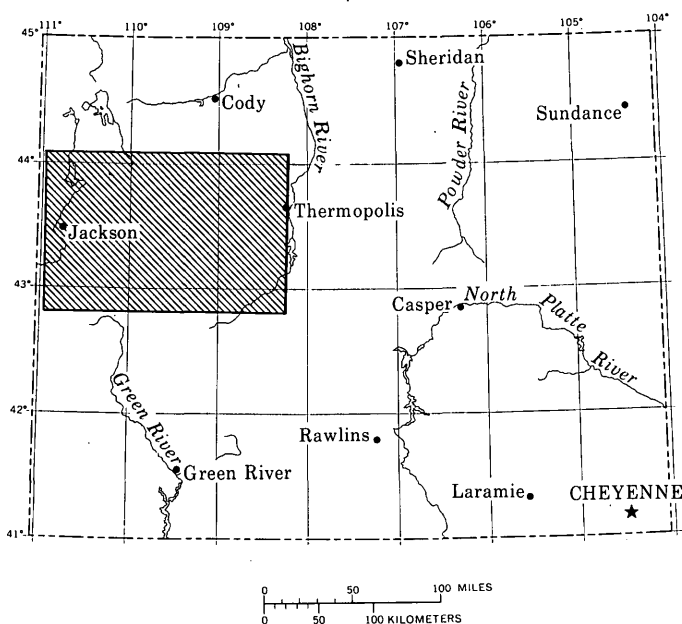
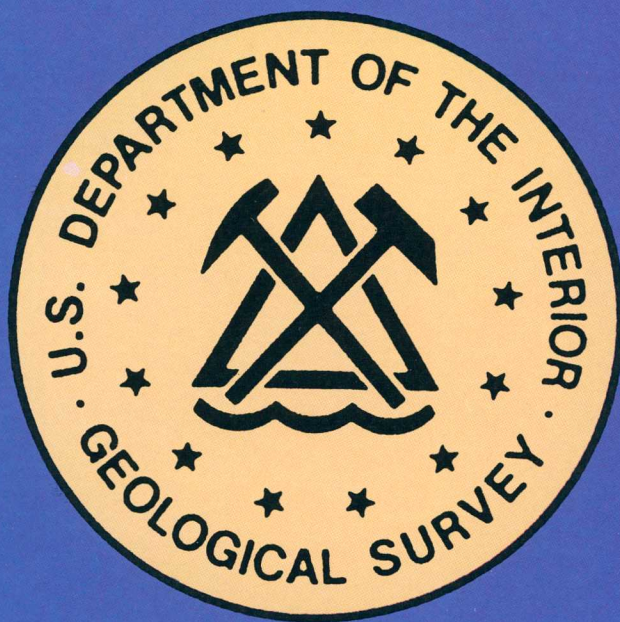


Front and back covers: A portion of the newly published Geologic Map of Wyoming (see index map). The wall-size map is at a scale of 1:500,000 (1 inch equals 8 miles) and shows 215 rock units in 128 colors and patterns. It depicts the history of the Earth's crust in Wyoming by showing the location and types of rocks and the geologic structures, such as faults and folds, that dynamically brought the rocks to their present positions. The history begins, for example, with the ancient rocks shown in mottled blue on the left side of the front cover (Wind River Range), which are over 3 billion years old. Other examples include the slightly younger, but still ancient, rocks in the Teton Range west of Jackson Lake (back cover), and the faults, shown as heavy black dotted and solid lines, that have uplifted them and placed them against much younger volcanic and sedimentary rocks (2 to 100 million years old) east of the lake. Some of these younger rocks, along with others even younger, are part of the dormant volcanic province in Yellowstone National Park just north of the Teton area, which is also shown on the new State map. South of the Teton Range, the map shows numerous thrust faults (heavy barbed lines) that are part of the Cordilleran thrust belt. These thrust faults are huge, nearly horizontal faults that have moved thousands of square miles of rock for tens of miles along individual faults and for more than 100 miles along the combined group of faults. These faults also created oil and gas traps, and their location and shape are used as critical information to guide oil and gas exploration. In addition to the faults, the distribution of the rocks that have potential to contain oil and gas is shown. The Geologic Map of Wyoming provides the foundation for regional evaluation of, and exploration for, mineral resources, oil and gas, coal, phosphate, sand and gravel, and almost every other natural resource found in the State. It also provides a regional foundation for seismic, volcanic, and landslide studies, evaluation of water resources, and specialized scientific studies. The map was compiled by J. D. Love and A. C. Christiansen and prepared in cooperation with the Geological Survey of Wyoming.

Location map of cover



**United States
Geological Survey Yearbook,
Fiscal Year 1985**



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Geological Survey Yearbook,
Fiscal Year 1985

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary



U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

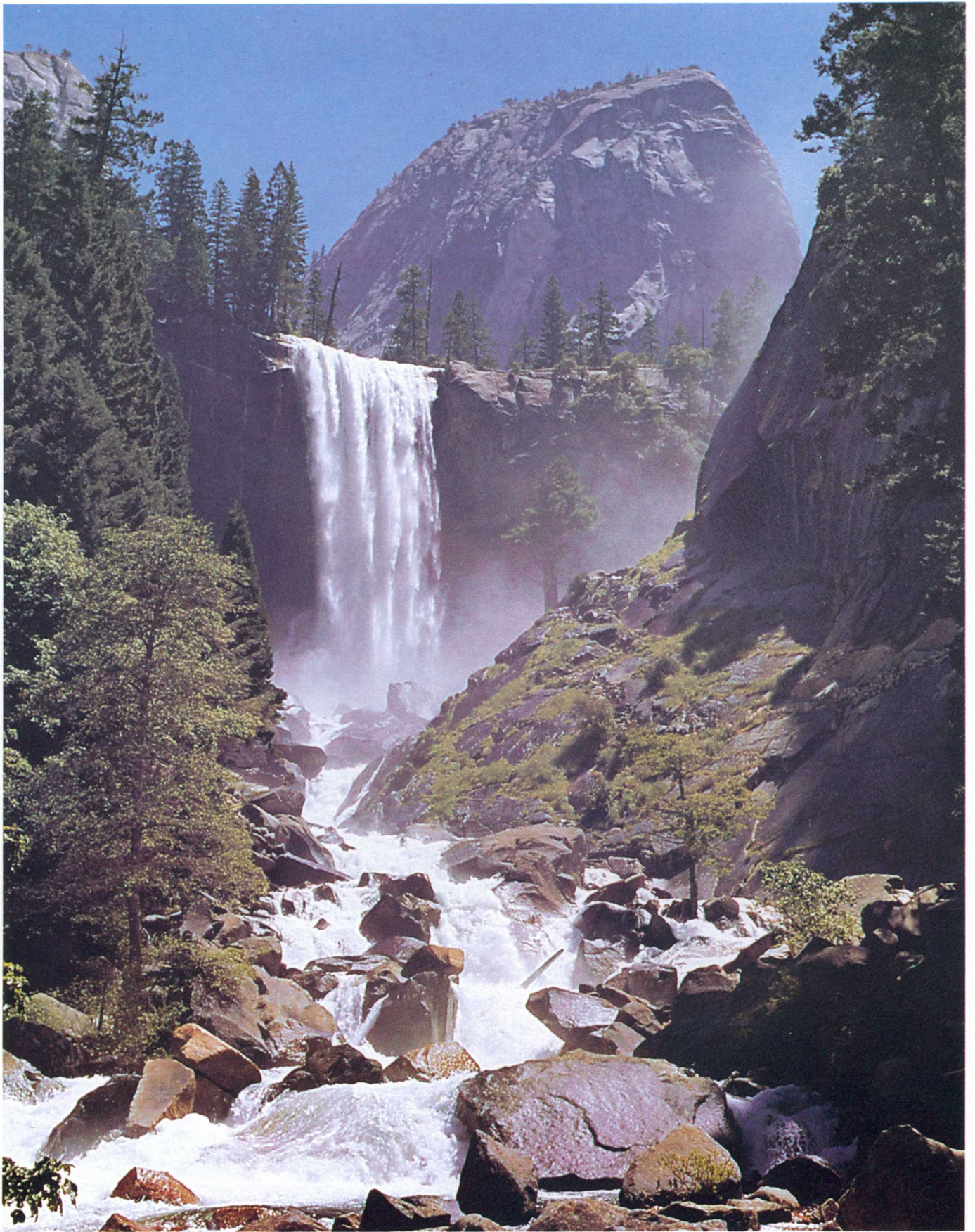
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The Year in Review

The 106th year of the U.S. Geological Survey produced significant advances in our continuing efforts to provide useful earth-science information to serve the public. In this yearbook, we have taken the opportunity to describe special contributions our people are making toward solving earth-science problems facing the Nation. As Director, I am pleased to introduce our annual report by highlighting some of these achievements.

One of the earth-science issues that has been the focus of much public concern in California is selenium contamination of waters and soils from irrigation drainage water in the western San Joaquin Valley. The problem of water-quality deterioration as a result of irrigation drainage is a potential concern in other areas of the country as well. The solution to this problem will require much better understanding of the complicated interactions between surface water, ground water, and soils. The USGS is actively involved in cooperative efforts at national, regional, and local levels defining the distribution in soil and water of selenium and other naturally occurring chemicals that may be harmful. Because this local issue has potential impacts beyond California, we have featured the problem and results of our work on selenium contamination as the first essay in this year's annual report.

On an even larger scale, there is increasing concern in all parts of the United States about the quality of our water resources. Existing water-quality issues such as ground-water contamination, acid rain, and the effects of toxic wastes, as well as other related problems, are regional and national in scope and require a coordinated effort to address. To move toward solutions for some of these problems, the USGS recently began seven pilot studies for a National Water Quality Assessment Program. The pilot studies, four for ground water and three for surface water, will develop the necessary technology and build the cooperative framework required to implement a complete national water-quality assessment in future years. In planning this major new research program, we are working closely with other water-related Federal agencies and a large number of State and local agencies through cooperative committees designated for each pilot study area. We expect the results to benefit a wide audience that needs critical information to make decisions concerning water-quality issues. Our preparation for these studies demonstrates our strong belief that our science can best serve the public when it is an integral part of Federal, State, and local efforts to improve the quality of the Nation's water.

Modern technology makes it relatively easy for earth scientists to accumulate massive and sometimes unwieldy amounts of data. Unfortunately, there have been stumbling blocks to applying much of this data because our methods of analysis have not always kept pace with our ability to collect data. Traditional

*Vernal Falls, Yosemite Park,
California. Photograph by
Dawn Reed.*

methods of analyzing data have become too inflexible and costly to meet demands for new products quickly. USGS scientists are making exciting advances toward new solutions for these data-handling problems by using computerized geographic information systems (GIS). With the emerging technology of GIS, we are entering a new age in presenting traditional spatial information in an almost unlimited array of visual products. The special value of these new systems is the relative ease with which they can be used to select, combine, and arrange various sets of data to fit the needs of many different users. Because GIS technology allows scientists to process and interrelate many more types of data than previously, the new systems show great promise in increasing scientific understanding of complex issues ranging from water quality to mineral-resource assessments to the study of risks from natural hazards. At a time when those of us in the Federal Government are being asked to do our share in reducing the budget deficit, the development of such advanced computer systems will help us meet the need to "do more with less."

In these times of budgetary restraint, it is especially important for us to maintain a careful balance between basic and applied research in the total USGS program of investigations. Each type of research has its own value, and each must be assessed on its own terms. It is the special nature—and the special benefit—of basic research that its undiscovered use yesterday often becomes the long-awaited answer needed tomorrow. The work our geologists are doing to decipher the intricacies of the continental crust is a good example of how basic research provides earth-science information for current as well as future needs. From the study of the deep crust in California, our geologists were able to identify the source of the 1983 Coalinga earthquake, a practical benefit of a long-term basic research effort that might have taken additional years to discover if we had not already had this research underway.

The recent, growing demand for information on radon gas and its effects on human health also underscores the benefits of ongoing basic research. Through our basic mineral research programs, which are an integral part of our overall mission to classify and define the national domain, the USGS has available a large amount of data on radioactive minerals and their distribution in rocks across the country. These data, which were acquired largely by the National Uranium Resources Evaluation program of the Department of Energy, have proven invaluable in helping other government agencies and private groups make critical judgments about radon distribution.

When an environmental concern such as radon becomes a national issue, the problems often develop too suddenly to allow for basic studies on the complex questions being asked. Long-term, basic earth-science research ensures that when anticipated problems arise, we will have developed the information needed to provide answers and solutions.

The growth and increasing complexity of our technological society have led to an ever-expanding need for new and more effective earth-science information. In recent years, we have come to depend more and more on technology to produce information and to solve problems. But we must not lose sight of the fact that it is ultimately with human resources and human ingenuity that we gather the needed information, analyze it, and derive the answers to those needs. The USGS recognizes that, despite all of our technological advances, much of the physical world around us remains an unsolved puzzle. The creativity and dedication of all our Survey people are now much more vital than ever before in finding the answers to the Nation's problems of water quality, mineral supply, and land use.

A handwritten signature in black ink, reading "Dallas L. Peck". The signature is fluid and cursive, with a large, stylized initial 'D'.

Dallas L. Peck
Director



Perspectives

Environmental Influence of Selenium in Waters of the Western United States

By Gerald L. Feder

There are approximately 30 chemical elements known to be required by plants and animals, including humans, for optimal health. Deficient intakes of any one of these chemical elements can result in poor health or death. These same chemical elements, and for that matter all chemical elements, can also cause poor health or death if they are taken in excessive quantities. The admonition of Paracelsus (1493–1541) is very pertinent in this context: “All substances are poison; there is none which is not a poison. The right dose differentiates a poison and a remedy.”

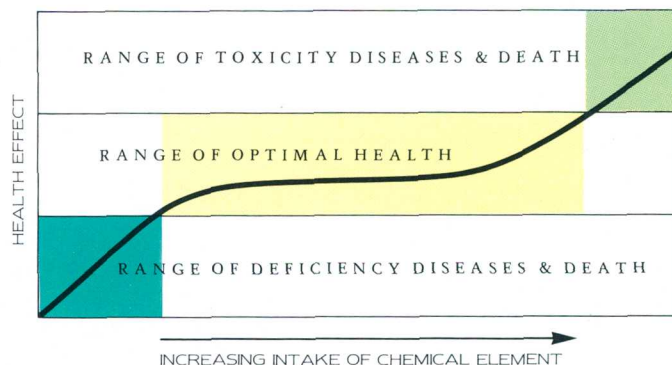
Different natural geochemical environments have very large variations in the concentrations of chemical elements present in their underlying rocks. These chemical differences are reflected in the soils derived from the rocks and in the waters flowing through and over the rocks and soils. Since plants and animals ultimately derive most of their chemical elements from the local soil and water, these large variations in chemical elements among natural environments are reflected in intakes by plants and animals. In living organisms, there is generally a large difference between the concentration range at which a chemical element is toxic and the concentration range at which it may result in poor health due to a deficiency (fig. 1). This “optimal” range not only varies between elements, it also varies among different living organisms. Some chemical elements (magnesium, for example) rarely if ever occur in natural geochemical environments in high enough concentrations to be toxic to humans, but, in some areas, they may cause health problems due to a deficiency. Other chemical elements, such as mercury, cadmium, and lead, are known to occur naturally in sufficient con-

centrations to be toxic to plants and animals, but they are not known to occur in low enough concentrations to cause deficiency diseases.

Between the two extremes described above are a group of chemical elements that individually may cause either a positive or negative effect on plant and animal health according to their availability at a particular site. A good example of such an element is selenium. Under various natural conditions that are mainly controlled by geochemical environment and climate, there are large areas of the world where selenium is known to cause health problems in farm animals, either due to natural deficiency or to toxicity. For example, large areas of New Zealand have soils and water that are very low in selenium, and unless sheep and cattle are given selenium additives in their feed, they suffer degenerative diseases and may die from this deficiency. On the other hand, in some other areas of the world, including parts of the Western United States, selenium may occur in high enough concentrations to be toxic to livestock. Selenium toxicity in livestock is especially prevalent in areas of the West where selenium-concentrating plants, such as the *Astragalus*, or loco weed, grow in soils containing high concentrations of selenium.

Even though rocks with high concentrations of selenium are found in many parts of the United States, almost all of the toxicity problems associated

Figure 1. Idealized graph showing the relationship between variations in intake of chemical constituents and plant and animal health.



Irrigated fields, central California.

with selenium in the natural environment occur in the West. The reason for this is the prevalent arid climate that has such an important control on the hydrologic cycle and, ultimately, the solubility of selenium in this region. The relationship between the solubility of selenium in water and different climatic and geochemical environments is shown diagrammatically in figure 2. This diagram shows that selenium is very insoluble under poorly aerated acidic conditions. This type of geochemical condition is common to many waters in the humid Eastern United States. In such areas, even if the rocks contain high concentrations of selenium, the element will not occur in high concentrations in the natural waters of the area. The same general principle holds for other trace elements that are geochemically similar to selenium, such as uranium, vanadium, and molybdenum.

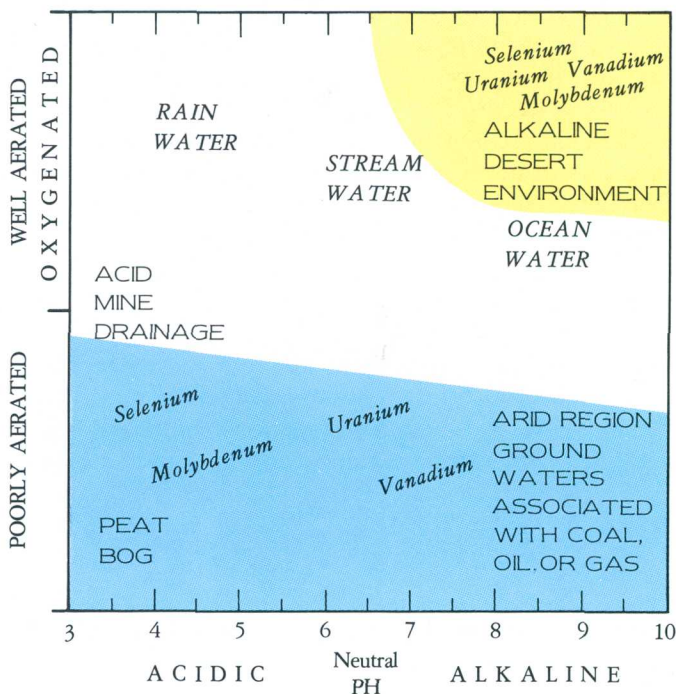
In the semiarid alkaline environments common to much of the Western United States, these elements are quite soluble, and they are readily dissolved and transported by surface and ground waters. Even in the arid West, however, where ground waters contact a localized geochemical environment without oxygen, as shown in the lower right-hand corner of figure 2, these elements will precipitate out of solution. The oxygen-deficient environment usually occurs where organic matter, such as coal, oil, natural gas, or even buried wood, is locally present. This process has been the source of most of the major uranium deposits in the Western United States, which often have large amounts of selenium, molybdenum, and vanadium

associated with them. As long as these areas of deposition are in their natural state, the elements generally remain insoluble and do not occur in local surface and ground waters. Pumping the ground water from these areas to mine uranium, however, introduces oxygen to these deposits that causes all of these chemical elements to go back into solution, increasing the probability of pollution.

In some areas of the Western United States, it is difficult to distinguish between toxicity problems attributable to selenium or to highly saline alkaline waters. For example, the recent practice of deep-ripping fields combined with fallowing has created a costly saline-seep problem in large areas of Montana, North Dakota, South Dakota, and Wyoming. The saline-seep problem manifests itself as seepage areas in fields and along streams in these areas; besides ruining cropland, the highly saline waters kill livestock, wildlife, and fish. During the summer and fall dry seasons, the increased evaporation of these seeps greatly increases the salt content of the water, including the levels of selenium. At present, it is difficult to determine whether the damage to animals in the saline-seep areas is caused by saline alkaline water or selenium toxicity.

Parts of the San Joaquin Valley of California have high salinity levels in waters accompanied by high selenium values. In this area, however, there is more evidence that selenium might be the culprit rather than high salinity. Wildlife experts cite the presence of selenium-tolerant fish as the only remaining fish in drainage canals containing waters high in sele-

Figure 2. Diagrammatic representation of hydrogeochemical environments related to oxygen content and acidity of natural waters. The blue area represents conditions where selenium and associated chemical elements are insoluble, and the yellow area represents conditions where they are soluble.





Aerial view (looking north) of Kesterson Reservoir in the Kesterson National Wildlife Refuge near Gustine, San Joaquin Valley, Calif. The San Luis Drain is to the right. (Photograph by David Gilmer, U.S. Fish and Wildlife Service.)

nium and distinctive damage to waterfowl hatchlings in Kesterson Reservoir as causes for concern. Even though man's activities in the San Joaquin Valley have exacerbated the selenium problem, the ultimate cause can be traced to the natural geochemical environment in the mountains west of the valley. Understanding the geochemical control on the occurrence of selenium in this region may lead to the anticipation of possible problems in other areas and to actions that could prevent those problems.

The climate in and around the San Joaquin Valley is conducive to the solution and mobilization of selenium, but the rocks on the east side of the valley,

granites of the Sierra Nevada, do not contain a significant source of selenium, and this situation produces selenium-deficiency problems rather than selenium-toxicity problems. In fact, the sediments derived from these mountains are so low in selenium that cattle feeding in this area do not get sufficient selenium from plants grown on the soils or from local water supplies, and their diets must be supplemented with selenium. As shown in the diagrammatic cross section of the San Joaquin Valley and the surrounding mountains (fig. 3), the rocks in the Coast Ranges on the west side of the valley are the ultimate source of selenium in the soils and waters of the valley.

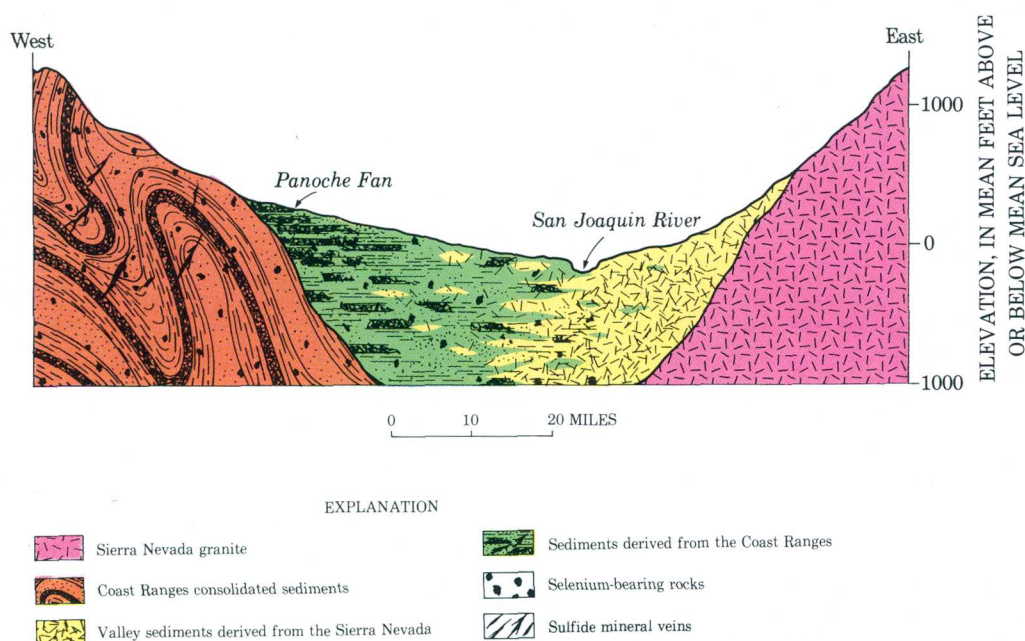


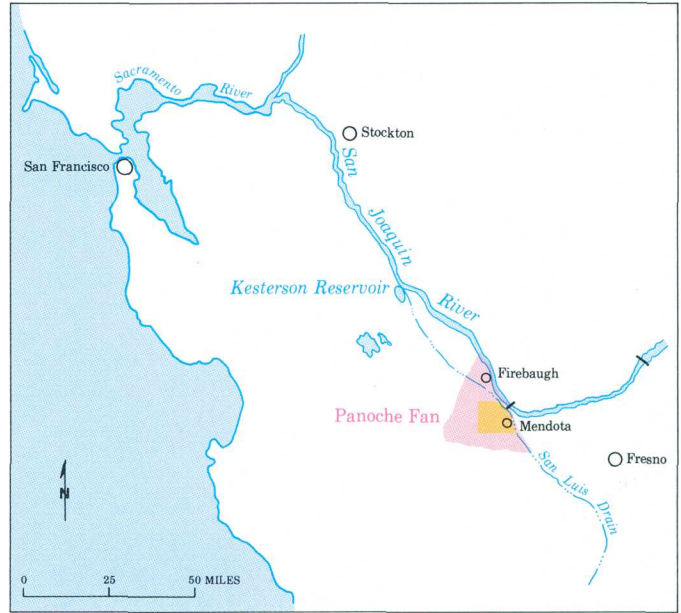
Figure 3. Idealized cross section across the San Joaquin Valley of California showing different compositions of source rocks in mountains on both sides of the valley.

Figure 4. Map of part of the San Joaquin Basin showing the location of the San Luis Drain and Kesterson Reservoir. Area in orange shows where underground tile drains have been constructed.

Solution of selenium from the many diffuse sources in these rocks has led to the present problems in the valley. The rocks are primarily sediments of marine origin and contain scattered metal-sulfide deposits. Iron, lead, zinc, mercury, molybdenum, and other metals are found in this area, combined with sulfur as sulfide minerals. Selenium, which is chemically similar to sulfur, is mostly found in these sulfur-containing minerals substituting for some of the sulfur. For example, pyrite, a chemical compound consisting of iron and sulfur, may have up to 1,000 parts per million of selenium substituting for the sulfur. Selenium can also substitute for sulfur in gypsum, in organic compounds such as proteins, and in many other minerals.

As a result of weathering processes, the selenium-containing minerals within rocks of the Coast Ranges are slowly dissolved and the now-soluble form of selenium, called selenate, is slowly removed by flowing surface and ground waters. Under natural conditions that prevailed before intensive farming in the valley and water diversion projects, the soluble salts were transported in solution during wet periods down to the valley where they were either precipitated out in the valley sediments due to evaporation or occasionally carried by streams into San Francisco Bay. Runoff from large storms transported both fresh and weathered rock containing selenium minerals to the valley floor, which created the large fans of sediment, such as the Panoche Fan, along the western edge of the San Joaquin Valley. Because of the arid climate within the valley, the selenium in the water and sediments transported to the fans is concentrated by evaporation. The selenium occurs in the fans as unweathered selenium-containing minerals, precipitated soluble-selenate-containing salts, and coatings adhering to clays, iron oxides, and fine sediments.

Before the advent of water control projects and farming in the valley, soluble selenium and other salts built up gradually in the valley soils and shallow sediments. The recent intensively irrigated agriculture and water control projects in the valley attempted to flush salt from the soils, but a near-surface clay caused waterlogging and salt buildup at the land surface that eventually damaged crops. This buildup of salts is still going on in much of the San Joaquin Valley. As shown in figure 4, in this area, underground tile drains have been constructed in



part of the Panoche Fan to remove the saline waters that build up in the soils. Even with the relatively small amount of tile drainage in the Panoche Fan, there is a large amount of saline drainage water being moved from the area into Kesterson Reservoir. The highly saline water moving into Kesterson Reservoir contains large amounts of selenium. Besides selenium, other chemical elements are present at high concentrations and may be harmful to plants and animals. Before the water in Kesterson Reservoir reaches levels toxic to organisms living in it, certain plants and animals in this environment concentrate some chemical elements sufficiently to be toxic to other organisms that use them as a food source. The selenium toxicity noted in waterfowl is believed to result from the bioaccumulation of selenium in the food chain; for example, the accumulation occurs from algae to insects to fish to birds.

Summary

Large areas in the Western United States, with its climate that often promotes the solubilization of selenium, are underlain by geologic formations containing high concentrations of selenium. Understanding the geochemical controls on the occurrence and movement of selenium in Kesterson Reservoir will help make possible the recognition of potential selenium problems in other areas so that mitigation measures can be taken. This knowledge will serve to alert persons in similar areas to the probability of selenium toxicity, both in the natural environment and in the environment altered by man's activities.

Geographic Information Systems: An Important Tool for Spatial Analysis

By Stephen C. Guptill and David A. Nystrom

Introduction

Today, Federal and State agencies must quickly respond to complicated problems involving natural resources data for a variety of geographic areas. Administrative and regulatory responsibilities assigned to governmental agencies have placed tremendous pressure on existing information delivery systems. The traditional methods of acquiring, storing, and analyzing natural resources data are proving to be too costly and inflexible in meeting these growing needs. Computerized geographic information systems (GIS) are emerging as the spatial data handling tools for solving complex geographical problems.

A geographic information system is a computer system designed to allow users to collect, manage, and analyze large volumes of spatially referenced data. The use of GIS technology has revolutionary implications for the way the Geological Survey conducts research and presents the results. As the Nation's primary producer of cartographic, geographic, hydrologic, and geologic data, the Geological Survey is using advanced GIS technologies to greatly improve its ability to perform traditional missions of earth science data collection, research, and information delivery.

The Geological Survey and other bureaus and offices of the Department of the Interior have created a number of digital spatial data bases that are being used in geographic information systems. Among these are the National Digital Cartographic Data Base, the Federal Mineral Land Information System, the Land Use and Land Cover Mapping Program, the National Coal Resources Data System, the National Uranium Resources Evaluation System, the Rock Analysis Storage System, and the National Water Data System. The Geological Survey is increasingly being required to serve as a central repository as well as the Federal authority on information regarding such critical issues as the Nation's energy and mineral potential, the assessment of risks from natural hazards, and questions of the quantity and quality of water supplies. Because GIS technology allows scientists to process and interrelate many more kinds of data than were previously feasible, GIS applications research can provide new scientific understanding of these issues.

Characteristics of Spatial Data

A GIS cannot function without digital spatial data. Spatial data consist of the various features that are associated with a geographic location. These features can be points, lines, or areal characteristics that are visually discernible, such as wells, roads, or lakes, or invisible boundaries, such as county lines or school districts. A GIS must be capable of storing and manipulating these types of point, line, and areal data. The association of a given spatial feature with a data type depends on the scale of the map or image. For example, a river can be shown as an area at large scale but only as a line at a smaller scale.

Two major methods, or data structures, are used to organize spatial data within a computer for use by a GIS: the raster data structure and the vector data structure. Each of these structures has distinct advantages and disadvantages that affect cost and efficiency.

A raster data structure is formed by partitioning the study area into a set of grid cells that are usually square. Each cell is assigned a code describing the feature contained within the cell, as in type of land use, elevation, or county name. The size of cell is selected on the basis of the resolution needed, or available, in the case of remote sensing satellites such as Landsat, and the capacity of the system.

Explicit x,y coordinates are not given to each cell because the cell location is implicit in its row and column in the grid. Separate thematic data sets over the same area, such as land use and counties, can be easily merged (overlaid) by combining the attribute codes, cell by cell, of each data set. The raster data structure is popular in large part because of the ease of programming the overlaying and other analytical operations. However, the cell-by-cell nature of the raster structure makes it difficult to retrieve information about specific areal or linear features (for example, the length of the shoreline of Great Salt Lake) or to traverse a network of linear features (for example, routing a train from Atlanta to Denver).

Vector data structures use a series of x,y coordinates to describe the point, line, and area (or polygon) features. In addition, information about the connections and relationships among the features portrayed on a map (the topology of the map) is

calculated and stored with the coordinates. Thus, system users can derive relationships such as adjacency and connectedness easily. This data structure is computationally more demanding than a raster structure but is being used increasingly in GIS's because of the decreasing cost of computers and the greater information inherent in such data. The digital line graph structure used in the National Digital Cartographic Data Base is an example of this type of data organization.

Functional Characteristics of a GIS

The principal functions commonly found in geographic information systems are given in table 1. Each functional component has counterparts that work on vector or raster data types. No known system contains all the possible functions given in the table, and it may be argued that no one system should. The functional components present in any particular GIS vary considerably according to its application. For example, one system might emphasize the creation of publication-quality map products, while another might stress statistical generation.

Data Requirements

Although GIS technology has been in use for more than a decade, the level of acceptance and use has, until recently, remained relatively low. Since data collection is perhaps the most expensive phase of GIS operations, it is likely that the lack of detailed base map and thematic information in digital form has hampered GIS growth. Efforts by the Geological Survey to link its various spatial data bases and to provide rapid, convenient, and cost effective access to the data will help alleviate this problem. In particular, the national data base of transportation and hydrologic features digitized from 1:100,000-scale base maps will serve not only as a fundamental data base for GIS studies but also as a catalyst for the addition of thematic data.

Application of a GIS

In 1984, the Geological Survey and the Natural Resources Center, Connecticut Department of Environmental Protection, agreed to test jointly the use of a GIS as a means to improve the traditional methods of obtaining, storing, updating, analyzing, and dis-

playing mapped natural resources data. This effort was a logical outgrowth of the extensive cooperative studies that the State and the Geological Survey have conducted in Connecticut over the last 50 years. The results of this test were presented at the Association of American State Geologists Annual Meeting held in Mystic, Conn., in June 1985.

A project area covering the Broad Brook and Ellington 7.5-minute quadrangles in north-central Connecticut was selected (fig. 1).¹ The area had been used in earlier studies on the application of mapped natural resources data in environmental planning and management. From 1968 to 1972 the Ellington quadrangle was the focus of the Connecticut Geology and Soil Task Force in demonstrating resource map overlay techniques for selecting potential landfill sites, and in the early 1970's both quadrangles had been included in the Geological Survey/State cooperative Connecticut Valley Urban Area Project. This project produced numerous interpretive and basic resource maps for use in local and regional planning. More recently, the Broad Brook subregional drainage basin, of which approximately half lies in each quadrangle, was selected by the University of Connecticut as a major hydrologic and meteorologic research area.

The ARC/INFO geographic information system developed by Environmental Systems Research Institute, Redlands, Calif., was the primary GIS used for the project. ARC/INFO consists of two major programs: ARC maintains the topologically structured vector data base in which points, lines, or areas are used to represent mapped features, and INFO stores and processes attribute information (land use, surficial materials, etc.) about the geographic features maintained by ARC. The State of Connecticut was already using INFO as its data base management system.

Data entered into the GIS came from existing digital data bases and from digitizing information from hard-copy maps. Digitizing was done at the Geological Survey's Eastern Mapping Center and Earth Resources Observation Systems Data Center. Source materials used in the digitizing process were 1:24,000-scale mylar overlays supplied by the Eastern Mapping Center and Connecticut's Natural Resources Center.

Approximately one-third of the data base was developed from existing digital data. These data included 1:24,000-scale digital line graphs for 1980

¹Figures 1 through 7 were produced by an ink jet plotter and are copies of images shown on a color display terminal. As such, they represent the types of graphic output an analyst would see while using a GIS on an applications project.

Table 1. Functional components of a GIS

Component	Definition	Example
Data capture	Assembling analog source data into some digital form.	Line digitizing.
Structuring	Processing data from initial digital form into a structured form.	The topological structuring of vector data.
Editing	Inserting, deleting, and changing attribute and coordinate data.	Moving a line segment.
Structure conversion	Moving between data structures.	Raster to/from vector.
Geometric correction	Fixing data to ground or image space in some referencing system.	Adjustment of map or image to latitude and longitude control points.
Projection conversion	Transforming coordinates between alternative referencing systems.	Geographic to/from Universal Transverse Mercator.
Spatial definition	Paneling or clipping of the data to change the area covered.	Limiting data to within a county boundary.
Generalization	Reducing detail in the data.	Changing a raster grid to a larger spacing, or reduction of points in a line.
Enhancement	Modification of detail in the data.	Edge definition.
Classification	Recoding of the data to form classes.	Classification by spectral response, by attribute codes, and choropleth mapping.
Statistical generation	Deriving descriptive statistics and (or) measurements from the data.	Polygon area measurements.
Retrieval	Selective extraction of data by attribute codes and (or) spatial searches, or neighborhood analysis.	Selection of certain features within a circle of a given radius from a point.
Overlaying	Relating two data sets in a logical and (or) arithmetic manner.	Creating composite maps.
Display	Generating a graphic image from the model.	Color cathode-ray tube displays, or symbolized line maps.
Analytical technique support	Using analytical manipulations and computations on the data.	Finding the shortest route through a road network.
Data management	Managing access and archiving of data models.	Security protection, data base control of storage, retrieval, and update.

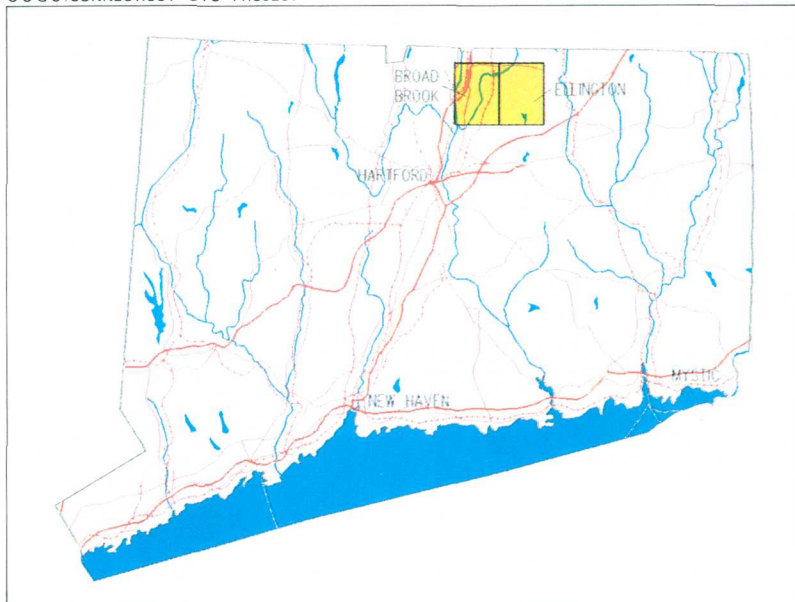
land use and land cover, political boundaries, hydrography, transportation, and State and Federal lands that were available through the Geological Survey. The Geological Survey also supplied an automated geographic names file and digital elevation model data. The basic data sets that were developed for the

project are given in table 2. The list includes the source of the data, its original scale, its data type (raster, point, line, or area), and an indication of its relative density (complexity). The table provides an indication of the large amount of information that a GIS must contain to perform various analyses.

Table 2. Basic data sets for U.S. Geological Survey/Connecticut GIS Project

Data set	Resolution/scale	Source	Data type	Density
Aeromagnetic survey	1:24,000	USGS ¹	Lines	Low
Bedrock elevations	1:24,000	USGS/NRC ²	Lines	Low
Bedrock geology	1:24,000	USGS/NRC	Areas	Low
Biophysical land classification	1:50,000	NRC	Areas	Low
Census boundaries	1:24,000	USGS	Lines	Low
Digital elevation models	30-meter grid	USGS	Raster	High
Drainage basin boundaries	1:24,000	USGS	Lines	Medium
Endangered species	1:24,000	NRC	Areas, points	Low
Geographic name file	1:24,000	USGS	Points	Low
Hydrography	1:24,000	USGS	Areas, lines	High
Land use/land cover	1:24,000	USGS	Areas	High
Landsat multispectral scanner scenes	80-meter grids	USGS	Raster	High
Mining inventory	1:24,000	NRC	Areas, points	Low
Municipal zoning	1:24,000	NRC	Areas	Low
National wetlands inventory	1:24,000	NRC	Areas, lines	High
Political boundaries	1:24,000	USGS	Lines	Low
Pollution sources	1:24,000	NRC	Points, areas	Low
Public water supply service areas	1:24,000	NRC	Areas, lines	Medium
Public water supply wells	1:24,000	NRC	Points	Low
Sewered area	1:24,000	NRC	Areas, lines	Low
Soils	1:15,840	SCS ³ /NRC	Areas	Very high
State and Federal lands	1:24,000	USGS	Lines	Low
Surficial materials	1:24,000	USGS/NRC	Areas	High
Transportation network	1:24,000	USGS	Lines	Medium high
Water quality classification	1:24,000	NRC	Points, lines, areas	Medium
Water table elevations	1:24,000	NRC	Lines	Medium high
Water utility lands	1:24,000	NRC	Areas	Low
100-year flood zone	1:24,000	NRC/FEMA ⁴	Areas	Medium low

¹USGS, U.S. Geological Survey.²NRC, Natural Resources Center.³SCS, Soil Conservation Service, U.S. Department of Agriculture.⁴FEMA, Federal Emergency Management Agency.



Base Map: U S G S Digital Line Graphs from 1:2,000,000 Data

Figure 1. Location of Broad Brook and Ellington, Conn., quadrangles.

Four application models were developed to test the utility of this GIS in actual governmental agency programs. The four application models were industrial site selection, ground-water flow, streams lowflow, and public water supply ground-water exploration. The models were designed to evaluate the effectiveness of GIS technology in integrating data from a variety of sources for use in research, planning, management, and regulatory programs.

The public water supply ground-water exploration model is a particularly useful example for demonstrating the application of a GIS in State water supply planning. Under the Connecticut water quality classification program, sites that are used or are proposed for public water supply are assigned a classification that precludes the issuance of wastewater discharge permits in the area.

A single water utility was selected for the analysis on the basis of a projected need for increased water supply. In the computer model a 0.5-mile buffer zone was created around the water utility's service area (fig. 2). This buffered zone served as the geographic window through which other spatial data sets were analyzed. Areas that were incompatible with ground-water development were eliminated as potential sites. These included all land uses and land covers other than forest and forested wetlands, areas of poor

water quality classifications, areas within 500 meters of pollution sources, areas within 100 meters of waste-receiving streams, areas within 100 meters of existing water supply wells, and areas that were zoned for incompatible land uses (figs. 3 and 4). Then geologic and hydrologic data were evaluated to identify the remaining areas of coarse-grained materials having more than 40 feet of saturated zone thickness (figs. 5 and 6). The final product was a map depicting suitable sites of new water supply within the 0.5-mile buffer zone surrounding the water utility's service area (fig. 7).

Conclusions

As the lead Federal agency in digital cartography and other earth science topics, the Geological Survey is developing advanced techniques in all aspects of data processing that relate to a geographic information system. Sufficiently advanced software and hardware capabilities must continue to be available to earth scientists so that GIS technologies can be used for accomplishing the data collection and research missions of the Geological Survey and for cooperative GIS projects with State and other Federal

Figure 2. Location of the Somers water service area. The service area boundaries have been extended with a 0.5-mile buffer zone.

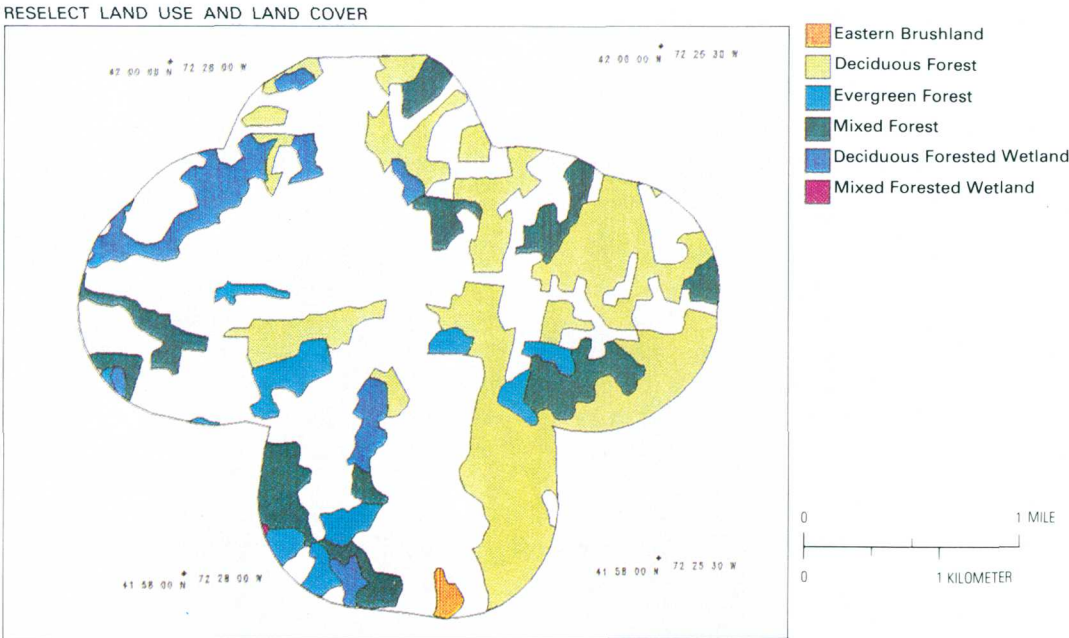
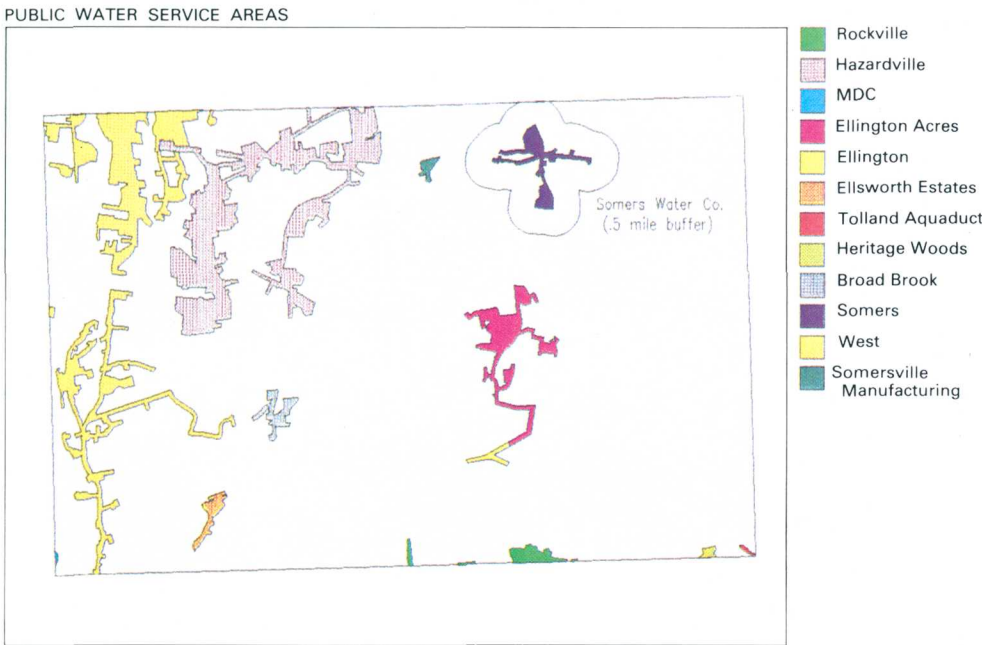


Figure 3. Land use and land cover classes within the project area. Areas of eastern brushland, deciduous forest, evergreen forest, mixed forest, and forested wetlands are acceptable for well locations.

POTENTIAL SITES AND BUFFERED POLLUTION SOURCES



Figure 4. Potential well sites (in purple). Areas within a 100-meter buffer zone surrounding streams with an existing or future water classification of B or below (waste discharges allowed in stream), as well as areas within a 500-meter buffer zone surrounding five point sources of pollution (in red), have been removed from consideration for well sites.

SURFICIAL MATERIALS GROUPED BY TEXTURE

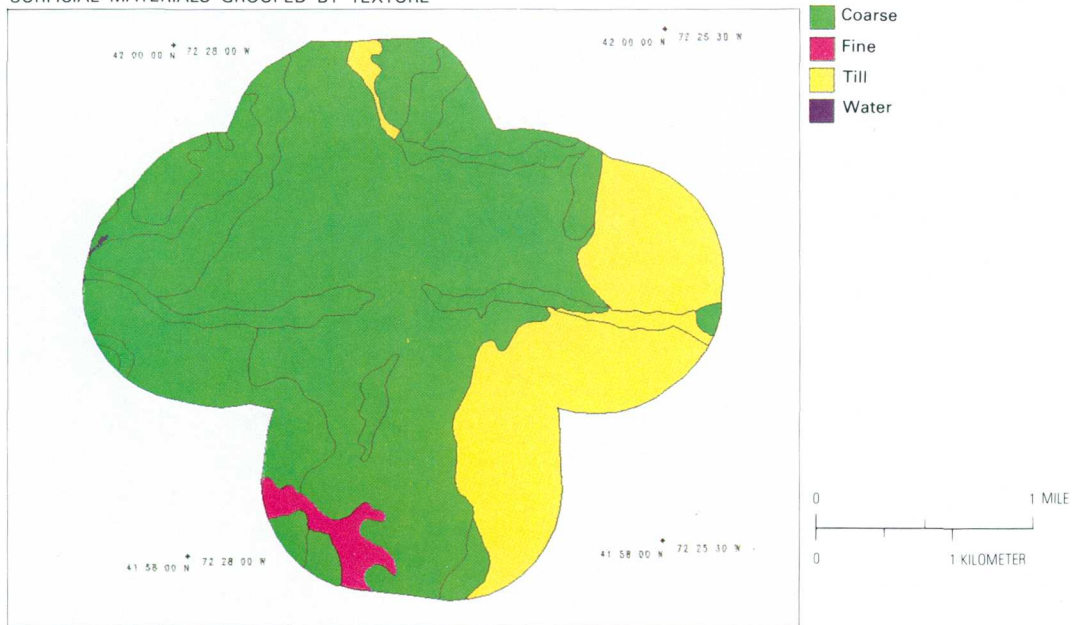


Figure 5. Surficial materials within project areas. The surficial material for the well location must be coarse grained.

SATURATED THICKNESS

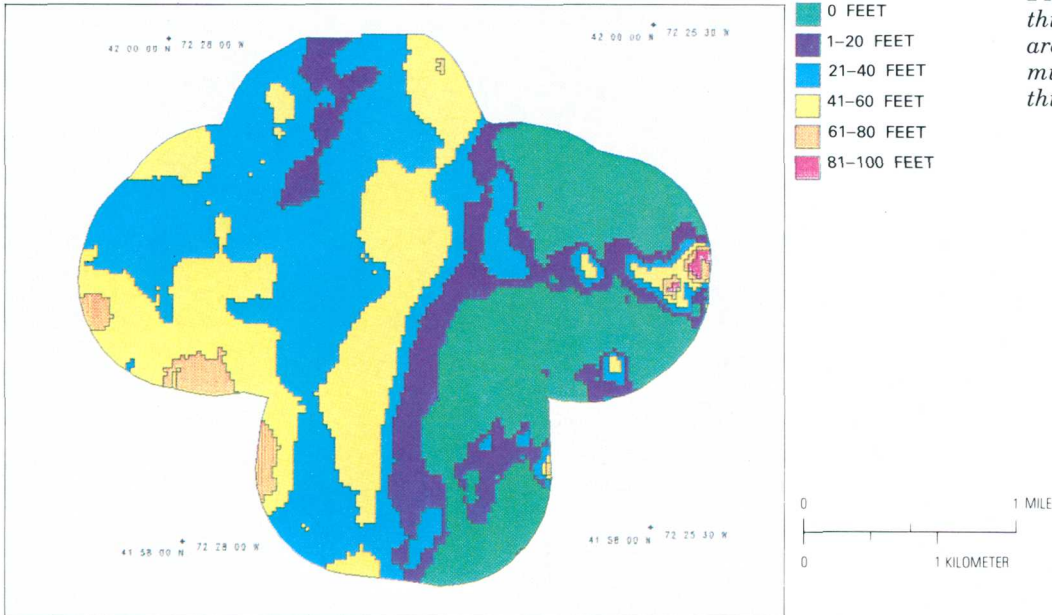


Figure 6. Saturated zone thickness within the project area. The well location area must have a saturated thickness of at least 41 feet.

POTENTIAL SITES FOR PUBLIC WATER SUPPLY WELLS (SITES IN GREEN)

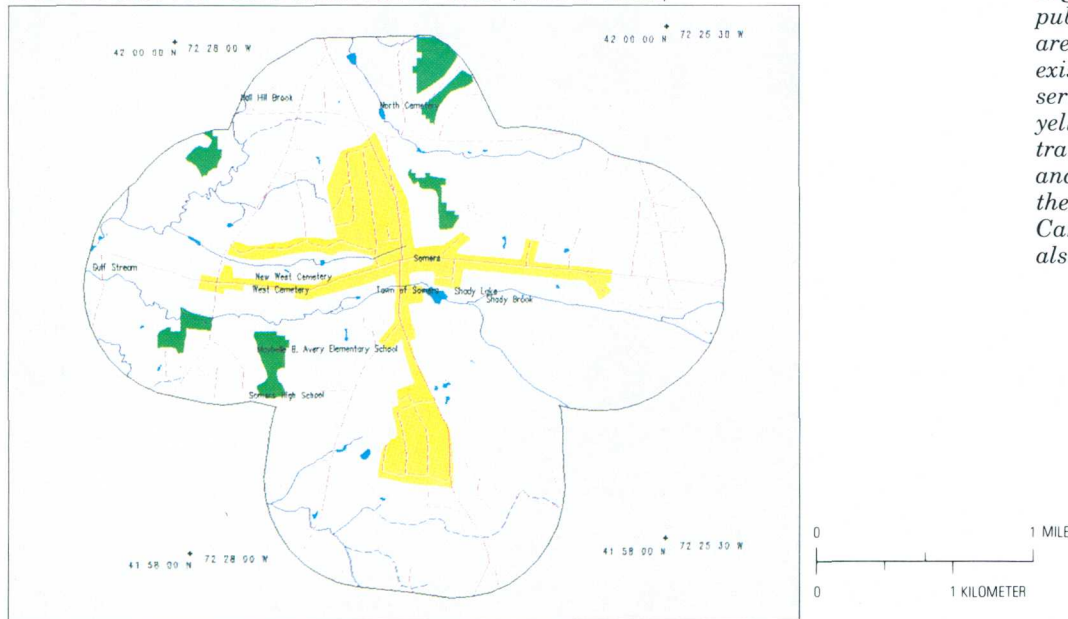


Figure 7. Potential sites for public water supply wells are shown in green. The existing Somers water service area is shown in yellow. Selected transportation, hydrography, and names information from the National Digital Cartographic Data Base are also shown.

agencies. Geological Survey scientists are also actively pursuing additional projects to facilitate exchange of data, knowledge, and capabilities with other scientists and managers. The Geological Survey is in a unique position, as a result of existing

programs, to continue its major Federal role in developing techniques for applying advanced GIS technology to local, State, national, and global earth science problems.

Looking Deep into the Earth's Crust with Seismic Reflection Profiling

By Carl Wentworth

An improved understanding of the structure and composition of the Earth's continental crust (down to depths of 30 miles) is now viewed as a key to solutions for many of the earth-science issues that affect our society. These issues range from determining the origin of mineral and energy deposits to more direct interpretations of the causes of earthquakes and volcanic eruptions. The importance of studies to obtain greater understanding of crustal processes was recently emphasized by the National Academy of Sciences, which reported that investigation of the deeper continental crust is a research area that will yield significant scientific advances in the near future.

The U.S. Geological Survey recently established a new program, Deep Continental Studies, to address this topic. The program will exploit the successful development of plate tectonic theory over the past 25 years, which provides a sound framework for analysis, and will take advantage of improved technology, which allows geological and geophysical delineation of the entire crust in useful detail (fig. 1). The program promotes multidisciplinary research that focuses on the deep crustal environments and processes that ultimately control near-surface geology and our own environment. Objectives of this program are to make geologic and geophysical investigations of the composition, structure, and deformational history of major continental features; to establish, jointly with the Department of Energy and the National Academy of Sciences, a program to directly sample the upper crust by drilling to depths as great as 10 miles; and to conduct laboratory research on the physics and chemistry of continental materials at the high temperatures and pressures characteristic of the deep crust.

Although the objectives in scientific drilling and studies of physical properties are new efforts within the Geological Survey, studies of the crust along transects across representative sections of the North American continent are already underway. Major

transects are being studied across central California, across central Maine, along the oil pipeline that crosses Alaska, and in southern California and Arizona. These studies combine information on surface geology with data from various geophysical methods, including advanced seismologic techniques.

Most of our geologic understanding of the Earth is based on direct observation of rocks exposed at the ground surface and is largely the result of geologists making geologic maps of these rocks, the structures affecting the rocks, and the interrelations of the rocks. In the past several decades this understanding has been greatly improved by new information from geophysical studies, such as seismic reflection and refraction methods, gravity measurements, and investigation of the Earth's magnetic field.

Seismic reflection profiling uses the reflection of downward-traveling seismic waves to produce a detailed vertical picture of rock structures along a profile line to depths of 5 to 30 miles in the Earth. Seismic refraction profiling, in contrast, uses the time that seismic waves take to travel laterally through rock to calculate the velocity of the seismic waves and the shape and depth of boundaries between layers of different velocity (fig. 2).

Seismic reflection profiling has been used for half a century and owes most of its development and refinement to the petroleum industry, which has very successfully used it to explore for oil and gas. The application of high-speed computers to process and enhance very weak seismic signals has now made reflection profiling extremely valuable not only in oil and gas exploration but in scientific investigation of the deep crust as well.

The seismic reflection technique involves generation of seismic waves at the ground surface that move downward and are reflected back from the boundaries between different types of rocks within the crust. The returning waves are detected at the surface by an array of seismometers that convert the waves to electrical signals, which are then recorded

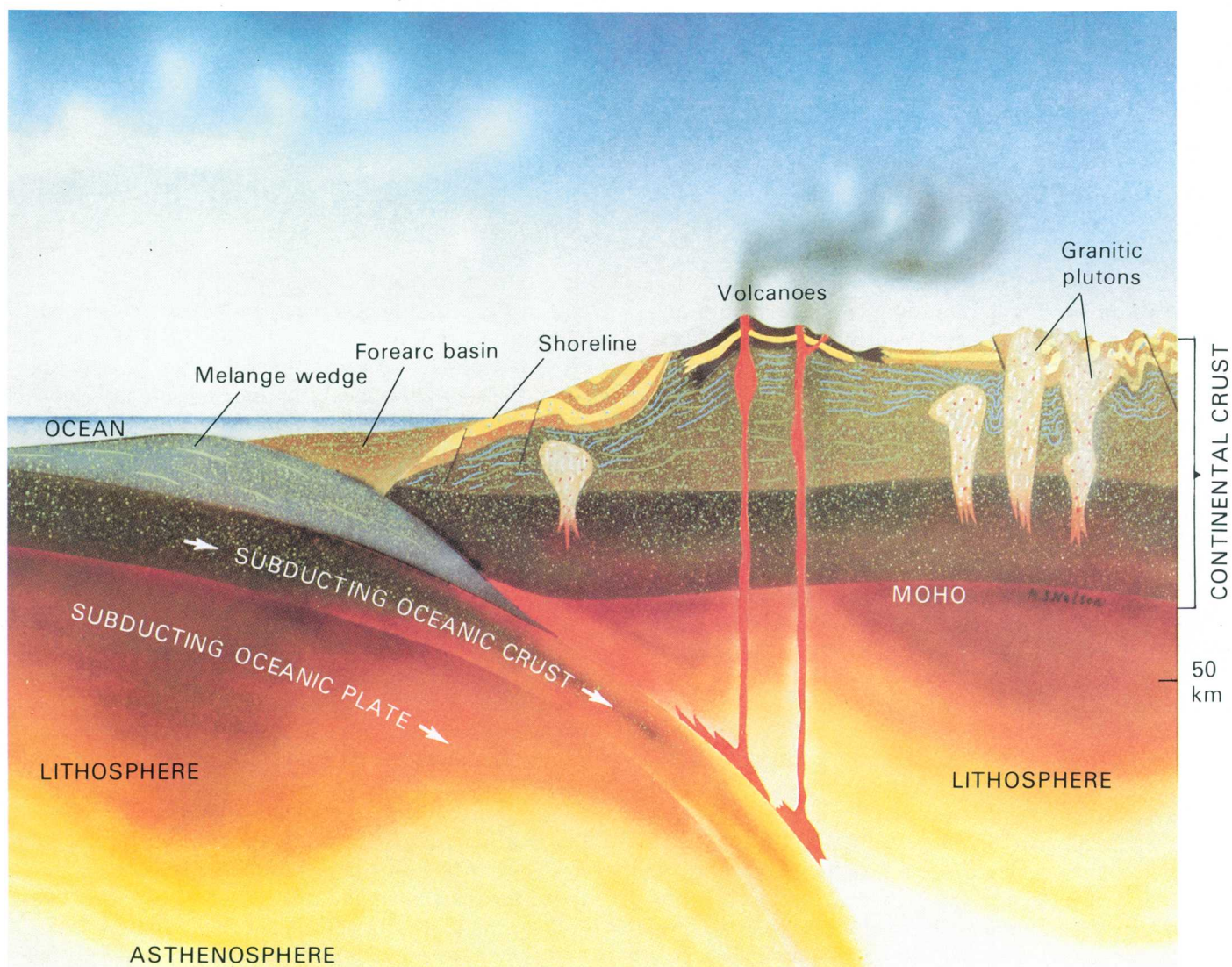


Figure 1. The continental crust, which has a history beginning as early as about 3 billion years ago, contains features representing such processes as accumulation of sediment, melting and movement of molten rock, and, on a larger scale, the growth, collision, and splitting of continental masses. Modern technology now permits geophysical exploration of the whole crust in useful detail and direct observation through drilling to depths as great as 6 to 10 miles in order to learn more about these crustal processes and their influence on man.

