

Introduction to Topographic and Geologic Maps and Remotely Sensed Imagery

MAPS AND SCALE

Many kinds of information can be presented in map form. Topographic and geologic maps are the two kinds most frequently used by geologists. This section presents a brief introduction to both types of maps.

A point to note at the outset is that, in the United States, topographic and geologic maps commonly carry English, rather than metric, units. Many of these maps were drawn before there was any move toward the adoption of metric units in the United States. The task of redrawing maps to convert to metric units is formidable, particularly with topographic maps. (A metric map series is being prepared by the U.S. Geological Survey, but it will be many years before its completion.)

A basic feature of any map is the map **scale**, a measure of the size of the area represented by the map. Map scales are reported as ratios—1:250,000, 1:62,500, and so on; or equivalently in words, for example, “one to two hundred fifty thousand.” On a 1:250,000 scale map, a distance of 1 inch on the map represents 250,000 inches (almost 4 miles) in reality; on a 1:62,500 scale map, 1 inch equals about 1 mile of actual distance. The larger the scale factor, the more real distance is represented by a given distance on the map. As a result, the fineness of detail that can be represented on a map is reduced as the scale factor is increased. The choice of scale factor often involves a compromise between minimizing the size of the map (for convenience of use) or the number of maps required to cover the area, and maximizing the amount of detail that can be shown.

TOPOGRAPHIC MAPS

Topographic maps primarily represent the form of the earth’s surface. Selected other features, both natural and artificial, may be included for information. Once one becomes accustomed to reading them, topographic maps can make excellent navigational aids.

Contour Lines, Contour Intervals

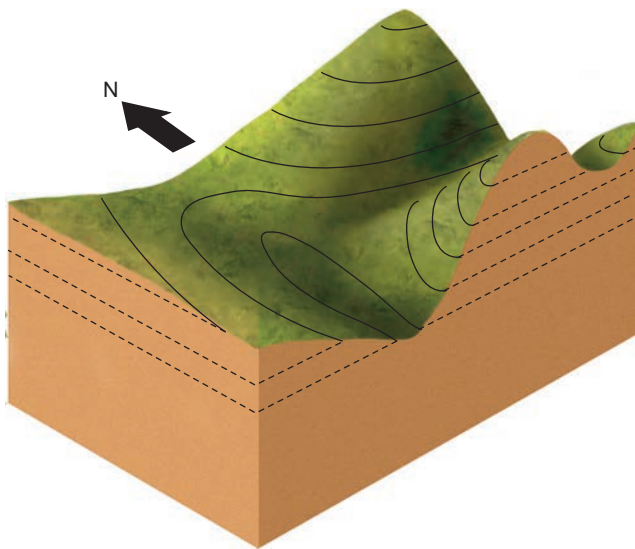
The problem of representing three-dimensional features on a two-dimensional map is addressed through the use of **contour**

lines. A contour line is a line connecting points of equal elevation, measured in feet or meters above or below sea level. The **contour interval** of a map is the difference in elevation between successive contour lines. For instance, if the contour interval is 10 feet, contour lines are drawn at elevations of 1000 feet, 1010 feet, 1020 feet, 1030 feet, and so on (in whatever range of elevations is appropriate to that map). If the contour interval is 20 feet, contours would be drawn at elevations of 1000 feet, 1020 feet, 1040 feet, and so on. The contour interval chosen for a particular map depends on the overall amount of relief in the map area. If the terrain is very flat, as in a midwestern floodplain, a 10-foot or even 5-foot contour interval may be appropriate to depict what relief there is. In a rugged mountain terrain, like the Rockies, the Cascades, or the Sierras, with several thousand feet of vertical relief, using a 10-foot contour interval would make for a very cluttered map, thick with contour lines; a 50-foot or even 100-foot contour interval may be used in such a case.

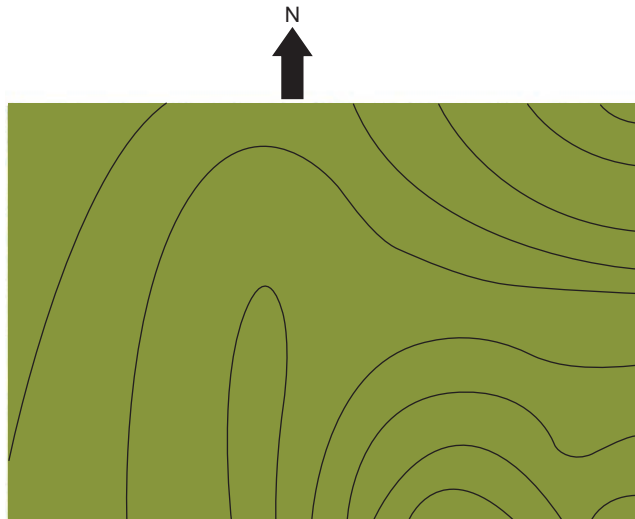
The relationship between the spacing of contours and the steepness of a slope can be seen in figure 1. A comparison of the actual relief, as shown in figure 1A, and the resultant arrangement of contour lines on the corresponding topographic map, shown in figure 1B, illustrates that on a given map, the more closely spaced the contours, the steeper the corresponding terrain. In other words, if the map shows many closely spaced contours, this means that there is a great deal of vertical relief over a limited horizontal distance. Note also that contours run across the face of a slope; the upslope and downslope directions are perpendicular to the contours.

Contours do close, although they may not do so on any one given map. A series of concentric closed contours indicates a hill. If there is a local depression, so that the same contour is encountered twice, once going up in elevation and again within the depression, the repetition of the contour within the depression is marked by a hachured contour, as shown in figure 2.

Where contour lines cross a stream valley, they point upstream, toward higher elevations (figure 3). Contour lines corresponding to different elevations should not ordinarily cross each other (that would imply that the same point has multiple elevations). The only exception to this would occur in the case of an overhanging cliff, where a range in elevations exists at one spot on the map.

