DRAFT -- To be published in DMT'07 Proceedings
(see http://ngmdb.usgs.gov/Info/dmt/)

The National Cooperative Geologic Mapping Program and Insight Into the Future of Geologic Map Production

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INTRODUCTION

Geologic maps form a primary foundation for virtually all applied and basic earth-science investigations. The process of constructing a geologic map involves basic scientific research on the Earth's history and the processes that operated to form the planet's rocks and surficial materials. The definition of what constitutes a geologic map has changed over the years from a traditional paper product to multi-use digital geologic map databases. In this paper, the term "geologic map" refers to the representation of the geology at the earth's surface, as well as the related subsurface interpretations of the geology, and includes any related databases.

The National Cooperative Geologic Mapping Program (NCGMP) has a mission to produce accurate geologic maps and three-dimensional geologic framework models that provide indispensable data and improved understanding of earth surface processes, ground-water availability, and onshore-offshore sediment transport processes. Collectively, this information is used to sustain and improve the quality of life and economic vitality of the Nation. These maps and frameworks support Department of Interior (DOI) land management decisions, mitigate hazards, and assist in ecological and climatic monitoring and modeling. This paper provides some background about the NCGMP and explores the impact of changing technology on geologic map products.

NATIONAL COOPERATIVE GEOLOGIC MAPPING PROGRAM

History and Background

In 1992, the 102nd Congress recognized that a coordinated program was needed to facilitate geologic map production for the Nation by means of a uniform system in which priorities are established according to customer needs. In the late 1980s, less than 20 percent of the United States had detailed geologic map coverage at scales necessary for land-use and resource managers to make wise decisions (National Research Council, 1987) and very few of these geologic maps were in a digital format that now is the standard for geologic map production.

The National Geologic Mapping Act (NGMA, Public Law 102-285), which was signed into law in 1992, created the National Cooperative Geologic Mapping Program to implement and coordinate an expanded geologic mapping effort by the U.S. Geological Survey (USGS) and the State geological surveys. The Act has been re-authorized twice, in 1997 (Public Law 105-36) and in 1999 (Public Law 106-148), and currently is in the process of its third reauthorization.

The program today represents successful cooperation among Federal, State, and academic partners to deliver modern digital geologic maps to the communities and users that need them. In doing so, the program delivers the regional-scale (generally 1:24,000 or smaller) geologic maps that are critically needed by society. For example, private sector geotechnical consultants have come to depend on these maps as a base for constructing their larger-scale, site-specific geologic maps to support planning and engineering projects. The metadata from these efforts across all of the U.S. will continue to be stored and made available in the National Geologic Map Database's Map Catalog (NGMDB, http://ngmdb.usgs.gov). In support of geologic mapping, a common set of geologic map cartographic standards was published in 2006 (Federal Geographic Data Committee, Geologic Data Subcommittee, 2006); this was developed by NCGMP in cooperation other Federal agencies, the state geological surveys, and the NGMDB.

The success of the NCGMP is evident as recent geologic mapping has been an important part of scientific advancement in areas as diverse as earthquake mechanisms, ground-water flow modeling, mineral and petroleum exploration, and the mitigation of natural hazards. The success of these efforts can also be gauged by the fact that the percentage of the Nation with geologic map coverage has risen dramatically. Also, geologic map production, compilation, and training have been promoted in 49 of the 50 states and Puerto Rico during the past 13 years (Figure 1).

