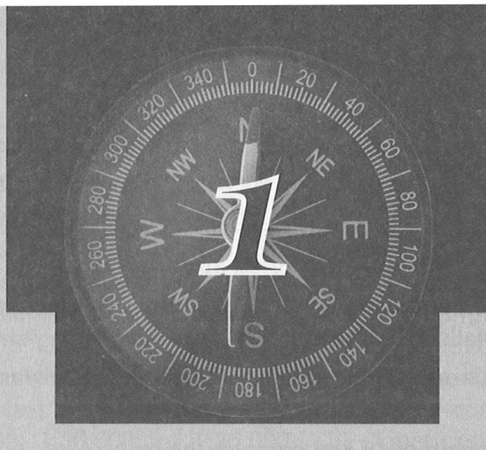
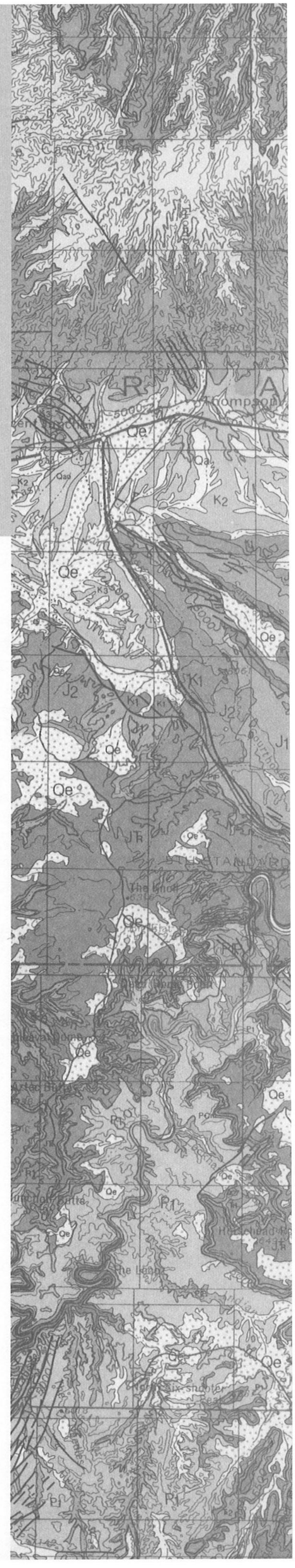




MAPS AND IMAGES USED IN THE STUDY OF EARTH

Many techniques are used to portray the surface and near-surface features of the Earth. Some of these, such as photographs and sketches of the landscape, depict the Earth's surface in ways in which we are accustomed to viewing it. Other techniques, such as geologic maps and cross sections, are designed to reveal features that are not obvious to the casual observer. Each method of illustration has certain advantages. These maps or illustrations are the end product of the accumulation of large amounts of data, interpretation, revision, and documentation of the Earth's surface. They allow the geologist, geographer, engineer, and planner to visually image this data and embark on an adventure to discern and understand the Earth's surface and the underlying structure in an area of interest. This is the logical first step in understanding the natural environment and in deciding the need for additional geologic study or engineering work.

TYPES OF INFORMATION YOU CAN OBTAIN FROM MAPS AND IMAGES

Maps and images contain a wealth of information. Much of this information can be obtained simply by reading the map—that is, by understanding the way the map is constructed and what the various symbols on the map represent. Much more information is available to those who have a more complete understanding of the subtle meaning of the patterns, shading, and configuration of contour lines and can interpret them in terms of natural processes and materials that are generally associated with them. For example, contour lines can be read to indicate the elevation at any point on a topographic map, but an understanding of the shape of the land may be interpreted to yield information about the processes that caused the observed shape and possibly about the type of material that is likely to be found in certain landforms. Some of the types of information that can be obtained from the most generally available maps and images are identified below.

Topographic Maps

The amount of detail available depends on the scale of the map.

Information Shown by Map Symbols

1. Cultural features—roads, trails, pipelines, towns, streets, power lines, houses, dams, quarries, churches, cemeteries, airports, mines, etc.
2. Natural features—streams, lakes, woodlands, mountain peaks, glaciers, beaches, waterfalls, swamps, etc.
3. Political boundaries—national, state, county, city, townships, ranges, section lines, etc.
4. Latitude and longitude of any point on the map.
5. Scale showing horizontal distances.
6. Elevation of the ground surface, indicated by contours and bench marks.
7. Magnetic declination.
8. Data of the map.

Information You Can Interpret from the Map

1. Shape of the land surface (profiles and block diagrams can be constructed).
2. Types of landforms. (A skilled interpreter can generally identify places where the landforms were created by erosion or deposition by glaciers, wind action, coastal currents, streams, and in some cases, by groundwater.)
3. Structure of the bedrock (e.g., folds, faults, flat layers, etc. may be inferred from some maps).
4. Drainage basins of streams.

Geologic Maps

Information Shown by Map Symbols

1. Topographic information. (If the geologic map is drawn on a topographic base, the information available on topographic maps of the same area is present on the geologic map, but contours may be difficult to read because colors are used to indicate geologic information.)
2. Type and location of bedrock units of various ages.
3. Contacts between different rock units.
4. Type and location of surficial deposits may be indicated.
5. Type and location of faults and folds.
6. Trend (strike) and inclination (dip) of rock layers.

Information You Can Interpret from the Map

1. Rock structure beneath the ground surface, as indicated by cross sections.
2. Rock type of the bedrock, both at the surface and at various depths in the subsurface (this information can be projected from the surface).
3. Rock hardness and consolidation (i.e., how difficult the rock will be to remove, if lithologies are known in detail).
4. Origin and type of material in surficial deposits if the map shows surficial geology.

Base Maps

A base map is a map showing geographic and cultural features. Geologic data are recorded and presented on a base, most commonly a topographic map. The ideal base map is one drawn in such a way that the map contains a minimum distortion of horizontal distances and directions between all points on the ground. As you will see, the curved surface of the Earth makes this a difficult task.

A number of different types of maps are used as bases for presentation of geological data. The most widely used bases in the United States are maps that depict topography by means of lines connecting points of equal elevation, called **contour lines**. Topographic contour maps are available at scales of 1:250,000; 1:100,000; 1:62,500; 1:50,000; and 1:24,000. Most of these are published by government surveys. Maps published by the US Geological Survey (USGS) are available from their website (http://store.usgs.gov) and from the USGS National Geologic Map Database (http://ngmdb.usgs.gov). Most recent maps published in other countries have scales of 1:250,000; 1:100,000; 1:50,000; or 1:25,000. The American Geosciences Institute annually publishes the addresses of state and national geological surveys throughout the world.

Base maps without contours are commonly used to depict large areas, e.g., states, regions, or an entire country. Bases without contours may also be used for maps containing data that might be confused by topographic contours.

If topographic maps are not available, or if greater detail is needed than can be placed on the most detailed map available, aerial photographs may be used as base maps. However, even vertical aerial photographs contain distortion from the center to the margins of the image.

Oblique Aerial Photographs

Photographs taken obliquely (at an angle) from the air (Figure 1-1a) retain some of the perspective of ground-level photographs (Figure 1-1b). Most features are familiar and are easily recognized, but distortion, caused by change of scale with distance, remains. Because of this distortion, only vertical aerial photographs are suitable for use as base maps for geologic mapping.

Vertical Aerial Photographs

Many photographs used in the preparation of maps, and for photographic interpretation, are taken from high altitude and with the camera pointing vertically down (Figure 1-2a on p. 5). These photographs have the advantage of showing features in their correct position relative to one another and with much less distortion than occurs in oblique photographs. Some distortion remains because the distance from the camera to the point on the ground shown in the center of the photograph is less than distances to points farther away from the center. Also, points on the ground at different elevations are distorted. These effects become less pronounced as the altitude of the camera increases.

Orthophotographs

The limitations of vertical aerial photographs (i.e., radial distortion of scale from the center of the photograph to the edge) are corrected in orthophotos. An orthophoto is an aerial image that is geometrically corrected so that the scale is uniform. The resulting photograph is planimetrically correct. Thus, accurate measurements of area, distance, and directions can be made on orthophotographs. For this reason, they make better base maps than other photographs, and they may be preferred in some instances over topographic maps for use as base maps. Many 1:24,000 quadrangles in the United States are now available as orthophotos. They may be obtained from the US Geological Survey.

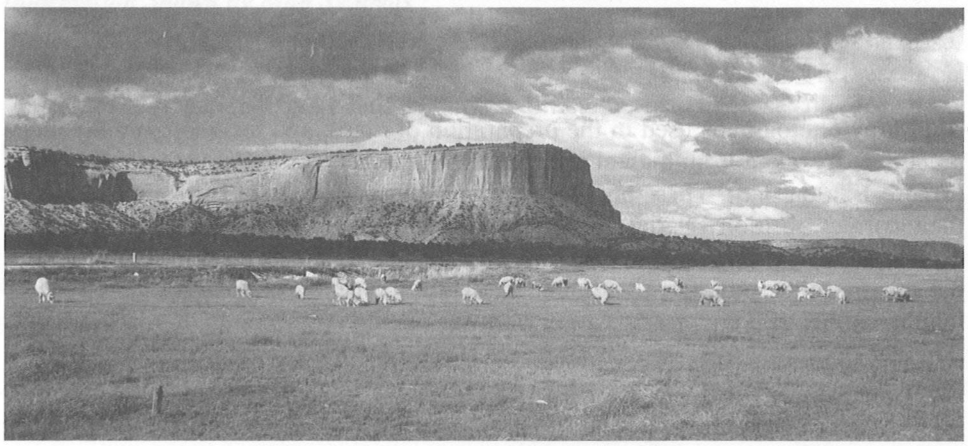
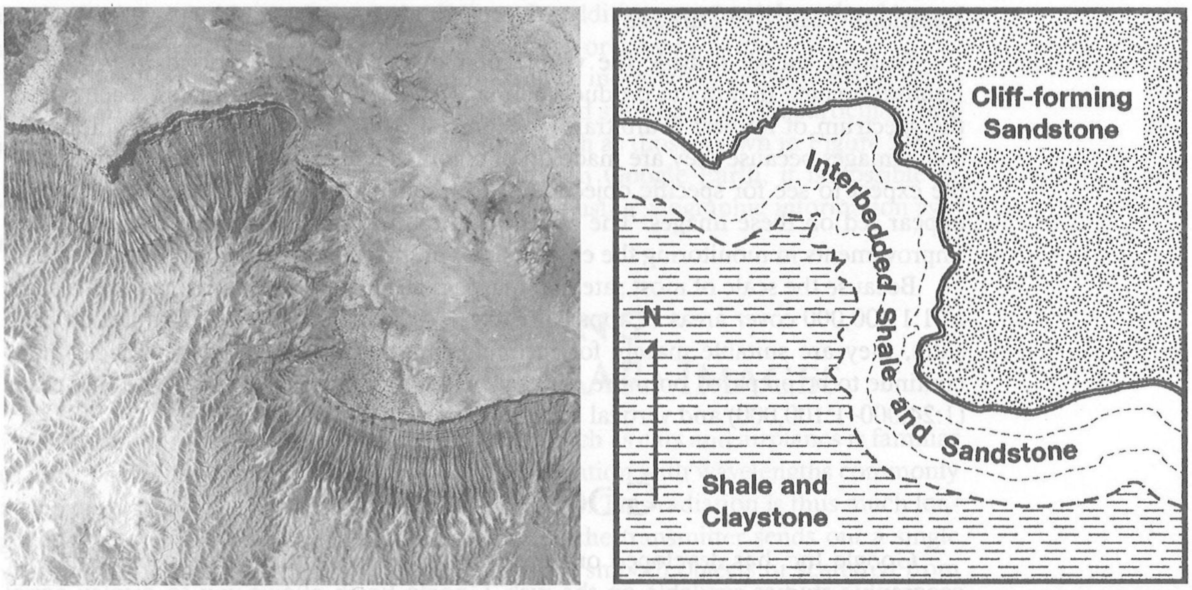


Figure 1-1 (a) This oblique aerial photograph shows the collapsed crater of Mauna Loa volcano located on the big island of Hawai'i. (Photograph from the US Geological Survey.) (b) Ground-level photograph of a massive cliff-forming sandstone layer underlain by thin-bedded sandstones and shales (this photograph was taken in the Colorado Plateau region of the southwestern United States). Clearly identifiable lithologic units such as these constitute ideal rock units of the type shown on most detailed geologic maps. Many rock units are not so clearly defined because the upper or lower contacts are gradational.

Remote Sensing Images

Images produced from remote sensing devices are used for mapping and monitoring the environment from satellites. These data are most helpful in revealing recent changes or new occurrences in an area. Images are especially important to environmental scientists and engineers who are studying time-dependent changes in the environment. Such changes may be natural or in response to a remediation technique. The devices used for this purpose are designed to detect radiation coming from the Earth. This radiation can be characterized as a spectrum that ranges in wavelength from very long waves, such as radio, radar, and infrared waves, to short waves, such as ultraviolet, X-rays, gamma rays, and cosmic waves. Some very short wavelengths can penetrate the Earth's surface and provide information concerning buried objects and



(a) (b)

Figure 1-2 (a) This vertical aerial photograph is the type commonly used by geologists in mapping. The area shown is located in Utah along a prominent cliff (similar to that shown in Figure 1-1b) known as the Book Cliffs. (Photograph from the US Geological Survey.) (b) A geologic sketch map illustrates the aerial distribution of the three rock units shown in Figure 1-2a.

shallow structure. For example, images obtained from very short wavelengths can reveal the presence of buried stream channels beneath sand. Most films used in photography are designed to be sensitive to and record the visible part of this spectrum. Filters are used to absorb some wavelengths and emphasize others. This same principle is used in some types of remote sensing. Essentially, a photograph is taken using only a few selected parts of the radiant energy reaching the camera to produce the image. This selection may be made by use of special combinations of films and filters.

Satellite images are also obtained by use of a scanning system rather than photographic film. In these systems, a rotating mirror directs the radiation from a small area on the ground onto a detecting device, which generates an electrical impulse, the magnitude of which varies depending on the amount of energy of particular wavelengths being reflected onto it. The electrical impulse is then digitally recorded. It may also be transformed into a light beam and recorded on film. The incoming radiation may be subdivided according to wavelength into as many as 18 channels, each of which is simultaneously digitally recorded. This offers a number of advantages, in that the signals can be manipulated before an image is produced. Such manipulations consist of filtering and electronic enhancement. In this way, various types of background "noise" can be eliminated, or certain wavelengths can be enhanced before the final signals are recorded as an image.

