3

Interpretation of Geologic Maps

Objectives

- **Determine the exact attitude of a plane from its outcrop pattern.**
- **Determine stratigraphic thickness from outcrop pattern.**
- **Determine the nature of contacts from outcrop patterns and attitudes.**
- **Construct a stratigraphic column.**

Every geologic project relies on the geologic maps available at the time of the investigation. You may be asked to check a geologic map for accuracy or to map an area in greater detail. Even if your particular project does not involve direct fieldwork, it is essential that you have the skills necessary to interpret published geologic maps.

Geologic maps are drawn primarily from observations made on the earth's surface, often with reference to topographic maps, aerial photographs, or satellite images. The purposes of a geologic map are to show the surface distributions of rock units, the locations of the interfaces or *contacts* between adjacent rock units, the locations of faults, and the orientations of various planar and linear elements. Standard geologic symbols used on geologic maps are shown in Appendix F.

Some aspects of constructing a geologic map, such as the defining of rock units, are quite subjective and are done on the basis of the geologist's interpretations of how certain rocks formed. This being the case, many neatly inked, multicolored maps belie the uncertainty that went into their construction.

Accompanying this manual is a geologic map of the Bree Creek Quadrangle. An important teaching strategy of this book is to have you analyze the map in detail throughout the course, one step at a time, and then to have you synthesize it all into a cohesive structural history. The analysis begins with this chapter; the synthesis will come in Chapter 11.

It is important to keep in mind that topographic and geologic maps are projections onto a horizontal surface. Therefore, distances measured on maps are horizontal distances ("as the crow flies"), not actual ground distances.

Determining exact attitudes from outcrop patterns

Because the strike of a plane is a horizontal line, any line drawn between points of equal elevation on a plane defines the plane's strike. Figure 3.1a is a geologic map with two rock units, Formation M and Formation X. The contact between these two rock units crosses several topographic contours. To find the strike of the contact, a straight

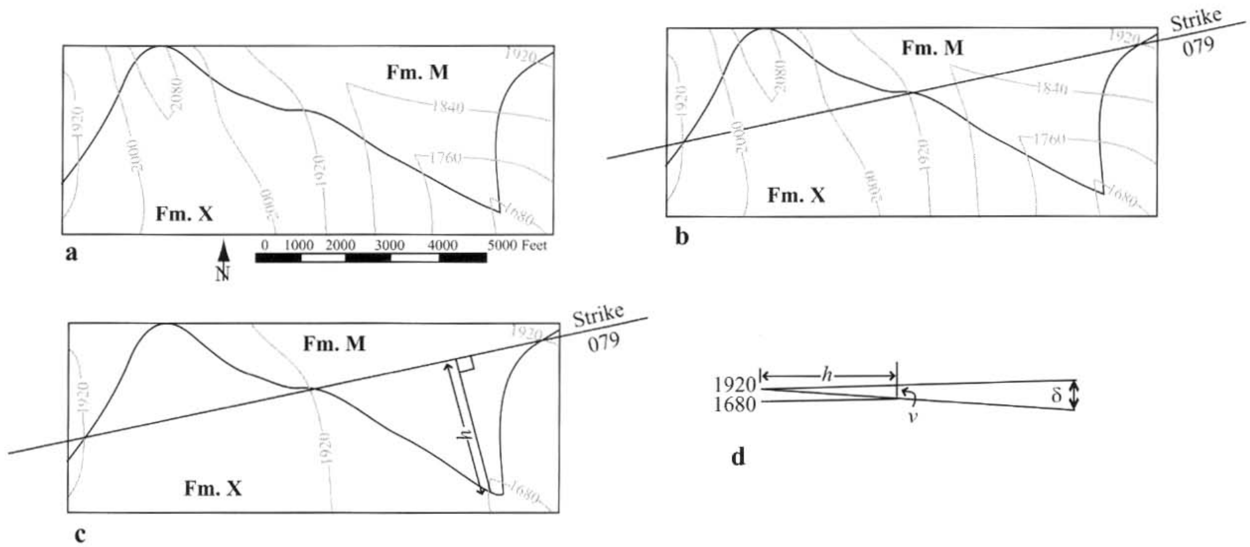

Fig. 3.1 Technique for determining the attitude of a plane from its outcrop pattern. (a) Contact between Formation M and Formation X. (b) The line connecting points of equal elevation defines strike. (c) A perpendicular is drawn to a point of contact at a different elevation. (d) Dip angle δ is found from tan δ = v/h.

line is drawn from the intersection of the contact with the 1920-ft contour on the west side of the map to the intersection of the contact with the 1920-ft contour on the east side of the map (Fig. 3.1b). The strike of this contact is thus determined to be 079°, as measured directly on the geologic map.