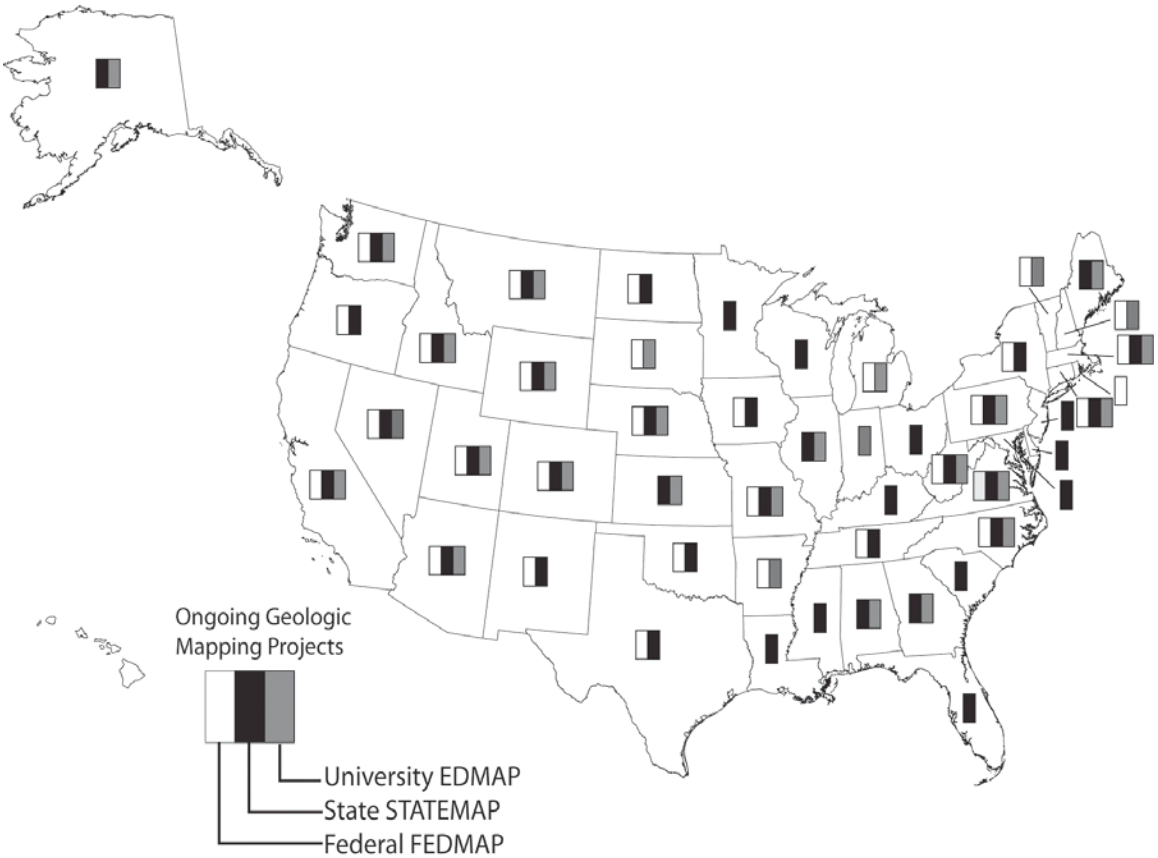


Figure 1. Geologic mapping projects by component of NCGMP for FY 2007.

Program Components

Each of three components of the program, as described below, has a unique role, yet all work cooperatively in the process of determining priorities for and producing new geologic maps. The Federal component of the program, FEDMAP, which officially began in 1993, creates regional geologic frameworks for areas that are vital to the economic, social, or scientific welfare of the Nation. The program annually supports approximately 25-30 multi-year USGS projects, which frequently include interdisciplinary studies that add value to the geologic mapping and promote dissemination of these products to a wide variety of consumers. National priorities are set with the advice of both a Federal Advisory Committee and a FEDMAP Review Panel, which have Federal, State, private industry, and academic members, and through less formal meetings with customers, collaborators, and cooperators. Program funding is also used to maintain the National Geologic Map Database (NGMDB), an effort mandated by the NGMA. The NGMDB provides information to the public about all geologic maps produced in the United States. Through the NGMDB, the Program also is developing a uniform set of map production standards for use by all Program components and the entire geologic mapping community, and is promoting the use of sophisticated data models for the construction and dissemination of geologic maps.