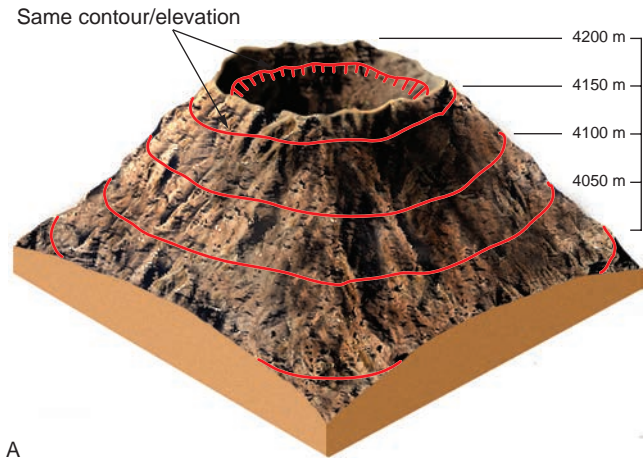


A

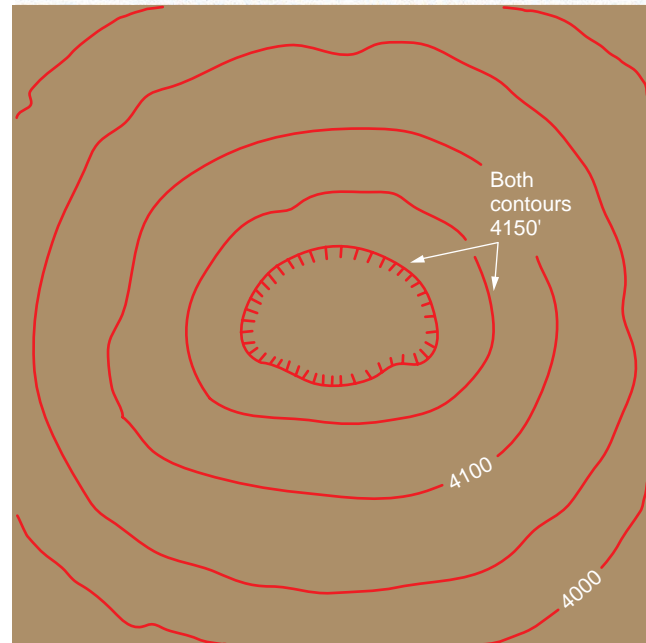


B

FIGURE 1 Contours and relief. (A) Perspective view of a hilly area, with contours superimposed for reference. (B) The same contours as they would appear on a topographic map.



A



B

FIGURE 2 Volcanic caldera with summit depression. (A) Actual relief. (B) As the volcano would appear on a topographic map.

Other Features on Standard Topographic Maps

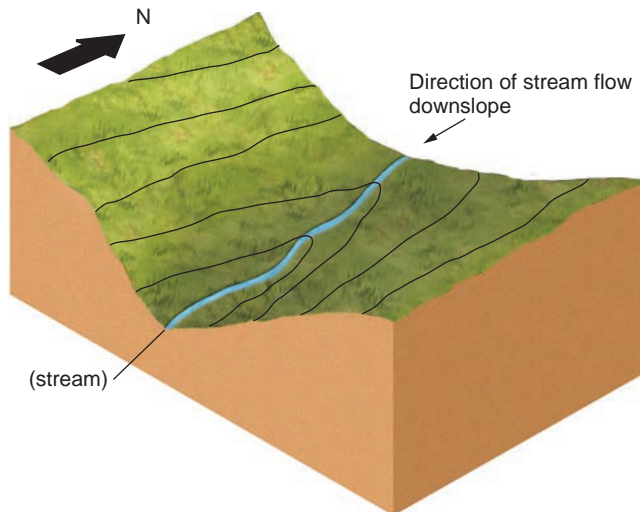
The most extensive topographic maps of the United States have been compiled by the U.S. Geological Survey (USGS). The USGS has adopted a uniform set of symbols for various kinds of features, which facilitates the reading of topographic maps. Some of these symbols are illustrated by figure 4.

Contour lines are drawn in brown. Major contours (typically, those contours corresponding to multiples of 100 feet, except on maps with large contour intervals) are drawn more boldly and labeled with the corresponding elevation. This is especially convenient in rugged terrain, where it would otherwise be easy to lose count of numerous closely spaced contours. Roads are drawn in black and/or red. Town limits are shown in

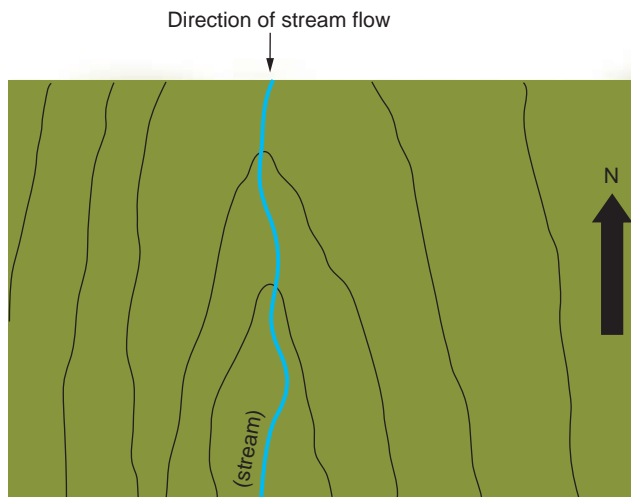
light red, and the names of towns, cities, and mountains, or any other labels, are printed in black. Watery features are drawn in blue: lakes and perennial streams in solid blue, intermittent streams in dashed blue lines, swampy areas represented by blue symbols resembling tufts of low grasses. The background color for wooded areas is green; for open fields, brushy areas, deserts, bare rock, or any area lacking overhead vegetative cover, the background color is white.

GEOLOGIC MAPS

Topographic maps show the form of the land surface; geologic maps are one way of representing the underlying geology. The most common kind of geologic map is a map of **bedrock**



A



B

FIGURE 3 Contours crossing stream valleys. (A) Relief with superimposed contours. (B) On topographic map, the contours point upstream.

geology, which shows the geology as it would appear with soil stripped away. (Other maps may show distribution of different soil types, glacial deposits, or other features of surface geology.) From a well-prepared geologic map, aspects of the subsurface structure can often be deduced.

Basics of Geologic Maps

Fundamental to making a geologic map is identifying a suitable set of **map units**. These may, for example, be individual sedimentary rock formations, distinguishable lava flows, or metamorphic rock units. The main requirement for a map unit is that it be identifiable by the presence or absence of some characteristic(s), and thus distinct from other map units chosen. The mapper then marks which of the map units are found at each place where the rocks are exposed.

Additional information, such as the orientation of beds or the location of contacts between map units, may also be recorded. Where obvious, contacts are drawn as solid lines; where only inferred, they are drawn as dashed lines. (If one finds granite at point A and limestone at point B a short distance away, one can infer a contact between the granite and limestone somewhere between A and B, even if the exact spot is covered by soil.)

