6

Folds

OBJECTIVES

Describe the orientation and geometry of folds

Classify folds on the basis of dip isogons

Chapters 1 through 5 have been devoted to various techniques of structural analysis; now it is time to use the techniques on folded and faulted rocks. Chapter 4 included techniques for drawing vertical structure sections of folded and faulted rocks, but the emphasis was on the mechanics of drawing the structure sections rather than on the structures themselves. Chapters 6 through 10 are devoted to an analysis of folds and faults.

An understanding of the formation of geologic structures begins with a precise description of the structures themselves. Listed below are the principal terms used to describe the geometric elements of folds.

Hinge point The point of minimum radius of curvature on a fold (Figs 6.1a and 6.2a).

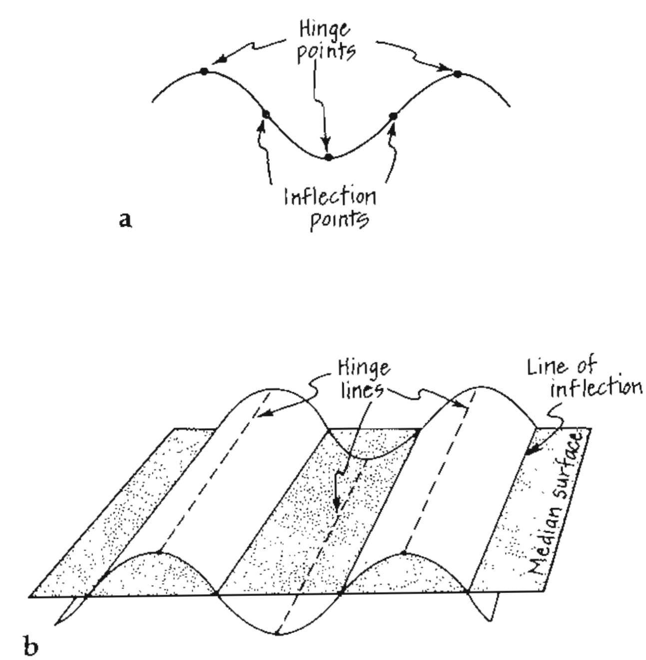

Fig. 6.1 Some terms for describing the geometry of folds. (a) Profile view. (b) Block diagram.

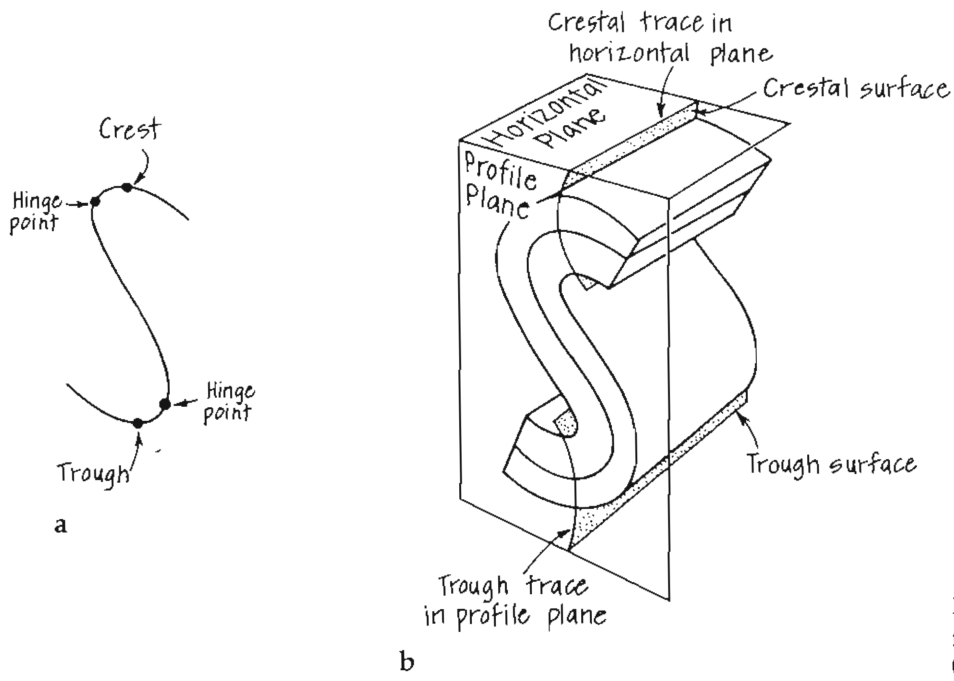

Fig. 6.2 More terms for describing the geometry of folds. (a) Profile view. (b) Block diagram.

Hinge line The locus of hinge points on a folded surface (Fig. 6.1b).

Inflection point The point on a fold where the rate of change of slope is zero, usually chosen as the midpoint of each straight section (Fig. 6.1a).

Line of inflection The locus of inflection points of a folded surface (Fig. 6.1b).

Median surface The surface that joins the successive lines of inflection of a folded surface (Fig. 6.1b).

Crest and trough The high and low points, respectively, of a fold, usually in reference to folds with gently plunging hinge lines (Fig. 6.2a).

Crestal surface and trough surface The surfaces joining the crests and troughs, respectively, of nested folds (Fig. 6.2b).

Crestal trace and trough trace The lines representing the intersections of the crestal and trough surfaces, respectively, with another surface, usually the surface of the earth (Fig. 6.2b).

Cylindrical fold A fold generated by a straight line moving parallel to itself in space (Fig. 6.3a).

Noncylindrical fold A fold that cannot be generated by a straight line moving parallel to itself in space (Fig. 6.3b).

Fold axis The straight line that generates a cylindrical fold. Unlike the hinge line, the fold axis is not a specific line but rather a hypothetical line defined by its attitude. Only cylindrical folds, or cylindrical segments of folds, have fold axes.

Symmetric folds Folds that meet the following criteria: (1) the median surface is planar, (2) the axial plane is perpendicular to the median surface, and (3) the folds are bilaterally symmetrical about their axial planes (Fig. 6.4a).

Asymmetric folds Folds that are not symmetric (Fig. 6.4b). Limbs of asymmetric folds are of unequal length.

Profile plane A plane perpendicular to the fold axis (Fig. 6.5).

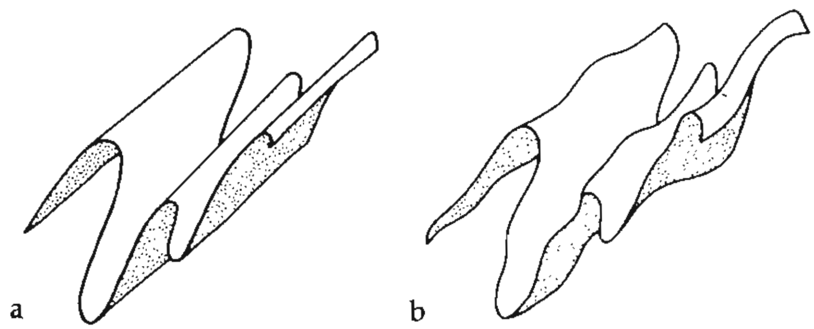

Fig. 6.3 (a) Cylindrical folds and (b) noncyclindrical folds.

