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

Geologic maps are drawn primarily from observations made on the earth's surface, often with reference to aerial photographs. 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 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.

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 contours. To find the strike of the contact a straight 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 contour on the east side of the map (Fig. 3.1b). The strike of this contact is thus determined to be N79E.

It should be clear to you from the outcrop pattern in

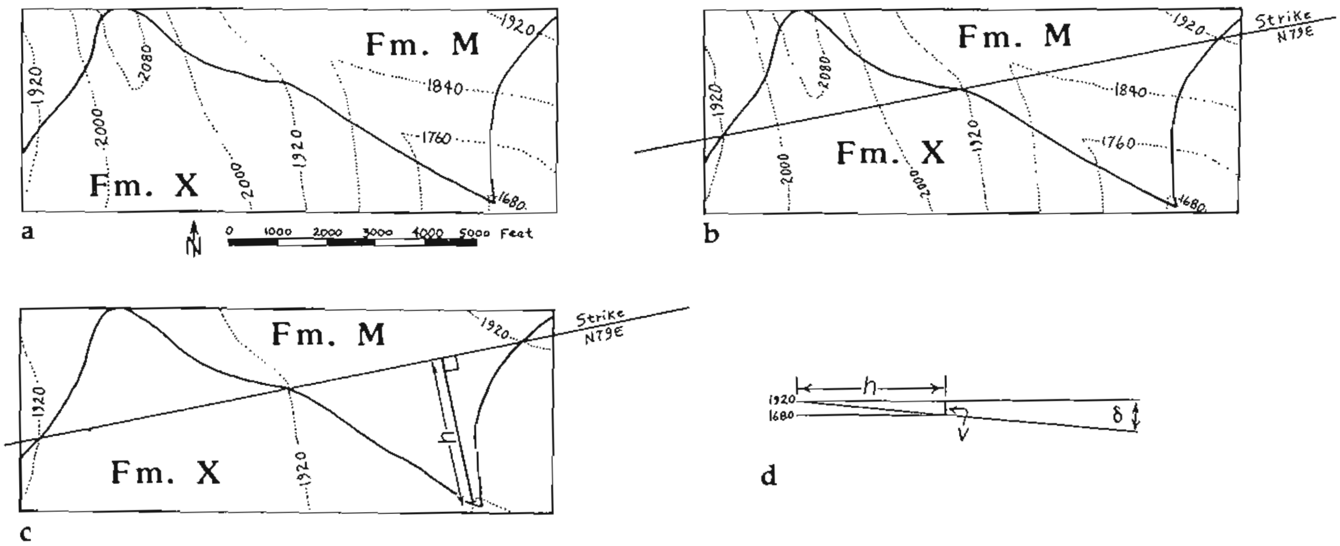


Fig. 3.1 Technique for determining the attitude of a plane from its outcrop pattern. (a) Contact between formations X and M. (b) Line connecting points of equal elevation defines strike of plane. (c) Perpendicular is drawn to a point on contact at different elevation. (d) Dip angle δ is found from $\tan \delta = v/h$.

Fig. 3.1a that the beds dip south. To determine the exact dip, draw a perpendicular line 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 contour. The length of this line h and the change in elevation from the strike line to this point v 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 only be used 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, is N16W, and the dip is 11NE as determined by:

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

$$\delta = 11^\circ$$

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 be routine when interpreting geologic maps.

