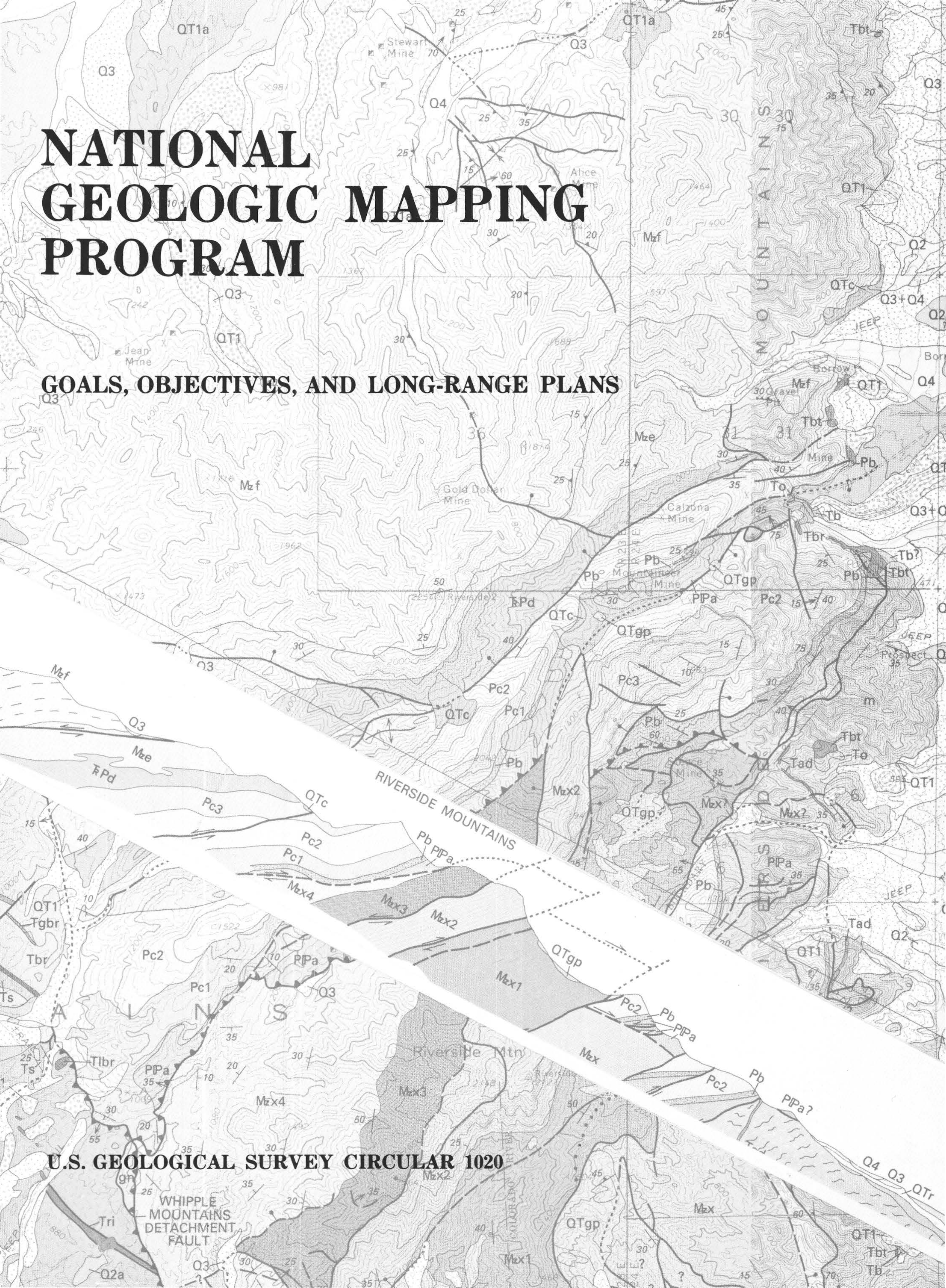
NATIONAL GEOLOGIC MAPPING PROGRAM

GOALS, OBJECTIVES, AND LONG-RANGE PLANS



U.S. GEOLOGICAL SURVEY CIRCULAR 1020

Cover: A portion of the geologic map of the Vidal and Parker SW quadrangles near the California-Arizona State border (U.S. Geological Survey Miscellaneous Investigation Map I-1125, by W.J. Carr and D.D. Dickey, 1980, scale 1:24,000). The superimposed cross section shows the geologists' interpretation of the geologic formations up to 2,000 feet below the ground surface along the line just above the cross section. The cross section was drawn by using measurements made on the surface as part of the geologic mapping, augmented by the geologists' broad training and experience.

National Geologic Mapping Program

Goals, Objectives, and Long-Range Plans

By U.S. Geological Survey

U.S. GEOLOGICAL SURVEY CIRCULAR 1020

1987

DEPARTMENT OF THE INTERIOR
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By U.S. Geological Survey

SUMMARY

- Geologic maps are the primary data source for nearly all pure and applied earth-science research.
- For at least 40 years, the need for geologic maps has steadily increased, as have their uses.
- During the second half of this 40-year period, production of geologic maps has steadily decreased.
- Current geologic mapping in the United States, from all sources, is inadequate to meet current needs.
- The U.S. Geological Survey plans to increase the quantity and versatility of geologic maps to meet national needs. The plan consists of four elements:

    1. Reorganize and expand U.S. Geological Survey geologic mapping efforts.
    2. Expand the State-Federal Cooperative Geologic Mapping Program (COGEOMAP).
    3. Initiate a program of grants to universities and other external organizations or individuals.
    4. Introduce new technology into map preparation and publication.

INTRODUCTION

Geologic maps are the primary data source for nearly all pure and applied earth-science research. Scientists, planners, exploration geologists, and engineers use not only the products of this map-dependent research but also the geologic maps themselves to address nearly every type of earth-science problem of concern to Federal, State, and local governments and to the private sector.

The number of uses to which geologic maps are put has increased markedly during the last three or four decades, as the number of earth-science-related problems has risen. Great strides have been made toward understanding many of these problems, which include geologic hazards, land use issues, waste disposal, and energy and mineral resource assessments. However, new and more precise information on these issues is needed. The accuracy and speed with which this information can be furnished to users are tied directly to the accuracy and availability of modern geologic maps.

...most of the country has not yet been mapped at ...scales required by most users of geologic maps...

The Geologic Division of the U.S. Geological Survey (USGS) and the State geological surveys conduct most of the geologic mapping done in the United States today; supplemental mapping is carried out by geologists in various universities across the country and by private industry. Although the efforts of these groups over the years have resulted in fairly complete coverage of the Nation by small-scale geologic maps (which cover large areas but lack detail), most of the country has not yet been mapped at the intermediate or large scales required by most users of geologic maps.

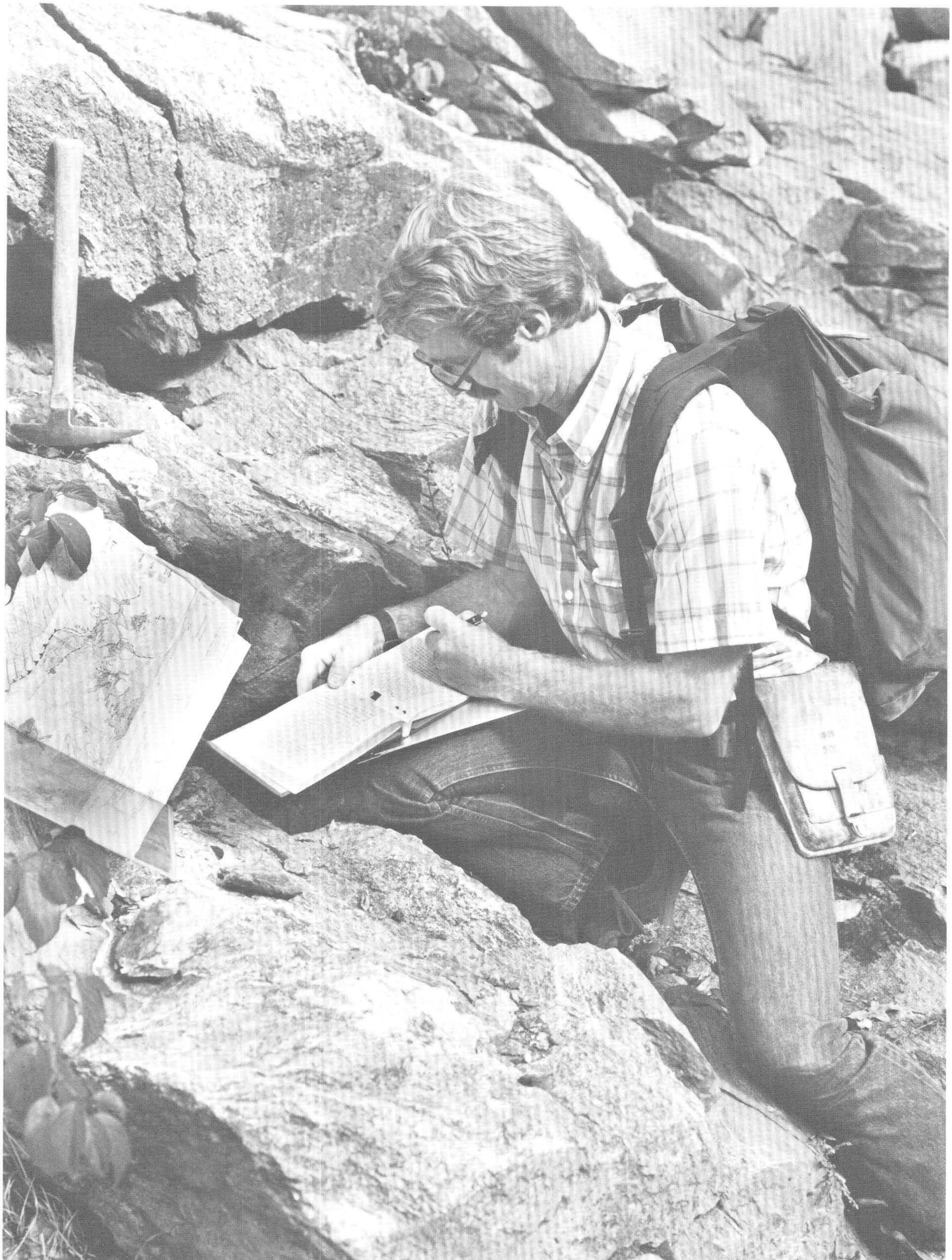
Geologic maps have been produced at steadily declining rates for the past two decades, even while the need for them has been increasing. The chief reason for this decline is that mappers have deferred to the demands brought on by earth-science crises, such as energy shortages, earthquakes, and volcanic eruptions. Research directed at these and other demands is vital to the national welfare but requires that money and manpower be used for activities other than geologic mapping. Over the past decade or two, these demands have increased, and the trend is likely to continue. In addition, over the same period, major scientific breakthroughs have caused geologists to shift their emphasis from field mapping research to theoretical and laboratory research.

Exacerbating this shift away from geologic mapping is the fact that some older maps are becoming obsolete. New scientific concepts such as plate tectonics require fundamental reinterpretations of data, and computerized integration of geophysical, geochemical, and isotopic information increases the breadth of information that can be brought to bear on a particular area. Expanded geologic mapping activities and modernized procedures are needed to fill the widening gap between increased user needs and current map production.

In 1983, the National Research Council of the National Academy of Sciences conducted a nationwide survey of earth-science information users to determine their present and future needs for all types of geoscience maps. The majority of respondents indicated that their greatest need was for detailed geologic maps. The National Academy of Sciences Committee Advisory to the USGS, in a 1986 report based on a detailed review of geologic mapping activities in the USGS, strongly recommended that geologic mapping within the USGS be increased and organized under a coordinated National Geologic Mapping Program.

...report...strongly recommended that geologic mapping within the USGS be increased and organized under a coordinated National Geologic Mapping Program.

Large-scale geologic mapping entails meticulous examination of all rock types in the area being mapped. Measurements of geologic structures and observations of rock properties, both typical and unusual, are recorded in the field in notes and on the map itself. Samples for chemical, isotopic, paleontologic, or microscopic analysis are collected and their exact locations recorded on the map. Hundreds of geologic observations, interpretations, and decisions are made in a single day of field mapping. Because of this detail, any given area receives a more comprehensive geologic examination during large-scale geologic mapping than it does under any other type of geologic investigation. Typically, the field geologist compiles and reviews his or her mapping and observations each evening, labels and catalogues all samples collected, and plans the following day's mapping accordingly. New discoveries often necessitate remapping areas covered only days before. When the map is complete, it is compiled and redrafted in the office and, along with the field notes, forms the basis for reports of both the general geologic framework and the specific aspects of the geology of the area. Normally, each month of fieldwork results in about 3 months of laboratory studies, compilation, and report writing.



In response to these recommendations, the USGS is working to establish a vigorous National Geologic Mapping Program along the lines described in this circular. Intended to revitalize the primary geologic map data base and to supply mission-related research with basic data, the proposed national program will (1) increase new geologic mapping, (2) coordinate increased Federal, State, and university mapping activities, and (3) augment development of new mapping and publication technologies.

THE ROLE OF GEOLOGIC MAPS IN SCIENCE AND SOCIETY

Most of the easily found mineral and energy resources in the United States have been depleted, and much of the accessible land near major cities has been developed. Increasingly, we must turn to science and technology to find subtle, often hidden mineral and energy deposits as well as to safely utilize land that has some type of geologic hazard associated with it.

...Geologic maps are the starting point and primary data source for most earth-science projects...

As societal needs for earth-science data change (for instance, needs are currently changing in response to an increasingly service-based economy), a large and multifaceted data base provides the best means for fast and informed responses to that change. General-purpose geologic maps and geophysical studies are among the most broadly based data forms in the earth sciences and can provide the data base needed for intelligent response to rapidly shifting societal needs.

Mineral and energy resources fluctuate in value on a short cycle (such as a decade) but, over the long term, become increasingly expensive as they become scarcer and harder to find. Land values and the cost and sophistication of new facilities have risen to levels never dreamed possible even 30 years ago. Many facilities, such as powerplants, hospitals, large office buildings, schools, scientific installations, waste repositories, military installations, and major pipelines are so expensive to build and so sensitive to any type of land movement or disturbance that intensive geologic studies before construction are mandatory to ensure their safe usage.