Remembering the rules of Vs from Chapter 2, it should be clear to you from the outcrop pattern in Fig. 3.1a that the beds dip toward the south. To determine the exact dip, draw a line that is perpendicular to the strike line from another point of known elevation on the contact. In Fig. 3.1c, a line has been drawn from the strike line to a point where the contact crosses the 1680-ft contour. The length of this line (h) and the change in elevation (v) from the strike line to this point yield the dip δ with the following equation (Fig. 3.1d):

$$\tan \delta = \frac{v}{h}$$

The solution to this example is:

$$\tan \delta = \frac{v}{h} = \frac{240}{3000} = 0.08$$
$$\delta = 5^\circ$$

This method for determining attitudes from outcrop patterns can be used only if the rocks are not folded.

Figure 3.2 shows the Neogene (Miocene and Pliocene) units of the northeastern block of the Bree Creek Quadrangle. Straight lines have been drawn connecting points of known elevation on the bottom contact of the Rohan Tuff, unit Tr. The strike, measured directly on the map with a protractor, is 344°, and the dip is 11°NE as determined by:

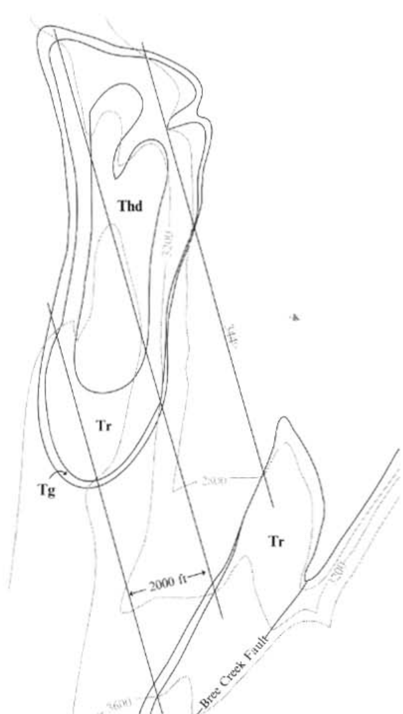

Fig. 3.2 Neogene units in the northeastern portion of the Bree Creek Quadrangle. Tg, Gondor Conglomerate; Thd, Helm's Deep Sandstone; Tr, Rohan Tuff.

$$\tan\delta = \frac{v}{h} = \frac{400}{2000} = 0.2$$
$$\delta = 11^\circ$$

But what is the attitude of the southern outcrop of the Rohan Tuff? Even though no two points of equal elevation can be found on the bottom contact, notice that the points of known elevation lie on the same straight lines drawn for the northern outcrop. This is strong evidence that the attitude of the southern outcrop of Rohan Tuff is exactly the same as that for the northern one. This kind of reasoning is typical of what must become routine when interpreting geologic maps. But become careful! This approach assumes that the base of the Rohan Tuff is planar. Many sedimentary and volcanic deposits have non-planar bases.

Solve Problem 3.1.

Determining stratigraphic thickness in flat terrain

If the attitude of a rock unit is known, it is usually possible to determine its approximate stratigraphic thickness from a geologic map. If a unit is steeply dipping, and if its upper and lower contacts are exposed on flat or nearly flat terrain, then the thickness is determined from the trigonometric relationships shown in Fig. 3.3.

$$t = h \sin\delta$$

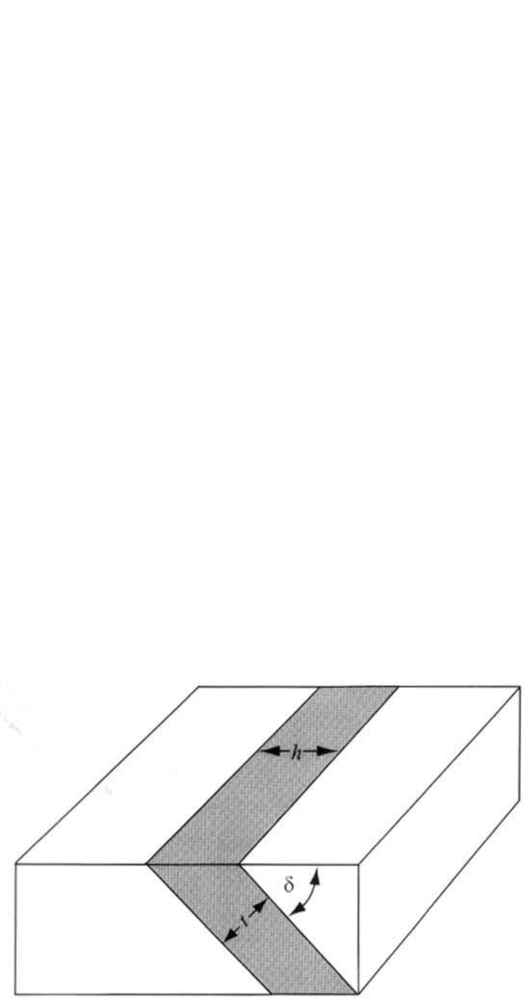

Fig. 3.3 Trigonometric relationships used for determining stratigraphic thickness t in flat terrain from dip δ and map width h.

where t is stratigraphic thickness, h is horizontal thickness (width in map view), and δ is dip.