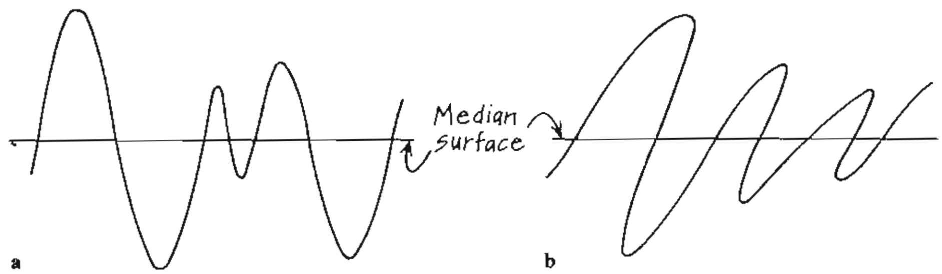

Fig. 6.4 (a) Symmetric and (b) asymmetric folds with varying amplitudes.

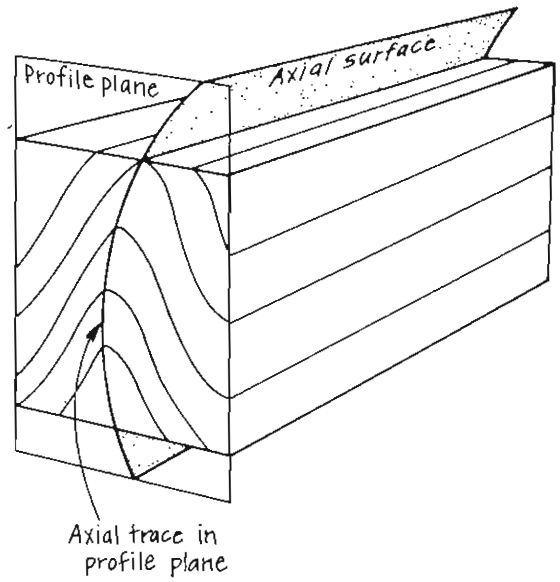

Fig. 6.5 Profile plane and axial surface of folds.

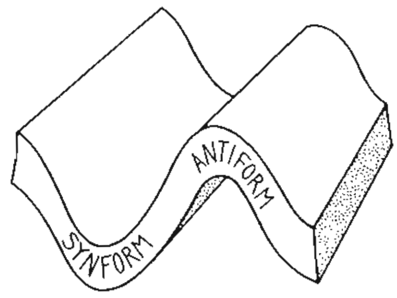

Fig. 6.6 Block diagram showing synform and antiform.

Axial surface The surface joining the hinge lines of a set of nested folds (Fig. 6.5). Whether or not the folds are cylindrical, the axial surface may or may not be planar.

Axial plane A planar axial surface.

Axial trace The line representing the intersection of the axial surface and another surface (Fig. 6.5).

Synform A fold that closes downward (Fig. 6.6).

Antiform A fold that closes upward (Fig. 6.6).

Syncline A fold with younger rocks in its core (Fig. 6.7).

Anticline A fold with older rocks in its core (Fig. 6.7).

Overturned fold A fold in which one limb, and only one limb, has been tilted more than 90°, resulting in both limbs dipping the same direction (Fig. 6.8).

Vertical fold A fold whose hinge line is vertical or nearly so (Fig. 6.9a).

Reclined fold A fold whose axial surface is inclined and whose hinge plunges down the dip of the axial surface (Fig. 6.9b).

Recumbent fold A fold whose axial surface is horizontal or nearly so (Fig. 6.9c).

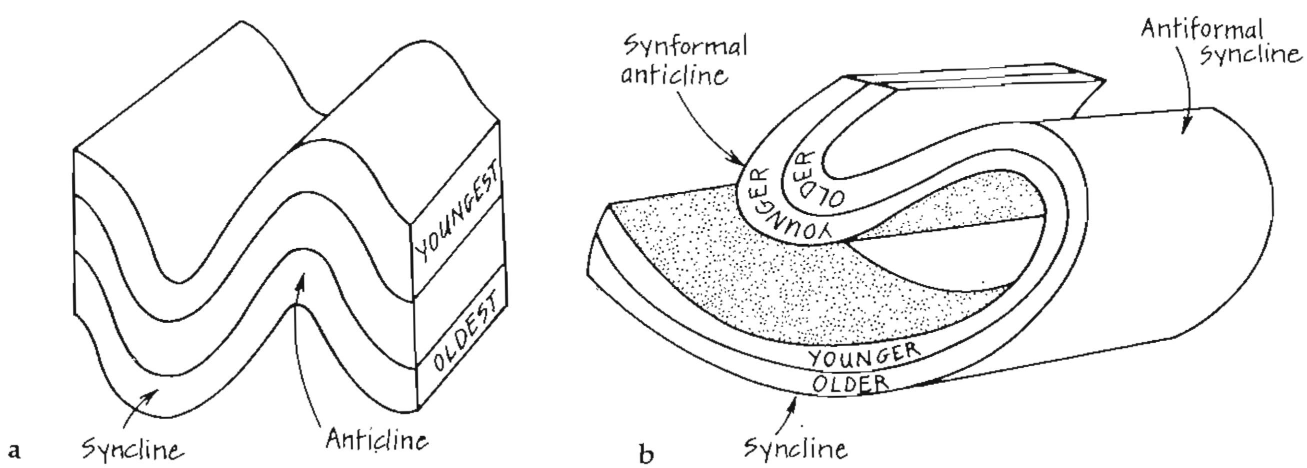

Fig. 6.7 Block diagrams showing (a) synclines and anticlines and (b) how they can differ from synforms and antiforms.

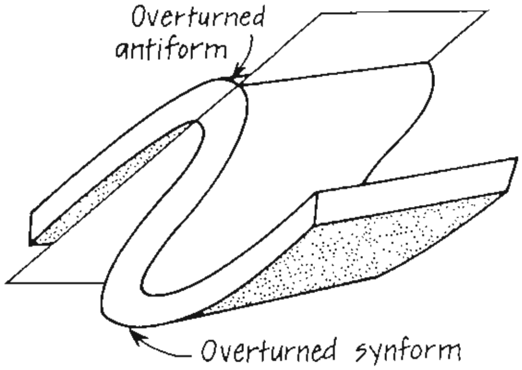

Fig. 6.8 Block diagram showing overturned folds.

Interlimb angle The angle between adjacent fold limbs. Figure 6.10 shows terms used to describe this angle.

> Problem 6.1
> In Fig. 6.11 is a block model to be cut out and folded. Describe the folds in this model. Your description should be one concise complete sentence and should include whether the folds are cylindrical or noncylindrical, symmetric or asymmetric, the attitude of the fold axis and the axial surface, and the interlimb angle. Finally, draw and label the crestal, trough, and axial traces of all folds.

