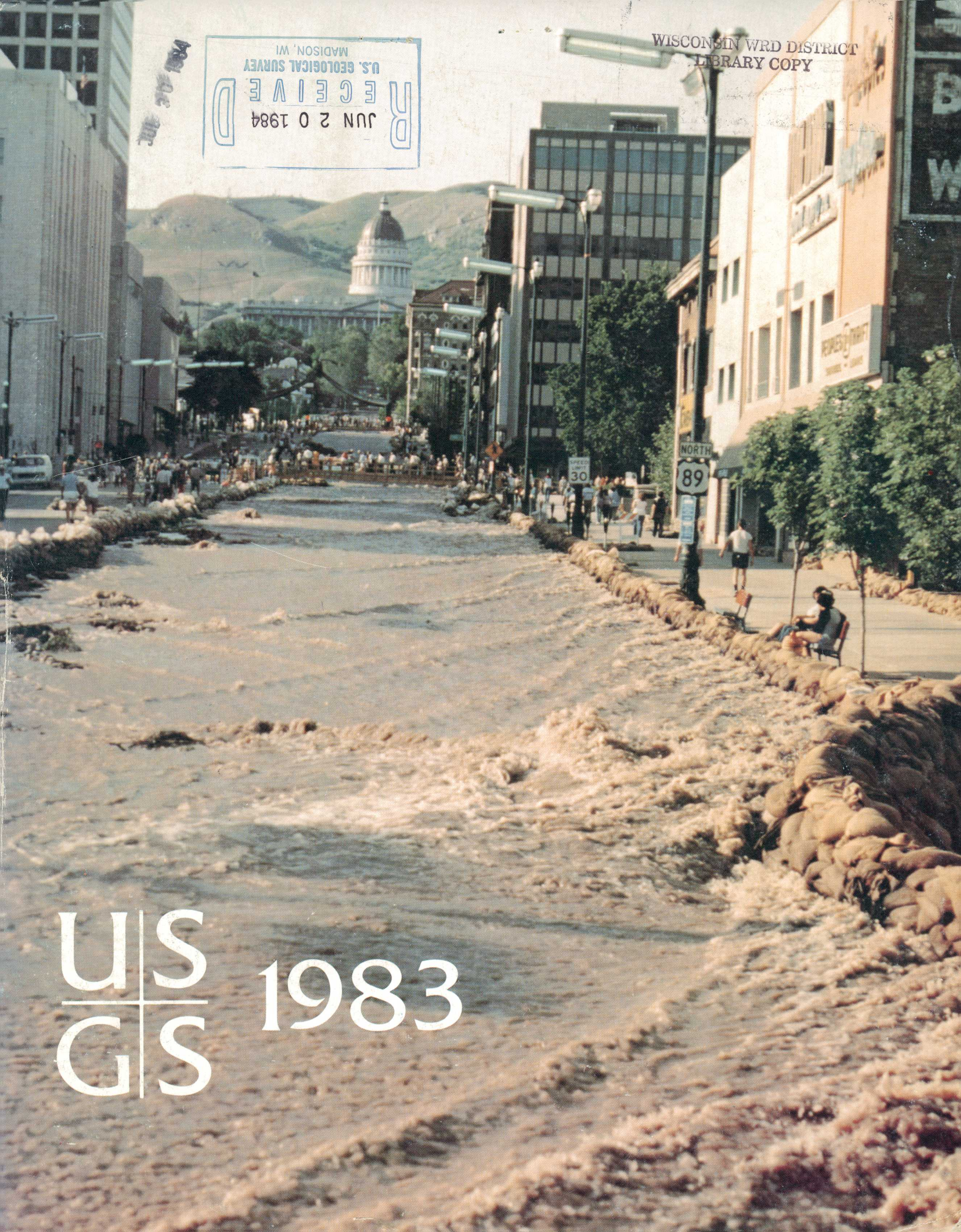
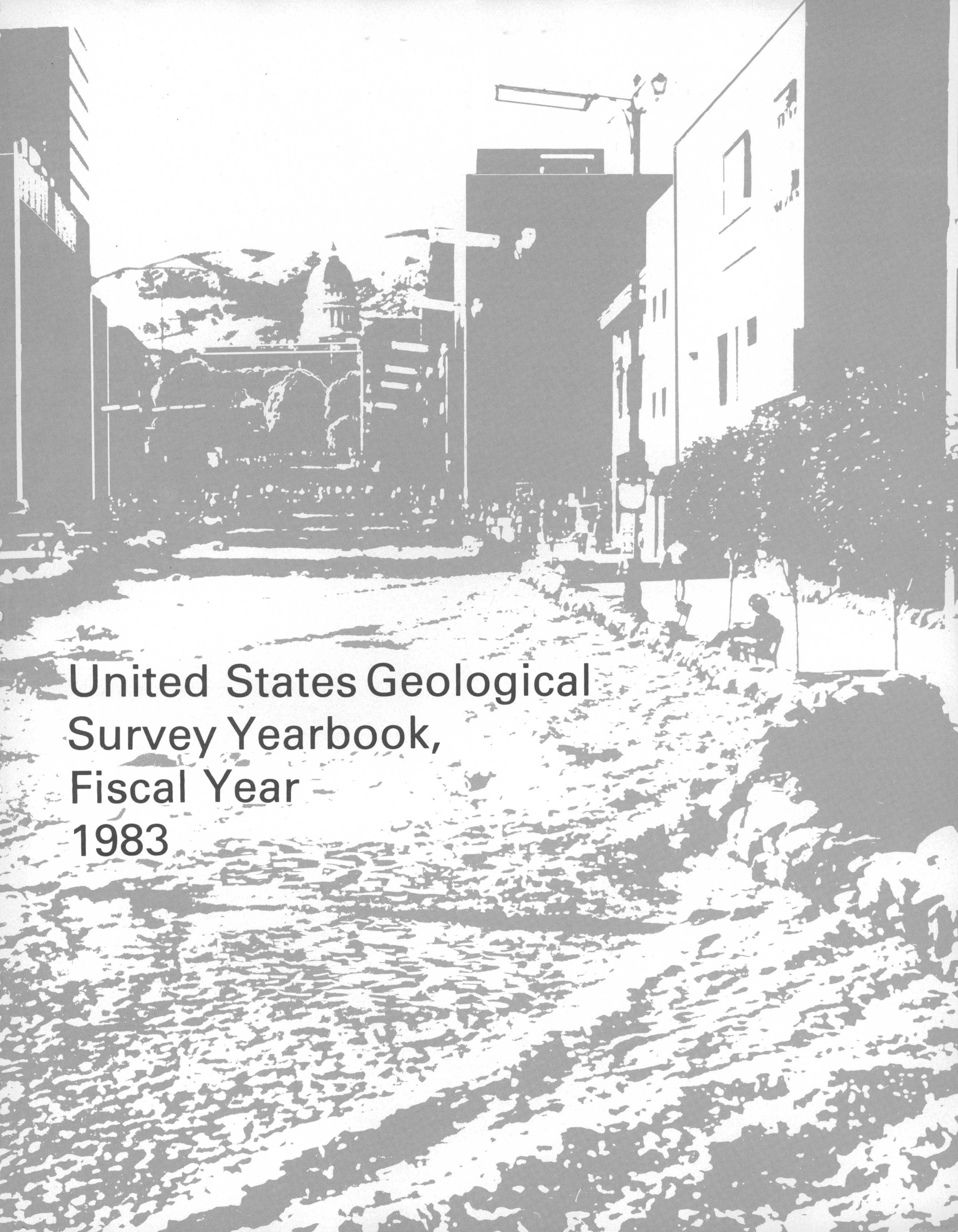


USGS 1983

Cover: *The 1982–83 water year was characterized by significant flooding throughout the country. In Salt Lake City, Utah, local authorities had to reroute City Creek flow from City Creek Canyon down State Street in order to control the May–June 1983 floodwaters. View of State Street, June 5, looking north toward the Capitol Building. (Photograph by Rulon Christiansen, U.S. Geological Survey.)*

United States Geological Survey Yearbook, Fiscal Year 1983



UNITED STATES DEPARTMENT OF THE INTERIOR
WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY
Dallas L. Peck, Director

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United States Geological Survey Yearbook, Fiscal Year 1983

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◀ Jagged peaks of the Teton Range tower more than 7,000 feet above the flat floor of Jackson Hole in northwest Wyoming.

Photograph by Dawn Reed, U.S. Geological Survey.

The Year in Review

For 104 years, the U.S. Geological Survey has served to meet the Nation's need for knowledge about the Earth and its resources. In the spirit of that proud tradition and as tribute to the many goals and accomplishments met and achieved, I am pleased to present the *U.S. Geological Survey Yearbook* for 1983.

Events during the past year reminded us of the fundamental importance of the earth sciences to the Nation and presented the Geological Survey with many challenges. The tremendous power of nature was once again demonstrated by unusually widespread flooding, a devastating earthquake in Coalinga, California, volcanic eruptions in Hawaii, and landsliding in California and Utah. Disposal of toxic and nuclear wastes repeatedly made headlines, as did acid rain. The increasing use of computers to store and analyze earth science data has sparked the growth in demand for digital cartographic data by State and Federal agencies and by the private sector. Continued emphasis on environmentally sound and expeditious development of the Nation's mineral and energy resources and the Presidential proclamation of an Exclusive Economic Zone, which expanded the Nation's area of jurisdiction by 170 percent, increased the need for earth science information.

The storms and flooding of 1982 and 1983 confronted the Nation with a rare series of hydrologic events. Severe flooding affected much of the Mississippi and Missouri River basins, the Texas Gulf Coast, the Great Lakes basin, coastal California, and the Colorado River basin. A description of many of these floods and of the Survey's role in responding to the floods is the subject of a major essay in this volume.

The Geological Survey has an important role in providing State and local agencies with current, accurate evaluations of water conditions and critical water issues. In March of this year, the Geological Survey added a new dimension to its role as the Nation's water resources information agency by beginning preparation of an annual *National Water Summary* that will provide an overview of changing water conditions and describe specific water situations and concerns. A large part of the first *National Water Summary* was developed through the technical contributions and aid of the more than 800 State and local agencies that form the non-Federal part of the Survey's Federal-State Cooperative Program. The report, scheduled to be published in January 1984, describes the major hydrologic events that occurred during 1982 to mid-1983, summarizes the water issues of concern in each State, and provides a hydrologic perspective on these issues. In addition to describing the condition of the Nation's water resources, future reports will focus on selected geographic areas and issues of special interest and importance.

The 1983 *National Water Summary* has identified ground-water contamination and acid rain as two prominent water resource issues. The Geological Survey has recently increased its scientific effort to address these concerns.

In 1982, we began a program to study toxic waste and ground-water contamination problems. This program is designed to provide the Nation with earth science information necessary to improve waste-disposal practices and to help solve existing and future ground-water contamination problems. This year, we began new research studies at three field sites having documented, but different, histories of ground-water pollution. These studies involve teams of scientists examining the physical, chemical, and biological processes affecting the movement and fate of the contaminants in a variety of ground-water environments.

In addition to research projects to develop an understanding of the processes of contamination, we are beginning a long-term program to assess the quality of the Nation's ground-water resources, particularly with regard to trace substances. This will be done by studying individual areas that are representative of wider regions in terms of climate, ground-water hydrology, and human activities. Over a period of years, a number of these studies will be carried out in each of the major climatic and geohydrologic regions of the Nation.

Considerable attention and debate are currently directed towards the environmental effects of acid rain and various emission-control strategies. Much of the debate stems from the fact that the relations between emissions, acid deposition, and environmental effects are poorly understood. The Geological Survey has been investigating the chemistry of precipitation and the affected streams and lakes for the past three decades and has published a number of significant findings related to acid rain. One recent study, however, deserves special mention. An analysis of sulfur dioxide emissions and Geological Survey water-quality data collected over the past 10 to 15 years at 47 small headwater streams having little or no development indicates that sulfur dioxide emissions in the Northeast have decreased over the past 15 years and that trends in the water-quality characteristics of these headwater streams are consistent with decreased acid deposition. Throughout much of the remainder of the country, sulfur dioxide emissions have increased over the past 15 years, and trends in the water-quality characteristics of streams are consistent with increased acid deposition. The Geological Survey is accelerating its research, areal studies, and monitoring activities to further define the critical relation between acid deposition and consequent changes in stream and lake chemistry.

Resource assessments were a major endeavor of the Geological Survey in 1983. Under the provisions of the Wilderness Act and subsequent related legislation, we and the U.S. Bureau of Mines completed a 20-year effort to assess the mineral resource potential of about 45 million acres of Forest Service wilderness areas. The summary of these mineral surveys, which was released in December 1983, indicates that there is evidence of mineralization in about 65 percent of the areas examined. The percentage of individual wilderness areas having mineral resource potential ranges from 0.1 of 1 to 100 percent and averages about 20 percent. Assessments of oil and gas resources of wilderness lands in 11 Western States also were completed this year. Results of the assessments indicate that about two-thirds of the wilderness lands have some petroleum potential. The study also marked the first systematic resource assessment to integrate the available geologic information on designated Federal lands through a computer-based digital cartography system. During the next several years, we plan to complete a similar program to assess the petroleum resources of wilderness lands in Alaska and other major Federal lands in Alaska and the Western United States.

On March 10, 1983, President Reagan proclaimed the "Exclusive Economic Zone," which extends jurisdiction of the United States for a distance of 200 nautical miles seaward of our shorelines. This new national boundary gives our Nation jurisdiction over the vast living and nonliving resources within those 3.9 billion acres. The importance of the Exclusive Economic Zone is emphasized when its size is compared to the total onshore area of the United States and its territories which is only 2.3 billion acres. Reconnaissance studies, in conjunction with the Federal Republic of Germany in 1982, suggested that mineral-rich crusts occurring on seamounts (underwater volcanoes) in the central Pacific contain significant quantities of cobalt, nickel, and manganese. There are more than 200 islands and seamounts within the boundaries of the Exclusive Economic Zone in the Pacific.

Recognizing the importance of the President's proclamation to the Nation's energy and mineral self-sufficiency, we have moved aggressively to coordinate our own marine geology activities with those of other Federal agencies, academia, and industry to identify and assess the resources of this vast area.

In August, we began an intensive 15-month program of marine geologic and geophysical investigations in the Pacific Ocean that will extend from the Arctic to Antarctica. Planned activities for scientists on board the Research Vessel *Samuel P. Lee* include sea-floor photography of sulfide deposits on the Juan de Fuca Ridge, seismic surveys in the Bering Sea and in the south Pacific, additional sampling in the central and south Pacific for cobalt-manganese crusts, and seismic profiling in offshore Antarctica.

The eruption of Kilauea Volcano in Hawaii, catastrophic landslides in Utah and California, and the earthquake at Coalinga, California, attracted considerable public attention in 1983 and emphasized the need for Geological Survey programs aimed at mitigating losses from these hazards. Volcanologists and seismologists from the Survey accurately predicted the reawakening of Kilauea Volcano and successfully forecast the continuing dome-building eruptions of Mount St. Helens. Survey landslide experts responded to an emergency request from the State of Utah to help identify potentially damaging landslides triggered by the rapid melting of a record mountain snowpack and locally heavy spring rains.

Mapping needs of Federal, State, and local agencies have caused the Geological Survey to accelerate completion of the standard large-scale map coverage of the United States to 1989. To reach our goal, we began publishing provisional edition maps in 1982. These interim products have the same level of information as the standard topographic maps but are prepared more rapidly and at lower cost by making some minor modifications to field and compilation procedures and by reducing some of the map-finishing operations—activities that can be performed in conjunction with the revision of the maps. This year, we published about 700 new topographic quadrangle maps and have completed about 82 percent of the large-scale map coverage of the conterminous United States and Alaska.

Recognizing the wide range of applications for digital cartographic data, we are in the process of building a National Digital Cartographic Data Base and of developing the necessary data standards, computer techniques, and equipment capabilities for its support. Production to date has primarily focused on providing the basic data categories shown on 7.5-minute published topographic quadrangle maps to meet the needs of other Federal and State agencies.

One major interagency effort getting underway is a program with the Bureau of Census to digitize all the hydrography and transportation data for the country at a scale of 1:100,000. The data resulting from this effort will not only be used to support the 1990 census but should be very useful to State and other Federal agencies for many other applications as well.

Another interagency effort is the development of a Federal Mineral Land Digital Data System that will contain information on Federal land surface and subsurface ownership, mineral occurrence, mining restrictions, and other data essential for establishing mineral development policy. Combining information from various data bases in a geographic information system will allow persons involved with resource development issues to more easily integrate and analyze these data to answer questions related to the availability and development of mineral resources on Federal lands.

If spatial or cartographic data are to be used for computer analyses and computer-aided decisionmaking, then such information must be organized into a data base that meets consistent and exacting standards for widespread public use. To address these issues and to avoid duplication and waste, the Department established the Interior Digital Cartography Coordinating Committee, which is chaired by the Geological Survey. The Committee addresses digital cartographic data standards, data production planning, applications development, and technological information exchange. Subsequently, in April 1983, we were designated by the Office of Management and Budget as lead agency for digital cartography data coordination in the Federal Government.

Nineteen eighty-three was a year of challenges, new beginnings, and accomplishments. Many ambitious tasks, however, remain on our agenda. Whatever the challenges, I have the utmost confidence that we shall meet them with the same dedication, ability, and success that has served the Nation so well for 104 years.

