Chapter 2: Topographic and Geological Maps

MUCH OF structural geology is concerned with the representation and production of geological maps. Such maps are prepared using base maps for the particular area covered. Base maps of various scales are usually available from national geographic surveys or may be prepared from field surveys and remote sensing data. The base map contains a scale bar, geographical north arrow, geographical gridlines, and location names. For detailed geological maps, a good basemap includes the morphology or shape of the landscape as represented by topographic elevation contours. On such geological maps, local irregularities in the terrain greatly affect the map pattern of rock formations.

Contents: The basic principles of elevation contours are explained in section 2-1. Any pronounced relief in the ground surface affects the shape of the outcrop pattern, as explained in section 2-2. Geological cross-sections and columnar sections are briefly introduced in sections 2-3 and 2-4, respectively.

2-1 Elevation contours

The Earth's surface displays a variety of landforms, including mountainous terrains incised by steep valleys, flat plains, meandering river channels, and monolithic mesas, remaining after extensive erosion of an uplifted formerly planar area. The topographic relief of the landscape can be represented by a series of smoothly curved lines, called *contour lines*. The great value of topographic maps is that these show the shape and elevation of the ground surface, using contour lines. A contour line connects points which are all at the same elevation. The coastline of an oceanic island outlines the contour line at sea level (Fig. 2-1a). Contour lines were originally constructed by measuring the elevation at a number of locations in the field. The contour lines were then sketched by extrapolating between the measured points. Modern topographic maps

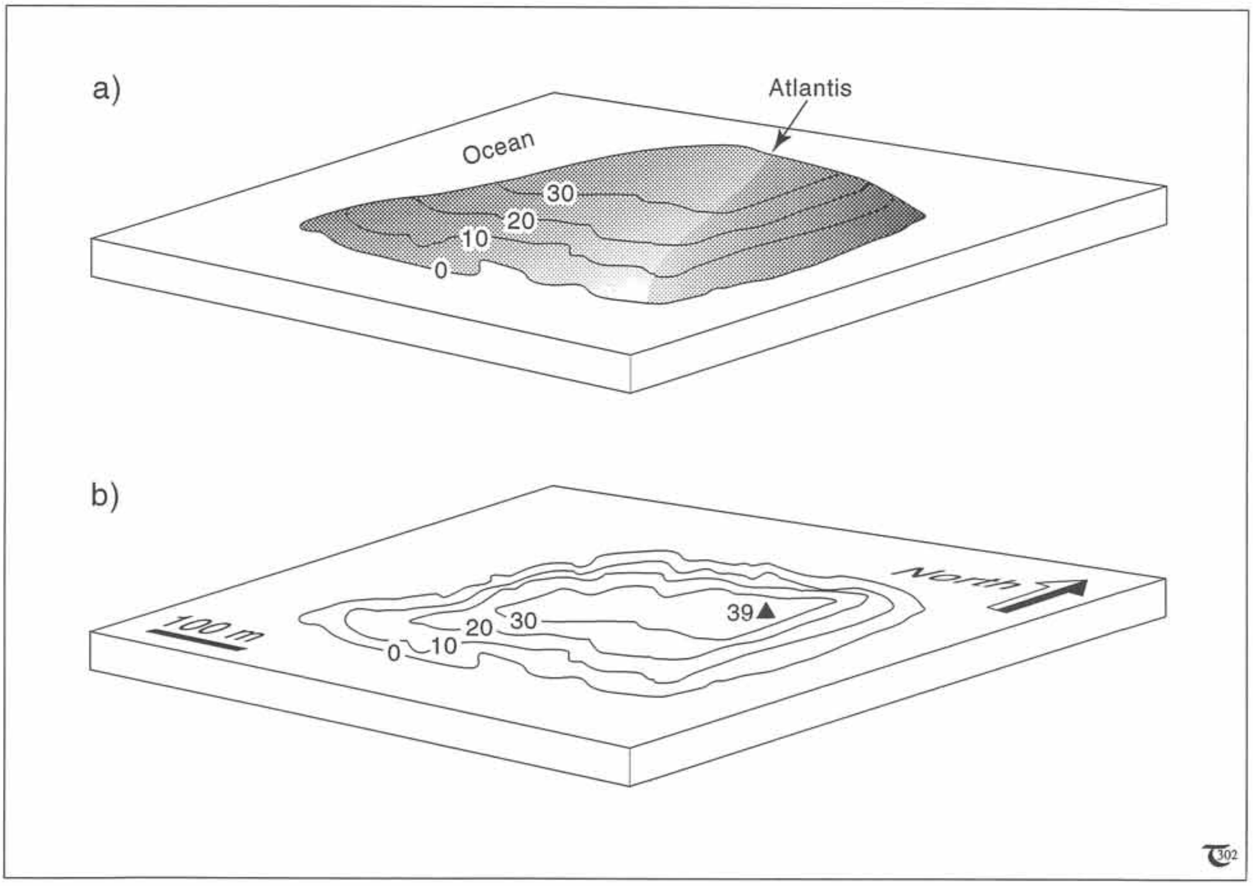

Figure 2-1: a) Perspective view of a hypothetical island with topographic elevation contours (in m). b) Topographic contour map of the island is obtained by projecting the contours on a plan map.

are prepared in digital format from stereoscopic pairs of aerial photographs.

Figure 2-1a shows topographic contours sketched on the slopes of an oceanic island. The topographic map is constructed by orthogonal projection of the contour lines onto a horizontal surface (Fig. 2-1b). The spacing of the elevation contours in this example is ten meters. This means that the elevation is indicated only at points of zero, ten, twenty, and thirty meters altitude above sea level. This number of contour lines is sufficient to define the shape of the island. The summit of the island may be an important landmark, and its exact height can be separately indicated and marked by a dot or triangle. The representation of most landscapes is by an orthogonal topographic map.

Although the principle of topographic maps resulting from the orthogonal projection of contour lines is simple, reading of contour maps requires some ability and experience to imagine the three-dimensional shape of the terrain represented. The following rules help us to understand better the concept of topographic contours: (1) Contour lines never cross or divide. They form a set of smooth and subparallel curves (Fig. 2-1b). (2) The spacing of the contour lines reflects the gradient of the slope. The closer the contours, the steeper the terrain. Contours which appear to overlap express a steep cliff. Widely spaced contours imply gently inclined slopes. (3) The difference in elevation between adjacent contour lines is constant on any given map. However, the contour interval on different maps may be different and is determined by what is convenient for

