

## Outcrop Patterns and Structure Contours

### OBJECTIVES

Determine the general attitude of a plane from its outcrop pattern

Draw structure contour maps

Solve three-point problems

Determine the outcrop patterns of planar and folded layers from attitudes at isolated outcrops

Because the earth's surface is irregular, planar features such as contacts between beds, dikes, and faults typically form irregular outcrop patterns. Thus outcrop patterns can serve as clues to the orientations of the planes. Following are seven generalized cases showing the relationships between topography and the outcrop patterns of planes as seen on a map. In Figs 2.1 through 2.7 cover the block diagram (a) and try to visualize the orientation of the bed from its outcrop pattern in map view (b). Note the symbols that indicate attitude.

1 Horizontal planes appear parallel to contour lines and "V" upstream (Fig. 2.1).

2 Vertical planes are not deflected at all by valleys and ridges (Fig. 2.2).

3 Inclined planes "V" updip as they cross ridges (Fig. 2.3).

4 Planes that dip upstream "V" upstream (Fig. 2.4).

5 Planes that dip downstream at the same gradient as the stream appear parallel to the stream bed (Fig. 2.5).

6 Planes that dip downstream at a gentler gradient than the stream "V" upstream (Fig. 2.6).

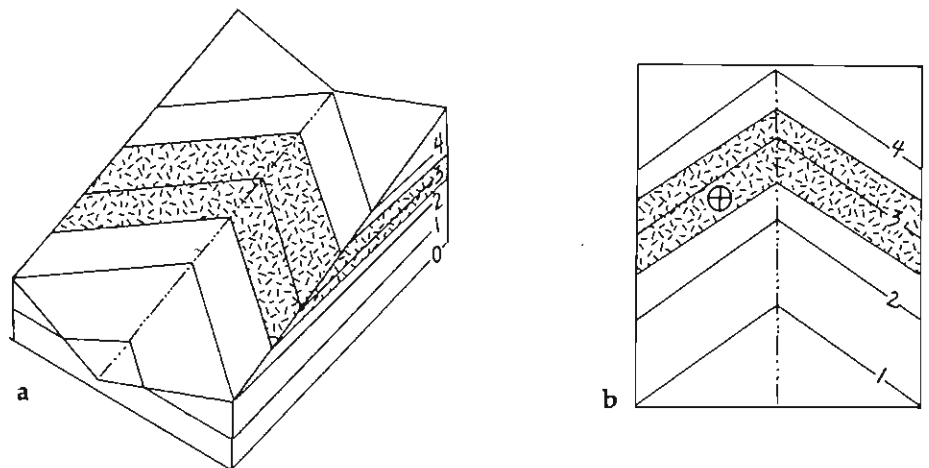


Fig. 2.1 Horizontal plane in a stream valley. (a) Block diagram. (b) Map view.

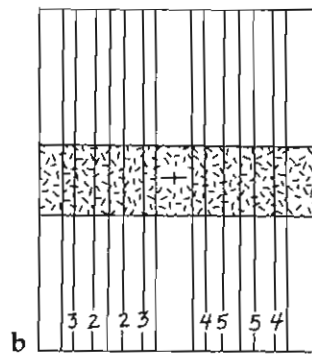
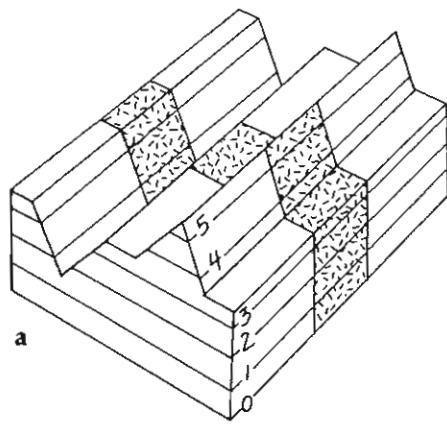


Fig. 2.2 Vertical plane crossing a ridge and a valley. (a) Block diagram. (b) Map view.

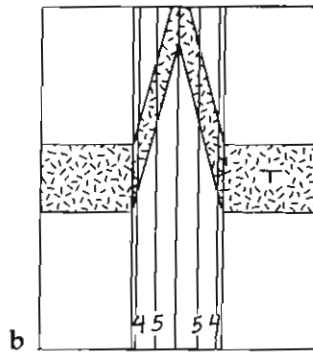
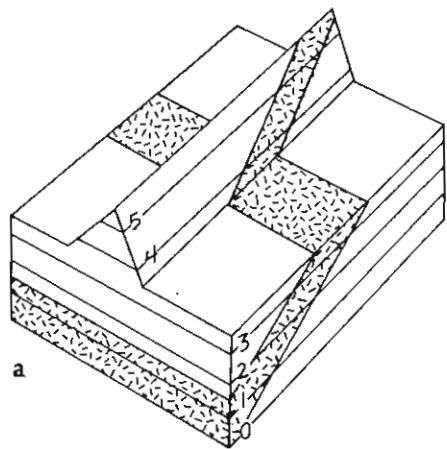


Fig. 2.3 Inclined plane crossing a ridge. (a) Block diagram. (b) Map view.

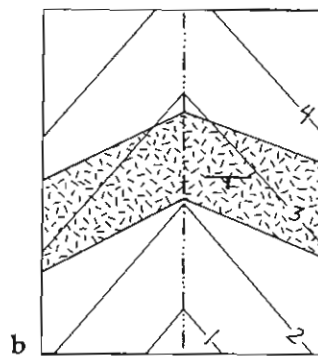
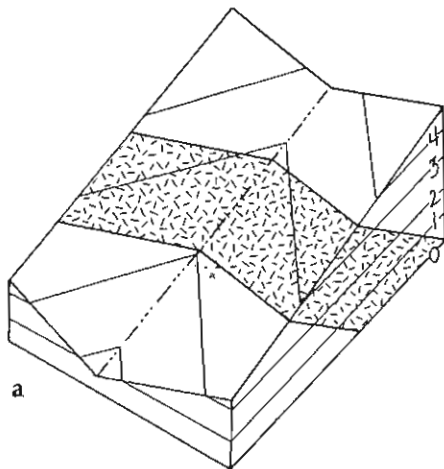


Fig. 2.4 Inclined plane dipping upstream. (a) Block diagram. (b) Map view.

Fig. 2.5 Plane dipping parallel to stream gradient. (a) Block diagram. (b) Map view.