Solve Problem 3.2.

Determining stratigraphic thickness on slopes

The thickness of layers exposed on slopes may be determined trigonometrically if, in addition to dip δ and map width h, the vertical distance v (i.e., difference in elevation) from the base to the top of the layer is known. Figure 3.4a shows a situation in which the layer and the slope are dipping in the same direction. Relevant angles have been added in Fig. 3.4b, from which the following derivation is made:

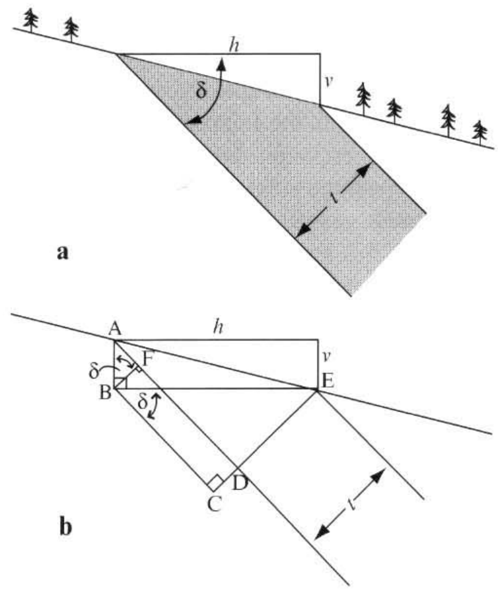

Fig. 3.4 Determining stratigraphic thickness t on slopes. (a) Lengths h and v and dip angle δ are needed to derive t. (b) Geometry of derivation.

$$t = \mathrm{DE} = \mathrm{CE} - \mathrm{CD}$$
$$\delta = \mathrm{CBE} = \mathrm{ABF}$$
$$\sin \mathrm{CBE} = \frac{\mathrm{CE}}{\mathrm{BE}} = \frac{\mathrm{CE}}{h}$$
$$\mathrm{CE} = h \sin \mathrm{CBE} = h \sin \delta$$
$$\cos \mathrm{ABF} = \frac{\mathrm{BF}}{\mathrm{AB}} = \frac{\mathrm{BF}}{v}$$
$$\cos \delta = \frac{\mathrm{BF}}{v} = \frac{\mathrm{CD}}{v}$$
$$\mathrm{CD} = v \cos \delta$$
$$t = h \sin \delta - v \cos \delta$$

This relationship applies to situations where bedding dips more steeply than topography and both dip in the same direction (right-hand example in Fig. 3.5). Similar trigonometric derivations can be used to show that in situations where bedding dips more gently than topography and both dip in the same direction (left-hand example in Fig. 3.5), the equation becomes:

$$t = v \cos \delta - h \sin \delta$$

Where bedding and topography dip in opposite directions (middle example of Fig. 3.5) the equation becomes:

$$t = h \sin \delta + v \cos \delta$$

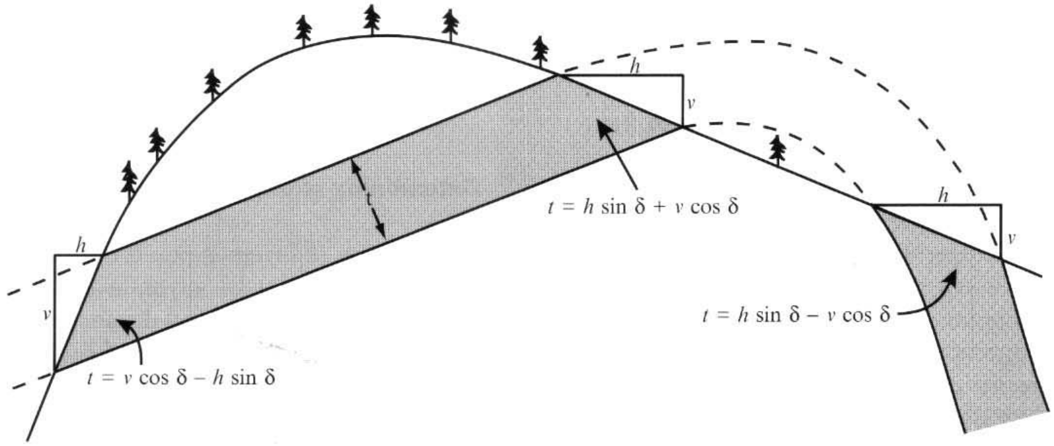

Fig. 3.5 Three combinations of sloping topography and dipping layers, with the appropriate formula for each.