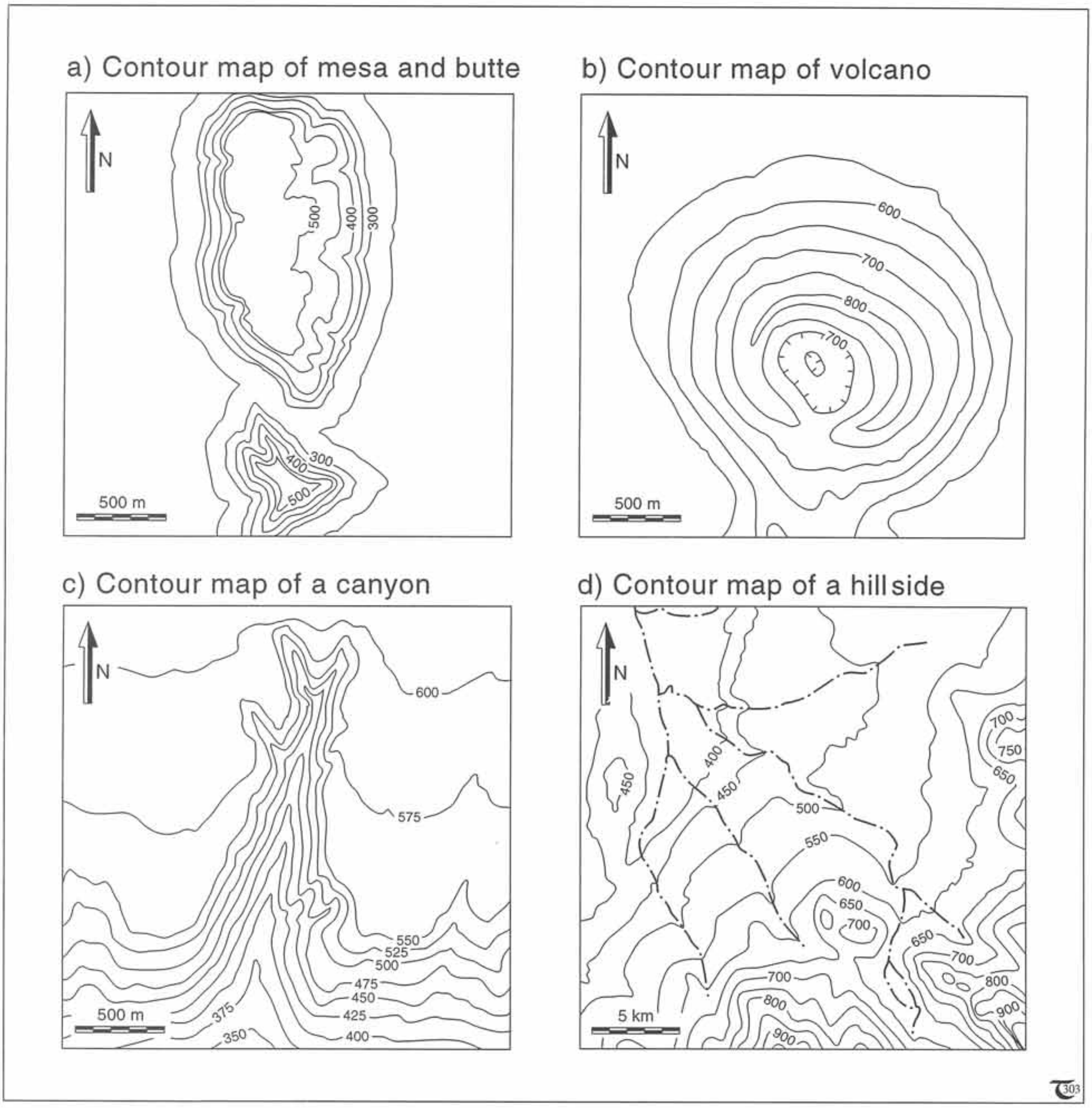

Figure 2-2: Topographic contour maps of: (a) mesa and butte, (b) volcano, (c) canyon, and (d) hillside.

the particular landform displayed. The elevation of the contours will be indicated along them at regular intervals.

Some basic contour patterns are outlined in Figure 2-2. The closed contours of Figure 2-2a are typical for hills. In this case, the top of the hill is relatively flat and the landform is a mesa or high plateau. The smaller isolated hill in the bottom of the map may be called a butte. The circular contour pattern of Figure 2-2b shows a steep-sided cone with a central depression. The depression is conventionally indicated by closed contours with hachures, short tick marks, pointing downslope. This landform typically is displayed by young, large stratovolcanoes and

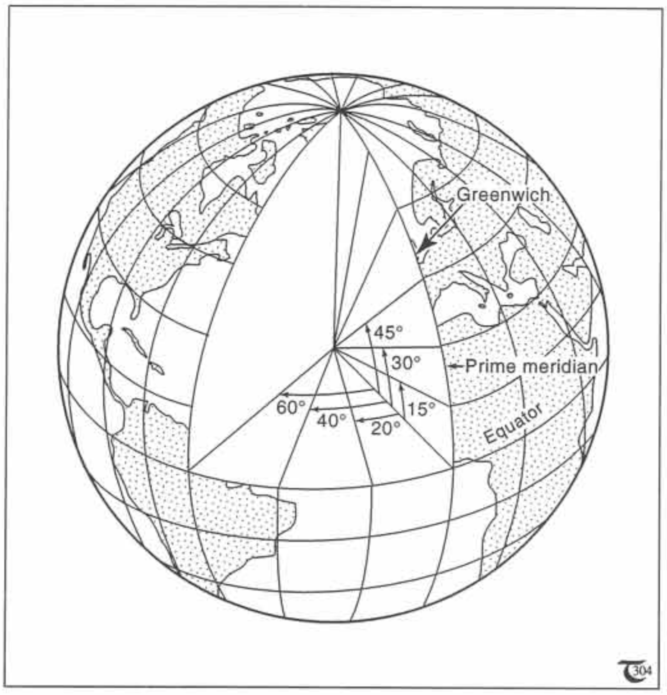

Figure 2-3: The global longitude and latitude grid; zero degree longitude is at a polar meridian passing over Greenwich, UK.

□Exercise 2-1: What is the average slope of the northern flank of the volcano in Figure 2-2b? Contours are in meters.

□Exercise 2-2: Determine the geographical coordinates of your own location using a geographical atlas or maps available to you.

smaller cinder cones. Figure 2-2c is a contour map of a steep-sided canyon. Contour lines trend up the valley, cross the stream, and extend down the valley on the opposite side. The contours form a V-shape, pointing upstream and uphill near the stream origin. Figure 2-2d shows the margin of a mountainous area in the southeast with a drainage pattern running off toward the more gently sloping terrain in the northwest.

Figures 2-1 and 2-2 do not have the geographical location marked on them, because they are imaginary examples of elevation contour maps. Professional topographic maps are framed in an outline with tick marks indicating latitude and longitude in degrees and minutes. Most commonly used is the global longitude and latitude grid, which places the Royal Observatory of Greenwich, United Kingdom, at the meridian of 0° longitude and the equator at 0° latitude (Fig. 2-3). The northern hemisphere is subdivided into 90 degrees of northern latitude and places the North Pole at latitude 90° N. The southern hemisphere is similarly divided into 90 degrees of southern latitude. The western hemisphere is subdivided into 180 degrees western latitude and the eastern hemisphere likewise. The longitude lines of 180° E and 180° W coincide in a meridian which, theoretically, defines the international date line. But, in reality, the date line wanders far from the meridian of 180° longitude.

2-2 Geological outcrop patterns and V-rule

The simplest geological structures are planar unfolded and continuous beds of sedimentary rocks. Such strata may either be horizontal or dip uniformly in a particular direction. Even if the contact between lithological boundaries is straight, these contacts are unlikely to appear as straight lines on the ground surface. The irregular topographic surface intersects the lithological contact, which is then outlined on the ground surface by a smooth, irregular *outcrop pattern*.

For example, consider a simple valley intersected by a straight rock layer (Fig. 2-4). Each of the four cases shown includes a single straight rock formation, sloping (or dipping): (a) westward, (b) vertically, (c) eastward, and (d) horizontally. Correspondingly, four basic map inter-