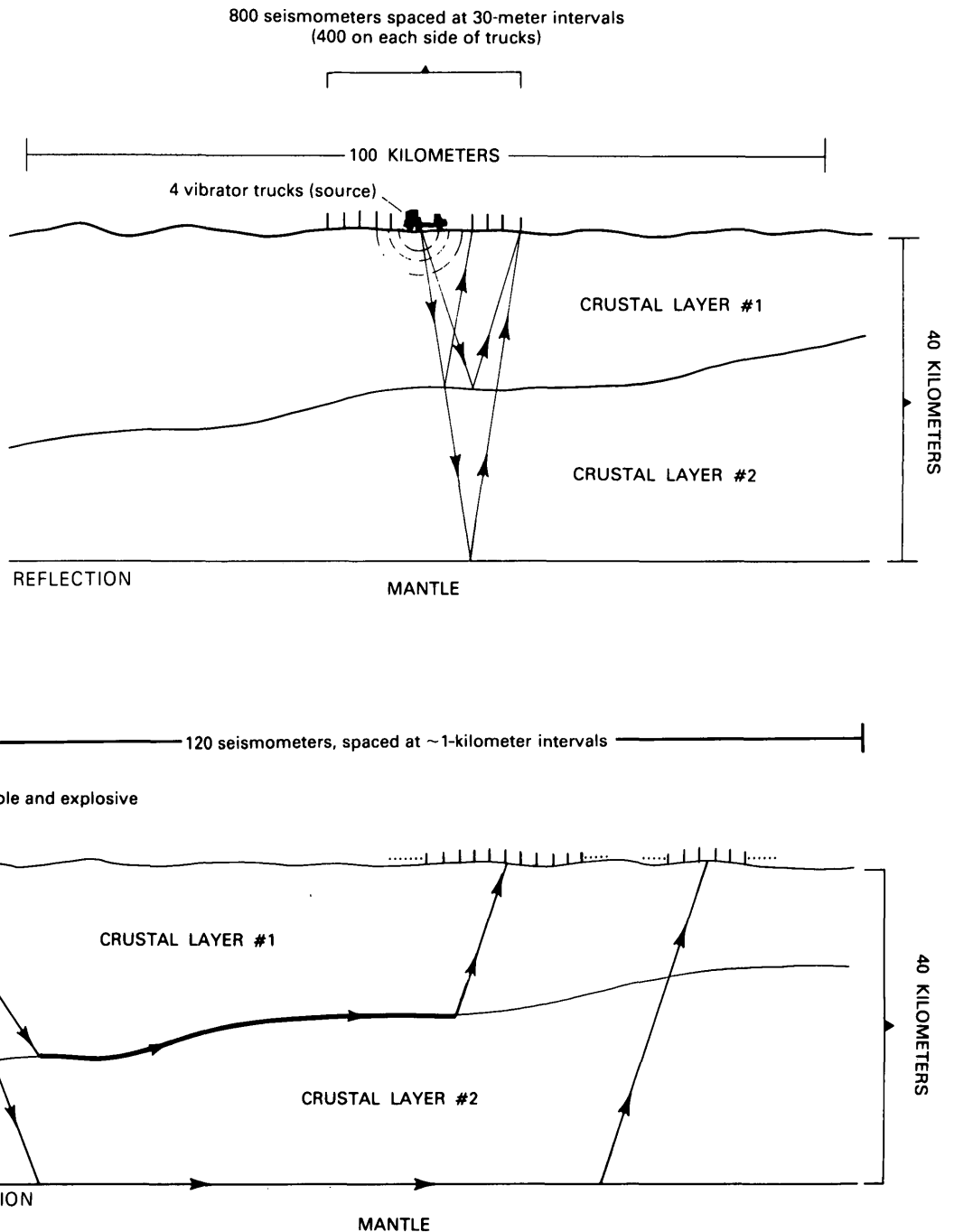
on magnetic tape. Explosives are a common source of seismic energy, but another technique uses huge vibrators, mounted on 20-ton trucks, to shake the ground. The seismometers are placed at regular intervals along a survey line to receive the returning signals from the vibrators, which move progressively along the line of receivers.

The seismometers collect a complex mass of data that represent the signals received at each of the

seismometers after each shot or set of vibrations. These field recordings are then processed in computers to create a single composite image of the subsurface structure along the profile line.

In central California (fig. 3), a project of reflection seismic profiling was designed to explore inferred crustal relations that for 25 years have served as a worldwide example of continental accretion. Reflection and refraction surveys were conducted from the

Figure 2. Seismic reflection and refraction profiling both introduce a seismic signal into the ground and record the returning signal through an array of seismometers. In reflection profiling, the signal travels nearly vertically and is reflected from various boundaries in the crust. In refraction profiling, the signal travels down, is refracted along layer boundaries, and then returns to the surface. In both cases the returning signal shakes the seismometers, and the varying amplitude of this shaking through time is recorded. The resulting records are then analyzed by computer to determine the structure and seismic properties of the rocks encountered in the crust.



Coast Ranges eastward to the foothills of the Sierra Nevada. Joint interpretation of these and associated gravity and magnetic data has indicated that the crustal relations are quite different from what was expected.

Much of the Coast Ranges consists of rocks, called the Franciscan assemblage, that were added, or accreted, to the North American continent beginning about 100 million years ago. The concept that large masses of marine sediments and oceanic land masses have been moved long distances and then attached to the edges of continents has only recently been developed. Sediment and small land masses carried along

by an oceanic tectonic plate can be scraped off against the margin of a continent as the oceanic plate moves toward and is subducted beneath the continent. The material scraped from the subducting plate is added to the edge of the continent as a distinct accreted terrane. If the accreted terrane is itself partly subducted before joining the continent, as has been inferred for the Franciscan assemblage, the junction, or suture, should extend back beneath the continental margin above the accreted terrane.

The central California deep-crustal experiment was designed to explore the subsurface extent and configuration of the suture that separates the western

accreted Franciscan terrane from the eastern continental crust. The key structural relations between the exposed Franciscan terrane in the Coast Ranges and the exposed continental crust in the Sierra Nevada, 50 miles to the east, are buried beneath the Great Valley of California and a thick pile of sediments.

The Franciscan assemblage consists of a great volume of sandstone and shale containing small scattered masses of volcanic rocks, red chert, and limestone. All these rocks formed in the Pacific Ocean; some, according to inference from magnetic inclinations recorded in the rocks, formed near the equator, 2,500 to 3,000 miles south of their present location. The ages of the few fossils found in the shales and microscopic fossils (called radiolaria) from the red cherts indicate that most of the rocks originally formed 100 to 150 million years ago. Subsequently, about 90 to 140 million years ago, the rocks that were to become the Franciscan assemblage were buried to depths of 6 to 18 miles in the crust, probably in a subduction zone, where they were extremely deformed and recrystallized (metamorphosed). Then they ascended to shallow depth by a poorly understood process of uplift.

The continental crust exposed in the Sierra Nevada consists of metamorphosed sedimentary and volcanic rocks of Paleozoic and Mesozoic age. These have been highly deformed and recrystallized, but largely at depths shallower than those experienced by the Franciscan assemblage. From about the middle to the end of the Mesozoic era (115 to 80 million years ago), these rocks were repeatedly invaded by great masses of molten rock that crystallized to form the granitic rocks of the Sierra Nevada batholith.

The sediments that appear to conceal the suture between the Franciscan assemblage and the western limit of the Mesozoic continent consist of sandstones and shales, called the Great Valley sequence, which were deposited at the same time that the Franciscan assemblage was formed. Unlike the Franciscan, however, they have never been deeply buried and recrystallized, and they are relatively undeformed. After deposition, the rocks were tilted eastward during deformation at the continental margin. Beneath the Great Valley, the strata overlie crystalline rocks that are physically continuous with the exposed rocks of the Sierra Nevada.

These geologic relations led to a theory in the early 1960's that the Franciscan assemblage had been thrust eastward beneath the Great Valley sequence along a low-angle fault. Emerging ideas about plate tectonics, the great unifying theme of geology, supported this model. For the past 25 years, geologists have confidently accepted the view that the oceanic Franciscan assemblage was carried east-

ward beneath the overriding continental margin by a subducting oceanic plate. The east boundary of the Franciscan assemblage thus was the suture between the continent and the accreted Franciscan assemblage. This suture was thought to extend eastward in the subsurface down through the crust between the accreted oceanic mass and the continent.

In the light of new seismic reflection information, this theory must now be revised. The high-pressure metamorphism of the Franciscan assemblage did not occur in its present juxtaposition with the Great Valley sequence across the Coast Range thrust. The absence of such metamorphism in the adjacent Great Valley sequence has always been an obstacle to so simple a history, and the structural anatomy revealed by the new seismic studies requires that a different sequence of events took place. The Franciscan mass seems to have been pushed eastward up onto the continental margin at the west side of the Great Valley, rather than down beneath it (compare figs. 4A and 4B). This newly discovered relationship may provide important information on the mechanism by which some accreted terranes become attached to continents.

The reflection and refraction profiling and magnetic modeling together show that the Coast Range thrust does not penetrate through the crust, as was previously thought. Instead, it terminates beneath the west side of the Great Valley at the west-dipping top of crystalline rocks that are physically continuous with rocks of the Sierra Nevada. To the east, beneath the Great Valley, the upper part of the Great Valley sequence was deposited directly on this crystalline basement. To the west, however, a thick wedge of rock, inferred from its structural position and seismic velocity to be Franciscan, separates the Great Valley sequence from its basement. The boundary between the Franciscan wedge and the overlying strata must be a fault. The Great Valley sequence cannot simply have been deposited on Franciscan rock, because it is the same age as the Franciscan. This structural configuration requires that the mass of Franciscan rock was driven eastward onto the continental margin where it concurrently peeled up the Great Valley sequence.

The time of thrusting and wedge emplacement is limited by the age of the rocks involved. Initial wedging may have occurred during the Cretaceous period, before all the Franciscan rocks had formed. Accretion of the Franciscan must have been largely complete by 50 million years ago in Eocene time, for by then Franciscan rocks had been uplifted and unroofed by erosion and were shedding sediment to younger deposits in the Great Valley sedimentary basin. More recently, continued eastward thrusting

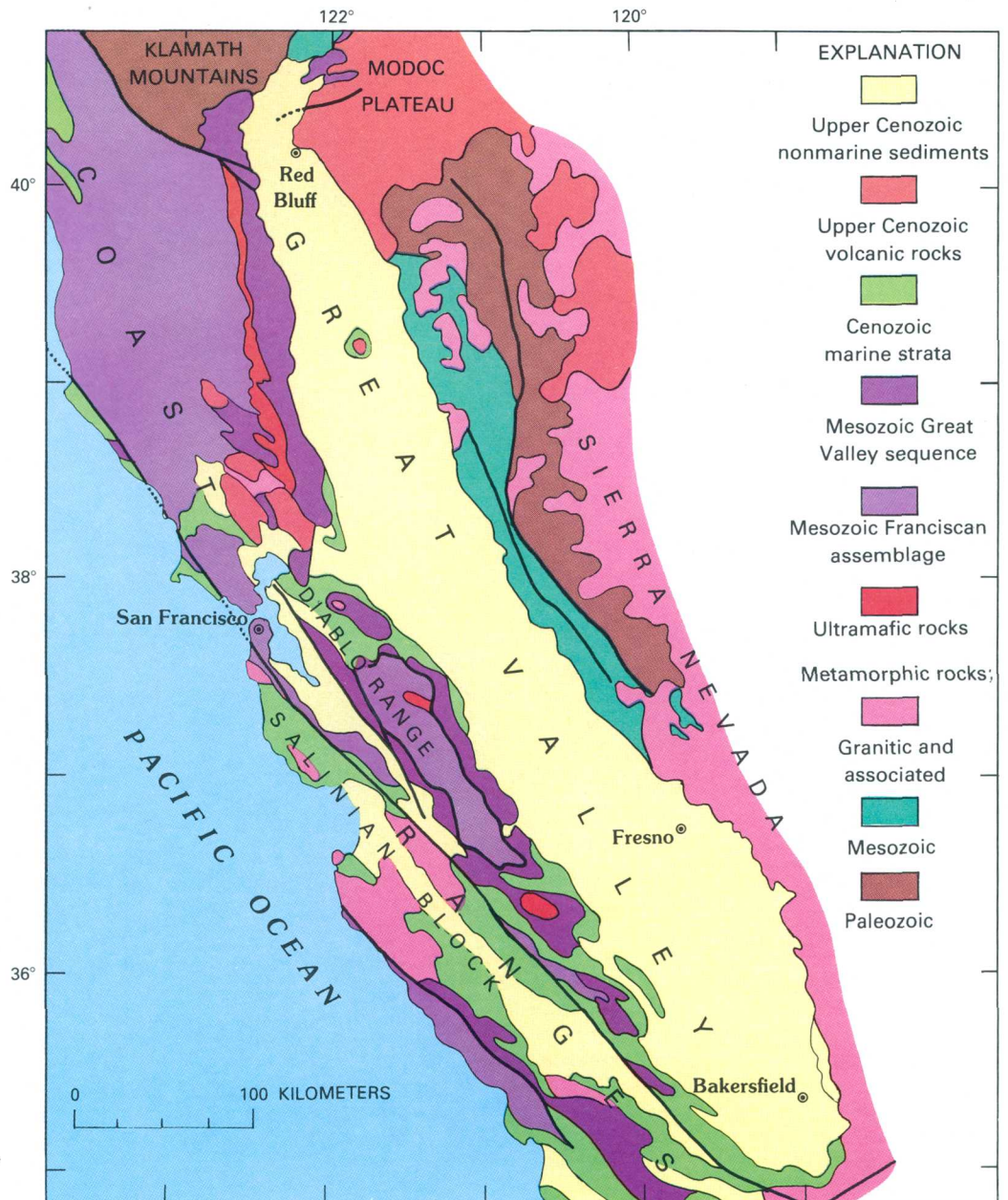


Figure 3. *Geologic map of central California.*

at the east margin of the Coast Ranges has been involved in forming the present topography and in generating modern earthquakes.

Finding the source of the 1983 Coalinga, California, earthquake, which occurred at the west edge of the Great Valley beneath a young fold, turned out to

be an immediate practical benefit of the study (fig. 5). The results also illustrate tectonic inheritance, an important process in which faults, once formed, can serve as the locus of continuing failure in a rock mass even under changing tectonic conditions. At Coalinga, interaction between the San Andreas fault

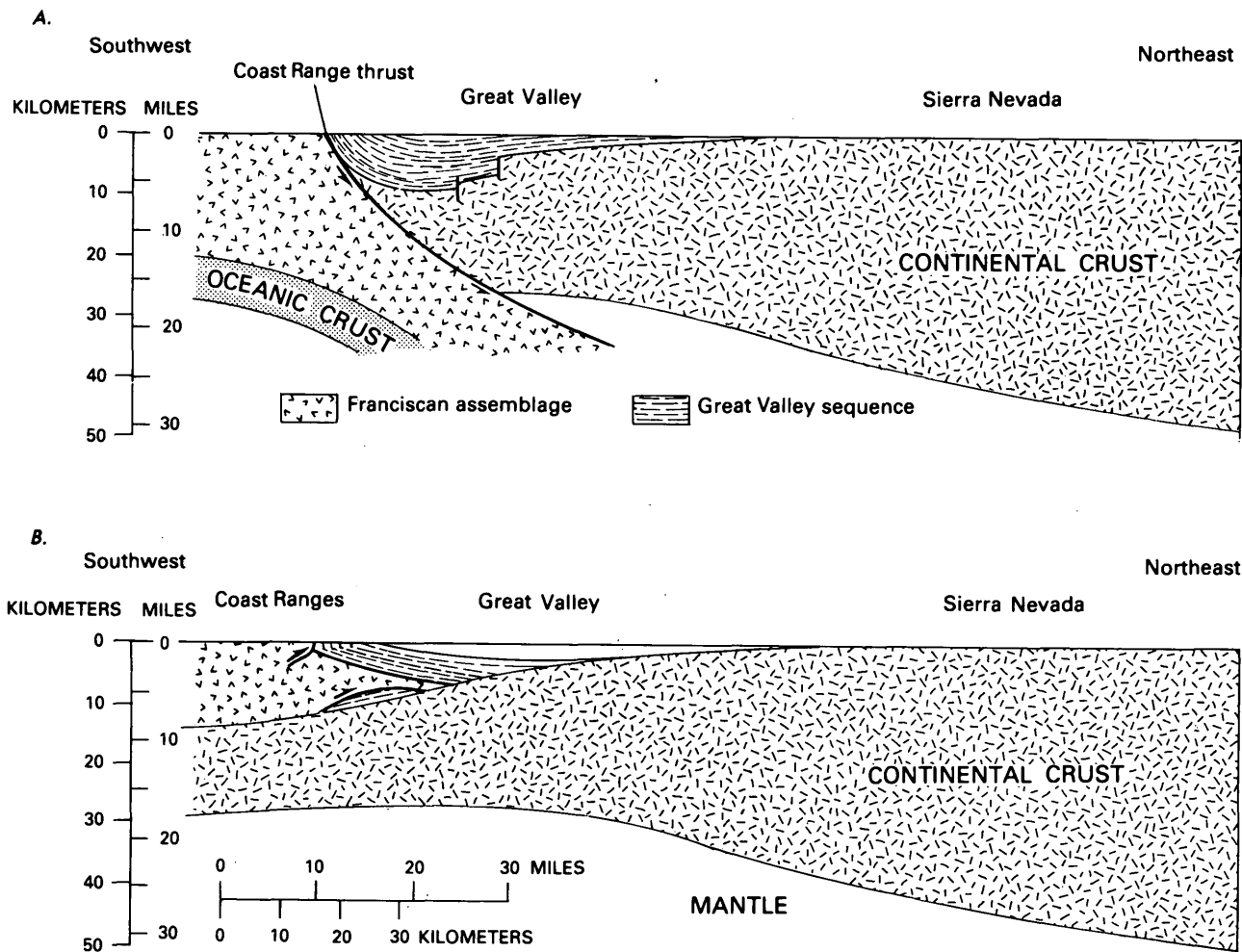


Figure 4. Views of the California continental margin in vertical cross section. A, The clear explanation for geologic relations in central California has, for the past 25 years, been that the Franciscan assemblage was accreted to the continental margin along the Coast Range thrust at a subduction zone. B, New geophysical study indicates that, instead, the Franciscan mass has been thrust onto the continental margin, an interpretation that is also consistent with the observed surface geologic relations.

system and the vast, west-tilted Sierran block is applying stress to the Franciscan wedge. The result is eastward thrusting that has folded the overlying strata and the ground surface. Such thrusting produced the 1983 earthquake and increased the height of the fold by 1½ feet. Prior to the earthquake these thrusts were unknown, but they are clearly evident in the reflection record. A later series of earthquakes in the summer of 1985 indicates similar, deeper thrust movement at the basement surface. Interplay between this thrusting near Coalinga and the behavior of the San Andreas fault just to the west may

bear on the timing and location of earthquakes near Parkfield, which is the site of an active earthquake indicator experiment by the Geological Survey.

This study of crustal structure in central California has led to new ideas about major events in the geologic history of the western margin of our continent. These ideas are important both in understanding the geology of central California and in using the geologic relations and history there as an analog in interpreting geology in other parts of the world. Comparison of surface and subsurface geology shows that the same surface geology is consistent with

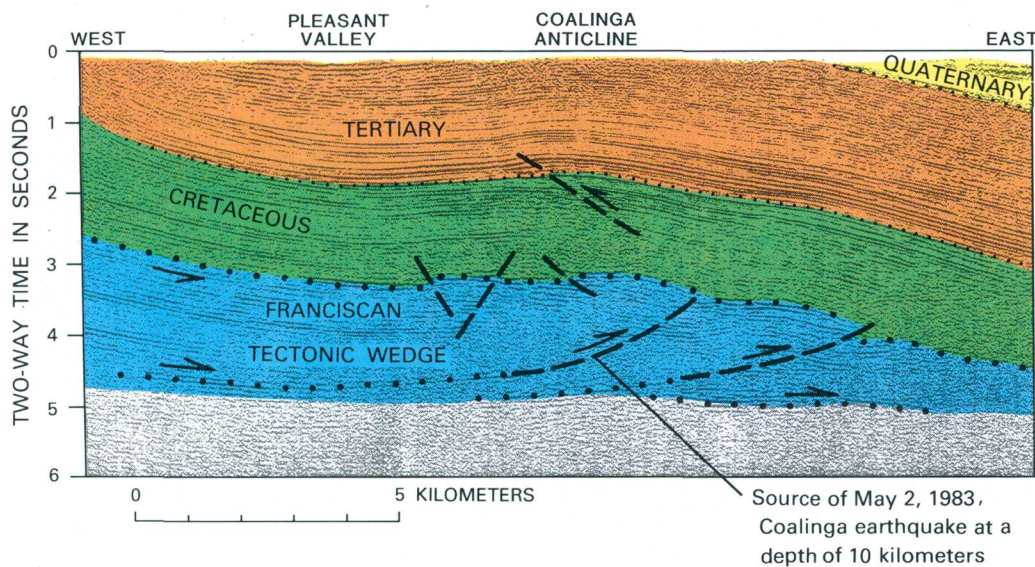


Figure 5. A seismic reflection record across Coalinga anticline contains reflections (the black lines) that record layering in the rocks and folding of those layers. Eastward thrusting has folded the strata above the faults near the eastern tip of the Franciscan wedge. The latest increment of thrusting, in 1983, produced the Coalinga earthquake.

quite different subsurface relations and illustrates the value of detailed geophysical study of crustal anatomy.

In addition to purely scientific information, the central California study has yielded new understanding of earthquake events and information about major geologic structures that may influence oil and gas exploration. The presence of continental basement beneath at least part of the Franciscan terrane may shed new light on the search for deep gas and on the presence of undiscovered mercury and gold de-

posits in the Coast Ranges. Ultimately, information from the seismic profiling and related studies improves our understanding of the tectonic evolution of the Pacific continental margin. This improved understanding bears on all geologic issues in the region as well as on use of the California Coast Ranges as a worldwide model of continental accretion. The success of the central California study demonstrates the results that can be achieved in this new national program to apply recent technological advances in the study of the continental crust.



Significant Accomplishments of Research Programs: 1985

Satellite Microwave Study of the Upper Colorado River Basin Snowpack

The 1983 record snowpack in the upper Colorado River basin and subsequent rapid melting that resulted in unprecedented flooding demonstrated the urgent need by local and regional forecasters for better synoptic (at one moment in time) descriptions of both the snow distribution and the melt progression through the basin. To develop a new technique to help provide this information, the Geological Survey began joint research with the National Aeronautics and Space Administration (NASA). The purpose of this project was to map the snowpack in the upper Colorado River basin using satellite-borne instruments that measure the natural electromagnetic emission from the snow in the microwave region of the spectrum. Such measurements can provide a synoptic map every 3 days regardless of the weather or darkness because clouds are transparent to microwave radiation and the radiative process is independent of daylight. The instrument used is the Scanning Multichannel Microwave Radiometer (SMMR) aboard the Nimbus-7 satellite (launched in 1979), which has collected microwave radiation data worldwide as well as from the Colorado basin. The Nimbus-7 satellite orbital path and period, combined with the instrument footprint, require 3 days to collect the spatial data for a complete map. These constraints, coupled with the present cycle of the satellite, allow a microwave mapping of the entire basin every 6 days.

This experiment consists of two parts. First is a statistical analysis of the 6-year satellite data set with the corresponding snow data from the Soil Conservation Service and the National Weather Service to determine how the water content and the depth of the snowpack correlate with the satellite microwave measurements. Second, data on the internal characteristics of the snowpack, collected by Geological Survey mobile field teams, is incorporated into the analysis to improve the correlation of the satellite measurements to the snow water equivalent.

Although extensive data on the snow depth and liquid water equivalent exists throughout the Colorado basin, several key snow characteristics that strongly influence the microwave emissions of the snowpack are not routinely measured. These characteristics include the vertical distribution of snow density, snow grain size, temperature, and the presence of crust and ice layers within the snowpack. To provide this information, the Geological Survey has conducted field studies at the time of maximum snowpack, the end of March, for 1984 and 1985. Five field teams dug pits in the snow at key snow measurement sites as well as in other

A typical excavation of 4 meters in depth in the snowpack near Steamboat Springs, Colo., dug to provide information for the joint Geological Survey/ National Aeronautics and Space Administration satellite microwave snow study. Measurements of density, grain size, and temperature of the snowpack are taken every 10 centimeters vertically. (Photograph by Edward G. Josberger, Water Resources Division, U.S. Geological Survey.)



areas of interest as determined by USGS and NASA scientists after analyzing satellite maps obtained during the previous evening. This combination of real-time satellite map analysis and data obtained from the field allowed the mobile teams to determine, for example, that the extremely negative gradient ratios (an index of liquid equivalent or snow depth that becomes more negative with increasing snowpack) observed in southwestern Wyoming were the result of the presence of snow grains as large as 5 millimeters.

Not only is the amount of snow important in runoff forecasts, but also the beginning of snowmelt and the progression of the melt patterns are essential information. No synoptic data are presently available to

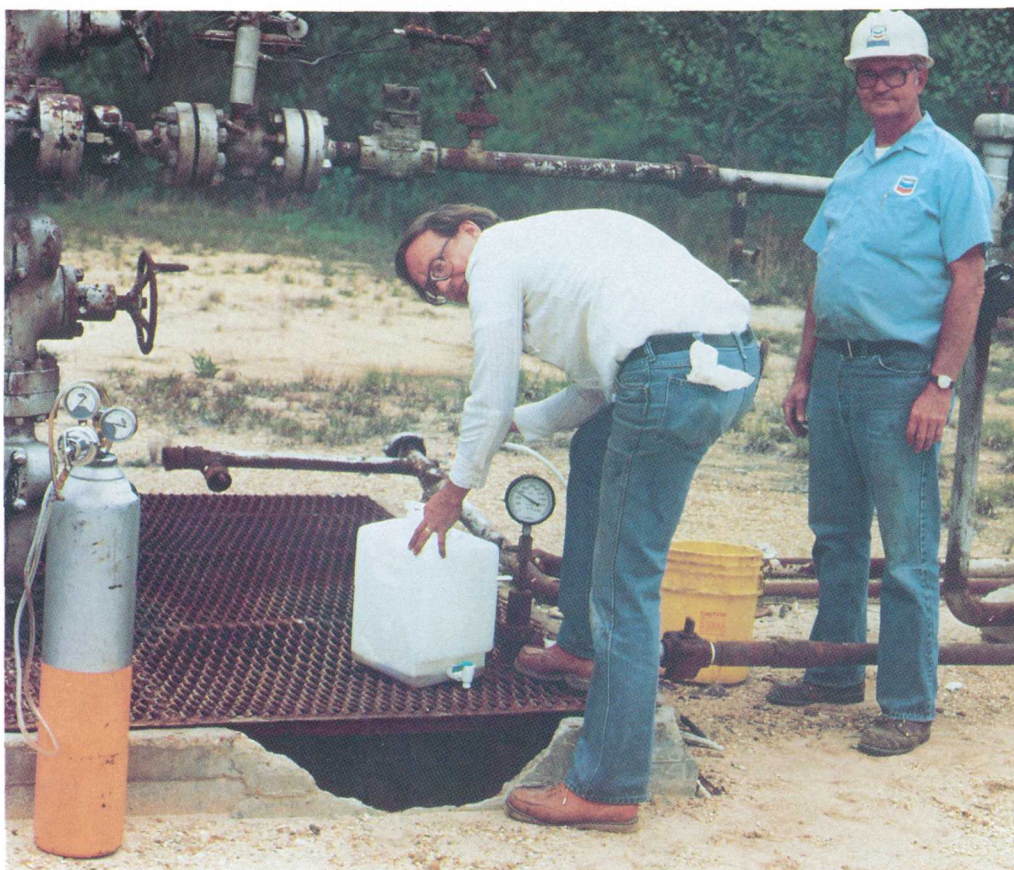
forecasters as to when the snowpack warms to near the freezing point to signal the onset of melting. Microwave techniques, however, can provide a means for charting the melt as it occurs in the basin because the presence of even very small amounts of liquid water within the snowpack causes the gradient ratio to quickly approach zero. Snowpacks that are about to begin melting show sudden large increases in the gradient ratio. These changes are easily seen on the sequential microwave maps, thus permitting the onset and progression of the snowmelt to be mapped. This information will greatly aid forecasters and water managers in their efforts to alert the public about conditions that may cause flooding.

Metal-Rich Oil-Field Waters from the Central Mississippi Salt Dome Basin

Many scientists have hypothesized that waters present in sedimentary basins associated with petroleum are the modern analogs for the fluids that deposited lead, zinc, and other metals in many economically important ore deposits. This analogy is made because the concentrations of the major dissolved salts in oil-field waters from many basins are similar to those reported in the ore-forming fluids for the so-called Mississippi Valley-type ore deposits. The temperature and pressure environments for the formation of these ores are similar also to those of oil-field waters.

The concentrations of lead and zinc in oil-field waters, however, are almost always very low,

measuring less than 0.1 milligram per liter (mg/L). There are only five known areas worldwide where the reported concentrations of these metals are higher than 10 mg/L, the minimum value required for the formation of ore deposits. The central Mississippi Salt Dome basin, covering an area of over 1,930 square miles, was identified in 1974 by A.C. Carpenter and his students from the University of Missouri as one of these five areas. Scientists from the Geological Survey received permission and assistance from several oil companies to study six carefully selected oil fields in this basin. The purpose of this research was to understand the geochemical processes responsible for the high concentrations of



Thomas F. Kraemer (Water Resources Division), accompanied by an oil company operator, collects a water sample from an oil well. The samples are collected from a point as close to the well head as possible, and nitrogen gas is used to exclude oxygen from the sample in order to minimize contamination and loss of metals by precipitation. (Photograph by Yousif K. Kharaka, Water Resources Division, U.S. Geological Survey.)

these metals and thus increase our knowledge of the conditions favorable for the formation of ore deposits.

Water, oil, and gas samples were collected from the oil fields for detailed chemical and isotope analyses. The samples were obtained from petroleum production zones that ranged in depth from 6,234 to 13,124 feet (158°F to 248°F) and in age from Late Cretaceous to Late Jurassic. These zones consist of sandstones interbedded with shales; the Smackover Formation (Jurassic) is mainly limestone. The Louann Salt (Jurassic), consisting of halite, is responsible for the numerous salt domes that contain the oil in this basin.

Results from this study show that the waters are brines with extremely high salt contents that range from 160,000 to 320,000 mg/L total dissolved solids. The salt content of the most concentrated brine is about 10 times that of seawater. Results further show that the concentrations of metals in many water samples are very high, reaching values of 70 mg/L for lead, 245 mg/L for zinc, 465 mg/L for iron, and 210 mg/L for manganese. These samples with high metal contents have extremely low concentrations (less than 0.02 mg/L) of hydrogen sulfide. Samples obtained from the Smackover Formation have low metal contents that are more typical of oil-field waters but have very high concentrations (up to 85 mg/L) of hydrogen sulfide.

Computer models developed by Geological Survey scientists were used to investigate the large number of possible reactions between these brines and the enclosing sediments. Analysis of data from these models leads to the following conclusions: (1) both lead and zinc are present in high concentrations because they form strong complexes (associations) with the abundant chloride ions; (2) metal complexes with organic anions, bisulfides, and borate are minor; (3) the solubilities of the minerals galena and sphalerite control the concentrations of lead and zinc in these waters; (4) the metals were probably leached from the enclosing rocks, as they could not have been derived from the associated oils with their low metal content; and (5) mixing of metal-rich brines deficient in hydrogen sulfide with hydrogen sulfide-rich brines low in metals is the most likely mechanism for the formation of ore deposits from these oil-field waters.

Floods from Dam Failures

Dams can be classed as constructed or natural. Constructed dams are usually concrete arch, buttress, or gravity dams, and earth- or rock-fill dams. Natural dams include ice dams, morainal dams, lava or volcanic debris dams, and landslide

dams. Floodflows resulting from dam failures are a major geologic hazard and often are much larger than those originating from snowmelt or rainfall.

In the last 100 years, there have been about 200 significant failures of constructed dams worldwide in which more than 11,100 people died. Over 60 percent of this loss of life occurred in three failures alone: Vaiont, Italy, in 1963, killing 2,600; South Fork (Johnstown), Pennsylvania, in 1889, killing 2,200; and Machu II, India, in 1974, killing more than 2,000. Major causes of constructed dam failures are overtopping from inadequate spillway (34 percent), foundation defects (30 percent), and piping and seepage (28 percent). In the United States, for the last two decades, loss of life from dam failures has been about 14 deaths annually. The average number of fatalities per dam failure is 19 times greater when there is little or no warning.

Ice-dammed lakes can be released by natural raising of the ice barrier from hydrostatic flotation (increased buoyancy from water pressure) or by the draining and enlarging of cracks and tunnels in the ice dam. Flood peaks from failure of glacial dams are most strongly correlated with volume of impounded water, and floods are generally smaller than peaks from constructed and landslide dams impounding the same volume. The "Spokane Flood" in eastern Washington State, however, the largest documented flood in recent geologic history, originated from the sudden release of an estimated 500 cubic miles of water from glacial Lake Missoula when an ice dam failed between 18,000 and 12,000 years ago. (See page 35.)

Landslide dams are a worldwide phenomenon. They typically are much thicker and involve larger volumes of sediment than constructed dams of the same height and width. Consequently, when a landslide dam fails, there is commonly much more sediment and debris to erode before a full breach is developed. Thus, landslide dams generally have smaller flood peaks than constructed dams with the same dam height and reservoir volume. Natural dams of pyroclastic (volcanic) sediments seem to be the most susceptible to rapid failure.

Following large floods from dam failures, one or more of the following effects can be expected: aggradation of the valley upstream by trapped sediment; triggering of landslides by the rapid draw-down of reservoir water levels; large amounts of local scour and deposition downstream; erosion of bedrock along valley walls; and the formation of wide, shallow, highly braided channels downstream.

For reconstructing past flood peaks from dam failures in paleohydrological or sedimentological investigations, regression equations with dam height and

volume as independent variables provide adequate estimates. For rapid prediction purposes when loss of life or property is threatened, however, a conservative peak-discharge estimate based on envelope curves developed from historic dam failures, an important tool that aids authorities in alerting the public to the possibilities of dam failures and subsequent floods, can be made from knowledge of dam height and reservoir volume.

Chemistry of Plutonium in Ground Waters

Of all the transuranium elements (those beyond plutonium in the periodic table of the elements) present in spent nuclear reactor fuel or reactor reprocessing waste, plutonium is the most important because of its relative abundance and its high toxicity. It is also the most complex chemically. To ensure that this plutonium does not reach the biosphere from a mined repository for radioactive waste by means of ground-water transport, a thorough knowledge of its chemical behavior in ground water that might come in contact with the repository is essential. Geological Survey research indicates that the chemical behavior of plutonium, and hence its mobility in ground waters, is greatly dependent on the chemical composition of the ground water.

The solubility of plutonium in ground water depends on the valence of the plutonium (the electrical charge on its atoms that can vary from three to six) and on its ability to react with components in the water to form soluble or insoluble substances known as complexes. Plutonium with a valence of four has the lowest solubility, but it also has the greatest tendency to react with certain components in ground waters to form complexes. As a result of these two often-contradictory factors, solubility of this element varies widely among different ground waters having different chemical compositions.

Twelve different ground waters were used in this study of plutonium solubility and valence. The waters were selected on the basis of their relevance to the proposed repository sites (waters from tuff at the Nevada Test Site, basalt at the Hanford site in Washington, bedded salt from the Permian Basin in Texas, and the vicinity of the Louisiana salt domes) or on their potential long-range relevance (water from the Pierre Shale, the Waste Isolation Pilot Plant in New Mexico, and the Tularosa Basin, also in New Mexico). In addition, two surface waters, one from the ocean and the other from Mono Lake in California, were studied because of their chemical

compositions. Laboratory studies consisted of introducing plutonium into samples of all these waters and determining its solubility and valence after different, measured periods of time.

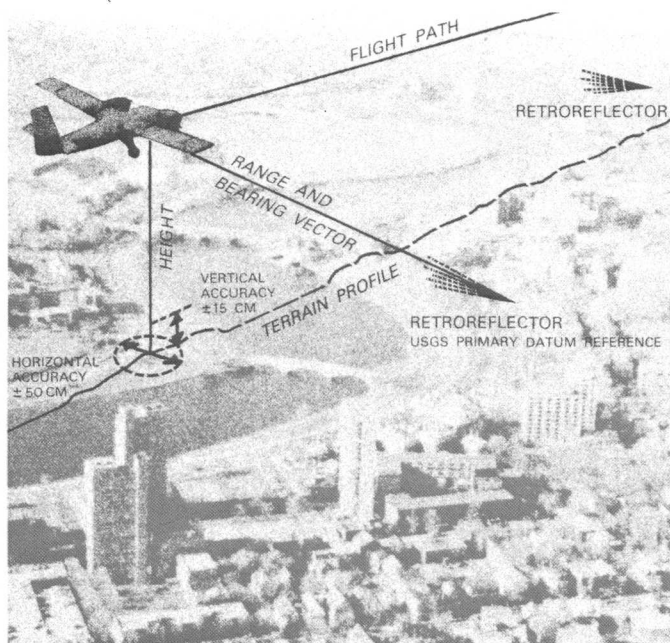
The experimental results provide the first comprehensive information on the influence of ground-water components on plutonium solubility, and hence mobility. Plutonium is most soluble in waters capable of oxidizing it (converting it to its highest valences, five and six), such as ocean water and the Tularosa Basin water, and in waters containing relatively large concentrations of components capable of reacting with it to form complexes, such as fluoride (Hanford water) and carbonate ions (Mono Lake water). In contrast, plutonium solubility is generally low in moderately reducing waters, those which convert it to a valence of four, particularly when the water, such as that from the Pierre Shale, contains a high concentration of sulfate ions.

It is obviously preferable that the inherent solubility be low in ground waters in the vicinity of a mined geologic repository. On the basis of this consideration, the ideal ground water is one that is moderately reducing, has a low concentration of complex-forming ions such as fluoride and carbonate, and has a relatively high concentration of sulfate ions. Moreover, the great differences in plutonium solubility in the various ground waters suggest that composition of ground water should be included with other criteria for selection of repository sites.

The Aerial Profiling of Terrain System

The development of the Aerial Profiling of Terrain System (APTS) by the Geological Survey began in 1974 with an engineering study by the Charles Stark Draper Laboratory of Cambridge, Mass., that concluded that a system capable of surveying the terrain with very high accuracy from a low-flying aircraft could be built. The design was based on a laser tracker that locks onto and tracks reflectors positioned on the ground as the aircraft passes overhead. The APTS now has been designed, fabricated, installed, and flight tested. The system consists of an inertial measuring unit, a laser profiler, a laser tracker, a computer, a video imaging system, and supporting electronics, all mounted in a Twin Otter aircraft. After successfully undergoing performance evaluation tests, the APTS is now undergoing a series of application tests.

The application testing program began with a project along the Charles River near Needham, Mass., to survey several well sites marked by reflectors along



Airborne surveying with the Aerial Profiling of Terrain System (APTS).

the river and to determine river surface elevations near these sites. Data collection flights were completed in 1984. Data collection flights for additional projects located near Plymouth, Mass., have also been completed. The Kettle Pond study determined how effectively APTS could measure the water surface elevation of more than 100 ponds to provide data for modeling the aquifer. On another project, profiles were measured and compared to four topographic maps to determine the APTS' capability to test the accuracy of older maps. The point positioning capability of APTS was tested further in the Plymouth area with impressive results. New positions can be located to an accuracy of 15 cm vertically and 50 cm horizontally when the APTS is updated on reflectors of known location at 5-minute intervals.

In its first major operational project, the APTS is being used to help Utah State officials design a proposed water drainage system to control the water level of the Great Salt Lake by diverting the water to form a large, shallow lake in the desert 30 miles west. Accurate elevation profiles are needed to determine the shoreline, depth, and volume the new lake will assume and to determine where dikes would be required. The APTS will be used to conduct other similar surveys for earth science projects of the Geological Survey.

Implementation of North American Datum 1983

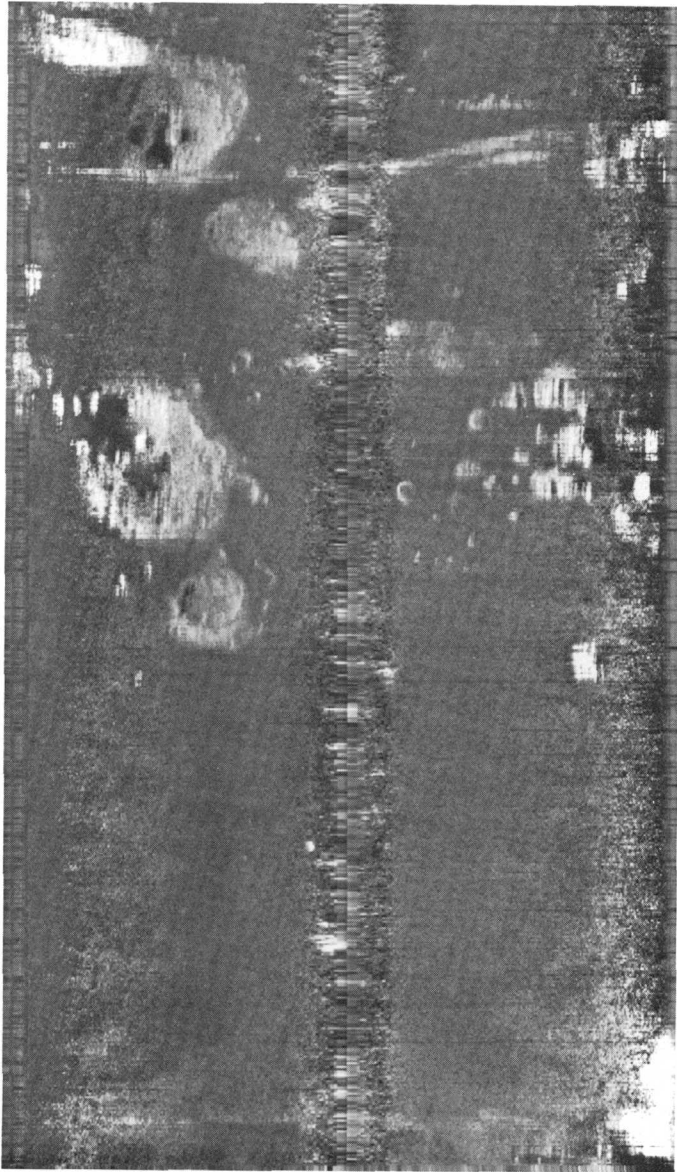
Investigations are continuing on the economic and technical aspects of implementing the North American Datum 1983 (NAD 83). The NAD 83 is a readjustment of the horizontal datum incorporating extensive precise measurement of the Earth's surface obtained through the use of new techniques, especially satellites, to relate the surface to the Earth's center of mass. The horizontal datum is the reference upon which all coordinates of features such as roads, dams, navigation facilities, wells, and boundaries are based. The NAD 83 is compatible with other modern geodetic systems, and conversion to such a system from the current North American Datum of 1927 has been recommended by the National Academy of Sciences and supported by the Federal mapping agencies. The National Oceanic and Atmospheric Administration has been responsible for the geodetic computations.

A new ellipsoid, referred to as GRS-80 (Geodetic Reference System), that represents an improved definition of the Earth's shape is a part of the definition of NAD 83. State Plane Coordinate Systems and the Universal Transverse Mercator projection will be redefined in accordance with the GRS-80 ellipsoid.

The Geological Survey currently has over 60,000 different map products. The 7.5-minute mapping program is nearly complete and the planimetric editions of the intermediate-scale map of the conterminous United States are scheduled for completion by 1986. Implementation of NAD 83 will profoundly affect these and all other map products, as well as the National Digital Cartographic Data Base and other data bases that include positioning information. The use of NAD 83 coordinates will provide more uniform and accurate reference coordinates for geodetic and geophysical measurements on a global basis. The change to NAD 83 will not occur instantaneously, and interim steps will be taken to help map users cope with the transition.

Sonar Image Mapping

Over the past 5 years, the Geological Survey and the British Institute of Oceanographic Sciences have had a cooperative program to collect, process, and analyze sonar images of the ocean bottom. The side-scan sonar images have been collected by the GLORIA (Geological Long-Range Inclined Asdic) system, designed, built, and operated by the Institute.



Sonar image of area off southern California coast after preprocessing to correct for radiometric and geometric distortions. Improved detail at near and far range is shown by the circular shape of the volcanoes. The scale is approximately 1:493,000. (Ship's track is through center of image.)

From April to June 1984, GLORIA was used to collect sonar image data off the west coast covering part of the newly declared Exclusive Economic Zone (EEZ). Here the EEZ extends from the United States-Mexico border to the United States-Canada border and 200 miles out to sea from the U.S. coast-

line. Because of the very large volume of data collected and the high interest in the EEZ, the computer software to process the GLORIA data was refined and expanded on the Mini Image Processing System. Some of the software was redesigned and made into an operational production package. Once the specific GLORIA preprocessing procedures are applied, any of the general Mini Image Processing System capabilities can be used for further information extraction, image enhancement, or analysis, including spatial filtering for low or high frequency enhancement, interactive color coding or contrast stretching, or further numerical evaluation.

The figure shows a small area about 100 miles off the southern California coast at about 1:493,000 scale. Various preprocessing steps have been applied; shading correction has improved the amount of detail visible in the near- and far-range areas, and geometric corrections have improved the cartographic aspects of the various features. In particular, the large volcanoes shown on the left side of the image have geometric shapes that are closer to the expected shape than those on the original image.

Data have been collected and are being processed to generate $2^{\circ} \times 2^{\circ}$ sheet mosaics of the west coast data. During the summer of 1985, new data were collected for most of the Gulf of Mexico and the extreme southern portion of the Atlantic coast. Developments continue in order to overlay the bathymetry and magnetic data recorded on the ship navigation tapes upon the images of the digital sonar data.

Satellite Image Map of Great Salt Lake and Vicinity

On July 2, 1984, the Great Salt Lake, Utah, crested at a peak elevation of 4,209 feet above mean sea level, the highest lake elevation since July 1, 1878. This level was recorded successfully on Landsat imagery acquired on June 25 and July 2, and the Great Salt Lake and Vicinity Satellite Image Map was prepared during the latter part of 1984 at a scale of 1:125,000. Production of the map involved several innovations in the art of image mapping.

Four Landsat images spanning an 8-day period were used to produce the mosaic image and required precise geometric and radiometric adjustment to a common base. Because the lake dominates the map, different band combinations and processing procedures were used for the open-water area and for the land area. This resulted in the display of more detail



Reduced version of the image used for the Great Salt Lake and Vicinity Satellite Image Map, shown here at approximately 1:846,000.

in both the water and land area than would have been possible with one selection of bands and one procedure, the standard practice for all previous satellite image maps.

In another innovation, three bathymetric contours and one topographic contour from conventional line maps were added to the image map. Extreme care was required in adding the contours, as even small

errors on contour position became obvious when superimposed on the exact shoreline displayed by the image.

The map took 7 months to produce after image acquisition, a far shorter period than that required for conventional map production. The map documents a very important transitory phenomenon, the highest level of the Great Salt Lake in over 100 years.

Nuclear Borehole Logging Tool for Measuring Low Manganese Concentrations

Because there are no known surface economic manganese deposits in the U.S., exploration for this important strategic metal must be directed toward potential moderately deep to deep deposits. Such exploration requires a method capable of making real-time measurements of manganese at low concentrations with instrumentation that is small enough to be used in the confines of a borehole. Neutron activation coupled with gamma-ray spectroscopy is one of the few methods that meets these requirements and that can be used in the environment of a water-filled borehole.

To fill the need for a geophysical manganese exploration tool, the Geological Survey developed a miniaturized neutron activation gamma-ray spectrometer probe. The device measures the intensity of the characteristic gamma rays emitted by manganese after irradiation with neutrons. The emission of these gamma rays is short-lived (half-life of 2.78 hours), so that no radioactivity remains in the borehole after the measurement is made. This probe continuously measures the manganese concentration of the rock surrounding the borehole as the probe is lowered underground. Manganese concentrations as low as 0.1 percent can be measured. With appropriate calibration, a depth profile of the manganese in the rock can be obtained that gives the actual percentage concentration of manganese. This information can then be used by a geologist to locate zones of high manganese concentration in the formation.

Measurements were made in a shallow borehole in the Arundel clay formation in northern Prince Georges County, Md. (manganese is associated with siderite nodules that are scattered throughout the clay). The results of the nuclear measurements have been compared with conventional chemical measurements made on a core taken from the borehole. The nuclear logs compare favorably with the chemical core analysis. Similar logs made in dry and water-filled boreholes in the same formation showed that the accuracy of the measurements is not significantly affected by the presence of water.

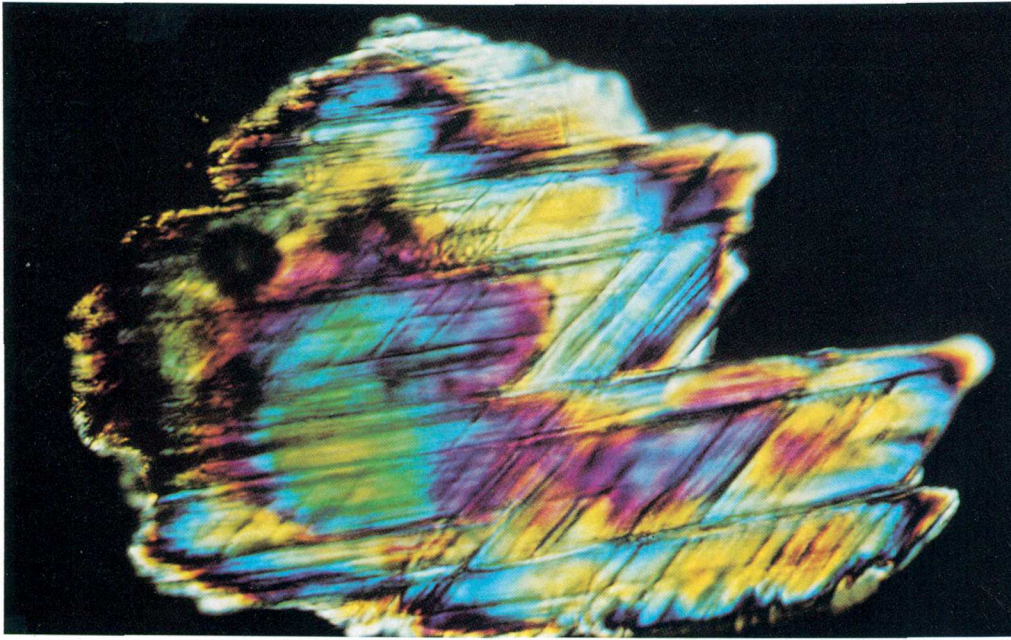
Research On Asteroid Impacts and Mass Extinctions

Geologists have recognized for nearly a century that a remarkable mass extinction event occurred at the end of the Cretaceous period, about 66 million years ago. During the immediately following Tertiary period, thousands of species of plants and animals that lived in the Cretaceous no longer existed. In 1980, researchers from the University of California advanced the startling hypothesis that a large asteroid, about 6 miles in diameter, struck the earth about 66 million years ago and caused a worldwide biosphere catastrophe that culminated in the mass extinctions.

The university team found anomalously large concentrations of iridium and other noble elements in a peculiar claystone layer that marks the Cretaceous-Tertiary (K/T) boundary in certain marine rocks in Italy, Denmark, and New Zealand. Iridium, a chemical element of the platinum group, is extremely rare in the Earth's crust relative to its abundance in certain type of meteorites. Because of this terrestrial iridium deficiency, the team concluded that the source of the iridium was extraterrestrially derived and that the claystone layer formed from fallout of ejecta after the impact occurred. Since this original proposal, more than 50 sites scattered around the globe have been reported where abundant anomalies of iridium occur in marine rocks at the K/T boundary, as defined by pronounced changes in the marine fossils.

In 1980, a team consisting of geologists from the Geological Survey and chemists from Los Alamos National Laboratory discovered an iridium-rich claystone layer at the K/T boundary, defined by the pollen record, in nonmarine rocks in the Raton Basin, N. Mex. Prior to this, almost all work on the K/T boundary had been done on marine rocks. Some geologists had suggested that the anomalous amounts of iridium in marine rocks may be normal because sedimentation in these rocks is slow and the amount of meteoritic dust that accumulated in sediments on the ocean floor would be relatively large—therefore, the iridium need not have come from a large asteroid impact. The discovery of an iridium abundance anomaly by USGS scientists in terrestrial nonmarine rocks in the Raton Basin removed this objection and provided important supporting evidence to the university team's hypothesis.

The iridium in the Raton Basin occurs at the top of a sedimentary layer less than an inch thick in the Raton Formation; this occurrence is informally called the K/T boundary claystone. This iridium-bearing



Photomicrograph of a grain of shock-metamorphosed quartz (.001 inch long) from a 1-inch-thick claystone bed that marks the Cretaceous-Tertiary boundary a few miles west of Trinidad, Colo., in the Raton Basin. The black lines that form the grid pattern are intersecting sets of fractures that run through the grain and were formed when the asteroid struck. Quartz grains containing such multiple intersecting sets of fractures have only been found in rocks at meteor impact and nuclear explosion sites. Such "shocked quartz" grains comprise about 30 percent of grains in the topmost laminae of the Cretaceous-Tertiary boundary claystone. The colors are caused by the grain being photographed in crossed-polarized light.

layer stratigraphically coincides with the disappearance of several kinds of fossil pollen called, collectively, the Proteacidites assemblage. Fossil pollen and spores had to be used to locate the K/T boundary in the Raton Basin because vertebrate remains, such as those from dinosaurs, have not been found there.

The iridium anomaly also marks an abrupt change in the ratio of fern spores to angiosperm (flowering plant) pollen. The proportion of fern spores to angiosperm pollen changes at the top of the K/T boundary claystone layer from the 15 to 30 percent fern spores commonly observed to as much as 100 percent. The proportion then returns to 15 to 30 percent fern spores normally within 4 to 6 inches above the boundary. This marked increase, termed the fern spore spike, implies a significant, though geologically brief, period of stress on the ecological system caused by the event or events responsible for deposition of the boundary claystone layer.

A nearly identical iridium-rich claystone layer was found in 1984 by USGS scientists at Brownie Butte and other nearby localities in the Hell Creek, Mont., area, nearly 800 miles north of the Raton Basin lo-

calities. The K/T iridium anomaly also has been found at Deer Valley, Alberta, Canada, by scientists of the Canadian Geological Survey. The disappearance of dinosaurs and other vertebrate fossils defines the K/T boundary at these northern localities, and the claystone layer marks the disappearance of another important pollen group. A fern spore spike is also present at all the northern K/T boundary sites examined to date.

A very unusual type of quartz (see fig.) was also found in 1984 by USGS scientists in the K/T boundary claystone bed in the Hell Creek-Brownie Butte area and in the Raton Basin. The grains of quartz are unusual because they contain multiple sets of closely spaced planar microfractures, clearly indicative of a shock-metamorphic origin. This discovery by Geological Survey scientists provides compelling evidence that a large asteroid struck an area of quartz-rich continental rocks, not an ocean basin as some have speculated, and furnishes direct physical evidence supporting the University of California hypothesis.

New Geologic Map of Wyoming

Continuing advances in knowledge of the geology of any particular State lead to successive geologic maps of that State. The most recent example of this process in the U.S. is the Geologic Map of Wyoming, prepared by the Geological Survey in cooperation with the Geological Survey of Wyoming, that was published in early 1985.

The first map of Wyoming, published by the USGS in 1925 at 1:500,000 scale, showed the main geologic features of the State but was very generalized. Geologic formations were portrayed separately where detailed studies had been made for minerals and fuels of economic interest, primarily oil, gas, and coal. Few faults were shown—almost none in the Idaho-Wyoming Thrust Belt.

Between 1925 and 1955, continued search for oil and gas and the new intensive search for uranium prompted detailed geologic studies. Results of these studies were incorporated in 1955 into the second State map, also published by the USGS.

The 1985 map reflects the great advances made possible by radiometric and fission-track dating, by the extensive detailed mapping that has been done since 1955, and by regional stratigraphic, paleontologic, and geophysical studies and interpretations. It also reflects the results of technological advances, such as aerial photography and remote sensing. About 90 percent of the map area was compiled from post-1955 geologic mapping. Maps, reports, and other data prepared by the USGS and the Wyoming Geological Survey, by other Federal and State agencies, by universities, and by private industry—from more than 450 references—were used in compiling the new map.

The distribution of 215 rock units as shown in 128 colors or patterns is depicted. In parts of the State where extensive areas of bedrock are covered, the unconsolidated deposits that concealed them are shown. The subsurface thrust faults near the basin margins or bounding many of the mountain ranges and the Thrust Belt are also shown for the first time on the State map; the approximate positions of these thrust features were based on new seismic and drillhole data. The map shows the surface distribution of rocks that, at some places, are known to contain oil and gas, uranium deposits, and coal; it also shows the recharge areas for the Madison and Tensleep aquifers, the sources of fresh ground water for much of Wyoming. The map, therefore, will be a valuable aid to government and private industry in exploration for minerals, oil and gas, coal, and underground water; it also will be helpful in land-use planning, especially in deciding where to locate highways

and county roads and in avoiding the building of facilities on areas threatened by geologic hazards such as landslides, ground subsidence, and recently active faults.

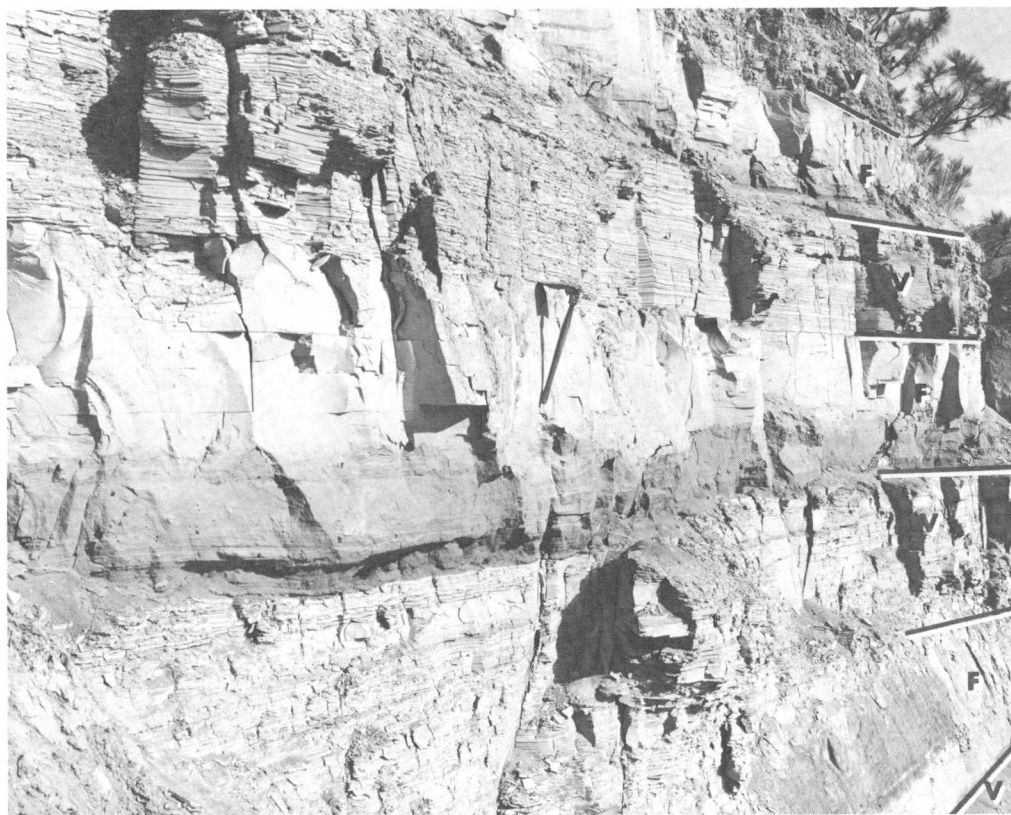
The geologic data are overprinted on a base map that shows major highways in red, streams and other water features in blue, topographic contours in brown, and cities, counties, and other features in black. The explanation, printed on a second sheet, consists of a correlation and list of map units and individual descriptions of 232 stratigraphic units, of which 55 units have been dated isotopically and range in age from 12,000 years to more than 3.5 billion years. More than 450 references to sources of geologic data used in the compilation of the map are listed on a third sheet.

Ice-age Floods in the Pacific Northwest

Floods as voluminous as 300 times the San Francisco Bay swept across much of the Pacific Northwest during Pleistocene ice ages (1.7 to 2.2 million years ago). Disputed decades ago in regard to their great size, these floods are once again controversial—this time because of their large number and their possible effects on a proposed radioactive-waste repository.

During the 1920's and 1930's, Chicago geologist J Harlan Bretz argued that a single great flood had cut the hundreds of scabland channels that lace the wheat fields of eastern Washington. This hypothesis outraged many prominent geologists. Not only did it depict geologic change as catastrophic at a time when gradualism reigned, but it mentioned no logical source for the water and thus seemed to flout explanation of geologic features by processes observable today. Eventually Bretz prevailed by presenting overwhelming proof of the enormity of the flood and by specifying an ice-age lake in western Montana (glacial Lake Missoula) as the flood's source. By the 1960's his catastrophism had become widely accepted, and in the 1970's it became an earthly basis for interpreting channels on Mars.