The scanning methods have been highly successful in providing relatively detailed images of large areas on the ground. They offer far greater flexibility than more conventional photographic methods and allow the user to enhance particular features by selecting and reproducing the radiation recorded in certain wavelengths during processing of the image. For example, selecting longer wavelengths of radiation (e.g., radar) results in excellent penetration of most clouds, haze, dust, and precipitation. Thermal infrared radiation (long wavelength) is emitted from warm and hot objects on the Earth even at night, so images in this range obtained at night can be used to locate thermal springs, volcanic centers, and even other lower-level heat sources. Other wavelengths or combinations of wavelengths may be used to make air pollution, suspended sediment in water, various types of crops, or other surface features more prominent on the image.

Landsat Satellite Images

Radiant energy outside the visible part of the spectrum is used in producing Landsat images. In order to produce an image of the nonvisible spectrum, each part of the spectrum of interest is arbitrarily assigned a color. These images are called false color images because they are made up of colors that are different from the ones people expect to see for specific objects. For example, trees and green fields commonly appear red on these images. The advent of these techniques has made possible vast improvements in monitoring the environment and inventorying land-based resources.

Because the scale of most satellite images is so small (Landsat images with a scale of 1:1,000,000 cover areas of approximately 10,000 square miles—100 miles on each side), they are suitable mainly for reconnaissance mapping. Most geological maps continue to be prepared on more conventional base maps, such as topographic maps (1:24,000–1:100,000) and vertical aerial photographs.

Google Earth

Google Inc. has developed one of the most interesting and useful programs for geographic studies available on the web. Google Earth allows you to display aerial images of any part of the Earth at scales that vary from hemispheric to local, and at view angles that vary from directly overhead to ground level from any viewpoint you select. The images are very much like aerial photographs, but are three-dimensional. Unlike aerial photographs, the viewpoint does not have to be from directly overhead. You can obtain views from any oblique angle and change that angle gradually in any direction you wish to use. Distortion increases as the angle between the vertical and the horizon increases (Figure 1-3).

The software also gives you options as to what is included in the image. For example, you may have superimposed on the image borders ranging from international borders to those of states, provinces, counties, and coastlines. These may be accompanied by names of countries, states, counties, cities, parks, important land-

(a) (b)

Figure 1-3 Google Earth images of the confluence of the Colorado and Green Rivers in Canyonlands National Park. Compare the vertical image (a) with the oblique view (b). With Google Earth it is possible to change the direction and the angle of the oblique view. This area is also covered on the Utah State map found in Appendix B (p. 212). (Images Landsat/Copernicus © 2016 Google.)

marks, highways with numbers, and rail lines. In addition, you may have landscapes shown as they would appear at various times of day or seasons of the year.

Google Earth may be very helpful in making or interpreting geologic maps, especially in areas where rocks are exposed at the ground surface or where particular rock units are characterized by distinctive landforms, such as those shown in Figure 5-6.

Although geologic maps are not included with Google Earth, it is possible to "drape" geologic maps over 3-D landscape images using geographic information systems software.

Side-Looking Airborne Radar (SLAR) Images

Using radar for purposes of detecting objects such as cars and airplanes is familiar to most people. In using radar, electromagnetic radiation with wavelengths commonly in the range of 0.5 mm to 10 m is directed outwardly. This radiation is thus much longer than the visible part of the spectrum. Usually the transmitter sends out a single wavelength. Part of that radiation is reflected from smooth objects or scattered from objects that have rough surfaces, and part of the reflected or scattered radiation is directed back toward the source and may be detected. To obtain images of the Earth's surface, a radar source and detector are located in an airplane and directed toward the surface of the Earth. The angle at which the detector is aimed can be varied to obtain energy returned at either a low or steep angle from the surface. The detector scans the surface, using a back-and-forth motion to detect returning radiation. These scan lines are recorded continuously as the airplane flies at a closely controlled altitude. The resulting image is a long strip oriented in the direction of the flight line. Strips can be placed together to produce a mosaic image of an area.

SLAR images resemble aerial photographs (Figure 1-4), but they are really quite different in a number of ways. The wavelength of radiation used for this purpose is much less affected by moisture and dust than is visible radiation. Thus, radar images contain no clouds. The longer wavelengths of radiation may even penetrate vegetation and dry sand or soil. Some images obtained in arid regions have successfully detected subsurface drainage systems now covered over with sand and dust. Like photographs, radar images cannot "see" the far side of objects. Thus, the back side of mountains or hills lie in shadows that are black on the images. The clarity of the images and the penetration of the radiation make SLAR images valuable sources of information.

Geologic Maps

Geologists depict their interpretations of the aerial distribution of different rock bodies and surficial materials on maps called geologic maps (Figures 1-2b and 1-5c). The "bodies of rock" depicted may be bedrock materials such as sedimentary strata, igneous intrusions, or metamorphic rocks; or they may be surficial deposits, such as stream alluvium, beach deposits, or volcanic extrusions.

On some geologic maps, the bodies of rock that are identified and distinguished from one another are what geologists call **rock units** (see Figure 3-2). These are bodies of rock that can be identified on the basis of their composition and texture. The basic rock unit is called a **formation**. These are bodies of rock that can be identified by their lithology and their stratigraphic position. By definition, they can be distinguished from the rock units stratigraphically above and below, and they can be recognized and mapped at the surface or in the subsurface. A thick, massive unit of sandstone, such as the one shown forming the cliff in Figure 1-2a, might be an example. Formations may be subdivided into thinner units called members; and in some cases, several formations that are related to one another are placed in larger stratigraphic subdivisions called groups.

On other geologic maps (e.g., the geologic map of the United States), the units differentiated on the map (called **map units**) are grouped on the basis of their age. For example, all sedimentary rocks of Cambrian age, regardless of composition, may be grouped together. Geologic maps always contain an explanation in which the units used on the map are identified and the symbols are explained. Common symbols used on geologic maps can be found on the inside covers of this text as well as on the explanations for the maps found in Appendix B. Always examine the explanation to find out what is differentiated on the map.

The amount of control—that is, the number of places on the ground where observations were made—used to construct geologic maps varies greatly from map to map. In most areas, the number of places where rocks crop out at the surface limits the amount of control. The number of control points used in the construction of the map may also be determined by the amount of time available to collect data or the ease of access to outcrops. The contacts between different rock bodies appear as lines on geologic maps. In some areas, it may be possible to work out the position of contacts in great detail. In other areas, the contacts may be largely concealed from view, and their

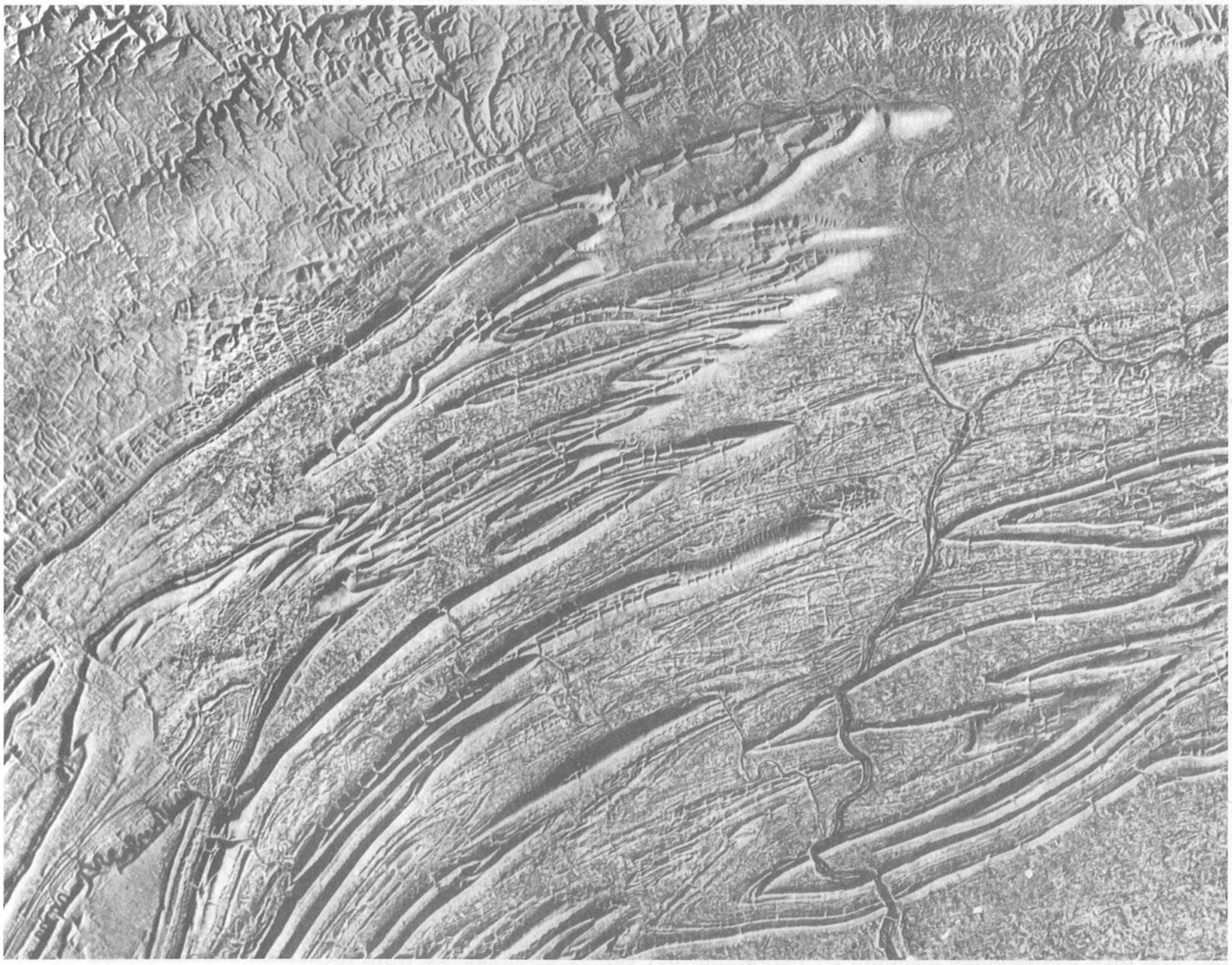
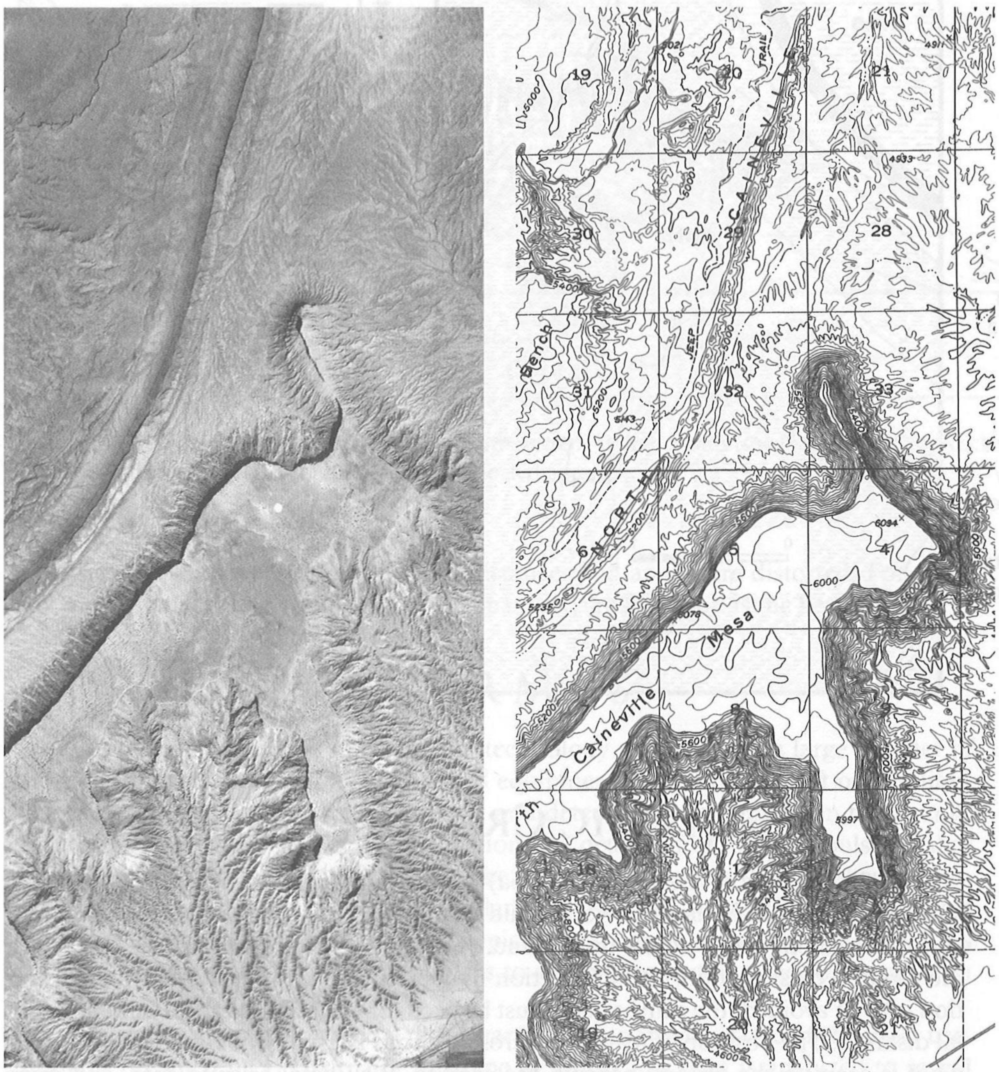


Figure 1-4 This SLAR image depicts a portion of the physiographic Valley and Ridge Province in Pennsylvania. Parts of the Great Valley (lower right), Valley and Ridge (central portion of the image), and Appalachian Plateau (upper left) are shown. Limestone forms the floor of the Great Valley. Folds developed in sandstone (ridges) and limestone and shale (valleys) form the dramatic topography of the Valley and Ridge Province. Flat-lying sandstones lie beneath the Appalachian Plateau. (Image compiled by Simulation Systems Inc. from data obtained from the US Geological Survey.)

position may be inferred. Where bedrock is concealed, sources of information about the subsurface may be available from wells, borings, pits that have been dug, or from geophysical surveys. Some geologic maps represent years of careful work on the ground; others are based largely on the interpretation of aerial photographs. Because geologic maps are interpretations based on a limited number of observations, locations of contacts and interpretations generally become more refined as an area is remapped and more detailed observations become available. Because geologic maps are drawn on a base map such as a topographic map (Figure 1-5b) or vertical aerial photograph (Figure 1-5a), it is possible to locate the geologic information in a geographic context.



