Meeting Challenges with Geologic Maps

AGI Environmental Awareness Series

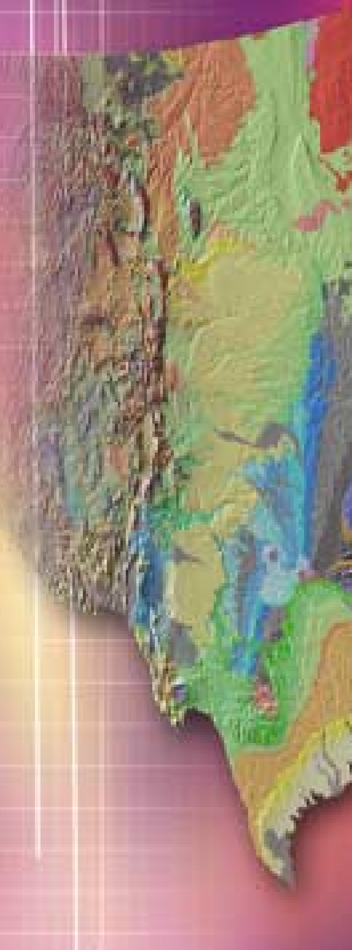
The Value of Geologic Maps

Geologic maps are the single most important and valuable tool we have for **understanding** and **living with the Earth** around us. Their usefulness is so broad that geologic maps are the most requested scientific product produced by state and federal geological surveys. Kentucky's experience with geologic maps exemplifies their value and utility.

Through a partnership between the Kentucky Geological Survey and the U.S. Geological Survey (1960 to 1978), Kentucky became the first state to be entirely mapped geologically at a scale of 1:24,000. This program, first envisioned by Wallace W. Hagan, the 10th State Geologist of Kentucky, produced 707 detailed geologic maps that originally were intended for use in natural resource development. Since that time, they have become important to every aspect of land use in Kentucky, including pollution prevention and clean up, transportation planning, and making site-specific decisions about the construction of houses, subdivisions, commercial buildings, airports, dams, and bridges.

The usefulness of the Kentucky geologic maps clearly demonstrates the economic value of producing geologic maps. An economic analysis (S. B. Bhagwat and V. C. Ipe, 2000, *Economic benefits of detailed geologic mapping to Kentucky*. Illinois State Geological Survey, Special Report 3, 30 p.), based on a survey of the map users, concluded that the value of geologic maps to Kentucky was at least $2.25 billion dollars and possibly as much as $3.35 billion (in 1999 dollars). This value exceeds the cost of developing the geologic maps (about $90 million in 1999 dollars) by 25 to 39 times. And Kentucky geologic maps continue to create value. More than 100,000 geologic maps have already been distributed in Kentucky and an additional 5,000 are sold — at nominal cost — each year. The Kentucky Geological Survey is now releasing digital versions of the geologic map data that ensure continued application to a wide variety of problems throughout the state.

However, Kentucky is the exception. Less than one third of the United States has been geologically mapped at 1:24,000 scale. Completing the job will require continued efforts and support by government, university, and other organizations to provide the geologic maps we need to understand and live with the Earth around us.



AGI gratefully acknowledges the AGI Foundation's support of the Environmental Awareness Series and the support of the following organizations. *See page two for more information on other titles in the Series.*

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AGI ENVIRONMENTAL AWARENESS SERIES, 7

Meeting Challenges with Geologic Maps

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Many persons contributed to the development of Meeting Challenges with Geologic Maps. Lead author **William A. Thomas** first envisioned this book. He is the James S. Hudnall Professor of Geology at the University of Kentucky, and he currently (2003-2004) serves as Vice President of the Geological Society of America. Thomas holds B.S. and M.S. degrees from the University of Kentucky and the Ph.D. from Virginia Polytechnic Institute and State University. Much of his research is based on geological mapping, especially in collaboration with the Geological Survey of Alabama, and includes mapping by graduate students with support of the U.S. Geological Survey EDMAP program.

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Meeting Challenges with Geologic Maps

ISBN: 0-922152-70-5

Design: DeAtley Design
Project Management: Julia A. Jackson, GeoWorks
Printing: CLB Printing

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Foreword

Geologic maps are useful. They provide predictive information for resource discovery as well as for the design of buildings, canals, roads, and drainage of farmland, environmental planning, and development. A papyrus scroll prepared in 1150 B.C. by a scribe, Amennakhte, during the reign of Pharaoh Ramses IV, portrayed different rock types in Wadi Hammamat, plus quarries for stone for the temples of ancient Egypt.

"The map that changed the world," as author Simon Winchester calls William Smith's geologic map (p. 6), contributed the earliest portrayal of geologic structure and stratigraphic correlation in England, Scotland, and Wales — information that enabled geologists to trace geographic trends and geologic formations that contained water, minerals, and energy resources.

The earliest geologic map of the United States was prepared by William Maclure and was published in 1817. It presented a sketch of the geologic structure from the Canadian boundary to the Gulf of Mexico and from the Atlantic coast to the 94^{th} Meridian. Subsequently, geologic maps were prepared by early state geological surveys and by the U.S.Geological Survey.

Today, the availability of aerial photography and remote sensing from satellite imagery, plus the computer capability for storage, recovery, and evaluation of data are used for geologic mapping and other purposes. These methods have replaced many old methods of geologic data collection, plotting, and interpretation. Remote sensing technology and satellite sensor platforms provide fast access to data. Also, a greater and finer resolution of data and images are readily available in planimetric and 3-D at any desired scale. These data can be integrated with Geographic Information Systems (GIS) for vertical and horizontal comparison. Maps can be combined with layers of information on topography, minerals, water, energy, and the environment. These technological advances have increased the usefulness of and public access to geologic maps.

This publication aims to give citizens, educators, and policy makers a better understanding of geologic maps and how and where the information they provide can be especially useful. The American Geological Institute produces this Environmental Awareness Series in cooperation with its 42 member societies and others to provide a non-technical geoscience framework considering environmental questions. *Meeting Challenges with Geologic Maps* was prepared under the sponsorship of the AGI Environmental Geoscience Advisory Committee; a summary of the Committee's charge and activities appears on page 64.

Philip E. LaMoreaux

Chair, AGI Environmental Geoscience Advisory Committee

Preface

Recognition of the enormous variety of materials at the Earth's surface may lead to an impression of non-systematic, even chaotic, distribution of rocks and unconsolidated materials. The need to understand the complex distribution of materials for obtaining resources, planning construction, and protecting the environment requires a method to organize and synthesize the information, and to communicate that information for effective use.

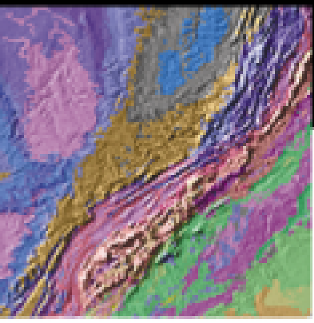
The first attempt to organize and communicate the distribution of rocks on a map was completed by William Smith in 1801. During the construction of a canal system in Great Britain, Smith quickly learned that the rocks in some places were harder to excavate than those in other places; some rocks made more watertight bases for the canals than others. The breakthrough for Smith was his realization that the different types of rocks were not randomly mixed together, but instead, layers of different kinds of rock were found everywhere in the same order of one above the other. For example, everywhere that a particular sheet-like layer of chalk (limestone) was found, a layer of distinctive sandstone was found beneath it. This observation led to the realization that the distribution of different types of rocks could be predicted before digging — a tremendous advantage in planning and budgeting canal construction. A map of the planned canal route was designed to show, not only the hills and valleys to be crossed, but also the types of rocks that would have to be excavated. A copy of William Smith's geologic map appears on page 6.

Like Smith's map or the one on the cover, a geologic map generally uses differently colored areas to show the geographic expanse of each of the different types of materials at the Earth's surface. A geologic map provides essential and interesting information; however, the technical requirements of making a map of such complex elements are challenging. This book explains the meaning of the colors, patterns, and symbols on geologic maps and provides an understanding of how geologic maps are used to solve problems of environmental protection, resource supplies, and foundation stability. The opening section discusses general concepts and objectives of geologic mapping, and the book concludes with a selection of 16 "real-life" examples of different uses of the information on geologic maps.

Preparation of this book has been a team effort, and I am grateful to the many contributors. Helpful reviews of my manuscripts were provided by Robert D. Hatcher, Jr., University of Tennessee; Peter T. Lyttle, Randall C. Orndorff, and Laurel M. Bybell, U.S. Geological Survey; James C. Cobb, Kentucky Geological Survey; Rex C. Buchanan, Kansas Geological Survey; Bruce Heise, National Park Service; Travis L. Hudson, American Geological Institute; and Rachel L. Thomas. The editorial content, design, and layout of the book reflect the creative work of Julia A. Jackson, GeoWorks, and Julie DeAtley, DeAtley Design. The American Geological Institute Environmental Geoscience Advisory Committee and our publishing partners have supported the production of the book. Our aim is to explain how geologic maps help in meeting many kinds of challenges in the stewardship of Earth's resources and environment.

William A. Thomas
January, 2004

Geologic Maps for Many Uses



1815

Fig. 1. The first complete geologic map of England, Wales, and Scotland was prepared by William Smith and was published in 1815.

Uses

The first geologic map (Fig. 1) was prepared to solve a practical problem involving the distribution of different types of rocks at and near the Earth's surface, and that is still the reason geologic maps are made today. Uses of geologic maps first expanded into exploration for natural resources, including minerals ***(Ex. 3, p.32)***, coal ***(Ex. 13, p.52)***, and petroleum. As an example, during World War II, maintaining the supply of strategic minerals became so critical that geologists in the U.S. military were assigned to make geologic maps for mineral exploration.

Supplies of another vital natural resource, water, are becoming increasingly stressed in many places, and sound management of water resources is becoming increasingly important. The ability of rocks and unconsolidated surficial materials to absorb rainwater through infiltration is the primary upstream control on potential for floods, as well as the ultimate source of groundwater. Geologic maps depict the distribution of the rocks and surficial materials that hold groundwater, data that are essential for the efficient development and protection of water supplies ***(Ex. 7, p.40; Ex. 16, p.58)***.

Most building materials, except wood, are from various specific rocks and rock products (Fig. 2). Stone for buildings and monuments comes from many different types of rocks, such as marble, limestone, and granite. Similar rocks are quarried for crushed stone, and the manufacture of cement depends upon particular types of limestone. Sand and gravel are available from the unconsolidated sediment along river valleys. Natural mineral and petroleum resources supply metal, glass, and plastic components of modern buildings. All of the resources used in construction have limited distribution, and geologic maps are essential to show the best places to obtain these materials, as well as to plan for protection of the environment during extraction ***(Ex. 12, p.50)***.

The suitability of rocks and unconsolidated surficial materials to support foundations is essential for construction of a single-family home, a skyscraper, a dam, a bridge, or simply a road (Fig. 3). We are all familiar with spectacular natural disasters, such as earthquakes ***(Ex. 8, p.42; Ex. 15, p.56)***, volcanoes ***(Ex. 11, p.48)***, storms, fires ***(Ex. 9, p.44)***, and floods. Less spectacular, but just as devastating, are landslides ***(Ex. 4, p.34; Ex. 6, p.38; Ex.14, p.54)*** and sinkholes ***(Ex. 2, p.30; Ex. 5, p.36)***, which are highly destructive to buildings and roads (Fig. 4). The geologic conditions that lead to earthquakes, volcanic eruptions, landslides, or sinkhole collapse are well known, and a geologic map shows areas that are most likely to be affected by these natural hazards.

Rocks and unconsolidated surficial materials fundamentally affect the nature of the soil cover, and plant growth is related to soil type. Geologic maps provide critical information for ecologic studies ***(Ex. 1, p.28; Ex. 10, p.46)***.

Fig. 2. The growth of population and technology places increasing demands on the supplies of building materials, as well as on the strength of foundations.

Fig. 3. Large bridges, tunnels, and dams pose specific problems, both for planning construction and for ensuring a suitable foundation.

Fig. 4. Sinkhole collapse destroyed this highway.

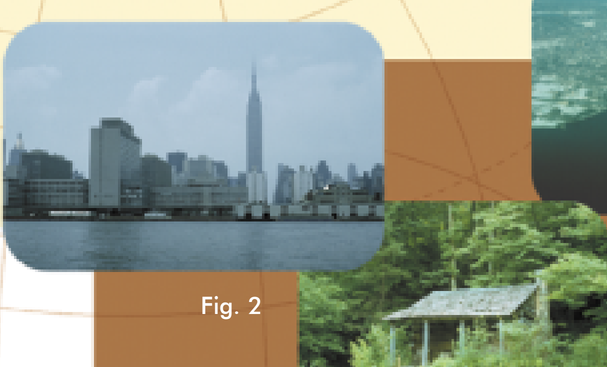
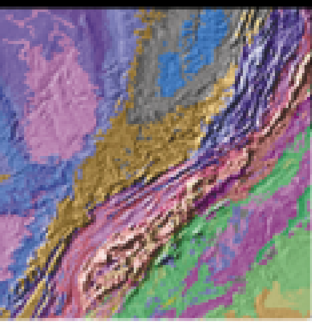


Fig. 2

Fig. 3

Fig. 4

Interpreting Geologic Maps



A geologic map graphically communicates important information about the distribution of rocks and unconsolidated materials at and near the Earth's surface. A geologic map uses different colors to represent different rocks and unconsolidated materials, and understanding the pattern of colors is the key to interpreting a geologic map. Each color on a geologic map marks an area of the Earth's surface that is on one particular type or age of rock, called a map unit. The shape of the colored area on a map corresponds to the shape of a map unit. In making a geologic map, geologists consider the characteristics of rocks, processes of origin, geologic age, and map patterns. Processes at work on the land surface and within the Earth form rocks of three fundamentally different types (Fig. 5):

- **igneous rocks** — crystallize from melted rock material (magma).
- **sedimentary rocks** — originate on the Earth's surface as accumulations of layers of loose sediment eroded from older rocks.
- **metamorphic rocks** — are altered by pressure and heat from older rocks.

Each of the three major types of rocks has distinctive shapes of map units. Movements within the Earth, recognizable on the surface as earthquakes, may deform the original shapes of map units by bending or breaking the rocks, and changing the shape that will appear on a geologic map.

The color patterns on a geologic map show the distribution of map units that are presently on the land surface, where erosion shapes the hills and valleys. The shape of the land surface is imposed onto a three-dimensional mosaic of various types of rocks that extend deep into the Earth. The shape of a map unit and the shape of the land surface together determine the distribution of map units shown by the many colors on a geologic map. Geologic maps are the basis for our understanding of the history of the Earth, and a geologic map greatly enhances our appreciation of scenic features, such as the Grand Canyon (p. 9-11).

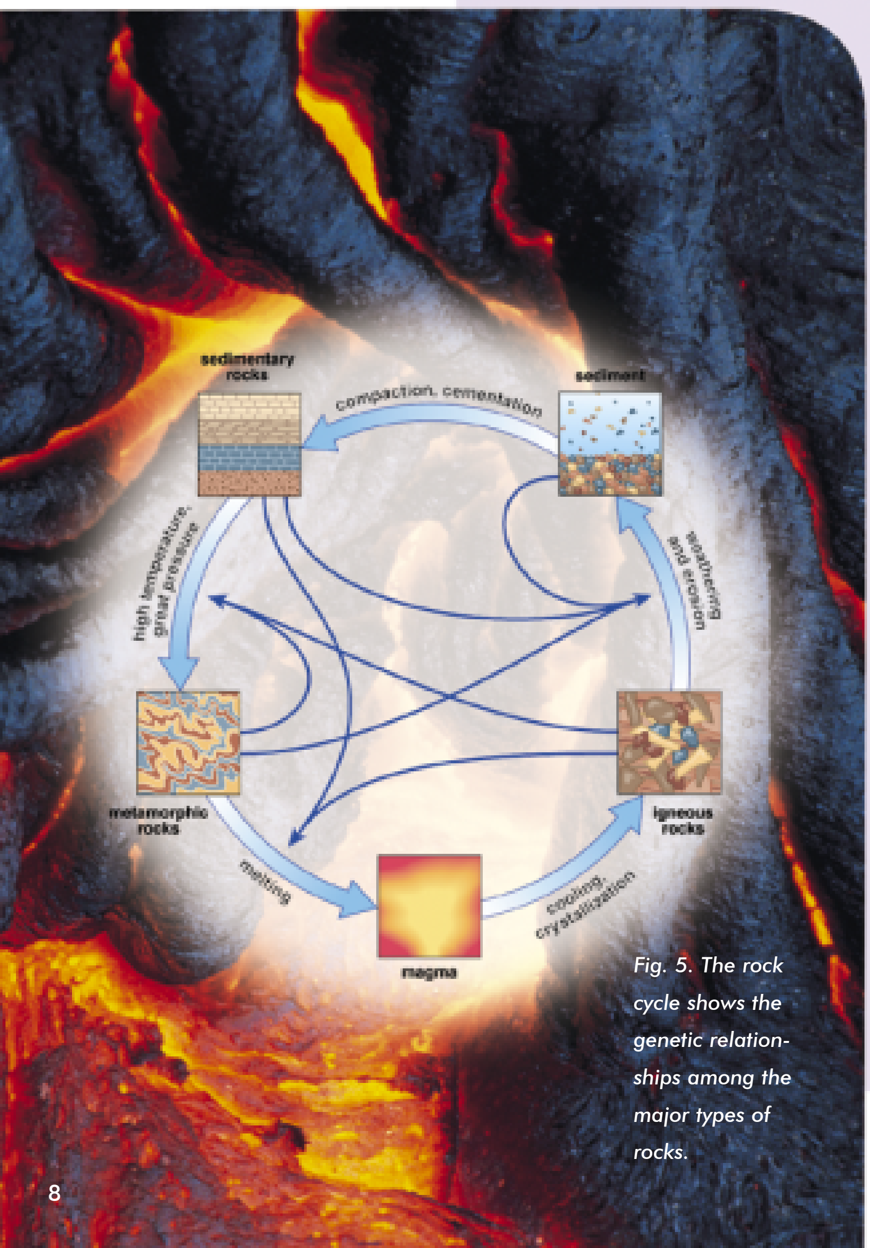
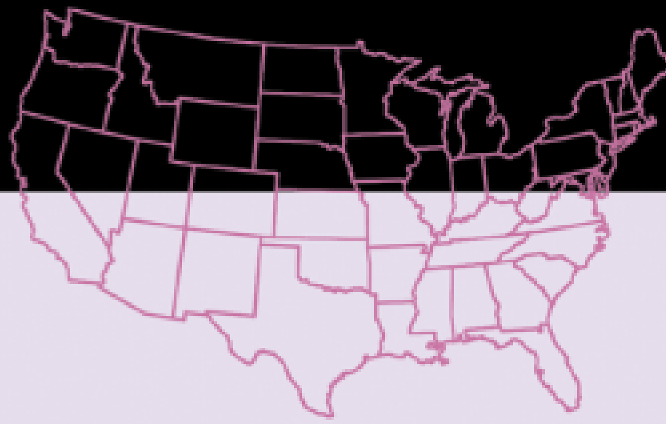
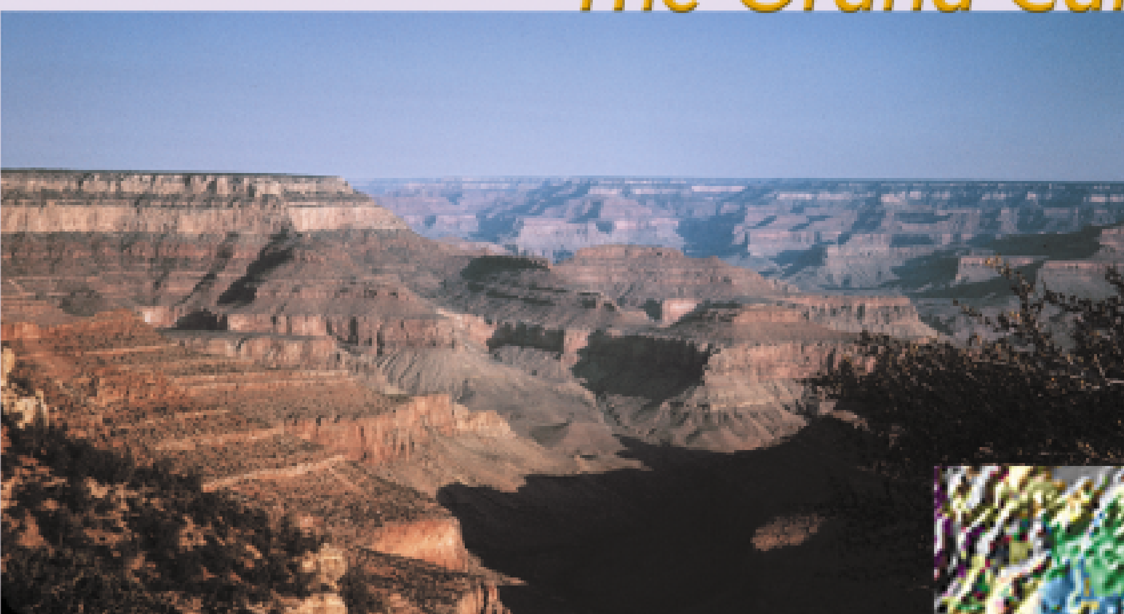


Fig. 5. The rock cycle shows the genetic relationships among the major types of rocks.



Interpreting

The Grand Canyon



The Grand Canyon reveals complex relationships between sedimentary rock layers, tilted sedimentary rock layers, faults, metamorphic rocks, intrusive igneous rocks, and erosion. The relationships depicted on the geologic map on page 11 illustrate a comprehensive interpretation of the history of geologic events, as well as the exposures of the different types of rocks that form the scenery. The paragraph numbers on page 10 are used to show locations of the items discussed on the geologic map, diagrams, and photographs.

Continued

Geologic maps increase our understanding and appreciation of awe-inspiring scenery, such as the Grand Canyon.

The Grand Canyon

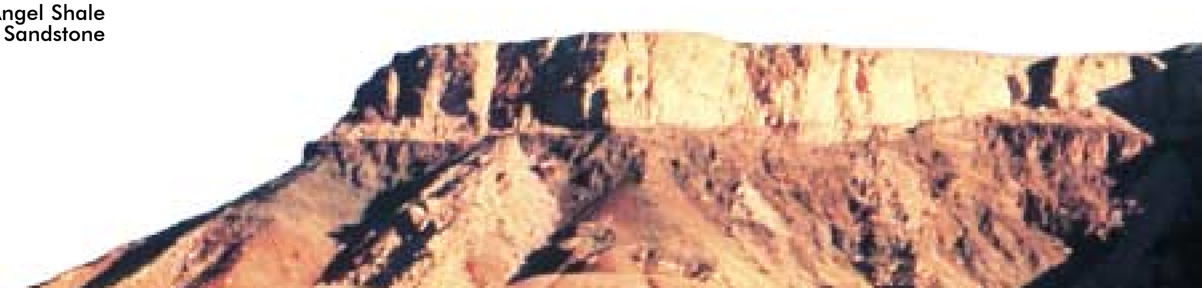
1. The historical succession of events recorded in the Grand Canyon can be derived using the principle that younger layers of sediment are deposited on top of older ones. The rim rocks (Kaibab Limestone) contain fossils of shallow-marine organisms, indicating a large amount of uplift above sea level. The Colorado River has cut the Grand Canyon down into the uplifted rocks exposing older and older rocks in the deepest part of the canyon. In the bottom of the Grand Canyon, the oldest exposed rock is the Vishnu Schist (**1** on the geologic map), a metamorphic rock.

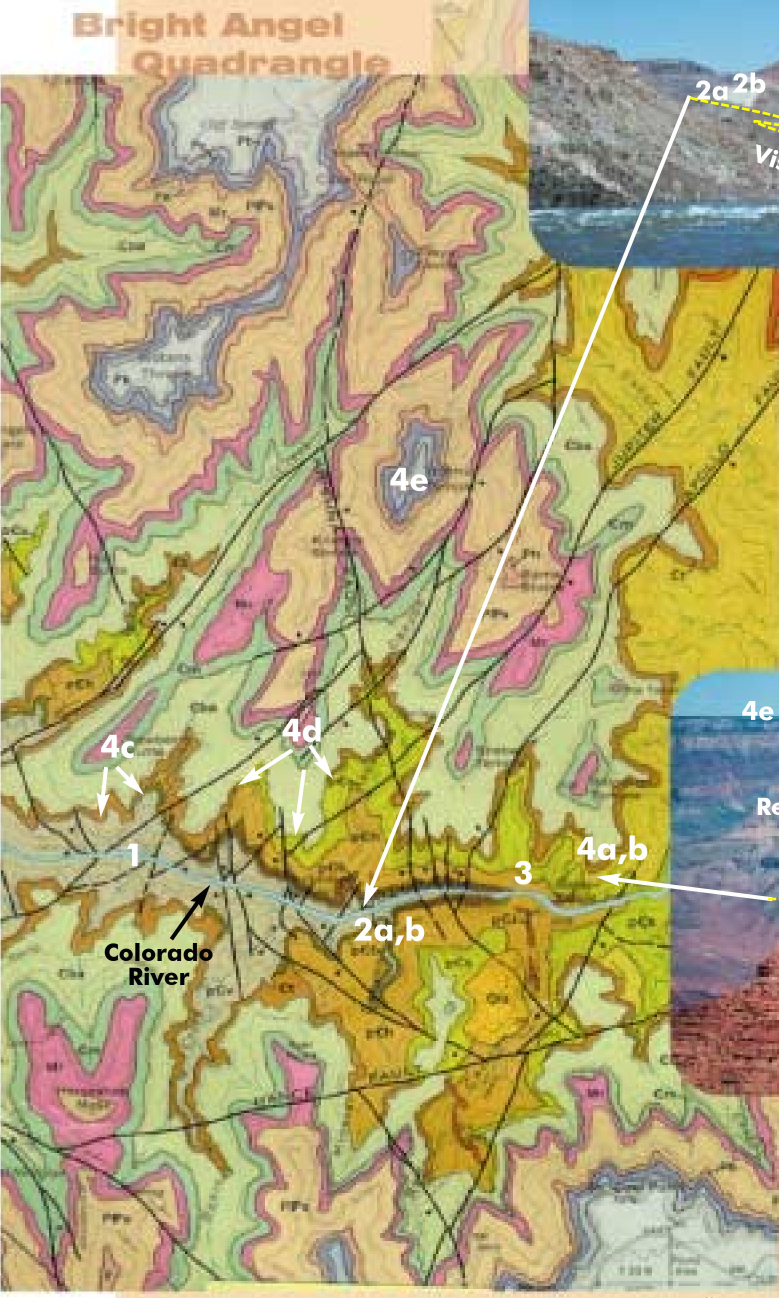
2. On top of the Vishnu Schist is a thick accumulation of sedimentary layers (Unkar Group of several formations, **2** on the geologic map). Deposition of sediment on the older metamorphic rock implies deep erosion **2a** to uncover the Vishnu Schist that was metamorphosed deep below the Earth's surface, followed by deposition **2b** of sediment of the Bass Limestone of the Unkar Group. The contact between the sedimentary layers (Bass Limestone) and the metamorphic rock (Vishnu Schist) is the old erosion surface. This contact is called a nonconformity.

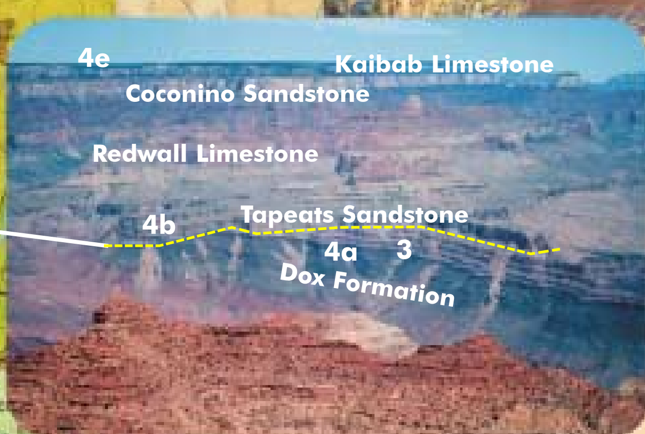
3. The geologic map shows that the formations of the Unkar Group are not horizontal, but instead dip eastward from high on the canyon wall down to the river (visible in the photograph). The dip of these sedimentary layers indicates that, after they were deposited, they were tilted by fault movement.

4. The tilted sedimentary layers end upward abruptly and younger sedimentary layers (Tapeats Sandstone and Bright Angel Shale on the geologic map) cover the eroded edges. The layers of Tapeats Sandstone and Bright Angel Shale are not parallel with layers in the Unkar Group (visible in the photographs at **4a** and **4b**, and shown on the geologic map), but instead the younger layers cross the older ones at an angle. This relationship shows that, after the Unkar Group sedimentary layers were tilted, erosion **4a** cut down to produce a new land surface and, later, deposition of sediment **4b** covered the erosion surface. Because of the angular relationship between the sedimentary layers, this contact is called an angular unconformity.