Controversy about great Pacific Northwest flooding flared anew in 1980, when the Geological Survey proposed that Lake Missoula had released some 40 colossal floods during the last ice age alone. This hypothesis found few supporters at first, largely because it seemed to challenge Bretz's catastrophism. But the multiflood hypothesis has gained converts because it explains the rhythmic bedding that was produced in certain flooded areas and because the many floods can be likened to those issued today



Rhythmic bedding in Ferry County, Wash., produced by periodic floods from glacial Lake Missoula, Mont., about 15,000 years ago. The flood-laid beds (F) alternate with sets of thinly laminated varves (V) that record decades between floods. Shovel handle is 1 1/2 feet long.

from glacial dams that partly float each time water rises high behind them. Now even 40 floods seem far too few, because the Geological Survey has recently found evidence that the Lake Missoula floods of the last ice age totaled about 100.

Predicted effects of floods from future Lake Missoulas may influence prospects for disposing of radioactive waste at Hanford, the federal nuclear facility in southern Washington. The proposed repository at Hanford would lie beneath the path of floods from past Lake Missoulas. Though more than 1/2 mile

deep, and therefore probably immune to scour by floods of the next 1 million years, the proposed repository would be in contact with ground water whose flow might change if floods eroded or pressurized surficial recharge aquifers. Because of this possibility, Missoula flood history may play an important role in the selection of a national radioactive-waste repository. Knowledge gained through esoteric controversy about ice-age catastrophe has thus found unexpected application to a major problem of health and safety.

Missions, Organization, and Budget

Missions

The U.S. Geological Survey was established by an Act of Congress on March 3, 1879, to answer the need for a permanent agency at the Federal level to conduct, on a continuing, systematic, and scientific basis, investigations of the "geological structure, mineral resources, and products of the national domain." Although a number of laws and executive orders have expanded and modified the scope of the Survey's responsibilities over its 106-year history, the Survey has remained principally a scientific and technical investigation agency as contrasted with an administrative or regulatory one. Today, the Survey is mandated to assess onshore and offshore energy and mineral resources; to provide information for society to mitigate the impact of floods, earthquakes, landslides, volcanoes, and droughts; to monitor and assess the quality of the Nation's ground- and surface-water supplies; to study the impact of man on the Nation's water resources; and to provide mapped information on the Nation's landscape and land use. Numerous technological advances and initiatives are contributing to a variety of program activities, including the compilation and production of cartographic data, investigations about the mineral and petroleum resources of the Exclusive Economic Zone, and real-time hydrologic data collection. The Survey is the principal source of scientific and technical expertise in the earth sciences within the Department of the Interior and the Federal Government. The *Yearbook* provides highlights of the wide range of earth science research and services in the fields of geology, hydrology, and cartography.

Organization

The U.S. Geological Survey is headquartered in Reston, Va. Its activities are administered through the major program divisions of National Mapping, Geologic, and Water Resources. These program operations are supported by the Administrative and the Information Systems Divisions. The Survey conducts its functions through an extensive field organization of some 200 offices located throughout the 50 States and Puerto Rico. At the national level, the functions of the Survey are coordinated through assistant directors for administration, program analysis, research, information systems, intergovernmental affairs, and engineering geology.

Budget

In fiscal year 1985, the U.S. Geological Survey had obligational authority for \$604.7 million. Of this total, \$416.4 million came from direct appropriations, \$0.6 million in unobligated balances transferred from the Bureau of Reclamation's water resources research grants activities, \$0.1 million from contributed funds, and \$187.6 million from reimbursements. The Survey received funds for reimbursable work performed under agreements with other Federal agencies, State and local governments, international organizations, and foreign governments. The

Percentage allocation of funds, by Division.



U.S. Geological Survey budget authority for fiscal year 1985, by appropriation

[Dollars in thousands]

Activity/Subactivity/Program Element	Fiscal year 1985 ¹ enacted
Surveys, Investigations, and Research:	
National Mapping, Geography, and	
Surveys -----	85,469
Primary Mapping and Revision -----	38,070
Digital Cartography -----	11,242
Small, Intermediate, and Special	
Mapping -----	16,323
Intermediate-Scale Mapping -----	5,538
Small-Scale and Other Special Mapping --	2,136
Federal Mineral Land Information -----	984
Land Use and Land Cover Mapping -----	3,368
Image Mapping -----	4,297
Modernization of Map Technology -----	4,701
Earth Resources Observation Systems --	9,594
Data Production and Dissemination -----	4,670
Applications and Research -----	4,924
Cartographic and Geographic Infor-	
mation -----	3,579
Side-Looking Airborne Radar -----	1,960
Geologic and Mineral Resource Surveys and	
Mapping -----	169,762
Geologic Hazards Surveys -----	51,206
Earthquake Hazards Reduction -----	36,696
Volcano Hazards -----	11,425
Ground Failure and Construction Hazards --	3,085
Land Resource Surveys -----	20,450
Geologic Framework -----	17,260
Geomagnetism -----	2,184
Climate Change -----	1,006
Mineral Resource Surveys -----	45,740
Alaska -----	9,401
Conterminous States -----	5,873
Wilderness Mineral Surveys -----	8,391
Strategic and Critical Minerals -----	9,349
Development of Assessment Techniques ---	12,726
Energy Geologic Surveys -----	30,221
Evolution of Sedimentary Basins -----	5,106
Coal Investigations -----	8,334
Onshore Oil and Gas Investigations -----	4,690
Oil Shale Investigations -----	565
Geothermal Investigations -----	7,314
Uranium-Thorium Investigations -----	4,212
Offshore Geologic Surveys -----	22,145
Offshore Geologic Framework -----	22,145

Activity/Subactivity/Program Element	Fiscal year 1985 ¹ enacted
Water Resources Investigations -----	132,844
National Water Data System—Federal	
Program -----	63,565
Data Collection and Analysis -----	16,899
National Water Data Exchange -----	1,318
Regional Aquifer Systems Analyses -----	14,401
Coordination of National Water Data	
Activities -----	962
Core Program Hydrologic Research -----	7,432
Improved Instrumentation -----	2,023
Water Resources Assessment -----	1,377
Supporting Services -----	3,358
Toxic Substances Hydrology -----	10,956
Acid Rain -----	3,151
Environmental Affairs -----	768
Water Resources Scientific Information	
Center -----	920
Federal-State Cooperative Program -----	51,679
Data Collection and Analysis, Areal	
Appraisals, and Special Studies -----	43,379
Water Use (Cooperative) -----	3,915
Coal Hydrology (Cooperative) -----	4,385
Water Resources Research Institutes -----	8,797
Energy Hydrology -----	8,803
Coal Hydrology -----	977
Nuclear Energy Hydrology -----	7,494
Oil Shale Hydrology -----	332
General Administration -----	15,244
Executive Direction -----	4,951
Administrative Operations -----	8,655
Reimbursements to the Department of Labor -	1,638
Facilities -----	13,049
National Center—Standard Level User's	
Charge -----	11,329
National Center—Facilities Management -----	1,720
TOTAL, Surveys, Investigations, and	
Research -----	416,368

¹Funding shown represents appropriated dollars and does not include reimbursable funding from Federal, State, and other non-Federal sources.

Survey performs services under these agreements when earth science expertise is required by other agencies and their needs complement Survey program objectives. Work done for State, county, and municipal agencies is almost always done on a cost-sharing basis.

The appropriations and reimbursements received by the Survey in fiscal year 1985 are distributed through budget activities that roughly correspond to

its mapping, geologic, hydrologic, and administrative areas of responsibility.

Awards and Honors

Each year, employees of the U.S. Geological Survey receive awards that range from modest monetary awards to recognition of their achievements by large professional societies. The large number of these

awards attests to the quality of the individuals who are the U.S. Geological Survey. This year, the Survey wishes to acknowledge those individuals who either received high honors from or were elected to high office in professional societies and those who received the highest award of the Department of the Interior.

Honors

Robert A. Baker, Regional Research Hydrologist, received the Research Award from the American Water Works Association for his research in potable water treatment processes and laboratory procedures for testing of water quality.

William A. Cobban, Geologist, was awarded the Paleontological Society Medal for his outstanding contributions to the stratigraphy of Cretaceous rocks of the High Plains.

Frederick J. Doyle, Research Cartographer, received the Alan Gordon Memorial Award from the American Society of Photogrammetry and Remote Sensing for significant achievements in remote sensing and photographic interpretation.

Mark F. Meier, Research Geologist, received the Seligman Crystal, the highest award of the International Glaciological Society, for his pioneering work on the flow of Saskatchewan Glacier and on the understanding of heat, ice, and water balances of glaciers.

Ferdinand Quiñones-Marquez, Chief of the Water Resources Division's District Office in San Juan, Puerto Rico, was named Engineer of the Year for the U.S. Geological Survey, Department of the Interior, by the National Society of Professional Engineers.

Edwin W. Roedder, Geologist, was awarded the Werner Medal of the Deutsche Mineralogische Gesellschaft for his outstanding original research on fluid inclusions in minerals.

Gordon Wood, Geologist, received the Cady Award of Geological Society of America for contributions to coal science.

Professional Societies

Service in professional societies is one of the most important professional contributions a scientist can make. Societies play a fundamental role in distributing knowledge, as well as providing a forum in which new ideas are tested. The active participation of Survey scientists in professional societies attests to the scientific vitality of the Bureau. The Bureau is particularly proud of those individuals who have been elected to society presidencies, or chairmanships of major sections of societies, by their professional peers.

Lucy Birdsall

Chairwoman, Pacific Section,
American Association of
Petroleum Geologists

Keith L. Kvenvolden

Chairman of U.S. National Committee for Geochemistry, National Academy of Sciences

Edwin R. Landis

President, Coal Section, Geological Society of America

Joel L. Morrison

President, International Cartographic Association

Marshall M. Moss

President, the Hydrology Section of the American Geophysical Union

A. Anthony Novotny, Jr.

President, American Cartographic Association

Department of the Interior Distinguished Service Awards

The highest honor given by the Department of the Interior to its employees is the Distinguished Service Award. Commemorated by a gold medal, this award for outstanding achievement was presented by Secretary Donald Hodel to eight Geological Survey employees. These individuals and the bases for their awards are:

Carl E. Diesen, Deputy Assistant Director for Information Systems, for leadership in information resources activities and centralized data processing support services.

George E. Ericksen, Geologist, for exceptional achievements in the Geological Survey's mineral resource programs, especially in the area of foreign technical assistance to the governments of Chile and Peru.

Thor H. Kiilsgaard, Geologist, for his significant contributions to the field of economic geology and for his successful administration and management of major scientific programs.

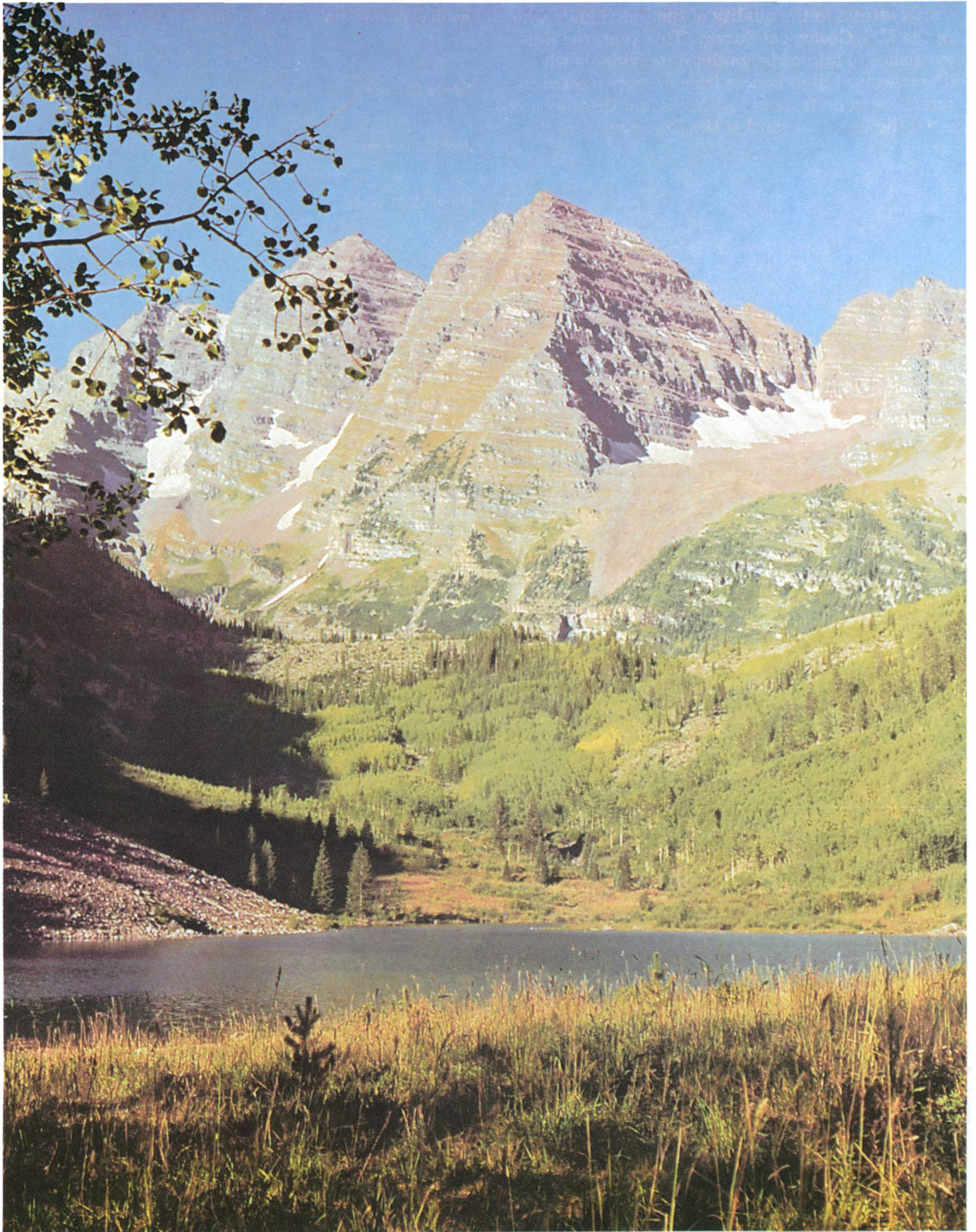
Harold Masursky, Geologist, for his imaginative leadership in the field of astrogeology which has influenced almost every facet of lunar and planetary exploration since the beginning of the Nation's space program.

Steven S. Oriel, Geologist, in recognition of his scientific contributions to the study of tectonic history of the Idaho-Wyoming overthrust belt and his expert guidance in the development of the new North American Code of Stratigraphic Nomenclature.

Sam H. Patterson, Geologist, in recognition of his many achievements in the investigations of mineral deposits and world resources of aluminum.

John R. Swinnerton, Chief, Western Mapping Center, in recognition of his outstanding service as a cartographer and administrator in the development and execution of the National Mapping Program.

Allen H. Watkins, Chief, EROS Data Center, for his exceptional contributions to the field of remote sensing and spatial data analysis and his achievements as administrator of the Earth Resources Observation Systems (EROS) Data Center.



Water Resources Investigations

Mission

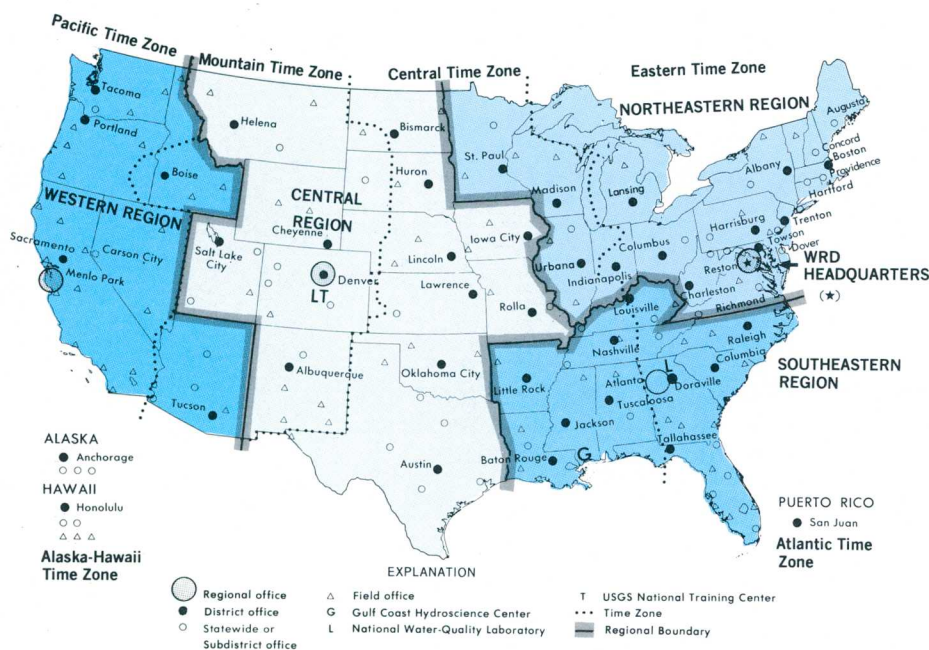
The mission of the U.S. Geological Survey's Water Resources Division is to provide the hydrologic information and understanding needed for the best use and management of the Nation's water resources for the benefit of the people of the United States. To accomplish this mission, the Division, in cooperation with State and local governments and other Federal agencies:

- Systematically collects data needed to continually determine and evaluate the quantity, quality, and use of the Nation's water resources;
- Conducts analytical and interpretive water-resources appraisals to describe the occurrence and availability of, and the physical, chemical, and biological characteristics of, surface and ground water;
- Conducts supportive basic and problem-oriented research into hydraulics, hydrology, and related fields of science and engineering to improve the basis for field investigations and measurement techniques and to understand hydrologic systems in order to predict quantitatively their response to natural or manmade stress;
- Provides to the public the water-resources data and the results of water-resources investigations and research through reports, maps, computerized information services, and other forms of public releases;
- Coordinates the activities of Federal agencies in the acquisition of water-resources data for streams, lakes, reservoirs, estuaries, and ground water; and
- Provides scientific and technical assistance in hydrology to other Federal, State, and local agencies, to licensees of the Federal Energy Regulatory Commission, and, on behalf of the U.S. Department of State, to international agencies.

Programs

The four Water Resources Division programs are the Federal Program, the Federal-State Cooperative Program, the Assistance to Other Federal Agencies, and the Non-Federal Reimbursable Program.

Federal Program.—This program is specifically identified in annual congressional appropriations and provides for the collection of water-resources data, investigations of resources, and research activities in areas where the Federal interest is paramount. These interests include water resources in the public



Location of principal offices of the U.S. Geological Survey's Water Resources Division in the conterminous United States. Cities named are those where Regional and District Offices are located. Puerto Rico is included in the Southeastern Region, and Alaska and Hawaii are included in the Western Region.

domain, river basins and aquifers that cross State boundaries, and other areas of international or interstate concern.

Federal-State Cooperative Program.—The Cooperative Program is based on the concept that Federal, State, and local governments have a mutual interest in evaluating, planning, developing, and managing the Nation's water resources. The Water Resources Division represents national interests, and the cooperating agencies represent State and local interests; the costs are shared 50/50 with the Federal share coming from direct congressional appropriations. The Geological Survey has cooperative agreements with all 50 States. Projects generally respond to recognized problems or define a potential one. In emergency situations, such as drought or flood, events are monitored, and the data accumulated under the Cooperative Program are made available for use by the public.

Assistance to Other Federal Agencies.—The Geological Survey performs a wide variety of water-resources investigations to meet the specific needs of each agency. Investigations are funded by reimbursements to the Geological Survey from the agencies requesting the work.

Non-Federal Reimbursable Program.—This Program covers situations where there is both Federal and State interest in the investigation of water resources but where matching Federal funds are either unavailable or are not otherwise applicable to cost sharing. Unmatched funds are provided to the Geological Survey by State and local agencies for these studies.

Highlights

The articles in this section of the *Yearbook* describe some of the significant accomplishments from the Water Resources Division's major programs during fiscal year 1985.

National Water Summary 1984

By David W. Moody

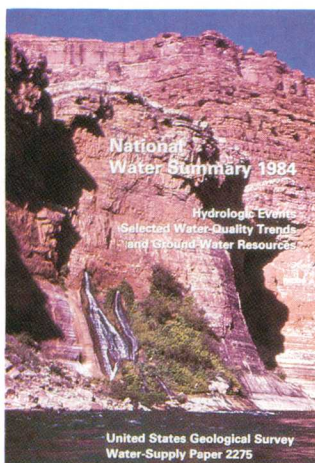
In May 1985, the U.S. Geological Survey published the second in an annual series of reports that describe the condition and trends of water resources in the United States. *National Water Summary 1984—Hydrologic Events, Selected Water-Quality Trends, and Ground-Water Resources*, Water-Supply Paper 2275, presents a synopsis of hydrologic conditions and water-related events that occurred during water year 1984, analyses of the occurrence and distribution of five water-quality constituents in major rivers, nitrate in ground water, and a description of the principal aquifers in each State.

"Hydrologic Conditions and Water-Related Events, Water Year 1984," the first part of *National Water Summary 1984*, provides an annual and seasonal summary of hydrologic conditions. Streamflow variations are compared with precipitation, temperature, and upper-air atmospheric pressure to relate surface water flows to climatic conditions. Water year 1984

was a year of extreme hydrologic conditions, with precipitation and runoff averaging well above normal in most of the Nation and by as much as 400 percent above average in parts of the Southwest. In contrast, west Texas and Hawaii experienced persistent drought.

Of 100 water-related events that are documented in the report, a number were selected for further discussion. Great Salt Lake, which has been on the rise for the past few years, reached its highest level since 1873 as a result of persistent wetter-than-normal conditions. Other lakes in the closed basins of the Western United States also reached unusually high levels that caused local flooding.

During eight consecutive days of rain in late May, parts of New England suffered the worst floods since Hurricane Diane in August 1955. Heavy rains in South Dakota, Nebraska, and Iowa during a 3-week period in June caused extensive flooding in those States. Runoff in the Colorado River basin between April and July was much higher than normal for the second year in a row, surpassing by 5 to 10 percent the peak flows in spring 1983. The sequence of operations of the Colorado River Storage Project enabled

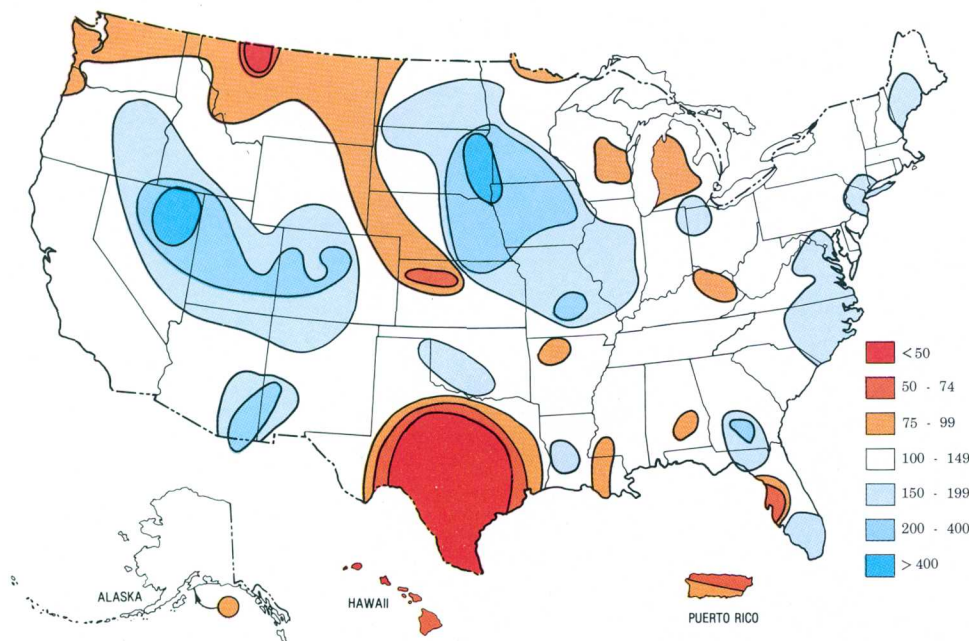


the reservoirs to accommodate the largest annual volume of runoff since 1917. Only minor flooding resulted, except in the upstream parts of the basin. Flood damage nationwide amounted to an estimated \$3.5 to \$4 billion in 1984.

“Hydrologic Perspectives on Water Issues,” the second part of the report, includes an overview of the occurrence, distribution, and trends of sediment, dissolved solids, phosphorus, nitrate, and pesticides in the country’s major rivers. All of these constituents are associated with runoff from sources of pollution in urban and agricultural areas.

Sediment is supplied to rivers as a natural consequence of geologic processes, but the rate at which it is supplied may be greatly accelerated by erosion associated with human activities, such as farming and construction. Once in a stream, sediment deposits lead to increased flooding, obstruct navigation channels, and decrease the storage capacity of reservoirs. Furthermore, contaminants, such as pesticides and toxic metals, adsorb on sediment particles and are transported, deposited, and stored with the sediment. The resolution of many water-quality issues will depend upon a better understanding of sediment transport.

Over the past 35 years, the construction of dams and reservoirs on the Missouri River and in other parts of its basin has reduced the sediment load carried by the Mississippi River by 50 percent. Even so, the Mississippi River still carries more sediment than any other U.S. river and ranks sixth or seventh in sediment transport in the world. Seaward trans-



Streamflow in water year 1984 as a percentage of normal in the United States and Puerto Rico for the period of record 1951–80. Line shows points of equal percentage; number shows percentage of normal annual streamflow. (Source: Compiled by Krishnaveni V. Sarma from U.S. Geological Survey data.)

port of sediment in the Colorado River and the Rio Grande has all but been halted by the construction of dams.

Dissolved solids have increased significantly in a large number of the Nation's rivers. The increases are thought to be related to the increasing use of

road salts for snow and ice control and the contribution of salts leaching from the soil of irrigated farmlands, especially in semiarid lands in the West and Southwest, by irrigation return flows. Phosphorus concentrations declined in the Great Lakes and Upper Mississippi regions, possibly due to major

The "Muddy Mississippi" River flows past the Gateway Arch at St. Louis, Mo., carrying with its waters more sediment than any other U.S. river. In fact, the Mississippi River ranks sixth or seventh in sediment transport in the world. View is from the Illinois side of the river. (Photograph by James H. Barks, Water Resources Division, U.S. Geological Survey.)



phosphorus-control efforts during the late 1970's. Increases in phosphorus concentrations that occurred in Florida, along the Gulf Coast, and in the Arkansas and Red River basins may be related to increased agricultural activities and use of fertilizer in these areas. Inorganic nitrogen (nitrate plus nitrite) concentrations increased at a large number of stream sampling sites nationwide, especially at sites in the eastern one-half of the country and in the Pacific coast basins of the Northwest. The relatively large number of increases are a result, at least in part, of widespread increases in atmospheric deposition of nitrate. A second factor contributing to increased inorganic nitrogen concentrations at stations on streams draining agricultural regions is the increased use of nitrogen fertilizers. During the period of record examined (water years 1975–81), the total quantity of nitrogen fertilizer applied nationwide increased by about 38 percent.

The Geological Survey and the Environmental Protection Agency monitored 22 common pesticides in water and bed materials at 150 river sites between 1975 and 1980. Detectable levels were found in fewer than 10 percent of the surface-water samples and fewer than 20 percent of the bottom-sediment samples. Concentrations of chlorinated hydrocarbons (dieldrin, chlordane, and DDT) have decreased in both the water and the bed materials of major rivers since the mid-1970's when the use of these pesticides was greatly curtailed. No clear trends were detected for the other pesticides that were monitored.

The use of ground water has increased nearly 190 percent nationwide since 1955. Ground water is looked upon as a clean, relatively inexpensive, generally drought-resistant source of water. Many State and water utility planners and managers are counting on ground water to meet future water demands. Increasing awareness that ground water cannot be assumed to be free of harmful chemicals and the discovery of many actual and potential sources of aquifer contamination have made protection of ground water from contamination a major topic of public interest.

To provide some insight into the degree to which human activities affect the quality of ground water, an analysis was undertaken of the maximum nitrate concentrations observed in water from 124,000 wells throughout the United States. Nitrate concentrations greater than 3 milligrams per liter (mg/L) were found in 20 percent of the wells and 6 percent had concentrations greater than 10 mg/L, the Environmental Protection Agency's established criterion for

drinking water. Nitrate concentrations greater than 3 mg/L are considered by the author to be elevated above natural levels. Because most of the wells with elevated nitrate concentrations are less than 100 feet deep, it appears that the probable sources of the nitrates include nitrogen fertilizers, seepage from feed lots and other agricultural activities, septic systems, and various waste disposal activities. The observed patterns of elevated nitrate concentrations correlate well with the known distribution of these activities.

Another issue examined in the section "Hydrologic Perspectives on Water Issues" is the significance of ground-water-level declines in various parts of the country that were identified in the *National Water Summary 1983—Hydrologic Events and Issues*, Water-Supply Paper 2250, as a growing concern in 35 States. Ground-water-level declines can lead to streamflow depletion, land subsidence, saltwater intrusion, and increased pumping costs for water producers and users. A number of areas have experienced ground-water-level declines of 40 feet or more in at least one aquifer since development began. The report describes the historical behavior of water levels in five important areas of ground-water use in which declines have occurred. These areas in California, Illinois, Louisiana, South Dakota, and Virginia illustrate the range of hydrologic conditions and water use practices that cause changes in water levels and the significance of these changes.

The final section of the report, "State Summaries of Ground-Water Resources," describes the principal aquifers in each State as well as the District of Columbia, Puerto Rico, the U.S. Virgin Islands, the Trust Territory of the Pacific Islands, Saipan, Guam, and American Samoa. The location of the aquifers is shown on multicolored maps and cross sections. A second illustration portrays the areas of major ground-water withdrawals and hydrographs of selected wells to indicate the long-term water-level trends. Tables depict statistics of ground-water use for 1980 in each State, and aquifer and well characteristics, including reference to water-quality constituents that limit use of the water. A section on ground-water management and selected references completes each State summary.

With the completion of this second National Water Summary, a foundation has been laid for a set of references that collectively will provide a comprehensive description of the Nation's water resources and make available to a wide audience the findings of the U.S. Geological Survey's water resources investigations.

Summary of the National Water-Quality Assessment Program

By Robert M. Hirsch

Protecting the quality of the Nation's ground-water and surface-water resources is a high-priority concern, for the quality of these resources directly affects public health, the economics of agriculture, industry, fish and shellfish harvesting, and recreation. Although the States have major responsibilities for the protection of water quality, a clear need exists for coordination at the Federal level because of the interstate nature of many of the problems, the pertinent body of Federal laws and regulations, and the substantial Federal expenditures associated, particularly for sewage treatment plants and for cleanup of toxic-waste sites. Presently there is no unified and consistent program of national water-quality assessment. Without such a program, policy decisions must be made on the basis of very limited data.

The Geological Survey has, for many years, played a major role in advancing the scientific understanding of water quality and has collected and interpreted water-quality data in many localities as part

of its Federal-State Cooperative Program, as a service to other Federal agencies, or as a part of special programs such as the river-quality assessments. These programs provide valuable information on water quality to local officials concerned with managing the water resource, but, because they are local

The clear water of Lake Michigan contrasts sharply with the sediment-laden water in the outer harbor (between the breakwater and the bridge near the smokestack at the mouth of the Milwaukee River) and the inner harbor at Milwaukee, Wis., the day after a minor summer thunderstorm. Runoff from severe thunderstorms can push a plume of sediment-laden water through the main harbor entrance (lighthouse at left-center in photograph) several thousand feet into the lake. (Photograph courtesy of the State of Wisconsin, Department of Natural Resources.)



in scope, they cannot be aggregated to constitute an integrated assessment of the status and trends in the Nation's water quality. The Geological Survey does operate the only national water-quality data acquisition networks—the Benchmark network (55 stations in pristine small basins) and the National Stream Quality Accounting Network (501 stations at the downstream ends of the Nation's major river basins). These two networks have provided insight on the movement of major chemical components through the Nation's rivers and the relation of these components to geologic features, climate, deposition of materials from the atmosphere (including acid rain), and the human population of the river basin. For ground water, there is no national sampling or quality assessment program.

The Geological Survey is starting a national long-term program of water-quality data acquisition, interpretation, and assessment. This proposed program builds on all the information from existing programs (National Stream Quality Accounting Network, Benchmark, Regional Aquifer-Systems Analysis, Toxic Substances Hydrology) and the experience of Geological Survey scientists in field offices in all the States.

Problems of organizing such an assessment program are formidable, with difficulties arising from the size of the area to be investigated, the multiplicity of water-quality variables to be measured, and the high cost of field work and laboratory analysis, especially for trace organic chemicals. To make the overall problem manageable, program planners must make several strategic choices. Some of the key features of the proposed program follow.

1. Efforts will be confined primarily to those fresh-water resources that are of adequate natural quality to be used for ordinary purposes, such as domestic supply or irrigation of crops, that have been mapped, and for which an understanding of the flow system already exists;
2. Each activity will be clustered into study units that are widely scattered around the Nation and will in aggregate account for a large percentage of the Nation's water use. This clustering greatly enhances the potential for obtaining useful information from the data collected;
3. The program will identify a nationally consistent set of water-quality variables for study. These water-quality variables are related to one or more water-quality issues: chemical contamination, nutrient enrichment, acidification, sedimentation, and acceptability of water for general use;
4. The program will measure or determine hydrological and biological characteristics of water in relation to land use, geology, and population to aid in the interpretations of water-quality data;
5. The work, and the reporting of results, will have three scales: National, regional study units (equivalent to river basins or aquifer systems), and locally studied areas (a few tens of river miles for surface water and a few tens of square miles for ground water);
6. Surface-water studies will be rotational. Within each study unit, the data-acquisition and interpretation will be stressed in a period of 3 years. Then, after a 6-year period of very limited activity, there will be a return to very active study for another 3 years. This 9-year cycle (3 years active, 6 years relatively inactive) will continue indefinitely. Each active phase will provide a "snapshot" of conditions to compare with all of the previous "snapshots." Different units will be studied at different times, so the national program will be maintained at a constant level of effort and be geographically diverse at all times;
7. Ground-water studies will be monitored by a computer-based procedure that relies on specific land use, hydrogeology, and contamination intended to classify segments of each study unit into three categories: those that are probably substantially contaminated, those probably not substantially contaminated but vulnerable to contamination, and those that are neither contaminated nor vulnerable;
8. Special attention will be given to sampling and summarizing the quality of drinking-water sources nationally; and
9. Existing quality-of-precipitation studies will be improved with special attention being given to the problem of trace metals deposited in rainfall and released from soils and rocks.

The proposed National Water-Quality Assessment Program will provide essential information on the effectiveness of many water-quality protection programs and help those responsible for the program's design and direction (the Congress and Federal regulatory agencies) to achieve their goals cost effectively. In addition, the program will contribute to the effective management of water resources by the State and local agencies that have management responsibilities by providing special information on contaminant sources, movement, and transformation. This information is the key to predicting the consequences of various pollution-control strategies being considered.

Investigations of the Regional Aquifer Systems in the United States, 1978–1984

By Ren Jen Sun

Increased use of ground water for irrigation, urban expansion, and industrial and energy development is expected during the next decade. In addition, ground water is widely recognized as an especially important component of the Nation's water supply during periods of drought. The projected increase in the use of ground water will have widespread impact on the Nation's aquifer systems.

Water pumped from wells initially removes water from storage in the aquifer, with an associated lowering of water levels. As water levels in the pumped aquifer decline, new hydraulic gradients are developed that either reduce natural ground-water discharge or induce recharge to the aquifer to balance the amount pumped. When pumpage is greater than the amount of water that can be obtained by increased recharge or reduced natural discharge, the result is sustained withdrawal of water from aquifer storage and continued lowering of water levels. In turn, water-level declines increase the cost of water to irrigators because pumping from increased depths results in higher energy costs. In water-table aquifers, the lowering of water levels can cause the progressive decrease of the saturated thickness of the aquifer, and the result is reduced well yields and eventually depletion of the ground-water resource. In areas where aquifers are covered with thick, easily compressed, fine-grained sediments of low permeability, such as silt and clay, land subsidence may occur because the sustained withdrawal of water from storage out of these fine-grained sediments allows the pressure from the weight of the overburden to compact the fine-grained sediments.

In irrigated areas where return flow from irrigation water recharges the shallow aquifer, constituents such as salts leached from soil or applied pesticides, herbicides, and fertilizers may move into the shallow aquifer and flow downward into deep and confined aquifers to degrade the ground-water quality. Recharge of irrigation water may also cause ground-water levels to rise, which may create conditions of water-logged soil. Water-quality degradation from waste disposal may also develop in industrial or urban areas.

Prompted by the 1977 drought, the 95th Congress provided funds to the Department of Interior to begin a Geological Survey program to identify the water resources of the major aquifer systems within the

United States. The purposes of this program, as stated in the appropriations report, were to establish the aquifer boundaries, to estimate the quantity and the quality of the water within the aquifer systems, and to characterize the recharge of the aquifer systems. As a result of these specifications, and in response to the need for regional information to support better investigations and management of the ground-water resources within the United States, the Geological Survey instituted the Regional Aquifer-System Analysis (RASA) Program in 1978.

On the basis of a series of Geological Survey reports presenting summary appraisals of the Nation's ground-water resources (fig. 1), and using economic and hydrologic considerations, 28 regional aquifer systems were identified for study under the RASA Program (fig. 2). As of September 1985, nine RASA studies have been completed and reports are being written. The studies cover the Central Valley aquifer system in California, the Floridan aquifer system, the Great Basin regional aquifer system in Nevada and Utah, the High Plains aquifer system, the Northern Atlantic Coastal Plain aquifer system, the Northern Great Plains regional aquifer system, the Northern Midwest regional aquifer system, the Snake River Plain aquifer system in Idaho, and the Southwest Alluvial Basins regional aquifer system. Another 11 RASA projects are being studied.

If major technical problems, issues, or deficiencies in data are identified that cannot be addressed adequately within the context of the initial investigations, follow-up studies, called RASA Phase II, are then undertaken at the conclusion of the initial studies. As of September 1985, six RASA Phase II studies are being undertaken. The geographic locations and status of all RASA studies are shown in figure 3.

The delineation and continuity of aquifers and confining units are dependent on the scale of the problem under study. Regional aquifer-system studies normally lump many discontinuous local aquifers together into a relatively small number of regional aquifers or confining units on the basis of the hydraulic characteristics of formations, rather than on the geologic ages, which are common for stratigraphic correlations. An aquifer delineated in a RASA study may contain many different geologic formations. A regional aquifer system, as defined in the

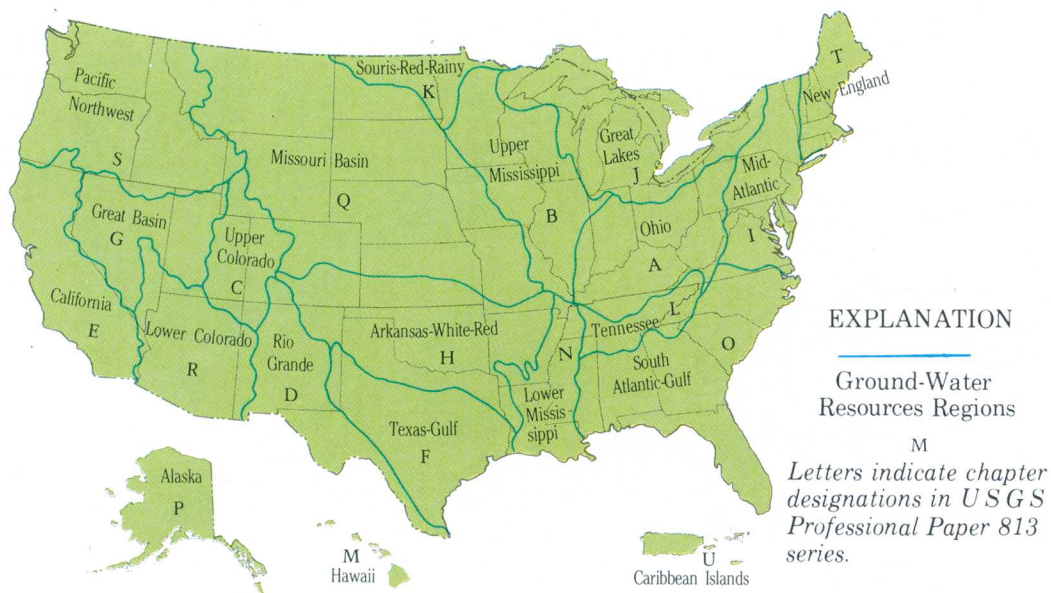


Figure 1. Map showing location of reports of Summary Appraisals of the Nation's Ground-Water Resources, U.S. Geological Survey Professional Papers 813-A through 813-U.

RASA Program, may be of two general types. It may be an extensive set of aquifers and confining units that locally may be discontinuous but act hydrologically as a single system on a regional scale (examples include aquifer systems underlying the Great Plains, High Plains, Gulf Coastal Plain, and Atlantic Coastal Plain), or it may represent a set of essentially independent aquifers that share so many common characteristics that investigation of a few of these independent aquifers can establish common principles and hydrologic factors controlling the occurrence, movement, and quality of the ground water throughout the aquifer systems.

Examples of this second type of the regional aquifer-system studies include the alluvial basins in Arizona, New Mexico, Utah, and Nevada, and the glacial aquifers in the Northeastern United States.

Computer-based numerical ground-water-flow models are used in all RASA studies to provide quantitative understanding of the delineated aquifer systems. The ground-water-flow simulation models developed during regional studies, however, may not always be appropriate for the evaluation of the effects of ground-water development at a local level. Subregional ground-water-flow

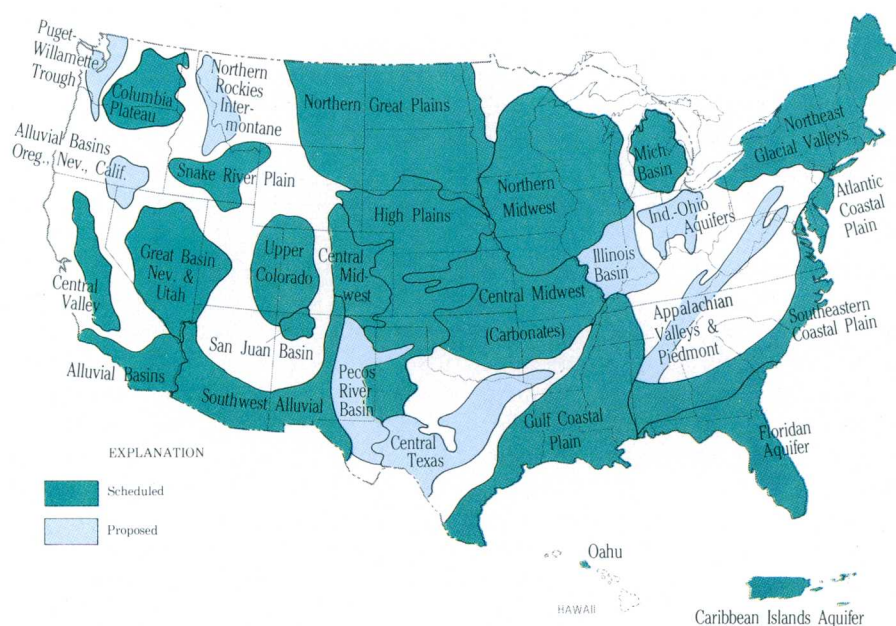


Figure 2. Map showing the location of the regional aquifer systems identified for study under the Regional Aquifer-System Analysis Program of the U.S. Geological Survey.

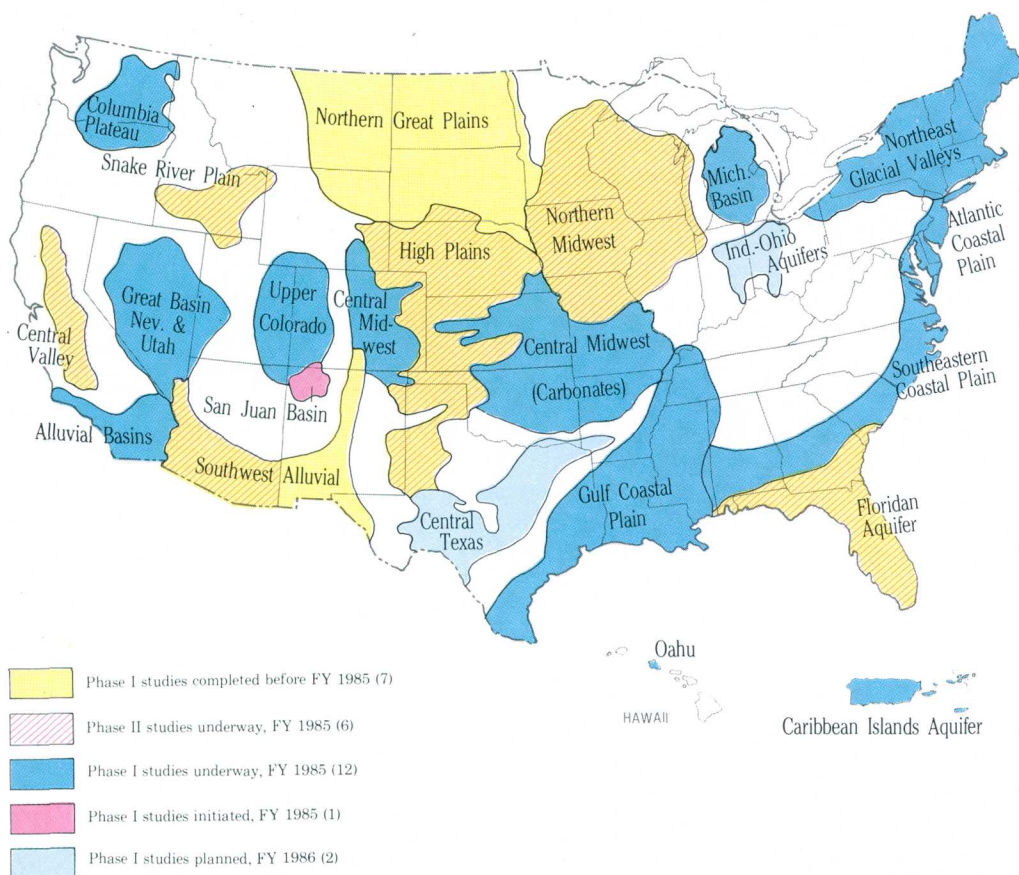


Figure 3. Map showing the locations of areas being investigated during 1978–84 and areas to be investigated in fiscal years 1985–86 under the Regional Aquifer-System Analysis Program.

models are then constructed for better resolution of the simulation results and for addressing specific areas of interest. For example, the use of regional flow models to supply correct information along the boundaries of the subregional models eliminates the incorrect boundaries assigned with-out the regional simulations.

The RASA studies rely primarily on interpretation of existing data; however, some new data are also collected in each investigation, and some exploratory drilling has been carried out. Examples include seven deep exploratory wells drilled in the Sacramento Valley in California and seven deep wells drilled in the Cambrian-Ordovician aquifer system during the Northern Midwest regional aquifer-system study. In 1979, an offshore oil test well drilled by Tenneco 55 miles east of Fernandina Beach, Fla., was used for hydrologic testing before the well was closed. Pressures measured in the test well indicate an equivalent freshwater head of 24 to 29 feet above sea level. A drill-stem test at an interval of 1,050 to 1,070 feet below sea level recovered water samples containing about 7,000 milligrams per liter of chloride. The head and salinity data suggest that the tested interval, 1,050 to 1,070 feet below sea level, lies in a transition zone between fresh ground water and sea-water.

As of September 1985, about 300 reports have been published under the RASA Program. The following are some significant findings resulting from the RASA studies.

Central Valley, California.—Digital simulation of ground-water flow indicates that during 1961–78, ground-water discharge was about 11.8 million acre-feet per year, of which 94 percent was for irrigation and 3 percent discharged to topographic depressions such as streams and lakes. The simulation also indicates that the ground-water recharge was about 11 million acre-feet per year, of which 81 percent was from irrigation return flow, 14 percent was infiltrated from precipitation, and 5 percent was induced from streams and lakes. The difference between the annual ground-water discharge and recharge was 0.8 million acre-feet per year. About half of this difference was water stored in the aquifer. Its removal caused water-level declines. The remaining half was derived from fine-grained sediments that compacted and resulted in subsidence of the land surface.

Subsidence in the Central Valley began in the mid-1920's as ground water was pumped for irrigation. By 1970, the maximum subsidence exceeded 29 feet at one location in the San Joaquin Valley, and over 5,000 square miles of land surface in the Central Valley had subsided more than

1 foot. The rate of subsidence in the most severely pumped areas in the San Joaquin Valley has been decreasing since delivery of surface water in 1968; it may recur if pumping reduces water levels below the previous maximum lows. For example, during the 1976–77 drought, water levels declined a maximum of nearly 200 feet in 8 months; the subsidence, which had nearly ceased after 1972, was as much as 0.5 foot in 1977.

The discovery of an easily compressed clay, over 50 feet thick, in the Sacramento Valley will be important to water managers when plans to develop ground-water resources in that area are considered. Land subsidence may occur when that clay is being compacted as a result of the lowering of hydraulic heads in the aquifers. Before irrigation pumping, heads in the deep aquifer were normally higher than those in the shallow aquifer, which contains water of poor quality in the western part of the San Joaquin Valley. This poor-quality water may flow downward to degrade the water in the deep aquifer. This potential for water-quality degradation in the deep aquifer was not investigated during the initial study of the regional aquifer system in the Central Valley, and a Phase II study was initiated in 1984 to study this possibility as well as the impact of irrigation return flow on the aquifer system in the San Joaquin Valley.

High Plains RASA Study.—Areas of water-level declines caused by pumping for irrigation resulted in the reduction of the saturated thickness of the aquifer materials in all States in the High Plains, except South Dakota where irrigation development is sparse. The largest area of water-level decline, exceeding 100 feet, occurred south of the Canadian River in parts of New Mexico and Texas and in some localized areas north of the Canadian River in parts of Kansas, Oklahoma, and Texas. The maximum water-level decline of nearly 200 feet occurred in Floyd County, Tex. Water levels have risen, however, in several places in the High Plains. In Gosper, Howard, Lincoln, Phelps, and Sherman Counties of Nebraska, water levels have risen more than 50 feet because of excessive recharge from surface-water irrigation. In Dawson and Lynn Counties of Texas, water levels have risen more than 25 feet after clearing sandy soil of native vegetation for cultivation resulted in an increase of water locally recharged to the aquifer. These findings indicate that land use can clearly affect the aquifer system, especially the water-table or shallow aquifers.

Northern Great Plains RASA Study.—A body of brine located at the eastern flank of the Williston

basin was studied to learn whether it was static or whether it was a very slow-moving segment of the regional ground-water flow system. Computer simulations of the ground-water regional flow system indicate that consistent low-velocity ground-water flow moves eastward and northeastward through the brine body. This suggests that a small component of the ground-water flow actually moves directly across the Williston basin from west to east, through the areas containing the brine, and that the brine probably is a slow-moving segment of the flow system.

Northern Atlantic Coastal Plain RASA Study.—The relation of concentrations of calcium, magnesium, sodium, potassium, and sulfate to concentrations of chloride indicates that a saltwater-freshwater transition zone in North Carolina is primarily a mixture of seawater and fresh ground water containing sodium bicarbonate. In areas from Virginia to New Jersey, however, the transition zone appears to be largely a mixture of a sodium calcium chloride brine and fresh ground water containing sodium bicarbonate.

For more information on the RASA Program, the reader should refer to U.S. Geological Survey Circular 1002, *Regional Aquifer-System Analysis Program of the U.S. Geological Survey—Summary of Projects, 1978–84*.

Ground Water Contamination

By Stephen E. Ragone

Public concern about ground water contamination, one of the most widely publicized environmental issues of the 1980's, has been aroused by the social and economic disruptions from ground water contamination at places like Love Canal in New York and Stringfellow Acid Pits in California. Estimates that billions of gallons of hazardous waste leak to ground water each year and that incidents of ground water contamination occur just about everywhere in the Nation further exacerbate the issue. Presently there is no understanding of the areal extent and the degree to which ground water has been degraded today or of the future risks to this resource. To gain clearer understanding of these issues, we must assess the complexity of the subsurface environment, the processes that may alter ground water quality, and the variability of the nature and amount of contamination.

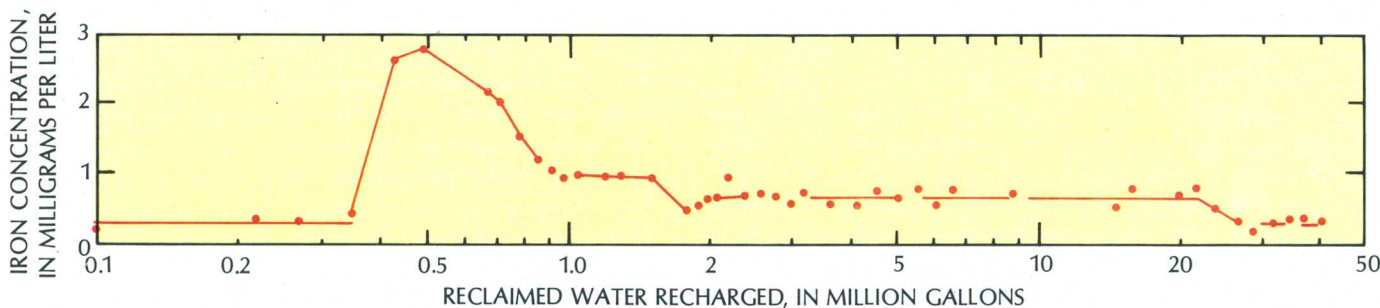


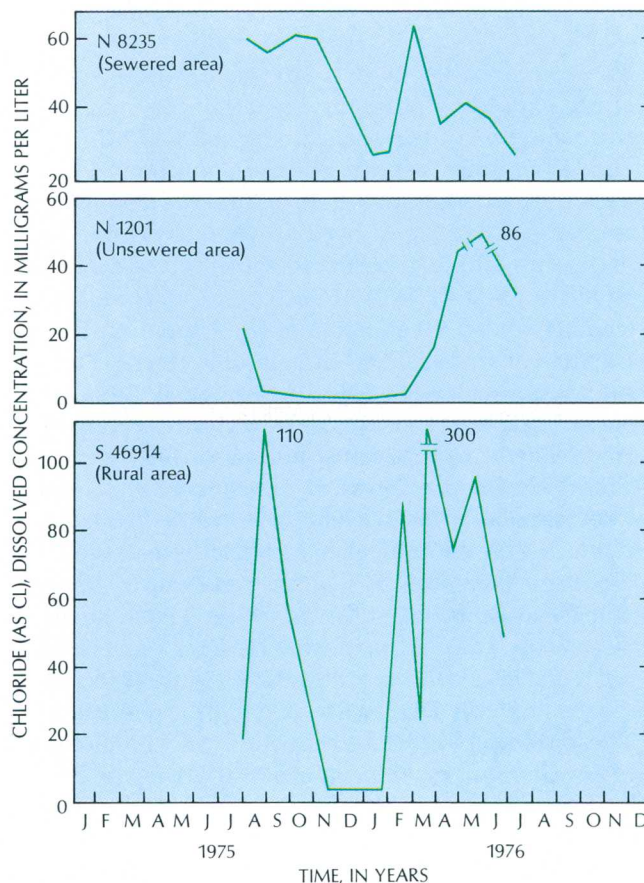
Figure 4. Change in iron concentration of water from an observation well 20 feet from the recharge well on Long Island, N.Y.

The complexity of the subsurface environment is illustrated by results from a study on changes in iron concentration in ground water. The changes occurred because of the injection of sewage into the Magothy aquifer on Long Island, N.Y. (fig. 4). Although the tertiary-treated sewage and the native water into which it was recharged contained iron in concentrations less than 0.5 milligrams per liter (mg/L), the iron in ground water at a well 20 feet from the point of injection reached nearly 3 mg/L during the early part of the recharge period. The iron was mobilized by reaction between the oxygen in the recharge water and the pyrite, a mineral, in the aquifer. Reactions such as this, along with the many other geochemical processes that can occur, may drastically alter the quality of ground water, resulting, as in the example, in a degradation in water quality or in its improvement. The variable effects of chemical constituents in the subsurface may be large (fig. 5). Fluctuation in the concentrations of chloride, for example, can vary by several orders of magnitude as a result of natural and human activities. Chloride is a stable constituent, so changes in chloride concentration in ground water reflect either increases or decreases in the amount of chloride entering the ground water, and, possibly, changes in the hydrologic condition in the vicinity of the well. Concentrations of trace metals and organic substances, however, may show even greater variability over time because of their reactivity.

Complexity in the hydrology and geochemistry of the subsurface, along with variability in the contaminant effects, may make it difficult to predict or explain regional patterns of ground water contamination. The distribution of nitrate in a water-table aquifer recharged by water from a suburban area presumably could be attributed to its introduction from homeowners' septic systems. A comparison of concentrations of nitrate from a sewered area with that of an unsewered area on Long Island, N.Y.,

however, showed the relation to be much more complicated. No significant difference was found between the concentration of nitrogen for sewered and unsewered areas over the entire 25-year period of record. A

Figure 5. Monthly fluctuations of chloride concentrations in water from wells in sewered, unsewered, and rural areas on Long Island, N.Y.



combination of factors may play a role in the distribution of nitrate in ground water. These include changes in hydrologic conditions resulting from periods of drought and the corresponding response of the ground water system, along with a variety in the sources of nitrogen recharged to the ground water. Thus, while much ground water contamination is attributable to the activity of humans, one would be ill advised to generalize about the impact of specific manmade activities on ground water quality.

In a program of studies on toxic waste, USGS scientists are currently studying the factors affecting the fate of contaminants in the subsurface, notably trace metals and manmade organic substances, and appraising their distribution in selected regions of the United States. Only by applying sound scientific principles can we gain a clear understanding of the extent of the degradation of ground water.

The Federal-State Cooperative Program Focuses on Priority Issues

By Bruce K. Gilbert

The Geological Survey's Federal-State Cooperative Program in fiscal year 1985 marks its 90th year of contributions to the development of knowledge about the Nation's water resources. The program was carried out in working partnership with more than 800 State, regional, and local agencies during the past year. Joint funding in this 50/50 matching activity totaled about \$107 million and comprised almost one-half of the overall program of the Water Resources Division.

The Cooperative Program, begun in Kansas in 1895, has grown and changed with time so that by 1985, hydrologic data collection and interpretive investigations were underway in every State, Puerto Rico, and several territories. Perhaps the most important characteristic of the program throughout its 90-year history is that it is, and has always been, responsive to recognized or potential problems. Most investigations provide hydrologic information and analyses needed for making decisions or for solving problems. The program continues to contribute to the advancement of hydrologic science and provides a major part of the Geological Survey's water-information data base.

Practically all of the Geological Survey's stream-flow data-collection stations, funded in large part by

this Cooperative Program, serve several purposes. In addition to responding to State or local needs, the stations provide information to satisfy the requirements of many Federal agencies, such as for flood prediction, land-use planning, streamflow regulation, production of hydroelectric power, establishment of waste-disposal standards, pollution regulation, mined-land reclamation, and energy development. In fiscal year 1985, the Federal-State Cooperative Program provided sole support for nearly one-half of the 7,000 continuous-streamflow stations in the total Geological Survey network, and, in combination with other funding sources, provided partial support for another 20 percent of the total network.

The operation of data-collection stations is a continuing activity. Many are operated on a long-term basis as components of national networks; some are discontinued each year when their purpose has been served. New stations are installed as demanded by changing needs and priorities. The Geological Survey's entire stream gaging program is being systematically analyzed to improve its cost effectiveness.

In addition to the data-collection activities, approximately 530 hydrologic investigations and water-resources research projects funded by the Federal-State Cooperative Program were underway in fiscal year 1985. These included areal appraisals and special studies conducted throughout the Nation. Areal water-resources appraisals, which range from small basin or county to statewide or regional studies, define, characterize, and evaluate the extent, quality, and availability of the water resource.

Special studies addressing existing and foreseeable hydrologic conditions and concerns are somewhat more specific in nature and smaller in size than areal appraisals and often involve applied research. They may require from a few months to 2 to 3 years to complete, and they result in analytical, interpretive, and predictive reports, data, and information leading to the solution of water-resource problems or to the more complete utilization and protection of the Nation's water resources.

The Geological Survey and its cooperating agencies work together in a continuing process that leads to adjustments in each year's program. Key hydrologic concerns and issues requiring priority consideration in the selection of new activities, or the retention of ongoing activities, are determined through discussions with State and local cooperators, with Federal agency officials, by guidance from Congress and the Department of Interior, and through awareness of the concerns of the general public. For 1985, five categories of water issues were identified as major national concerns and were considered of highest priority in developing the program: water quality,



The Potomac River cascades over the rocks near Great Falls, Va. The Potomac River investigation, one of seven river-quality assessments and the only one to concentrate on the estuarine environment, began in October 1977. (Photograph by William A. Dize, Jr., U.S. Geological Survey.)

toxic-waste hydrology, erosion and sedimentation, water supply and demand, and hydrologic hazards.

