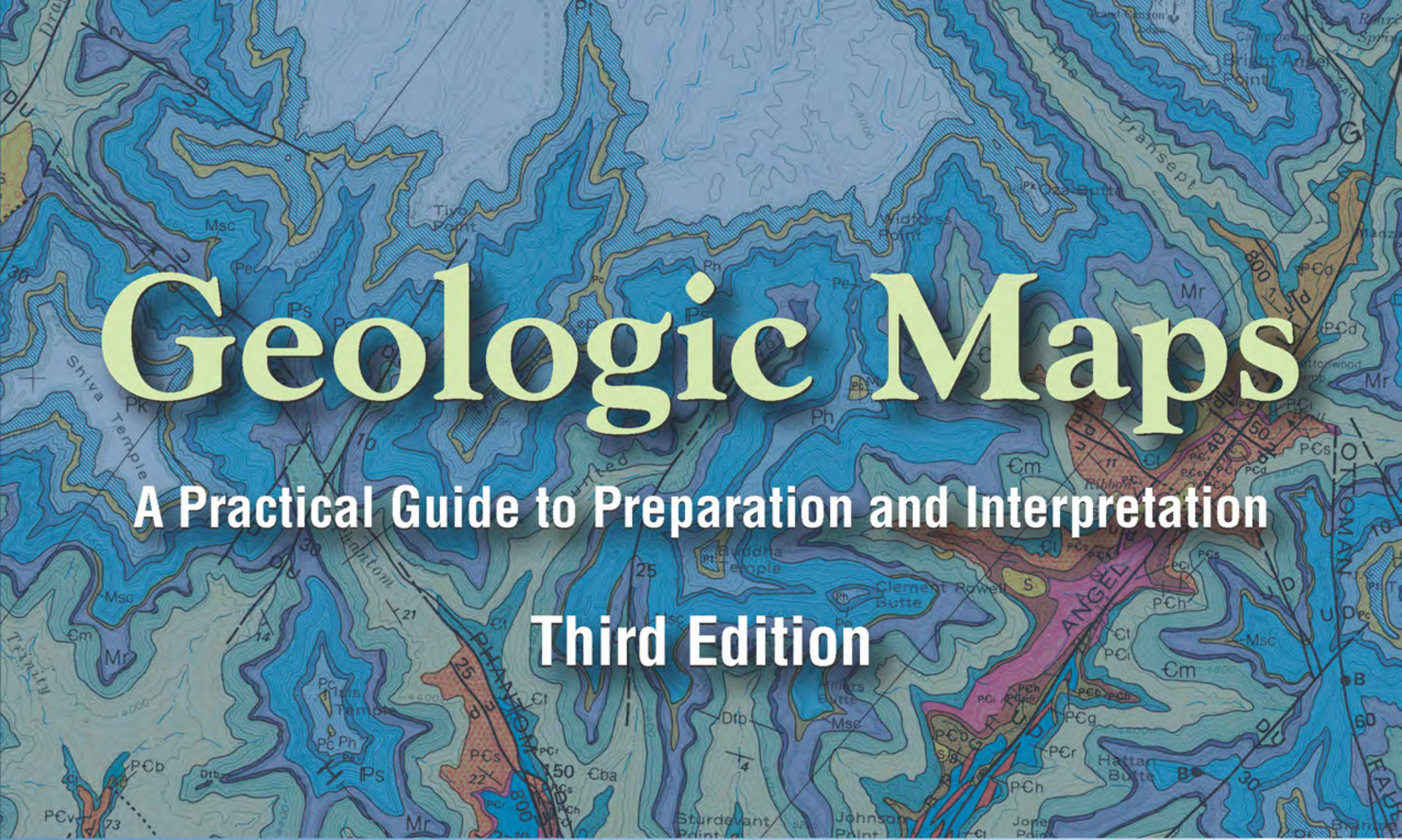

Geologic Maps

A Practical Guide to Preparation and Interpretation

Third Edition

Edgar W. Spencer

MAP ABBREVIATIONS

The United States Geological Survey has established standard symbols for use on the maps it publishes. These are used on most other maps also. The standard abbreviations for formations consist of a capital letter to indicate the period in which the unit was formed, followed by one or more lowercase letters to indicate the name of the formation (i.e., Ob is the symbol for the Beekmantown Formation of Ordovician age). Standard letters for periods are as follows.

