

MAPS AND IMAGES USED IN THE STUDY OF EARTH

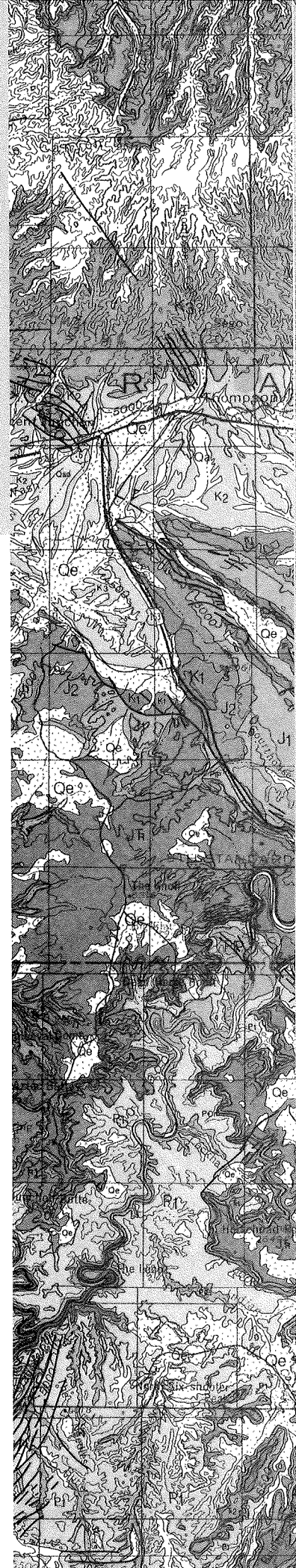
Many techniques are used to portray the surface and near-surface features of the Earth. Some of these, such as photographs and sketches of the landscape, depict the Earth's surface in ways in which we are accustomed to viewing it. Other techniques, such as geologic maps and cross sections, are designed 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.

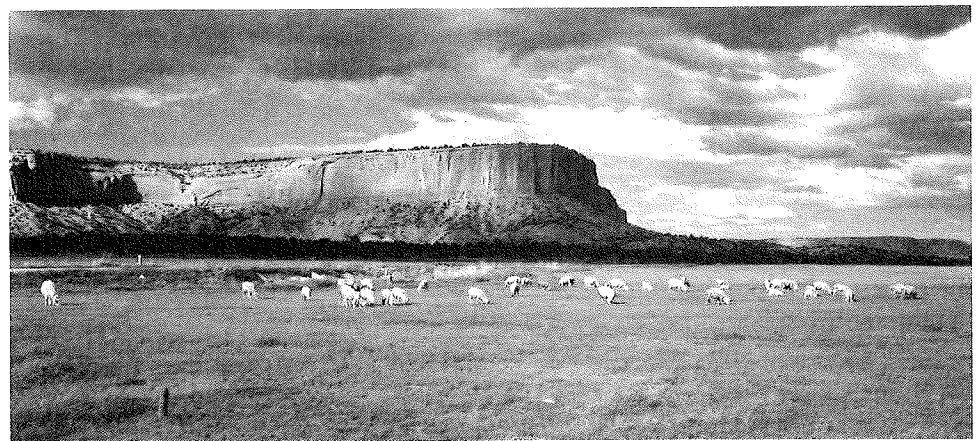
ORTHOPHOTOGRAPHS

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.



(a)

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.



(b)