The National Water Summary 1983 reports that contamination from hazardous wastes, point and non-point sources of pollution, saltwater intrusion, eutrophication, acid precipitation, and other water-quality issues are of concern throughout the United States. The Nation's rivers have historically been used for water supplies, dilution of waste, recreation, commerce, and for production of fish and aquatic crops. These uses are not all compatible, and many problems that can affect human health and the economy have surfaced, such as the deterioration in the quality of water supplies from domestic, municipal, industrial, and agricultural uses. In spite of considerable progress in solving complex water problems, stresses on the quality of surface and ground waters are multiplying. Ground water supplies drinking water for at least one-half of the Nation's population. Disposal of toxic wastes has made some ground water

unsafe for use, especially in densely populated and industrialized areas. For an isolated source of contamination, such as an industrial disposal drain, the consequences may be severe in magnitude but only local in extent; in some places, however, many separate industries located over a large area and some agricultural practices are contributing to widespread contamination.

Water-quality issues, heading the 1985 list of priorities for the Cooperative Program, continue the trend whereby the emphasis given to ground- and surface-water quality has increased significantly during the past several years. At present, nearly three-fourths of the investigations undertaken in the Cooperative Program in part address water-quality concerns. Of these, one in four focuses principally on surface water or ground water that has been contaminated with hazardous substances. A few of the highlights of the 1985 program are described below.

Saltwater Contamination, Central Oklahoma

An investigation of the impact of saltwater in the Vamoosa-Ada aquifer of central Oklahoma has been underway since 1979 in cooperation with the Oklahoma Geological Survey. More than 80 stream and well sites have been identified as contaminated by brine in the 1,700-square-mile area of study. Geophysical measurements indicate a possible increase in saltwater encroachment into the freshwater layer in the Vamoosa-Ada aquifer. Indices developed to identify brine contamination in surface- and ground-water resources in this area will have application in other parts of the country.

Identification of Ground-Water Problems in Arkansas

The Geological Survey, in support of Arkansas' ground-water protection strategy, has prepared a report that identifies existing and potential ground-water problems in the State. Existing problems that were documented include poor natural-water quality, saltwater intrusion, contamination, low yields from fractured-rock aquifers, and water-level declines in principal aquifers. Areas of the State were categorized as high-, medium-, or low-recharge zones, and the areas having the greatest potential for aquifer contamination are waste-disposal sites located in the medium- or high-recharge zones.

Evaluation of Ground-Water Resources, Los Osos Basin, San Luis Obispo County, California

In the coastal areas of California, the principal limit on future development typically is the availability of water supplies. Many of the aquifers in these areas are subject to contamination from land-use practices and from saltwater intrusion caused by declining ground-water levels. San Luis Obispo County requested an investigation of the Los Osos basin to evaluate the ground-water resources to assist officials in developing plans for improved water-

resources management in the area. Initial results of this project have provided a considerable amount of encouraging information. Clearer definition of the characteristics and areal extent of the confining layer indicates that contamination of the water-supply aquifer from the upper aquifer is not an immediate concern. In addition, a previously unmapped Pliocene-age formation, presenting potential for the development of additional water supplies, has been identified.

Water-Quality Characteristics of the Proposed Swatara Creek Reservoir, Pennsylvania

Quality of the water to be impounded by a dam on Swatara Creek in Schuylkill County, Pa., may not be acceptable for maintaining a warm-water fishery or for water-contact recreation. Acid mine drainage has been identified as the principal contributor to the poor water quality, and releases from the reservoir may degrade the water quality downstream in Swatara Creek. Construction of this \$40 million dam project has been halted pending resolution of the water-quality issues.

Modeling of Suspended-Sediment Discharges, Warrior Coal Field, Alabama

The amount of sediment entering Alabama streams and transported as suspended sediment because of surface coal mining activities in the State continues to be of major concern to regulatory agencies. The Geological Survey, in cooperation with the Alabama Surface Mining Commission, is studying the application of a surface-water model, based on local geohydrology, to selected streams in the Warrior Coal Field area. The model, being calibrated to simulate suspended-sediment yield characteristics in areas with ungaged streams, will provide significant information on sediment-related impacts of surface mining that will be applicable to similar situations nationwide.

Preliminary Evaluation of Buried Crystalline Rock in the Northern Atlantic Coastal Plain for the Disposal of High-Level Radioactive Waste

By Orville B. Lloyd, Jr.

Introduction

The Geological Survey is conducting hydrologic and geologic studies that will assist the U.S. Department of Energy in the identification of geohydrologic environments that are suited for the construction of a required repository for the disposal of high-level radioactive wastes. One of the environments that has received much attention and study is that found in crystalline igneous and metamorphic rocks that are exposed at the land surface. The crystalline rocks have been studied as potential sites for waste repositories because they are abundant on the continents, provide stable mined openings, have thermal properties that give them the capacity to withstand and dissipate heat from the wastes, and have low interstitial permeability.

Most crystalline rocks are fractured, however, and these fractures constitute a major disadvantage of the exposed crystalline-rock waste-storage environment. It is very difficult to predict, with any reasonable certainty, the direction and rate of ground-water movement through a system of fractures because the geometry and hydraulic properties of the fractures are difficult to measure, characterize, and model. Prediction of ground-water flow is important because ground-water transport is the major vehicle for the migration of radionuclides from a repository.

In contrast, ground water in sedimentary rocks generally occurs in and moves through closely spaced intergranular openings, and the rate and direction of movement can be predicted with greater confidence. In sedimentary rocks, favorable geohydrologic conditions may be found where flow paths are long and flow rates are slow in the clay subsurface. These conditions enhance the chances for the long term isolation of wastes from the biosphere.

The attributes of both sedimentary and crystalline rocks might be combined if repositories for high-level radioactive waste can be developed in crystalline rock that is buried beneath a thick blanket of low-permeability sedimentary rock. With this approach, the minability, thermal conductivity, and other favorable properties of the crystalline rock could be combined with the predictability of ground-water movement in the overlying sedimentary rocks. This buried-crystalline-rock concept, as proposed in 1981

by J. D. Bredehoeft and Tidu Maini, was endorsed by the National Academy of Sciences in 1983 as worthy of further consideration, and the Geological Survey conducted a study to determine regions in the eastern part of the United States where application of the concept might be feasible.

The following criteria were used to identify areas where geohydrologic conditions are considered potentially suitable:

The top of crystalline rock lies between 1,000 and 4,000 feet below land surface;

Crystalline rock is overlain by sedimentary rock whose lowermost part, at least, contains saline water (water with a dissolved-solids concentration of 10,000 milligrams per liter or more);

Shale or clay confining beds overlie at least the lowermost aquifer that contains the saline water; and

The flow system in the saline-water aquifers is known or determinable from presently available data.

Application of these preliminary guidelines revealed that parts of the Atlantic Coastal Plain and parts of the Cincinnati arch area (the Cincinnati arch covers parts of Kentucky, Tennessee, Ohio, and Indiana) meet most of the criteria. The Northern Atlantic Coastal Plain has been studied in further detail, by use of published and unpublished data compiled by the Northern Atlantic Coastal Plain Regional Aquifer-System Analysis Group, most of it from the relatively freshwater-bearing aquifers in the upper part of the sediment mass. The lack of data on the saline-water-bearing section makes it difficult to appraise the hydrology of the deeper part of the system. Nevertheless, some useful preliminary observations can be made.

Evaluation Factors for the Atlantic Coastal Plain

The following four factors were used to make a preliminary evaluation of the geohydrology of the Northern Atlantic Coastal Plain sediments where the

top of the crystalline rocks lies between 1,000 and 4,000 feet below the land surface in the area:

- The estimated thickness of sediments containing saline water;
- The estimated thickness and continuity of the deepest confining beds;
- The estimated permeability of the deepest aquifers; and
- The inferred direction of lateral ground-water flow in the deepest aquifers.

Thickness of Sediments Containing Saline Water.—In general, saline water will serve as a buffer between any buried-crystalline-rock disposal site and the system of freshwater circulation. Thus, it is assumed that the chance for contamination of fresh ground water and the biosphere decreases with an increase in the thickness of the saline-water-bearing sediments. The sediments that overlie the basement rocks contain saline water in about two-

thirds of the area that meets the depth criterion (fig. 6). The thickness of the saline-water-bearing sediments exceeds 3,000 feet in North Carolina and Virginia and 2,000 feet in Delaware and New Jersey (fig. 1).

Thickness of Confining Beds.—The confining beds impede vertical ground-water flow that might carry radionuclides upward from a repository. In addition, the confining beds have chemical properties that make them able to sorb radionuclides. The effectiveness of the confining beds in preventing the migration of radionuclides is assumed to be directly proportional to their estimated thickness. Confining beds composed of clay and silty clay occur between the basement rocks and the fresh-water circulation system in the area where both the depth and the saline-water criteria are met (fig. 7). Because of the discontinuous and lenticular nature of the confining beds, it is possible that radionuclides might migrate upward across at least the lowermost confining bed. To allow for this pos-

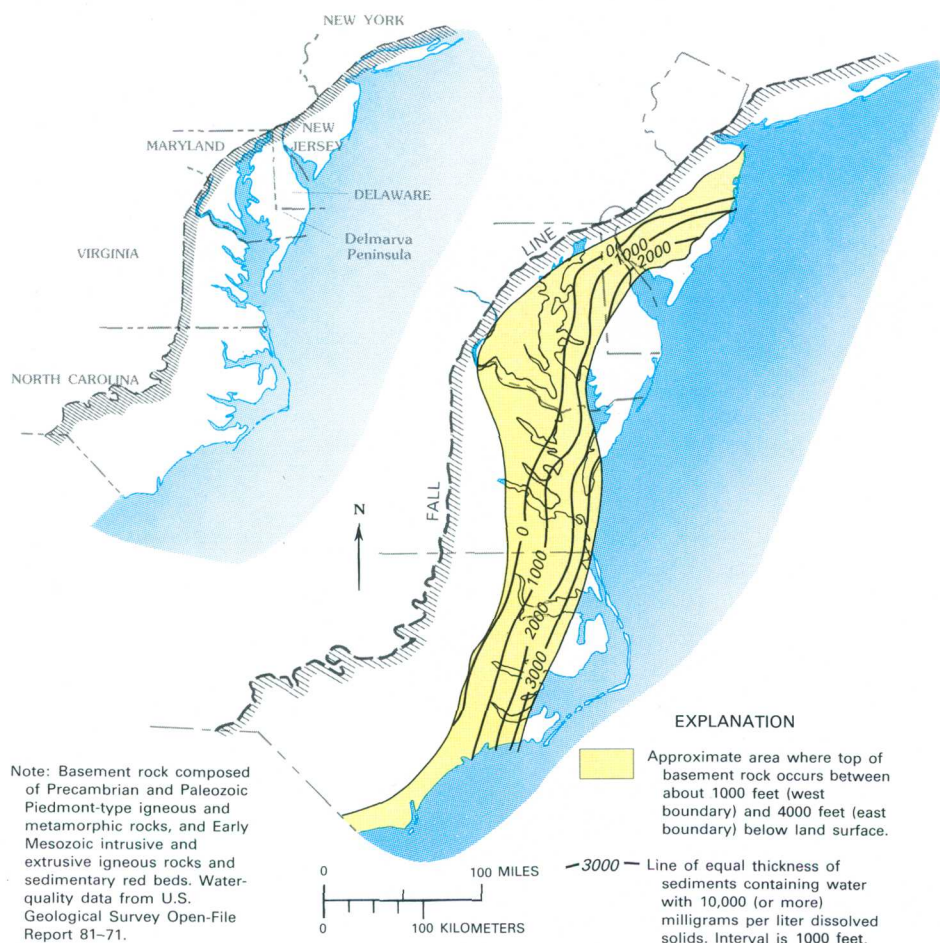


Figure 6. Approximate thickness of sediments containing saline water in the Northern Atlantic Coastal Plain.

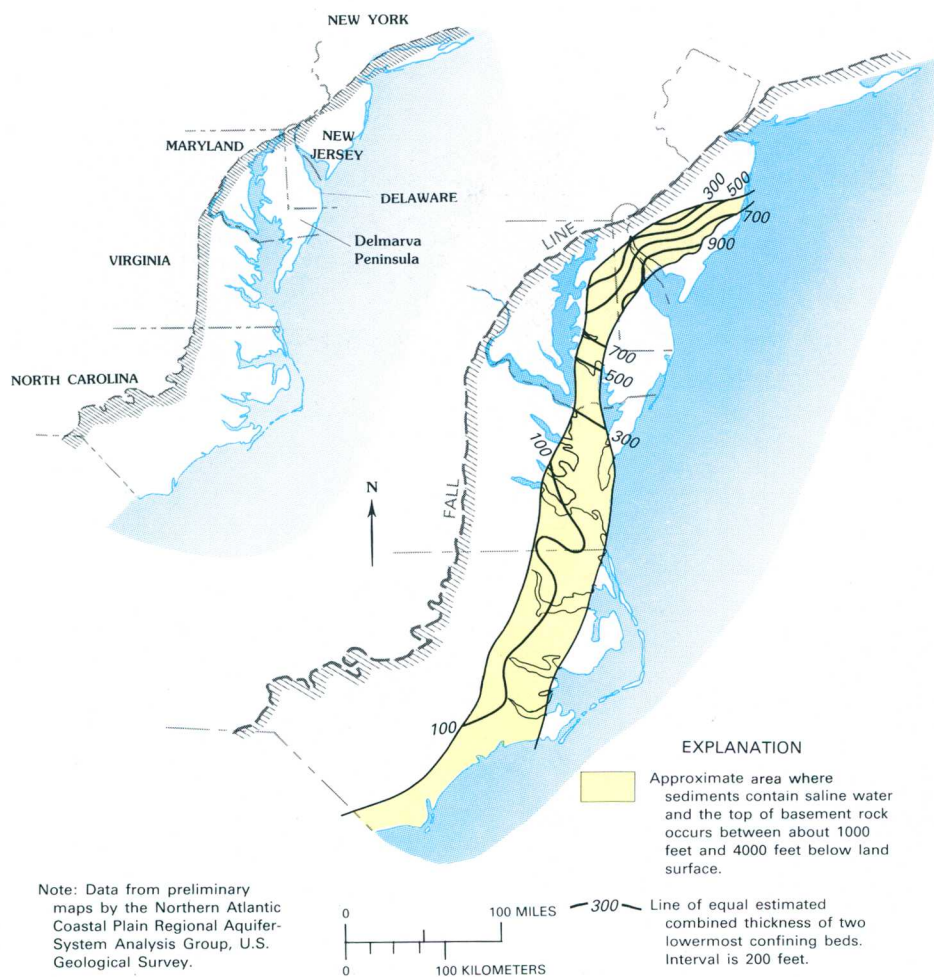
sibility, the combined estimated thickness of the two lowermost confining beds was used as an indicator of relative confining potential. The thickness ranges from more than 900 feet in parts of New Jersey and Delaware to less than 100 feet in parts of Virginia and North Carolina. The average is about 100 feet in the southern part of the area and about 500 feet in the north (fig. 7).

Permeability of Aquifers.—Because of the inferred discontinuous and lenticular nature of the confining beds, ground-water movement in the two lowermost aquifers likely could be involved in the migration of radionuclides. Ground-water movement also is directly proportional to hydraulic conductivity of and the hydraulic gradient within the aquifers, but, because these data are insufficient for the lowermost aquifers in the downdip saline-water-bearing parts of the section, the potential migration rate is assumed to be directly propor-

tional to the estimated relative permeability of the aquifer material. In general, the sedimentary material comprising the lowermost aquifers becomes finer grained and less permeable to the east, away from the source of the material. Thus, the potential migration rate through the aquifer material is estimated to be lowest in the eastern parts of the area where both the depth and the saline-water criteria are met. In addition to association with low flow rates, low permeability values may be associated with large clay content and sorptive properties.

Direction of Lateral Ground-Water Flow.—Cones of depression that have developed around centers of fresh ground-water withdrawal from the lower aquifers of the Coastal Plain have spread to areas where these aquifers are saturated with saline water. Water is estimated to have moved and may still be moving very slowly from parts of the saline-water zone westward toward centers of

Figure 7. Approximate combined thickness of the two lowermost confining beds in the Northern Atlantic Coastal Plain.



pumping. This movement is most likely where the large and increasing withdrawals have caused pressure levels in the two lowermost aquifers to decline significantly and continually, at or near the saline-water front. Published and unpublished water-level and water-use data, compiled by the Northern Atlantic Coastal Plain Regional Aquifer-System Analysis Group, suggest that these pressure conditions may exist along 50 percent or more of the saline-water front in the area (fig. 8). At present, the largest areas that are estimated to be relatively unaffected by ground-water withdrawals are located in the west-central part of the Delmarva Peninsula and in southeastern North Carolina (fig. 8). This pattern could change if the amount or distribution of the withdrawals changes. The lateral ground-water flow conditions are assumed to be least favorable to the application of the buried-crystalline-rock concept in the areas where movement is toward major centers of ground-water withdrawal.

Summary

A preliminary evaluation of available data suggests that parts of the Northern Atlantic Coastal Plain might be technically worthy of further investigation for the disposal of high-level radioactive waste in crystalline rock buried beneath the Coastal Plain sediments. The areas of major interest occur where the top of the basement rock lies between about 1,000 and 4,000 feet below land surface, the lowermost aquifers above the basement rocks contain saline water and have low permeability, confining material overlies the saline-water aquifers, and where centers of ground-water withdrawal have little or no effect on ground-water flow in the lowermost saline-water aquifers. When viewed collectively, the data suggest that eastern parts of the area of interest meet most of the proposed criteria. Further investigation will be needed to better define the geology and hydrology of the area and to test these preliminary findings.



Figure 8. *Approximate direction of lateral ground-water flow at the saline-water front induced by withdrawals from the lower aquifers of the Northern Atlantic Coastal Plain.*

Water Research Institutes and Project Grants Programs

By Frank T. Carlson and Francis H. Coley

The Water Resources Research Act of 1984 (Public Law 98-242) directs the Secretary of the Interior to administer programs of grants and contracts for research, technology development, and information transfer that will aid the Nation and the States in solving important water resources and related land-use problems. Responsibility of the administration of these programs has been delegated to the Director, U.S. Geological Survey.

State Water Institute Program

Equal grants to each of 54 Institutes at colleges and universities in the 50 States, the District of Columbia, Guam, Puerto Rico, and the U.S. Virgin Islands provide partial funding for research, information transfer, training, and management of programs that aid in the solution of critical State water problems. The Institutes are organized in eight regional associations for identification of common problems and coordination of research.

Institutes have the responsibility to set priorities, to solicit and select proposals from colleges and universities in the State, to manage programs accepted by the Survey, and to inform the public about the results of research funded by the Institutes. Training is accomplished principally by involving students in the projects.

Research into the deterioration of water quality focuses on sources, transport mechanisms, transformation and fate of contaminants, methods to improve quality or prevent further degradation, and effects of contaminants on the environment. Eighty-eight percent of the Institute research funds spent in the Northeastern United States, 59 percent in the Southeastern States, and 36 percent for the remainder of the country are for studies of water-quality deterioration.

Basic research on water resources in projects dispersed throughout the country consists principally of understanding the mechanics of water movement and of the relation of rainfall to runoff.

Land-use and water-management research is on methods of increasing efficiency in irrigation technology, artificial recharge, and conjunctive use of surface and ground water as a means of saving or augmenting existing supplies.

There are 261 individual projects in the total program, including in-situ biological treatment of ground water (Alabama), behavior of salts in irrigated clay soils (Arkansas), integration of quality- and quantity-control techniques in stormwater management (Florida), methods of rapid detection for the presence of human intestinal disease-producing viruses in Hawaii's water resources, transport of chlorinated hydrocarbons in cohesive deposits (Louisiana), dose-to-response relation for acid-sensitive lakes (Minnesota), modeling of the movement of manmade radionuclides (South Carolina), immobilization of hazardous heavy metals in ground water (Utah), and refined simulation of the movement of water and pollutants in the partially saturated zone (Washington).

Water-information transfer in Institute programs is accomplished through newsletters, articles in professional journals, technical bulletins, popular articles, specialized training courses, and public forums on principal State water issues. For example, the Nebraska Institute convenes annual conferences for farmers on the latest developments in irrigation technology. In Michigan, the Institute regularly convenes conferences on lake and pond management. The Pennsylvania Institute is one of a few to employ a full-time water-information-transfer specialist. *Water News*, published by the Virginia Water Resources Center, provides monthly coverage of the principal water issues in the Commonwealth.

Water Research Grants Program

Under Section 105 of the act, the Secretary is authorized to make grants, on a dollar-for-dollar matching basis, to qualified educational institutions, foundations, private firms, individuals, or agencies of local or State governments for research on any aspect of a water-resources-related issue deemed to be in the national interest. The broad scope of the activity provides for the continuation of the research programs administered previously by the former Offices of Saline Water, Water Resources Research, and Water Research and Technology.

Proposals for the 1985 grant program were solicited by Announcement Number 105, dated January 15, 1985. In the announcement, the research priorities listed were:

1. Aspects of the hydrologic cycle;
2. Supply and demand for water;
3. Demineralization of saline and other impaired waters;
4. Conservation and best use of available supplies of water and methods of increasing such supplies;

5. Water reuse;
6. Depletion and degradation of ground-water supplies;
7. Improvements in the productivity of water when used for agricultural, municipal, or commercial purposes; and
8. The economic, legal, engineering, social, recreational, biological, geographic, ecological, and other aspects of water problems.

In addition, the following particular areas of interest were named and described:

1. Better utilization of existing water supplies;
2. Management techniques for future water demand and supply;
3. Contamination of ground-water and surface-water supplies; and
4. Geologic controls on the hydrologic cycle.

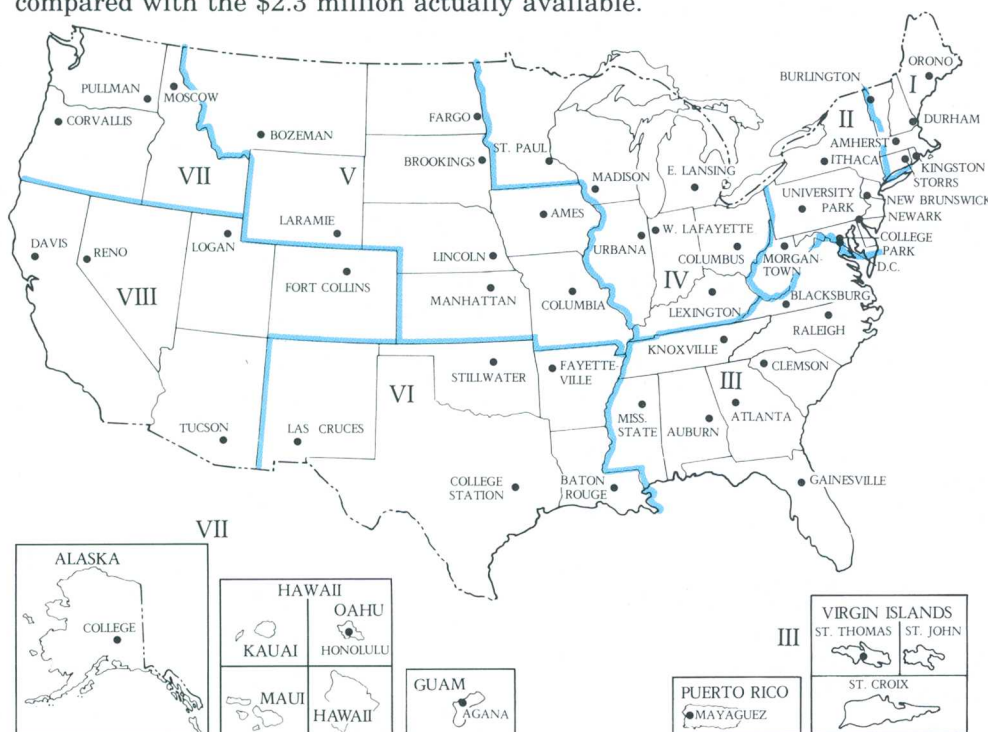
When the announcement was issued, over 5,000 copies were mailed to State Water Research Institutes, universities, subdivisions of State and local governments, private institutions and companies, and individuals known to have an interest in water-resources research. By the closing date of April 15, 1985, 368 proposals had been received. These applications requested over \$33 million in Federal funds compared with the \$2.3 million actually available.

A process of peer review was used for the initial screening of the proposals. Through a contractual arrangement with the Universities Council on Water Resources, each proposal was reviewed by at least three recognized specialists in that field of investigation.

At the same time, the proposals also were submitted for review by experts in Federal agencies having active interests in the appropriate discipline. The combined reviews from these sources were then used to select the 45 proposals with the highest ratings.

The final step in the review procedure combined Federal and non-Federal experts into panels for the purpose of ranking the final 45 applications in order of merit. From this number, the highest-ranking proposals were then submitted to procurement personnel for negotiation of appropriate grant agreements to obligate appropriated funds.

Institute and national project grants together provide for supplementary research within the Federal Government on the important water resources issues of the Nation. In administering these two programs, the Geological Survey works closely with other Federal agencies, the States, and the private sector to reduce unnecessary duplication of research and to ensure that information produced from these programs is provided to all who are interested in the water resources of the Nation.



- | | | | |
|--------------------|---------------------------|--------------------|------------------------|
| I New England | III South Atlantic - Gulf | V Missouri River | VII Pacific Northwest |
| II Middle Atlantic | IV Great Lakes | VI Southern Plains | VIII Pacific Southwest |

Locations and regional associations of State Water Research Institutes.



National Mapping Program

Mission

The Geological Survey, through the National Mapping Division's National Mapping Program, provides graphic and digital cartographic and geographic products and information for the United States, territories, and U.S. possessions. The products include several series of topographic maps in both graphic and digital form, photoimage maps, land use and land cover maps and associated data, geographic names information, geodetic control data, and remotely sensed data.

The products originate from four regional mapping centers and the Earth Resources Observation Systems Data Center. The Division's Printing and Distribution Center prints, stores, and distributes all Geological Survey maps and related texts. The Division also operates Public Inquiries Offices and National Cartographic Information Centers that, along with the Earth Resources Observation Systems Data Center, provide information about and fill orders for cartographic, geographic, earth science, and remotely sensed data.

Major Programs and Activities

In support of the National Mapping Program, Division efforts are concentrated on the following major activities:

- Primary mapping and revision, which include the production and revision of 7.5-minute, 1:24,000-scale topographic maps in the conterminous United States and Hawaii and 15-minute, 1:63,360-scale topographic maps in Alaska. A few maps are prepared at 1:25,000 scale. During fiscal year 1985, about 1,350 revised and 1,500 new primary quadrangle maps were published, mostly in the 7.5-minute series. Published topographic maps are available for about 86 percent of Alaska and for 90 percent of the other 49-State area (figs. 1 and 2). Twenty-four States have complete 7.5-minute series map coverage.
- Intermediate-scale, small-scale, and special mapping, which include the preparation of maps and map products from the intermediate-scale (1:50,000 and 1:100,000) series to the small-scale (1:250,000) series and other smaller scale U.S. base maps. Complete topographic coverage of the United States is available at 1:250,000 scale. More than 85 percent of the conterminous United States is mapped in one or more of the intermediate-scale series, which include 1:50,000-scale topographic quadrangle maps, 1:50,000- or 1:100,000-scale topographic or planimetric county maps, and 1:100,000-scale topographic or planimetric maps (fig. 3). More than 170 topographic-

*National Mapping Division
cartographer reads data off
leveling staff and records it
into calculator during precise
leveling operation.*

- Digital cartography, which includes the production of base categories of cartographic data at standard scales, accuracies, and formats suitable for computer-based analysis. The categories include the Public Land Survey System, boundary, hydrography, transportation, and elevation data at

- Information and data services, which include the acquisition and dissemination of information

Primary Maps

Yellow	40-59%
Orange	60-89%
Dark Orange	90-99%
Red	100%

15-Min Maps

Diagonal lines (top-left to bottom-right)	1-19%
Diagonal lines (bottom-left to top-right)	20-39%
Vertical lines	40-59%

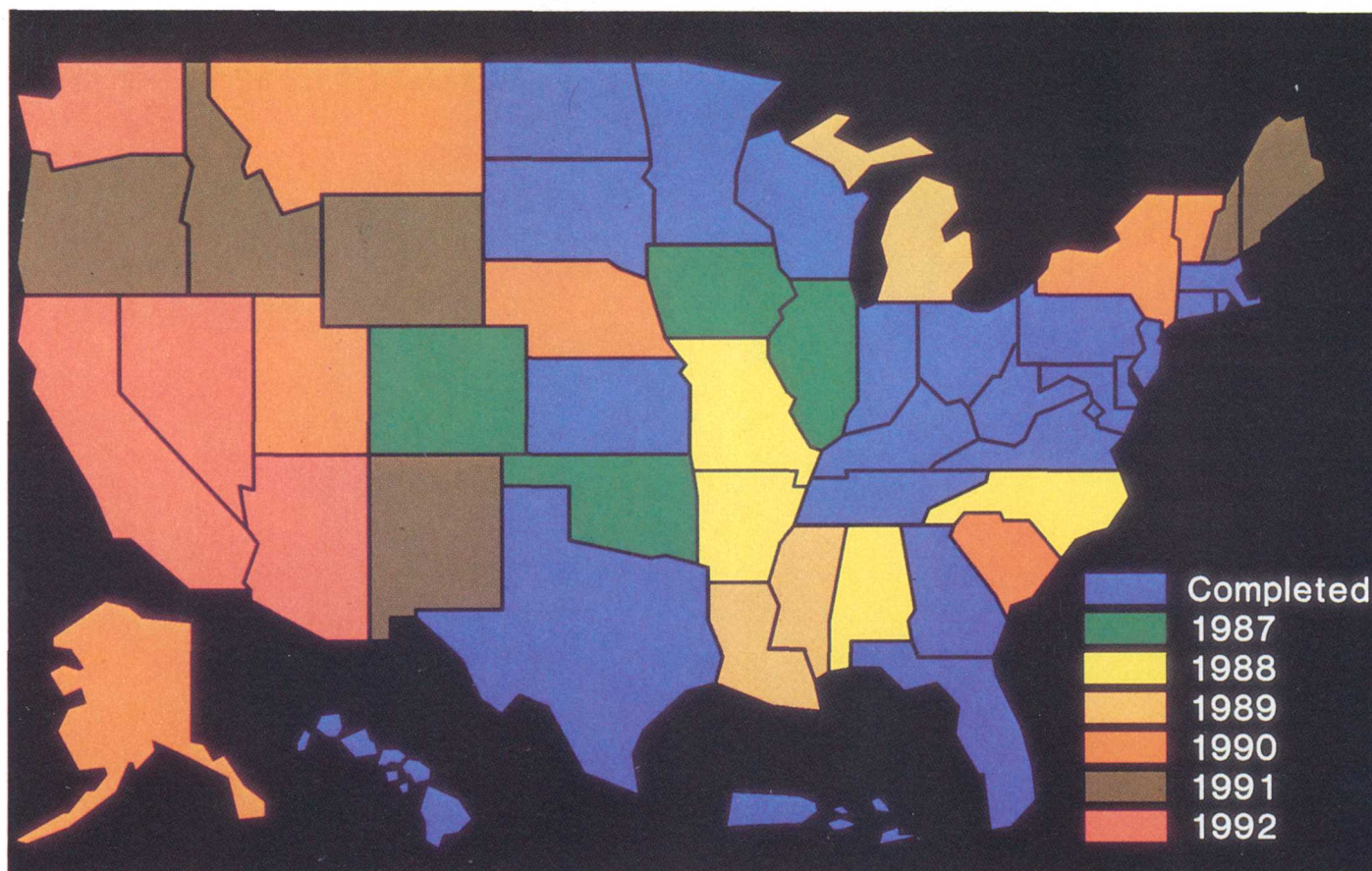


Figure 2. Map showing estimated completion dates of primary quadrangle mapping.

about U.S. maps, charts, aerial and space photographs and images, geodetic control, cartographic and geographic digital data, and other related information; distribution of earth science information to the public; and sale of maps and map-related products directly and through over 2,900 commercial dealers.

- Cartographic and geographic research and development to improve the quality of standard products, to provide new products that make maps and map-related information more useful to users, to reduce costs and increase productivity of mapping activities, to acquire innovative and more useful equipment, and to design and develop techniques and systems to advance the mapping of high-priority areas of the country.
- International activities, which include the coordination of Division participation in international cartographic, geographic, surveying, remote sensing, and other map-related activities.

Budget and Personnel

For fiscal year 1985, funding for the National Mapping Division totaled approximately \$115 million. Funding sources included direct congressional appropriations, funds transferred from other Federal agencies, joint funding agreements through the Federal-State Cooperative Program, and funds received from the sale of published maps and other cartographic products to non-Federal customers.

The permanent full-time personnel strength of the Division at the end of fiscal year 1985 was 1,875, representing a workforce skilled in cartography, geography, computer science, engineering, physical science, photographic and remote sensing technology, and information dissemination.

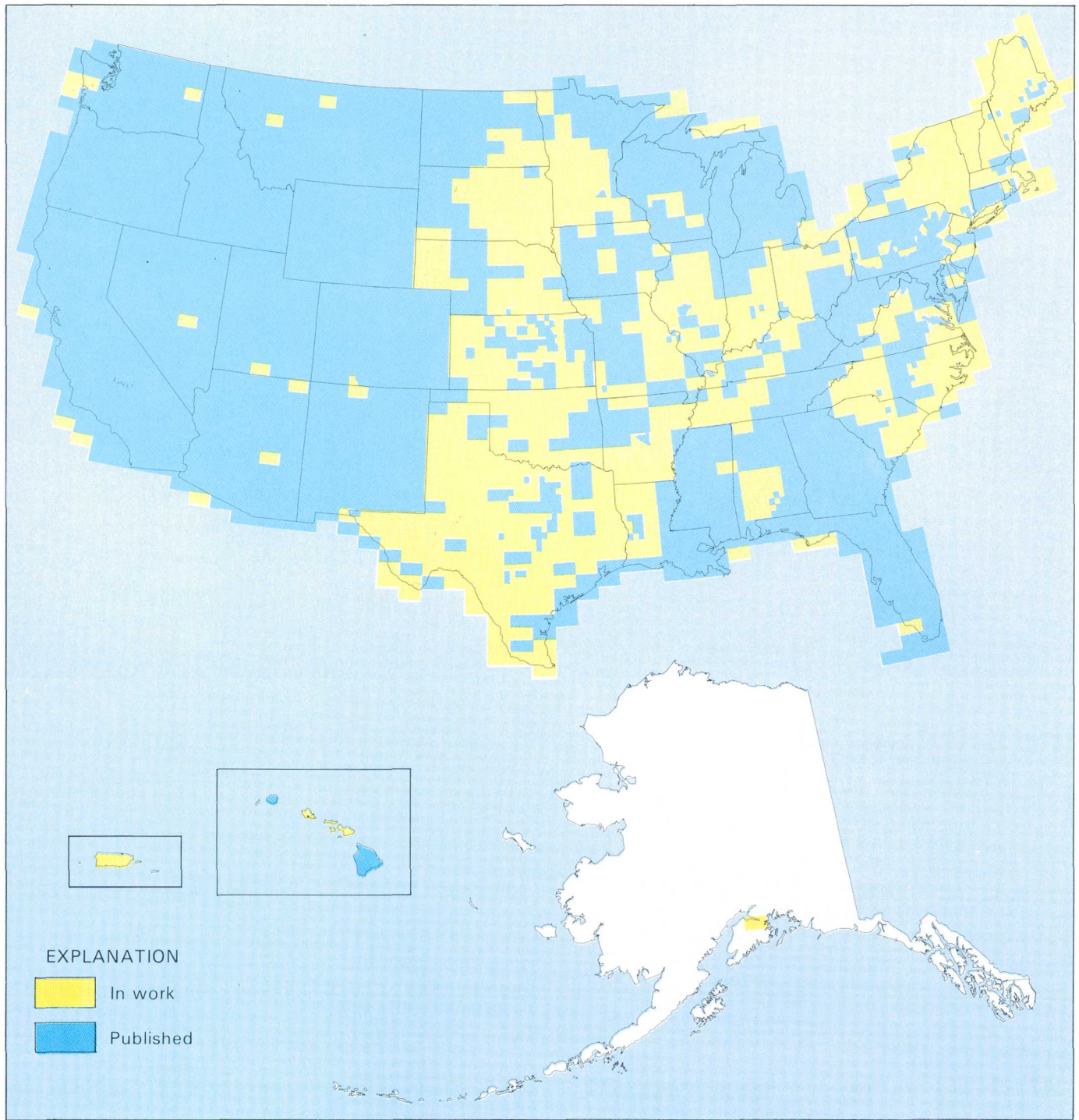


Figure 3. *Status of intermediate-scale mapping program.*

Highlights

In the following sections, highlights of some of the major activities are described.

Primary Mapping Transition

The Geological Survey, through the National Mapping Program, is responsible for meeting mapping needs of government organizations, industry, and the public. The Geological Survey must produce and maintain both graphic and digital cartographic data that are highly accurate, complete, and current to meet these nationwide requirements. As total map coverage of the United States nears completion in the 7.5-minute, or primary, map series (15-minute in Alaska), major emphasis of the primary mapping activity will shift from initial, first-time mapping to revision mapping. In addition to revision, the mapping activity will also support the further development of the National Digital Cartographic Data Base to respond to those users who are now relying on digital cartographic and thematic data, automated data handling techniques, and geographic information systems for land resource applications.

User needs for accurate, current map and digital cartographic data, coupled with the development of automated cartographic capabilities, are major considerations to be addressed during the transition. The Geological Survey incorporates National Map Accuracy Standards into graphic map products and has, in accordance with responsibilities mandated by the Office of Management and Budget, developed standards of accuracy for digital cartographic data that mirror the accuracy of the graphic maps. The Geological Survey is also incorporating geodetic adjustments to the primary map series associated with the 1983 adjustment of the North American Datum. Map and digital cartographic data users depend on adherence to such standards as a measure of the accuracy and acceptability of these products.

High-Altitude Photography

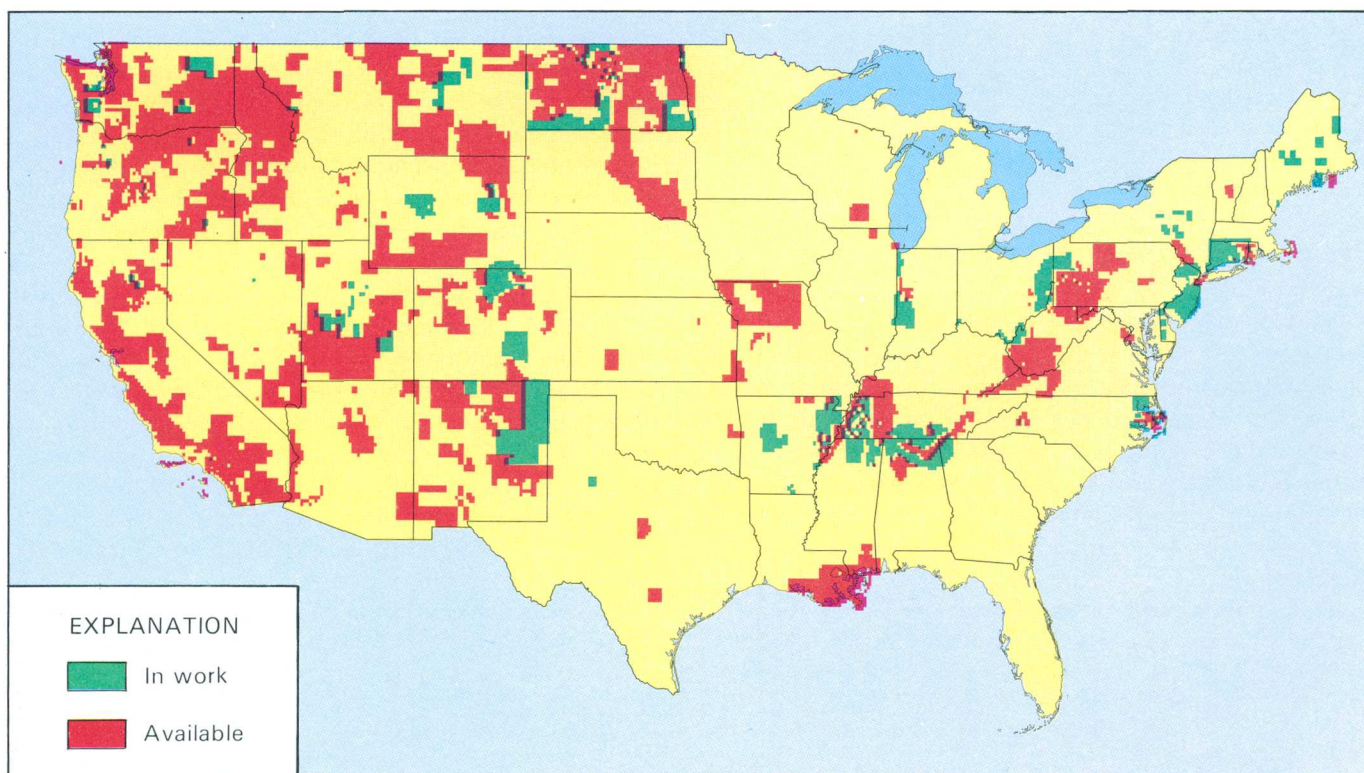
The National High-Altitude Photography (NHAP) Program was established in fiscal year 1980 by Federal bureaus and offices to acquire 1:80,000-scale black-and-white and 1:58,000-scale color-infrared photographs of the conterminous United States during the dormant (leaf-off) season for vegetation. The initial effort (NHAP-I) is approximately 86 percent complete, with photographs available for about 2,600,000 square miles.

The second major effort (NHAP-II), begun in fiscal year 1985 by participating Federal bureaus and offices, has two principal changes: acquisition of photographs during the growing (leaf-on) season rather than the dormant season and contracting of entire State areas in a specific year instead of contracting by $1^{\circ} \times 1^{\circ}$ areas. Camera and photograph specifications remain the same as NHAP-I. In fiscal year 1985, contracts were awarded for photographs over the States of Alabama, Kansas, Mississippi, and Tennessee. The primary goal of the NHAP Program is to provide photographic source material for multiple uses at the least cost to the Federal government. NHAP-I (leaf-off, dormant season) photographs are primarily for cartographic, hydrographic, geologic, soils, and other earth science applications. NHAP-II (leaf-on, growing season) photographs are primarily for forest, crop, and other vegetative resource-management applications.

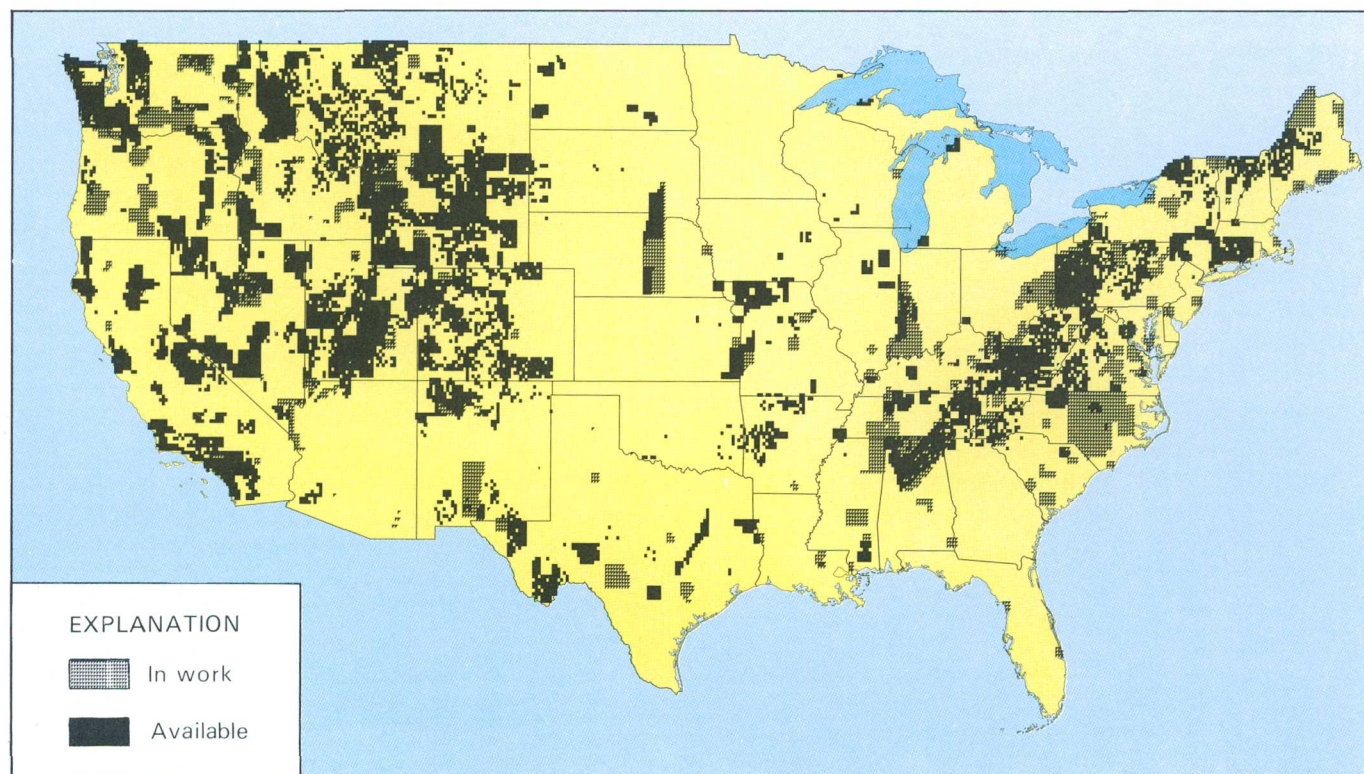
Digital Cartography

Map data in digital form are being applied to diverse and complex problems in the earth sciences. An important catalyst to the growth of digital cartographic data applications is the development of geographic information systems. These systems can sort rapidly through large amounts of digital data on multiple land and resource topics. Maps depicting the results of the analysis can be prepared quickly and more accurately than conventional methods by using automated procedures.

To meet the demand for standardized digital cartographic data, the Geological Survey is digitizing base categories of information from its topographic maps and making these data available from the National Digital Cartographic Data Base in two forms: digital line graphs and digital elevation models (fig. 4). Digital line graphs are digital files consisting of planimetric (line map) information. Currently, the following categories of digital line graphs are being collected from 1:24,000-scale maps: the Public Land Survey System, boundaries, hydrography, transportation, and a limited amount of topographic relief. Digital elevation models are digitized elevations horizontally spaced at 30-meter intervals throughout a 7.5-minute quadrangle. The Public Land Survey System, hydrography, boundaries, and transportation features also are being digitized from 1:100,000-scale maps. Boundary, hydrography, and transportation features from the 1:2,000,000-scale sectional maps of the National Atlas of the United States of America are available in digital form for the entire United



A.



B.

Figure 4. Digital cartography. A, Status of digital line graph production. B, Status of digital elevation model production. Limited digital cartographic data are available or are authorized for production in the Anchorage area, Alaska, and on the islands of Hawaii and Oahu, Hawaii.

States. The data base also includes elevation data from the 1:250,000-scale map series and land use, land cover, and geographic names information.

In a related area of activity, the Geological Survey has been delegated the lead role in implementing the Office of Management and Budget objective of fostering better coordination of all Federal digital cartography programs. In that role, the Geological Survey chairs the Federal Interagency Coordinating Committee on Digital Cartography. The Geological Survey also coordinates digital cartographic data programs and activities within the Department of the Interior by chairing the Interior Digital Cartography Coordinating Committee. The Geological Survey continues to identify and respond to Federal digital cartography data requirements, to provide a means for development of data standards, to serve as a forum for exchange of information on digital technology and methods, and to facilitate private sector use of the data.

Image Mapping

The term image map describes a number of specialized map products derived from special sources, such as satellite sensors, radar, sonar, or advanced photographic systems. The Geological Survey is developing these various products in response to a recognized need for special map supplements, alternatives to standard maps, or coverage of unmapped areas. The two most common types of image maps are those prepared from Landsat imagery and the orthophotoquad series prepared from aerial photographs.

Image mapping in the form of orthophotoquads provides relatively low-cost products prepared with considerable cost and time savings as compared to line maps. For areas of the conterminous United States not mapped at 1:24,000 scale, black-and-white orthophotoquads serve as interim maps. For areas having 7.5-minute coverage, orthophotoquads serve as map supplements and may show recent cultural changes and land use and land cover information not shown on topographic maps. These products have also proven to be a valuable tool in field mapping of thematic data such as soils information. During fiscal year 1985, the Geological Survey prepared about 1,500 7.5-minute black-and-white orthophotoquads. Orthophotoquads are now available for about 66 percent of the conterminous United States. In addition, 12 experimental 7.5-minute color-infrared orthophotoquads at 1:24,000 scale are being prepared for two areas of the Chesapeake Bay, Maryland.

In Alaska, 15-minute black-and-white orthophotoquads are being prepared at 1:63,360 scale in cooperation with the Bureau of Land Management and the State of Alaska. In fiscal year 1985, about 250 quadrangles were produced. Orthophotoquads are now available for about 21 percent of Alaska. Coverage of the remaining portions of the State is anticipated over the next decade.

In cooperation with the U.S. Forest Service and the California Office of Emergency Services, the Geological Survey has been producing a standard set of maps and orthophotoquads to meet emergency response needs and a computer data base to support planning for potential fires. This effort is part of the FIREScope (Firefighting Resources of Southern California Organized for Potential Emergencies) project, which assists in responding to wildfires in nine southern California counties. The Geological Survey has produced orthophotoquads, line map separates, and digital elevation model data for this project. The FIREScope products have also been used for search and rescue efforts.

The Survey, in cooperation with the U.S. Customs Service and the International Boundary and Water Commission, is preparing image maps of the international boundary between the United States and Mexico. Currently, 48 of the projected 203 photoimage maps in simulated natural color at 1:25,000 scale have been published.

One of the key challenges in producing maps from Landsat multispectral data is to select band combinations and processing techniques that provide the most information. In studying this issue, the Geological Survey used enhancement procedures to improve the detectability of terrain features and patterns and statistical analysis procedures to determine the amount and distribution of information contained in multispectral data. The Survey now plans to prepare about 25 Landsat image maps annually in fiscal years 1985 and 1986 to meet the emerging needs for this product. New Landsat multispectral scanner image maps are in progress for areas of Alaska, California, Colorado, Nevada, and Virginia, and thematic mapper image maps for areas of Kansas and Nevada. Additional image maps are being considered for areas of New Mexico and Utah.

The Survey continues to acquire side-looking airborne radar (SLAR) imagery for use in geoscience mapping. Since 1980, the Survey has acquired SLAR data for approximately 700,000 square miles of selected portions of the conterminous United States and Alaska. Radar is a sensor, and consequently provides its own source of illumination. Thus SLAR is particularly valuable for obtaining imagery in poor weather or in low light conditions, and it has permit-

ted the preparation of image base maps of normally cloud-covered areas where conventional aerial photographs are very difficult to acquire. Clear imagery of the Aleutian Island arc in Alaska was obtained through the use of SLAR, and this imagery was used to prepare twelve 1:250,000-scale radar image mosaics of the Aleutian Islands. The image mosaics were printed by screenless lithographic methods and are available with or without updated topographic maps on the reverse side. Other data available include thirty-eight 1:250,000-scale $1^{\circ} \times 2^{\circ}$ radar image mosaics of the Appalachian region from Alabama to Maine, as well as other selected areas.

During fiscal year 1984, sonar image data were collected for the west coast offshore area including the Exclusive Economic Zone of California, Oregon, and Washington. The Exclusive Economic Zone is a region that extends seaward 200 nautical miles from the coast and brings within the national domain over 3 million square nautical miles of submarine lands. In fiscal year 1985, sonar coverage was acquired for most of the Gulf of Mexico and the extreme southern portion of the U.S. Atlantic coast. The data will be used to generate $2^{\circ} \times 2^{\circ}$ sheet mosaics at 1:500,000 scale.

The Large Format Camera on Space Shuttle Mission STS-41G

On October 5, 1984, the Large Format Camera was launched on Space Shuttle Mission STS-41G. The camera was designed to provide coverage suitable for topographic mapping at 1:50,000 scale and for geologic and other types of earth science interpretation. Camera operations were started on the second revolution after the Shuttle had attained an orbit of 57° inclination. Performing flawlessly, the camera acquired reasonably good coverage over the United States and Canada. Coverage over western Europe was considerably less than had been planned, and much of it had heavy cloud cover. Several useful passes were obtained over Latin America, Africa, and India, and some spectacular photographs were acquired over the Himalayas, China, and Nepal. Good coverage was obtained over Australia and some of the Pacific islands.

From the lowest altitude of 225 km, a single frame covers a ground area of 170 by 340 km. Such an area covers the equivalent of about 12 standard topographic quadrangles at 1:100,000 scale, about 100 standard quadrangles at 1:50,000 scale, and about 400 standard quadrangles at 1:25,000 scale. The best ground resolution is about 6 meters per line pair on

the black-and-white film. That is, the smallest object that can be distinguished from its surroundings would measure about 6 meters on the ground. For the color-infrared film, the smallest object that can be distinguished is about 20 meters on the ground.

After the National Aeronautics and Space Administration evaluated the film, they transferred it to the Geological Survey's Earth Resources Observation Systems Data Center in Sioux Falls, S. Dak. About 50 investigators from different countries have ordered Large Format Camera photographs from the Data Center. Some of the investigations currently underway include the following:

- Determination of ground resolution of the various film types on the original, the master copy, and the copy delivered to users;
- Analytical block triangulation to establish supplementary control points;
- Preparation of image base maps at scales of 1:100,000, 1:50,000, and possibly 1:25,000;
- Topographic and planimetric map compilation at the same scales;
- Preparation of annotated orthophotomaps at the same scales; and
- Digitization of sections of the high-resolution black-and-white photographs for combination with Landsat thematic mapper data to produce high-resolution color-infrared image products.

The Large Format Camera represents the highest ground resolution sensor yet operated by the National Aeronautics and Space Administration. This feature, plus the high geometric integrity and excellent stereoscopic overlap of the photography (figs. 5 and 6), makes the camera particularly suitable for standard cartographic purposes. The investigations currently underway by the Geological Survey and other organizations will determine the best applications of Large Format Camera photographs for solving earth science problems. Several potential uses of the photographs are (1) preparation of orthophoto and planimetric base maps for management of natural resources, (2) revision of shorelines, ports, and harbors on nautical charts, (3) measurement of stream widths and floodplain delineations, and (4) monitoring environmental reconstruction.

The 1:100,000-Scale Data Base

In late 1981, the Geological Survey and the Bureau of the Census formed an interagency task force to review current and projected requirements of both agencies for cartographic and geographic products.

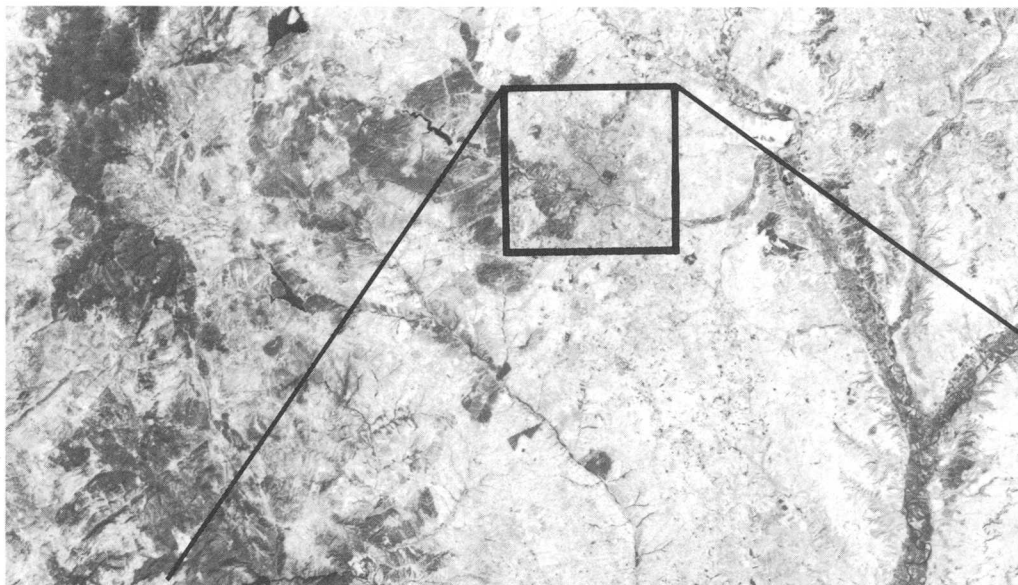


Figure 5. A portion of a full-frame Large Format Camera photograph over central Spain. The area outlined is the city of Madrid.



Figure 6. An 8× enlargement of the outlined area in figure 5 (Madrid), which shows the exceptional ground detail in the photograph.

This review consisted of a series of research projects that addressed (1) the application of modern technology to the production of new and updated maps and related graphics and (2) the digital products needed to support both the National Mapping Program and the 1990 Decennial Census of Population and Housing. As a result, the need for an intermediate-scale (1:100,000) digital cartographic data base was identified.

In early 1983, a cooperative pilot project was begun to collect and process the transportation data (roads, railroads, powerlines, pipelines) and hydrographic data (streams, rivers, water bodies) shown on the forty-eight 1:100,000-scale maps that cover the State of Florida. This project enabled the Geological Survey to develop and test new production procedures and to incorporate the Scitex scanning and editing equipment into a production system.

The success of this project led to the commitment of both agencies to the completion of a national 1:100,000-scale digital cartographic data base by mid-fiscal year 1987. To meet the deadline, both agencies have begun complementary high-volume 1:100,000-scale digital production systems. The Geological Survey has the responsibility for digitizing all transportation and hydrographic features and assigning feature classification codes to all data except roads; the Bureau of the Census has the responsibility for assigning feature classification codes to the road data.

Concurrent with these digital efforts, the Geological Survey is expediting the production of the 1:100,000-scale quadrangle base maps in order to have map materials available for digitizing. This series of maps has comprised primarily topographic (contour) editions since it began in fiscal year 1976. However, to ensure that base maps are available, emphasis has shifted primarily from the topographic editions to the production of planimetric bases (without contours).

A digital cartographic data base containing transportation and hydrographic features from Geological Survey 1:100,000-scale maps will exist before the end of the decade. The data base will not only enable the widespread use of geographic information systems for a host of resource-management, area-analysis, and planning activities, but it may serve as the catalyst for the widespread use of geographic information systems technology in the United States.

Information Services

Efforts in distributing Geological Survey information during fiscal year 1985 were concentrated on es-

tablishing a comprehensive public outreach program that included the addition of new information services, facility equipment and services upgrades, preparation of a new index to high-altitude aerial photographs, and sponsorship of an exhibit and special map in commemoration of the 75th anniversary of the Boy Scouts of America and their National Jamboree. In addition, a special program to encourage earth science education for students attending colleges in the Association of Historically Black Colleges and Universities was begun, educational workshops for training secondary school mathematics and science teachers took place, and a series of workshops for State and Federal highway planning departments was continued.

The National Cartographic Information Center continued to serve Federal, State, and local agencies and the general public by providing information on aerial photographs, map-related products, and digitized cartographic and earth science data on tapes through a network of 7 regional offices and 40 Federal and State affiliated offices. This past year, a special effort was made to catalog cartographic data in computer format and applications software held by other organizations. To this end, inquiries were sent to numerous potential Federal sources and State agencies. The National Cartographic Information Center also supported the development of a new browse file located at the Library of Congress that contains a full set of aerial and space image microfilm indexes.

The network of 11 Public Inquiries Offices continued to upgrade and expand office facilities in order to provide better information service and to make available at each location a greater variety of earth science products. The Offices in Anchorage, Alaska, Denver, Colo., Reston, Va., and San Francisco, Calif., completed major improvements.

The Public Inquiries Offices also improved their services by using the Earth Science Information Network to access new and expanded bibliographic and geographic data bases and by automating office procedures. New procedures were initiated for distributing custom software and for accepting orders for open-file reports of the Geological Survey, State publications, aerial photographs, imagery, and special products. During fiscal year 1985, the network responded to approximately 354,000 inquiries.

The Geological Survey produced a new two-sided multicolor index to national high-altitude photography that shows the year photography was flown (between 1980 and 1985) for both color-infrared and black-and-white aerial photography. The index will be published quarterly. In addition, eight other indexes were updated and printed. The indexes are

Status and Progress of Topographic Mapping, Land Use and Land Cover Mapping, Land Use and Land Cover Digital Data, Geological Survey/Defense Mapping Agency 1:50,000-Scale Mapping, Intermediate-Scale Mapping, County Formatted Mapping, Digital Data, and Orthophotoquad Mapping.

In cooperation with the Boy Scouts of America, the Geological Survey sponsored a major exhibit at the Scouts' 1985 National Jamboree at Fort A.P. Hill, Va. Eight Earth Science Trail Stations were set up to demonstrate activities such as tree-ring interpretation, streamflow measurement, map reading, aerial photograph interpretation, and rock and mineral identification. The Survey also prepared a special jamboree-site commemorative map of the Fort A.P. Hill area. A multicolored reproduction of an oil painting depicting various Scout activities was printed on the reverse side of the map.

The Applications Assistance Facility, located at the National Space Technology Laboratories in Bay St. Louis, Miss., continued its education operations for geographic, cartographic, and remote sensing training. A new program was initiated to assist the Association of Historically Black Colleges and Universities to develop a strong earth science curriculum. Faculty from 11 universities participated in workshops teaching microcomputer use in modern cartography and remote sensing.

As part of the same educational activity, personnel from the Applications Assistance Facility and the Mid-Continent Mapping Center conducted lectures at Jackson State University Center for Urban Affairs. The 2-week graduate-level workshop was titled "Geography for Teachers." Two laboratory sessions demonstrated microcomputer use in remote sensing techniques suitable for the secondary education level.