(a) (b)

Figure 1-5 North Caineville Mesa, Utah. (a) Vertical aerial photograph. (b) Topographic map. *(continued on next page)*

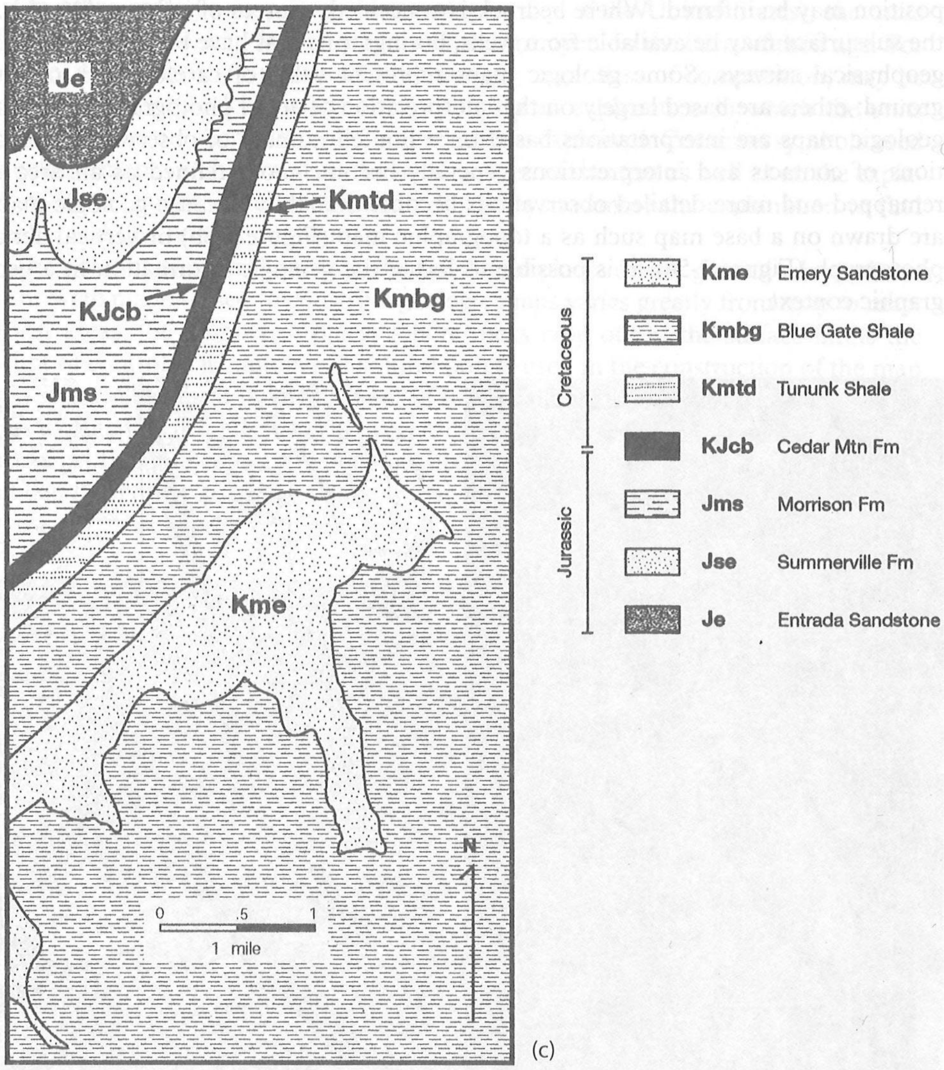


Figure 1-5 (c) Geologic sketch map. North Caineville Mesa has a flat top and is surrounded by a cliff formed of the Emery Sandstone. The Blue Gate Shale surrounds it. The ridge labeled North Caineville is held up by a steeply inclined sandstone known as the Cedar Mountain Formation. Northwest of the ridge, rock units of Jurassic age are flat lying. (Photograph and topographic and geologic maps from the US Geological Survey.)

Geologic Cross Sections

Ideally, a cross section (Figure 1-6a) shows the positions of contacts between strata or other rock bodies that you would be able to see if it were possible to make a vertical cut along a line across the ground. A profile of the ground surface is used for the top of a cross section, and the section may extend to any depth. If serious distortion is to be avoided, the same scales must be used for elevation (vertical) and horizontal distance. The position of features in cross sections is usually obtained by projecting what is seen on the ground beneath the surface. Well data, seismic data, and mine maps are also important sources of subsurface control, where they are available.

Geologic Block Diagrams

Block diagrams (see Figure 1-6b) give a three-dimensional view of a portion of the Earth. The perspective from which the block is drawn may be varied, but usually the surface and two sides of the block are depicted. Because the perspective is more familiar, we can see the relationships of features on the surface to their subsurface continuations more easily on block diagrams than we can on the combination of a map and

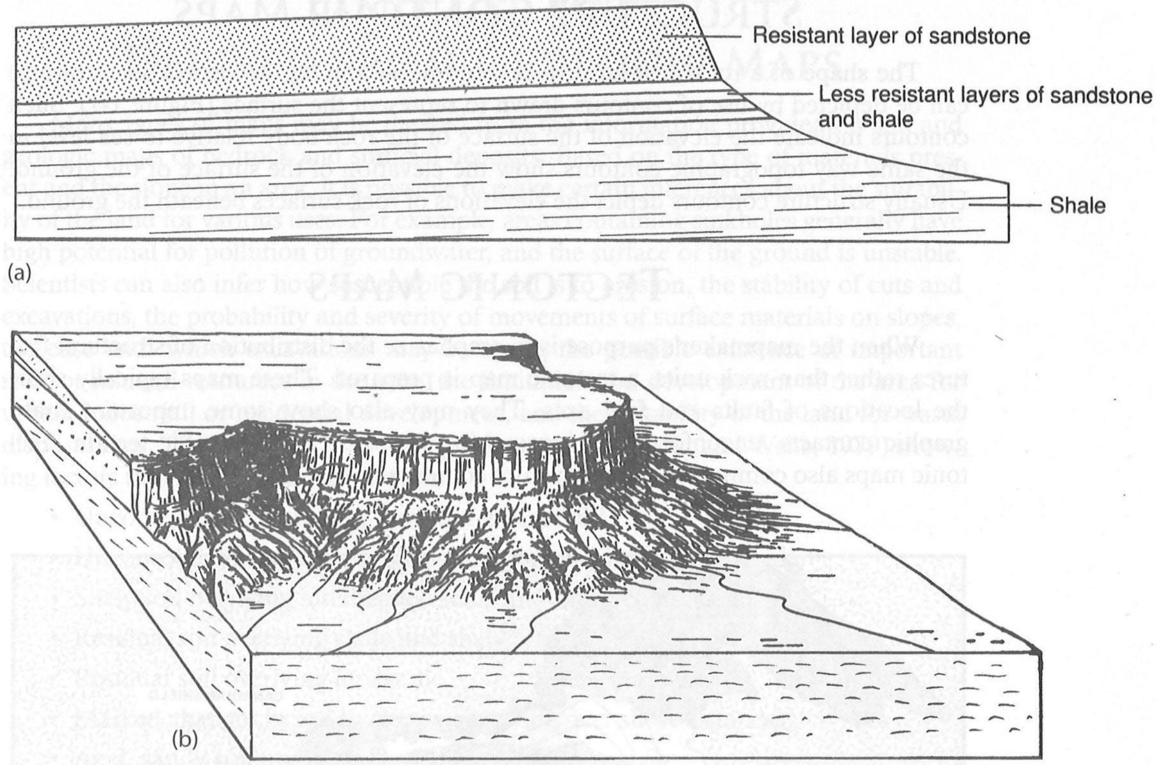


Figure 1-6 Colorado Plateau region of the southwestern United States (see Figure 1-1b). (a) A schematic geologic cross section of the area. (b) A block diagram.

cross section. However, on blocks, both distances and angles are distorted. For accurate measurements, the combination of a map and cross section is the best choice.

LIDAR MAPS

LiDAR (light detection and ranging) technology makes use of a large number of short laser pulses produced by specialized equipment carried on aircraft or satellites. The pulses are reflected from the ground, and detected by equipment on the aircraft or satellite. The time between the production and detection of the laser pulses makes it possible to determine the elevation of the ground. When this data is taken repeatedly along a number of flight paths similar to those used for aerial photography it may be used to produce an image that depicts the shape of the ground surface. This data can be processed in a variety of ways to emphasize certain types of features on the ground.

For geologists what is called a "bare-earth" terrain model is one of the most useful maps obtained by LiDAR. For this type of model, the data is analyzed to reveal the shape of the ground surface that may be covered by trees or other plants. Faults and rock outcrops that would be covered on aerial photographs become clear. This is an excellent tool for detailed study of landforms. By making repeated high-resolution digital images produced from LiDAR, it is possible to measure active changes in the shape of the ground surface. This makes it possible to measure the amount, and even the rate, of displacement along active faults.

The main disadvantages of LiDAR images come from the cost of making the surveys and analyzing the data. In addition, they may contain so many fine-scale features on the ground that they may obscure the large-scale features commonly used in mapping.

Structure Contour Maps

The shape of a rock or fault surface (commonly the top of a particular stratum) can be depicted by use of contours drawn to represent the surface (Figure 1-7). Such contours indicate the elevation of the surface of the rock body relative to sea level in the same way topographic contours show the elevation of the surface of the ground. Usually structure contours depict the elevations of rock surfaces beneath the ground.

Tectonic Maps

When the mapmaker's purpose is to emphasize the distribution of structural features rather than rock units, a tectonic map is prepared. These maps typically show the locations of faults and fold axes. They may also show some important stratigraphic contacts, unconformities, igneous intrusions, or metamorphic terrain. Tectonic maps also commonly show structure contours.

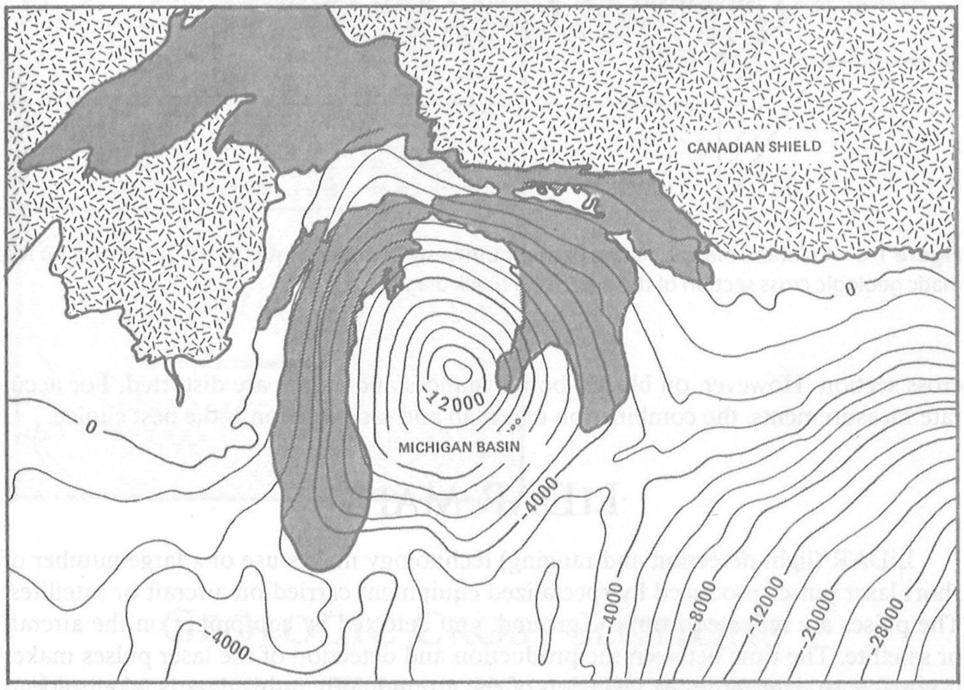


Figure 1-7 The Canadian Shield is a long-stable part of the North American craton where Precambrian igneous and metamorphic rocks are exposed. In the area south of the shield margin, Paleozoic sedimentary rocks cover the Precambrian crystalline rocks of the craton. The contours are lines connecting points of equal elevation on the top of the Precambrian crystalline rocks. The sedimentary rocks lie in a deep basin in Michigan. In the center of this basin, the Precambrian rocks are about 12,000 feet below sea level. Toward the eastern edge of this map area, the depth to the Precambrian crystalline rocks increases. Near the southeastern corner of the map, which is located in the Appalachian Basin, the Precambian rocks are nearly 10 kilometers (about 5.5 miles) below sea level. (After The Basement Map of North America. 1967. American Association of Petroleum Geologists and the US Geological Survey.)

Land-Use Maps Derived from Geologic Maps

Many types of maps may be derived from the information provided on soil and geologic maps of bedrock and surficial deposits. Based on the type of materials present and the slope in an area, it is possible to make certain inferences about the suitability of the land for various uses. For example, areas containing sinkholes generally have high potential for pollution of groundwater, and the surface of the ground is unstable. Scientists can also infer how susceptible the soil is to erosion, the stability of cuts and excavations, the probability and severity of movements of surface materials on slopes, the ease with which excavations may be made, the possible existence of important rock or mineral resources in the area, the limitations on development of the area for urban, industrial, or residential development, and the suitability of the land for waste disposal sites. The following list was taken from a map (Rader and Webb, 1979) showing factors that affect land modification.

- Unconsolidated alluvium, human deposited fill
- Unconsolidated pebbles, cobbles, and boulders in clay and sand
- Shaly soil overlying interbedded shale and sandstone
- Residual soil overlying shale and shaly limestone
- Residual soil overlying limestone
- Marked changes in soil thickness occurring over short distances
- Acid, sandy soil underlain by sandstone and quartzite
- Landslides
- Karst areas with sinkholes

Professional Uses of Geologic Maps

In addition to the more general uses of maps and images for purposes of location, individuals in a number of professions regularly use maps and images in their work. Among these are geologists; geophysicists; geographers; planners, including land-use planners and architects; and civil and environmental engineers.

Geologists

1. To locate rocks of particular age, lithology, or structure.
2. To construct cross sections that will reveal the rock structure beneath the ground surface.
3. To reconstruct the geologic history of an area.
4. To explore for natural resources.
5. To locate water supply and groundwater recharge zones.

Civil and Environmental Engineers and Engineering Geologists

The basic information available concerns the type of materials that will be encountered at or beneath the ground surface and rock structure. This information is valuable for the following purposes:

1. Identification of natural hazards that may exist in any given area. This information is important in planning, design, and maintenance of engineering structures and in making environmental assessments.
2. To determine how difficult it will be to remove materials (e.g., can the surface be ripped, removed with earth-moving equipment, or will blasting be needed?).

3. To aid in the evaluation of cost and problems that may be encountered at the site location for dams, building foundations, highway location, tunnels, canals, pipelines, and other structures.
4. In planning coastal structures and modification of or protection of shorelines.
5. Location of sites with bedrock suitable for waste disposal.
6. By understanding the type of earth material present in an area, an engineer can estimate its strength, deformation, and permeability characteristics. These physical properties must be verified by laboratory testing.

