said to be contained within the plane and are parallel to the plane. With the exception of line 5 the lines are not horizontal; we say they are plunging lines. Line 5 is non-plunging. *Plunge* is used to describe the tilt of lines, the word dip being reserved for planes. The plunge fully expresses the three-dimensional orientation of a line and has two parts:

(a) the angle of plunge, and
(b) the plunge direction.

Consider the plunging line on the dipping plane in Fig. 2.5 and an imaginary vertical plane containing the plunging line. The *plunge direction* is the direction in which this vertical plane runs, and is the direction towards which the line is tilted. The *angle of plunge* is the amount of tilt; it is the angle, measured in the vertical plane, that the plunging line makes with the horizontal. The angle of plunge of a horizontal line is 0° and the angle of plunge of a vertical line is 90°. The plunge of a line can be written as a single expression, e.g. 23–220 describes a line that plunges 23° towards the direction 220°N. So far we have illustrated the concept of plunge using lines drawn on a dipping plane but, as we shall see later, there are a variety of linear structures in rocks to which the concept of plunge can be applied.

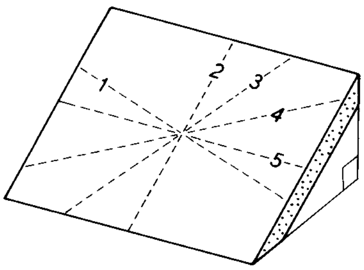


Fig. 2.4 Lines geometrically contained within a dipping plane.

2.4 Strike lines

Any dipping plane can be thought of as containing a large number of lines of varying plunge (Fig. 2.4). The *strike line* is a non-plunging or horizontal line within a dipping plane. The line numbered 5 in Fig. 2.4 is an example of a strike line; it is not the only one but the other strike lines are all parallel to it. If we think of the sloping roof of a house as a dipping plane, the lines of the ridge and the eaves are equivalent to strike lines.

Within a dipping plane the line at right angles to the strike line is the line with the steepest plunge. Verify this for yourself by tilting a book on a flat tabletop as shown in Fig. 2.6. Place a pencil on the book in various orientations. The plunge of the pencil will be steepest when it is at right angles to the spine of the book (a strike line). The angle of plunge of the steepest plunging line in a plane is equal to the angle of dip of that plane.

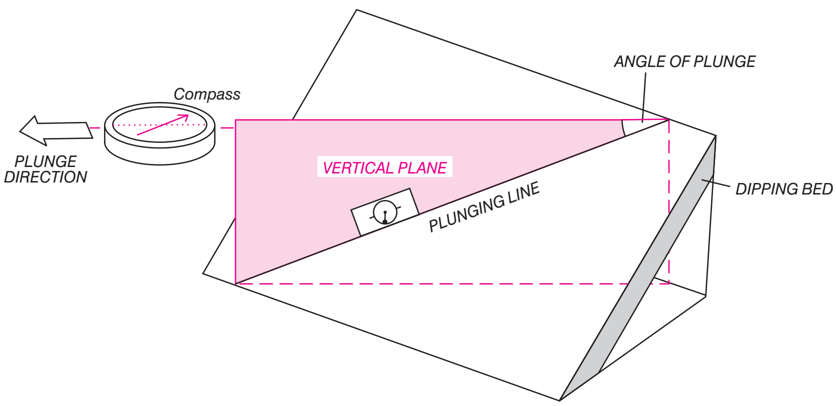


Fig. 2.5 The concepts of direction of plunge and angle of plunge.

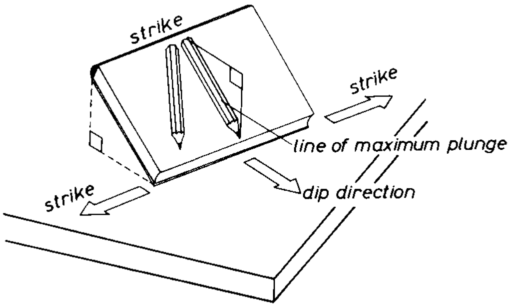


Fig. 2.6 A classroom demonstration of a dipping plane.

When specifying the direction of a strike line we can quote either of two directions which are 180° different (Fig. 2.6). For example, a strike direction of 060° is the same as a strike direction of 240°. The direction of dip is always at right angles to the strike and can therefore be obtained by either adding or subtracting 90° from the strike whichever gives the down-dip direction.

The map symbol used to represent the dip of bedding usually consists of a stripe in the direction of the strike with a short dash on the side towards the dip direction (see list of symbols at the beginning of the book). Some older maps display dip with an arrow that points in the dip direction.

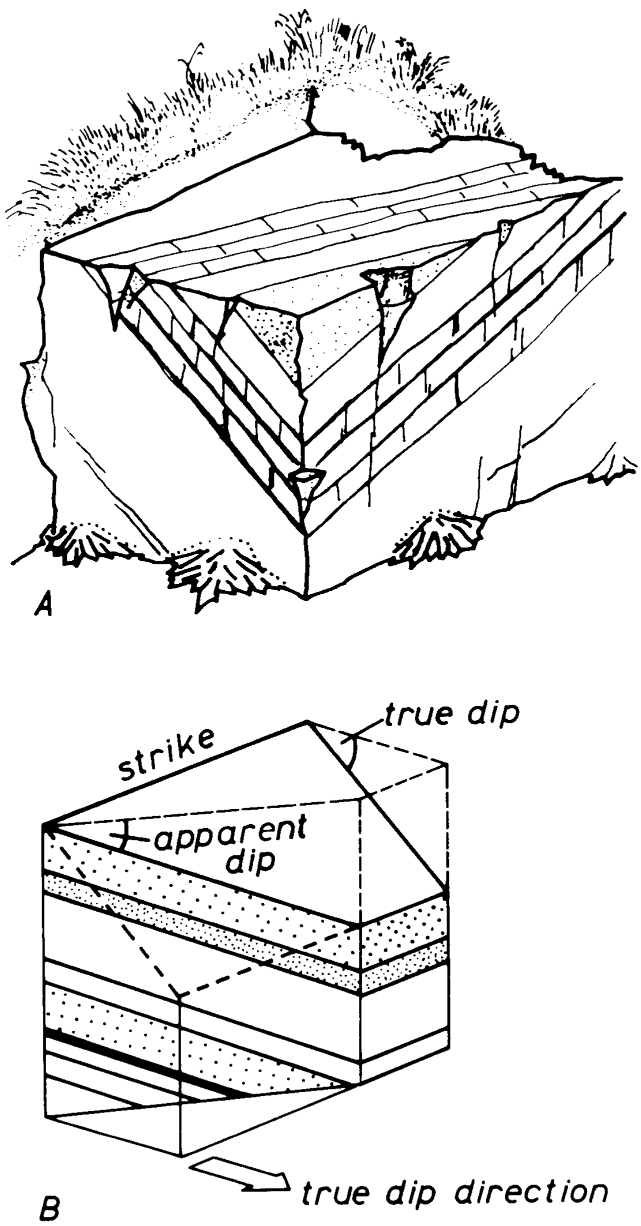


Fig. 2.7 Relationship between apparent dip and true dip.

2.5 Apparent dip

At many outcrops where dipping beds are exposed the bedding planes themselves are not visible as surfaces. Cliffs, quarries and cuttings may provide more or less vertical outcrop surfaces which make an arbitrary angle with the strike of the beds (Fig. 2.7A). When such vertical sections are not perpendicular to the strike (Fig. 2.7B), the beds will appear to dip at a gentler angle than the true dip. This is an *apparent dip*.

It is a simple matter to derive an equation which expresses how the size of the angle of apparent dip depends on the true dip and the direction of the vertical plane on which the apparent dip is observed (the section plane). In Fig. 2.8 the obliquity angle is the angle between the trend of the vertical section plane and the dip direction of the beds.

From Fig. 2.8 we see that:

the tangent of the angle of apparent dip = p/q,
the tangent of the angle of true dip = p/r
and the cosine of the obliquity angle = r/q.

Since it is true that:

$$p/r \times r/q = p/q$$

it follows that:

$$\tan\,(\text{apparent dip}) = \tan\,(\text{true dip}) \times \cos\,(\text{obliquity angle})$$

It is sometimes necessary to calculate the angle of apparent dip, for instance when we want to draw a cross-section through beds whose dip direction is not parallel to the section line.

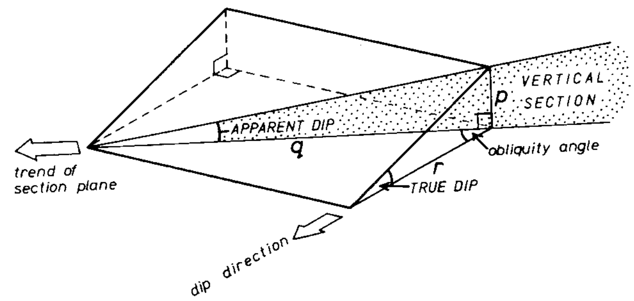


Fig. 2.8 Relation of apparent dip to true dip.

2.6 Outcrop patterns of uniformly dipping beds

The geological map in Fig. 2.9A shows the areal distribution of two rock formations. The line on the map separating the formations has an irregular shape even though the contact between the formations is a planar surface (Fig. 2.9B).

To understand the shapes described by the boundaries of formations on geological maps it is important to realize that they represent a line (horizontal, plunging or curved) produced by the intersection in three dimensions of two surfaces (Fig. 2.9B, D). One of these surfaces is the 'geological surface' – in this example the surface of contact between the two formations. The other is the 'topographic surface' – the surface of the ground. The topographic surface is not planar but has features such as hills, valleys and ridges. As the block diagram in Fig. 2.9B shows, it is these irregularities or topographic features which produce the sinuous trace of geological contacts we observe on maps. If, for example, the ground surface were planar (Fig. 2.9D), the contacts would run as straight lines on the map (Fig. 2.9C).

The extent to which topography influences the form of contacts depends also on the angle of dip of the beds. Where beds dip at a gentle angle, valleys and ridges produce pronounced 'meanders' (Fig. 2.10A, B). Where beds dip steeply the course of the contact is straighter on the map (Fig. 2.10C, D, E, F). When contacts are vertical their course on the map will be a straight line following the direction of the strike of the contact.

2.7 Representing surfaces on maps

In the previous section two types of surface were mentioned: the geological (or structural) surface and the ground (topographic) surface. It is possible to describe the form of either type on a map. The surface shown in Fig. 2.11B can be represented on a map if the heights of all points on the surface are specified on the map. This is usually done by stating, with a number, the elevation of individual points such as that of point X (a spot height) and by means of lines drawn on the map which join all points which share the same height (Fig. 2.11A). The latter are *contour lines* and

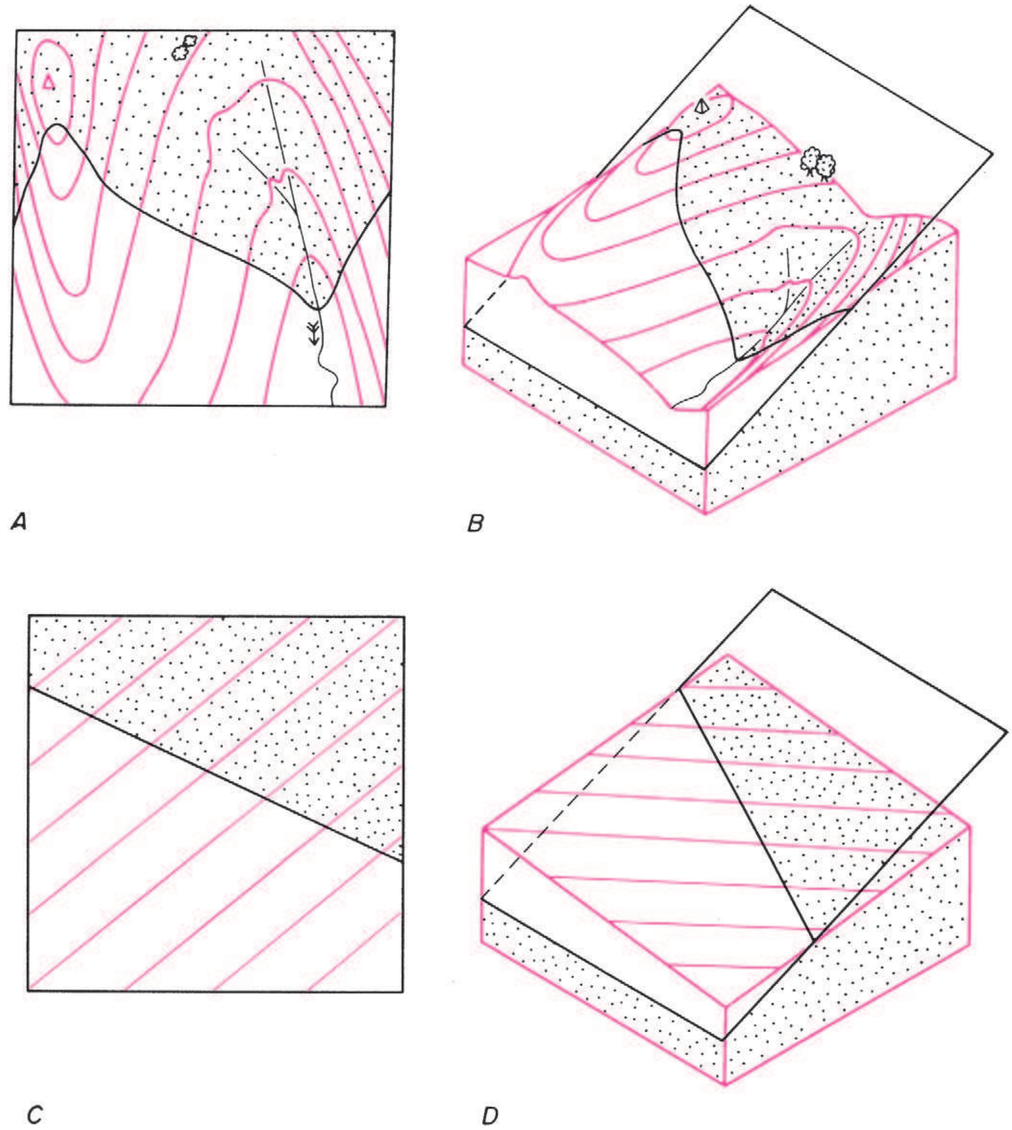


Fig. 2.9 The concept of outcrop of a geological contact.