Because of these natural and societal factors, earth sciences now play a more important role in our lives than ever before. Correspondingly, the demand for basic, detailed, and often site-specific geologic information has increased. The primary source of this information is geologic maps.

...probably in excess of five million geoscience maps are used annually in the United States.

The expanded usage of geologic data was underscored by the results of the 1983 National Research Council survey. The geoscience map users sampled estimated that they used more than 150,000 maps annually. Extrapolating that number of maps to the estimated total number of map users indicates that probably in excess of five million geoscience maps are used annually in the United States.

Geologic maps and associated subsurface and geochemical studies are the starting point and primary data source for most earth-science projects, whether they are pure research or the application of established principles to a practical problem (fig. 1, table 1). Water, mineral, and energy resource exploration and assessment are particularly dependent on geologic maps. Earthquake, volcanic, and landslide hazard studies also use such maps extensively, as do land use planning studies. Large-scale (detailed) geologic maps are the chief information source for compiling smaller scale regional, county, and State geologic maps. They are also the primary data source for regional framework compilations and syntheses and show where to find specific rock types, minerals, or fossils for topical research studies.

The roles that geologic maps play in several different categories of basic and applied research include but are not limited to the examples given in the following sections.

Basic Earth-Science Research

Geologic mapping and subsurface information provide fundamental geologic information for nearly all fields of basic earth-science research.

Geologic terranes.—Geologic mapping revealed that the geology of large regions in western North America was totally unrelated to the geology found in adjacent regions. This mapping formed the basis for the paleontologic and paleomagnetic studies that, supported by further geologic mapping, determined that the rocks in many of these adjacent but geologically dissimilar regions (subsequently called terranes) originated at widely separated places on

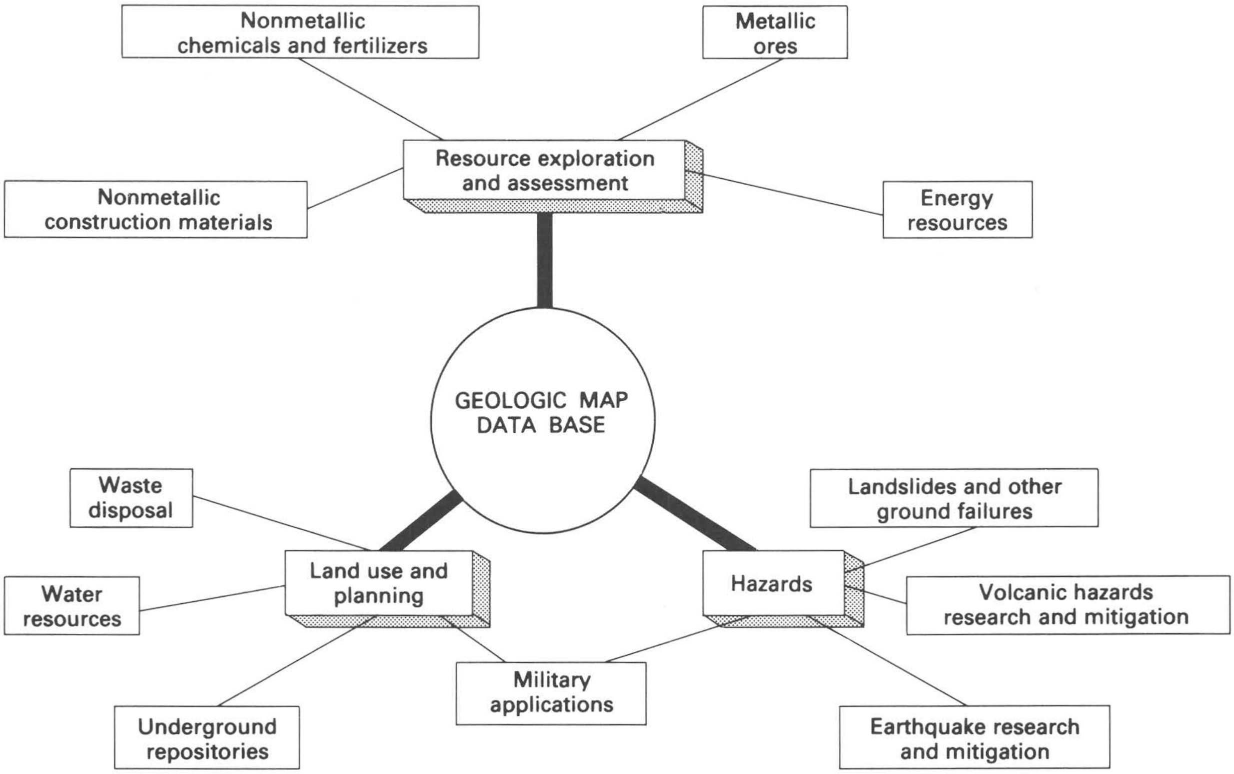


Figure 1. Use of geologic maps. Geologic maps are the basic data source for almost every type of study involving the earth sciences. Many of these studies provide data that eventually lead to improved or revised geologic maps and thereby upgrade the original data base.

the Earth. The revolutionary concept developed from these findings explained how continents grow by adding fragments of preexisting terranes (fig. 2).

Active faults.—Basic research on active faults uses geologic maps to (1) locate the faults best suited for study, (2) establish the relative ages of faults, and, most important, (3) facilitate interpretation of the faulting process in a regional geologic framework.

Mineral-forming processes.—Studies of mineral-forming processes use geologic maps to (1) locate areas containing rocks associated with a specific type of mineral, (2) determine the extent and age of the rocks associated with the mineral-forming processes, (3) determine the extent of associated rock alteration typically found with concentrations of some types of minerals, and (4) place the study in a regional geologic framework.

Sedimentary basins.—Basic studies of sediments and the basins in which they form, which bear heavily on oil and gas exploration, use geologic maps to (1) define the extent of sedimentary formations or basins, (2) determine the location, distribution, and thickness of formations, (3) determine changes in sediment composition in the basin, (4) determine the structure and distortion of the basin to find its original shape and extent, and (5) place the formation or basin in a regional geologic framework to interpret its history and origin.

Scientific Uses Outside Basic Earth-Science Research

The areal distribution, composition, and age relationships of rock and sediment shown on geologic maps and their subsurface distribution provide information fundamental to a wide range of research related only peripherally to the earth sciences. This research addresses a variety of problems such as those discussed below.

Acid rain.—The character and composition of bedrock and surficial materials are basic factors to be monitored in assessing the effect of acid rain on the purity of ground and surface waters within any drainage basin. Geochemical balances cannot be determined without detailed knowledge of the types and distribution of rocks shown on a geologic map.

Climate change.—The distribution of young coastal deposits is the primary evidence that climatic changes have altered shoreline positions during the last few million years. These deposits and the patterns of shoreline change

Table 1. Uses of geologic map information
[– –, minor importance; ——, major importance]

Application	1900 1940 1980 Future
Resource exploration and assessment	
Metallic ores:	
Precious metals	– – ————————
Base metals	– – ———————
Strategic minerals	– – ————
Uranium	————
Nonmetallics:	
Construction material	– – – – – ————
Phosphate and potash fertilizers.	– ————
Energy resources:	
Oil and gas	– ———————
Coal	– ———————
Nuclear reactor siting	– ———
Geothermal	– – – ———
Oil shale	– ————
Peat	———
Land use and planning	
Subsurface repositories, excavations:	
Gas storage	– ————
Oil storage	– ———
Underground quarries, warehouses.	– ——
Pumped hydroelectric peak storage.	– ——
Thermal energy storage	——
Large-diameter accelerators.	——
Waste disposal:	
Deep well injection	– – ———
Locating landfills	– ———
Nuclear waste	———
Toxic waste	– ——
Water resources:	
Aquifer systems	– – – – – – ———
Modeling ground water	– – ———
Contaminated ground water.	– ——
Military applications:	
Nuclear weapons testing	– ———
Underground command facilities.	– ——
Missile silos	– – —
Natural hazards	
Seismic hazards:	
Active faults	– – – ————
Seismic ground response	– ———
Volcanic hazards:	
Eruptive histories	– ———
Ash fall patterns and thickness.	– ———
Mudflow potential	– ———
Ground failure, construction:	
Dams, highways, tunnels	– – ————
Sinkholes and karst	– ———
Subsidence areas, swelling clays.	– ———
Landslide potential	– ———

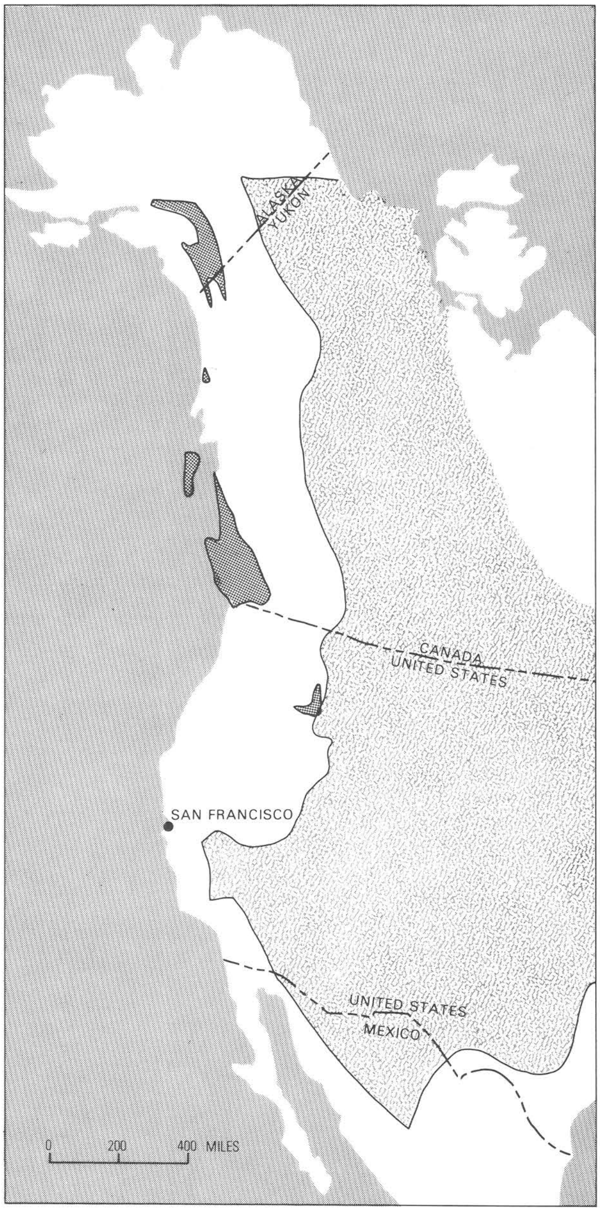


Figure 2. Original configuration of the western boundary of the North American continent (edge of the patterned area) illustrating how much land area has been gained by accreted terranes. The five dark-gray areas indicate the locations of several terranes that once formed a single microcontinent but were fragmented during the process that attracted them to North America. The white area is made up of many larger and smaller accreted terranes.

are tools for predicting future changes associated with a continuing sea-level rise through the end of this century.

Desertification.—The growing Earthwide problem of desertification could be better understood and mitigated, in places, by more complete geologic analysis, beginning with surficial geologic mapping. The size, composition, and stability of materials at the Earth's surface, in combination with topography and weather, influence the fertility and productivity of the land; the geology and water resources of an area are major factors in making agricultural land use decisions.

Mineral and Energy Resource Exploration

Geologic maps are used in a variety of ways by the mineral and energy exploration industries, depending on the commodity sought and the stage at which maps are needed in a particular exploration program.

An exploration team seeking a metal or mineral will first locate large areas of rock normally associated with the commodity sought by studying published small-scale geologic maps covering large regions. After selecting a target area, exploration geologists turn to medium- and large-scale geologic maps to identify specific areas where the rock types that they seek coincide with other features that may control ore localization. The larger scale maps provide details of these features, including distribution of the rock types, ages of the rocks, and descriptions of faults, folds, and other structures. The relationship of a discovered ore deposit to the local and regional geologic framework provided by geologic maps affords a basis for predictive models for future exploration programs.

Oil and gas are generated from and commonly accumulated in sedimentary rocks; thus, successful exploration requires knowledge of geologic structures, distributions of specific types and ages of sedimentary rock, and lateral variations in such rocks. Geologic maps and the explanation accompanying them contain all or most of this information. Used in combination with geophysical subsurface information, geologic maps have provided the basis for discovery of many oil fields throughout the world. In southwestern Wyoming and adjacent Utah and Idaho, for example, geologic mapping by the USGS established a regional stratigraphic and structural framework, including faults and folds that formed potential traps for oil and gas. Geologic conditions were specifically recommended as drilling targets in USGS publications as early as 1975. This geologic framework, augmented by advanced seismic profiling and computerized data processing for studying the subsurface, formed the basis for exploration that, in the past 8 years, has located 26 new oil and (or) gas fields that will ultimately produce an estimated 3.2 billion barrels of oil and 16.5 trillion cubic feet of gas.

Water Resources

Many of the same techniques used in oil and gas exploration are used in water resource studies. These studies make extensive use of geologic maps and subsurface studies to (1) locate and delineate the extent and depth of aquifers, (2) identify areas of natural recharge for protection against contamination, (3) locate sites for the most effective artificial recharge, and (4) provide the framework to develop models for ground-water flow under natural and pumped conditions.

The three-dimensional configuration of rock units is one of the features that make geologic maps extremely useful in water resource studies. In turn, as the subsurface characteristics of an area become better known through the drilling of water wells and geophysical studies, three-dimensional aspects of the geologic map can be refined.

Many parts of the Northern United States, particularly the populous Northeast, obtain much of their water from young unconsolidated sediments. In these regions, hydrologists make extensive use of geologic maps showing surficial materials as well as of general-purpose geologic maps; both map types depict these deposits in detail.

Hazards Investigations

Geologic mapping provides basic information to hazards investigations in a number of specific ways.