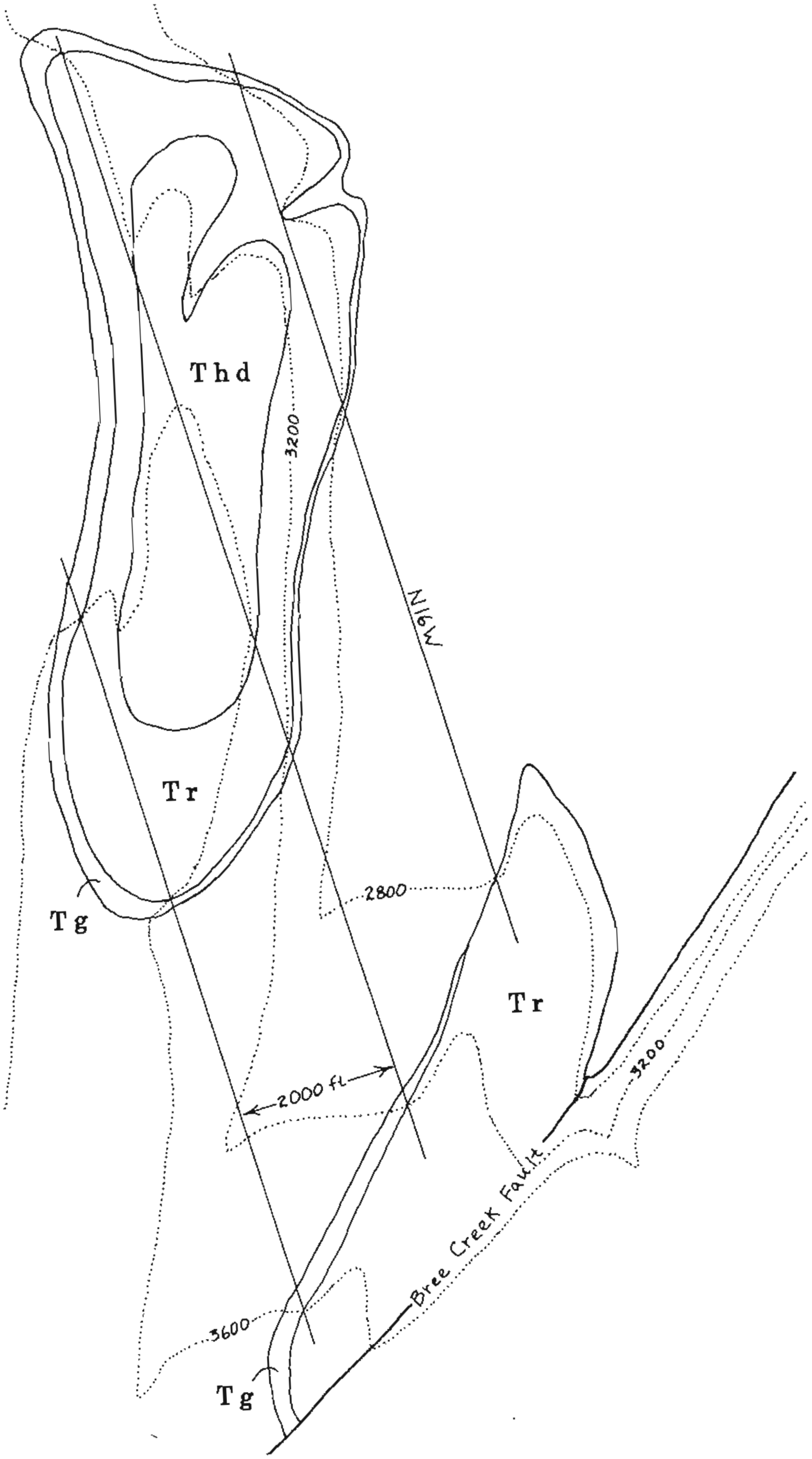


Fig. 3.2 Neogene units in northeastern portion of Bree Creek Quadrangle.

Problem 3.1
On the Bree Creek Quadrangle map determine the exact strike and dip of the Miocene and Pliocene units and label the map accordingly with the appropriate symbol. List each attitude in the space below as well as on your map. Use the lower contact of each unit, because the upper contact may have been eroded. After determining the strike and dip of each formation, try to visualize the geology in three dimensions. Make sure that the attitude you determined is in agreement with the outcrop pattern. (Answer sheet for Problems 3.1, 3.2, and 3.3 on p. 46.)

	Thd	Tr	Tg
Northeastern fault block			
Northern exposures	____	____	____
Southern exposures		____	____
Central fault block			
Northern area		____	____
Galadriel's Ridge		____	____
Southwestern area		____	____
Western fault block			
Gandalf's Knob	____		
Southern exposures	____		

Determining stratigraphic thickness in flat terrain

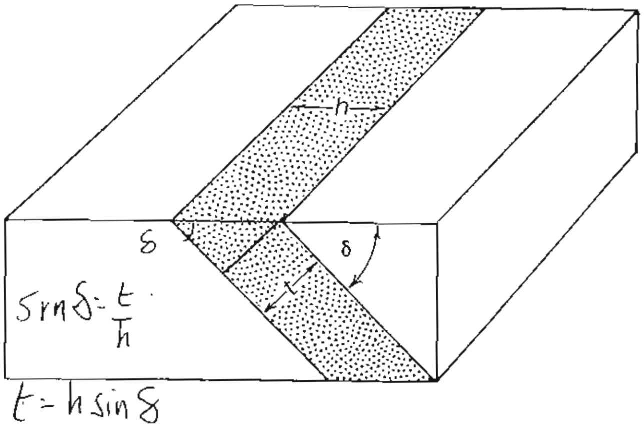
It is usually possible to determine the approximate stratigraphic thickness of a rock unit from a geologic map if its attitude is known. If a unit is steeply dipping, and if its upper and lower contacts are exposed on flat or nearly flat terrain, then the thickness is determined from the trigonometric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

$$t = h \sin \delta$$

where t is stratigraphic thickness, h is horizontal thickness or plan width, and δ is dip.

Problem 3.2
The Paleogene (Paleocene through Oligocene) units of the Bree Creek Quadrangle were folded and then eroded nearly flat. Determine the approximate stratigraphic thickness of each of these Paleogene units. To do this, for each unit find a place that is not in the hinge zone of a fold, that is nearly flat, that contains exposures of both the upper and lower contacts, and where the dip is fairly constant. The horizontal distance h must be measured perpendicular to the strike. A good place to measure the Bree Conglomerate, for example, is where Galadriel's Creek crosses it in the southwestern corner of the map. In places where the dip is not completely consistent you may have to use an average dip. (Because of the large contour interval and the absence of completely flat terrain, thickness determinations will be somewhat variable.)

Tmm	____	(northeast corner at 1600 ft contour)
Tm	____	(east of Galadriel's Ridge at 36E dip)
Tts	____	(northeast corner at 2000 ft and 2400 ft contours)
Tb	____	(at Galadriel's Creek)
Te	____	



$t = h \sin \delta$

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

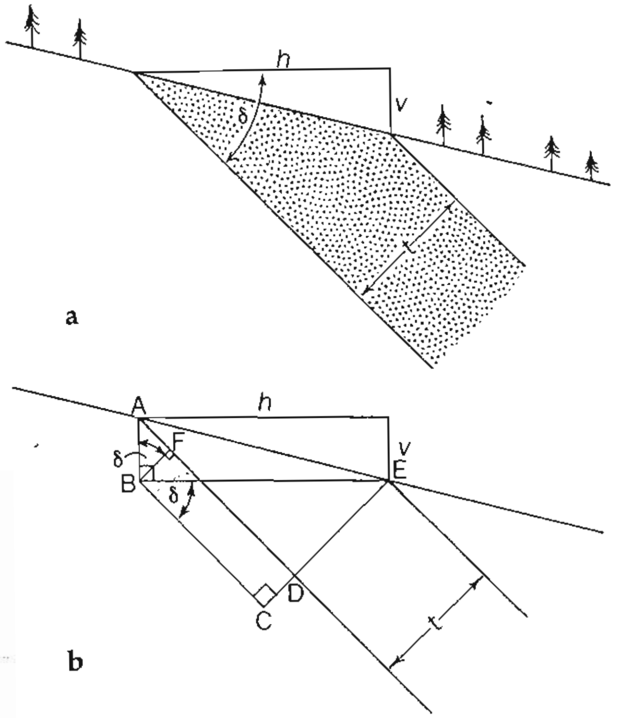


Fig. 3.4 Determining stratigraphic thickness t on slopes. (a) Lengths h and v and dip angle δ are needed to derive t. (b) Geometry of derivation.