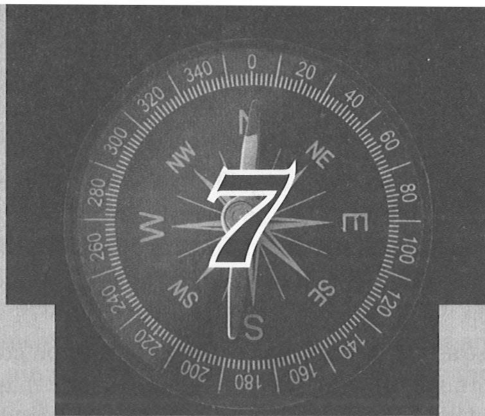
Planners and Architects

As they prepare plans for the future use of the land surface, planners need to have available much of the type of information that environmental engineers and geologists use in designing solutions to specific problems. The planning process provides an opportunity to avoid many of the site-specific problems that may arise as a result of failure to recognize potential environmental problems. Many of these problems are related to the character of the materials at or near the surface of the ground, surface and groundwater conditions, and the presence of natural hazards. Recognition of areas or features in the landscape that may influence the suitability of the land for various uses is important. For example, geologic maps enable identification of the following features:

1. Karst areas (sinkholes, caverns, disappearing rivers, etc.).
2. Flood-prone areas (if surficial geology is shown).
3. Areas where slope instability may exist.
4. Groundwater basins and recharge areas.
5. Active fault zones.
6. Geothermal areas.
7. Surface stream drainage basins.
8. The types of bedrock present and, for surficial geologic maps, the type of material that may lie on top of bedrock.

Soil Scientists

The composition and character of soil that has formed as a result of weathering of the underlying bedrock are closely related to that bedrock. Thus, geologic maps provide an important source of information concerning the origin and character of the soil. In the absence of detailed soil maps, geologic maps can be used to make generalized predictions about the character of the soil.



7

Introduction to Geologic Maps of Bedrock

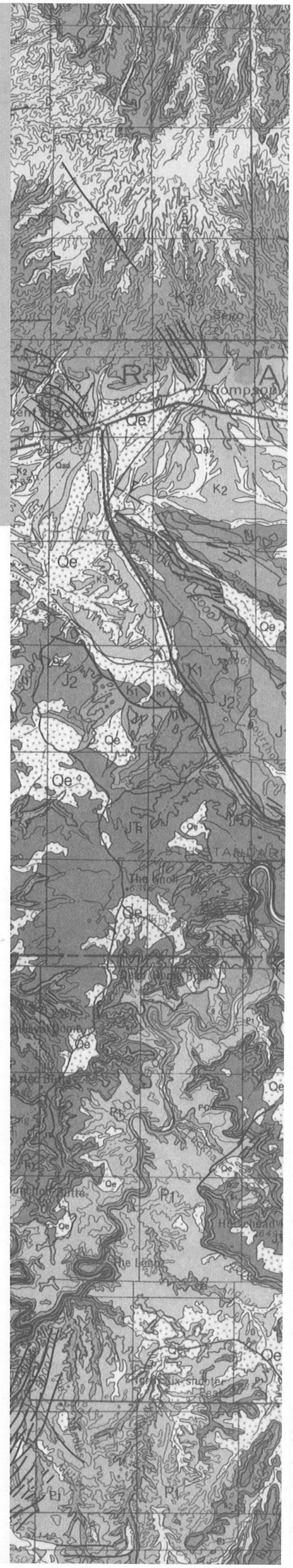
Ideally, geologic maps show the actual distribution of map units. Several factors limit the realization of this ideal. For maps of surficial materials, a limitation may be the accuracy with which the mapper identifies the materials in the field or interprets them from aerial photographs or images. In the case of maps of bedrock, the extent of exposure and the character of the map units are factors. Natural rock units of suitable thickness for mapping at the intended scale, and composed of an easily identifiable rock type, are the exception rather than the rule. This frequently means that the identification of map units is not entirely objective. Typically, large portions of the map area reveal no outcrops. Consequently, outcrop information must be extrapolated to cover the entire map. This extrapolation is based on an understanding of the structure and stratigraphy of the area. Mapping, then, proceeds by observation, hypothesis, testing, further observation, and so on. The final product is a mixture of recorded observations and the hypotheses that the mapper considers best to connect those observations.

Although geologic maps appear to represent complete information about the areal distribution and geologic relations of the underlying rocks, they are, in fact, based on a limited number of outcrop control points. When the geologic map covers a small area (i.e., a 1:4,000, 1:25,000, or 1:50,000 quadrangle map), the sedimentary rocks are usually subdivided into smaller rock units.

Geologic maps may depict the distribution of rocks of certain types or of certain ages. Commonly, the map depicts a combination of these two characteristics of crustal materials. When the map covers a large area (i.e., a state or country), the map is likely to show all sedimentary rocks deposited during a certain period of geologic time with the same color or pattern. Igneous or metamorphic rocks of that age may be differentiated by a different color or pattern. This system is used on the geologic map of the United States, published by the US Geological Survey.

Given an unfamiliar geologic map, you should begin interpretation by examining the information given around the margins of the map. This will generally include the following:

1. **Location**. Small inset maps showing the location of the map may be present. Otherwise, the name of the area and the longitude and latitude will indicate its location. From its location, those familiar with regional geology will know what age rocks and surficial materials to expect, and what types of major structural features may be present.



2. **Scale**. The map scale provides a guide to the size of the area covered by the map and the size of the features shown on the map. Maps have a bar scale or a fractional scale that indicates the ratio of a unit of horizontal distance across the map relative to the corresponding horizontal distance across the ground (e.g., 1:50,000).
3. **Map units**. A stratigraphic column is always shown on geologic maps, and it is the most important source of information about the map. From the explanation, you can determine exactly what was differentiated on the ground. The choice of map units will indicate to what extent bedrock and unconsolidated surficial materials have been included on the map. Generally, the stratigraphic column is arranged with the youngest material or rock unit shown at the top; other units are arranged in order of increasing age. The geologic period during which the map unit was formed is indicated; and the color, map pattern, and abbreviations used to identify each map unit on the map are shown.
4. **Symbols**. Geologic maps may contain a great variety of symbols. A chart showing the most commonly used symbols is provided on the inside back cover of this book.

After initial inspection, interpretation of the map will generally proceed in different ways, depending on the basic purpose for which the map was prepared, the intended use, and the type of information it contains. There are many specialized maps, but most "standard" geologic maps are designed primarily to illustrate unconsolidated materials found at the Earth's surface, bedrock geology, or combinations of these two. Maps showing surficial materials are especially important for planners, engineers, and others whose primary need is for information about near-surface materials. Specialized geologic maps have been designed to emphasize the location of various types of natural hazards or areas that are environmentally sensitive.

Maps that depict both bedrock and surficial materials are much easier to interpret if the surficial materials are removed from the map and considered separately. This "stripping" of the surficial materials may be done mentally, but it is helpful to place an overlay on the map and trace the contacts of bedrock units, faults, etc. In making this tracing, the contacts between beds and faults are projected under the surficial materials. In areas of relatively simple bedrock structure, projecting contacts is easily done, but where the geologic structure is complex or the surficial materials are extensive, considerable uncertainty may exist.

Primary Shape of Sedimentary Rock Bodies

We tend to think of "ideal" sedimentary rock bodies as being layers that are uniform in composition and thickness and of great lateral extent. Some "real" rock bodies come close to having this shape. From the rim of the Grand Canyon, layer after layer of rocks in the canyon walls appear to extend with nearly uniform thickness from horizon to horizon. For many rock units, the ideal model of a uniformly thick plate is valid over small areas (e.g., across a 1:24,000 or 1:50,000 quadrangle), but if traced over great distances, even these layers vary in thickness. Almost all sedimentary units either thin out in such a way that they are wedge-shaped along their margins, or they gradually change composition and interfinger with other rock types laterally (Figure 7-1a, b, and c). Sedimentary rock units that were deposited on continental shelves or platforms and those laid down on the deep sea floor come closest in shape to the "ideal" model. Sedimentary rock units deposited on unstable continental margins vary greatly in thickness and may undergo rapid lateral changes. Where lateral changes in lithology and thickness occur over short distances, it is often difficult to define and map the rock units.

A number of conditions during sedimentation may cause layer thicknesses to vary. Sediments tend to accumulate in areas that subside (see Figure 7-1a, b, and c). Thus, sediment accumulation is commonly thicker where subsidence is rapid or continues for a long time. Strata may also increase in thickness toward the source area, as in the cases of fault-bounded sedimentary basins (Figure 7-1d) or intermontane basins. Layers of sediment eroded from the Rocky Mountains are thicker closer to the mountains than they are far out in the Great Plains. During the Paleozoic era, large basins and domes were present on the North American Craton. Today, we find much thicker units in basins such as the Michigan Basin and the Appalachian Basin than in

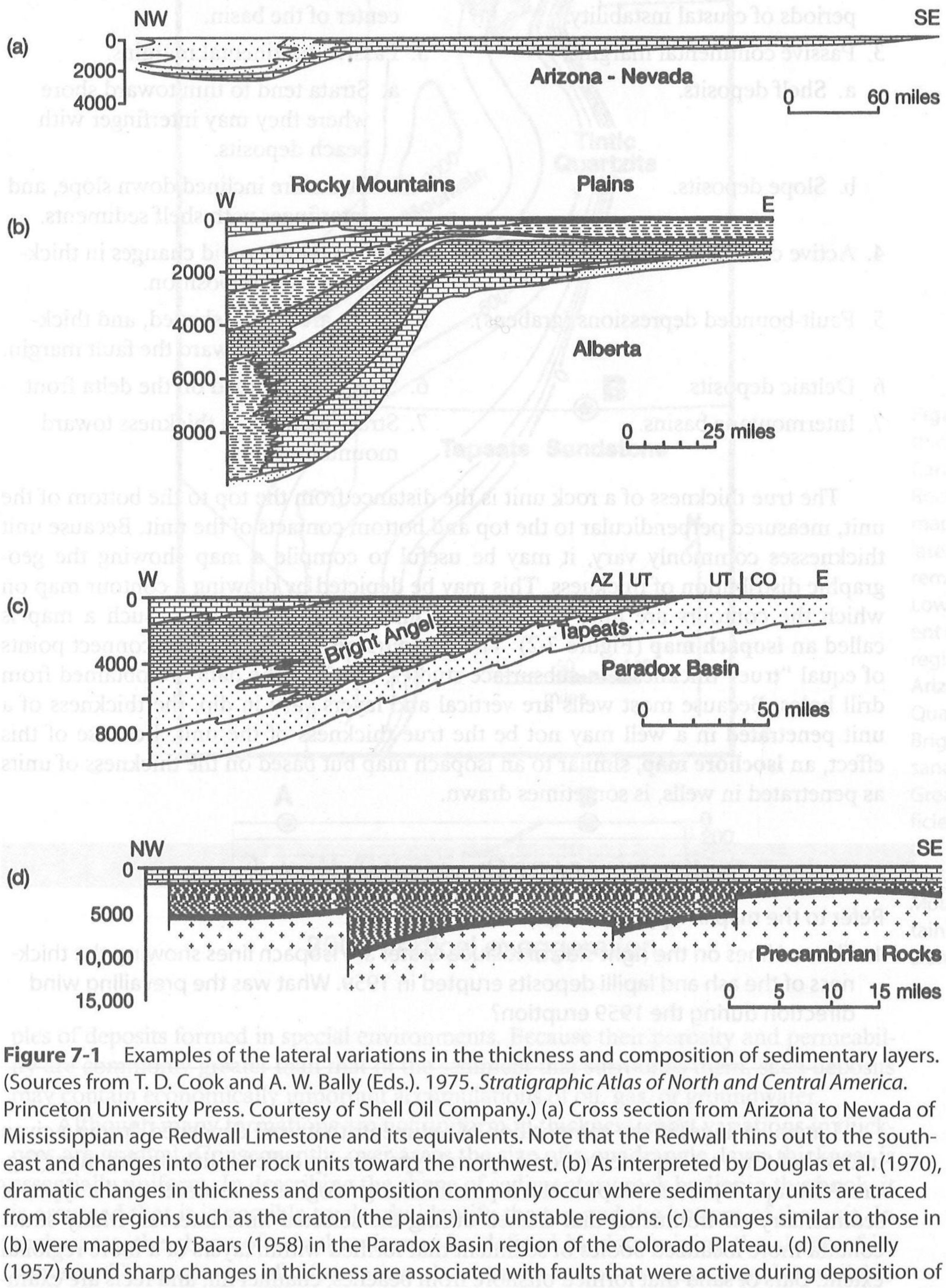


Figure 7-1 Examples of the lateral variations in the thickness and composition of sedimentary layers. (Sources from T. D. Cook and A. W. Bally (Eds.). 1975. *Stratigraphic Atlas of North and Central America.* Princeton University Press. Courtesy of Shell Oil Company.) (a) Cross section from Arizona to Nevada of Mississippian age Redwall Limestone and its equivalents. Note that the Redwall thins out to the southeast and changes into other rock units toward the northwest. (b) As interpreted by Douglas et al. (1970), dramatic changes in thickness and composition commonly occur where sedimentary units are traced from stable regions such as the craton (the plains) into unstable regions. (c) Changes similar to those in (b) were mapped by Baars (1958) in the Paradox Basin region of the Colorado Plateau. (d) Connelly (1957) found sharp changes in thickness are associated with faults that were active during deposition of the Cambrian units in Kentucky.

surrounding areas on the craton. Rock units tend to thin out toward areas such as the Ozark and Adirondack Domes that remained topographically high over long periods of geologic time.

The following is a list of common types of framework of sedimentary rock bodies and the characteristics of the strata formed in those environments.

Framework of Sedimentary Rock Bodies	**Characteristics of Strata**
1. Shallow-water deposits laid down over cratons and continental margins during periods of crustal stability.	1. Strata tend to be uniform in thickness, but change in composition laterally.
2. Basins develop within cratons during periods of crustal instability.	2. Strata gradually thicken toward the center of the basin.
3. Passive continental margins.	3. Passive continental margins.
a. Shelf deposits.	a. Strata tend to thin toward shore where they may interfinger with beach deposits.
b. Slope deposits.	b. Strata are inclined down slope, and interfinger with shelf sediments.
4. Active continental margins.	4. Strata exhibit rapid changes in thickness and in composition.
5. Fault-bounded depressions (grabens).	5. Strata are wedge shaped, and thickness increases toward the fault margin.
6. Deltaic deposits.	6. Strata are inclined on the delta front.
7. Intermontane basins.	7. Strata increase in thickness toward mountain fronts.