Determining stratigraphic thickness by orthographic projection

In some situations the preceding trigonometric techniques for determining stratigraphic thickness cannot be used. On the Bree Creek map, for example, the 400-ft contour interval does not allow the difference in elevation from the base to the top of a unit to be precisely determined. In such cases orthographic projection can be used to determine stratigraphic thickness.

Suppose you want to determine the thickness of the Gondor Conglomerate (Tg) at Galadriel's Ridge in the Bree Creek Quadrangle. Begin by finding two points of equal elevation at the same stratigraphic level. A line between such points defines the strike (as discussed above). In Fig. 3.6a one such line is drawn through the top of Tg at 4800 ft, and another is drawn through the top of Tg at 4400 ft. The object of this construction is to draw a vertical cross-section view perpendicular to strike. This view will be folded up into the horizontal plane.

Line AB is drawn perpendicular to the two strike lines (Fig. 3.6a). This will represent the 4800-ft elevation line in the orthographic projection. A second line, CD, is now drawn, also perpendicular to the two strike lines. Line CD represents the 4400-ft elevation line. The distance between lines AB and CD is taken directly off the map legend. Next we draw line AD, which represents the eastward-dipping top of Tg in orthographic projection.

Repeating this same procedure with the bottom contact of Tg results in points W, X, Y, and Z (Fig. 3.6b). Line WZ represents the base of Tg in orthographic projection, and the thickness can be measured directly off the diagram. The precision is primarily limited by the scale of the map. In this example Tg can be measured to be about 100 ft thick.