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

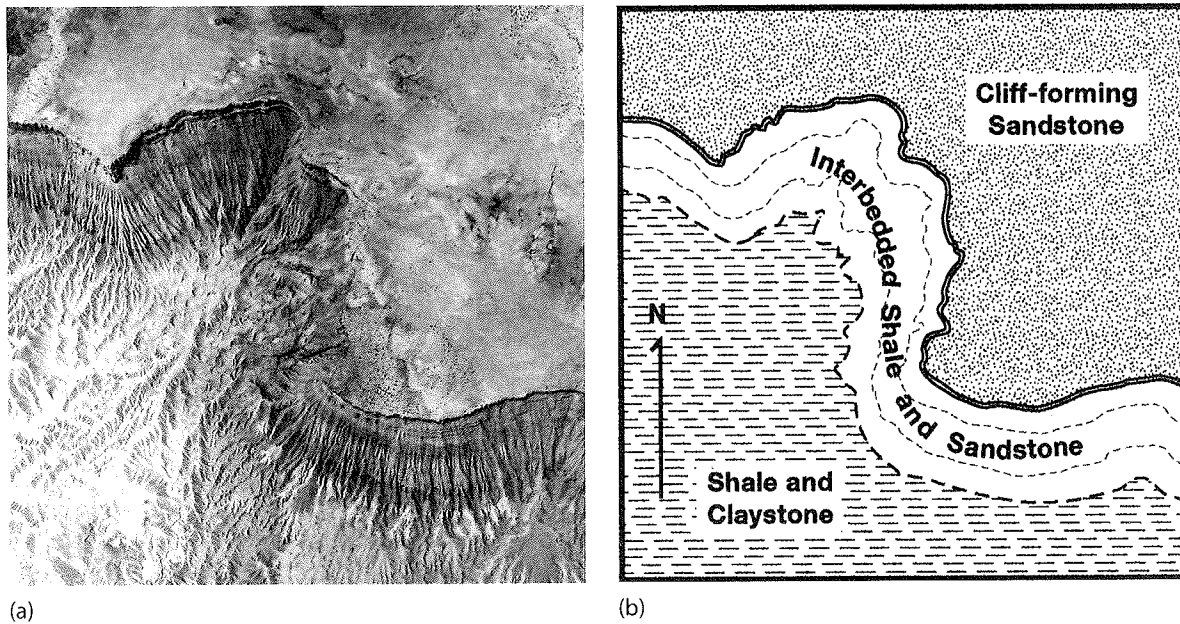


Figure 1-2 (a) This vertical aerial photograph is the type commonly used by geologists in mapping. The area shown is located in Utah along a prominent cliff (similar to that shown in Figure 1-1b) known as the Book Cliffs. (Photograph from the US Geological Survey.) (b) A geologic sketch map illustrates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

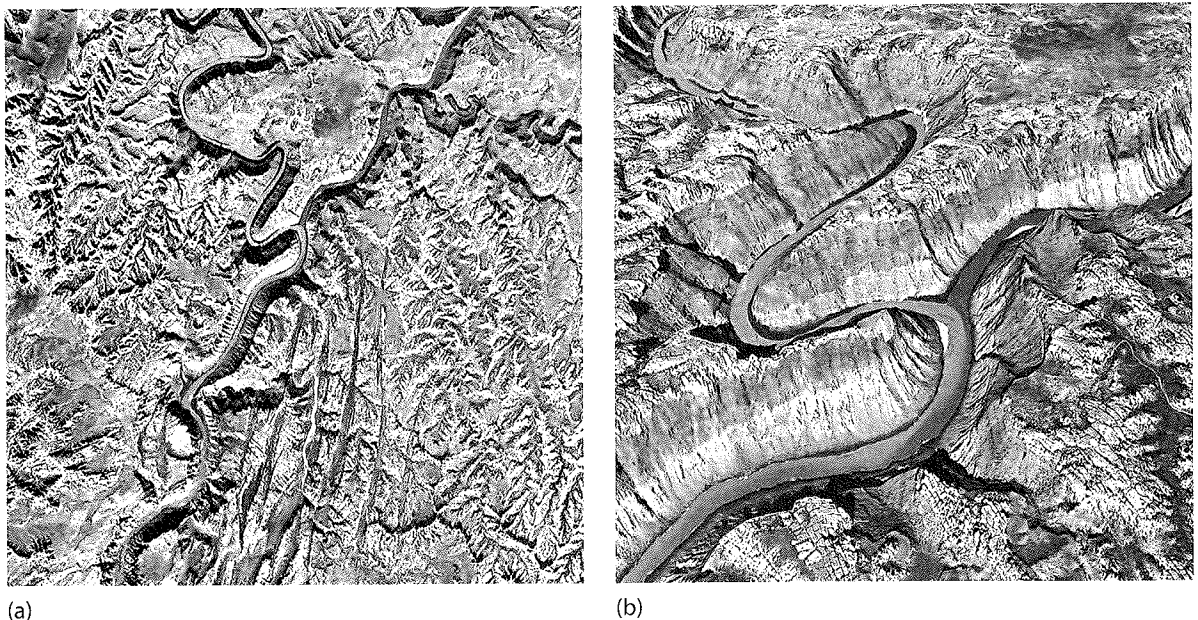


Figure 1-3 Google Earth images of the confluence of the Colorado and Green Rivers in Canyonlands National Park. Compare the vertical image (a) with the oblique view (b). With Google Earth it is possible to change the direction and the angle of the oblique view. This area is also covered on the Utah State 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.