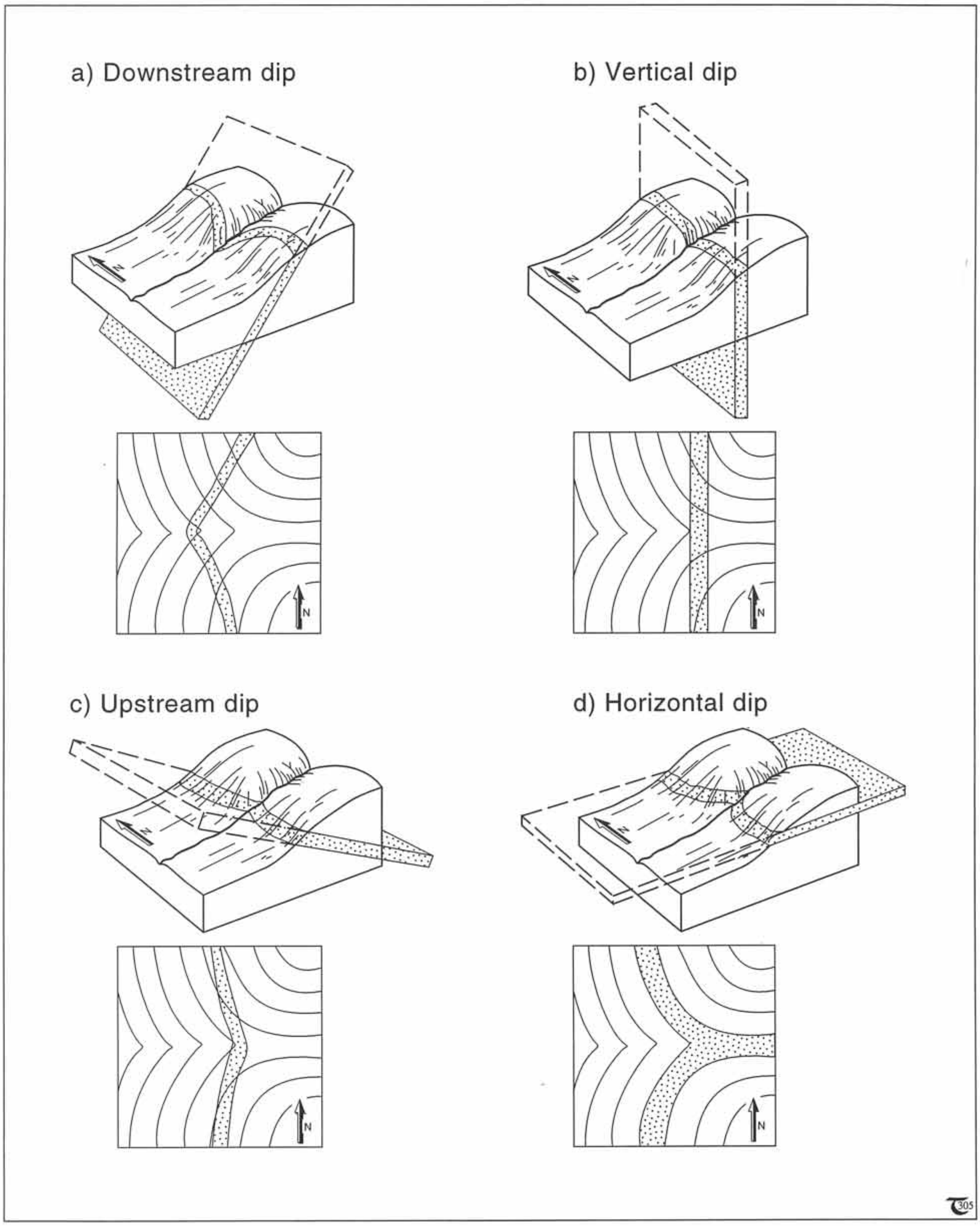

***Figure 2-4:** a) to d) Perspective views and map patterns of a simple valley, cutting into a single straight bed in various orientations.*

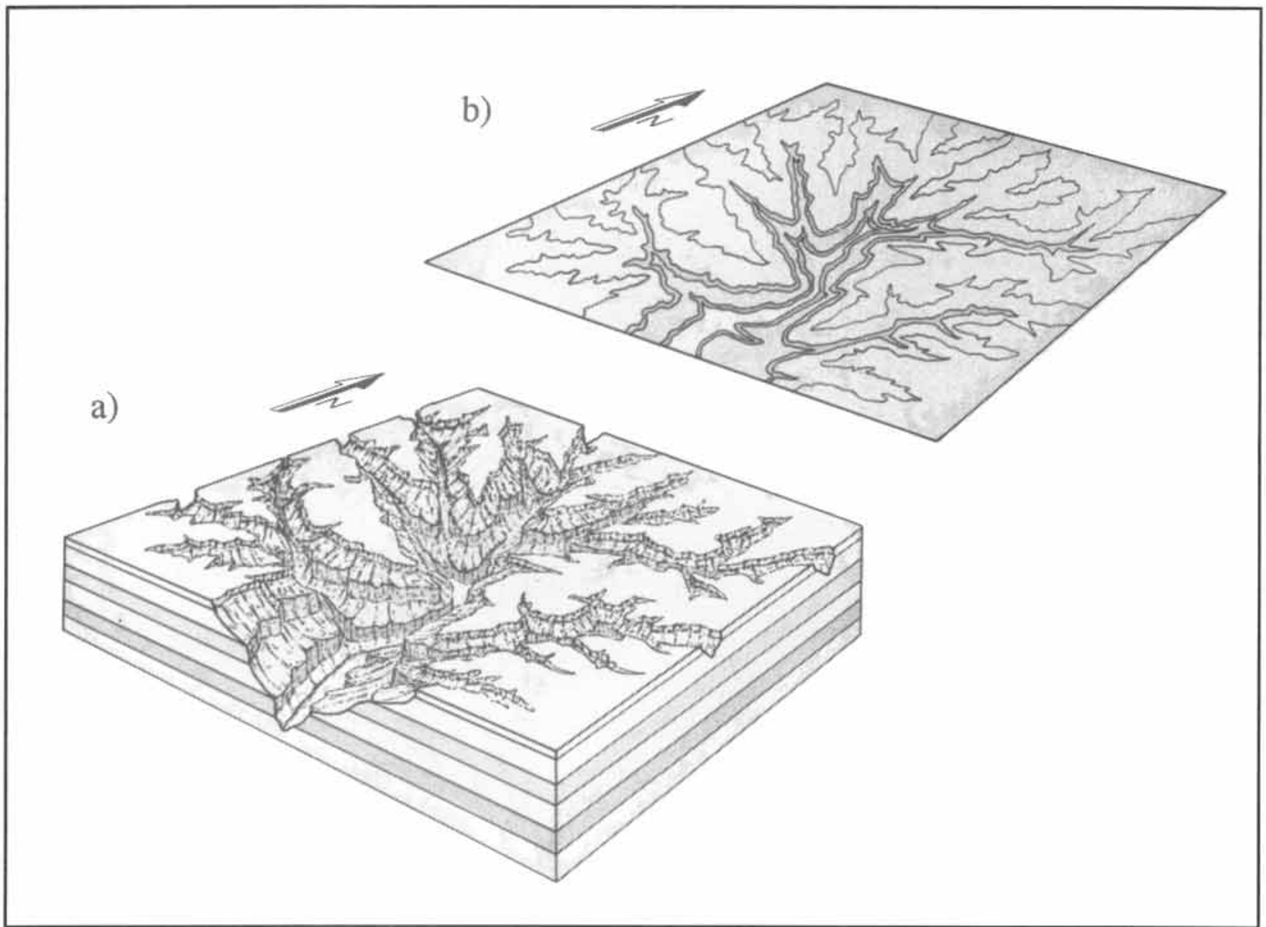

Figure 2-5: a) Perspective diagram of a terrain, comprised of horizontally stratified rock formations incised by a dendritic pattern of deeply eroded channels. b) Geological map view of the same area.

section patterns can be distinguished. If the layer dips downstream, a V-shaped intersection occurs on the topographic map projection and the V points *down dip* (Fig. 2-4a). If the layer is exactly vertical, the intersection of its boundaries with the topography will map as straight lines (Fig. 2-4b). If the layer dips upstream, a V-shaped intersection reappears on the topographic map and the V points *down dip* (Fig. 2-4c). Boundaries of horizontal layers remain entirely parallel to topographic contour lines and appear as V-shaped stream intersections on the topographic

Figure 2-6: Orthographic aerial photograph of a terrain, exposing horizontal beds in the walls of the valleys and on the hillsides.