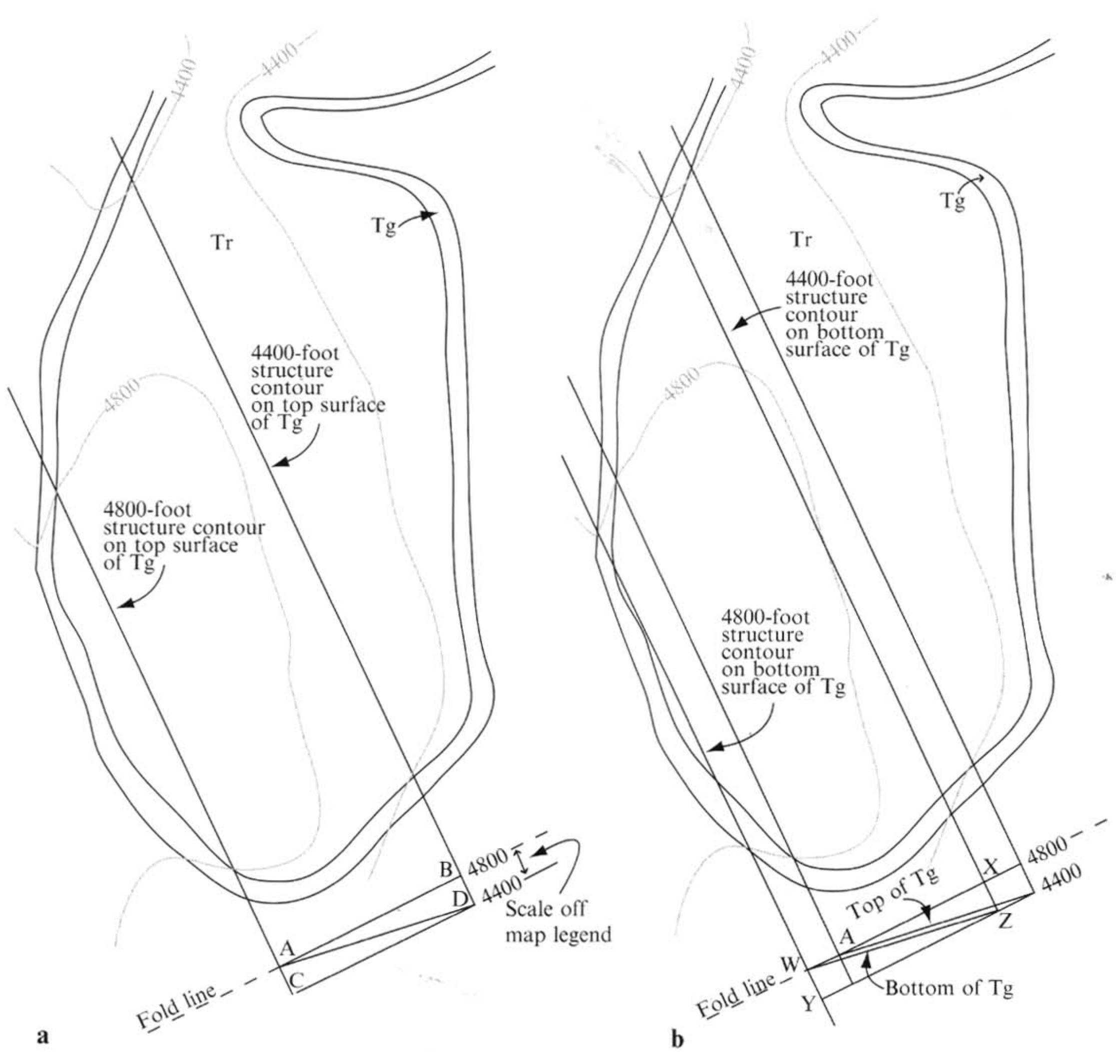

Fig. 3.6 Technique for determining stratigraphic thickness by orthographic projection. (a) Plotting top surface. (b) Plotting bottom surface and deriving the thickness.

Determining the nature of contacts

A contact is the surface between two contiguous rock units. There are three basic types of contacts: (1) depositional, (2) fault, and (3) intrusive. It is important to be able to interpret the nature of contacts from geologic maps whenever possible. Following are a few map characteristics of each type of contact.

Where sedimentary or volcanic rocks have been deposited on top of other rocks, the contact is said to be *depositional*. If adjacent rock units have attitudes parallel to one another, and there is no evidence of erosion on the contact, then the contact is a *conformable* depositional contact. On the map, conformable contacts display no abrupt change in attitude across the contact. In Fig. 3.7, for example, although the dips in Formation X are steeper than those in Formation Y, there is a gradual steepening across the contact. A cross-section view is shown below the map view.

If a demonstrable surface of erosion or non-deposition separates two rock units then the contact is an *unconformity* — a buried erosion surface. There are three basic types of unconformities (Fig. 3.8): (1) nonconformities (sediments deposited on crystalline rock), (2) angular unconformities (sediments deposited on deformed and eroded older sediments), and (3) disconformities (sediments deposited on eroded but undeformed older sediments). Notice that a disconformity would be indistinguishable from a conformable contact on a geologic map because in both cases the beds are parallel across the contact. Disconformities can only be recognized in the field. In the case of a nonconformity, the strike of the sedimentary layers is parallel to the contact (Fig. 3.9a). In angular unconformities the layers overlying the unconformity are always parallel to the contact, while those beneath it are not (Fig. 3.9b).

Fault contacts are best diagnosed in the field on the basis of fault gouge, slickensides, offset beds, and geomorphic features. On geologic maps, faults are often conspicuous because of the rock units that are truncated. Figure 3.10 shows a contact that is best interpreted as a fault because of the strong discordance of strike and the fact that neither unit strikes parallel to the contact.

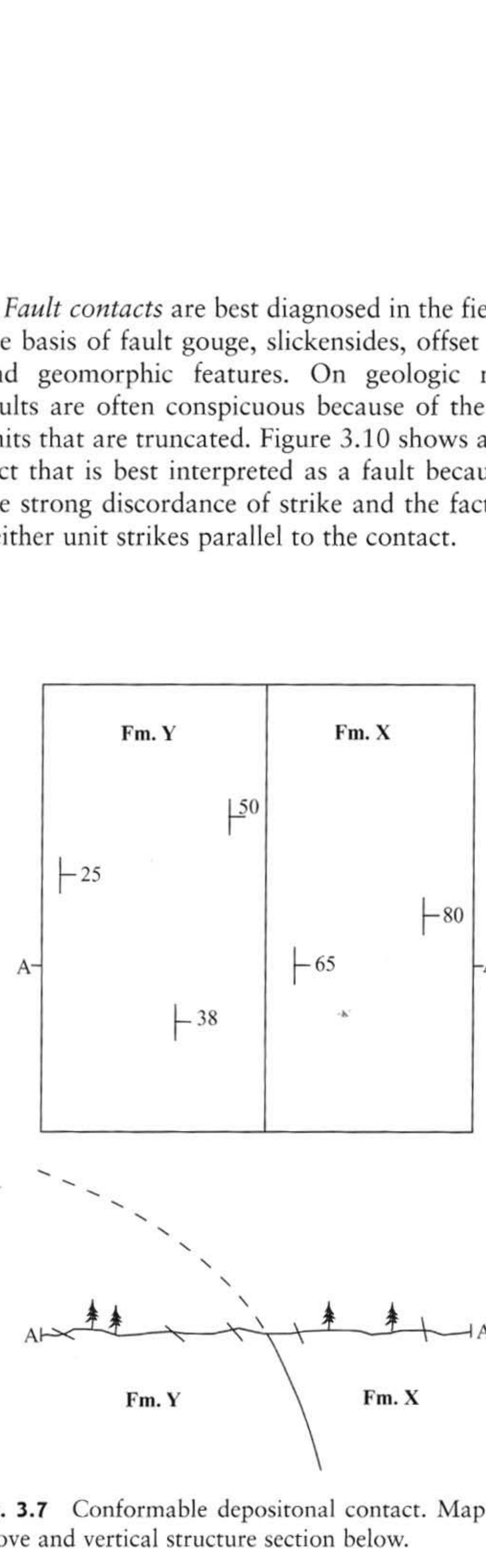

Fig. 3.7 Conformable depositonal contact. Map view above and vertical structure section below.