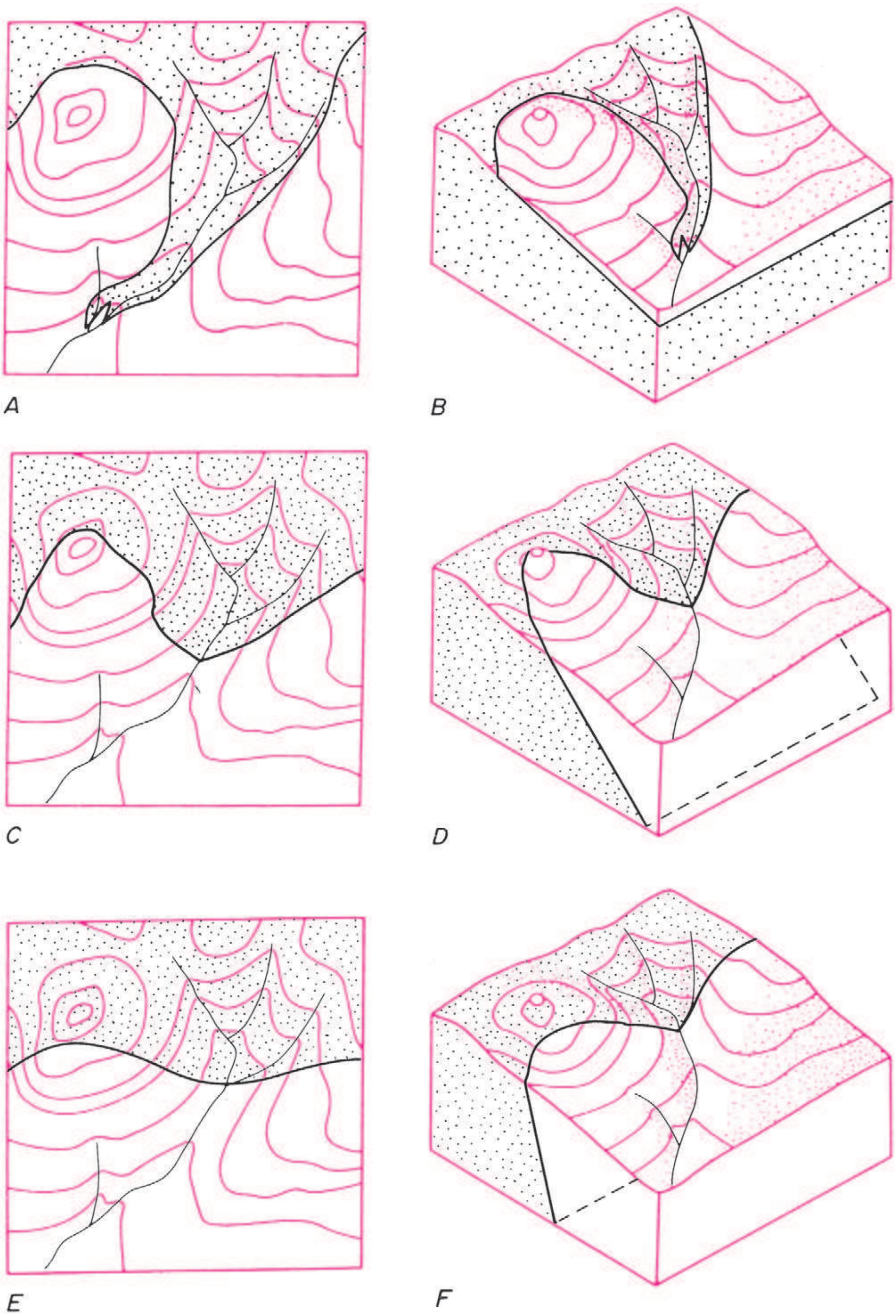


Fig. 2.10 The effect of the angle of dip on the sinuosity of a contact's outcrop.

are drawn usually for a fixed interval of height. Topographic maps depict the shape of the ground usually by means of *topographic contours*. *Structure contours* record the height of geological surfaces.

2.8 Properties of contour maps

Topographic contour patterns and structure contour patterns are interpreted in similar ways and can be discussed together. Contour patterns are readily understood if we consider the changing position of the coastline, if sea level were to rise in, say, 10-metre stages. The contour lines are analogous to the shoreline which after the first stage of inundation would link all points on the ground which are 10 metres above present sea level and so on. For a geological surface the structure contours are lines which are everywhere parallel to the local strike of the dipping surface. The local direction of slope (dip) at any point is at right angles to the trend of the contours. Contour lines will be closer together when the slope (dip) is steep. A uniformly sloping (dipping) surface is represented by parallel, equally spaced contours. Isolated hills (dome-shaped structures) will yield closed concentric arrangements of contours and valleys and ridges give V-shaped contour patterns (compare Figs 2.12A and B).

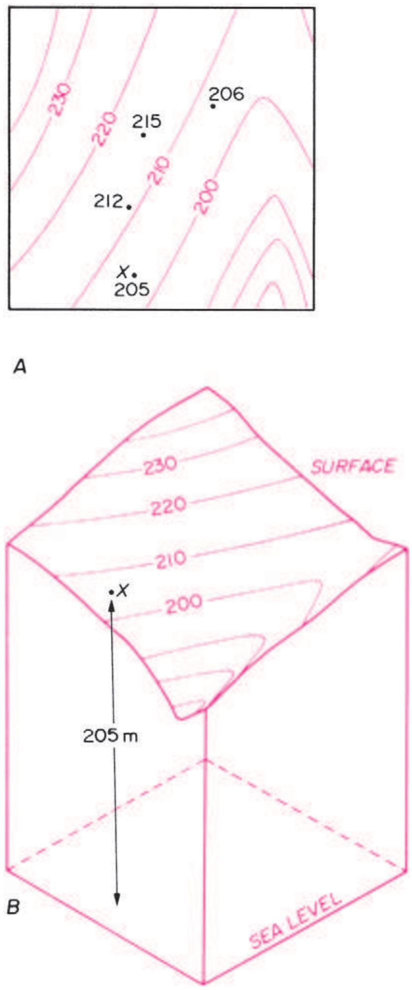


Fig. 2.11 A surface and its representation by means of contours.

2.9 Drawing vertical cross-sections through topographical and geological surfaces

Vertical *cross-sections* represent the form of the topography and geological structure as seen on a 'cut' through the earth. This vertical cut is imaginary rather than real, so the construction of such a cross-section usually involves a certain amount of interpretation.

The features displayed in the cross-section are the lines of intersection of the section plane with topographical and geological surfaces. Where contour patterns are given for these surfaces the drawing of a cross-section is straightforward. If a vertical section is to be constructed between the points X and Y on Fig. 2.13, a base line of length XY is set out. Perpendiculars to the base line at X and Y are then drawn which are graduated in terms of height (Fig. 2.13B). Points on the map where the contour lines for the surface intersect the line of section (line XY) are easily transferred to the section, as shown in Fig. 2.13B.

Provided the vertical scale used is the same as the horizontal scale, the angle of slope will be the correct slope corresponding to the chosen line of section. For example, if the surface being drawn is a geological one, the slope in the section will equal the apparent dip appropriate for the line of section. If an exaggerated vertical scale is used, the gradients of lines will be steepened and the structures will also appear distorted in other respects (see Chapter 3 on Folds). The use of exaggerated vertical scales on cross-sections should be avoided.

Worked example

Vertical sections. *Figure 2.14A shows a set of structure contours for the surface defined by the base of a sandstone bed. Find the direction of strike, the direction of dip and the angle of dip of the base of the sandstone bed. What is the apparent dip in the direction XZ (Fig. 2.14B)?*

The *strike* of the surface at any point is given by the trend of the contours for that surface. On Fig. 2.14A the trend of the contours (measured with a protractor) is 120°N.

The *dip direction* is 90° different from the strike direction; giving 030° and 210° as the two possible directions of dip. The heights of the structure contours decrease towards the southwest, which tells us that the surface slopes down in that direction. The direction 210° rather than 030° must therefore be the correct dip direction.

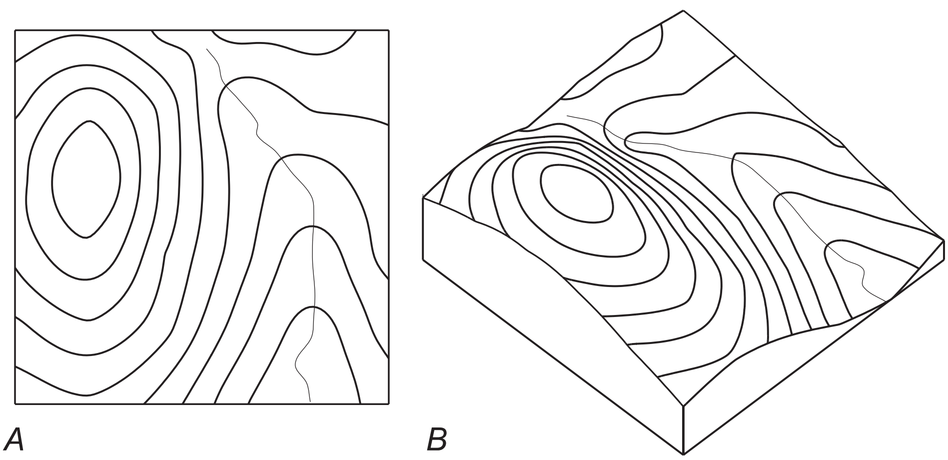


Fig. 2.12 Contour patterns and the form of a surface.

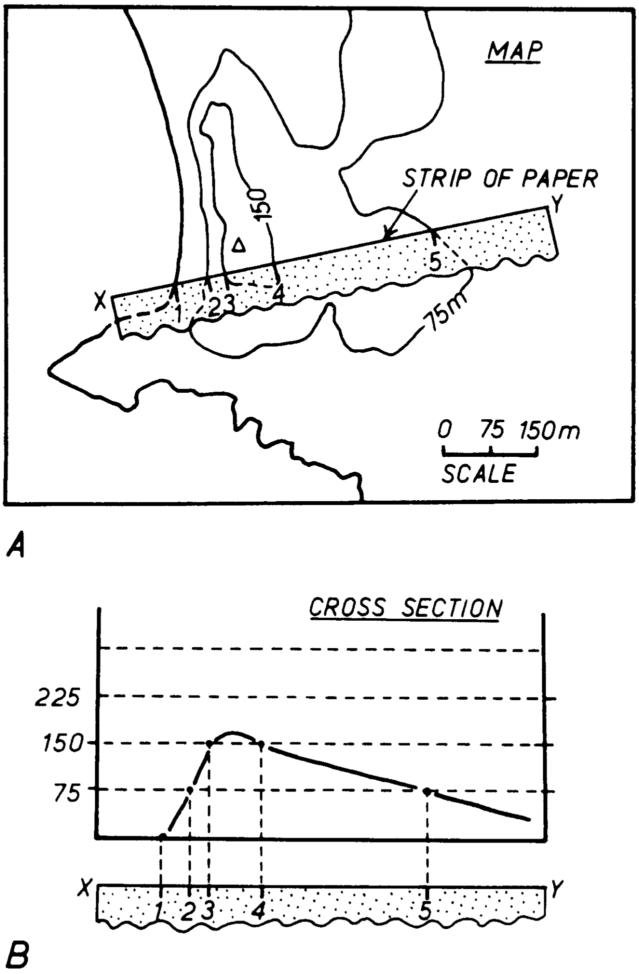


Fig. 2.13 Construction of a cross-section showing surface topography.