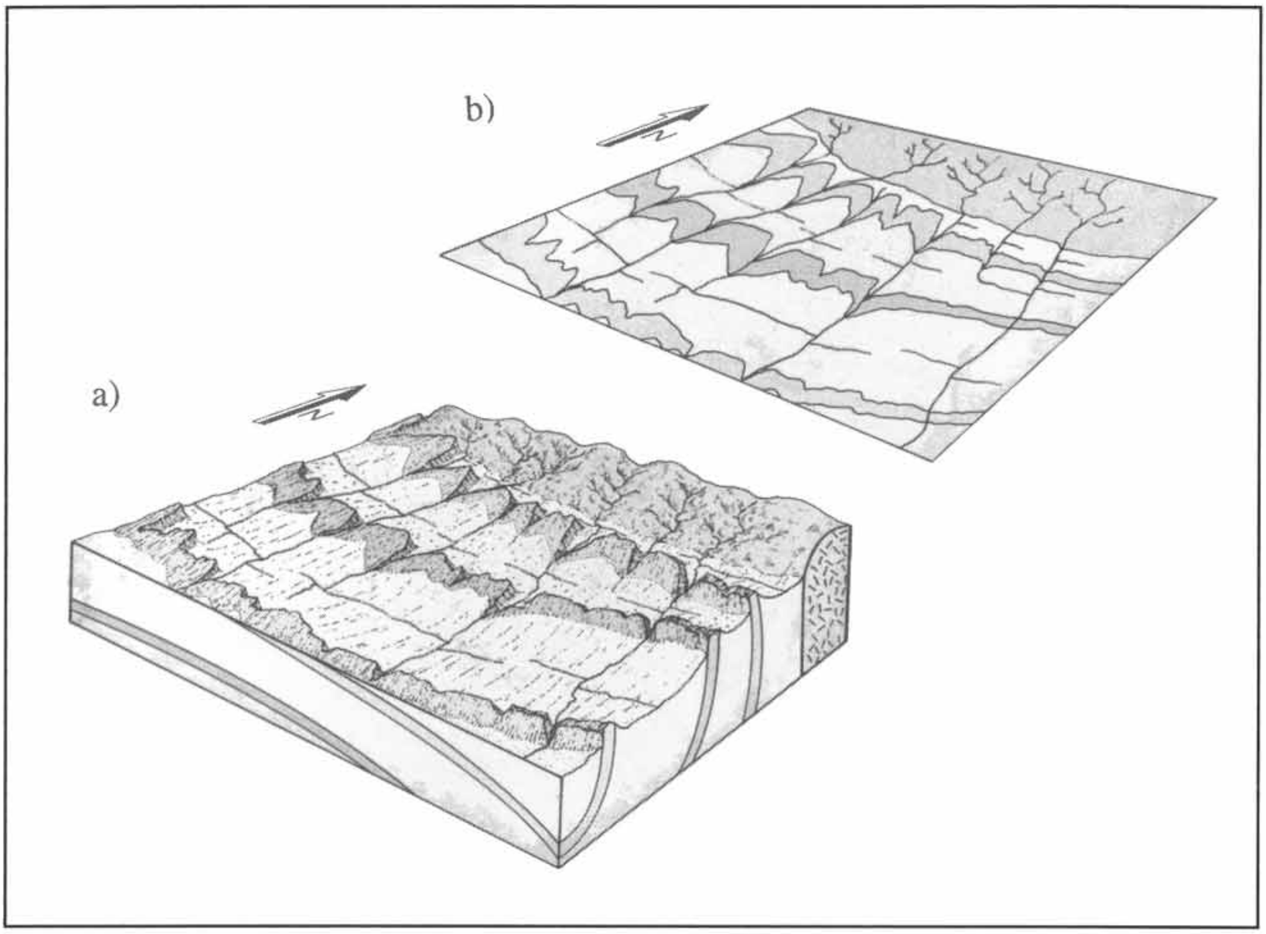

Figure 2-7: *a) Perspective diagram of steeply southward dipping rock strata, leaning against a granitic basement in the north. b) Geological map view displays V-shapes, where beds cross stream channels.*

map (Fig. 2-4d). All map patterns are different, but the V-pattern outlined by the geological boundaries in the valley floor consistently points toward the down-slope direction of the geological bed. None of the V's in the map views corresponds to folded rock layers; all rock strata are perfectly planar and straight.

The topography shown in Figure 2-4 is extremely simple, and, therefore, the intersection pattern of the sedimentary layer with the ground surface has a simple geometry. However, if the

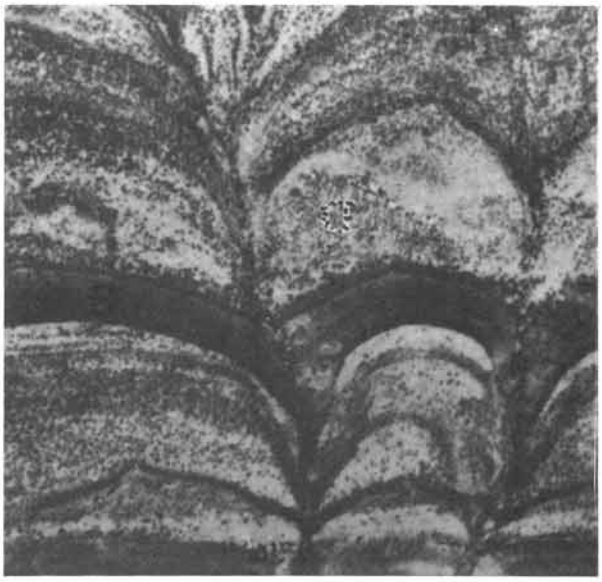

Figure 2-8: *Orthographic aerial photograph of rock strata intersected by erosion valleys. The direction of dip is indicated by the V-pattern.*

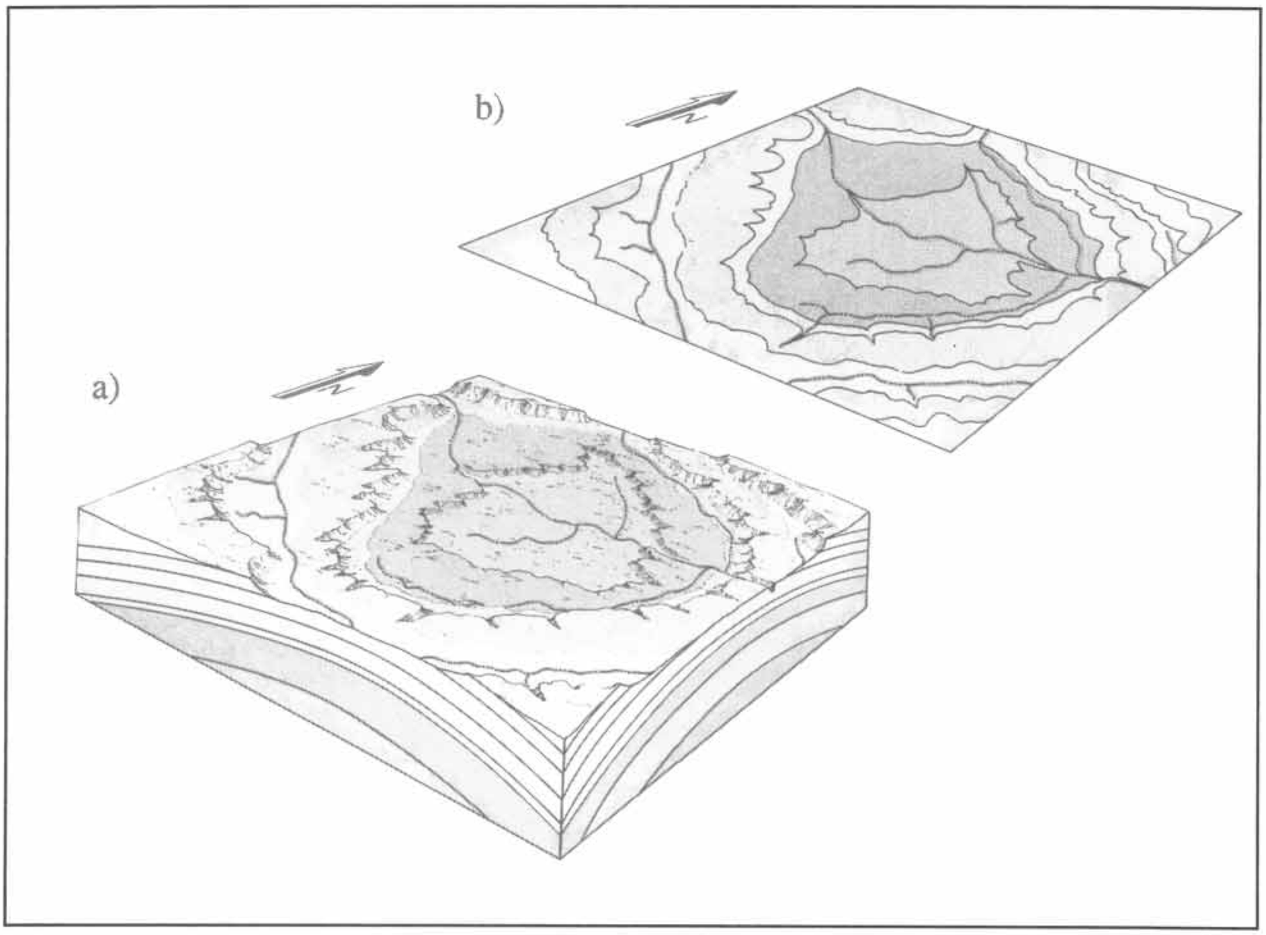

Figure 2-9: a) Perspective diagram of a subcircular dome with strata dipping outward from the center of the dome. b) Geological map of the same area.