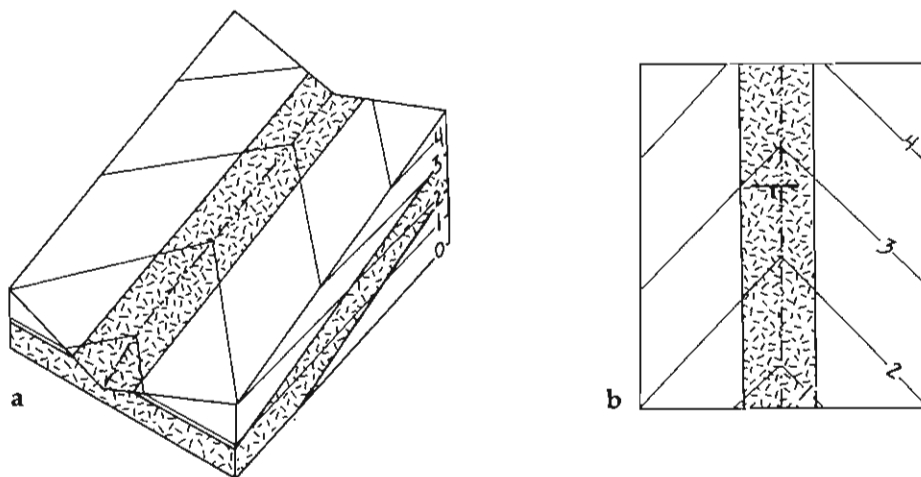


Fig. 2.6 Gently dipping plane downstream. (a) Block diagram. (b) Map view.

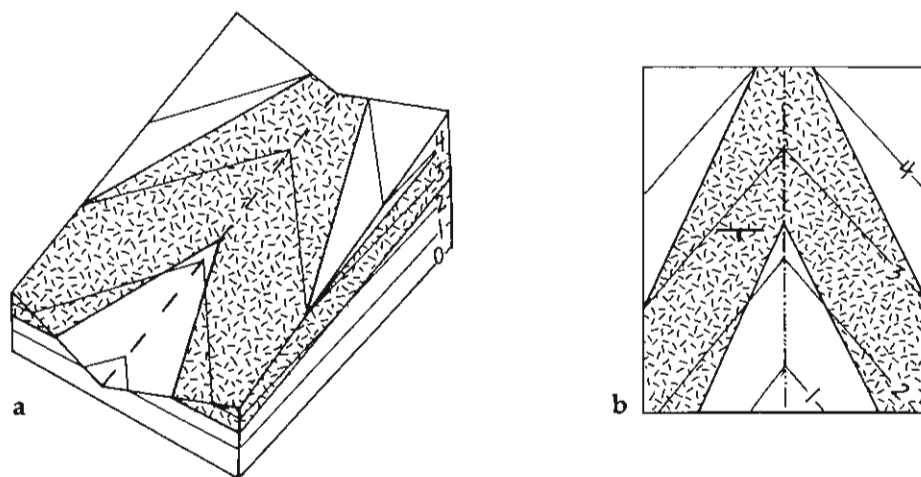
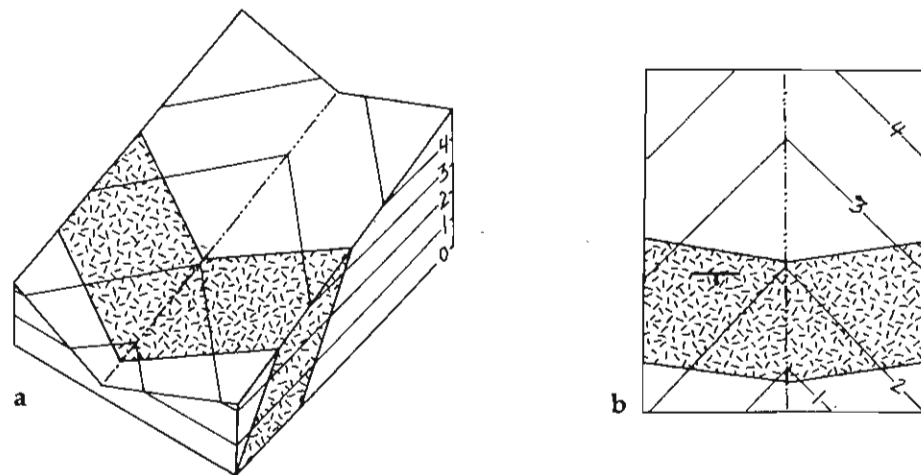


Fig. 2.7 Steeply dipping plane dipping downstream. (a) Block diagram. (b) Map view.



7 Planes that dip downstream at a steeper gradient than the stream bed (the usual case) "V" downstream (Fig. 2.7).

### Problem 2.1

On the geologic map in Fig. 2.9 draw the correct strike and dip symbol in each circle to indicate the attitude of formation B and each dike. To verify your attitude symbols, Fig. 2.10 can be cut out and folded to form a block model of this map. Appendix F shows standard symbols for geologic maps.

## Structure contours

A *structure contour* is an imaginary line connecting points of equal elevation (a contour) on a single surface, such as the top of a formation. Structure-contour maps are analogous to topographic maps: the former shows the surface of a geologic horizon, the latter shows the surface of the earth.

Structure-contour maps are most commonly constructed from drill-hole data. See Fig. 2.8, for example, which shows a faulted dome. Notice that unlike topographic contours, structure contours sometimes terminate abruptly. Gaps in the map indicate normal faults, and overlaps indicate reverse faults.

Structure contour maps are used extensively in petroleum exploration to identify structural traps and in hydrology to determine the subsurface configuration of aquifers. The objective here will be to introduce you to structure-contour maps so that you are generally familiar with them and can use them to determine outcrop patterns later in the chapter.

Figure 2.11 is a map showing the elevation (in feet) of the top of a formation in 26 drill holes. This area is in the northeastern corner of the Bree Creek Quadrangle, and the formation involved is the Bree Conglomerate. The geologic map of the Bree Creek Quadrangle may be found on six pages in the back of this book. As explained later in this chapter, you will combine these into one big map and use it often as you work through the following chapters.

There are various techniques for contouring numerical data such as the elevations in Fig. 2.11. In the case of geologic structure contours, there are usually not enough data to produce an unequivocal map, so experienced interpretation becomes extremely valuable.

### Problem 2.2

Draw structure contours on Fig. 2.11. Use a 400-ft contour interval (including 0, 400, 800, 1200, etc.).

If you do not know how to begin, here are some suggestions. Find a point whose elevation is close to the elevation of a contour line, for example, the 779-ft point. You know that the 800-ft contour passes very close to this point, but where does it go? To the east and northeast are two points with elevations of 516 ft and 1013 ft. 800 lies between these two elevations, so the 800-ft contour must pass between these two points, closer to the 1013-ft point than to the 516-ft point. Once you have a few lines drawn, the rest will fall into place. Your structure contours should be smooth, subparallel lines. Use a pencil, because this is a trial-and-error operation.