Fold classification based on dip isogons

It was once thought that there are two basic processes for the development of folds in rocks and two types of folds

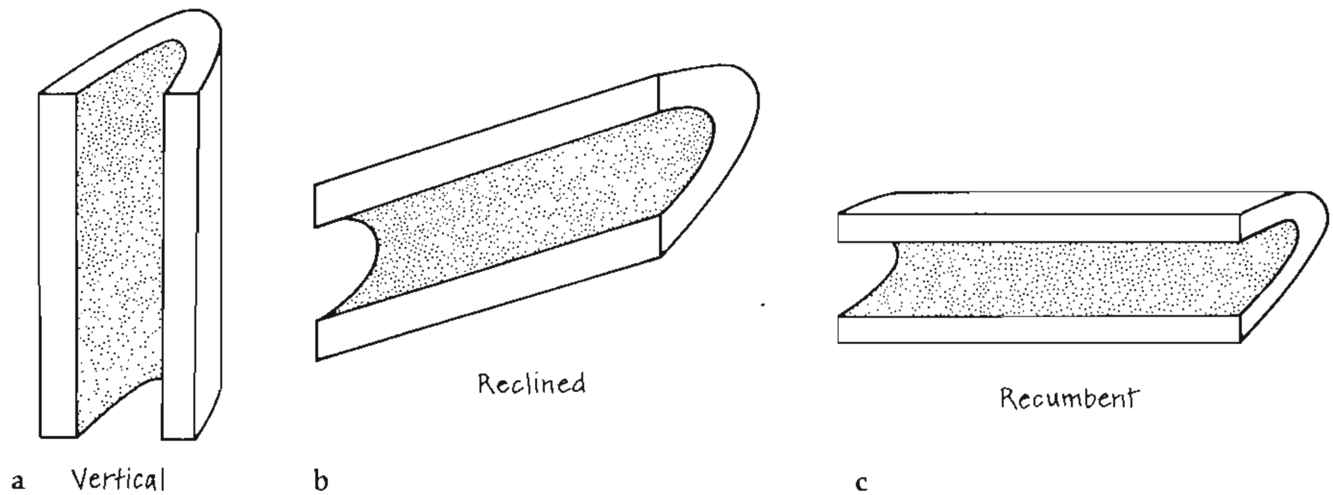

Fig. 6.9 (a) Vertical, (b) reclined, and (c) recumbent folds.

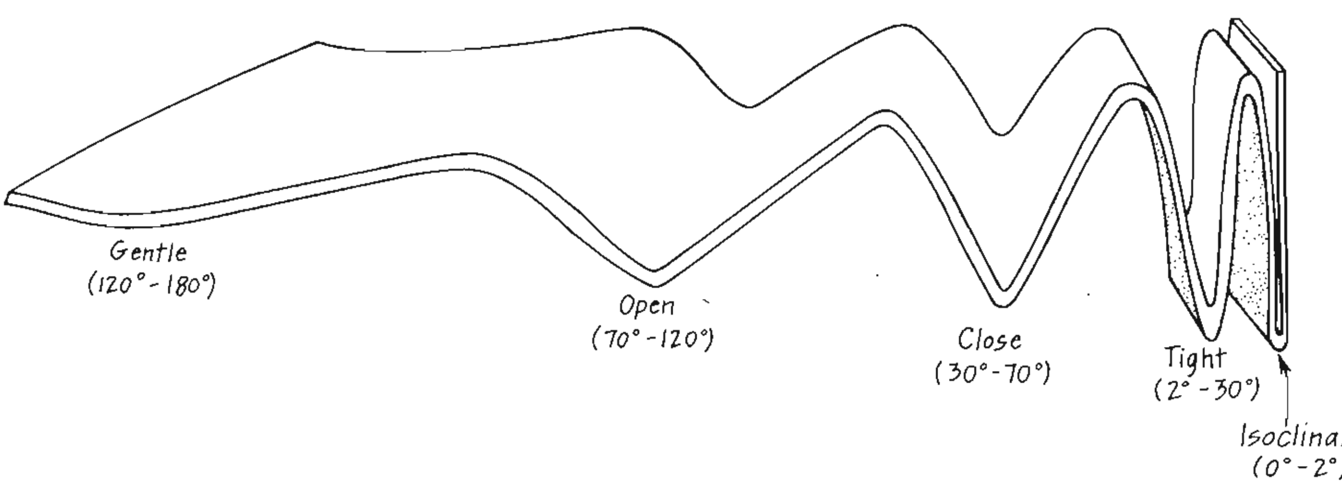

Fig. 6.10 Terms used for describing interlimb angles.

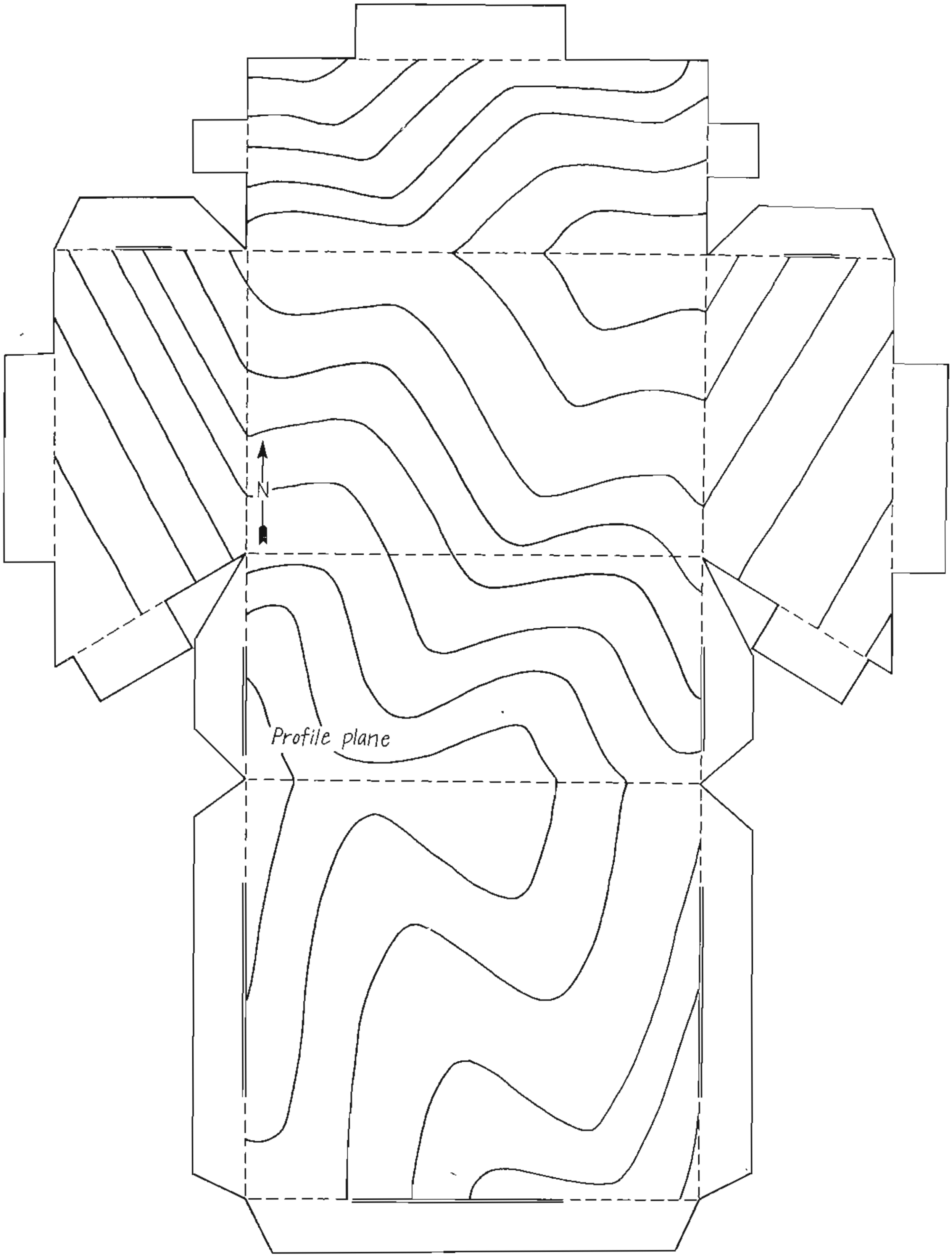

Fig. 6.11 Block model to be cut out and folded for use in Problem 6.1.