How easy it is to produce an accurate and complete geologic map depends on several factors (aside from the competence of the mapper!). Bedrock exposure is one. Thick soil, water or swamps, and vegetation can all obscure what lies below. In some areas, the geology is well exposed only along stream valleys; in others, the rocks are completely exposed, and mapping is greatly simplified. In glaciated areas, too, one need not only deal with the cover of glacial till (assuming that is not the material of interest) but also be cautious about mistakenly identifying a large, partially buried bit of glacial debris as a small exposure of bedrock. And some areas are simply much more complicated, geologically, than others.

On a geologic map, different units are represented in different colors for clarity (figure 5). Units of similar age may be shown in different shades of the same color. The map is accompanied by a key showing all the map units, arranged in chronological order (insofar as their ages are known), with the youngest at the top. Ordinarily, a brief description of each map unit is given; alternatively, standard patterns may be used to indicate the general rock type (figure 6). Each unit is also assigned a symbol. The first part of the symbol consists of one or two letters corresponding to the unit's age (generally, the geologic era or period; see appendix A). This is usually followed by one to three lowercase letters corresponding to the rock type or unit's name (if any). For example, "pC qm" might be used for an unnamed Precambrian quartz monzonite, "Dl" for the Devonian Littleton Formation, "Qa" for Quaternary alluvium along a stream channel. These symbols are useful for distinguishing units mapped in similar colors, as well as for providing a general indication of the age of each unit directly on the map.

Interpretation of geologic maps likewise varies in difficulty, depending on the fundamental complexity of the geology and the extent of exposure (completeness of map). Sometimes, too, how much of the geology can be seen depends not only on cover or lack of it, but on topography. That is, in rugged terrain with considerable vertical relief, one has more of a three-dimensional look at the geology than in flat terrain. For example, in the vicinity of the Grand Canyon, the Paleozoic sedimentary sequence is quite flat-lying. So, for the most part, is the land surface. Outside the canyon, only the Kaibab limestone is exposed, forming a nearly level plateau and giving no evidence of what lies below. The cutting of the canyon has exposed many more rock units, down to the Precambrian. This is apparent on a geologic map (figure 7).

The Grand Canyon has a regular, layer-cake geology that has a straightforward interpretation. Where the geology is more complex, patterns of repetition of units and orientation of beds must be



FIGURE 4 Representative section of standard topographic map: a portion of Yellowstone National Park. Note the closely spaced contours along the Grand Canyon of the Yellowstone and edges of plateaus, the shapes of contours that cross streams, the closed contours around hills (for example, Junction Butte), and the swampy flat area (along Slough Creek).

Source: U.S. Geological Survey.

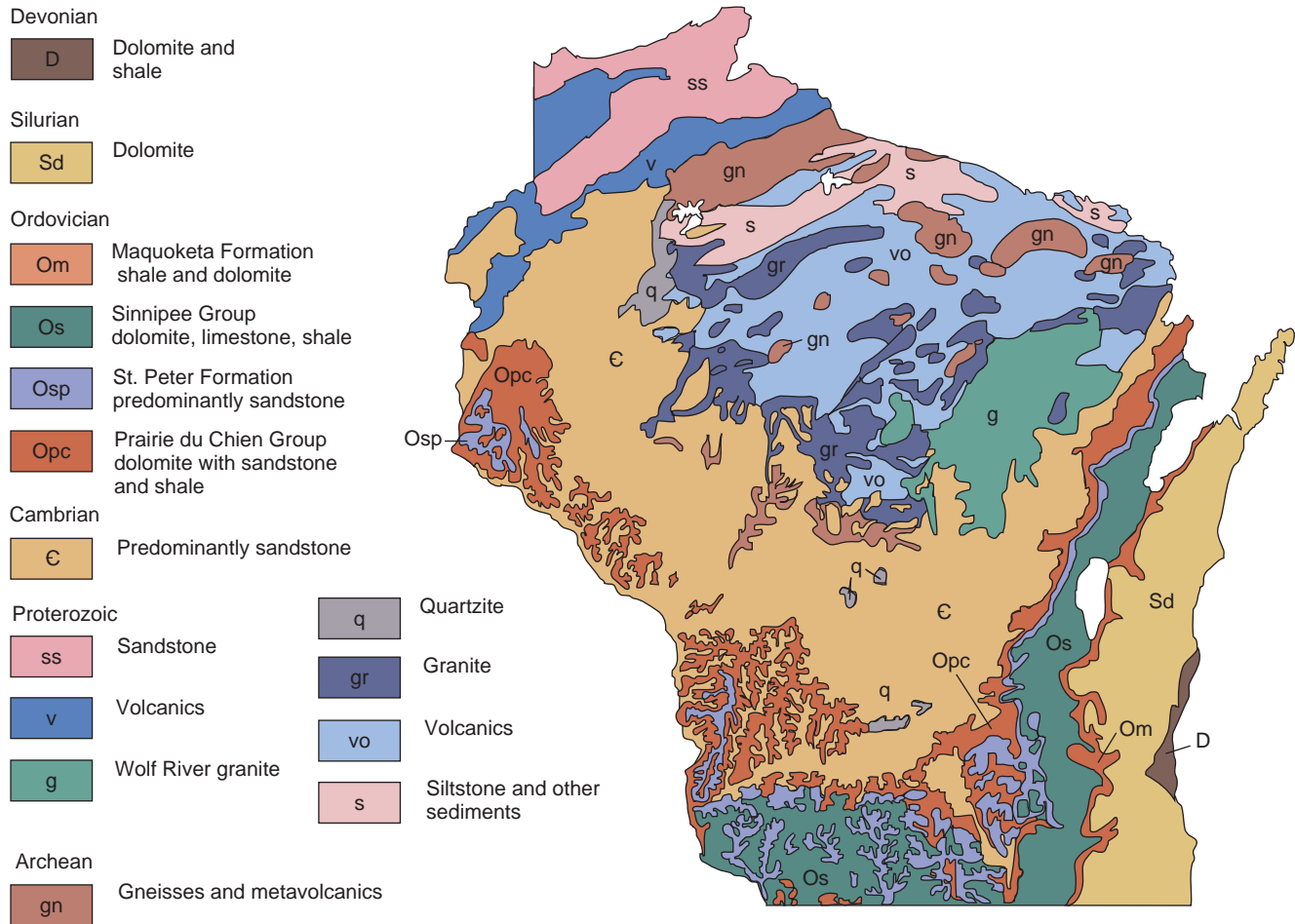


FIGURE 5 Sample of geologic map with key: Simplified bedrock geology of Wisconsin.
 Source: After M. E. Ostrom, *Wisconsin Geological and Natural History Survey*, April 1981.

