2

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. In situations where strike and dip symbols are not provided (such as on regional, small-scale maps), 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. As you examine Figs 2.1 through 2.7, cover the block diagram (parts a) and try to visualize the orientation of the bed from its outcrop pattern in map view (parts 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).
7 Planes that dip downstream at a steeper gradient than the stream bed (the usual case) "V" downstream (Fig. 2.7).

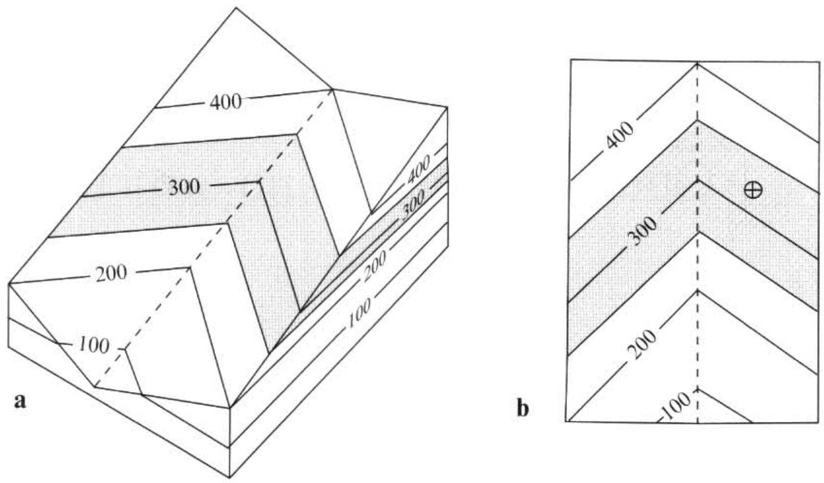

Fig. 2.1 Horizontal plane in a stream valley. (a) Block diagram. (b) Map view.

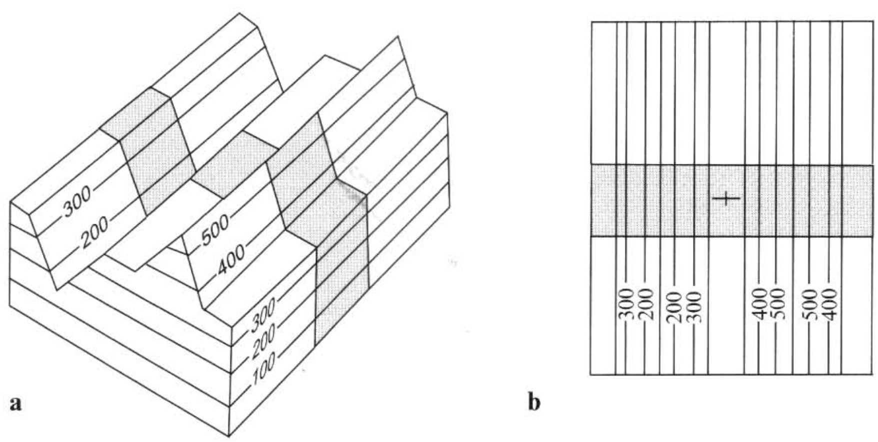

Fig. 2.2 Vertical plane crossing a ridge and valley. (a) Block diagram. (b) Map view.