Two other aspects of the erosion surface beneath the Tapeats Sandstone are evident from the geologic map. Tracing the Tapeats Sandstone westward along the canyon shows that the unconformity cuts down across all of the formations of the Unkar Group, and the Tapeats Sandstone rests directly on the Vishnu Schist **4c**. At some places along the canyon, however, the Tapeats Sandstone is absent and is not shown on the geologic map, and the Bright Angel Shale is directly on the eroded sedimentary layers of the Unkar Group at the angular unconformity **4d**. This relationship indicates a buried hill on the old erosion surface. The hill was high enough that it was not completely covered by the Tapeats Sandstone; however, continued deposition of the Bright Angel Shale was sufficient to cover the hill. Above the Bright Angel Shale are many other sedimentary layers, continuing up to the Kaibab Limestone on the rim of the canyon **4e**.







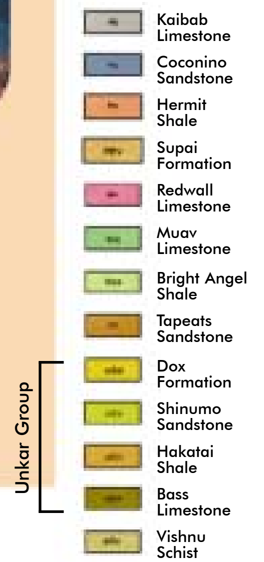


Fig. 6. Photographs and diagrams illustrate interpretation of the geologic map of part of the Grand Canyon.

Map Units

Fig. 7. *Former courses of the Mississippi River are evident in the distribution of sediment on the flood plain in northern Mississippi.*

Unconsolidated Surficial Materials

Processes of origin. Present-day stream erosion provides sediment (mud, sand, and gravel) that is moved downstream by creeks and rivers. Some of the sediment accumulates as alluvium along river channels and on floodplains (Fig. 7). Because the alluvium is not covered and not deeply buried beneath other sediment, it remains unconsolidated and is not solidified or lithified into rock. Other types of unconsolidated surficial materials include wind-blown sand dunes, beach sands, lake and swamp sediment, and landslide debris. In the recent geologic past, vast continental glaciers covered the northern part of North America, and the continental ice sheet, along with outflow of streams from melting ice, spread sediment from southern Canada southward across the northern United States *(Fig. 25, p. 26-27)*.

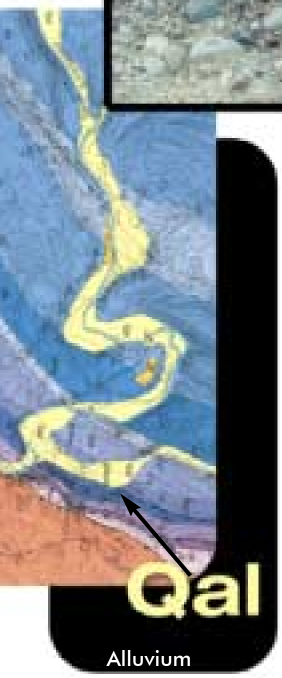


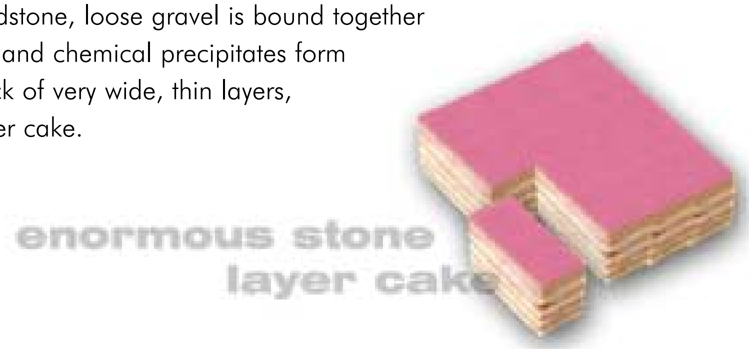
Fig. 8. Qal is the map symbol for materials deposited by running water during comparatively recent geologic time. "Q" stands for Quaternary and "al" for alluvium.

Geologic map patterns. Alluvium appears on a geologic map as a band of color (generally yellow) along streams (Fig. 8). Because stream alluvium is geologically young, it covers older rocks, and the map pattern of alluvium crosses the other map patterns, creating discontinuities on the geologic map.

Uses of geologic maps. Along many rivers, the alluvium forms an important aquifer. Alluvium contains important resources of sand and gravel. Because many cities are built along rivers, alluvium must be used as the base for building foundations. For all of these uses, geologic maps are necessary to show the distribution of unconsolidated sediments ***(Ex. 12, p.50)***.

Sedimentary Rocks

Processes of origin. Sedimentary rocks begin from the same processes that spread unconsolidated sediment along river valleys. Streams move sediment (mud, silt, sand, and gravel) to lowland areas, shorelines, deltas, and shallow seas on continental shelves, where the sediment accumulates in layers on the floodplain, delta, shoreline, or sea floor. Other sediment accumulates as broken shells and chemical precipitates in shallow seas. Through time, the pressure of burial beneath many layers of sediment results in lithification. For example, mud hardens to form shale, sand becomes sandstone, loose gravel is bound together to form conglomerate, and shells and chemical precipitates form limestone. The end result is a stack of very wide, thin layers, much like an enormous stone layer cake.



Geologic map patterns. Where movements within the Earth uplift the rocks above sea level, a renewed cycle of erosion carves a landscape of valleys and hills into the layers of sedimentary rock. Viewed from above, as one would view a geologic map, each of the layers of sedimentary rock is visible as a band on the map, extending around the slope of each of the valleys and hills (Fig. 9a).

Each layer of rock that is exposed on the slope extends in three dimensions entirely beneath the hill, and if a well were drilled at the hilltop, it would pass downward through each layer. Each layer of rock that is exposed on one hill may be matched to a corresponding layer on the adjacent hill; the rock layers originally extended across the space that is now in the valley between the hills, but the rock that was once there has been removed by erosion. Cross sections are used to show the extent of rock layers beneath the land surface (Fig. 9b).

In looking at the total succession of sedimentary rock layers in a place such as the Grand Canyon, many thousands of separate layers (called beds) of rock are recognizable; but the individual beds are too thin to be shown separately on a geologic map. Geologists combine similar types of rocks, such as hundreds of beds of shale, lying one above the other, into a single formation and depict the entire formation by a single color on the geologic map. Each formation is

"M" — Mississippian Period

"r" — Redwall

Fig. 9a. Colors on the map show the surface area of five formations on the upper slopes of Isis Temple; the photograph shows the relationship between the various rock types and steepness of slope. The more resistant layers form steep slopes and cliffs.

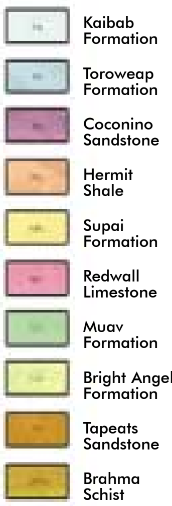
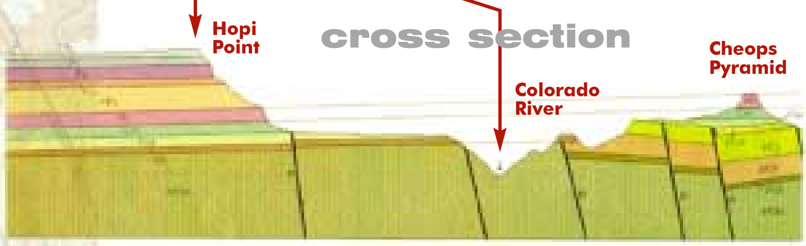


Fig. 9b. Cross sections show the position of rock layers beneath the surface.



assigned a two-part name that includes the name of a prominent geographic feature in the vicinity and an identification of rock type, e.g., Redwall Limestone. In so far as possible, each formation consists of a single distinctive rock type, such as limestone; however, thinly interlayered rocks of multiple types (e.g., sandstone and shale) may be assigned to one formation. In a succession of layers of sedimentary rock, each bed must be assigned to a formation, leaving no gaps.

The identity of a formation considers not only the type of rock but also the geologic age in terms of the geologic time scale (Fig. 10). The order of stacking of layers defines the relative age; the bottom layer is oldest, and successively higher layers of sediment are successively younger. The successive sedimentary layers contain different kinds of fossil animals and plants, which similarly can be placed in order of relative age, and a worldwide network of data on fossil

Geologic Time Scale

Era	Period	Map Units		Boundaries Million Years Ago
Cenozoic	**Quaternary**	Q	Modern humans appear	2
	Tertiary	T	Abundant mammals	65
Mesozoic	**Cretaceous**	K	Flowering plants; dinosaur & ammonoid extinctions	140
	Jurassic	J	First birds & mammals; abundant dinosaurs	205
	Triassic	TR	Abundant coniferous trees	245
Paleozoic	**Permian**	P	Extinction of trilobites & other marine animals	290
	Pennsylvanian	IP	Fern forests; abundant insects; first reptiles	325
	Mississippian	M	Sharks; large primitive trees	355
	Devonian	D	Amphibians & ammonoids	415
	Silurian	S	Early plants & animals on land	440
	Ordovician	O	First fish	495
	Cambrian	€	Abundant marine invertebrates; trilobites dominant	545
Precambrian	**Proterozoic**	p€	Primitive aquatic plants	2500
	Archean	p€	Oldest fossils: bacteria & algae	3800 ?

Fig. 10. The geologic age of map units is an important part of the information on a geologic map.

successions documents the geologic time scale. Both a color and a symbol label designate each formation on a geologic map. In Fig. 9a, the Redwall Limestone is shown by a red color and by the symbol, "Mr" — the "M" denotes the Mississippian Period of the geologic time scale, and the "r" denotes the name, Redwall (by convention, the "M" is upper case and the "r" is lower case). The map explanation shows the color and symbol in position in the succession of formations and gives the complete name of the formation. The color area on the geologic map shows only that part of each hill slope where a particular formation is exposed on the present land surface.

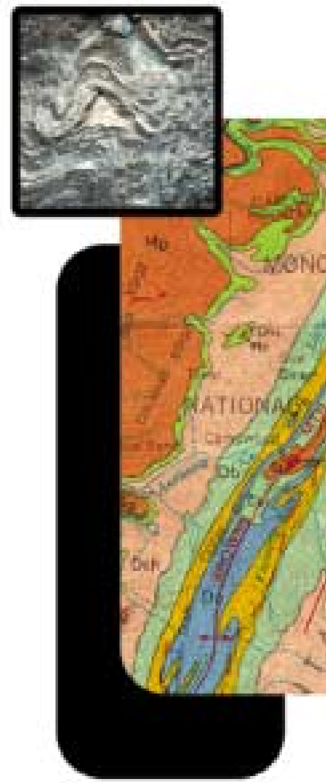
Uses of geologic maps. A geologic map, showing the locations of various types of rocks at the surface, allows planning for land use *(Ex. 4, p.34; Ex. 14, p.54)*. For example, some shales are particularly susceptible to landslides, and a geologic map shows where such a shale is at the surface and where landslides are most likely to occur.

The geologic map provides information for prediction of the extent of the rock layers beneath the surface. Many sedimentary rocks are used for building stones, and limestone is an essential ingredient in cement. Coal is a sedimentary rock, and the underground extent of a layer of coal is essential information for mine planning *(Ex. 13, p.52)*.

Tilted and Folded Sedimentary Rocks

Processes of origin. Although sedimentary rocks are deposited in horizontal layers, later geologic processes may move and deform the rocks by tilting them or bending them into folds. The geometry of any tilted sedimentary layer can be described with two measurements, strike and dip (Fig. 11). The compass direction of a horizontal line on a tilted surface is called strike. The angle of inclination downward from the horizontal in a compass direction perpendicular to strike is called dip. Measuring the strike and dip of a sedimentary layer uniquely describes the orientation of the layer in three dimensions, and special symbols show the strike and dip measurements on the geologic map.

Rather than simple tilting of sedimentary rock layers away from the original horizontal position, some layers are folded. Folds take many geometric shapes and sizes; however, they all have the general form of waves or pleats in an accordion (Fig. 12).



Geologic map patterns. An erosion surface on tilted or folded sedimentary rock layers is depicted by a distinctive pattern of colors that represent formations on a geologic map. The layers resistant to erosion stand high as ridges, while the weak layers are eroded down into valleys. Thus, erosion produces a valley-and-ridge topography, where long straight valleys separate long straight ridges, parallel with the strike of the sedimentary layers. Erosion generally progresses to make a flattened land surface, and the rocks in upward folds are eroded, while those in downward folds are preserved (in other words, erosion removes the tops of high-standing folds).

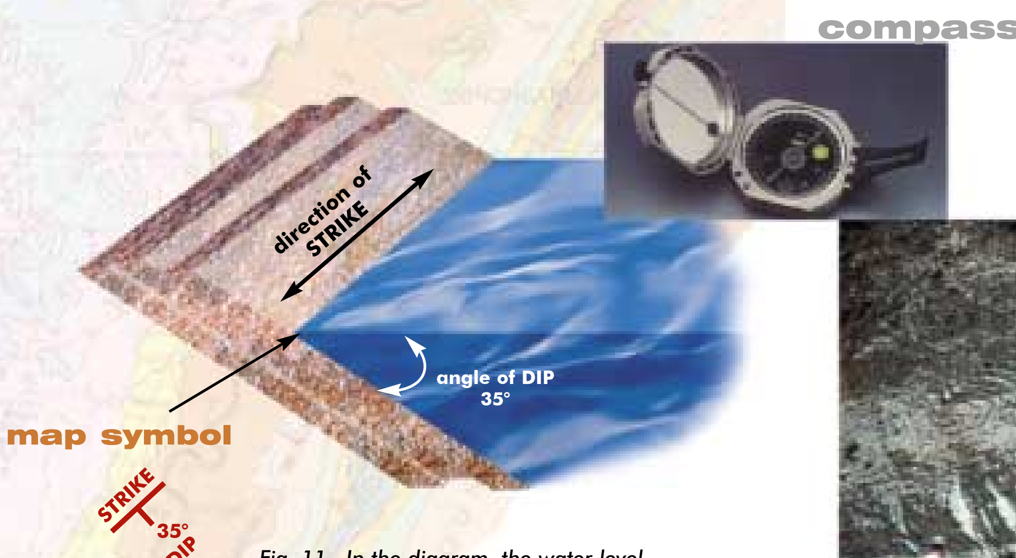
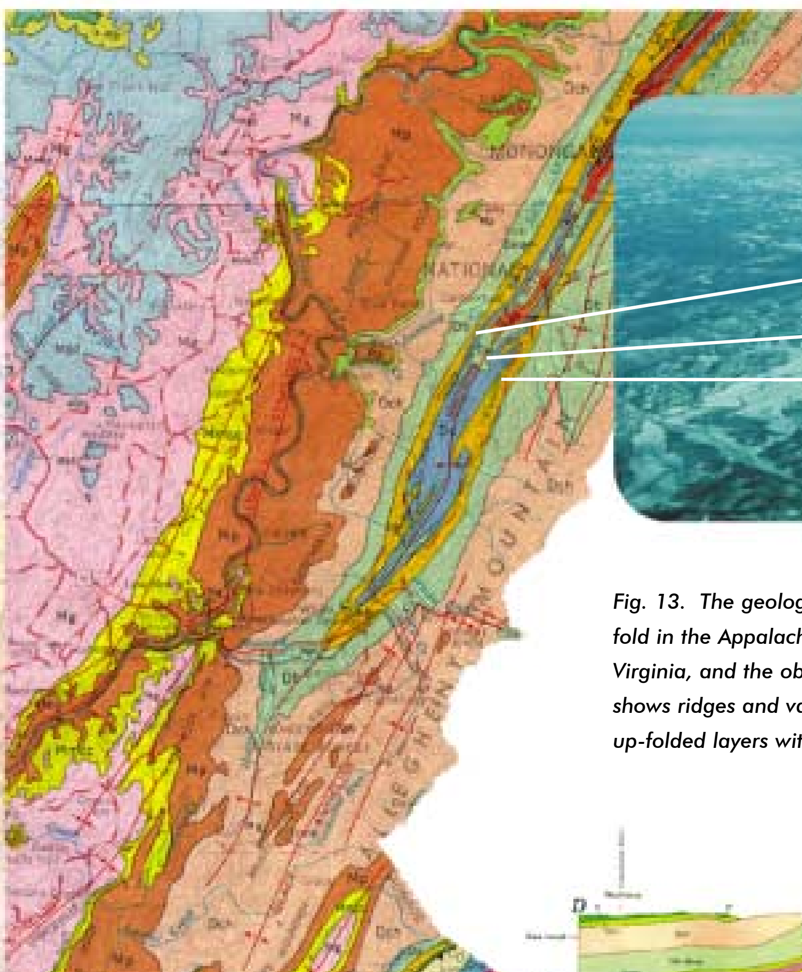


Fig. 11. In the diagram, the water level marks a horizontal line on the tilted rock layers. The compass direction (orientation) of the horizontal line is called strike. The position of the horizontal line is identified by the use of a level built into a compass, and the orientation of the line is measured with the compass. The angle between the tilted rock layer and a horizontal surface is called dip.

Fig. 12. Folded layers of sedimentary rocks in the Ouachita Mountains, Arkansas.

Where tilted rock layers are exposed by erosion at the present land surface, geologic maps show bands of color that represent the eroded up-turned edges of the tilted formations, like tilting a layer cake on edge, so that only the edges show. Folded rocks give a geologic map pattern that appears as two sets of tilted rock layers dipping in opposite directions, each representing one of the two limbs of the fold. The geologic map pattern of eroded formations in a fold appears as long, narrow bands of color corresponding to the strike direction of the up-turned and eroded formations on each limb of the fold (Fig. 13).

Uses of geologic maps. Measurements of strike and dip are necessary to several uses of geologic maps. A rock layer persists at a constant elevation along strike. A layer descends to progressively lower elevations in the direction of dip, and the difference in elevation depends on the angle of dip. Where a rock layer dips beneath the present erosion surface, the dip angle can be used to calculate the depth to that rock layer in the subsurface. This information is essential to planning the development of any resources that are contained within sedimentary rocks, such as groundwater ***(Ex. 7, p.40)***, petroleum, coal, building stone, or sedimentary ore.



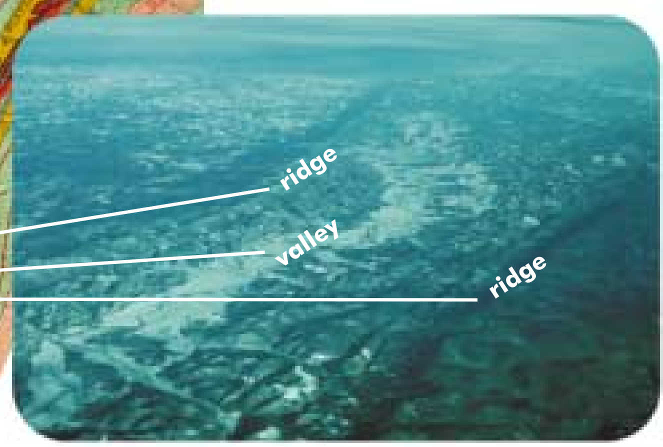
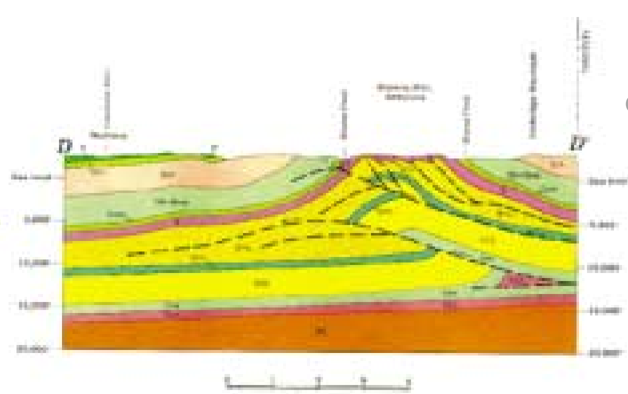
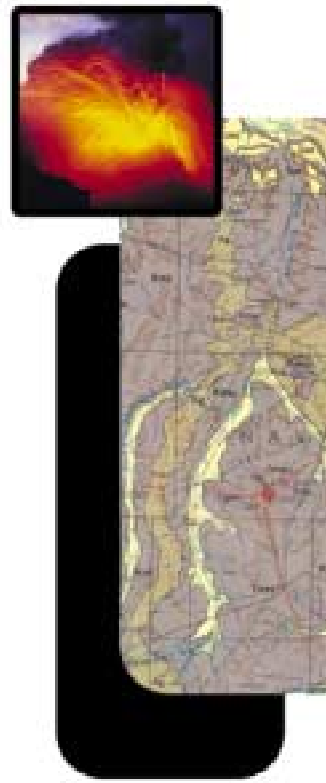


Fig. 13. The geologic map shows a large fold in the Appalachian Mountains in West Virginia, and the oblique aerial photograph shows ridges and valleys eroded on the up-folded layers within the fold.



Igneous Rocks



Processes of origin. Igneous rocks are aggregates of minerals that crystallized — literally froze — from melted rock, a liquid called magma. Melting of rocks requires very high temperatures, greater than any naturally occurring temperatures on the surface of the Earth. Igneous rocks represent crystallization on the land surface (extrusive igneous rocks) and also deep below the surface (intrusive igneous rocks).

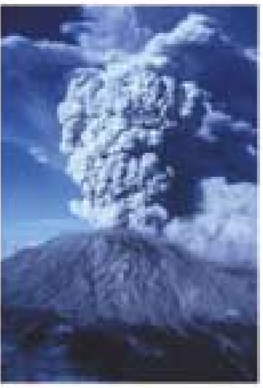


Fig. 14. Explosive eruption of Mount St. Helens on May 18, 1980.

Hot lava spills from volcanoes and flows over the land surface, where it crystallizes into an igneous rock. A new lava flow literally builds a new part of the Earth's surface, and lava flows build up layers of igneous rocks that are similar in shape to layers of sedimentary rocks. In contrast to lava flows, other volcanoes erupt with violent explosions, for example, Mount St. Helens (Fig. 14). Violent eruptions spread broken blocks of rock and steaming gaseous flows of volcanic glass across the landscape adjacent to the volcanic peaks, and catastrophic flows (lahars) of water, mud, and volcanic debris flash down the local drainages causing great devastation ***(Ex. 11, p.48)***. Volcanic ash spreads widely in the atmosphere. These volcanic materials add irregularly shaped layers of new rock to the Earth's surface. We can observe volcanoes and lava flows in action, but what is deep underground beneath a volcano? We can infer that magma moves (intrudes) upward through fractures and opens larger spaces by melting of rocks deep within the Earth, because earthquakes associated with volcanic eruptions record movements deep under ground. After a volcano has become dormant, erosion removes the volcanic rocks, revealing the igneous rock that had crystallized from magma below the surface. In eroded old volcanoes (Fig. 15), we can see the distribution of magma relative to the surrounding older rocks into which it was intruded. Some eroded masses of intrusive igneous rock have no clear connection to a volcano, indicating original magma intrusion deep in the Earth.

Geologic map patterns. Because they are layered, lava flows and other extrusive igneous rocks have geologic map patterns similar to those of sedimentary rocks. The map pattern of intrusive igneous rocks traces the boundary between them and the older surrounding rocks. Intrusive igneous rocks cut across the older rocks, indicating the relative age.

Uses of geologic maps. Geologic maps of volcanic centers help to predict the risk associated with lahars. Chemical alterations caused by hot fluids from magmas are the sources of many types of metallic ores and other rare minerals, and geologic map patterns are the key to tracing the likely extent of these rocks ***(Ex. 3, p.32)***. Maps of the extent of lava flows, some of which are important aquifers, are essential to developing and protecting some groundwater resources.

Fig. 15. Erosion of an extinct volcano exposes the previously underground feeder system of the"neck" of the volcano and fractures filled with intrusive "dikes", as seen at Shiprock, New Mexico.

Metamorphic Rocks

c

Processes of origin. Metamorphic rocks are altered (without melting to form magma) from existing sedimentary, igneous, or older metamorphic rocks by pressure, heat, and chemically active fluids. Recrystallization and reorientation of minerals under pressure produce layering, called foliation, within the rock. Metamorphic foliation is produced in entirely different ways and has a different appearance from sedimentary layers (Fig. 16). In mildly metamorphosed sedimentary rocks, both the original sedimentary layering and the metamorphic foliation are visible; but in strongly metamorphosed rocks, the effects of recrystallization obliterate the original characteristics of the rock. The orientation of foliation in metamorphic rocks (strike and dip) indicates orientation of forces that caused the metamorphism.

a

b

Fig. 16. **a** *Mildly metamorphosed sedimentary rock shows sedimentary layering and metamorphic foliation.* **b** & **c** *More intensely metamorphosed rock shows only metamorphic foliation.*

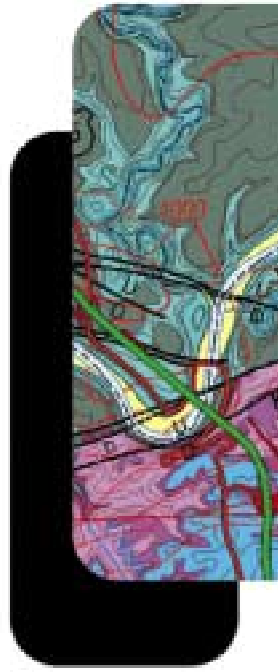
Geologic map patterns. Mapping of metamorphic rocks uses the technique of grouping similar rocks together to define map units, the distributions of which are shown by specific colors on a geologic map. Where the original sedimentary or igneous rock is recognizable within metamorphic rocks, the geologic map patterns are similar to those of sedimentary or igneous rocks. For more intensely metamorphosed rocks, the new metamorphic mineral compositions are used to define map units. Strike and dip of foliation are shown by special symbols on geologic maps.

Uses of geologic maps. Like igneous rocks, some metamorphic rocks host valuable mineral deposits. Water supply is commonly a problem in areas of metamorphic rocks, which are very compact.

Fractures and Faults

Processes of origin. Most rocks are brittle and, rather than bending into folds during deformation, they fracture and break into blocks. Some fractures (called joints) simply break the rock, for example, where a sedimentary layer is stretched over a fold, or where a lava flow cools and shrinks. Along other fractures (called faults), large blocks of rock move up, down, or sideways relative to each other; for example, where sedimentary rock layers are broken by a fault, the once-continuous layers are separated, disrupting the original continuity. Movements between blocks along faults cause earthquakes.

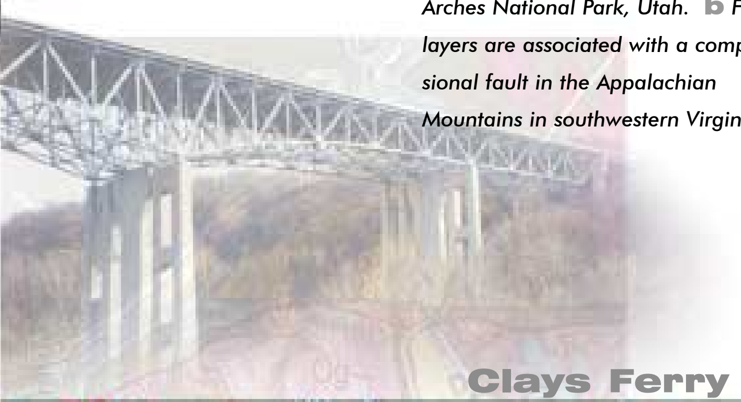
Relative movements along faults are caused by stresses (forces) within the Earth, and the stresses range from extensional (stretching) to compressional (squeezing). Extensional faults are commonly associated with tilted blocks, whereas compressional faults are generally associated with folded rocks (Fig. 17).



Geologic map patterns. Faults form boundaries between the separate blocks of rocks, and on geologic maps, faults are shown as lines, crossing and separating the color patterns for various rocks (Fig. 18). Because faults are roughly planar surfaces, the orientation of a fault may be expressed by strike and dip.

Uses of geologic maps. Rocks that are broken by many closely spaced fractures become aquifers, and geologic maps showing orientation, abundance, and intersections of joints provide essential information for evaluating groundwater resources. Fracture aquifers are especially important in some compact sedimentary rocks, lava flows, and metamorphic rocks ***(Ex. 16, p.58)***. Flow of water along fractures enhances the solution of water-soluble minerals, especially calcite, the primary mineral in limestone, and geologic maps enable the identification of areas that may be susceptible to solution collapse of caves and sinkholes ***(Ex. 2, p.30; Ex. 5, p.36)***. Faults pose a particular problem in mining, because the underground continuity of the mine rocks ends abruptly at a fault ***(Ex. 3, p.32)***.