The true thickness of a rock unit is the distance from the top to the bottom of the unit, measured perpendicular to the top and bottom contacts of the unit. Because unit thicknesses commonly vary, it may be useful to compile a map showing the geographic distribution of thickness. This may be depicted by drawing a contour map on which the contours are lines connecting points of equal thickness. Such a map is called an **isopach map** (Figure 7-2). The contours on an isopach map connect points of equal "true" thickness. In subsurface studies, much of the data are obtained from drill holes. Because most wells are vertical and layers vary in dip, the thickness of a unit penetrated in a well may not be the true thickness of the unit. Because of this effect, an **isochore map**, similar to an isopach map but based on the thickness of units as penetrated in wells, is sometimes drawn.

Lateral changes in the composition of sediments that were deposited during a given interval of time are represented on a special type of map called a **lithofacies map** (Figure 7-3 on p. 76). Such maps make it possible for geologists to reconstruct the types of sedimentary environments that existed during the selected time interval. Many strata contain more localized bodies of sediment that formed within layers of a more regional extent. Bars of sand that formed offshore from beaches, channel fill, and reefs are exam-

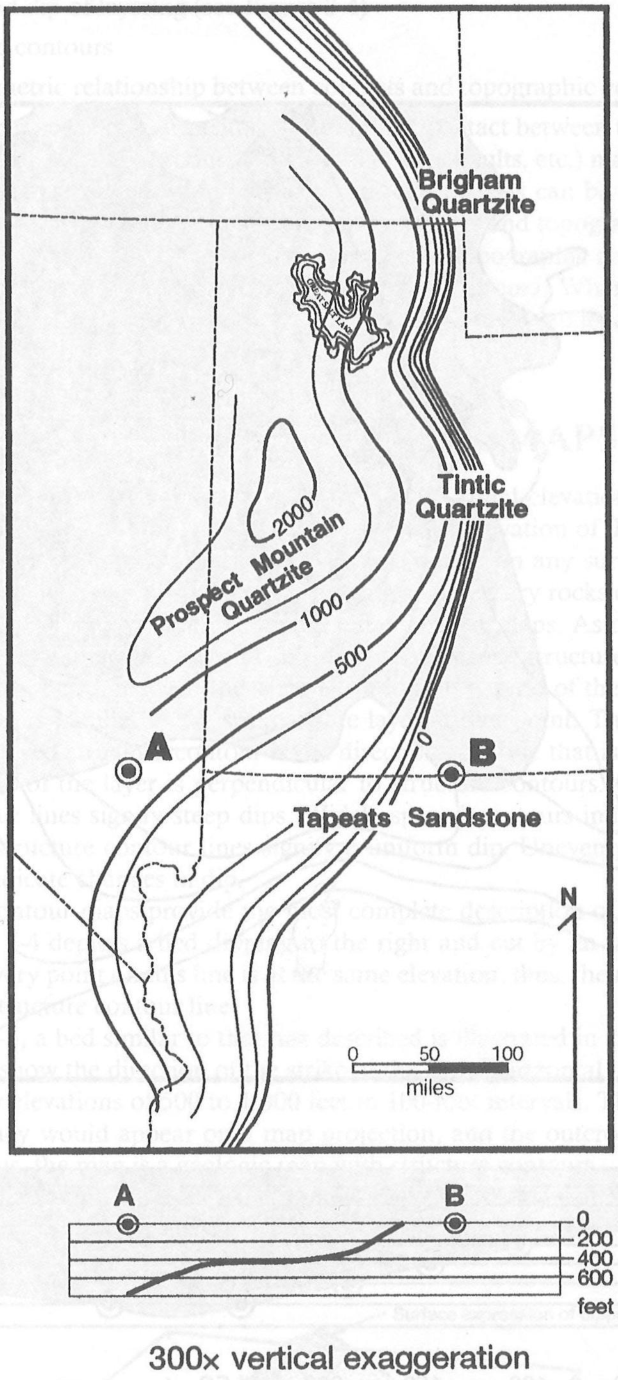


Figure 7-2 Map of the restored thickness and lithofacies of Lower Cambrian Sandstones in the Rocky Mountains. In making a map of this type, the effects of later deformation and erosion are removed. The sandstones of Lower Cambrian age carry different names in different parts of the region. The Tapeats Sandstone of Arizona is equivalent to the Tintic Quartzite of Utah and the Brigham Quartzite of Idaho. The sandstones thin out toward the Great Plains, and data are not sufficient to complete the map to the west. (After C. Lockman-Balk. 1972. *Geologic Atlas of the Rocky Mountain Region*. Rocky Mountain Association of Geologists, Denver, Colorado.)

ples of deposits formed in special environments. Because their porosity and permeability are commonly greater than that of the sediment that surrounds them, such deposits may contain economically important accumulations of oil, gas, or groundwater.

Although many formations are not uniform in thickness, most variations in thickness are gradual. Consequently, over areas the size of a quadrangle, layer thickness is essentially uniform. In describing the shape of sedimentary rock bodies in this book, it is assumed that it is possible to clearly identify the top and the bottom of the unit. In such cases, the shape of a rock unit may be defined by determining the shape of its contacts. Three sources of information about the shape of a contact may be available on geologic maps:

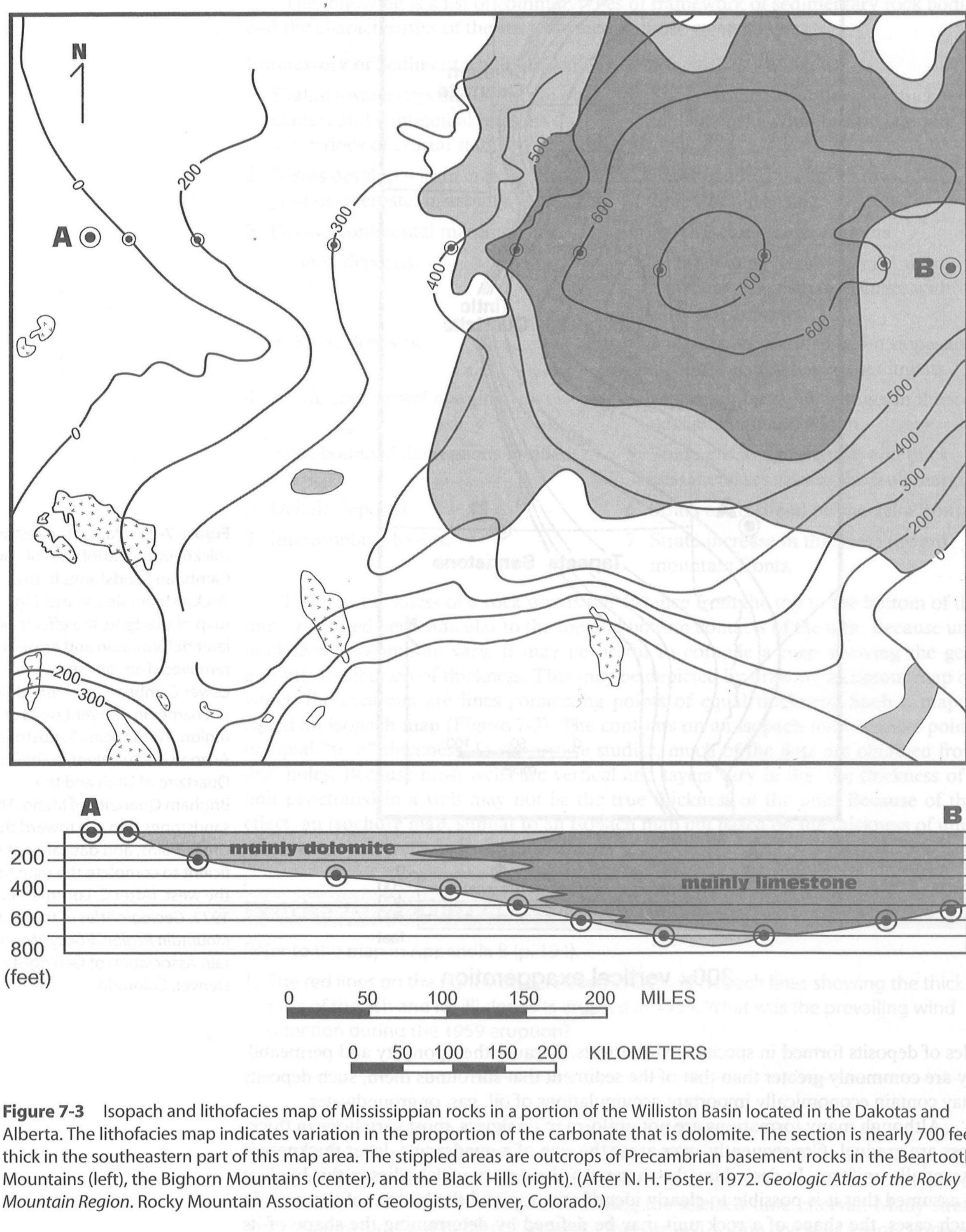


Figure 7-3 Isopach and lithofacies map of Mississippian rocks in a portion of the Williston Basin located in the Dakotas and Alberta. The lithofacies map indicates variation in the proportion of the carbonate that is dolomite. The section is nearly 700 feet thick in the southeastern part of this map area. The stippled areas are outcrops of Precambrian basement rocks in the Beartooth Mountains (left), the Bighorn Mountains (center), and the Black Hills (right). (After N. H. Foster. 1972. *Geologic Atlas of the Rocky Mountain Region*. Rocky Mountain Association of Geologists, Denver, Colorado.)

1. Strike and dip of layering (see Figure 3-4)
2. Structure contours
3. The geometric relationship between contacts and topographic contours

The orientation in space of sedimentary layering, the contact between two rock units, or any other planar feature (layering, cleavage, fractures, faults, etc.) may be described by strike and dip (see Figure 3-4). The strike and dip of beds can be determined by analyzing the relationship between the trace of the contact and topographic contours. Where contacts are horizontal, the contact is parallel to topographic contours. Where contacts are vertical, the contact cuts straight across contours. Where contacts are inclined, the trace of the contact cuts across contours at angles related to the angle of dip. These effects will be considered in more detail later.

STRUCTURE CONTOUR MAPS

A **structure contour** is a line connecting points of equal elevation on a specific geologic surface. Most structure contour maps show the elevation of the top of some particular rock unit, but structure contours may be drawn on any surface, including the contact between crystalline rocks and overlying sedimentary rocks or on a fault.

Structure contour maps resemble topographic contour maps. As on topographic maps, structure contours are drawn at set intervals. Because structure contour lines connect points on the same level (the same elevation), the trend of the structure contour at any point is parallel to the strike of the layer at that point. The strike at any point along a curved structure contour is the direction of a line that is tangent to the contour. The dip of the layer is perpendicular to structure contours. Closely spaced structure contour lines signify steep dips. Widely spaced contours indicate low dips. Evenly spaced structure contour lines signify a uniform dip. Unevenly spaced structure contours indicate changes in dip.

Structure contour maps provide the most complete description of the shape of a contact. Figure 7-4 depicts a bed dipping to the right and cut by an imaginary horizontal plane. Every point on this line is at the same elevation; thus, the map projection of the line is a structure contour line.

In Figure 7-5, a bed similar to that just described is illustrated in a block that has been rotated to show the direction of the strike of the bed. Horizontal lines on the top of the bed show elevations of 500 to 1,000 feet in 100-foot intervals. These elevations are shown as they would appear on a map projection, and the outcrop of the bed is also shown. Thus, the map is a geologic map with structure contours.

The structure contour lines connect points of equal elevation on the contact. Of course, the accuracy of such a map is a function of the amount of data that was avail-

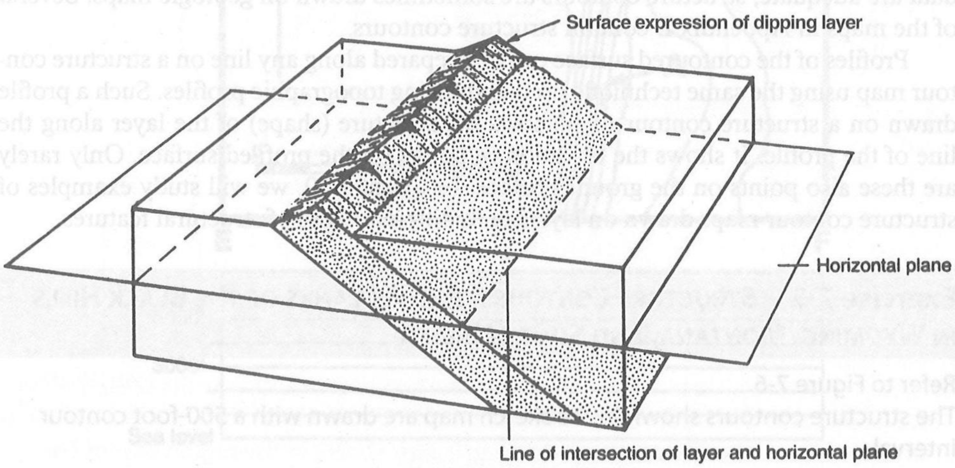


Figure 7-4 Block diagram showing a layer of sandstone dipping to the right.