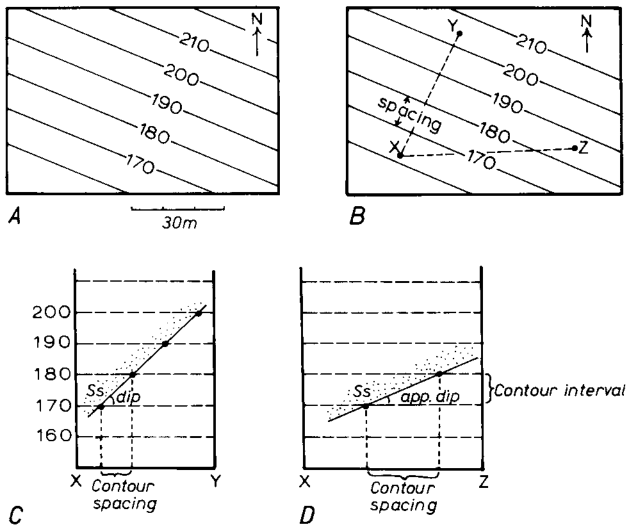


Fig. 2.14 Drawing sections.

To find the *angle of dip* we must calculate the inclination of a line on the surface at right angles to the strike. A constructed vertical cross-section along a line XY on Fig. 2.14B (or any section line parallel to XY) will tell us the true dip of the base of the sandstone. This cross-section (Fig. 2.14C) reveals that the angle of dip is related to the spacing of the contours: i.e.

$$\text{Tangent (angle of dip)} = \frac{\text{contour interval}}{\text{spacing on map between contours}} = \frac{10\,\text{m}}{10\,\text{m}} = 1$$

In the present example (Fig. 2.14C) the contour interval is 10 m and the contour spacing is 10 m.

$$\text{Tan (angle of dip)} = \frac{10\,\text{m}}{10\,\text{m}} = 1$$

Therefore the angle of dip = Inverse Tan (1) = 45°.

The *apparent dip* in direction XZ is the observed inclination of the sandstone bed in true scale (vertical scale = horizontal scale) vertical section along the line XZ. The same formula can be used as for the angle of dip above except 'spacing between contours' is now the apparent spacing observed along the line XZ.

2.10 Three-point problems

Above we have considered a surface described by contours. If, instead of contours, a number of spot heights are given for a surface, then it is possible to infer the form of the contours. This is desirable since surfaces represented by contours are easier to visualize. The number of spot heights required to make a sensible estimate of the form of the contour lines depends on the complexity of the surface. For a surface which is planar, a minimum of three spot heights are required.

Worked example

A sandstone-shale contact encountered at three localities A, B *and* C *on Fig. 2.15A has heights of 150, 100 and 175 metres respectively. Assuming that the contact is planar, draw structure contours for the sandstone-shale contact.*

Consider an imaginary vertical section along line *AB* on the map. In that section the contact will appear as a straight line since it is the line of intersection of two planes: the planar geological contact and the section plane. Furthermore, in that vertical section the line representing the contact will pass through the points *A* and *B* at their respective heights (Fig. 2.15C). The height of the contact decreases at a constant rate as we move from *A* to *B*. This allows us to predict the place along line AB where the surface will have a specified height (Fig. 2.15B). For instance, the contact will have a height of 125 metres at the mid-point between *A* (height equals 150 metres) and *B* (height equals 100 metres). In this way we also locate the point *D* along *AB* which has the same height as the third point *C* (175 metres). In a section along the line

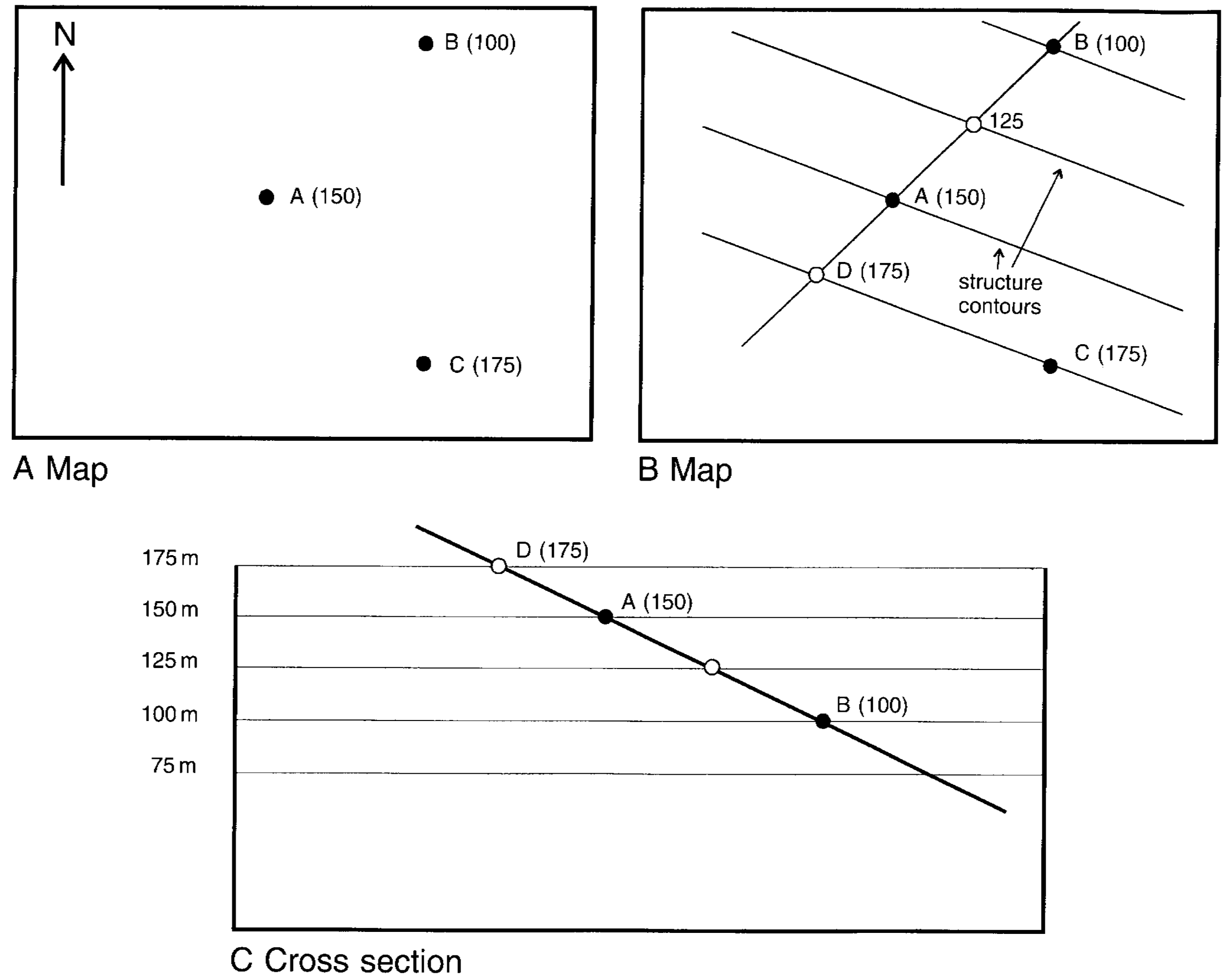


Fig. 2.15 Solution of a three-point problem

CD the contact will appear horizontal. Line *CD* is therefore parallel to the horizontal or strike line in the surface. We call *CD* the 175 metre structure contour for the surface. Other structure contours for other heights will be parallel to this, and will be equally spaced on the map. The 100 metre contour must pass through *B*. If it is required to find the dip of the contact the method of the previous worked example can be used.

2.11 Outcrop patterns of geological surfaces exposed on the ground

We have seen how both the land surface and a geological surface (such as a junction between two formations) can be represented by contour maps. The line on a geological map representing the contact of two formations marks the intersection of these two surfaces. The form of this line on the map can be predicted if the contour patterns defining the topography and the geological surface are known, since along the line of intersection both surfaces will have equal height.

A rule to remember:

A geological surface crops out at points where it has the same height as the ground surface.

Worked example

Given topographic contours and structure contours for a planar coal seam (Fig. 2.16A) predict the map outcrop pattern of the coal seam.

Points are sought on the map where structure contours intersect a topographic contour of the same elevation. A series of points is obtained in this way through which the line of outcrop of the coal seam must pass (Fig. 2.16B). This final stage of joining the points to form a surface outcrop would seem in places to be somewhat arbitrary with the lines labelled *p* and *q* in Fig. 2.16B appearing equally possible. However *p* is incorrect, since the line of outcrop cannot cross the 150 metre structure contour unless there is a point along it at which the ground surface has a height of 150 metres.

Another rule to remember:

The line of outcrop of a geological surface crosses a structure contour for the surface only at points where the ground height matches that of the structure contour.

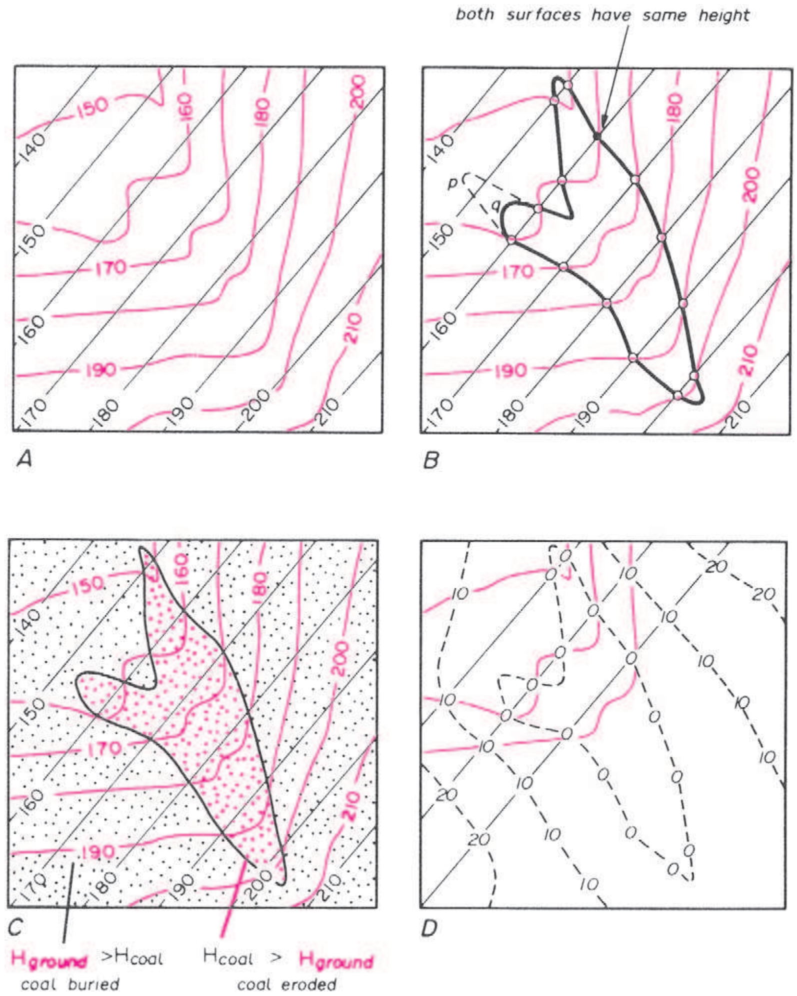


Fig. 2.16 Predicting outcrop and isobaths from structure contour information. Topographic contours are shown in red; structure contours for the coal seam are black.

2.12 Buried and eroded parts of a geological surface

The thin coal seam in the previous example only occurs at the ground surface along a single line. The surface at other points on the map (a point not on the line of outcrop) is either buried (beneath ground level) or eroded (above ground level). The line of outcrop in Fig. 2.16B divides the map into two kinds of areas:

(a) areas where height (coal) > height (topography), so that the surface can be thought to have existed above the present topography but has since been eroded away, and
(b) areas where height (coal) < height (topography) so that the coal must exist below the topography, i.e. it is buried.

The boundary line between these two types of areas is given by the line of outcrop, i.e. where height (coal) = height (topography).

Worked example

Using the data on Fig. 2.16A shade the part of the area underlain by coal.

The answer to this is red shaded area in Fig. 2.16C. The outcrop line of the coal forms the boundary of the area underlain by coal. The sought area is where the contours for the topography show higher values than the contours of the coal.

2.13 Contours of burial depth (isobaths)

A geological surface is buried below the topographic surface when height (topography) > height (geological surface). The difference (height of topography minus height of geological surface) equals the depth of burial at any point on the map. Depths of burial determined at a number of points on a map provide data that can be contoured to yield lines of equal depth of burial called *isobaths*.

Worked example

Using again the data from Fig. 2.16A construct isobaths for the coal seam.

In the area of buried coal, determine spot depths of coal by subtracting the height of the coal seam from the height of the topography at a number of points.