Fig. 17. **a** *Tilted blocks are associated with extensional faults that broke this sandstone layer near Delicate Arch in Arches National Park, Utah.* **b** *Folded layers are associated with a compressional fault in the Appalachian Mountains in southwestern Virginia.*



a

b

Clays Ferry bridge

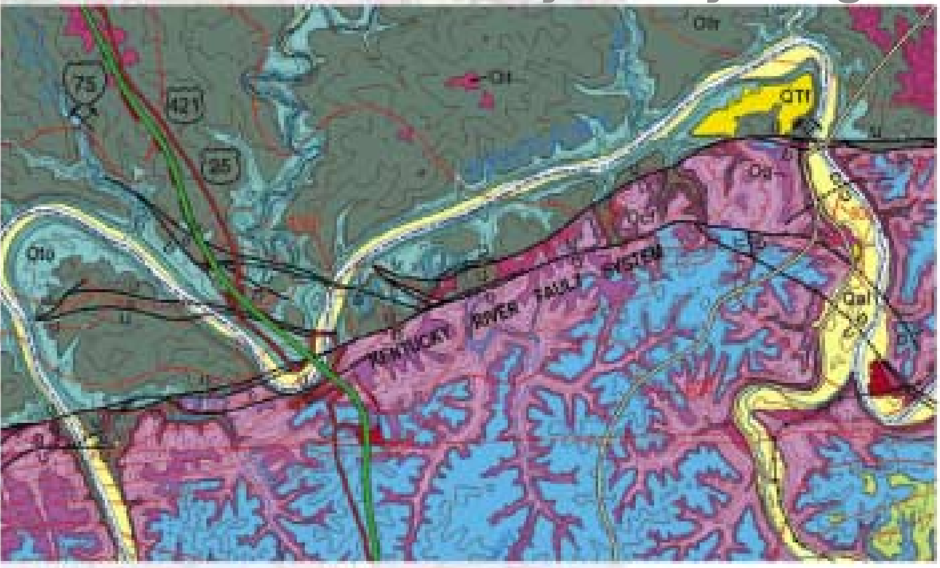
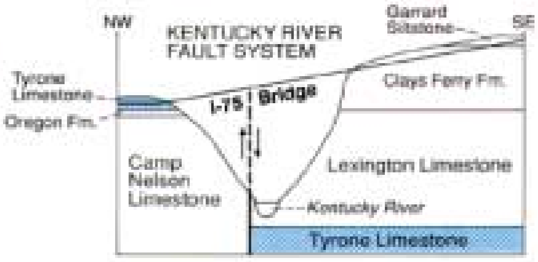
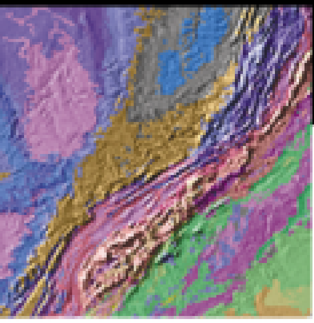


Fig. 18. Geologic map and cross section showing a fault that offsets horizontal sedimentary layers at the Clays Ferry bridge over the Kentucky River on Interstate Highway 75.



U.S. Geologic Map



The United States contains every common type of rock and surficial material. Even at this scale, a quick look at a generalized geologic map (Fig. 19) reveals numerous important differences in patterns of rock distribution.

The **Great Plains** region is shown by a few colors, indicating that only a few different map units cover very large areas which are underlain by nearly horizontal layers of sedimentary rock.

In the **Gulf and Atlantic Coastal Plains**, the extensive areas of the map units also indicate nearly horizontal layers of sedimentary rocks. Under natural conditions in the past, river deposits spread widely across the Mississippi River floodplain south of St. Louis; however, artificial levees constructed along the river have contained the natural process of flooding in recent years. The geologic map shows (in gray) the area that was covered by sediment from natural floods.

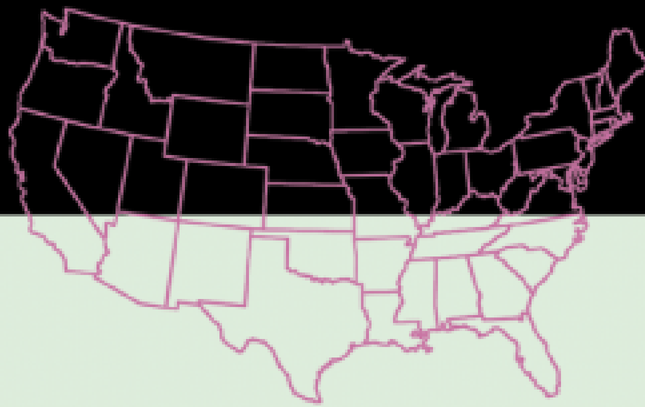
The **Appalachian Mountains** region is marked by a distinctive pattern of long, linear map units. This pattern shows folded and faulted sedimentary rocks that have been eroded into the distinctive topography of the Appalachian Valley and Ridge province; the orientation of the linear patterns shows that the strike of the folded rocks is generally northeastward. Toward the east, the sedimentary rocks give way to folded and faulted metamorphic and igneous rocks of the Blue Ridge and Piedmont provinces. These rock units record ancient collisions of continental plates that formed the Appalachian Mountains. Younger sedimentary layers of the Atlantic and Gulf Coastal Plains cover folded and faulted rocks of the Appalachians. In the southeastern states, the edge of the younger cover (green and yellow on the map) crosses the older map units (pink, red, and dark green) of the Appalachians.

Between the Appalachians and the Great Plains, geologic map patterns in the **Interior Lowland** in the upper Mississippi and Ohio River valleys show very broadly folded sedimentary rocks. Erosion has exposed older rocks (pink) on large "up" folds.

The **Rocky Mountains** comprise two types of mountains, each with its distinctive map pattern. The Rockies through western Montana and western Wyoming to Utah are eroded from folded and faulted sedimentary rocks. The map units are shown by narrow, linear patterns of colors. In contrast, the Rockies of central Wyoming southward through Colorado to New Mexico are up-faulted blocks and folds of older igneous and metamorphic rocks (red and dark orange), separated by relatively wide down-faulted blocks that are filled with younger sedimentary rocks (light orange).

On the **Colorado Plateau**, deep canyons dissect nearly horizontal sedimentary rocks, which appear on the map as wide map units (shades of green and blue). The Grand Canyon exposes the oldest rocks in the Colorado Plateau.

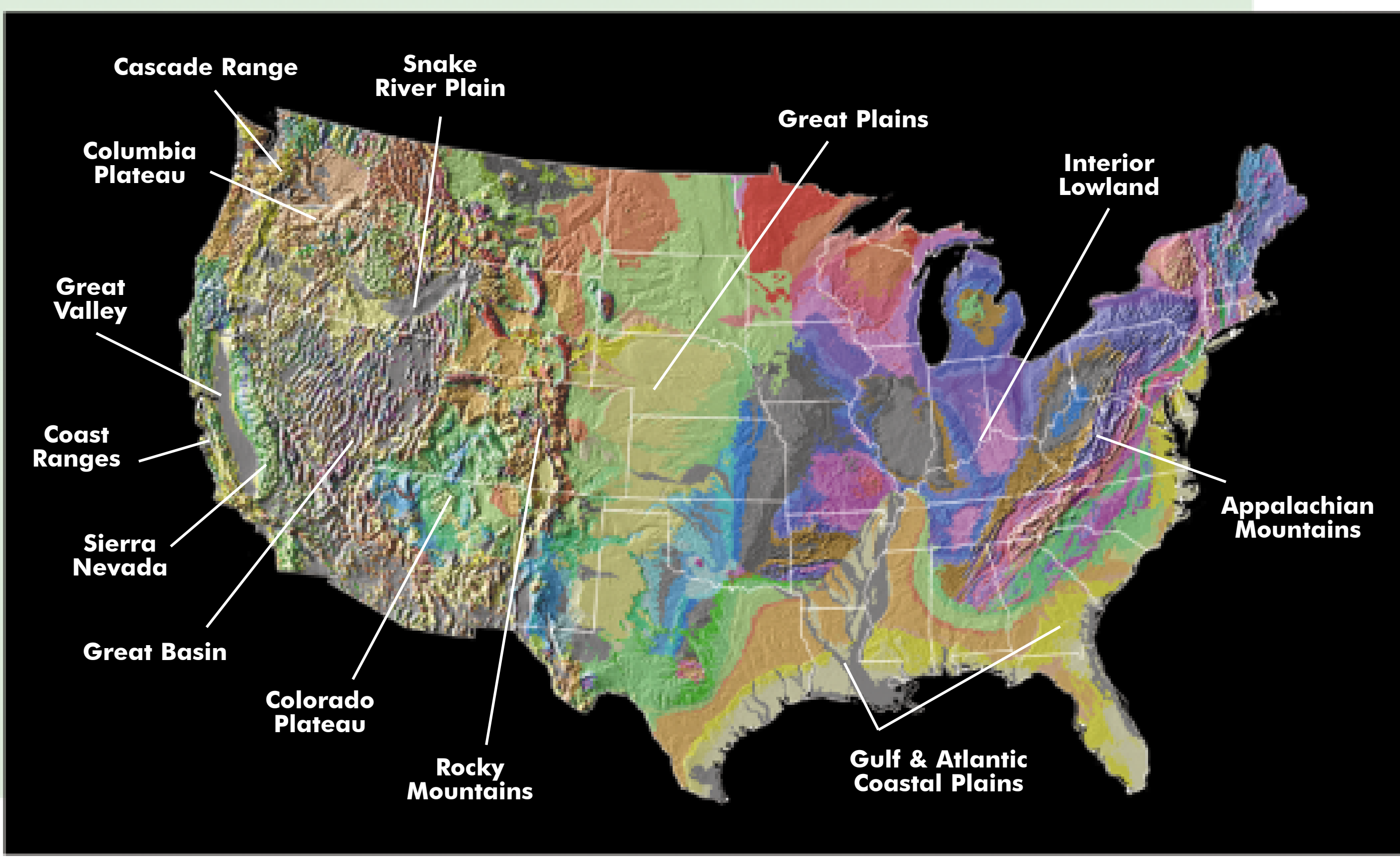
The **Great Basin** (or **Basin and Range**) province is a region of faulted and tilted blocks of sedimentary and volcanic rocks. Narrow up-faulted blocks expose the older rocks (orange and red), and geologically young surficial sediment is continuing to accumulate now in the down-faulted blocks (gray). North of the Great Basin, the faulted rocks are completely covered



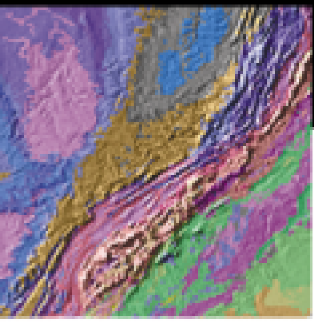
by extensive lava flows in the **Columbia Plateau** (salmon color). The lava flows are nearly horizontal, and map units cover a wide area. The **Snake River Plain** (gray) is covered by geologically very young volcanic rocks, which are well displayed at Craters of the Moon National Monument and at Yellowstone National Park.

The distribution of map units along the Pacific-coast region indicates present-day movement of two of the large plates into which the Earth's crust is separated. The plate that forms the floor of part of the Pacific Ocean is being forced down beneath the North American plate, the western edge of which includes deformed rocks and volcanoes. Movement between the plates is accommodated along faults, and these are sites of earthquakes. The **Coast Ranges** are faulted and folded rocks shown by linear map patterns (yellow and green). The **Great Valley** is a deep basin covered by young nearly horizontal sedimentary layers (gray). The **Sierra Nevada** is a very large mass of intrusive igneous rock (green) that represents the deeply eroded roots of a volcanic arc. In the Pacific Northwest, a chain of volcanoes forms the **Cascade Range** (yellow), an active volcanic arc.

Fig. 19. This geologic map is a modification of a digital version produced in 1994 of a paper map produced in 1974. A complete legend for this map is available at www.agiweb.org.



Making a Geologic Map



Robert D. Hatcher, Jr.
(University of Tennessee – Knoxville)

Collecting Data A geologist begins a mapping project by obtaining available information on the nature of rocks in the field area, along with any existing geologic maps. Geophysical or subsurface geologic and hydrologic data are assembled. Once in the field, the geologist will begin systematically making observations and measurements along roads, trails, then along streams and ridges, and other places where rocks are likely to be exposed. In an urban area, this study would include artificial exposures like highway cuts, quarries, and foundation excavations for new buildings, as well as natural exposures in parks and greenways.

Wherever a rock exposure is located, the geologist makes sure of its location on the topographic map or air photo, and records data in a field notebook, along with observations of rock type, the rock unit (formation) if known, and the kind(s) of fossils that may be present. Where the rocks have been deformed, strike and dip of bedding in sedimentary rocks and other planar structures, such as foliation in metamorphic rocks, will be measured and recorded. One or more of the measurements will be plotted on the map, most commonly bedding or other prominent layering, and some color(s) will be marked on the map to indicate the rock type(s) present. Where an exposure is found that contains no structures, color is marked on the map to indicate rock type.

topographic base map

1

Fig. 20. ***Topographic Base Map*** *(green background indicates forest) showing part of the 1:24,000-scale Prentiss quadrangle, North Carolina, containing a small amount of geologic map data. The colors represent different rock types, and the symbols with numbers represent structural measurements, here mostly of foliation. Even with the small amount of data, the geologist was able to identify a boundary (contact) between two formations, indicated by the solid and dashed line separating the silver and red colors.*

intermediate field map

2

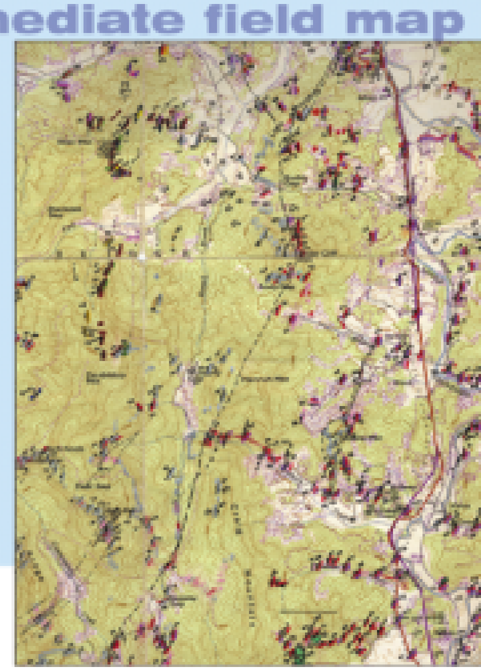


Fig. 21. ***Intermediate Field Map*** *of the same area with bedrock formation contacts drawn. Contacts for slope and stream deposits had not been drawn, but the data are indicated by Qc and Qt symbols, along with the largely flat stream bottoms which are covered by floodplain deposits.*

Some geologists also record locations of "stations" where data were collected on a separate station map. Boundaries—contacts—between formations are commonly exposed in desert or above-timberline regions, and can be traced directly on the ground. In areas where exposure is less continuous, contacts between scattered exposures must be located by extrapolating across streams and ridges, and by collecting data from roads and trails. Contacts are joined across the intervening areas by careful projections based on the dip angles and topographic slopes. As the geologic map is being made, the kind of contact being mapped, unfaulted (separating rock types), faulted, or an unconformity, is inferred by the geologist in the field.

Collected field data are either drafted by hand onto a stable mylar™ film or compiled into a computer graphics or GIS (geographic information system) program. The data are preserved in case the field maps are lost and, as subsequent data are added, the collected data evolve into a geologic map.

3 completed geologic map

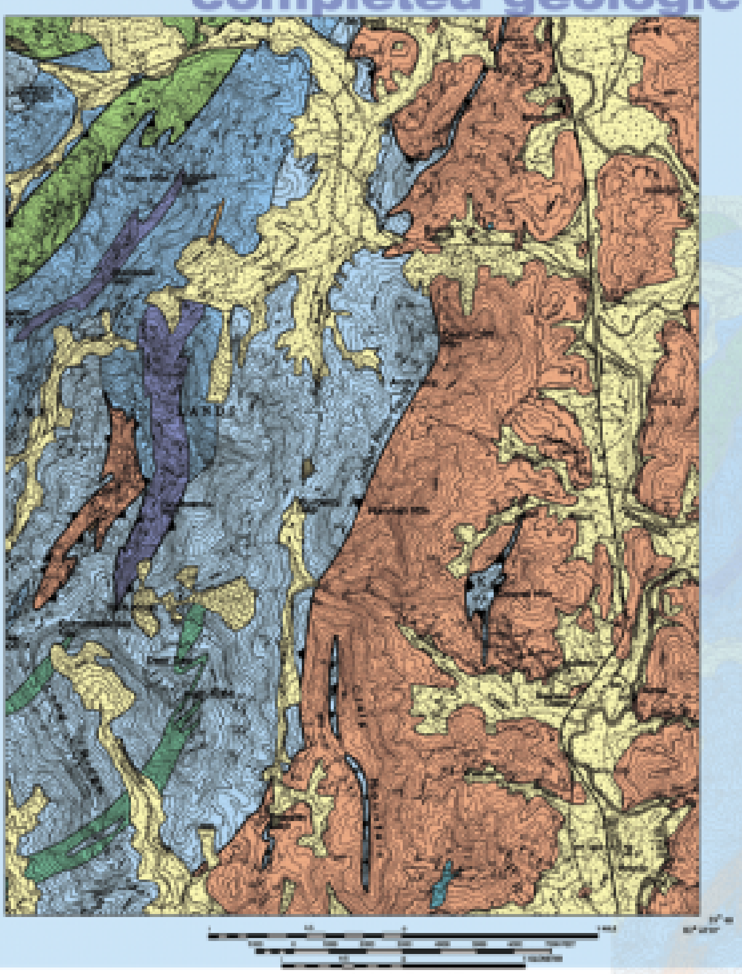


Fig. 22. ***Completed Geologic Map***
This geologic map (of the same area as maps 1 and 2) is the product of systematic data collection, plotting data on the topographic base map, identification of and drawing boundaries (contacts) between formations, and interpreting the nature of contacts. Colors represent different formations; the yellow unit that appears to cut across the others represents the youngest unit: surficial slope and stream deposits. The orange color is a metasandstone and schist, whereas the light blue is a 468-million-year-old granite. The medium blue is metasandstone, and the blue purple unit is garnet schist. The dark green formation consists of metabasalt rock, and the yellow green in the northwest part of the map consists of another metasandstone. Lines with teeth on them have been interpreted as thrust faults; all other boundaries are interpreted as normal contacts between metasedimentary or metaigneous rock units. The various symbols with numbers beside them are mostly measurements of strike and dip of layering (here foliation, because these are metamorphic rocks); others represent the orientations of other structures.

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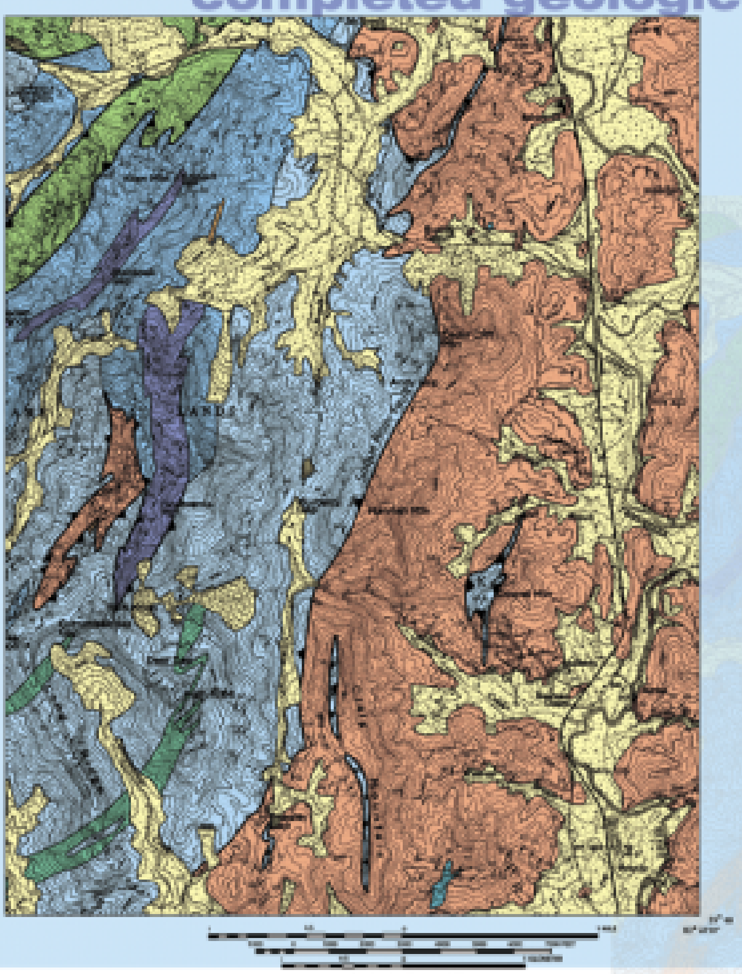
completed geologic map

3



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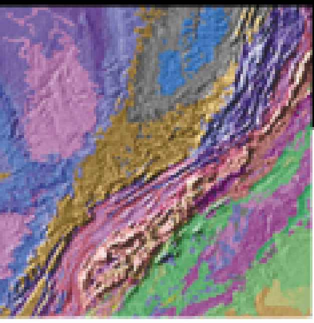
Using Geologic Maps



Geologic maps are our most important and complete compilation of information about the solid Earth we live on, and we cannot understand the Earth without them. We use geologic maps and the fundamental information they provide in many ways. The 16 examples presented in this book show how geologic maps help delineate fragile habitat and ecosystems, protect against natural hazards (earthquakes, volcanic eruptions, landslides, and sinkholes), and find needed resources (groundwater, metals, coal, and sand and gravel). The following information will help you interpret the geologic maps in the examples.

Scale

A map scale gives the quantitative relationship, or ratio, between a distance on the map and the actual distance on the ground. For example, on a map of a small area, such as a detailed street map, 1 inch on the map may be equal to 2,000 feet on the ground. In a road atlas, a large area, such as a state, may be at a scale of 1 inch on the map equals 20 miles on the ground. Scale is expressed also as a ratio, and a common ratio scale for a detailed geologic map is 1:24,000. At this scale, one inch on the map equals 24,000 inches (2,000 feet) on the ground. The most common geologic map at a scale of 1:24,000 is a 7.5-minute quadrangle, measuring 7.5 minutes of latitude and 7.5 minutes of longitude. Larger quadrangles, measuring 30 minutes of latitude by 60 minutes of longitude, are generally produced at a scale of 1:100,000. A small inset diagram on each 30 x 60-minute map shows which 7.5-minute quadrangle maps were used to make it (Fig. 23). The entire state of Kentucky has been geologically mapped at a scale of 1:24,000; Kentucky contains more than 700 of these "7.5-minute" quadrangles. With the exception of Alaska, base maps are available at both scales for the United States, but geologic maps at detailed scales have not been completed for many large areas.

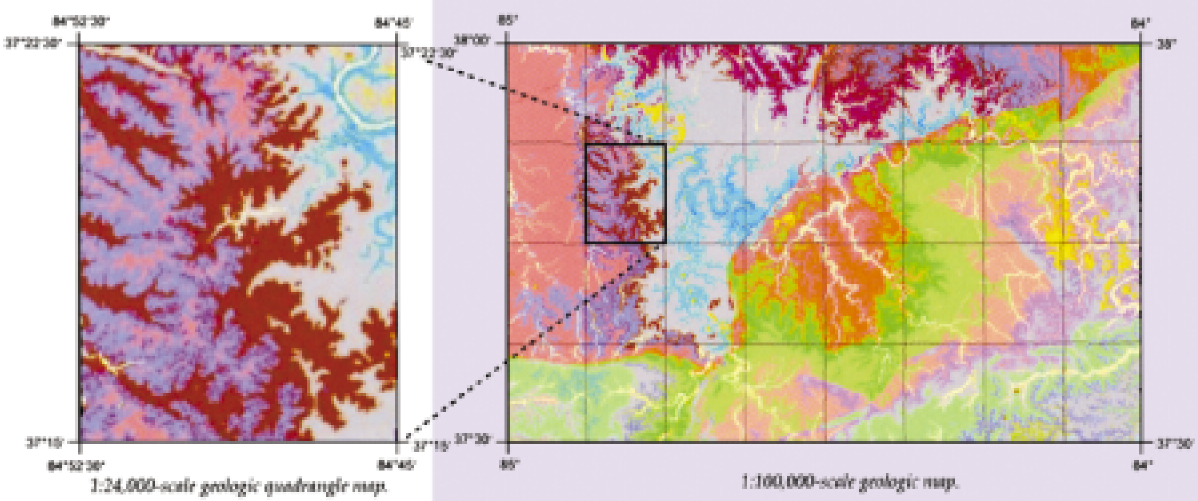
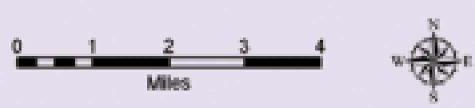
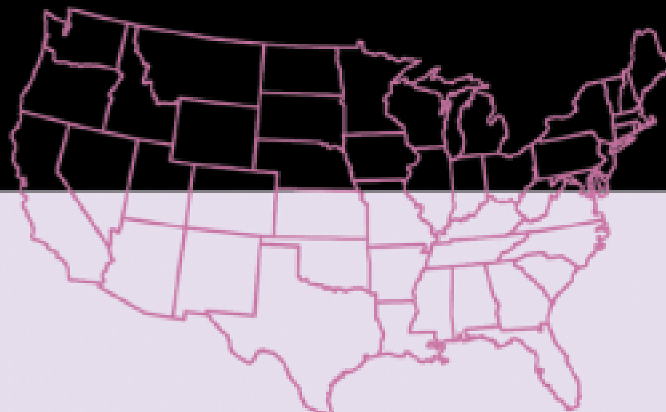


Fig. 23. Outline maps showing the relative sizes of the areas on standard 1:24,000-scale quadrangle maps and 1:100,000-scale quadrangle maps with reference to latitude and longitude boundaries.





The level of detail of information presented on a map varies with scale. A 1:24,000-scale geologic map is an excellent source of information for making site-specific decisions about the construction of houses, subdivisions, commercial buildings, airports, dams, and bridges. A 1:100,000-scale geologic map is ideal when a broader regional or county-level perspective is required for making decisions about the construction of highways, watershed management, wetland restoration, and land-use planning. A map scale commonly appears below the center of the map, both as a ratio (e.g., 1:24,000) and in a scale bar. A scale bar shows how distance measured on a map is converted to distance on the ground.

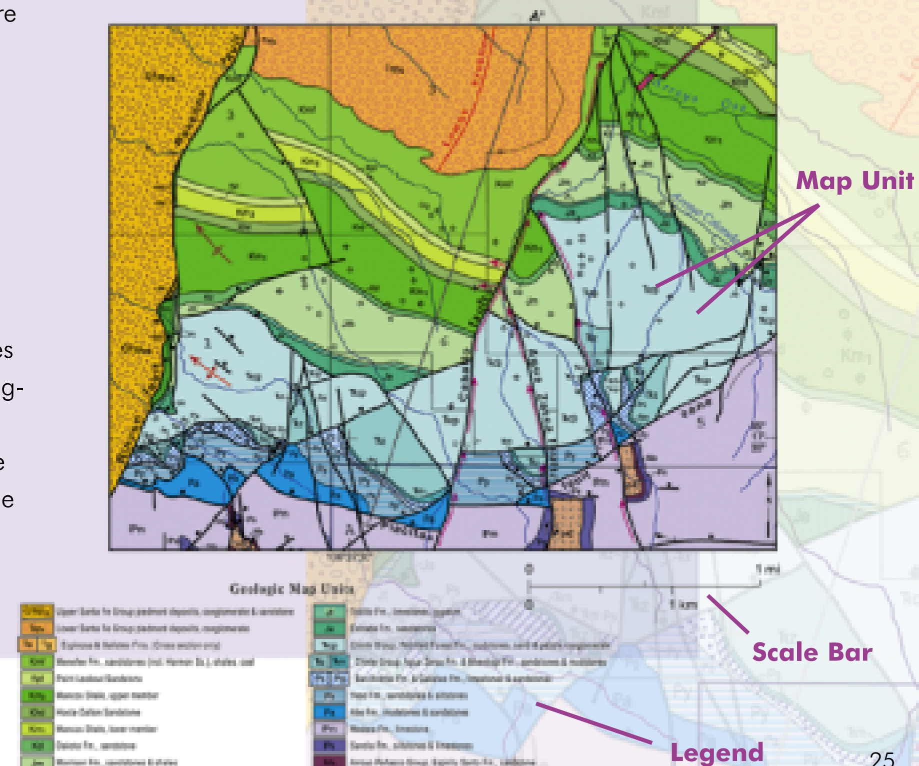
Legend

A legend describing the geologic map units and explaining the symbols shown on the map commonly appears in the margin of a geologic map (Fig. 24). The descriptions of the map units in the legend commonly are complete enough to enable the user to identify the corresponding rocks on the ground ("in the field"). The map unit descriptions are tied to the geologic map by color and by symbol, and they are listed vertically in the legend in the order of geologic age from youngest to oldest.

Geologic Time Scale

The geologic age of map units is an important part of the information on a geologic map. Standard divisions of Earth history are defined in the geologic time scale (Fig. 10, p. 14) and are used by geologists to identify rock unit ages.

Fig. 24. Geologic map from New Mexico Bureau of Geology and Mineral Resources (Ex. 16, p.58).



The 16 Examples

The following examples represent the wide range of uses of geologic maps. The examples are widely distributed geographically, as geologic maps have valuable uses in every part of our country (and throughout the world). These examples and many others are available on the AGI Website **www.agiweb.org**.