topography is complex, the boundaries of geological strata may appear as complex outcrop patterns. Figure 2-5a shows a dendritic canyon system, incising a peneplain underlaid by a succession of subhorizontal sedimentary strata. The geological map projection of the outcrop pattern mimics the dendritic pattern of the canyon system. Even though the topographic contours are not indicated in the map, it can be concluded from the map pattern alone that the layers are subhorizontal. The V's are everywhere pointing *upstream*, but toward inconsistent directions, and,

Figure 2-10: High-altitude aerial photograph of the Richat dome, Mauritania. Image shows an area about fifty kilometers in width.

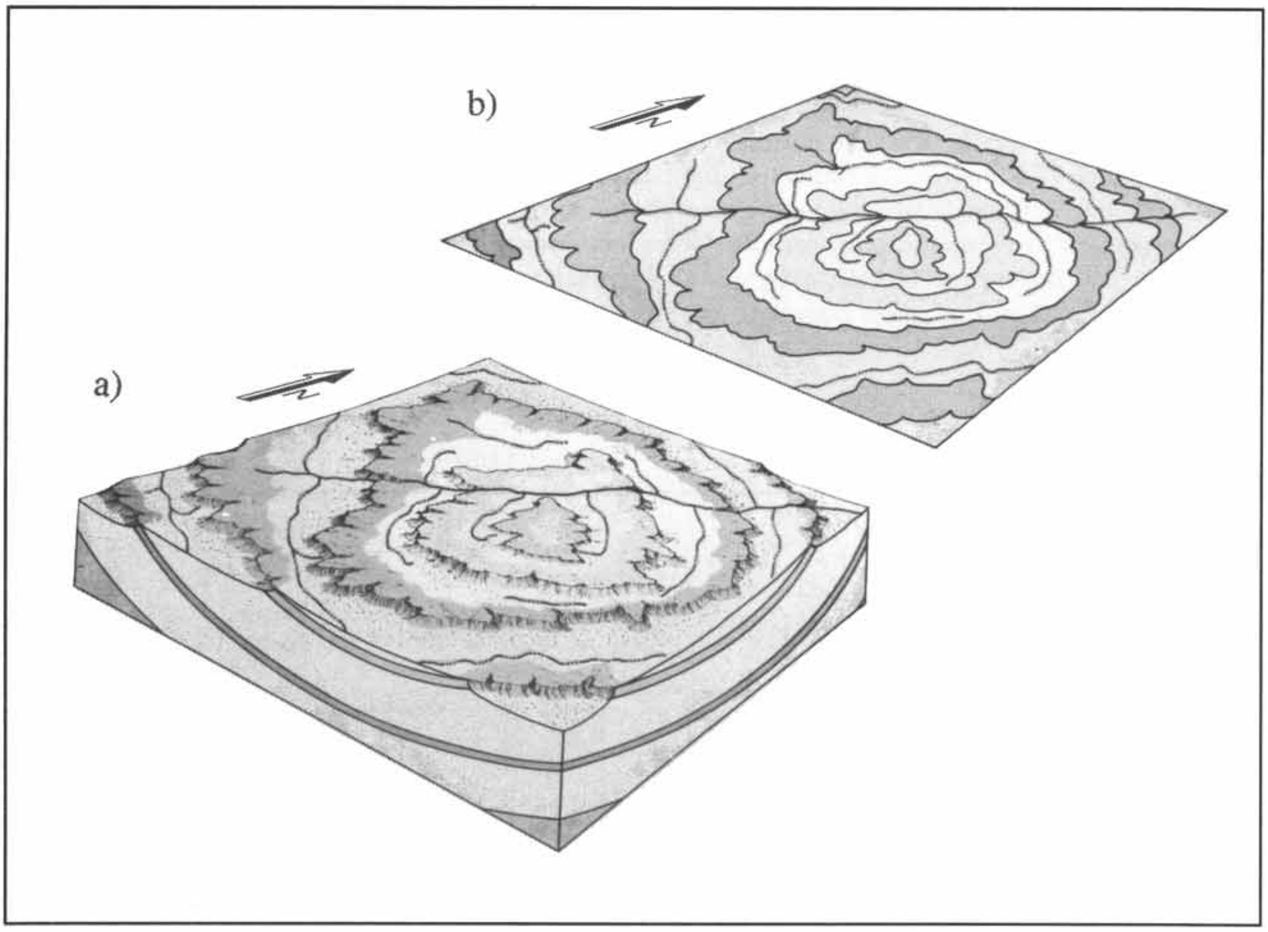

Figure 2-11: *a) Perspective diagram of a subcircular basin with strata dipping toward the center of the basin. b) Geological map of the same area.*

therefore, do not correspond to any non-horizontal slope of the beds. Once it is realized that the lithological contacts are, in fact, outlining the topographic contours themselves, albeit at an uneven spacing, it becomes simple to understand the structure of an area with horizontal beds. Assuming a normal stratigraphic succession, older strata are exposed in the valleys and younger rocks occur at the higher elevations. Figure 2-6 is an aerial photograph of horizontal rock strata intersected by a southward-running drainage pattern.

Figure 2-12: *Vertical aerial photograph of the Paredon basin, Mexico. Image shows an area about ten kilometers in width.*

□ **Exercise 2-3: Figure 2-13 shows a geological outcrop pattern of horizontal strata in an area eroded by a dendritic drainage pattern. Color the various outcrops of the same strata in the same color, and answer the following questions: a) Which letter code represents the oldest formation? b) What is the youngest deposit? c) Are there any unconformable stratigraphic relationships? d) Topographic contours have not been drawn separately on the map, but indicate all contour elevations, given that the contact between bed O and S is at 1000 meters above sea level and all other beds are 100 meters thick. e) Where is the highest peak of the area? f) Which formation occurs at the highest point and why?**