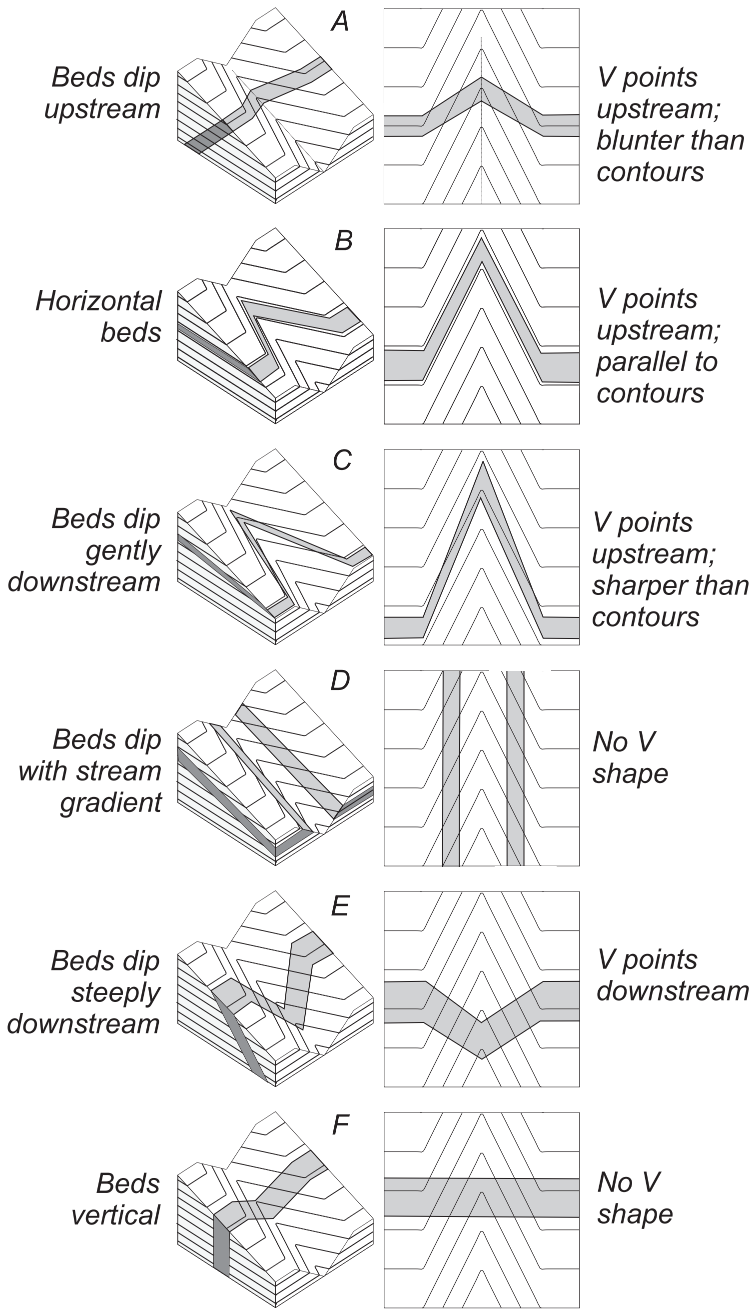


Fig. 2.17 To illustrate the V-rule.

Isobaths, lines linking all points of equal depth of burial, can then be drawn (dashed lines in Fig. 2.16D).

Devise an alternative way to draw isobaths, noting that a 100 metre isobath for a given geological surface is the line of outcrop on an imaginary surface which is everywhere 100 metres lower than the ground surface.

2.14 V-shaped outcrop patterns

A dipping surface that crops out in a valley or on a ridge will give rise to a V-shaped outcrop (Fig. 2.17). The way the outcrop patterns vee depends on the dip of the geological surface relative to the topography. In the case of valleys, patterns vee upstream or downstream (Fig. 2.17). The rule for determining the dip from the type of vee (the 'V rule') is easily remembered if one considers the intermediate case (Fig. 2.17D) where the outcrop vees in neither direction. This is the situation where the dip is equal to the gradient of the valley bottom. As soon as we tilt the beds away from this critical position they will start to exhibit a V-shape. If we visualize the bed to be rotated slightly upstream it will start to vee upstream, at first veeing more sharply than the topographic contours defining the valley (Fig. 2.17C). The bed can be tilted still further upstream until it becomes horizontal. Horizontal beds always yield outcrop patterns which parallel the topographic contours and hence, the beds still vee upstream (Fig. 2.17B). If the bed is tilted further again upstream, the beds start to dip upstream and we retain a V-shaped outcrop but now the vee is more 'blunt' than the vee exhibited by the topographic contours (Fig. 2.17A).

Downstream-pointing vees are produced when the beds dip downstream more steeply than the valley gradient (Fig. 2.17E). Finally, vertical beds have straight outcrop courses and do not vee (Fig. 2.17F).

Worked example

Complete the outcrop of the thin limestone bed exposed in the northwest part of the area (Fig. 2.18A). The dip of the bed is 10° towards 220° (220/10).

This type of problem is frequently encountered by geological mappers. On published geological maps all contacts are shown. However, rocks are not everywhere exposed. Whilst mapping, a few outcrops are found at which contacts are visible and where dips can be measured, but the rest of the map is based on interpretation. The following technique can be used to interpret the map. Using the known dip, construct structure contours for the thin bed. These will run parallel to the measured strike and, for a contour interval of 10 metres, will have a spacing given by this equation (see Section 2.9).

$$\text{Spacing between contours} = \frac{\text{contour interval}}{\text{Tangent (angle of dip)}}$$

Since the outcrop of the bed in the northwest part of the map is at a height of 350 metres, the 350 metre structure contour must pass through this point. Others are drawn parallel at the calculated spacing. The crossing points of the topographic contours with the structure contours of the same height, yield points which lie on the outcrop of the thin limestone bed. The completed outcrop of the thin limestone bed is shown in Fig. 2.18B.

2.15 Structure contours from outcrop patterns

A map showing outcrops of a surface together with topographic contours can be used to construct structure contours for that surface. The underlying principles are:

(a) where a surface crops out, the height of the surface equals the height of the topography,

(b) if the height of a planar surface is known at a minimum of three places, the structure contours for that surface can be constructed (see 'Three-point problems', Section 2.10).

Worked example

Draw strike lines for the limestone bed in Fig. 2.20A. What assumptions are involved?

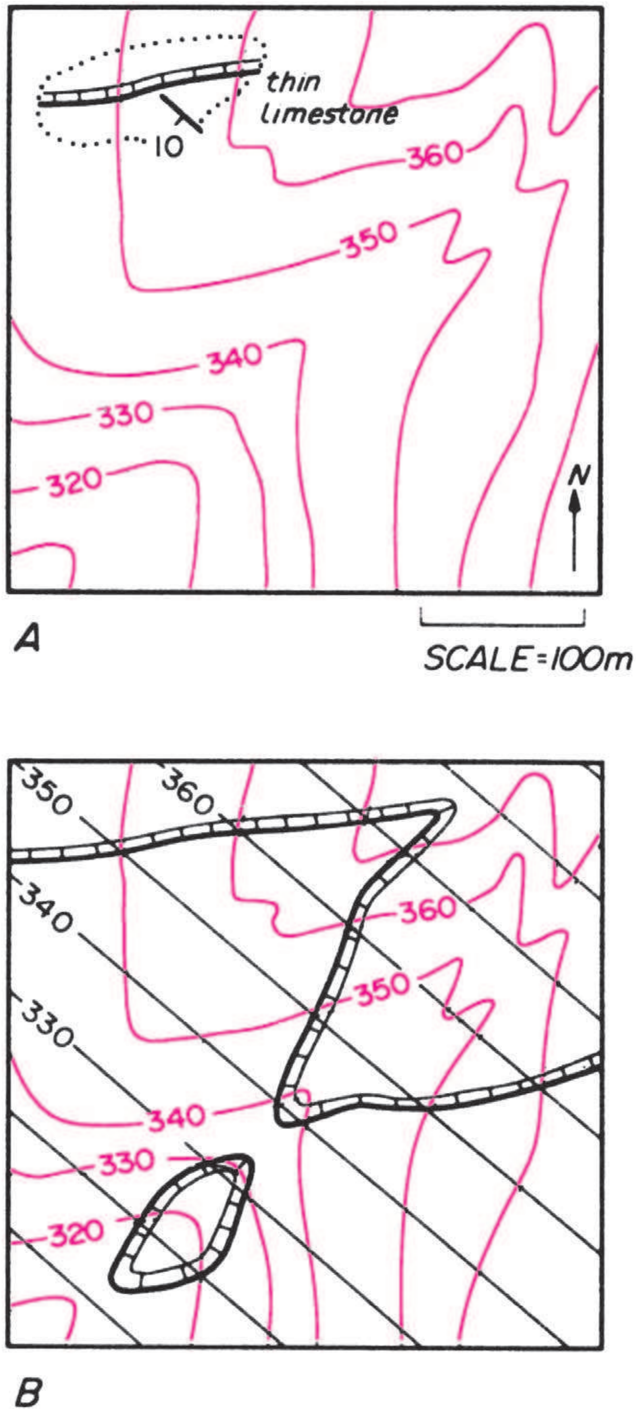


Fig. 2.18 Interpreting the shape of a geological contact in an area of limited rock exposure.

Join points on the outcrop which share the same height. These join lines are structure contours for that particular height (Fig. 2.20B).

Draw as many structure contours as possible to test the assumption of constant dip (planarity of surface). The structure contours in Fig. 2.20B are parallel and evenly spaced. This confirms that the limestone bed has a uniform dip.

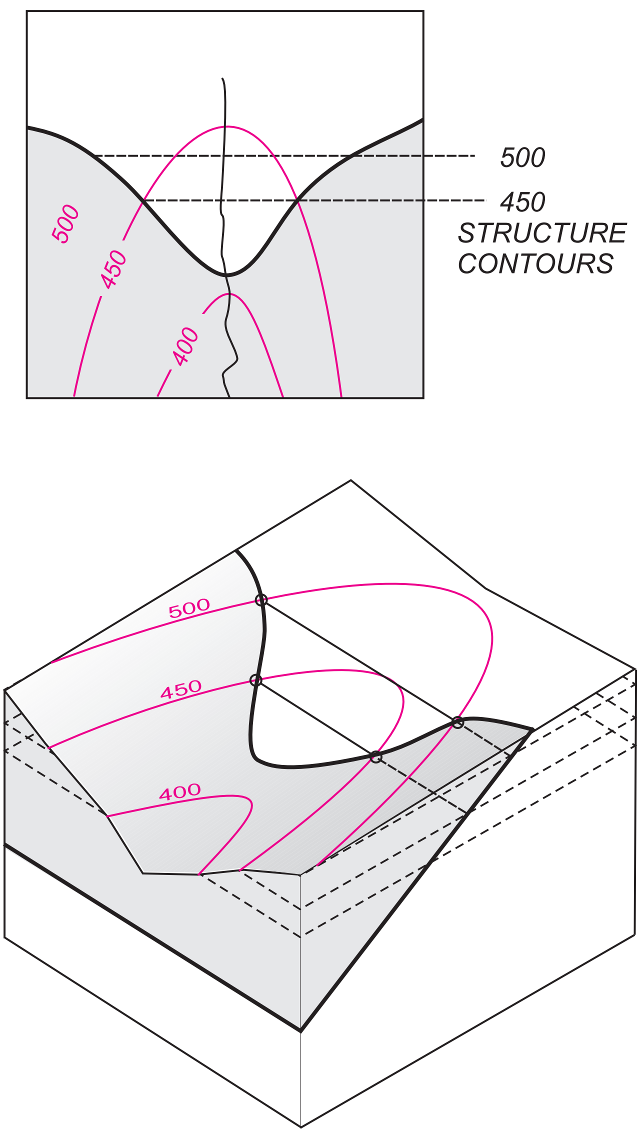


Fig. 2.19 Please supply caption.