Personnel at the Applications Assistance Facility, working with a special education team from the National Aeronautics and Space Administration, provided instruction on digital image processing and digital cartography to teachers from seven States. The teachers were selected by the National Science Foundation, the National Council for Teachers of Mathematics, and the National Science Teachers Association to participate in the National Aeronautics and Space Administration Education Workshop for Math and Science Teachers, one of the purposes of which is to improve knowledge of current Federal technology.

The Applications Assistance Facility continued a series of workshops begun in fiscal year 1984 on modern mapping methods. Sponsored by the Federal Highway Administration, the workshops introduced attendees to digital cartography and Federal digital cartography data standards. Participants included

representatives from 7 Federal Highway Administration field regions, 36 State highway departments, and 10 major regional and urban planning commissions.

The National Gazetteer of the United States

The National Gazetteer series is being published in cooperation with the U.S. Board on Geographic Names as U.S. Geological Survey Professional Paper 1200. A separate volume is being prepared for each State and Territory. Each volume is published after two phases of compilation. Phase I, which is now complete for all States and Territories, includes the compilation of most of the 2 million named features (except roads and highways) found on the large-scale topographic maps of the Geological Survey. Phase II includes research and compilation from other Federal and State sources and historical materials.

Each gazetteer contains official, unofficial, and historical geographic names listed in alphabetical order. Variant names are cross-referenced to official or primary name listings. Each entry includes information on the type of feature, official status of the name, county in which it is located, geographic coordinates (including sources of linear features), elevation of place of feature, and the name of the topographic map on which the feature is found.

New Jersey was the first volume published in the Gazetteer series in 1982. Volumes for Delaware and Kansas have been published, and Arizona and Indiana are scheduled for publication in the near future. An abridged, concise volume containing the major populated places, physical features, and other key entries for all States is also being prepared. Currently, research and compilation of volumes for Oregon, South Dakota, North Dakota, Iowa, Florida, Idaho, Alabama, and Mississippi are underway.

Land Cover Mapping in Alaska

Geological Survey scientists are currently conducting several land cover mapping projects in Alaska. Conventional land use and land cover mapping has been scheduled for most of the 48 contiguous States, but only one quadrangle in Alaska has been mapped and no additional quadrangles have been proposed. Two special problems have led to this situation: few suitable high-altitude photographs of Alaska were available until recently, and existing classification systems were limited when used to describe Alaska's predominantly wildland environment.

However, in response to the need for land cover maps, the Geological Survey has been assisting the State of Alaska and other Federal agencies in producing digitally processed land cover classifications from Landsat multispectral scanner data for specific regional areas of interest. Land cover mapping for National Wildlife Refuges and other Federal lands in Alaska has received special attention. Over the past 5 years, cooperative projects with several Federal and State resource management agencies have produced land cover classifications for approximately 150 million acres of Alaska.

The Alaska National Interest Lands Conservation Act of 1980 required each land management agency in Alaska to provide comprehensive resource management plans. Each agency adopted its own approach, but all of the agencies based their land cover classifications on the "Revision of the Preliminary Classification System for Vegetation of Alaska," prepared by L. A. Viereck, C. T. Dyrness, and R. A. Battem for the U.S. Forest Service. Recognizing the need for an immediate statewide program of land cover mapping using a single classification system, and using the experience gained from regional land cover mapping projects, the Geological Survey proposed an interim program to coordinate individual agency efforts based on the 1:250,000-scale quadrangle series.

The classification system for the interim mapping program was derived from the ground-based Viereck classification system and the level II Geological Survey classification system for use with remotely sensed data and has been approved for use in Alaska by a subcommittee of the Committee on Natural Resource Information Management. The interpretation of the vegetation and land cover classes is to be derived from digitally processed multispectral scanner and digital elevation model data and other ancillary data.

The proposed program provides a complete interim land use and land cover classification system, including maps, registered Landsat digital data, and area summaries by land cover class. Six 1:250,000-scale maps are in preparation: Dillingham, Arctic, Fairbanks, Valdez, Mount Michaelson, and Meade River.

Soil Landscape Analysis Project

Soil surveys provide valuable information for the management of land for a variety of uses. Although National Cooperative Soil Surveys are available for nearly 1.3 billion acres, over one-third of the United States lacks a modern soil survey. A cooperative effort of the Geological Survey, the Soil Conservation

Service, and the Bureau of Land Management concerns ways in which computers and other information sources can be used to assist in making and using soil surveys (fig. 7).

Some interpretation of aerial photographs is usually required to generate a soil pre-map prior to fieldwork. During photographic interpretation, several aids, such as geologic maps and general soil maps, are used to determine the distribution of the soils. Often the pre-map lines are drawn directly on aerial photographs; at other times they are drawn on or transferred to 7.5-minute orthophotoquads. The 7.5-minute quadrangle is the base map until later stages of the survey, when all quadrangles are edge-matched and mosaicked into a single map of the survey area. This method is time consuming and provides no specific information about slope, aspect, or elevation.

The cooperative Soil Landscape Analysis project was designed to determine the utility of computer-generated slope and aspect data, and to determine how the data can best be used to increase the accuracy of soil surveys and to reduce the field time of soil scientists. In addition, a tabular data base was to be developed and evaluated for use by soil scientists in describing the smallest identifiable soil unit and in making interpretations for various uses.

The areas selected to develop and test the methods included various types of landforms on slopes ranging from level to very steep. Barren lands having little or no vegetation and 5 to 9 inches of precipitation annually were evaluated, as well as areas of dense pasture and forest cover and 25 or more inches of precipitation annually. The project was conducted over a period of 3 years in areas of Wyoming, Idaho, and Nevada. The soil maps produced with the aid of these methods conform to the standards of the National Cooperative Soil Survey.

Field evaluations showed a general accuracy of 88 to 98 percent for slope- and aspect-class maps and for the maps made with the aid of these products.

Map Projections

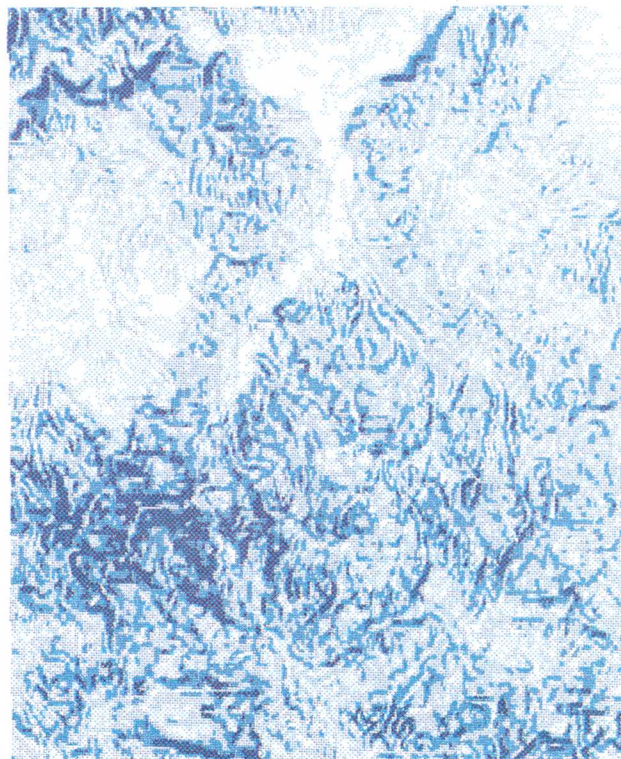
The first comprehensive map projection manual published by the Geological Survey, *Map Projections Used by the Geological Survey* (U.S. Geological Survey Bulletin 1532), was first printed in 1982. It has now entered a third printing to meet requirements for 2 or 3 years while a revised and expanded edition is being prepared. The manual was deliberately limited to projections used by the Geological Survey. However, in response to user requests for a broader



Aspect Classes

North
East
South
West

Aspect masked out
where slope < 15%



Slope Classes

0 - 5 %
6 - 15 %
16 - 30 %
31 - 50 %
51 + %

Slope calculation
by RMS method

Figure 7. Aspect and slope maps such as these are currently being tested for use in soil surveys and for the management of Federal lands. (Tumey Hills, Calif., 7.5-minute quadrangle.)

range of projections, the Geological Survey will incorporate additional projections in the next edition.

Computer-Assisted Map Projection Research (U.S. Geological Survey Bulletin 1629), the latest Geological Survey publication on map projections, describes the derivations and computer programs involved in (1) calculating polynomial coefficients for general data transfer between maps, (2) determining projection parameters for a map that has insufficient labeling, and (3) using least-squares analysis to determine optimum parameters for minimum-error maps of given regions (fig. 8). The latter program is used for several new maps currently being produced.

A new publication, tentatively titled *An Album of Map Projections*, will include computer-generated outline maps based on several dozen different map projections and brief descriptions and categorizations.

This forthcoming work will assist in selecting and understanding the range of available projections. A minimum of mathematical information will be included, and distortions will be displayed with specially prepared computer-generated maps.

EROS after Landsat Commercialization

Landsat commercialization has significantly affected the Earth Resources Observation Systems (EROS) Data Center in two respects. First, satellite land remote sensing legislation calls for continued involvement of the Data Center with Landsat and other satellite remote sensing systems. Second, the Data Center's longstanding commitment to remote

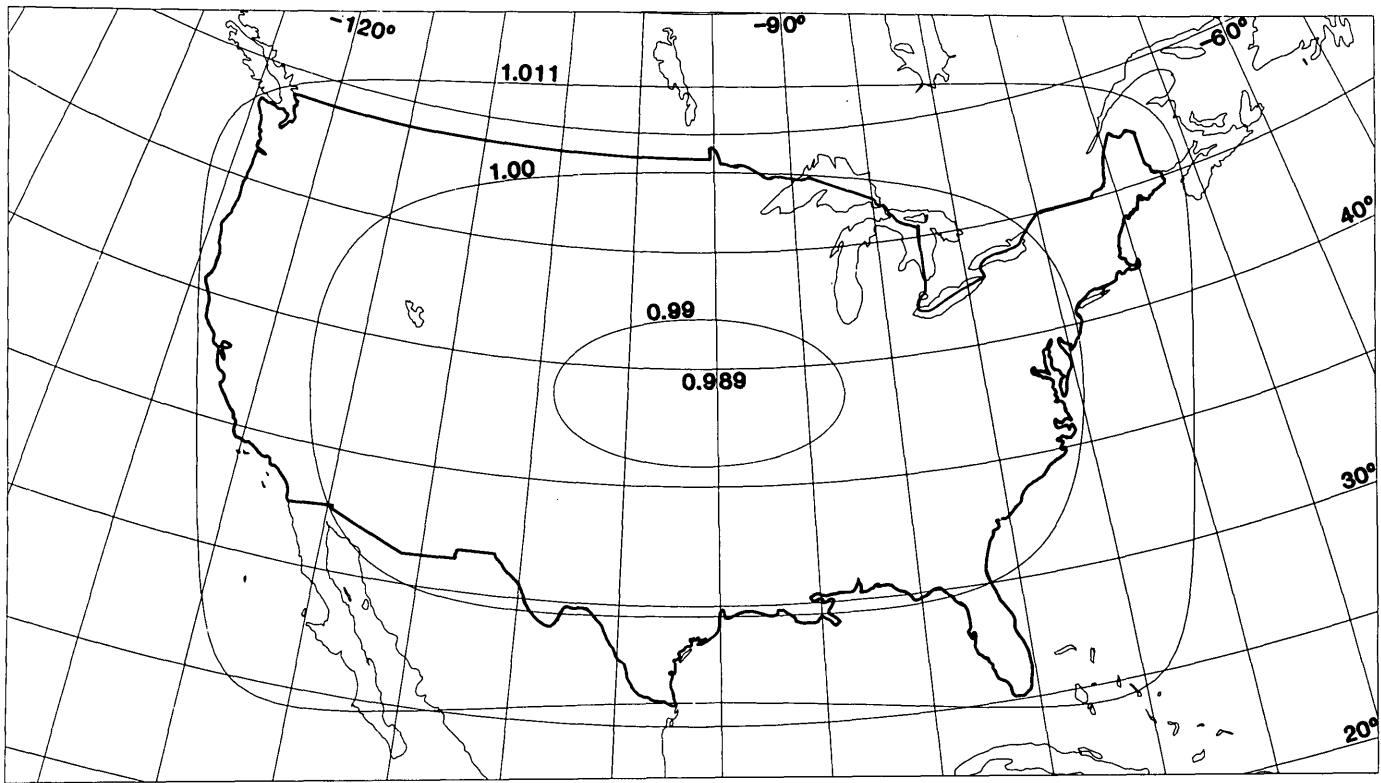


Figure 8. An outline map of the United States showing a special conformal projection in which the country is enclosed within a near-rectangle of constant scale. The enclosed region is shown with less overall error than with any other conformal map projection. The numbers represent the ratios of local scale to nominal map scale.

sensing research, development, and training will not only continue but may broaden, since the commercialization legislation calls for significant land remote sensing research, development, and technology transfer by the Department of the Interior.

The Land Remote-Sensing Commercialization Act of 1984 provides the framework for establishing a commercial U.S. land remote sensing industry. The commercialization process will take place in three phases:

- In the first phase, the Secretary of Commerce contracts with a private firm to market raw data generated by the existing Landsat systems (Landsats 1–5). The Government retains ownership of the systems, but commits to a plan of

rapid market expansion through an aggressive private marketing effort.

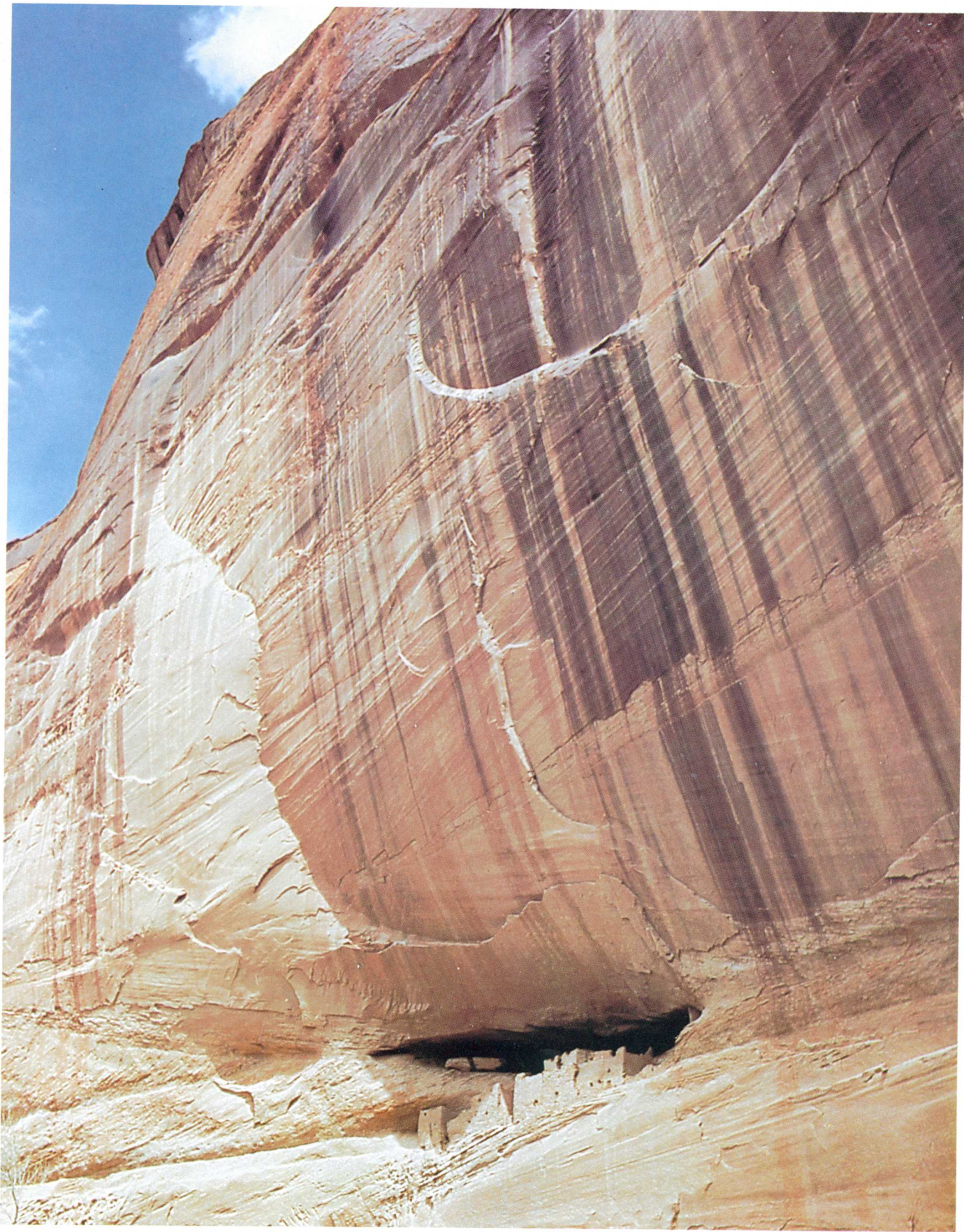
- The second phase provides for data continuity after Landsat 5 and consists of a 6-year transition from Government to commercial land remote sensing during which the Secretary contracts out for the private operation and ownership of a follow-on system. A private firm will bid for Federal support to develop this new system.
- The final phase completes the process by providing a framework for licensing of commercial land remote sensing systems. Land remote sensing will be an independent, but regulated, industry. The legislation further provides for continuation of a strong Federal research and development

program and for a Federal satellite land remote sensing data archive.

The Earth Observation Satellite (EOSAT) Company, a joint venture of RCA Astroelectronics and Hughes Aircraft Companies, signed a contract in 1985 with the Department of Commerce to carry out the first two phases of commercialization.

For the Data Center, changes will be gradual. It will be 1987 or 1988 before construction is completed on EOSAT facilities, including new Landsat data-handling headquarters in Maryland. Until EOSAT launches Landsat 6 in 1988 or 1989 or until the failure of Landsat 5, the Data Center will continue to receive, store, and process Landsats 1-5 data for the Department of Commerce's National Oceanic and Atmospheric Administration, much the same as the Data Center has done since October 1982. As the commercial operator, EOSAT will market Landsat data, operate Landsats 4 and 5, and retain all Landsat revenue.

Planning began in 1985 for a Federal satellite land remote sensing archive at the Data Center. Data will be obtained from EOSAT and from operators of future Earth observation satellites, including systems to be launched by France, Japan, India, the European Space Agency, and Canada. An increasing number of non-Landsat earth science data bases are also being housed in Data Center facilities. Among them are the National High-Altitude Photography Program of coast-to-coast, conterminous U.S. photographic coverage in black-and-white and color infrared. In all, over 6 million aerial photographs of U.S. sites reside at the Data Center. Another photoimage data base comes from the Geological Survey's Side-Looking Airborne Radar Program. The Scientific Committee for Antarctic Research Photo Base is another recent addition. Large collections of digital data are also housed at the Data Center, such as results of the National Uranium Resources Evaluation Program originally compiled by the Department of Energy.



Geologic Investigations

Mission and Outlook

During fiscal year 1985, the Geologic Division continued its programs to assess energy and mineral resources onshore and offshore, to identify and investigate geologic hazards, and to determine the Nation's geologic framework, the geologic processes that shaped it, and their relation to long-term climatic changes.

The articles in this chapter of the *Yearbook* describe some of the most significant accomplishments in the Geologic Division during fiscal year 1985. We believe that these articles, while representing only a select few of the activities of the Division, show how basic geological research simultaneously spurs new developments in the geosciences as well as provides basic information needed to conduct missions that are central to the needs of the Nation.

Major Programs

The Geologic Division program is presented to Congress under five major program headings. A discussion of accomplishments under these subactivities during this last fiscal year follows.

Geologic Hazards Surveys

The Geological Survey, working with the Oklahoma Geological Survey and Nuclear Regulatory Commission, confirmed that the Meers fault in southwestern Oklahoma has been recently active. Geologists of the three agencies have found stratigraphic evidence that movement has occurred on the fault within the last several thousand years. The fault (with the possible exception of surface disturbances in the New Madrid area) is the first geologically youthful surface break to be recognized in the Eastern or Central United States.

In California, USGS analysis of the Kettleman Hills magnitude 5.5 earthquake that occurred on August 4, 1985, 11 miles east of Coalinga, indicates that the Kettleman and Coalinga earthquake mechanisms are similar but that the fault system in the region is more complex than originally thought. Apparently, the earthquakes occurred on low-angle detachment faults (decollements) that underlie the eastern Diablo Mountains of coastal California.

More than a dozen large to great earthquakes in the Circum-Pacific region have been successfully forecast worldwide since 1965 as seismic gaps. On March 3, 1985, central Chile was shaken by a major earthquake located about 20 miles offshore, southwest of Valparaiso, Chile. This event confirmed the earthquake forecast that was made at a 1978 USGS conference by researchers at Lamont-Doherty

White House Ruins, Canyon de Chelly, Arizona. Photo-graph by Dawn Reed.

Geological Observatory (supported jointly by the USGS, the National Science Foundation, and the Department of Energy).

On April 5, 1985, the Survey announced that studies forecasting a moderate-size earthquake near Parkfield, Calif., had been officially endorsed by a State and Federal evaluation panel. Both the National Earthquake Prediction Evaluation Council and the California Earthquake Prediction Evaluation Council reviewed and accepted the forecast that an earthquake of magnitude 6 is likely to occur in the Parkfield area within the next several years (1985–1993). Observations and accounts of past Parkfield earthquakes are being used to guide construction of the earthquake prediction experiment.

Director Dallas L. Peck joined Dr. George Keyworth, Presidential Science Advisor, in opening the fourth annual meeting of the United States–People's Republic of China Science and Technology Commission. The meeting was held in Washington, D.C., to summarize the progress made in more than 15 cooperatively sponsored projects that have resulted in important findings about the fundamental characteristics of earthquakes and new insights in the mitigation of earthquake hazards.

An analysis of landslide hazards in the Cincinnati, Ohio, area was also completed in which landslide susceptibility information was integrated with economics in an innovative technique for defining landslide risk. Articles regarding the geologic hazards programs in this *Yearbook* include a discussion of 5 years of activity at Mount St. Helens, an article explaining the Cincinnati landslide analysis, and a discussion of prehistoric earthquakes near Charleston, S.C.

Land Resource Surveys

The Survey completed its first year in the implementation of the Cooperative Geologic Mapping Program, COGEOMAP, and accepted proposals for new State/USGS cooperatives in fiscal year 1986; a total of 28 States are now involved. Among the first products to be completed under COGEOMAP are geologic maps of 7 1/2-minute quadrangles in the southern Illinois basin, two surficial geologic maps in southeastern New Hampshire, a digital geophysical folio of Ohio, and digital aeroradioactivity maps of New Mexico. Further discussion of the Cooperative Geologic Mapping Program, COGEOMAP, is included in this *Yearbook*. This new program with the States is a particularly important element in our efforts to plan for systematic national geologic mapping.

In the Deep Continental Studies Program, the Survey is actively preparing for drilling at Cajon Pass in southern California and in the Creede, Colo., mineral district. Further information on this program is included in the "Perspectives" section of this volume.

Mineral Resource Surveys

Work continued toward meeting the 1990 deadline for completion of mineral resource assessments of Bureau of Land Management (BLM) land being considered for wilderness status. During 1985, a total of 4.9 million acres of BLM land was under study. Under the Alaska Mineral Resource Assessment Program, detailed and comprehensive studies began of large, high-grade zinc-lead deposits in the western Brooks Range, including the Red Dog and Lik deposits, and continued in the Ambler district, where the copper-base metal deposits are unusually rich in cobalt, a strategic commodity. In addition, a public meeting was held to describe the results of multidisciplinary studies on the Seward Peninsula, a region of Alaska that is rich in precious and base metals and tin. Under the Conterminous United States Mineral Assessment Program, the following geologic, mineral resource, and associated geochemical and geophysical maps were published: the Charlotte quadrangle, North Carolina and South Carolina; Iron River quadrangle, Michigan; Medford quadrangle, Oregon; Silver City quadrangle, New Mexico and Arizona; Richfield quadrangle, Utah; Walker Lake quadrangle, California and Nevada; and Wallace quadrangle, Montana and Idaho.

In mineral resource research, high emphasis continued on the development of exploration and assessment techniques for concealed mineral deposits. Studies of two base-metal deposits in Colorado have demonstrated that the presence and magnitude of paleothermal anomalies associated with the deposits act as vectors that indicate their locations. At Rico, a major molybdenum-porphyry deposit is located 3,700 feet beneath the surface. This deposit can be detected 2 miles away by observing thermal changes in the minerals of rocks that are not obviously altered. The deposits of Colorado's largest zinc-silver mine at Gilman can be detected from more than 1 mile away. Geobotanical and remote-sensing techniques are being developed that recognize alteration in mineralized areas associated with deposits covered by dense vegetation. Plants change their reflectance slightly when they absorb metals through their roots. These effects are notable in the thermal and infrared part of the spectrum and can be detected quickly and efficiently and will help to evaluate the resource po-

tential of areas covered by dense vegetation. Preliminary products are being published for the multidisciplinary study of the mineral potential of parts of 14 States that comprise the midcontinent region. The reports cover the nature and configuration of the buried Precambrian basement, which is the host for many strategic and critical commodities to the north, where exposed in Canada; thickness and lithofacies of the overlying Phanerozoic rocks that are hosts for the Mississippi Valley-type mineral deposits; and regional hydrologic conditions, including paleodrainage systems and concentrations of dissolved metals that may control the location of mineral deposits. Additionally, articles in this *Yearbook* address the use of geologic history as a guide to manganese exploration and geophysical detection of toxic waste.

Energy Resource Surveys

The Survey completed a summary report on coal resources in New Mexico, the first of a series of State coal reports. The overall goal is to survey important aspects of all energy commodities in each State and, ultimately, to compile a national energy summary.

Survey geologists completed studies on uranium in the San Juan Basin and developed a geologic model to explain the origin of these uranium deposits, which constitute the largest district in the United States. The extensive data bases of the uranium program have also become a major source of the information required to deal with the rapidly unfolding radon hazard issue. Much of the data will be derived from the data base that was transferred from the Department of Energy to the Geological Survey.

Further, under the Evolution of Sedimentary Basins program, a data base consisting of USGS and Oklahoma and Kansas Geological Surveys field data and wire-log data for the Anadarko Basin has been organized. Under the Oil and Gas Investigations program, an analysis of approximately 300 plays has been completed in the first phase of the Federal Land Assessment program. Geologic characterization of these plays is underway and will result in a quantitative estimate of undiscovered hydrocarbon resources on federal lands. This effort is the precursor to a new national oil and gas assessment; the offshore portion will be conducted in cooperation with the Minerals Management Service (MMS), as mandated by Congress. Additionally, an article in this *Yearbook* includes highlights of the Survey's oil and gas assessment of the Arctic National Wildlife Refuge.

In the Geothermal Investigations program, work was conducted with the National Park Service and the Department of Justice to evaluate the hydrologic connection between geothermal areas outside of Lassen Volcanic National Park, Calif., and the major geothermal system centered in fumarole areas under the park.

Offshore Geologic Surveys

The USGS conducted a survey of the Gorda Ridge off the coast of Oregon and Washington that resulted in the first discovery of a polymetallic sulfide occurrence in the Exclusive Economic Zone (EEZ). In cooperation with the British Institute of Oceanographic Sciences, the Survey also completed GLORIA sonar imaging of the Pacific coast EEZ and published an interpretive atlas of the sonographs. GLORIA sonar surveys have also been concluded in the EEZ of the Gulf of Mexico, Puerto Rico, and the Virgin Islands. The digital data base of the first map of the continental margin map series (Baltimore Canyon) was completed as the first of a series of folios that will ultimately cover the entire EEZ. New studies in shallow environments offshore from Georgia, Virginia, and New Jersey discovered the presence of large quantities of titanium-bearing sands in Pleistocene beach and barrier-island complexes now submerged under waters of the EEZ. Recent coring indicated that some of these heavy-mineral concentrations are as much as 20 feet thick and are richer than currently producing deposits onshore. Geophysical instruments that can be towed from ships in shallow water are being developed to assess these new resources. Articles describing the accomplishments of the Offshore Geologic Framework program, including the GLORIA mapping program and the results of dives using the submersible, ALVIN, are a part of this chapter.

Earthquake-Induced Sand Blows Near Charleston, South Carolina

By Stephen F. Obermeier

The strongest historic earthquake in the Southeastern United States occurred in 1886 near Charleston, S.C. The magnitude of the earthquake is estimated to have been between 6.6 and 7.1. Throughout much of the epicentral region the shaking intensity ranged from MM (Modified Mercalli) IX to X. The potential for recurrence of an 1886-sized earthquake, considering the area's 300-year history

of continuing weak seismic activity, is of major concern in estimating earthquake hazards in the Southeastern United States.

The causative mechanism of earthquakes in the Charleston area is unknown, and hypotheses concerning the fault that generated the earthquake are widely disparate, despite much geologic, geophysical, and seismic research during the past decade. Because of this uncertainty, and because the short historic record is wholly inadequate for estimating the frequency of moderate to strong earthquakes, the Geological Survey undertook a search for pre-1886 earthquake-induced liquefaction-flowage features called sand blows.

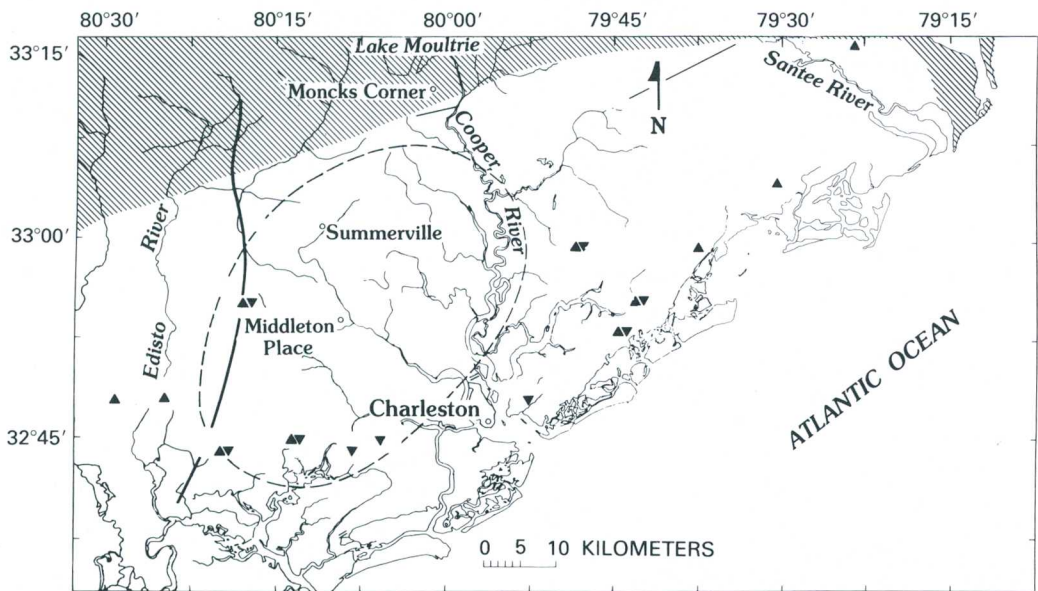
Sand blows result from the liquefaction of water-saturated sediment at shallow depth (9–45 feet) during earthquake shaking, followed by venting of the sediment and water to the surface. Figures 1 and 2 are photographs of two typical moderate- to large-sized sand blows from the 1886 earthquake.

Many pre-1886 sand blows, similar in original form to those in figures 1 and 2, were first discovered near the town of Hollywood, about 15 miles west of Charleston, by Survey scientists in 1984. That discovery prompted a further search for sand blows throughout the area near Charleston. The objective was to define epicentral regions and estimate the strengths of the pre-1886 earthquakes; the premise was that the areal extent of the sand blows caused by an earthquake is a function of the earthquake strength for a fixed liquefaction susceptibility (i.e., geologic and ground water) setting. Many widely scattered moderate- to large-sized sand blows have been discovered recently. Their locations and approximate ages (1886 or pre-1886) are shown in figure 3, which indicates that pre-1886 sand blows are more widely distributed than 1886 sand blows. All the sites in figure 3 contain several sand blows; at least three or four are exposed within a distance of several hundred feet in most places.



Figure 1. Sand-volcano crater generated by the 1886 Charleston, S.C., earthquake. (Photograph from the Charleston Museum.)

Figure 2. Typical 1886 sand-blow crater photographed near Charleston. (Photograph from the Charleston Museum.)



- Approximate boundary of strongest shaking during 1886 earthquake (MMI-X)
- Western limit of 1886 craters
- ▲ Pre-1886 sand blow
- ▼ 1886 sand blow

Figure 3. Location and approximate age of 1886 and pre-1886 sand blows in the Charleston region. Shading indicates boundary of study area.

Multiple generations of prehistoric Holocene (about 10,000 years ago) and possibly very late Pleistocene (about 2 million years ago) earthquake-induced sand blows are present at many of the newly found sites. These sand blows occur far beyond the limits of 1886 earthquake-induced sand blows, in sediments of approximately the same liquefaction susceptibility (based on geologic age and mode of deposition). The location of the seismic source zone for these prehistoric sand blows is unknown. The different distributions of prehistoric Holocene and 1886 sand blows indicate that either (1) moderate to strong earthquakes in the area had seismic source zones that varied in location through time or (2) at least one earthquake much stronger than the 1886 event has also originated from the 1886 seismic source zone. Studies in the Charleston area are continuing to provide additional information on the earthquake history of the Southeastern United States and, thus, to explain events that might occur in the future.

Five Years of Activity at Mount St. Helens

By Norman S. MacLeod

Twenty eruptions have occurred in the 5 years since the May 18th, 1980, catastrophic eruption of Mount St. Helens. The first five eruptions, in the spring to fall of 1980, were explosive and produced flows and ash falls. Eruptions from December 1980 to 1985 have been dominantly nonexplosive and have resulted in the periodic addition of lava into or onto the surface of a large dome in the crater produced by the May 18th eruption (compare figs. 4 and 5).

The reawakening of Mount St. Helens in 1980 was marked by a magnitude 4.0 earthquake on March 20 and numerous earthquakes for the following 2 months. Steam-blast eruptions at and near the summit of the volcano started on March 27 and continued into May. Survey geologists monitoring the volcano with electronic distance measuring (EDM) equipment noted that the north flank was bulging.

Figure 4. A view of Mount St. Helens and Harry's Ridge in September 1980, about 5 miles north of the volcano. The eruption of May 18, 1980, removed much of the north flank of the mountain, forming an amphitheater and a gigantic debris avalanche. Note the flat bottom of the amphitheater, the small fume cloud rising from the crater vent, and the relatively smooth surface of the avalanche debris plain between the volcano and Harry's Ridge. Compare with figure 5.



Measurements indicated outward movement of as much as 4 1/2 feet per day, with a total movement of about 300 feet by mid-May. This deformation, the seismic activity, and the steam-blast eruptions were interpreted to be the result of injection of viscous magma into the volcano.

On May 18 at 8:32 a.m., a magnitude 5.1 earthquake caused the bulging north flank to fail as a catastrophic avalanche—the largest ever observed in historic times. The debris avalanche slid northward into the valley of the North Fork Toutle River and Spirit Lake. Parts of the avalanche crossed a 1,500-foot-high ridge north of the river, but the bulk of it went westward down the North Fork Toutle River as much as 14 miles from the volcano. The avalanche exposed the hot interior of the volcano, releasing pressure on the hydrothermal and magmatic system within the volcano, triggering an enormous north-directed blast. This blast of steam and rock fragments, which had velocities of many hundreds of

miles per hour, overtook the debris avalanche and devastated an area of about 360 square miles (fig. 6). Mudflows sped down the flanks of the volcano on all sides to fill many of the nearby streams and rivers. Surface water incorporated in the debris avalanche and water from melting glacial ice in the avalanche produced mudflows and floods that swept down the North Fork Toutle River, into the Cowlitz River, and eventually into the Columbia River. An eruption column rose more than 15 miles above the newly formed crater. Ash from this eruption column, blown eastward by high-altitude winds, was deposited across eastern Washington and as far eastward as the Great Plains. Lightning caused numerous small forest fires, and the sky became dark as night for 120 miles east of the volcano. From shortly after noon until early evening hot pumiceous pyroclastic flows sped from the crater down the north flank to Spirit Lake. A massive search and rescue effort resulted in saving many lives, but 57 people were killed on May



Figure 5. *Mount St. Helens in July 1985, 5 years after the catastrophic eruption. A series of nonexplosive pasty lava flows have built a lava dome in the crater. Erosion by flowing water has incised the flanks of the volcano and the debris plain, modifying the original blast topography. Compare with figure 4.*



Figure 6. Tree stumps and logs in the blow-down area near Coldwater Peak, 7 miles north of Mount St. Helens. The force of the tremendous blast on May 18th stripped vegetation and soil from the underlying bedrock. Five years later, wild flowers and other vegetation have begun to reclaim the desolate landscape.

18th. Among those who died was David A. Johnston of the Geological Survey, who was making measurements of the bulging north flank from a site just north of the volcano.

Eruptions on May 25, June 12, July 22, August 7, and October 16–18, 1980, produced pyroclastic flows that swept down the north flank of the volcano as far as Spirit Lake. Eruption columns reached heights of 3 to 9 miles, and ash was spread by prevailing winds in various directions from the volcano. A small lava dome was emplaced in the vent crater at the end of the June eruption only to be blown out during the initial phase of the July eruption. A similar dome produced in August was blasted apart in October.

The dome that grew at the end of the October eruption was the first to survive. It now forms the core of a composite dome 3,000 feet across and 750 feet high. The dome has been built during dominantly nonexplosive eruptions by pasty lava flows or by lava injected into the dome that has caused it to

swell internally. The rate of growth of the dome has been relatively constant since 1982, averaging about 30,000,000 cubic feet per month; the volume of individual eruptions is approximately proportional to the length of time that has elapsed since the preceding eruption. Explosive activity has accompanied several of the dominantly dome-growth eruptions. The largest event was on March 19, 1982, when an explosion from the south side of the dome blasted pumice against and beyond the crater walls and generated snow and rock avalanches and large mudflows that swept down the north flank into Spirit Lake and into the North Fork Toutle River.

As a consequence of the renewed activity at Mount St. Helens, the Survey established the David A. Johnston Cascade Volcano Observatory (CVO) in Vancouver, Wash. Geologists and geophysicists at CVO are responsible for monitoring activity at Mount St. Helens and for studies of other Cascade volcanoes. Seismic monitoring of Mount St. Helens is

Figure 7. Scientists from the Geological Survey Cascades Volcano Observatory using electronic distance measurement equipment to measure deformation of the lava dome from a station within the crater. Measurements of this type document the growth of the dome and allow scientists to predict the times of future eruptions.



carried out mostly by the University of Washington (UW) Geophysics Program under contract to the USGS.

CVO and UW scientists have successfully predicted most eruptions since the catastrophic eruption of May 18, 1980. Injection of new magma into the upper part of the conduit beneath the dome and into the dome causes small earthquakes and deforms the crater floor and dome. Measurements indicate that the deformation accelerates as the time of eruption approaches (figs. 7 and 8). During a typical period, prediction notices are issued to the public 2 weeks before an expected eruption, and as the time of the eruption approaches, more time-specific predictions are issued. These successful predictions have allowed much greater use of the area around Mount St. Helens.

Many valuable lessons have been learned at Mount St. Helens. Prior to 1980, only three volcanoes were known to have had large debris avalanches, and one

of those was a century ago. Catastrophic avalanches were not considered to be a common major volcanic hazard. Studies around the world since 1980 have resulted in recognition of more than 100 volcanoes that have had major debris avalanches. Indeed, a newly recognized debris avalanche at Mount Shasta, Calif., is about 10 times larger than the 1980 deposit at Mount St. Helens. Thus, evaluations of hazards at volcanoes now routinely consider the possibility of major avalanches. Studies of deposits from the lateral blast, pyroclastic flows, tephra falls, and mudflows have application to studies of similar deposits elsewhere. The investigations of deformation and seismic activity at Mount St. Helens have led to successful predictions of the time, place, and type of eruptions, more so than at any other volcano in the world. As a consequence, numerous foreign scientists have visited CVO and Mount St. Helens to learn new monitoring techniques.



Figure 8. Scientists use electronic distance measurement equipment to measure deformation at the summit of the lava dome.

A Quantitative Approach to Mapping Landslide Risk and its Economic Implications

By Richard L. Bernknopf, Russell H. Campbell, and Carl D. Shapiro

Economic losses from landslides in the United States now exceed \$1 billion annually. Although some public officials and land developers have demonstrated that mitigation can be effective in reducing losses, little attention was devoted to evaluating the economic efficiency of different levels of loss reduction. At one extreme, for example, the cost of mitigation applied to a property where the probability of loss is low might be greater than the expected loss. The recent application of economic techniques by the U.S Geological Survey to the modeling of landslide risk provides a means to evaluate the cost

effectiveness of different levels and types of mitigation strategies.

The new procedure integrates geologic, topographic, and residential property value data in a model that estimates the economic benefits of various loss-reduction methods. The approach was applied to residential property for a part of Hamilton County (Cincinnati), Ohio. The net economic benefits are measured as the difference between the total savings effected by mitigation and the cost of the loss-reduction activity within the area studied. The cost of mitigation is estimated to be the cost of grading activities that maintain or improve hillside slope stability under foundations for new residential construction. The procedure does not address the benefits or costs associated with zoning restrictions or the modification of existing structures. Although the model proceeds from an idealized set of situations, its utility lies in providing a systematic method for comparing the economic benefits of various levels of mitiga-

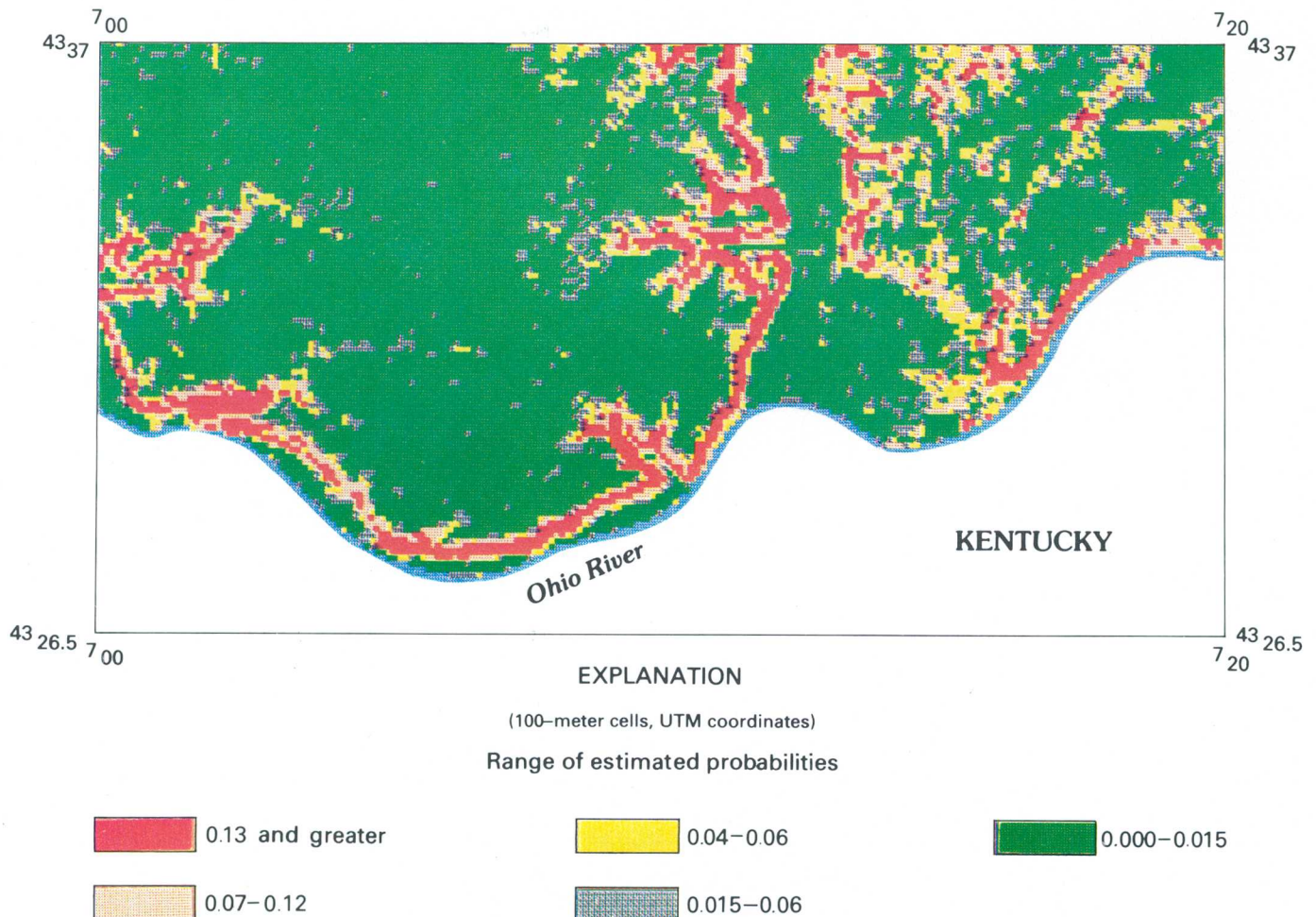
tion for new construction and urban redevelopment.

To demonstrate the procedure, the Cincinnati, Ohio, study area was divided into 14,255 square parcels of land, 300 feet on each side, referred to as cells. For each cell, the probability of a landslide occurring (fig. 9) was estimated on the basis of statistical relationships among attributes of the cell, such as mean and maximum ground slope, strength of the natural earth materials, and the presence or absence of potential triggering activities (e.g., new road construction). The statistical relationships were established using the 1970–79 historical record of landslides in the study area. The distribution of residential property values in each cell was obtained from the 1980 census (fig. 10). Discounting the property value over a 10-year period and multiplying by

the landslide probability yields an annualized expectation of loss. If these “expected losses” are avoided as a result of mitigation, they are, by definition, the “net benefits” of mitigation. Summing the net benefits for all the cells where the same loss-reduction measures are applied yields the net benefits to an idealized jurisdiction where alternative mitigation plans are considered.

Table 1 lists a few examples from among numerous possible mitigation alternatives using a broad range of slope and strength criteria for selecting cells for mitigation, also listing the number of cells affected and the net benefits. If the same kind of loss-reduction measures are applied in all cells, all \$4.9 million in annualized expected losses will be avoided, but the estimated cost of grading to assure

Figure 9. *Estimated probability of at least one landslide per cell in the Cincinnati, Ohio, study area.*



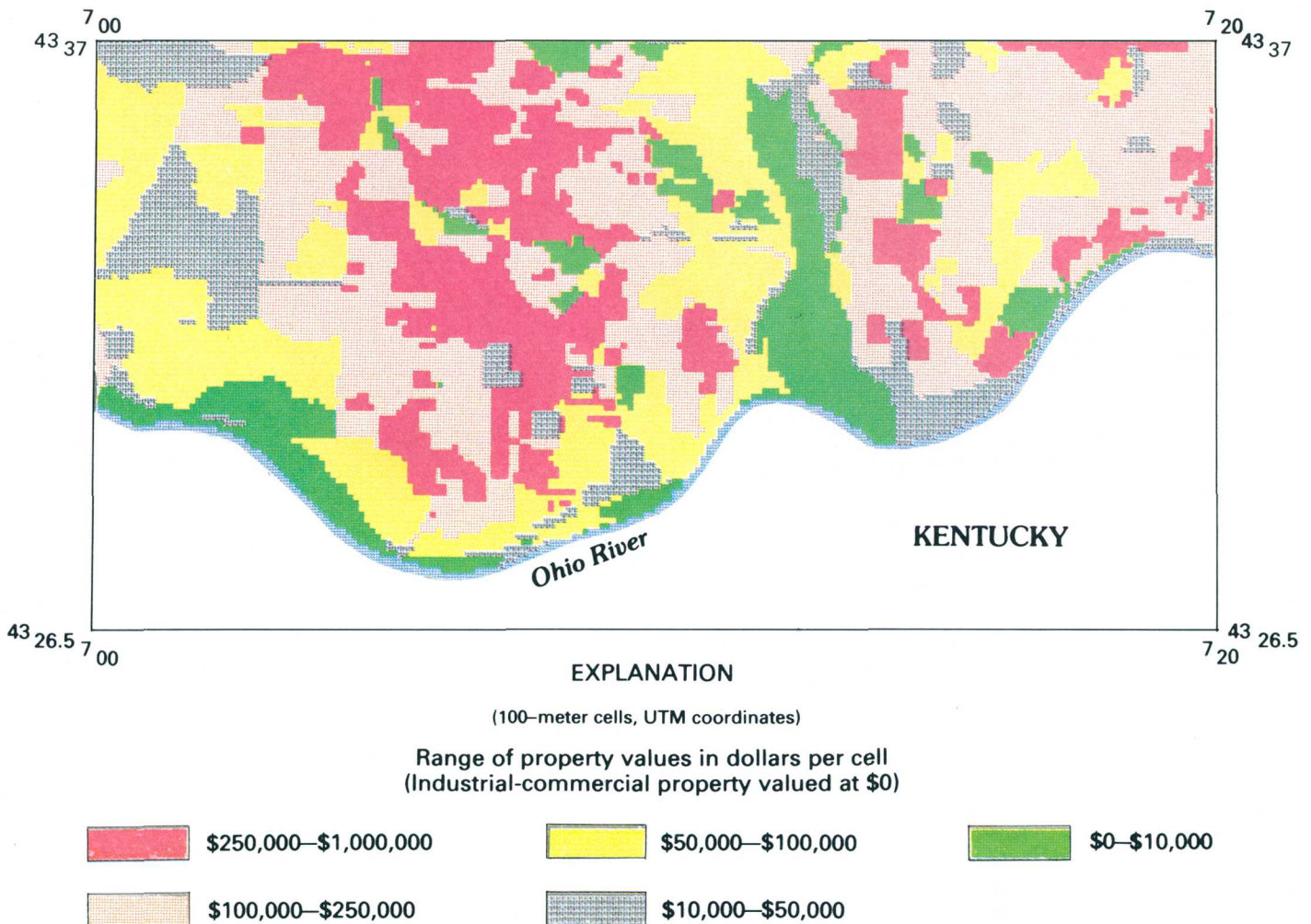
stable slope conditions will exceed the expected benefits by \$0.1 million, an annual net loss.

If cells are selected for mitigation solely on the basis of slope information—i.e., standardized loss-reduction measures are applied only to those cells having slopes steeper than a specified threshold—the highest net benefits that can be achieved, \$1.4 million, are yielded when the threshold is 8 degrees. If cells are selected for mitigation on the basis of both slope and strength information—i.e., those cells having slopes steeper than a specified threshold or strength parameters lower than a specified threshold—the highest net benefits that can be achieved, \$1.7 million, are yielded when the slope threshold is 14 degrees and the strength threshold is 0.49. Other combinations of slope and strength threshold criteria produce lower net benefits. The optimum selective plan would provide a cost-effective

Table 1. Annualized net benefits of alternative building code site preparation rules (in millions of dollars)

Site preparation rule	Number of 2.5-acre parcels of land selected for mitigation	Annualized net benefits
Mitigate everywhere	14,255	-0.1
Average slope steeper than 3°	11,406	0.3
Average slope steeper than 8°	2,851	1.4
Average slope steeper than 6° or shear strength less than 0.65	6,911	1.1
Average slope steeper than 14° or shear strength less than 0.49	2,569	1.7

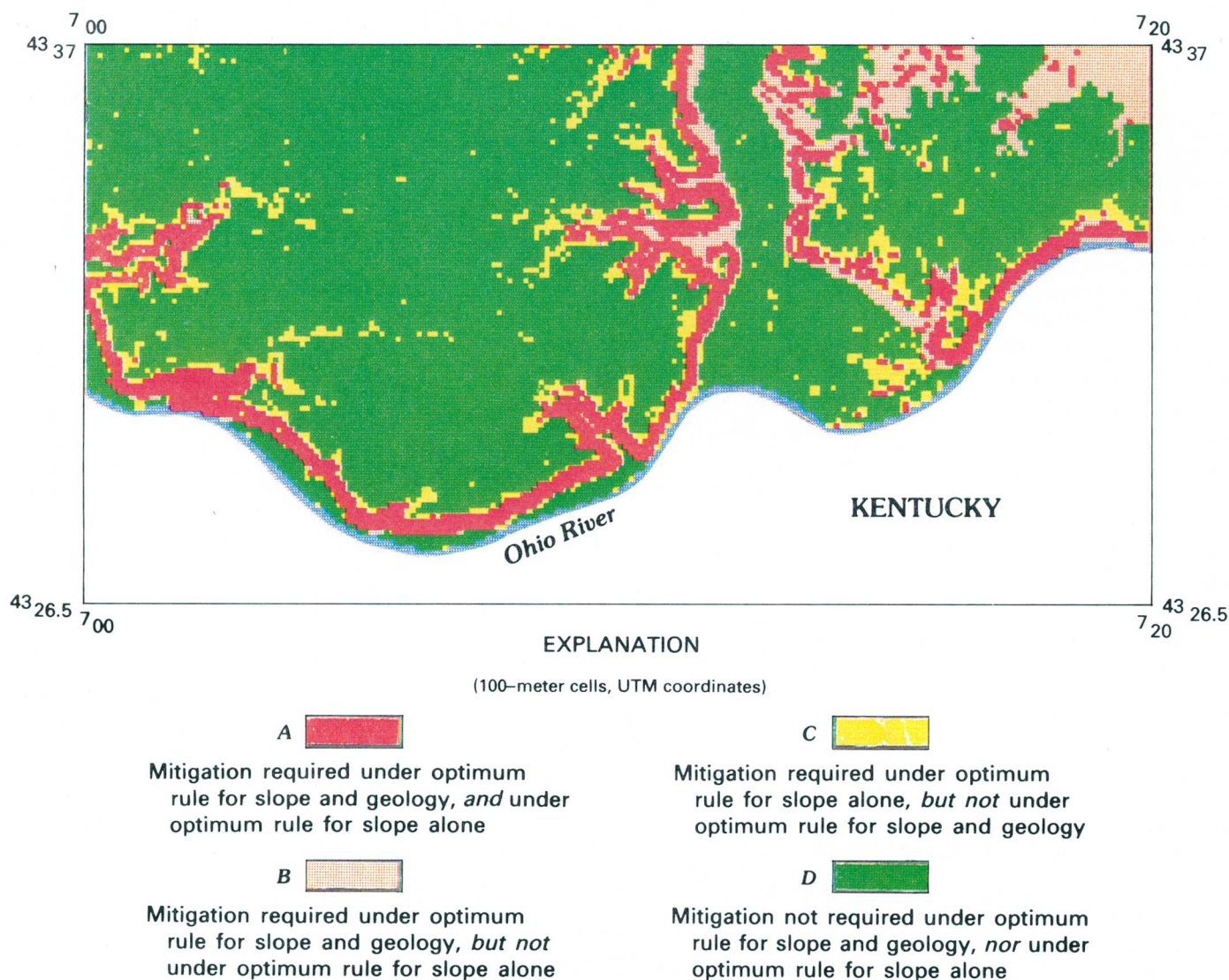
Figure 10. Residential property values from the 1980 census.



potential for a 37-percent reduction in annual landslide losses. Thus, the application of this procedure indicates that selective mitigation using regional geologic and topographic information would improve this community's effectiveness in avoiding losses from landslides.

Figure 11 compares the areas affected by the two best plans for selective mitigation described above. Some cells would be selected under both of the optimum decision rules, some would not be selected under either. There is an incremental increase in net benefits where both slope and strength criteria can be applied. That is, an improvement in selectivity is achieved by not mitigating in cells with materials stronger than 0.49 and slopes between 8 and 14 degrees, and by including for mitigation those cells having materials weaker than 0.49. The net benefits are increased by \$0.3 million annually.

Figure 11. Areas affected by two different mitigation criteria (see text): A, Cells with slopes greater than 14 degrees and strengths less than 0.49 (selected by topographic and geologic criteria). B, Cells with slopes less than 14 degrees and strengths less than 0.49 (selected by topographic and geologic criteria, but not by topographic criterion alone). C, Cells with slopes greater than 8 degrees and less than 14 degrees (selected by topographic criterion, but not by topographic and geologic criteria together). D, Cells with slopes less than 8 degrees and strengths greater than 0.49 (not selected under either set of criteria).



The combination of economics and geologic techniques in modeling landslide risk provides a method for estimating the cost-effectiveness of different landslide mitigation activities. This approach uses available regional information about topographic and geologic factors that influence landslide susceptibility to discriminate among areas having different potentials for landslide hazard. The new approach may also have broader application. Not only can it identify the "economic best" among alternative plans, but, by comparing plans, it can provide a systematic way to estimate the value of different kinds of information to the reduction of landslide losses.

The Federal-State Cooperative Geologic Mapping Program (COGEOMAP)

By Juergen Reinhardt

The Geologic Division began a new program of cooperative geologic and geophysical mapping (COGEOMAP) with State geological surveys during fiscal year 1985. This program is a part of the Geologic Framework Program and was started because of an increasing concern that a fundamental mission of the USGS, geologic mapping, is not keeping pace with the needs of programs throughout the Geologic Division and the earth-science community that use geologic maps as their basic data source. The geologic map shows the spatial arrangement of rocks and surficial materials, predicts the three-dimensional arrangement of rock units at depth, and provides an interpretation of the geologic history of a region. In contrast, a geophysical map portrays the distribution of subsurface Earth properties (gravity, magnetics, or radioactivity) and is an important key to understanding the distribution of subsurface structures. Used together, these maps provide geologists, engineers, and planners with vast quantities of information about the crust of the Earth from the surface to the upper mantle. Practical uses of geologic maps include exploration for mineral and energy resources, delineation of potentially hazardous areas, delineation of potential underground water sources, and location of sources of construction materials.

The COGEOMAP program is mutually beneficial to the Federal Government and the States in that the States can provide local expertise and detailed geologic information, while the USGS can offer regional mapping expertise, laboratory facilities for dating rocks, and excellent facilities and cartographic capability for the preparation and printing of geologic maps. The program consists of 21 cooperative

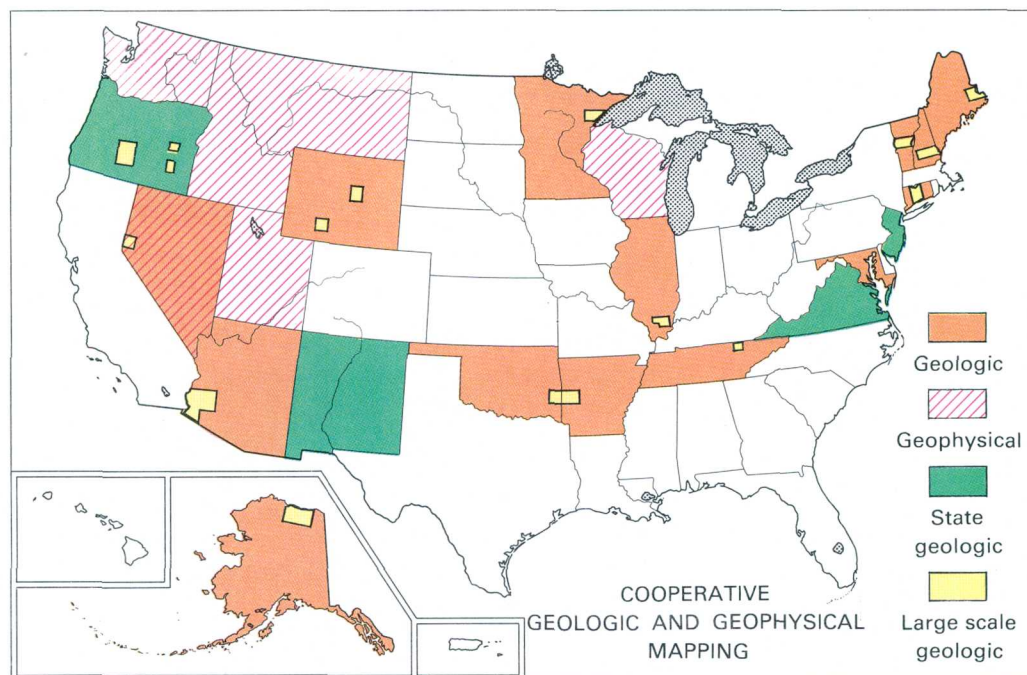
projects, but, as a result of the strong response of the States and the initial success of the program, it is anticipated that the program will expand in the future.

The primary goals of the COGEOMAP program are to improve the quality and to increase the number of geologic and geophysical maps being produced throughout the United States in areas of mutual interest to Federal and State agencies. The objectives of the program are (1) to begin new large- and intermediate-scale geologic mapping projects in high-priority areas where only limited geologic data exists, (2) to focus geologic mapping activities in areas of suspected mineral or energy potential where limited mapping may have impeded resource exploration, (3) to aid in the conception and compilation of new State geologic maps, and (4) to compile and digitize geophysical data and prepare State digital geophysical maps. In general, the priorities for the geologic mapping within a specific State have been set by the State survey, but the organization of the project(s) and the work plan(s) have been established through joint planning between various groups and individuals within the Geologic Division and the State surveys.