Era	Period	Symbol
Cenozoic	Quaternary Tertiary	Q T
Mesozoic	Cretaceous Jurassic Triassic	C J Ŧr
Paleozoic	Permian Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian	P IP M D S O €
Precambrian		p€

An explanation of the symbols used on the map accompanies a geological map (generally beside the map). The explanation usually includes the following information:

1. Name of the map.
2. Scale of the map, shown both as a fraction and as a bar scale.
3. Name of the author of the map.
4. A stratigraphic column showing the rock units and sediments recognized in the map area. These are placed in a column with the youngest sediment or sedimentary rock unit at the top. Others follow in order of age. Igneous and metamorphic rocks are usually shown at the bottom of the column.
5. All other symbols (e.g., strike and dip of beds, faults, foliations, etc.) used on the map are defined.

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About the Author

Edgar Winston Spencer is the Ruth Parmly Professor of Geology Emeritus at Washington and Lee University where he served as department head from 1959 until 1995. He grew up in Arkansas and went to college at Vanderbilt and Washington and Lee University. While a graduate student at Columbia University, he worked at the Lamont–Doherty Geological Observatory and taught at Hunter College. His dissertation concerned the structure of the Beartooth Mountains in Montana. He continued mapping and structural work in the Madison Mountains in Montana and later in the Appalachians where he has done regional mapping in the Blue Ridge and in the Valley and Ridge for the Virginia Division of Geology and Mineral Resources. He conducted field seminars in the central western Valley and Ridge for the American Association of Petroleum Geologists. In 1991, he received an outstanding faculty award from the Virginia Council of Higher Education, and was given the Anna Jonah Award for Outstanding Contributions to Virginia Geology by the Virginia Geological Field Conference in 2013. He is a member of Sigma Xi and an honorary member of Phi Beta Kappa and Omicron Delta Kappa. Spencer is the author of a structural geology text and several introductory geology textbooks. More recently he wrote the *Guide to the Geology and Natural History of the Blue Ridge Mountains*. He continues mapping in the central Appalachian Mountains and has served as a guide with many alumni colleges at Washington and Lee University.

PREFACE

Geologic maps are among the basic tools used by anyone who wants to gain an understanding of the surface and shallow subsurface of the earth. They provide information about the types of materials that are present and the configuration of those materials in three dimensions. They reveal the three-dimensional structure of the bedrock, identifying the location of faults, folds, and breaks in the rock record. Some maps show the distribution of surficial materials, some depict only bedrock, and commonly, both are represented. In the hands of a skilled interpreter, geologic maps reveal the location of many types of natural hazards, indicate the suitability of the land surface for various uses, reveal problems that may be encountered in excavation, provide clues to the natural processes that have shaped an area, and lead to the potential location of important natural resources. For these reasons, civil and environmental engineers, land-use planners, soil scientists, and geographers, as well as geologists, use geologic maps.

This book is designed to provide instruction for students who are enrolled in a map interpretation and field geology course. It is also suitable for individual self-instruction by students and professionals who find that they need to understand and use geologic maps. To accomplish these goals, the book is written as a work manual. The steps used in map interpretation follow a brief discussion of basic information about map projections and the types of information present on geologic maps. The text covers maps showing surficial materials as well as bedrock geology. After the text describes representative examples of features found on geologic maps, exercises direct the attention of students to those features on published geologic maps. Geometric techniques are explained using a step-by-step approach.