11
Volcanic Hazards
Washington
14
Transportation Planning
North Dakota
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Earthquake Damage
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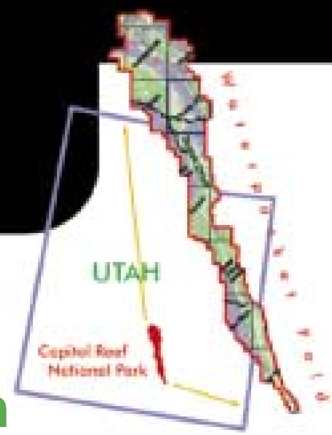
Glacial deposits
Stream & lake deposits
Layered sedimentary rocks
Carbonate rocks
Iron-rich sedimentary rocks
Igneous Rocks
Light-colored volcanics from lava or ash
Light-colored intrusives, such as granite
Gray to black volcanics from lava or ash
Gray to black intrusives from magma
Black, medium to coarse-grained intrusives
Metamorphic Rocks
Sedimentary rocks altered by pressure and/or temperature
Light-colored crystalline rocks
Various colored crystalline rocks
Mixed Types
Sedimentary, igneous, & metamorphic rock bodies

Fig. 25. Location map highlighting the following examples, which describe uses of geologic maps. This lithologic map shows the distribution of rock types and is derived from the geologic map (Fig. 19).

Capitol Reef



Using Geologic Maps for Habitat Prediction

Tim Connors (National Park Service)

Defining the Problem

Congress established **Capitol Reef National Park** (Fig. 1) to protect the geological feature known as the Waterpocket Fold, which contains unique microhabitats that support more than 40 rare and endemic plant species. The Park Service needs baseline information on the distribution and occurrence of these rare plants (Fig. 2) to determine whether visitor activities, especially in heavily used areas, are damaging them.

The Geologic Map

The blue, green, yellow, and brown patterns on the geologic map (Fig. 3) show the distribution of the ancient sedimentary rocks that predominate at Capitol Reef. These rocks were formed in a variety of geologic environments including open marine, near shore, river, lake, and desert over the last 275 million years. Digital versions of geologic maps of the Capitol Reef area were prepared for use in a Geographic Information System (GIS). The geologic data may be used in GIS analyses and integrated with other datasets to define spatial relationships between physical and biological resources. Here, the Mesozoic sedimentary formations found in the Waterpocket Fold can be used to **predict** which areas are most likely to include fragile habitats.

Applying the Geologic Map

Direct connections between geologic substrate and **habitat** exist for a number of species (Fig. 4). For example, Barneby reed-mustard is confined to north facing, cliff exposures in the Triassic Moenkopi Formation. Jones cycladenia is found only in the Owl Creek Member of the Triassic Chinle Formation. Beck's Spring Parsley seems to occur only in north facing narrow canyons within the Jurassic Navajo Sandstone. Harrison's milkvetch, Maguire's daisy, and Rabbit Valley gilia are spatially correlated with the Navajo Sandstone. Winkler's cactus is confined to geologic exposures of the Salt Wash Member of the Jurassic Morrison Formation.

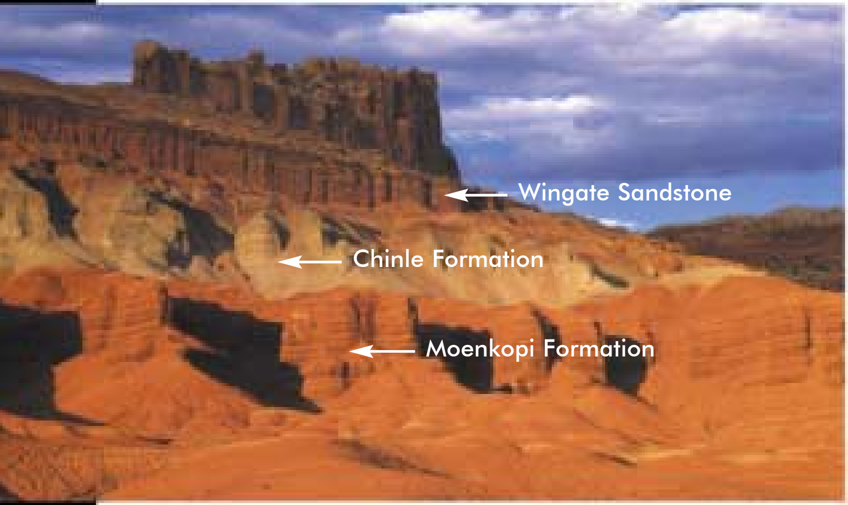
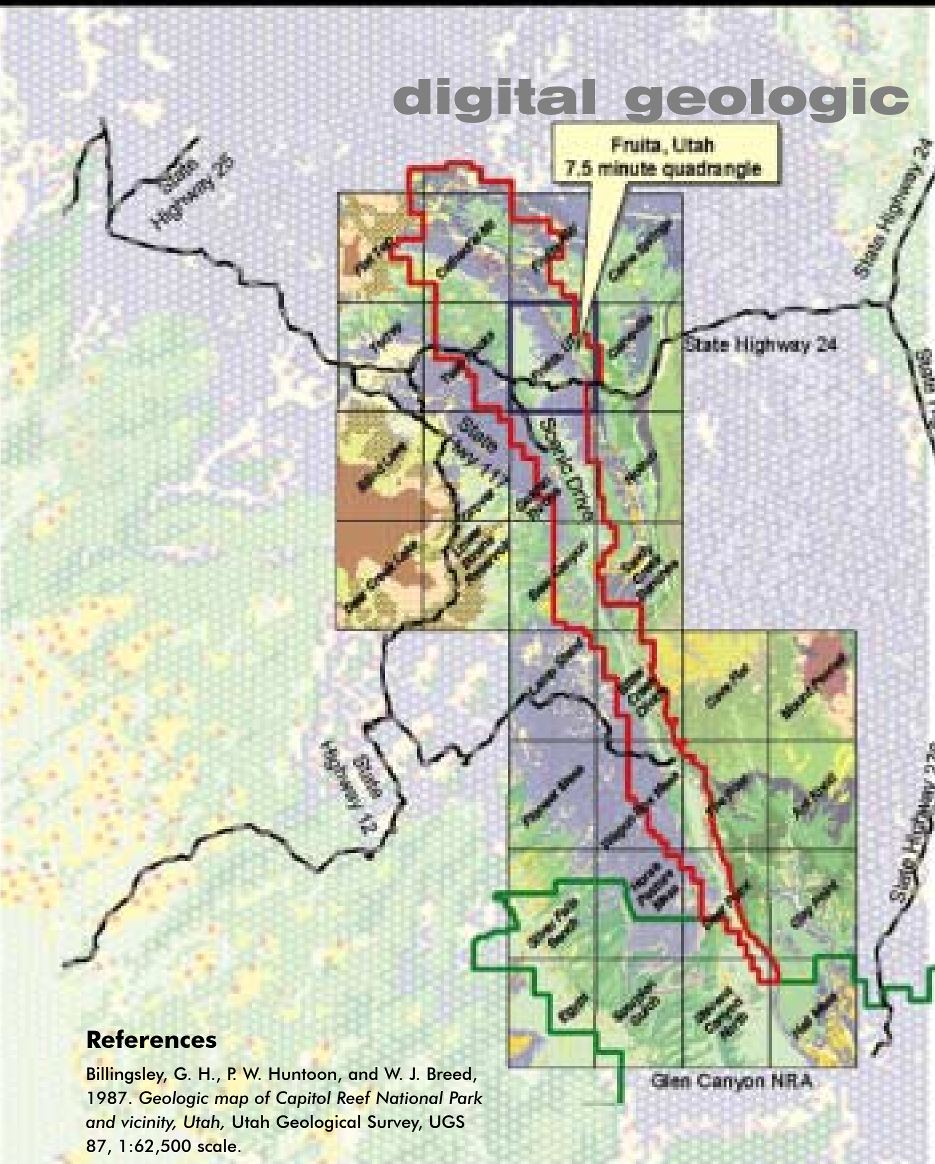


Fig. 1. The Castle and Fluted Wall is one of the most recognizable features in Capitol Reef National Park.

Conclusion

By using digital geologic map data, along with soil, slope, and other parameters, better predictive models can be developed to locate habitat for known threatened and endangered species. When combined with visitor-use data, this information helps pinpoint areas for which it would be beneficial to monitor effects of human impacts and develop resource protection measures to mitigate further impacts. Maps predicting potential habitat can be used for land management purposes.

digital geologic map



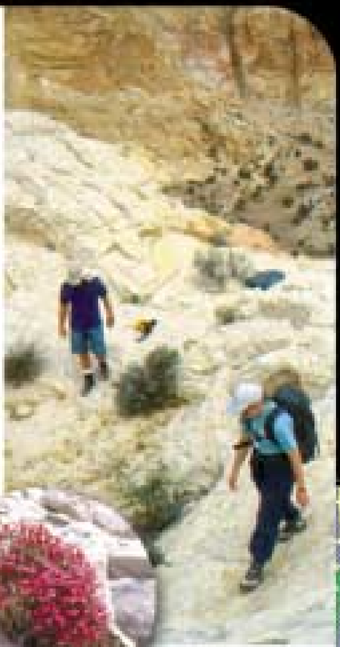
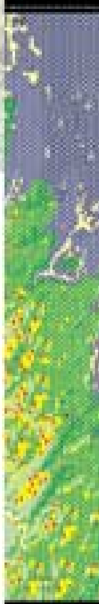


Fig. 2. Field crews inventory endemic plant species growing on the Navajo Sandstone in Capitol Reef National Park.

Rabbit Valley gilia

Fig. 3. On this geologic map the Capitol Reef National Park boundary is red, the boundaries of the "heavy use" quadrangles are blue, and the boundary of the Glen Canyon National Recreation Area adjoining the Park on the south is green.



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geo-ecological habitat map

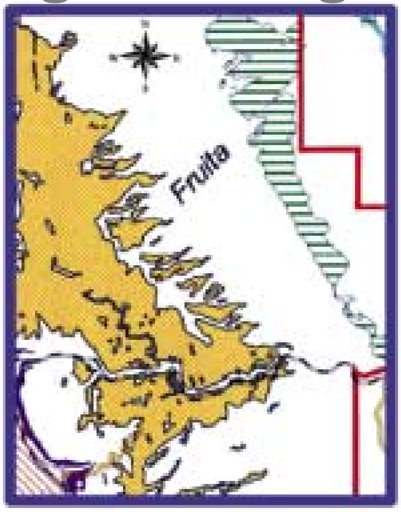


Fig. 4. This map, based on information derived from geologic maps and known ties to geologic formations, shows potential habitat in the Fruita quadrangle for a few threatened and endangered plant species.

Kentucky

Geologic Maps and Cave Resources

Kentucky Geological Survey

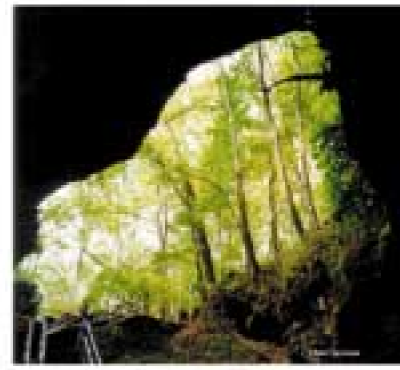


Fig. 1. Entrance to Mammoth Cave.

Defining the Problem

A new interstate highway, I-66, is being planned to pass through the vicinity of Mammoth Cave National Park (Fig. 1). It is one of the nation's most popular parks and is also extremely vulnerable to environmental impacts. This area is a classic **karst** terrain characterized by caves and sinkholes (Fig. 2). These features form as naturally acidic water moving from the surface landscape through fractures in limestone bedrock slowly dissolves away the rock. Mammoth Cave depends upon groundwater for its natural development and fragile ecology, but runoff water or contaminants can drain directly into karst passageways with little filtration. Karst features can also subside or collapse under roadways. In order to make informed decisions about the location and design of I-66, transportation officials need information about the local rock units, as well as their structure and relationship to surface features and subsurface drainage. A geologic map provides this information.

The Geologic Map

The geologic map (Fig. 3) shows the important rock units in the **I-66 planning area**. The map shows that the southern boundary of the Park is on a resistant sandstone plateau underlain by limestone in which the caves are developed. Figure 4, the geologic cross section, A-A', was constructed from the geologic map. The map and cross section show the physical relationships between the caves, resistant sandstone plateau, highly-soluble limestone, insoluble chert bed, and sinkhole plain.

Applying the Geologic Map

The distribution of surface features, such as sinkholes and streams, is directly related to the rock units shown on geologic maps. **Transportation planners** can use these maps to identify areas with high karst potential, and thus protect the public and minimize road construction costs by avoiding these regions. Figure 5 shows the distribution of sinkholes and surface streams in relation to the Lost River Chert — an insoluble rock layer within the karst-forming limestones. The presence of the chert layer in the shallow subsurface has resulted in formation of relatively shallow, but broad and complex sinkholes in the overlying limestone north of the chert outcrop. Where the chert layer has been eroded, the underlying limestone contains numerous and deep sinkholes.

Fig. 2. Sinkholes form from the dissolving and collapse of underlying bedrock.

Conclusion

Understanding karst and conducting karst investigations would not be possible without geologic maps. Karst terranes are present in most of the states in the United States. Geologic maps are being used in Kentucky to identify areas that have high potential for development of karst features, such as sinkholes and caves. Geologic maps are also being used to analyze existing sinkholes to provide an increased understanding of karst development in geologic rock units and to protect areas vulnerable to goundwater pollution.

simplified geologic map

of the I-66 planning area

Fig. 3. Simplified geologic map of the I-66 planning area showing principal rock types of the region.

cross section

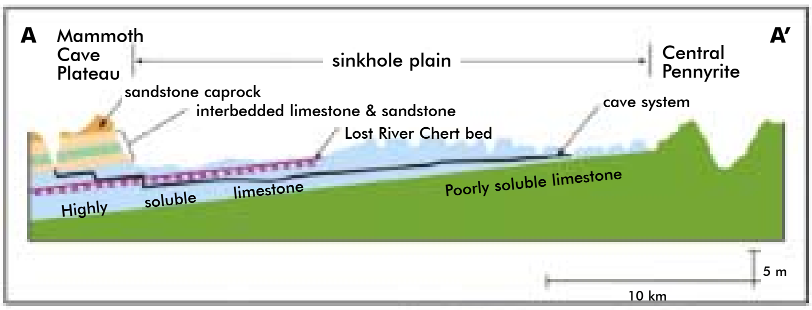


Fig. 4. Geologic cross section (A-A') of the study area showing relationship between rock units and karst landforms. Topographic surface exaggerated to show landforms.

karst features map

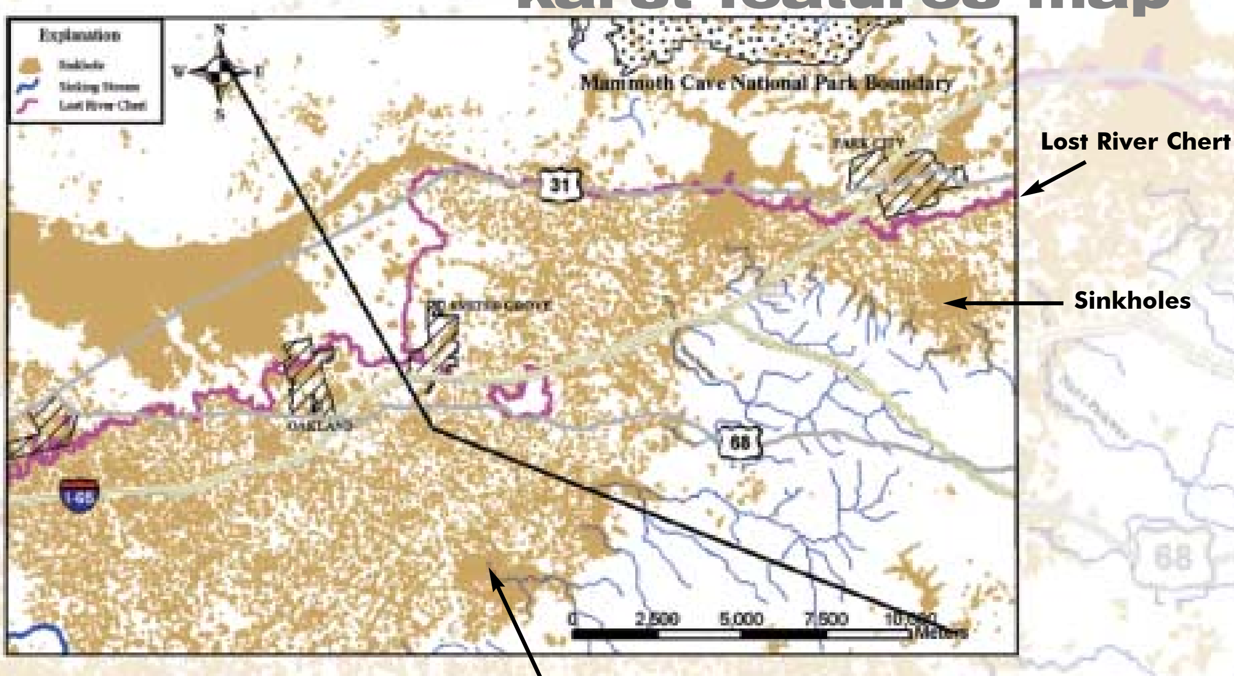
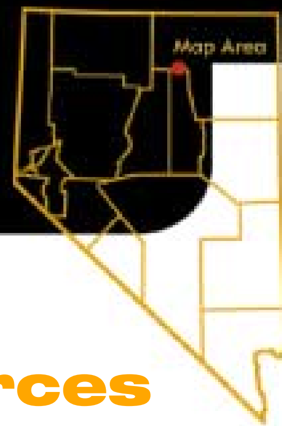


Fig. 5. Distribution of karst features within the geologic map area relative to the outcrop of Lost River Chert layer.

Nevada



Geologic Maps and Mineral Resources

Jonathan G. Price (Nevada Bureau of Mines and Geology)

Defining the Problem

The western states contain many gold deposits (Fig. 1), and a zone of faulted sedimentary and igneous rocks in northeastern **Nevada**, known as the "Carlin" trend, is the most productive region in the country. Since the 1961 discovery of the Carlin deposit and the subsequent development of mines, the region has become the **largest U.S. gold producer** (more than 1,600 metric tons worth $21 billion). Geologic maps have been vital in the process of discovering and developing these deposits. Geologists used the maps to show relationships between rocks that host gold deposits and structures that localized ore-forming fluids. These relationships, which are key to delineating areas favorable for gold deposits, cannot be defined without geologic maps. The Genesis Mine area is a good example of how geologic maps guide mineral exploration on the Carlin trend.

The Geologic Map

Figure 2, which includes the **Genesis Mine**, is part of a larger geologic map of the Carlin trend. As the map illustrates, the geology is complex. These rocks have been folded and overridden and broken by faults. Green and blue denote the predominant Paleozoic sedimentary rocks that host gold in this region. Light purple denotes other Paleozoic sedimentary rocks in the upper plate of a major thrust fault. In addition, local metamorphism occurred when Jurassic and Tertiary rocks intruded the Paleozoic rocks. Yellow areas marked "Tmc" and "Qls" indicate young Tertiary sedimentary rocks and a Quaternary landslide, respectively. The Genesis Mine area is marked on the right side of the map.

Applying the Geologic Map

Geologic mapping of the sedimentary and igneous rocks indicates that gold deposits of the Carlin trend formed about the same time as the igneous activity that produced the northeast-trending dikes (Fig. 3). Gold occurs in the Paleozoic rocks and also locally in the igneous rocks. **Geologic mapping** points to an origin of the gold deposits about 40 million years ago, considerably younger than most of the rocks in which the gold occurs. The mapped relationships between favorable host sedimentary rocks, mineralized dikes, and large fault structures have been important guides to gold exploration in this area.

Conclusion

Geologic maps have provided the key to **finding** new **gold deposits** in Nevada. Production from mines on the Carlin trend and similar deposits elsewhere in the Great Basin revived gold mining in the United States to unprecedented levels. These activities far exceed the booms of the '49ers on the Mother Lode in California and gold rushes of the late 1800s and early 1900s in both annual production and duration. We are currently in the midst of the biggest gold-mining boom in American history, a boom that provides tens of thousands of jobs, contributes billions of dollars to the U.S. economy, and helps to reduce the U.S. trade deficit.

Fig. 1. Gold, 3.3 cm high, Round Mountain Mine, Nye County, Nevada. L. McMaster collection.

Nevada gold

geologic map

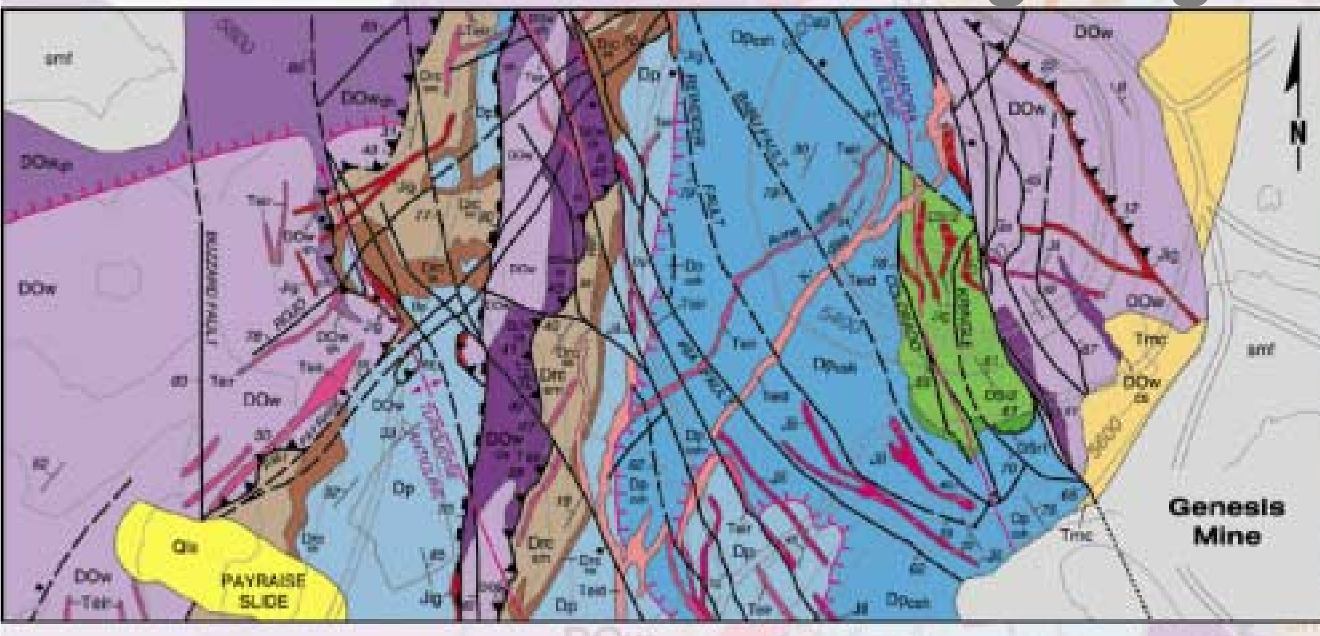


Fig. 2. Central portion of the geologic map of the northern Carlin trend (1:12,000 scale). In 2002, the Carlin trend became the only gold-mining region in the United States, and one of only a handful in the world to produce more than 50 million troy ounces (1,555 metric tons) of gold. Current annual production is about $1 billion worth of gold, and geologists continue to discover new deposits on the trend.

Tertiary dike

Fig. 3. A Tertiary dike cuts Paleozoic sedimentary rocks in the Betze-Post Mine, the largest open-pit gold mine in the United States. Geologic studies indicate that gold deposits in these sedimentary rocks formed about the same time as the igneous activity that produced the dikes.

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Kansas

Geologic Map Delineates Landslide Hazards

Gregory C. Ohlmacher (Kansas Geological Survey), James R. McCauley (Kansas Geological Survey), and John C. Davis (Davis Consultants Inc.)

4

Example

Defining the Problem

Damaging landslides occur even in "vertically challenged" states like Kansas (Fig. 1). It is important to be able to delineate **landslide hazard** areas in order to develop appropriate land-use plans. In Leavenworth County, Kansas, geologic maps combined with maps of landslide features and slope steepness were used to predict landslide hazards and guide land management.

The Geologic Map

The geologic map of Leavenworth County (Fig. 2) shows the surface **distribution** of Quaternary glacial deposits and Pennsylvanian **bedrock**. The glacial deposits, a loose mixture of glacially transported clay- through boulder-sized fragments, cover many upland areas. Below the glacial deposits, the Oread Limestone is a relatively strong unit that supports hilltops. Much of the city of Leavenworth, however, is developed on the weaker shales, siltstones, and sandstones of the Lawrence and Stranger formations, which underly the Oread Limestone.

Applying the Geologic Map

Gravity, weak soil and rock, steeply sloping ground, and water-saturated soil and rock are the basic causes of landslides. Because the local soils develop from weathering of bedrock, a geologic map is a good indicator of the distribution of soil properties. The Lawrence and Stranger formations contain shale layers that readily break down to form **unstable**, clay-rich soils that are very susceptible to landslides. The Oread Limestone, which consists of interbedded limestone and shale layers, is the next most **susceptible** unit. The glacial deposits are the least susceptible to land sliding. A statistical analysis that takes into account slope steepness, bedrock geology, and the distribution of previous landslides (Fig. 3) enables a landslide-hazard map to be developed (Fig. 4).

Fig. 1. House destroyed by 1995 landslide in Overland Park, Kansas.

Conclusion

The risk of landslides is great in many areas of the Midcontinent. The statistical approach used for this study evaluates the relative stability of slopes by relating previous landslides to the slope steepness and bedrock geology. The **analysis** shows that slope steepness is the primary factor determining slope stability, but bedrock geology and geologic maps also provide important information on the landslide susceptibility of soil and rock. Landslide **hazard** maps based on geologic maps are a tool for local government officials, planners, developers, engineers, insurance companies, lending institutions, and landowners to **assess** the **risk** and take appropriate actions.

geologic map

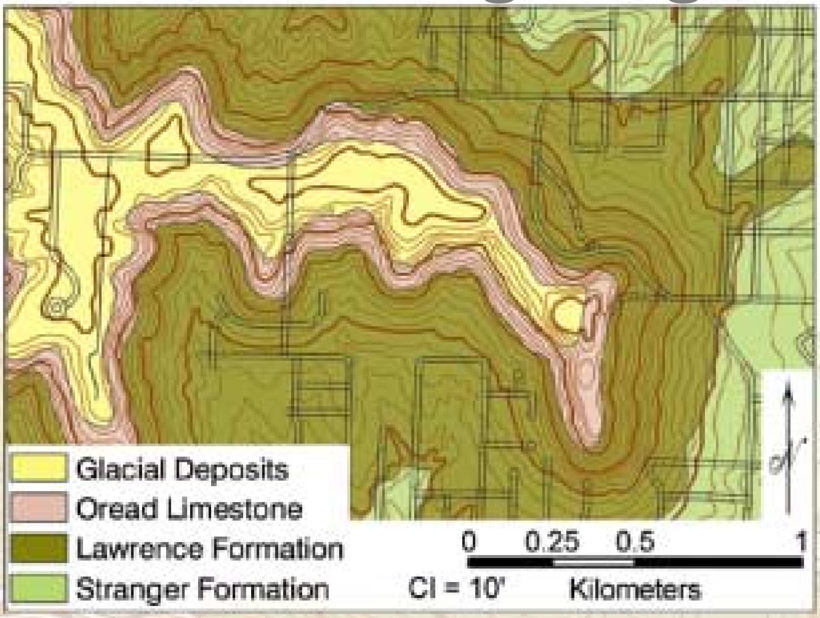

Fig. 2. Part of the geologic map of Leavenworth County, KS. Leavenworth County is in the Kansas City metropolitan area.

landslide map

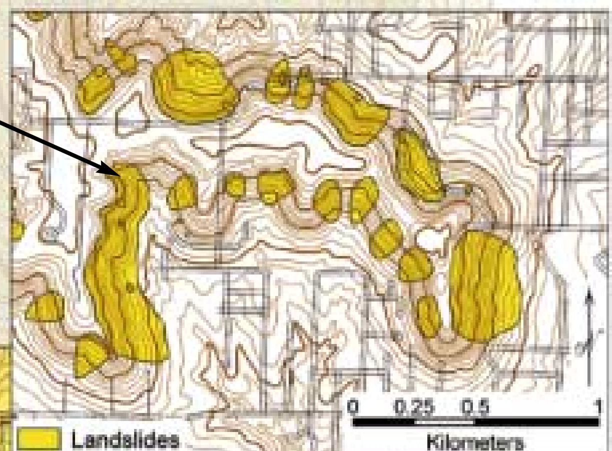

Fig. 3. A map showing landslides in a portion of the city of Leavenworth.

landslide-hazard map

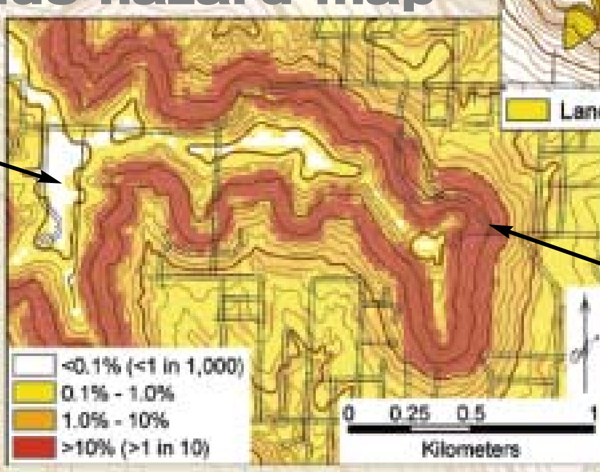

Fig. 4. This map of a portion of the city of Leavenworth shows the probability of a future landslide given the slope steepness and bedrock geology, where 0% means no chance of landslides. Areas shown in red have a greater than 1 in 10 chance (> 10% probability) of being involved in a landslide.