Initiation of a COGEOMAP project involves the evaluation of the proposal from the State geological survey by a USGS selection panel following review by the scientific managers within the Geologic Division. The entire proposal procedure, including the criteria for selection, has been formalized and sent to the State geological surveys through the USGS Office of Procurement and Contracts. The proposals need (1) to meet at least one of the COGEOMAP program objectives listed above, (2) to represent a truly cooperative effort between the State survey and USGS, and (3) to complement any ongoing USGS projects in the same geographic region.

Although the geologic mapping part of the program was only started with the States during fiscal year 1985, the State digital geophysical folios project has already completed its prototype phase with a complete geophysical folio of Ohio and digital radioactivity maps of New Mexico. The States with digital geophysical maps underway are shown on figure 12. In many cases, the States are providing the USGS access to data that have been unavailable to the Federal Government in the past. In all cases, the geophysical maps are providing a valuable guide to future geologic mapping targets. Geophysical data are already being integrated with surface geology and subsurface drill hole information to develop a better understanding of the three-dimensional arrangement of rock units in the Ouachita Mountains COGEOMAP project in Oklahoma and Arkansas.

Figure 12. To improve the quality and quantity of geologic mapping throughout the Nation, the U.S. Geological Survey has begun COGEOMAP, a program of cooperative geologic mapping with State geological surveys. The new program expands the USGS cooperative work with the State surveys.



Although space does not permit the description of all the projects included in the COGEOMAP program, the map shows the States participating in the 1985 program and the general location of the geologic and geophysical maps in preparation. Most of the geologic mapping supported by the program is large-scale, at 1:24,000 or 1:62,500; this includes mapping projects in Alaska, Oregon, Nevada, Wyoming, Oklahoma, Arkansas, Minnesota, Illinois, Tennessee, Maryland, Connecticut, New Hampshire, Vermont, and Maine. Mapping projects in other States, like Arizona, New Jersey, and Virginia, involve mapping at similar scales, but the primary map products will be at intermediate (1:100,000) or small scales (1:250,000).

The State geologic map projects are an especially important part of the COGEOMAP program because these projects involve outstanding opportunities for a joint assessment of the status of the quantity and quality of geologic mapping within a specific State. In the past, formal cooperative efforts between the USGS and States have led to the publication of new

State geologic maps in Kentucky (1982), Massachusetts (1983), Arkansas (1979), Colorado (1977), and, most recently, Wyoming and Connecticut (1985). The State geologic map project in Oregon has been funded by the Geologic Framework Program for a number of years, and, now that cooperative arrangements are underway through the COGEOMAP program, the completion of this map will be considerably expedited. The State map projects in Virginia and New Mexico involve varying amounts of new geologic mapping. The revision of the geologic map of New Jersey involved the most detailed mapping (to be compiled at 1:100,000) of any ongoing State map project.

In summary, the COGEOMAP program has established a valuable new area of cooperation and communication between the USGS and the State geological surveys. This program is a positive first step by the USGS to reverse the trend of declining geologic map production in the United States and to produce high-quality geologic maps at the appropriate scales for both national and local needs.

Detection of Hazardous Wastes by Using Geophysical Techniques

By Gary R. Olhoeft

Hazardous materials often do not look, smell, taste, or feel hazardous and may exist in extremely minute, yet highly toxic, amounts. Drilling to find and sample such materials may be hazardous in itself, because drilling may release the wastes through the drill holes to the uncontaminated environment. Geophysical studies provide techniques that may safely and noninvasively find, map, and identify distributions of such materials. After they are located, similar studies may also provide the necessary information to allow prediction of their fate in the hydrologic and geologic environment and to monitor this fate.

To be observable with geophysical tools, the hazardous materials must have at least one physical or chemical property that is different in some way from the surrounding uncontaminated ground. Drums containing hazardous materials may be detected by magnetometers if the drums are made of a magnetic metal such as iron. However, magnetometers cannot find metal drums in rock such as basalt, which is naturally magnetic, nor can they find glass containers, which are nonmagnetic. All geophysical techniques fail when there are no contrasts in physical properties to measure; thus, no one geophysical technique can solve all problems. However, not all geophysical techniques measure the same properties, so that where one fails another may succeed.

In Henderson, Nev., the city needed to locate the extent of a waste plume from leakage at an industrial park. High-clay-content soil prevented the use of ground-penetrating radar, but the inorganic portion of the plume provided an electrical conductivity contrast that allowed the plume to be mapped by electromagnetic-induction devices. The organic portion of the plume reacted chemically with the natural clay soils to provide a chemical contrast measured with the complex resistivity technique. The latter measurements also showed that the organic

portion of the plume was separated from the inorganic portion and that it had penetrated into an otherwise impermeable clay layer.

At an Environmental Protection Agency superfund site in Pensacola, Fla., the location of a plume from leakage of creosote needed to be identified, along with geologic factors that affected the fate and movement of the plume. The location of the site, in the middle of downtown Pensacola, resulted in interference with electromagnetic techniques from radio stations, telephone and power lines, and gas and water pipes. The proximity of the site to the highly conductive saltwater of Pensacola Bay also masked direct detection of the plume by electromagnetic-induction techniques. However, ground-penetrating radar clearly mapped discontinuous clay layers (fig. 13). Inconsistencies in the drilling data and hydrological models were explained by the holes in the clay layers that had been assumed to be continuous.

In Falmouth, Mass., a sewage plume needed to be outlined for the Otis Air Force Base. The high salt content of the plume provided an electrical conductivity contrast for mapping by the electromagnetic-induction method. Ground-penetrating radar also mapped geologic stratigraphy and water-table levels for making predictive models.

Experience at these and other sites has shown that the most useful geophysical techniques are electromagnetic induction, complex resistivity, and ground-penetrating radar. Electromagnetic induction quickly and inexpensively maps electrical conductivity enhancements from inorganic contaminants in the ground water. Complex resistivity detects clay-organic reactions and the attack of impermeable clay barriers by organics causing increased permeability. Ground-penetrating radar maps detailed geologic and hydrologic stratigraphy and sometimes directly detects organic pollutants.

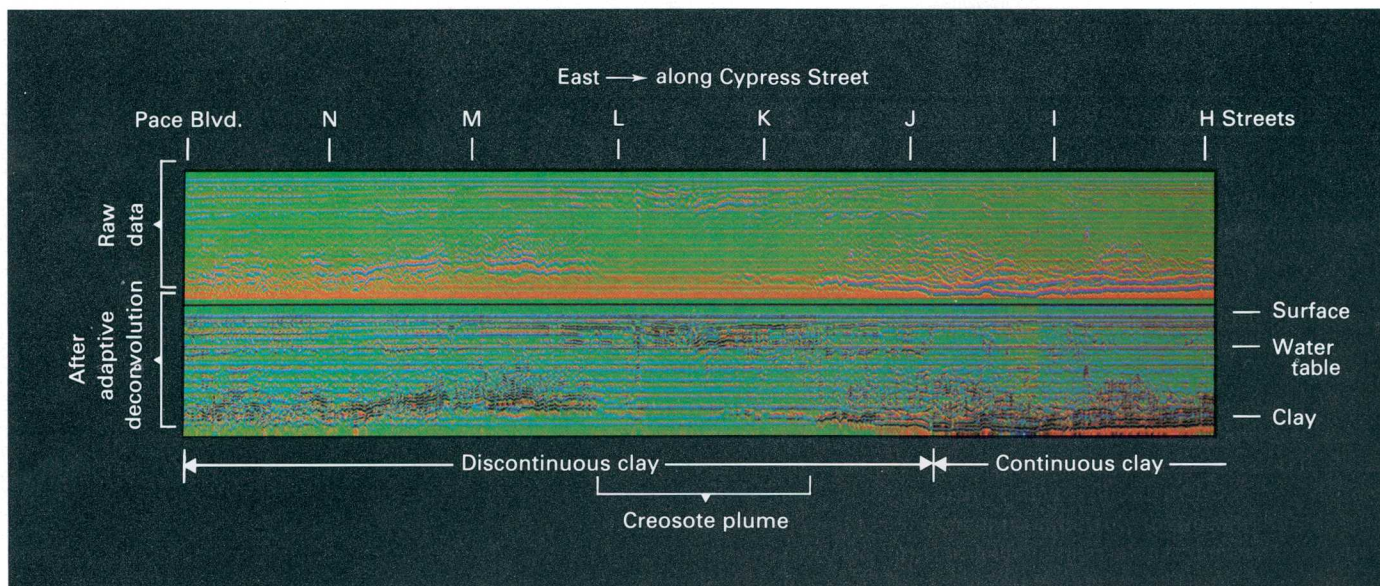


Figure 13. Ground-penetrating radar traverse along Cypress Street from Pace Boulevard to H Street in Pensacola, Fla. The upper record is the raw, digitized data. The lower record is after computer processing through an adaptive deconvolution filter. The surface to the bottom of the record is approximately 45 feet. The black lines across the bottom of the lower record are clay layers. On the right (east), they are continuous, but on the left (west), they are discontinuous. The area in the middle, where the texture of the record changes, is the creosote plume.

Geologic History as a Guide to Manganese Exploration

By William F. Cannon and Eric R. Force

Manganese is a metal critical to modern industrial society; it is an essential ingredient of steel and it also serves a variety of chemical uses. No minable concentrations are known in the United States and the Nation is dependent on imports for virtually all manganese supply, most of which now comes from central and southern Africa (fig. 14). Minalable manganese deposits overseas are, for the most part, unusual manganese accumulations, some remarkably pure, that formed in vast sedimentary layers millions of years ago, interlayered with other sedimentary rocks that were deposited on ancient sea bottoms. Where these rocks today are exposed on land, they support an active manganese mining industry.

Because manganese is virtually absent from modern ocean water, these ancient deposits must have formed in response to some unusual conditions that existed in ancient oceans. Geologists at the U.S. Geological Survey are conducting research to understand what these conditions were and where and when

they occurred in the geologic past. Such understanding is being used to develop a predictive capability to guide exploration for such deposits in the United States. This research has shown that a great majority of the world's sedimentary manganese deposits share important geologic characteristics: (1) they formed on shallow ocean margins by chemical precipitation of manganese from sea water, (2) they formed synchronously with extensive stagnation of oceanic circulation, and (3) they formed most commonly during periods of Earth history when global sea level was high and when global climate was warm.

Recent results from the disciplines of paleogeography, paleoclimatology, paleoceanography, and geochemistry show that the three phenomena are interrelated (fig. 15). High global sea level, and the consequent higher percentage of the globe covered by water, tends to promote warm global climates by increasing the Earth's ability to absorb and retain so-

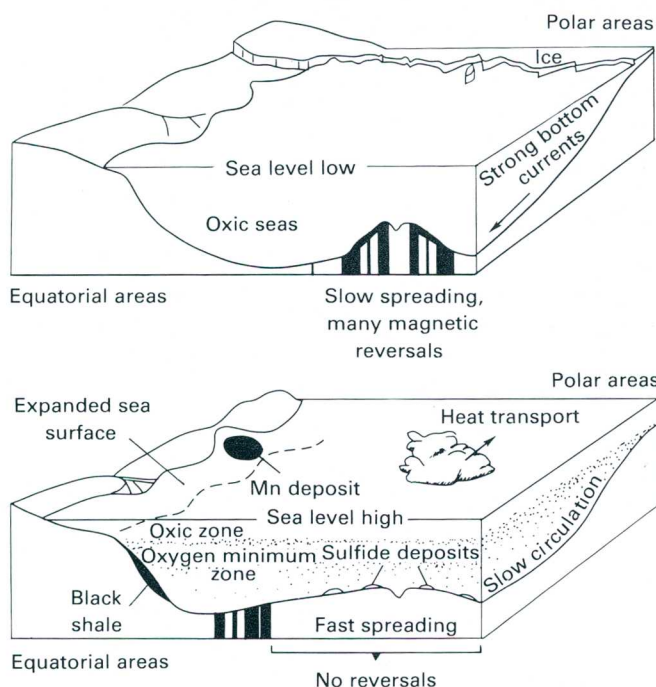


Figure 14. Manganese mine in the Kalahari district of South Africa, the world's largest. The horizon mined for manganese is 40 feet thick and forms the lowest three benches in the mine. Sedimentary manganese deposits including these and others in the U.S.S.R. and Mexico constitute the large majority of world reserves.

lar radiation. These warm climatic conditions in turn cause a decrease of circulation in the oceans that is driven largely by thermal contrasts between equatorial and polar regions. When circulation declines, the replenishment of oxygen from the atmosphere to deeper parts of the ocean likewise declines. In some areas, biological oxygen demand may totally consume all oxygen in deeper waters, resulting in a stratified ocean in which deep water is totally oxygen depleted. The deep water is overlain by only a thin layer of water that remains oxygen-bearing by direct

interchange with the atmosphere. This stratification and lack of oxygen in deep water is the key to formation of manganese deposits, for the solubility of manganese in sea water is strongly controlled by the water's oxygen content. In oxygen-bearing water, manganese is virtually insoluble, but in oxygen-free water its solubility increases markedly. Hence, during times when oceans were stratified, the amount of manganese dissolved in ocean water may have been several orders of magnitude more than in today's oceans and the potential to form manganese deposits

Figure 15. Different processes operating at different types of times in Earth history. In the state shown above, like today, slow sea-floor spreading results in low sea level and well-mixed oceans. In the state below, fast spreading causes higher sea level, warmer climate, and stagnant stratified oceans. It is at such times that shallow-marine manganese deposits can form.



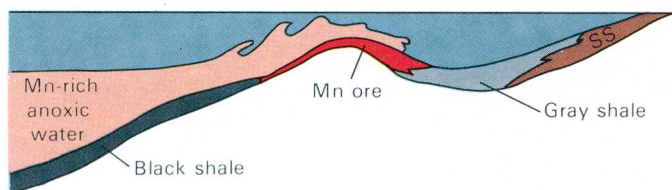


Figure 16. *Idealized setting for manganese deposition. Mixing processes such as upwelling between manganese-rich anoxic deep water and surficial oxic water precipitate manganese.*

was likewise much greater. Manganese appears to have precipitated near the margins of stratified ocean basins where deep, manganese-rich anoxic water mixed with oxygenated surface waters (fig. 16).

Armed with these concepts of how manganese deposits formed, of what intervals of geologic time were most favorable for formation of deposits, and of the most favorable paleogeographic settings for formation of deposits, geologists can use their knowledge of the geologic evolution of a region to quickly and efficiently identify rock units that could contain undiscovered manganese deposits. Such regional analyses are currently being done by USGS researchers, and areas considered favorable to contain undiscovered manganese deposits are being identified. These areas are being examined in the field for more direct evidence of manganese accumulations.

This work is a good example of a way in which general principles of earth sciences can be applied to understanding the formation of ore deposits and how that understanding can be coupled with knowledge of the geologic history of a region to define targets for mineral exploration. This approach has the potential to simultaneously advance our knowledge of Earth history, ore-forming processes, and mineral resources.

Petroleum Assessment of the Coastal Plain of the Arctic National Wildlife Refuge, Alaska

By Cornelius M. Molenaar and Oswald W. Girard, Jr.

Alaska has been described as the last frontier of the United States. It is a huge State with tremendous living and nonliving resource value. The North Slope of Alaska contains the largest oil field ever discovered in North America, Prudhoe Bay. Since the discovery of this super-giant oil field in 1968, petroleum geologists have been eager to explore for

additional supplies of the valuable commodity. The coastal plain of the Arctic National Wildlife Refuge (ANWR), which is 50 to 150 miles east of Prudhoe Bay, has long been regarded as the most promising area for future onshore oil and gas discoveries (fig. 17). However, until passage of the Alaska National Interest Lands Conservation Act (ANILCA) in 1980, ANWR was "off-limits" to exploration.

Section 1002 of ANILCA provides for a continuing inventory and assessment of the fish and wildlife resources of the coastal plain of ANWR and also authorizes seismic and surface geologic exploratory activity within the coastal plain in a manner that avoids significant adverse effects on the fish, wildlife, and other resources. The purpose of such exploration is to obtain data and information about the oil and gas potential of the coastal plain that will be used by the Department of the Interior in preparing a report to Congress, as required by Section 1002(h) of the Act. The report to Congress is required to contain:

- Identification, by means other than drilling of exploratory wells, of those areas within the coastal plain that have oil and gas resource potential and an estimate of the volume of the recoverable oil and gas.
- A description of the fish and wildlife, their habitats, and other resources that are within the areas having oil and gas potential.
- An evaluation of the adverse effects that further exploration, development, and production of oil and gas will have on fish, wildlife, and other resources.
- A description of how oil and gas, if produced in ANWR, would be transported to processing facilities.
- An evaluation of how the oil and gas potential of ANWR relates to the national need for additional domestic sources.
- The recommendations of the Secretary to Congress with respect to whether further exploration, development, and production of oil and gas within the coastal plain should be permitted, and, if so, what additional legal authority is necessary to ensure that the adverse effects of such activities on fish and wildlife, their habitats, and other resources are avoided or minimized.

The Fish and Wildlife Service (FWS) has the lead responsibility for preparing the Secretary's report to Congress, which is due by September 1986. The FWS has asked the Geological Survey and Bureau of Land Management (BLM) for technical assistance in preparing the Secretary's report and the USGS has been given the responsibility for preparing the oil and gas assessment of ANWR.

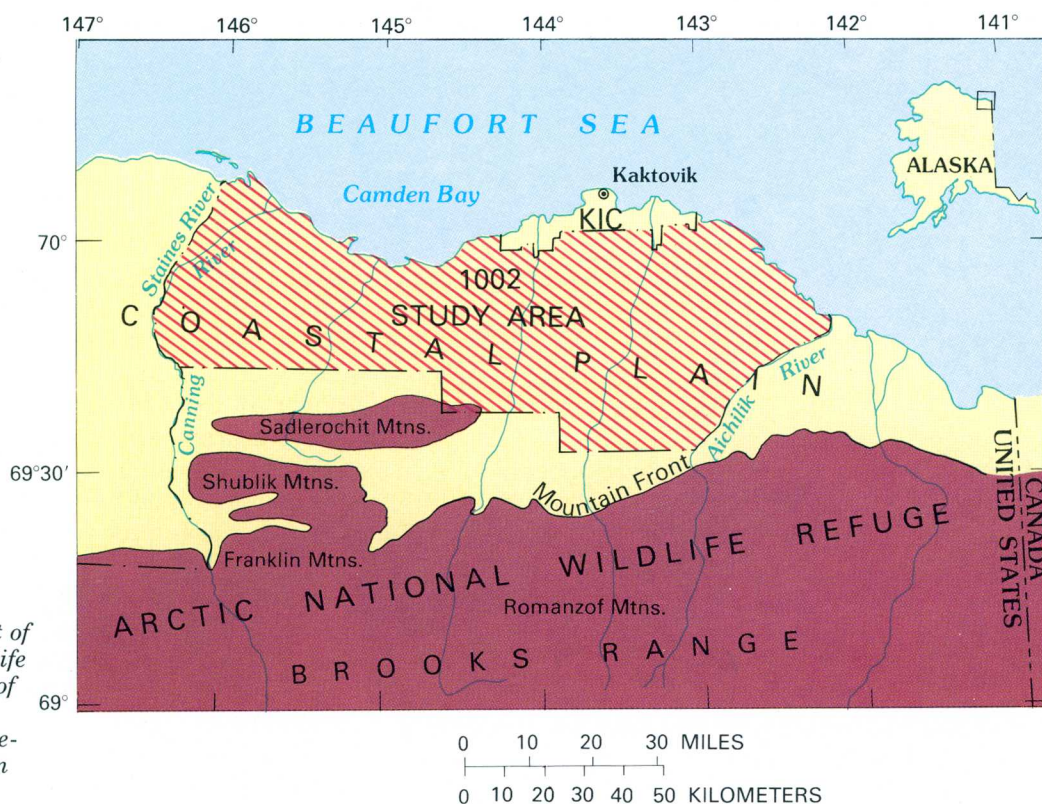


Figure 17. Northern part of the Arctic National Wildlife Refuge showing the part of the coastal plain (cross-hatched area) currently being assessed for petroleum potential.

It was the intent of Congress to have the private sector fund and acquire the exploration data for the report. During the 1984 and 1985 field seasons, approximately 1,300 line miles of common-depth-point seismic data was acquired over the 1.4 million acres of the coastal plain of ANWR. This provides a 3-by-6-mile seismic grid over the area. Gravity measurements were also made at selected stations along the seismic lines, and samples for paleontologic and geochemical analysis were taken from many of the 75- to 100-foot-deep shot holes that penetrated bedrock.

In addition to the geophysical surveys, industry, USGS, and BLM field parties conducted surface geological studies in and adjacent to the coastal plain of ANWR. Scientists from the Branch of Oil and Gas will integrate the industry-acquired seismic and surface geological data with topical oil and gas investigations in the areas of geologic framework, geophysics, geochemistry, direct detection, and hydrocarbon resource assessment. This effort to understand the petroleum geology of ANWR will culminate in an assessment of the undiscovered oil and gas and the probable locations of future exploration activity. A modified "play analysis" approach will be used in assessing the oil and gas potential of ANWR. The play analysis method was used in the Department of the Interior's assessment of the National Petroleum Reserve in Alaska (NPR) and for the

USGS 1980 assessment of ANWR (then called the William O. Douglas National Wildlife Range). A "play" consists of a group of prospects having common geologic characteristics—such as source rocks, trapping mechanisms, and structural history—that may indicate oil and (or) gas occurrence. The play concept considers all significant aspects of structure, stratigraphy, geochemistry, and geologic history, even though knowledge of these may be uncertain.

ANILCA and the implementing regulations require that the data, analysis, and interpretations generated from the ANWR assessment be kept confidential until the Secretary submits his report to Congress in the fall of 1986. At that time, the ANILCA legislation requires that the "raw" data, which include the digital seismic tapes, be released to the public. The processed, analyzed, and interpreted data obtained as a result of exploratory activities and submitted by the private sector will not be released to the public until 10 years after the submittal of the data, or until 2 years after any lease sale, including the area within ANWR from which such data or information were obtained, whichever period is longer.

Section 1002 of ANILCA is a unique piece of legislation in that all competing interest groups will have the opportunity to acquire raw subsurface information and be able to influence Congress in their decision as to the future disposition of the coastal plain

of ANWR. Congress will truly be in a position to make an informed decision about oil and gas exploration and environmental trade-offs in one of the most controversial areas in Alaska. From a scientific standpoint, the USGS is afforded the unprecedented opportunity to analyze industry's state-of-the-art subsurface geophysical data and other exploration information in an unexplored area and openly discuss the results of the analysis. The information acquired on ANWR will greatly add to our understanding of the geologic evolution and petroleum geology of the North Slope of Alaska.

Submarine Massive Sulfide Deposits

By William R. Normark

The U.S. Geological Survey began a program to study the formation processes of submarine massive sulfide deposits and related hydrothermal systems in late 1979. The southern Juan de Fuca Ridge, which lies in international waters about 270 nautical miles west of the central Oregon coast, was selected as the study area, and the first cruise to explore for active hydrothermal vents was made the following year.

The summer of 1985 marked the sixth consecutive year for the USGS's seagoing activities in the study area as well as an expansion of the submarine massive sulfide studies to include the Gorda Ridge, which lies within the U.S. Exclusive Economic Zone (EEZ) southeast of the Juan de Fuca study area.

The USGS program has been multidisciplinary from the outset, involving marine scientists as well as specialists in volcanism, geothermal systems, economic geology, and sulfide-mineral geochemistry. In addition, this program has actively involved scientists from five universities (University of Washington, Lamont-Doherty Geological Observatory of Columbia University, Oregon State University, Dalhousie University, Nova Scotia, and the University of Victoria, British Columbia), the National Oceanic and Atmospheric Administration (NOAA), and the Smithsonian Institution. Since 1982, a joint agreement between the USGS and the Geological Survey of Canada (GSC) has facilitated interchange of personnel and equipment in cooperative studies within both countries' study areas on the Juan de Fuca Ridge system.

In fiscal year 1985, an attempt to determine the depth, width, or even the existence of an axial magma chamber was conducted in cooperation with Oregon State University. Ocean-bottom seismometers recorded both natural seismic activity at the vent sites as well as large energy pulses from the air-gun system on the USGS Research Vessel *Samuel P. Lee*;

the data from this study will provide improved structural and velocity models for the Juan de Fuca Ridge axis through both refraction and wide-angle reflection techniques.

The next phases of the USGS program include additional electric rock-core drilling in the summer of 1986 and continued mapping of the vent sites using ALVIN, which is now scheduled to return to the northeast Pacific in 1987. The drilling program will be in cooperation with GSC, and the submersible program will be in cooperation with hydrochemical studies of NOAA.

Mineral Deposits of the Southern Juan de Fuca Ridge

Analyses of both the 1983 photographic and 1984 ALVIN data sets are in progress with more than 20 teams from the USGS, academic, and other government agency laboratories. Preliminary results provide the following general picture of the hydrothermal vent settings, deposit mineralogy, and fluid chemistry.

GEOLOGIC SETTING

The study area encompasses the shallowest area along the longitudinal profile of the axial valley floor where the spreading axis is characterized by a low-relief (300 feet deep) symmetrical central valley. The valley floor is a little over one-half mile wide and remarkably flat, except for a narrow cleft along the center of the valley. The cleft is not a single symmetrical notch but one that widens locally and exhibits apparently overlapping strands and small (less than 50 feet) offsets.

The dominant lava morphology of the valley floor is lobate sheet flows. In general, the lobate lava surface of the valley floor is relatively unbroken away from the axial cleft; within 300 to 600 feet of the cleft, however, small collapse pits 3 to 6 feet deep and several feet wide are common. Within 30 to 90 feet of the cleft rim, collapse pits are much more extensive and locally exceed 15 feet in depth and tens of feet in width. Photographic mosaics indicate that the areas of extensive collapse pits tend to be wider adjacent to the major hydrothermal vent extending as much as 300 to 450 feet from the cleft.

The floor of the axial cleft typically is underlain by very glassy lineated sheet flows or rubble with local collapse and subsidence especially near the cleft walls. Talus from lobate flow surfaces and locally lava drapes also are common along the base of the cleft walls. The hydrothermal vents are generally found at or near the base of the cleft walls in areas of talus.

HYDROTHERMAL VENTS AND MINERAL DEPOSITS

Except for one small, photographed vent site on the eastern inner valley wall, the known hydrothermal vents are located within the central cleft. Each vent zone is elongated along the strike of the cleft, with vent faunal communities and sulfide deposits occurring over a distance of as much as 1,500 feet. A thick blanket of yellow sediment generally surrounds the zones of mineralization.

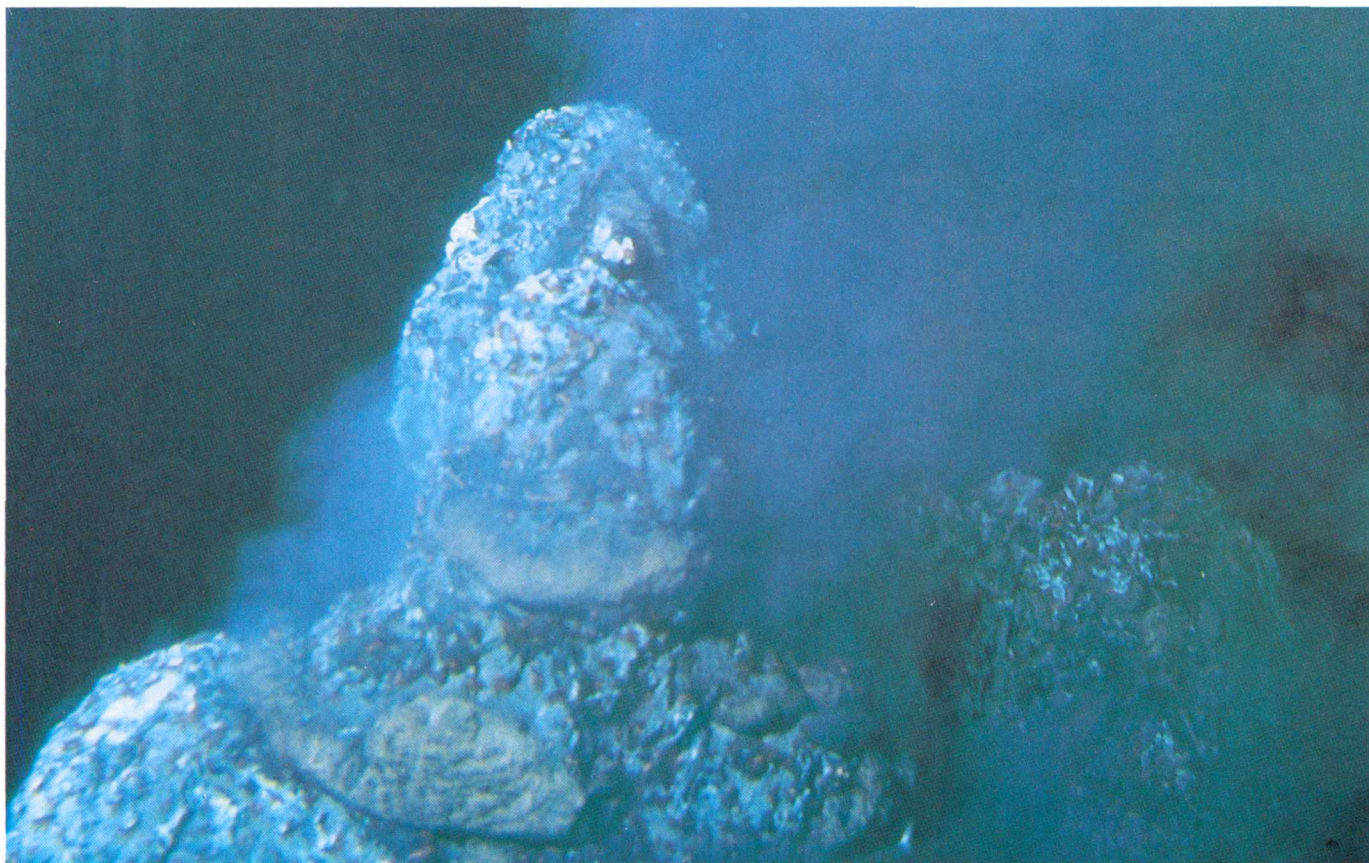
Sulfide deposits occur as irregular mound fields (areas of 140 to 900 square feet) of chimney-like structures and as sulfide encrustations along the steep walls of the central cleft (fig. 18). Chimney structures typically are 8 to 16 inches in diameter and 3 to 6 feet high, with an asparagus-shaped profile widening near the top. In a typical vent, which would contain at best a few tons of sulfide, only a few chimneys show open central conduits and active venting of hydrothermal fluids. Diffuse leakage of

hydrothermal fluid from throughout the fields is more common and locally produces small mounds and spires of sulfide (fig. 19). The sulfide samples dredged in 1981 are similar to those recovered during our dives, and zinc-sulfide minerals predominate in nearly all of the samples.

The vent fluids from the southern Juan de Fuca are unique in comparison to that of other spreading ridge vent systems, which have total dissolved solids nearly double normal seawater. Thus, our samples have the highest chlorinity of any vent fluids yet studied, and they also have anomalously high silica values compared to other vent systems, perhaps resulting from enhanced solubility in the higher-salinity fluid. In addition, the vent fluids have extremely low pH and high zinc and iron contents. The copper content is low, in agreement with the generally low copper levels in the sulfide samples.

Most discharge sites within each vent area are surrounded by extensive faunal communities that in-

Figure 18. Sulfide chimney
photographed from the
ALVIN submersible.



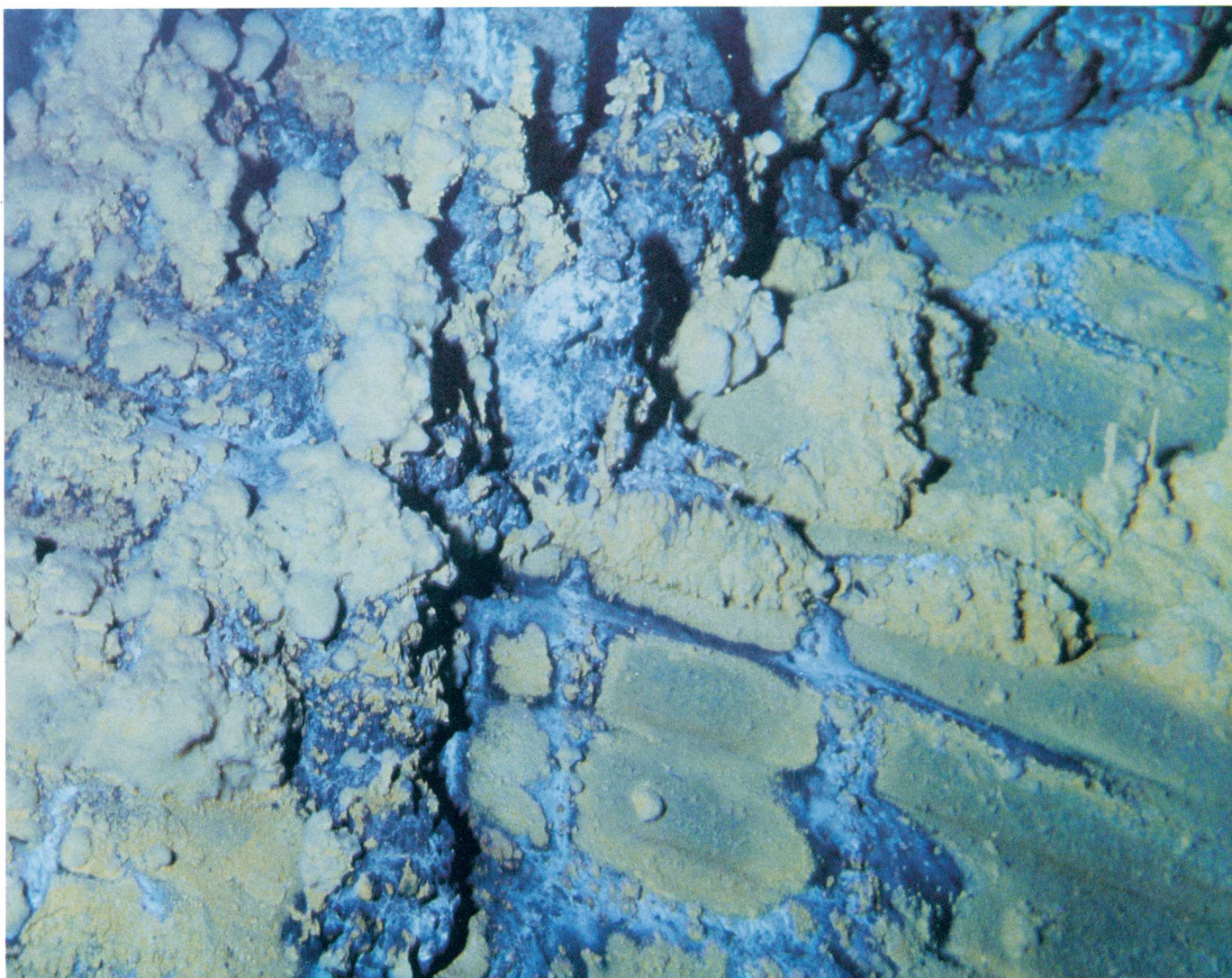


Figure 19. *Small spires and mounds of sulfide mineral deposits in an area of diffuse venting.*

clude tube worms, mollusks, and other vent-related species as well as numerous predators, especially spider crabs. Some sites, however, especially those surrounded by thick sediment accumulations, appear relatively devoid of at least the larger animals.

The discovery of hot springs presently depositing metallic sulfides on volcanically and tectonically ac-

tive segments of the seafloor presents a unique opportunity to apply the uniformitarian principle of geology—"the present is the key to the past." Continued research of the midoceanic ridge system will stimulate and improve our concepts in such diverse fields as volcanology, evolutionary biology, ore genesis, mineral exploration, and deep seabed mining.

Image Mapping the West Coast U.S. Exclusive Economic Zone

The Research Vessel *Farnella* steamed from San Diego Harbor into the open waters of the Pacific Ocean on April 26, 1984, to begin Project EEZ-Scan, a seafloor mapping effort of unprecedented scope. During the next 96 days at sea, the *Farnella* trailed a 24-foot, 2-ton towfish (a towed instrument containing transducers that send and receive acoustical signals to and from the seafloor) along a 12,000-mile stitchwork pattern of tracklines that extend between the Mexican and Canadian borders. The towfish is the heart of the Geological Long-Range Inclined ASDIC (GLORIA), a unique side-scanning sonar system developed and operated by the United Kingdom's Institute of Oceanographic Sciences (IOS). Teams of USGS and IOS scientists used the GLORIA during four consecutive cruises to compile a mosaic of acoustically sensed images, resembling an aerial photograph, of 328 square miles of the seafloor within the newly established U.S. Exclusive Economic Zone (EEZ) off the western conterminous States. Never before has a complete picture of such a vast expanse of seafloor been obtained or even attempted.

When the *Farnella* returned to San Diego on August 15, 1984, shipboard-constructed mosaics at 1:375,000 scale and preliminary geologic interpretations covering the portion of the Western U.S. EEZ from the continental-shelf break to the seaward boundary 222 miles from shore were ready for public display.

The sonograph mosaic clearly shows the large-scale geomorphic and sedimentologic features of the seafloor (fig. 20). The extent and continuity of features such as submarine fans, seafloor channels, and crustal fracture zones are shown in a manner that confirms or often modifies the configurations inferred from previous investigations that used linear-profiling acoustic-reflecting methods. When properly interpreted within the constraints of the sonographic technique, the mosaic can be an invaluable base for deciphering geologic structures and processes at and beneath the seafloor, for planning marine scientific expeditions, and for making optimum decisions regarding use of the EEZ.

One of the most striking aspects of the compiled mosaic is the regional geologic diversity. The contrast between the transform tectonic regime south of Cape Mendocino and the convergent tectonic regime north of it are obvious at a glance. The canyons that incise the continental slope and the sediment fans

that extend from them across the abyssal plain have an immense range of size and form, whose accurate portrayal on the mosaic surely will lead to critical testing and evolution of existing sedimentary models. Some channels on the deep seafloor are straight, whereas others are highly sinuous, hinting that a variety of river-like processes occur on the seafloor.

The basins of the continental borderland off southern California show as dark-floored depressions encircled by intricately dissected steep slopes. Between the basins, the continuity of the mosaic is interrupted by banks that are too shallow for safe operation of the GLORIA system. Comparison of the mosaic with existing marine geologic maps has added more than 120 previously uncharted submarine volcanoes to the known volcano population within the Baja Seamount Province west of the borderland. Many of the seamounts have large summit craters, attendant lava flows, and other distinctive morphologic features. The potential now exists for precisely choosing the location of bedrock and sediment samples critical to determining the age and origin of the seamounts. The patterns of volcanic ridges and seamounts as seen with GLORIA sonographs, when combined with the magnetic data, will now allow for interpretation of seafloor evolution in this complex area.

The massive Monterey and Delgada submarine fans off central California possess an intriguing pattern of channels, depositional lobes, and sediment waves that extend up to hundreds of miles from the source of sediment-laden, gravity-driven currents that built them. The scattered distribution of channels and depositional lobes attests to a dynamic history of sediment transported first to one area, then seemingly abandoned suddenly in favor of some other course. The records show clear examples of basement ridges that block sediment dispersal, and sediment slides and associated mass-flow deposits that alter sediment-transport pathways.

The mosaic is dominated in the northern region by the linear basement ridges that were generated at the Gorda and Juan de Fuca spreading centers and later moved apart in conveyor-belt fashion by seafloor spreading. The ridges are abruptly truncated by the Mendocino and Blanco Fracture Zones that accommodate horizontal slip between adjacent lithospheric plates (fig. 21). Sonographic display of subtle to distinct divergence, bending, and offset of the basement

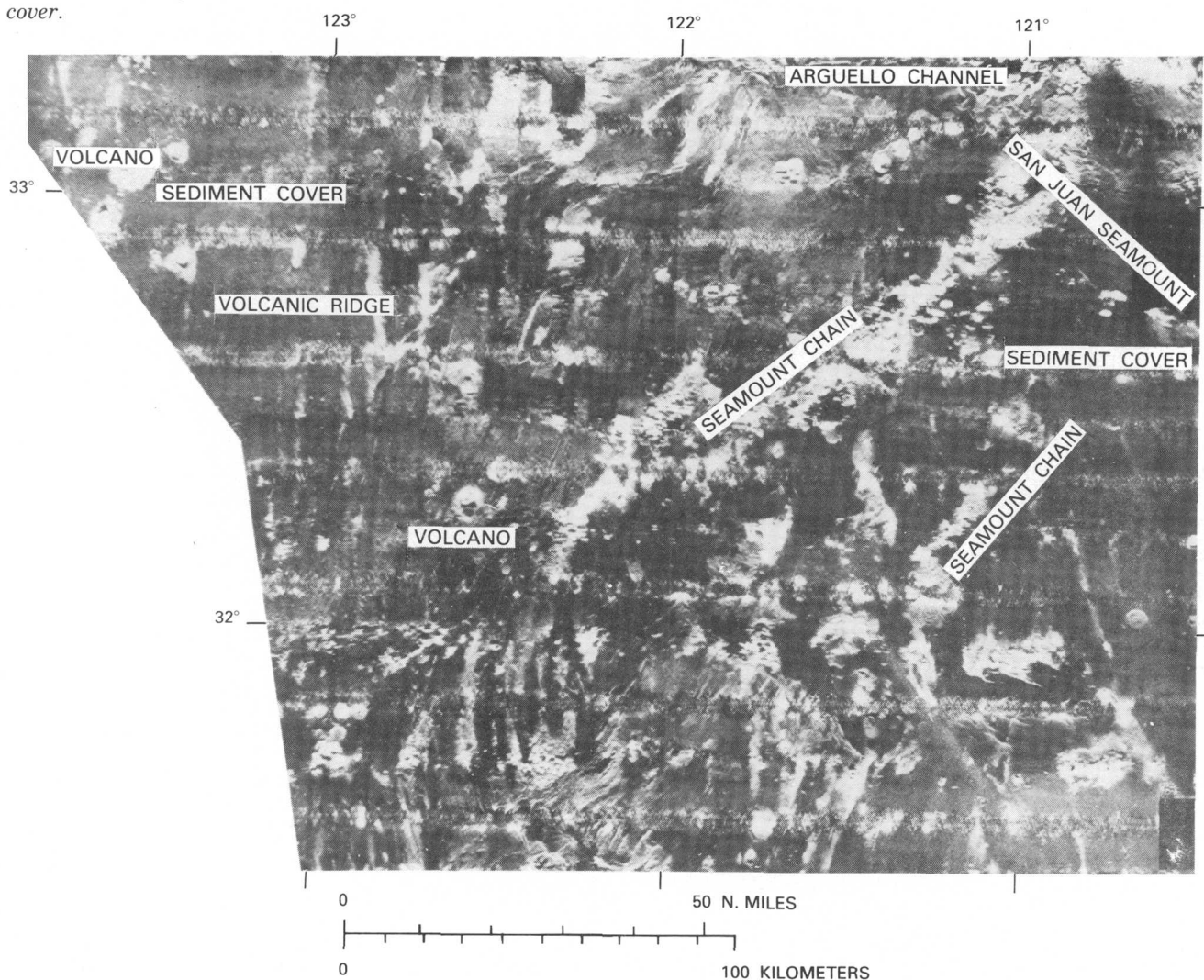
ridges attests to past changes in spreading rate and propagation of spreading centers. Both oceanic and terrigenous sedimentation have tended to subdue the rugged linear basement topography, especially away from the spreading centers toward older and deeper oceanic crust.

The continental slope in the region of convergent tectonics is crumpled into numerous folds that manifest themselves as discontinuous ridges on the sonographs (fig. 22). Submarine canyons and blankets of

sediment modify the steep compressional-ridge topography, the former tending to dissect and complicate it and the latter tending to smooth and simplify it.

Since completion of the EEZ-Scan field operations, the digitized data have been subjected to image processing and enhancement procedures through the assistance of the USGS Astrogeology Branch and the National Mapping Division. A recently constructed second-generation mosaic is significantly more detailed and smoother than the preliminary version be-

Figure 20. Digitally processed GLORIA sonograph mosaic off southern California that demonstrates light areas of igneous rock (volcanoes and basement ridges) and dark areas of sediment cover.



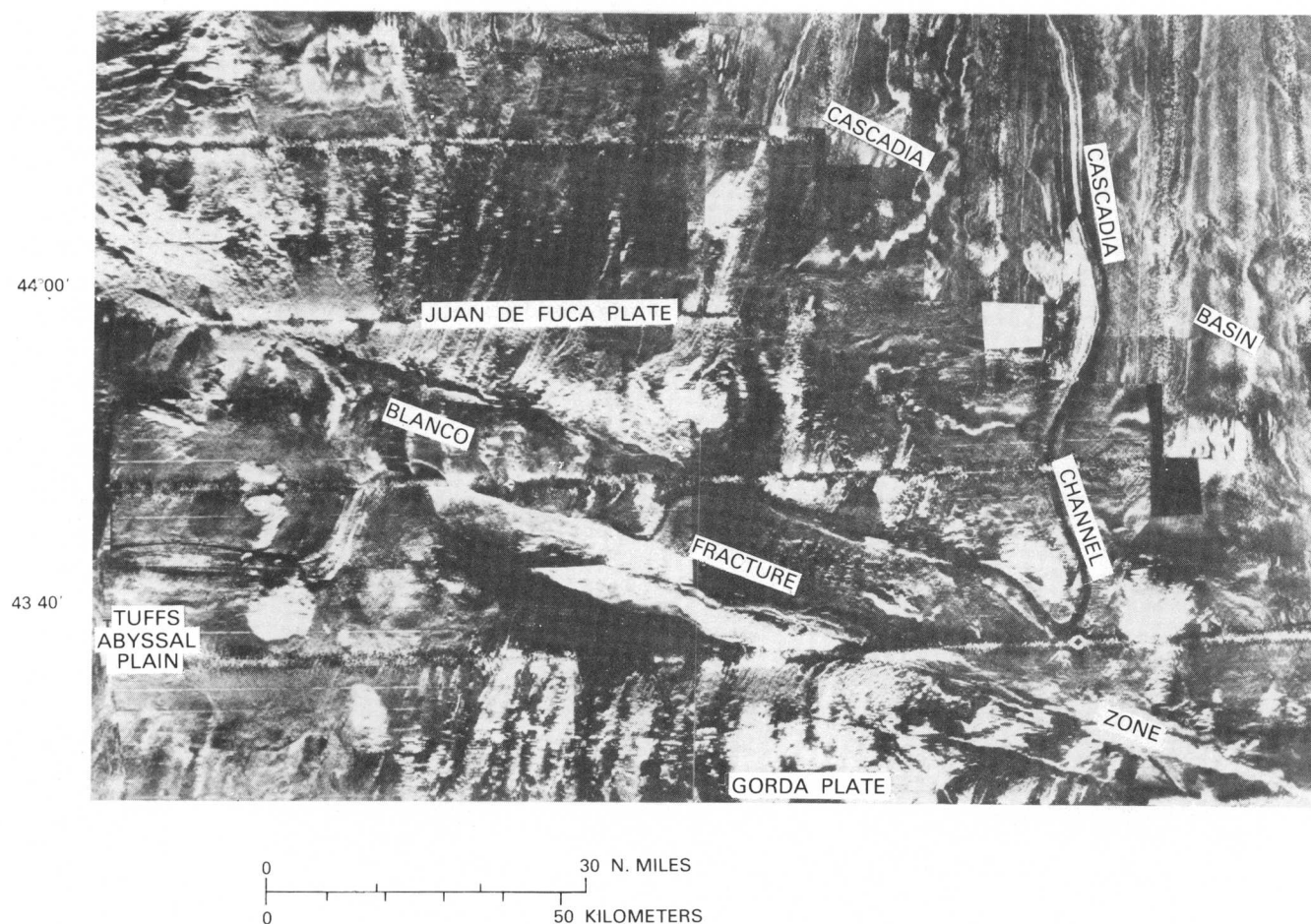
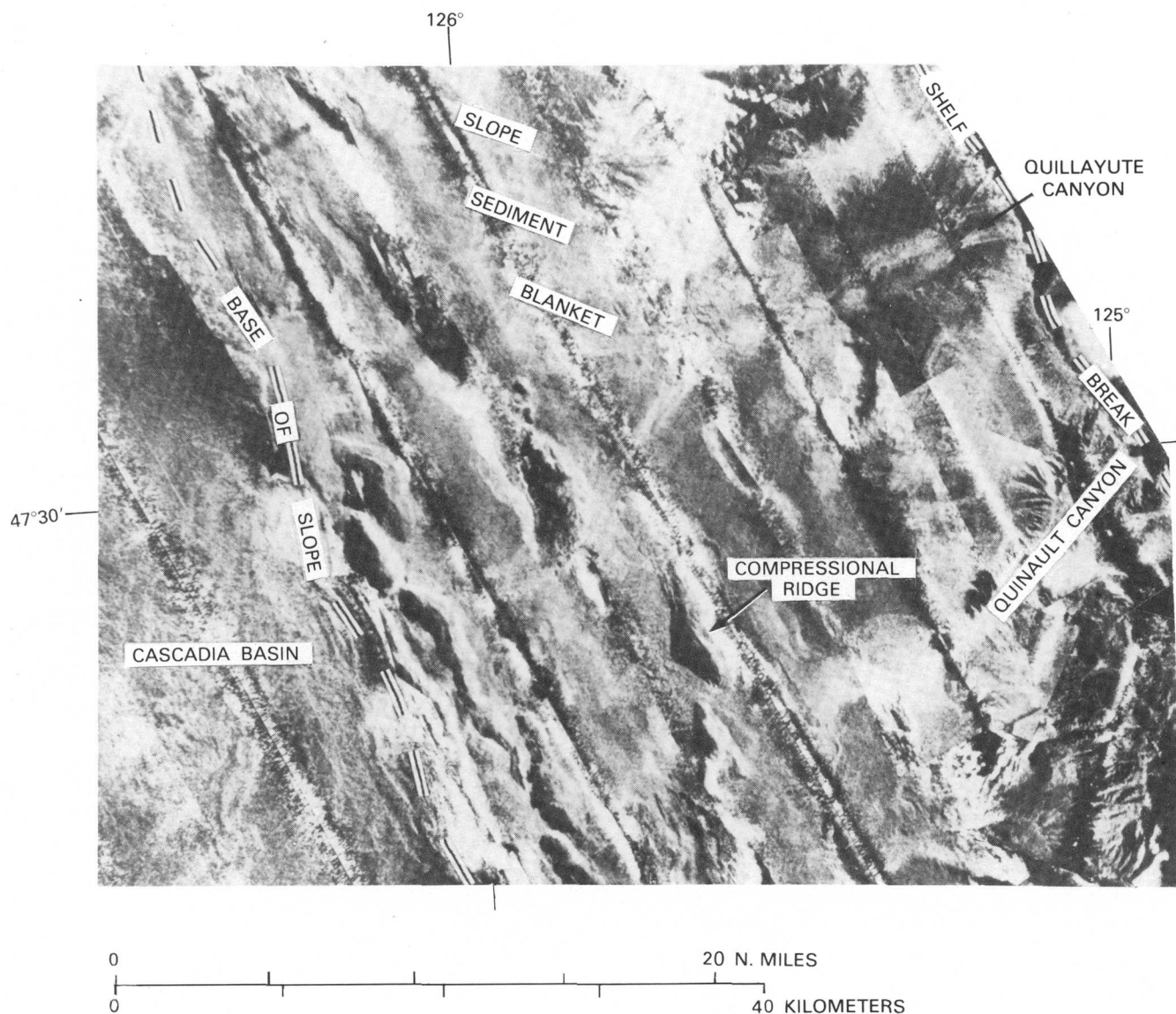


Figure 21. Seafloor geologic features off Oregon. Major plate-tectonic features are evident: Blanco Fracture Zone and spreading ridges of the Juan de Fuca and Gorda lithospheric plates. Cascadia Channel is incised more than 900 feet into the sediment of Cascadia Basin at the abrupt westward turn into the Blanco Fracture Zone.

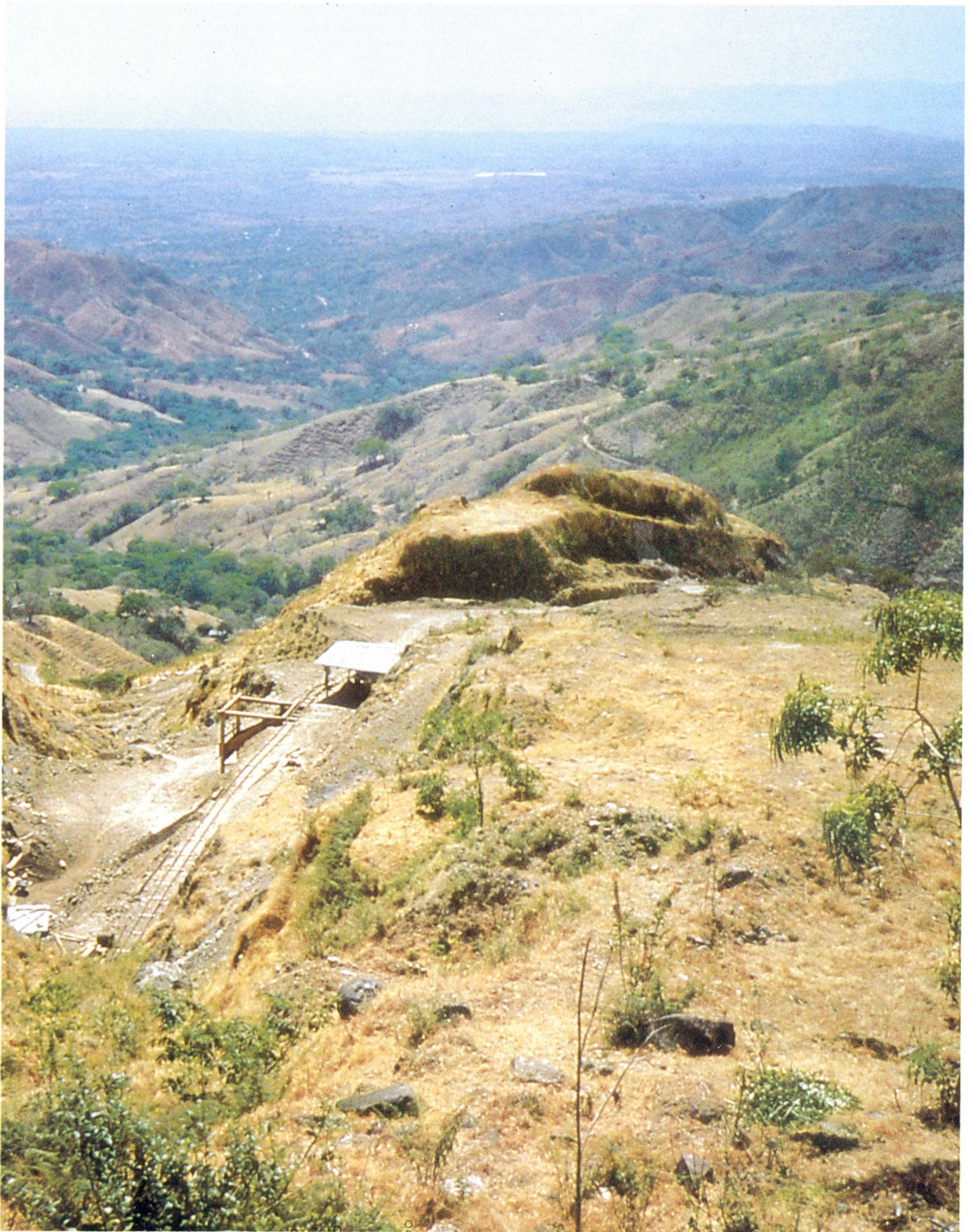
cause of removal of water-column pixels, correction of across-track shading gradients, and optimal stretching of the contrast range in all images. Further enhancement will be performed on an area- or feature-specific basis as scientific investigations proceed.

The mosaic and the interpretation are being compiled into 36 sheets, each covering 2 degrees of latitude and longitude at 1:500,000 scale, for publication as an atlas. Copies of the seismic-reflection and mag-



netometer profiles also will be included in the atlas, as will overlays of bathymetric contours and designation of named physiographic features. Continuation of Project EEZ-Scan to cover the remaining Pacific Ocean EEZ will commence in the summer of 1986 with a 3-month research cruise into Alaskan and Hawaiian waters. Upon completion and publication, "road maps" of the ocean floor will be available to the Nation for the first time.

Figure 22. A segment of the continental slope off Washington. The shelf break is at about 600 feet and the base of the slope is at about 7,500 feet water depth. Tectonic, erosional, and sedimentary features determine the slope morphology.



International Activities

Mission

Under the Organic Act, as revised, and the Foreign Assistance Act and related legislation, the U.S. Geological Survey is authorized to conduct investigations in foreign countries when such studies are deemed by the Departments of the Interior and State to be in the interests of the U.S. Government. The international activities, a part of the Geological Survey's program for more than 40 years, are undertaken with these principal objectives:

- To expand the scope and help achieve domestic research objectives through the comparative study of scientific phenomena abroad and in the United States;
- To obtain information about existing and potential foreign resources of interest to the United States;
- To develop and maintain relations with counterpart institutions and programs that will facilitate scientific cooperation and exchange; and
- To provide support for the international programs of other Federal agencies, including those of the U.S. Department of State, that contribute to foreign policy objectives.

Major Programs and Activities

Two general types of activities comprise the major international programs of the Geological Survey. One type, technical assistance to foreign countries or international organizations, uses funds from other Federal agencies, international organizations, or foreign governments as authorized under the Foreign Assistance Act. Such programs involve technology transfer to foreign nationals through advice, training, and demonstration; some require that Geological Survey personnel alone accomplish all project tasks. The other type, bilateral or multilateral scientific cooperation with foreign counterpart organizations under U.S. Government-approved cooperative agreements to achieve common research objectives, uses both funds appropriated for Geological Survey research and funds made available by the cooperating countries or organizations. The majority of such cooperative research activities are supported on the basis that each participant pays its own expenses. Activities in this category range from informal discussions and correspondence, through formal, jointly staffed research projects, to multinational projects focused on particular problems or topics.

Many related activities that form integral parts of the programs commonly stem from international work, for example, institutional development, exchange of sci-

Sacra Familia goldmine near Desmonte, Costa Rica. USGS geologists are working with Costa Rican counterparts to find new sources of gold and other valuable metals. Photograph by Sherman Marsh.

entists, training of foreign nationals, and representation of the Geological Survey or the U.S. Government in international organizations, commissions, or associations.

Formal training for foreign nationals was provided by the Geological Survey during fiscal year 1985 through the following courses: "24th International Remote Sensing Workshop," held in Sioux Falls, S. Dak., with 30 participants and "Techniques of Hydrologic Investigations," held in Denver, Colo., with 19 participants. In addition, the Survey provided or arranged on-the-job or academic training for 66 other

foreign nationals either at Geological Survey facilities or at other organizations on behalf of the Survey; the 115 trainees during 1985 came from 29 foreign countries. Also in 1985, the Geological Survey planned and administered programs for 47 visiting scientists from 22 countries who conducted cooperative research at the Survey or at Survey-selected institutions.

U.S. Geological Survey international activities in fiscal year 1985 are listed in the accompanying table. The following summaries describe various aspects of the programs.

International scientific activities conducted by the U.S. Geological Survey in fiscal year 1985

Country or region	Technical assistance activities
Bangladesh	Training of Geological Survey personnel.
Caribbean	Seismic hazards workshop in Puerto Rico.
Central America	Workshop on development of mineral, energy, and water resources and mitigation of geologic hazards.
Circum-Pacific	Earthquake and tsunami potential.
Colombia	Stream-flow modeling related to dam operations; training in earthquake risk assessment.
Costa Rica	Coal-resources assessment; mineral resources assessment.
Dominican Republic	Offshore geologic studies; phosphate resource assessment.
East Asia	Critique of multinational coal information system; consultancies on remote-sensing program; U.S. Government representation at United Nations regional meetings.
Egypt	Mapping of subsurface geologic features by remote sensing; training in map preparation and publication.
El Salvador	Earthquake hazards reduction.
Ethiopia	Training in mineral-resources study.
Fiji	Study of coastal sediment distribution.
Guatemala	Earthquake hazards reduction.
Haiti	Coal-resources investigations.
Indonesia	Volcanic research and hazards mitigation; negotiations for consultancies in marine geoscience program.
Italy	Seismic and volcanic monitoring program.
Jordan	Seismic systems; water resources.
Kenya	Regional remote-sensing facility; Landsat imagery; map publication.
Latin America	Earthquake disaster mitigation in Andean region.
Liberia	Analytical laboratory consultancy; mineral-resources project development.
Mauritania	Mineral- and energy-resources project development.
Mexico	Surface-water resources.
Morocco	Landsat base-map compilation; mineral deposit assessments; geophysical investigations.
Oman	Mineral-resources studies.
Pakistan	Coal-resources assessment; water sediment transport.
Panama	Earthquake hazards reduction; coal geology program development.
Papua New Guinea	Mineral-resources data systems and assessment.
Paraguay	Hydrologic hazards related to floods.
Peru	Mineral-resources assessment; flood hazards in Cuzco.