Determining stratigraphic thickness on slopes

The thickness of layers exposed on slopes may be determined trigonometrically if, in addition to dip δ and plan width of the layer h, the vertical distance v (i.e., difference in elevation) from base to 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:

$$t = \mathrm{DE} = \mathrm{CE} - \mathrm{CD}$$

$$\delta = \mathrm{CBE} = \mathrm{ABF}$$

$$\sin \mathrm{CBE} = \frac{\mathrm{CE}}{\mathrm{BE}} = \frac{\mathrm{CE}}{h}$$

$$\mathrm{CE} = h \sin \mathrm{CBE} = h \sin \delta$$

$$\cos \mathrm{ABF} = \frac{\mathrm{BF}}{\mathrm{AB}} = \frac{\mathrm{BF}}{v}$$

$$\cos \delta = \frac{\mathrm{BF}}{v} = \frac{\mathrm{CD}}{v}$$

$$\mathrm{CD} = v \cos \delta$$

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

This relationship applies to situations where bedding dips more steeply than topography and both dip in the same direction (right-hand example of 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 of 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

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

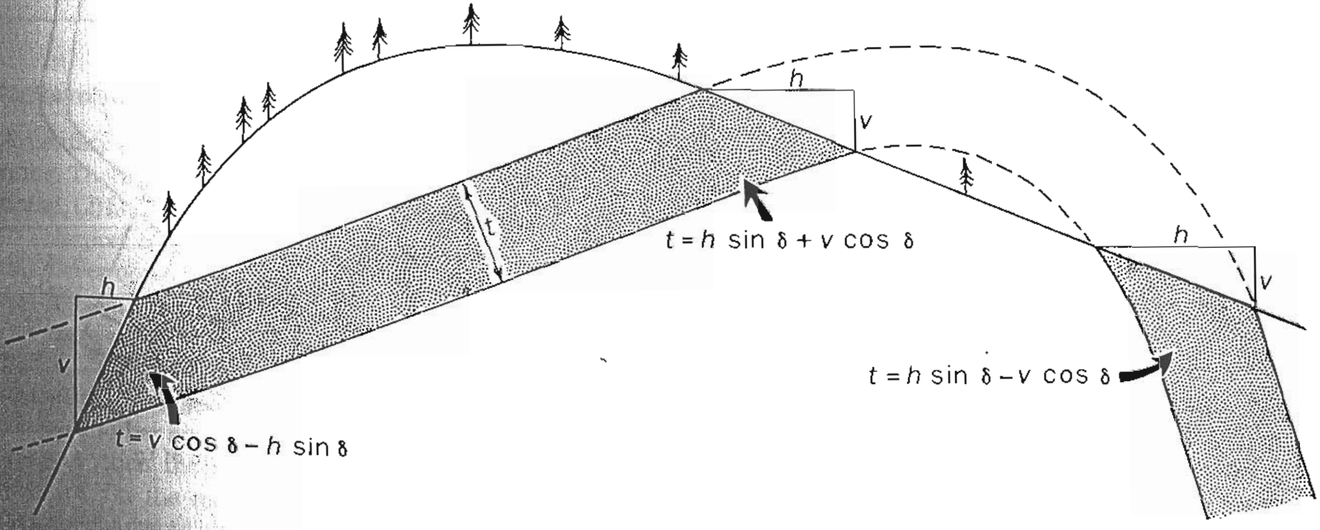


Fig. 3.5 Three combinations of sloping topography and dipping layers, with the appropriate formula for each.

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. Orthographic projection can be used in such cases, however.