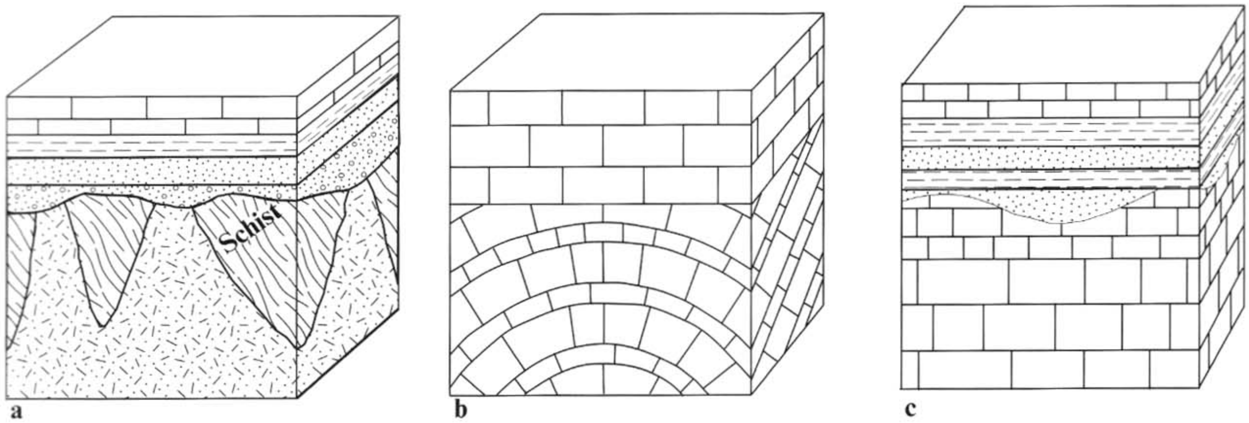

Fig. 3.8 Three types of unconformities: (a) nonconformity, (b) angular unconformity, and (c) disconformity.

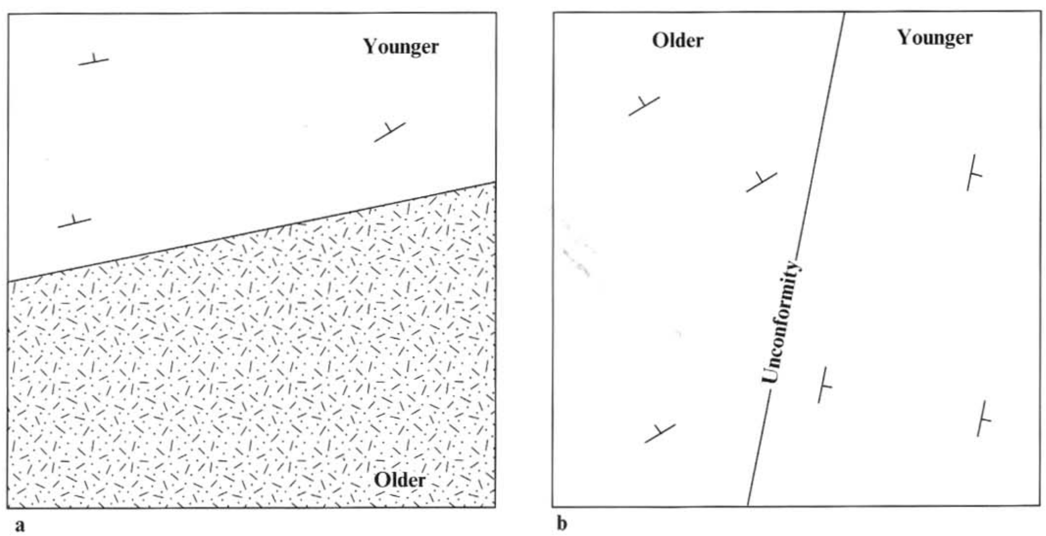

Fig. 3.9 (a) Nonconformity and (b) angular unconformity in map view.

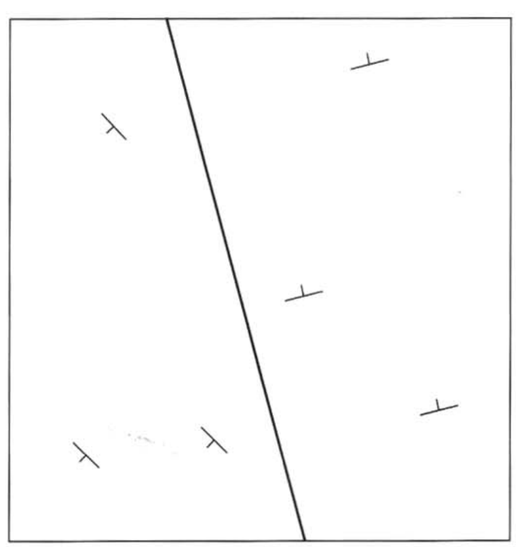

Fig. 3.10 Fault contact in map view.