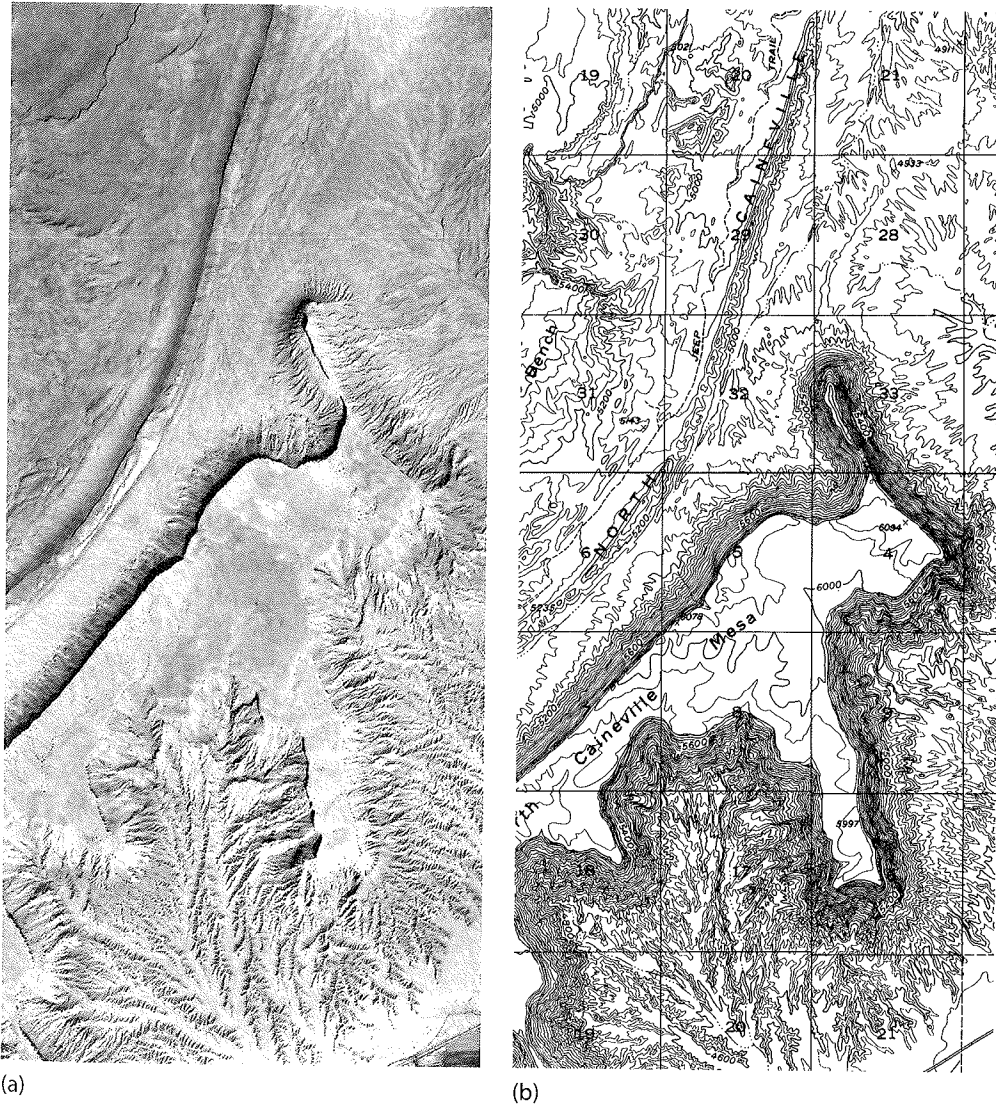


Figure 1-5 North Caineville Mesa, Utah. (a) Vertical aerial photograph. (b) Topographic map.
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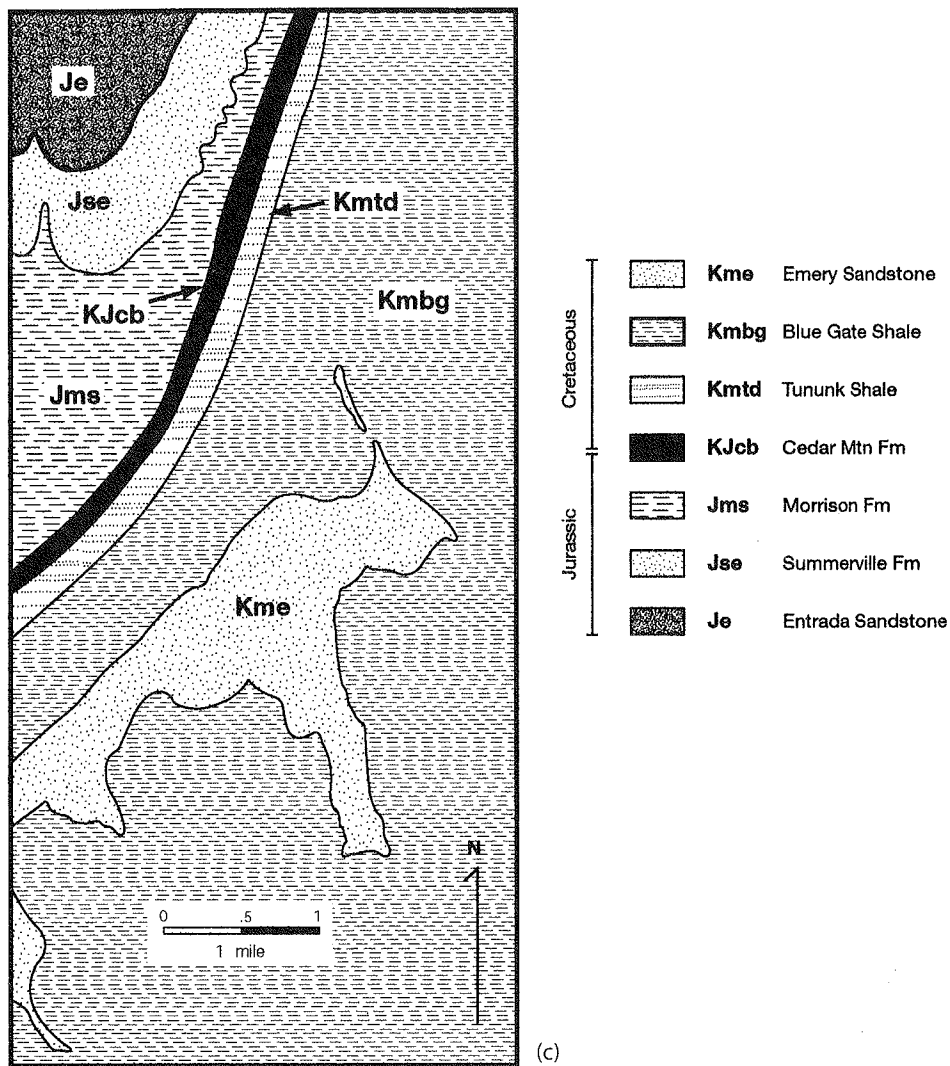


Figure 1-5 (c) Geologic sketch map. North Caineville Mesa has a flat top and is surrounded by a cliff formed of the Emery Sandstone. The Blue Gate Shale surrounds it. The ridge labeled North Caineville is held up by a steeply inclined sandstone known as the Cedar Mountain Formation. Northwest of the 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