Suppose we 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

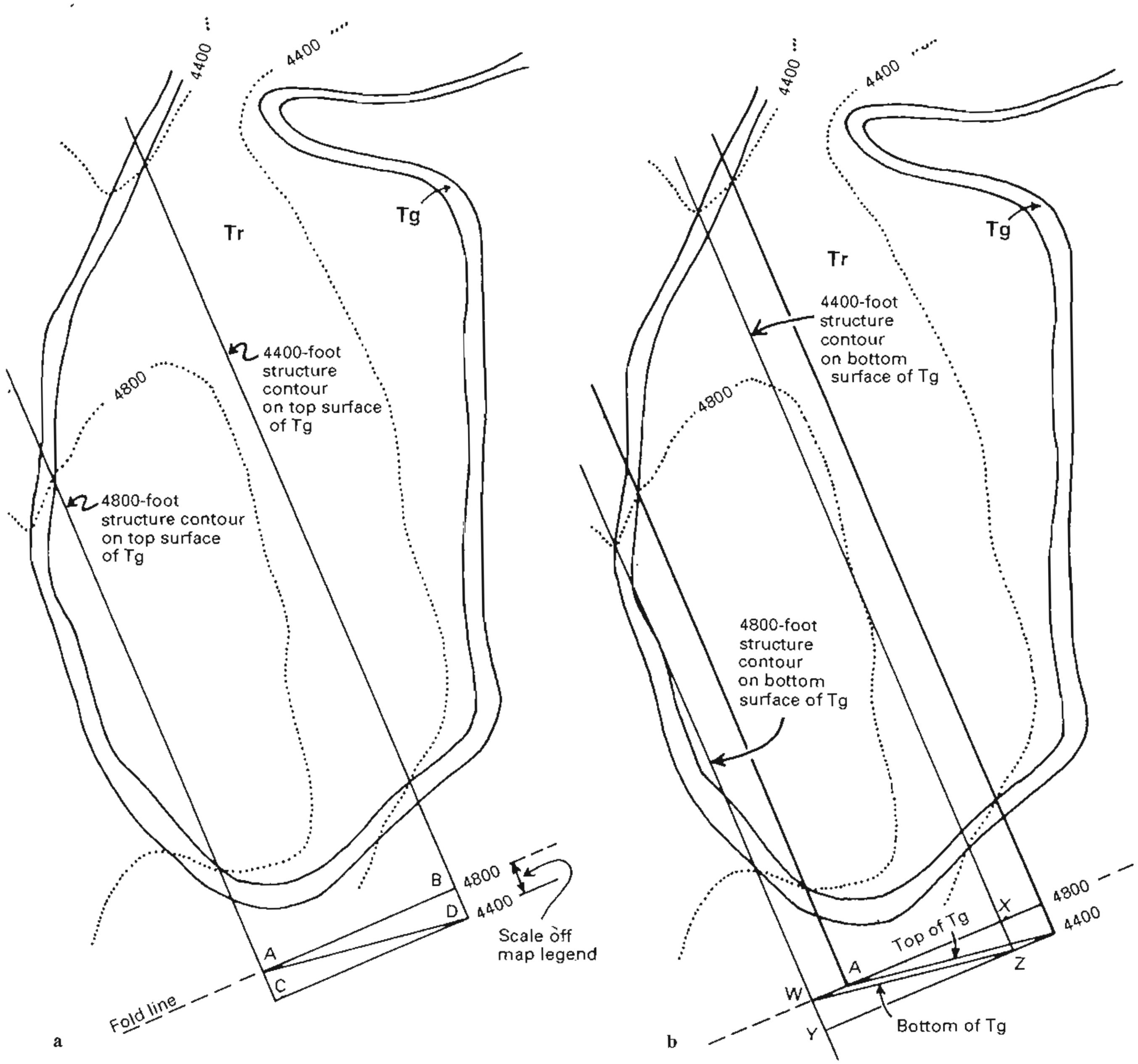


Fig. 3.6 Technique for determining stratigraphic thickness by orthographic projection. (a) Plotting top surface. (b) Plotting bottom surface and deriving thickness.

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 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. Now 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 limited primarily by the scale of the map. In this example Tg can be measured to be about 100 ft thick.

Problem 3.3

Determine the approximate thickness of the Neogene units in the areas indicated. (Both the Helm's Deep Sandstone and the Rohan Tuff have quite variable thicknesses. The Rohan Tuff was tilted and partly eroded prior to the deposition of the Helm's Deep Sandstone, and the Helm's Deep Sandstone has no upper contact. Where appropriate determine the range of thicknesses.)

	Thd	Tr	Tg
Gollum Ridge	______		
Gandalf's Knob	______		
Galadriel's Ridge		______	______
Mirkwood Creek			______
N. of Edoras Creek	______		

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 nondeposition 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).

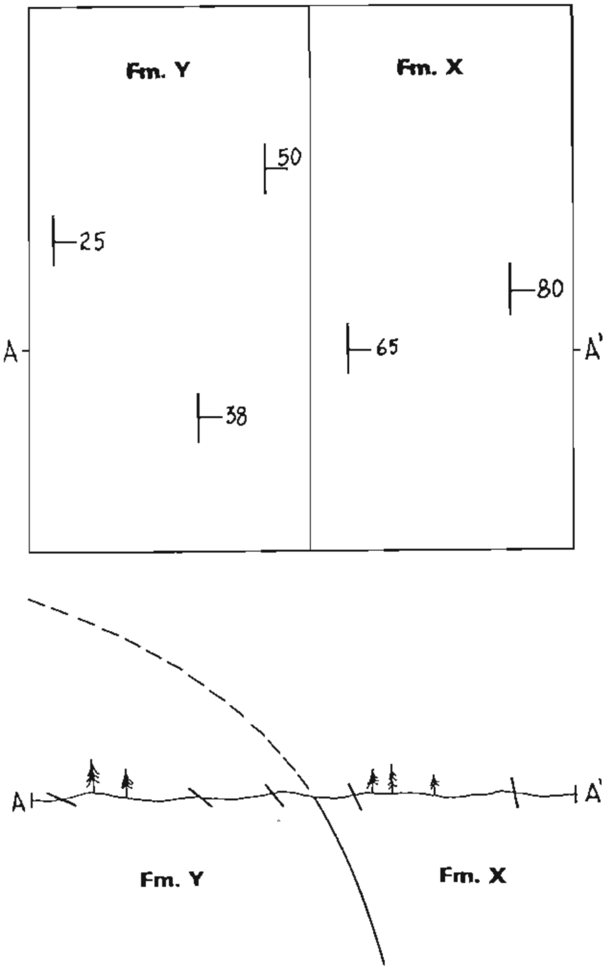


Fig. 3.7 Conformable depositional contact. Map view above and vertical structure section below.

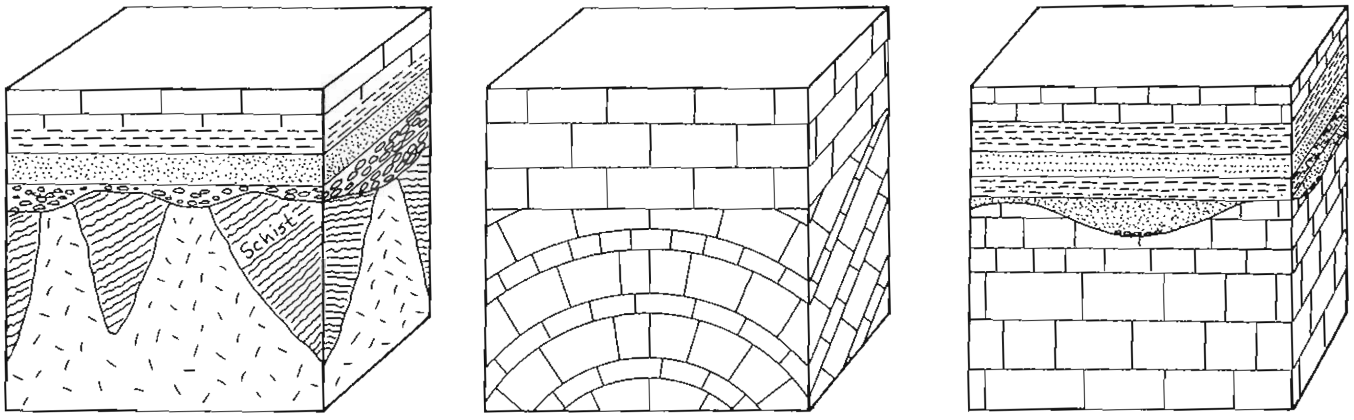


Fig. 3.8 Three types of unconformities: (a) nonconformity, (b) angular unconformity, (c) disconformity.

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 due to strong discordance of strike and the fact that neither unit strikes parallel to the contact.

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 plan view, a geologist drawing a structure section (cross-section view) must show the nature of the contact. In Figure 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, and 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.