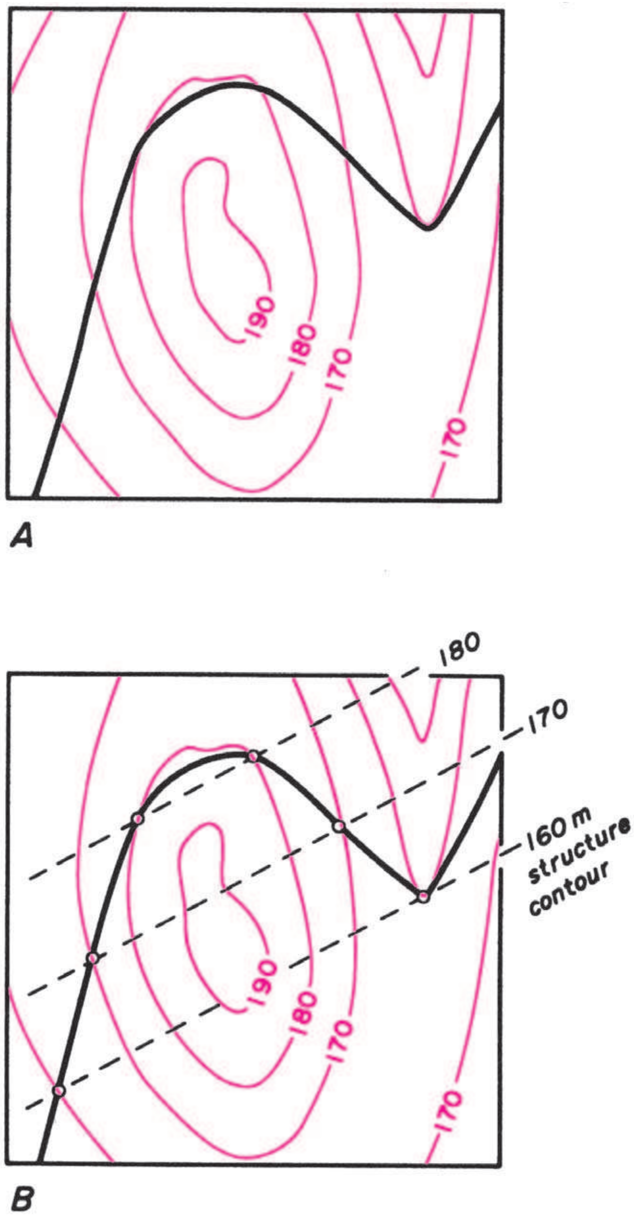


Fig. 2.20 Drawing structure contours.

2.16 Geological surfaces and layers

So far in this chapter the geological structure considered has consisted of a single surface such as the contact surface between two rock units. However formations of rock, together with the individual beds of sediments from which they are composed, are tabular in form and have a definite thickness. Such 'layers' can be dealt with by considering the two bounding surfaces which form the contacts with adjacent units.

2.17 Stratigraphic thickness

The *true* or *stratigraphic thickness* of a unit is the distance between its bounding surfaces measured in a direction perpendicular to these surfaces (TT in Fig. 2.21).

The *vertical thickness* (*VT*) is more readily calculated from structure contour maps. The vertical thickness is the height difference between the top and base of the unit at any point. It is the vertical 'drilled' thickness, and is obtained by subtracting the height of the base from the height of the top. Depending on the angle of dip, the vertical thickness (*VT*) differs from the true thickness (*TT*), because from Fig. 2.20B:

$$\cos(\text{dip}) = TT/VT$$

and

$$TT = VT \cos(\text{dip}).$$

This equation can be used to calculate the true thickness if the vertical thickness is known. The *horizontal thickness* (*HT*) is a distance measured at right angles to the strike between a point on the base of the unit and a point of the same height on the top of the unit. It can be found by taking the separation on the map between a contour line for the base of the bed and one for the top of the bed of the same altitude.

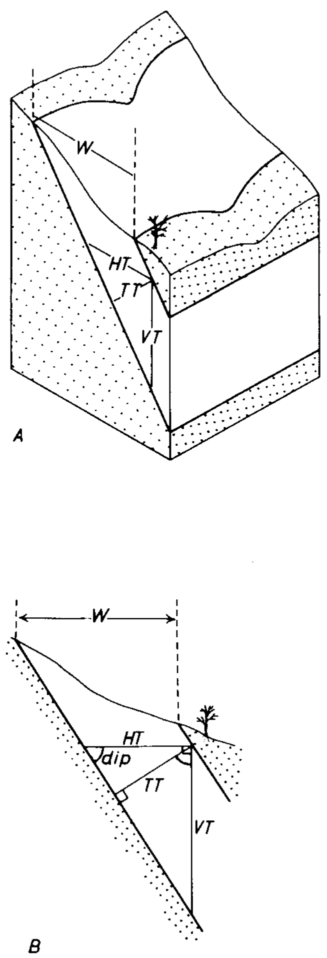


Fig. 2.21 Bed thickness and width of outcrop.

From Fig. 2.21B is can be also seen that

sin (dip) = *TT*/*HT*

therefore,

TT = sin (dip) *HT*.

If *VT* and *HT* are both known, the dip can be calculated from

$$\tan(\text{dip}) = \frac{VT}{HT.}$$

It is important to note that the *width of outcrop* of a bed on a map (*W* on Fig. 2.21) is not equal to the horizontal thickness unless the ground surface is horizontal. In cross-sections care must be taken when interpreting thicknesses. Vertical thickness will be correct in any vertical section but the true thickness will only be visible in cross-sections parallel to the dip direction of the beds.

Worked example

Find the vertical thickness, horizontal thickness, true thickness and angle of dip of the sandstone formation from the structure contours in Fig. 2.22.

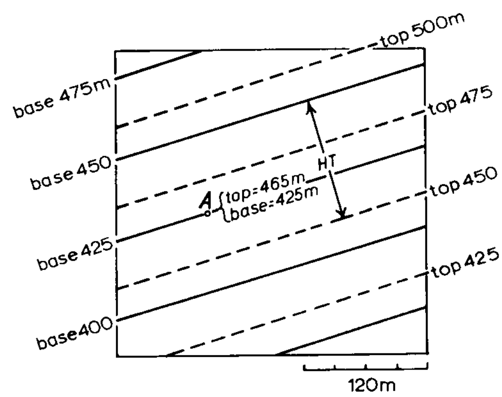


Fig. 2.22 Calculation of thickness from structure contours.

The vertical thickness is obtained by taking any point on the map, say *A*, and using the equation:

Vertical thickness = height of top – height of base
= 465 m – 425 m
= 40 m.

The horizontal thickness is given by the horizontal separation of any pair of structure contours of the same altitude (one for base, one for top). The horizontal thickness in this example is 120 m.

2.18 Isochores and isopachs

Contour lines and isobaths are examples of lines drawn on a map which join points where some physical quantity has equal value. *Isochores* are lines of equal vertical thickness and *isopachs* are lines of equal stratigraphic (true) thickness.

2.19 Topographic effects and map scale

If the surface of the earth's surface were everywhere horizontal, geological map reading would be much easier, since all contacts on the map would run parallel to their strikes. For a geological surface it is the existence of slopes in the landscape which causes the discrepancy between its course on the map and the direction of strike. This 'terrain effect' is most marked on a smaller scale because natural ground slopes are generally steeper at this scale. On 1:10,000 scale maps for instance, the presence of valleys and ridges exercises a strong influence on the shape of all but the steepest dipping surfaces. On the other hand the run of geological boundaries on, say, the 1:625,000 geological map of the United Kingdom, is a direct portrayal of the local strike of the rocks. Only where dips are gentle and relief is high (e.g. the Jurassic outcrops of the Cotswolds) does the 'terrain effect' play any significant role. The generally lower average slopes of the earth's surface at this scale makes the interpretation of the map pattern much more straightforward.

PROBLEM 2.1

The photograph shows dipping beds of Carboniferous Limestone at Brandy Cove, Gower, South Wales. The north direction is shown by an arrow in the sand.

(a) What is the approximate direction of the strike of these beds? (Give a three-figure compass direction.)
(b) What is the approximate angle of dip?
(c) Write down the attitude of the bedding as a single expression of the form: Dip direction/angle of dip.

PROBLEM 2.2

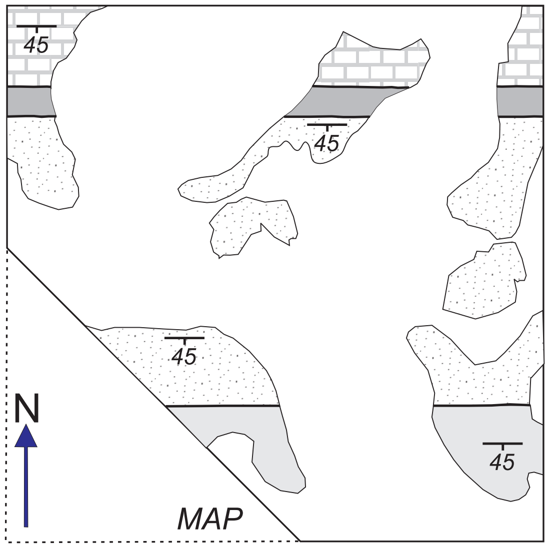
The map shows outcrops on a horizontal topographic surface.

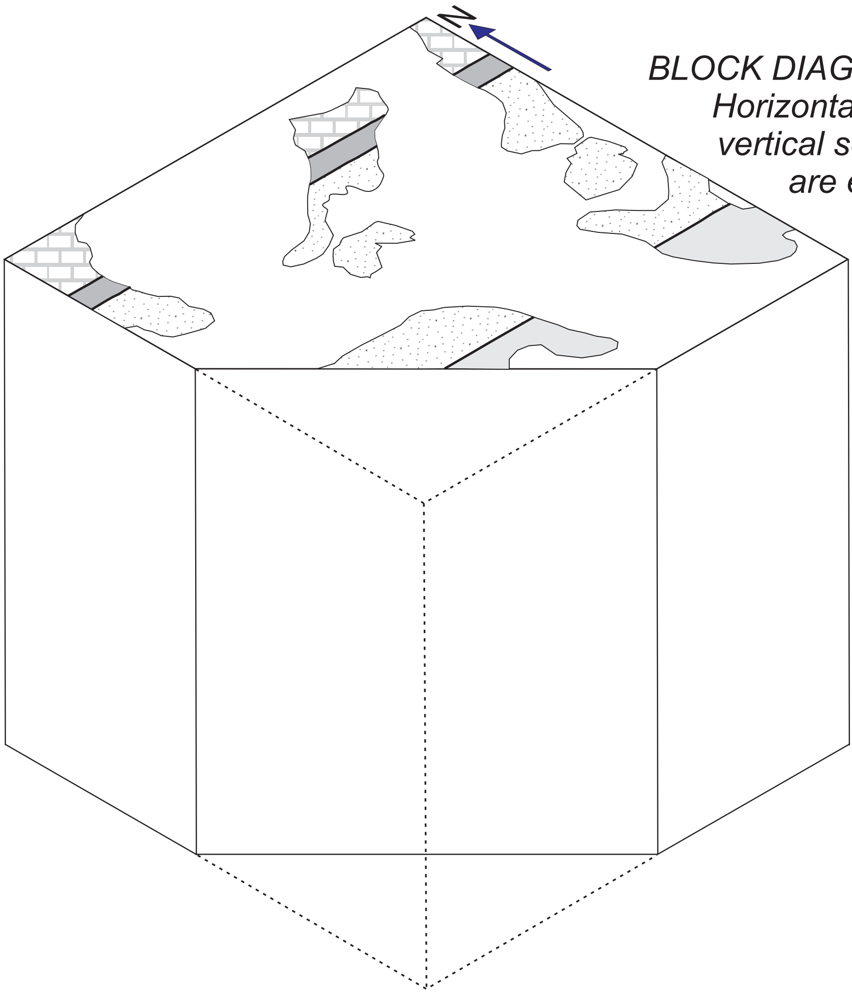
Interpret the run of the geological boundaries and complete the map.

Draw the structure on the three vertical faces of the block diagram (below).

Label the following on the completed block diagram:

(a) angle of dip
(b) angle of apparent dip
(c) the strike of the beds
(d) the direction of dip of the beds





PROBLEM 2.3

An underground passage linking two cave systems follows the line of intersection of the base of a limestone bed and a vertical rock fracture. The bedding in the limestone dips 060/60 and the strike of the fracture is 010°. What is the inclination (plunge) of the underground passage?

PROBLEM 2.4

An imaginary London to Swansea railway has a number of vertical cuttings which run in an east-west direction.

At Port Talbot, Coal Measures rock dip 010/30; near Newport, Old Red Sandstone rocks dip 315/20; and at Swindon, Upper Jurassic rocks have the dip 160/10.

At which cutting will railway passengers observe the steepest dip of strata? (NB: apparent dips are observed in the cuttings).