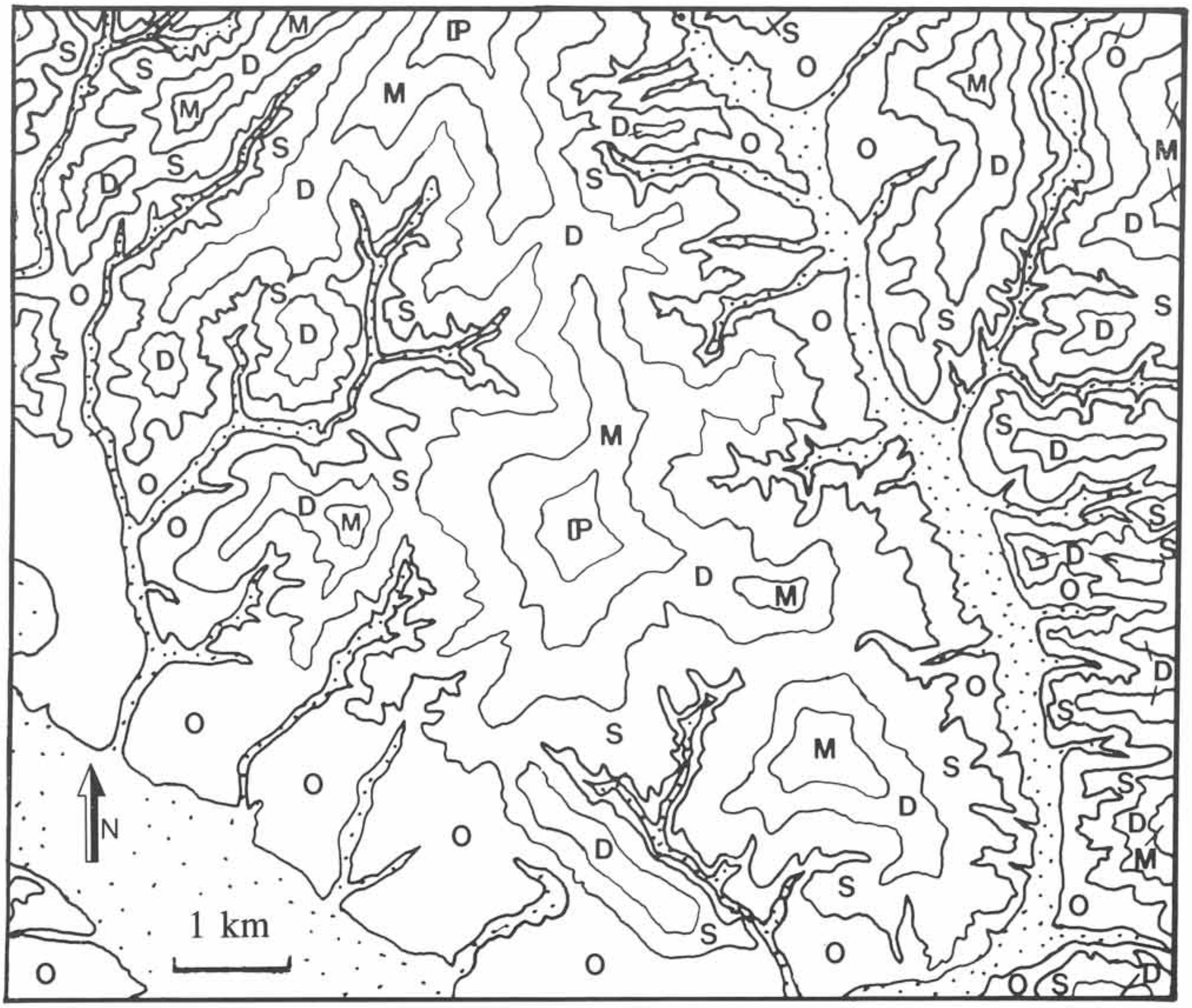

Figure 2-13: *Geological map studied in exercise 2-3.*

If layers dip uniformly, their direction of dip can commonly be inferred from aerial photographs and geological maps. Such layers form geological boundaries with V-shapes where incised by river valleys (Fig. 2-7a & b). The V's on map patterns of Figures 2-5b and 2-7b differ in the sense that the V's point more or less randomly in the dendritic erosion pattern of Figure 2-5b but point in uniform direction for the dipping layers of Figure 2-7b. Figure 2-8 is an aerial view of uniformly inclined or homoclinal rock strata. The variations in width of the various lithological units is only apparent and arises from the way in which the ground surface intersects the southward-dipping beds.

The use of the V-cusps, outlining the lithological boundaries where transected by drainage patterns, to estimate the dip direction of the rock contact is known as the *V-rule* for dipping strata. Originally horizontal strata, which have been warped into domes by tectonic processes, will display eroded outcrop patterns with V-cusps pointing outward from the core of the dome (Figs. 2-9a & b; 2-10).

☐Exercise 2-4: Figure 2-14 shows an incomplete geological map. The formations in the northwest have been mapped from an aerial photograph and were transferred to a topographic map of the same scale. Study the map pattern and proceed as follows: a) What is the orientation of the strata? b) Complete the outcrop pattern of the entire map, assuming that no faults transect the unmapped area. Use the same symbols as on the map. c) Which area can be mapped only with some uncertainty? d) The thickness of most units can be determined; but which two units are of unknown thickness?

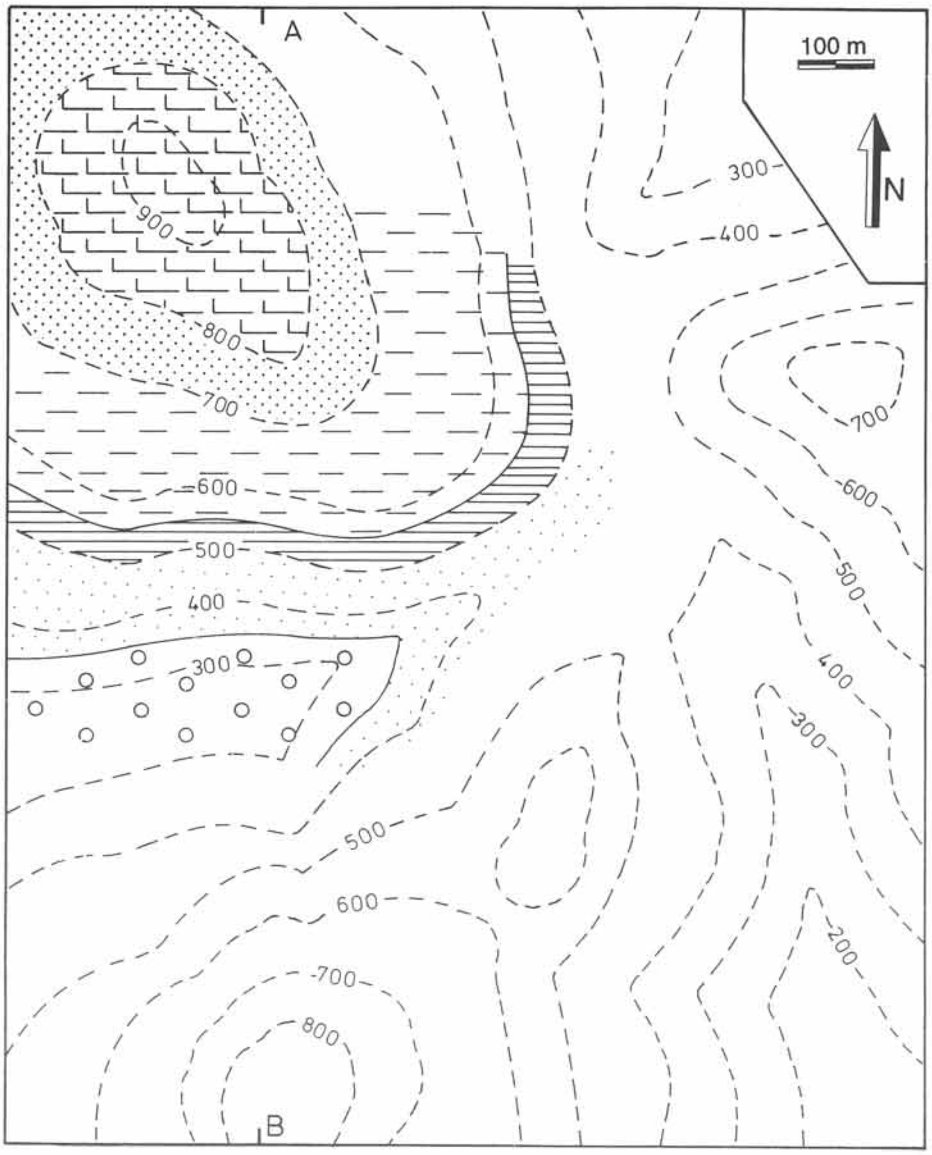

Figure 2-14: Topographic map with incomplete geology to be analyzed in exercise 2-4. Contours are in meters.