Potentially active faults.—Identifying potentially active faults is essential for land use planning and for understanding the causes of earthquakes. The fault on which the disastrous 1971 San Fernando, Calif., earthquake occurred could have been identified before the earthquake if modern large-scale geologic mapping had been available for that area. The worst damage and loss of life occurred along this previously unidentified fault. Once faults are identified by geologic mapping, such high-risk areas can be zoned by local governments to mitigate earthquake risks.

Earthquake prediction and investigation.—Geologic maps contain information used in the development of earthquake prediction systems, which depend on understanding the causes of earthquakes. For example, the maps are needed to select optimum sites for deploying instruments that gather information required for predicting earthquakes. Geologic mapping is also providing a foundation for multidisciplinary earthquake investigations in many areas, including the New Madrid seismic zone in the Central Mississippi Valley, the site of three extremely powerful earthquakes in 1811 and 1812. Although not the severest with respect to the amount of energy released, these earthquakes were the most widely felt in the history of the United States.

Volcanic eruptions.—Studies directed at understanding the causes, mechanisms, and frequency of volcanic eruptions are most effectively interpreted within the context of the regional geologic framework as derived from geologic maps. Studies on Mount St. Helens and of the potentially catastrophic Long Valley caldera in California, for example, can be applied to other areas in relation to the local geologic framework. Geologic mapping also is used to identify areas most susceptible to mudflows, lava, and pyroclastic flows related to volcanic processes. Basaltic lava flows from the East Rift of Kilauea Volcano in Hawaii and pyroclastic flows from Augustine Volcano in Alaska, for instance, were monitored in 1986. Careful geologic mapping of these areas might have led to more accurate predictions of the times and places of their eruptions.

Landslides and sinkholes.—Landslides and sinkholes, although not always as newsworthy as earthquakes, are as destructive of life and property and affect many parts of the Nation. These hazards result from various combinations of geologic factors, many of which can be identified from large-scale geologic maps.

Land Use Planning

Information derived from geologic maps is used by land use planners and civil engineers in Federal, State, and local government agencies and in the private sector. Land use decisions, which include locating highways, dams, quarries, water-supply wells, electric utilities, sanitary landfills, toxic waste dumps, shopping centers, industrial sites, and vacation and residential developments, need to be made with an understanding of the natural geologic setting, the hazards and (or) resource tradeoffs, and the possible benefits or problems that will result from such developments.

Industrial and construction resources.—Land use planners use geologic map information to locate industrial and construction resources such as sand, gravel, crushed rock, and cement, all of which are large-volume materials involving major transportation costs. Accurately locating these construction materials can save industry and governments hundreds of millions of dollars a year as well as stimulate industrial development in areas for which adequate geologic information is available.

Mineral resources.—Mineral resource assessments of public lands begin with preparing or compiling a geologic map. Millions of dollars have been spent on mineral resource assessments of proposed wilderness areas over the past two decades, much of it for preparing geologic maps, because none existed for these areas.

Environmental impact.—Much of the earth-science information needed for environmental impact statements is taken directly from geologic maps, whether assessments are required for the proposed subdivision of an area for residential purposes or for the construction of a gas pipeline across thousands of miles of geologically diverse terrane.

Waste disposal.—Identifying sites for safe disposal of urban wastes and refuse, industrial and toxic wastes, and low- and high-level nuclear wastes requires careful examination of geologic maps and integration of the information that they contain. The recent Department of Energy study of all crystalline rock bodies in the Eastern United States as potential high-level nuclear waste repository sites revealed major gaps and inconsistencies in the existing geologic map data base.

Military Applications

Geologic maps have important applications to military needs. Locating missile guidance systems requires exact knowledge of geologic and geophysical characteristics, especially near the launch site. Planning underground installations and testing facilities requires detailed geologic data. A recent example of geologic map use in a defense-related project is the weapons testing program at the Nevada Test Site, where accurate geologic maps were essential to ensure containment against venting to the atmosphere during underground tests of nuclear weapons.

STATUS OF GEOLOGIC MAP COVERAGE

Tabulating Published Geologic Maps

Accurate knowledge of where geologic mapping has been done is necessary to evaluate map needs and to effectively plan short- and long-term geologic mapping efforts. The USGS maintains a State-by-State index to geologic mapping, which in the past has been updated and published on about a 5- to 10-year cycle. This index is currently being converted to a system that can be maintained on microcomputers. The conversion will allow all new geologic mapping to be entered into the records annually, and the indexes will be made available to users in digital format. Input will be requested from State and university sources and will include solicitations in geologic news publications.

How Much of the Nation Has Been Mapped?

How much of the Nation has been mapped depends on the mapping scale. Much of the United States has been covered at small scales, but mapping at the more detailed intermediate to large scales required by most geologic map users still is largely incomplete for most of the country. The present geologic map coverage of the United States varies from 100 percent for the smallest scale (1:2,500,000) to about 11 percent for the largest scale (1:24,000 or larger). Combining all the areas shown in

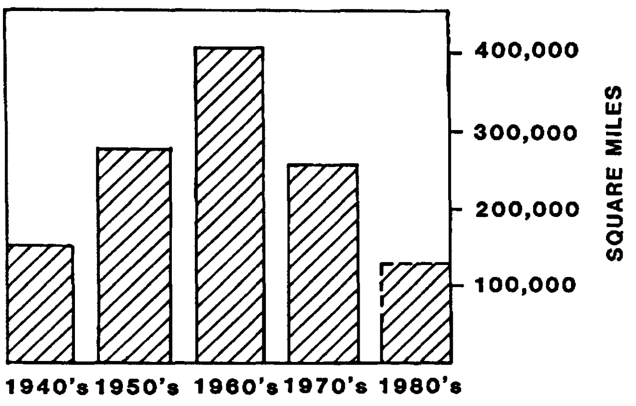


Figure 3. Number of square miles mapped by geologists during each of the last five decades. Only maps at scales of 1 mile to the inch or larger, by far the most widely used, are included. Although map production increased from the 1940's to the 1960's, the decline since then has resulted in a production rate that is now lower than it was in the 1940's. The 1980's bar is a projection based on data for 1980 through 1985.

figure 3 indicates that, since 1940, approximately one-third of the Nation has been covered at scales of 1 mile to the inch (1:62,500) and larger. The bar graphs, which represent mapping by the USGS, State geological surveys, and university geologists, indicate the progress made by the geologic community in the last 45 years. For comparison, many of the "developed" countries are far more advanced in their national mapping programs; Great Britain, for example, has 100 percent coverage at 1:25,000 scale, and the Soviet Union is projected to have 100 percent coverage at 1:50,000 scale by the mid-1990's.

The Decline in Geologic Mapping

In addition to showing the total amount of maps published in the last 45 years, figure 3 also indicates a pronounced decline in geologic mapping over the past 20 years. Within the USGS, this decline is reflected to varying degrees in all types of map publications. The USGS issues geologic maps in several publication series, from the highest quality color maps in the Geologic Quadrangle (GQ) and Miscellaneous Investigation series to hand-drafted black-and-white maps in the least formal type of release, the Open-File Report. In addition, geologic maps are published in the Miscellaneous Field Studies series and as plates accompanying Professional Paper and Bulletin book reports. Geologic maps at all scales and special-purpose geologic maps are published in all but the GQ series, which includes only standard USGS topographic scales.

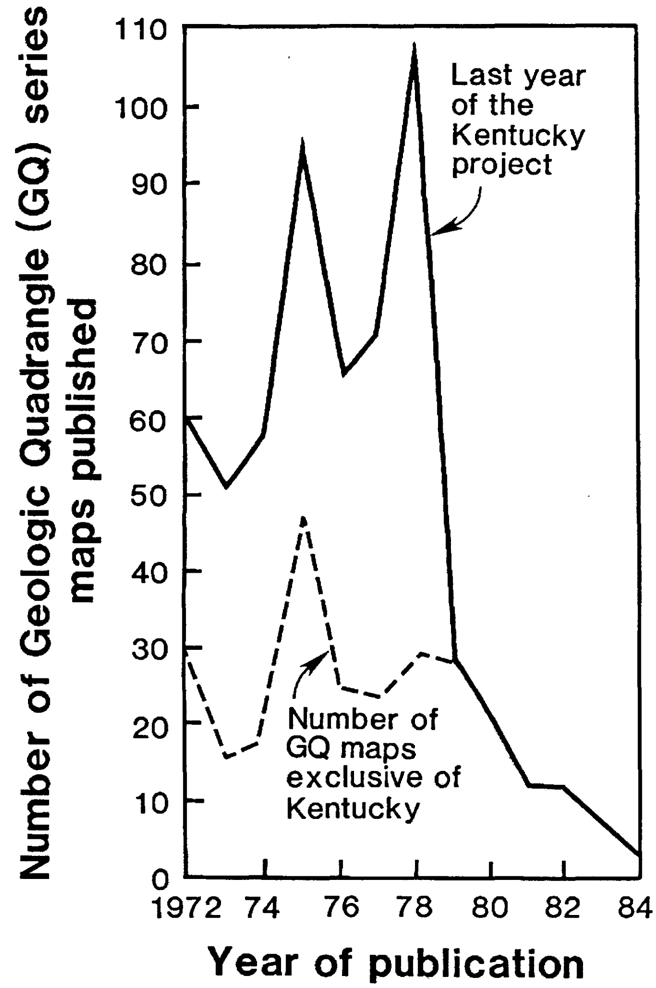


Figure 4. Number of maps published in the U.S. Geological Survey's Geologic Quadrangle series between 1972 and 1984. Geologic maps are also shown exclusive of those produced under the USGS-Kentucky cooperative project, because the Kentucky project was of finite length, separate from all other USGS mapping efforts, and represents a period of anomalously high map production.

The decline in geologic maps published annually in the GQ series during the past decade is dramatic and well documented (fig. 4). With slight variations, this trend is also apparent in other USGS map series. The decline appears to have occurred not only within the USGS but also in every segment of the geologic community that produces geologic maps.

The reasons for the decline are complex and vary from organization to organization, but most have similar underlying causes. Probably most important, the obligation of the earth-science community to respond to societal problems has far outstripped its ability to do so. In response to these problems, research activities within the USGS changed markedly in the last two decades. Two programs based on using large-scale geologic mapping to develop a comprehensive geologic data base splintered to the present 20 programs as a result of the increasing cost of scientific investigations in fields dependent on rapidly developing instrumentation, plus a series of earth-science-related concerns and crises. The Alaska and San Fernando earthquakes, the oil embargo of 1973, concern over nuclear powerplant siting, the need to assess proposed wilderness areas, the eruption of Mount St. Helens, and land use problems associated with a technologically and numerically expanding population all drew heavily on the manpower and research dollars available to the earth-science community. All of these problems emphasized the importance of the earth sciences in maintaining an adequate level of energy and mineral resources and avoiding natural hazards. New programs established to address these high-priority issues changed the focus of research to those aspects of the earth sciences that related directly to the goals of specific programs. The previous goal—development of a comprehensive geologic data base—diminished in importance in the face of the need to directly apply studies to specific national earth-science problems. Ironically, it was the foundation of the previously developed general geologic map data base that allowed rapid response to these problems through special-purpose mapping. However, the decline in the amount of new basic information being added to that data base is impairing our current ability to respond to new problems.

In addition to the decline in geologic mapping, the obsolescence of many older maps or of maps done at small scales has exacerbated the erosion of the geologic map data base. The usefulness and longevity of a geologic map are greatly influenced by the state of geologic knowledge at the time when that map is made, the scale at which mapping is done, and the time available to do the mapping. Three geologic maps of an area in west-central Arizona, made over a period of 62 years, illustrate this point (fig. 5). The 1924 map was made in a relatively short time and published at a scale of 1:500,000. Although the 1969 map was published at the same scale, it reflects an increase in the general state of geologic mapping and also was compiled from a larger scale map, which the geologist had more time to make. The 1986 version, originally mapped at a scale of 1:24,000 but generalized for the new 1:500,000-scale State map (shown in fig. 5), reflects a large increase in general geologic knowledge. The original map, at 1:24,000 scale, is detailed enough to be used for almost any purpose for which a geologic map is needed.

CURRENT GEOLOGIC MAPPING

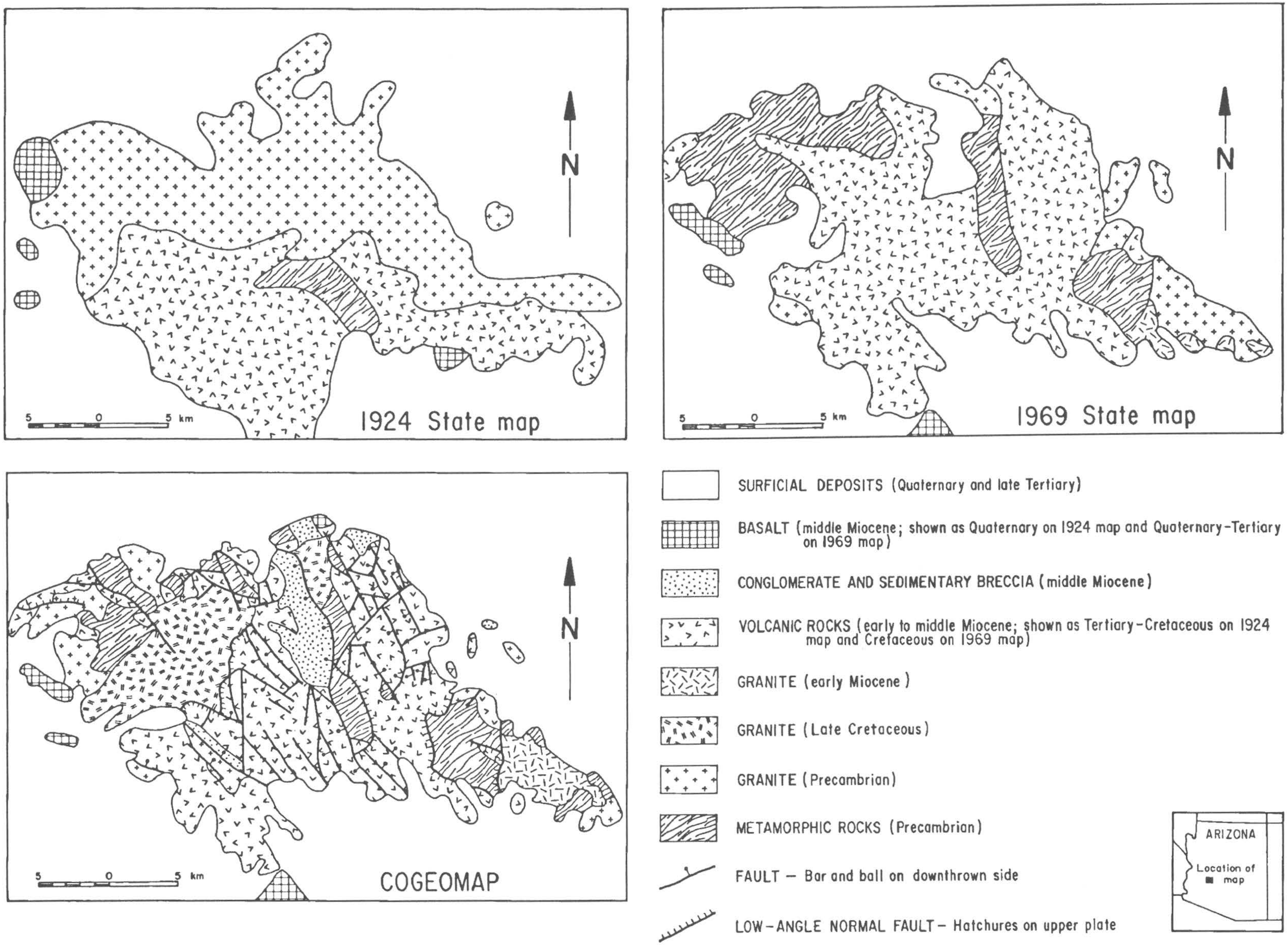
Geologic mapping conducted by the Geologic Division of the USGS and by State geological surveys constitutes most of the geologic mapping done in the United States today. Supplementing the government mapping is mapping by geologists in universities across the country. Geologic and geophysical mapping done for mining and petroleum companies is usually proprietary and only occasionally is made available to the public. Despite these wide-ranging mapping activities, a national geologic mapping program in a formal, institutional sense does not exist.