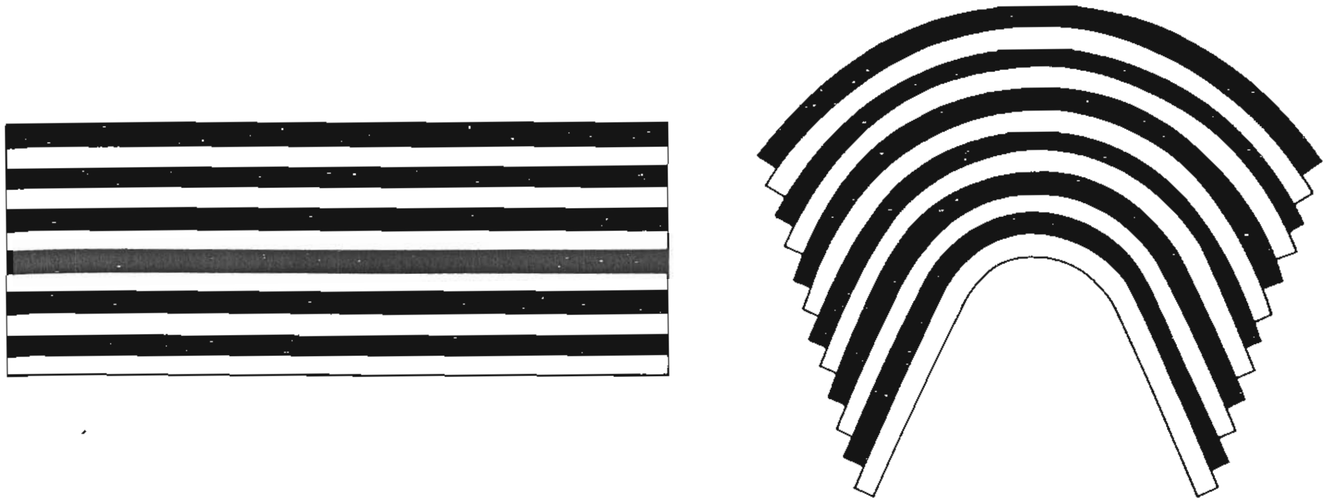

Fig. 6.12 Development of concentric folds by flexure-slip folding.

produced. The first process, *flexure-slip folding*, involves slip between adjacent layers during buckling and bending (Fig. 6.12). The second process, *passing folding*, involves slip on surfaces that are at an angle to the layering in the rock (Fig. 6.13). Flexure-slip, it was thought, produces *concentric folds* (also called *parallel folds*) such as the ones you drew using the arc method in Chapter 4 (Problem 4.2). Folds produced by passive folding were called *similar folds*. Note that the vertical lines in Fig. 6.13 are *not* slip planes, but are axial-planar cleavages produced largely by the mechanism of pressure solution.

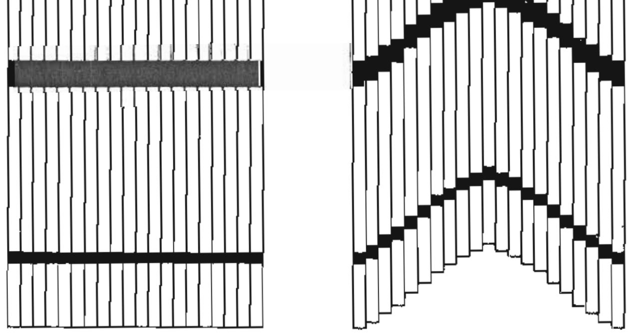

Fig. 6.13 Development of similar folds by passive folding.

These two categories of fold were first described in 1896 and, though they may be intellectually satisfying, they have not proved to be useful for most naturally occurring folds. A more promising fold classification based on *dip isogons* was proposed by J.G. Ramsay (1967) and has become widely used. This classification is purely geometric and says nothing about process.

Dip isogons are lines connecting points of equal dip on adjacent folded surfaces. They are constructed as shown in Fig. 6.14. The axial plane trace is drawn on a profile view of the fold, and another line is drawn perpendicular to the axial plane trace. With a protractor, points along the folded surface are located whose tangents intersect the horizontal line at specific angles (Fig. 6.14a). A set of points on adjacent folded surfaces permits the drawing of dip isogons (Fig. 6.14b).

From the characteristics of the dip isogons three classes of fold are defined (Fig. 6.15). Class 1 folds have dip isogons that converge toward the core of the fold. Class 2 folds have dip isogons that are parallel to the axial trace. Class 3 folds have dip isogons that diverge toward the core of the fold. Class 1 folds are subdivided further into class 1A (strongly convergent isogons), class 1B (concentric folds with moderately convergent isogons), and class 1C (weakly convergent isogons). In this classification system concentric folds are class 1B folds and similar folds are class 2 folds.

Problem 6.2

Figure 6.16 is a sketch of the profile view of a set of folds exposed in the face of a cliff. Draw dip isogons at 10° intervals for each of the three layers. Indicate the class of each layer.