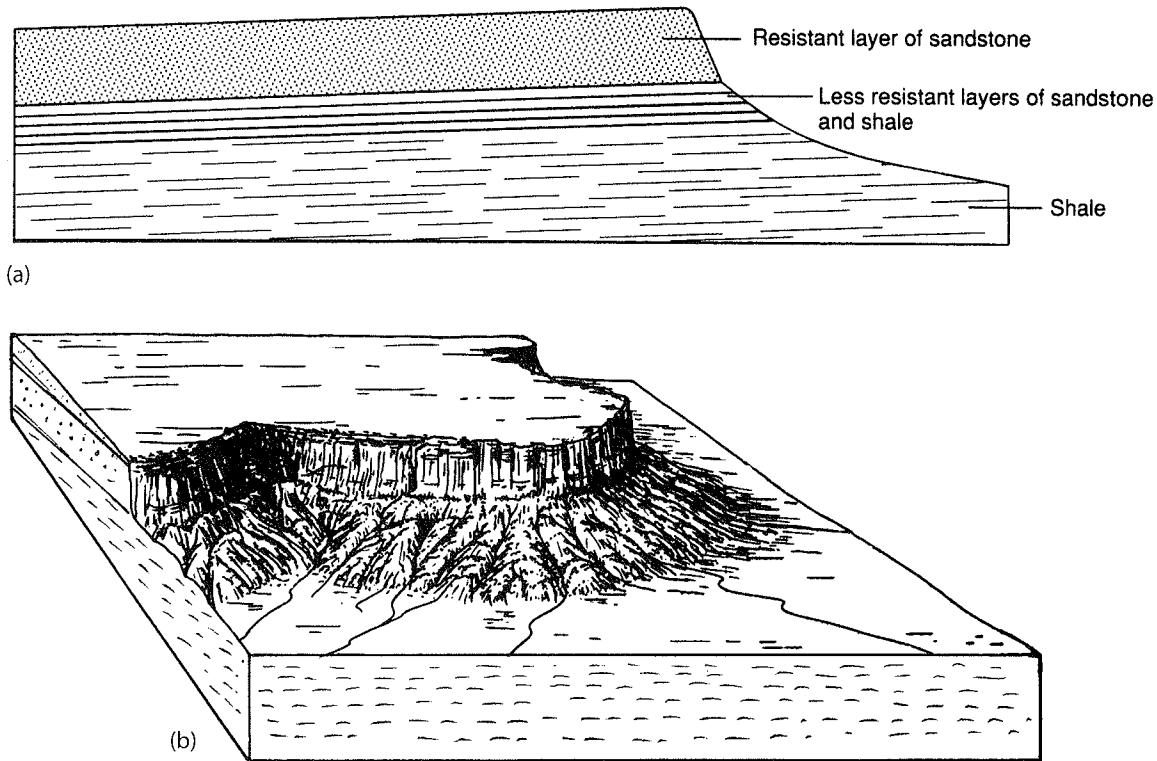


Figure 1-6 Colorado Plateau region of the southwestern United States (see Figure 1-1b). (a) A schematic geologic cross section of the area. (b) A block diagram.

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.

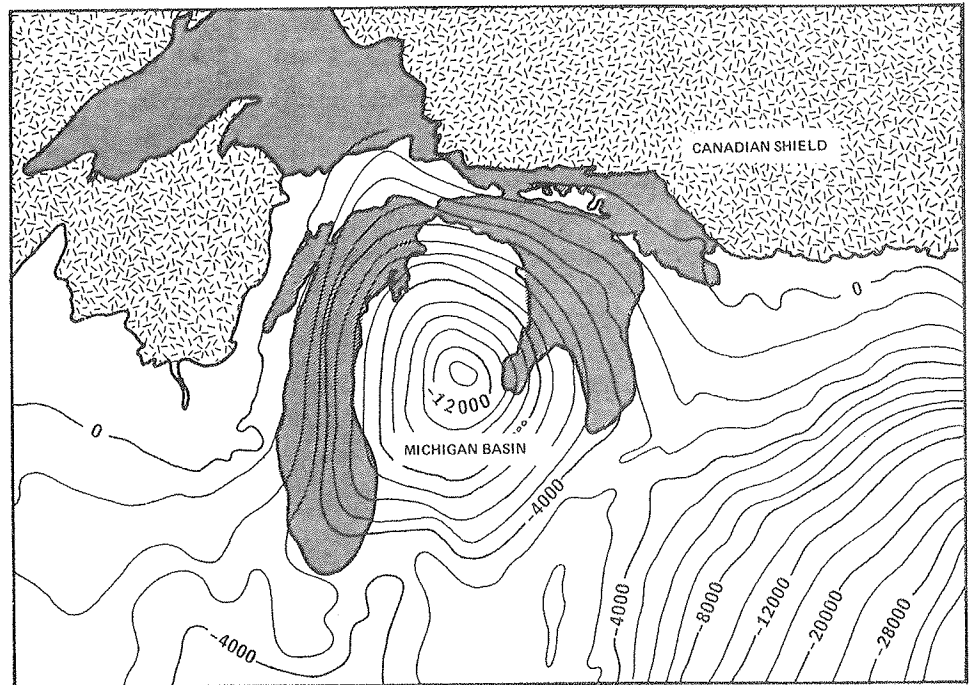


Figure 1-7 The Canadian Shield is a long-stable part of the North American craton where Precambrian igneous and metamorphic rocks are exposed. In the area south of the shield margin, Paleozoic sedimentary rocks cover the Precambrian crystalline rocks of the craton. The contours are lines connecting points 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 Precambrian 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.