The STATEMAP component creates geologic frameworks for areas that are vital to the economic, social, or scientific welfare of individual States. State geological surveys first received STATEMAP funding in 1993. While contributing to the NCGMP mission priorities, each State Geologist determines the State's mapping priorities in consultation with a State Mapping Advisory Committee. The highest priority efforts address multiple societal issues, a compelling single issue, or where geologic maps are essential for solving critical Earth science problems in a given State. The Association of American State Geologists, an organization consisting of all 50 State Geologists, routinely provides the Program with insightful guidance on critical issues that affect the States collectively. Each year, the NCGMP funds approximately 120 projects in as many as 47 States. STATEMAP is a competitive grants program where Federal funding is matched one-to-one with State funds. Proposals are reviewed by national award panels made up of scientists from the USGS and selected representatives from the State geological surveys.

EDMAP, which began in 1996, provides university students with a carefully mentored education in the fundamental principles of geologic mapping and field studies. College or university geology professors, who are skilled in geologic mapping and willing to provide appropriate mentorship, request EDMAP funding to support their undergraduate and graduate students' participation in geologic mapping field projects. EDMAP geology professors and their students are required to have a partner geologist from a State geological survey or USGS project, which provides opportunities for shared information and resources. The NCGMP allocates funds to colleges and universities in the United States and Puerto Rico through an annual competitive grant process. Proposals are reviewed by national award panels made up of scientists from the USGS, State geological surveys, and universities. Every Federal dollar that is awarded is matched one-to-one with university or other non-federal funds.

The success of this component is realized in that more than 90% of EDMAP students have pursued additional geoscience degrees or developed geoscience careers. The program fills a unique role in its training of new geologic mappers because other programs, such as the National Science Foundation, rarely support basic research devoted to geologic mapping.

USES OF GEOLOGIC MAPS

Decision makers at the Federal, State, and local levels are increasingly in need of objective scientific information to make sound decisions regarding planning, development and natural resource use. A modern digital geologic map often is the best scientific product for conveying this information because such a map is the single best source for understanding the history of the Earth. Geologic maps depict and interpret the bedrock and surficial geologic units that occur at and beneath the Earth's surface. They also present information about the complex depositional and tectonic histories that the rocks have undergone, and may provide information about geologic age, mineral resources, fossils, geochemistry, and a host of other basic earth science information. Although the original decision to map an area may have been based on a specific need or issue, the resulting maps have significant derivative value because of the quality and type of information found in the geologic maps. These maps also are being used to address a multitude of other land-use issues for years after their original publication. The derivative uses continue to provide a substantial and prolonged return on the initial research investment. Bernknopf and others (1996) discussed the uses, derivatives and values of geologic maps and how land-use decisions are based on these products. In 2000, Bhagwat and Ipe (2000) found through a survey of geologic map users in the state of Kentucky that the return on the investment of producing geologic maps for the entire state was about 30 times the cost of production. This economic value was realized through multiple uses of the maps for energy exploration in the 1970's and water resources in the 1990's and 2000's.

Prior to the NGMA, the major justifications for geologic mapping in the U.S. involved the use of maps in discovering and developing energy and mineral resources. In recent years, the need to maintain adequate clean water resources has become a major impetus for geologic mapping (Figure 2). Another recent demand for geologic maps is to solve a broad array of environmental concerns, such as ecosystem restoration and proper siting of waste facilities. The NCGMP will continue to recognize and support new uses for geologic maps through sustained close communication with customers and stakeholders, especially the input received through the State Geologic Mapping Advisory Committees.