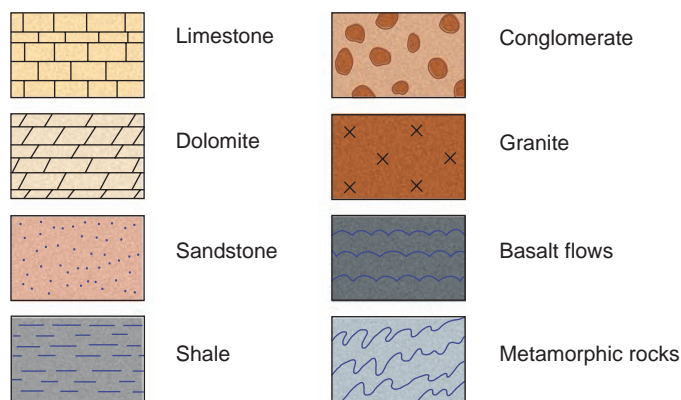


FIGURE 6 Selected standard map symbols for various rock types.

used to interpret the structure. For example, when sets of rocks are repeated, this may indicate the presence of a fault. In the map pattern shown in figure 8, the same sequence of units is repeated; moreover, all are dipping in the same direction. It is difficult to

create such a pattern by folding. A fault, however, can account for the result (figure 8). Offset of features that are otherwise continuous is another sign of possible faulting (figure 9).

Cross Sections

Interpreting structure from geologic map patterns and rock orientations requires some practice and the ability to visualize in three dimensions. Often, the maker of a geologic map assists the map reader by supplying one or more geologic **cross sections**. A cross section is a three-dimensional interpretation of the geology seen at the surface. The line along which the cross section is drawn is indicated on the map. The cross section uses the same map units and symbols as the map proper and attempts to show the geometric relationships inferred to exist among those units—folds, faults, crosscutting relationships, and so on.

A cross section is drawn by starting with a topographic profile along the chosen line and marking on it the geology as seen

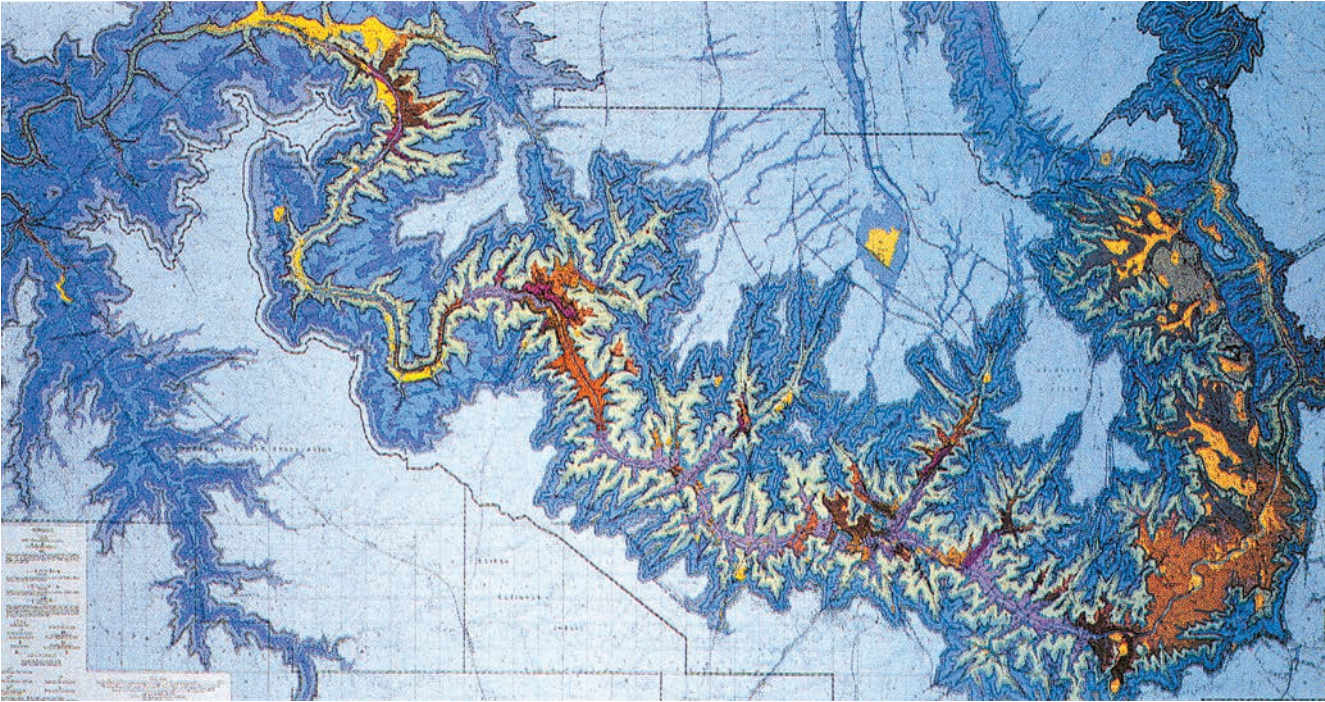


FIGURE 7 The presence of the Grand Canyon allows much better knowledge of the area's subsurface geology. Geologic map shows different rock units in different colors. Note monotony outside canyon.

Used with permission Grand Canyon Natural History Association.

from the surface (figure 10A). A structural interpretation that is consistent with all the known data is then devised (figure 10B). Depending on the complexity of the geology and the completeness of exposure on which the original geologic map has been based, it may or may not be possible to develop a unique structural interpretation for the observed map pattern. If it is not, several plausible alternatives might be presented. Cross sections can be very valuable in evaluating site suitability for construction or other purposes.

REMOTE SENSING AND SATELLITE IMAGERY

Remote-sensing methods encompass all of those means of examining planetary features that do not involve direct contact. Instead, these methods rely on detection, recording, and analysis of wave-transmitted energy—visible light, infrared radiation, and others. Aerial photography, in which standard photographs of relatively large regions of the earth are taken from aircraft, is one example. Radar mapping of surface topography, using airplanes or spacecraft, is another. Still another involves analyzing the light reflected from the surface of a body. In the case of many planets, remotely sensed data may be the only kind readily available. In the case of the earth, remote sensing, especially using satellites, is a quick and efficient way to scan broad areas, to examine regions having such

rugged topography or hostile climate that they cannot easily be explored on foot or with surface-based vehicles, and to view areas to which ground access is limited for political reasons. Probably the best-known and most comprehensive earth satellite imaging system is the one initiated in 1972, known as Landsat.