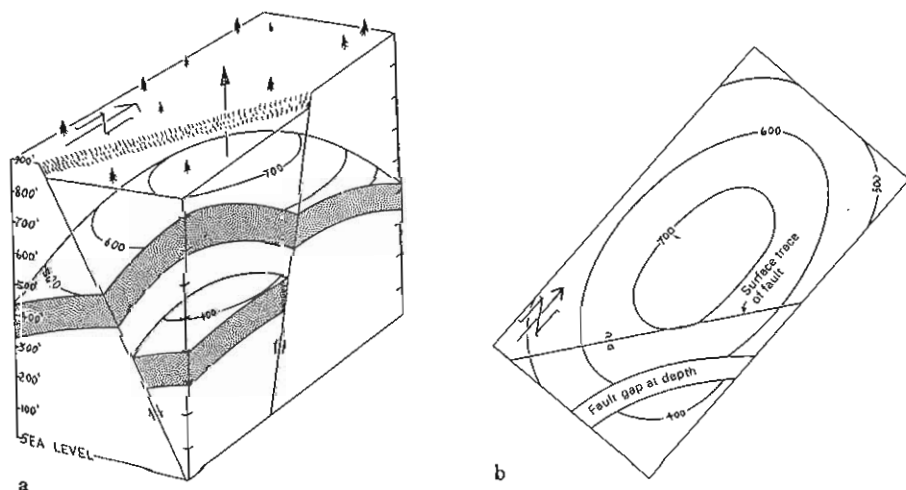


Fig. 2.8 Block diagram (a) and structure contour map (b) of a faulted dome.

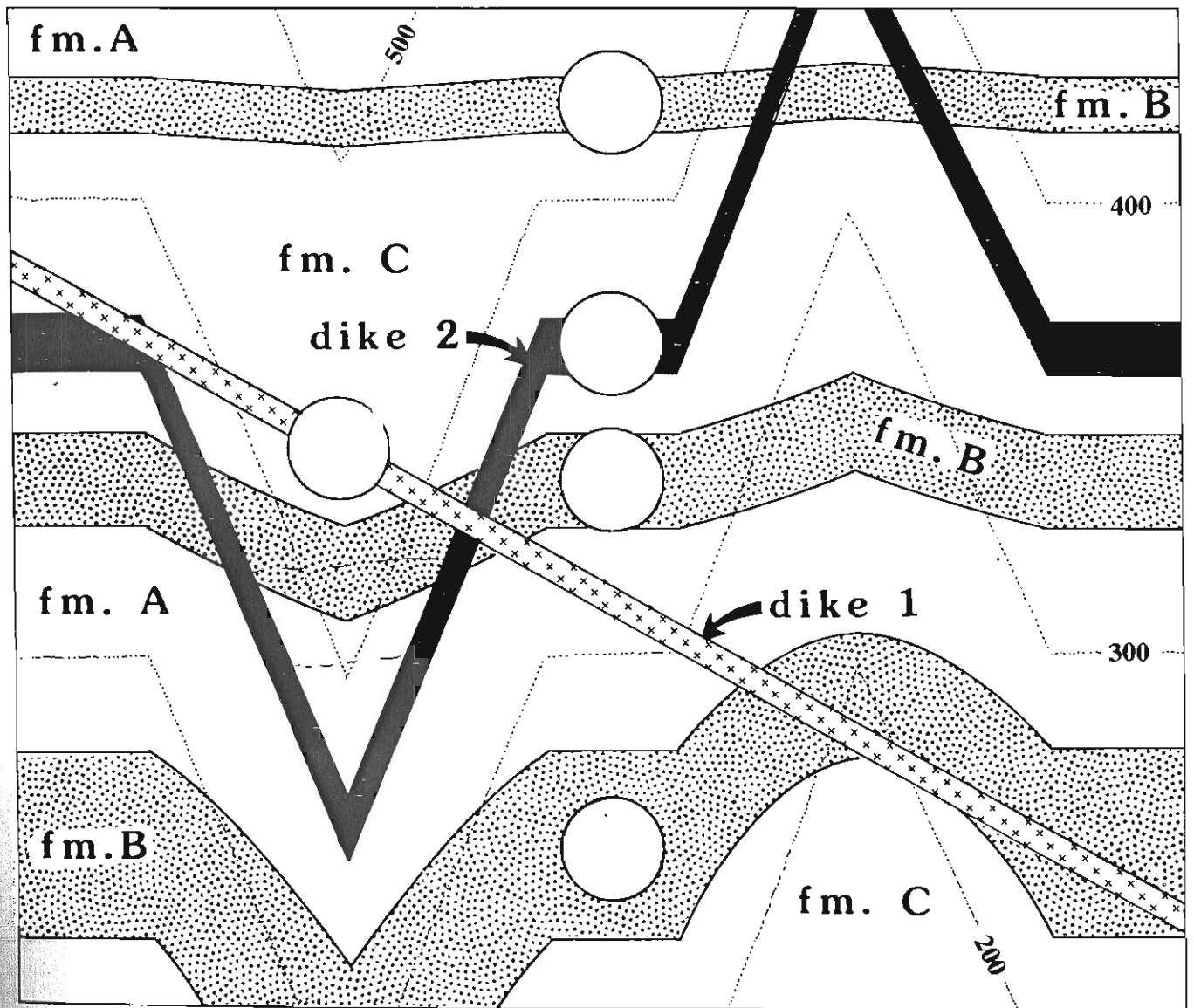


Fig. 2.9 Geologic map for use in Problem 2.1. Contours are dotted lines. Formation A is the oldest unit. Contour interval is 100 m.