Perspectives

Flooding: A Unique Year

By A. L. Putnam

Background

Floods have been and continue to be one of the most destructive hazards facing the people of the United States. Of all the natural hazards, floods are the most widespread and the most ruinous to life and property. Today, floods are a greater menace to our welfare than ever before because we live in large numbers near water and have developed a complex reliance upon it. From large rivers to country creeks, from mountain rills to the trickles that occasionally dampen otherwise arid wastelands, every stream in the United States is subject to flooding at some time. Floods strike in myriad forms, including sea surges driven by wild winds or tsunamis churned into fury by seismic activity. By far the most frequent, however, standing in a class by themselves, are the inland, freshwater floods that are caused by rain, by melting snow and ice, or by the bursting of structures that man has erected to protect himself and his belongings from angry waters.

An inland, freshwater flood is any abnormally high streamflow that overtops the banks of a stream. Such flooding is a natural characteristic of rivers. Flood plains are normally dry-land areas that act as natural reservoirs and temporary channels for floodwaters. If more flow is generated than the stream banks can accommodate, the water will overtop the banks and spread over the flood plain causing social and economic disruption and damage to crops and structures.

Floods can take place in the United States in all seasons, but, in particular areas, they are more likely at certain times of the year. Winter floods due to rainfall and abnormal temperature patterns take place in the Eastern United States. The incidence of winter floods progresses northward from the Gulf States in January to the Ohio River valley in March. Winter floods, caused by eastward moving cold fronts, also occur along the western slopes of the Sierra Nevada and Cascade Range in California, Oregon, and Washington.

Early spring floods are common in the northwestern States, the Great Lakes area, the Missouri River basin, the Red River of the North basin, the eastern slopes of the Cascade Range in Washington and Oregon, the Sierra Nevada Range in California, and the mountains of Arizona. The floodwater results from melting snow that accumulated during the previous winter. Ice jams also frequently cause flooding in some northern States and in some of the mountainous areas. Early spring floods in the lower Mississippi River basin are caused by the seasonal rainfall pattern. Late spring floods in the mountains mainly result from melting snow at high altitudes.

Summer floods are likely to occur in any part of the United States, but they are rare along the west coast. Although some summer floods have been caused by general cyclonic storms, most are caused by thunderstorms that affect small areas. Some are severe enough to cause considerable property damage and loss of life. During late summer and in the autumn, hurricanes commonly cause floods along the coasts of the Gulf of Mexico and the Atlantic Ocean.

Finally, catastrophic dam failures have also caused major flooding resulting in property damage and loss of life. These can occur at any time of the year but are more likely during periods of heavy runoff.

To rate floods on a statistical basis, hydrologists use a rather simple system. Depending upon the records of the historical behavior of a given river, a particular inundation may be classified as a 10-year or a 100-year flood, meaning that a flood of that size or greater may be expected to occur, on the average, every 10 or every 100 years, respectively. This does not mean, of course, that floods are neatly spaced at regular 10- or 100-year intervals. What the system does do is assess the chances of, say, a specific flood occurring in any specific year; for example, a 100-year flood has, roughly, 1 chance in 100 of occurring.

To provide information for this flood-frequency rating system, collection of data about floods, whether large or small, is a continuing objective of the U.S. Geological Survey. A network of about 8,000 continuous-record streamflow gaging stations is maintained throughout the United States and the trust territories. Flood information is only one aspect of the data from that network, and it is supplemented by several thousand high-flow stations that provide annual maximum stage and discharge data. During major floods, data on discharge and peak elevation are collected on ungaged streams in addition to the gaged sites to help determine the areal distribution and magnitude of the floods.

From data collected by the Geological Survey, information is furnished to the public and private sectors. The information is widely used in the design of bridges, channel capacities, and roadbed elevations; for flood-plain zoning and for flood-forecast, flood-alert and flood-warning systems; and in studies of the economics of flood-protection works, water supply, and flood-insurance programs. The most common use of flood information is by regulatory authorities who use it to establish design criteria that properly balance the hydrologic, economic, social, and political variables that might be considered in a comprehensive analysis. Afterwards, planners and designers use the information in analyses that ensure compliance with the minimum regulatory criteria which are usually stated as a frequency value.

In flood-warning activities, streamflow data are used by the National Weather Service, in combination with other data, to forecast the stage and time of an imminent flood. Telemetering and satellite data relay systems are used by the Survey to obtain current stage information that supports flood forecasting. Improvements in the capability to provide data for the prediction of timing and extent of floods is a continuing objective of the Survey.

1982–83 Conditions and Events

In most average years, one or more of the seasonal events generally produce some significant flooding in a few random locations throughout the United States. In some rare years, one particular seasonal event may produce a flood of such magnitude and widespread distribution that the flood is classified among the greatest floods of the United States. Since December 1, 1982, however, almost every State in the United States and the Virgin Islands has experienced significant flooding. This in itself may uniquely place the 1982–83 sequence of events among the great flood episodes in the United States. Highlights of some of the most outstanding events since December 1, 1982, are described in the following paragraphs.

Mississippi River Basin

Winter rainfall and temperature patterns began prematurely in late autumn. Two main storms, December 2 to 7 and December 24 to 29, 1982, were both related to deep low-pressure troughs over Texas and the Southwest. The resulting flow pattern fed warm air over the lower Mississippi River basin and created atmospheric disturbances over the Gulf of Mexico and southeast Texas that encouraged development of the storm systems. Subsequent slow movement of these systems toward the northeast produced tornadoes, severe thunderstorms, and intense rainfall of long duration. Additional moderate, but spotty, rains in December served to maintain a high soil moisture content, thereby contributing to high runoff and extreme floods.

The floods of December 1982 and early January 1983 affected an area approximately 250 miles wide and 1,000 miles long through the central and southern part of the United States extending from the Great Lakes to the Gulf of Mexico. This area was roughly centered over the central and southern part of the Mississippi River basin.

Illinois, Missouri, and Arkansas were affected severely by the December 2 to 7 storm. The December 24 to 29 storm had the greatest affect in Lousiana and Mississippi. Western Tennessee, Kentucky, and other States on the fringe of the storms were not severely affected by either storm but had moderate to heavy rainfall from both events that caused moderate flooding on some streams.

Many of the outstanding peak flood flows during December were on large streams because of the generally widespread and long duration of the rainfall. Previous peaks of record were exceeded, and recurrence intervals were greater than 100 years at many sites.

Backwater from the Pearl River near Slidell, Louisiana, looking east along Old River Road, April 11, 1983. (Photograph by Verne Schneider, Water Resources Division, U.S. Geological Survey.)

Illinois was affected most severely by the early December storm with several streams exceeding previously known maximum floods. Missouri, like Illinois, was affected most by the early December storm and also had many new peaks of record established.

Arkansas had severe flooding caused by the early December storm, and the southeastern part of the State received additional flooding from the late December storm. Peaks of record were exceeded at many locations. An outstanding example occurred near Poughkeepsie on the Strawberry River where the maximum peak since 1936 was exceeded by 6.6 feet and the December 3 peak discharge was more than 3 times the previous maximum. This flood was greater than a 100-year event.

Large flood peaks in Mississippi were mostly in the western part of the State. Only a few really unusual peaks occurred because Mississippi was on the eastern fringe of the storms.

Louisiana was affected by both December storms. The late December storm was the most severe. The Little River near Rochelle exceeded the previous maximum since 1958 by 5.6 feet. The December 29 peak discharge was nearly twice as large as the previous maximum and had a frequency in excess of 100 years.

The mainstem of the Mississippi River, although not exceeding any previous maximum floods, had fairly high peaks from Illinois downstream to its mouth. Peak discharges in the lower reaches exceeded 1 million cubic feet per second at Tarbert Landing, Mississippi.

Ironically, as the passing of winter led into the seasonal rainfall patterns of spring, the storms brought abnormally intense rainfall of extended duration. From April 6 to 10, 1983, southeastern Louisiana and southern Mississippi were again deluged with intense rainfall for extended time periods. Several streams experienced record breaking floods, and frequencies exceeded 100 years. Most notable was the Pearl River where the maximum flood of record since I874 caused extensive flooding in the Slidell and Pearl River, Louisiana, area for the third time in 5 years. The April 9 peak discharge had a frequency greater than 200 years. Of further interest at this location, only one flood greater than a 25-year event had been experienced during the first 78 years of record and that was in the first year of recorded events. During the last 5 years of record, three events have exceeded the 25-year frequency with the 1983 flood exceeding the 200-year event.

Again in late April and early May, the middle and upper Mississippi River basin experienced extensive flooding. Rainfall from this storm combined with snowmelt runoff to produce the fifth largest peak stage of record on the lower Mississippi River at Baton Rouge, Louisiana. The late May peak exceeded that of spring 1973, a flood that ended a 23-year period of relative tranquility. The 1983 discharge of about 1.5 million cubic feet per second was slightly greater than a 25-year frequency.

May 19 to 22 brought more suffering to the already weary people of central and northeastern Mississippi. The Pearl River and the Tennessee Tombigbee River system were the hardest hit. More streams experienced record floods with frequencies in excess of 100 years.

For the 6-month period December 1, 1982, through May 31, 1983, the cumulative total rainfall exceeded 60 inches, or roughly 3 times the seasonal normal, and also exceeded the normal annual total rainfall. During the same period, the Pearl River at Carthage, Mississippi, experienced 51 inches of runoff, or roughly 85 percent of the known rainfall-produced streamflow.

At Jackson, Mississippi, flood stage was exceeded for 98 days from December 1, 1982, through May 31, 1983. Each month experienced significant flooding: December, 23 days over flood stage; January, 13 days; February, 21 days; March, 11 days; April, 18 days; and May, 12 days. In some locations, residents have had to evacuate their homes as much as 50 percent of the time.

With the summer thunderstorm season just beginning, heavy rainfall from July 2 to 4, 1983, in a band 50 miles wide from DeKalb, Illinois, to Valparaiso, Indiana,

Staff gage upstream near left abutment of Military Road bridge crossing French Branch Creek, a tributary of the Pearl River, near Slidell, Louisiana, April 11, 1983. (Photograph by Verne Schneider, Water Resources Division, U.S. Geological Survey.)

caused flooding with a frequency in excess of 100 years on some streams in northern Illinois. The 24-hour rainfall generally exceeded 5 inches, with a maximum of about 7 inches.

Virgin Islands

More than a foot of rain fell in a 12-hour period beginning late April 17, 1983, on St. Thomas and St. Johns. Torrents of water, mud, and debris, along with fallen rocks, trees, and utility poles, made most island roads impassable. The total cumulative rainfall from the fierce thunderstorm dumped more than 14 inches of rain on St. Thomas. Maximum reported rainfall was in excess of 18 inches on an island whose average annual rainfall is just 20 inches.

Extensive flooding was recorded in several areas throughout both islands. In Charlotte Amalie, the main city on St. Thomas and capital of the Virgin Islands, the Harry S Truman Airport had as much as 2 feet of water throughout the runway system and remained closed for 2 days. On both St. Thomas and St. Johns, urban areas were affected by as much as 3 feet of water. Throughout the islands, flooding exceeded previously known maximums with frequencies estimated to exceed 100-year events.

California—Coast and Western Slopes

California was plagued with severe storms from the Pacific during December 1982 through March 1983, and, in most of coastal California, the cumulative rainfall through the beginning of spring was approximately double the seasonal normal. In many parts of the State, the cumulative total rainfall equaled or exceeded 100-year frequency. The principal damaging activity associated with the rainstorms was the reactivation of deep-seated landslides as the rains infiltrated to raise the ground-water levels. Because infiltration in many areas requires days, weeks, or even months to raise local ground-water levels to maximum, the spring runoff from snowmelt triggered massive mud and debris flows and land and rock slides.

Localized floods, most often in urban areas, occurred with each storm. Flood peaks in California, although not generally exceeding many previous long-term maximums, were significant in comparison to previous floods. On the Cache Creek near Yolo, the historic maximum of 41,400 cubic feet per second occurred on February 25, 1958. The January 27, 1983, peak discharge was 33,000 cubic feet per second; however, since the 1958 flood, Cache Creek has been partially controlled by the Indian Valley Reservoir, which was completed in 1974. The March 2, 1983, peak discharge on the Sacramento River at Butte City had a frequency of about 35 years. Clear Lake at Lakeport is the largest freshwater lake in the State. The lake level is regulated by gates on a dam at the outlet, and water is released down the natural channel on Cache Creek. The previous known maximum level for Clear Lake since 1874, which was 11.12 feet, occurred on January 28, 1914, before the dam was completed in 1915. The March 3, 1983, peak level was 11.16 feet.

The Great Basin

California, Nevada, and Utah experienced one of the most severe winters since the collection of climatic data began in the late 1880's. Many of the snowpack measuring sites set new records for depth and water content. Resulting runoff from this snow caused record peak discharges and cumulative-flow volumes at many sites. Temperatures for most of the winter and spring remained well below normal, with only a short break during early March 1983. Warm days and nights during this break, combined with rain on existing snow at altitudes below 6,000 feet, caused major flooding along the Humboldt River in northern Nevada and most small streams in eastern Nevada. The peak discharge on the Humboldt River at Elko exceeded the estimated magnitude of the 50-year flood.

In western Nevada, winterlike conditions with heavy snowfall continued through mid-May. Then the weather changed dramatically, and daytime temperatures rose into the 80's. Water saturated the steep slopes of the eastern Sierra Nevada causing numerous land-slope failures. On May 29, a 400-foot segment of the major road connecting Lake Tahoe to Carson City and Reno slid to the bottom of a 250-foot ravine, causing some minor damming but no major flooding on already swollen Glenbrook Creek. One day later, at noon on Memorial Day, a massive landslide on the flank of Slide Mountain displaced two small lakes and sent a mud-and-debris flow roaring down Ophir Creek into Washoe Valley between Carson City and Reno. Preliminary estimates suggest that the flow traveled at speeds of about 20 miles per hour, with a peak-flow rate that may have been as great as 30,000 cubic feet per second.

Streamflow in the three major western Nevada rivers, the Truckee, Carson, and Walker, is breaking long-time cumulative-flow records. The yearly average discharge on the Truckee River at Reno is 657 cubic feet per second for 55 years of record. The projected average flow for the 1983 water year is estimated at approximately 2,000 cubic feet per second. Pyramid Lake, the closed-basin terminus of the Truckee River, is expected to rise a total of 13 feet by the end of the water year. Already the lake has reached an altitude last seen in April 1950. The Carson River is projected to have a record average discharge of about 1,000 cubic feet per second for the 1983 water year. This will exceed the 42-year average by 254 percent. Walker Lake, the closed-basin terminus of the Walker River, has already risen 7.5 feet since October 1, 1982. Only two other similar rises have been recorded since 1928: 6 feet in 1938 and 7 feet in 1969. High flows in northern Nevada continued into late July.

In Utah, Great Salt Lake rose 5.2 feet from September 18, 1982, to July 1, 1983, the greatest seasonal rise ever recorded. The previous largest known seasonal rise was 3.4 feet in 1906–07. The rise in 1982–83 was caused by considerably above-average rainfall in 1982, above-average snowfall during winter 1982–83, and continued snowfall and unseasonably cool temperatures during spring 1983 that prevented normal evaporation of water from the lake.

The level of Great Salt Lake on July 1, 1983, was 4,205.0 feet above sea level. This is the highest level the lake has reached since 1924. The increase in area covered by the lake from September 1982 to July 1983 was 171,000 acres (267 square miles). This has created problems with the roads, railroads, wildfowl-management areas, recreational facilities,

Thirteenth South St. between West Temple and Second West, looking east, Salt Lake City, Utah, May 28, 1983. The conduit beneath Thirteenth South is unable to handle the runoff and spouts water into the street, sandbagged as a canal. (Photograph by Paul Blanchard, Water Resources Division, U.S. Geological Survey.)

and industrial installations that have encroached on the exposed lake shores.

The level of Utah Lake, by agreement of 1885 between the land owners around the lake in Utah Valley and the users of water from the lake in Salt Lake County, is to be controlled so that it does not rise above "compromise" level. In 1983, however, Utah Lake rose considerably above that level, peaking at 4.94 feet above "compromise" level June 23. Previous known maximum stages are 4.9 feet above "compromise" level in July 1884 and 6.42 feet above "compromise" level sometime in 1862.

In Utah, several streams exceeded previous known maximum floods, and recurrence intervals were greater than 50 and 100 years at many locations. The Sevier River near Lynndyl, for instance, experienced a peak discharge nearly double the previously known discharge since 1944 and more than double the magnitude of the 100-year flood.

In Salt Lake City, underground conduits have been designed to carry much of the streamflow. City Creek normally flows through a portion of these underground conduits. Red Butte, Emigration, and Parleys Creeks normally flow westward under the city in a conduit beneath 13th South Street. In late May and June 1983, the worst possible scenario of flooding had developed for the canyons that produce floodwaters for these streams. Conduits in the city became blocked with silt, gravel, and debris swept down from the channels and flood plains where it had accumulated during long periods without major floods. The conduits could not begin to handle all the water which overflowed into the streets above. The streets were sandbagged and formed into canals, and floodwaters were channeled down 13th South and State Streets—thus, the emergence of two new rivers, the "State Street River" and the "13th South Street River."