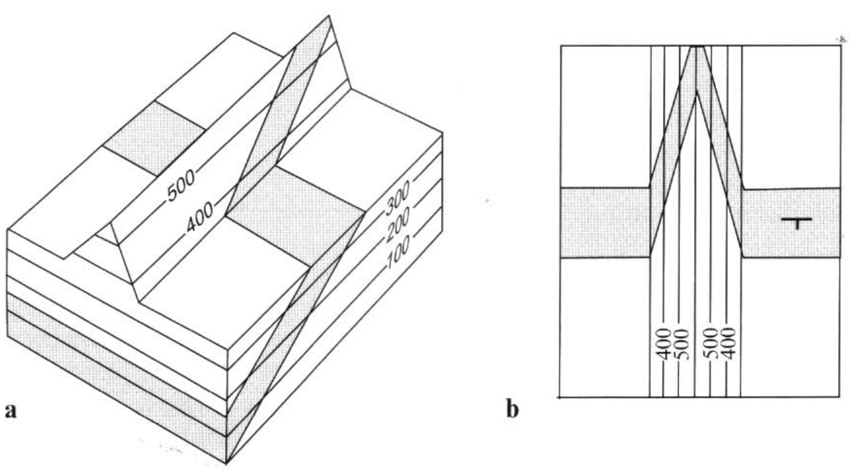

Fig. 2.3 Inclined plane crossing a ridge. (a) Block diagram. (b) Map view.

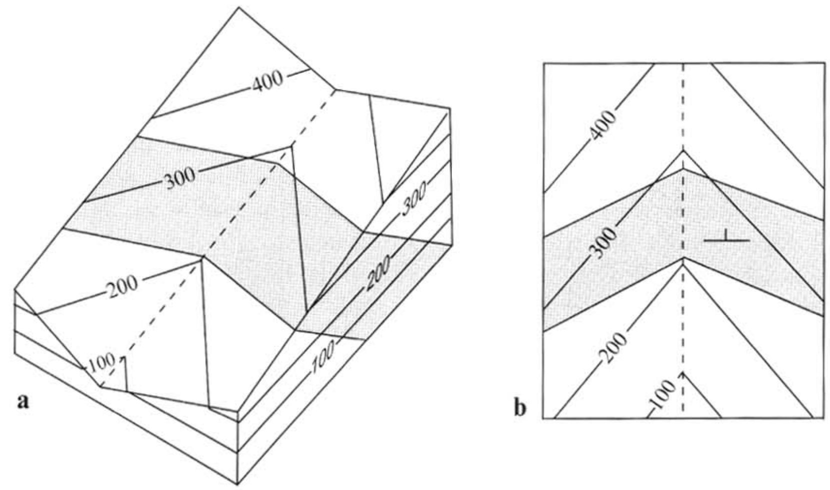

Fig. 2.4 Inclined plane dipping upstream. (a) Block diagram. (b) Map view.

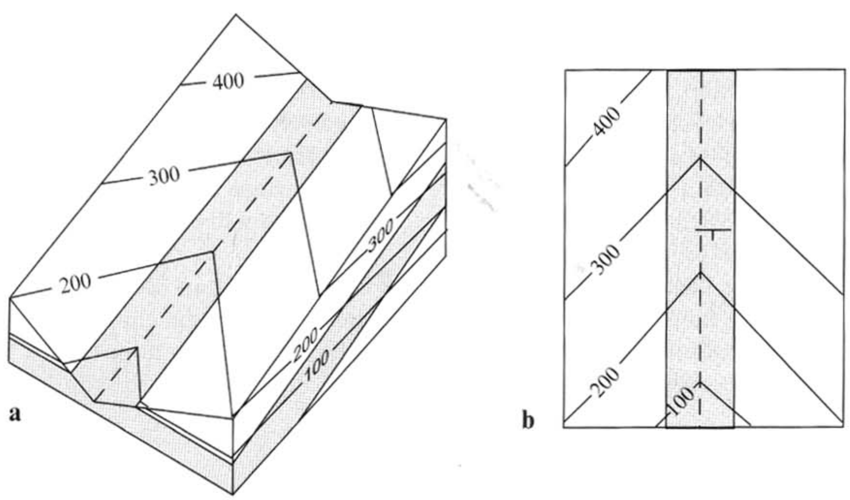

Fig. 2.5 Plane dipping parallel to stream gradient. (a) Block diagram. (b) Map view.