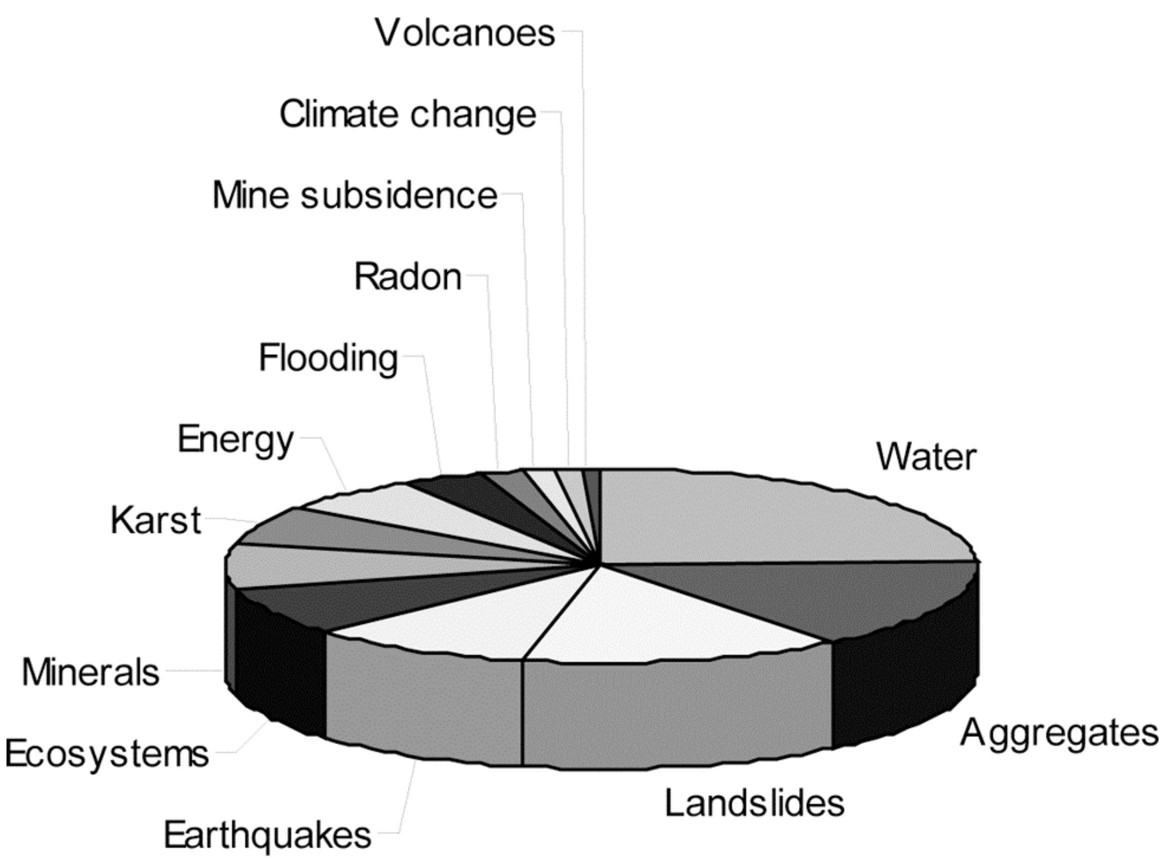


Figure 2. Justifications and purposes of geologic mapping for FY 2007 FEDMAP and STATEMAP projects. Information was compiled from NCGMP project descriptions.

NCGMP MAPPING IN PROGRESS

The productivity of NCGMP is measured in the number of geologic maps and the square miles mapped each year. The Program has developed a mapping-in-progress database to track all geologic mapping occurring through the Program across the U.S. This database is linked to internal NCGMP spreadsheets, USGS Geography Discipline databases showing the square miles for each quadrangle in the U.S., and the NGMDB where information can be obtained by the public (http://ngmdb.usgs.gov/MapProgress/MapProgress_home.html). Information stored in the mapping-in-progress database includes quadrangle name and state, square miles to be mapped, bedrock or surficial mapping, and principal investigator contact information (Figure 3). Within one year of notification that a map is published and recorded in the NGMDB, it will be removed from the mapping-in-progress database.