Colorado River Basin

Larger than normal accumulation of snow occurred in the Rocky Mountains during winter and spring 1982–83. The U.S. Soil Conservation Service maintains a network of snow courses, some telemetered, to provide information on the rate of snow accumulation and equivalent water content. Preliminary data and information show that as of January 1, 1983, the equivalent water content of the snow cover in much of the Rockies was 121 percent of the long-term (1963–77) average. Lack of snow during January and February caused estimates of the snow water content to be decreased to about 90 percent of the long-term average on February 1 and March 1. Then, late winter and early spring snows caused estimates of the equivalent water content to be increased to 120 percent of the 1963 to 1977 average April 1, and, by May 1, estimates were 142 percent of the long-term average.

Cooler than normal temperatures in May caused snowmelt from only the lower elevations. This is illustrated by the fact that some stations that receive runoff from lower elevations experienced peak discharges about the end of May, and the frequencies were generally less than 10 years. However, a larger than normal snow cover still existed above 8,000 feet. Melting of the high-elevation snow took place at a gradual rate until the last week of June when daytime high temperatures in the mountains reached 70° to 80°F. and a frontal system moved through from June 23 to 25 bringing general rainfall in excess of 0.5 inch. This combination of warm temperatures and rainfall generated peak discharges at gaging stations that had a range in recurrence intervals from 5 to 200 years. The most significant high flows occurred on the Colorado, Gunnison, and White Rivers. An outstanding example occurred near Meeker, Colorado, on the White River where the discharge exceeded all previous maximum discharges that occurred in 78 years of station operation. The peak discharge frequency was estimated to be about 200 years.

Flooding in Arizona and California along the Colorado River was caused by releases from Lake Powell (Glen Canyon Dam) and Lake Mead (Hoover Dam). A June 6, 1983, forecast predicted inflow to Lake Powell for the months of April through July at 131 percent of normal runoff. Updated estimates of inflow to Lake Powell made June 28 called for 210 percent of normal runoff.

Inflow to Lake Powell increased from about 16,000 cubic feet per second to over 30,000 cubic feet per second in late April 1983. In late May, the inflow increased from 36,000 to about 90,000 cubic feet per second. The peak inflow of about 126,000 cubic feet per second occurred in June. On July 10, estimated inflow was 69,000 cubic feet per second. Releases from Lake Powell increased steadily during June, reaching a maximum average daily discharge of 92,600 cubic feet per second.

Releases from Lake Mead were increased in January to meet storage amounts in accordance with operation criteria. In late June, releases from Hoover Dam were being held at 40,000 cubic feet per second. However, flow over the spillway of Hoover Dam began on July 3, and the maximum release was 42,000 cubic feet per second on July 10. Flow over the spillway had occurred only one other time since the completion of the dam in 1935 and that occasion was in 1943 during controlled operations to test the newly completed system.

Summary

Above-normal precipitation prevailed in most of the United States in 1982 and 1983, filling lakes and reservoirs, recharging many aquifers, and, when unusually excessive, causing floods. Meltwater from extremely heavy snows in parts of the West caused floods and posed continuing threats of flooding in many areas in spring and summer 1983.

The intense flooding that affected much of the Mississippi and Missouri River basins, the Great Basin, and the Colorado River basin boosted streamflows on many streams to their highest in 55 years, possibly even during the 20th century. The frequency for floods in parts of at least 14 States exceeded that which can be expected to occur on the average of once in 100 years, with a few exceeding frequencies of once in more than 200 years. When all the data and information have been collected, analyses might very well show such widespread climatic and hydrologic events in one year to be the unique situation of modern man's experience.

The National High-Altitude Photography Program

By Charles W. Beetschen

High-altitude photography—aerial photography taken from aircraft operating at altitudes of 40,000 feet and above—has been recognized for many years as one of the most versatile, accurate, and economical remote sensing techniques used to evaluate, map, and monitor the Nation's resources and environment. Federal and State agencies and private users make extensive applications of high-altitude photography in mapping and charting and in studies of topography, geology, hydrology, land use and land cover, soils, wetlands, and other resources. In site-specific studies, high-altitude photography provides information to estimate timber volumes, to detect crop diseases and forestry infestations, to take wildlife censuses, to estimate traffic flows, to plan highway and pipeline routes, to aid in archeological investigations, and for many other applications concerned with the inventory, management, and development of natural and manmade features. High-altitude photography taken at frequent intervals over the same area provides information necessary for change detection, such as observation of shoreline changes in the coastal zone, changes in land use and land cover, or alterations in the landscape caused by floods, storms, and other natural disasters. When used with other forms of remote sensing in a systems approach to data acquisition and analysis, high-altitude photography aids in providing spatial data important to thematic mapping and land use planning and management (fig. 1).

In recognition of the multiple uses of high-altitude photography now and in the foreseeable future and the need to acquire photography in the most efficient manner, Federal agency users agreed in 1978 to consolidate their requirements and to pool their resources in a coordinated cost-saving effort to systematically photograph the approximately 3 million square miles of the conterminous United States (48 States). The agreement provided for the establishment in 1980 of a National High-Altitude Photography Program designed to develop a national high-altitude photographic data base composed of black-and-white and color-infrared photography. The U.S. Geological Survey, the principal coordinating agency, shares the responsibilities for program planning and for funding the acquisition of photography with 12 other Federal agencies participating in the program. When the remaining photographs for the national high-altitude photography data base are acquired in 1986, the Nation will have for the first time complete photographic coverage at uniform scale of the conterminous United States.

Background

High-altitude photography became a reality in the 1950's and 1960's as a result of improvements in aircraft and photographic technology during World War II and the immediate postwar period. These innovations included the introduction of new propulsion systems, pressurization, and other design changes to aircraft to permit high-altitude operations; modifications to photographic systems including the use of color and color-infrared films providing a high degree of spatial resolution and spectral discrimination; significant new photogrammetric equipment and procedures that could prepare a standard mapping product to prescribed national standards of accuracy and content; and many other improvements. During this period, high-altitude photography depended on the use of military aircraft converted for civilian applications. The high cost of flight operations for these aircraft counterbalanced the savings in production costs normally realized from application of photography taken at higher altitudes. Federal agencies deferred major acquisitions of high-altitude photography until a more cost-effective photographic system was developed.

In the late 1960's, the introduction of a small business jet capable of operating at high altitudes provided commercial aerial survey firms an aircraft that required modest capital outlay and made the acquisition of high-altitude photography economically feasible for Federal agencies. Interest in high-altitude photography intensified, and competition began for the services of the few aircraft available. However, individual agencies planned for the acquisition of high-altitude photography with only minimal coordination of requirements. The result was duplication of photography in some areas of the country, a lack of photography in others, and a slowdown in programs relying on high-altitude photography for data acquisition and analysis. A large amount of high-altitude photography was acquired, but with little semblence of national coverage; also lacking was a central source where all users could obtain information about the availabilty of existing photographic coverage.

The Geological Survey, exercising responsibilities for coordination of aerial photography assigned under Office of Management and Budget Circular A–16, began preliminary studies in 1970 to identify the needs of the Federal agencies for high-altitude photography with the objective of developing a program to achieve national coverage.

In 1972, the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying was established by the Office of Management and Budget to conduct a broad study on how best to use Federal resources to meet overall cartographic requirements. The 1973 report of the task force recommended a centrally coordinated effort to assemble, review, and validate the aerial photographic needs of all civilian agencies and indicated the need for a central source to provide information to all users about existing aerial photography.

During the next several years, the Geological Survey continued studies to determine Federal agency requirements for high-altitude photography. A separate survey was conducted by the U.S. Department of Agriculture to identify agency data needs to support departmental programs. This survey indicated that high-altitude color-infrared photography would support a majority of the data needs that could be satisfied by photographic film sensors. The information from the Department of Agriculture, combined with similar results from the Geological Survey, provided sufficient justification for a single draft proposal for a National High-Altitude Photography Program which could be submitted to other interested Federal agencies for review.

In August 1978, the Geological Survey invited representatives of 24 Federal agencies to meet and discuss the draft proposal, to identify the products, and to consider funding procedures. The agency representatives fully supported the need for a national program which would lead to the formation of a high-altitude photography data base for the conterminous United States, eliminate duplication by consolidating the needs of many Federal and State agencies, result in substantial savings in the cost of acquiring high-altitude photography, and make high-altitude photography readily available to all users, both public and private.

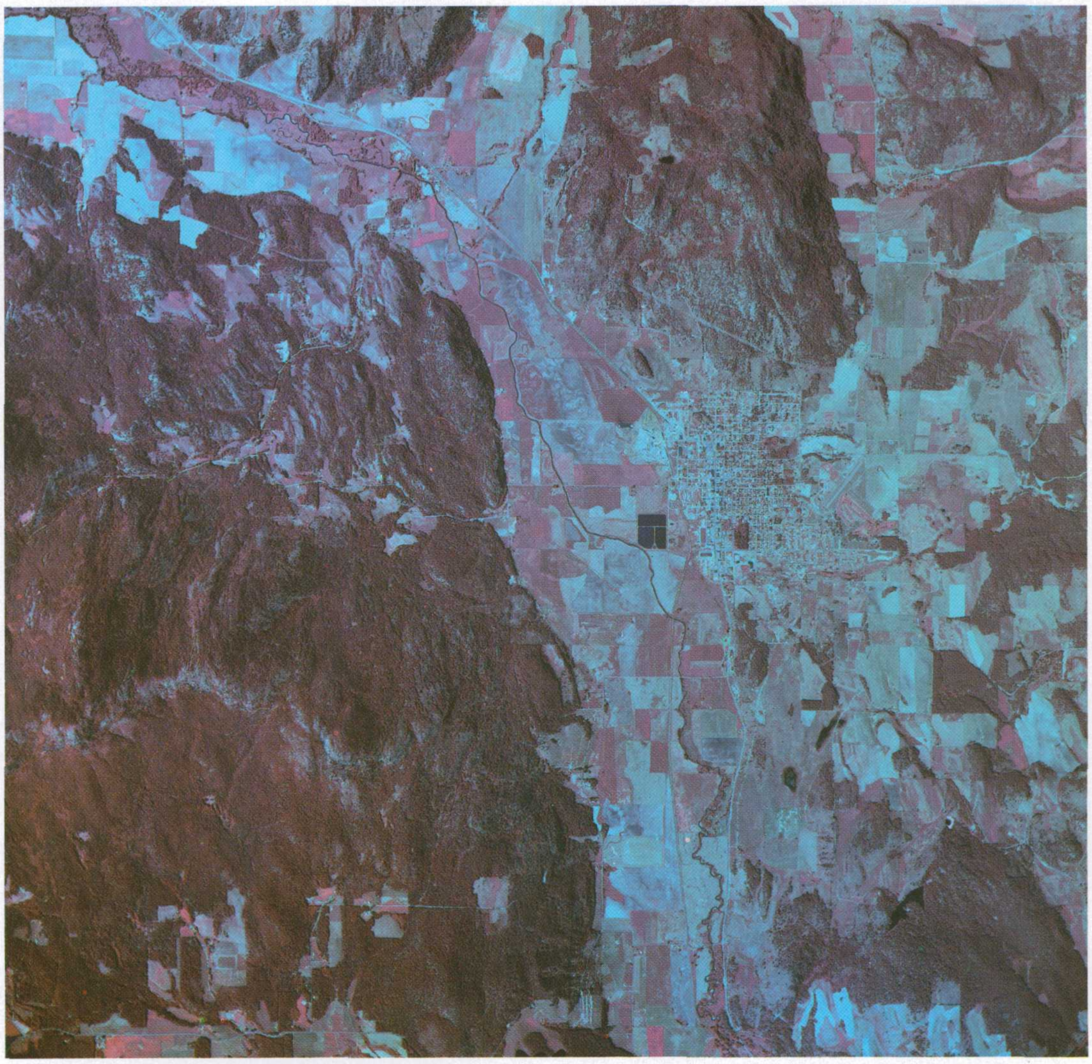
An interagency steering committee was organized to consider the findings of the August 1978 meeting and to complete a program proposal. Discussions were held with potential commercial aerial survey firms on the technical requirements of the program and with Federal agencies to identify priority areas and funding for the first-year flight operations and to discuss the processing of film and distribution of products. The plan for a National High-Altitude Photography Program was approved by the Federal agencies in 1979, and contracts were awarded to commercial aerial survey firms to permit the start of photographic operations in fiscal year 1980.

Program Description and Products

The jet aircraft employed in the National High-Altitude Photography Program by the commercial contractors are equipped with 9- by 9-inch format precision aerial mapping cameras. These cameras take vertical aerial photographs that are compatible with precision stereoscopic mapping equipment. One camera has a 6-inch (153-millimeter) focal length lens, uses Kodak 2405 panchromatic black-and-white film, and produces a photograph at a scale of 1:80,000 (1 inch equals about 1.25 miles). The other camera has an 8¼-inch (210-millimeter) focal length lens, uses Kodak 2443 color-infrared film, and produces a photograph at a scale of 1:58,000 (1 inch equals about 0.9 mile). Each black-and-white photograph covers an area of about 130 square miles; each color-infrared photograph covers an area of about 68 square miles. The theoretical ground resolution of both black-and-white and color-infrared photographs is approximately 6½ feet (2 meters).

The aircraft fly in a north-south direction over predetermined flight lines along the centers of Geological Survey 7.5-minute

Figure 1.—*Photographs of Colville, Washington, and vicinity taken August 6, 1983, showing the rectilinear pattern of the urban area (airport on the east; sewage treatment facility on the west) surrounded by agricultural land (alfalfa and grain fields) and forest land (ponderosa pine, Douglas fir, and western larch). The distinct north-south linear features include the Colville River, Burlington Northern Railroad, and U.S. Route 395. A, Color-infrared (scale 1:58,000). B, Black-and-white (scale 1:80,000).*



A

quadrangles at an altitude of 40,000 feet above mean terrain. Film is exposed over ground stations established in advance of the flight missions and patterned to produce overlapping photographs required for stereoscopic coverage (fig. 2). There are an average of three black-and-white exposures and four color-infrared exposures for each 7.5-minute quadrangle. Approximately 120,000 black-and-white photographs and 175,000 color-infrared photographs are required for complete coverage of the conterminous United States.

Photographic operations must consider the flying season and other environmental factors. The flying season selected for the initial coverage of the 48 States is the leaf-off season. This time of the year is of primary concern in the deciduous forest areas generally located east of 96° west longitude. Useful photography can be taken only when the Sun angle is greater than 30° and when cloud cover, snow, smoke, and haze are absent. Photographs cannot contain hot spots (reflections) or excessive shadowing. These requirements limit the flying season to specific time periods for all areas of the conterminous United States so that no single area can be flown throughout the year. Generally, flights are limited to spring in the deciduous forest areas. Photographic operations in all areas are subject to seasonal changes and local variations in terrain.

The primary products of the National High-Altitude Photography Program are 9- by 9-inch black-and-white and color-infrared photographs in film or paper-print format. Film positives and paper prints are available for black-and-white and color-infrared in the 9- by 9-inch size; however, a film negative is available as a standard product for only the black-and-white photography. Photography from the National High-Altitude Photography Program is not for the exclusive use of the Federal agencies but is available to everyone.

B

The Geological Survey's National Cartographic Information Center serves as the central source for information about the National High-Altitude Photography Program and the approximately 13 million frames of aerial photography acquired by other programs. Photography from the National High-Altitude Photography Program can also be obtained directly from the primary processing and distribution centers of the Earth Resources Observation Systems Data Center in Sioux Falls, South Dakota, or the Agricultural Stabilization and Conservation Service in Salt Lake City, Utah.

Current Program Organization and Status

The National High-Altitude Photography Program Steering Committee established in 1978 continues as the principal organizing and coordinating body for the program. The committee considers short- and long-range program objectives and new requirements for high-altitude photography. The committee is chaired by the Geological Survey, with member representatives from the Soil Conservation Service and the Agricultural Stabilization and Conservation Service, Department of Agriculture; the Bureau of Land Management, Department of the Interior; the U.S. Army Corps of Engineers, Department of Defense; and the Tennessee Valley Authority. Representatives from the Office of Surface Mining, Department of the Interior, and the Defense Mapping Agency, Department of Defense, serve as ad-hoc members in an advisory capacity.

Each year, the committee hosts a conference where representatives from the Federal agencies participating in the program review status and progress, identify priority areas for photographic missions during the succeeding year, and indicate the level of funding support available for that year. A plan for photography is prepared which balances the requests for photographic coverage with the amount of funding available from each agency.

Since the beginning of the program in fiscal year 1980, a total of 2.85 million square miles, or 93 percent of the area of the conterminous United States, has been contracted. About 52 percent of the contracted photography has been completed and is available to users (fig. 3). The final 7 percent of the area will be contracted in fiscal year 1985. All contracted photography is scheduled to be completed in fiscal year 1986.

Federal agencies that have provided financial support for the National High-Altitude Photography Program are Agricultural Stabilization and Conservation Service, Forest Service, Soil Conservation Service, and Statistical Reporting Service of the Department of Agriculture; U.S. Army Corps of Engineers and the Defense Mapping Agency of the Department of Defense; Bureau of Indian Affairs, Bureau of Land Management, Bureau of Mines, Geological Survey, National Park Service, Office of Surface Mining, and Fish and Wildlife Service of the Department of the Interior; and the Tennessee Valley Authority.