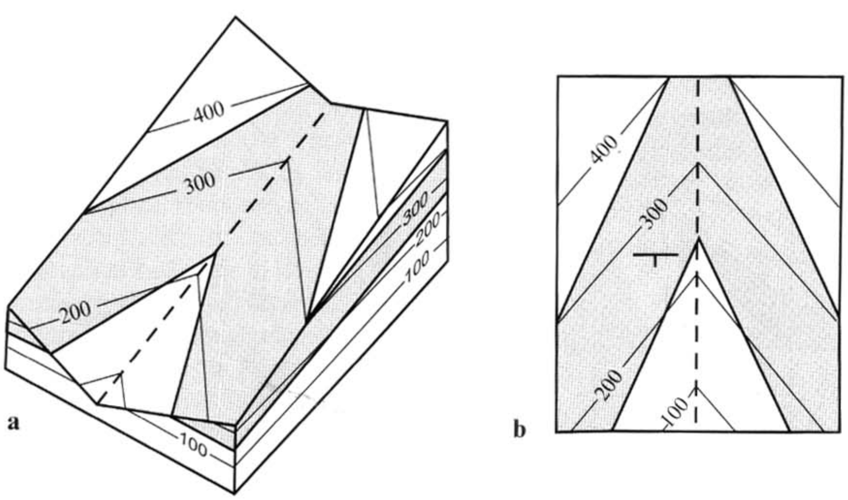

Fig. 2.6 Plane dipping downstream more gently than the stream gradient. (a) Block diagram. (b) Map view.

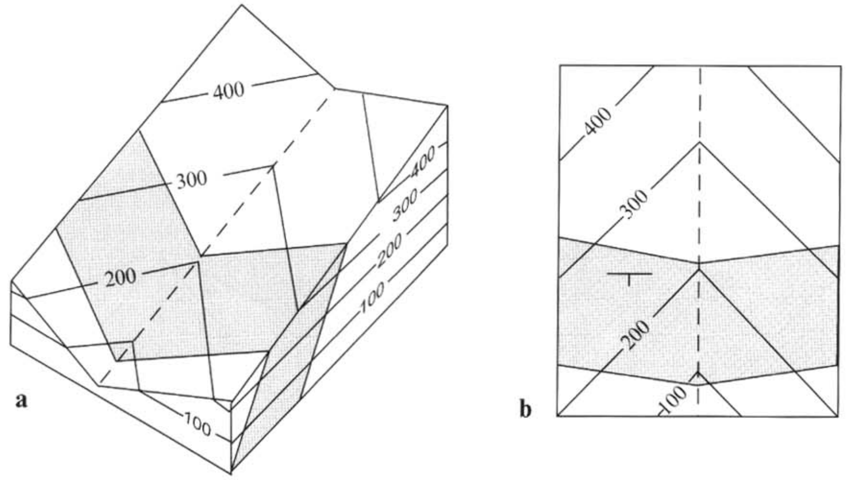

Fig. 2.7 Plane dipping downstream more steeply than the stream gradient. (a) Block diagram. (b) Map view.

Structure contours

A contour line is one that connects points of equal value. On a topographic map, each contour line connects points of equal elevation on the earth's surface. A *structure contour* is a line that connects points of equal elevation on a structural surface, such as the top of a formation.

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 help geologists recognize structures in the subsurface. They are used extensively in petroleum exploration to identify structural traps and in hydrology to characterize the subsurface configurations 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 G-3 (Appendix G) is a map showing the elevation (in feet) of the top of a formation in 26