The Landsat satellites orbit the earth in such a way that images can be made of each part of the earth. Each orbit is slightly offset from the previous one, with the areas viewed on one orbit overlapping the scenes of the previous orbit. Each satellite makes 14 orbits each day; complete coverage of the earth takes 18 days. Therefore, images of any given area should be available every 18 days, although in practice, shifting distributions of clouds obscure the surface some part of the time at any point. Eight Landsat satellites have been launched; two are still functioning. Landsat 9 is scheduled to launch in 2020.

Satellite Images and Applications

The sensors in the Landsat satellites do not detect all wavelengths of energy reflected from the surface (figure 11). They do not take photographs in the conventional sense. They are particularly sensitive to selected green and red wavelengths in the visible light spectrum and to a portion of the infrared (invisible heat radiation, with wavelengths somewhat longer than those of red light). These wavelengths were chosen particularly because plants reflect light most strongly in the green and the

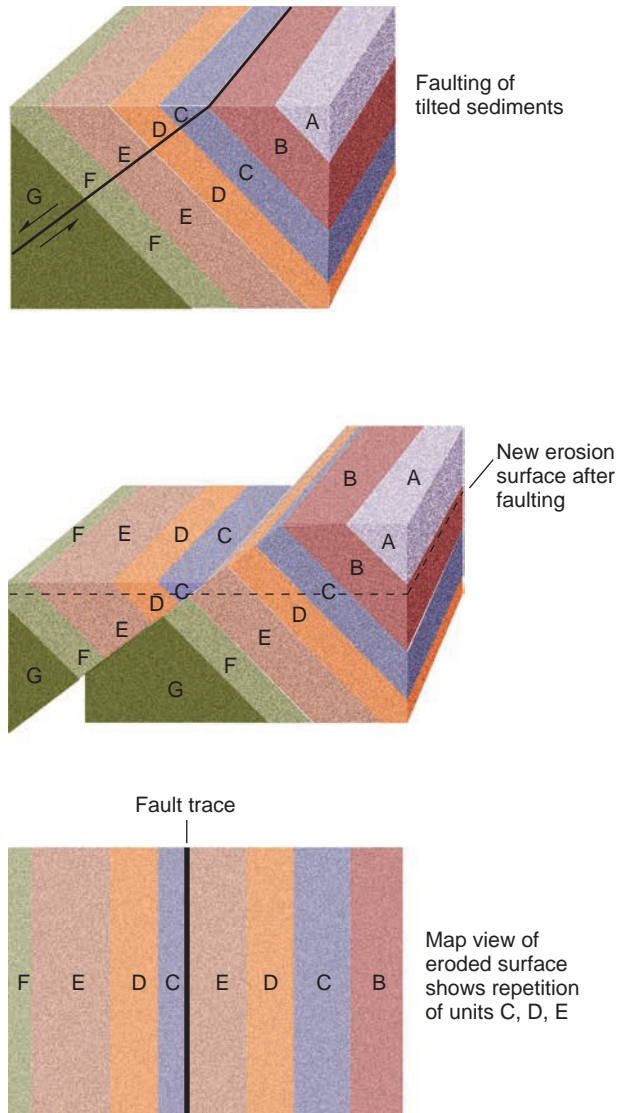


FIGURE 8 Faulting can produce repetition of map units. Top surface of top block is the original surface exposure of units; bottom diagram is map result after faulting and erosion to the dashed surface of center diagram.

infrared. Later Landsat satellites (4 and 5) included sensors sensitive to more wavelengths in the visible part of the electromagnetic spectrum. Different plants, rocks, and soils reflect different proportions of radiation of different wavelengths. Even the same feature may produce a somewhat different image under different conditions. Wet soil differs from dry; sediment-laden water looks different from clear; a given variety of plant may reflect a different spectrum of radiation depending on what trace elements it has concentrated from the underlying soil or how vigorously it is growing. Landsat images can be powerful mapping tools.

A common format for Landsat imagery is photographic prints at 1:1,000,000 scale. At that scale, a 23-centimeter (9 inch) print covers 34,225 square kilometers (13,225 square miles). The smallest features that can be distinguished in the image are

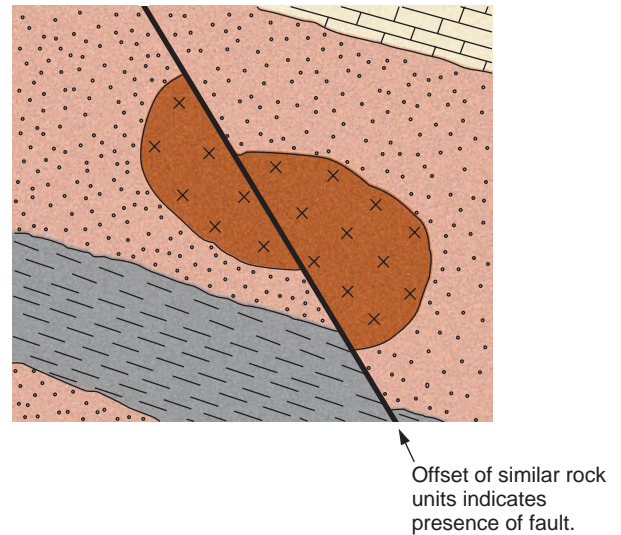


FIGURE 9 Igneous body and surrounding rocks offset by faulting.

about 30 meters (100 feet) in size, which gives some idea of the quality of the resolution. Multiple images can be joined into mosaics covering whole countries or continents.

Images are commonly presented either in black and white or as *false-color composites*. The latter are produced by projecting the data for individual spectral regions through colored filters and superimposing the results. The false-color images are so named because the resulting pictures, though superficially resembling color photographs, do not present all features in the colors they would appear to the human eye. The most striking difference is in vegetation, which appears in shades of red, not green. Rock and soil usually show as white, blue, yellow, or brown, depending on composition. Water is blue to bluish black; snow and ice are white. Examples of false-color Landsat images have been used throughout this text. Landsat image data can also be further processed by computer to produce images in more “realistic” (expected) colors or to enhance particular features by emphasizing certain wavelengths of radiation.