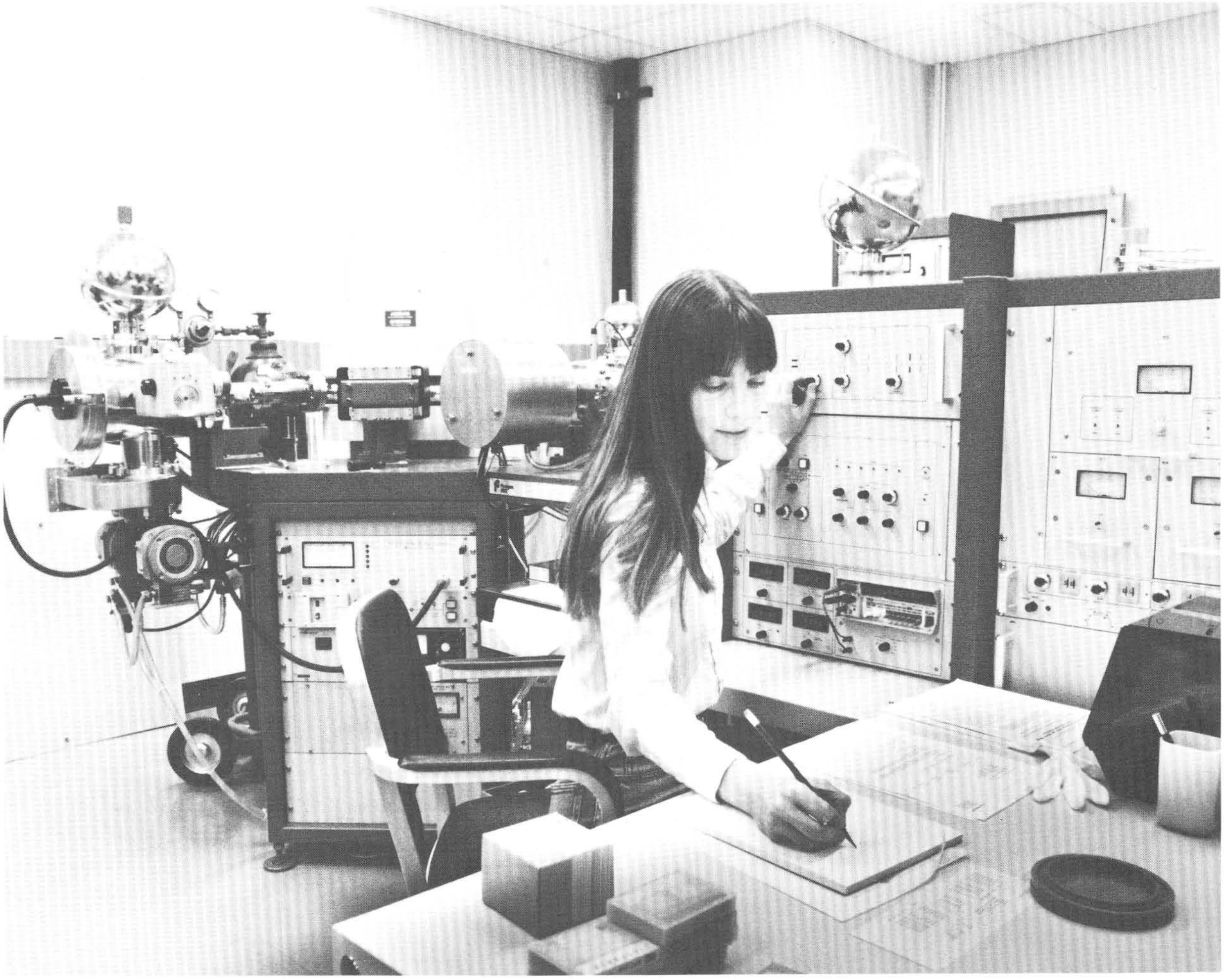
Federal Geologic Mapping

Almost all geologic mapping done by Federal agencies is done by the USGS. The largest single geologic mapping element of the USGS is performed under the Geologic Framework and Synthesis (GFS) Program. Geologic mapping is also a necessary part of other geologic research programs carried out by the USGS (for example, hazards, minerals, and energy programs). Whereas many of the maps produced by these research programs are highly specialized, focused on a specific aspect of geology rather than covering all aspects of the geologic framework,

...acquisition of baseline earth-science information...provides the foundation not only for present and future mission activities but also for the geological sciences overall.

Figure 5. Evolution of bedrock geologic mapping in the Big Horn Mountains, west-central Arizona. The three maps cover exactly the same area. The 1924 and 1969 maps were published at a scale of 1:500,000 (1 mile is about ⅛ inch on the map) and were both based on reconnaissance geologic mapping. The third map was produced under a Federal-State Cooperative Geologic Mapping (COGEOMAP) project with the State of Arizona, originally at a scale of 1:24,000 (1 mile equals about 2⅝ inches on the map). Recompiled for a planned new State geologic map, the 1986 map depicts the same area at the same scale as the previous two maps. The increased complexity of the maps over time is the result of careful detailed geologic mapping, building on previous work and using new concepts. The latest version will be of greater value to users of the State geologic map because it more accurately portrays geologic relationships. This type of geologic map evaluation is particularly striking in many Western States and Alaska, where large areas have never been mapped in detail. (Illustration courtesy of Geological Survey Branch, Arizona Bureau of Geology and Mineral Technology.) ▶


N
5 0 5 km
1924 State map
N
5 0 5 km
1969 State map
N
5 0 5 km
COGEOMAP
SURFICIAL DEPOSITS (Quaternary and late Tertiary)
BASALT (middle Miocene; shown as Quaternary on 1924 map and Quaternary-Tertiary on 1969 map)
CONGLOMERATE AND SEDIMENTARY BRECCIA (middle Miocene)
VOLCANIC ROCKS (early to middle Miocene; shown as Tertiary-Cretaceous on 1924 map and Cretaceous on 1969 map)
GRANITE (early Miocene)
GRANITE (Late Cretaceous)
GRANITE (Precambrian)
METAMORPHIC ROCKS (Precambrian)
FAULT — Bar and ball on downthrown side
LOW-ANGLE NORMAL FAULT — Hatchures on upper plate
ARIZONA
Location of map

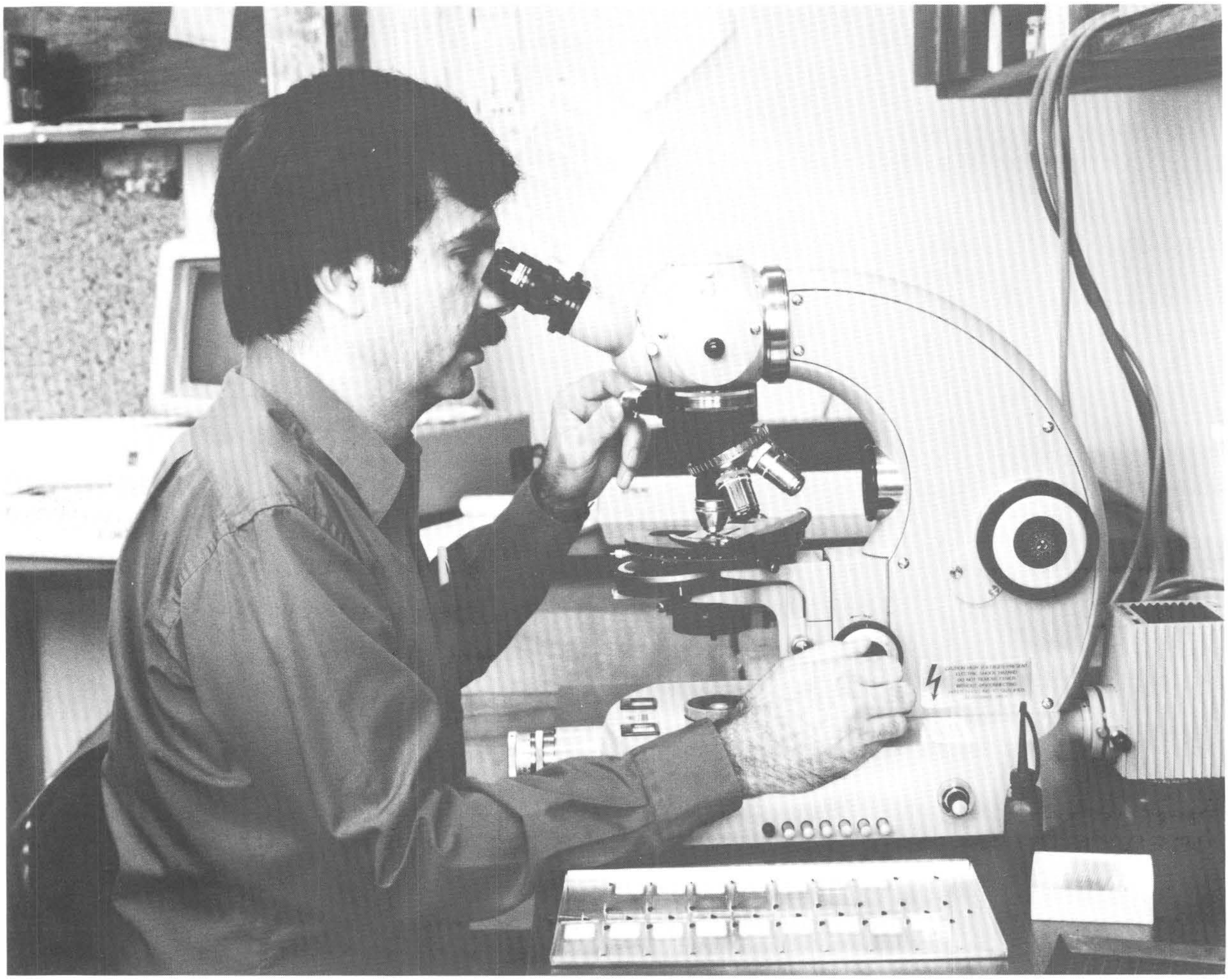


Mass spectrometers such as the one shown here are used to determine the age of rocks by analyzing the relative amounts of uranium and lead isotopes contained in them. Uranium decays naturally to lead at a uniform rate that has been accurately measured by physicists. By measuring the amounts of the uranium and lead isotopes in a mineral, it is possible to calculate how long it took for the amount of lead present to form (that is, the age of the mineral and the rock in which it was found). Different isotopes, such as rubidium and strontium, potassium and argon, and carbon are also used to date rocks and sediments. Knowing the age of rocks is essential to geologic mapping, because the geologic map, in addition to being a basic data source, shows the timing of events and rock formation.

these programs also publish some multipurpose geologic maps. Specialized geologic mapping is an essential part of these mission programs and commonly emphasizes one aspect of the geologic record far beyond what can be shown on a general purpose geologic map.

The GFS Program emphasizes acquisition of baseline earth-science information that provides the foundation not only for present and future mission activities but also for the geological sciences overall. This program includes three main areas of research, of which geologic mapping is one. Geochronology and earth processes studies, both vital to geologic mapping, are the other two major research areas. In addition to providing the basic geologic maps for other Geologic Division programs, the geologic mapping element of GFS also provides maps for much of the other research done under the GFS Program and for earth-science research done by the Water Resources Division as well as by private industry, academia, and other government agencies.

GFS mapping project areas are selected to augment the overall national geologic data base and to improve our understanding of (1) regional synthesis, (2) regional framework problems, and (3) problems related to basic earth processes. In addition, the resulting maps provide the starting point for specialized mapping. For example, three east-west transects of the Western United States



Sedimentary rocks, which are the most important rock type in terms of energy and water resources, do not in general lend themselves to isotopic dating techniques. Instead, their ages are determined by the fossils contained in them. In the past few decades, microscopic fossils have become extremely valuable for this purpose, perhaps more so than the fossil shells and bones that most people think of when they read about fossils. The paleontologist shown here is using a modern high-powered microscope to identify extremely small fossil foraminifera, which are critical for determining the age of the rocks containing most of the oil in the Western United States. These fossils not only tell the age of the rocks but also furnish the geologic mapper with valuable information on the environment in which the rocks were formed.

provide regional framework maps for analysis of geologic provinces typical of larger parts of that region. Other examples include (1) compilations of State geologic maps (a State map of Wyoming, published in 1985, was compiled from existing large-scale maps but also entailed conducting additional large-scale mapping in critical areas); (2) intermediate-scale geologic mapping (in the eastern Cascade Range in Washington, detailed and generalized geologic maps of areas in which accreted terranes are postulated were produced); and (3) geologic maps of overthrust belts (maps ranging from 1:24,000 to 1:250,000 scale in Wyoming, Utah, and Idaho have been pivotal in unravelling the complex structure of gas and oil fields). Some mapping under the GFS Program is done to provide a geologic data base for research in support of a specific mission study, but much work is sponsored only when the mapping will contribute to the national data base.