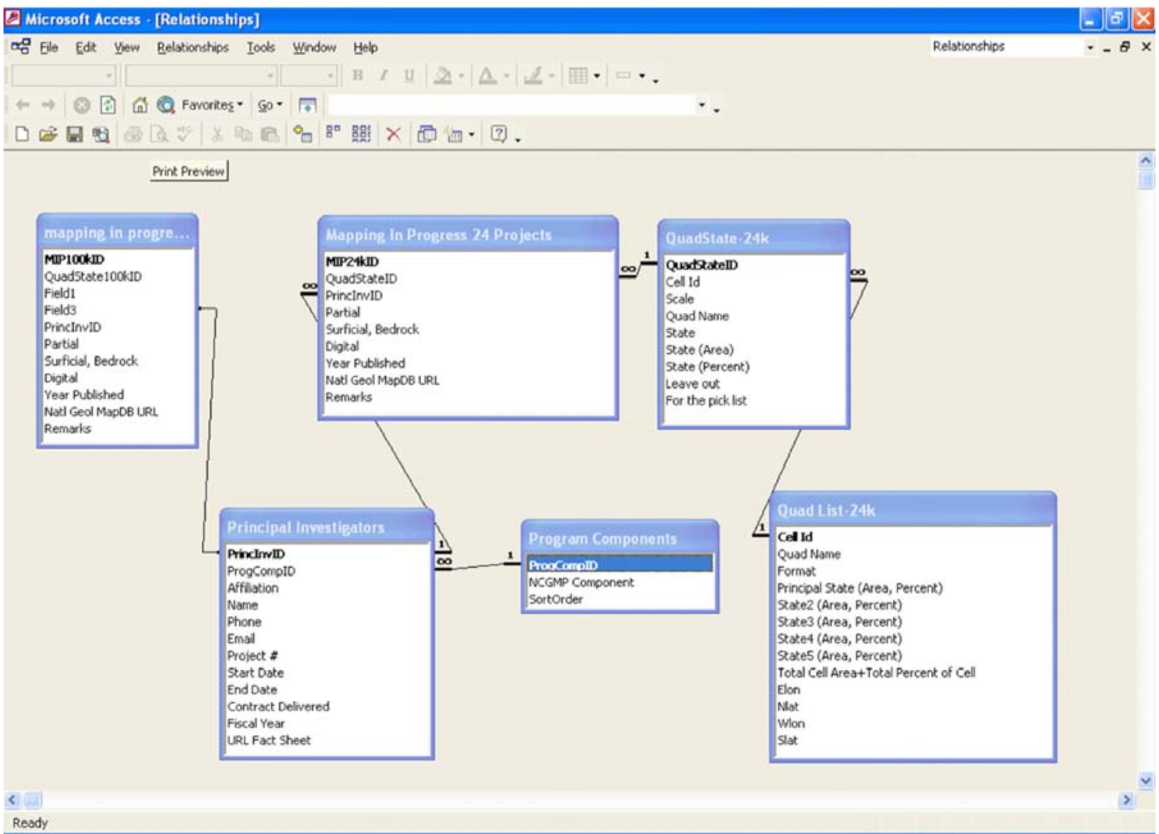


Figure 3. Diagram showing linkages within NCGMP mapping-in-progress database.

The mapping-in-progress database serves several functions. If a geologic map is unpublished or not included in the geologic map catalog of the NGMDB, it directs the public to the organization (USGS, State geological survey, or university) that is currently mapping a particular area. Also, the NCGMP uses this database to internally track geologic maps from time of proposal, to formal agreement, and to delivery of the map to the Program. The Program can evaluate trends in geologic mapping such as amount of bedrock and surficial geologic mapping, amount of digital compilation of previously published geologic maps, and differences in costs of geologic mapping over time and regions of the U.S. Another important use of this database is the ability to compile information to respond to requests from Government accountability programs for the Office of Management and Budget and for Congress (see also Soller, 2005).