Dozens of applications of Landsat and other space imagery exist in the natural sciences—for example, basic geologic mapping, identification of geologic structures, and resource exploration. It is helpful in identifying patterns of land use and in monitoring the progress of crops and the extent of damage to vegetation from fires, insects, or disease. Because satellites scan the same area repeatedly over time, seasonal or long-term changes, the progress and extent of occasional events such as flooding, and changes related to human activities can be observed (figure 12). Satellite imagery also can be used to monitor the development of and changes in surface features such as stream channels and currents. As imaging technology has become more sophisticated, ever-better images have become available. Crews of the International Space Station have provided excellent images.

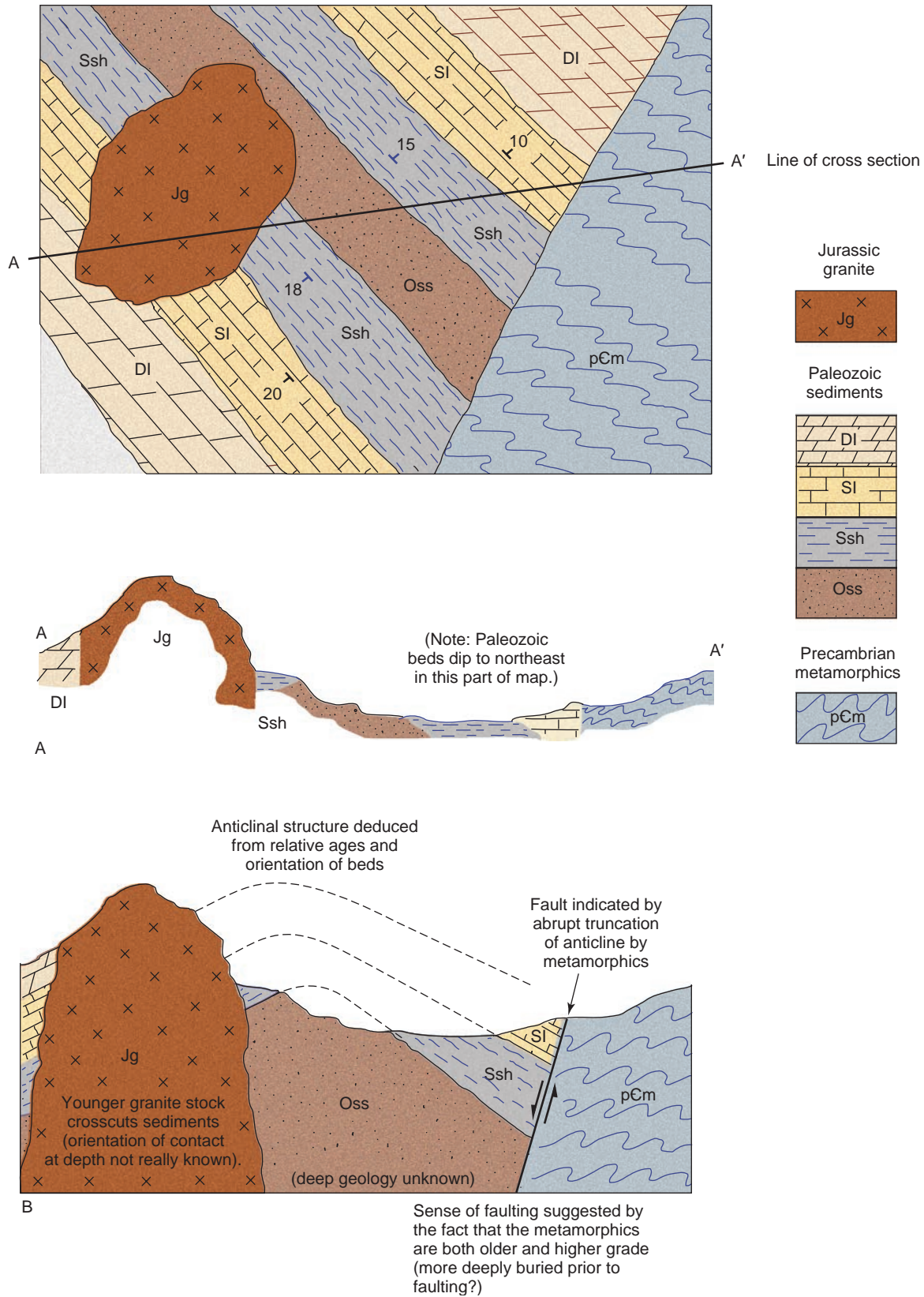


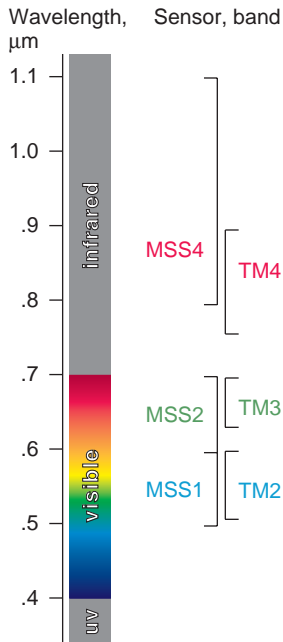
FIGURE 10 Constructing a cross section. (A) Geology as seen at surface is sketched onto a topographic profile. (B) The pattern is interpreted, and a set of structures consistent with the pattern seen at the surface is sketched in.

Introduction to Topographic and Geologic Maps and Remotely Sensed Imagery

A wide spectrum of solar energy reflects off the earth, with some wavelengths measured by Landsat sensors.

Three bands are shown in one image, by assigning each band a primary color (red, green, blue) and mixing them.

Different surfaces reflect differently. Vegetation looks red, water black, bare earth bright, clouds and ice white.



RGB = NRG:

Red means Near-infrared. . .

Green means visible Red. . .

Blue means visible Green.

In a typical image:

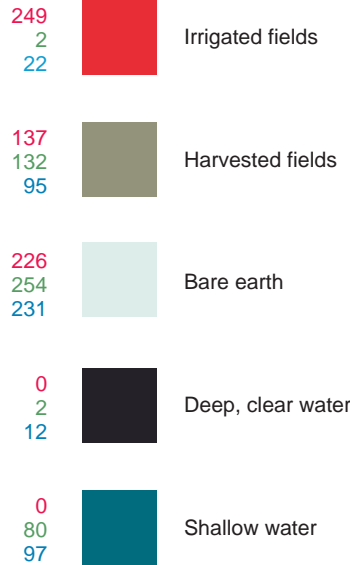


FIGURE 11 Selected wavelengths of visible light or infrared radiation detected in three selected MultiSpectral Scanner (MSS) or Thematic Mapper (TM) bands are converted to the three primary colors and combined for a false-color composite, based on relative amounts of radiation detected in each band.