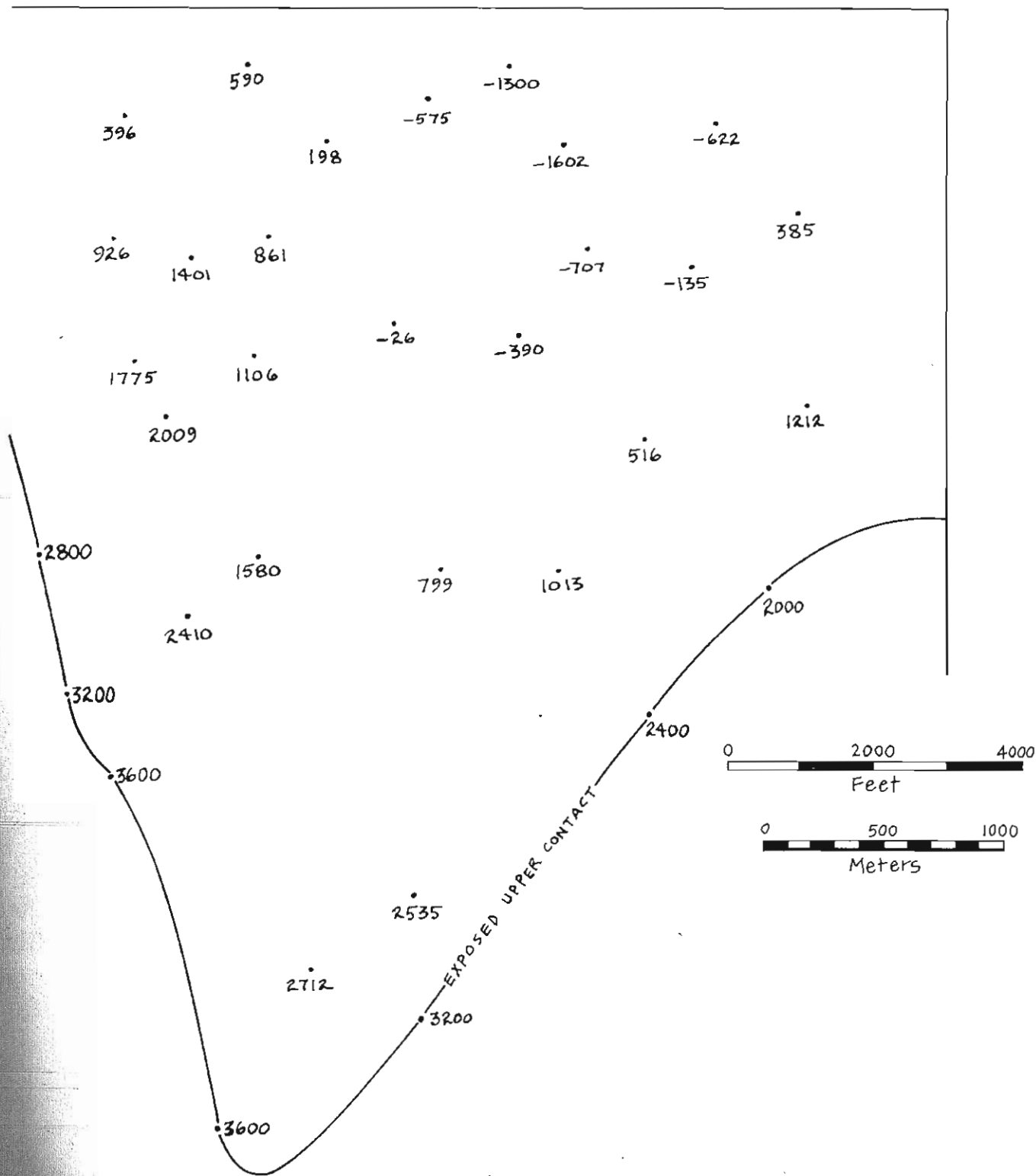


Fig. 2.11 Map to accompany Problem 2.2. Elevation of upper surface of Bree Conglomerate in 26 drill holes, northeastern Bree Creek Quadrangle.

### The three-point problem

In many geologic situations, a bedding plane or fault surface may crop out at several localities. If the elevations of three of these points are known, then the classic "three-point" problem can be used to determine the attitude of the plane. Consider Fig. 2.12a, which shows three points (A, B, C) on a topographic map. These three points lie on the top of a sandstone layer. The problem is to determine the attitude of the layer. We will solve this problem two different ways, using first a structure-contour approach, then a two-apparent-dip approach.

#### Solution 1

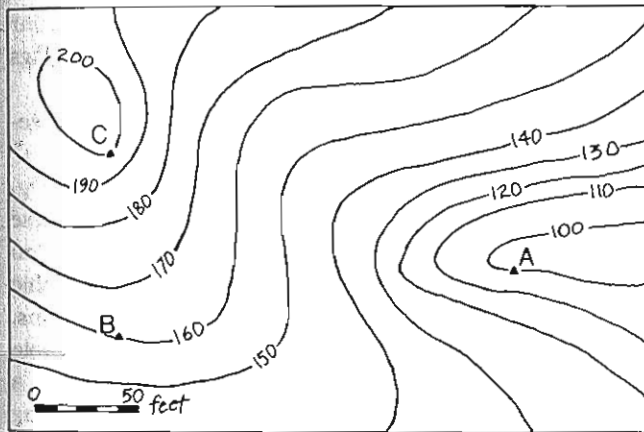
1 Place a piece of tracing paper over the map, and label the three known points and their elevations. On the tracing paper draw a line connecting the highest of the three points with the lowest. Take the tracing paper off the map, then find the point on this line that is equal in elevation to the intermediate point. In Fig. 2.12b point B

has an elevation of 160 ft, so the point B' on the AC line equal in elevation to the point B lies 6/10 of the way from point A (200 ft) to point C (100 ft).

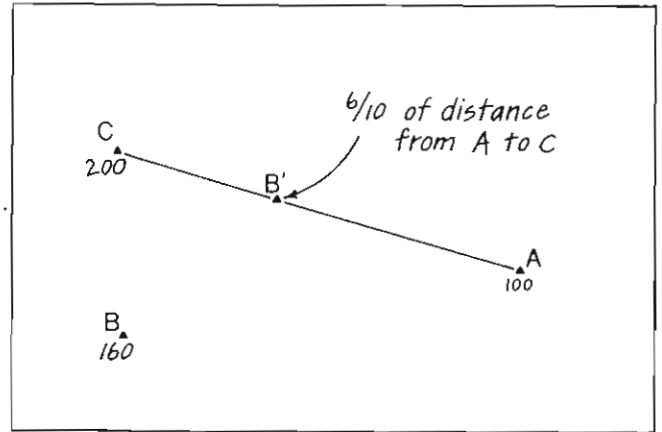
2 The bed in question is assumed to be planar, so B' must lie in the plane. We now have two points, B and B', of equal elevation lying in the plane of the bed, which define the strike of the plane. The structure-contour line B-B' is drawn, and the strike is measured with a protractor to be N48E (Fig. 2.12c).

3 The direction and amount of dip are determined by drawing a perpendicular line to the strike line from point A, the lowest of the three known outcrop points (Fig. 2.12d). The amount of dip can be determined trigonometrically as shown:

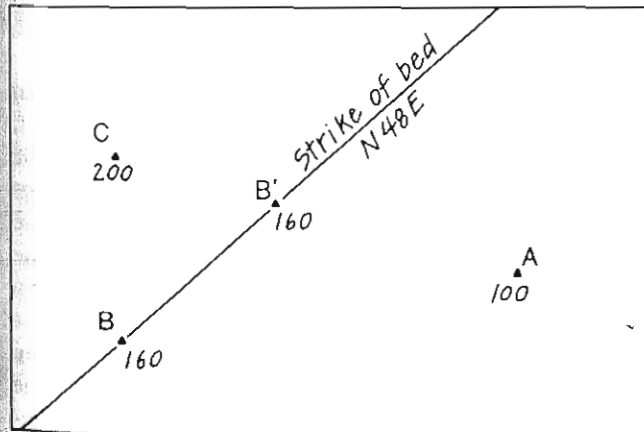
$$\begin{aligned} \tan \delta &= \frac{\text{change in elevation}}{\text{map distance}} \\ &= \frac{60'}{104'} = 0.57 \\ 0.57 &= \tan 30^\circ \quad \delta = 30^\circ \end{aligned}$$



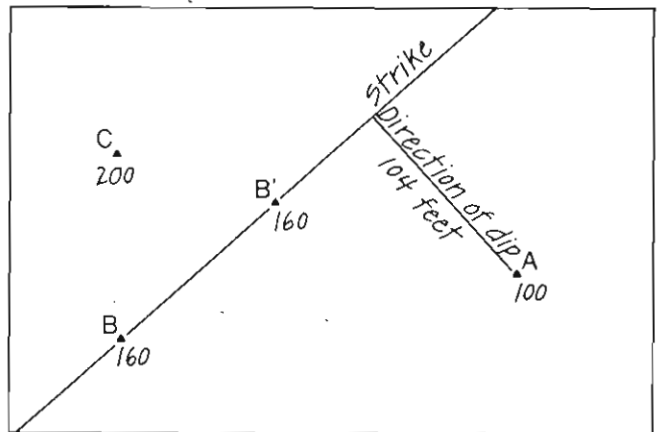
a



b



c



d

Fig. 2.12 Solution of a three-point problem using a combination of graphical and trigonometric techniques. (a) Three coplanar points (A, B, and C) on a topographic map. (b) Location of a fourth point, B', at the same elevation as point B. (c) Line B-B' defines the strike of the plane. (d) Dip-direction line perpendicular to the line B-B'.