International scientific activities conducted by the U.S. Geological Survey in fiscal year 1985—Continued

Country or region	Technical assistance activities
Philippines	Volcanic hazards analyses and mitigation; coal-resources assessment.
Qatar	Water resources and artificial recharge of ground water.
Saudi Arabia	Geologic mapping and mineral-resources assessment; hydrologic studies; Landsat image base maps; seismic studies.
Southeast Asia	Earthquake engineering and hazards mitigation; engineering seismology.
South Pacific	Marine cruise for hydrocarbon resources studies; workshop on coastal processes mapping; cobalt crust studies on Marshall Island seamounts; crater studies in Marshalls; mineral reconnaissance in Palau.
Sri Lanka	Ground-water-resources assessment.
Sudan	Landsat base-map compilation; map publications.
Turkey	Karst geophysics consultancy.
Venezuela	Hydrology and water resources of Orinoco Basin.
Worldwide	Global seismic network; hydrologic training course; remote-sensing training workshop.
Country or region	Scientific Cooperative Activities
Antarctica	Topographic and satellite image mapping; marine geological and geophysical surveys; mineral-resources studies.
Australia	Antarctic mapping; tectonics and resources of South Pacific.
Bolivia	Subvolcanic intrusions related to ash-flow tuff terranes and tin resources.
Brazil	Mineral-resources studies; river-sediment studies; technology transfer in remote sensing.
Canada	Strategic minerals inventory; sea-floor mineral exploration; borehole geophysics; continental deep seismic reflection; cartographic data exchange; techniques for hydrologic data analysis.
Chile	Volcanic and seismic risk investigations; March 3, 1985, earthquake studies.
Costa Rica	Geothermal energy consultation; magnetic observatory instrumentation; volcanic studies.
East-Southeast Asia	Base-map preparation (1:2,000,000-scale); sedimentary basin analysis; tin geology review.
France	Marine hydrothermal mineralogy; mineral deposit modeling.
Germany	Strategic minerals inventory; marine seismic studies of continental margins; radioactive waste; petroleum-resource assessment; Antarctic research; multipurpose cadastral information exchange.
Greece	Geochemistry of petroleum; structural geology studies.
Hungary	Seismic stratigraphy; seismic modeling, electromagnetic, mineralogic, paleomagnetic, and paleoenvironmental studies.
Iceland	Volcanic, geothermal, and glacial studies.
India	Science and technology review for possible cooperative program development.
Italy	Seismology and seismic-risk assessment; geochemistry; volcanology; marine geology.
Japan	Joint panels on earthquake prediction, marine geology, and marine mining; ore deposit research; landslide studies; geodetic leveling.

International scientific activities conducted by the U.S. Geological Survey in fiscal year 1985—Continued

Country or region	Scientific cooperative activities
Mexico	Volcano studies; geochemical and geophysical exploration; mineral and metallogenic map analyses; regional structure and stratigraphic studies; tectonostratigraphic terrane studies; base-map compilation of U.S. border area.
New Zealand	Antarctic mapping.
Pacific region	Circum-Pacific mapping program; chromite resource studies.
People's Republic of China	Surveying, mapping, and geographic information systems; surface-water hydrologic studies; China digital seismic network; Beijing digital seismic network computer system; magnetic and deformation observations; crustal stress measurements; intraplate active faults and earthquakes; fault zone xenoliths; landslide and debris-flow studies; rock mechanics; petroleum geology of carbonate rocks; saline lakes and potash deposits; exploration geochemistry; coal-derived gas; isotope geology.
South Africa	Strategic minerals inventory; seismic studies.
South Korea	Offshore petroleum-resources and geothermal-resources assessments.
Spain	Ground-water resources; remote sensing for mineral deposits; earthquake research; marine geology of continental margins.
Sweden	Nuclear waste disposal; subsurface water transport.
United Kingdom	Marine geology; world coal resources; strategic minerals inventory.
U.S.S.R.	Joint committee on earthquake prediction.
Worldwide	International Strategic Minerals Inventory; World Energy Resources Program; geologic and hydrologic hazards mitigation training.
Yugoslavia	Crustal structure research; seismology and earthquake hazards; subsidence research; geochemical surveys; remote sensing; engineering geology; geophysics.

Development of Mineral, Energy, and Water Resources and Geologic Hazards Mitigation in Central America

A workshop entitled "Development of Mineral, Energy, and Water Resources and the Mitigation of Geologic Hazards in Central America: A Workshop Concerning Opportunities for Resource Development" was presented in Antigua, Guatemala, April 21–27, 1985, by the U.S. Geological Survey assisted by the Instituto Centroamericano de Investigacion y Tecnologia Industrial (ICAITI), with funding provided by the U.S. Agency for International Development (USAID).

The workshop was conducted under the assumption that contributions to the economic self-sufficiency of the nations of Central America, and thus to the political stability of the region, to be effective must reduce the balance of payments problems in the region, substitute local for imported commodities, augment the availability of local jobs, increase the efficiency of agricultural production, and transfer technology, so

that local scientists will be able to conduct future surveys of the resource potential of the region without outside assistance.

Objectives of the workshop were to make an initial assessment of the nature, scope, and availability of earth and water resource data; to identify potential geologic hazards in the region; to identify opportunities for resource development and hazards mitigation; to identify those factors that might inhibit resource development; and to identify those programs needed to further appropriate development. Representation included Belizean, Guatemalan, Honduran, Salvadoran, Costa Rican, and Panamanian governmental agencies concerned with earth and water resources and geologic hazards, the Inter-American Development Bank, and geoscience and resource development specialists from the U.S. Department of the Interior.

The workshop met in plenary session for the first 2 days, during which time Central American representatives presented assessments of the state and needs for mineral, energy, and water resource development and hazards mitigation in each of their countries and representatives of the Department of the Interior (Bureau of Mines, Bureau of Reclamation, and the Geological Survey) presented topical papers on a broad range of resource development subjects. Representatives subsequently participated in discussion groups, each chaired by a Central American representative, to determine regional and local needs for development. Although recommendations of the discussion groups ranged widely, all agreed upon the following:

- Need for training (both for professional growth and for basic academic instruction) conducted chiefly within the region and preferably at the Central American School of Geology, University of Costa Rica;
- Utilization of ICAITI as a unique Central American center for geoscience and related technology; and
- Centralization of all earth science activities within each of the participating Central American countries into one institution in each nation.

The most important recommendations presented by individual discussion groups on the final day of the conference were as follows.

Geologic Framework Studies

- Conduct geologic mapping within each country as a base for assessment, exploration, and development of mineral, energy, and water resources as well as mitigation of geologic hazards.
- Place in an archive context (ICAITI) all available geophysical and geochemical data.
- Produce derivative maps as appropriate for both nongeological and geological users.

Geologic Hazards

- Construct a seismic net where one does not now exist in Central America and establish a regional seismological association.
- Map all known faults and volcanoes and survey landslide/mudflow potential in the region as a preliminary step in geologic risk assessment.
- Convene meetings of directors of geologic hazards agencies to coordinate activities and consider requests for assistance from outside the region.

Water-Resource Management

- Undertake an assessment of the region for surface- and ground-water resources, including quality, and establish a regional information center and a hydrological association.
- Analyze extreme events to develop statistical tools for prediction of maximum and minimum flow in ungaged areas.
- Conduct assessments for rural water supply, small irrigation, and low-head hydropower projects.

Mineral-Resources Assessment

- Promote technology transfer in updated assessment methodologies.
- Assess development requirements in each country, encourage searches in unprospected areas, and create an information center accessible by both private and public sectors.

Regional Energy Resources Assessment

- Establish a regional energy resources laboratory with appropriate equipment.
- Conduct training for personnel involved in technology transfer and management of energy resource programs.

Future of Exploration in Central America

- Prepare a regional geologic map and a stratigraphic lexicon for each country.
- Designate energy resources, gold and silver, platinum family minerals, nickel, and heavy mineral placers as high priorities.
- Provide technical advice to executive governmental levels throughout the region to formulate mining codes.

Training, Technology Transfer, and Information Management

- Define national and regional goals in all earth science disciplines.
- Centralize library information on the geosciences at the chief university in each country or develop a shared regional library.

The Geological Survey's assistance in the geosciences to the countries of Central America is a continuation of long-established and enduring ties to the region. Some countries have a highly developed geoscience discipline, and basic geologic data have been

collected to assess mineral, energy, and water resources. Other countries have few trained personnel, and little information has been assembled for assessments. The role of the Geological Survey in these latter cases will be to cooperatively determine priorities for short-term geoscience projects and to assist the foreign governmental agencies in preparation of suitable proposals to support those priorities.

Global Resources

The Geological Survey conducts research on foreign energy and mineral resources in order to increase the number of analogs available for assessing domestic potential and to assess the foreign potential available to satisfy domestic and world needs for these resources. During 1985, using both appropriated and reimbursable funds, Geological Survey scientists continued their studies of foreign energy resources through the World Energy Resources Program; compiled and exchanged geologic and mineral economic information on the world's major mineral deposits in the International Strategic Mineral Inventory; and topically studied selected world-class mineral deposits. The Geological Survey also provided training and support for reporting of foreign mineral data in the State Department Regional Resource Officer Program.

World Energy Resources Program

Because the World Energy Resources Program was not funded in fiscal year 1985, studies were limited to areas of reimbursable contract and to completion of in-progress scientific publications. Activities included:

- Update study of Barents Sea and surrounding lands. New drilling reports from the Norwe-

gians plus a field trip to Svalbard permitted significant new understanding.

- Basin studies of western China provided the first modern English-language synthesis of the general geology and petroleum geology of this vast area.
- Basin studies from Chinese, Russian, and English literature initiated in eastern China.
- Completion for publication of a report on studies of the petroleum geology of south Asia, including Pakistan, India, Sri Lanka, Bangladesh, and Burma.
- Completion for publication of a report on updated studies of Indonesia.
- Completion for publication of a report on studies of eastern Siberia that provided the first English language synthesis of the petroleum geology of that region.

International Strategic Mineral Inventory (ISMI)

This inventory, a cooperative undertaking of six industrialized countries, has as its goal the collection, analysis, and dissemination of information on major world deposits of selected strategic mineral commodities. By cooperating in this effort, earth-science and mineral-resource agencies from Australia, Canada, Germany, South Africa, the United Kingdom, and the United States are able to obtain reliable information on production, reserves, and identified resources of major mineral deposits in order to improve the basis for sound mineral-policy decisions. At the same time, participation in the ISMI allows countries to avoid a great deal of duplication of effort and to encourage scientific exchange between mineral-commodity specialists. The United States representation in the ISMI is by the U.S. Geological Survey and the U.S. Bureau of Mines. Some recent activities include:

New Worldwide Directory

The U.S. Geological Survey has issued as Circular 934 a new edition of the Worldwide Directory of National Earth-Science Agencies and Related International Organizations. The publication lists national earth-science agencies for 160 countries and 87 international organizations that are concerned with one or more of the earth sciences. This 102-page directory provides the name, address, and, if available, the name of the chief administrator of more than 900 major governmental earth-science agencies that have functions similar to those of the U.S. Geological Survey; each agency is coded as to its major functions: geologic, hydrologic, cartographic, or regulatory.

- ISMI summary reports were published on manganese, chromium, and phosphate as Geological Survey Circulars 930-A, 930-B, and 930-C. These circulars contain summary tables of location, geologic, resources, and production data collected for all deposits in the inventory as well as maps, graphs, and text that summarize the data.
- The fifth meeting of the ISMI Working Group was held in September 1984, at Perth, Western Australia. Initial work on compilation and summary reports for cobalt, graphite, and vanadium was reviewed. Field visits to nickel, gold, aluminum, titanium sands, and tin/tantalum deposits were arranged as part of the meeting.
- Data records for manganese, chromium, and nickel deposits from the ISMI were added to the Geological Survey Mineral Resources Data System (MRDS).
- The ISMI summary report for nickel was completed and scheduled for publication in late 1985 or early 1986.
- Work was started on compilation of platinum-group-element, titanium, and tungsten records.
- The sixth ISMI Working Group meeting was held in St. Ives, Cornwall, England, in October 1985.
- During the last 3 years, a program of technical assistance in coal-resources assessment has been carried on by the Geological Survey with Costa Rica in cooperation with the Gerencia de Exploracion de Refinadora Costarricense de Petroleo (RECOPE) and under the auspices of the Agency for International Development (AID). General reconnaissance was done in nine areas where coal had been reported. Six of these areas received surface geologic studies. Surface exploration, drilling, and bore hole geophysical logging are being done in two of the six areas. Because the coal exploration program received publicity in the national media, citizens reported two more areas of coal occurrence; one of these areas is now receiving geologic reconnaissance study. Technology transfer and on-the-job training of RECOPE counterparts were primary elements of the technical assistance program that terminated at the end of fiscal year 1985, and several Costa Rican counterparts can now carry on coal-resource assessments. More than 20 drill holes have been completed, and core samples needed for quality determinations have been obtained. Approximately 15 to 17 million tons of coal have been estimated in four coal beds of primary interest in an intensely studied area. The estimate will be formally reported to AID along with results of laboratory analyses. The data will be used in determining mining feasibility for development of the coal resources in this area.

Cooperative Energy Resource Investigations

During fiscal year 1985, the following energy resource investigations produced significant results:

- Geological Survey analyses of material from Saudi Arabia verified that the Kingdom has a subbituminous coal deposit similar to a coalified log from Utah. This discovery provides the impetus for expanding exploration in Saudi Arabia to locate ancient interchannel or deltaic swamps that might contain sizable coal beds.
- In the Philippines, the Geological Survey determined that Semirara Island, off the coast of the Island of Mindoro, contains adequately large minable reserves of coal of acceptable quality to support a conversion of the Sucat electric generating station near Manila on the Island of Luzon from imported fuel oil to coal-water-mix (CWM) fuel. The coal assessment was done as part of an AID-funded project to determine the feasibility of introducing CWM fuels to the Philippines.
- CWM fuel technology is considered commercial in the United States and other developed countries. The project results are highly positive: the coal supply is adequate, formulation of a

Mineral Deposit Investigations

World-class mineral deposits studied during fiscal year 1985 included:

- South African nickel and platinum deposits to serve as models for exploration of deposits in Mesozoic basins of the Eastern United States.
- Potentially major nickel deposits in the High Atlas Mountains of Mauritania as alternative foreign sources and as analogies for similar deposits in Mesozoic basins of the Eastern United States.
- Titanium-bearing sands along the southeast and

west coasts of Africa as alternate sources of this strategic mineral.

- Polymetallic sulfide deposits of the Semail Nappe, Oman, as alternate source and as analogy to submarine deposits in the United States Exclusive Economic Zone of Gorda Ridge in the Pacific Ocean.
- Massive sulfide deposits of the Green Tuff Belt of Japan, classic localities for Kuroko-type ore deposits that occur in volcanic belts in the United States, especially in Alaska.
- Electrical conductivity studies in Saudi Arabia identified a potentially mineralized area that will be further investigated using geophysical techniques and drilling. Result of these studies may make it possible to develop and define conceptual ore-occurrence models that could be extrapolated to other areas.
- Epithermal gold and other mineral deposits of Papua New Guinea that are newly developing and potentially very large sources for precious and other metals.

Training Program

Under the State Department Regional Resource Officer Program, the Geological Survey and the Bureau of Mines share responsibility for obtaining information and reporting on domestic and foreign mineral resources. The Survey focuses on resource potential and exploration, whereas the Bureau seeks to document identified reserves and exploitation. Foreign data is obtained largely through periodic reports from American Embassies in mineral-producing countries. Nine embassies, in key mineral countries, have Regional Resource Officers with primary responsibility for resource reporting. In other embassies, economic officers provide mineral data as an additional duty. The Departments of State and Interior agreed in 1983 to strengthen foreign mineral reporting through a cooperative program of training, review of candidates for resource officer positions, and review of resource officer posts. Since that time the Geological Survey and Bureau of Mines have arranged for and provided instruction in the geology, engineering, and economics of mineral resources for newly assigned resource officers. The Geological Survey's portion of this training includes participation by commodity geologists to explain needs for mineral intelligence and to conduct field trips for examination of mines and exploration areas in the Western United States. Geological Survey and Bureau of Mines mineral experts have also provided instruction to resource officers and economic officers at meetings held yearly on a rotational basis in one of the major

regions of the world. Recent meetings were held in 1984 for the Asian region in Phuket, Thailand, and in 1985 for the African region in Harare, Zimbabwe. Additional efforts to strengthen the reporting program include plans to have Geological Survey mineral experts and State Department resource officers visit and jointly prepare reports on selected foreign mineral deposits and districts.

Under an agreement with the Ministry of Agriculture and Water, the Kingdom of Saudi Arabia, the Geological Survey's Water Resources Division continues to define the availability and quality of ground and surface waters of the Kingdom, stressing modern methods of data storage, retrieval, and analysis, while training Saudi nationals in these methods. A major effort in data synthesis has culminated in the publication of the bilingual "Water Atlas of Saudi Arabia."

Significance of Agricultural Minerals in Relief of Starvation

Geological Survey scientists cooperated with geoscientists from the United States' private and public sectors and from foreign countries in research on agricultural minerals (phosphate, zeolite, potash). Chief objectives of the work were to discover new and improved methods of identifying agricultural minerals essential to increased agricultural production and to teach these methods to geoscientists in the lesser developed countries. Significant results of this research included the following:

- Ability to rapidly map potential zeolite-bearing rocks, which are soil and feed amendments, by using Landsat Thematic Mapper spectral data;
- Identification, using remote-sensing methods, of spectral signatures that distinguish various zeolites;
- Initiation of studies in the development of spectral signatures that would allow mapping of phosphate rock, a basic raw material for fertilizer, in areas of light vegetation; and
- Initiation of studies in the development of remote-sensing methods of mapping zeolite-bearing rocks in heavily vegetated terrane.

The Geological Survey sponsored three international phosphate-agricultural minerals symposia/workshops to exchange results of research and to encourage exploration for agricultural minerals in developing countries. Two workshops were held

under the auspices of the International Geological Correlation Project No. 156, Phosphates, in Greenville, N.C., under the joint sponsorship by the East Carolina University. During the first, July 9–13, 1984, discussions by delegates from Colombia, Costa Rica, Dominican Republic, Guatemala, Honduras, Jamaica, Mexico, and the United States focused on the potential for phosphates in Central America and the Caribbean Basin. The second workshop, May 6–17, 1985, included a field trip along the Atlantic phosphate belt as far south as Florida. This workshop focused on newly developed theory in phosphate deposit models and included a week-long training session on techniques for phosphate exploration. Potential for phosphate, zeolite, and potash resources was also a major discussion topic during the Central American workshop in Guatemala, April 21–27, 1985.

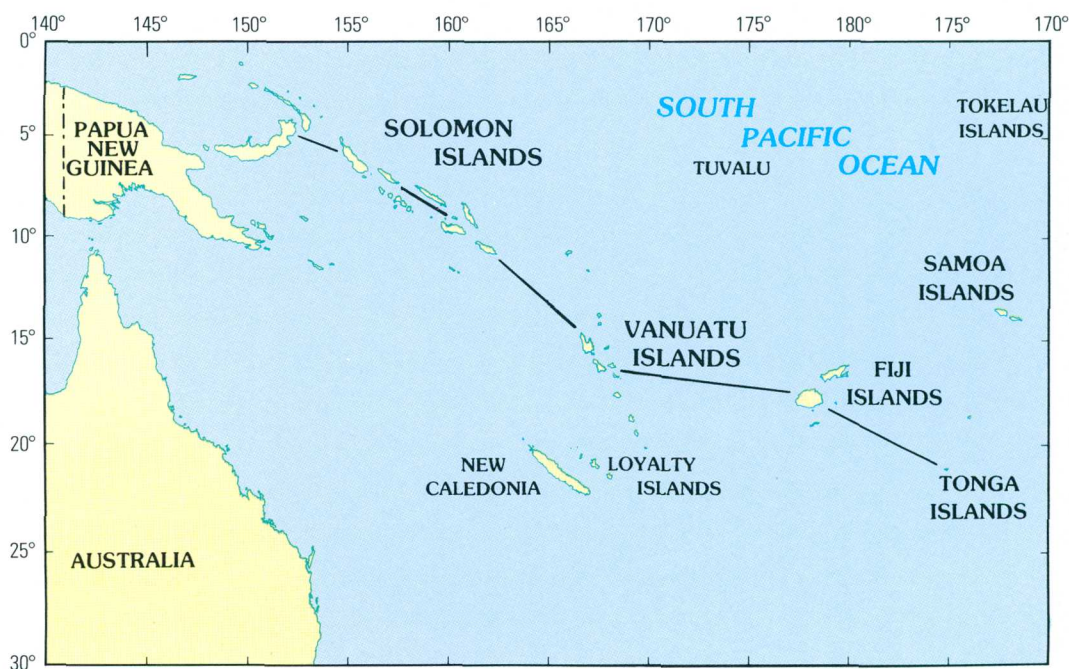
The Geological Survey continues to train geoscientists from developing countries in exploration for agricultural minerals in the belief that a most effective remedy for worldwide hunger is to increase agricultural productivity through the transfer of appropriate technology and the use of materials and skills indigenous to the developing countries.

Investigating the Hydrocarbon and Mineral Resources of the Southwest Pacific

By Florence L. Wong and H. Gary Greene

Under a Tripartite Agreement with Australia, New Zealand, and the United States in cooperation with the United Nations-sponsored Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC), the Geological Survey completed over 10,800 miles of data collection from aboard the R/V *Samuel P. Lee* during 1984. The resulting data has contributed greatly to the volume of knowledge about the basic framework geology, the hydrocarbon and mineral resource potential, and the geologic hazards in a tectonically complex region. In this region, the Australia-India plate is being subducted beneath the Pacific plate along a sinuous boundary between Papua New Guinea and Tonga, which gives rise to a series of island arcs and associated trenches that are sites of major deposition and magmatic hydrothermal mineralization.

Approximate route of the Research Vessel Samuel P. Lee during the 1984 survey under a Tripartite Agreement with Australia and New Zealand, in cooperation with the Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas sponsored by the United Nations.



The 1984 survey of the Tonga Ridge found a southward continuation of the thick sedimentary wedge overlying the ridge platform that was delineated during a 1982 survey. The existence of an extensive (greater than 66 miles long) magma chamber beneath the Valu Fa Ridge, 264 miles west of the Tonga Ridge, was confirmed. Sampling over the Valu Fa Ridge produced anomalously warm water and warm sediment at the sea bottom, suggesting that this may be a site of base-metal mineralization. The geometry and chronology of the separation of Lau Ridge from Tonga Ridge and the boundary of the southern Lau Basin with the Hunter fracture zone also were addressed during this survey. All of the data gathered are contributing to our understanding of arc-island tectonics, to determining the age, evolution, and extent of the as-yet-unexplored marginal sedimentary basins, and to assessing the hydrocarbon and mineral potential of the Tonga Ridge.

In Vanuatu, new data were acquired on the geology of the shallow- and deep-water sedimentary basins that were defined in the previous surveys. The newly named Vanikolo basin, which straddles northern Vanuatu and the southeastern Solomon Islands, is a likely area for further hydrocarbon exploration.

Significant data were collected about hazards, deposition, and mineralization in a volcanically active area in the offshore area of eastern Epi Island. The contact of the D'Entrecasteaux fracture zone with the New Hebrides trench is characterized by basinal or

abyssal plain sediments in the west, an accretionary wedge in the central area, and volcanic units in the east.

Surveys in the Solomon Islands and Papua New Guinea refined our information on the limits of sedimentary basins and improved the correlation of onshore and offshore geology. Trench-fill sediments northeast of Bougainville and the tectonic relation of the oceanic basement of Ontong Java Plateau to the inner wall of the Kilinailau Trench were examined.

A repeat survey of Rabaul Harbour, Papua New Guinea, aided the Rabaul Volcanological Observatory in monitoring the current magma activity and deformation. In the past year, several emergency alerts for volcanic eruptions that threatened nearby communities were issued.

The combination of the 1982 and 1984 surveys will give us more information about hydrocarbon resources in geologically young volcanic regions that have received little attention, but which may be a major economic resource for the developing Pacific island nations. These surveys have been funded by the U.S. Geological Survey, the U.S. Agency for International Development, the Australian Development Assistance Bureau, and the New Zealand Ministry of Foreign Affairs, External Aid Division. The surveys have been staffed by an international team of geologists, geophysicists, and technicians led by co-chief scientists from the U.S. Geological Survey, CCOP/SOPAC, and the funding nations.

Administrative Division

Mission

The Administrative Division provides continuing administrative direction and coordination to the support service aspects of the scientific, research, and technical programs of the U.S. Geological Survey. These administrative services include such essential functions as financial management, personnel services, procurement activities, property and space management, management analysis and improvement efforts, safety and occupational health, and administrative systems management.

Budget and Personnel

The cost of the central administrative services provided to the U.S. Geological Survey by the Administrative Division totaled about \$25 million in fiscal year 1985. Division staffing consisted of about 475 employees. These employees are located primarily at the Reston, Va., headquarters and two Regional Management Offices in Denver, Colo., and Menlo Park, Calif.

Program Highlights

Consistent with the objective of Reform '88 and other governmentwide initiatives, in 1985 the Administrative Division continued its strong emphasis on improving the economy, efficiency, and effectiveness of Geological Survey administrative operations. Indicative of a "do more with less" approach, the Division streamlined its field structure with the abolition of its Eastern Region Management Office and the assumption of its functions by headquarters staff in the Administrative Division. Through automation and other improvement programs such as those highlighted below, the Division was able to maintain high quality and responsive administrative support services despite workload increases.

Automation of Services

Payroll/Personnel System

During fiscal year 1985, the Administrative Division coordinated the completion of the Geological Survey's conversion to the Department of the Interior's single integrated payroll/personnel system (PAY/PERS). Conversion to a single system effected a more efficient administrative system by eliminating costs incurred for

duplicate systems development, maintenance, and operation. The PAY/PERS system performs a full range of payroll and personnel functions, calculating and reporting, automated reporting, and query capabilities. An evaluation is now underway to improve operation of the system within the Geological Survey to best meet the Bureau's specific needs. This effort is focusing on streamlining timekeeping, personnel, and payroll front-end processing systems and procedures, and on enhancing the PAY/PERS reporting and query capabilities.

Personnel Action Requests

The Geological Survey is serving as the Department of the Interior's principal architect in designing and developing an automated Personnel Action System (PAS). The Administrative Division, with the assistance of the Information Systems Division, is undertaking this task. The system will automate the Personnel Action Request process, from the initiation of a Request through its review and approval and its final transmission to the Department's PAY/PERS system. The net effects of this automated system will be to expedite the process and to acquire more accurate and complete personnel information. Important features of the PAS will include the capability of providing up-to-date information on Personnel Action Requests, producing management reports, and expanding to include other personnel applications. Systems analyses, design, and a majority of the programs providing for the electronic transmission of information to the servicing personnel offices were completed in fiscal year 1985. The complete system is scheduled to become fully operational within the Geological Survey in fiscal year 1986. The Department then will assess its application to other bureaus.

Budget Information Management System

The Budget Information Management System (BIMS) is an automated system providing bureau managers at all levels of the organization vital budget information in real time. This system was developed by the Administrative Division and became fully operational in fiscal year 1985. The BIMS takes advantage of the Geological Survey's mainframe data base management system for interactive data entry, updating, and querying, and it interfaces with the conventional files of the Financial Management System. BIMS users have experienced reduced error rates for data entry, increased capability to respond rapidly to funding fluctuations, and an increase in

productivity due to improved quality, accuracy, and timeliness of information.

Microcomputers receive summary budget data from the mainframe for further analysis through the use of spreadsheet technologies. New capabilities have been established to report planned obligations by program element against actual obligations and perform trend analysis, forecasting, and modeling. Results are reported in tabular and graphics form to provide a clearer picture of the budget to management.

Geological Survey Records Management Program Commended

The National Archives and Records Administration (NARA) has cited the Geological Survey's records disposition scheduling program as "outstanding" in its April 1985 Report to Congress. In commenting on key records management improvements in the report, officially titled *Fiscal Year 1984 Report to Congress on the Records Disposition Activities of the Federal Government*, NARA highlighted efforts authorizing disposition of nearly 20,000 cubic feet of Water Resources Division streamflow, water quality, and other records in the Federal Records Centers. This is just one example of the strides the Geological Survey has made over the last 3 years in managing its records in all of its divisions. The commendation is a direct reflection of the collaborative efforts between the Administrative Division and the program divisions.

Procurement

Whether in personnel, financial, records management, or any of its other programs, in fiscal year 1985 the Administrative Division again demonstrated that it plays a key and essential role in direct support of the Geological Survey's earth science missions. Several significant contract awards in 1985 reflected, for example, the procurement and contracting contribution in this regard:

- Two contracts for development and production of digital mapping techniques, funded by the Defense Mapping Agency. These contracts provide for first-time-ever production of maps through digital technology.
- GEONET—this contract provides a nationwide network for transmission of Geological Survey data through telecommunications systems. The estimated 5-year life cycle cost of this contract is

\$20 million, representing a 30 percent savings over previous costs. Currently in use throughout the Geological Survey, the network is also available to other Department of the Interior bureaus and offices.

- Award of a contract to provide and install earthquake monitoring equipment in the first seismic station in Antarctica. Installation is scheduled for the upcoming summer season in Antarctica. When operational, this station will become part of the U.S. Geological Survey Global Telemetered Seismic Network.

Colocation of U.S. Geological Survey Offices, Anchorage, Alaska

February 1985 marked the realization of a long-standing goal of the U.S. Geological Survey to colocate primary activities of the program divisions in Anchorage, Alaska. This was achieved by establishing a Geological Survey "earth science center" on the Alaska Pacific University campus.

The Branch of Alaskan Geology of the Geologic Di-

vision occupied Gould Hall on the Alaska Pacific University campus in November 1981. Relocation of activities of the National Mapping and Water Resources Divisions to a new facility adjacent to Gould Hall was completed in January 1985. Arrangements for construction and leasing of the new building, which was dedicated in February, involved cooperation between officials of the University, the General Services Administration, and the Geological Survey.

Housing our activities together sets the stage for a more cohesive approach in carrying out our mission in Alaska, including interdisciplinary research essential to solving a wide range of geotechnical problems found in the far north.

Colocation will be more convenient to visitors to Geological Survey offices and will result in cost savings from mutual use of supporting resources such as laboratories, data processing equipment, and technical files. The campus location also affords the added advantage of interaction with faculty and students of Alaska Pacific University and the adjacent Anchorage campus of the University of Alaska, as well as convenient access to the consortium library maintained by the schools.

Information Systems Division

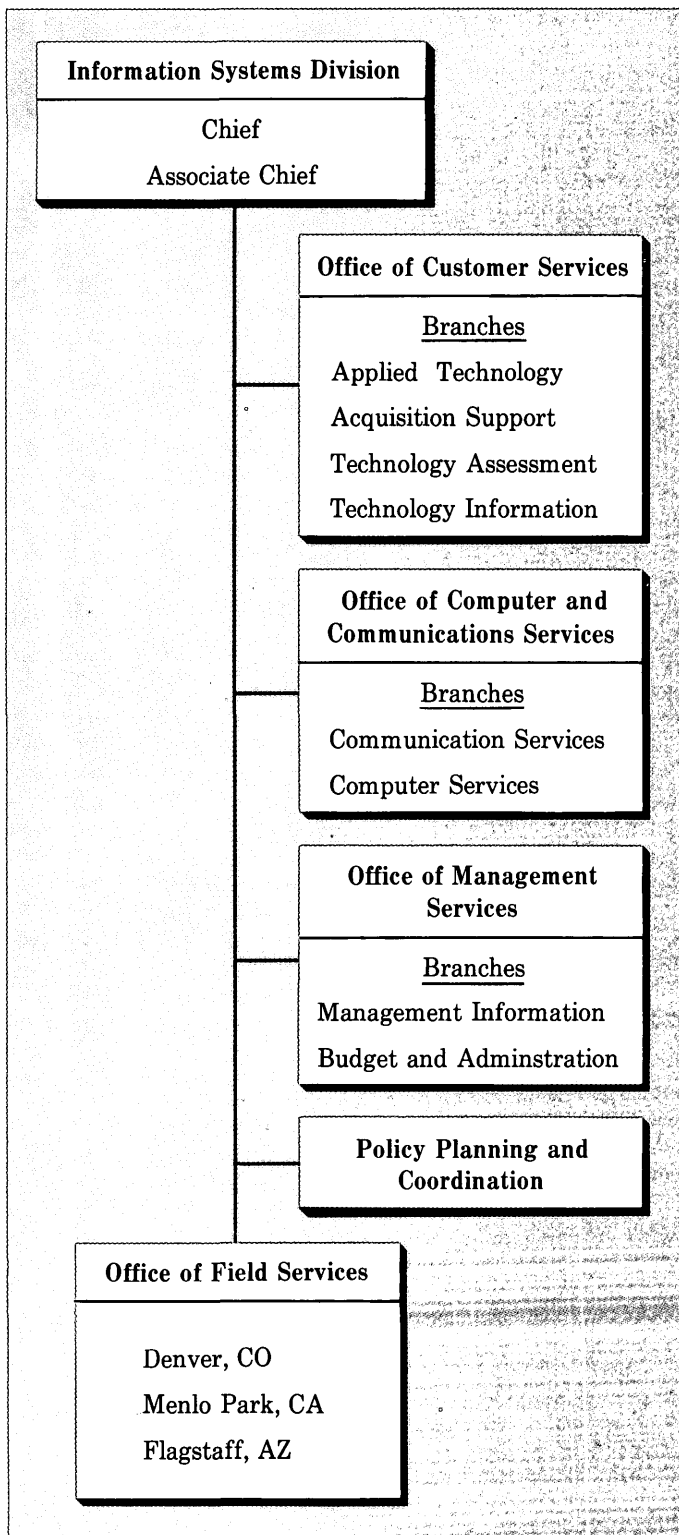
Mission

The Information Systems Division provides support and advice to the Director of the U.S. Geological Survey, the Department of the Interior, other government agencies, and the other Divisions of the Geological Survey on all matters relating to information technology and automated data processing. It provides these services, along with acquisition assistance, for users of large general-purpose computers, smaller special-purpose computers, and telecommunications. The Division provides for coordination and improvement of information systems through systems analysis and design and conducts research into better ways to use data processing technology to solve mission-related problems. It is responsible for guidelines for data standards, data administration, data-base management, telecommunications, and computer operations.

Information Systems Division Reorganization

During fiscal year 1985 the Information Systems Division completed a major reorganization. This reorganization was prompted by the need to provide better service and to respond to rapid technological changes that have had a direct and decided bearing on Geological Survey information systems applications. Over the last several years the Geological Survey has experienced a significant change from centralized mainframe computer operations toward end-user computing and distributed processing using mainframe computers, minicomputers, and microcomputers.

The color shaded relief map of the Southwestern United States was created from digital topographic data of 1:250,000-scale quadrangles obtained from the National Cartographic Information Center. The four-State mosaic contains 42 quadrangles to cover Arizona, 59 for California, 28 for Utah, and 33 for Nevada. After mosaicking, seams were removed on the edges between quadrangles to smooth over some bad data on the boundaries. Certain elevation ranges have been set to specific colors. The digital topographic model was used to produce a shaded relief image that has a given sun direction and elevation, which enhance the localized topography. Scale is approximately 1:5,700,000.



Specific goals of the reorganization are to better use recently acquired telecommunications resources, to strengthen support for field customers, to give greater attention to long-range automatic data processing and telecommunications planning, to disseminate current technical information, and to more efficiently deliver services to the U.S. Geological Survey and other customers.

Budget and Personnel

The Information Systems Division had a budget of \$18.5 million for fiscal year 1985. This reimbursable program was funded by providing services to other U.S. Geological Survey Divisions and Department of the Interior and Federal agency customers. Division staffing consisted of 143 full-time employees, primarily computer specialists, computer analysts, mathematicians, computer scientists, systems programmers, and computer technicians. The staff was augmented by part-time and intermittent employees and contract computer operations personnel who assisted in fulfilling the mission of the Division. These employees served customers from four ADP service centers nationwide: Reston, Va., Denver, Colo., Menlo Park, Calif., and Flagstaff, Ariz.

Highlights

Telecommunications

By Jim Hott

Changes in the telecommunications industry significantly affected the Geological Survey in fiscal year 1985. Charges from telecommunications companies continued to rise, and maintenance of the antiquated voice equipment in Reston and Menlo Park was very costly and difficult to obtain. To counter these developments, the Geological Survey acquired new voice systems in Reston, Va., and Menlo Park, Calif., and a new nationwide data communications network (GEONET).

Voice Communications

A contract was awarded on September 6, 1984, to Rolm, Inc., for a series digital private automatic branch exchange that will be installed in Reston at 4,000 voice and data stations and in Menlo Park at 3,000 voice and data stations. Key features of the new systems are:

- digital technology (voice digitized at the handset);
- simultaneous transmission of voice and data over the same wiring;
- touchtone service;
- data transmission up to 56,000 bits per second;
- least-cost routing, which selects the least-cost link to the desired destination;
- single line concept so that each station is responsible for answering its phone;
- integrated voice store and forward system (PhoneMail);

- data interface to GEONET; and
- local area network switching capabilities.

These systems will provide the Geological Survey with significant cost savings, better quality service, and easier maintained equipment with less energy consumption. Installation will be completed in early 1986 at both locations.

Data Communications

A contract was awarded to Tymnet, Inc., on May 7, 1985, for a nationwide data communications network capability called GEONET. The contract included a private subnetwork to initially link 73 host computers; public data network support to permit access from locations not served by the private subnetwork; a network control center owned and operated by a contractor; and many other services such as personnel support, electronic mail, data communicating equipment, training, and documentation. GEONET will replace most of the existing Geological Survey data communications network facilities and will support Survey needs for the next 5 years. This service has inherent flexibility for expansion and offers the major communications software used today. The private network permits fixed-cost communication between the terminals and computers attached to it.

GEONET will be expanded to support other Department of the Interior bureaus. The Geological Survey was designated as the lead bureau in the acquisition of data communications services for the Department of the Interior. Eventual use by other Departmental bureaus will provide significant savings on a nationwide basis. The Department will also test the feasibility of a single, departmentwide electronic message system, a service provided under the GEONET contract.

The computing resources of the Geological Survey are being made accessible to any authorized user no matter where that user or that resource is located, and any form of public domain information on any of the computers connected to GEONET will be readily available for retrieval.

Improved Computer Facilities

The Information Systems Division has provided automatic data processing facilities and services to the U.S. Geological Survey and other bureaus within the Department of the Interior since 1966. In fiscal year 1985, the Division moved its computer and telecommunications equipment and services to a new location within the National Center. The improved

facility offers support for both scientific and administrative applications; fast, reliable service responsive to user needs; a telecommunications network linking Survey computers nationwide; a center-wide uninterruptible power supply that provides continuous service in the event of power fluctuations or failure; and improved physical security.

Equipment available in the new facility includes two large mainframe computers—an Amdahl 470/V7 and an Amdahl 470/V8—running the MVS/SP operating system with a UNIX operating system to be added, 40 billion bytes of online disk storage, 9-track tape drives with recording density up to 6,250 bits per inch, 2,250 and 3,000 line per minute printers, network and local communications support for both asynchronous and synchronous protocols, a Calcomp high speed drum plotter, and a VAX 11/780 mini-computer running VMS.

General purpose software available includes interactive processing, data-base management systems, statistical packages, programming languages, graphics software, and mainframe to microcomputer linkage.

Services provided by the new facility include a secured area for printouts; contracts for data preparation, microform processing, and offsite data storage; tape and disk management; operations support for several other user-maintained systems; and user assistance in computer graphics, telecommunications, and general purpose software.

Earth Science Data Dictionary

By Tom Ciciarelli

The Information Systems Division developed and maintains the Earth Science Data Directory, an online computer directory providing referral to, and information about, data sources related to earth science. The directory is currently in use at all Geological Survey Public Inquiries Offices and National Cartographic Information Centers.

When developed in 1981, the Earth Science Data Directory contained only references to Geological Survey data sources. In time, references to holdings from several other Department of the Interior bureaus were added. During the past year, the directory was improved to accommodate descriptions of data holdings from State agencies as well. The new directory, containing information from the Geological Survey, Bureau of Land Management, Minerals Management Service, and five States, was demonstrated at the annual meeting of the American Association of State Geologists in Mystic, Conn. The presentation of the directory was favorably received at

the meeting, and a number of States expressed an interest in providing information about their data sources for inclusion in the directory. Efforts are underway to arrange for their participation. In addition, plans to obtain participation by more Federal agencies are underway.

The objective of the Earth Science Data Directory is to identify, locate, and make available information about earth science data sets maintained by State and Federal agencies by developing a comprehensive directory to improve access to existing data within the earth science community, thus reducing data collection costs and providing opportunities for information sharing.

The directory resides on a mainframe computer in Reston, Va., and is accessible remotely by a variety of computer terminals. The data are thoroughly cross-referenced to permit keyword-embedded string and range searches, keyword browse, geographical area searches, and more. The computer directory is easy to access so that even first-time users can successfully retrieve data.

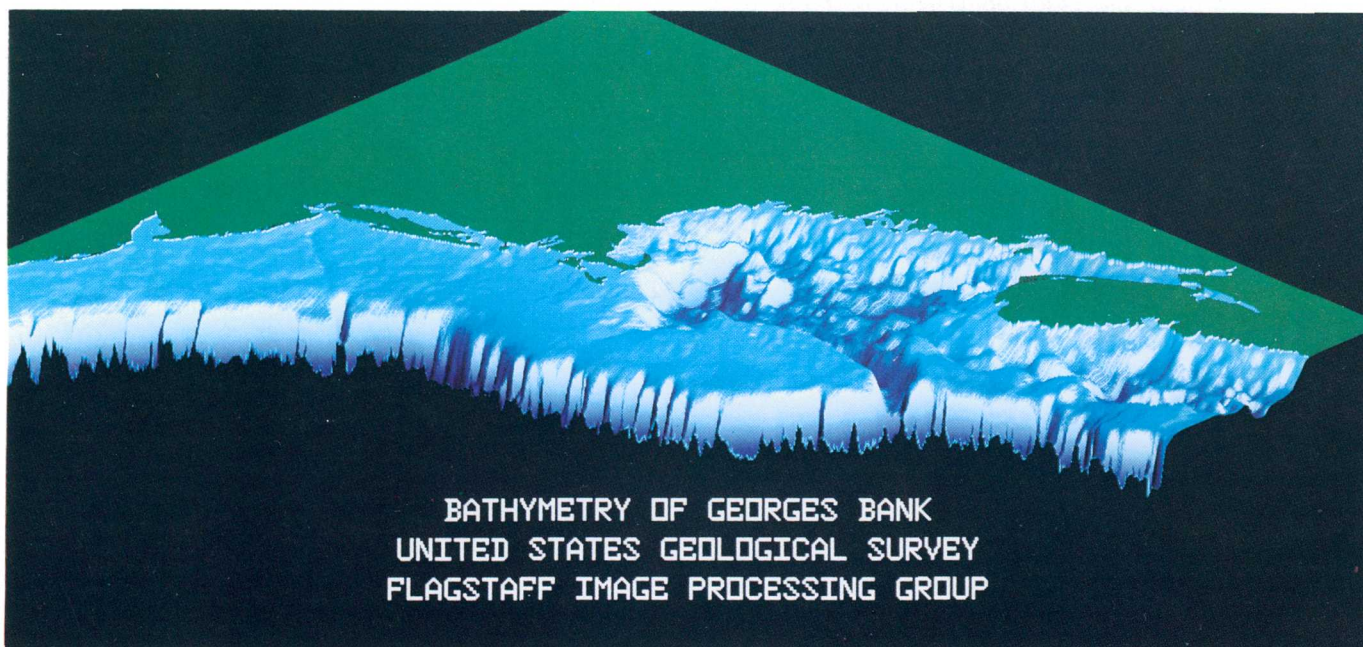
Some examples of how the directory can assist users are in determining locations of potential ground-water problems, securing information about geologic hazards such as landslides and fracture zones, conducting geomorphic studies of features such as glacial deposits, and ascertaining land use and land cover applications associated with wetland and vegetation types.

Image Processing Techniques Applied to Georges Bank Fishing Dispute

By Ellen Sanchez

In fiscal year 1985 the World Court in The Hague, with the help of the Geological Survey, settled a boundary dispute between the United States and Canada over fishing rights in the vicinity of Georges Bank. Georges Bank is an extremely rich fishing area of the Atlantic Ocean off the northeastern United States and southeastern Canada. The Canadian claim for rights was based on the visible coastline, while the United States' position was based on the bathymetry, or ocean floor topography, which is not directly visible. The United States needed a way to clearly show the topography. The Information Systems Division's Flagstaff ADP Service Center, with other Government agencies, used bathymetry data recorded on computer tape by latitude, longitude, and depth in tenths of meters to produce imagery showing the Continental Shelf from Cape Charles, Va., to the northeastern end of Nova Scotia. The image processing techniques used in this display of bathymetric data can be applied to any type of continuous data, such as topography, magnetics, or gravity. The techniques do not interpret data, but they do make it easier for the observer to do so. In ruling on the dispute, the Court gave the United States 61 percent of Georges Bank; however, Canada received a valuable spawning area and two lobster sections.

Image of Georges Bank produced by the Flagstaff Image Processing Group to clearly show the area's topography.



Technology Information Center in Denver

By Louise Nichols

The Information Systems Division operates four computer technology information centers, one at Reston, Va., headquarters, and the others at the field centers in Menlo Park, Calif., Flagstaff, Ariz., and Denver, Colo. The primary purpose of the technology information centers is to provide a place where employees can obtain information and help with the information management aspects of the Geological Survey programs.

The Geological Survey has always been a leader in the use of computers within the government. This began with large-scale computers in the mid-1960's and has continued over the years with minicomputers and now microcomputers. With the rapid evolution of microcomputers and their application to information management, there is a need to provide a new type of service to present and potential computer users. The technology information centers address this need.

The Denver center is based on the successful center in Reston but serves a larger audience, both geo-

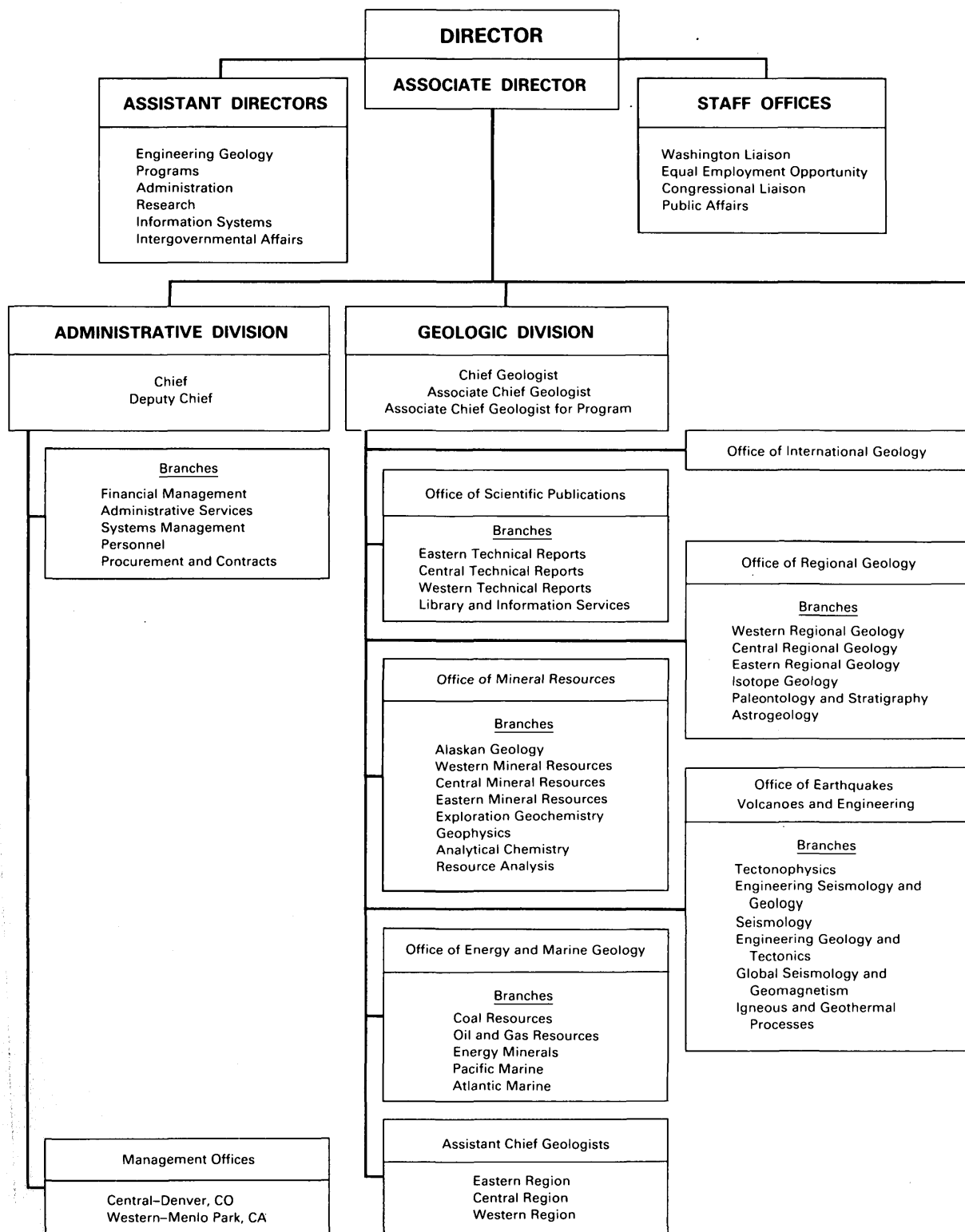
graphically—the States of the Central Region—and organizationally—all Department of the Interior agencies in the region. To ensure that the center will be a valuable resource to all those it serves, an inter-agency committee provides ideas, review, and publicity for center activities. In addition, center personnel actively solicit information from customers about areas in which the center can provide a service.

The center has microcomputers, printers, plotters, and a wide variety of programs for customers to use. Training is provided as required and includes workshops, short demonstrations, videotape programs, and computer-aided instruction. Experts are available to answer questions about new devices and methods, to provide comparisons between products, and to make recommendations. Technical and procedural help is offered in acquiring all types of automatic data processing equipment and services.

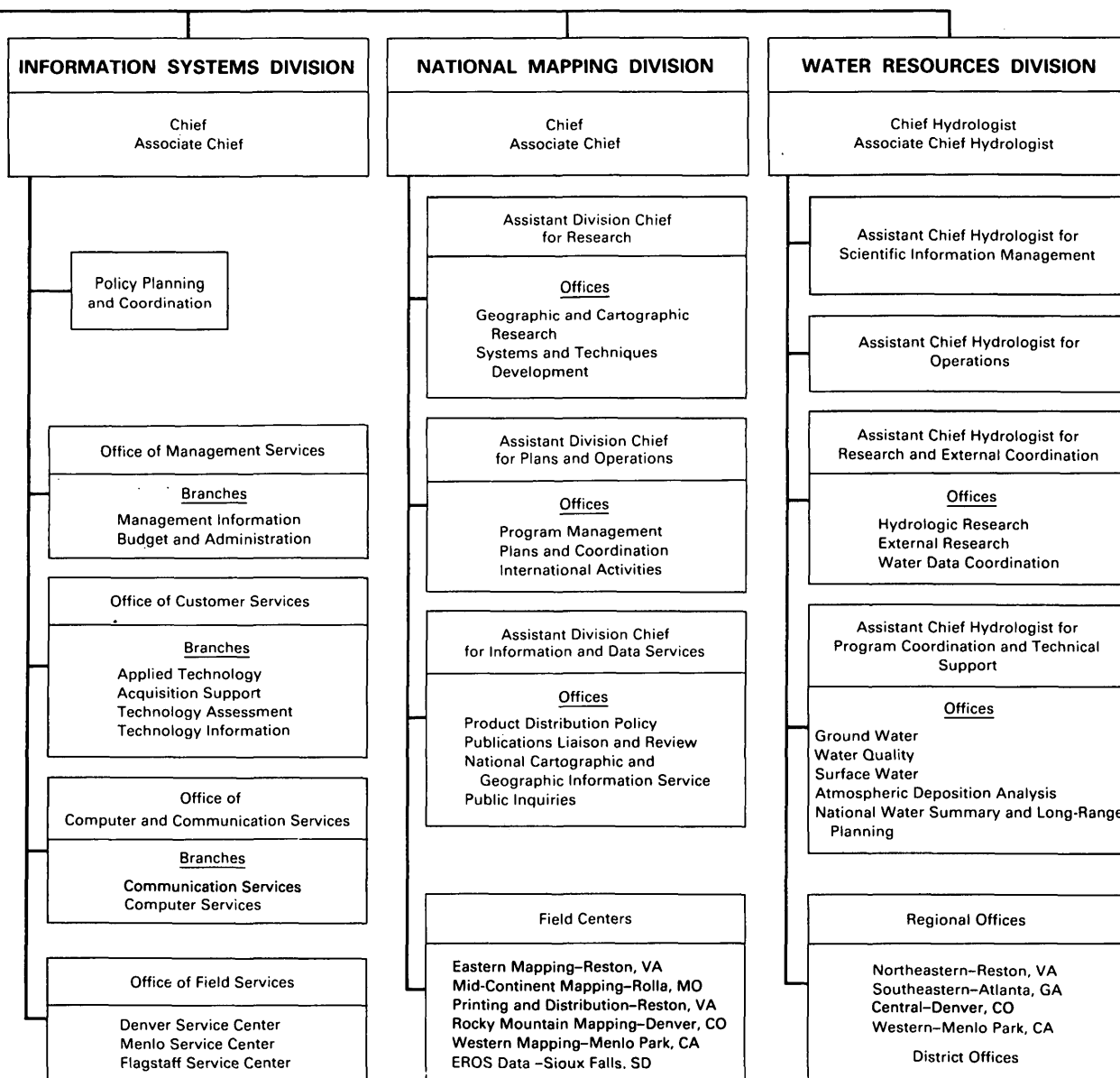
The following services are provided:

- Consultation on information management problems—suggestions, alternatives, and recommendations on procedures, methods, hardware (machines or devices), software, and data communications.
- Hardware to use—microcomputers; dot matrix, letter quality, and color printers; color plotter; desktop digitizer.
- Software packages and programs to use—language compilers; spreadsheet, word processing, data base management, graphics, statistics, communications, and project management programs.
- Programming assistance—for large and small computers, in many computer languages such as FORTRAN, PL/1, BASIC, and Pascal.
- Data communications—setting up communications links (from several feet to many miles in distance) between computers of all sizes, transferring information between the same or different types of equipment.
- Microcomputer and other equipment installation and failure diagnosis—setting up a system, trouble-shooting, performing minor repairs.
- Automatic data processing procurements—technical advice; assistance in completing the paperwork; information on policy, rules, and regulations.
- Training—introduction to computers; comparison of programs for areas such as data base management, word processing, graphics, or statistics; workshops on a specific program; videotapes on general ADP topics.
- Reference library—technical journals, magazines, newspapers, handbooks, and books with hardware and software specifications and comparisons.