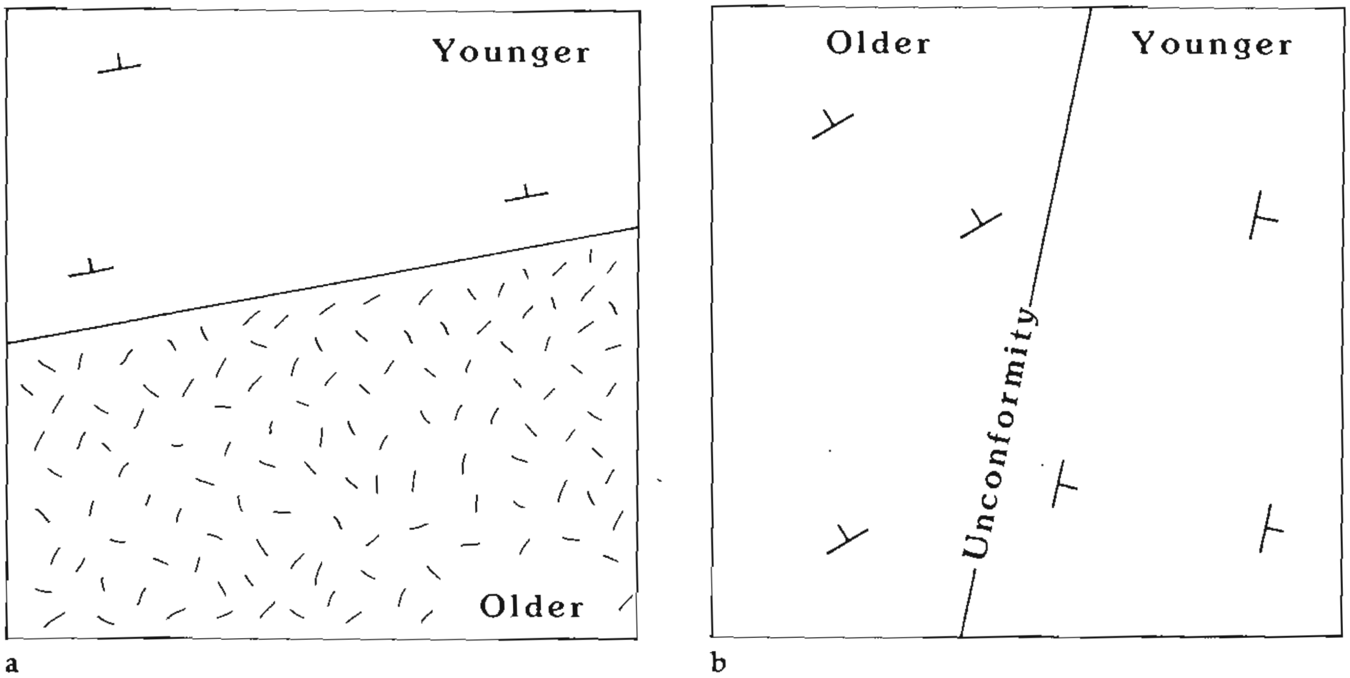


Fig. 3.9 (a) Nonconformity and (b) angular unconformity in map view.

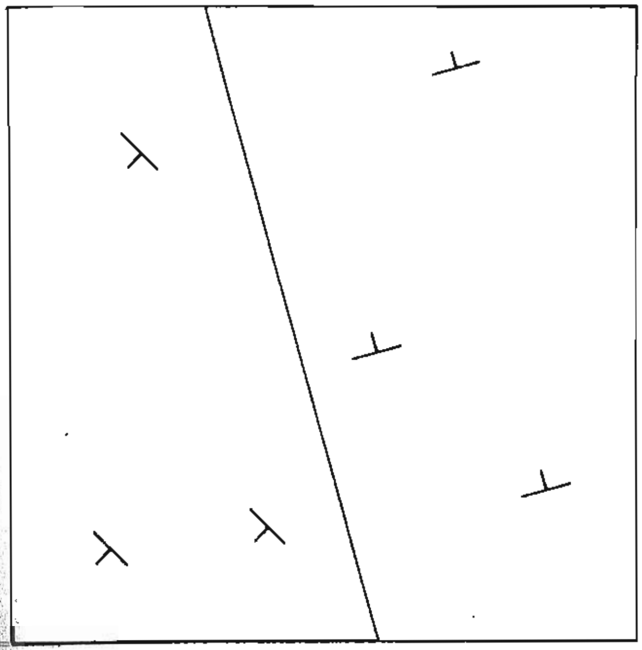


Fig. 3.10 Fault contact in map view.

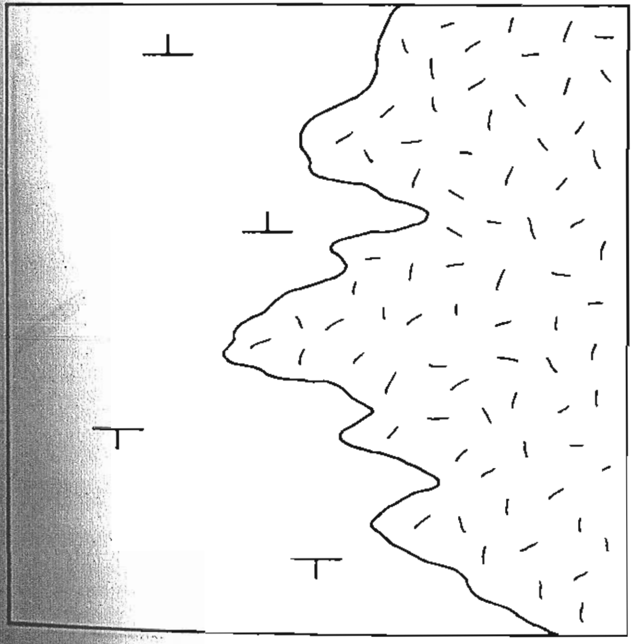


Fig. 3.11 Intrusive contact in map view.