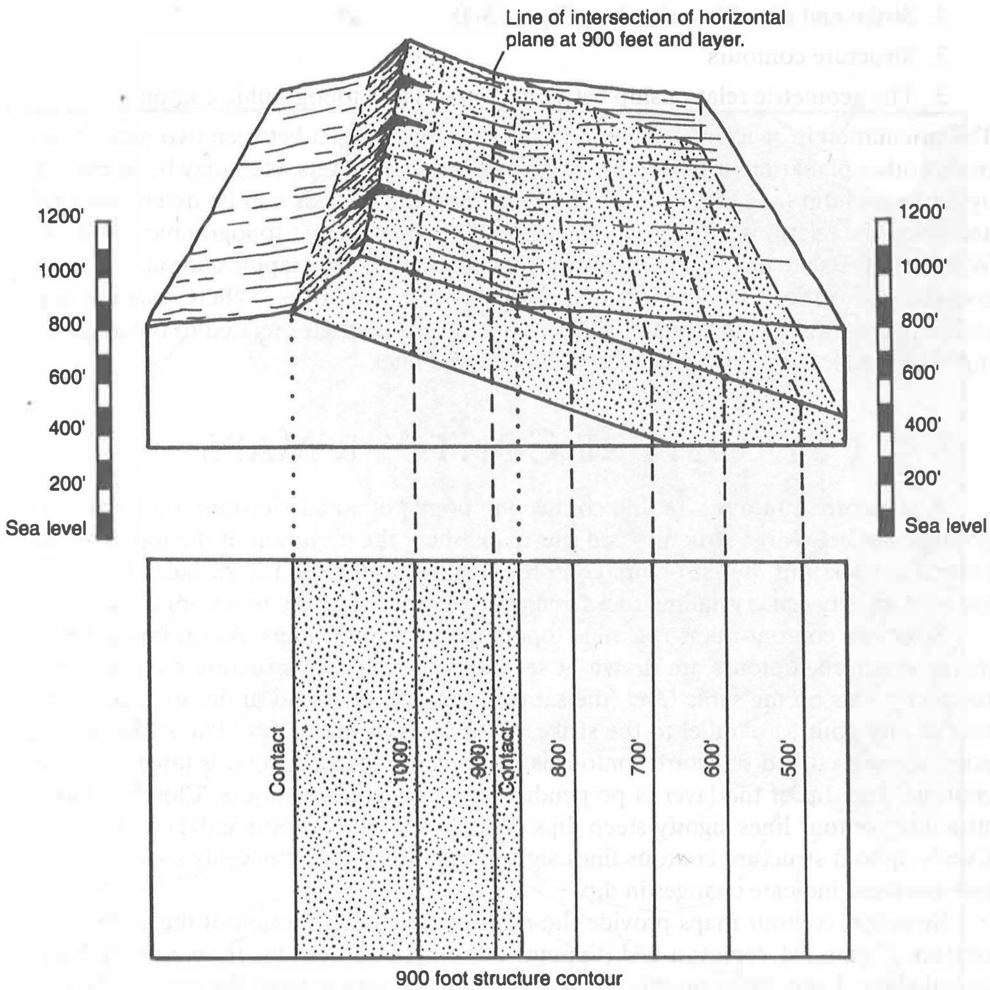
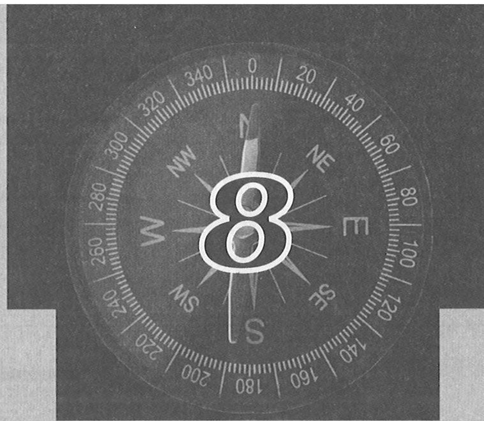


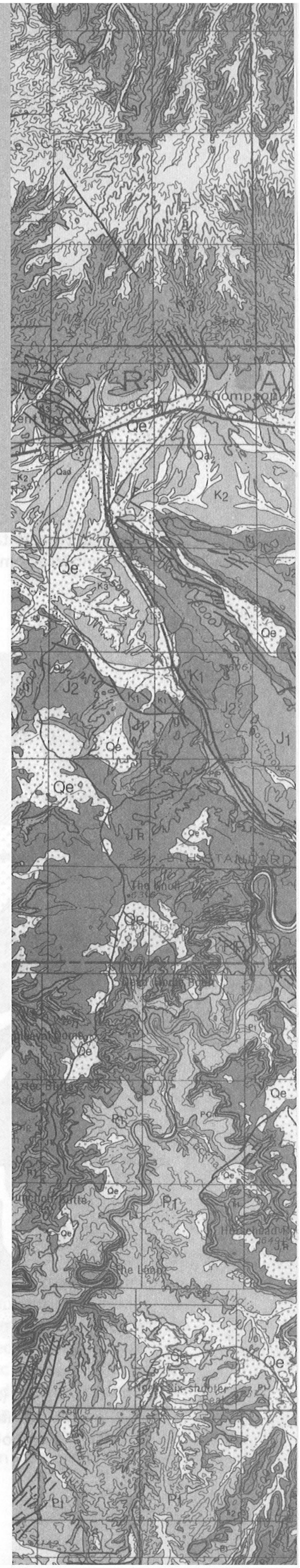
Figure 7-5 Above: A bed similar to the bed illustrated in Figure 7-4. The block has been rotated so we look in the direction of the strike of the bed. Below: Horizontal lines (structure contours) on the top of the bed show elevations of 500 to 1,000 feet in 100-foot intervals. These structure contours are shown as they would appear on a map projection, and the outcrop of the bed is also shown.

able for its construction. Good elevation control data are available where the contact cuts the ground surface, and in some areas considerable amounts of subsurface data may also be available from wells, seismic lines, or other geophysical studies. Where data are adequate, structure contours are sometimes drawn on geologic maps. Several of the maps in Appendix B contain structure contours.

Profiles of the contoured surface can be prepared along any line on a structure contour map using the same technique used in drawing topographic profiles. Such a profile drawn on a structure contour map shows the structure (shape) of the layer along the line of the profile. It shows the elevation of points on the profiled surface. Only rarely are these also points on the ground surface. In Chapter 10, we will study examples of structure contour maps drawn on layers with different types of structural features.



Geologic Maps of Homoclinal Beds



The term **homoclinal** applies to all contacts of uniform dip, whether layers are horizontal, vertical, or inclined. The term *homocline* is sometimes confused with *monocline*. **Homocline** refers to a single dip; **monocline** refers to a flexure (Figure 8-1). Only rarely do layers remain perfectly planar for great distances, but many layers are nearly planar, and the maps of such layers closely resemble those that are plane. The exercises in this section will help bring out these subtle differences.

While perfectly plane beds are the exception, beds that are only slightly warped or curved are widespread in North America. Beds fitting this description cover vast areas in the Great Plains, in the Atlantic and Gulf coastal plains, and in the Appalachian and Colorado plateau regions.

In some regions, such as the Colorado Plateau near the Grand Canyon, the beds are so nearly flat that careful examination of the changes in elevation of contacts over long distances is needed to detect the dip. In such cases, structure contour maps are especially valuable as a way of illustrating the tilt and shape of the surface. For this reason, geologic maps with structure contours are used in the following exercises. Remember that structure contours are drawn on only one bed. Thus if beds change thickness, the shape of surfaces higher or lower in the section will be different.

Patterns of Homoclinal Beds on Geologic Maps

Because their geometry is so simple, it is easy to understand the appearance of homoclinal contacts on maps (Figure 8-2). Complexities in the map patterns of homoclinal contacts are due mainly to the irregularities in the topography. Even these pose little difficulty if the following characteristics of such beds are kept in mind:

1. The contacts of horizontal layers are parallel to topographic contours.
2. Contacts of vertical layers form straight lines on maps regardless of the topography.
3. Contacts of dipping beds form V-shaped patterns where they cross ridges or stream valleys.

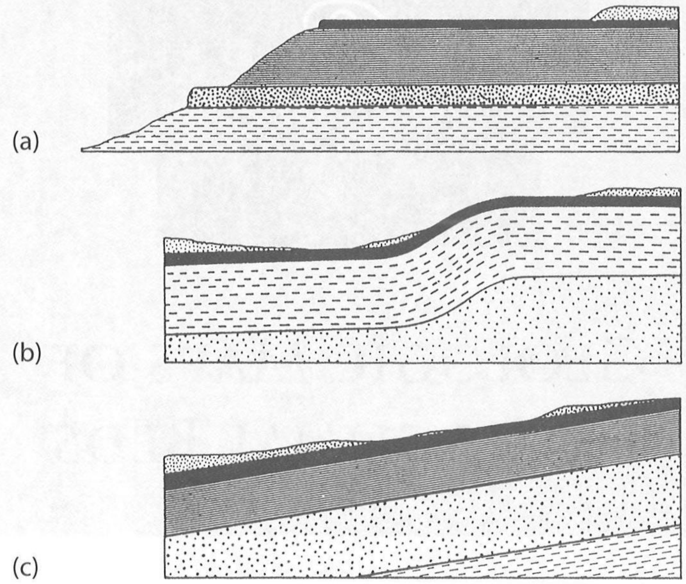


Figure 8-1 Schematic cross sections of (a) flat-lying strata, (b) a monocline, and (c) a homocline.

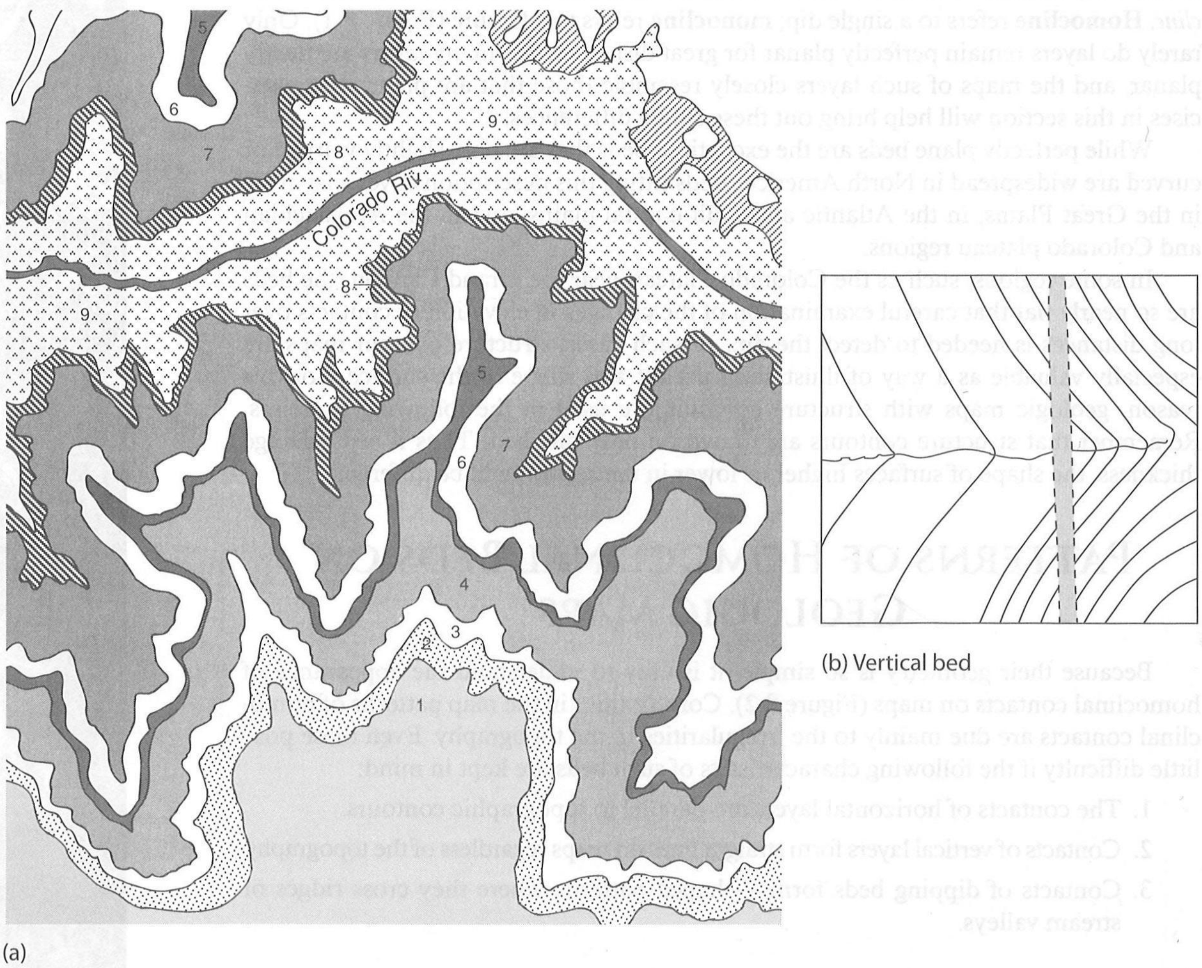


Figure 8-2 (a) Sketch map based on the geologic map of the Grand Canyon. Contacts of the rock units are parallel to topographic contours. (b) The contacts of a vertical bed or dike cut across the topography in straight lines. Note how the contacts show no deflection as they cross contours.

V-SHAPED CONTACT PATTERNS ON GEOLOGIC MAPS

On detailed geologic maps, contacts between rock units generally have the shape of a V where a stream crosses the contact (Figure 8-3). If the V-shaped pattern occurs in a stream valley, the V generally points in the direction of dip of the layers, regardless of whether the layer dips upstream or downstream.

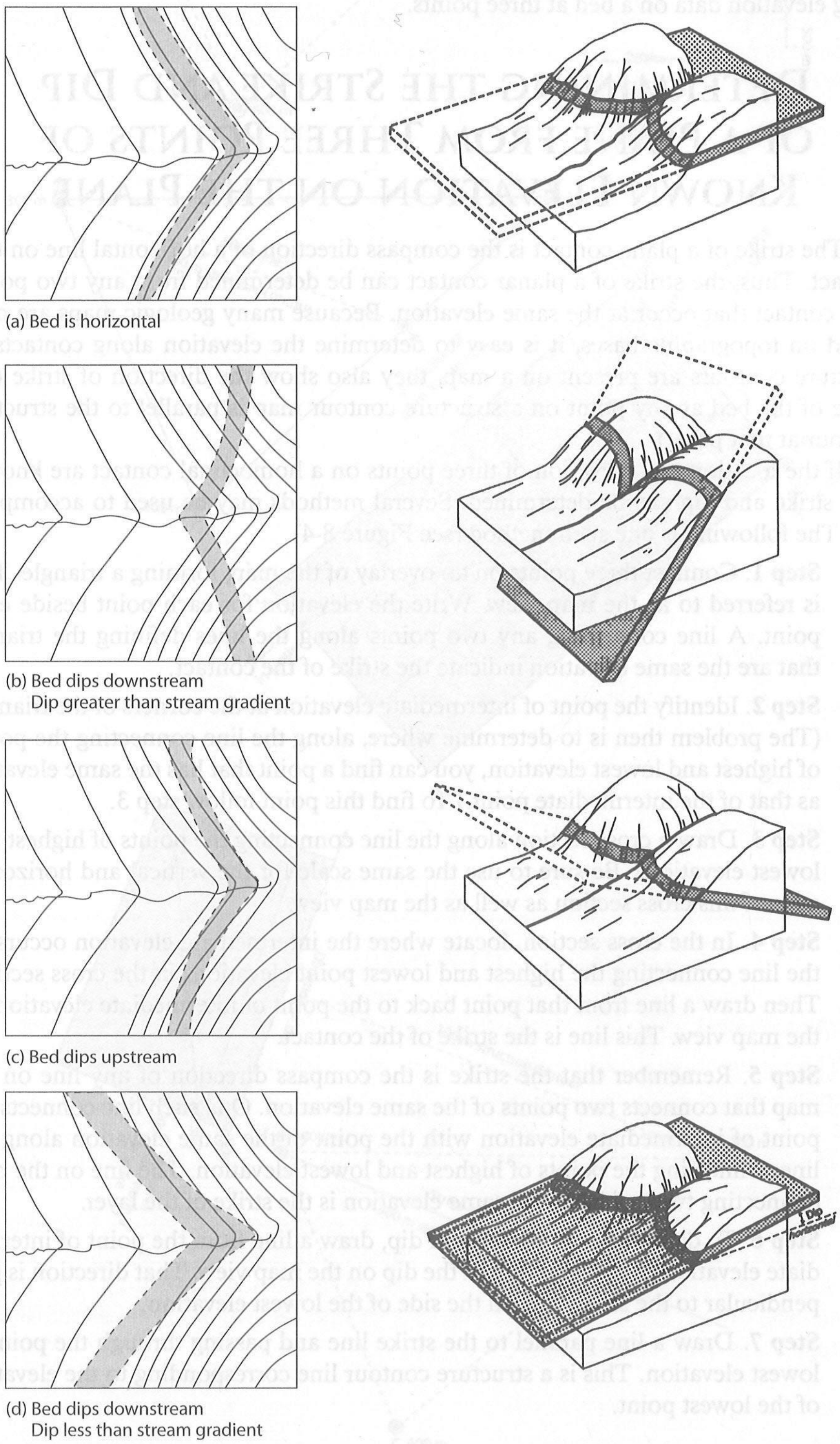


Figure 8-3 Block diagram and corresponding geologic maps illustrating the relationships between the dip of layers and the V-shaped patterns of contacts on geologic maps. (a) Horizontal bed. (b) Bed dipping downstream. (c) Bed dipping upstream. (d) Bed dipping downstream at an angle less than the slope of the stream.