Maryland

Geologic Map Depicts Sinkhole Susceptibility

David K. Brezinski, James P. Reger, and Gerald R. Baum (Maryland Geological Survey)

Defining the Problem

Sinkholes, which abound in the Frederick Valley in west-central Maryland, impact urban growth and development (Fig. 1). Sinkholes form in carbonate areas as the dissolving and weakening of bedrock cause it to collapse. Activities, such as quarrying, which alter surface drainage and lower the water table also can decrease ground strength and exacerbate the **sinkhole** hazard. It is important to assess potential **risks** of infrastructure damage and personal injury due to sinkhole formations.

Fig. 1. Sinkholes in collapsed parking area, Frederick, MD. Sinkholes form in carbonate areas as the dissolving and weakening of bedrock cause it to collapse.

The Geologic Map

The geologic map of the Frederick Valley shows the presence of two **limestone** formations, the Frederick and Grove (Fig. 2). At the formational level, there is no discernable difference in sinkhole proclivity between the two units. When the two formations are subdivided into lithologically distinct parts, the increased detail allows the geologic map to be used as a **predictive tool** for potential sinkhole development.

Applying the Geologic Map

The map of bedrock units and sinkholes demonstrates the **correlation** between sinkhole distribution and rock type. Table 1 shows that most sinkholes are present in the upper part of the Frederick Formation, contradicting the long-held belief that the Grove Formation is the unit most susceptible to sinkhole development in the Frederick Valley. While the Grove Formation clearly has a significant number of sinkholes, a **ranking** of geologic units **demonstrates** that the upper member in the Frederick Formation is the most susceptible to sinkhole occurrence (Fig. 3). An increased level of detail in both the lithologic description and the mapping practices facilitates the evaluation of the **susceptibility** of these geologic units to sinkhole formation. By subdividing and mapping units as precisely as possible, and accurately locating sinkholes with a Global Positioning System (GPS), geologists are able to develop a new tool, the susceptibility index (SI), that portrays the relative sinkhole propensity for each unit (Fig. 3). Planners and developers can use the SI as a comparative tool to evaluate the likelihood of sinkhole occurrence in areas considered for development.

Conclusion

Sinkholes and other **karst** features represent one of the most widespread and **underevaluated** geologic **hazards** in carbonate terrains. Geologic maps are the principal tools for displaying and conveying data important to understanding reasons for sinkhole distribution. Although sinkhole development in susceptible areas cannot be completely prevented, policy makers and the public can use geologic maps that delineate karst features to **develop strategies** that can minimize or avoid property damage and personal injuries.

geologic map

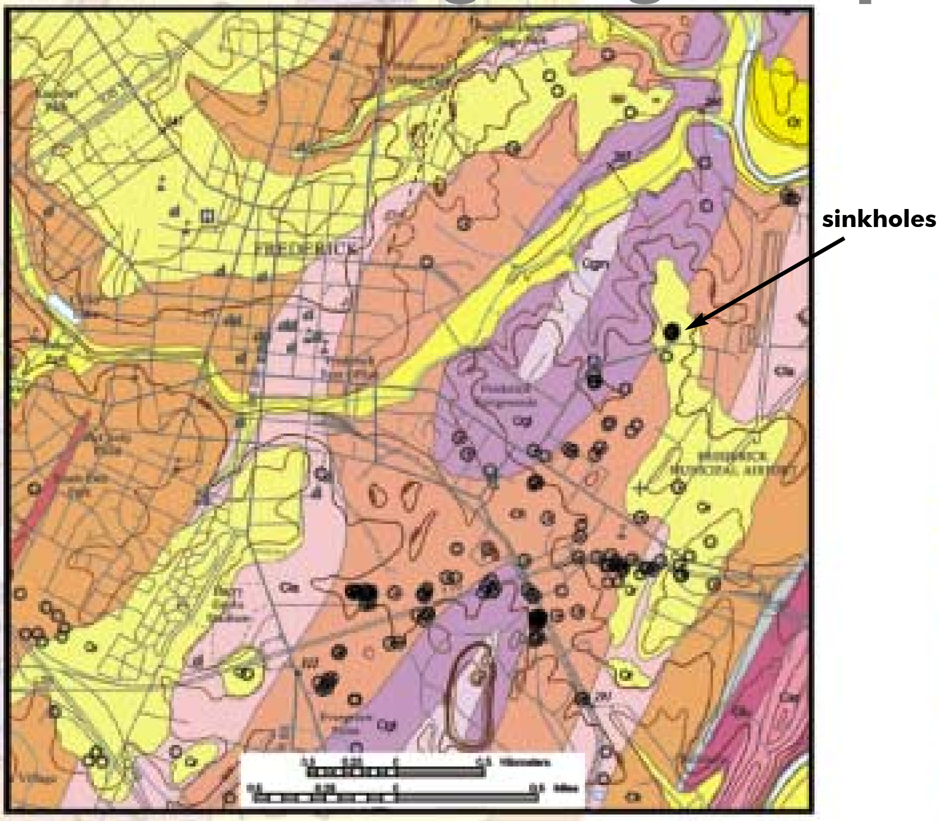

Fig. 2. On this geologic map of the Frederick, MD, area, note the prevalence of sinkholes (circles with hachures) in the Lime Kiln Member of the Frederick Formation. Sinkholes and other karst features are among the most widespread and underevaluated natural hazards in carbonate areas.

sinkhole susceptibility

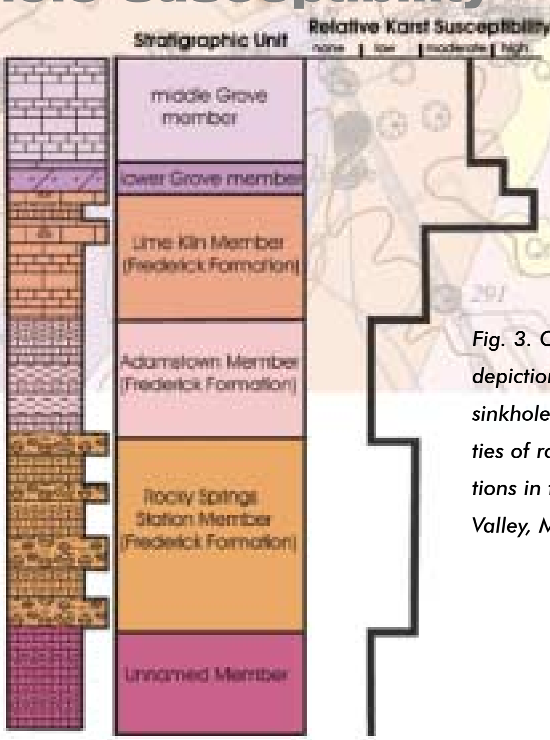

Fig. 3. Conceptual depiction of relative sinkhole susceptibilities of rock formations in the Frederick Valley, MD.

sinkholes

Stratigraphic Unit	Number of Sinkholes
Grove Formation middle member	0
Grove Formation lower member	20
Frederick Formation Lime Kiln member	83
Frederick Formation Adamstown member	17

Table 1. Number of sinkholes occurring in various stratigraphic units as revealed by recent geologic mapping.

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California

Geologic Maps Identify **Landslide Hazards**

Russell W. Graymer and Richard J. Pike (U.S. Geological Survey)

Defining the Problem

The geologic history of the Oakland, California, area has produced **steep** hillsides and **unstable** rock and soil that generate damaging landslides during severe storms and wet winters (Fig. 1). During the 1997-98 rainy-season, the two-county area surrounding Oakland experienced more than **200 landslides** leading to **losses** estimated in excess of **$47 million**. The landslide hazard is exacerbated by the presence of the highly active Hayward Fault, which runs through Oakland and surrounding cities, and is considered to be the most likely source of a large earthquake in the area. Such an earthquake would likely trigger many landslides in the surrounding hills. The challenge is to predict what areas are more likely to suffer future landslides so that proper engineering can be applied for hazard mitigation or appropriate zoning restrictions applied to the most susceptible undeveloped areas.

The Geologic Map

The geologic map of the Oakland metropolitan area (Fig. 2) shows the **complex** geologic **structure** and distribution of rock units that are typical of the region where the active Hayward Fault Zone (HFZ) separates metamorphic rocks of the Franciscan Complex (fss, fs, fm) from sedimentary and volcanic rocks. The same natural forces responsible for the complicated geology are still at work, deforming the rocks and raising the hills that occupy the eastern portion of the mapped area. A complementary map (Fig. 3) shows the large landslide deposits (red) that have accumulated in the landscape since the uplift of the hills.

Applying the Geologic Map

Statistical analysis of the relations between the accumulated **large landslides** in the area and the underlying rock units and slope reveals which slope/rock-unit combinations are more likely to experience future landslides (Fig. 4). By calculating the expected ground-shaking from an earthquake and using additional data from the geologic map, we can also assess the susceptibility to earthquake-induced landslides in the area. The resulting **susceptibility** maps (Fig. 5) show which areas are most susceptible. The analysis also revealed that intermediate slopes are more likely to have landslide deposits than the steepest areas. The steepest slopes may truly be less susceptible, or landslides may have occurred at steep slopes but the deposits are resting on steep slopes down the hillside.

Conclusion

The California Geological Survey is producing **zoning maps** for earthquake-induced landslides. The fundamental requirement for the analysis is availability of detailed, modern geologic maps, including an accurate map of landslides. With the advent of digital map technology, this approach to **evaluating** landslide **hazards** can be rapidly applied in any area.

1958

1998

Fig. 1. Homes in Oakland, CA, destroyed by landslides in 1958 and 1998.

geologic map

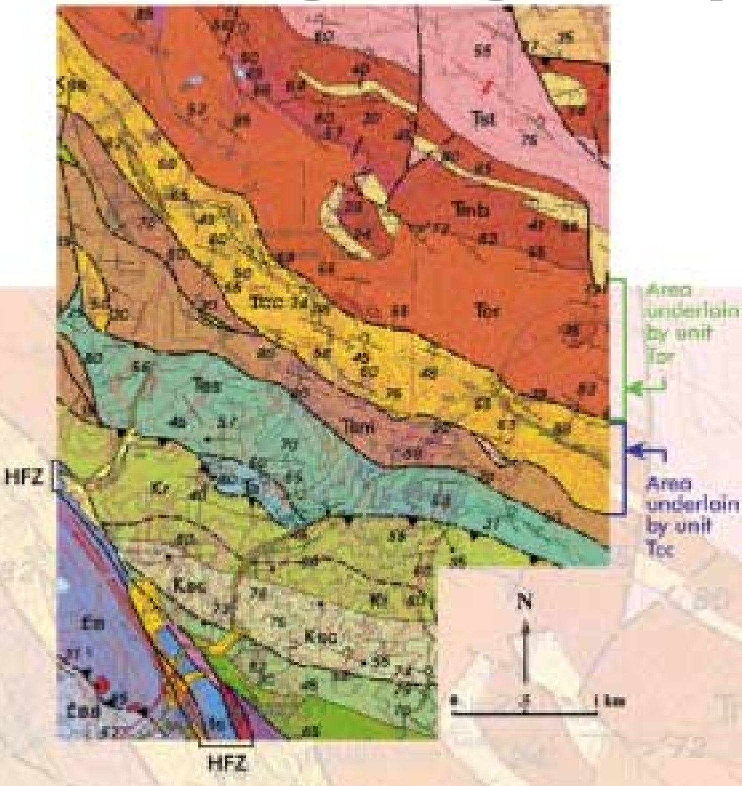
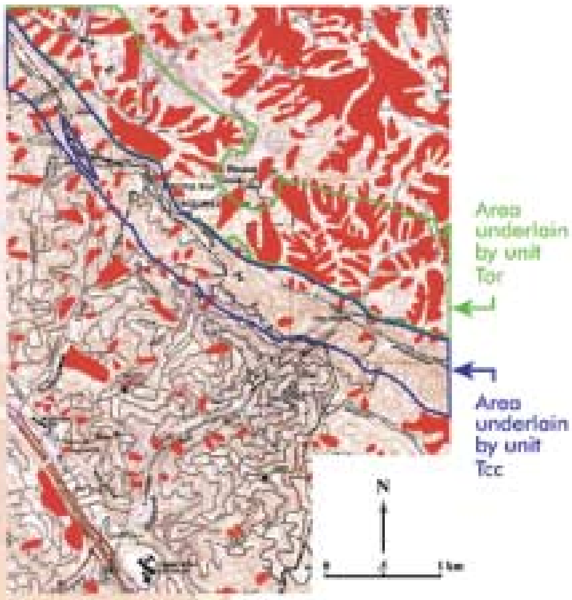


Fig.2. A portion of the geologic map of the Oakland, CA area, including part of the active Hayward Fault Zone (HFZ) separating metamorphic rocks of the Franciscan Complex (fss, fs, fm) from sedimentary and volcanic rocks.

Fig.3. Red areas are large landslide deposits in the Oakland area. Note that many more landslide deposits cover the area underlain by unit Tor than the area underlain by unit Tcc.

landslide deposits



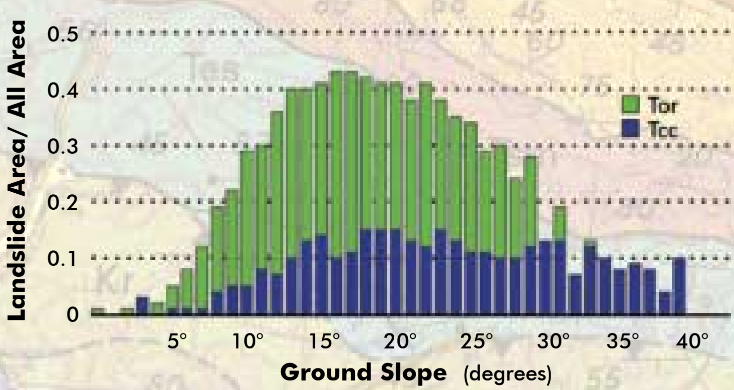


Fig. 4. Comparison of large landslide distribution at different slopes in two rock units in the Oakland metropolitan area. The unit Tor is more than doubly covered by large landslide deposits at most slope angles, and so is mapped as twice as susceptible. Note that susceptibility is lower at near-flat and very steep slopes, which is also reflected in the mapped susceptibility.

landslide susceptibility

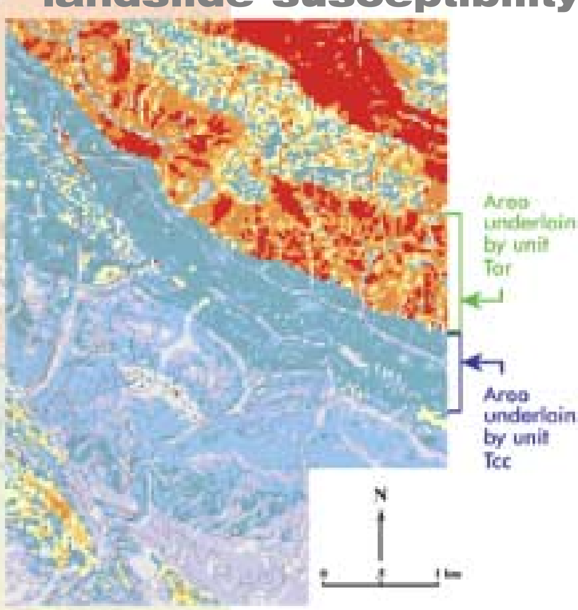
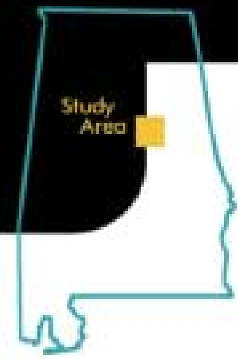


Fig.5. Large-landslide susceptibility map in the Oakland area. Orange and red areas have the highest relative susceptibility to landslides.

Alabama



Geologic Map Helps to Protect Groundwater

William A. Thomas (University of Kentucky), Willard E. Ward (Geological Survey of Alabama), and W. Edward Osborne (Geological Survey of Alabama)

Defining the Problem

In central Alabama, the Mississippian-age Fort Payne Chert is an important **aquifer** for domestic and municipal water supplies. Rainfall recharges groundwater where the chert is exposed at the land surface. Where the chert has been quarried, many of the abandoned pits have become trash dumps (Fig. 1) containing potentially toxic material that can contaminate the water supply. Planning for protection of the groundwater recharge from **pollution** requires information about the precise location of the chert at the land surface.

The Geologic Map

The Fort Payne **Chert**, a fossiliferous cherty limestone, is resistant to erosion. The geologic map (Fig. 2) shows the extent of the chert (medium blue, Mfpm) and provides the basis for construction of a cross section to show the **location** and depth of the aquifer below the land surface (Fig. 3).

Applying the Geologic Map

The porous, fractured, thin-bedded chert is highly permeable and allows the free passage of **groundwater**. Water from rainfall percolates into the chert where it is exposed at the land surface (Fig. 4). In contrast, the overlying Floyd Shale is impermeable, and where the beds dip below the land surface, water in the Fort Payne Chert is confined beneath the Floyd Shale. Wells drilled through the shale into the chert find **excellent** supplies of water at relatively shallow depths.

The Fort Payne Chert is also an economically attractive source of road material. Quarries or pits in the chert can be opened easily, and production generally can begin using only a backhoe or bulldozer. Quarrying sites shift as road construction advances, and numerous pits are **abandoned**. Because of dumping of trash, water entering abandoned chert **pits** and reacting with waste can contaminate groundwater in the aquifer.

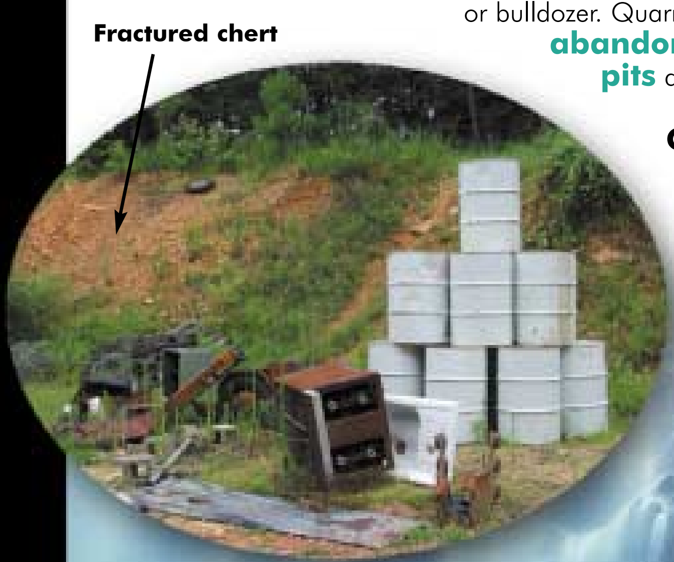


Fig. 1. Abandoned quarries in the Fort Payne Chert often become trash dumps containing materials that can contaminate the water supply.

Conclusion

Geologic mapping shows the extent of Fort Payne Chert exposure at the ground surface — this is the **recharge** area for this important aquifer. The recharge area is a relatively small proportion of the total ground surface; however, it is precisely the area that must be protected from pollution if **groundwater** resources are to be safeguarded. Information from the geologic map enables careful planning for land uses that will protect critical aquifer recharge areas and avoid pollution of groundwater resources (Fig. 5).

geologic map

Fig. 2. The geologic map of part of the Pell City quadrangle, AL, accurately identifies the recharge area of the Fort Payne Chert aquifer (medium blue) that must be protected from pollution.

cross section

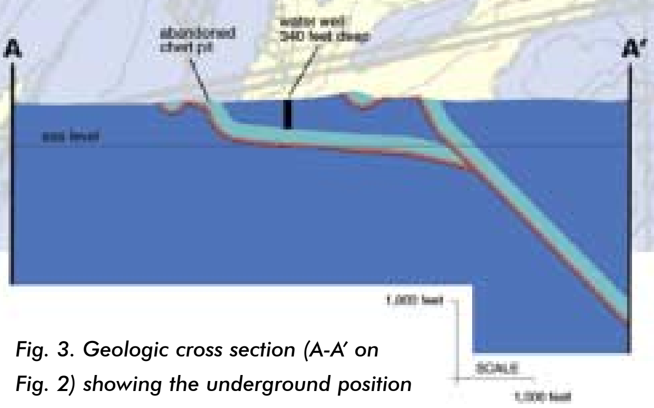
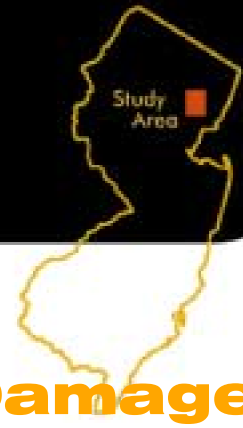


Fig. 3. Geologic cross section (A-A′ on Fig. 2) showing the underground position of the Fort Payne Chert aquifer, the depth required for drilling water wells, and the location of abandoned chert pits.

Fig. 4. Where the fractured Fort Payne Chert is exposed, water entering cracks and moving along fractures recharges the aquifer. When this water becomes contaminated, the aquifer and its water resources are at risk.

Fig. 5. On the wooded ridge behind the farmhouse, the Fort Payne Chert aquifer lies just beneath the soil, making this an ideal recharge area for clean water.



New Jersey

Geologic Map Guides Earthquake Damage Prediction

Scott D. Stanford (New Jersey Geological Survey)

Defining the Problem

The density and value of its buildings place **New Jersey** tenth among all states for **potential** economic loss from earthquakes (Fig. 1). Soft soils amplify the motion of earthquake waves, producing greater ground shaking and increasing the stresses on structures. Loose, wet, sandy soils may lose strength and flow as a fluid when shaken (a process known as *liquefaction*), causing foundations and underground structures to shift and break. Understanding the shaking and liquefaction potential of soils is an essential component in predicting earthquake **damage**.

The Geologic Map

Newark, New Jersey's largest city, is built on glacial and postglacial deposits that overlie sandstone bedrock (Fig. 2). **Geologic** data acquired during the **mapping** of these deposits include soil observations, records of more than 800 borings and wells, and archival maps of the extent of swamps and salt marshes prior to land filling in the early 20th century. These **data** permit mapping of the bedrock surface, the thickness and layering of the glacial deposits, and the extent of swamp and salt-marsh peats that are now completely covered by fill.

Applying the Geologic Map

The soft, saturated soils that underlie much of the eastern half of the city are highly susceptible to **shaking** and liquefaction (Fig. 3). The narrow belt of sand and gravel deposits through the center of the city is of intermediate compaction and has medium shaking and **liquefaction** potential. A simulation for a magnitude 5.5 earthquake centered about 5 miles northwest of the city center was run with these data (Fig. 4). Earthquakes of similar magnitude occurred in this area in 1737 and 1884. Less than 10% of buildings underlain by till (unsorted glacial deposits) were significantly damaged, whereas between 20 and 30% of those underlain by wetland and glacial-lake deposits were significantly damaged. The **vulnerable** eastern section of the city includes vital transportation links, including Newark Airport, the New Jersey Turnpike, Interstate 78, the Amtrak **Northeast Corridor** rail line, and the Port Newark marine terminal. The mapping and simulations indicate that this is a priority area for strengthening vulnerable structures.

Conclusion

Similar soil **mapping** and earthquake **simulations** have been completed for four counties, and are planned for eight others in northern New Jersey. Geologic mapping provides the data foundation that makes these simulations possible. This approach also can be used to **predict damage** in areas where the historical record indicates a risk of potential earthquakes.

Earthquake Damage Factors

- Location, depth, and magnitude
- Thickness and composition of soil and bedrock
- Types of structures

Fig. 1. Densely built urban areas on soft soils are prone to earthquake damage. Geologic maps provide vital information on the extent of these soils.

geologic map

of the Newark, NJ area

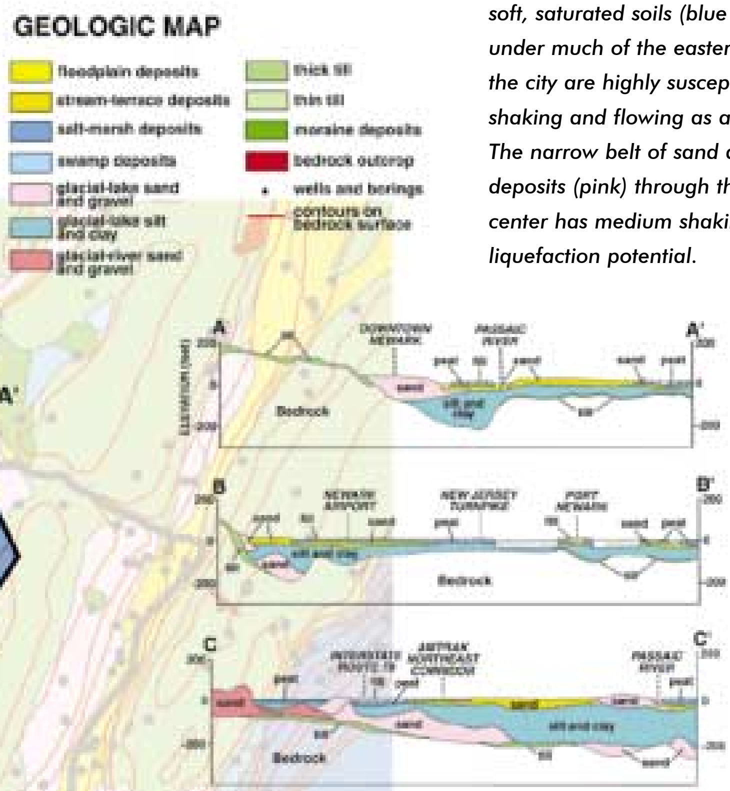
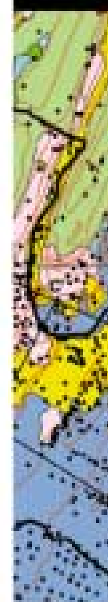
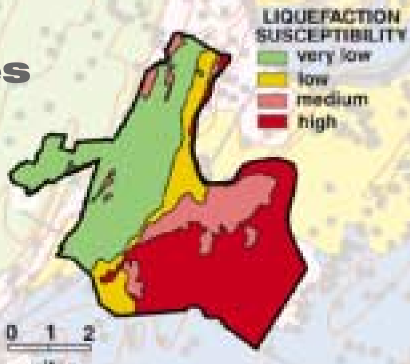


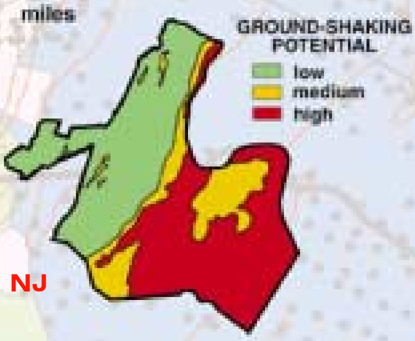
Fig. 2. Unsorted glacial deposits, till, (light green) has low liquefaction and ground-shaking potential. The soft, saturated soils (blue and gold) under much of the eastern half of the city are highly susceptible to shaking and flowing as a fluid. The narrow belt of sand and gravel deposits (pink) through the city center has medium shaking and liquefaction potential.



seismic soil properties

Fig. 3. Soft soils amplify the motion of earthquake waves, producing greater ground shaking and increasing the stresses on structures. Loose, wet, sandy soils may lose strength and flow as a fluid when shaken (a process known as liquefaction), causing foundations and underground structures to shift and break.

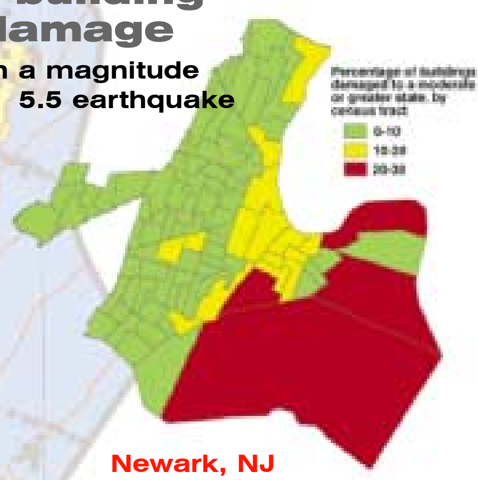




Newark, NJ

simulated building damage

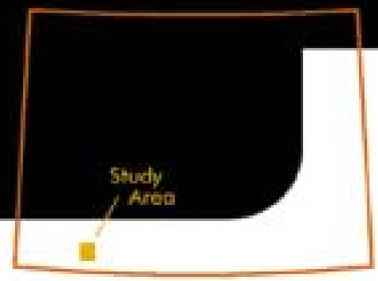
from a magnitude 5.5 earthquake



Newark, NJ

Fig. 4. A computer model commissioned by the Federal Emergency Management Agency and now used as a nationwide standard analyzes earthquake factors on a census-tract basis to generate damage estimates.