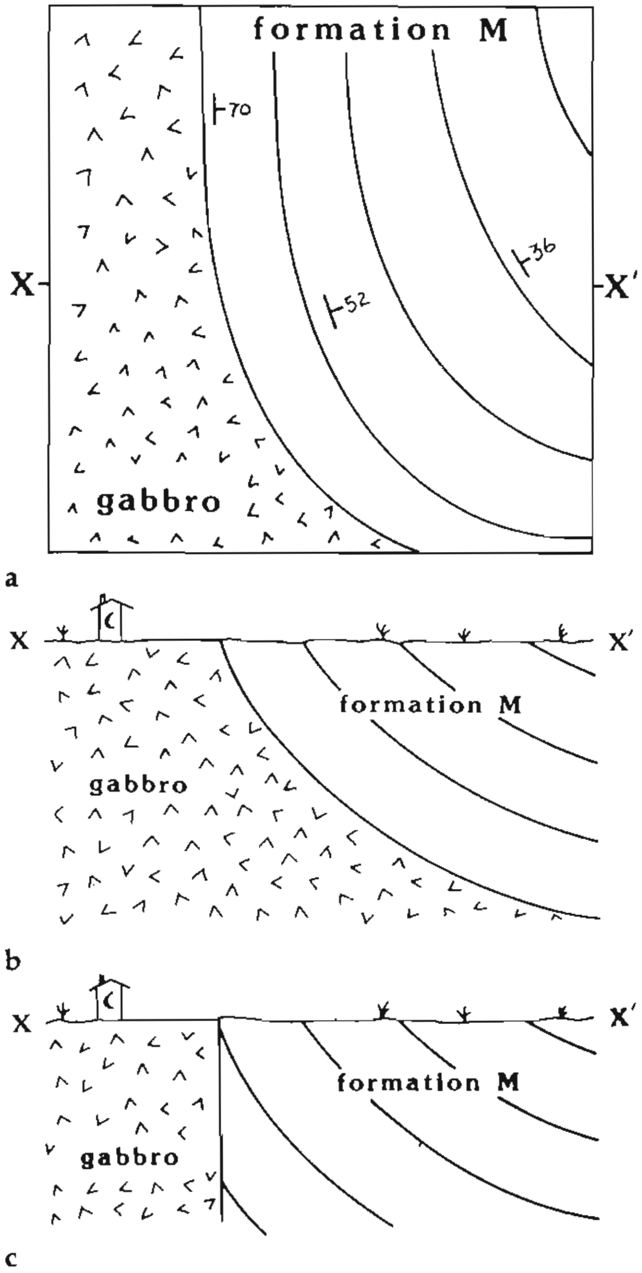


Fig. 3.12 (a) Geologic map with two possible structure-section interpretations: (b) unconformity, and (c) fault.

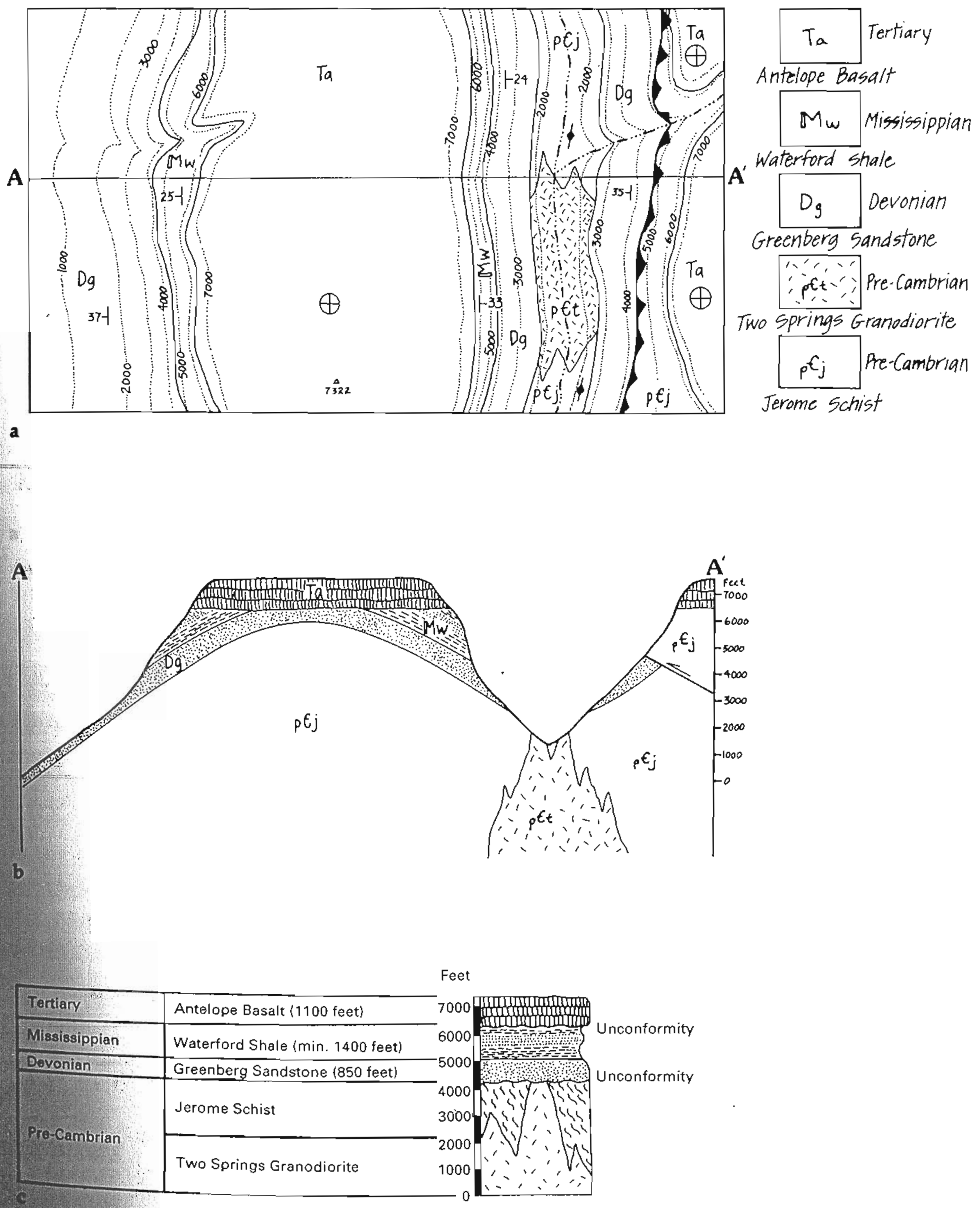
Problem 3.4
In Fig. 3.14 are three geologic maps (each drawn twice). For each map there are at least two possible interpretations for the contact. Sketch structure sections showing both possibilities, as was done in Fig. 3.12. Indicate the one you consider most likely to be correct and *give your reasons*. In your structure sections do not worry about calculating and measuring each apparent dip, merely approximate the dips freehand.