Conversely, basin structures are revealed by outcrop patterns with V-cusps consistently pointing towards the center of the basin (Figs. 2-11a & b; 2-12). The V-shape of the outcrop pattern points in the direction in which the rock unit dips below the ground surface. This principle is distinct from the V-shape for topographic contours, where V-patterned contours always point upstream.

2-3 Cross-sections of homoclinal layers

Vertical cross-sections provide a tool to display the internal geological structure of a terrain, and thus these are complementary to the geological map. A cross-section shows the positions of the contacts between strata and other rock bodies that one would see if it were possible to make a vertical cut through the ground. For example, the sides of the block diagrams of Figures 2-4a to d show the orientation of uniformly dipping or *homoclinal* layers in cross-section. Detailed techniques for cross-section construction will be discussed later (see chapter four), but it is useful to introduce a few of the basic principles at this stage.

Consider the map of Figure 2-15a, which is a combined geological and topographic map. First, a *section line* must be selected. For this area, the most complete subsurface view is provided by an east-west section line, transecting the three topographic highs outlined by the topographic contours. Second, the vertical profile or section scale must be selected. If vertical exaggeration is to be avoided, the vertical scale of the profile should be equal to the horizontal scale. Third, the topography of the ground surface is transferred pointwise to the profile box. Elevations are plotted in the cross-section using contours that intersect the section line on the map (Fig. 2-15b). The surface profile is completed on the cross-section by extrapolating between the plotted elevation points. Fourth, the geological boundaries are transferred from the map to the cross-section using only their intersection points with the section line on the

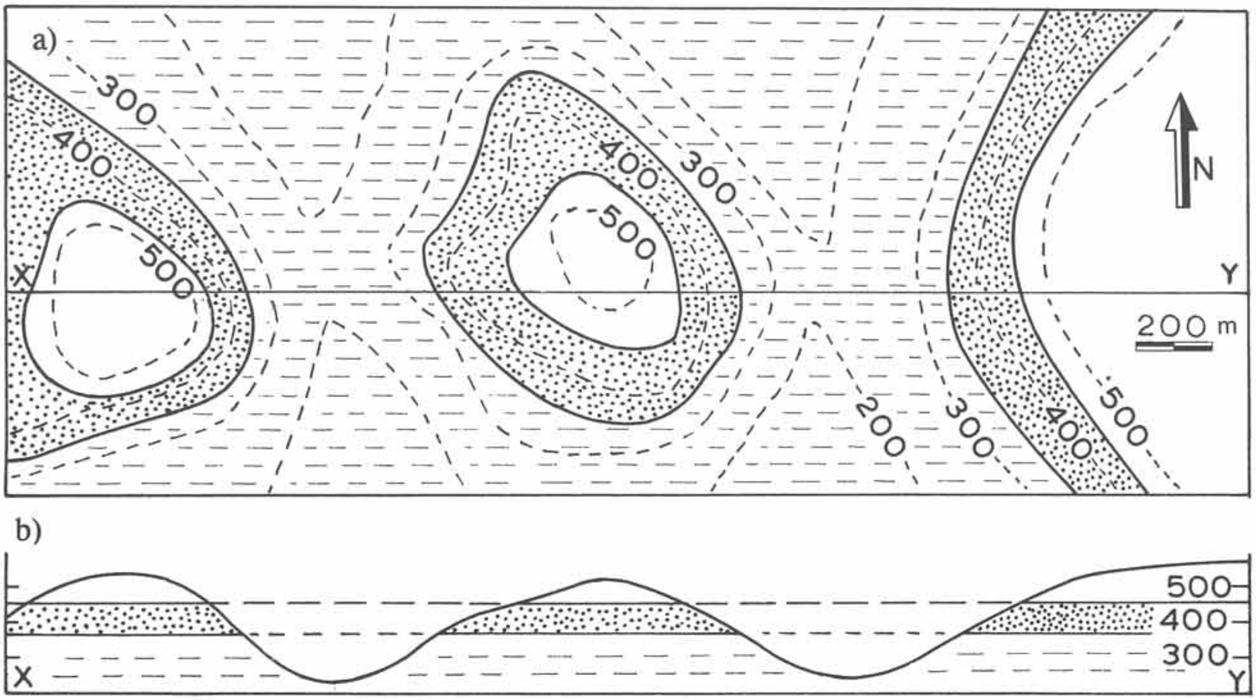

Figure 2-15: *a) Geological map with elevation contours (in m). b) Cross-section along line X-Y. Shown are the topographic relief of the ground surface and the detailed position of the rock strata.*

map. These geological check points are plotted along the ground surface in the cross-section. Subsequently, all corresponding stratigraphic contacts are connected in the subsurface. The completed subsurface section is shown in Figure 2-15b. The cross-section illustrates the simplicity

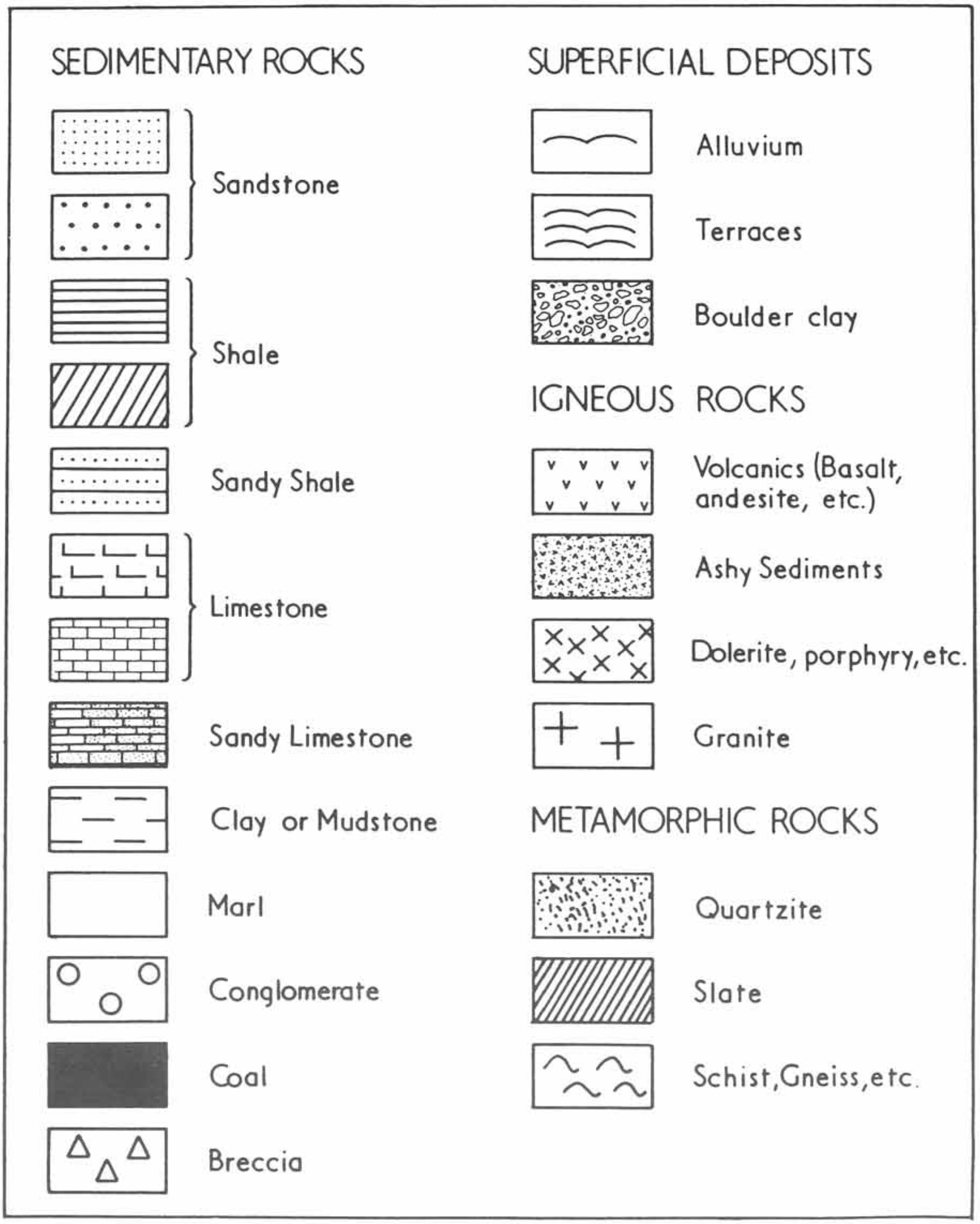

Figure 2-16: *Elementary symbols used to indicate rock types on geological maps and sections.*

of the area's geologic structure, shown to comprise of nearly horizontal rock strata only. Cross-sections provide a powerful means to demonstrate the geological structure of an area. The rock types in such sections are indicated by conventional symbols. Figure 2-16 shows examples of commonly used lithological symbols. However, lithological notation is not standardized and many different symbols are in use throughout the world.