PROBLEM 2.5

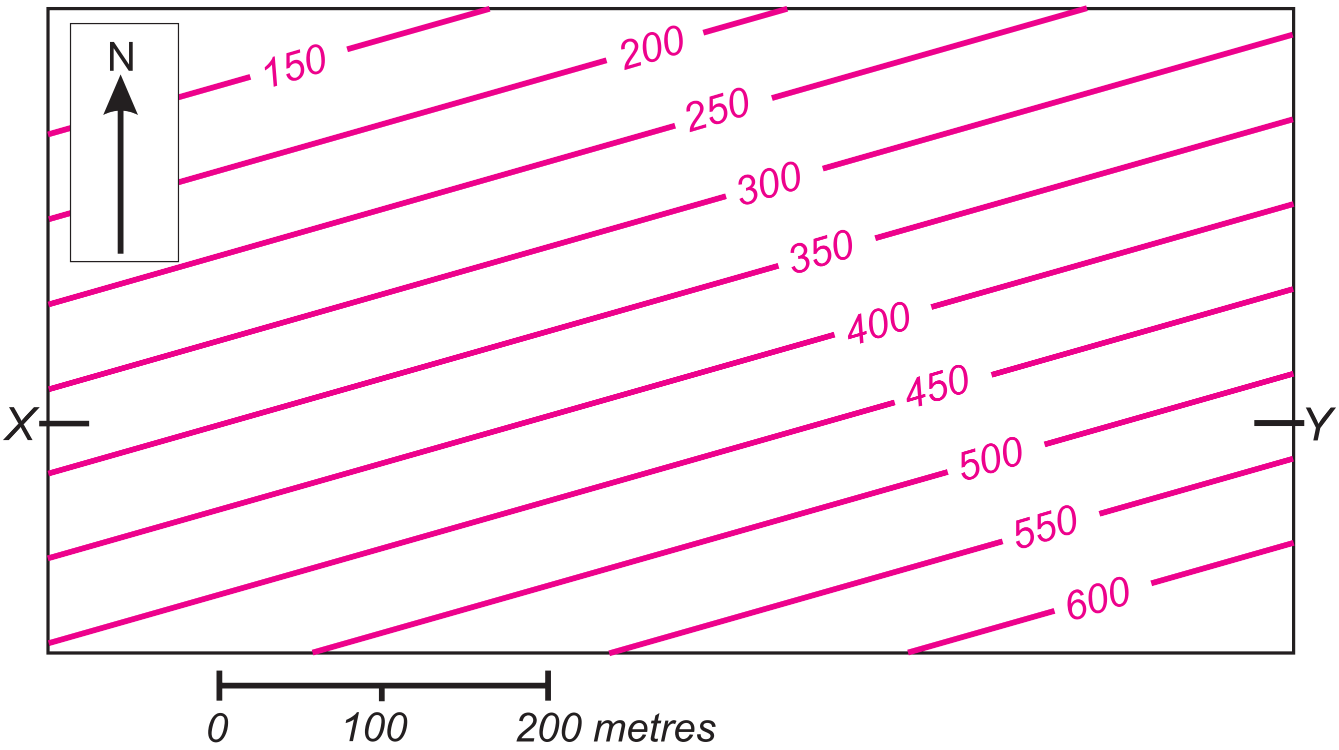
The map shows structure contours for the basal contact of a unit of mudstone.

What is the strike of the contact?
What is the dip direction of the contact?
What is the angle of dip of the contact?

Construct an east-west true scale cross-section (equal vertical and horizontal scales) along the X–Y to show the contact.

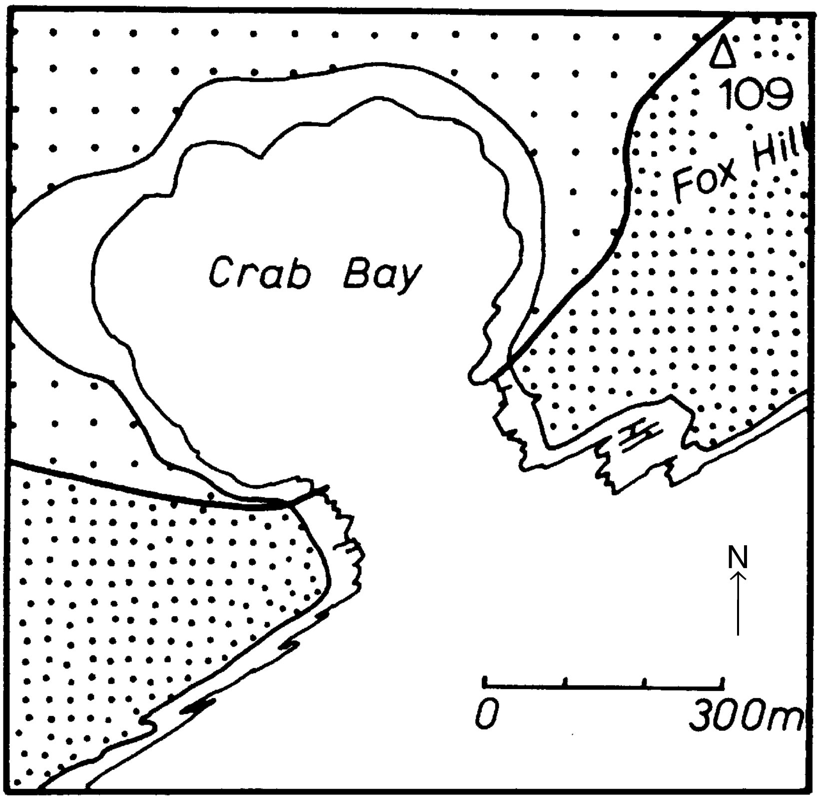
Explain why the angle of dip seen in the drawn section differs from the dip calculated above.

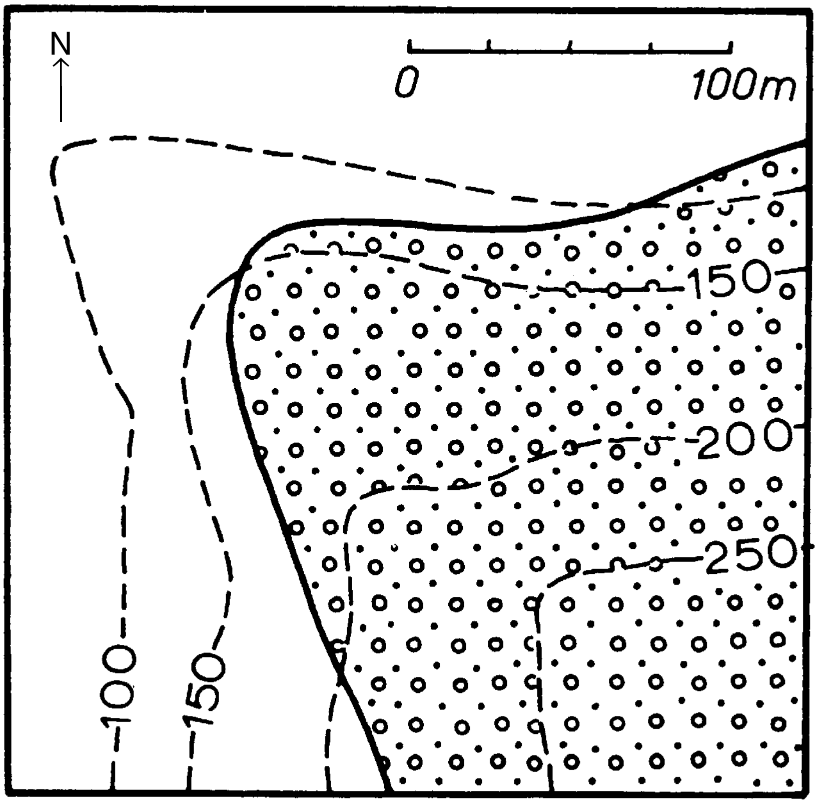
Use a formula to calculate the dip observed in the section and to check the accuracy of the cross-section.



PROBLEM 2.6

For each map, determine the direction and angle of dip of the geological contact shown.





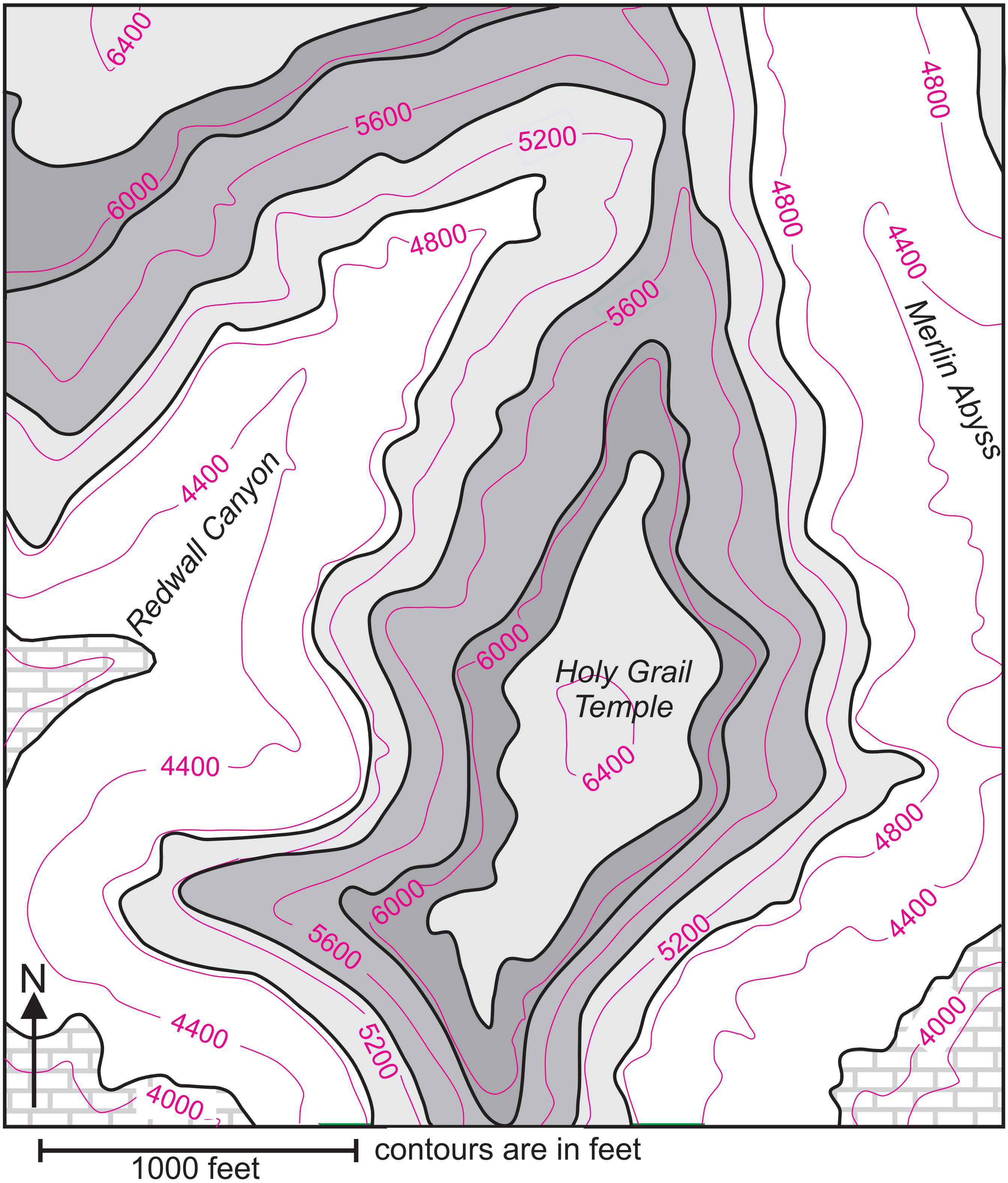
PROBLEM 2.7

This is a geological map of part of the Grand Canyon, Arizona, USA. Examine the relationship between geological boundaries and topographic contours and deduce the dip of the rocks.

Deduce as much as possible about the thicknesses of the formations exposed in this area.

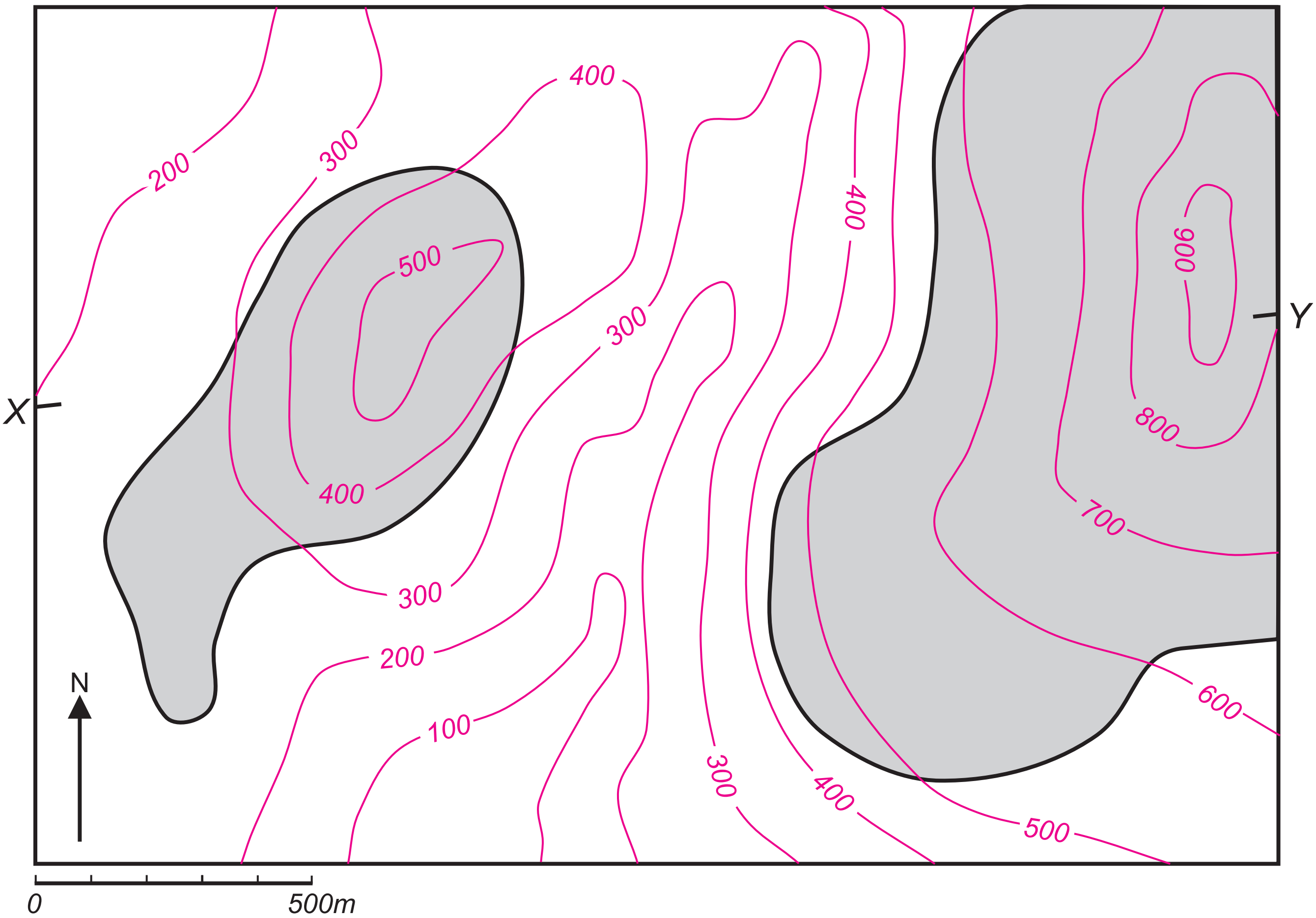
Draw a cross-section along a line between the NW and SE corners of the map.