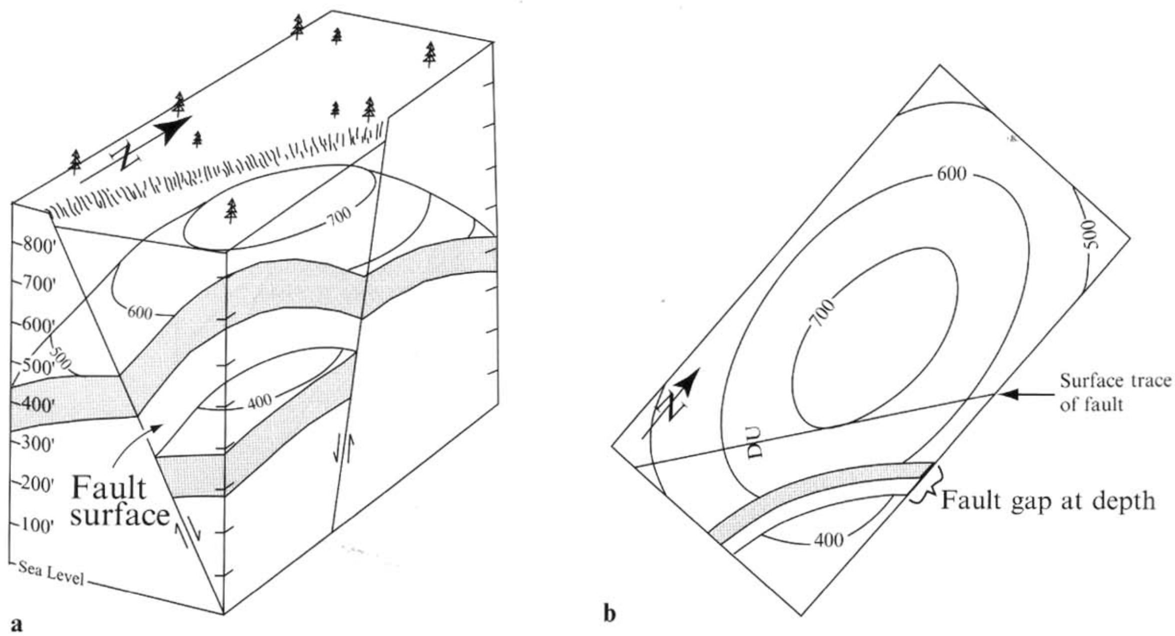

Fig. 2.8 Block diagram (a) and structure-contour map (b) of a faulted dome. D, down; U, up.

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 in an envelope at the back of this book. As explained later in this chapter, you will use it often as you work through the following chapters.

There are various techniques for contouring numerical data such as the elevations in Fig. G-3. In the case of geologic structure contours, there are usually not enough data to produce an unequivocal map, so experienced interpretation becomes extremely valuable. Although there are computer programs that will draw contour lines between data points, such a program cannot substitute for the judgment of an experienced geologist. For example, if four structure contours must pass between two elevation points, a computer program may space these contours at equal intervals. If the geologist has independent evidence that the surface to be contoured steepens toward one of the elevation points, he or she can draw the structure contours accordingly (i.e., progressively closer together) to depict the steepening surface.

The three-point problem

In many geologic situations, a bedding plane or fault surface may crop out at several localities. If the surface is planar and the elevations of three points on the surface are known, then the classic "three-point" problem can be used to determine the attitude of the plane. Consider Fig. 2.9a, which shows three points (A, B, C) on a topographic map. These three points lie on the upper surface of a sandstone layer. The problem is to determine the attitude of the layer. We will solve this problem in two different ways, using first a structure-contour approach, then a two-apparent-dip approach.

Solution I

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. Now find the point on this line that is equal in elevation to the intermediate point. In Fig. 2.9b, point B has an elevation of 160 ft, so point B′, the point on the AC line that is equal in elevation to point B, lies 6/10 of the way from point A (100 ft) to point C (200 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 N48°E (Fig. 2.9c).
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. 2.9d). The amount of dip can be determined trigonometrically as shown:

$$\tan\delta = \frac{\text{change in elevation}}{\text{map distance}} = \frac{60'}{104'} = 0.57$$