□Exercise 2-5: Construct a N-S vertical cross-section along trace A-B across the map of Figure 2-14. The cross-section must show both the topography of the ground surface and the geology of the layers beneath. Use the appropriate symbols for the layers in the cross-section (Fig. 2-16).

2-4 Columnar sections

Geologists divide sedimentary rocks into formations. A formation is a mappable rock unit, consisting of uniform or uniformly alternating rocks. Formations are defined on the basis of lithology and fossil-content, and comprise a continuous sequence of beds without any interruption by unconformities (for details on unconformities, see chapter nine). Formations have well-defined, either definite or gradational boundaries. The extent of a formation must be large enough to be mappable at the surface or traceable in the subsurface. The name of each formation consists of two parts. The first part refers to a locality where the formation is clearly exposed; the second part of the name indicates the dominant rock type. Both terms are capitalized, as in, for example, the Kaibab Limestone, Navajo Sandstone, and Burgess Shale. If no single rock type dominates the formation, it is simply referred to as the Rus formation, Dammam formation, and so forth. A formation may be subdivided into members, which in turn may include distinctive beds. Several formations with some stratigraphic unity may be combined to form groups, and groups can be combined into supergroups. The terms formation (lower case f) and Formation (upper case F) are used to distinguish between informal and formal use of a stratigraphic unit. Formal acceptance of stratigraphic subdivisions is a process of accreditation by peers, endorsed at meetings of professional societies.

Columnar sections show the sequence of rocks and their characteristics and include the subdivision into formations and members (Fig. 2-17). Each unit is shown with the stratigraphic thickness scaled vertically, so that the relative thickness of units and the contact relationship between them become clear at a glance. The lithology of each unit is indicated by conventional symbols, denoting the dominant rock type. Accessory features, also, may be indicated by special symbols, and their meaning is explained in a legend to the columnar section. The relative resistance to weathering and erosion of the beds is indicated by relief in the horizontal length of the layers in the column. Many details can be included, but attempts to illustrate too many features usually result in confusing and illegible columns. However, properly organized columnar sections show the most significant stratigraphic data at a glance.

Columnar sections are based either on original measurements of rock strata across cliffs and benches in the field or can be reconstructed from geological maps. In the latter case, the stratigraphic thickness of the mapped units is estimated from the map and compiled in a columnar section to illustrate their relative thickness. If the layers are horizontal, topographic contours can be utilized to obtain the vertical thickness of the rock units. If the layers are tilted, their true, stratigraphic thickness can be obtained, using methods discussed in the next chapter. If not observed in the field, the relative resistance to erosion, indicated in the relief of the stratigraphic column, can be tentatively inferred from the rock type. Limestone and sandstone commonly form steep cliffs, while shale and marl are much softer and erode more rapidly into gentle slopes. More commonly columnar sections are based on detailed strati-

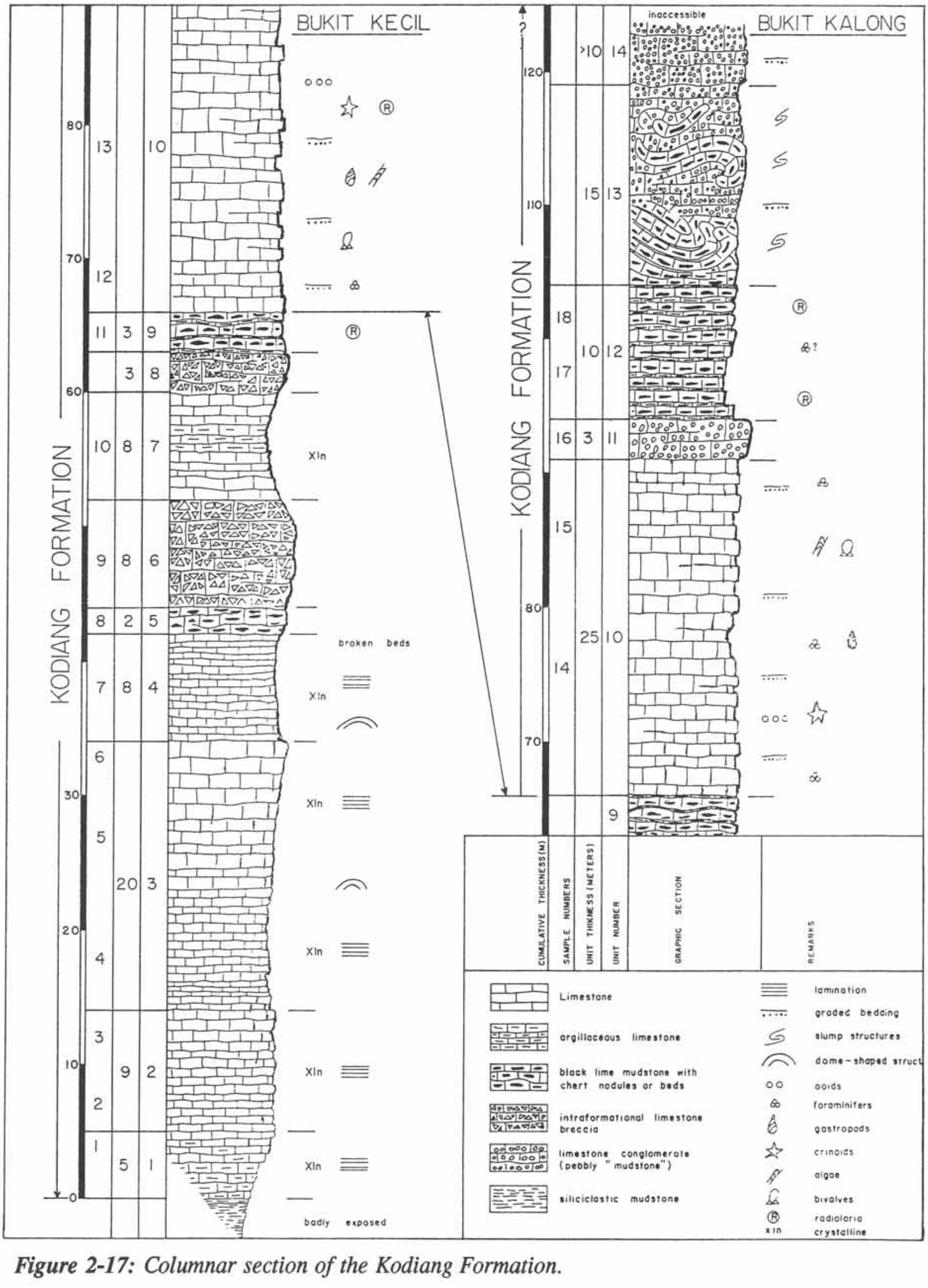

Figure 2-17: Columnar section of the Kodiang Formation.

graphic data measured in the field. Such measured columnar sections usually are cleaned-up compilations of a number of overlapping partial sections taken at different locations, as continuous exposure of a complete succession in a single location is a rarity.

□ Exercise 2-6: Construct a columnar section scaled for the stratigraphic units of the area mapped in Figure 2-14.