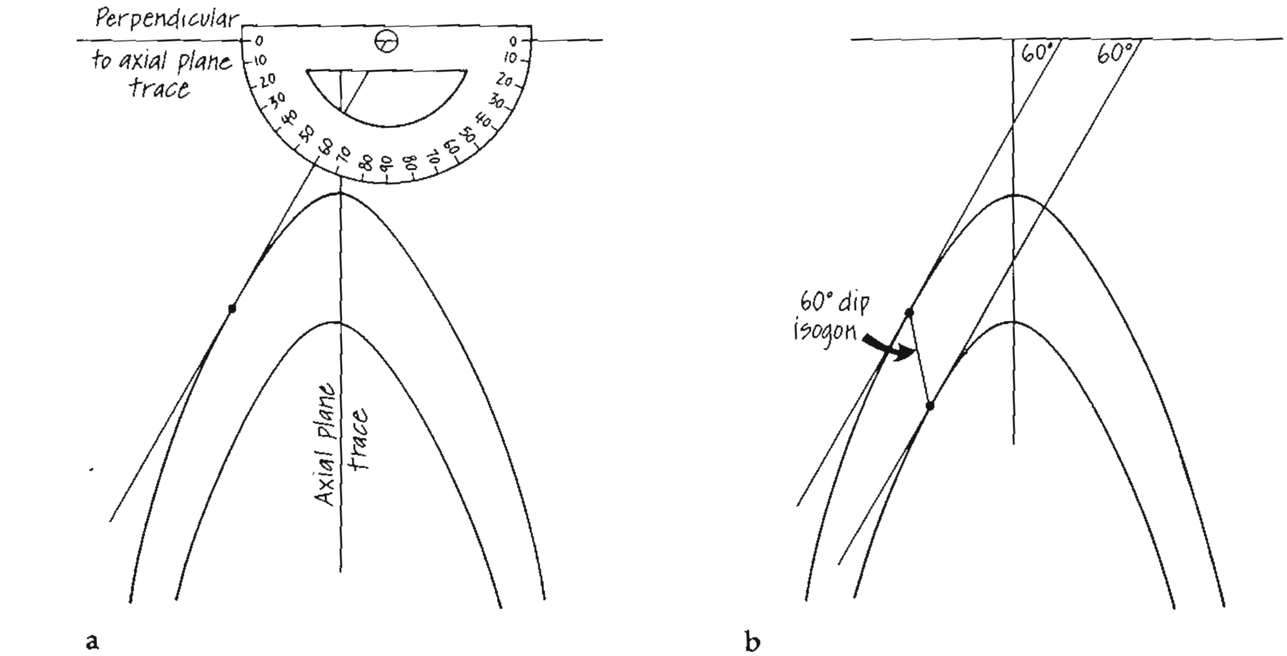

Fig. 6.14 Construction of dip isogons. (a) Drawing tangents at a particular angle. (b) Drawing the isogon.

> **Problem 6.3**
> Figure 6.17 contains photographs of four rock slabs. Without actually drawing dip isogons try to determine what types of fold are represented in each slab. Then tape a piece of tracing paper over the photographs and draw a few dip isogons on each fold. Indicate the class to which each fold belongs.

Outcrop patterns of folds

Figures 6.18 and 6.19 show sets of folds in which the outcrop patterns are identical, but the folds are plunging in opposite directions. Clearly, outcrop pattern alone is not sufficient to determine the orientation of a fold. The direction and amount of dip of axial surface and plunge of fold axis must also be determined. The outcrop pattern of beds in symmetric folds with vertical axial surfaces, such as those in Figs 6.18 and 6.19, are symmetrical on

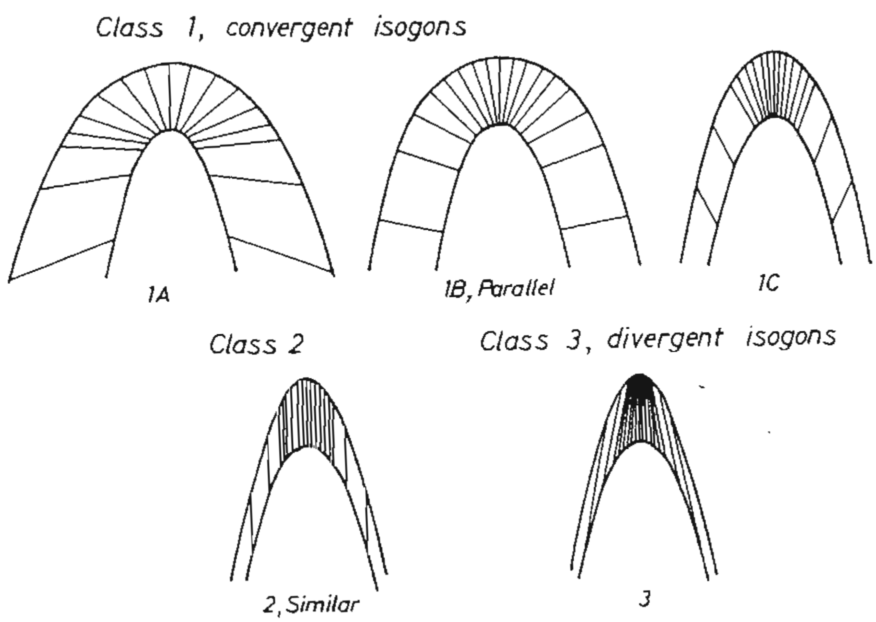

Fig. 6.15 Classification of folds based on the characteristics of dip isogons. After Ramsay (1967).

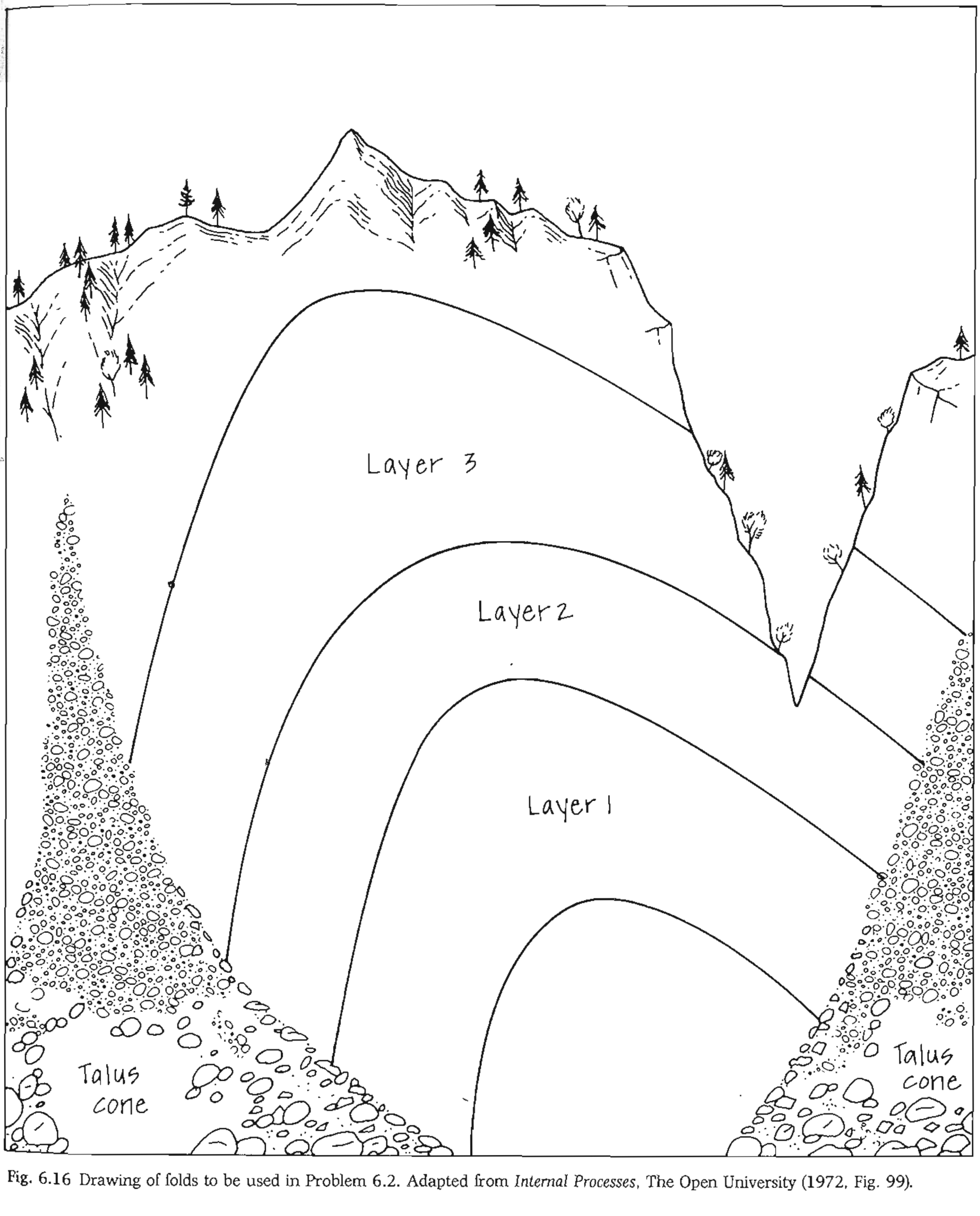

Fig. 6.16 Drawing of folds to be used in Problem 6.2. Adapted from *Internal Processes*, The Open University (1972, Fig. 99).