Chapter 3 of the book provides basic information needed to prepare geologic maps. This chapter is designed for students who are beginning a field mapping project. It gives those whose primary interest is in map interpretation insight into the mapping process and an appreciation of the level of precision represented by data on geologic maps. Because aerial photographs are widely used in mapping, a short discussion of the use and interpretation of aerial photographs is included.

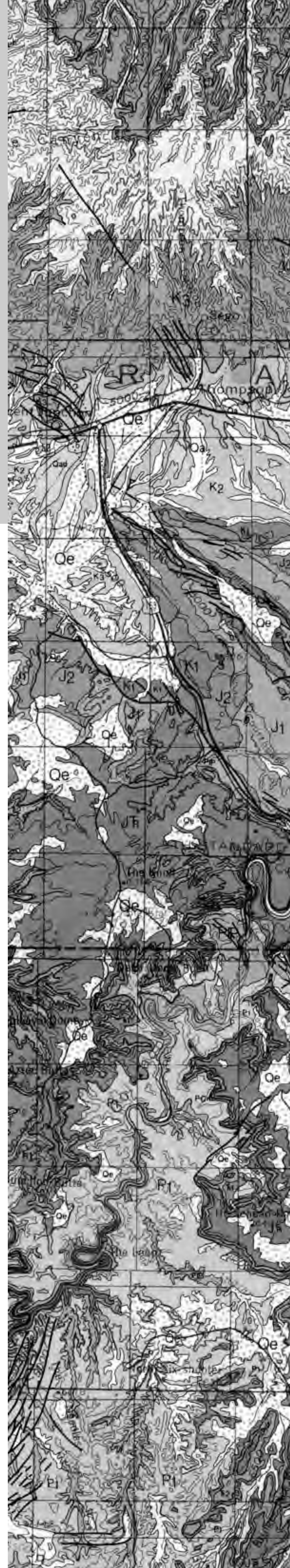
Attention is given to new maps and mapping techniques in this edition. These include use of Google Earth, Global Positioning System (GPS), geographic information systems (GIS), LiDAR (light detection and ranging) maps, and drones. Addition of the rock types associated with the formations listed in Appendix B will help students understand the regional geology of the areas covered by the maps.

More emphasis has been placed on large-scale regional and tectonic maps in this third edition. A number of new maps, including the Gulf of Mexico Coastal Plain, Rocky Mountain Front Range, Yellowstone region, Moab, Utah, area, Shenandoah National Park area, and Hawai'i, have been added. These changes will make the text more helpful for classes taught in field camps, in which the regional geology is an important component of the course work. A new chapter devoted to tectonic maps is intended to serve this purpose.

I gratefully acknowledge the help of many generations of students who have shared their experiences in learning to prepare and interpret geologic maps with me.

Special thanks are extended to Kent Ratajeski, Daniel Bryant Imrecke, and Dorina Murgulet for suggestions about the third edition; to Ronald Erchul, Mary Westerback, Grenville Draper, and my daughter Shannon Spencer for their help in preparing the first edition; to Marcs Bursik, Marie Johnson, Edward Hansen, Peter Copeland, Jay Van Tassell, Daniel Murray, Rena Thiagarajan, Christine Metzger, Andrea Creech, Andrew Thompson, Greg Bank, and Madelyn Miller for help in editing and preparing the second edition for publication; and my daughter, Shawn Spencer, who prepared many of the illustrations for the first two editions. Thanks to my colleagues at Washington and Lee for their support, and to Sarah Wilson, Emily Falls, Veronica Sanchez, and Seth McCormick-Goodhart for their help with the manuscript. It has been a pleasure to work with Diane Evans at Waveland Press, who edited and supervised the layout of this new edition.