Solution 2

Another approach to solving a three-point problem is to convert it into a two-apparent-dip problem.

1 Draw lines from the lowest of the three points to each of the other two points (Fig. 2.13a). These two lines represent apparent-dip directions from B to A and from C to A.

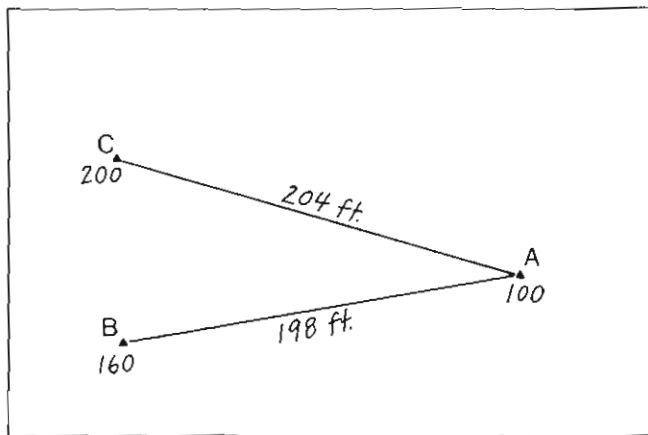
2 Measure the bearing and length of lines CA and BA on the map (Fig. 2.13b), and determine their plunges:

$$\theta_1 = 80^\circ \quad \theta_2 = 107^\circ$$

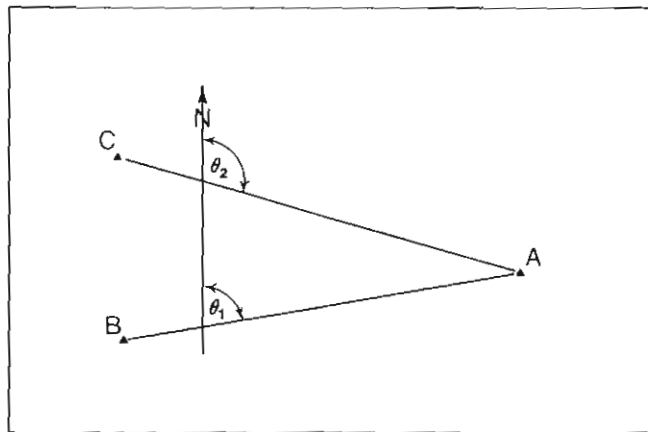
$$\tan \alpha_1 = \frac{\text{diff. in elevation}}{\text{map distance}} = \frac{60'}{198'} = 0.303$$

$$\tan \alpha_2 = \frac{100'}{204'} = 0.490$$

3 Use equation 1.4 to find the true-dip direction, and then equation 1.3 to find the amount of dip.



a



b

Fig. 2.13 Three-point problem converted to a two-apparent-dip problem. (a) Three coplanar points. Lines are drawn to the lowest of the three points from the other two points. (b) Apparent-dip directions  $\theta_1$  and  $\theta_2$ .

Problem 2.3

Points A, B, and C in Fig. 2.14 are oil wells drilled on a flat plain. All tap the same oil-bearing sandstone. The depth (not the elevation) of the top of this sandstone in each well is as follows: A = 5115 ft, B = 6135 ft, and C = 5485 ft.

- 1 Determine the attitude of the sandstone.
- 2 If a well is drilled at point D, at what depth would it hit the top of the sandstone?

*MAPLE FL. OF SURFACE 10,000 FT*

Determining outcrop patterns with structure contours

Earlier we discussed structure-contour maps derived from drill-hole data. Structure contour maps may also be constructed from surface data. Suppose, for example, that an important horizon is exposed in three places on a topographic map, as in Fig. 2.12a. If this horizon is planar we can determine its outcrop pattern on the map by the following technique.

- 1 On a piece of tracing paper draw the structure contour that passes through the middle elevation point (Figs 2.12b and 2.12c).
- 2 Find the true dip as described above under the three-point problem.
- 3 Draw structure contours parallel to the line B-B' (Fig. 2.12c). In order to determine the outcrop pattern, these structure contours must have a contour interval equal to (or a multiple of) the contour interval on the topographic map. They also must represent the same elevations. Because the surface we are dealing with in this example is assumed to be planar, the structure contours will be a series of straight, equidistant parallel lines. The spacing can be determined trigonometrically:

$$\text{map distance} = \frac{\text{contour interval}}{\tan \delta}$$

In this example the spacing turns out to be 17.5 ft in plan view (Fig. 2.15a). Point B is at an elevation of 160 ft, which is conveniently also the elevation of a topographic contour. Points on the bedding plane whose elevations are known (points A and C in this problem) should serve as control points; that is, lay the tracing paper over the map and make sure that the elevations of known outcrop points match their elevations on the structure contour map. If the surface is not quite planar but is changing dip slightly, adjustments can constantly be made on the structure contour map. Figure 2.15b shows the completed structure-contour map for this example.