Although there is information on past geologic mapping projects for NCGMP dating back to 1996, the most comprehensive data for the mapping-in-progress database has been collected since 2003. Since 2003, the USGS, state geological surveys, and university geoscience departments have mapped nearly 3000 7 ½-minute quadrangles (full or in part) equaling nearly 150,000 square miles (Figure 4). For 30’ x 60’ quadrangles, these same organizations have mapped 126 quadrangles (full or in part) equaling 171,968 square miles.

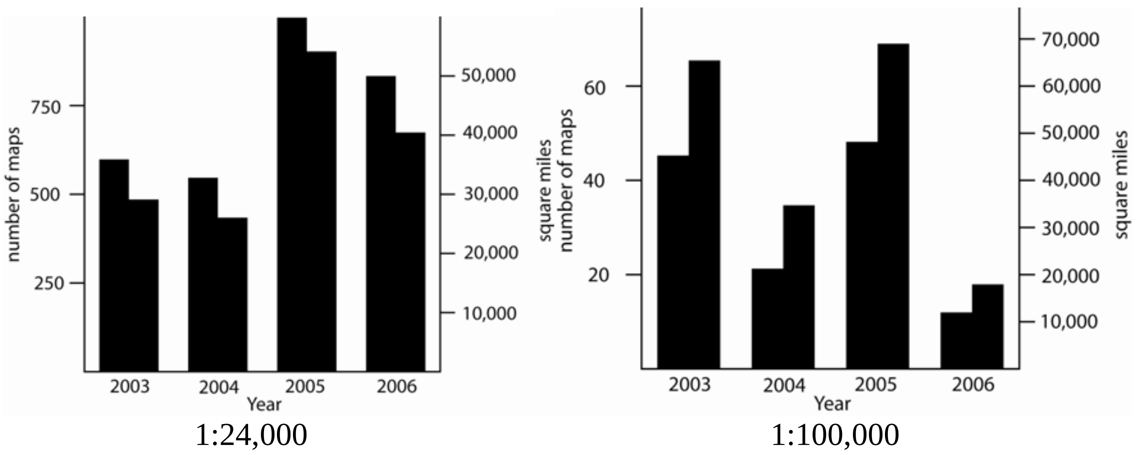


Figure 4. Number of maps (left bar) and square miles (right bar) funded for geologic mapping each year from 2003 through 2006 for 1:24,000 and 1:100,000 scales.

THE FUTURE OF GEOLOGIC MAPPING

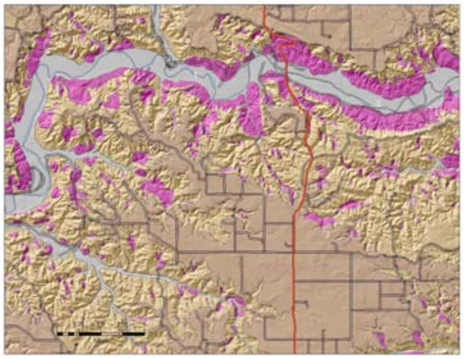
While a traditional geologic map portrays all of its information on a large sheet of paper, new digital techniques and computer software enable geologic mappers to represent the information in ways that are easier for their customers to visualize, understand, and use. These digital presentations frequently include additional information that was difficult or impossible to portray on paper maps. For instance, regional geophysical data sets such as gravity and aeromagnetic anomalies can be combined with a robust set of point data such as earthquake epicenters and water wells, to form one component or layer of the digital geologic map.

The dilemma of geologic mapping in the 21st Century is the need to bridge a transition from the traditional paper map products to digital geologic map databases that can be used in geographic information systems (GIS). The paper geologic map places all information from the geologic mapping study in one place displayed at the scale it was intended by the author. Descriptions of the map units, cross sections, explanations of map symbols, correlation charts, and other information are presented with the map and can be carried in the field by the map user. In many cases, the paper map can be used in places that a computer is not practical. Also, the entire map can be viewed at its proper scale and in its entirety, something that cannot be done on a computer screen.