Future of National High-Altitude Photography Program

On completion of the initial photographic coverage of the conterminous United States, the National High-Altitude Photography Program will be directed toward a second photographic cycle based on the coordinated requirements of Federal and State agencies and other users. Under the aegis of the program's interagency steering committee, studies are in progress to review the need for extending photographic coverage to Alaska, Hawaii, and other areas; to examine the use of new cameras, films, and other modifications to current photographic systems; to investigate requirements for changes in the flying

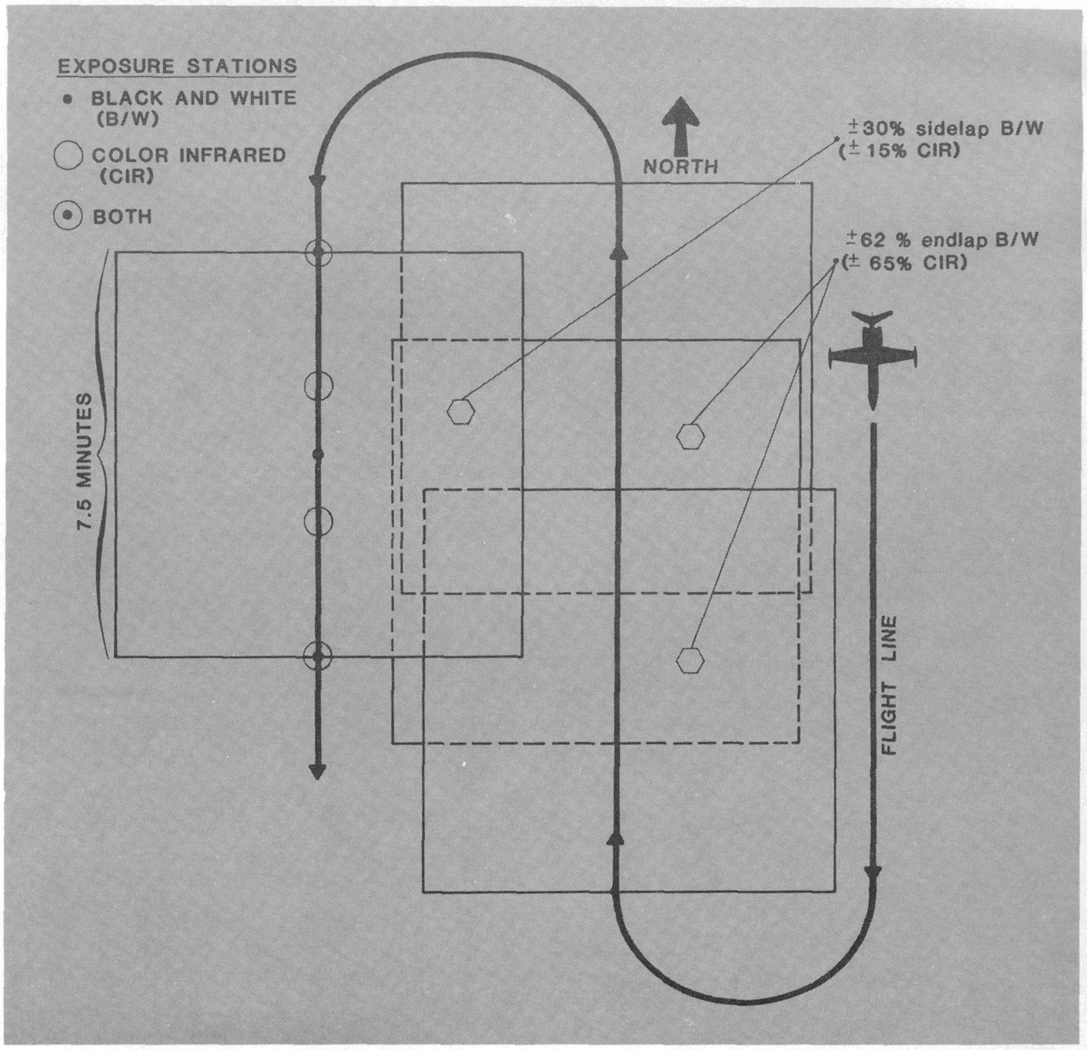


Figure 2.—Pattern of exposure stations, endlap, and sidelap for high-altitude photography.

season and other environmental conditions; and to review user needs for better methods of obtaining archived photography.

The use of new photographic technology and other improvements envisioned by the program planners should result in a more reliable and flexible product to address a broader range of interests and applications.

The National High-Altitude Photography Program is a successful response to the deficiencies in the acquisition of aerial photography within the Federal establishment noted by the Office of Management and Budget Task Force in 1973. The recommendations of the Task Force have been satisfied, and the goal of national photographic coverage is within sight. The program is also an example of how a scientific activity can be coordinated between Federal agencies and the user community to result in savings to the taxpayer and in a product that is of immediate and significant value to the Nation.

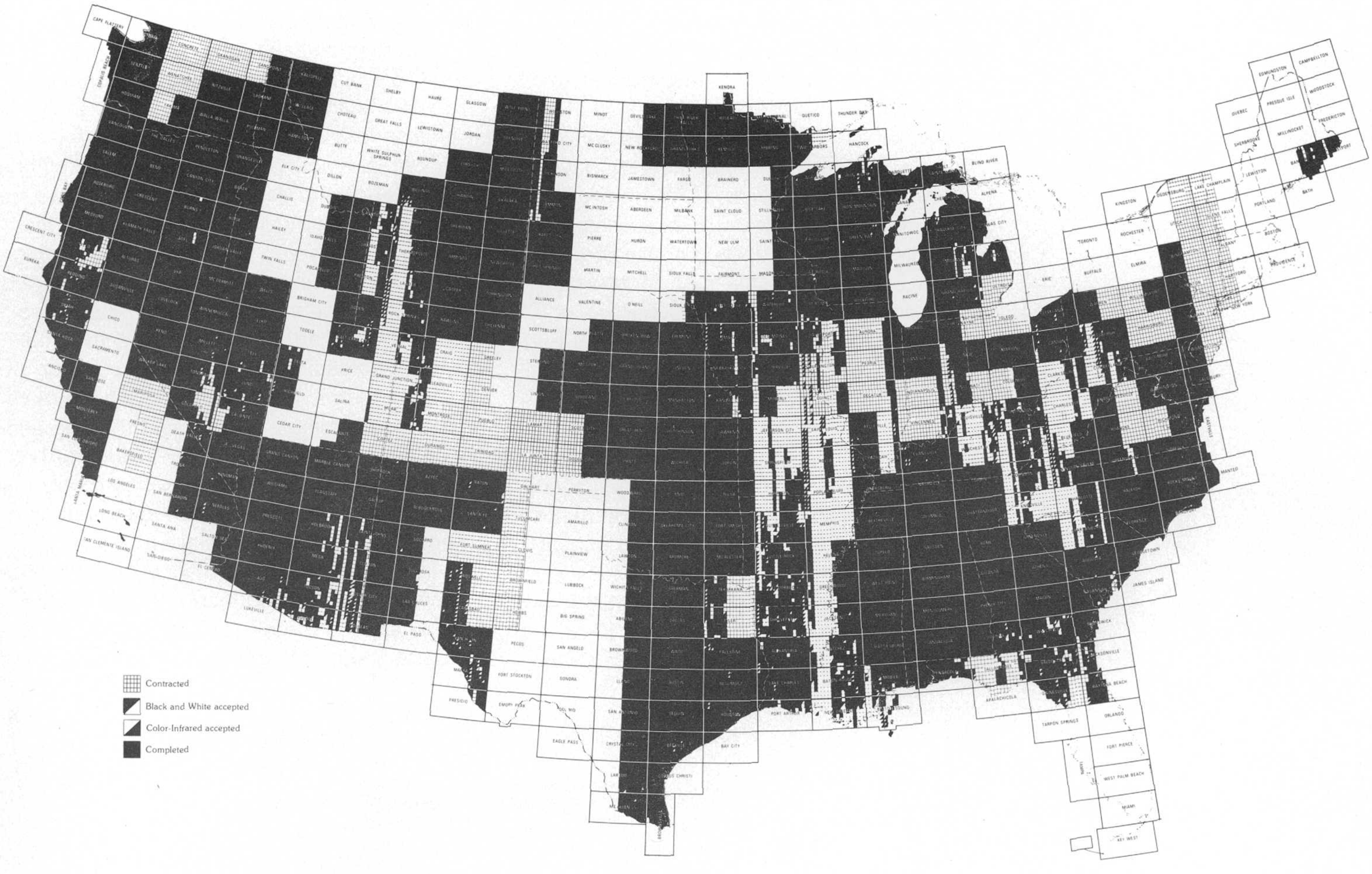


Figure 3. *— Status of national high-altitude photography coverage.*

Research in the Marine Frontier

By Bonnie A. McGregor and Gary W. Hill

On March 3, 1879, the U.S. Congress established the U.S. Geological Survey and charged it with the responsibility for the classification of public lands and the examination of the geologic structure, mineral resources and products of the national domain. In 1879, much of this Nation's land area was frontier. Today, the Nation's geographic frontiers primarily lie beneath its surrounding oceans. By Presidential proclamation in 1983, the U.S. Exclusive Economic Zone was established. The proclamation claimed the seabed resources in this underwater frontier to 200 nautical miles offshore (fig. 1). This zone, which includes the waters surrounding the continental United States, Hawaii, Alaska, Puerto Rico, and U.S. territories and possessions, constitutes an area about 170 percent larger than the size of the onshore area. Within this vast underwater domain lie resources of immense importance to the Nation: an estimated 35 percent of the economically recoverable oil and gas yet to be found in the United States; strategic metals like cobalt, manganese, and nickel in sea-floor crusts and nodules; massive sulfide deposits actively forming today on ridge crests; and major concentrations of heavy minerals in nearshore sand bodies.

Along with the immense potential for increasing our domestic resource base, exploration of the seabed provides an exciting scientific frontier. Most of the geologic framework of the Nation's continental margins (shelf, slope, and rise) is known from a relatively few and widely spaced deep seismic reflection profiles and a few deep drillholes that recovered rocks from within the margin. The frontier character of the offshore domain is emphasized when one considers that major sedimentary basins with petroleum potential have been discovered within the last 8 years, sulfide deposits at sea-floor spreading centers have been known only since 1978, cobalt-rich manganese crusts on Pacific seamounts (underwater extinct volcanoes) were recognized as important potential resources in 1982, and additional sea-floor features, such as submarine canyons and seamounts, are discovered virtually every year. Through marine geologic surveys, the dynamic aspects of plate tectonics can be studied: the continual creation of the Earth's new crust at the mid-ocean spreading centers; the formation of volcanic arcs, basins, and trenches where the crustal plates collide; and the migration of the plates over hotspots in the Earth's mantle, creating chains of volcanic islands. Through geologic time, this plate tectonic process has caused rocks formed on the sea floor (even whole marine basins) to be accreted to the continents where erosion may expose them for study today. Because these rocks originated in the oceans,

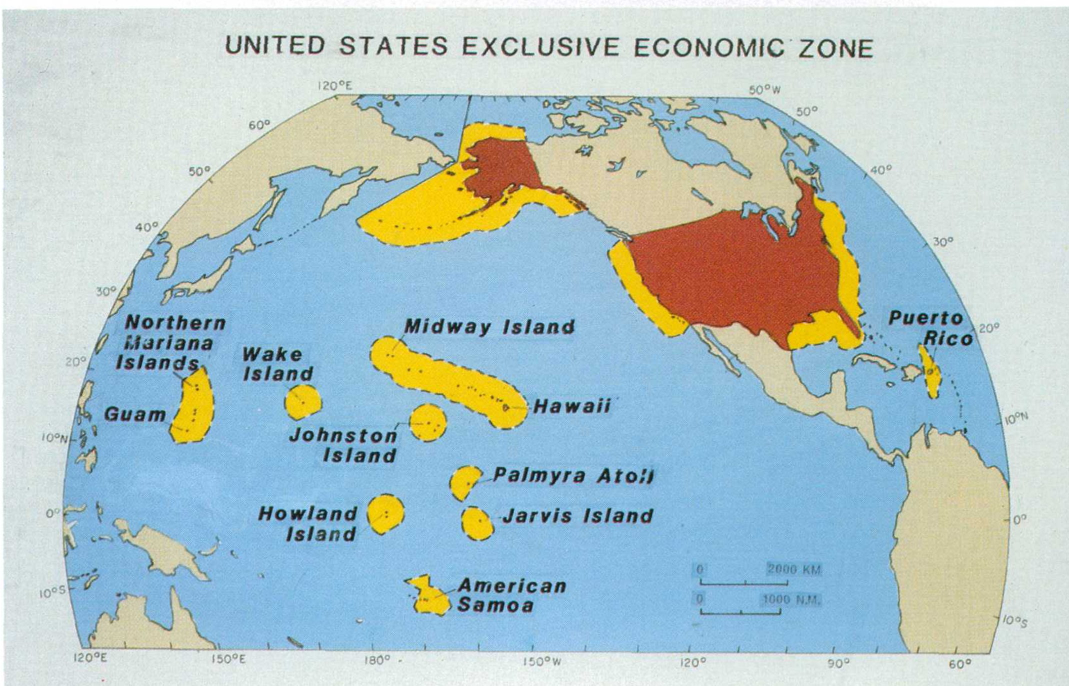


Figure 1. — Boundaries of the Exclusive Economic Zone.

the marine realm remains the natural laboratory where the fundamental tectonic and volcanic processes responsible for their formation and resource potential may be studied best.

Marine Program

The marine program has three major elements: Regional Geologic Framework, Sedimentary Dynamics, and Marine Energy and Mineral Deposits. Scientific studies in these program elements provide answers to major geologic questions that bear on the fundamental geologic makeup of the Earth and concerns about the future availability of resources.

The Regional Geologic Framework element includes investigations in regional stratigraphy, paleoenvironmental conditions, and structural settings of the continental margins, and marginal sea and deep ocean basins. These investigations focus on processes that influence the formation of petroleum and mineral deposits. Other studies of tectonism, seismicity, magmatism, and volcanism provide information on the settings of marine deposits, the process of ocean-floor spreading, the development of oceanic trenches, the evolution of landmasses or islands, and the geologic hazards that could impede future use of offshore lands. In the context of geologic history and crustal framework, these activities lead to the analysis and interpretation of the evolution of continental margins, spreading centers, and island masses.

The Sedimentary Dynamics element includes studies of active geologic processes that are modifying the sea floor and coastal zone today, with awareness that similar processes acted to form sedimentary deposits throughout geologic time. Topics of concern are the shape and sedimentologic character of major marine sedimentary deposits and the mechanics of how they formed. Sedimentary dynamics research defines the geologic conditions which control large-scale sediment failures (subsea landslides), the erosional processes forming scarps and submarine canyons on the continental margin, the dynamics of transport of sediments and pollutants on the sea floor, and the geologic processes operating in and shaping estuaries and coastal zones. Because many basins on land today formed in marine environments, there is much transfer of information and insight from marine studies to land studies and vice versa.

As we seek to understand the nature of the zone where the ocean and continental crusts meet and the dynamic processes that are involved, we are becoming increasingly aware of significant processes of erosion on the continental shelf and slope. The first evidence was seen in geophysical profiles that revealed buried ancient continental shelves as much as 113 miles seaward of the present shelf edge. More recently, high-resolution acoustic (sonar) imaging devices have revealed sea-floor features never before seen. Many more canyons on the continental slope have been discovered than were previously suspected, suggesting that submarine erosion is a geologic agent modifying the morphology of the slope at a higher rate than previously considered. Geologists on deep submersible dives east of Florida have observed a near vertical wall of limestone about 2.5 miles high that may have eroded back as much as 9 miles in the past 37 million years. The evidence for erosion on such a scale in the past has significant implications for the preservation of oil and gas trapped within the continental margin and for resource exploration and development in deep water.

Finds of new mineral deposits in the oceans are high on the list of exciting geologic discoveries of the past decade. The Marine Energy and Mineral Deposits element supports investigations of these deposits and the processes that formed them. For several years, geologists had speculated that seawater and rock might react in areas of volcanic heating to form mineral deposits. In 1979, massive sulfide deposits were discovered accumulating around a hydrothermal vent on the crest of the midocean ridge in the Pacific Ocean. The midocean ridge is a world-encircling mountain range, the crest of which is a rift zone and spreading center where new sea-floor crust is formed. As the sea floor is pulled apart along the rift zone, molten rock rises to the sea floor. Cold sea water percolates downward along faults or cracks in the sea floor and is heated by and reacts with the hot rock. Then it is convected vigorously to the surface where it discharges in geyser like plumes of hot water (350° C.) laden with sulfides of zinc, copper, and silver, some of which precipitate on the sea floor (figs. 2, 3).

Since the initial discovery, such sulfide deposits have been found at five other locations along the ridge. For the first time, geologists can witness a massive-sulfide type of deposit actually being formed on the sea floor. Research into this process provides important insights into exploration techniques for new onshore deposits.

In addition to these rapidly forming sulfide deposits, manganese crusts recovered from seamounts in the Pacific Ocean contain cobalt, the concentration of which varies with water depth. The most favorable water depth range, where the cobalt content exceeds that of commercial deposits onshore, is about 3,280 to 8,530 feet. These deposits lie on the flanks of islands and seamounts, some of which are located within 200 nautical miles of U.S. territory.