4 Superimpose the structure-contour map and the topographic map (Fig. 2.15c). Every point where a structure contour crosses a topographic contour of equal elevation



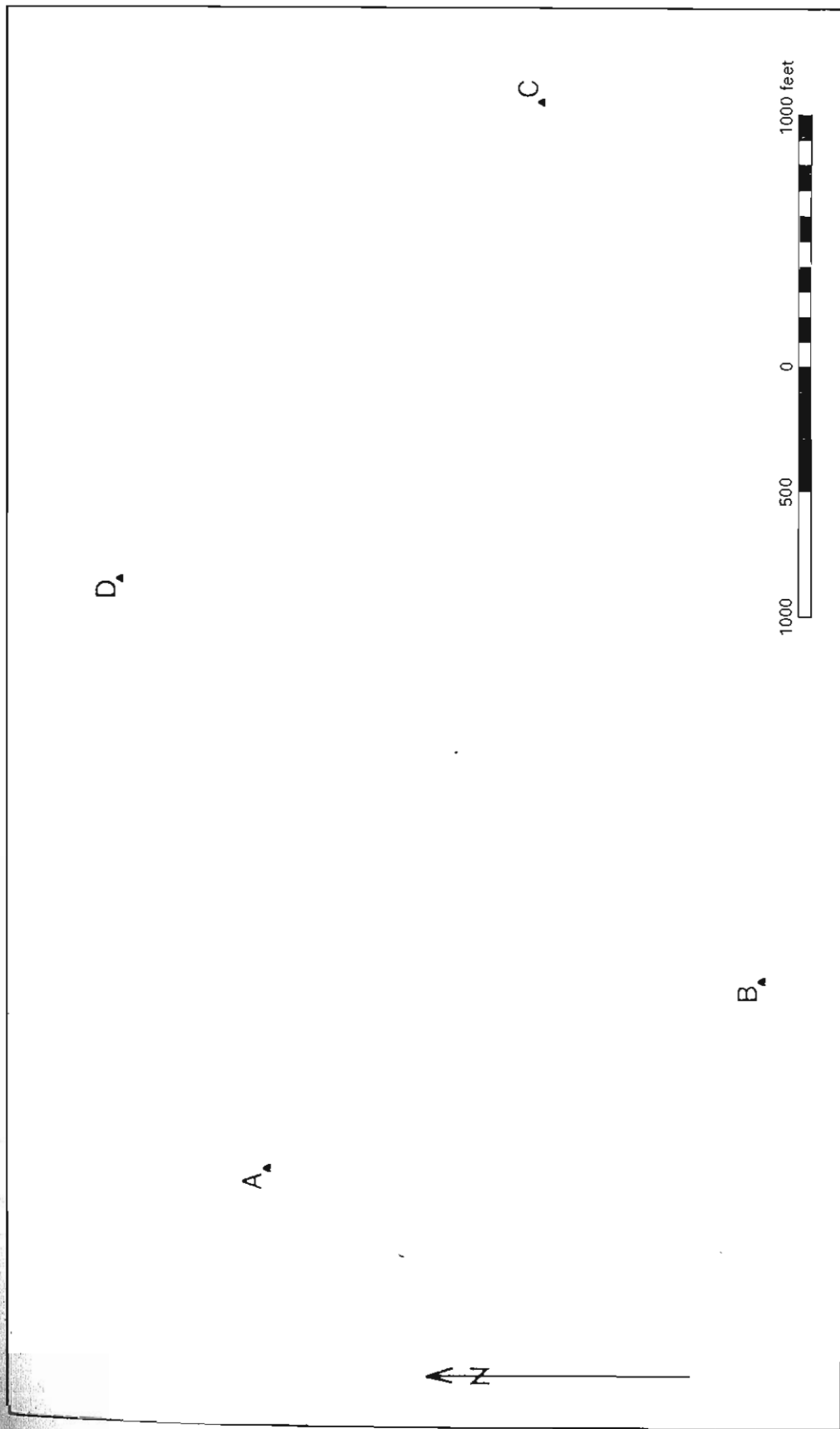


Fig. 2.14 Map for use in Problem 2.3.

is a surface outcrop point. The outcrop line of the plane is made by placing the structure-contour map beneath the topographic map and marking each point where contours of the same elevation cross. A light table may be necessary to see through the topographic map. The points of intersection are connected to display the outcrop pattern on the topographic map (Fig. 2.15d).

This same technique can be used to locate a second

surface parallel to the first. Suppose that the contact shown in Fig. 2.15d is the top of a bed, and we wish to determine the outcrop pattern of the bottom as well. If a single outcrop point on the topographic map is known, then the outcrop pattern can easily be found using the structure-contour map already constructed for the bed's upper surface.

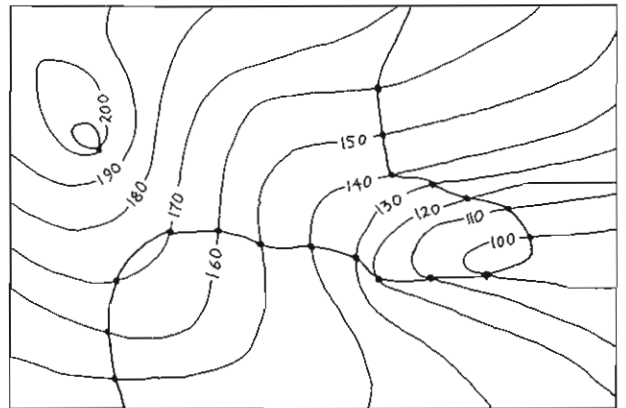
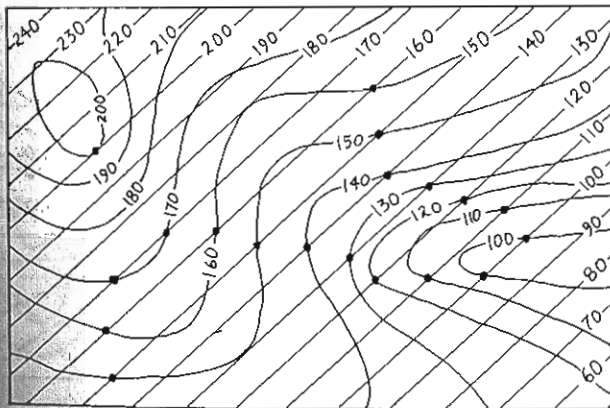
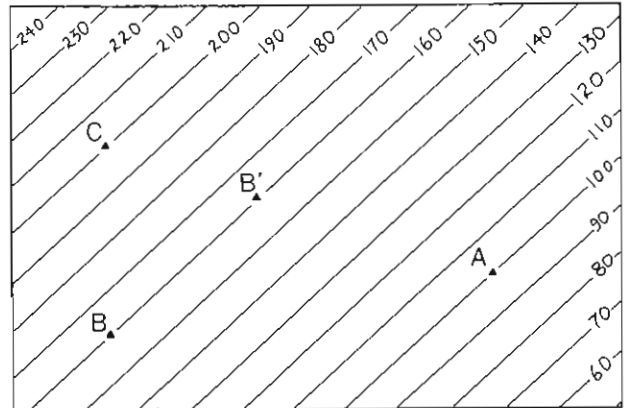
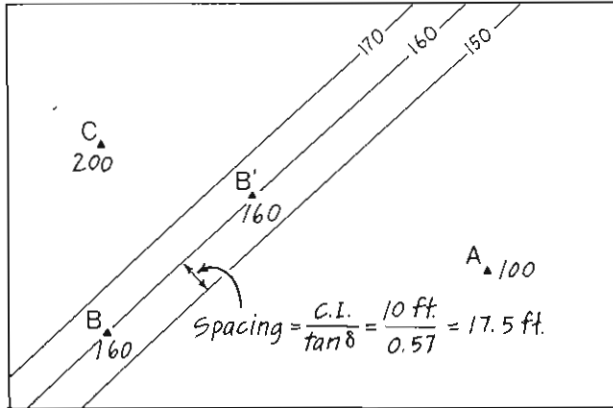
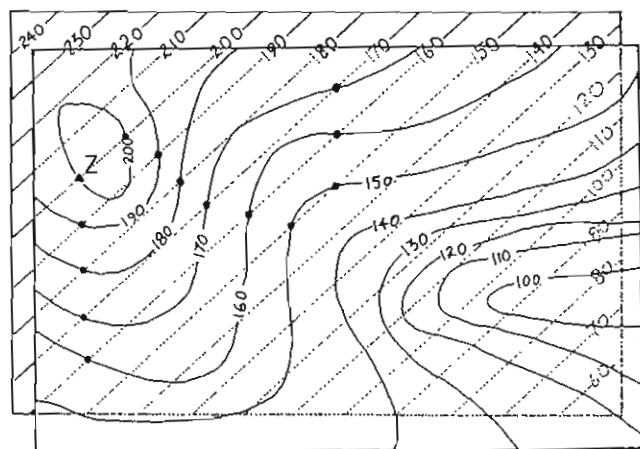