However, the power and usefulness of digital map products is limitless. Various geologic layers can be displayed and combined with other map products to produce desired derivative products for decision-making. Derivative maps from geologic maps have long existed and are one of the most powerful products of the original comprehensive geologic map. Geologic maps from the early 19th Century of Great Britain were used to develop engineering maps for building of canals and resource maps of coal resources (Winchester, 2001). With the advent of GIS, geologic layers can now be combined with many other types of map products to allow for maps useful for land-use decisions. Geologic maps combined with land-use maps help to define zoning, protect sensitive ecosystems, and define critical recharge areas for ground water.

The concept of scale has changed with the advent of digital maps. Scale has traditionally referred to the ratio of linear distance on a map to the corresponding distance on the Earth's surface being mapped. However, with digitally displayed map information, it is possible to zoom in and out on maps that can be viewed on computer monitors projecting the map at various scales. Therefore, the term scale in digital mapping becomes the resolution of the map, or the scale at which the map data was compiled. This can cause map users to misuse maps by looking at detail that is not part of the original compilation. For example, a map compiled at 1:100,000 scale should not be used to zoom into a site at a much larger scale of 1:24,000 or larger. Contacts and other map information lose their accuracy when viewed at inappropriate scales. Digital geologic maps should include disclaimers notifying the user of the accuracy of the maps at particular scales. Ideally, digital maps could include an algorithm that prohibits the map user from zooming in too far.

Another powerful aspect of digital geologic maps is the inclusion of the third dimension. The term "three-dimensional geologic maps" can mean different things to different people. As one example, the draping of geologic map polygons on digital elevation models shows the three-dimensional relationships of geologic units where they occur at land surface (Figure 5a). In another example, cross sections developed from drillhole and other information can be interpolated to make a block diagram showing geology in the third dimension (Figure 5b). The power of the block geologic map is that it can be used as the boundary and three-dimensional conditions for models. For instance, geologic conditions related to faulting and shaking can be displayed and interpreted for earthquake hazards. Also, three-dimensional geologic maps are used to build ground-water models to assess recharge, storage, and discharge of aquifers.



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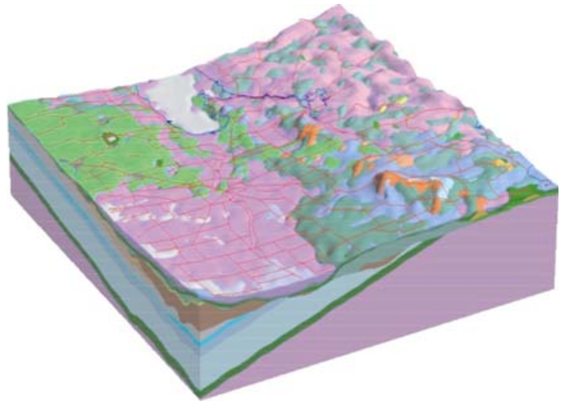

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Figure 5. Examples of three-dimensional geologic maps. A) Geologic units draped over a digital elevation model, from North Dakota (Thomas, 2004). B) Geologic framework showing subsurface extent of geologic units.

The need for both the traditional geologic map product and digital geology layers requires more resources than previously, when just a paper map was produced. Development of digital geologic maps does not necessarily make production more efficient. However, efficiency can be increased by digitally collecting field data on handheld computers with mapping software. Efficiency is also realized in map compilation where the field data can be easily transferred to a GIS to develop the digital map and database. However, to effectively develop digital geologic map data, knowledge of geology (geologic mapping), cartography, GIS, and computer programming is necessary. Also, effective distribution of digital maps requires use of the worldwide web.

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