Constructing a stratigraphic column

A stratigraphic column is a thumbnail sketch of the geology of an area showing relationships and thicknesses. It is an extremely useful tool for summarizing the history of deposition and erosion of an area and for comparing it with 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 shows an example of a geologic map and accompanying structure section and stratigraphic column. 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 two of the units on all three diagrams.

Problem 3.5
On a piece of graph paper construct a stratigraphic column for the Cenozoic and Mesozoic units of the Bree Creek Quadrangle. Choose a scale that allows your column to fit on a full sheet of paper.



Tertiary	Antelope Basalt (1100 feet)
Mississippian	Waterford Shale (min. 1400 feet)
Devonian	Greenberg Sandstone (850 feet)
Pre-Cambrian	Jerome Schist
	Two Springs Granodiorite

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

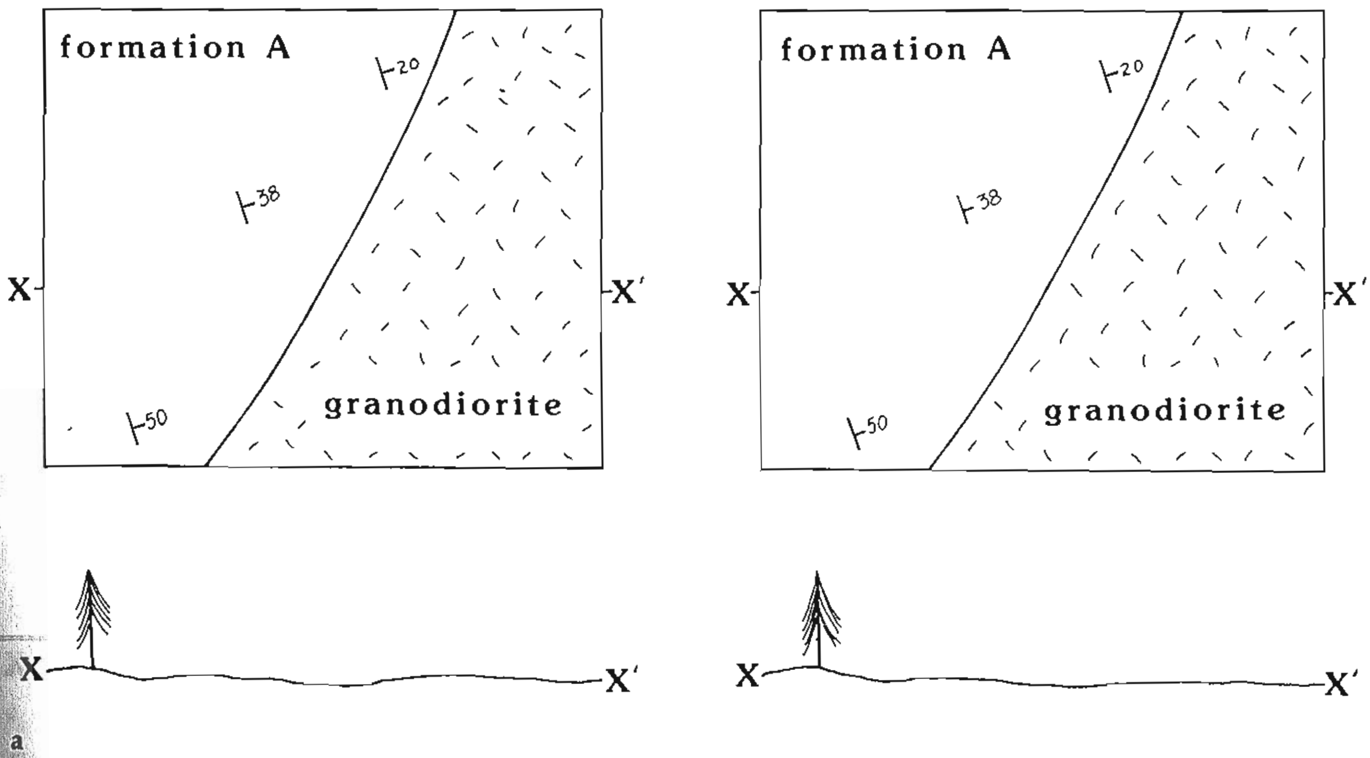


Fig. 3.14 Three geologic maps for use in Problem 3.4. Continued on pp. 44 and 45.