Fig. 2.15 Determination of outcrop pattern using structure contours. (a) Three structure contours on a base map (from Fig. 2.12c). (b) Structure-contour map. (c) Structure-contour map superimposed on a topographic map. (d) Outcrop pattern of a plane on a topographic map.

1 Position the structure-contour map beneath the topographic map such that the bottom surface outcrop point (or points) lies (lie) at the proper elevation on the structure-contour map. With the structure contours parallel to their former position, proceed as before. In Fig. 2.16a, point Z, at an elevation of 200 ft, is a known outcrop point of the bottom of the bed. The structure contour map has been moved so that the 200-ft structure contour passes through point Z, and the predicted outcrop points have been located as before.

2 Once the upper and lower contacts are drawn on the topographic map, the outcrop pattern of the bed can be shaded or colored (Fig. 2.16b).

This technique for locating the intersection of a geologic surface with the surface of the earth may be used even when the surface is not a plane, as long as a structure-contour map can be constructed. In Fig. 2.17a, for example, three attitudes of a fault plane are mapped, and all are different. If we assume a constant slope and a gradual change in dip between outcrop points, a structure-contour map may easily be constructed as follows.



a

1 Arithmetically interpolate between known elevation points to locate the necessary elevation points on the surface (Fig. 2.17b).

2 Draw smooth parallel structure contours parallel to the strikes at the outcrop points (Fig. 2.17c).

3 Superimpose the structure-contour map and the topographic map and mark points where contours of equal elevation intersect (Fig. 2.17d).

4 Connect these intersection points to produce the outcrop map (Fig. 2.17e).

#### Problem 2.4

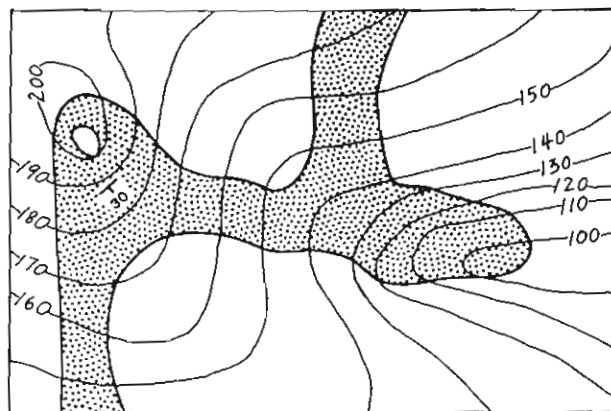
Figure 2.18 is a topographic map. Points A, B, and C are outcrop points of the upper surface of a planar coal seam. Point Z is an outcrop point of the base of the coal seam.

1 Determine the attitude of the coal seam.

2 Draw the outcrop pattern of the coal seam.

3 Determine the thickness of the coal seam.

Attach any drawings and computations you use.



b

Fig. 2.16 (a) Structure-contour map shifted to the position of point Z on the bottom of formation whose top is shown in Fig. 2.15d. (b) Outcrop pattern of rock unit dipping  $30^\circ$  to the southeast.

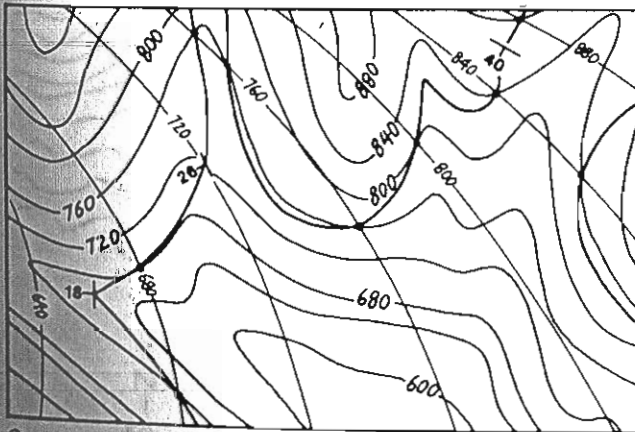
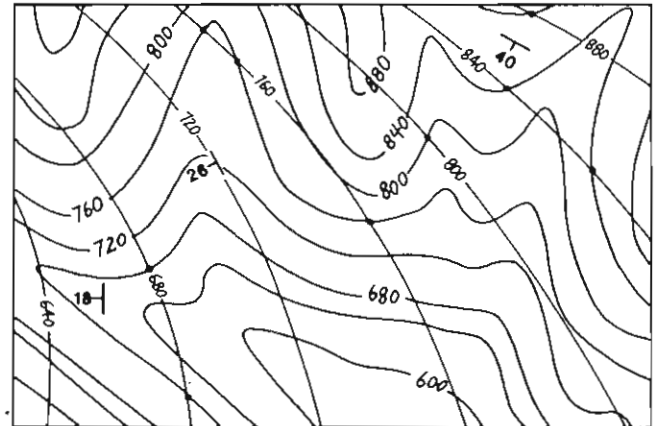
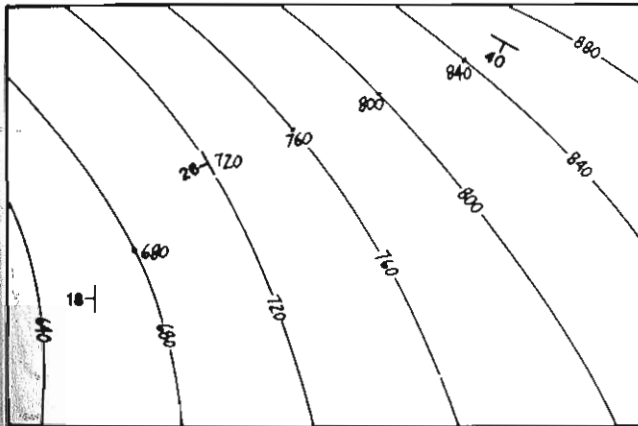
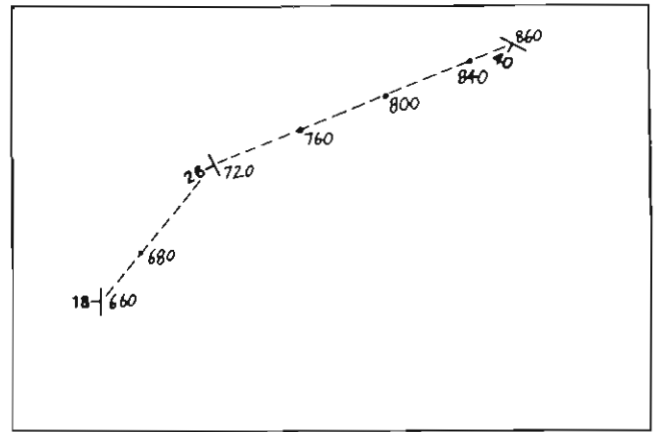
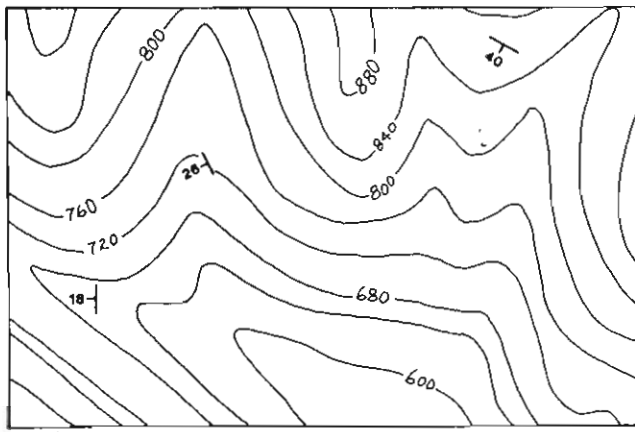