State Geological Surveys

Each State has an official designated as State geologist. Nearly all of these State geologists are in charge of a State geological survey, ranging from a few to dozens of geologists. The roles of these surveys vary from State to State; some have large regulatory responsibilities, especially in the area of oil and gas drilling, whereas others have more basic research orientations. The emphasis on geologic mapping varies accordingly. As a result, some States publish several geologic map series, and some publish no geologic maps at all.

Since 1973, the USGS and the State geological surveys have made a concerted effort to exchange information on their plans and activities; the Geologic Division of the USGS meets annually with regional groupings of State geologists for this purpose. In addition, the Division sends annual letters to all State surveys describing USGS projects that will be active in their States, and proposals for new projects are distributed for their comments. Geologic mapping is coordinated to varying degrees through these communications.

Joint Federal-State Mapping

Most State geological surveys have mandates for collecting and compiling geologic information within their States and thus possess detailed knowledge of their regions and resources. This mandate contrasts with the USGS mandate to collect and synthesize geologic data from all parts of the Nation, a task that includes identifying and analyzing regional geologic problems that cross State boundaries. Few States have the resources to support major geologic mapping programs and also maintain the State geologic data bases required for them to respond effectively to questions relating to the earth sciences. Cooperation between the USGS and State geological surveys has augmented the capabilities of both. Cooperative investigations that have benefited the USGS and the States over the years are continuing in several programs but have not been organized under a single program.

Cooperation between the USGS and State geological surveys has augmented the capabilities of both.

In recognition of the contribution that States make toward understanding the geologic framework of the Nation and helping to reverse the decline of general geologic mapping, the Federal-State Cooperative Geologic Mapping Program (COGEOMAP) was started in 1985 as a component of the GFS Program. The long-term objectives of the program are to augment geologic mapping in regions of mutual interest to Federal and State agencies.

In the COGEOMAP Program, geologic mapping proposals submitted by State geological surveys are evaluated by a USGS selection panel after being reviewed by scientific managers within the Geologic Division. Program priorities include (1) new large- and intermediate-scale geologic mapping in areas of high hazard or resource potential; (2) geologic mapping to aid formulation and synthesis of data for new State geologic maps; (3) subsurface mapping directly related to active surface mapping projects to elucidate the relationship between geologic and geophysical features; (4) geochronologic support for geologic mapping through isotopic and biostratigraphic studies; and (5) formulation of digital geophysical maps in States where an adequate geophysical data base already exists.

The COGEOMAP Program provides State geological surveys with an opportunity to take advantage of the highly specialized facilities and technical expertise of the USGS. Under joint funding agreements with State geological surveys, the USGS fulfills its traditional Federal role of coordinating and integrating assistance to the States. Because resources, geologic problems, and terrain of the States vary greatly, cooperative activities and arrangements vary among the States. The many accomplishments of the program during its first years reflect the high level of enthusiasm of individual State geological surveys.

Universities, Private Industry, and Geologic Mapping

Although geologic mapping by members of the academic community (faculty and students of geoscience departments) has declined, many professors who are recognized experts on the geology of specific regions continue to do geologic mapping and to oversee Master's and Doctoral theses involving geologic mapping. These professors and their students are funded by research grants from a variety of sources, including State surveys and the USGS. The costs of such investigations have been low but are increasing. In a recently published Geological Society of America newsletter, a university professor attributed the decline in financial support for university geologic mapping to the increasing costs of incorporating geophysical and other support studies into field mapping. Cooperative efforts with private industry will be encouraged where conflicts of interest are not an issue.

ASSESSMENT OF CURRENT AND FUTURE GEOLOGIC MAP NEEDS

National Research Council Survey

In 1983, the National Research Council of the National Academy of Sciences sent out questionnaires to assess the current and future needs of geoscience map users nationwide (fig. 6). Although all types of geoscience maps were covered, respondents singled out large-scale, multipurpose, colored geologic maps as the type most in

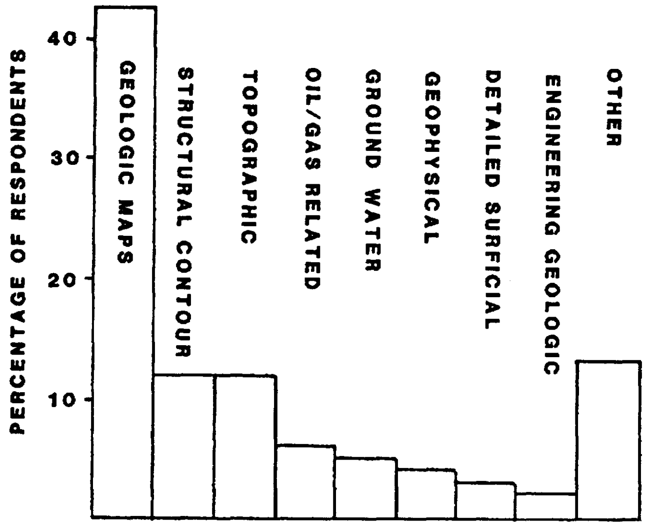


Figure 6. Relative need for different types of geoscience maps as indicated by responses to a nationwide survey of geoscience information users. The statistically based survey was made by the National Research Council in 1983. Geologic maps are indicated as the geoscience product most in demand by a margin of more than 3 to 1.

demand. The survey addressed such topics as the intended uses of geoscience maps, the relative importance of map sources, present and future map needs by region, and the scales of maps most needed. The questionnaire identified

Almost every user group responding to the survey emphasized the need for general or multipurpose geologic maps...

geoscience map users by their major scientific discipline or by the technical areas to which they applied geoscience information. The survey was sent to selected members of nine major professional associations spanning the breadth of the earth sciences and land use planning:

American Association of Petroleum Geologists
Association of Engineering Geologists
American Institute of Certified Planners
American Water Resources Association
Geological Society of America
Society of Exploration Geophysicists
Society of Economic Geologists
Society of Economic Paleontologists and Mineralogists
Society of Mining Engineers–American Institute of Mining Engineers

The National Research Council is preparing a comprehensive report on the survey, the major findings of which can be summarized as follows:

1. Respondents from almost every technical area of the geosciences indicated a growing need for large- (1:24,000 and larger) and intermediate-scale (less than 1:24,000 to 1:100,000) geologic maps.
2. Nearly two-thirds of the invited written responses stressed a need for increased emphasis on geologic mapping.
3. Most map users considered that special-purpose geoscience maps and derivative maps were best prepared by appropriate agencies or companies but that high-quality detailed geologic maps were needed as a starting base.
4. The USGS and, to a somewhat lesser degree, the State surveys were considered the most important sources of geologic maps (see fig. 7).
5. The original questionnaire included a map of the United States divided into 41 geologic provinces, 9 of which were offshore. The National Geologic Mapping Program will deal with the 32 onshore provinces shown in figure 8. Respondents indicated increased future geologic map needs in 30 of the onshore provinces.

Almost every user group responding to the survey emphasized the need for general or multipurpose geologic maps portraying all aspects of the geologic makeup of a

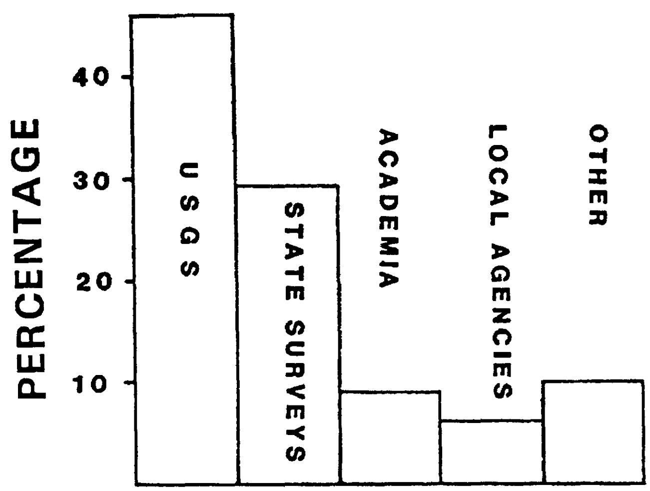
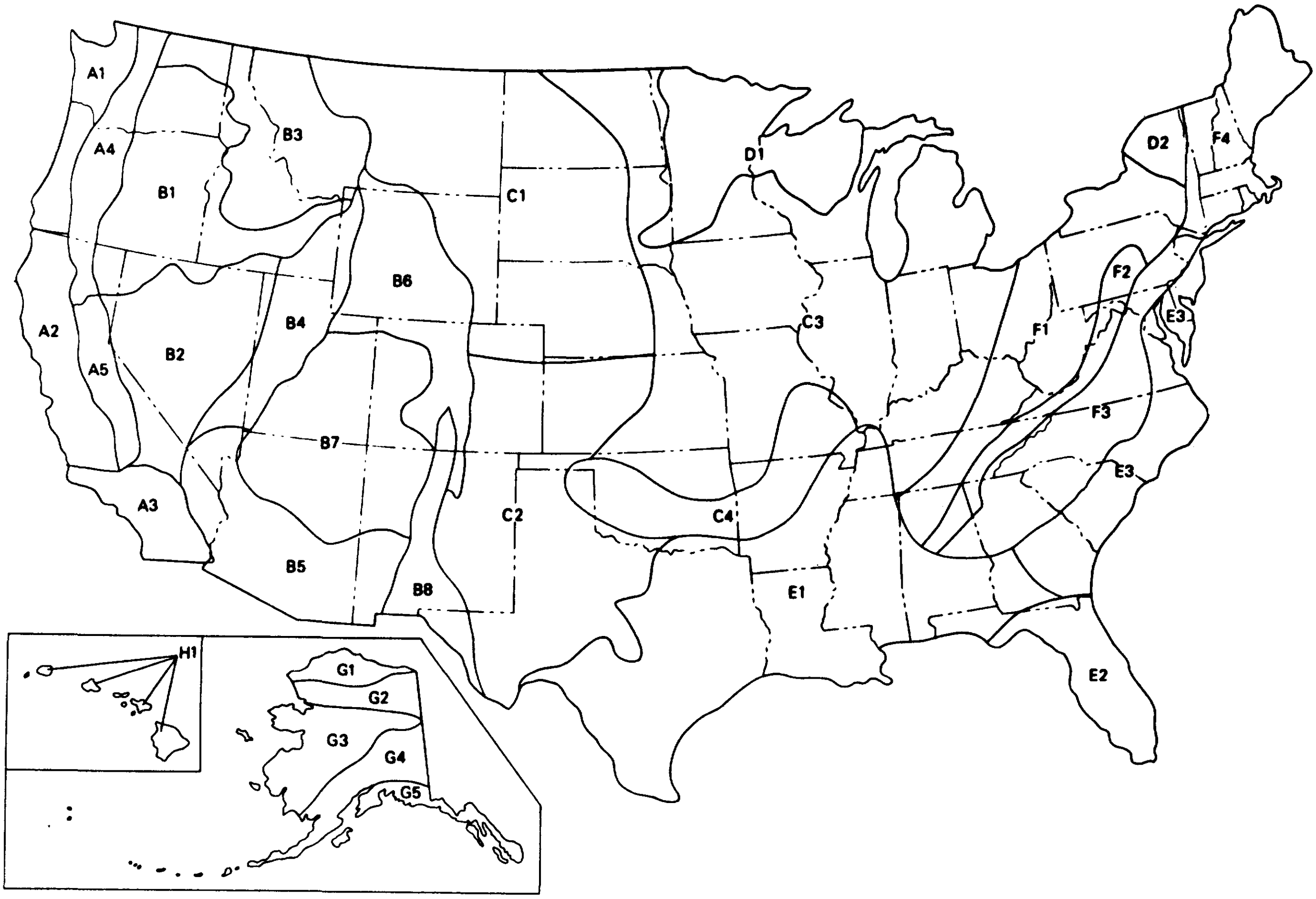


Figure 7. Sources of geologic maps used in the United States as indicated by the National Research Council survey of geoscience map users. Although USGS maps are most frequently used, map users also indicated that State geological surveys meet about 30 percent of their map requirements. Under cooperative agreements, some mapping published by State surveys is done by USGS or university geologists, and some published by the USGS is done by State or university geologists.



Western Cordillera (A)
A1 Pacific Northwest
A2 Northern California
A3 Southern California
A4 Cascades
A5 Sierra Nevada

Basin Range-Rocky Mountains (B)
B1 Columbia Plateau/Snake River Plain
B2 Basin Range
B3 Northern Rocky Mts. Thrust Belt
B4 Central Rocky Mts. Thrust Belt
B5 Southern Rocky Mts.
B6 Foreland Province
B7 Colorado Plateau
B8 Rio Grande Rift

Great Plains-Midcontinent (C)
C1 Northern Great Plains (Includes Black Hills)
C2 Southern Great Plains
C3 Midcontinent
C4 Ouachita/Ozark Region

Canadian Shield (D)
D1 Lake Superior Region
D2 Adirondack Region

Coastal Plain (E)
E1 Gulf
E2 Florida Platform
E3 Atlantic

Appalachian (F)
F1 Appalachian Plateaus
F2 Appalachian Fold and Thrust Belt
F3 Southern-Central Crystalline Belt
F4 New England Appalachians

Alaska (G)
G1 North Slope
G2 Brooks Range
G3 Interior Basins
G4 Aleutian Islands/Alaska Range
G5 Southeastern Alaska

Hawaii (H)
H1 Hawaii

Figure 8. Physiographic provinces used in the 1983 National Research Council questionnaire distributed to users of geoscience information. Each area or physiographic province outlined on the map is characterized by particular geologic structures or rock types. Map users were asked to indicate which provinces they were currently interested in and which they would need geologic information on in the future. The responses constitute an important piece of data that will be needed to establish geologic mapping priorities in the United States.

particular area. Unlike a special-purpose geologic map, the multipurpose map is comprehensive and has a wide range of uses. For example, a special-purpose geologic map depicting alteration halos around granitic rocks is very useful in mineral exploration research but is of limited use in earthquake or landslide hazard research, research related to energy resources, or general land use decisions. Multipurpose geologic maps, on the other hand, can be used in all these areas and in many cases provide the starting point for special-purpose geologic maps. The value of special-purpose geologic mapping should not be minimized, however, because it is essential in dealing with specific research problems being addressed.