After U.S. Geological Survey.



A



B

FIGURE 12 (A) In this image, taken from the International Space Station in 2002, the importance of water from the Salton Sea to agriculture is obvious. Note how the U.S./Mexico border stands out as a result of lush vegetation on the U.S. side. (B) Digital photograph of deforestation in eastern Bolivia, taken from the International Space Station. Agricultural development radiates outward from each of a series of small communities established by resettlement for the purpose of growing soybeans.

Images courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center.

In all cases, imagery taken from space is especially useful when some *ground truth* can be obtained. Ground truth is information gathered by direct surface examination (best done at the time of imaging, if vegetation is involved), which can provide critical confirmation of interpretations based on remotely sensed data.

Other Airborne Imaging Techniques

A still newer technique, or set of techniques, involves the use of imaging radar. This has been likened to taking a photograph with a flash camera. Just as such a camera generates light that illuminates the pictures it takes, so imaging radar sends pulses

of microwaves that bounce off the surface or scene being imaged. The techniques of processing the returned signal have become increasingly refined since NASA and the Jet Propulsion Laboratory initiated the SEASAT imaging radar system in 1978 (figure 13). Some radar-imaging devices are flown on jets, and some have been carried on the space shuttle. One of the advantages of radar imaging (by comparison with visible-light images, for example) is that microwave radiation is penetrating enough that it is unaffected by cloud cover, heavy rain, or other such conditions that can obscure a visual image. Therefore, it can be used to monitor such phenomena as shifting lahars on Mount Pinatubo during monsoon season (figure 14).

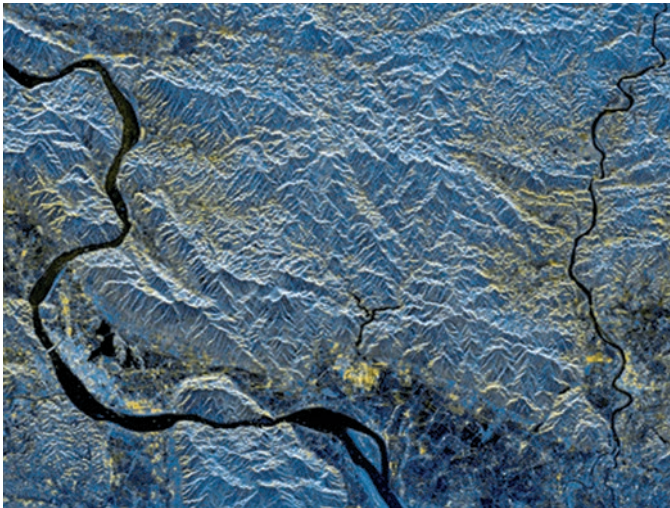


FIGURE 13 Spaceborne radar image of a part of Guangdong province, China. This is a mineral-rich area, and radar imagery may assist in prospecting for additional deposits.
Image courtesy NASA.

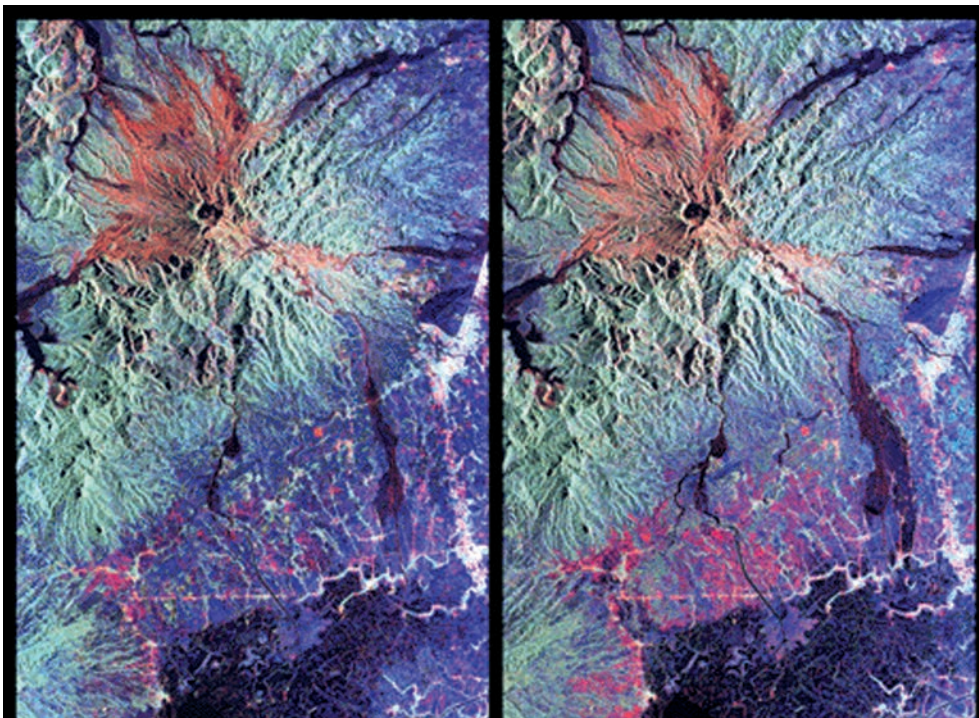


FIGURE 14 Years after the 1991 explosive eruptions, lahars can still be triggered by monsoon rains on Mount Pinatubo. Ash from those eruptions is shown in red, lahars in black. Comparison of April (left) and October (right) 1994 images shows evolution of lahars and their deposits, and helps in hazard evaluation.
Images courtesy NASA.

Imaging spectroscopy is similar to Landsat imaging in that it relies on detection of a number of different wavelengths of radiation in the UV, visible-light, and infrared parts of the spectrum. It has become increasingly sophisticated as instrumentation has been refined. Now scans can involve detection of hundreds of individual specific wavelengths, not just a few broad bands, and certain wavelengths can serve as “fingerprints,” indicating the presence of individual minerals whose crystal structures absorb energy at those precise wavelengths. The instrumentation can also be deployed from low-flying aircraft. The resultant detailed, high-resolution images can be much more useful than other types

of images for certain applications, as was shown by the Leadville, Colorado, example of chapter 17.