There are two exceptions to the preceding rule. The first is that a V-shaped pattern formed where a stream cuts across horizontal beds always points upstream. Thus, the presence of a V pattern does not always signify dipping beds. The other exception occurs where a contact dips downstream in a valley in which the slope of the valley floor is steeper than the dip of the bed. Under this unusual circumstance, the V-shaped contact pattern points upstream, in the opposite direction from the dip of the bed.

If a geologic map is drawn on a topographic base map, the approximate direction of dip can be determined by noting the direction in which the elevation along the contact decreases. An exact determination of the strike and dip of contacts can be made using elevation data on a bed at three points.

Determining the Strike and Dip of a Plane from Three Points of Known Elevation on the Plane

The strike of a plane contact is the compass direction of a horizontal line on that contact. Thus, the strike of a planar contact can be determined from any two points on a contact that occur at the same elevation. Because many geologic maps are published on topographic bases, it is easy to determine the elevation along contacts. If structure contours are present on a map, they also show the direction of strike (the strike of the bed at any point on a structure contour map is parallel to the structure contour at that point).

If the location and elevation of three points on a homoclinal contact are known, both strike and dip can be determined. Several methods may be used to accomplish this. The following is one such method (see Figure 8-4).

Step 1. Connect three points on an overlay of the map, forming a triangle. This is referred to as the map view. Write the elevation for each point beside each point. A line connecting any two points along the lines defining the triangle that are the same elevation indicate the strike of the contact.

Step 2. Identify the point of intermediate elevation at the corners of the triangle. (The problem then is to determine where, along the line connecting the points of highest and lowest elevation, you can find a point that has the same elevation as that of the intermediate point.) To find this point follow step 3.

Step 3. Draw a cross section along the line connecting the points of highest and lowest elevations. Be sure to use the same scale for the vertical and horizontal axes of this cross section as well as the map view.

Step 4. In the cross section, locate where the intermediate elevation occurs on the line connecting the highest and lowest point elevations in the cross section. Then draw a line from that point back to the point of intermediate elevation on the map view. This line is the strike of the contact.

Step 5. Remember that the strike is the compass direction of any line on the map that connects two points of the same elevation. One such line connects the point of intermediate elevation with the point of the same elevation along the line connecting the points of highest and lowest elevation. The line on the map connecting two points of the same elevation is the strike of the layer.

Step 6. To determine the amount of dip, draw a line from the point of intermediate elevation in the direction of the dip on the map view. That direction is perpendicular to the strike and on the side of the lowest elevation.

Step 7. Draw a line parallel to the strike line and passing through the point of lowest elevation. This is a structure contour line corresponding to the elevation of the lowest point.

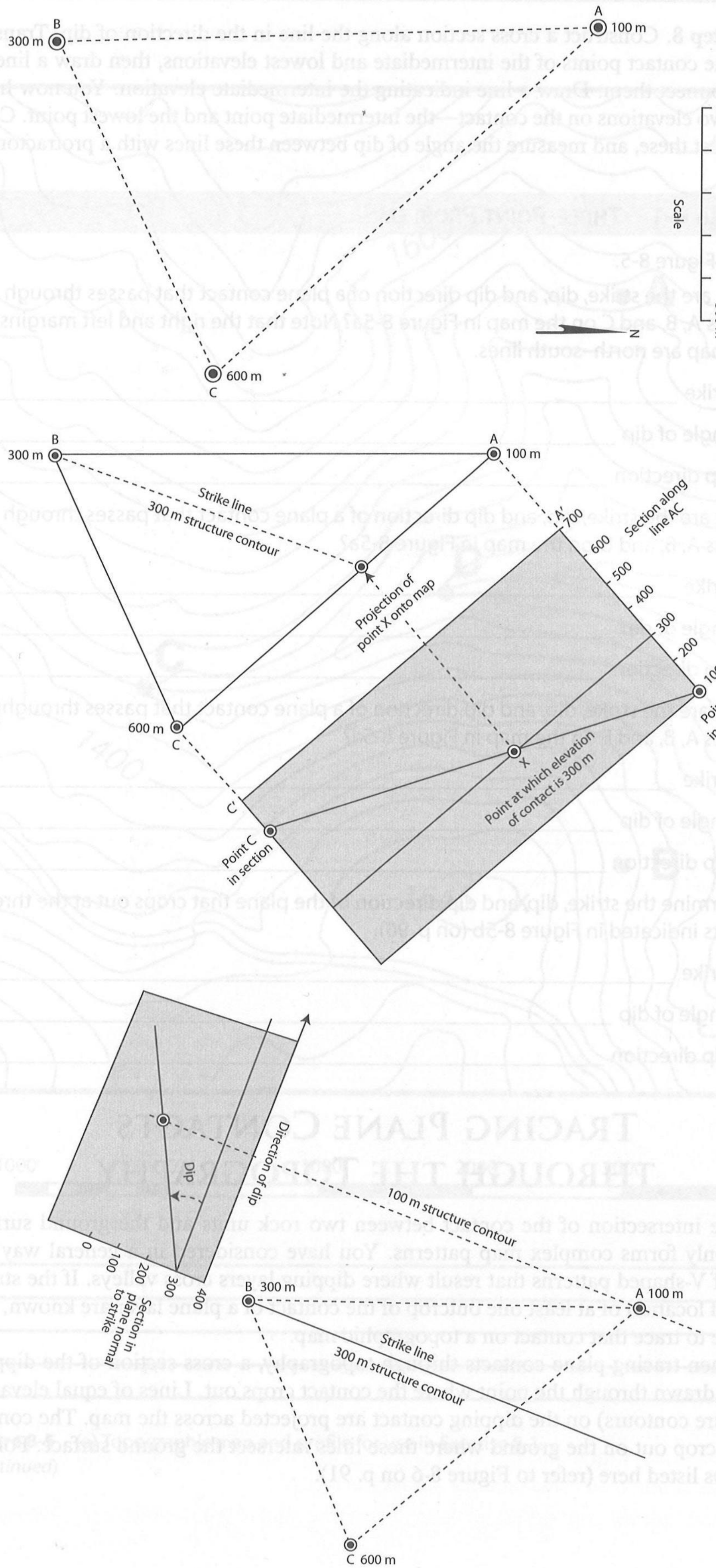


Figure 8-4 Steps in the solution of a three-point problem. See the text for discussion.

Step 8. Construct a cross section along the line in the direction of dip. Transfer the contact points of the intermediate and lowest elevations, then draw a line to connect them. Draw a line indicating the intermediate elevation. You now have two elevations on the contact—the intermediate point and the lowest point. Connect these, and measure the angle of dip between these lines with a protractor.

Tracing Plane Contacts through the Topography

The intersection of the contact between two rock units and the ground surface commonly forms complex map patterns. You have considered in a general way the types of V-shaped patterns that result where dipping layers cross valleys. If the strike, dip, and location of at least one outcrop of the contact of a plane layer are known, it is possible to trace that contact on a topographic map.

When tracing plane contacts through topography, a cross section of the dipping layer is drawn through the point where the contact crops out. Lines of equal elevation (structure contours) on the dipping contact are projected across the map. The contact should crop out on the ground where these lines intersect the ground surface. Follow the steps listed here (refer to Figure 8-6 on p. 91).

Step 1. Place a piece of graph paper on which the scale of the paper matches the scale of the topographic map. It must be oriented so the strike of the contact to be traced is perpendicular to the cross section.

Step 2. Project the point where the outcrop occurs onto the cross-section paper. Indicate this point on the cross-section paper at the same elevation at which it occurs on the topographic map.

Step 3. Using the known dip of the layer, draw a cross section showing the bed.

Step 4. Draw structure contours for a number of elevations on the layer across the map. (Sketch them in lightly.) For a plane surface, all structure contours will be parallel, straight lines.

Step 5. Place a point on the map at each place where a structure contour on the contact crosses a topographic contour of the same elevation as the structure contour.

Step 6. Connect the points with a smooth line. This line shows the trace of the bed across the topography.

Note: This same procedure can be used to trace a fault or even a folded bed, provided the fold is not plunging (e.g., the fold axis is horizontal) and its shape is the same in all cross sections across the fold.

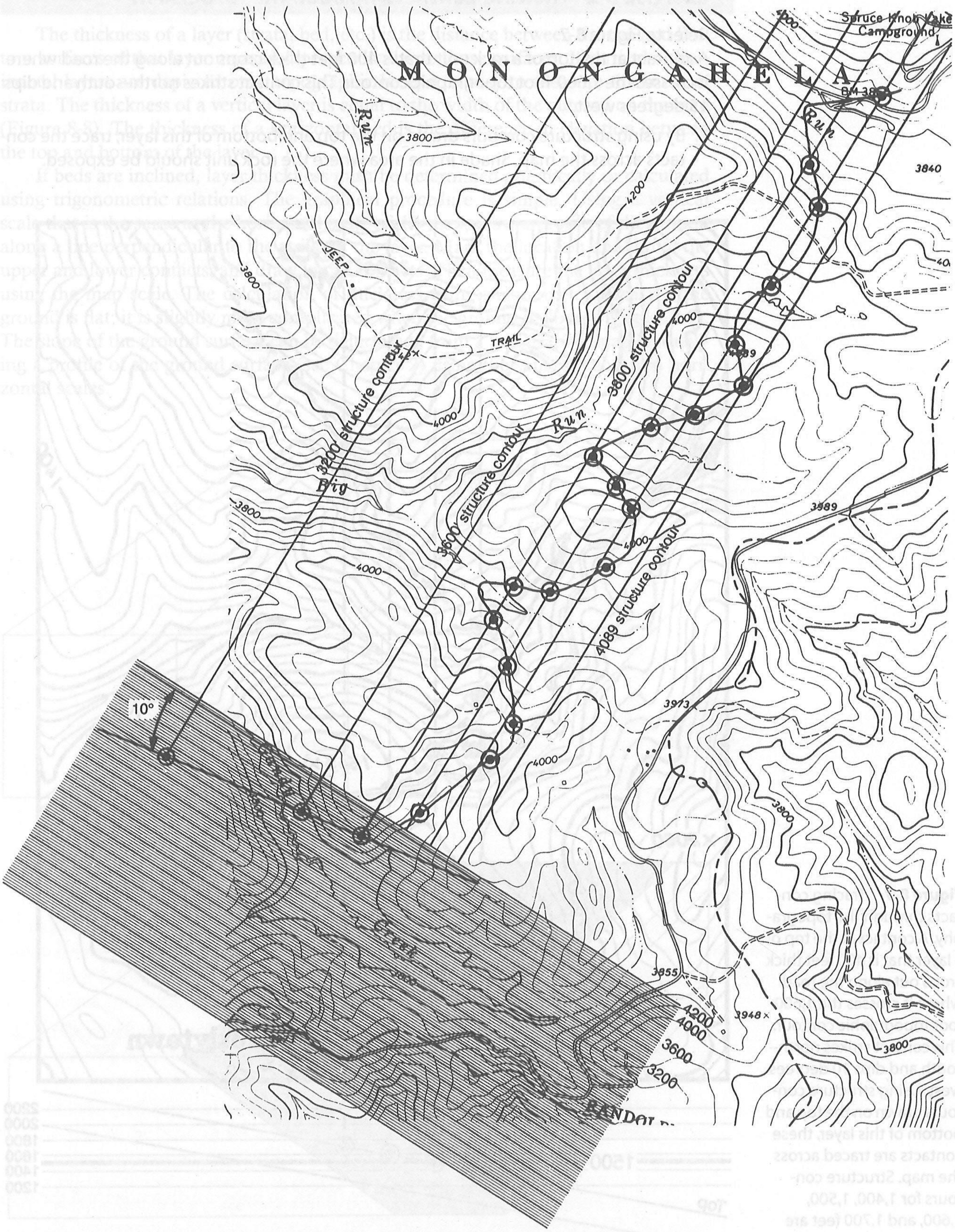


Figure 8-6 The method used to trace a contact through the topography. See the text for discussion.

LAYER THICKNESS AND WIDTH ON MAPS

The thickness of a layer (strata, bed, etc.) is the distance between the top and bottom surfaces of that layer measured perpendicular to those surfaces. If vertical or horizontal layers are depicted on a topographic base, it is easy to measure thickness of strata. The thickness of a vertical layer is equal to the width of the outcrop on the map (Figure 8-8). The thickness of a horizontal bed is the difference in elevation between the top and bottom of the layer.

If beds are inclined, layer thickness must be determined graphically or calculated using trigonometric relations. The graphical procedure is simple. Using a vertical scale that is the same as the horizontal scale of the map, draw a profile of the ground along a line perpendicular to the strike of the layer. Mark the location and dip of the upper and lower contacts, and draw in the contacts. Then measure the layer thickness using the map scale. The calculation of thickness using trigonometry is easy if the ground is flat; it is slightly more complicated when the ground is sloping (Figure 8-9). The slope of the ground surface can be determined from a topographic map by drawing a profile of the ground surface (see Chapter 2) using the same vertical and horizontal scales.