The program element for marine energy and minerals is concerned with developing geologic concepts from which settings and conditions of the origin and concentration of marine minerals and hydrocarbons can be defined. The United States is dependent on foreign sources for a large percentage of its petroleum and for several strategic minerals, such as cobalt. This dependence underscores the need to perform research on the distribution and origins of these and other resources in the marine realm.

All three program elements converge in the study of marine basins and sediment fans or wedges for hydrocarbons. It is necessary to understand the setting and character of the sediment accumulation, the source of the sediments, the amount of organic material present, and whether the thermal maturity is sufficient to generate hydrocarbons that might migrate and become trapped. During the past few years, research by the Geological Survey has revealed previously unknown Arctic offshore basins with good petroleum resource potential. In addition, program scientists identified the possible occurrence of gas in the deep Aleutian Basin of the Bering Sea, through inferences from seismic records, and they confirmed the presence of gas hydrates (frozen gas) in sediments lying in deep water off the Atlantic coast. Gas hydrates may also form an impermeable seal under which recoverable gas and oil may collect. As technology advances, the gas hydrate itself may become an exploitable resource.

Marine Surveys

The life blood of a marine geology program is its marine operations, and the Geological Survey operations are based in Menlo Park, California, and Woods Hole, Massachusetts. Two large research vessels

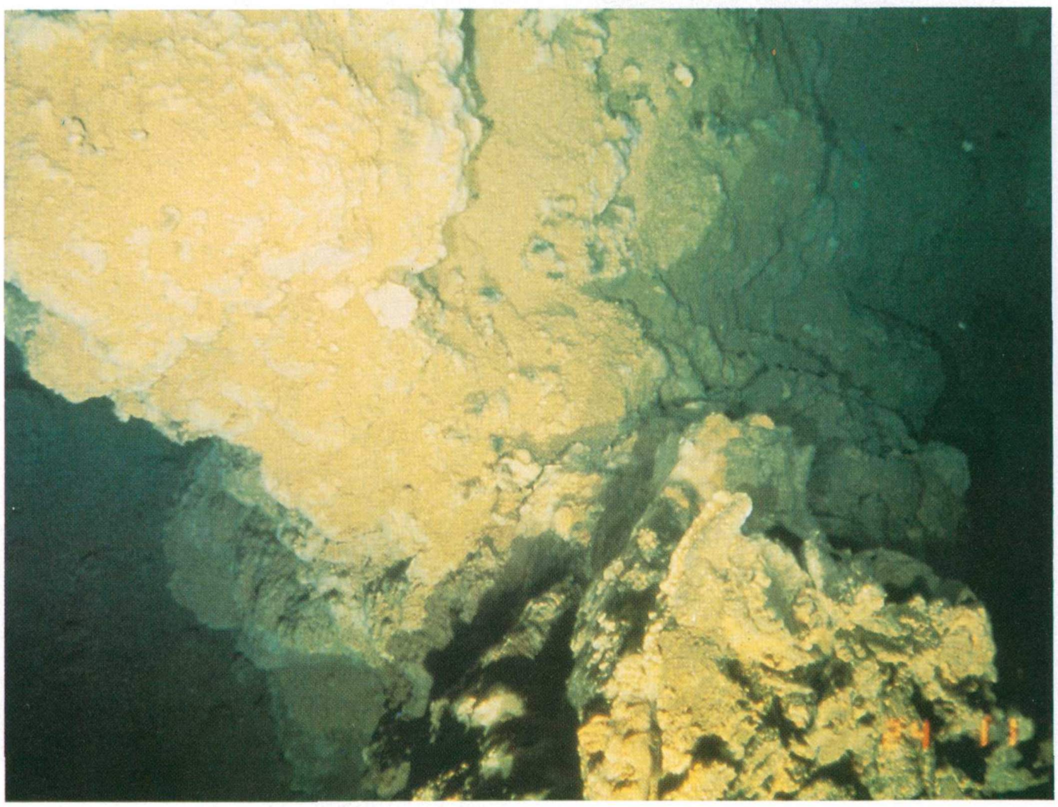


Figure 2. *— Hydrothermal deposits at site of plume on Juan de Fuca Ridge.*

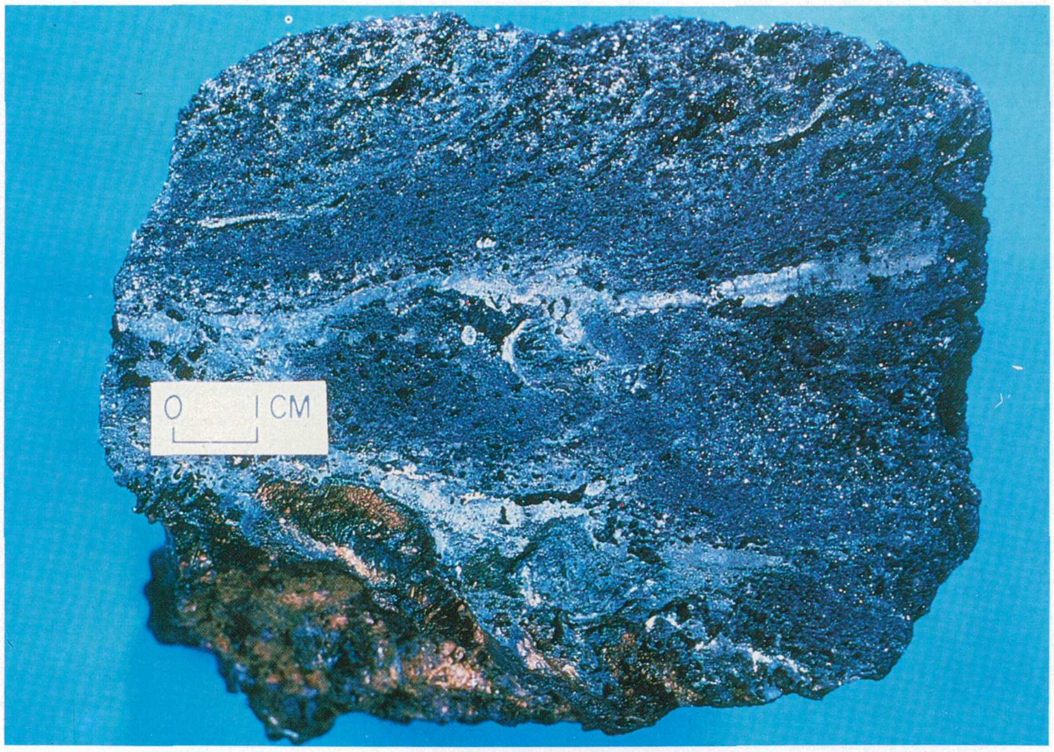


***Figure 3.**—Hydrothermally deposited zinc sulfide showing light-colored layers of iron sulfide.*

(R/V) capable of open-ocean surveys are operated by the Survey and are in steady use. The R/V *Samuel P. Lee* (208 feet) is equipped for deep-penetration seismic reflection profiling and other geophysical surveys. It is ice strengthened and is used for research operations at high latitudes where ice may be a danger. The R/V *Polaris II* (160 feet) is equipped for high-resolution seismic reflection profiling, light geophysical surveys, and sea-floor sampling. In addition, the Survey maintains four smaller vessels for nearshore marine surveys. Each year, other vessels from oceanographic institutions and industry are used as needed to accomplish the Geological Survey mission to acquire knowledge about the Nation's underwater domain.

In 1982, the R/V *Samuel P. Lee* conducted research in waters off Alaska to add information on the geologic framework and potential for petroleum resources of large sedimentary basins on the continental shelf and to obtain new data on the plate tectonic setting of the Aleutian Island chain. Other important cruises added to our understanding of the Atlantic continental margin, especially concerning the basic framework and processes of sedimentation and erosion but also concerning mineral resources of the large underwater Blake Plateau off the coast of the Carolinas. Also in 1982, the R/V *Samuel P. Lee* conducted geophysical surveys, sponsored by the United States, Australia, New Zealand, and the United Nations, around the Pacific island areas of Tonga, Vanuatu, and the Solomon Islands. During a cooperative investigation in the central Pacific, Geological Survey and German Government scientists recognized the potential for cobalt resources in manganese crusts on the sea floor.

In August 1983, the longest, most elaborate marine survey ever planned by the Geological Survey began. The R/V *Samuel P. Lee* left San Francisco on a scheduled 40,000-mile cruise from pole to pole. Planned activities included sea-floor photography of sulfide deposits on Juan de Fuca Ridge, seismic surveys in the Chukchi Sea north of the Bering Straits in the Arctic, sampling in the central and southern Pacific for cobalt-manganese crusts, seismic surveys in the south Pacific, and framework/resource surveys in the Ross Sea-Wilkes Land continental shelf area off Antarctica. In addition, a joint Survey-Geological Survey of Canada expedition used a Canadian-developed sea-floor mounted drill to obtain samples from sulfide deposits on Juan de Fuca Ridge. As 1983 ended, prospects appeared bright for a proposed expansion of the marine program to cover the vast new national frontier of the Exclusive Economic Zone.

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 government 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 104-year history, the Survey has remained principally a scientific and technical investigation agency as contrasted with a developmental 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 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. 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. This Yearbook provides highlights of the wide range of earth science research and services in the fields of geology, hydrology, and cartography. These activities represent the continuing pursuit of the longstanding scientific missions of the Survey.

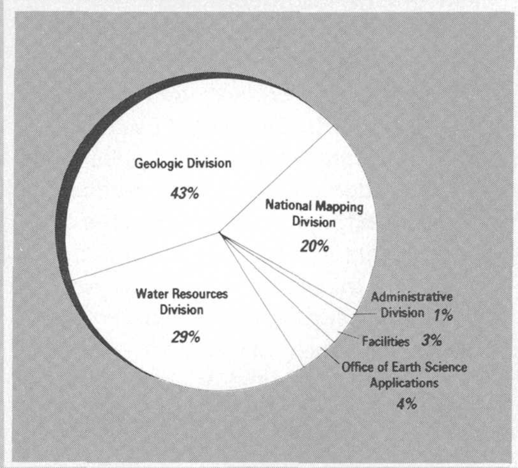
Organization

The U.S. Geological Survey is headquartered in Reston, Virginia. 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 Information Systems Divisions. The Survey conducts its functions through an extensive field organization of 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 1983, the U.S. Geological Survey had obligational authority for $556.0 million, of which $378.2 came from direct appropriations, $18.7 million came from transfers from accounts discussed below, and $159.1 million came from reimbursements. The Survey received funds under two congressional appropriations, ''Barrow Area Gas Operations, Exploration and Development'' ($6.4 million), and ''Surveys, Investigations, and Research,'' which is the traditional source of direct funding for all other Survey activities ($371.8 million). Transfers to the latter account equaled $16.2 million unobligated balance from the National Petroleum Reserve in Alaska account as required in the appropriation language, $2.2 million from the same account under emergency authority to cover the Redwood City, California, flood damage, and $0.3 million unobligated balance from the Office of Water Research and Technology for the Water Resources Scientific Information Center Program. The Survey also received funds for reimbursements for work performed under agreements with other Federal agencies, State and local governments, international organizations, and foreign governments. The 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

Percentage allocation of funds, by Division.



U.S. Geological Survey budget authority for fiscal year 1983, by appropriation

(Dollars in thousands)

Activity/Subactivity/ Program Element	Fiscal year 1983[1] enacted
Surveys, Investigations, and Research:	
National Mapping, Geography and Surveys	**81,138**
Primary Quadrangle Mapping	**38,960**
Primary Quadrangle Mapping	35,106
Modernization of Mapping Technology	3,854
Map Revision and Orthophotoquads	**17,002**
Revision	10,840
Orthophotoquads	6,162
Digital Mapping	**3,970**
Small, Intermediate, and Special Mapping	**14,367**
Intermediate-Scale Mapping	6,756
Land Use and Land Cover Mapping	3,409
Airborne Profiling of Terrain System	1,691
Small-Scale and Other Special Mapping	2,511
Cartographic and Geographic Information	**3,839**
Side-Looking Airborne Radar	**3,000**
Geologic and Mineral Resource Surveys and Mapping	**159,190**
Geologic Hazards Surveys	**51,611**
Earthquake Hazards Reduction	34,952
Volcano Hazards	10,840
Ground Failure and Construction Hazards	2,729
Reactor Hazards Research	3,090
Land Resource Surveys	**16,845**
Geologic Framework	13,735
Geomagnetism	2,115
Climate Change	995
Mineral Resource Surveys	**41,072**
Alaska Mineral Surveys	9,252
Conterminous U.S. Mineral Surveys	5,582
Wilderness Mineral Surveys	8,425
Strategic and Critical Minerals	5,752
Development of Assessment Techniques	11,959
Mineral Discovery Loan Program	102
Energy Geologic Surveys	**34,176**
Coal Investigations	14,175
Onshore Oil and Gas Investigations	6,922
Oil Shale Investigations	823
Geothermal Investigations	7,090
Uranium-Thorium Investigations	4,166
World Energy Resource Assessment	1,000
Offshore Geologic Surveys	**15,486**
Offshore Geologic Framework	15,486
Water Resources Investigations	**115,096**
National Water Data System—Federal Program	**54,201**
Data Collection and Analysis	15,888
National Water Data Exchange	1,247
Regional Aquifer Systems Analyses	14,665
Coordination of Water Data Activities	894
Core Program Hydrologic Research	5,982
Improved Instrumentation	1,899
Subsurface Waste Storage	1,453
Flood Hazards Analysis	464
Water Resources Assessment	329
Supporting Services	3,594
Toxic Wastes—Ground-Water Contamination	4,451
Acid Rain	2,462
Water Resources Scientific Information Center	873
Federal-State Cooperative Program	**45,782**
Data Collection and Analysis, Areal Appraisals and Special Studies	39,390
Water Use (Cooperative)	3,230
Coal Hydrology (Cooperative)	3,162
Energy Hydrology	**15,113**
Coal Hydrology	6,849
Nuclear Energy Hydrology	6,993
Oil Shale Hydrology	1,271
Earth Sciences Applications	**11,132**
Earth Resources Observation Systems	9,563
Environmental Affairs	943
Land Resources Data Applications	626
General Administration	**14,931**
Executive Direction	4,956
Administrative Operations	8,628
Reimbursable to Department of Labor	1,347
Facilities	**9,022**
National Center—Standard Level User Charge	7,364
National Center—Facilities Management	1,658
TOTAL, Surveys, Investigations, and Research	**390,509**
Barrow Area Gas Operation	**6,400**
TOTAL, U.S. Geological Survey	**396,909**

[1]Funding shown represents appropriations under "Surveys, Investigations, and Research" only and does not include other sources of funding such as reimbursements from other Federal or State organizations.

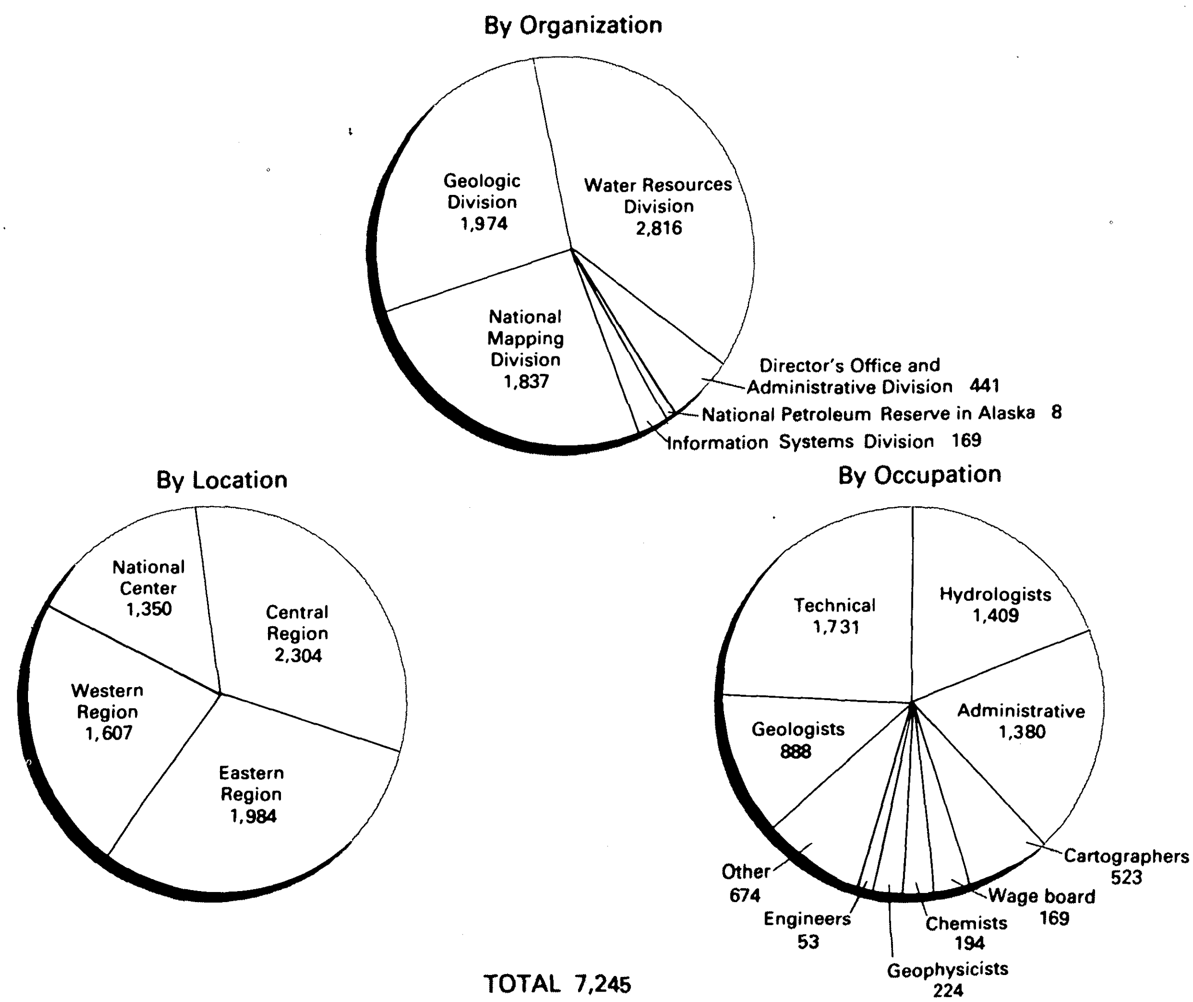
almost always done on a cost-sharing basis.