Colorado



Geologic Maps Identify **Post-Wildfire Hazards**

Vince Matthews (Colorado Geological Survey)
and David Gonzales (Fort Lewis College)

Defining the Problem

Wildfires, such as the Missionary Ridge fire that burned for more than a month in 2002 near Durango, Colorado (Fig. 1), and their **aftermath** can cause subsequent property and environmental damage. Many areas denuded by the **fire** are now susceptible to **rapid erosion** during heavy precipitation with resulting debris flows, or "mudslides."

The Geologic Map

Geologic maps are tools for **evaluating** post-fire, debris-flow **hazards**. The geologic map (Fig. 2) shows the distribution of rock types and surface deposits in relation to topography. The darker yellow pattern (Qfy) shows the location of alluvial fans created by historic **debris flows**. The areas most susceptible to post-fire erosion are the glacial moraine (Qm, A), colluvium (Qc, A), and Cutler Formation (Pc, A).

Applying the Geologic Map

The Missionary Ridge fire illustrates how **geologic** maps can be used to assess and predict natural hazards. Although this 73,000-acre fire was extinguished in July 2002, emergency managers are still planning for, and coping with, post-fire debris flows. Digital mapping capabilities produced color copies of the geologic map soon after the fire for researchers and emergency response teams to use in identifying high-risk debris-flow areas. The digital map also could be added as a layer in a user's GIS database.

Mapping in 2002 shortly after the fire **revealed** a sequence of older debris flows exposed in the incised channel of a modern, fire-induced debris flow that formed after the Missionary Ridge fire (Fig. 3). Associated charcoal layers dated by C14 methods showed a record of **repeated** fire followed by debris flows extending back 4300 years. The cycles of major fires in the Durango area correlated well with a fire sequence established in Yellowstone National Park, hinting at a broader geographic extent of repeated wildfires and debris flow **events**.

Fig. 1. Homeowners and emergency managers are still coping with debris flows and the aftermath of the 2002 Missionary Ridge wildfire near Durango, CO.

Missionary Ridge wildfire

Conclusion

Geologic maps are useful in identifying areas that may be affected by post-wildfire debris flows. **Land-use planners** use these maps to identify potential hazards in areas that are proposed for development and to develop mitigation strategies. The maps can also focus post-wildfire emergency planning on the areas with the highest **likelihood** of debris flows. It is cheaper to avoid or mitigate problems than to repair damage.

geologic map

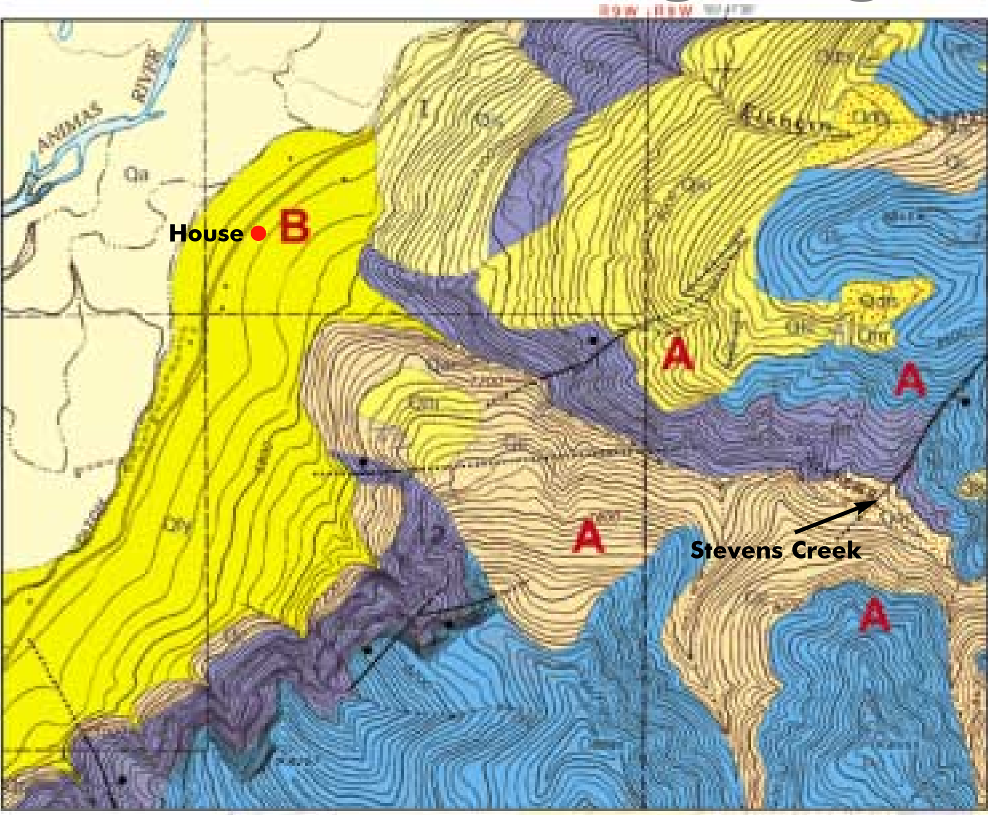
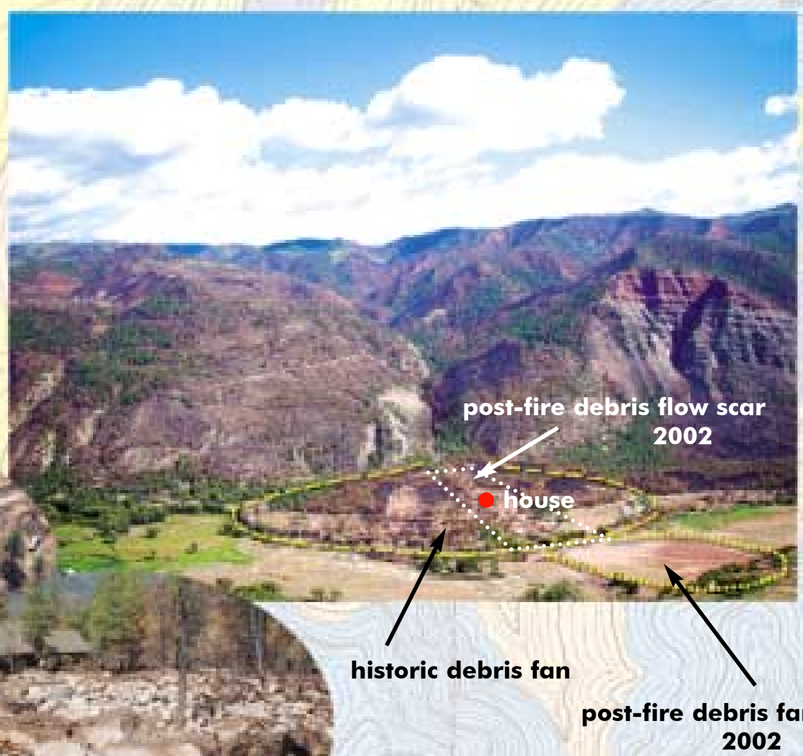
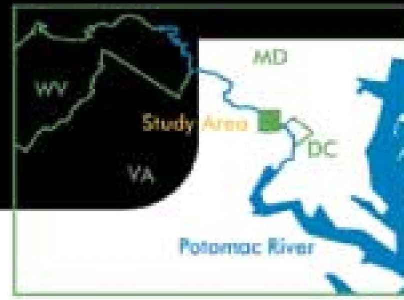


Fig. 2. This part of the Hermosa geologic quadrangle map covers the burn area around Stevens Creek. The darker yellow pattern (Qfy) shows debris fans mapped in 2001. The fan marked B at the mouth of the creek suffered major debris flow activity after the Missionary Ridge fire (Fig. 3). Units particularly susceptible to erosion are the glacial moraine (Qm, A), colluvium (Qc, A), and Cutler Formation (Pc, A).

Fig. 3. Aerial view looking up Stevens Creek at burn area of the 2002 Missionary Ridge wildfire and the debris fan at the mouth of the creek. After the fire, the house, which was built on an ancient debris fan, was engulfed by a debris flow (see map and photos).



Appalachians



Geologic Maps Guide the Delineation of Ecosystems

Scott Southworth, Danielle Denenny (USGS)

10

Example

Defining the Problem

Responsible land management requires a complete and accurate understanding of the location and character of ecosystems, including physical environments, **habitat**, and both native and exotic biota. In the Potomac River gorge area (Fig. 1), man, animals, and water have introduced exotic and alien plants, as well as many native plant communities along the alluvial valleys, flood plains, and terraces. More than 15 **globally rare species** and more than 400 individual occurrences of 200 species rare to Virginia and Maryland are found within 30 different vegetation communities.

The Geologic Map

A geologic map of part of the Potomac River gorge area (Fig. 2) reveals that the bedrock at Great Falls is a complex assemblage of metamorphic and igneous rocks (€Zmg, €Zmm, €Zms, and Ob). These strong, erosion-resistant **rocks** are an important **control** on the topography. Downstream, the sedimentary and metamorphic bedrock is generally less resistant to erosion. Here, erosion deposited young gravels along river channels, and terraces were incised into bedrock. The side slopes of the uplands along the river consist of unconsolidated rock debris (colluvium). The flat terraces are subject to periodic floods that continue erosion but also locally deposit silt. Terraces that are elevated above the river have a veneer of alluvial silt, whereas the terraces along the river are bedrock with only local accumulations of alluvium. These bedrock terraces may contain pinnacles, water-filled potholes, and/or cliffs along their margins.

Fig. 1. Cliffs and terraces along the Potomac River gorge provide habitats for rare plants.

Applying the Geologic Map

Bedrock units on the geologic map have been reclassified according to their rock types (lithology) and general chemistry. The resulting map units are spatially associated with either basic or acidic soil. Surficial deposits were also reclassified on the basis of lithology of clasts and matrix, as well as topographic setting. The new bedrock and surficial deposit units were then combined with a digital elevation model to create the Geo-ecological Landscape Unit Map (Fig. 3). Distribution of upland forest communities is controlled by the type of underlying bedrock, colluvium, or gravel deposits. The detailed maps showing these units are excellent guides for locating the locally unique habitats of the study area.

Conclusion

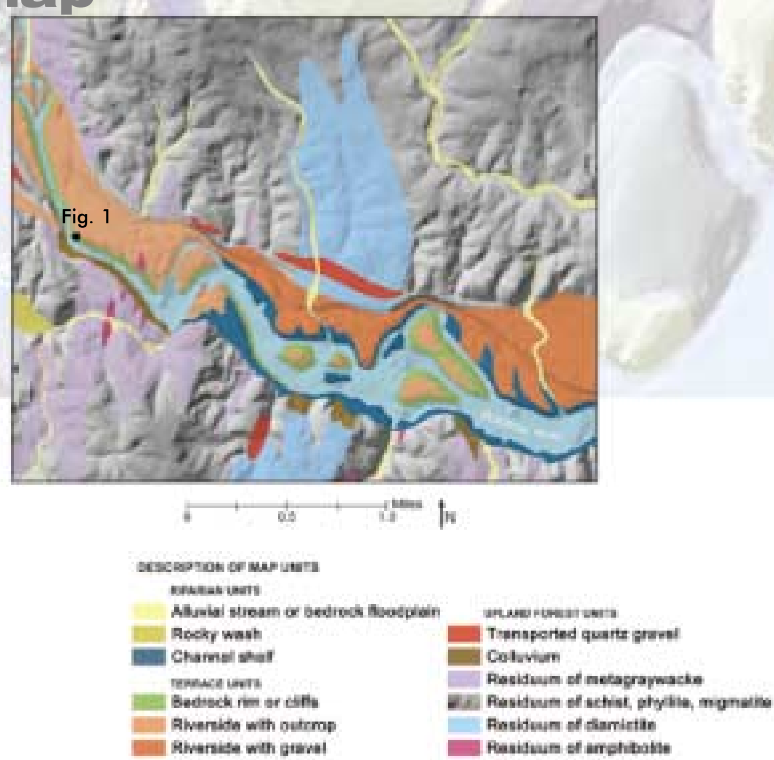
Geology is a major influence controlling habitat development in the Potomac River gorge area where rare plants, critical habitats, and vegetation communities are closely associated with bedrock and surficial units. Individual communities are established on discrete geologic features within the 9700-acre area of the Potomac River gorge. Thus, geologic maps are a valuable resource for improving ecosystem delineation and analysis.

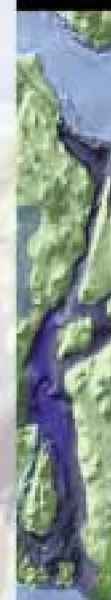
geologic map

Fig. 2. Data from this geologic map of the Potomac River gorge area, Virginia and Maryland was used to produce the Geo-ecological Landscape Unit Map (Fig. 3).

geo-ecological landscape unit map

Fig. 3. The Geo-ecological Landscape Unit Map of the Potomac River gorge area is a valuable tool for land-management planning. Based on geologic map data, the geo-ecological map delineates ecosystem characteristics. The map covers an area containing about 30 vegetation communities.





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Washington

Geologic Map Delineates **Volcanic Hazards**

Joe D. Dragovich and David K. Norman (State of Washington Department of Natural Resources, Division of Geology and Earth Resources)

Defining the Problem

Active volcanoes, such as Glacier Peak (Fig. 1), pose a variety of potential **hazards**. Like Mount Rainier (Fig. 2) and Mount St. Helens (Fig. 3), the history of Glacier Peak includes explosive eruptions and **lahars**. Eruptions, earthquakes, or precipitation can trigger landslides that with the incorporation of water become lahars or mudflows. Lahars and lahar runouts (the dense deposits they form) have been known to travel more than 160 km, and they place infrastructure and people living in valleys draining the volcano at risk (Fig. 4).

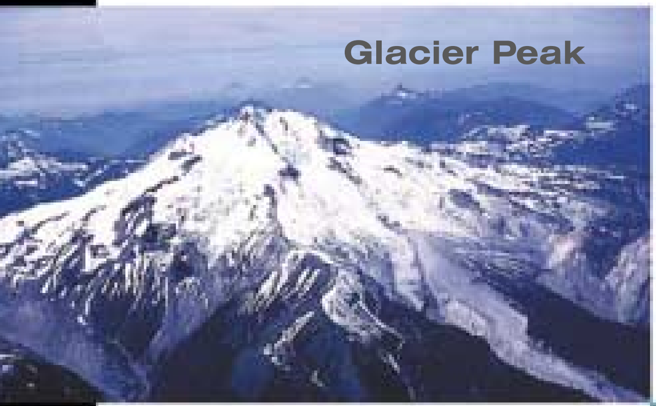
The Geologic Map

Geologic mapping provides information on the frequency, magnitude, distribution, and style of these volcanic events that is useful for **land management planning** and emergency preparedness. The geologic map (Fig. 5) delineates two distinct volcanic eruptions, one about 5000 years ago and the other about 1800 years ago. The 5000-year-old event deposited more than 15 km^3 of material — five times the amount of the 1980 Mount St. Helens eruption.

Applying the Geologic Map

The cities of Lyman, Sedro-Woolley, and Burlington are built on terraces composed of lahar-runout deposits from Glacier Peak volcano. Near the town of La Conner and Puget Sound, 135 km down the valley from Glacier Peak, the lahar-runout deposits are 3 to 18 m thick. Although the frequency of large destructive volcanic events from Glacier Peak is once every few thousand years, the impact of such an event could be catastrophic. Lahars could bury entire towns and valuable agricultural land in the lower Skagit Valley, as well as I-5, a critical transportation corridor between Seattle and Vancouver, B.C. Lahar deposits could also block tributary stream valleys, causing upstream flooding. The lahar dam itself could then be breached by water from the inundated valley causing sudden downstream flooding.

Fig. 1. Although Glacier Peak normally can not be seen from any urban areas, this active volcano periodically erupts in an explosive catastrophic manner that could affect the lower part of the populated Skagit River Valley.



Conclusion

Because lahar deposits are typically composed of saturated deposits of uncompacted sand and gravel, areas underlain by such materials have an increased susceptibility to become lahars during strong earthquakes. Surface and subsurface mapping of lahar and lahar-runout deposits from Glacier Peak volcano contributed important geologic information relevant to land-management planning and **emergency preparedness** in the lower Skagit Valley.

Fig. 2. Mount Rainier threatens Tacoma, WA.

Mount St. Helens

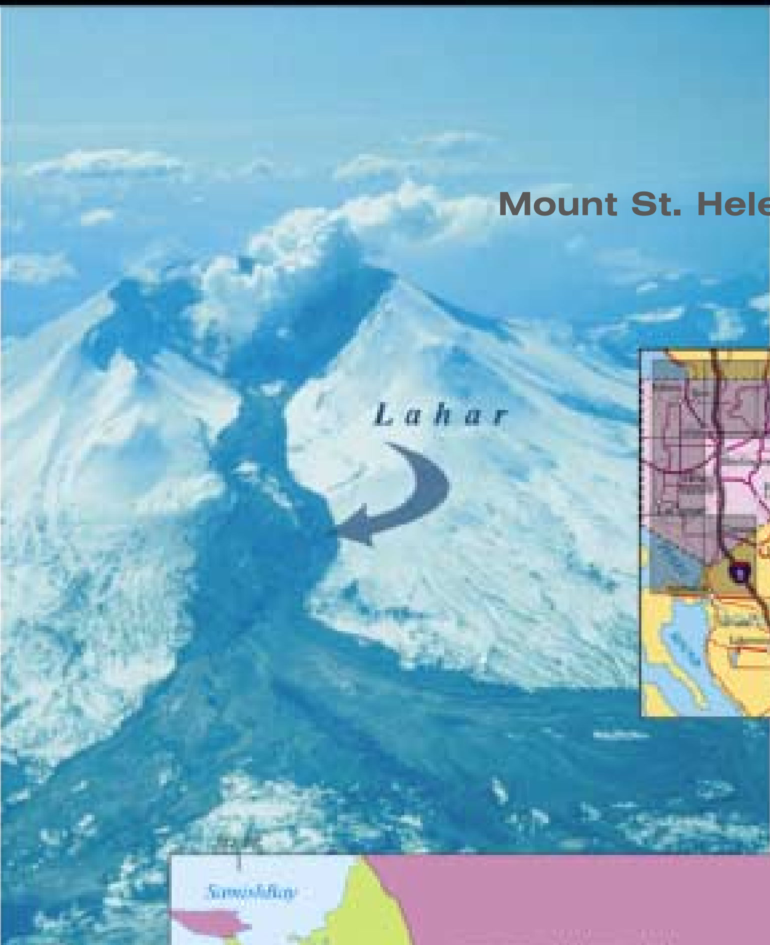


Fig. 3. Lahar racing down the slopes of Mount St. Helens. A lahar is a mud flow consisting of a thick mixture of water and volcanic debris.

area map

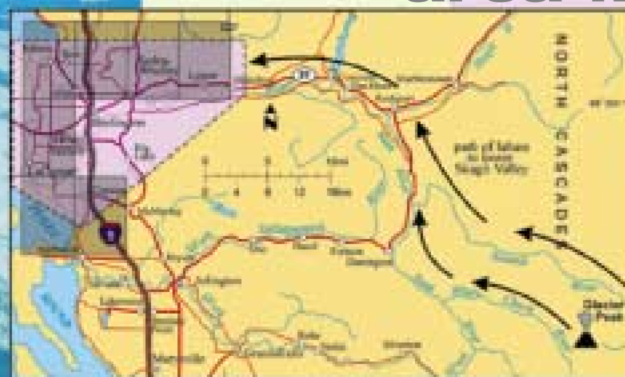


Fig. 4. Note the location of Glacier Peak volcano and the path lahars have taken down stream valleys to reach the plain of the lower Skagit Valley. Gray rectangles indicate geologic mapping study area.

geologic map

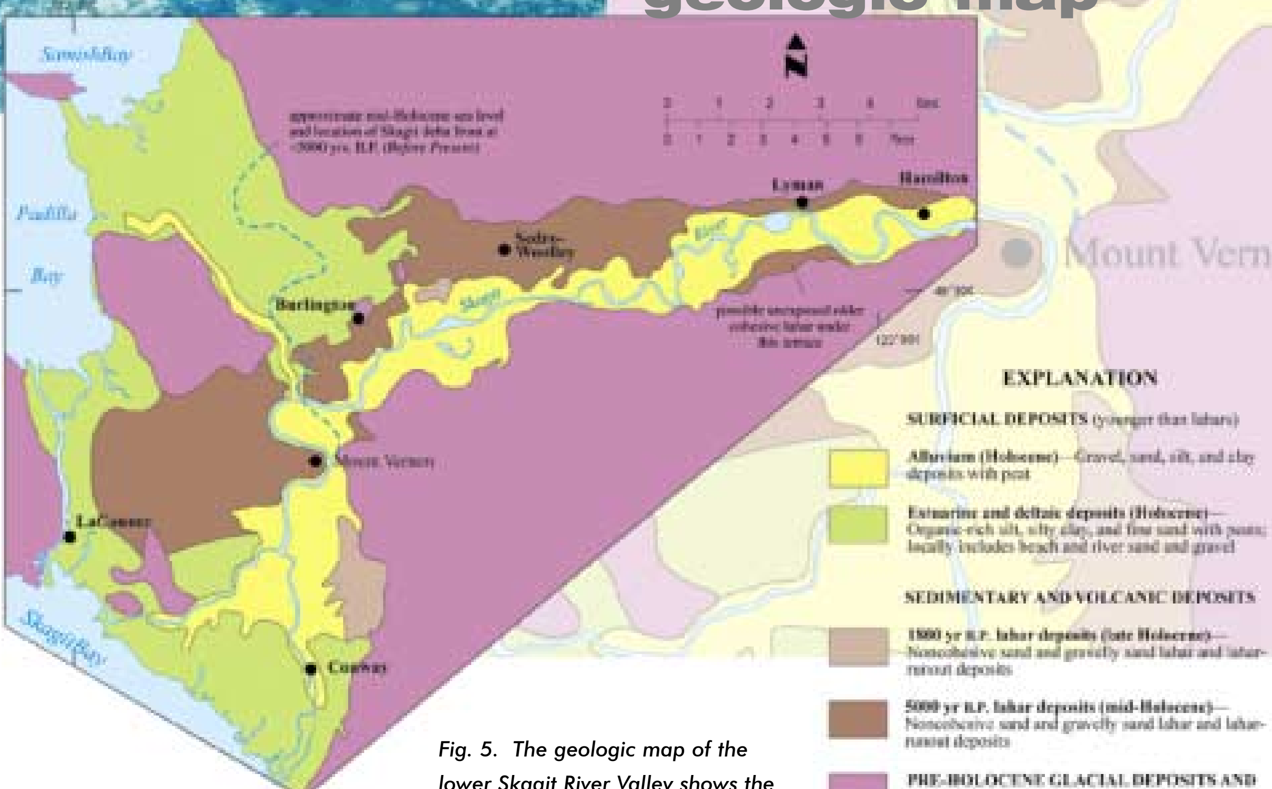


Fig. 5. The geologic map of the lower Skagit River Valley shows the extent of exposed lahar deposits from Glacier Peak volcano. This information is vital to regional and local land planning and emergency preparedness in the area.

Colorado

Geologic Maps Delineate Sand and Gravel Resources

Beth L. Widmann and Jim Cappa (Colorado Geological Survey)

12

Example

Defining the Problem

As population and urban **development** have **escalated** along the Colorado River valley in Garfield County, Colorado, the **demand** for sand and gravel resources has **increased** dramatically (Fig. 1). Sand and gravel are the basic materials used in most construction projects from roads and bridges to house foundations and office buildings. For example, construction of a small house requires an average of 250 tons of rock material. The relatively high cost to transport sand and gravel necessitates that these resources be obtained as close to where they will be used as possible.

The Geological Map

Geologic maps of the Colorado River valley (Fig. 2) show both bedrock and surface units. All of the geologic maps include descriptions of the unconsolidated sand and gravel units (yellow) as well as wind-blown deposits (loess) (yellow with black dots). Bedrock in the areas includes sedimentary rocks of the Tertiary Wasatch Formation (orange) and the Cretaceous Mesaverde Group (green).

Applying the Geologic Map

Geologic maps were the necessary starting point for **delineating** and characterizing sand and gravel resources in a study area. Field observations and map descriptions were used to group surface deposits according to their sand and gravel **resource** potential. Areas of high, good, moderate, and low sand and gravel resource potential were identified and outlined (Fig. 3). High potential sand and gravel areas, Category 1, include recent stream alluvium and terrace gravel characterized by moderately well-sorted, slightly bouldery, pebble- and cobble-gravel in a sandy or silty matrix. Good **potential** sand and gravel areas, Category 2, include glacial deposits, stream alluvium and terrace gravels in tributary drainages, and Colorado River terrace gravel. Moderate potential sand and gravel areas, Category 3, include pediment deposits, older mud-flow and debris-flow deposits, and some alluvial-fan deposits that contain volcanic pebbles and cobbles. Low potential sand and gravel areas, Category 4, include alluvium in some drainages tributary to the Colorado River, some alluvial-fan deposits, and modern debris-flow deposits.

Fig. 1. The flat areas adjacent to the Colorado River are underlain by thick gravel deposits.

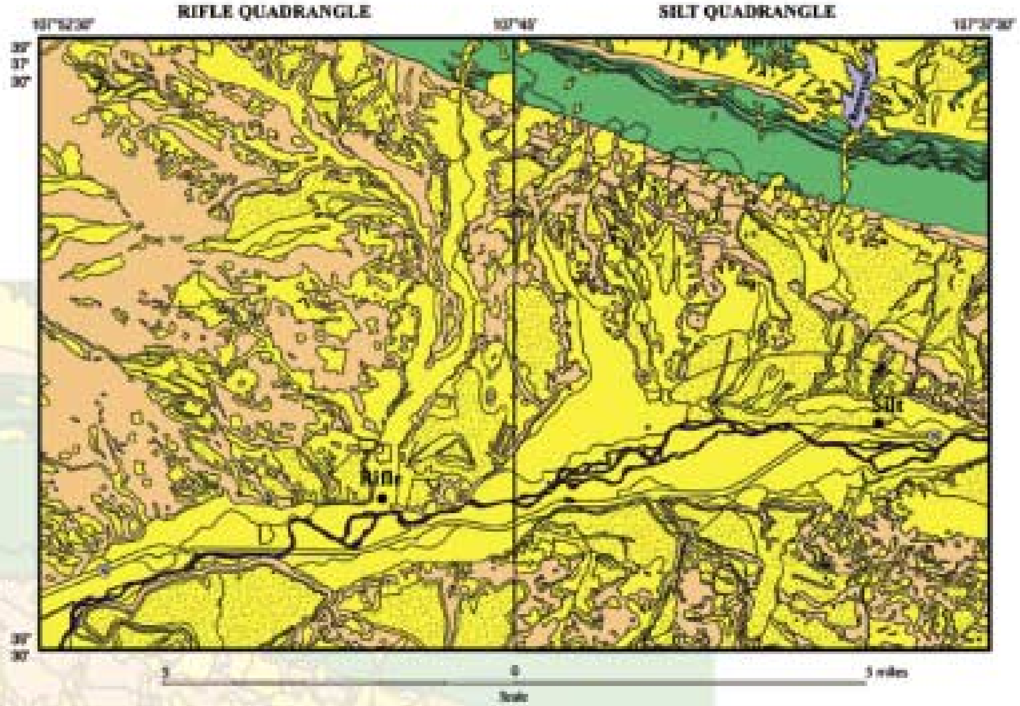
Conclusion

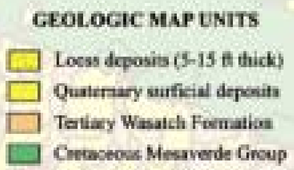
In Garfield County, an area of multiple land uses, geologic maps show the location and quality of the sand and gravel resources. Planners, citizens, and resource developers use this information to **locate** and **evaluate** potential **deposits** and make informed land-use choices.