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)

(b)

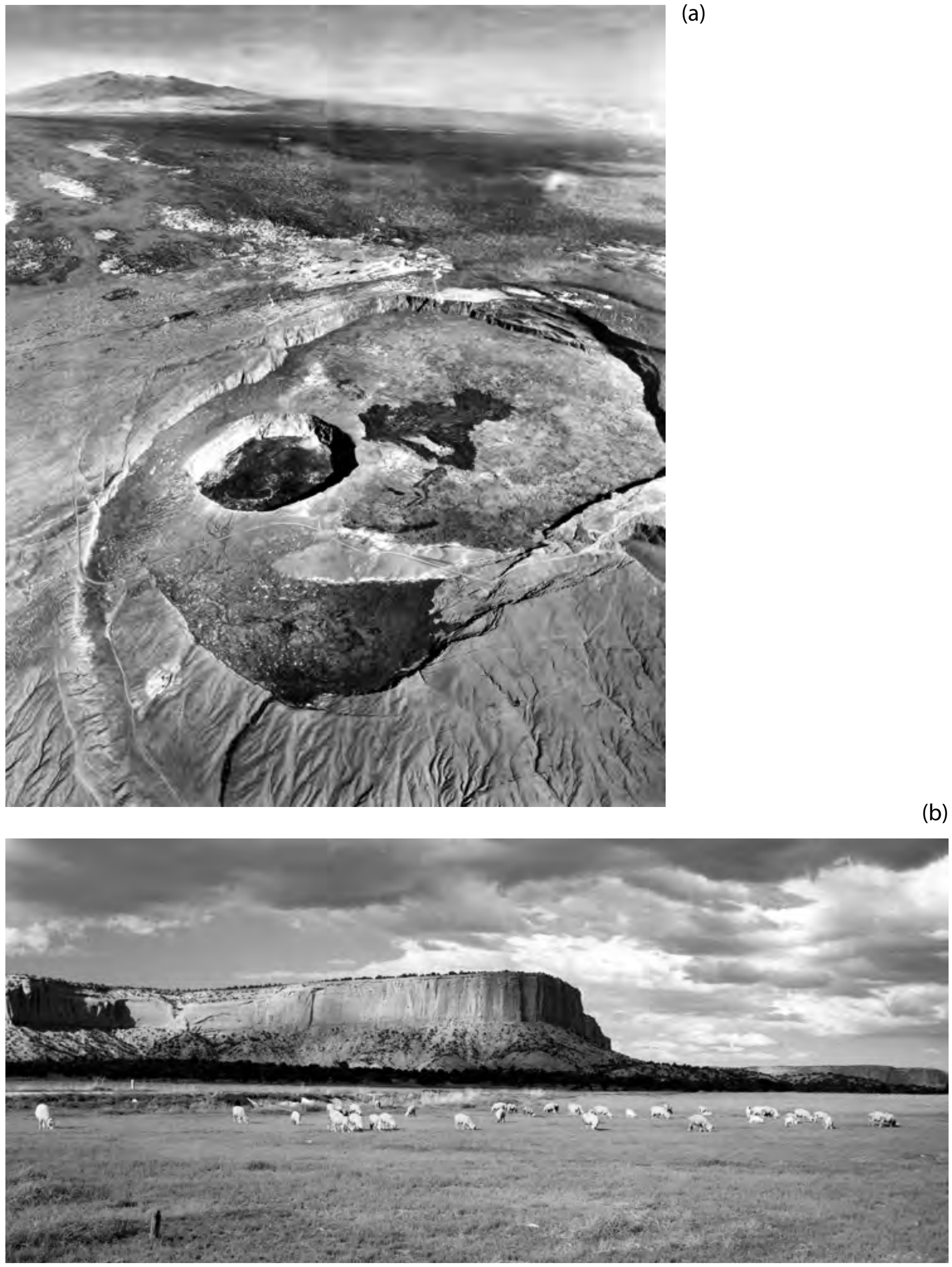
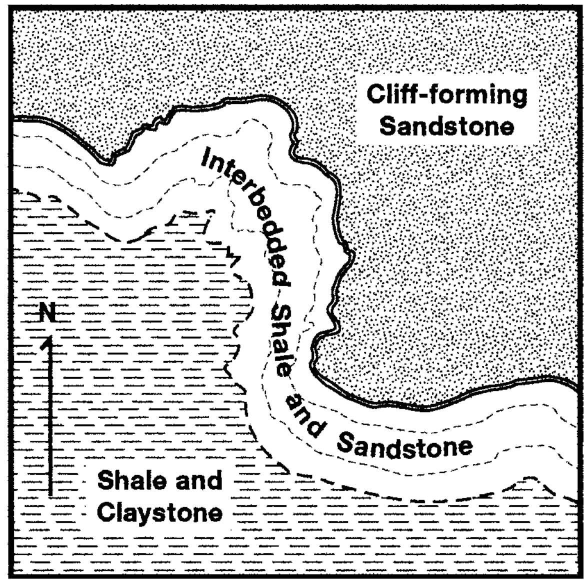