Fig. 2.17 Determining outcrop pattern of a gently folded surface using structure contours. (a) Three attitudes of folded horizon on a topographic map. (b) Interpolation of elevations between points of known elevation. (c) Structure-contour map of gently folded surface. (d) Structure-contour map superimposed on topographic map. (e) Outcrop pattern on topographic map.

### Bree Creek Quadrangle map

Beginning in Chapter 3, many of the exercises in this book will deal with the mythical Bree Creek Quadrangle. The geologic map of this quadrangle is found in the back of this laboratory manual in six sheets. It has been carefully designed to provide you with a variety of structural relationships and challenging problems of appropriate complexity. Before continuing on to Chapter 3, lightly color the six sheets of the Bree Creek Quadrangle, trim the margins, and tape them together to form one large map. More than mere busywork, coloring a map forces you to look closely at the distribution of various rock units. For maximum contrast, avoid using similar colors, such as red and orange, for consistently adjacent rock units.

Because you will be using this map often, it is important that you treat it carefully. Tape the seams carefully on the back (not the front) after it is colored, and then fold it up so that it fits into an envelope that you keep with the rest of your structural equipment.

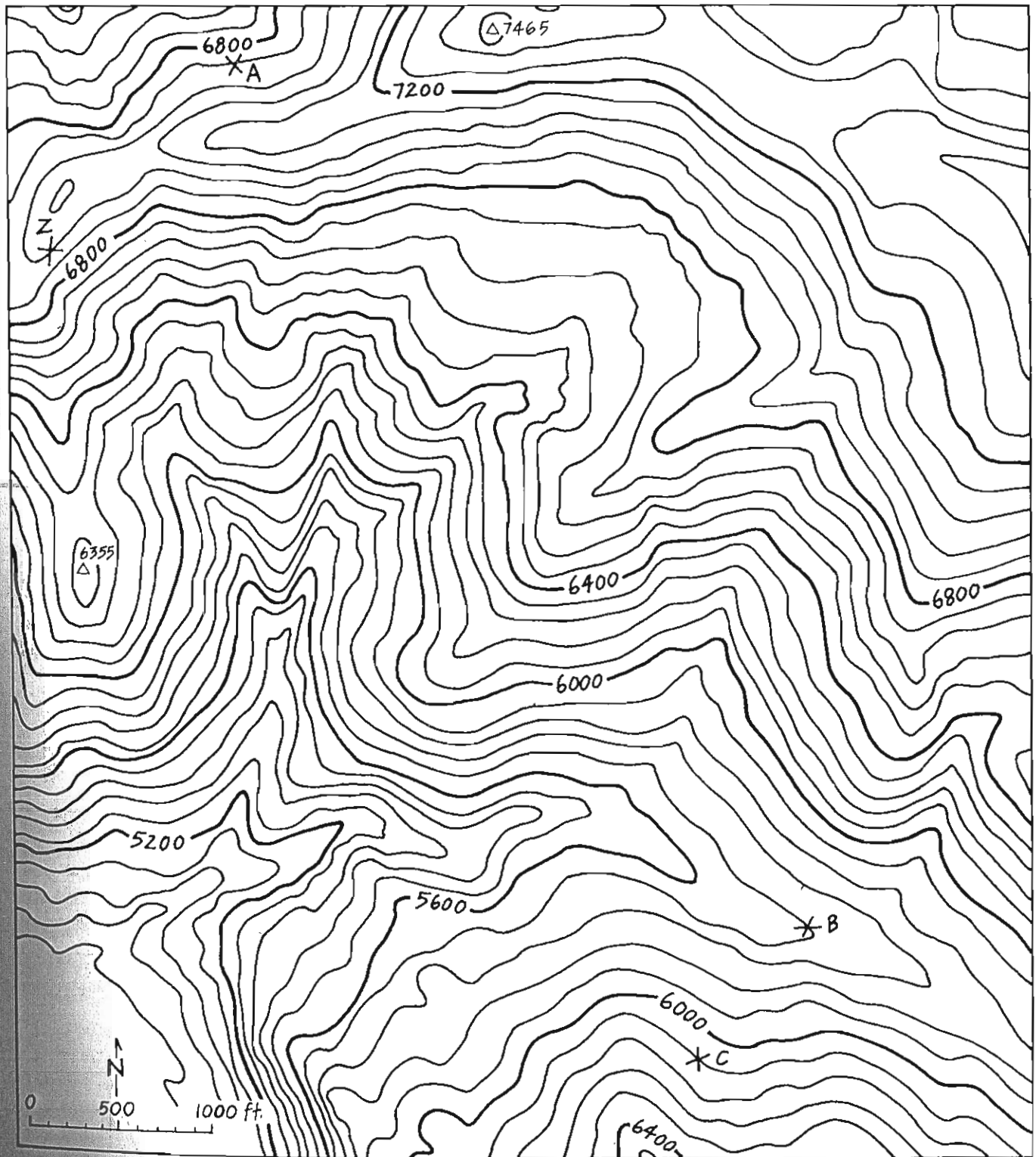


Fig. 2.18 Map for use in Problem 2.4.