$$0.57 = \tan 30^\circ,\ \delta = 30^\circ$$

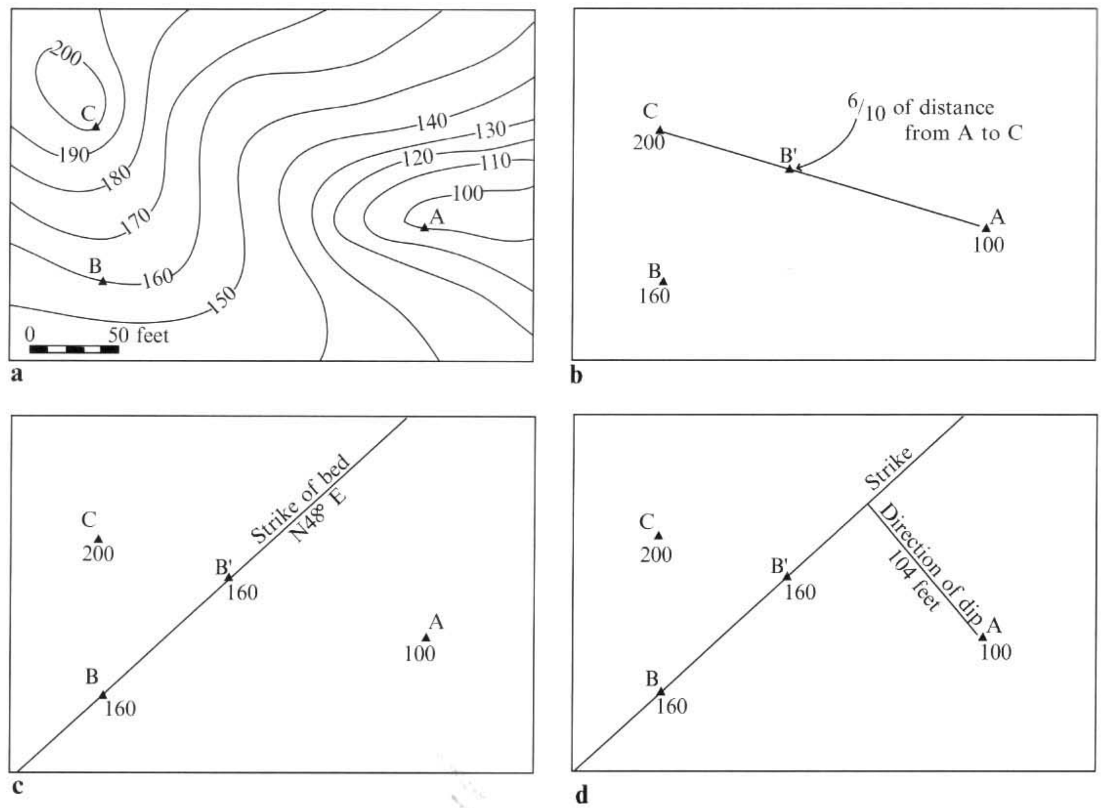

Fig. 2.9 Solution of a three-point problem using a combination of graphical and trigonometric techniques. (a) Three coplanar points (A, B, and C) on a topographic map. (b) Location of a fourth point, B′, at the same elevation as point B. (c) Line B–B′ defines the strike of the plane. (d) Dip-direction 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, as follows:

1 Draw lines from the lowest of the three points to each of the other two points (Fig. 2.10a). 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. 2.10b), and determine their plunges:

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

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

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

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

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,

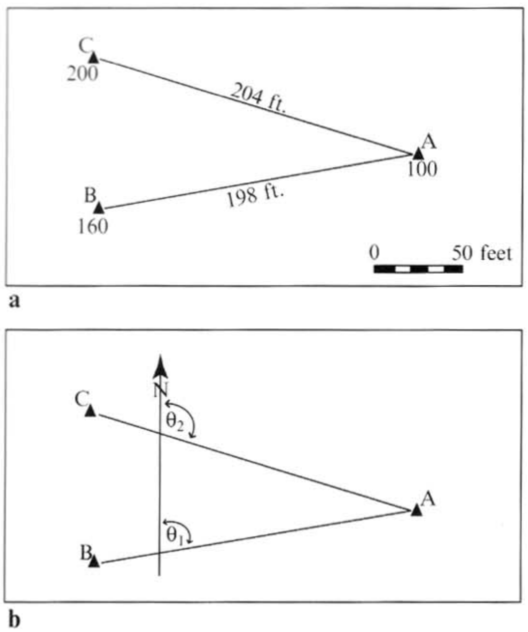

Fig. 2.10 Three-point problem converted to a two-apparent-dip problem. (a) Three coplanar points. Lines are drawn to the lowest of the three points from the other two points. (b) Apparent-dip directions θ_1 and θ_2.