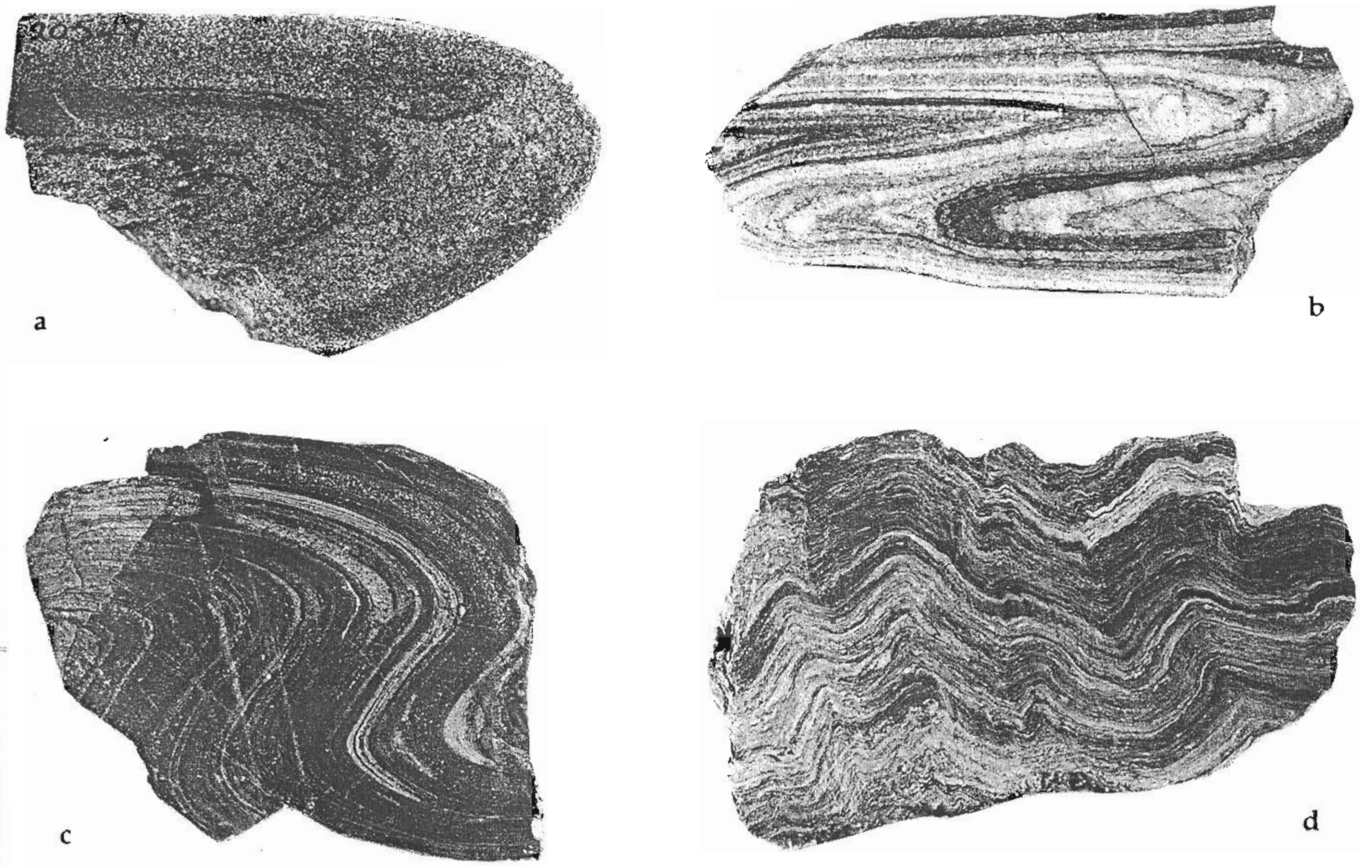

Fig. 6.17 Slabs of folds for use in Problem 6.3. From the collection of O.T. Tobisch.

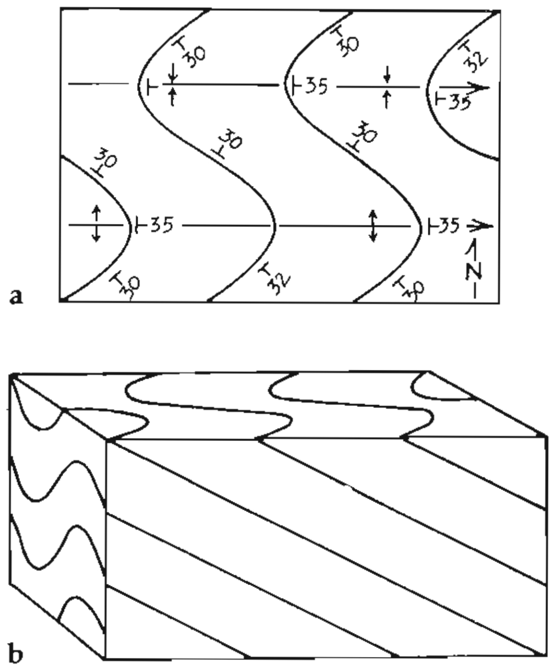

Fig. 6.18 Eastward-plunging folds. (a) Map view. (b) Block diagram.

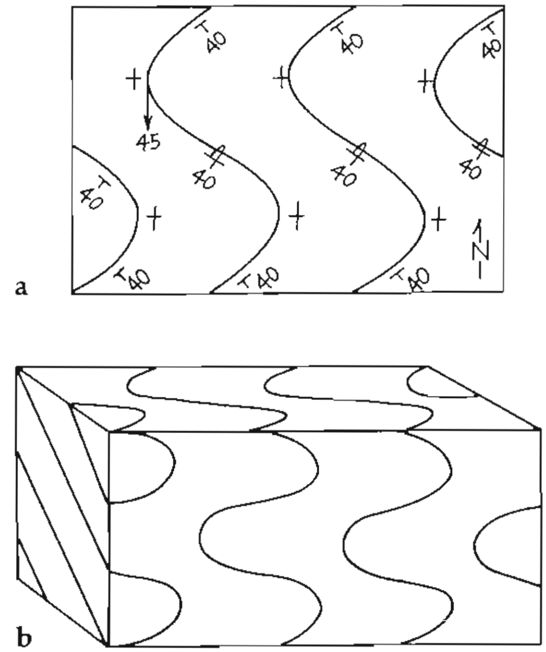

Fig. 6.20 Southward-plunging overturned folds. (a) Map view. (b) Block diagram.