**ORGANIZATION OF THE GEOLOGICAL SURVEY
U.S. Department of the Interior**



Organizational Data



U.S. Geological Survey Offices

Headquarters Offices
12201 Sunrise Valley Drive,
National Center, Reston, VA 22092

Office	Name	Telephone Number	Address
Office of the Director			
Director -----	Dallas L. Peck	(703) 648-7411	National Center, Stop 101
Associate Director -----	Doyle G. Frederick	(703) 648-7412	National Center, Stop 102
Special Assistant (Washington Liaison) and Deputy Ethics Counselor -----	Jane H. Wallace	(202) 343-3888	Rm. 7343, Interior Bldg., Washington, DC 20240
Assistant Director for Research -----	Bruce B. Hanshaw	(703) 648-4450	National Center, Stop 104
Assistant Director for Engineering Geology -----	James F. Devine	(703) 648-4423	National Center, Stop 106
Assistant Director for Administration ----	Edmund J. Grant	(703) 648-7200	National Center, Stop 201
Assistant Director for Programs -----	Peter F. Bermel	(703) 648-4430	National Center, Stop 105
Assistant Director for Intergovernmental Affairs -----	John J. Dragonetti	(703) 648-4427	National Center, Stop 109
Director's Representative—Central Region -----	Harry Tourtelot	(303) 236-5438	Box 25046, Stop 406, Denver Federal Center, Denver, CO 80225
Director's Representative—Western Region -----	George Gryc	(415) 323-8111 ext. 2711	345 Middlefield Rd., Stop 144, Menlo Park, CA 94025
Congressional Liaison Officer -----	Talmadge W. Reed	(703) 648-4457	National Center, Stop 112
Chief, Public Affairs Office -----	Donovan B. Kelly	(703) 648-4460	National Center, Stop 119
Staff Assistant (Special Issues) -----	Harold Mattraw	(703) 648-7413	National Center, Stop 121
Special Assistant to the Director for Alaska -----	Philip A. Emery	(907) 271-4398 or (907) 263-7429	Gould Hall—APU Campus University Drive, Anchorage, AK 99504
Assistant Director for Information Systems -----	James E. Biesecker	(703) 648-7108	National Center, Stop 801
National Mapping Division			
Chief -----	Lowell E. Starr	(703) 648-5747	National Center, Stop 516
Associate Chief -----	Roy R. Mullen	(703) 648-5744	National Center, Stop 516
Assistant Division Chief for Research ----	Vacant	(703) 648-4639	National Center, Stop 519
Assistant Division Chief for Plans and Operations -----	Richard E. Witmer	(703) 648-4610	National Center, Stop 514
Assistant Division Chief for Information and Data Services -----	Gary W. North	(703) 648-4783	National Center, Stop 508
Geologic Division			
Chief Geologist -----	Robert M. Hamilton	(703) 648-6600	National Center, Stop 911
Associate Chief Geologist -----	William F. Cannon	(703) 648-6601	National Center, Stop 911
Assistant Chief Geologist for Program ---	Benjamin A. Morgan	(703) 648-6640	National Center, Stop 911
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Policy and Budget Officer -----	Norman E. Gunderson	(703) 648-6650	National Center, Stop 910
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Office of Energy and Marine Geology, Chief -----	Terry W. Offield	(703) 648-6470	National Center, Stop 915
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Office of International Geology, Chief ----	A. Thomas Ovenshine	(703) 648-6047	National Center, Stop 917

Office	Name	Telephone Number	Address
Water Resources Division			
Chief Hydrologist	Philip Cohen	(703) 648-5215	National Center, Stop 409
Associate Chief Hydrologist	R. Hal Langford	(703) 648-5216	National Center, Stop 408
Assistant Chief Hydrologist for Scientific Information Management	James F. Daniel	(703) 648-5699	National Center, Stop 440
Assistant Chief Hydrologist for Research and External Coordination	Marshall M. Moss	(703) 648-5041	National Center, Stop 436
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Office of Water Data Coordination, Chief	Edgar A. Imhoff	(703) 648-5014	National Center, Stop 417
Office of External Research, Chief, Acting	Marshall M. Moss	(703) 648-5042	National Center, Stop 436
Assistant Chief Hydrologist for Program Coordination and Technical Support, Acting	Roger G. Wolff	(703) 648-5229	National Center, Stop 414
Office of Atmospheric Deposition Analysis, Chief	Ranard J. Pickering	(703) 648-6874	National Center, Stop 416
Office of Ground Water, Chief	Eugene P. Patten, Jr.	(703) 648-5001	National Center, Stop 411
Office of Surface Water, Chief, Acting ---	Verne R. Schneider	(703) 648-5301	National Center, Stop 415
Office of Water Quality, Chief, Acting ---	David A. Rickert	(703) 648-6864	National Center, Stop 412
Office of National Water Summary and Long-Range Planning, Chief	David W. Moody	(703) 648-6856	National Center, Stop 407
Assistant Chief Hydrologist for Operations	Thomas J. Buchanan	(703) 648-5032	National Center, Stop 441
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Chief	James E. Biesecker	(703) 648-7108	National Center, Stop 801
Associate Chief	Carl E. Diesen	(703) 648-7106	National Center, Stop 801
Office of Customer Services, Chief, Acting	Virginia L. Thomas	(703) 648-7178	National Center, Stop 805
Office of Computer and Communications Services	Doug R. Posson	(703) 648-7157	National Center, Stop 807
Office of Management Services	Rollin F. Nelson	(703) 648-7103	National Center, Stop 802
Office of Field Services	Fred B. Sower	(303) 236-4944	Denver Federal Center
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Branch of Administrative Services, Chief	William F. Gossman, Jr.	(703) 648-7338	National Center, Stop 207
Branch of Systems Management, Chief --	Phillip L. McKinney	(703) 648-7256	National Center, Stop 206
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National Mapping Division			
Regional Centers			
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Mid-Continent	Lawrence H. Borgerding	(314) 341-0880	1400 Independence Road, Rolla, MO 65401
Rocky Mountain	Merle E. Southern	(303) 844-5825	Box 25046, Stop 510, Federal Center, Denver, CO 80225
Western	John R. Swinnerton	(415) 323-8111, ext. 2411	345 Middlefield Road, Menlo Park, CA 94025
Printing and Distribution	Vacant	(703) 648-5181	National Center, Stop 580

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Public Inquiries Offices			
Alaska -----	Elizabeth C. Behrendt	(907) 561-5555	Room 101, 4230 University Dr. Anchorage, AK 99508
		(907) 271-4307	E-146 Federal Bldg., Box 53, 701 C Street Anchorage, AK 99513
California:			
Los Angeles -----	Lucy E. Birdsall	(213) 894-2850	7638 Fed. Bldg., 300 N. Los Angeles St., Los Angeles, CA 90012
Menlo Park -----	Bruce S. Deam	(415) 323-8111, ext. 2817	345 Middlefield Rd., Stop 533, Bldg. 3, Menlo Park, CA 94025
San Francisco -----	Patricia A. Shiffer	(415) 556-5627	504 Customhouse, 555 Battery St., San Francisco, CA 94111
Colorado -----	Irene V. Shy	(303) 844-4169	169 Fed. Bldg., 1961 Stout St., Denver, CO 80294
District of Columbia -----	Bruce A. Hubbard	(202) 343-8073	1028 GSA Bldg., 18th and F Sts., NW., Washington, DC 20405
Texas -----	John P. Donnelly	(214) 767-0198	1C45 Fed. Bldg., 1100 Commerce St., Dallas, TX 75242
Utah -----	Wendy R. Hassibe	(801) 524-5652	8105 Fed. Bldg., 125 S. State St., Salt Lake City, UT 84138
Virginia -----	Margaret E. Counce	(703) 648-6888	1C402 National Center, Stop 503, 12201 Sunrise Valley Dr., Reston, VA 22092
Washington -----	Jean E. Flechel	(509) 456-2524	678 U.S. Courthouse, W. 920 Riverside Ave., Spokane, WA 99201
Distribution Branch Offices			
Alaska -----	Natalie Cornforth	(907) 456-0244	101 12th Ave., Box 12, Fairbanks, AK 99701
Colorado -----	Dwight F. Canfield	(303) 236-7477	Box 25286, Stop 306, Denver Federal Center, Denver, CO 80225
Earth Resources Observation Systems Data Center			
South Dakota -----	Allen H. Watkins	(605) 594-7123	EROS Data Center, Sioux Falls, SD 57198
Geologic Division			
Regional Offices			
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Central -----	Harry A. Tourtelot	(303) 236-5438	Box 25046, Stop 911, Denver Federal Center, Denver, CO 80225
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Water Resources Division			
Regional Offices			
Northeastern -----	Stanley P. Sauer	(703) 648-5817	National Center, Stop 433

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Southeastern -----	James L. Cook	(404) 221-5174	Richard B. Russell Federal Bldg., 75 Spring St., SW, Suite 772, Atlanta, GA 30303
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Western -----	John T. Conomos	(415) 323-8111, ext. 2337	345 Middlefield Road, Stop 470, Menlo Park, CA 94025
District Offices			
Alabama -----	Charles A. Pascale	(205) 752-8104	520 19th Ave., Tuscaloosa, AL 35401
Alaska -----	Philip A. Emery	(907) 271-4138	4230 University Dr., Suite 201, Anchorage, AK 99508
Arizona -----	Robert D. Mac Nish	(602) 629-6671	Federal Bldg., 300 W. Congress St., Tucson, AZ 85701
Arkansas -----	Ector E. Gann	(501) 378-6391	2301 Federal Office Bldg., 700 W. Capital Ave., Little Rock, AR 72201
California -----	Gilbert L. Bertoldi	(916) 978-4633	Room W-2235, Federal Bldg., 2800 Cottage Way, Sacramento, CA 95825
Colorado -----	James F. Blakey	(303) 236-4882	Box 25046, Stop 415, Denver Federal Center, Denver, CO 80225
Connecticut (<i>See Massachusetts</i>)			
Delaware (<i>See Maryland</i>)			
District of Columbia (<i>See Maryland</i>)			
Florida -----	Irwin H. Kantrowitz	(904) 681-7620	227 North Bronough St., Suite 3015, Tallahassee, FL 32301
Georgia -----	Jeffrey T. Armbruster	(404) 221-4858	6481 Peachtree Industrial Blvd., Suite B, Doraville, GA 30360
Hawaii -----	Stanley F. Kapustka	(808) 546-8331	P.O. Box 50166, 300 Ala Moana Blvd., Rm 6110, Honolulu, HI 96850
Idaho -----	Ernest F. Hubbard, Jr.	(208) 334-1750	230 Collins Road, Boise, ID 83702
Illinois -----	Larry G. Toler	(217) 398-5353	Champaign County Bank Plaza, 102 E. Main St., 4th Floor, Urbana, IL 61801
Indiana -----	Dennis K. Stewart	(317) 927-8640	6023 Guion Road, Suite 201, Indianapolis, IN 46254
Iowa -----	John M. Klein	(319) 337-4191	P.O. Box 1230, Room 269, Federal Bldg., 400 S. Clinton St., Iowa City, IA 52244
Kansas -----	Joseph S. Rosenshein	(913) 864-4321	1950 Constant Ave., Campus West, University of Kansas, Lawrence, KS 66044
Kentucky -----	Alfred L. Knight	(502) 582-5241	572 Federal Bldg., 600 Federal Pl., Louisville, KY 40202
Louisiana -----	Darwin D. Knochenmus	(504) 389-0281	P.O. Box 66492, 6554 Florida Blvd., Baton Rouge, LA 70806
Maine (<i>See Massachusetts</i>)			
Maryland -----	Herbert J. Freiburger	(301) 828-1535	208 Carroll Bldg., 8600 La Salle Rd., Towson, MD 21204

Office	Name	Telephone Number	Address
Massachusetts -----	Ivan C. James II	(617) 223-2822	150 Causeway St., Suite 1309, Boston, MA 02114
Michigan -----	T. Ray Cummings	(517) 377-1608	6520 Mercantile Way, Suite 5, Lansing, MI 48910
Minnesota -----	Donald R. Albin	(612) 725-7841	702 Post Office Bldg., St. Paul, MN 55101
Mississippi -----	Garald G. Parker, Jr.	(601) 960-4600	Suite 710 Federal Bldg., 100 West Capitol St., Jackson, MS 39269
Missouri -----	Daniel P. Bauer	(314) 341-0824	1400 Independence Rd., Stop 200, Rolla, MO 65401
Montana -----	Joe A. Moreland, Acting	(406) 449-5302	428 Federal Bldg., 301 South Park Avenue, Drawer 10076, Helena, MT 59626
Nebraska -----	William M. Kastner	(402) 471-5082	406 Federal Bldg. 100 Centennial Mall, North, Lincoln, NE 68508
Nevada (<i>See Idaho</i>)			
New Hampshire (<i>See Massachusetts</i>)			
New Jersey -----	Donald E. Vaupel	(609) 771-0065	Suite 206, Mountain View Office Park, 810 Bear Tavern Road, West Trenton, NJ 08628
New Mexico -----	Robert L. Knutilla	(505) 766-2246	Western Bank Bldg., Rm. 720, 505 Marquette, NW., Albuquerque, NM 87102
New York -----	Lawrence A. Martens	(518) 472-3107	P.O. 1669, 343 U.S. Post Office and Courthouse, Albany, NY 12201
North Carolina -----	James F. Turner	(919) 856-4510	P.O. Box 2857, Rm. 436, Century Postal Station, 300 Fayetteville Street Mall Raleigh, NC 27602
North Dakota -----	L. Grady Moore	(701) 255-4011, ext. 601	821 East Interstate Ave., Bismarck, ND 58501
Ohio -----	Steven M. Hindall	(614) 469-5553	975 West Third Ave., Columbus, OH 43212
Oklahoma -----	James H. Irwin	(405) 231-4256	Rm. 621, 215 Dean A. McGee Ave., Oklahoma City, OK 73102
Oregon (<i>See Washington</i>)			
Pennsylvania -----	David E. Click	(717) 782-4514	P.O. Box 1107, 4th Floor, Federal Bldg., 228 Walnut St., Harrisburg, PA 17108
Puerto Rico -----	Ferdinand Quinones-Marquez	(809) 783-4660	GPO Box 4424, Bldg. 652 GSA Center, San Juan, PR 00936
Rhode Island (<i>See Massachusetts</i>)			
South Carolina -----	Rodney N. Cherry	(803) 765-5966	Suite 658, 1835 Assembly St., Columbia, SC 29201
South Dakota -----	Richard E. Fidler	(605) 352-8651, ext. 268	Rm. 317 Federal Bldg., 200 4th St., SW, Huron, SD 57350
Tennessee -----	Larry R. Hayes	(615) 251-5424	A-413 Federal Bldg., U.S. Courthouse, Nashville, TN 37203
Texas -----	Charles W. Boning	(512) 482-5766	649 Federal Bldg., 300 E. 8th St., Austin, TX 78701
Utah -----	Theodore Arnow	(801) 524-5663	1016 Administration Bldg., 1745 W. 1700 South, Salt Lake City, UT 84104

Office	Name	Telephone Number	Address
Vermont (<i>See Massachusetts</i>)			
Virginia (<i>See Maryland</i>)			
Washington -----	Leslie B. Laird	(206) 593-6510	1201 Pacific Ave., Suite 600, Tacoma, WA 98402
West Virginia -----	David H. Appel	(304) 347-5130	603 Morris St. Charleston, WV 25301
Wisconsin -----	Vernon W. Norman	(608) 262-2488	1815 University Ave., Madison, WI 53705
Wyoming -----	Richard M. Bloyd	(307) 772-2153	P.O. Box 1125, 2120 Capital Ave., Rm. 4004, Cheyenne, WY 82003
Administrative Division			
Regional Management Offices			
Central -----	George A. Honold	(303) 236-5900	Box 25046, Stop 201, Denver Federal Center, Denver, CO 80225
Western -----	George F. Hargrove, Jr. Avery W. Rogers	(415) 323-8111, ext. 2211	345 Middlefield Rd., STOP 211, Menlo Park, CA 94025

Guide to Information and Publications

Throughout this report, reference has been made to information services and publications of the U.S. Geological Survey. During fiscal year 1985, the Survey produced over 6,797 new and revised topographic, hydrologic, and geologic maps; printed 16,834,005 copies of 6,797 different maps; distributed 7,480,084 copies of maps; and sold 5,789,711 copies for \$10,877,118. The number of reports approved for publication by the Geological Survey in fiscal year 1985 was 4,850, with 67 percent designated for publication in professional journals and monographs outside the Survey and the remainder scheduled for publication by the Survey. In addition, 241,448 copies of technical reports were distributed of which 41,046 copies were sold for \$171,996 and 1,135 open-file reports were released of which 36,640 copies were sold for \$313,414.

To buy maps of all areas of the United States and to request Survey catalogs, pamphlets, and leaflets (limited quantities free), write or visit:

U.S. Geological Survey
Map Distribution Section
Federal Center, Box 25286
Denver, CO 80225

To buy Alaskan maps, residents of Alaska may write or visit:

U.S. Geological Survey
Alaska Distribution Section
101 12th Avenue, Box 12
Fairbanks, AK 99701

To buy Survey book publications, to request Survey circulars, or to obtain information on the availability of microfiche or paper-duplicate copies of open-file reports, write:

U.S. Geological Survey
Books and Open-File Reports Section
Federal Center, Box 25425
Denver, CO 80225

To get on the mailing list for the monthly list of *New Publications of the Geological Survey* (free), write:

U.S. Geological Survey
Computer Operations Office
582 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

To subscribe to the *Earthquake Information Bulletin*, write:
Superintendent of Documents
Government Printing Office
Washington, DC 20402

To obtain information on programs, publications, and services or to obtain copies of reports and maps, visit the U.S. Geological Survey Public Inquiries Offices at the following addresses:

Alaska:
Room 101
4230 University Dr.
Anchorage, AK 99508

E-146 Federal Bldg.
Box 53
701 C St.
Anchorage, AK 99513

California:
7638 Federal Bldg.
300 N. Los Angeles St.
Los Angeles, CA 90012

Bldg. 3, Stop 533
345 Middlefield Rd.
Menlo Park, CA 94025

504 Customhouse
555 Battery St.
San Francisco, CA 94111

Colorado:
169 Federal Bldg.

To obtain information on cartographic data, write or visit the U.S. Geological Survey National Cartographic Information Centers (NCIC) in the following States:

Alaska:
U.S. Geological Survey
National Cartographic
Information Center
4230 University Dr.
Anchorage, AK 99508

1961 Stout St.
Denver, CO 80294

Texas:
1C45 Federal Bldg.
1100 Commerce St.,
Dallas, TX 75242

Utah:
8105 Federal Bldg.
125 S. State St.
Salt Lake City, UT 84138

Virginia:
1C402 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

Washington:
678 U.S. Courthouse
W. 920 Riverside Ave.
Spokane, WA 99201

Washington, DC:
1028 General Services Admin.
Bldg.

18th and F Sts., N W.
Washington, DC 20405

California:
Western Mapping Center
National Cartographic
Information Center
345 Middlefield Rd.
Menlo Park, CA 94025

Colorado:
Rocky Mountain Mapping
Center
National Cartographic
Information Center
Box 25046, Stop 504
Bldg. 25, Federal Center
Denver, CO 80225

Mississippi:
National Space Technology
Laboratories
National Cartographic
Information Center
U.S. Geological Survey
Bldg. 3101
NSTL Station, MS 39529

Missouri:
Mid-Continent Mapping
Center

National Cartographic
Information Center
1400 Independence Rd.
Rolla, MO 65401
Virginia:
National Cartographic
Information Center
507 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

Eastern Mapping Center
National Cartographic
Information Center
536 National Center
12201 Sunrise Valley Dr.
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To obtain information on aerial photographs and satellite and space imagery, write or visit:

U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198

To obtain assistance in locating sources of water data, identifying sites at which data have been collected, and specific data, write:

U.S. Geological Survey
National Water Data Exchange
421 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on ongoing and planned water-data acquisition activities of all Federal agencies and many non-Federal organizations, write:

U.S. Geological Survey
Office of Water Data Coordination
417 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on water resources in general and about the water resources of specific areas of the United States, write:

U.S. Geological Survey
Hydrologic Information Unit
419 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on geology topics such as earthquakes, energy and mineral resources, the geology of specific areas, and geologic maps and mapping, write:

U.S. Geological Survey
Geologic Inquiries Group
907 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

Cooperators and Other Financial Contributors

Cooperators listed are those with whom the U.S. Geological Survey had a written agreement cosigned by Survey officials and the cooperating agency for financial cooperation in fiscal year 1985. Parent agencies are listed separately from their subdivisions whenever there are separate cooperative agreements for different

projects with a parent agency and with a subdivision of it. Agencies with whom the Geological Survey has research contracts and to whom it supplied research funds are not listed.

Cooperating office of the Geological Survey

g—Geologic Division
n—National Mapping Division
w—Water Resources Division

State, County, and Local Cooperators

Alabama:

Alabama Department of—Conservation and Natural Resources (w), Environmental Management (w), Highways (w); Alabama Surface Mining Commission (w); Birmingham, City of (w); Coffee County Commission (w); Dauphin Island (w); Geological Survey of Alabama (n,w); Huntsville, City of (w); Jefferson County Commission (w); Linden, City of (w); Montgomery, City of (w); Tuscaloosa, City of (w)

Alaska:

Alaska Department of—Environmental Conservation (w), Fish and Game (w), Natural Resources (n); Division of—Geological and Geophysical Surveys (g,w), Lands and Water Management (w), Technical Services (w), Transportation and Public Facilities (w); Alaska Power Authority (g,w); Anchorage, Municipality of—Department of Health and Environmental Protection (w), Department of Planning (w), Department of Solid Waste Services (w), Water and Wastewater Utility (w); Fairbanks North Star Borough (w); Juneau, City and Borough of (w); Kenai Peninsula Borough (w); King Cove, City of (w); Matanuska Susitna Borough (w); Sitka, City and Borough of (w); Wasilla, City of (w)

American Samoa: (See Hawaii)

Arizona:

Department of—Health Services, Bureau of Water Quality Control (w), Land, Parks and Tourism (w), Water Resources (w); Gila Valley Irrigation District (w); Maricopa County—Flood Control District (w), Municipal Water Conservation District No. 1 (w); Metropolitan Water District of Southern California (w); Pima County, Board of Supervisors (w); Salt River Valley Water Users Association (w); San Carlos Irrigation and Drainage District (w); Show Low Irrigation Company (w); Tucson, City of (w); University of Arizona, Water Resources Research Center (w); Arizona Municipal Water Users Association (w)

Arkansas:

Arkansas Department of Pollution Control and Ecology (w); Arkansas Soil and Water Conservation Commission (w); Arkansas Geological Commission (n,w); Arkansas State Highway and Transportation Department (w); Arkansas Department of Parks and Tourism (w)

California:

Alameda County—Flood Control and Water Conservation District (Hayward) (w), Flood Control and Water Conservation District, Zone 7 (Livermore) (w), Water District (w); Antelope Valley-East Kern Water Agency (w); California Department of—Boating and Waterways (g,w), Fish and Game (Sacramento) (w), Fish and Game, Region II (Rancho Cordova) (w), Health Services (w), Transportation, District 3 (Marysville) (w); Water Resources—Central District (Sacramento) (w), Northern District

(Red Bluff) (w), San Joaquin District (Fresno) (w); California Regional Water Quality Control Board—Central Coast Region (San Luis Obispo) (w), Colorado River Basin Region (Palm Desert) (w), North Coast Region (Santa Rosa) (w), San Francisco Bay Region (Oakland) (w), Santa Ana Region (Riverside) (w); California Water Resources Control Board (w); Carpinteria County, Water District (w); Casitas Municipal Water District (w); Coachella Valley, County Water District (w); Contra Costa County—Department of Health Services (w), Flood Control and Water Conservation District (w); Crestline-Lake Arrowhead Water Agency (w); Desert Water Agency (w); East Bay Municipal Utility District (w); East San Bernardino County Water District (w); East Valley Water District (w); El Dorado County (w); Fresno County, Department of Resources and Development (w); Fresno Metropolitan Flood Control District (w); Georgetown Divide Public Utility District (w); Goleta County Water District (w); Humboldt Bay, Municipal Water District (w); Imperial County, Department of Public Works (w); Imperial Irrigation District (w); Indian Wells Valley Water District (w); Inyo County Water Department (w); Kern County Water Agency (w); Kings River Conservation District (w); Lake County, Planning Department (w); Los Angeles County, Flood Control District (w); Los Angeles Department of Water and Power (w); Madera County, Flood Control and Water Conservation Agency (w); Madera Irrigation District (w); Marin County, Department of Public Works (w); Marin Municipal Water District (w); Merced, City of (w); Merced Irrigation District (w); Modesto, City of, Department of Public Works (w); Modoc County, Department of Public Works (w); Mojave Water Agency (w); Montecito County Water District (w); Monterey County Flood Control and Water Conservation District (w); Monterey Peninsula, Water Management District (w); Napa County Flood Control and Water Conservation District (w); Newport Beach, City of (w); Orange County—Environmental Management Agency (w), Water District (w); Oroville-Wyandotte Irrigation District (w); Pacheco Pass Water District (w); Paradise Irrigation District (w); Placer County Water Agency (Auburn) (w); Placer County Water Agency (Foresthill) (w); Rainbow Municipal Water District (w); Rancho California Water District (w); Riverside County Flood Control and Water Conservation District (w); Sacramento Municipal Utility District (w); Sacramento Regional County Sanitation District, Department of Public Works (w); San Benito County Water Conservation and Flood Control District (w); San Bernardino Valley Municipal Water District (w); San Diego, City of (w); San Diego County, Department of—Planning and Land Use (w), Public Works (w); San Diego County Water Authority (w); San Francisco, City and County of, Hetch Hetchy Water and Power (w); San Francisco Water Department (w); San Joaquin County Flood Control and Water Conservation District (w); San Luis Obispo County, Engineering Department (w); San Mateo County—Department of Planning (w), Department of Public Works (w); Santa Barbara, City of, Department of Public Works (w); Santa Barbara County—Flood Control and Water Conservation District (w), Water Agency (w); Santa Clara Valley, Water District (w); Santa Cruz County—Flood Control and Water Conservation District (w), Planning Department (w); Santa Cruz, City of, Water Department (w); Santa Maria Valley Water Conservation District (w); Scotts Valley Water District (w); Siskiyou County Flood Control and Water Conservation District (w); Sonoma County—Planning Department (w), Water Agency (w); Soquel Creek County Water District (w); Tahoe Regional Planning (w); Terra Bella Irrigation District (w); Thousand Oaks, City of (w); Tulare County, Flood Control District (w); Turlock Irrigation District (w); United Water Conservation District (w); University of California—Berkeley

(g), Agricultural Experiment Station, Department of Forestry and Resource Management (w); Ventura County, Public Works Agency (w); Western Municipal Water District (w); Westlands Water District (w); Woodbridge Irrigation District (w); Yolo County, Flood Control and Water Conservation District (w)

Colorado:

Arkansas River Compact Administration (w); Arvada, City of (w); Aspen, City of (w); Aurora, City of (w); Boulder, County of, Department of Public Works (w); Breckenridge, Town of (w); Castle Rock, Town of (w); Central Yuma Ground Water Management District (w); Cherokee Water and Sanitation District (w); Colorado Department of—Health (w); Colorado Division of Mined Land Reclamation (w); Colorado Division of Water Resources, Office of the State Engineer (w); Colorado Geological Survey (w); Colorado River Water Conservation District (w); Colorado Springs, City of—Department of Public Utilities (w), Office of the City Manager (w); Custer, County of (w); Delta County, Board of County Commissioners (w); Denver, City and County, Board of Water Commissioners (w); Denver Regional Council of Governments (w); Douglas, County of (w); Eagle County, Board of Commissioners (w); El Paso County Water Users Association (w); Englewood, City of, Bi-City Wastewater Treatment Plant (w); Evergreen Metro District (w); Fountain Valley Authority (w); Frenchman Ground Water Management District (w); Fruita, City of (w); Garfield County (w); Glendale, City of (w); Glenwood Springs, City of (w); Grand County Board of Commissioners (w); Kiowa-Bijou Ground Water Management District (w); Larimer-Weld Regional Council of Governments (w); Longmont, City of (w); Marks Butte Ground Water Management District (w); Metropolitan Denver Sewage Disposal District No. 1 (w); Mineral, County of (w); Moffat County Commissioners (w); Northern Colorado Water Conservancy District (w); Northwest Colorado Council of Govt. (w); Pitkin County, Board of Commissioners (w); Pueblo Board of Water Works (w); Pueblo Civil Defense Agency (w); Pueblo West Metropolitan District (w); Purgatoire River Water Conservancy District (w); Rio Blanco County, Board of County Commissioners (w); Rio Grande Water Conservation District (w); Round Mountain Water & Sand District (w); St. Charles Mesa Water District (w); Sand Hills Ground Water Management District (w); Southeastern Colorado Water Conservancy District (w); Southern High Plains Ground Water Management District (w); Southwestern Colorado Water Conservancy District (w); Steamboat Springs, City of (w); Trinchera Conservancy District (w); Uncompahgre Valley Water Users' Association (w); Upper Arkansas River Water Conservancy District (w); Upper Black Squirrel Creek (w); Upper Yampa Water Conservancy District (w); Urban Drainage and Flood Control District (w); Water Users No. 1 (Rangely) (w); W-Y Ground Water Management District (w); Yellow Jacket Water Conservancy District (w)

Connecticut:

Connecticut Department of Environmental Protection (g,n,w); Enfield, Town of (w); Fairfield, Town of, Conservation Commission (w); Meriden, Town of, Department of Public Works (w); New Britain, City of—Board of Water Commissioners (w), Improvement Commission (w); Northeast Connecticut Regional Planning Agency (w); Norwalk, Town of (w); Ridgefield, Town of (w); Simsbury, Town of (w); South Central Connecticut Regional Water Authority (w); Stonington, Town of (w); Torrington, City of (w)

Delaware:

Department of Natural Resources and Environmental Control

(w); Geological Survey (w); New Castle County, Public Works Department (w)

District of Columbia:

Department of Public Works (w)

Florida:

Big Cypress Basin Board (w); Boca Raton, City of (w); Bradenton, City of (w); Brevard County, Board of County Commissioners (w); Broward County—Environmental Quality Control Board (w), Water Resources Management Division (w); Cape Coral, City of (w); Clearwater, City of (w); Collier, County of (w); Cocoa, City of (w); Coordinating Council on the Restoration of Kissimmee River Valley and Taylor Creek-Nubbins Slough Basin (w); Daytona Beach, City of (w); Department of Natural Resources (n); Englewood Water District, Board of Supervisors (w); Escambia County, Board of County Commissioners (w); Flagler County, Board of County Commissioners (w); Florida Department of—Environmental Regulation, Bureau of Water Resources Management (w), Division of Recreation and Parks (w), Natural Resources, Division of Marine Resources (w); Transportation (n,w); Florida Institute of Phosphate Research (w); Florida Keys Aqueduct Authority (w); Fort Lauderdale, City of (w); Fort Walton Beach, City of (w); Gainesville, City of (w); Hallandale, City of (w); Highland Beach, Town of (w); Hillsborough County (w); Hollywood, City of (w); Indian River County (w); Jacksonville, Consolidated City of—Department of Health and Environmental Services (w), Department of Public Works (w); Jacksonville Electric Authority (w); Jacksonville Plan Department (w); Joshua Water Control District (w); Juno Beach, Town of (w); Jupiter Inlet District (w); Lake County—Board of County Commissioners (w), Pollution Control Department (w); Lee County, Board of County Commissioners (w); Leon County—Courthouse (w), Department of Public Works (w); Manatee County, Board of County Commissioners (w); Marion County, Board of County Commissioners (w); Metropolitan Dade County—Department of Environment Resources Management (w); Miami-Dade Water and Sewer Authority (w); Northwest Florida Water Management District (w); Old Plantation Water Control District (w); Orange County, Board of County Commissioners (w); Palm Beach County—Board of County Commissioners (w), Solid Waste Authority (w); Pasco, County of (w); Perry, City of (w); Pinellas County (w); Pinellas Park Water Management District (w); Plant City (w); Polk County, Board of County Commissioners (w); Pompano Beach, City of, Water and Sewer Department (w); Quincy, City of (w); Reedy Creek Improvement District (w); Sarasota, City of (w); Sarasota, County of (w); South Dade Soil and Water Conservation District (w); South Florida Water Management District (w); Southwest Florida Regional Planning Council (w); Southwest Florida Water Management District (w); St. Johns, County of (w); St. Johns River Water Management District (w); St. Petersburg, City of (w); Stuart, City of (w); Sumter County, Recreation and Water Conservation and Control Authority (w); Suwannee River Authority (Live Oak) (w); Suwannee River Authority (Trenton) (w); Suwannee River Water Management District (w); Tallahassee, City of, Underground Utilities (w); Tampa, City of (w); University of Central Florida (w); University of South Florida (w); Volusia, County of (w); Walton, County of (w); West Coast Regional Waters Supply Authority (w); Winter Park, City of (w)

Georgia:

Albany, City of, Water, Gas, and Light Commission (w); Bibb County, Board of County Commissioners (w); Brunswick, City of

(w); Chatham County, Board of County Commissioners (w); Clayton County, Water Authority (w); Consolidated Government of Columbus (w); Covington, City of (w); Georgia Department of—Natural Resources—Environmental Protection Division (w), Geological Survey (n,w); Transportation (w); Macon-Bibb County, Water and Sewage Authority (w); Valdosta, City of (w)

Guam: (See Hawaii)

Hawaii:

American Samoa, Government of (g,n,w); Guam, Government of (w); Hawaii Department of—Health (w), Land and Natural Resources, Division of Water and Land Development (w), Transportation (w); Honolulu, City and County—Board of Water Supply (w), Department of Public Works (w); Trust Territory of the Pacific Islands (w)—Commonwealth of the Northern Mariana Islands (w), Federated States of Micronesia (w)—State of Kosrae (w), State of Ponape (w), State of Truk (w), State of Yap (w); Republic of Marshall Islands (w); Republic of Palau (w); University of Hawaii, Water Resources Research Center (w)

Idaho:

Idaho Department of—Fish and Game (w), Health and Welfare, Lands (n), Water Resources (w); Sun Valley Water & Sewer District (w); Teton County, Board of Commissioners (w); The Shoshone-Bannock Tribes, Fort Hall Indian Reservation (w); Twin Falls, City of (w); University of Idaho (w); Water District No. 01—Idaho Falls (w); West Cassia Soil & Water Conservation District (w)

Illinois:

Bloomington and Normal Sanitary District (w); Cook County, Forest Preserve District (w); Decatur, City of (w); Illinois Department of—Energy and Natural Resources, State Water Survey Division (w), Nuclear Safety (w), Transportation, Division of Highways (n), Division of Water Resources (n,w); Illinois Environmental Protection Agency (w); Illinois State Geological Survey (n); Metropolitan Sanitary District of Greater Chicago (w); Springfield, City of (w)

Indiana:

Carmel, Town of (w); Elkhart, City of, Water Works (w); Indiana State Board of Health (w); Indiana Department of—Highways (w), Natural Resources (n)—Division of Water (w), Division of Reclamation (w); Indianapolis, City of, Department of Public Works (w)

Iowa:

Cedar Rapids, City of (w); Des Moines, City of (w); Fort Dodge, City of (w); Iowa Department of—Transportation—Highway Division (w); Water, Air, and Waste Management (w); Iowa Geological Survey (n,w); Iowa State University (w); University of Iowa, Institute of Hydraulic Research (w), Hygienic Laboratory (w)

Kansas:

Arkansas River Compact Administration (w); Hays, City of (w); Kansas Department of—Health and Environment (w), Transportation (w); Kansas Corporation Commission (w); Kansas Geological Survey (n,w); Kansas State Board of Agriculture, Division of Water Resources (w); Kansas Water Office (w); Sedgwick, County (w); Southwest Kansas Ground Water Management District No. 3 (w); Western Kansas Ground Water Management District No. 1 (w); Wichita, City of (w)

Kentucky:

Elizabethtown, City of (w); Kentucky Department of—Natural Resources and Environmental Protection Cabinet (w), Transportation Cabinet, Division of Design (w); Louisville, City of (w); University of Kentucky, Kentucky Geological Survey (n,w); University of Louisville (w); Western Kentucky University (w)

Louisiana:

Baton Rouge City-Parish Government (w); Capital-Area Groundwater Conservation Commission (w); Jefferson Parish Department of Public Utilities (w); Louisiana Department of—Natural Resources—Geological Survey (g,w), Environmental Quality, Water Pollution Control Division (w); Transportation and Development—Office of Highways (w), Office of Public Works (n,w), Office of Surface Mining (w); Louisiana State Planning Office (n); Sabine River Compact Administration (w)

Maine:

Androscoggin Valley Regional Planning Commission (w); Cobbossee Watershed District (w); Maine Department of—Conservation, Geological Survey (n,w), Environmental Protection (w), Transportation (w), Human Services (w); Washington County Regional Planning Commission (w); Wilton, Town of (w)

Maryland:

Anne Arundel County, Planning and Zoning Office (w); Baltimore County—Department of Permits and Licenses (w), Department of Public Works (w), Office of Planning and Zoning (w); Calvert County (w); Caroline County (w); Carroll County, Board of County Commissioners (w); Howard County, Department of Public Works (w); Interstate Commission on the Potomac River Basin (w); Maryland Department of—Health and Mental Hygiene, Office of Environmental Programs (w), Transportation, State Highway Administration (w); Maryland Energy Administration (w); Maryland Geological Survey (n,w); Maryland Water Resources Administration (w); Montgomery County—Department of Environmental Protection, Office of Environmental and Energy Planning (w), Division of Pollution Control (w); Poolesville, Town of (w); St. Marys County, County Commissioners (w); Upper Potomac River Commission (w); Washington Suburban Sanitary Commission (w)

Massachusetts:

Barnstable County, County Commissioners (w); Cape Cod Planning and Economic Development Commission (w); Massachusetts Department of Environmental Management, Division of Water Resources (w); Massachusetts Department of Environmental Quality Engineering Division of Water Pollution Control (w); Massachusetts Department of Public Works—Division of Research and Materials (w); Metropolitan District Commission, Water Division (w); New England Interstate Water Pollution Control Commission (w); Plymouth, Town of (w)

Michigan:

Ann Arbor, City of (w); Battle Creek, City of (w); Clare, City of (w); Coldwater, City of, Board of Public Utilities (w); Elsie, Village of (w); Flint, City of, Water Supply and Pollution Control, Department of Public Works and Utilities (w); Genesee County Drain Commission, Division of Water and Waste Services (w); Grand Traverse County (w); Huron-Clinton Metropolitan Authority (w); Imlay, City of (w); Kalamazoo, City of, Department of Public Utilities (w); Lansing, City of, Board of Water and Light, Water and Stream Division (w); Macomb County (w); Mason, City of (w); Michigan Department

of—Agriculture, Soil and Water Conservation Division (w), Natural Resources—Geological Survey Division (w), Office of Budget and Federal Aid (w); Transportation (w); Michigan Tech University (w); Oakland County, Drain Commission (w); Otsego County, Road Commission (w); Portage, City of (w); St. Johns, City of (w); Van Buren County, Board of Commissioners (w); Ypsilanti, City of (w)

Minnesota:

Bassett Creek Watershed Management Organization (w); Carnelian-Marine Watershed District (w); Coon Creek Watershed District (w); Eagan, City of (w); Elm Creek Conservation Commission (w); Fond Du Lac Reservation Bus. Comm. (w); Iron Range Resources Rehabilitation Board (w); Lower Red River Waste Management Board (w); Metropolitan Council of the Twin Cities Area (w); Metropolitan Waste Control Commission (w); Middle River-Snake River Watershed District (w); Minnesota Department of—Energy, Planning and Development (w), Health (w), Natural Resources (w), Transportation (w); Minnesota Geological Survey (w); Minnesota Pollution Control Agency (w); Minnesota Waste Management Board (w); Morrison County, Soil and Water Conservation District (w); Red Lake Tribal Council (w); Red Lake Watershed District (w); St. Louis Park, City of (w); St. Paul, City of (w); University of Minnesota (w); Wesmin Resource, Conservation and Development Association (w); White Earth Reservation Business Community (w)

Mississippi:

Harrison County—Board of Supervisors (w), Development Commission (w); Jackson, City of (w); Jackson County—Board of Supervisors (w), Port Authority (w); Laurel, City of (w); Mississippi Department of—Highways (w), Natural Resources—Bureau of Geology (w), Bureau of Land and Water Resources (w), Bureau of Pollution Control (w); Pat Harrison Waterway District (w); Pearl River Basin Development District (w); Pearl River Valley Water Supply District (w)

Missouri:

Little River Drainage District (w); Missouri Department of—Conservation (w), Natural Resources—Division of Environmental Quality, Lab Services Program (w), Division of Geology and Land Survey (n,w), Land Reclamation Commission (w); Missouri Highway and Transportation Commission (w); Springfield, City of—City Utilities, Engineering Department (w)

Montana:

Daniels, County of (w); Helena, City of (w); Montana Bureau of Mines and Geology (w); Montana Department of—Fish, Wildlife, and Parks (w), Health and Environmental Sciences (w), Highways (w), Natural Resources and Conservation (w), State Lands (w); Montana Reserved Water Rights Compact Commission (w); State of Montana, Governor's Office (w); Salish and Kootenai Tribes of Flathead Reservation (w); University of Montana (w); Wyoming State Engineer (w)

Nebraska:

Blue River Association of Ground Water Conservation District (w); Central Platte Natural Resources District (w); Grand Island, City of (w); Kansas-Nebraska Big Blue River Compact Administration (w); Lincoln, City of (w); Little Blue Natural Resources District (w); Nebraska Department of—Environmental Control (w), Water Resources (w); Nebraska Natural Resources Commission (w); University of Nebraska, Conservation and Survey Division (w)

Nevada:

Carson City, Department of Public Works (w); Douglas County, Department of Planning (w); Elko, County of (w); Las Vegas Valley Water District (w); Mackey School of Mines (w); Nevada Bureau of Mines and Geology (g,n,w); Nevada Department of—Conservation and Natural Resources—Division of Environmental Protection (w), Division of Water Resources (w); Transportation (w); Nye, County of (w); Reno, City of (w); Tahoe Regional Planning Agency (w); University of Nevada—Reno (w)

New Hampshire:

Conway, Town of (w); Nashua Regional Planning Commission (w); New Hampshire Water Resources Board (w); Water Pollution Control Commission (w)

New Jersey:

Bergen, County of (w); Bridgewater, Township of (w); Camden County, Board of Chosen Freeholders (w); Cranford, Township of (w); Delaware River Basin Commission (w); Greenwich, Township of (w); Logan, Township of (w); Morris County, Municipal Utilities Authority (w); New Jersey Department of Environmental Protection, Division of Water Resources (g,w); North Jersey District Water Supply Commission (w); Passaic Valley Water Commission (w); Somerset County, Board of Chosen Freeholders (w); West Windsor Township, Environmental Commission (w)

New Mexico:

Alamo Navajo Chapter (w); Alamogordo, City of (w); Albuquerque, City of (w); Albuquerque Metropolitan Arroyo Flood Control Authority (w); Bernalillo, County of (w); Costilla Creek Compact Commission (w); Jemez River Indian Water Authority (w); Las Cruces, City of (w); Navajo Indian Nation (w); New Mexico Bureau of Mines and Mineral Resources (w); New Mexico Environmental Improvement Division (w); New Mexico Department of Highways (w); New Mexico Oil Conversation Division, Energy and Minerals Department (w); Office of State Engineer (w); Pecos River Commission (w); Pueblo of Acoma (w); Pueblo of Laguna (w); Pueblo of Zuni (w); Raton, City of (w); Rio Grande Compact Commission (w); San Juan County (w); Santa Fe Metropolitan Water Board (w); Veremejo Conservancy District (w)

New York:

Albany, City of, Department of Water and Water Supply (w); Amherst, Town of, Engineering Department (w); Auburn, City of (w); Brookhaven, Town of (w); Chautauqua, County of, Department of Planning and Development (w); Cheektowaga, Town of (w); Clarence, Town of (w); Cornell University—Department of Natural Resources (w), Department of Utilities (w); Cortland, County of, Planning Department (w); Dutchess County, Environmental Management (w); Erie County, Division of Environmental Control, Department of Environment and Planning (w); Genesee-Fingerlakes Regional Planning Council (w); Hudson-Black River Regulating District (w); Irondequoit Bay Pure Waters (w); Kirkwood, Town of (w); Kiryas Joel, Village of (w); Long Island Regional Planning Board (w); Monroe, County of—Engineering Department (w), Health Laboratory (w), Water Authority (w); Montgomery, County of, Planning Department (w); Nassau, County of, Department of Public Works (w); Newstead, Town of (w); New York City—Department of Environmental Protection, Air Resources-Water Resources-Energy (w), Department of Sanitation, Office of Resource Recovery (w); New York State Department of—Environmental Conservation—Division of Air (w), Division of Water (w); Transportation, Bridge and

Construction Bureau (w); New York State Energy Resources and Development Authority (w); New York State Power Authority (w); Nyack, Village of, Board of Water Commissioners (w); Oneida, County of, Planning Department (w); Onondaga, County of—Department of Drainage (w), Environmental Management Council (w), Water Authority (w); Orange, County of, Planning Department (w); Oswego, County of, Planning Board (w); Putnam, County of, Planning Department (w); Rockland, County of, Planning Department (w), Drainage Agency (w); Seneca Nation of Indians (w); Shelter Island, Town of (w); Southern Tier West Regional Planning and Development Authority (w); Suffolk, County of—Department of Health Sciences (w), Department of Public Works (w), Water Authority (w); Sullivan, County of, Planning Department (w); Susquehanna River Basin Commission (w); Temporary State Commission on Tug Hill (w); Ulster, County of, Planning Department (w), County Legislators (w); University of the State of New York, Regents Research Inc. (w); Westchester, County of—Department of Health (w), Department of Public Works (w)

North Carolina:

Ayden, Town of (w); Charlotte, City of (w); Durham, City of, Department of Water Resources (w); Farmville, Town of (w); Greene County (w); Greensboro, City of (w); Greenville Utilities (w); Guilford County S.W.C.D. (w); Kinston, City of (w); LaGrange, Town of (w); New Bern, City of (w); North Carolina State Department of—Human Resources (w), Natural Resources and Community Development (n,w), Transportation, Division of Highways (w); Pinetops, Town of (w); Rocky Mount, City of (w); Snow Hill, Town, of (w); Stantonsburg, Town of (w)

North Dakota:

Burleigh County, Water Resources District (w); Dickinson, City of (w); Lower Heart Water Resources District (w); North Dakota Geological Survey (w); North Dakota State University (w); Oliver County, Board of Commissioners (w); Public Service Commission (w); State Department of Health (w); State Water Commission (w)

Northern Mariana Islands: (See Hawaii)**Ohio:**

Akron, City of (w); Canton, City of, Water Department (w); Columbus, City of, Department of Public Services (w); Freemont, City of (w); Miami Conservancy District (w); Northeast Ohio Areawide Coordinating Agency (w); Northwood, City of (w); Ohio Department of—Natural Resources—Division of Geological Survey (w), Division of Oil (w), Division of Reclamation (w), Transportation (n,w); Ohio Environmental Protection Agency (w); Oregon, City of (w); Seneca Soil and Water District (w); Toledo, City of (w); Williams, County of (w)

Oklahoma:

Ada, City of (w); Altus, City of (w); Association of Central Oklahoma Governments (w); Central Oklahoma Master Conservancy District (w); Claremore, City of (w); Fort Cobb Reservoir Master Conservancy District (w); Foss Reservoir Master Conservancy District (w); Lawton, City of (w); Lugert-Altus Irrigation District (w); Mountain Park Master Conservancy District (w); Oklahoma City, City of (w); Oklahoma Department of Transportation (n,w); Oklahoma Geological Survey, University of Oklahoma (w); Oklahoma State Health Department (w); Oklahoma Water Resources Board (w); Sapulpa, City of (w); Tulsa, City of (w)

Oregon:

Benton County Board of Commissioners (w); Burnt River Irrigation District (w); Confederated Tribes of—Umatilla Indian Reservation (w), Warm Springs Indian Reservation (w); Coos Bay-North Bend Water Board (w); Douglas, County of, Department of Public Works (w); Eugene, City of, Water and Electric Board (w); Lane Council of Governments (w); Lane, County of, Office of the Chief Administrator (w); McMinnville, City of, Water and Light Department (w); North Wasco County People's Utility District (w); Oregon Department of—Fish and Wildlife (w), Geology and Mineral Industries (n), Transportation, Highway Division (w); Water Resources (w); Oregon State University (w); Portland, City of, Bureau of Water Works (w); Rajneeshpuram, City of (w); Salem, City of (w)

Pennsylvania:

Altoona City Authority (w); Bethlehem, City of (w); Chester, County of, Water Resources Authority (w); Delaware River Basin Commission (w); Harrisburg, City of, Department of Public Works (w); Lancaster County Planning Commission (w); Letort Regional Authority (w); Millcreek, Township of (w); Neshaming Water Resources Authority (w); New York State Department of Environmental Conservation (w); Philadelphia, City of, Water Department (w); Pennsylvania Department of—Environmental Resources—Abandoned Mines Reclamation Bureau (w), Mining and Reclamation Bureau (w), Office of Resources Management (w), Oil and Gas Management (w), Solid Wastes and Management Bureau (w), State Parks Bureau (w), Topographic and Geologic Survey Bureau (g,n,w), Water Quality Management Bureau (w); Susquehanna River Basin Commission (w); University Area Joint Authority (w); Warren, County of (w); Washington County—Conservation District (w), Planning Commission (w), Supervisors (w)

Puerto Rico:

Puerto Rico Aqueduct and Sewer Authority (w); Puerto Rico Department of—Agriculture (w), Health (w), Natural Resources (g,w); Puerto Rico Environmental Quality Board (w); Puerto Rico Industrial Development Company (w); Puerto Rico Mineral Resources Development Corporation (g); Puerto Rico Rice Corporation (w); Puerto Rico Vegetable Corporation (w); University of Puerto Rico—CEER (w); (*See also* Virgin Islands)

Rhode Island:

Narragansett Bay Water Quality Commission (w); Rhode Island State Department of Environmental Management, Division of Water Resources (w); State Water Resources Board (w)

South Carolina:

Charleston, Commission of Public Works (w); Cooper River Water Users Association (w); Grand Strand Water and Sewer Authority (w); Hilton Head Island, Public Service District No. 1 (w); Jasper County Administration (w); Myrtle Beach, City of (w); North Myrtle Beach, City of (w); South Carolina State—Department of Highways and Public Transportation (w), Geological Survey (w), Health and Environmental Control (w), Public Service Authority (w), Water Resources Commission (w); Spartanburg Water Works, Commissioners of Public Works (w)

South Dakota:

Black Hills Conservancy Subdistrict (w); East Dakota Conservancy Subdistrict (w); James River Watershed (w); Lower James Conservancy Subdistrict (w); Rapid City, City of (w); Sioux Falls, City of (w); South Dakota Department of—Water and Natural Resources—Geological Survey Division (w), Water Rights Division (w); Watertown, City of (w)

Tennessee:

Lawrenceburg, City of (w); Memphis, City of—Light, Gas, and Water Division (w), Public Works Division (w); Metropolitan Government of Nashville and Davidson County (w); Shelby, County of (w); Tennessee Department of—Conservation, Division of Surface Mines (w), Division of Water Management (w), Geology Division (w), Health and Environment (w); Transportation, Bureau of Highways (w); Tennessee Wildlife Resources Agency (w); Tennessee Tech. University (w)

Texas:

Abilene, City of (w); Alice, City of (w); Arlington, City of (w); Athens Municipal Water Authority (w); Austin, City of (w); Bexar-Medina-Atascosa Counties, Water Improvement District No. 1 (w); Bistone Municipal Water Supply District (w); Brazos River Authority (w); Cleburne, City of (w); Clyde, City of (w); Coastal Industrial Water Authority (w); Colorado River Municipal Water District (w); Corpus Christi, City of (w); Dallas, City of, Public Utilities (w); Dallas, County of, Public Works Department (w); Dallas-Fort Worth Airport (w); Edwards Underground Water District (w); El Paso, City of, Public Service Board (w); Franklin, County of, Water District (w); Gainesville, City of (w); Galveston, County of (w); Garland, City of (w); Georgetown, City of (w); Greenbelt Municipal and Industrial Water Authority (w); Guadalupe-Blanco River Authority (w); Harris, County of, Flood Control District (w); Harris-Galveston Coastal Subsidence District (w); Houston, City of (w); Lavaca-Navidad River Authority (w); Lower Colorado River Authority (w); Lower Neches Valley Authority (w); Lubbock, City of (w); Mackenzie Municipal Water Authority (w); Nacogdoches, City of (w); North Central Texas Municipal Water Authority (w); Northeast Texas Municipal Water District (w); Orange, County of (w); Pecos River Commission (w); Red Bluff Water Power Control District (w); Reeves, County of, Water Improvement District No. 1 (w); Runaway Bay, City of (w); Sabine River Authority of Texas (w); Sabine River Compact Administration (w); San Angelo, City of (w); San Antonio, City of—Engineering Department (w), Water Board (w); San Antonio River Authority (w); San Jacinto River Authority (w); Tarrant, County of, Water Control and Improvement District No. 1 (w); Texas A&M Research Foundation (g); Texas Department of Water Resources (n,w); Texas Parks and Wildlife Department (w); Titus, County of, Fresh Water Supply District No. 1 (w); Trinity River Authority (w); Upper Guadalupe River Authority (w); Upper Neches River Municipal Water Authority (w); Upper Trinity Basin Water Quality Compact (w); West Central Texas Municipal Water District (w); Wichita, County of, Water Improvement District No. 2 (w); Wichita Falls, City of (w); Wood, County of (w)

Trust Territory of the Pacific Islands: (*See* Hawaii)**Utah:**

Bear River Commission (w); Department of Transportation (w); Salt Lake, County of—Board of County Commissioners (w), Division of Flood Control and Water Quality (w); Utah Department of—Natural Resources—Geological and Mineral Survey (g,w), Oil, Gas and Mining Division (w), State Lands and Forestry Division (n), Water Resources Division (w), Water Rights Division (w), Wildlife Resources Division (w); Utah Health Department, Division of Environmental Health (w)

Vermont:

Agency of Environmental Conservation (n); Vermont Department of Water Resources and Environmental Engineering (w)

Virginia:

Alexandria, City of, Department of Transportation and Environmental Services (w); Charles City, County of (w); Hanover, County of (w); James City, County of, Department of Public Works (w); James City Service Authority (w); New Kent, County of (w); Newport News, City of, Department of Public Utilities (w); Northern Virginia Planning District Commission (w); Division of Mined Land Reclamation (w); Roanoke, City of, Utilities and Operations (w); Southeastern Public Service Authority of Virginia (w); University of Virginia, Department of Environmental Sciences (w); Virginia Department of—Conservation and Economic Development, Division of Mineral Resources (n), Highways and Transportation (w); Virginia Polytechnic and State University (w); Virginia State Water Control Board (w); Williamsburg, City of (w); York, County of (w)

Virgin Islands:

Department of Public Works (w); Virgin Islands, College of (w)

Washington:

Bellevue, City of, Public Works Department (w); Chelan, County of, Public Utility District No. 1 (w); Hoh Indian Tribe (w); Ketsap County Board of Commissioners (w); King, County of, Department of Public Works (w); Lewis, County of, Board of Commissioners (w); Makah Tribal Council (w); Municipality of Metropolitan Seattle (w); Pullman, City of (w); Puyallup Indian Nation (w); Quinault Indian Business Committee (w); Seattle, City of, Department of Lighting (w); Skagit, County of (w); Snohomish County (w); Stillaguamish Indian Tribe (w); Tacoma, City of—Public Utilities Department (w), Public Works Department (w); Yakima Tribal Council (w); Washington Department of—Ecology (w), Emergency Management (w), Fisheries (w), Natural Resources (g,n,w), Transportation (w)

West Virginia:

Marshall County Commission (w); Morgantown, City of, Water Commission (w); Washington Public Service District (w); West Virginia Department of—Highways (w), Natural Resources—Division of Water Resources (w), Wildlife (w); West Virginia Geological and Economic Survey (w)

Wisconsin:

Bad River Tribal Council (w); Beaver Dam, City of (w); Dane, County of—Department of Public Works (w), Regional Planning Commission (w); Delavan Lake Sanitary District (w); Fond Du Lac, City of (w); Forest County Potawatomi Community (w); Fowler Lake Management District (w); Green Bay Metropolitan Sewerage District (w); Green Lake Sanitary District (w); Hills Lake District Association (w); Lac du Flambeau Indian Reservation (w); Lac La Belle Management District (w); Madison Metropolitan Sewage District (w); Madison Water Utility (w); Medford, City of (w); Menominee Indian Tribe of Wisconsin (w); Middleton, City of (w); Morris Lake Management District (w); Okauchee Lake Management District (w); St. Croix Tribal Council (w); Southeastern Wisconsin Regional Planning Commission (w); University of Wisconsin, Extension, Geological and Natural History Survey (n,w); University of Wisconsin, Milwaukee (w); Waupun, City of (w); Wisconsin Department of—Natural Resources (n,w), Transportation (n)—Bridge Section (w), Division of Highways (w); Wolf Lake Management District (w); Wood, County of (w)

Wyoming:

Attorney General (w); Cheyenne, City of (w); Sulleter, County of (w); Teton County Board of Commissioners (w); Uinta, County of

(w); Water Development Commission (w); Wyoming Department of—Agriculture (w), Economic Planning and Development (w), Environmental Quality (w), Highways (w); Wyoming State Engineer (n,w)

Federal Cooperators**Central Intelligence Agency (g)****Department of Agriculture:**

Agricultural Stabilization and Conservation Service (n); Economics, Statistics, and Cooperatives Service (w); Forest Service (n,w); Graduate School (w); Agricultural Research Service (w); Soil Conservation Service (g,n,w); Statistical Reporting Service (n)

Department of the Air Force:

Air Force Academy (w); Bolling Air Force Base (g); Hanscom Air Force Base (g); Headquarters, AFTAC/AC (g); Vandenberg Air Force Base (w); Wurtsmith Air Force Base (w)

Department of the Army:

Aberdeen Proving Ground (w); Armament Research and Development Command (w); Avionics R and D Activity (g); Coastal Engineering Research Center (g); Corps of Engineers (g,w); Fort Bliss (w); Fort Carson Military Reservation (w); Mobility Equipment Research and Development Command (g); Research Office, Triangle Park, N.C. (g); Signals Warfare Laboratory (n); Waterways Experiment Station (g); White Sands Missile Range (w)

Department of Commerce:

Census (n); Coastal Plains Regional Action Planning Commission (g); National Bureau of Standards (g); National Ocean Survey (n); National Oceanic and Atmospheric Administration (n); National Marine Fisheries Service (w); National Weather Service (g,n,w)

Department of Defense Agencies:

Defense Advanced Research Projects Agency (g); Defense Mapping Agency (g,n); Defense Nuclear Agency (g); Defense Intelligence Agency (g)

Department of Energy:

Albuquerque Operations Office (g,w); Bonneville Power Administration (w); Chicago Operations Office (w); Idaho Operations Office (w); Lawrence Livermore Laboratory (g); Nevada Operations Office (g,n,w); Oak Ridge Operations Office (n,w); Office of Energy Research (g); Procurement Operations Office (g); Richland Operations Office (g,w); San Francisco Operations (g); Sandia National Laboratories (g); United States Arms Control and Disarmament Agency (g); Western Area Power Administration (g)

Department of Health and Human Services (w)**Department of the Interior:**

Bureau of Indian Affairs (g,n,w); Bureau of Land Management (g,n,w); Bureau of Mines (g,n,w); Bureau of Reclamation (g,n,w); Minerals Management Service (g,n,w); National Park Service (g,n,w); Office of the Secretary (g,w); Office of Surface Mining Reclamation and Enforcement (g,n,w); U.S. Fish and Wildlife Service (g,n,w); Water and Power Resources Service (g)

Department of the Navy:

Naval Explosive Ordnance Disposal Test Center (g); Naval Oceanographic Office (g); Naval Weapons Center, China Lake (g,w); Office of Naval Research (g); U.S. Marine Corps, Camp Pendleton (w)

Department of State:

Agency for International Development (g,w); International Boundary and Water Commission, U.S. and Mexico (w); International Joint Commission, U.S. and Canada (w)

Department of Transportation:

Federal Highway Administration (g,n,w); U.S. Coast Guard (g,w)

Department of Treasury:

U.S. Customs Service (n)

Environmental Protection Agency (n):

Corvallis Environmental Research Laboratory (w); Environmental Monitoring Systems Laboratory (g); Office of Administration and Resources Management (n) Office of Environmental Engineering and Technology (g); Office of Monitoring and Technical Support (w)

Federal Emergency Management Agency (g,w)**Federal Energy Regulating Commission Licensees (w)****General Services Administration (w)****International Boundary and Water Commission (n)****National Aeronautics and Space Administration (g,w)****National Science Foundation (g,n,w)****Nuclear Regulatory Commission (g,w)****Tennessee Valley Authority (n,w)****Veterans Administration (g,w)****Other Cooperators and Contributors****Government of American Samoa (g)****Government of Peru (g)****Government of Saudi Arabia (g,n,w)****Government of Venezuela (w)****People's Republic of China (g)****United Nations:**

United Nations Development Program (g,w); UNESCO (w); World Meteorological Organization (w)

Budgetary Data

Table 1. Geological Survey budget for fiscal years 1980 to 1985, by activity and sources of funds¹

[Dollars in thousands; totals may not add because of rounding]

Budget activity	1980	1981	1982	1983	1984	1985
Total	\$782,136	\$769,757	\$661,842	\$556,054	\$596,177	\$604,664
Direct program	639,143	623,057	509,983	396,909	423,885	417,021 ²
Reimbursable program	142,993	146,700	151,859	159,145	172,292	187,643
States, counties, and municipalities	46,849	48,700	50,418	51,972	55,801	59,454
Miscellaneous non-Federal sources	16,817	19,605	24,376	21,215	21,142	26,075
Other Federal agencies	79,327	78,395	77,065	85,958	95,349	102,114
National Mapping, Geography, and Surveys	82,683	89,177	88,133	91,611	112,447	115,155
Direct program	72,759	77,449	77,687	81,138	90,985	85,469
Reimbursable program	9,924	11,727	10,446	10,473	21,462	29,686
States, counties, and municipalities	3,083	2,985	3,000	2,700	2,700	1,937
Miscellaneous non-Federal sources	610	1,095	1,100	1,204	2,362	9,450 ³
Other Federal agencies	6,231	7,648	6,346	6,569	16,400	18,299
Geologic and Mineral Resource Surveys and Mapping	193,652	208,287	212,355	206,517	217,584	216,921
Direct program	146,963	162,756	163,731	159,190	164,354	169,851
Reimbursable program	46,489	45,531	48,624	47,327	53,230	47,070
States, counties, and municipalities	640	758	480	490	988	1,016
Miscellaneous non-Federal sources	11,258	13,192	16,844	14,293	15,030	13,261
Other Federal agencies	34,791	31,761	31,300	32,544	37,212	32,793
Water Resources Investigations	184,871	194,016	190,096	199,697	220,390	238,131
Direct program	108,664	115,458	108,637	115,096	129,441	133,408
Reimbursable program	76,207	78,558	81,459	84,601	90,949	104,723
States, counties, and municipalities	43,126	45,138	46,938	48,782	52,113	56,500
Miscellaneous non-Federal sources	1,778	2,088	2,679	3,914	3,600	3,327
Other Federal agencies	31,303	31,332	31,842	31,905	35,236	44,896
Conservation of Lands and Minerals	106,395	127,001	130,468	-----	-----	-----
Direct program	105,928	125,739	129,868	-----	-----	-----
Reimbursable program	467	1,262	600	-----	-----	-----
Miscellaneous non-Federal sources	12	29	210	-----	-----	-----
Other Federal agencies	455	1,233	390	-----	-----	-----
Office of Earth Sciences Applications	23,734	23,205	20,853	18,452	-----	-----
Direct program	18,935	18,849	14,359	11,132	-----	-----
Reimbursable program	4,799	4,356	6,494	7,320	-----	-----
States, counties, and municipalities	-----	-----	-----	-----	-----	-----
Miscellaneous non-Federal sources	2,808	3,139	3,482	1,728	-----	-----
Other Federal agencies	1,991	1,217	3,012	5,592	-----	-----
National Petroleum Reserve in Alaska	169,845	107,001	2,196	-----	-----	-----
Direct program	169,845	107,001	2,196	-----	-----	-----
Allocation transfer	-----	-----	-----	-----	-----	-----
Reimbursable program (Federal)	-----	-----	-----	-----	-----	-----
General Administration	3,776	3,896	3,407	16,313	15,962	15,354
Direct program	3,776	3,896	3,407	14,931	15,642	15,244
Reimbursable program (Federal)	-----	-----	-----	1,382	320	110
Facilities	12,273	11,909	10,093	9,167	10,608	13,089
Direct program	12,273	11,909	10,093	9,022	10,463	13,049
Reimbursable program	-----	-----	-----	145	145	40
Miscellaneous services to other accounts	4,907	5,266	4,236	7,917	6,186	6,014
Reimbursable program	4,907	5,266	4,236	7,917	6,186	6,014
Miscellaneous non-Federal sources	351	62	61	96	150	37
Other Federal agencies	4,556	5,204	4,175	7,821	6,036	5,977
Barrow Area Gas Operations	-----	-----	-----	6,400	13,000	-----
Direct program	-----	-----	-----	6,400	13,000	-----

¹Includes 1982 appropriation for Minerals Management Service.

²Direct program includes \$416,365 for current year, \$89 for indefinite appropriation, and \$567 for unobligated balance transferred.

³Includes \$7,108 for map receipts previously shown under direct program column.

Table 2. Geological Survey reimbursable program funds from other Federal agencies for fiscal years 1980 to 1985, by agency

[Dollars in thousands]

Budget activity	1980	1981	1982	1983	1984	1985
Total	\$79,326	\$78,395	\$76,675	\$85,958	\$95,349	\$102,114
Department of Agriculture	3,878	3,567	2,675	2,774	2,770	3,066
Department of Commerce	276	-----	-----	111	910	617
National Oceanic and Atmospheric Administration	2,388	823	1,781	5,750	6,139	6,876
Ozarks Regional Commission	76	-----	-----	-----	-----	-----
Department of Defense	17,447	18,490	21,459	25,429	33,707	31,883
Department of Energy	14,406	10,885	10,529	5,858	13,828	15,893
Bonneville Power Administration	61	81	75	103	120	132
Department of Housing and Urban Development	302	188	-----	-----	-----	-----
Department of the Interior	22,926	22,553	20,328	23,955	16,167	19,859
Bureau of Indian Affairs	9,295	3,999	5,001	4,796	4,299	5,530
Bureau of Land Management	7,807	13,800	10,551	7,150	3,446	2,900
Bureau of Mines	297	299	275	200	56	54
Bureau of Reclamation	2,257	2,231	1,800	3,411	3,524	8,510
Minerals Management Service	-----	-----	-----	5,284	2,347	744
National Park Service	818	1,121	1,015	1,957	1,037	1,122
Office of the Secretary	203	154	100	223	244	17
Office of Surface Mining	1,563	469	1,176	606	95	90
U.S. Fish and Wildlife Service	686	480	410	328	1,119	892
Department of State	2,449	2,272	3,445	573	700	619
Department of Transportation	291	273	500	483	600	458
Environmental Protection Agency	2,645	1,259	675	883	1,012	1,476
National Aeronautics and Space Administration	2,793	5,065	3,885	3,716	3,999	3,979
National Science Foundation	1,211	2,001	1,958	1,300	774	242
Nuclear Regulatory Commission	1,325	1,781	1,544	2,272	2,003	1,236
Tennessee Valley Authority	243	317	290	151	250	247
Miscellaneous Federal agencies	2,105	3,717	3,431	4,882	6,334	9,554
Miscellaneous services to other accounts	4,556	5,204	4,175	7,821	6,036	5,977

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Information Systems Division
Administrative Division



As the Nation's principal conservation agency the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