Intrusive contacts are obvious where the intrusive rocks have clearly been injected into the country rock. As in the case of faults, this is best determined in the field. Figure 3.11 shows an unequivocal intrusive contact, but sometimes intrusive contacts are not so jagged and cannot be easily distinguished from faults. Intrusions such as sills may even be parallel to the bedding of the country rock, making the contact appear to be a nonconformity.

While the nature of a contact may not always be clear in map view, a geologist drawing a structure section (cross-section view) must show the nature of the contact. In Fig. 3.12a, a geologic map is shown with two possible structure sections. Figure 3.12b interprets the contact between the gabbro and Formation M as an unconformity, while Fig. 3.12c interprets the same contact as a fault. The fact that the strike of the beds in Formation M exactly parallels the contact makes the unconformity the preferred interpretation. A fault, or even an intrusive contact, cannot be ruled out, however, without examining the contact in the field.

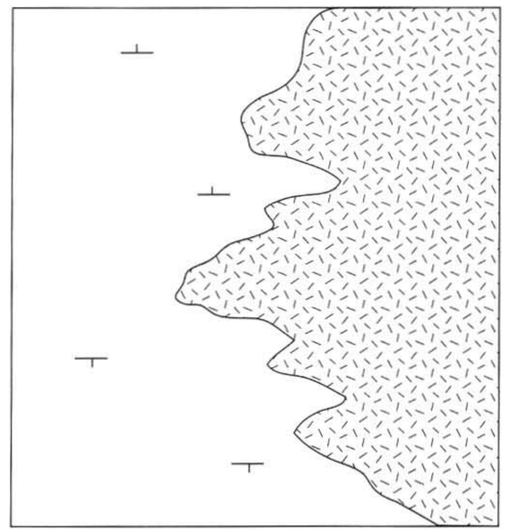

Fig. 3.11 Intrusive contact in map view.

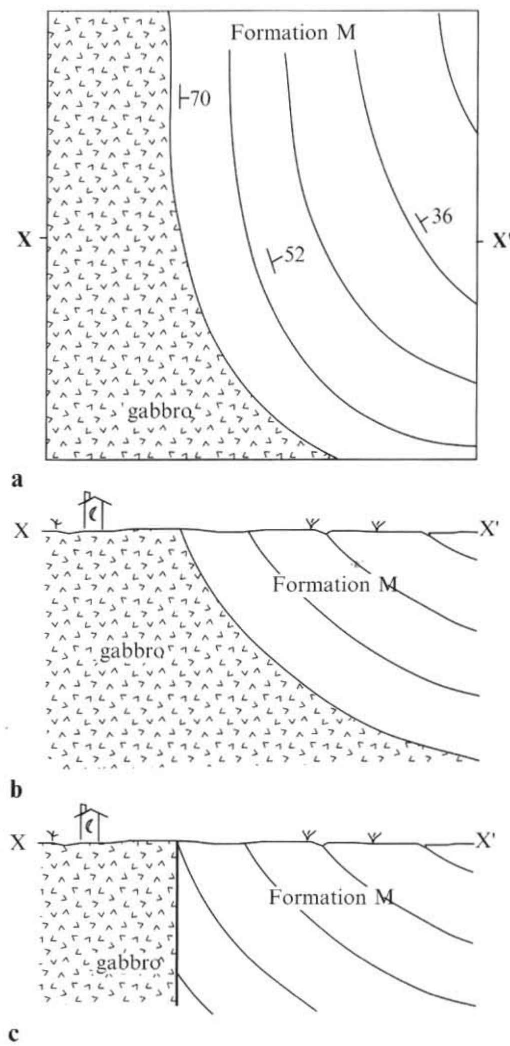

Fig. 3.12 Geologic map with two alternative structure-section interpretations. (a) Geologic map. (b) Unconformity interpretation. (c) Fault interpretation.

Constructing a stratigraphic column

A stratigraphic column is a thumbnail sketch of the stratigraphy of an area, showing the relationships between rock units and thicknesses of strata. It is usually a composite of several stratigraphic sections measured at different locations. Stratigraphic columns are extremely useful tools for summarizing the history of deposition and erosion of an area and for comparing the geology of one area with that of other areas. A stratigraphic column does not summarize the structural history of an area because folds and faults are not shown. It is, nonetheless, a first step in understanding an area's structural history. For your work with the Bree Creek Quadrangle, a stratigraphic column will be very handy.