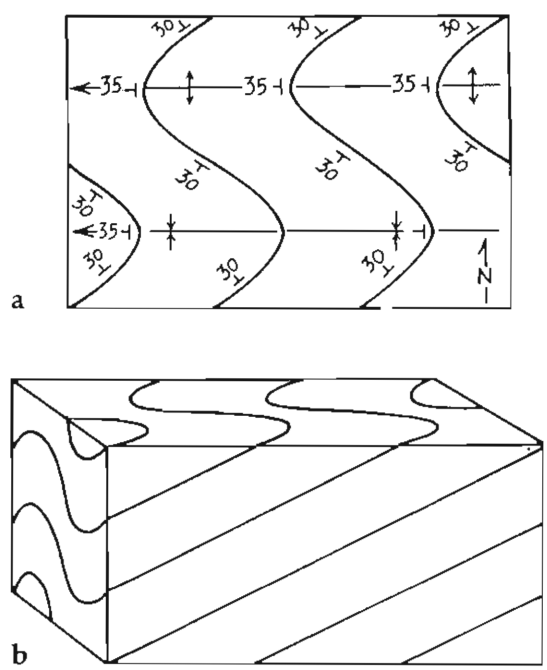

Fig. 6.19 Westward-plunging folds. (a) Map view. (b) Block diagram.

opposite sides of the crestal and trough traces. The crestal and trough traces of such folds are also axial traces, and the dip at the axial trace is equal to the plunge of the fold axis. The folds shown in Fig. 6.18 plunge 35° due east, and those in Fig. 6.19 plunge 35° due west.

Figure 6.20 shows an outcrop pattern identical to that in Figs 6.18 and 6.19, but here the folds are overturned and plunging 45° south. Fold a piece of paper and tilt it to simulate one of the folded layers in Fig. 6.20. Notice that these folds, and all overturned folds, contain vertical beds—the strike of the vertical beds in overturned folds is parallel to the trend of the fold axis.

Because the folds in Fig. 6.20 have no unique high and low points, they have no crestal and trough traces. In most cases of plunging folds with tilted axial surfaces, the crestal and trough traces are not axial traces. Sometimes the crestal and trough traces are not even parallel to the axial traces.

Figure 6.21 shows a set of folds whose axial surface dips northwest, whose axis plunges 20° north, and whose crestal and trough traces are clearly not axial traces. The axial traces of such folds can only be reliably located in the profile plane.

For any cylindrical fold, the dip of the bedding at the crestal or trough trace is the same as the trend and plunge of the fold axis. So the crestal and trough traces are the most meaningful lines to be drawn on map outcrop patterns of folds.

Down-plunge viewing

Features of folds are best examined in profile view, when your line of sight is *parallel to the fold axis*. This is apparent in the block model from Problem 6.1. A profile plane need not be available, however, to obtain a profile view. Turn the block model from Problem 6.1 around and look

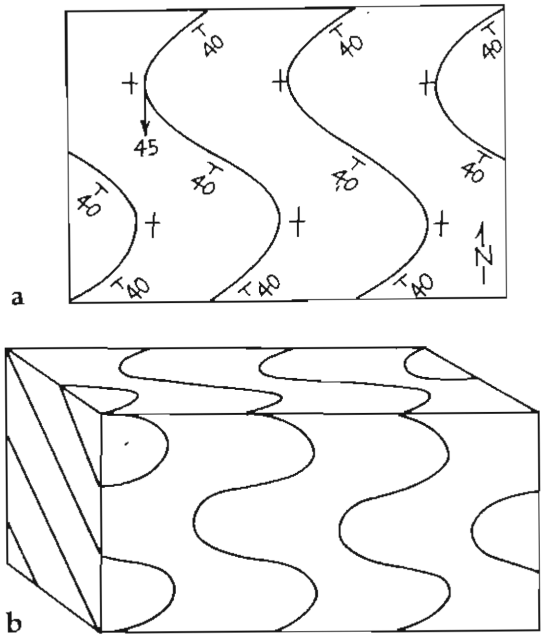

Fig. 6.21 Example of folds whose crestal and trough traces are not axial traces. (a) Map view. (b) Block diagram.

parallel to the axis but on the opposite side of the block from the profile plane (Fig. 6.22). The folds should appear the same as in the profile plane. This technique, in which you look down the plunge (or up the plunge in this case), is an effortless way to obtain a profile view of a fold even in irregular terrain. On a map where the trend and plunge of a fold are known, you merely place your eye so that your line of sight intersects the map at approximately the same angle as the plunge of the fold axis. Try it on the folds of the Bree Creek Quadrangle. A technique for constructing the profile view of a fold exposed in flat terrain is explained in Chapter 7 (see Fig. 7.6).

Problem 6.4

On each geologic map in Fig. 6.23 draw the crestal and/or trough trace with the appropriate symbol to indicate the type of fold and attitude of the fold axis (symbols are in Appendix F). Fold a piece of paper to help you visualize each fold's shape and orientation.

Determine the exact trend and plunge of the fold axis on each map and write it in the space provided.

Problem 6.5

Figure 6.24 shows the sides and top of a block model of folded layered rocks. Cut it out, and fold it into a block. Look at the block from different angles until you see a set of cylindrical folds. At this point you are looking down-plunge. If you have trouble, try coloring one or more units.

1 Make a drawing of the block as it appears in the down-plunge view, showing the folds.

2 What is the approximate attitude of the axial surfaces?

3 What is the approximate attitude of the fold axis?

4 By comparing the folds with those in Fig. 6.15, determine the classes of folds in the block model and label each fold on your drawing accordingly.

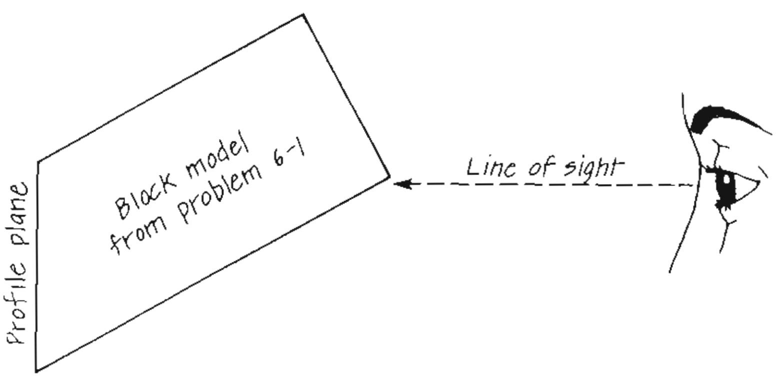

Fig. 6.22 Illustration of down-plunge viewing technique for obtaining a profile view of a fold.