Construction of a small house requires an average of 250 tons of sand and gravel.

geologic map

Fig. 2. Simplified geologic map of the Rifle and Silt quadrangles in Garfield County, CO. Yellow indicates unconsolidated sand and gravel deposits. Yellow with black dots indicates deposits of wind-blown silt (loess).





resources map

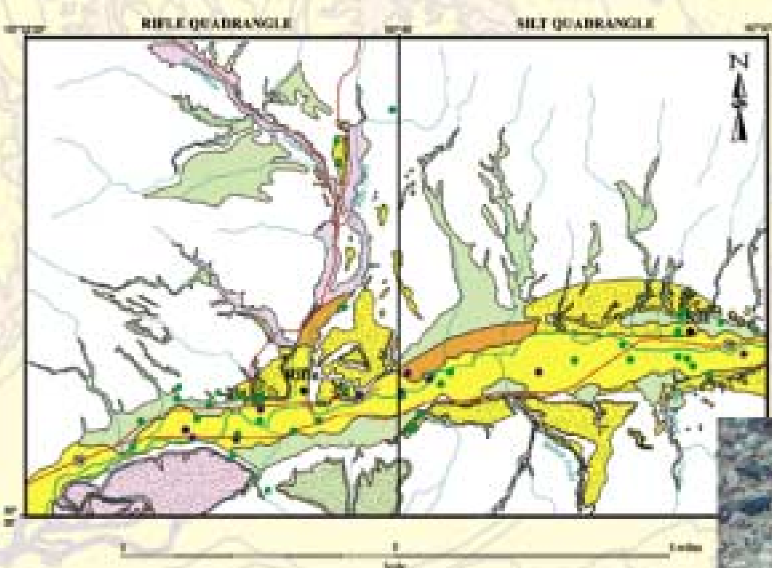


Fig. 3. High potential sand and gravel resources of the Rifle and Silt quandrangles in Garfield County, CO, (yellow) include recent stream alluvium and terrace gravels. Good potential sand and gravel areas (orange) include glacial deposits, stream alluvium and terrace gravels in tributary drainages, and Colorado River terrace gravel inundated with locally derived material.

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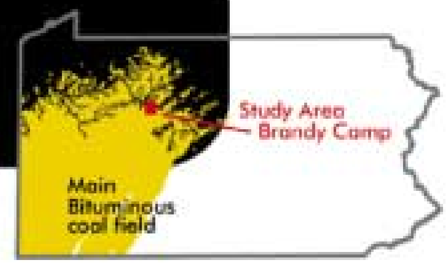
Pennsylvania



Geologic Maps Identify Coal Resources and Past Mining

Clifford H. Dodge (Pennsylvania Geological Survey)

13

Example

Defining the Problem

Despite Pennsylvania's long history as a major **coal** producer, information on the coal geology (Fig. 1), remaining resources, and extent of past **mining** is not available for many areas of the state. Such **information** is critical for present and future coal exploration and development, environmental protection, mine-hazard identification and mitigation, and land-use planning.

The Geologic Map

The geologic maps (Figs. 2 & 4) are from a set of 13 maps for the Brandy Camp quadrangle, Elk County, an area in Pennsylvania's Main Bituminous coal field. The bedrock geologic map (Fig. 2) shows the Allegheny Formation (green), which contains nearly all of the **minable** coals in the quadrangle, and the Glenshaw Formation (yellow), which rarely contains commercial coals. The small inset map (Fig. 3) indicates where the economically important Lower Kittanning coal is present or mined throughout the quadrangle and also shows the area of the two maps in Figs. 2 & 4 (green outline). The coal-resource geologic map (Fig. 4) shows where the coal occurs at land surface (coal crop lines) and depicts areas of known mining. Similar resource maps exist for the other 10 commercial coals in the quadrangle.

Applying the Geologic Map

The maps define the coal geology and coal mining. The locations and areas of past mining are used to estimate remaining coal resources and to **assess potential** or occurring environmental degradation and mine hazards. In particular, information on underground mines, adits, and shafts helps identify sources of acid mine drainage and causes of land subsidence. Locations of underground-mine boundaries are needed to design barriers to separate future operations from past ones. Such barriers help reduce the risk of cutting into older, abandoned workings. The elevation of the Lower Kittanning coal can be determined anywhere on the map from the structure contours. These coal elevations may be used to calculate overburden thicknesses for **resource estimates** and mine planning, to predict mine-pool locations, and to determine mine-water (and groundwater) flow directions. Geologic information from the maps has been used for coal exploration, resource estimation, mine permitting, landfill siting, and acid-mine-drainage abatement. Based in part on this information, the Pennsylvania Department of Environmental Protection issued a permit to a coal company in early 2003 to operate the first new underground mine in this area in more than four decades.

Conclusion

Geologic maps provide critical information for resource exploration and for planners, regulators, decision makers, and the general public.

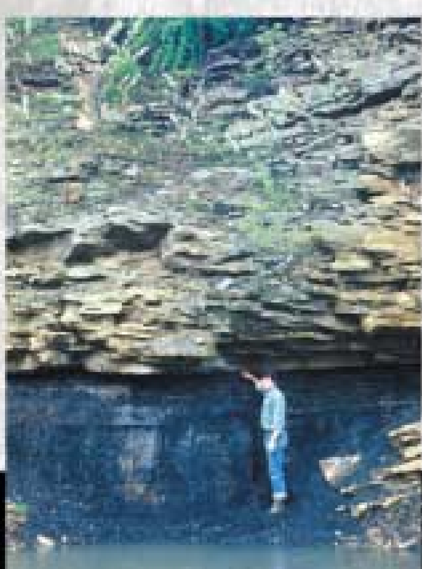


Fig. 1. Exposure of sandstone capping an economic coal bed.

geologic map

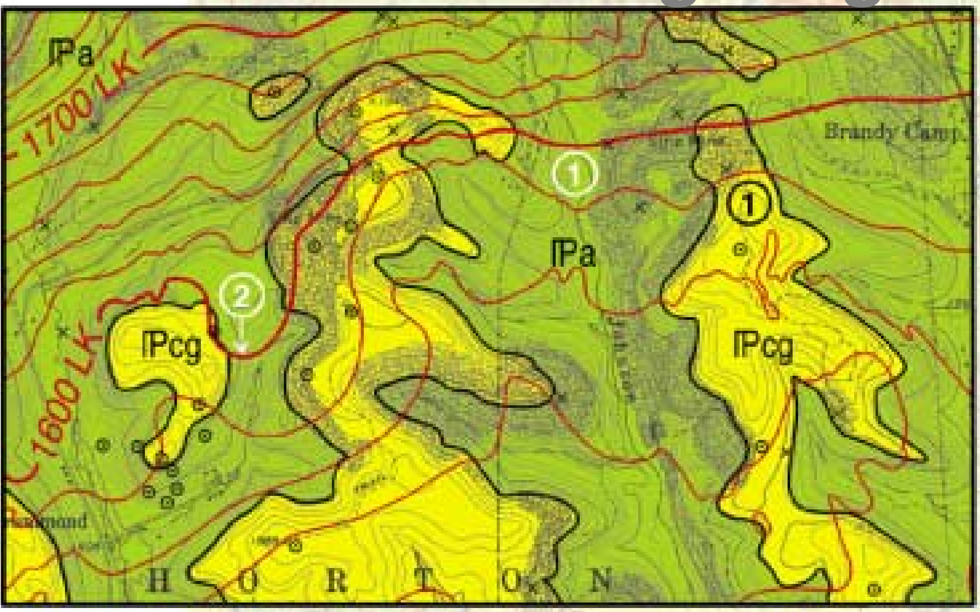


Fig. 2. ① The bedrock geologic map distinguishes between the surface areas underlain by economic coals (Allegheny Formation) and those that are not (Glenshaw Formation). ② Structure contours show the amount and direction the rocks are inclined.

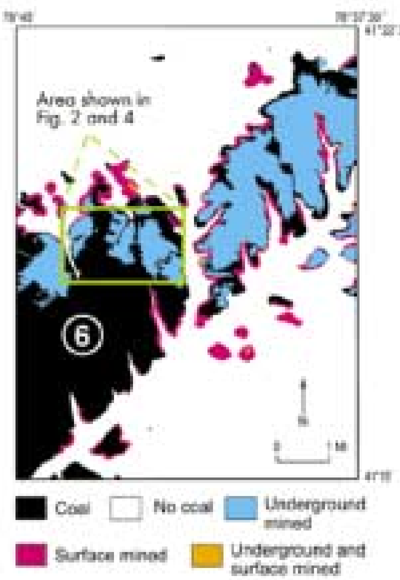


Fig. 3. ⑥ Areas of remaining Lower Kittanning coal.

coal resource map

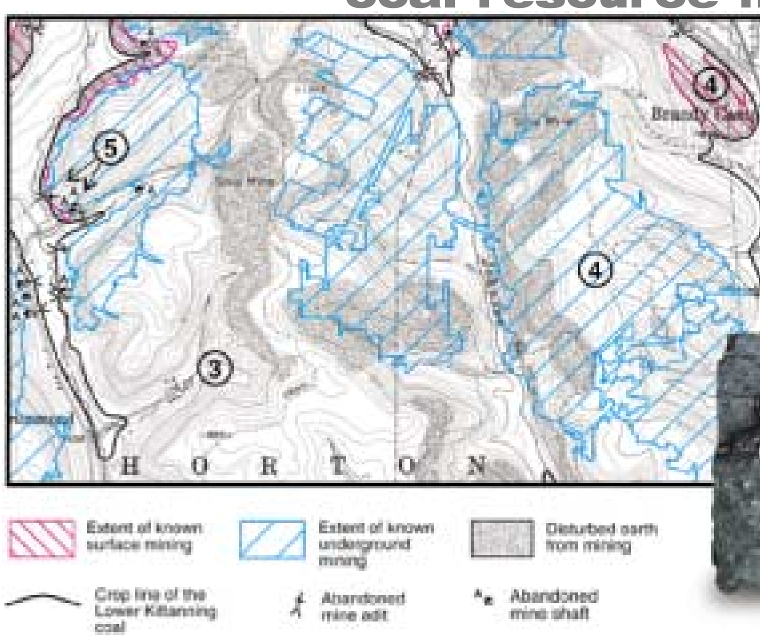


Fig. 4. ③ Areas originally occupied by Lower Kittanning coal. ④ Known extent of surface (red) and underground (blue) mining. ⑤ Locations of mine openings (adits and shafts). Specimen of Pennsylvania bituminous coal.

North Dakota

Geologic Map Guides **Transportation Planning**

Edward C. Murphy (North Dakota Geological Survey)

14

Example

Defining the Problem

U.S Highway 85 and ND Highway 22, along with numerous county roads, buildings, pipelines, and power lines, have been constructed over existing landslides in the Little Missouri Badlands of western North Dakota. Since 1980, the **repair** and **rerouting** of damaged sections of **highways** in this area have **cost taxpayers** more than $5 million (Fig 1). In one instance, a one-mile segment of U.S. Highway 85 was rerouted from one area of landslides into another. Better understanding of landslide hazards is needed in this area.

The Geologic Map

The geologic map encompasses an area of 125 square miles adjacent to the North Unit of Theodore Roosevelt National Park (Fig. 2). In customizing the **map** for use by design engineers, land planners, and developers, several Quaternary river deposits (gray, Qal), were lumped together to make the **landslides** (pink, Ql), stand out more clearly. In addition, the geologic units were draped over a shaded-relief background to further emphasize the relationship between the landslides and the surrounding topography.

Applying the Geologic Map

Approximately 37% of the slopes in the **badlands** in and around the North Unit of the Theodore Roosevelt National Park have failed, and 700 landslides, covering an area of 15,000 acres (6,070 hectares), were identified and mapped in the study area. (Since many of these slides are large complexes, as much as 660 acres (267 hectares) in area, the total number of individual landslides is several times this number.) Most of the landslides are well vegetated, appear relatively stable, and are likely hundreds, if not thousands, of years old (Fig. 3). Without a geologic map showing the location of landslide topography, it is practically impossible for a non-geologist to recognize where there may be a problem. The high percentage of slopes that have failed in this area (1 in 3) demonstrates that the badlands **topography** is very **unstable**. Avoiding areas that have already failed will not guarantee that all slope-stability problems will be avoided, but should reduce the number of future impacts.

Conclusion

The high density of unstable lands in this area makes it difficult to avoid siting infrastructure on old landslides. However, if a geologic **map** is not consulted during the initial planning phase of a project, it is impossible to avoid these problem areas. In general, geologic maps can be expected to **delineate controls** on landslide occurrence and therefore directly assist in making optimum engineering design choices for needed infrastructure.

Fig. 1. Two recent landslides impacting ND Highway 22 along the south edge of the Little Missouri River Valley. It cost $2 million to stabilize the area and realign the road.

geologic map

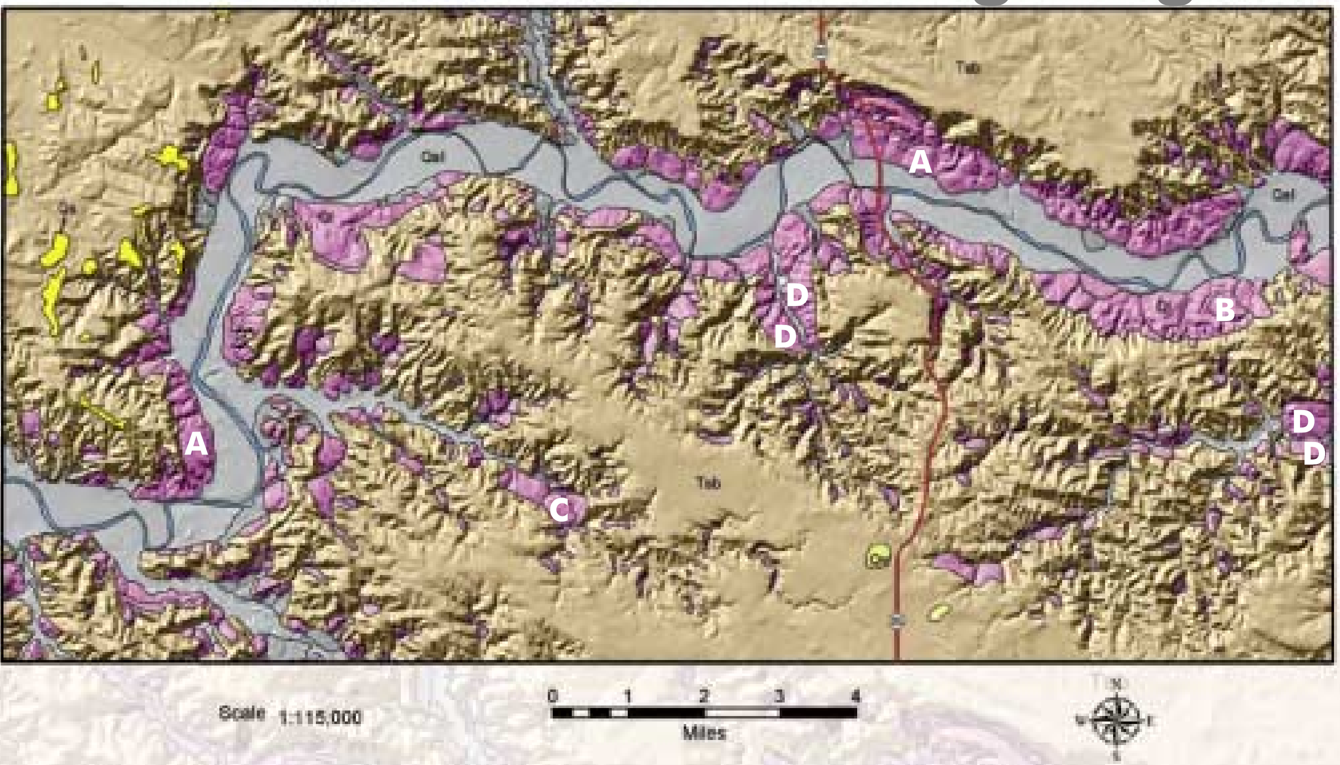
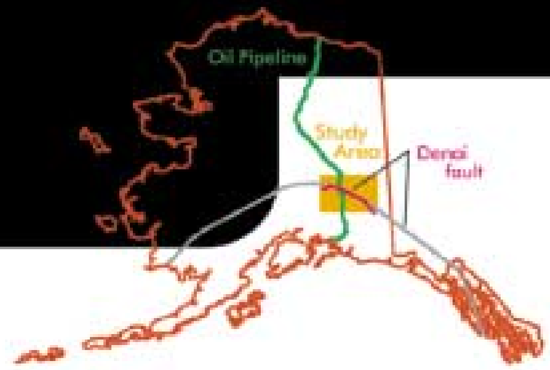


Fig. 2. *In the region where U.S. Highway 85 crosses the Little Missouri River Valley, alternating beds of sandstone, siltstone, claystone, mudstone, and lignite in the Sentinel Butte Formation (Paleocene) are the dominant rock units. Landslides are most prevalent along the sides of the Little Missouri River Valley (A), and landslide complexes may extend for more than five miles (B). Landslides occur throughout the extent of the adjacent drainages including the heads of ravines (C). Landslides do not appear to have occurred preferentially on specific slopes such as east-west or north-south (D). Thin deposits of sand and gravel (Qs) and windblown silt (Qw) are present in the uplands.*

Fig. 3. U.S. Highway 85 crossing the Little Missouri River at Long X Bridge. Seventy-five percent of the rocks in this photograph, all of those in the foreground and the rocks along the north valley wall in the background (below the top of the Ql labels), have slid and are out of place.

Alaska



Geologic Map Aids Mitigation of **Earthquake Damage**

George Plafker (U.S. Geological Survey)

15

Defining the Problem

The 800-mile long **Trans-Alaska Pipeline** can carry 2 million barrels of oil per day — equal to 17% of the nation's daily consumption. A major earthquake along the Denali Fault where the pipeline crosses the Delta River in the rugged Alaska Range, could cause a potentially **catastrophic** oil spill.

The Geologic Map

Geologic mapping of bedrock and unconsolidated deposits along the 1,000 mi. extent of the **Denali Fault** revealed a long and complex history that involved large-scale dominantly horizontal right-lateral slip, as well as local vertical separations (Fig. 1). The geologic map (Fig. 2) shows the distribution of several regional terranes, as well as many local details, along the active fault.

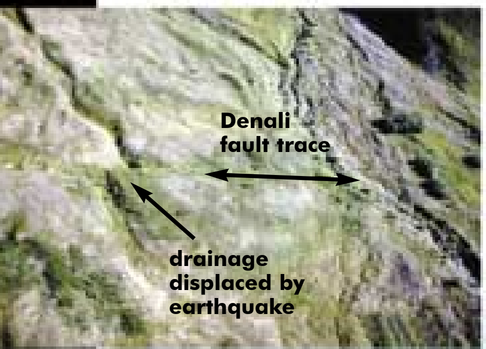
Applying the Geologic Map

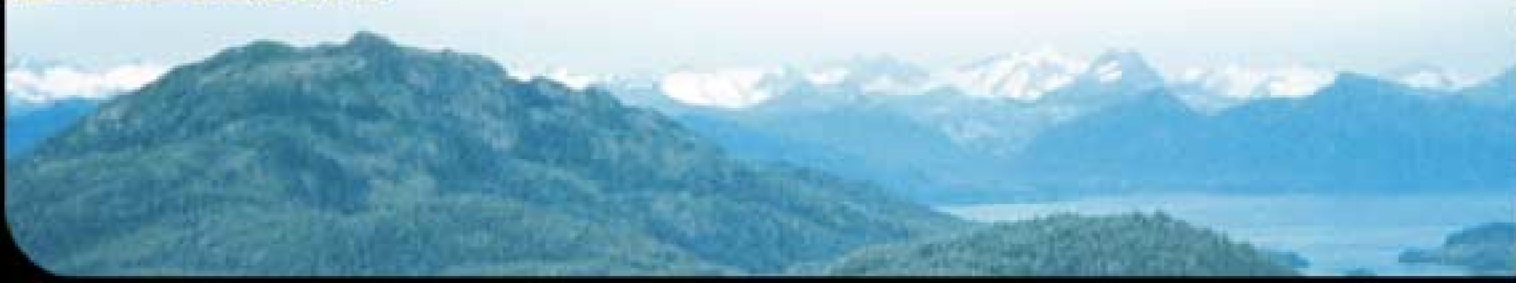
By matching geologic units of known age on opposite sides of the fault, geologists determined that horizontal offset totals about 280 mi. since Early Tertiary time (55-65 million years ago): about 22 mi. since early Oligocene time (38 million years ago); and 98-164 yds. since the late Pleistocene glacial maximum (8,000-12,000 years ago). On the basis of the relative freshness of **fault** features, it was determined that the eastern 220 mi. of the Denali and Totschunda fault system — including the pipeline **crossing** — was the most likely segment to have movement which could generate an 8+ magnitude earthquake.

Conclusion

On November 3, **2002**, the magnitude 7.9 **earthquake** generated by movement along the Denali fault and the Totschunda fault was the largest ever recorded in North America from a dominantly strike-slip event. Horizontal and vertical surface fault offsets were as much as 30 and 3.3 ft. respectively, and violent and prolonged shaking triggered thousands of landslides and avalanches. The **pipeline** remained intact despite ground offset beneath the pipeline of 18 ft. horizontally and 3.3 ft. vertically within a zone about 230 ft. wide, and violent shaking. Survival of the pipeline was a **triumph** of innovative engineering design that met stringent earthquake design specifications (Fig. 3). The pipeline was able to withstand the largest recorded earthquake for the Denali fault without spilling a drop of oil and with only 3 days shutdown time for inspections. The survival of the pipeline demonstrates the value of combining careful **geologic studies** of earthquake hazards and creative engineering design.

Fig. 1. An earthquake offset the drainage shown in this 1976 aerial view of the Denali Fault by 26 ft. horizontally and 5 ft. vertically. Sites such as this one provided the data for designing the pipeline fault crossing.





geologic map

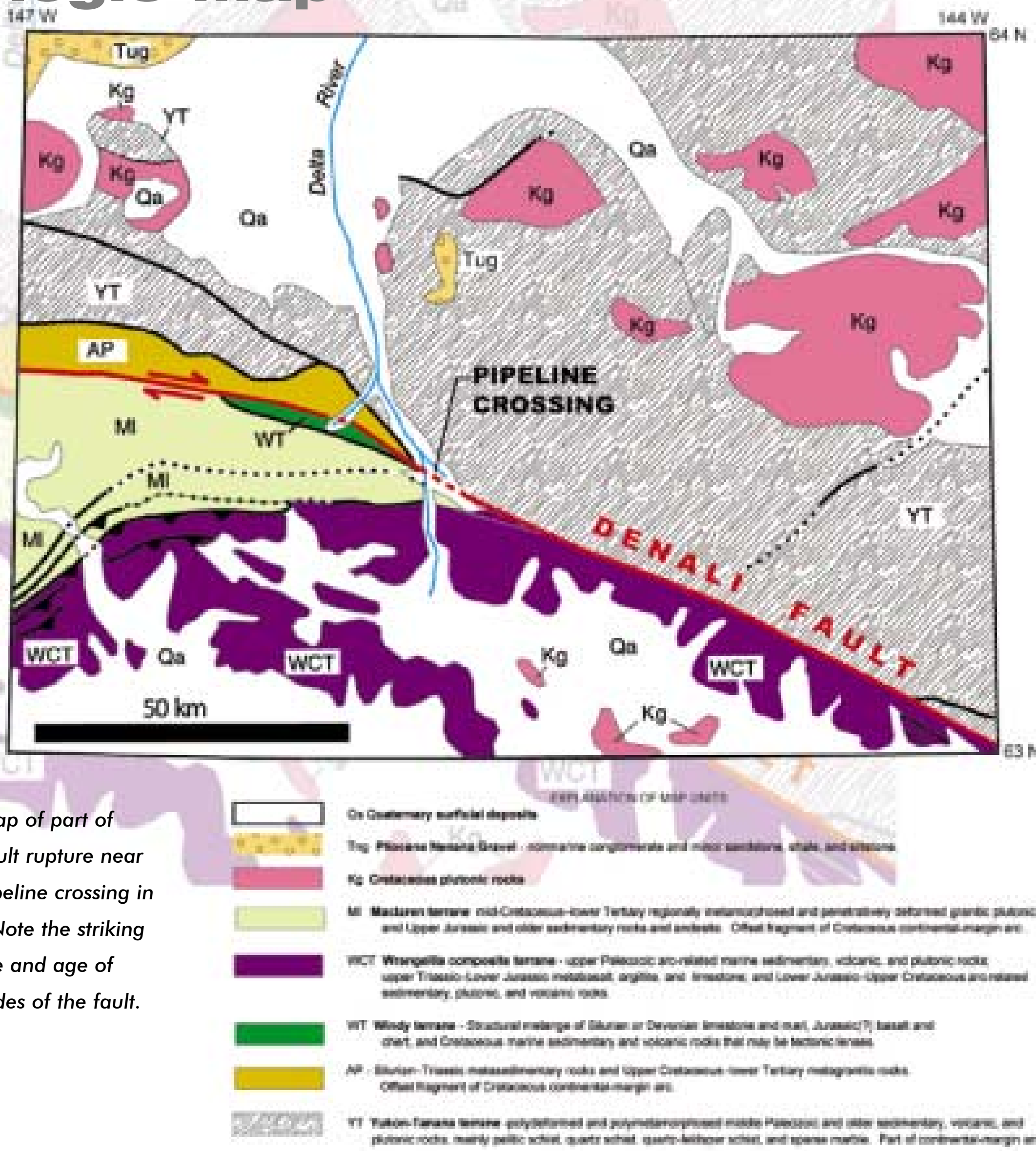


Fig. 2. Geologic map of part of the 2002 Denali Fault rupture near the Trans-Alaska Pipeline crossing in the Alaska Range. Note the striking contrast in rock type and age of units on opposite sides of the fault.

Fig. 3. View of part of the Trans-Alaska Pipeline at the Denali Fault showing major design features. Fault movement and intense ground shaking were accommodated by zigzagging the pipeline and leaving it free to slide by supporting it on Teflon shoes mounted on long horizontal steel slider beams that parallel the fault trend. This slider design was used in a corridor 1900 ft. wide to accommodate uncertainties in the exact position of the fault trace at the pipeline crossing.

New Mexico

Using Geologic Maps to Find Groundwater

Peggy S. Johnson (New Mexico Bureau of Geology and Mineral Resources)

16

Defining the Problem

The **population** of the historic village of Placitas, New Mexico, in the picturesque and geologically complex Sandia foothills north of Albuquerque, has **tripled** since 1970. Increased domestic well development, combined with persistent **droughts**, have culminated in dry and depleted wells (Fig. 1), reduced discharge from perennial springs, reduced property values, and a growing awareness of the potential for aquifer **depletion**.

The Geologic Map

The Placitas area straddles the geologic boundary between the Sandia Mountains and the Albuquerque Basin of the Rio Grande rift (Fig. 2). The availability of potable groundwater is highly variable and controlled entirely by the complicated geology of the region. The geologic map (Fig. 3) enables us to better understand these controls and the **complexity** of this tectonically dynamic region. The geologic units exposed in Placitas vary from Precambrian granite and gneiss to Paleozoic limestone and sandstone, a variety of fine-grained Mesozoic sedimentary rocks, and Cenozoic alluvium composed of 23.7-million- to 700,000-year-old Santa Fe Group basin fill. Major **faults** in the region, including the complex Placitas fault zone, dissect the Paleozoic and Mesozoic strata (Fig. 4).

Applying the Geologic Map

In this region, faults and stratigraphic barriers compartmentalize groundwater into small isolated bedrock aquifers, control the movement of mountain recharge, and affect water potability and availability. Digital geologic maps provided the geologic framework for a three-year **hydrogeologic** study of this maze of aquifers and aquitards (confining beds). When combined with subsurface geologic information from water well records, the maps provided a basis for locating water-level monitoring and water-quality sampling networks. By synthesizing these data, the **study** was able to delineate the locations of aquifers, aquitards, hydrologic boundaries, and preferential flow pathways (Figs. 5).

Conclusion

The geologic and groundwater mapping products support county land use and planning decisions in this rapidly developing area. State water agencies, planners, developers, home owners, home buyers, real estate agents, and county officials **use** the maps to support an array of decisions regarding water rights, lot size, well placement, water system design, and other land use decisions. Similar applications of geologic **maps** are being used throughout New Mexico.

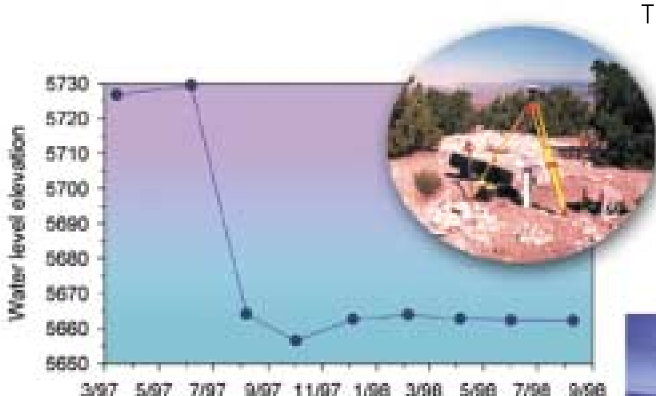


Fig. 1. A groundwater hydrograph from a domestic well completed in an isolated sandstone of the Cretaceous lower Mancos Shale. The water level dropped about 70 ft in one year and the well subsequently went dry.