A National Perspective on the Need for Geologic Maps

Geologic maps are used in a wide range of national programs within many departments of the Federal Government (for example, Department of Energy nuclear waste repository studies, Department of Transportation highway construction and modernization projects, Department of Defense siting of military installations, and Environmental Protection Agency siting of waste disposal sites to avoid contamination of ground and surface water). The USGS offices responsible for geologic hazards, energy resources, and mineral resources were asked to project their future mapping needs. Their responses, together with the ongoing needs of other Federal agencies, will be addressed in another circular to be published at a later date.

...Geologic maps are used in a wide range of national programs...

EXAMPLES OF AREAS WHERE GEOLOGIC MAPPING IS NEEDED

The following lists of national geologic map needs, subdivided by discipline, have been distilled from the comprehensive internal USGS review mentioned above. The lists are examples only and by no means represent complete geologic map needs.

Geologic Hazards

Regions that include potential geologic hazards, such as earthquakes, volcanic eruptions, landslides, and land subsidence (fig. 9), require detailed mapping to address both regional and site-specific land use questions. Particularly pressing are hazard problems in areas supporting dense populations and in rapidly growing urban areas. The table below identifies some potentially hazardous areas where geologic mapping is needed.

Region	Need
San Francisco Bay region	Geologic base is needed for variety of hazards application.
San Andreas fault, California.	Detailed mapping needed to characterize timing, amount of movement, and past movement history.
Cascade Range	Active tectonic zone and volcanism require geologic mapping.
Seattle-Tacoma regions, Washington.	Detailed geologic maps are needed to evaluate the potential for large earthquakes and volcanic eruptions.
Island of Hawaii	Active volcanic eruptions and tsunami hazards require mapping.
Intermountain Seismic Belt	Detailed geologic maps in parts of Idaho and Montana are needed to ascertain the potential for destructive earthquakes.
San Andres fault, New Mexico.	Holocene movement on this large fault and on the Rio Grande Rift must be evaluated, because major defense bases and cities lie near them.
Basin and Range province	Maps of parts of Nevada, Utah, and California are needed to determine recency of seismic and volcanic activity in this geologic province.
Wasatch Front, Utah	Active faults and associated young volcanism need to be evaluated and placed in a regional context.
East-central Arkansas	Mapping is needed to determine if recent earthquakes are related to major Paleozoic faults.
Cincinnati, Ohio	Geologic maps are needed to delineate severe landslide hazards.
Mississippi Embayment	Several youthful faults need further study for earthquake hazards, and surrounding area needs to be analyzed for seismic risk.
Adirondack Mountains, New York.	Detailed geologic maps are needed to evaluate recent uplift and seismicity.
Connection between Gettysburg and Newark basins, Pennsylvania.	Geologic mapping is needed to determine if a recent earthquake may have occurred along reactivated faults.
Alaska coast and Aleutians	Active volcanoes and faults and landslide processes require detailed mapping.
Alaska	Permafrost, landslide, and frost heaving problems require mapping, particularly along transportation corridors.

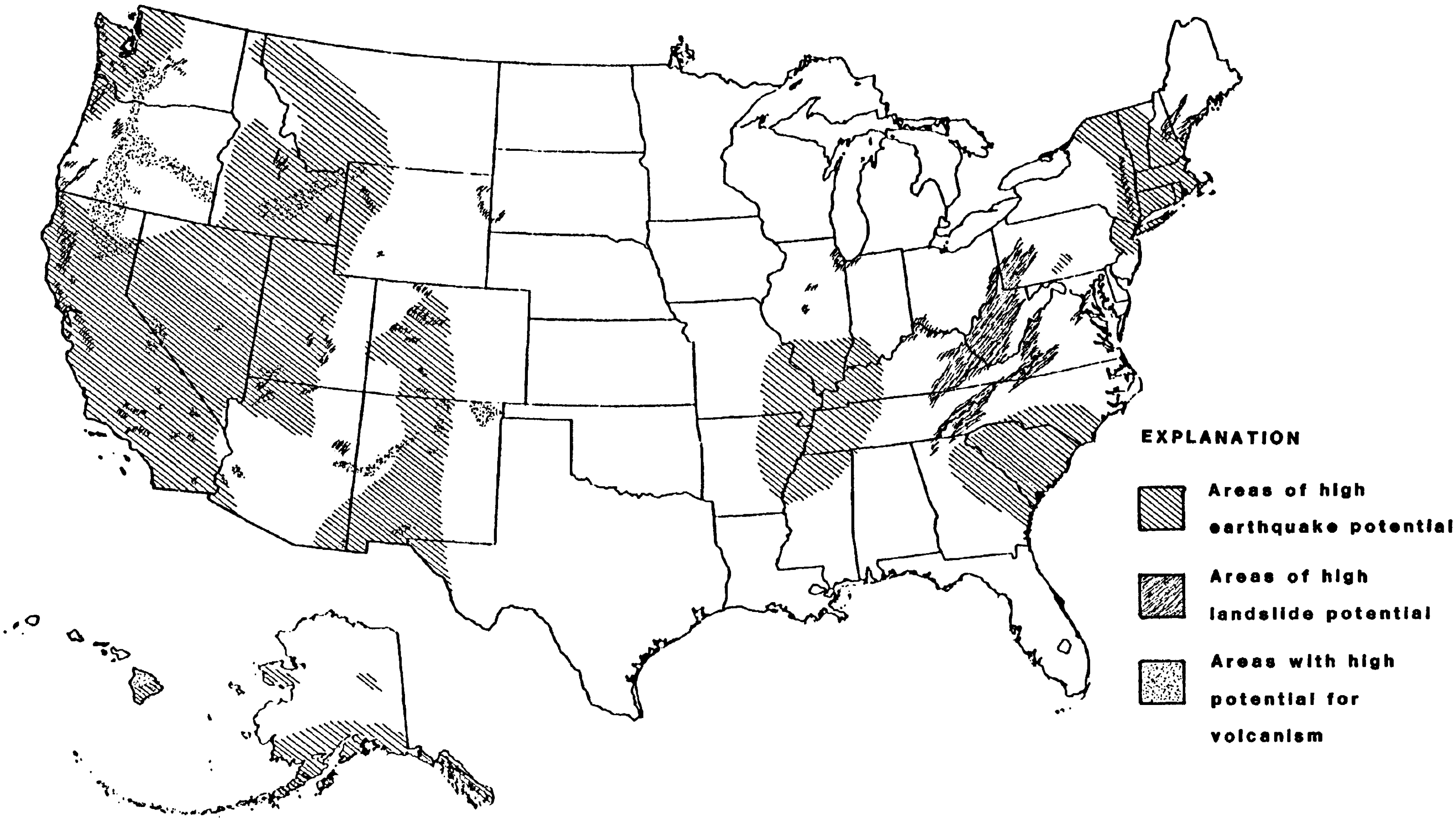


FIGURE 9. Regions of the United States most in need of geologic mapping for hazards research.

Mineral Resources

Wide areas of the Western and Eastern United States are in need of geologic mapping to provide information for mineral resource research, exploration, and assessment (fig. 10). In some areas, mineral resource potential must be assessed before land use decisions can be made in urban and wilderness study areas. The table below presents examples of high-priority areas where detailed mapping is required to provide mineral resource information.

Region	Need
Belt Supergroup, Montana, Idaho, Wyoming.	Detailed maps are needed to study sediment-hosted silver, gold, and massive sulfide deposits.
Southeastern California	Geologic mapping of recently discovered fault-related gold deposits is needed.
Basin and Range province, Nevada, Utah, California.	Geologic maps are needed on which to base studies of a wide variety of metals in many settings.
Western Sierra Nevada, California.	Gold resources need to be evaluated.
Coastal California	Studies of mercury and gold deposits require new geologic maps.
Laramie Mountains, Wyoming.	Geologic mapping is needed to evaluate mineralized strata and fault zones.
Colorado Mineral Belt	Geologic mapping of mineralized "Laramide" age granite is needed.
Central and southern Idaho batholith.	Study of mineralized granite requires new geologic maps.
Colorado Plateau–Basin and Range transition zone, Arizona.	Geologic maps are needed to evaluate Mesozoic plutons and Proterozoic metamorphic rocks that may contain metallic resources.
San Juan Field, Colorado	Geologic maps are needed of selected parts of a volcanic field that includes several richly mineralized caldera systems.
Arizona volcanic rocks	Volcanic rocks associated with major porphyry copper deposits need geologic mapping.
Rio Grande Rift, New Mexico.	Molybdenum and other metallic ore deposits require new geologic mapping for detailed studies.
Atlantic Coastal Plain	Geologic mapping is needed to study sediments that may contain phosphate resources.
Triassic basins in the Appalachians.	Many basins are potential hosts for uranium, copper, nickel, platinum, and cobalt resources; detailed maps are needed in many areas.
Halifax County, North Carolina, to Brunswick County, Virginia.	A volcanic-plutonic complex having the potential for metal sulfides and gold requires geologic mapping for exploration and resource studies.
Alaska	Six regions containing numerous mineral deposits require further study to evaluate resources of several metals, uranium, and thorium.

Energy Resources

Coal, oil, and gas exploration requires detailed geologic maps for evaluating resources. Several sedimentary basins where geologic mapping is needed are shown in the table below and in figure 11.

Region	Need
Westernmost United States (general).	Selected areas along the west coast should be mapped to better define the accumulation of hydrocarbons associated with subduction tectonics.
Alaska	Selected basins in northern and southern Alaska need to be mapped.
Public domain and Forest Service lands, mainly in Western United States.	Areas in need of land classification for multiple use (or best use), planning purposes, and coal, oil, gas, and uranium assessments for leasing purposes need to be mapped.
Santa Maria and Ventura basins, California.	Juncture of the Coast Ranges and Transverse Ranges should be mapped to understand the stratigraphy and tectonics of offshore basins and related hydrocarbon occurrences.
Anadarko Basin	Boundary between the basin and the Wichita uplift should be mapped in detail to understand basin evolution and hydrocarbon accumulation.
Powder River Basin, Wyoming; San Juan Basin, New Mexico; Uinta Basin, Utah.	Mapping is needed to define relationship of bounding tectonic elements to the history of basin filling, accumulation of fossil fuels, and minerals.
Rocky Mountains	Selected areas along the western overthrust belt need remapping in light of new geologic concepts and subsurface information.
Illinois Basin	Detailed stratigraphy of the coal beds and their lateral relationships is needed; oil and gas resources need more study.

Region	Need
Central West Virginia, Alabama, Ohio, Pennsylvania, Kentucky.	Stratigraphic sections require detailed mapping to assess coal resources.
Eastern Tennessee and southwestern Virginia.	Mapping is needed in eastern part of the Appalachian overthrust belt to delineate structural traps and the extent of dry gas.
Newark Rift System	Mapping is needed in selected quadrangles in the Hartford, Gettysburg, Newark, Durham, Danville, and Richmond basins to evaluate fossil fuel resources.

NEEDS FOR CHANGE

Although geologic mapping has been undertaken by various groups, the lack of an overall coordinated mapping program in the United States has resulted in shortcomings that will grow more serious in the future.

The present output of new geologic maps is inadequate to satisfy the projected requirements of the Nation, as the responses to the National Research Council questionnaire indicate. New mapping is needed in every region outlined on the questionnaire, but the amount and scale of mapping vary from region to region. As the need is growing, the production of new general-purpose USGS geologic maps is declining.

...present output of new geologic maps is inadequate to satisfy the projected requirements of the Nation...

Much of current geologic mapping does not result in general geologic maps describing the overall geology of the area but rather focuses on limited aspects of geology. The priorities of special-purpose mapping rarely allow time to do the additional work necessary for a general-purpose map. Solutions to this problem include augmenting special-purpose mapping to allow the production of general-purpose maps and using digital technology to make general-purpose maps that can be easily modified to produce derivative specialized forms.

It is increasingly difficult to establish and guide USGS geologic mapping priorities because mapping activities are scattered throughout a number of programs, each of which must be responsive to its particular program goals first. A method of monitoring progress toward the general goal of adequate map coverage of the Nation and the establishment of a national geologic map data base is needed. Areas covered by published geologic maps need to be indexed annually, and ongoing geologic mapping efforts across the country must be coordinated.

At present, the collection of geologic maps in USGS libraries and in the files of the State geological surveys is the best national geologic data base available. However, these collections are maintained independently, on various cartographic bases and projections and at an assortment of scales. Until recently, it was not possible to revise a map or to combine data obtained for a single purpose (for example, a detailed fault map) without completely drafting a new map. Consequently, such revisions rarely were attempted, and accumulated geologic data were fractionated into a number of data subsets of mixed quality and accuracy.

The USGS has completed trial applications of digital technologies for converting geologic maps into a modern geologic data base. Work continues on a system to digitize new and existing geologic maps. Such a data base could be upgraded as new information is added, portrayed at varying scales and projections, and integrated with the wide assortment of other geographic data bases already available. Except for geophysical data, which are largely digitized, the present geologic data bases in the USGS cannot be integrated with other data bases (for example, those used in geographic information systems) to easily address land use decisions across the Nation.

Initial experiments in the USGS and notable efforts by other government agencies suggest that the time required to produce multicolored geologic maps can be shortened and the cost of such work reduced by adopting new digital techniques.