Most of the appropriations and reimbursements received by the Survey in fiscal year 1983 are distributed through budget activities that roughly correspond to its mapping, geologic, hydrologic, and administrative areas of responsibility.

Personnel

At the end of fiscal year 1983, the U.S. Geological Survey had 7,245 permanent full-time employees on board, an increase of 80 from fiscal year 1982. With the exception of the transfer of approximately, 2,500 employees to the Minerals Management Service in 1982, the Survey's full-time permanent work force has been relatively constant since 1973. The Survey's diversified earth science research programs and services are reflected in its workforce which is composed of personnel in over 170 disciplines, with more than 50% possessing a Bachelor's or higher level degree. More than one-half of the Survey's staff are professional scientists, and approximately one-fourth are technical specialists. Hydrologists, geologists and cartographers predominate among the professional group which includes members of more than 30 other disciplines such as geophysicists, chemists and engineers.

The number of other-than-full-time permanent employees has more than doubled since 1973 and includes many students and faculty members from colleges and universities as well as part-time personnel. The Survey has profited greatly from its association with the academic community. The expertise of many eminent specialists has become available to the Survey in this manner and has provided great flexibility in solving problems and meeting surges in workload, especially during the field season. The relationship also has been an invaluable channel for recruiting young professionals of demonstrated ability for permanent full-time positions upon the completion of their studies.



Permanent full-time U.S. Geological Survey employees

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 individuals who received the Department of the Interior's highest award.

Honors

Kenneth L. Pierce, Geologist, was selected for the Kirk Bryan Award of the Geological Society of America in recognition of his studies on the glacial geology of Yellowstone Park.

Eugene M. Shoemaker, Geologist, was awarded the Arthur L. Day Medal of the Geological Society of America in recognition of his imaginative contributions to astrogeology, volcanology, and petrology and for his dedication to science.

James P. Bennett, Hydrologist, was named Engineer of the Year for the Department of the Interior by the National Society of Professional Engineers.

Thomas D. Fouch, Geologist, was appointed a Distinguished Lecturer by the American Association of Petroleum Geologists.

Honors From Foreign Governments

George E. Ericksen, Research Geologist, was made a Knight Commander in Chile's Order of Bernardo O'Higgins in Santiago, Chile, June 9, 1983. The Chilean government honored Ericksen's outstanding contributions to the study of mineral resources in that country.

Presidents of Professional Societies

Service in professional societies is one of the important professional contributions a scientist can make. Societies play a fundamental role in the distribution of new knowledge, in addition to 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 by their professional peers.

Robert M. Hamilton	Seismological Society of America;
Frederick J. Doyle	International Society for Photogrammetry and Remote Sensing;

Department of the Interior Distinguished Service Awards

The highest honor given by the Department of the Interior is the Distinguished Service Award. This award for outstanding achievements in challenging and difficult assignments was given to 13 U.S. Geological Survey employees this year. These individuals and the bases for their awards were as follows:

Lawrence H. Borgerding, Chief, Mid-Continent Mapping Center, for his outstanding service and achievements with the Geological Survey as a cartographer and administrator in the development of the National Mapping Program;

Hilton H. Cooper, Jr., Research Hydrologist, in recognition of his unparalleled technical accomplishment in the mathematical analysis of the dynamic behavior of ground-water systems;

Robert E. Davis, former Chief, Office of Scientific Publications, in recognition of his outstanding achievements in the management of research programs in the earth sciences and the publications program of the Geological Survey;

Roy E. Fordham, Chief, Eastern Mapping Center, for his outstanding service and achievements with the Geological Survey as a cartographer and administrator in the development and execution of the National Mapping Program;

Philip W. Guild, Research Geologist, in recognition of his exceptional achievements in the investigation of mineral deposits and leadership in domestic and international programs for metallogenic studies and maps;

Daniel B. Krinsley, Research Geologist, in recognition of his outstanding achievements in pioneering scientific research, his major contributions to the use of earth science data by planners and decisionmakers, and his exemplary career as a manager of scientific programs;

Leslie B. Laird, former Assistant Chief Hydrologist for Research and Technical Coordination, for his exceptional contributions to the management of water resource programs in the Geological Survey;

Alfred T. Miesch, Research Geologist, Grand Junction, Colorado, in recognition of his outstanding contributions to geostatistics and geochemistry in the Geological Survey;

Roy R. Mullen, Associate Chief, National Mapping Division, for his exceptional contributions to the Geological Survey as a scientist and executive of the National Mapping Program;

Ralph J. Roberts, Research Geologist, in recognition of his many creative scientific contributions to Geological Survey studies and programs in the geology of mineral deposits, structural geology, and geologic processes;

Robert L. Smith, Research Geologist, Branch of Igneous and Geothermal Processes, in recognition of his outstanding contributions to the research program of the Geological Survey in the areas of silicic volcanism, igneous processes, and assessment of volcanic hazards;

Lowell E. Starr, Assistant division Chief for Research (NMD), for his outstanding leadership and exceptional contributions to the development of technology in the field of topographic mapping; and

Robert F. Yerkes, Research Geologist, Branch of Western Regional Geology, in recognition of his major contributions to the Geological Survey, fundamental geologic research, especially in the southern California region, and leadership in applying geology to solving man's problems.

National Mapping Program

Mission and Organization

The National Mapping Division conducts the National Mapping Program, which 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, land use and land cover maps and associated data, geographic names information, geodetic control data, and remote sensing data.

The products are produced by four regional mapping centers and the Earth Resources Observation Systems Data Center. The Division's Printing and Distribution Center prints Survey map products and stores and distributes all Survey maps and texts. The Division also operates the National Cartographic Information Centers and the Public Inquiries Offices which, along with the Earth Resources Observation Systems Data Center, provide information about and fill orders for earth science, cartographic, geographic, and remote sensing data.

Major Programs and Activities

In support of the National Mapping Program, the Division concentrates its efforts on the following major activities:

- Primary quadrangle mapping and revision, including the production and revision of 7.5-minute 1:24,000- and 1:25,000-scale maps in the conterminous United States and Hawaii and the 15-minute 1:63,360-scale maps in Alaska. During fiscal year 1983, about 1,300 revised and 1,370 new standard topographic maps were published, mostly in the 7.5-minute series (fig. 1). Published topographic maps are available for about 85 percent of Alaska and for 80 percent of the other 49-State area. Fifteen States have complete 7.5-minute series map coverage.
- Small-scale and special mapping, including 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 the scale of 1:250,000. More than 70 percent of the conterminous United States is mapped in one or more of the intermediate-scale series (fig. 2), which include 1:50,000-scale quadrangle maps, 1:50,000- or 1:100,000-scale county maps, and 1:100,000-scale topographic or planimetric quadrangle maps. More than 80 topographic-bathymetric maps have been published for coastal area planning. Land use and land cover maps are complete for 2.2 million square miles.
- Digital cartography, including the production of base categories of cartographic data at standard scales, accuracies, and formats suitable for computer-based analysis. In early fiscal year 1983, the Geological Survey chaired a newly formed Department of the Interior committee to coordinate digital cartography activities within the Department. The Office of Management and Budget later issued a memorandum to foster better coordination of all Federal digital cartography programs. The Geological Survey has been delegated the lead role in this activity and will chair a Federal committee to implement this objective.
- Information and data services, including the acquisition and dissemination of information 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 about 3,000 commercial dealers.
- Advanced development and engineering to improve the quality of standard products; to provide new products, such as digital cartographic data, that make maps and map-related information more useful to users; to reduce costs and to 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.
- Cartographic and geographic research, with particular emphasis on spatial data techniques for studies using modern geographic analysis with new and improved cartographic concepts and techniques.

Budget and Personnel

For fiscal year 1983, National Mapping Division funding of about $107 million included the $17 million associated with the Earth Resources Observation Systems Program, which was integrated into the Division at the beginning of fiscal year 1983. Funding sources included direct congressional appropriations, funds transferred from other Federal agencies, joint funding agreements through the Federal-State Cooperative Program, and funds transferred from local agencies.

The permanent full-time personnel strength of the Division at the end of fiscal year 1983 was 1,829, representing a work force skilled in cartography, geography, computer science, engineering, physical science, photographic and remote sensing technology, and information sciences.

Figure 1. *— Status of standard topograhic mapping and revision.*

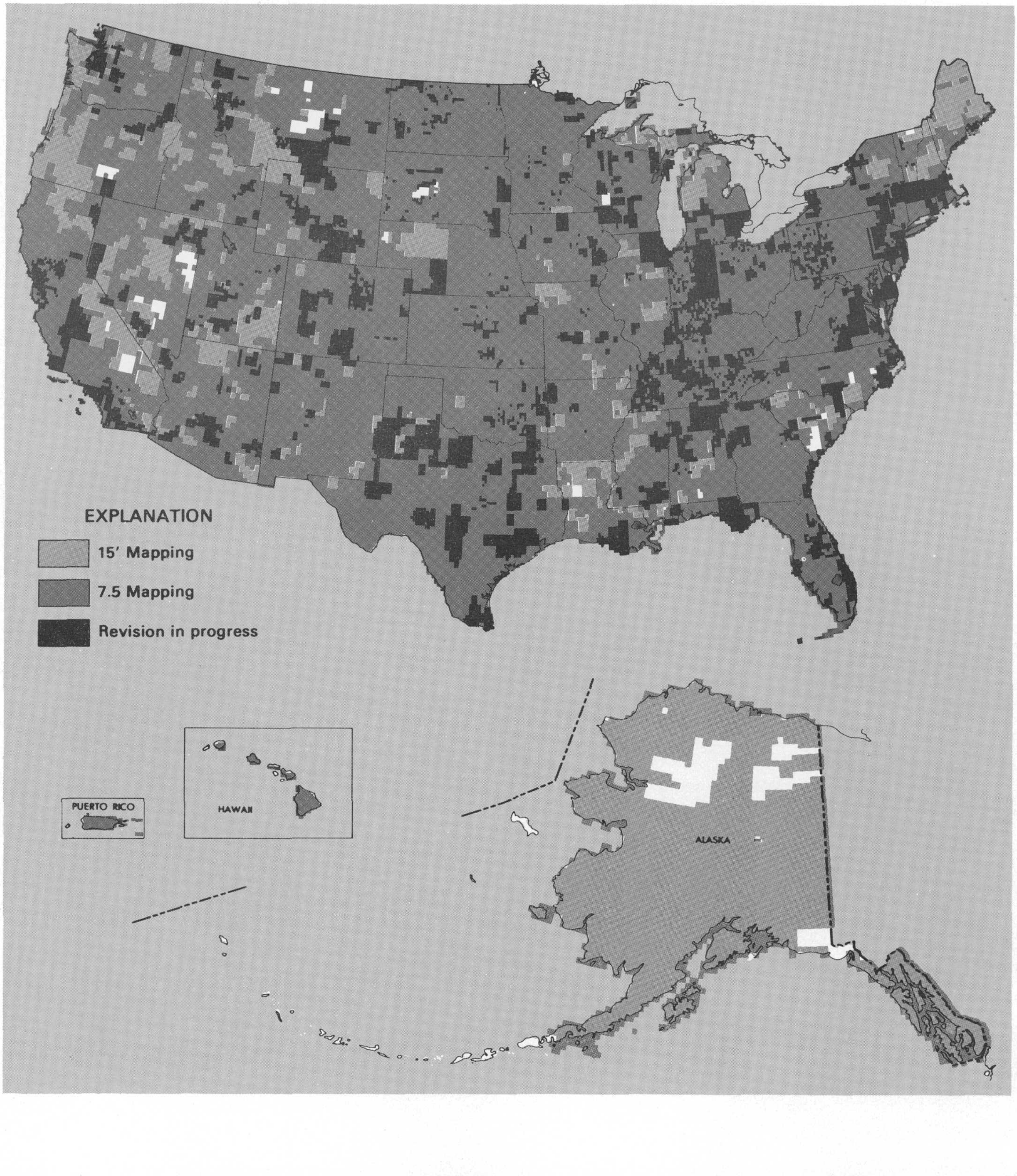
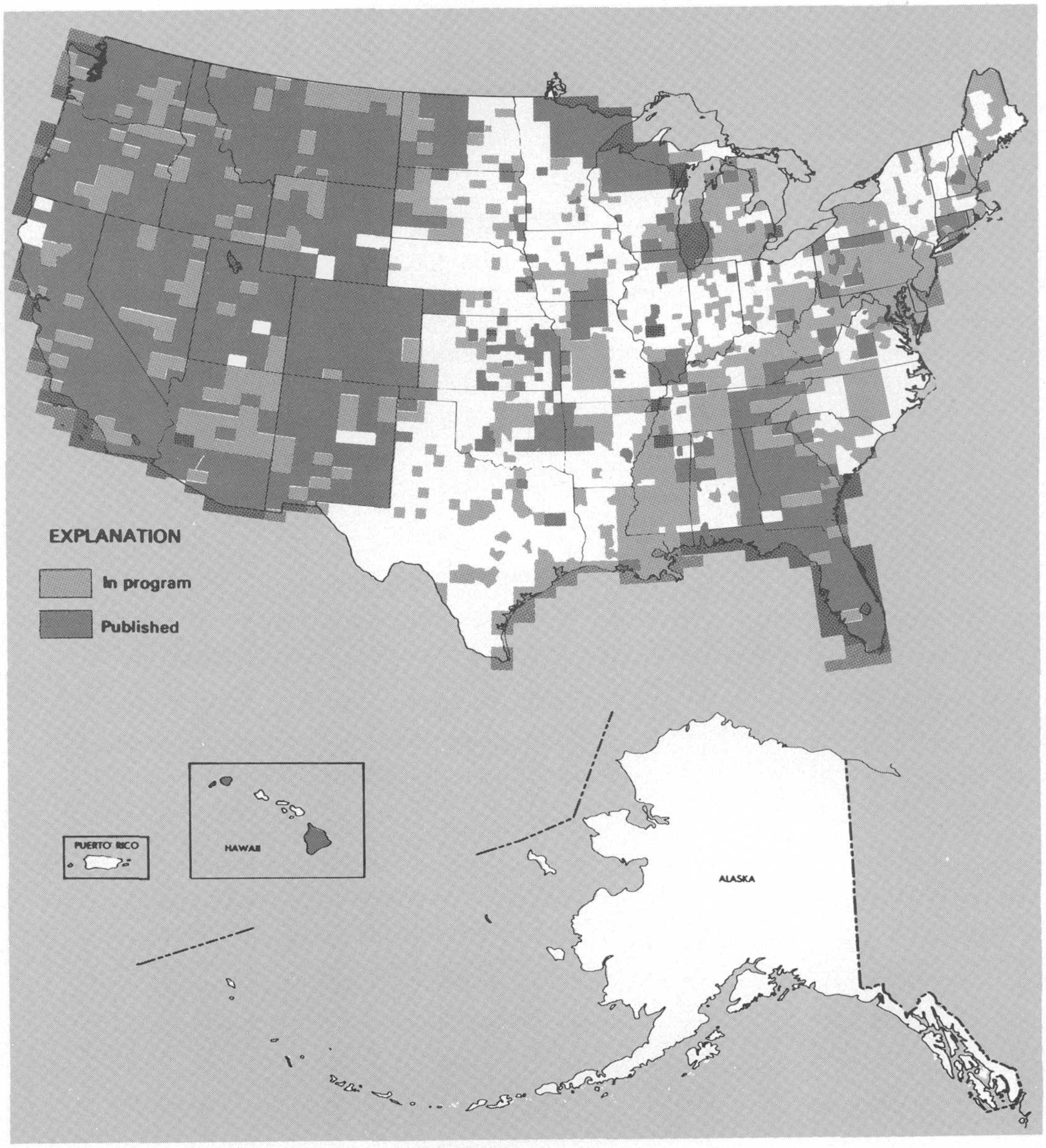


Figure 2.— Status of the intermediate-scale mapping program.



Highlights

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

Provisional Maps

In 1982, the Geological Survey initiated a series of provisional edition topographic maps to expedite completion of the 8,500 7.5-minute quadrangle areas not covered by 1:24,000-scale mapping. Under this accelerated mapping program, practically all of the unmapped areas are targeted for provisional mapping, allowing complete 7.5-minute map coverage of the conterminous United States by 1989. Provisional maps of unmapped 15-minute quadrangle areas in Alaska will also be produced, allowing 1:63,360-scale map coverage of Alaska to be completed concurrently with the 1:24,000-scale coverage of the conterminous United States.