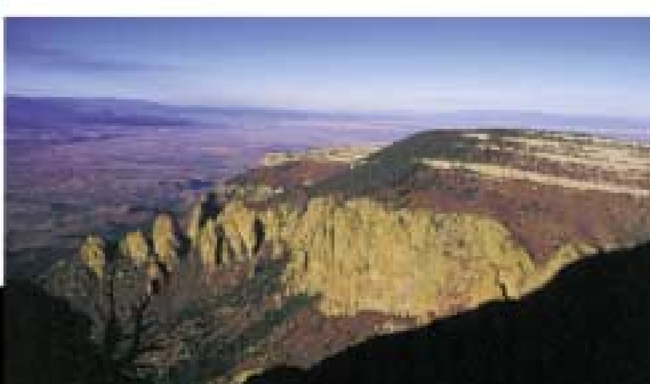


Fig. 2. The Sandia Mountains, looking north along the crest into the Albuquerque Basin.

geologic map

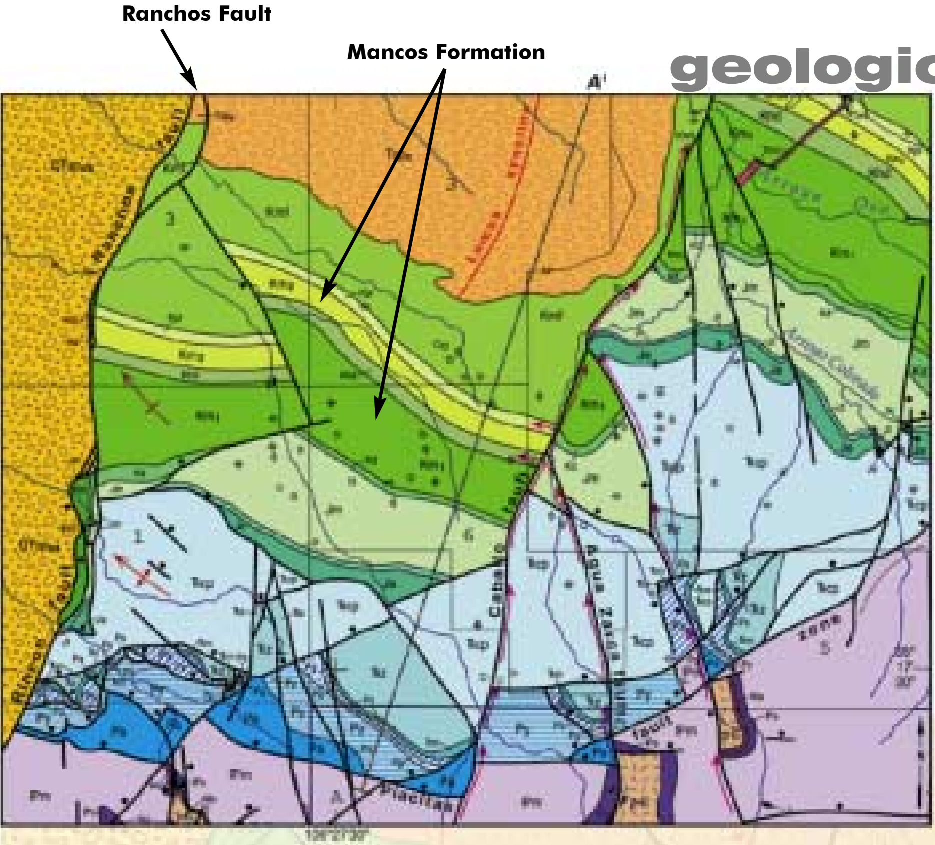
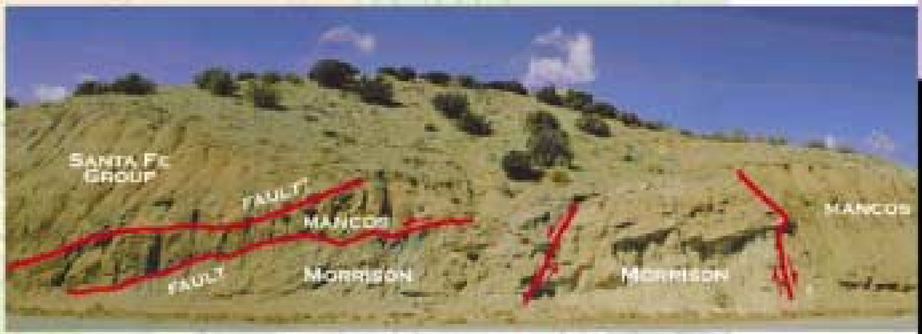


Fig. 3. A portion of the geologic map of the Placitas area shows that major faults and structures have disrupted the largely sedimentary formations. Red arrows mark the preferential groundwater flow pathways.

References

A downloadable PDF version of the Placitas 7.5-minute geologic map and a CD-ROM describing the report *Hydrogeology & Water Resources of the Placitas Area, Sandoval County, New Mexico* (NMBGMR Open File Report 469) are available at http://geoinfo.nmt.edu/publications/home.html.

Fig. 4. This road cut shows the Ranchos fault zone west of Placitas, where older Mesozoic strata (Mancos and Morrison formations) are faulted against younger Santa Fe Group basin fill. This rift-margin fault is associated with a major hydrologic discontinuity.



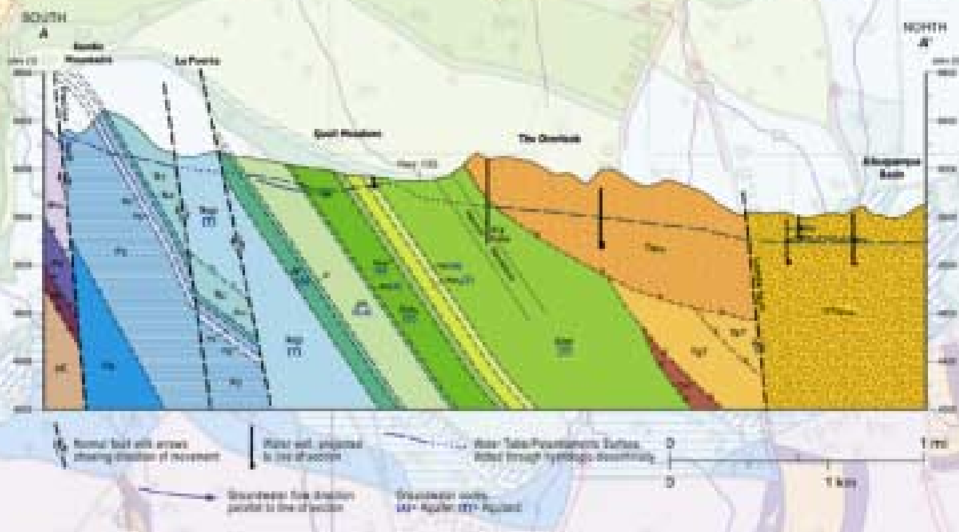


Fig. 5. This geologic cross section through the Paleozoic and Mesozoic strata in Placitas, NM, shows sub-vertical strip aquifers (A) layered between aquitards (T). Aquitards are the less-permeable rock layers confining the aquifers.

Glossary

alluvium
Unconsolidated mud, silt, sand, or gravel deposited in recent geologic time by a stream or other running water.

aquifer
A rock that has sufficient open space, either between particles or in fractures, to yield economically significant quantities of groundwater to wells and springs.

extrusive igneous rock
Igneous rock that crystallized from a magma on the Earth's surface. Origins of extrusive igneous rocks include, for example, lava flows, spatter-cone volcanoes, volcanic bombs, and submarine pillow lavas.

fault
A fracture within rocks along which the rocks on one side are moved (displaced) relative to those on the other side. Earthquakes are associated with movement along faults.

fold
A curve or bend of rock layers, either sedimentary beds or foliation in metamorphic rocks.

fold hinge
The point of maximum curvature or bending of rock layers within a fold.

foliation
A planar arrangement of mineral particles, appearing as layers, within a metamorphic rock, caused by metamorphism.

formation
A fundamental map unit that is of sufficient thickness for practical tracing of boundaries on a geologic map. In a sedimentary succession of many beds (layers), each bed must be assigned to a formation. Formations may be combined into groups or divided into members. Between the upper and lower boundaries, a formation may contain a single type of rock or an alternation of two or more types of rocks.

fossil
Any evidence of past life, including, for example, shells, bones, petrified wood, imprints, and tracks.

intrusive igneous rock
Igneous rock that crystallized from a magma at a location surrounded by older rocks beneath the Earth's surface. Shapes of intrusive igneous rocks range from flat slabs that fill cracks in older rocks to large masses with irregular boundaries.

joint
A fracture within rocks along which the rocks are parted, but the separated rocks do not move relative to each other.

magma
Melted rock material generated at high temperatures within the Earth and capable of intrusion or extrusion, from which igneous rocks are crystallized.

metaigneous rock
A metamorphic rock that originated as an igneous rock and was later metamorphosed.

metasedimenary rock
A metamorphic rock that originated as a sedimentary rock and was later metamorphosed.

sediment
Loose particles of mud, silt, sand, or gravel.

sedimentary bed
A single layer of a sedimentary rock.

structure
A general term for the geologic arrangement or relative positions of rock masses, including folds and faults.

unconformity
A gap in the geologic record where one rock unit is overlain by another that is not next in geologic age. An unconformity represents an interruption in the succession of deposition of sediment or a time of erosion of older sedimentary, igneous, or metamorphic rocks followed by deposition of younger sediment. Types of unconformities include: angular unconformity (layers of sedimentary rock above and below the unconformity are not parallel, indicating tilting or folding of older layers, followed by erosion and later deposition of younger sediment); disconformity (layers of sedimentary rock above and below the unconformity are parallel, but a gap in the geologic time record indicates a time of no deposition or erosion between the times of deposition of older and younger layers of sedimentary rock); nonconformity (sedimentary layers rest on an eroded surface on igneous or metamorphic rocks that have no sedimentary layering, so that no angular relationships can be determined).

unconsolidated surficial materials
Sediment that is loosely arranged so that the particles are not cemented together.

Credits

Front Cover — Gravel (B. Widmann); Water (Digital Vision); Lava (Digital Vision); Missionary Ridge fire (P. Winkworth); Nevada gold (J. Scovil); Digital U.S. Geologic Map (Modified from Schruben and others, 1994, USGS).

Inside Front Cover/Title Page — Digital U.S. Geologic Map (Modified from Schruben and others, 1994, USGS).

Copyright/Contents — Earth (NASA); Digital U.S. Geologic Map (Modified from Schruben and others, 1994, USGS).

Foreword/Preface — W. Smith map, 1815, (IPR/47-4C British Geological Survey. ©NERC. All rights reserved.); Digital U.S. Geologic Map (Modified from Schruben and others, 1994, USGS); Grand Teton Mountains and Grand Canyon (W. Thomas); Water (Digital Vision); Earth (NASA).

Geologic Maps for Many Uses

Page 6 — Fig. 1, W. Smith map, 1815, (IPR/47-4C British Geological Survey. ©NERC. All rights reserved.).

Page 7 — Fig. 2, New York City, Cabin in eastern KY (W. Thomas); Fig. 3, Veranzo Narrows Bridge, Hoover Dam (W. Thomas); Fig. 4, Sinkhole (Files of the Florida Sinkhole Research Institute courtesy of B. Beck, original photographer unknown).

Interpreting Geologic Maps

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Grand Canyon

Page 9 — Fig. 6, Grand Canyon (W. Thomas); Digital U.S. Geologic Map (Modified from Schruben and others, 1994, USGS).

Pages 10-11 — Fig. 6 cont., Geologic map symbols (J. DeAtley, modified from W. Thomas); Grand Canyon photos (W. Thomas); Map (J. Maxson, 1967, *Preliminary geologic map of the Grand Canyon and vicinity, Arizona*: Grand Canyon Natural History Association, scale 1:62,500).

Map Units

Page 12 — Fig. 7, Mississippi River flood plain (W. Thomas); Layer cake illustration (J. DeAtley); Grand Canyon (W. Thomas); Fig. 8, Map, (R. Orndorff et al,1999, Geologic Quadrangle Map GQ-1803, USGS); Gravel (B. Widmann); Digital U.S. Geologic Map (1994, USGS).

Page 13 — Fig. 9, Isis Temple (W. Thomas); Map and cross section (J. Maxson, 1961, *Geologic map of the Bright Angel quadrangle, Grand Canyon National Park, Arizona*: Grand Canyon Natural History Association, scale 1:48,000).

Page 14 — Fig. 10, Time Scale (J. DeAtley, adapted from various sources).

Page 15 — Fig. 11, Strike & Dip illustration (J. DeAtley, modified from W. Thomas); Brunton Compass (Brunton); Fig. 12, Folded rocks (W. Thomas).

Page 16 — Fig. 13, Map (*Geologic map of West Virginia*: West Virginia Geological and Economic Survey, scale 1:250,000; Photo (W. Thomas).

Page 17 — Fig. 14, Mount St. Helens (USGS); Lava (Digital Vision); Fig. 15, Map, (R. O'Sullivan and H. Beikman, 1963, USGS Miscellaneous Investigations Map I-345; (Shiprock (H. James).

Page 18 — Geologic Map (USGS, MF-2342); Fig. 16, Photos a.& b. (W. Thomas) c. (R. Hatcher); Fractured rock (W. Thomas).

Page 19 — Fig. 17, Photos a. & b. (W. Thomas); Fig. 18, Geologic map and cross section (Kentucky Geological Survey); Clays Ferry bridge (University of Kentucky Transportation Research Center).

U. S. Geologic Map

Page 21 — Fig. 19, Digital map (Modified from P. Schruben et al, 1994, *Geology of the Conterminous United States at 1:2,500,000 scale — a digital representation of the 1974 P.B. King and H.M. Beikman Map*, USGS).

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Page 23 — Fig. 22 Geologic map (Geology by R. Hatcher).

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Page 24 — Fig. 23, (C. Ruthven et al., 2003, *Geologic Maps and Geologic Issues in Kentucky: A Citizen's Guide*, Special Publication 3, Kentucky Geological Survey).

Page 25 — Fig. 24, Geologic map (New Mexico Bureau of Geology and Mineral Resources).

Page 26 — Fig. 25, Lithologic map (De Atley Design, Adapted from Geological Investigation Series Map 1-2654, USGS).

Pages 28-29 — Fig. 1, Castle and Fluted Wall (© J. Wilson); Fig. 2, photos (T. Clark, National Park Service); Fig. 3, Digital geologic map (Adapted from Billingsley et al. 1987); Fig. 4, Geo-ecological map (Connors Design, adapted from Geologic Map of the Fruita 7.5 minute quadrangle, Wayne County, Utah, BYU unpublished map).

Pages 30-31 — Fig. 1, Cave entrance (© B. Davidson); Fig. 2, Sinkhole, Barren County, Kentucky (© J. Currens); Fig. 3, Geologic map (Kentucky Geological Survey), Fig. 4, Cross section (adapted from J. Quinlan and R. Ewers, 1985, *Groundwater flow in limestone terranes: rationale for a reliable stragegy for efficient monitoring of ground water*); Fig. 5, Karst map (Kentucky Geological Survey).

Pages 32-33 — Fig. 1, Gold (J. Scovil); Fig. 2, Map (S. Moore, 2002, *Geology of the northern Carlin trend*, Nevada Bureau of Mines and Geology Bulletin 111, 204 p., 1:12,000 scale.); Fig. 3, Tertiary dike (J. Price).

Pages 34-35 — Fig. 1, House (J. Charlton, Kansas Geological Survey); Fig. 2, Geologic Map (from McCauley, 1998); Fig. 3, Landslide Map (adapted from Ohlmacher, 2003); Fig. 4, Hazard Map (from Ohlmacher and Davis, 2003).

Pages 36-37 — Fig. 1, Sinkhole (D. Brezinski); Fig. 2, Geologic map (from D.K. Brezinski, in progress); Fig. 3, Sinkhole susceptibility & Table 1 (from Brezinski and Reger, 2002)

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Pages 40-41 — Fig. 1, Quarry (E. Osborne); Fig. 2, Map (W. Ward, 2002, *Geology of the Pell City 7.5-minute quadrangle, St.Clair and Talladega Counties, Alabama*: Alabama Geological Survey); Fig. 3, Cross section (W. Thomas); Fig. 4, Diagram (J. DeAtley adapted from W. Thomas); Fig. 5, Farm (E. Osborne).

Pages 42-43 — Fig. 1, Newark (N. J. Department of Environmental Protection, 1995); Fig. 2, Geologic map and cross section (N. J. Geological Survey, Open-File Maps OFM 41 and OFM 42, 2002); Fig. 3, Seismic soil properties; Fig. 4, Simulation (N. J. Geological Survey, Earthquake Loss Estimation Study for Essex County, New Jersey, 2001).

Pages 44-45 — Fig. 1, Fire (P. Winkworth); Fig. 2, Geologic Map of the Hermosa 7.5' quadrangle (Colorado Geological Survey Open File Report 02-1); Fig. 3, Photos (San Juan Composite Squadron of the Civil Air Patrol).

Pages 46-47 — Fig. 1, Potomac Gorge (R Wiegand); Fig. 2, Geologic map (USGS); Fig. 3, Geo-ecological map (S. Southworth and D. Denenny).

Pages 48-49 – Fig. 1, Glacier Peak (D. Mullineaux, USGS); Fig. 2, Mount Rainier (Lyn Topinka, USGS); Fig. 3, Lahar (USGS); Maps, Figs. 4 & 5 (J. Dragovich et al., 2000, *Washington Geology*, v. 28, no. 1/2, p. 19-21, 59).

Pages, 50-51 — Fig. 1, Colorado River (B. Widmann, Colorado Geological Survey; Fig. 2, Geologic map (USGS); Fig. 3, Resources map (USGS), Gravel (B. Widmann, Colorado Geological Survey).

Pages, 52-53 — Fig. 1, Coal bed (J. Shaulis, Pennsylvania Geological Survey); Fig. 2, Geologic map (C. Dodge, Pennsylvania Geological Survey); Fig. 3, Areas of remaining Lower Kittanning coal (C. Dodge, Pennsylvania Geological Survey); Fig. 4, Resource map (C. Dodge, Pennsylvania Geological Survey).

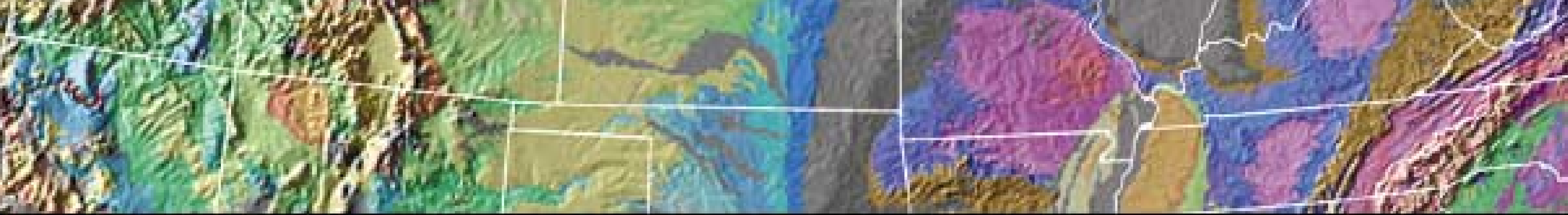
Pages, 54-55 — Photos, Figs. 1 & 3, (E. Murphy); Fig. 2, Geologic map (Geology by E. Murphy; E. Kadrmas, compiler).

Pages, 56-57 — Alaska photo (S. Nelson, USGS, AK); Fig. 1, Fault trace (G. Plafker); Fig. 2, Geologic map (compiled by K. Ridgeway, Purdue Univ.); Fig. 3, Trans-Alaska Pipeline (M. Metz, Anchorage).

Pages, 58-59 — Fig. 1, Hydrograph and photo (P. Johnson); Fig. 2, Sandia Mountains (A. Read); Fig. 3, Geologic map (New Mexico Bureau of Geology and Mineral Resources); Fig. 4, Road cut (L. Price); Fig. 5, Cross section (New Mexico Bureau of Geology and Mineral Resources).

AGI Environmental Geoscience Program/ AGI Foundation

Page 64 — Mountain landscape (Digital Vision)



STATE GEOLOGICAL SURVEYS

Geological Survey of Alabama
www.gsa.state.al.us

Alaska Division of Geological and Geophysical Surveys
wwwdggs.dnr.state.ak.us/

Arizona Geological Survey
www.azgs.state.az.us

Arkansas Geological Commission
www.state.ar.us/agc/agc.htm

California Geological Survey
www.consrv.ca.gov/cgs/

Colorado Geological Survey
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Connecticut Geological and Natural History Survey
http://dep.state.ct.us/cgnhs/

Delaware Geological Survey
www.udel.edu/dgs/index.html

Florida Geological Survey
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Georgia Geologic Survey Branch
www.dnr.state.ga.us/dnr/environ/aboutepd_files/branches_files/gsb.htm

Hawaii Geological Survey
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Idaho Geological Survey
www.idahogeology.org/

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Montana Bureau of Mines and Geology
http://mbmgsun.mtech.edu/

Nebraska Conservation and Survey Division
http://csd.unl.edu/csd.htm

Nevada Bureau of Mines and Geology
www.nbmg.unr.edu

New Hampshire Geological Survey
www.des.state.nh.us/descover.htm

New Jersey Geological Survey
www.state.nj.us/dep/njgs/

New Mexico Bureau of Geology and Mineral Resources
www.geoinfo.nmt.edu

New York State Geological Survey
www.nysm.nysed.gov/geology.html

North Carolina Geological Survey
www.geology.enr.state.nc.us/

North Dakota Geological Survey
www.state.nd.us/ndgs/

Ohio Division of Geological Survey
www.ohiodnr.com/geosurvey/

Oklahoma Geological Survey
www.ou.edu/special/ogs-pttc/

Oregon Department of Geology and Mineral Industries
www.oregongeology.com/

Pennsylvania Bureau of Topographic and Geologic Survey
www.dcnr.state.pa.us/topogeo

Puerto Rico Departamento de Recursos Naturales
www.kgs.edu/AASG/puertorico.html

Rhode Island Geological Survey
www.uri.edu/cels/gel_home/ri_geological_survey.htm

South Carolina Geological Survey
water.dnr.state.sc.us/geology/geohome.htm

South Dakota Geological Survey
www.sdgs.usd.edu/

Tennessee Division of Geology
www.state.tn.us/environment/tdg/

Texas Bureau of Economic Geology
www.beg.utexas.edu/

Utah Geological Survey
http://geology.utah.gov/

Vermont Geological Survey
www.anr.state.vt.us/geology/vgshmpg.htm

Virginia Division of Mineral Resources
www.geology.state.va.us

Washington Division of Geology and Earth Resources
www.wa.gov/dnr/htdocs/ger/ger.html

West Virginia Geological and Economic Survey
www.wvgs.wvnet.edu/

Wisconsin Geological and Natural History Survey
www.uwex.edu/wgnhs/

Wyoming State Geological Survey
www.wsgsweb.uwyo.edu/

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AGI Environmental Geoscience Program

Through the Environmental Geoscience Advisory Committee, the American Geological Institute (AGI) Environmental Affairs Program develops and guides projects that

- Increase public awareness and understanding of environmental issues and the control of Earth systems on these issues,
- Communicate societal needs for managing resources, protection from Earth hazards, and evaluation of risks associated with human activities related to Earth processes and resources,
- Increase dissemination of information related to environmental programs, projects, research, and professional activities in the geoscience community,
- Promote appropriate science in public policy through improved communication within and without the geoscience community related to environmental policy issues and legislation, and
- Identify opportunities for AGI, its member societies, and other contributors to participate in priority environmental projects and activities, such as the Environmental Awareness Series of publications. Publications in the Series, such as *Meeting Challenges with Geologic Maps*, promote better understanding among citizens and policy makers of the role of Earth sciences in all aspects of understanding and mitigating environmental concerns.

The Committee and the Institute gratefully acknowledge the generous support the AGI Foundation has provided for development of the Environmental Awareness Series.

AGI Foundation

The AGI Foundation assists the American Geological Institute in seeking funding and partnerships with foundations, corporations, other organizations, and individuals that share our commitment to create innovative Earth science programs of benefit to all citizens — not just those who will choose geoscience as a career.

The Environmental Awareness Series publications, for example, provide a balanced review and discussion of key environmental geoscience concerns. The colorful booklets and posters in the Series present accurate environmental geoscience information in an easy-to-digest format. AGI has produced the Series with Foundation support — and in cooperation with its member societies and others — to raise public understanding of society's complex interaction with the Earth. In addition to groundwater, soils, metal mining, karst, and petroleum, the Series will cover environmental geoscience concerns related to aggregates, coal, global climate change, and other important topics.

AGI Environmental Awareness Series

Groundwater Primer

Sustaining Our Soils and Society

Metal Mining and the Environment

Living with Karst — A Fragile Foundation

Water and the Environment

Petroleum and the Environment

Meeting Challenges with Geologic Maps

To purchase additional copies of books in the Environmental Awareness Series please contact AGI by mail or telephone, send an e-mail request to pubs@agiweb.org*, or visit the online bookstore at* www.agiweb.org/pubs.

The National Geologic Mapping Act

In the early 1990s Congress recognized that less than 20 percent of the Nation was mapped geologically at the detailed scale needed to make land-use, water-use, and living-resource-use decisions. They realized that those with primary responsibility for geologic mapping, the U.S. Geological Survey (USGS) and state geological surveys, were struggling to keep up with the increasing demand for geologic maps needed for important decision making at local, state, and national levels.

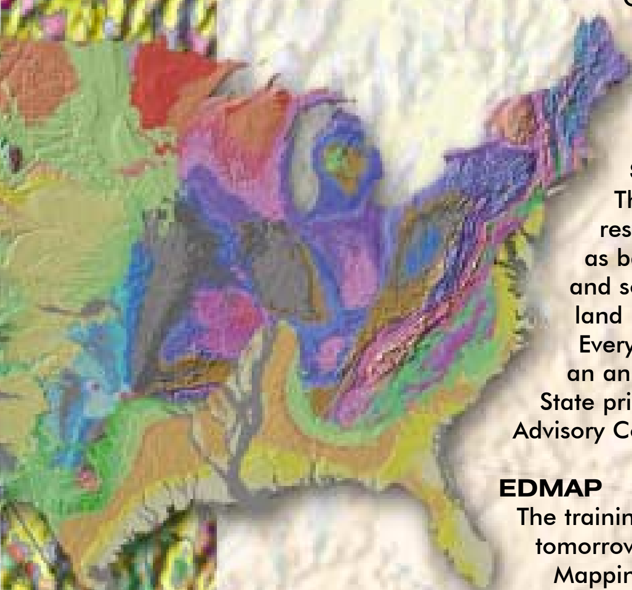
The 102d Congress in 1992 signed into law the National Geologic Mapping Act (Public Law 102-285), a coordinated program between the USGS and state geological surveys to prioritize the geologic mapping requirements of the Nation and to increase production of geologic maps.

The National Cooperative Geologic Mapping Program represents successful cooperation among federal, state, and university partners striving to deliver modern digital geologic maps to the communities that need them. Each partner has a unique role, yet all work cooperatively to determine the areas of highest priority for new geologic mapping.

FEDMAP

The role of the federal partner, the USGS, is to:

- Address issues crossing jurisdictional boundaries between states
- Develop new applications for the resolution of basic earth science processes
- Study federal lands, such as our national parks, to guide wise management of the public lands
- Build the National Geologic Map Database on the Internet to facilitate community access to geologic map information



National priorities are set with the advice of a Federal Advisory Committee and a FEDMAP review panel made up of federal, state, private industry, and academic members. FEDMAP projects address issues related to natural hazards, groundwater resources, energy and mineral resources, and landscape evolution.

STATEMAP

The community partner is the state geological surveys whose responsibilities vary from state to state. The state surveys function as basic scientific information sources for their state governments, and some have regulatory responsibilities for water, oil and gas, and land reclamation. Many are associated with state university systems. Every federal dollar awarded to a state geological survey through an annual competitive grant process is matched by a state dollar. State priorities are set with the advice of a broad-based State Mapping Advisory Committee.

EDMAP

The training partners of the Program are universities whose role is to train tomorrow's geologic mappers. Prior to passage of the National Geologic Mapping Act, the number of university students being trained to do high-quality geologic mapping was in sharp decline. Every federal dollar awarded to a university through an annual competitive grant process is matched by a university dollar. On average, about 70 students from more than 40 universities participate annually. The Program brings together university professors and their students with scientists from the USGS and state geological surveys and provides the students with highly qualified mentors.

Meeting Challenges with Geologic Maps

William A. Thomas
and contributing authors

The first geologic map was prepared to solve a practical problem involving the distribution of different types of rocks at and near the Earth's surface, and that is still the reason geologic maps are made today. Geologic maps are our most important and complete compilation of information about the solid Earth we live on, and we cannot understand the Earth without them. We use geologic maps and the fundamental information they provide in many ways. *Meeting Challenges with Geologic Maps* presents 16 examples that show how geologic maps are helping to delineate fragile habitat and ecosystems, protect against natural hazards (earthquakes, volcanic eruptions, landslides, and sinkholes), and find needed resources (groundwater, metals, coal, and sand and gravel).

Produced by the American Geological Institute
in cooperation with

Association of American State Geologists
Geological Society of America
National Park Service
U.S. Geological Survey

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(703) 379-2480 • www.agiweb.org

AGI Environmental Awareness Series

ISBN 0-922152-70-5

9780922152704 51595

Recycled paper