Figure 1-1 (a) This oblique aerial photograph shows the collapsed crater of Mauna Loa volcano located on the big island of Hawai'i. (Photograph from the US Geological Survey.) (b) Ground-level photograph of a massive cliff-forming sandstone layer underlain by thin-bedded sandstones and shales (this photograph 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

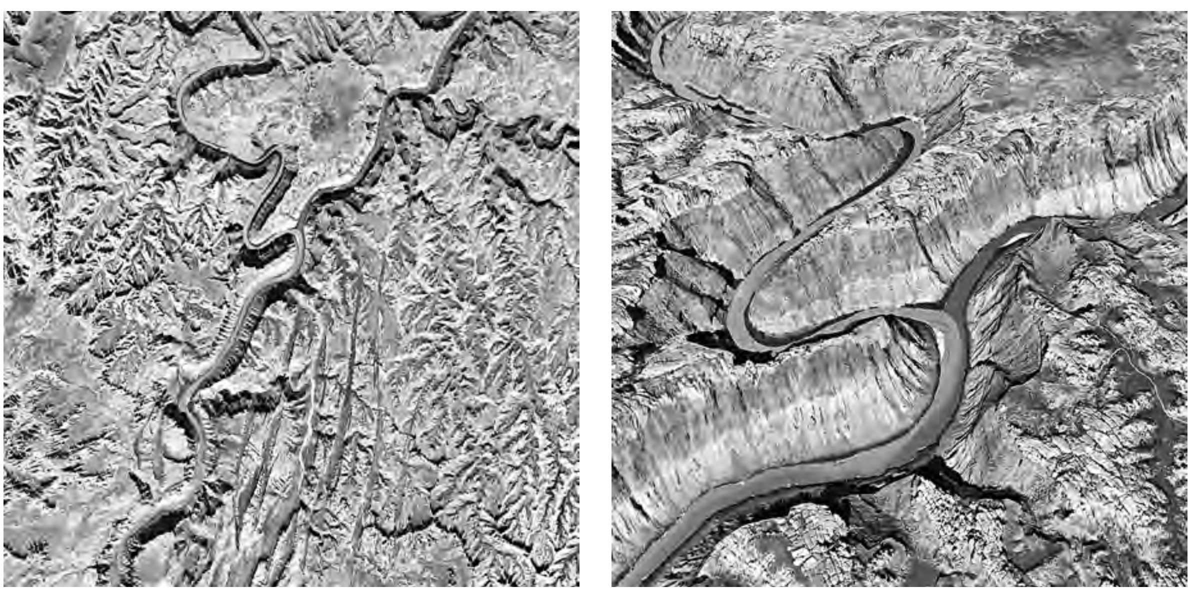
Radiant energy outside the visible part of the spectrum is used in producing Landsat images. In order to produce an image of the nonvisible spectrum, each part of the spectrum of interest is arbitrarily assigned a color. These images are called false color images because they are made up of colors that 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.