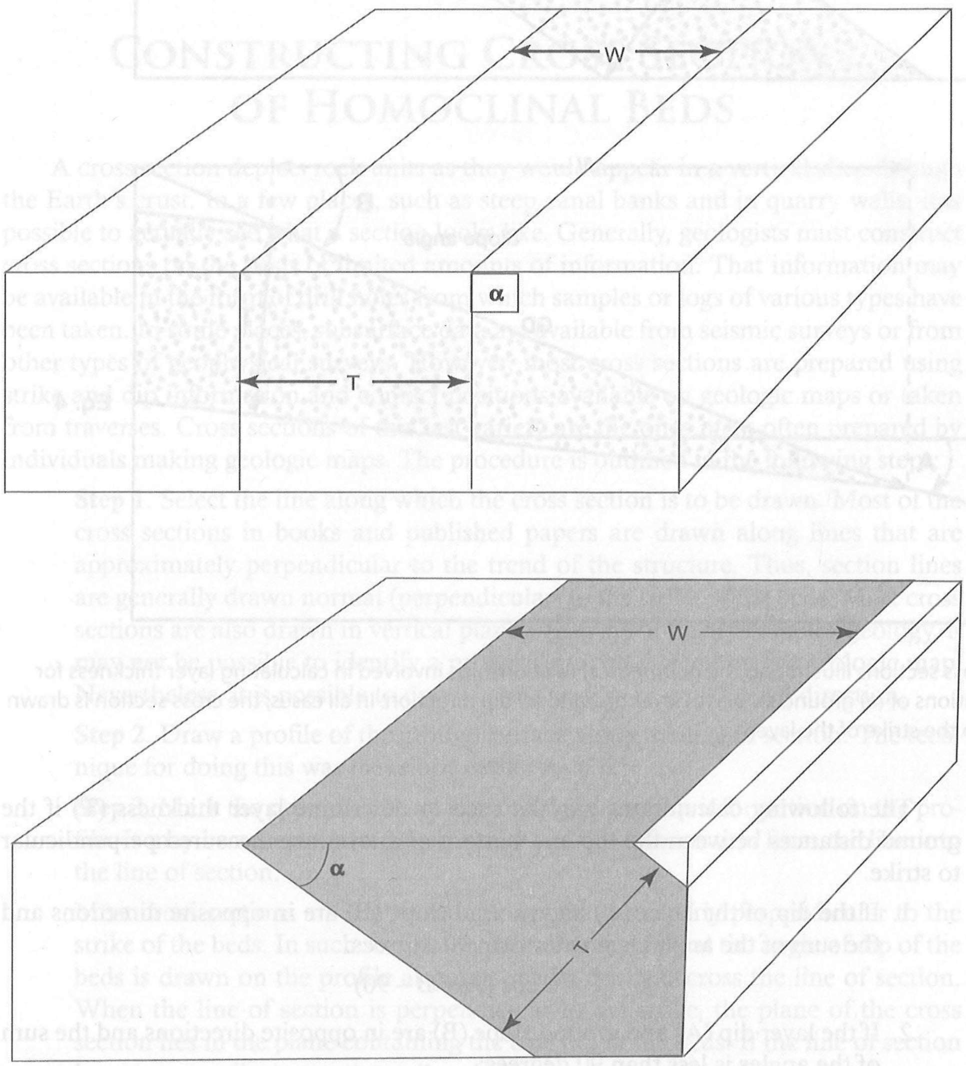


Figure 8-8 Block diagrams showing the relationship between the angle of dip of a layer and the width of the outcrop belt (measured perpendicular to the strike of the layers).

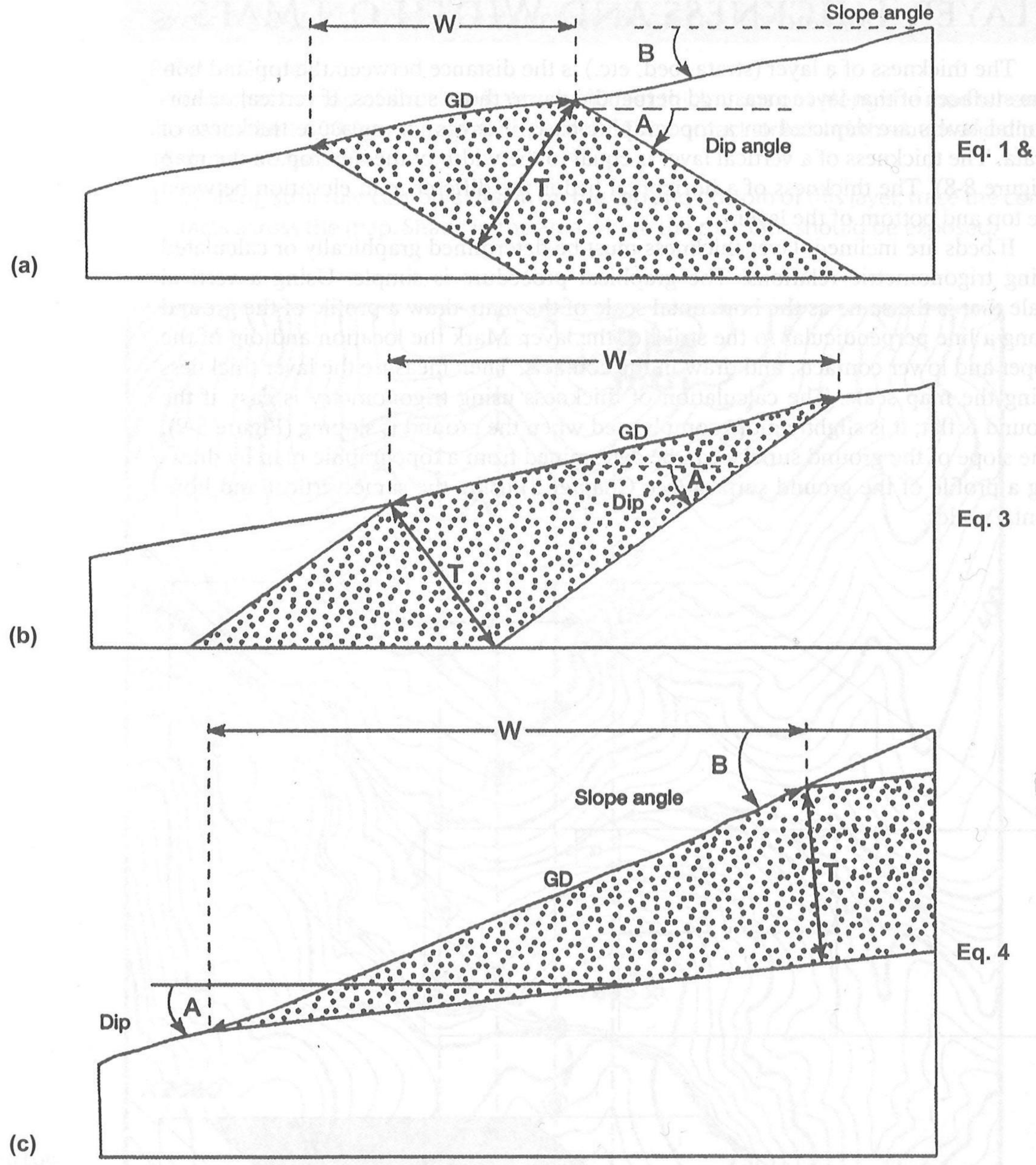


Figure 8-9 Cross sections illustrating the geometrical relationships involved in calculating layer thickness for various combinations of (a) ground slope, (b) layer dip, and (c) dip direction. In all cases, the cross section is drawn perpendicular to the strike of the layer.

The following calculations may be used to determine layer thickness (T) if the ground distances between the top and bottom of a layer are measured perpendicular to strike.

1. If the dip of the layer (A) and ground slope (B) are in opposite directions and the sum of the angles is greater than 90 degrees:

$$T = x \cos (A + B - 90)$$

2. If the layer dip (A) and ground slope (B) are in opposite directions and the sum of the angles is less than 90 degrees:

$$T = x \sin (A + B)$$

3. If the layer dip (A) and ground slope (B) are in the same direction and the slope is less than the dip:

$$T = x \sin (A - B)$$

4. If the layer dip (A) and ground slope (B) are in the same direction, and if the dip angle is less than the slope:

$$T = x \sin (B - A)$$

Constructing Cross Sections of Homoclinal Beds

A cross section depicts rock units as they would appear in a vertical slice through the Earth's crust. In a few places, such as steep canal banks and in quarry walls, it is possible to actually see what a section looks like. Generally, geologists must construct cross sections on the basis of limited amounts of information. That information may be available in the form of drill holes from which samples or logs of various types have been taken. In some places, subsurface data are available from seismic surveys or from other types of geophysical surveys. However, most cross sections are prepared using strike and dip information and contact positions available on geologic maps or taken from traverses. Cross sections of this last variety are the ones most often prepared by individuals making geologic maps. The procedure is outlined in the following steps:

Step 1. Select the line along which the cross section is to be drawn. Most of the cross sections in books and published papers are drawn along lines that are approximately perpendicular to the trend of the structure. Thus, section lines are generally drawn normal (perpendicular) to the strike of the beds. Most cross sections are also drawn in vertical planes. In areas of highly complex geology, it may not be possible to identify a primary structural trend on the geologic map. Nevertheless, it is possible to draw a cross section in any desired direction.

Step 2. Draw a profile of the ground surface along the line of section. The technique for doing this was described earlier on p. 25.

Step 3. Mark the position of contacts and strike and dip information on the profile. It may be necessary to project strike and dip information from the line into the line of section.

Most cross sections are drawn along lines that are nearly perpendicular to the strike of the beds. In such sections, a short line inclined at the angle of dip of the beds is drawn on the profile at points where contacts cross the line of section. When the line of section is perpendicular to the strike, the plane of the cross section lies in the plane containing the true dip of the beds. If the line of section is not perpendicular to the strike, the apparent dip of the contact in the cross section must be determined. The **apparent dip** of a contact is the angle that the contact appears to dip in any given plane. The closer that plane comes to being perpendicular to the strike, the closer the apparent dip is to the true dip. Apparent dips can be read from a nomograph (Figure 8-11). To use the nomograph, draw a straight line from the angle of true dip (the left-hand column) to the angle between the strike direction and the line of the section (shown in the right column). In Figure 8-11, the true dip is 43 degrees, and the angle between the strike and line of section is 35 degrees. The apparent dip in that direction is about 28 degrees.

Step 4. Once all surface data have been entered on the profile, decisions must be made regarding how to project that data into the subsurface. These decisions

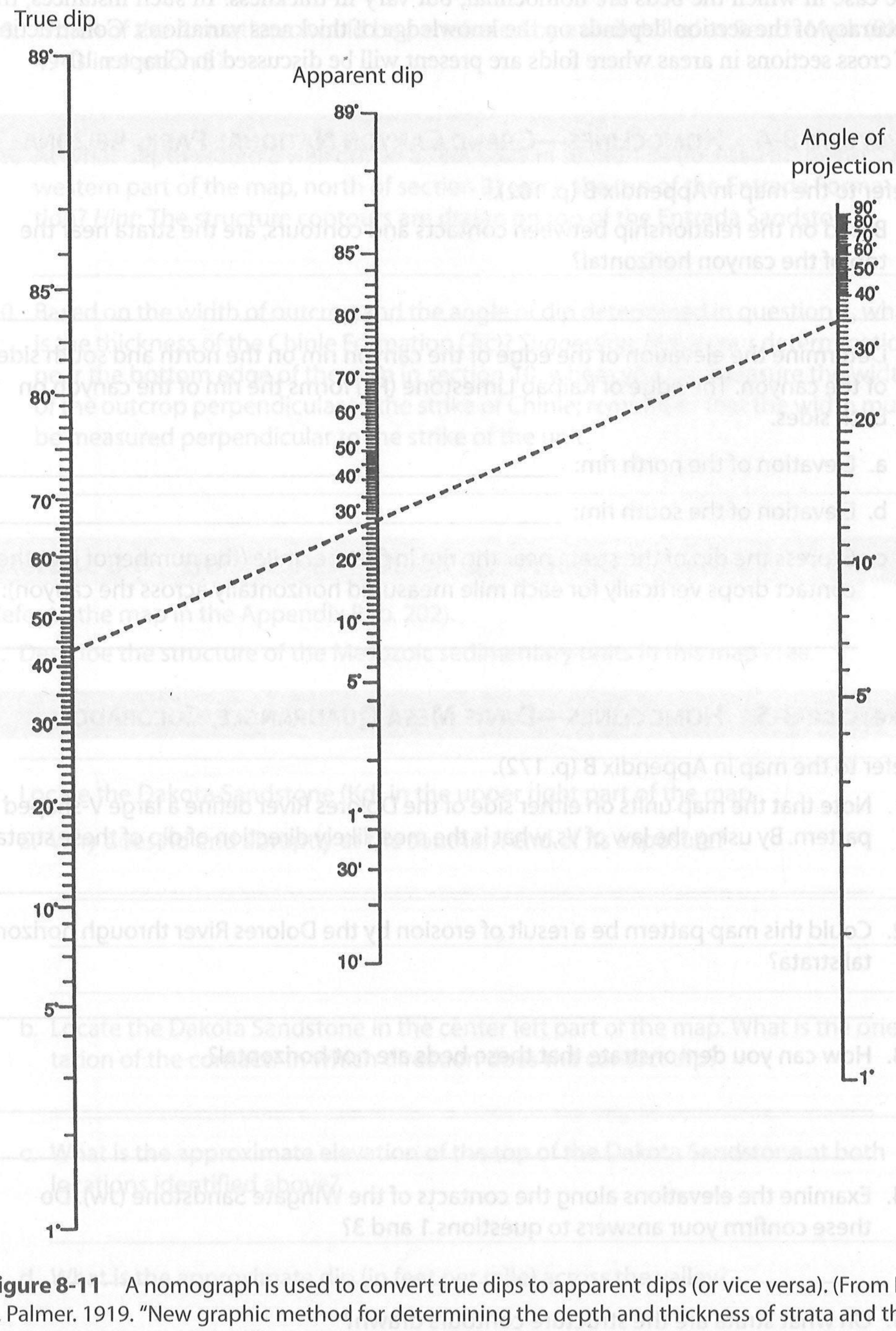


Figure 8-11 A nomograph is used to convert true dips to apparent dips (or vice versa). (From H. S. Palmer. 1919. "New graphic method for determining the depth and thickness of strata and the projection of dip." In *Shorter Contributions to Geology, 1918*. US Geological Survey Professional Paper 120-G.)

involve consideration of (a) the probable geometry of the structure, (b) continuity of beds, and (c) uniformity of bed thickness. At this point, knowledge of the types of structures present in a particular area becomes important. This information may be found in published papers about the region. Generally, a cross section is redrawn until it comes as close as possible to fitting all the data and information you have about the area. In addition to the strike and dip information, it is important to have the best available information about the thickness of the rock units.

The simplest case for which a cross section may be prepared is that in which the beds are homoclinal and uniform in thickness. In that case, the contacts are straight lines spaced apart at distances appropriate to the thickness of the beds. A variation on this is the case in which the beds are homoclinal, but vary in thickness. In such instances, the accuracy of the section depends on the knowledge of thickness variations. Construction of cross sections in areas where folds are present will be discussed in Chapter 10.