Part of the Grand Canyon, Arizona



PROBLEM 2.8

The geological map shows the distribution of two formations and their contact. Draw structure contours for the contact and use these to construct a cross section along the line X to Y.



PROBLEM 2.9

The topographic map shows an area near Port Talbot in South Wales. In three boreholes drilled in Margam Park the 'Two-Feet-Nine' coal seam was encountered at the following elevations relative to sea level:

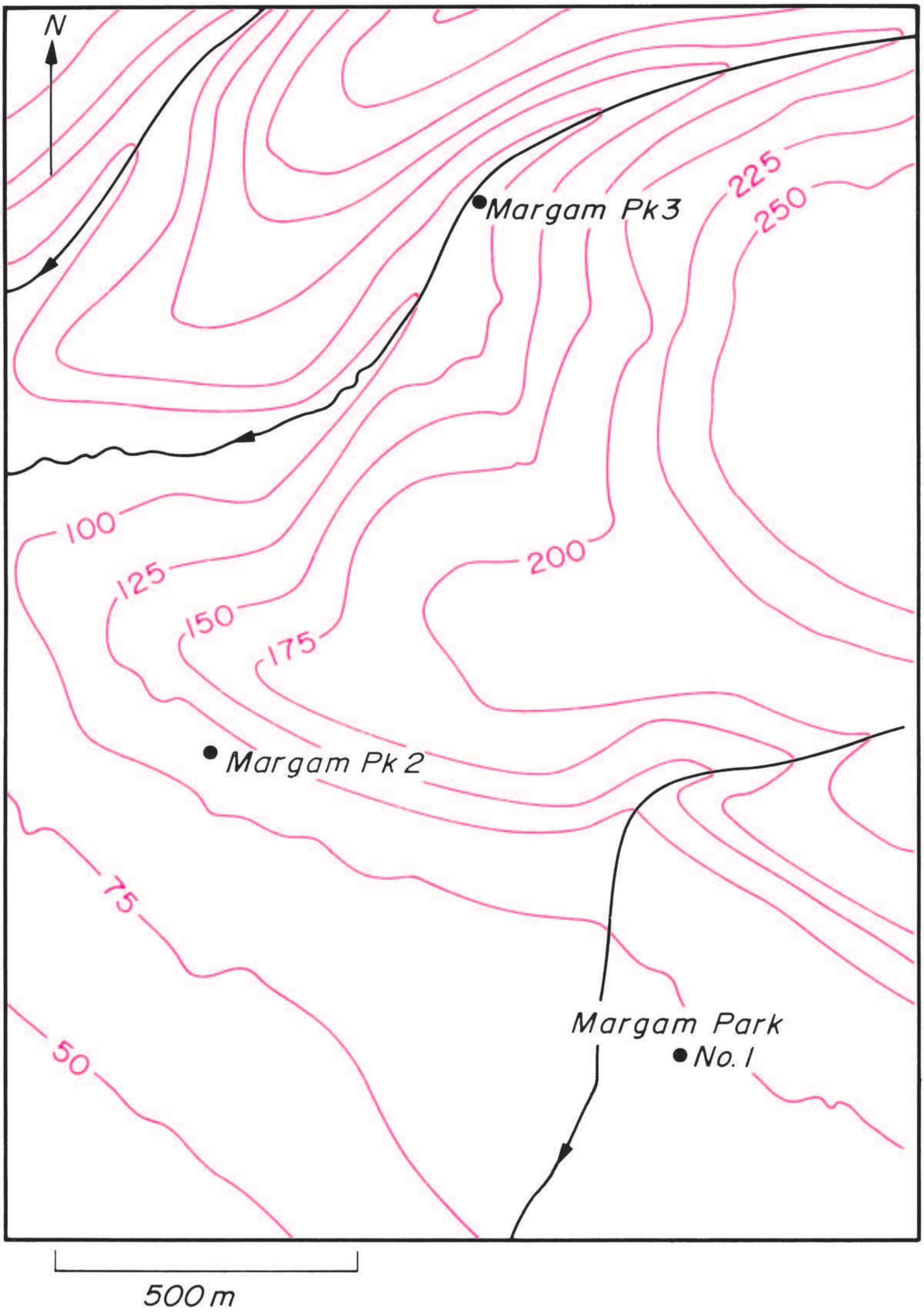
Borehole	*Elevation*
Margam Park No. 1	–110 m
Margam Park No. 2	–150 m
Margam Park No. 3	–475 m

Draw structure contours for the Two-Feet-Nine seam, assuming it maintains a constant dip within the area covered by the map.

What is the direction of dip and angle of dip of the Two-Feet-Nine seam?

Does the seam crop out within the area of the map?

A second seam (the 'Field Vein') occurs 625 m above the Two-Feet-Nine seam. Construct the line of outcrop of the Field Vein.



PROBLEM 2.10

The map shows a number of outcrops where a breccia/ mudstone contact has been encountered in the field.

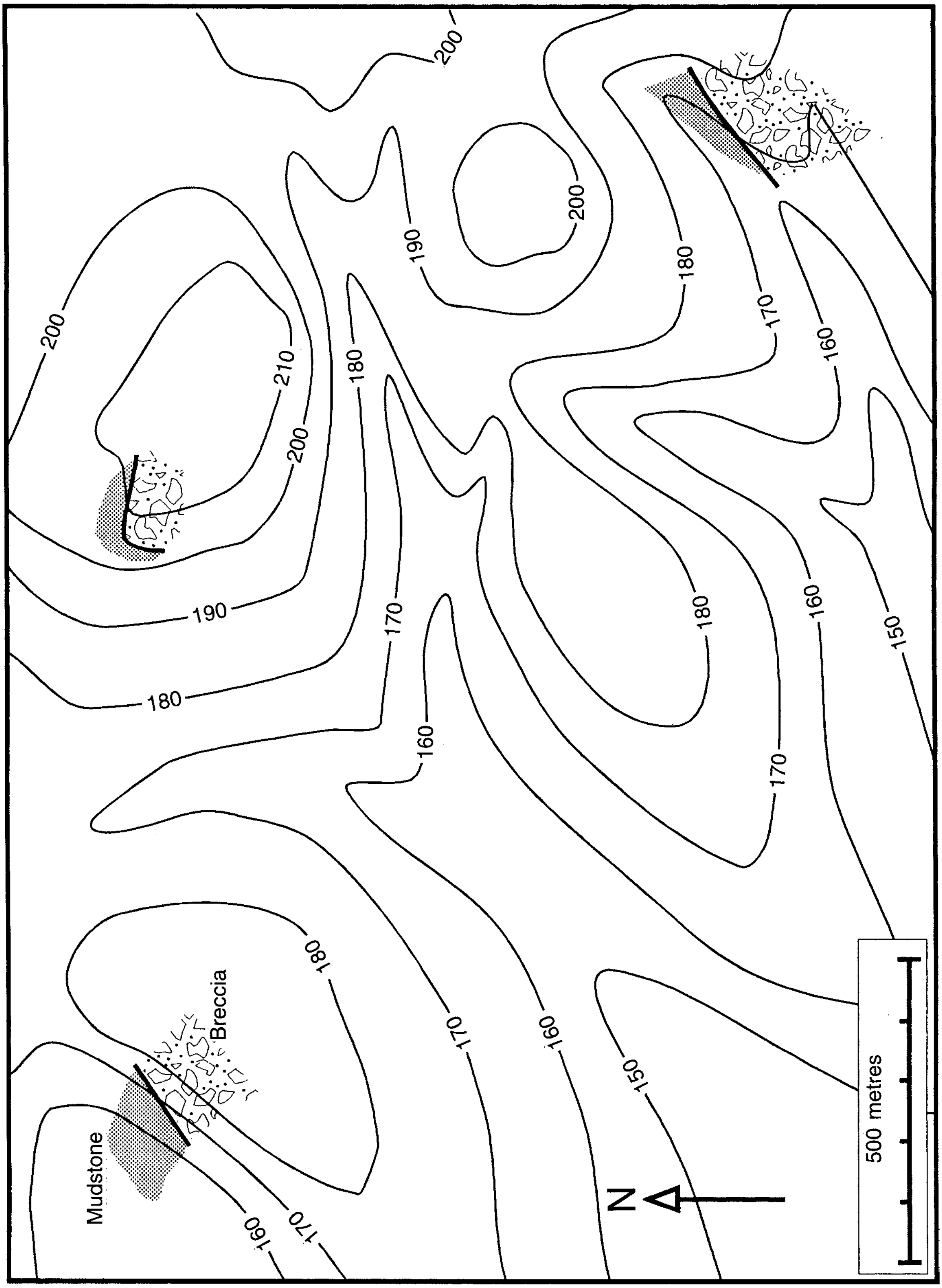
Interpret the run of the contact through the rest of the area covered by the map.

Calculate:

(a) the direction of dip expressed as a compass bearing and

(b) the angle of dip

of the contact.



PROBLEM 2.11

The base of the Lower Greensand is encountered in three boreholes in Suffolk at the following attitudes relative to sea level:

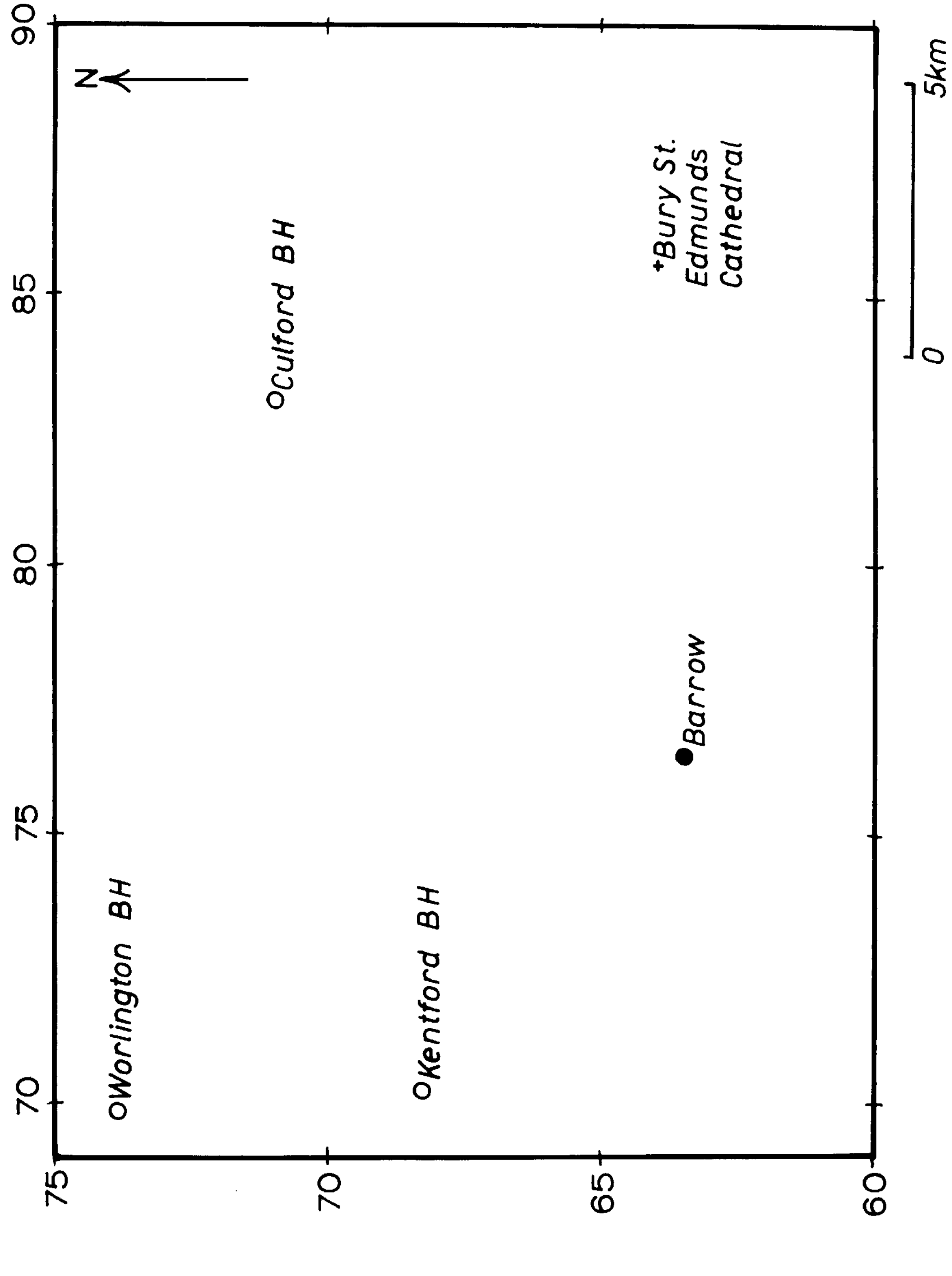
–150 m at the Culford Borehole (Map Ref. 831711)
–75 m at the Kentford Borehole (Map Ref. 702684)
–60 m at the Worlington Borehole (Map Ref. 699738)