as in Fig. 2.9a. 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 (Fig. 2.9b,c).
2 Find the true dip as described above under the three-point problem.
3 Draw structure contours parallel to the line B–B′ (Fig. 2.9c). 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. 2.11a). Point B is at an elevation of 160 ft, which is conveniently also the elevation of a topographic contour. Points on the bedding plane with known elevations (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 changes dip slightly, adjustments can constantly be made on the structure-contour map. Figure 2.11b shows the completed structure-contour map for this example.
4 Superimpose the structure-contour map and the topographic map (Fig. 2.11c). Every point where a structure contour crosses a topographic contour of equal elevation 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. Connect the points of intersection to display the outcrop pattern on the topographic map (Fig. 2.11d).

This same technique can be used to locate a second surface that is parallel to the first. Suppose that the contact shown in Fig. 2.11d 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 as follows:

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. 2.12a, 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. 2.12b).

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. 2.13a, for example, three attitudes

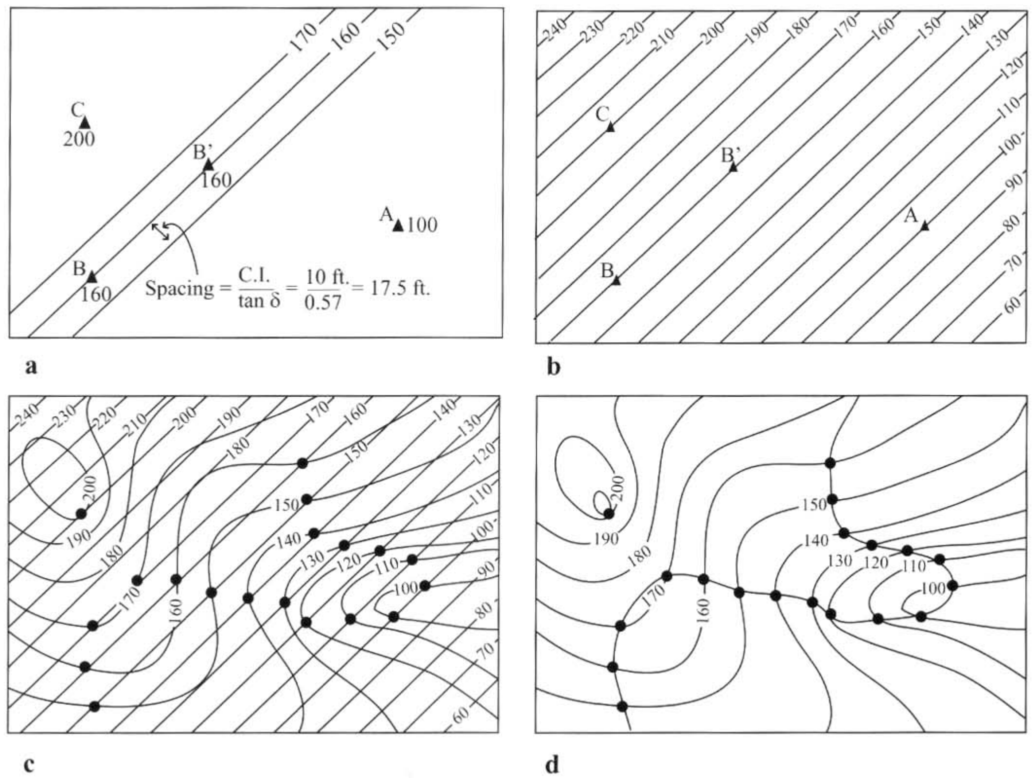

Fig. 2.11 Determination of outcrop pattern using structure contours. (a) Three structure contours on a base map (from Fig. 2.9c). (b) Structure-contour map. (c) Structure-contour map superimposed on a topographic map. (d) Outcrop pattern of a plane on a topographic map.