APPLICATION OF NEW TECHNOLOGY TO MAPPING AND MAP PUBLICATION

The lengthy process leading to publication of a geologic map includes geologic field mapping, office compilation and drafting, and scribing and preparing peel coats for color reproduction. From completion of fieldwork to printing typically requires more than 3 years. Currently,

From completion of fieldwork to printing typically requires more than 3 years.

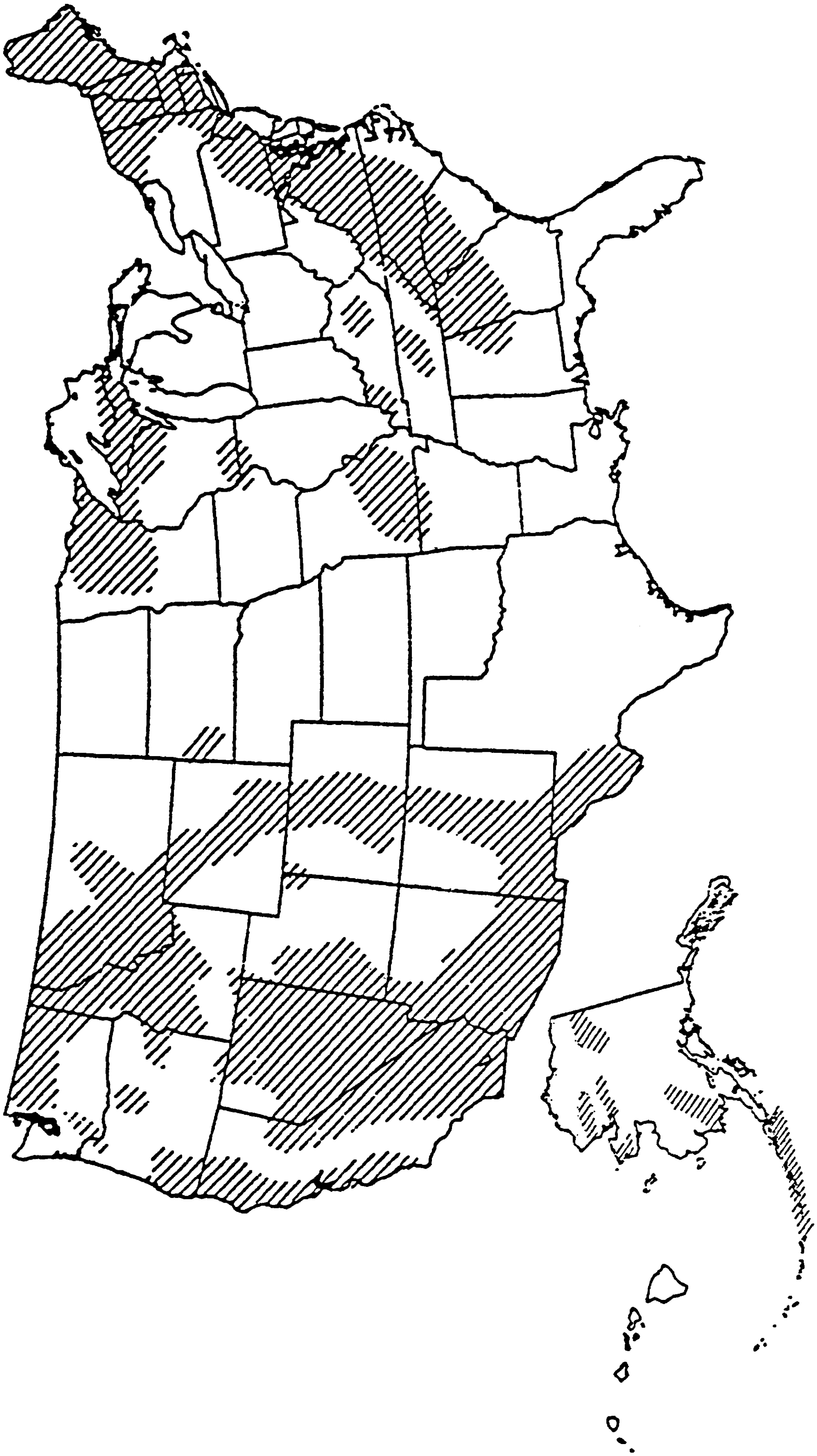


FIGURE 10. Regions of the United States most in need of geologic mapping for mineral resource research.

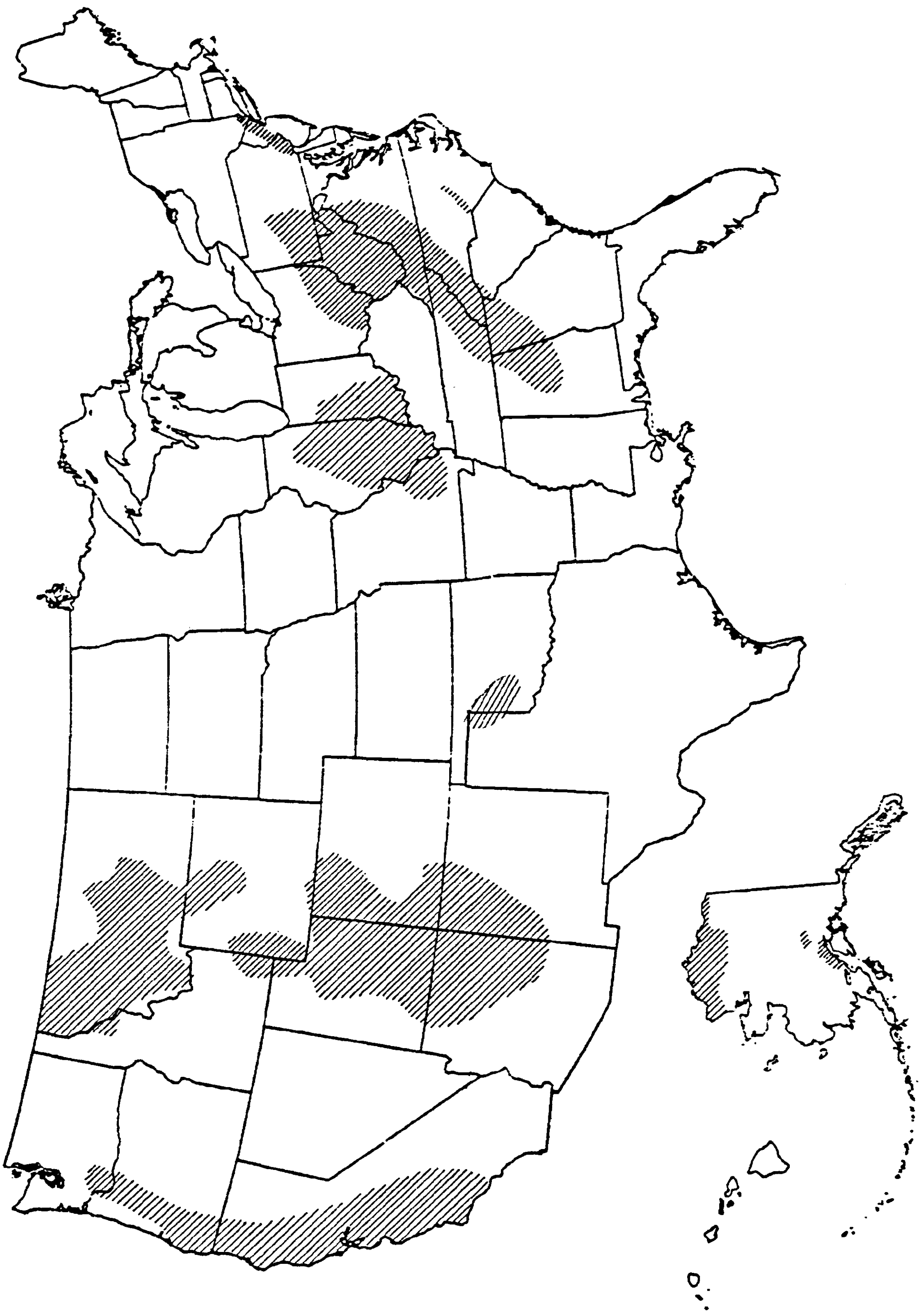


FIGURE 11. Regions of the United States most in need of geologic mapping for energy resource research.

over half of that time is needed for the nongeologic mechanical procedures involved in preparing the materials for printing, procedures essentially the same as those in use for nearly half a century. Technology is now available for integrating other data bases at the time of fieldwork and for modernizing and speeding publication by using high-capacity digital systems, scanners, and sophisticated editing programs. Perhaps even more important, the integration of geologic maps, in digital form, with other geologic, geophysical, geochemical, and geographic data allows rapid generation of specialized derivative maps that heretofore could not have been produced. A digital data base will also allow geologic data to be quickly updated or compiled at other scales, at major cost savings.

From Field Mapping to Publication

Integrating digital cartographic techniques into the entire map production process—from data collection through publication—will speed up the process and introduce new capabilities. Digital methods allow field data to be compiled by using microcomputer-based geologic work stations; field data can then be integrated with geophysical, geochemical, remote sensing, and other data bases during field mapping. In many cases, merging these data sets during fieldwork can result in higher quality geologic maps. For example, anomalous values on a digital printout of gravity or magnetic data could alert a field geologist to areas where subsurface geologic features may be only subtly reflected by the surface rocks. Using digital techniques to revise the map data throughout the various stages of compilation and review by using digital techniques will end time-consuming and costly redrafting.

Although they are not yet usable on a routine basis, systems exist that employ a vector-based digital record produced on microcomputers; that record can be converted to raster-based files for editing and laser printing. Editing and color selection on such a system allow rapid preparation of color separation negatives for publication. An automated production system will increase the rate of map publication and thereby satisfy projected user demands.

...computer techniques not only will accelerate the map production process but also can produce...a geologic data base that provides a wider range of information to users.

Modernizing the geologic mapping process must involve this integrated application of computer technology to data collection and publication. Properly applied, computer techniques not only will accelerate the map production process but also can produce a digitally generated conventional geologic map plus a geologic data base that provides a wider range of information to users. Even though conventional paper maps will continue to be the most important published form of the geologic map, digital data sets designed to be used in geographic information systems will be required by increasing numbers of geologic information users.

Development of Digital Capability

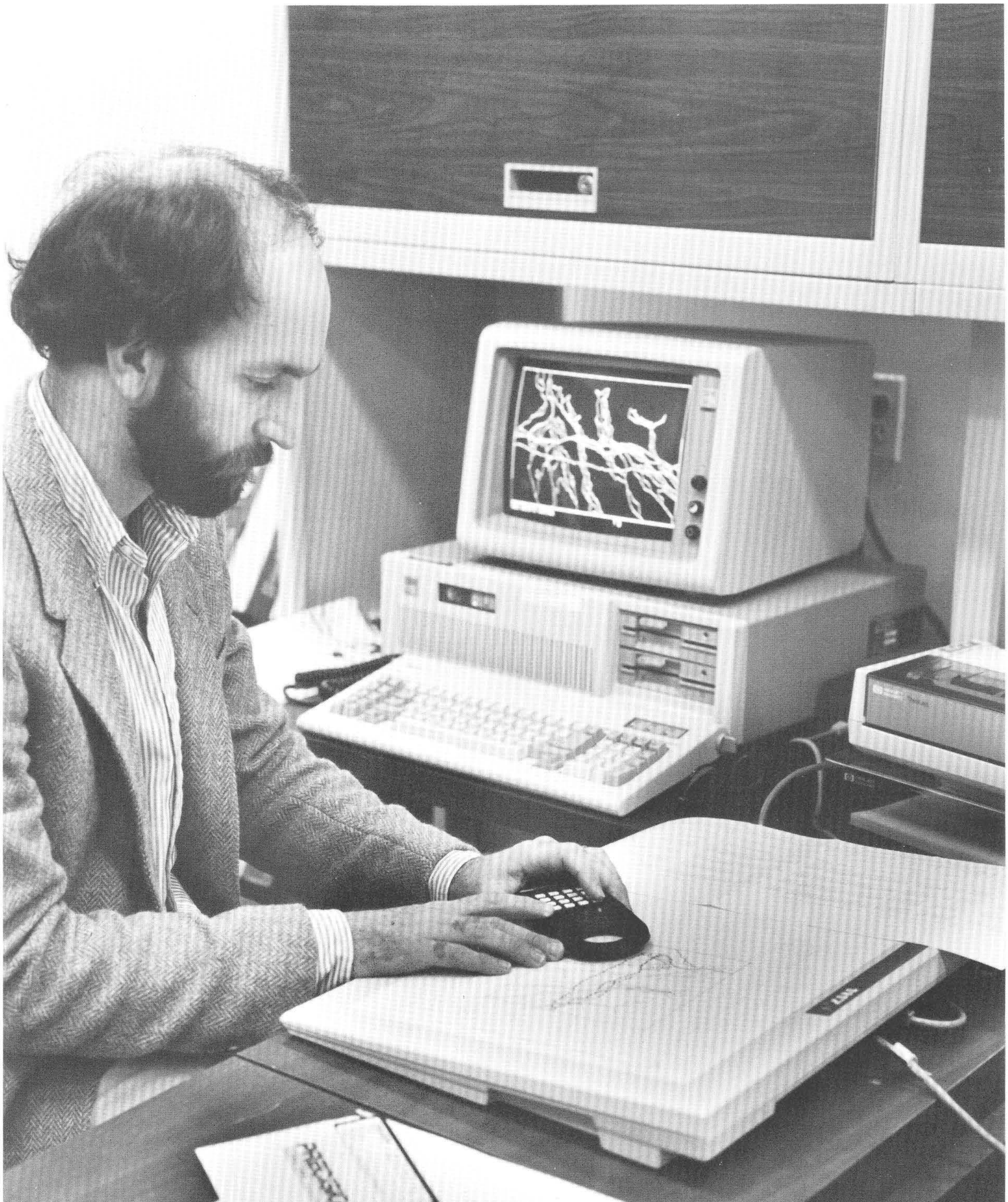
Modernization and development of automated techniques require two distinct technologies: (1) automated digital cartography, for more rapid and efficient production of geologic maps, and (2) geographic information systems (GIS's), to analyze geologic data and information in preparation for publication and to provide a digital delivery format to satisfy the rapidly growing population of information users having GIS capabilities. Excellent isolated examples of the application of these two technologies exist, but the two have not yet been integrated in a production process that will benefit both the geologists who produce maps and the users who apply the map information.