Provisional maps are prepared to the same map accuracy standards and contain essentially the same level of content as standard topographic maps but reflect a provisional rather than a finished map appearance. They are printed in four or five colors and are made available through standard distribution procedures. The maps can be produced manually or with automated techniques. The first maps in the provisional series were produced manually using standard compilation techniques, with some linework and lettering done by hand.

Computer technology is the basis for the automated processing of provisional maps. Maps are produced in the following stages:

(1) information collection: aerial photographs are used in plotting equipment to record information from the photographs on computer tapes, (2) information editing: appropriate map symbols are applied to properly represent the features on the map, and errors and deficiencies are corrected, and (3) cartographic plotting: newly developed computer programs produce complete lettering and place certain descriptive lettering, contour labels, and control elevations on the maps. These automated processes further shorten the map production cycle for provisional maps and place the product in the hands of the user at an earlier date.

After completion of the provisional mapping program, the maps will be updated, fully finished, and reissued as standard topographic editions.

Digital Cartogaphy

Map data in digital form are being applied to an increasing number of complex problems. Applications are not limited to the earth sciences but are as diverse and complex as the many uses of a map. An important factor in the growth of digital cartographic data applications is the development of geographic information systems. These systems have the capability to compare rapidly and to sort through large amounts of digital data on multiple topics about the land and its resources. Also, maps can be prepared much faster and more accurately using automated procedures.

To meet the demand for standardized digital cartographic data, the Geological Survey is digitizing base categories of cartographic information from its various national series of topographic maps. The primary effort is devoted to building a national digital cartographic data base containing the basic categories shown on published 7.5-minute topographic maps. The digitized data, available in two forms, are digital line graphs and digital elevation models (fig. 3). The digital line graphs are graphic data digitized from published maps. Currently, four categories of digital line graphs are being collected: public land net, boundaries, hydrography, and transportation. The digital elevation models are digitized elevations collected at regularly spaced intervals throughout a quadrangle.

Other data being collected include the planimetric features from 1:2,000,000-scale sectional maps of the *National Altas of the United States of America* and selected 1:500,000-scale State base maps, elevation data from the 1:250,000-scale map series, land use and land cover data, and geographic names data.

In a related, broader area of activity—the coordination of Federal digital cartographic data programs—the Survey expanded its coordination activities within the Department of the Interior by chairing the newly established Interior Digital Cartography Coordination Committee. Subsequently, the Office of Management and Budget issued a memorandum to foster better coordination of all Federal digital cartography programs. The Geological Survey was delegated the lead role in implementing this objective. In May 1983, representatives of Federal agencies met at the Survey's Reston, Virginia, offices to form a committee to begin coordination efforts.

Although the expanded Federal coordination activity has been underway only a short time, significant new requirements for digital cartographic data have been identified. The most pressing of these requirements is the development of a 1:100,000-scale digital cartographic data base to support the 1990 census. Accordingly, a pilot project has been initiated by the Geological Survey in cooperation with the Bureau of the Census to digitize transportation and hydrography data in the State of Florida.

Plans for fiscal year 1984 include continued cooperation with the Bureau on the pilot project and, in the broader coordination area, the establishment of work groups to further identify Federal digital cartographic data requirements, to assist in insuring that needs are met, to provide a mechanism for development of data standards, to serve as a forum for exchange of information on technology and methods, and to facilitate private sector use of the data.

Image Mapping

The Geological Survey has recognized a national need for image products as valuable mapping tools, map supplements, and as alternatives to standard maps. As a result, it is responding to these needs through three programs that provide such products, namely its high-altitude photography, orthophotography, and satellite imagery programs.

Image mapping in the form of orthophotoquads provides relatively low-cost products that can be prepared in about one-third the time required for line maps. For areas of the conterminous United States unmapped at the 1:24,000 scale, black-and-white orthophotoquads serve as interim maps until new 7.5-minute topographic maps become available. Orthophotoquads have been prepared for about 56 percent of the conterminous United States. During fiscal year 1983, the Survey prepared 1,950 orthophotoquads.

In Alaska, 15-minute orthophotoquads are being prepared at the 1:63,360 scale in cooperation with the Bureau of Land Management and the State of Alaska. In fiscal year 1983, 95 quadrangles were produced. Coverage of most portions of the State is anticipated over the next decade.

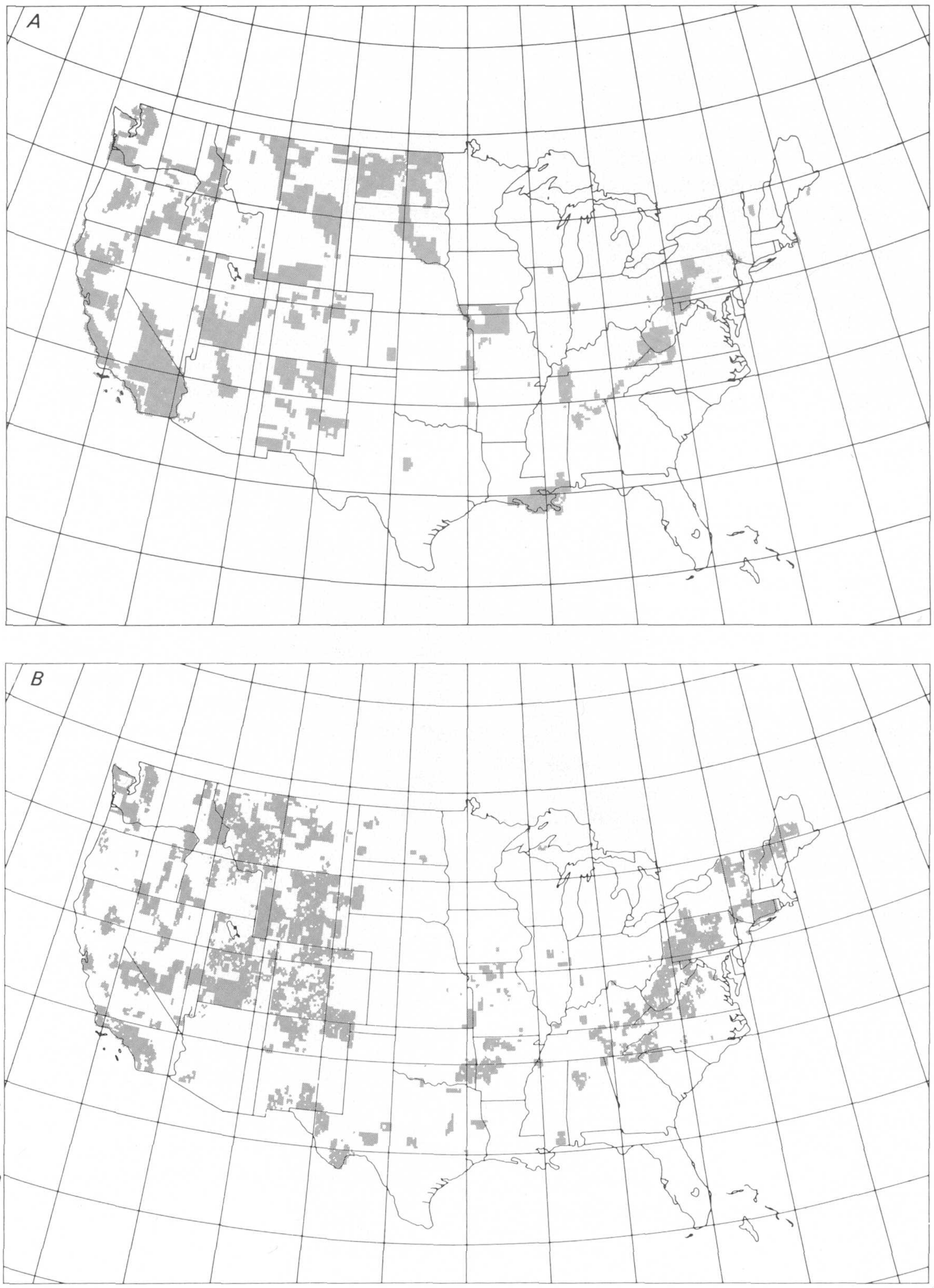


Figure 3. *— Digital cartographic mapping. A, Status of digital line graph production. B, Status of digital elevation model production.*

Production of color infrared and simulated natural color orthophotoquads during fiscal year 1983 included areas in Delaware, North Carolina, and Washington at scales of 1:24,000 and 1:25,000. The Geological Survey is also preparing a series of simulated natural color image maps at 1:25,000 scale of the United States–Mexico international boundary in cooperation with the Customs Service, U.S. Department of the Treasury.

During fiscal year 1983, the National Mapping Division, in cooperation with the Minerals Management Service, completed 25 Landsat 1:250,000-scale black-and-white image maps for the Alaskan North Slope above the 68th parallel. These products will be used to help support the management of the Federal Government's oil and gas program in that area. Plans are being made to publish the Landsat image maps as part of standard Alaskan map coverage. Other Landsat image maps are under consideration.

The Survey also has been evaluating Side-Looking Airborne Radar for use in topographic and geologic mapping. Twelve controlled 1:250,000-scale quadrangle image mosaics of the Aleutian Island Arc in Alaska are being prepared from radar imagery acquired in 1982. Six of the mosaics will be printed back-to-back with updated line maps; the remaining mosaics will be printed without line maps.

Information Services

The Geological Survey disseminates much of the Nation's earth science information through its Public Inquiries Offices, National Cartographic Information Centers, and Earth Resources Observation Systems Data Center. The National Mapping Division operates these public access points for the Survey and sells the Survey's maps, books, photographs, and machine-readable tapes. Four areas where significant advances have been made in providing improved service to the public are in the map reference library program, the product-inventory distribution system, the cooperative information service system, and the National Cartographic Information Center's State affiliate network.

The Geological Survey's map reference library network has been an important extension of the Survey in many communities across the country. At present, there are over 500 libraries that house collections of Geological Survey topographic and scientific maps. To provide access to a greater number of citizens and to eliminate duplication among depository systems, thereby cutting costs, several map depository programs (including the Geological Survey and Defense Mapping Agency programs) are being consolidated within the larger Congressional depository system. The consolidated, but expanded, program will be administered by the Government Printing Office under the policy direction of the Joint Committee on Printing. The program will be implemented in early 1984, following a survey by the Government Printing Office to determine which products each depository library wishes to receive. The Geological Survey will then make monthly mailings to the libraries of the Survey and Defense Mapping Agency maps.

In the area of product distribution, a computer-based system has been installed to track the various types of Survey maps and books that are stored for public sale and distribution. Major Survey warehouses in Arlington, Virginia, Alexandria, Virginia, and Denver, Colorado, have been equipped with terminals that communicate over telephone lines with the host computer, which contains descriptive information about each product, its storage location, and its stock quantity. In 1984, an additional capability to handle and track the thousands of orders received each year will be developed.

To meet the increasing need for earth science data, the Survey is considering the development of a cooperative information service that will coordinate the existing information services of the Geologic, Water Resources, and National Mapping Divisions. As part of this service, the Survey has linked its Public Inquiries Office and National Cartographic Information Center public access points via a computer-based network and plans to exchange and share information with other Interior bureaus and selected State offices. The network, referred to as the Earth Science Information Network, will help to provide the public and other Government agencies with the earth science data stored in various major data bases, to develop the flow of information among public access points, and, when necessary, to bring information together quickly to focus attention on national problems.

The National Cartographic Information Center's network of State affiliates continued to grow during the year. Newcomers to the network include the States of Idaho, Massachusetts, and Rhode Island. Since the initial affiliate agreement with the State of Texas in April 1976, 36

States have become linked with the National Cartographic Information Center. The State affiliates handle cartographic and geographic data, distribute pamphlets, brochures, and topographic indexes, and sell maps of their respective States.

Research, Investigations, and Developments

Vegetation-Land Cover Classification in Alaska

The National Mapping Division has cooperated during the past 3 years with several State and Federal resource management agencies in Alaska to produce vegetation and land cover classifications to support comprehensive planning, research, and management mandates of the 1980 Alaska National Interest Lands Conservation Act and inventory requirements of the Forest and Rangeland Renewable Resources Planning Act of 1974.

The vegetation-land cover classifications have been derived from Landsat digital data and digital elevation data using standard digital processing techniques. With few exceptions, the analysis procedures (including field data collection) and classification descriptions follow a standard format. By the end of fiscal year 1983, approximately 110 million acres of Alaska were classified for vegetation-land cover. Projects in progress will complete an additional 80 million acres by the middle of fiscal year 1984. At that time, over half the State will have detailed land cover classifications. The primary use of these data is for estimates of land cover acreages and for producing habitat suitability models for various wildlife species.

Digital Cartographic Data Standards

As a part of the development of a national digital cartographic data base, the Survey also develops technical standards that govern the information that is stored in the data base. An agreement between the National Bureau of Standards and the Geological Survey assigns the Survey the responsibility to develop and maintain the standards for computer-based and graphic information for the earth sciences.

The Survey is preparing technical standards for the various types of cartographic information in the national data base. Interim standards are being published as *Geological Survey Circular 895*, which currently consists of seven chapters. The circular includes technical standards for applying digital line graph techniques (a way to represent line map information in digital form) for the Public Land Survey System and a description of digital elevation models (collections of elevation values stored on a computer). Work is essentially complete on technical standards for digital line graphs for hydrography and for 1:100,000-scale maps. These standards will be included as additional chapters of the circular.

The Survey recognized that other public groups and individuals who use its products should be involved in the development of digital cartographic standards and actively supported the work of the National Committee for Digital Cartographic Data Standards. The goal of the committee, established under the auspices of the American Congress on Surveying and Mapping, is to provide a professional forum for Federal, State, and local agencies, private industry, and professional individuals to share their opinions, assessments, and proposals on digital cartographic data standards. After the standards are formulated, they will be subjected to extensive review. When the Survey is confident that the standards are acceptable, they will be submitted to the National Bureau of Standards for application throughout the Federal Government.

Petroleum Resource Assessment of Undeveloped Federal Lands

The Survey has prepared a series of maps and associated statistics to support an assessment of petroleum potential in undeveloped Federal lands in 11 Western States. These undeveloped lands include wilderness areas and other lands being considered for wilderness designation. Administrative and legal boundary information on these areas was compiled using computer-assisted techniques developed by the National Mapping Division. Resource boundaries of potential petroleum-yielding areas and geologic basins were compiled in the same way.

Additional computer programs were developed to provide a geographic analysis of the combined boundary information. By using these programs, the National Mapping Division prepared maps that combined the areas that have petroleum potential with the various categories of Federal lands. The potential of the petroleum areas was classified from low to high, and the size of these areas was also calculated.

Satellite Glaciology

Satellite image maps are highly useful as multipurpose base maps for various types of geological, glaciological, and geophysical data. The National Mapping Division used a 1:500,000-scale Landsat image mosaic of the Amery Ice Shelf, Antarctica, as the base map for compilation of 1- and 5-meter contours derived from Seasat radar altimeter data. Division scientists have also collected data for preparation of a 1:5,000,000-scale digital mosaic of Antarctica using National Oceanic and Atmospheric Administration very high resolution radiometer images. The mosaic will be unique because it will be the first cartographically and geometrically accurate image base of the entire continent made from one data source. It will be used as the basis for a new map of the continent and for maps on specialized topics.

Image Map Research

Since the launch of Landsat 1 in 1972, the Survey has published a variety of experimental image maps based on the multispectral scanner data. The 80-meter picture element data of the multispectral scanner, when properly processed, can provide resolution, geometric accuracy, and content comparable to a 1:250,000-scale line map.

Early in 1982, the Las Vegas 1:250,000-scale quadrangle was selected to test a newly developed geometric registration capability together with advanced digital image processing techniques available at the Earth Resources Observation Systems Data Center. The Las Vegas area was selected because of the diversity of features—urban areas, desert, mountains, lakes, rivers, and irrigated agriculture. Four Landsat scenes were required to cover the map area. The final product was a conventional color-infrared image map with a standard line map printed on the back.

The area around Dyersburg, Tennessee, located along the Mississippi River in the northwestern part of the State, was the first area to be mapped (scale 1:100,000) with data from the Landsat 4 Thematic Mapper. The process used to develop the Dyersburg map laid the groundwork for future uses of Thematic Mapper data. The Thematic Mapper has a picture element size of 30 meters and produces data on seven bands. By combining and manipulating this data, numerous color combinations can be used to produce a three-color map. After examining many of these combinations, bands 2, 3, and 5 were selected to produce the final map.

Each band was processed to achieve the optimum density, or brightness, for processing. A digital edge enhancement technique was used to accent the boundaries between different areas on the images. The map developed from the Thematic Mapper images was printed on the reverse of a standard line map. Both the Las Vegas and Dyersburg maps incorporate a Universal Transverse Mercator grid so that each can be cross-referenced to its companion line map.

Rolla Conterminous United States Mineral Assessment Program Activity

The Geologic Division, the Earth Resources Observation Systems Data Center, and the Missouri Geological Survey developed and tested a digital geologic data base for mineral resource assessment of the Rolla, Missouri, 1° by 2° quadrangle. The data base consisted of 20 numerically encoded layers of surface and subsurface geological, geochemical, and geophysical data that were digitized from 1:250,000-scale maps compiled as part of the Conterminous United States Mineral Assessment Program. Using defined geological and geochemical characteristics, two additive numerical models were developed and applied to the data base to identify and rank favorable areas for the occurrence of Mississippi River valley-type lead-zinc mineralization.