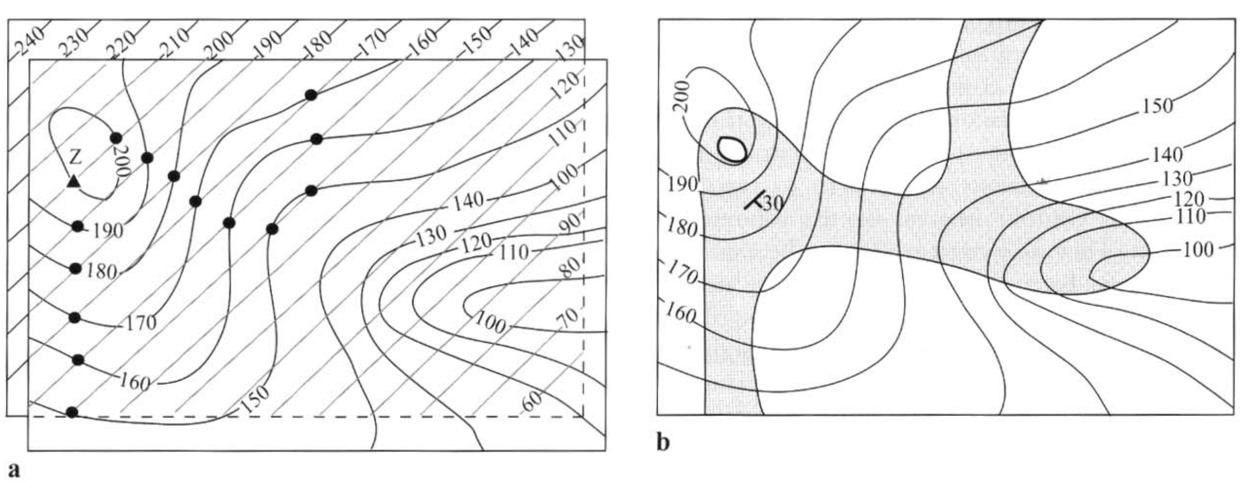

Fig. 2.12 (a) Structure-contour map from Fig. 2.11 shifted such that the 200-ft structure contour lies on point Z. Point Z is a point where the bottom of a layer is exposed. The top of this same layer is exposed at points A, B, and C from Fig. 2.9a. (b) Outcrop pattern of this layer, which dips 30° to the southeast.