New ways are still being found to use visible light in remote sensing, too. LIDAR (Light Detection and Ranging) is an aircraft-based laser-altimetry system for examining topography. A major application of LIDAR has been in monitoring coastal change (figure 15). Precise assessment of coastal response to major hurricanes as well as everyday geologic processes can be important to land-use planning in such dynamic regions.

So new tools are continually developed to expand the ways we can explore and understand our planet.

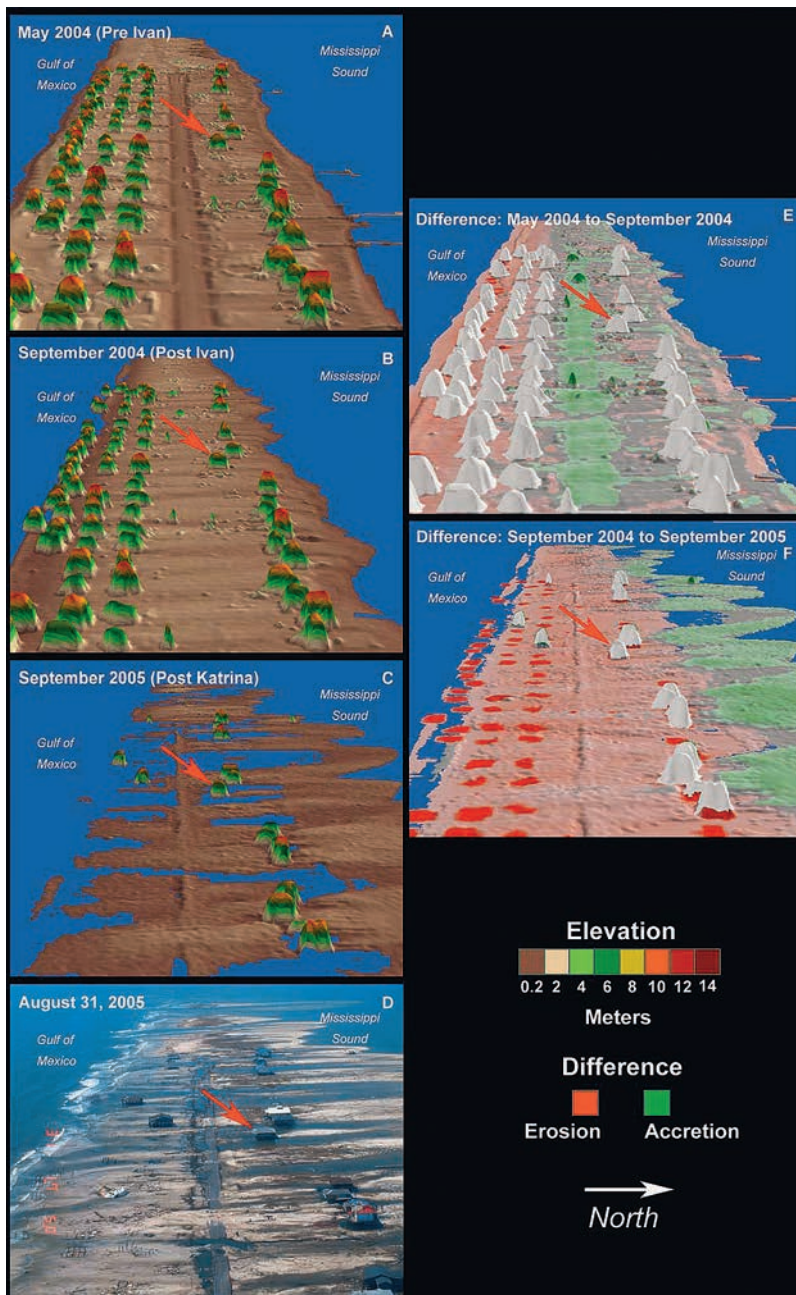


FIGURE 15 LIDAR images (A–C) provide more precise topographic data than aerial photographs (D) and can be analyzed so that elevation changes can be mapped (E, F). Dauphin Island, AL, a barrier island.

Images courtesy U.S. Geological Survey Coastal and Marine Geology Program.

Key Terms and Concepts

bedrock geology
contour interval
contour lines

cross section
map unit

remote-sensing
scale (map)

Net Notes

Information about the U.S. Geological Survey Photographic Library and the availability of its products may be found at library.usgs.gov/photo/#/

USGS also maintains a media library at www.usgs.gov/products/multimedia-gallery/images

Maps can be ordered from the USGS store at store.usgs.gov/maps

The USGS Spectroscopy Lab works extensively with imaging spectroscopy. Its home page is speclab.cr.usgs.gov

and an introduction to aspects of imaging spectroscopy maps is found at speclab.cr.usgs.gov/map.intro.html

A variety of images has been collected as “Earthshots,” and an explanation of the imaging techniques is featured at the same site: earthshots.usgs.gov/earthshots/

A large collection of Landsat imagery is available through the EROS data center, at eros.usgs.go

The Landsat program, the satellites, and their imagery are described at landsat.usgs.gov

The home page for NASA/JPL imaging radar can be found at uavsar.jpl.nasa.gov/

NASA maintains a wonderful image archive of images from space at the “Earth Observatory” site: earthobservatory.nasa.gov/

NOAA explores the applications of LIDAR to coastal change; an introduction to LIDAR can be found at oceanservice.noaa.gov/facts/lidar.html

Suggested Readings/References

Brock, J., and Sallenger, A. 2001. *Airborne topographic LIDAR mapping for coastal science and resource management*. USGS Open-File Report 01-46.

Gardner, J. V., Dartnell, P., Gibbons, H., and MacMillan, D. 2000. *Exposing the sea floor: High-resolution multibeam mapping along the U.S. Pacific Coast*. USGS Fact Sheet 013-00.

Holz, R. K. 1985. *The surveillant science: Remote sensing of the environment*. New York: John Wiley & Sons.

Short, N. M., Lowman, P. D., Jr., Freden, S. C., and Firch, W. A., Jr. 1976. *Mission to Earth: Landsat views the world*. National Aeronautics and Space Administration. Washington, D.C.: U.S. Government Printing Office.

Slaney, V. R. 1981. *Landsat images of Canada—A geological appraisal*. Geological Survey of Canada Special Paper 80-15.

Thompson, M.M. 1987. *Maps for America*. U.S. Geological Survey. U.S. Government Printing Office, Washington, D.C.