Figure 3.13 contains a geologic map (Fig. 3.13a), an accompanying structure section (Fig. 3.13b), and a stratigraphic column (Fig. 3.13c). The construction of structure sections is discussed in detail in Chapter 4. Notice that the structure section shows the structural and stratigraphic relationships in a specific locality, line A-A′. The stratigraphic column, on the other hand, shows the generalized stratigraphic relationships over a larger area. For example, even though the Antelope Basalt lies unconformably on the Jerome Schist in the eastern part of the map, in the stratigraphic column the Antelope Basalt appears overlying the Waterford Shale, the youngest unit it overlies in the area. If you have trouble seeing how the map, structure section, and stratigraphic column relate to one another, try coloring one or more of the units on all three diagrams.

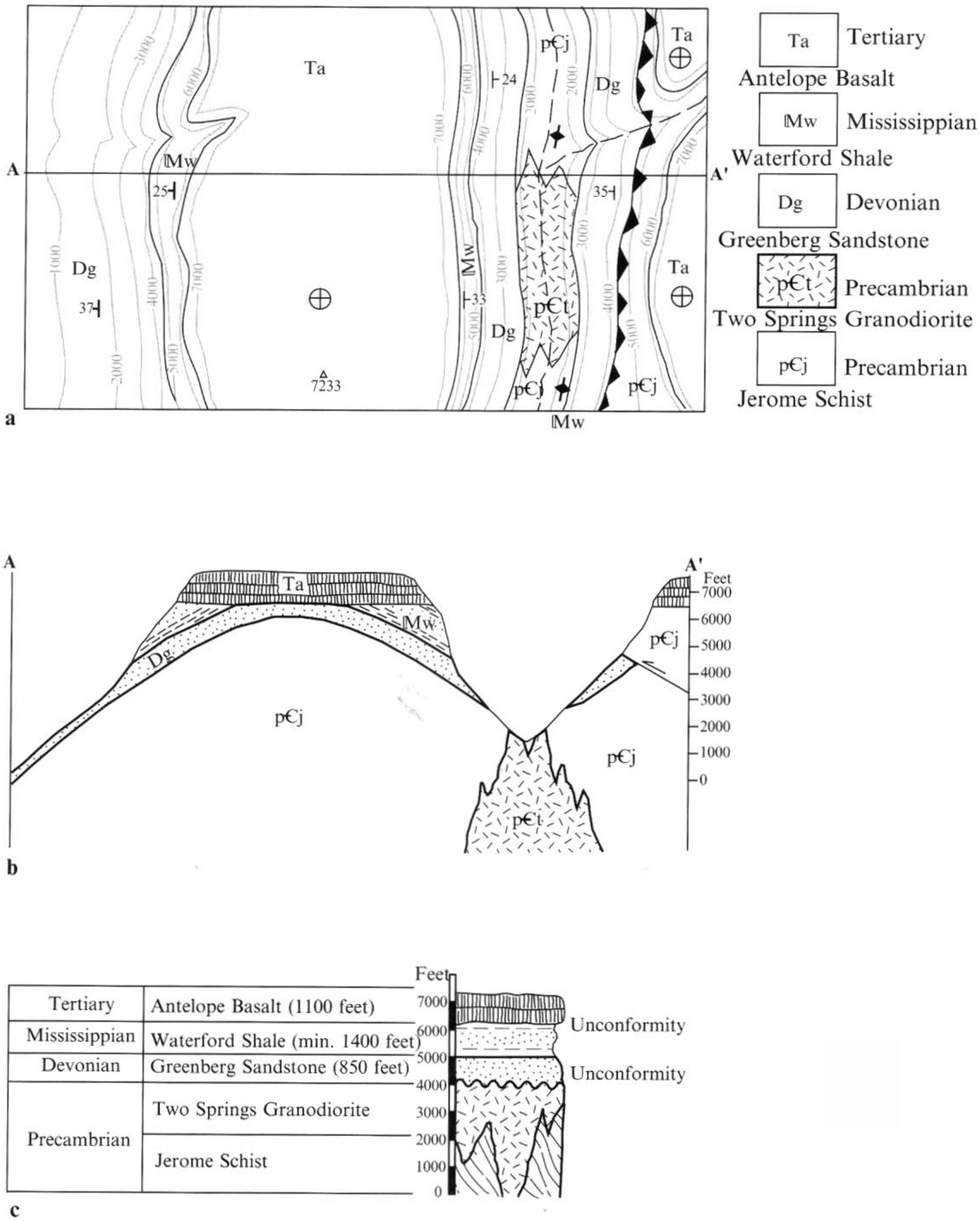

Fig. 3.13 (a) Geologic map, (b) corresponding structure section, and (c) stratigraphic column.