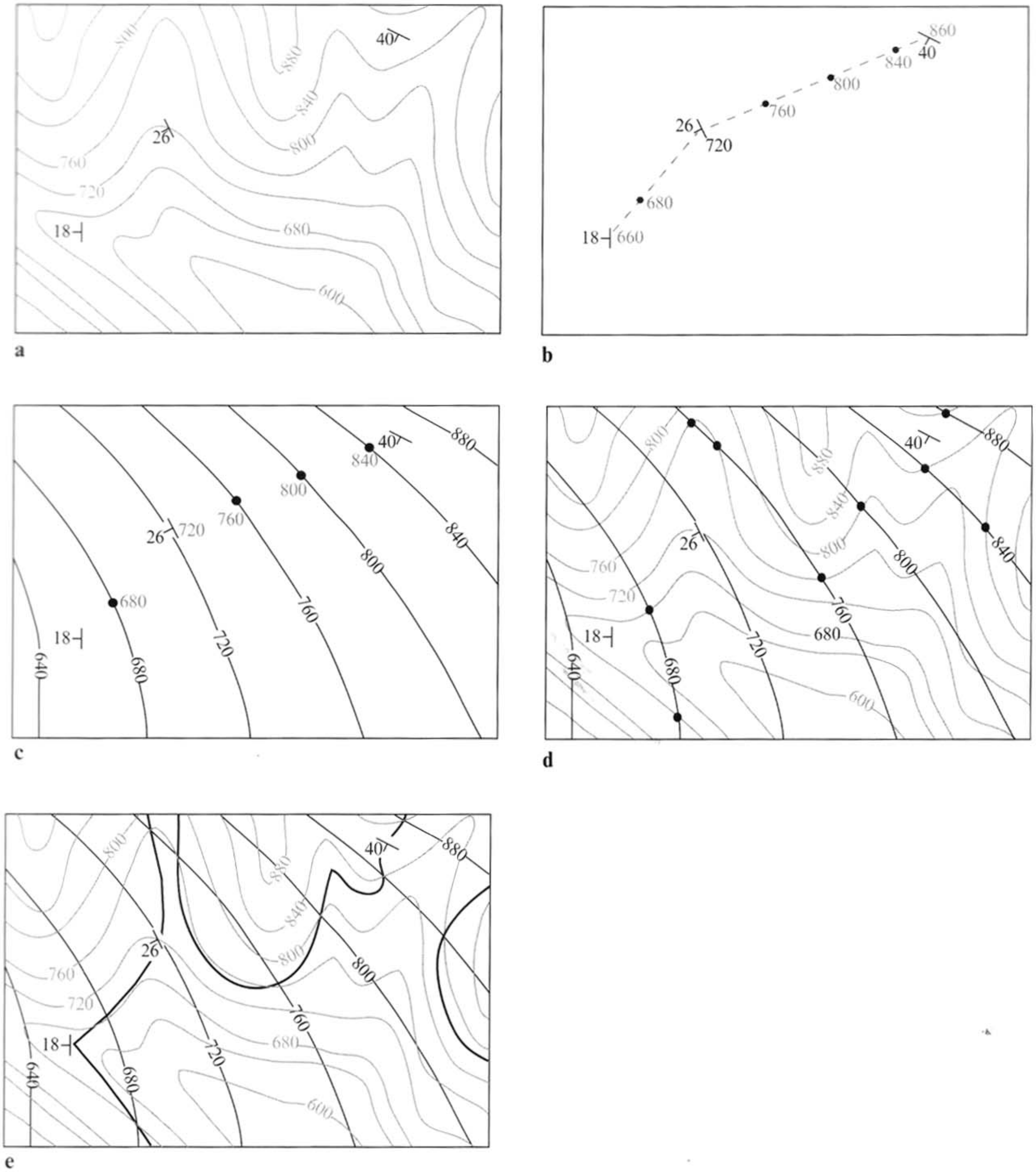

Fig. 2.13 Determination of outcrop pattern of a gently folded surface using structure contours. (a) Attitude of a gently folded marker bed at three points on a topographic map. (b) Interpolation of elevations between points of known elevation. (c) Structure-contour map of a gently folded bed. (d) Structure-contour map superimposed on topographic base. (e) Inferred outcrop pattern of marker bed.

of a marker bed 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:

1 Arithmetically interpolate between the known elevation points to locate the necessary elevation points on the surface (Fig. 2.13b).
2 Draw smooth parallel structure contours parallel to the strikes at the outcrop points (Fig. 2.13c).
3 Superimpose the structure contour map and the topographic map, and mark the points where contours of equal elevation intersect (Fig. 2.13d).
4 Connect these intersection points to produce the outcrop map (Fig. 2.13e).

Bree Creek Quadrangle map

Beginning in Chapter 3, many of the exercises in this book will deal with the structures of the mythical Bree Creek Quadrangle. A geologic map of this quadrangle, copied from the original map that Aragorn smuggled out of the Mines of Moria, is found in the back of this structure manual. This map records a variety of structures and structural relationships, and it will provide you with problems of appropriate complexity throughout the course. Before continuing on to Chapter 3, lightly color the Bree Creek Quadrangle 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 rock units that consistently occur adjacent to one another on the map. Because you will be using this map often, it is important that you treat it carefully.