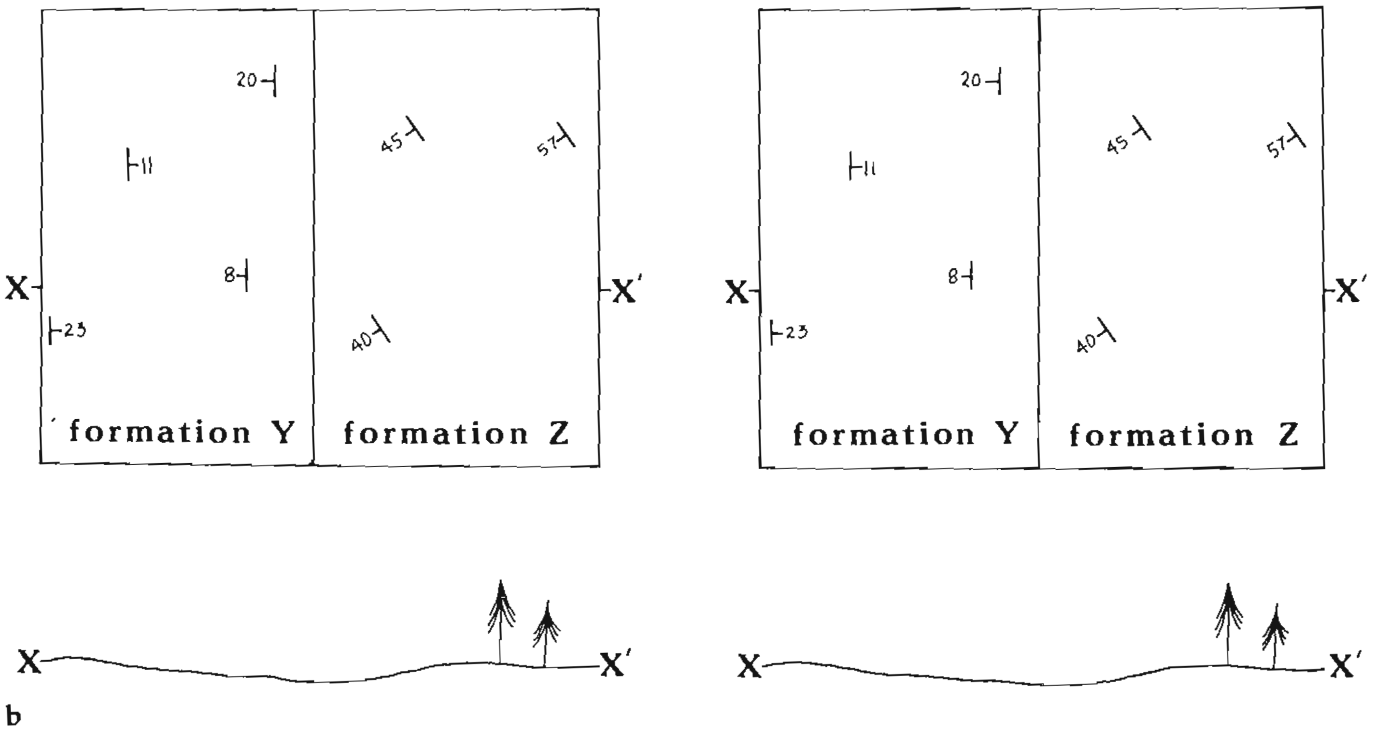


Fig. 3.14 Continued.

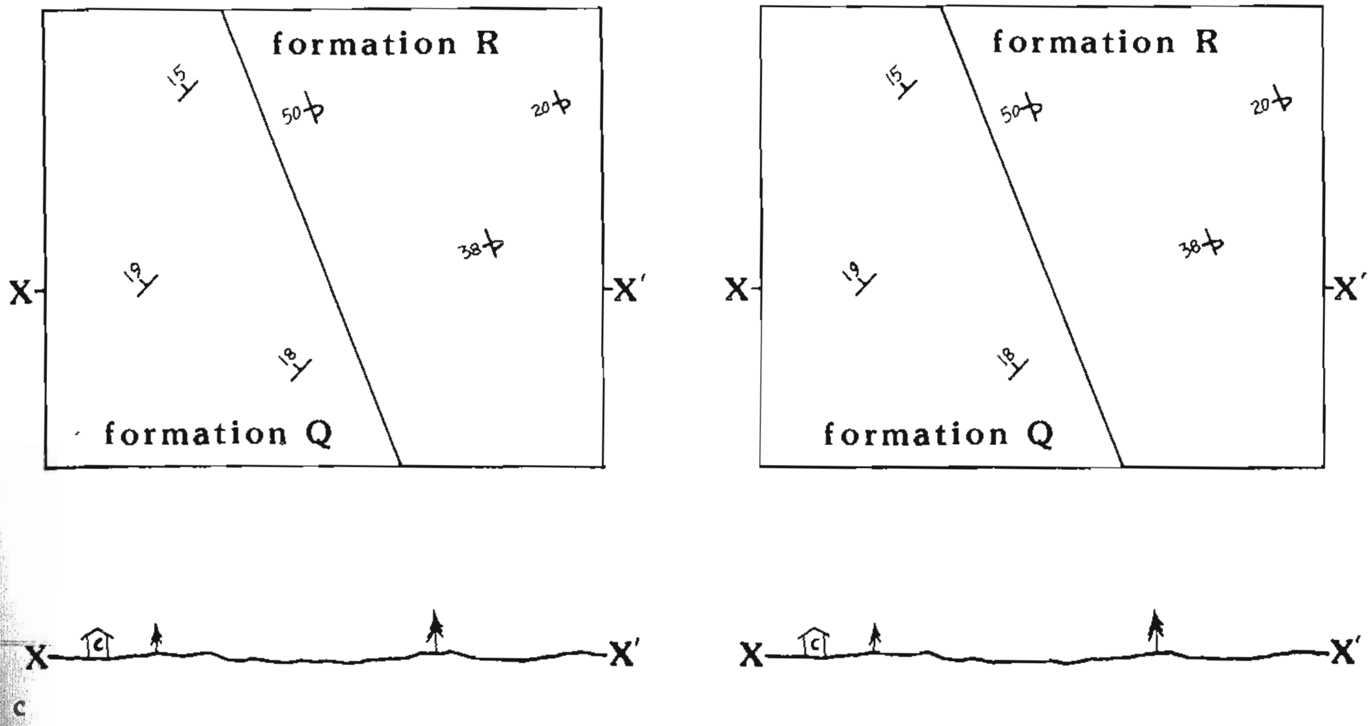


Fig. 3.14 Continued.

Answer Sheet for Problems 3.1, 3.2, and 3.3

Problem 3.1

	Thd	**Tr**	**Tg**
Northeastern fault block			
Northern exposures	______	______	______
Southern exposures		______	______
Central fault block			
Northern area		______	______
Galadriel's Ridge		______	______
Southwestern area		______	______
Western fault block			
Gandalf's Knob	______		
Southern exposures	______		

Problem 3.2

Tmm ___

Tm ___

Tts ___

Tb ___

Te ___

Problem 3.3

	Thd	**Tr**	**Tg**
Gollum Ridge	______		
Gandalf's Knob	______		
Galadriel's Ridge		______	______
Mirkwood Creek			______
N. of Edoras Creek	______		