Construct structure contours for the base of the Lower Greensand.

Predict the height of the base of the Lower Greensand below the Cathedral at Bury St Edmunds (856650).

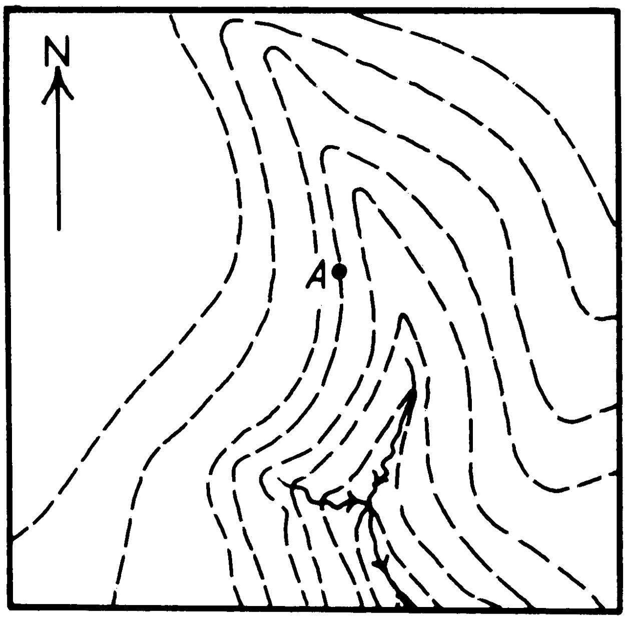
Where, closest to Bury St Edmunds, would the base of the Lower Greensand be expected to crop out if the topography in the area of outcrop is more or less flat at a height of 50 m above sea level?

If a new borehole at Barrow (755635) were to encounter Lower Greensand at height –100 m, how would it affect your earlier conclusions.

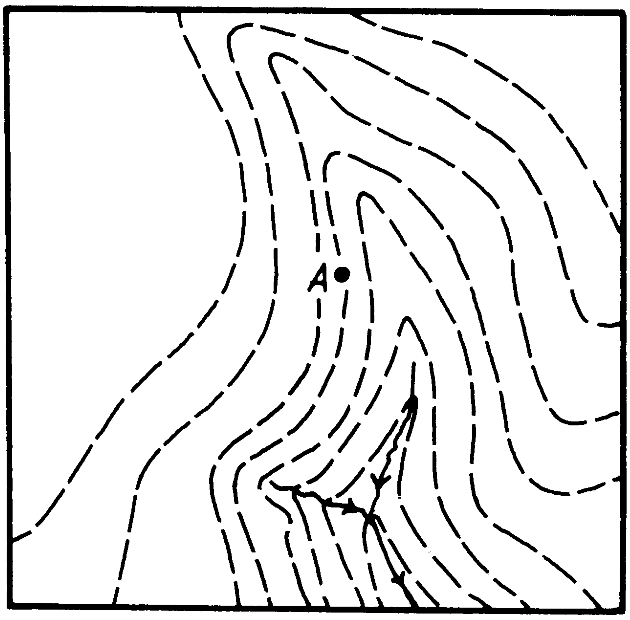


PROBLEM 2.12

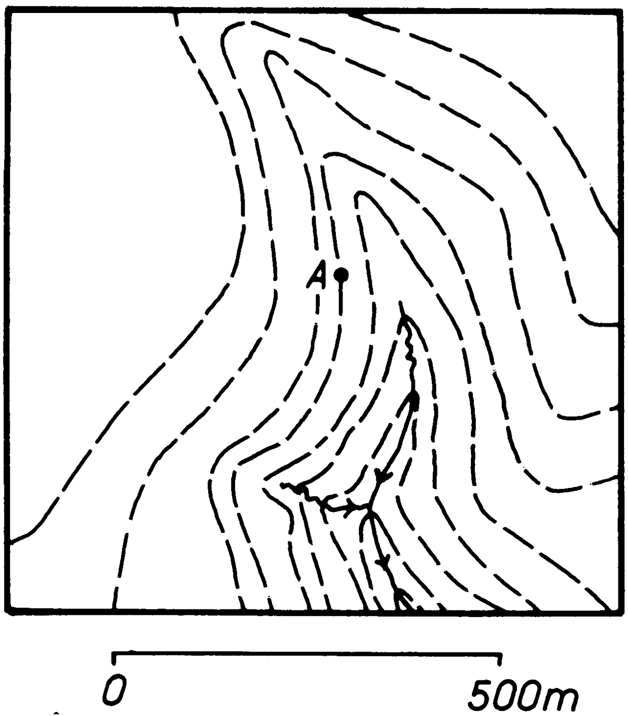
For each map predict the outcrop of a thin bed which occurs at *A*. In each map the bed has a different dip. On map (a) the dip is 11° northwards, on map (b) the dip is 11° southwards, in (c) the dip is vertical and the strike is east-west, and in (d) the dip is 3.4° southwards. (Note: tan(11°) = 0.2, tan (3.4°) = 0.06.



A



B



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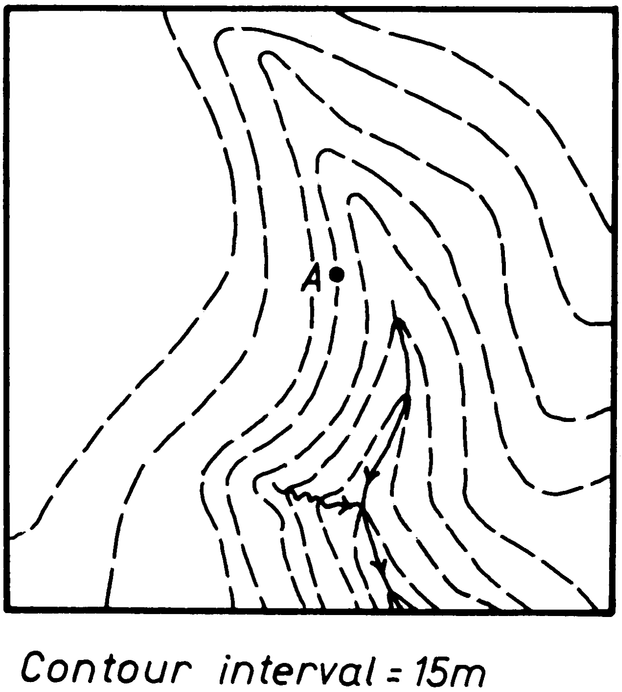


D

PROBLEM 2.13

Dipping Jurassic strata, southeast of Rich, Morocco

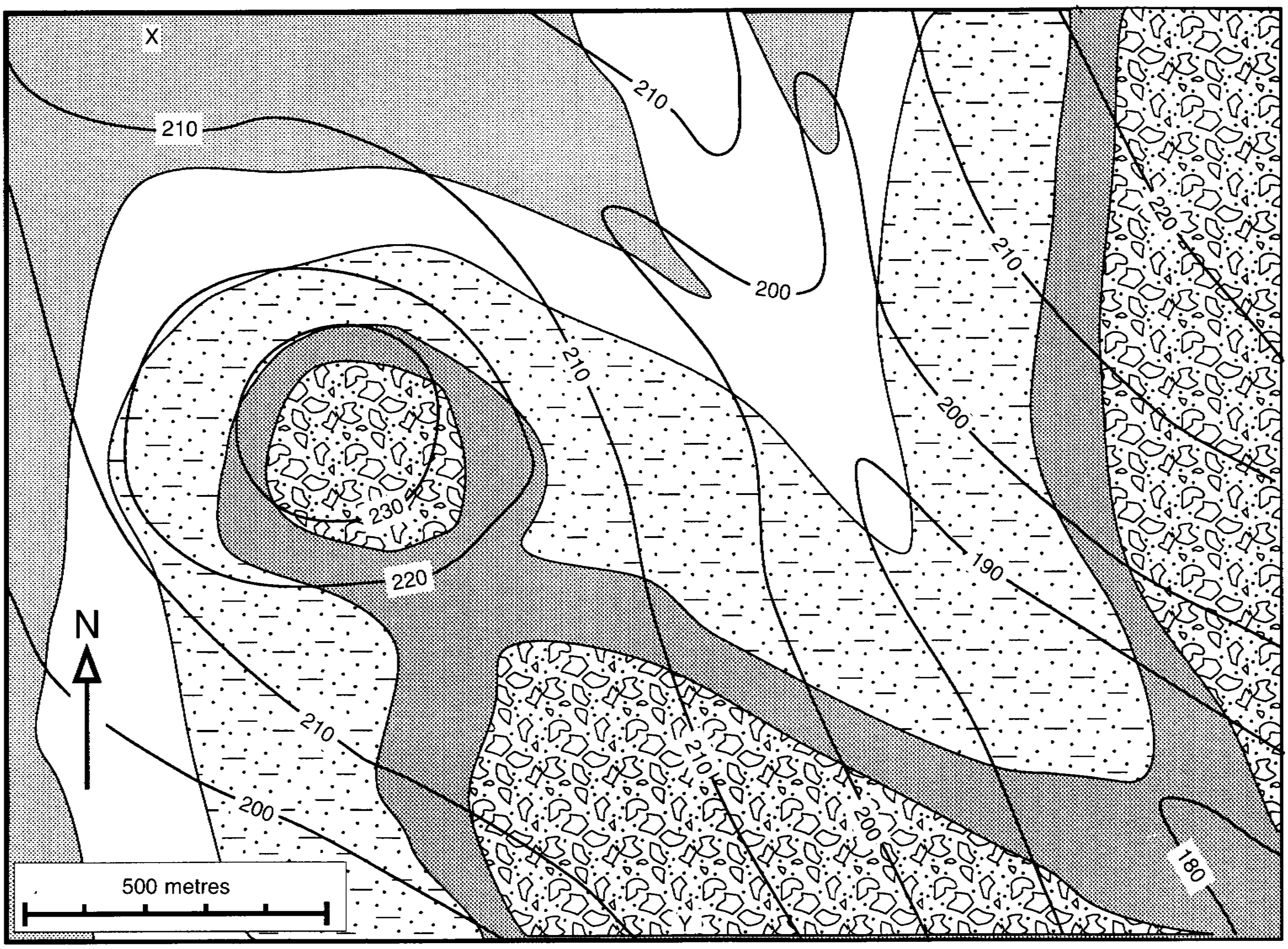
(a) Draw a geological sketch map based on the photograph (kindly provided by Professor M. R. House). On this map show the general form of topographic contours together with the outcrop pattern of a number of the exposed beds. (Note the way the dipping strata 'vee' over the ridge in the foreground.)

(b) Re-write the V-rule in Section 2.14 of this chapter to express the way the outcrop pattern of beds exposed *on a ridge* varies depending on the dip of the strata.

N S

PROBLEM 2.14

Construct a cross-section along the line X-Y. Find the dip and dip direction of the beds.



PROBLEM 2.15

Draw a cross-section of the map between points *A* and *B*.

Calculate the 30, 60, 90 and 120 m isobaths for the 'Rhondda Rider' coal seam.

Calculate the stratigraphic and vertical thickness of the Llynfi Beds.