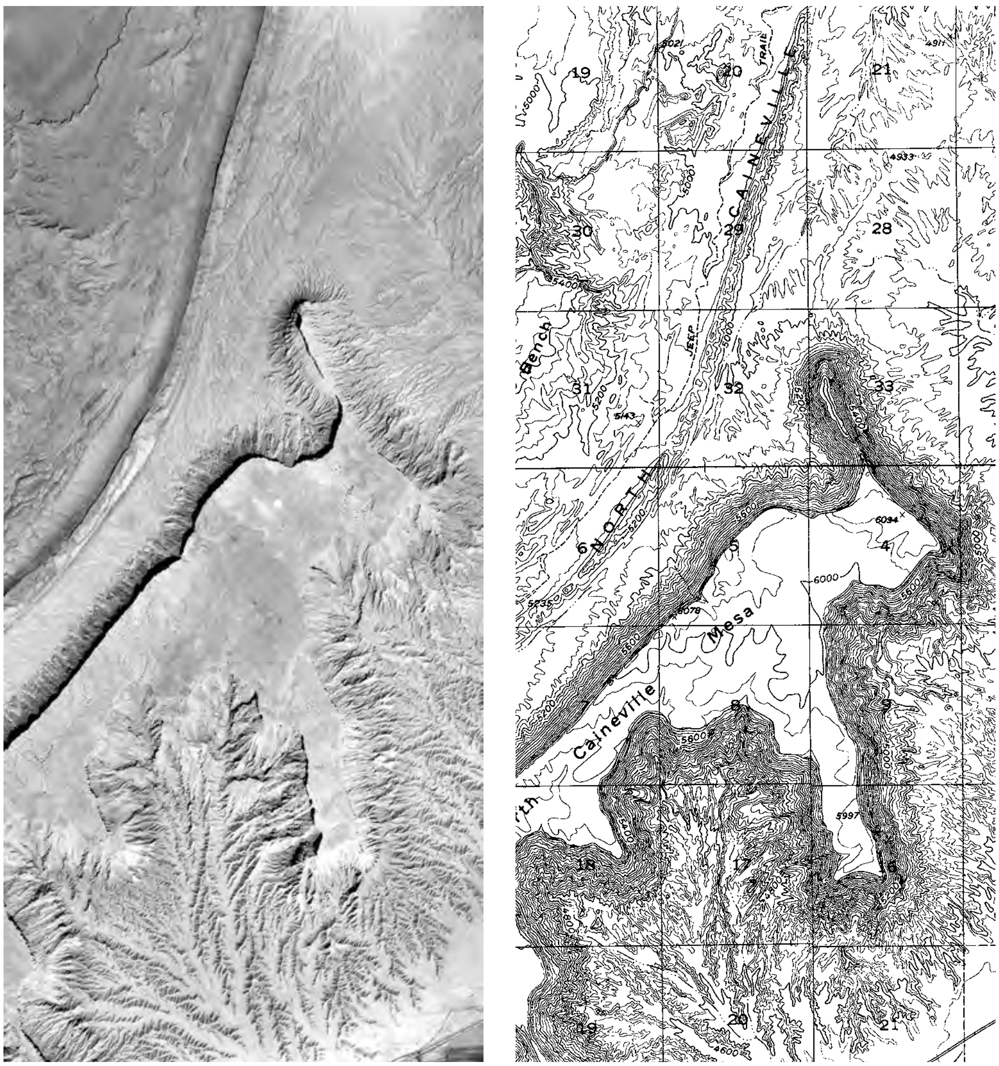
On some geologic maps, the bodies of rock that are identified and distinguished from one another are what geologists call **rock units** (see Figure 3-2). These are bodies of rock that can be identified on the basis of their composition and texture. The basic rock unit is called a **formation**. These 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)*