Developing a system integrating the two technologies entails:

1. Establishing a process for producing geologic maps that incorporates both manual and automated techniques, that stresses continuity for the most efficient transfer of results from step to step, and that has as a goal the production of both printed and digital publications.
2. Evaluating existing techniques and systems by initiating pilot projects to apply the systems to specific steps in the process. The pilot projects must focus on discrete elements that require more design, such as geologic work stations, standard data exchange formats, software for data conversion, and methods for storing, displaying, and manipulating three-dimensional data.
3. Integrating this process into the National Mapping Division's MARK II National Digital Cartographic Data Base design concept.

Approach

Two specific tasks require initial pursuit: (1) developing and testing the microcomputer scientific work station for map compilation and (2) expanding the use of raster-based procedures for producing color separations. Pilot projects using these two elements in large-scale geologic mapping should provide information regarding design requirements and cost-benefit relationships. Subsequent investigations must develop specific procedures to link the microcomputer-aided map compilation to the raster-based production methods.



A LONG-RANGE PLAN FOR A NATIONAL GEOLOGIC MAPPING PROGRAM

The USGS provides a national perspective on geologic mapping. State geological surveys maintain an overview on mapping within their borders and how it contributes to their individual missions. National organizations such as the Association of American State Geologists and the National Academy of Sciences provide integrated scientific perspectives. Because its staff is highly trained in all geologic disciplines, the USGS is the Nation's chief resource for producing comprehensive geologic data and is a logical focal point for any effort to organize and coordinate geologic mapping nationwide. The USGS provides leadership in developing standards for maps, developing uniform Indexes of Geologic Mapping for each State, and coordinating Federal mapping activities with the State geological surveys. After assessing the need for general geologic map data and evaluating the concerns and interests of various segments of the earth-science community, the USGS has devised a plan for establishing a National Geologic Mapping Program.

The program has three main goals:

1. To increase geologic mapping in response to increasing national needs for geologic maps.
2. To improve coordination among all Federal, State, and university producers of geologic maps to encourage cooperative efforts and avoid unnecessary duplication.
3. To adopt new technologies and innovative methods for improving the geologic mapping and map production processes and combining general geologic data with other earth-science and geographic data bases to make derivative maps.

◀ The geologist shown here is using a digitizing table to transcribe his field map onto a computer disk. A cross hair in the circular area of the key pad that he holds is centered on one point of a line on his map. Pressing one of the buttons on the key pad causes the digitizing table to record that exact point in the computer. Performing this operation for many points along the line allows the computer program to link the points and thereby record the line in its memory. The lines displayed on the screen were formed by this process and can be printed out to create a final map for review or publication. Digital map compilation has a number of advantages over conventional geologic map compilation. Revisions do not entail costly and time-consuming redrafting of a map, and the digitized geologic map can be digitally integrated with other earth-science (geophysical, geochemical, and so on) and geographic data bases to produce heretofore impossible-to-make second-order customized maps for specific land use, mineral, and energy exploration and geologic hazard assessment purposes. Also, scale can be changed instantly for regional compilation or detailed analysis without redrafting. Publication techniques now being developed will use the digital materials prepared by geologists to allow rapid publication and dissemination of information.

The new program provides for reorganization and expansion of USGS mapping efforts, increased cooperation with States and industry, and grants to universities. The program will establish national goals and priorities for geologic mapping and maintain a data base for the completed published work. The program will foster the development of tools and methodologies to make the acquisition of field data more efficient and will develop new techniques for producing thematic maps and custom-designed geologic and derivative maps through GIS techniques. The program will be organized under four major components, which result from the reorganization of the GFS Program:

1. A Federal component for geologic data acquisition.
2. A cooperative component with the States through COGEOMAP.
3. A grants component to universities to utilize their capabilities and aid in training graduate students in field mapping projects. Grants may be made available to other external groups or individuals.
4. A component to modernize and develop new techniques for data acquisition, presentation, and publication.

To provide optimum response to the national need for basic geologic data, the long-range program has a balanced set of activities, which are to be carried out at a relatively stable and consistent level of effort for an extended period of time. Because of the broad expertise needed, the time-consuming work involved in making geologic maps, and the developmental phase of the modernization component, the projected time required to significantly improve the general geologic data base is about 15 years.

The existing roles and responsibilities of the USGS, the State geological surveys, the universities, and other organizations will remain essentially the same under the proposed program, which will draw on the strengths and capabilities that each organization can bring to the national need for geologic data. Changes that will have the most immediate impact are the improved organization and direction of existing geologic mapping activities and the establishment of a formal USGS mapping component to increase the national geologic data base.

The following section describes more specifically the roles and responsibilities of each participant in achieving the long-range goals of the program and how the program will be funded and presents an outline of the program's goals, objectives, and tasks. Detailed information on the scientific investigations that will be considered for inclusion in the National Geologic Mapping Program is being prepared and will be published at a later time.

Roles of Participants in a National Geologic Mapping Program

The National Geologic Mapping Program will involve the USGS, State geological surveys, and universities; groups such as the National Academy of Sciences will act as consultants. The proposed roles of these participants are outlined below.

Role of the USGS.—The USGS will assume the leadership role in a National Geologic Mapping Program. The USGS will coordinate assessments of the requirements of Federal and State governments, other government agencies, industry, and the private sector for geologic data and, in consultation with these other groups and with the National Academy of Sciences, establish priorities for mapping carried out with USGS funds. The USGS will also establish standards for a national geologic data base and coordinate contributions by the USGS, State geological surveys, universities, and others. It will be the responsibility of the USGS to operate and maintain this data base. The USGS will continue to conduct, either on its own or cooperatively, projects in geologic provinces where mapping is considered to be of national priority.

Role of the State geological surveys.—The State geological surveys will identify mapping needs within their States and set appropriate priorities. Just as the USGS has assumed leadership in mapping at the national level, the States will assume leadership at the State level. State surveys will be the lead agencies for their respective States and will assume primary responsibility for coordination with the USGS. After determining their priorities, States will be requested to communicate them to the USGS to be integrated with national goals. If a mapping need is strictly a State concern, the State geological survey will be responsible for funding and carrying out the mapping; if the need is of mutual State and Federal concern, the State will propose projects under the COGEOMAP Program to obtain assistance and (or) funding from the USGS.

Role of the universities.—Universities will play a dual role in a National Geologic Mapping Program. They will continue to train graduate students in the science and art of field mapping and, with these same graduate students, participate in mapping programs with the USGS and State geological surveys. The USGS, under the university grants component of the program, will provide support to faculty and graduate students and may, in conjunction with certain States, publish maps resulting from their work. Supporting faculty and graduate students will additionally benefit the discipline by helping to train high-quality field geologists for the future. Faculty and graduate students will, in turn, benefit by having their maps published and made readily available to the earth-science community.

Role of the National Academy of Sciences.—The National Academy of Sciences Committee Advisory to the USGS will periodically assist in reviewing mapping priorities developed by the USGS and the progress made in developing a national geologic data base. The committee will advise the Director of the USGS as to whether the program has achieved the balance necessary to address the projected scientific needs of the Nation as well as to support the short- and long-term practical needs of the Nation.

Role of the private sector.—The private sector, consisting chiefly of corporations, consultants, and independent exploration groups, is principally a user of geologic data, because most of its geologic mapping is proprietary. Even so, members of the private sector contribute important data used in geologic mapping, particularly in studies directed at understanding the processes by which certain types of rocks form. The private sector can play an important supporting role in geologic mapping by participating in workshops, advising on national priorities, and allowing access to private property.

Resources for Conducting a National Geologic Mapping Program

The resources needed to conduct the proposed National Geologic Mapping Program will be spread among Federal, State, and university sectors to achieve a balanced overall program. The USGS, supported by appropriation, will be responsible for (1) providing matching support for State mapping activities through COGEOMAP, (2) preparing new geologic maps in high-priority provinces, (3) augmenting field investigations associated with special-purpose mapping in the USGS to assure that data collected will result in general multipurpose geologic maps, (4) supporting university geologic mapping in high-priority regions through a grants program, (5) coordinating Federal, State, and university geologic mapping activities in developing the national geologic data base, and (6) integrating new technologies and techniques into the compilation and production of geologic maps.

State geological surveys are expected to draw upon State appropriations as well as matching Federal COGEOMAP funds. In addition, States are encouraged to work cooperatively with the USGS in the high-priority geologic provinces as well as in other USGS programs.

The USGS will and, at their option, State geological surveys may support the research and training efforts of universities if general-purpose geologic maps are to be a product of those efforts. As it has in the past, support of faculty and graduate student fieldwork in geologic mapping both serves to train the mappers and adds to the national geologic data base. USGS support of faculty and graduate students, in essence, is reciprocated by university support in the form of faculty training of graduate students.

Proposed National Geologic Mapping Program

The USGS proposes a program having the following goals, objectives, and tasks:

Goal I. Increase geologic mapping in response to increasing national needs for basic geologic maps.

Objective A. Identify, on a province-by-province basis, critical earth-science data needs that require new or additional intermediate- to large-scale geologic mapping.

Task 1. Review the National Research Council survey conducted in 1983 as the initial step in identifying user needs for geologic data acquired through mapping.

Task 2. Poll USGS scientists to identify geologic map data needed to address major earth-science problems and circulate the results of that poll to non-USGS groups for comment.

Task 3. Through the COGEOMAP Program and surveys, determine long-term State priorities for geologic mapping.

Task 4. Solicit, through meetings and questionnaires, the geologic map needs of other government agencies.

Task 5. Publish a document that identifies major geologic data needs to be addressed by the National Geologic Mapping Program.

Task 6. Review this document as needed (but no less than every 5 years) to identify and document new needs for geologic data.

Objective B. Establish national geologic mapping priorities by province in order to focus future mapping on critical areas.

Task 1. On the basis of needs identified in accomplishing Objective A, establish an initial set of national priorities for future geologic mapping.

Task 2. Circulate the initial set of geologic mapping priorities for comment. The procedures and priorities will be published in professional publications and *The Federal Register.*

Task 3. Develop final priorities, taking into consideration recommendations received in Task 2. Publish adopted priorities.

Task 4. At 5-year intervals, evaluate the needs for geologic mapping in all provinces, and establish new priorities by using the procedures developed above.

Objective C. Increase the coverage of the United States by intermediate- and large-scale geologic maps in provinces or portions of provinces of highest national priority. Coordinate with and integrate subsurface studies, particularly geophysical, geochemical, and hydrologic investigations, with surface geologic mapping.

Task 1. Begin new USGS mapping projects in the most expeditious sequence, and augment existing USGS projects in high-priority provinces to produce geologic maps appropriate to the National Geologic Mapping Program.

Task 2. Develop and expand COGEOMAP projects with State geological surveys in high-priority provinces.

Task 3. Encourage universities, through grants, to conduct graduate studies in high-priority provinces that will result in publishable geologic maps meeting the established standards.

Task 4. Where other agencies have concerns in high-priority provinces, negotiate reimbursable geologic mapping programs to meet their needs as well.

Task 5. Increase geophysical and geochronological data for high-priority provinces to meet the needs of the geologic mapping program, and augment seismic reflection transects where warranted. Geophysical data are acquired under other programs, but their acquisition will be coordinated with geologic mapping. If extra funding becomes available, deep subsurface data may be acquired within the mapping program.

Task 6. Publish biannual reports on mapping progress in high-priority provinces or portions of provinces.

Task 7. Develop an overall synthesis of the geologic framework in regions where geologic mapping and geophysical data are adequate.

Goal II. Improve coordination among all Federal, State, and university producers of geologic maps to encourage cooperative efforts and avoid unnecessary duplication.

Objective A. Prepare and maintain a system for an annual nationwide inventory of current geologic mapping and published map coverage.

Task 1. In cooperation with State geological surveys, prepare a plan for a national inventory of current geologic mapping activity.

Task 2. Obtain and assemble data on current mapping by means of an annual questionnaire printed in *Geotimes*, other periodicals, *The Federal Register*, and publications distributed internally within the USGS and State surveys. Provide copies of geographic subsets of data to States and interested parties as requested.

Task 3. Keep records of published maps and completed mapping readily available through annual updating of State Geologic Map Indexes.

Objective B. Encourage greater production and public availability of geologic maps.

Task 1. Increase geologic map production of State geological surveys by assisting them through cooperative COGEOMAP projects.

Task 2. Increase geologic map production within the USGS by assisting programs that could produce general-purpose geologic maps, given modest additional resources.

Task 3. Initiate general-purpose geologic mapping in high-priority areas.

Task 4. Encourage greater university mapping by supporting their studies and publishing the resulting maps.

Objective C. In cooperation with the State geological surveys and the National Academy of Sciences, set standards for future geologic maps.

Task 1. Evaluate existing national standards for geologic maps (which were adopted by the USGS in 1956 and revised in 1978) for completeness and applicability to geologic maps produced by all sources. Draft revised standards.

Task 2. Circulate revised standards for comment by State geologists, professional organizations, and the National Academy of Sciences Committee Advisory to the USGS.

Task 3. Develop standards, taking into consideration the comments and suggestions made in Task 2. Discuss new standards at State geologist cluster meetings and with the National Academy of Sciences Committee Advisory to the USGS.

Task 4. Adopt agreed-upon standards for geologic maps, and publish a USGS circular disseminating information on the standards.

Goal III. Adopt new technologies and innovative methods for improving geologic map compilation and production and combining general geologic data with other earth-science and geographic data bases to make derivative maps.

Objective A. Evaluate new technologies and methodologies for geologic map compilation.

Task 1. Review possible new technologies or adaptations of existing methods for producing digitized geologic maps from data collected in the field.

Task 2. Test available methods of producing and revising geologic maps by producing prototype digitized maps, evaluating their technical aspects, and combining them with other geographic data bases to produce derivative maps.

Objective B. Implement new technologies for geologic map compilation and publication.

Task 1. Select the most suitable technologies for assembling and manipulating data away from the office and for expediting map publication.

Task 2. Obtain the necessary equipment to support field-based digital operations and map publication.

Task 3. Convert map production to new methods by providing training and equipment to geologists.

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