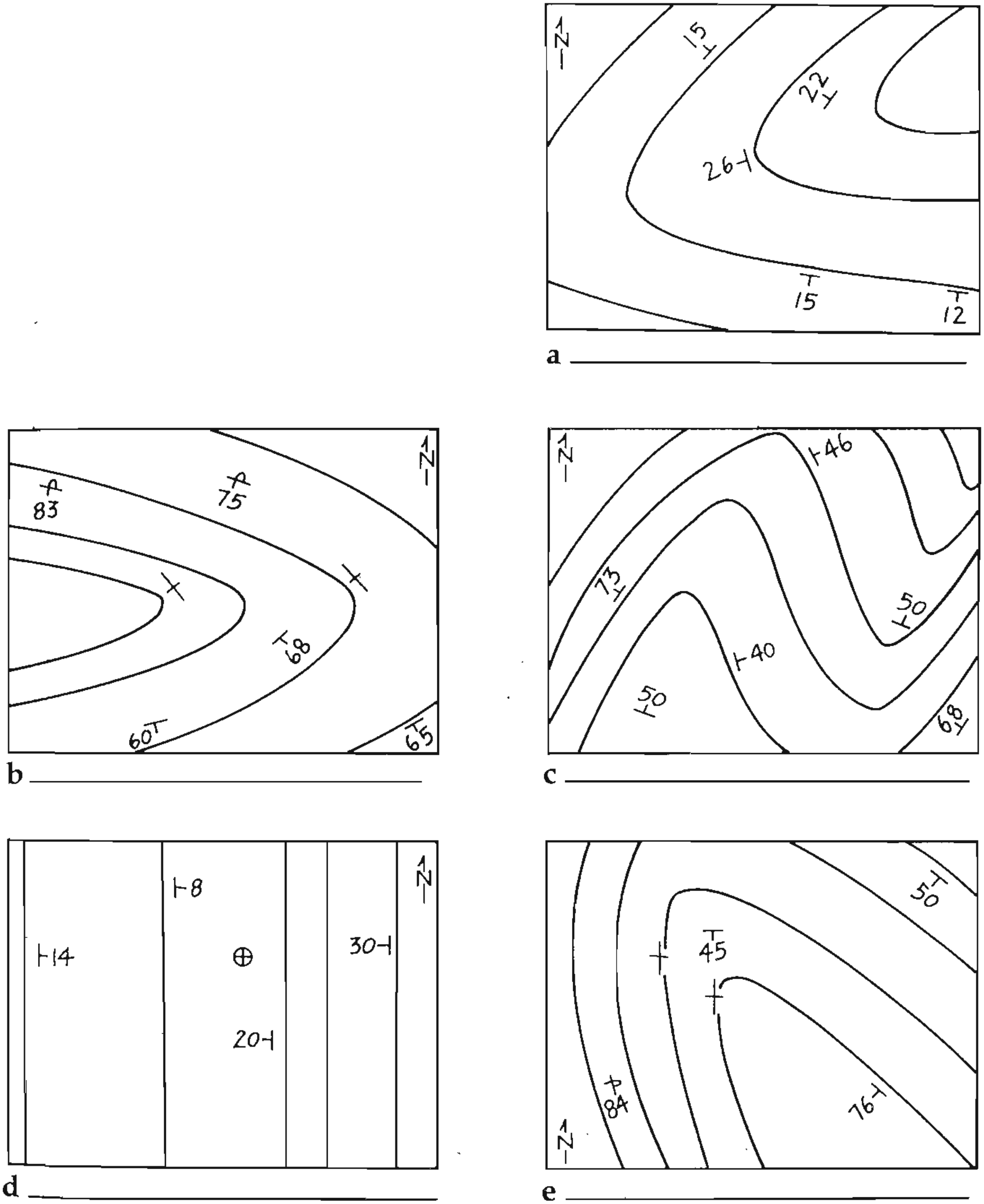

Fig. 6.23 Geologic maps to be used in Problem 6.4.

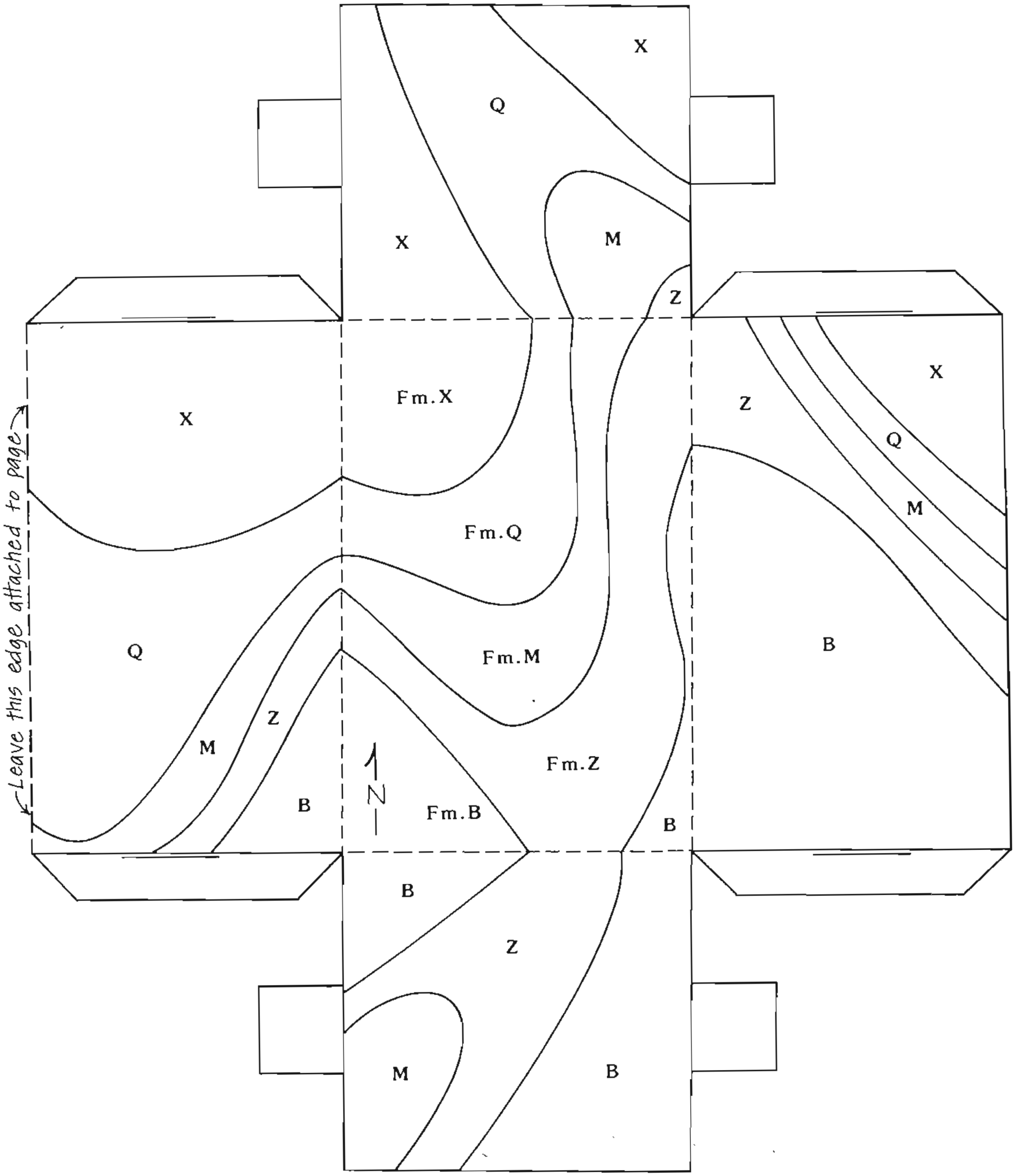

Fig. 6.24 Layout of block diagram to be constructed in Problem 6.5. After Dahlstrom (1954) in Whitten (1966).