Federal Mineral Land Information System

The Federal Mineral Land Information System is being designed as a tool to develop land management and policy objectives for the Nation's strategic and critical minerals and energy resources. Central to this objective is the creation of a data base on Federal surface ownership, subsurface mineral rights, Federal restrictions to mineral development, and mineral occurrence and potential. These types of information will be compiled and analyzed using a geographic information system currently under development.

A pilot project, based on questions which might be asked of an operational system by national policymakers, was conducted on the Medford, Oregon, 1:250,000-scale quadrangle. The Medford quadrangle was selected because a Conterminous United States Mineral Assessment Program report was available, as well as other mineral deposit and occurrence data. Surface mineral management status maps were also available at 1:100,000 scale. Results of the pilot project have been analyzed and a report has been prepared outlining the potentials and limitations of using a digitized approach for national level data bases.

Arctic Lake Digital Data Base Project

The National Mapping Division has cooperated with the Water Resources Division to develop a digital data base containing the geographic location, acreage, and other attributes for lakes greater than 5 acres on the North Slope of Alaska. The data will be used by the Bureau of Land Management in its onshore oil and gas assessment and leasing program.

The basic information for the project is the water categories derived from a digital land cover classification of the National Petroleum Reserve in Alaska. The classification was originally performed by National Mapping Division personnel at Moffett Field, California, using Landsat digital data. The product is a computer file from which items can be retrieved by specifying latitude-longitude coordinates of an area of interest, or by entering an index number for a particular lake.

The lake surface area and any other lake attribute (such as depth, water quality, or temperature) that has been entered into the file will be listed. In addition, the computer can sort and display lakes by size classes (5–10 acres, 10–50 acres, and over 50 acres) and summarize surface area by lake classes. The lake inventory has been completed for nine quadrangles within the National Petroleum Reserve. Work on six additional quadrangles on the North Slope is underway.

Fuel Mapping and Monitoring for Wildlife Management

The National Mapping Division, the Bureau of Land Management, and the National Oceanic and Atmospheric Administration jointly evaluated the use of advanced very high resolution radiometer data for mapping wildland fire fuels and monitoring the growth of grasslands and biomass accumulation of over 9 million acres of public lands in northwestern Arizona. Bureau of Land Management fire managers require a low-cost, effective means of mapping fire fuels for millions of acres of public lands and for annually monitoring fire fuel conditions.

A geologically referenced computer file was developed containing terrain information, road network, ownership, and advanced very high resolution radiometer data acquired on six dates in March and April 1982 (during the spring growth cycle of the grasslands). These data were processed to compute an index related to the greenness of vegetation. Bureau of Land Management personnel used resulting greenness images to monitor the spring growth patterns and the date of grassland maturation.

A wildland fire fuels map with 13 categories was produced from the previously collected advanced very high resolution radiometer data, digital terrain data, and Bureau of Land Management information on the area. This fuel map is being used by fire management officers as a base map for fire planning, and advanced very high resolution radiometer data have proved useful for mapping and monitoring wildland fire fuels for the Bureau of Land Management's National Wildfire Management Program.

Geologic Investigations

Mission and Outlook

During fiscal year 1983, the Geologic Division continued its programs to assess energy and mineral resources onshore and offshore, to identify and investigate geologic hazards, and to evaluate the Nation's geologic framework, the geologic processes that have shaped it, and their relationship to long-term climatic changes.

The articles in this section of the *Yearbook* describe some of the most significant accomplishments of the Geologic Division during fiscal year 1983. We believe that these articles, while representing only a select few of the activities of the Division, show how geologic research simultaneously opens new avenues in geoscience and provides the basic information to conduct missions that are central to the national welfare.

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 eruption of Kilauea Volcano in Hawaii, catastrophic landslides in Utah and California, and a damaging magnitude 6.5 earthquake near Coalinga, California, focused attention in 1983 on the Survey's Geologic Hazards programs. In 1983, U.S. Geologic Survey volcanologists and seismologists accurately predicted the reawakening of Hawaii's Kilauea volcano; successfully forecast the continuing eruptions of the State of Washington's Mount St. Helens; and monitored seismic activity and ground deformation that may portend potential volcanic activity at Long Valley, California, and Mauna Loa Volcano, Hawaii. Survey landslide experts responded to an emergency request from the State of Utah to help identify and mitigate potentially damaging landslides triggered by rapid melting of a record mountain snowpack and locally heavy spring rains. One landslide near Thistle, Utah, alone caused more than $200 million in property losses. The Coalinga earthquake demonstrated again the vulnerability of unreinforced masonry buildings in the United States to damaging earthquake ground motion. Survey earthquake specialists, studying strong ground motion accompanying the Coalinga event and similar data from the 1979 Imperial Valley, California, earthquake, produced mathematical formulae that permit the prediction of damaging earthquake ground motion. Efforts to accurately forecast potentially damaging earthquakes in California continued with the calculation of probabilities for earthquakes in each of the several parts of the San Andreas fault system. The first set of comprehensive earthquake ground-shaking hazards maps for interval times of 10, 50, and 250 years were published for the conterminous United States. In 1983, Survey geologists and seismologists also drew national attention to the potential for damaging earthquakes in the Eastern United States, for identifying buried active faults in the central Mississippi Valley which were probably responsible for the great New Madrid, Missouri, earthquakes of 1811-12, and for recognizing the possibility that tremors like the Charleston, South Carolina, earthquake of 1886 might occur elsewhere along the eastern seaboard.

Land Resource Surveys

During fiscal year 1983, research within the varied tasks of the Geologic Framework Program contributed significantly towards advancing our understanding of the fundamental geologic framework of the Nation and the nature of the geologic processes that have shaped it. Multidisciplinary studies along geologic transects that cross major portions of the continent have added greatly to the achievement of these objectives. Research on the rapidly developing accreted terrane concept, wherein the margin of North America was formed by the welding together of many microcontinents, contributes to and depends upon results from the transect studies. These studies, together with research on igneous terranes, geologic processes, the ages of rocks, and the Precambrian core of the United States, continue to produce numerous maps and reports that not only increase the body of scientific knowledge of the Nation's geologic framework but have immediate applied uses. These uses are particularly evident in evaluating the Nation's energy and mineral resources and in identifying and understanding geologic hazards. Studies conducted under the Climate Program are progressing towards understanding the natural climatic history of the Earth. These studies provide the basis for assessing the effects of man's activities on long- and short-term changes in global climate. In response to the President's Caribbean Basin Initiative, geologic investigations have been initiated in that region. These studies will contribute to the economic and political health of the Caribbean Basin countries in addition to advancing knowledge of the important geologic relationships between that region and the North American continent. The Geologic Division will continue to place heavy emphasis on basic geologic research capabilities because of the importance not only to the Division's other programs but also to the Nation and a large and growing user community.

Mineral Resource Surveys

During fiscal year 1983, the Geologic Division completed the 20-year program conducted jointly with the Bureau of Mines to assess the mineral resource potential of National Forest lands being considered by Congress for designation as Wilderness Areas. The results of those investigations were compiled in a two-volume professional paper entitled *Wilderness Mineral Potential*, which discusses nearly 800 study areas. (Publication of this book is scheduled for early in fiscal year 1984.) Significant advances were also made in the analogous program which is being conducted by the Bureau of Mines and Geologic Division on behalf of the Bureau of Land Management. In addition, the Division completed mineral resource assessments in Montana, Idaho, and Utah under the Conterminous United States Mineral Appraisal Program.

The Division made great strides in other significant mineral-related research projects during fiscal year 1983. New remote sensing techniques were developed to delineate zones of altered rocks associated with ore deposits. Genetic models of epithermal gold-alunite ore deposits and a number of new exploration techniques to aid in the conduct of mineral resource assessment activities also were developed. A prototype International Strategic Mineral Inventory of worldwide major mines and deposits of chromium, nickel, manganese, and phosphate was completed in cooperation with the Bureau of Mines and representatives of Canada, West Germany, Australia, and South Africa.

Energy Geologic Surveys

During fiscal year 1983, the Geologic Division completed an assessment of undiscovered potential oil and gas resources in all categories of Wilderness or designated Wilderness Study Lands in 11 Western States. Digital cartographic techniques were used by the National Mapping Division to produce base maps and to combine sets of geologic and geographic data for the final assessment products. Planning to provide similar assessments of oil, gas, and coal for all categories of federally owned land is underway; the actual work will begin in fiscal year 1984. Research and development continued toward the production of a major information base to be called the *National Oil and Gas Information Atlas*.

A major compendium of research papers summarizing many years of uranium studies in the Jurassic rocks of the San Juan Basin, New Mexico, was completed and prepared for publication. These studies included regional stratigraphic and sedimentologic work, compilations and interpretations of huge amounts of subsurface data, geochemical and petrographic examination into the processes of ore formation, geophysical surveys, and a new geostatistical approach to resource assessment.

Coal geologists of the Geologic Division continued to provide information on the geology, quantity, and quality of coal in support of the Department of the Interior's coal-leasing program for Federal lands. A total of 12 quadrangle folios was completed; these will be added to the growing base of information used in land use planning and lease-program management. The data, together with other information from cooperating State geological surveys, further improved the capability of the National Coal Resources Data System.

Offshore Geologic Surveys

In fiscal year 1983, the Geologic Division provided substantial information in support of the decision process that led to the Presidential proclamation of the "Exclusive Economic Zone" on March 10, 1983. A discussion of progress to date and projected future activities is provided in an essay on marine research in the "Perspectives" section of this volume. Survey scientists gathered new seafloor photographs and geological samples of the area around the polymetallic sulfide vents at the southern end of the Juan de Fuca Ridge. Sampling of the sulfide deposits, previously done from the surface, was attempted on the seafloor by a joint U.S. Geological Survey–Geological Survey of Canada group using a special core drill developed in Canada. A side-scan sonar survey was conducted to obtain sea floor images of the Juan de Fuca and Gorda Ridges; this survey has added greatly to the understanding of the geology of these ocean spreading centers and the likely distribution of their sulfide resources. Near the end of the year, the Research Vessel *Samuel P. Lee* embarked on "Operation Deep Sweep," a research cruise covering geologic framework, process, and resource surveys in the Arctic and Central and South Pacific Oceans, and the waters around Antarctica.

Petroleum Potential of Wilderness Lands in the Western United States

National concerns over sources for continuing energy supplies within the United States have generated a great deal of interest in the last few years with respect to the probable occurrence of energy and nonenergy resources on Federal lands that have limited access for exploration and development. As a part of the U.S. Geological Survey's continuing efforts to inventory the energy resources on Federal lands, a special investigation was conducted to assess the potential oil and gas resources occurring in the designated and proposed Wilderness Lands in the Western United States.

To properly assess the petroleum potential of these lands, petroleum geologists in the Survey conducted systematic studies that were based on the available geological and geophysical information to determine the geologic favorability for the occurrence or lack of petroleum resources in these Wilderness Lands.

The scope of the investigation is limited to conventional petroleum resources occurring in the Wilderness Lands administered by the Bureau of Land Management, the U.S. Forest Service, the National Park Service, and the U.S. Fish and Wildlife Service. The total area of the study covers nearly 74 million acres of Wilderness Lands in Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

This investigation is unique in that it is the first Federal program to conduct systematic geologic studies of the petroleum resource potential on specifically designated Federal lands and to integrate all the available information concerning these lands through the use of a computer-based digital cartographic data system. Map data portraying the boundaries of the Wilderness Lands, the terrane and underlying geologic structure, and previously delineated petroleum resource provinces have been digitized and correlated by using computer techniques. These data, when merged with data from wells drilled and from petroleum production on adjoining lands, enable the geologists to conduct a systematic study of each wilderness tract.

An analysis of all the geologic characteristics favorable or unfavorable for petroleum occurrence in conjunction with the geologic settings for the Wilderness Lands in the western petroleum provinces was performed by a team of geologists on each of the wilderness tracts. The geologic characteristics reviewed for each tract included the presence or absence of the following: adequate source beds and reservoir rocks, adequate trapping mechanisms, favorable thermal and maturation histories, presence of petroleum seeps or adjacent wells with oil or gas shows or actual production, and the presence of favorable sedimentary rock sections underlying volcanic terrane or faulted and overthrust areas.

The assessments of the petroleum resources on Wilderness Lands were both qualitative and quantitative. Each tract was assigned a qualitative rating describing the potential for the favorable occurrence of recoverable oil and gas resources, such as high, medium, low, low to zero, zero or unknown potential. The quantitative assessment was subjectively estimated based on the richness and the potential of the wilderness tracts relative to the total petroleum potential for the respective basin or province within which they occurred.

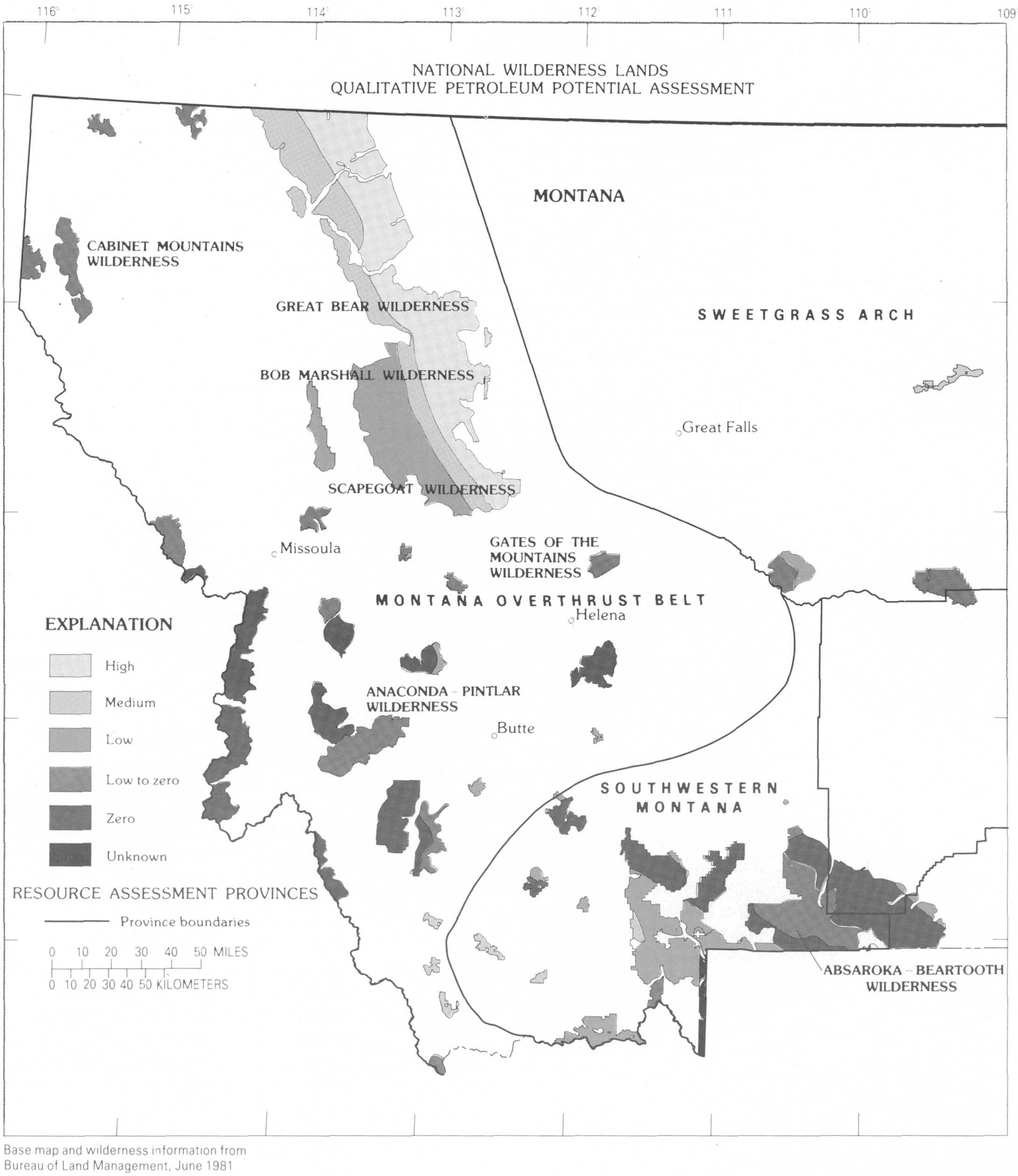
The results of the qualitative analysis of the petroleum potential of the Wilderness Lands are tabulated by total acreages for each wilderness tract as classified by its potential rating. These tabulations are reported for the Wilderness Lands by State and for the total Wilderness Lands in the 11 Western States. At least 34 percent of the total acreage for Wilderness Lands, or approximately 25 million acres, has the geologic characteristics necessary for the occurrence of petroleum resources in varying amounts. An additional 33 percent of the Wilderness Lands may have some limited potential where small sedimentary areas are mixed within igneous and metamorphic terranes but are more likely to fall in the low to zero potential. Finally, 33 percent of the Wilderness Lands probably have no petroleum potential because they are located in terranes with predominantly igneous and (or) metamorphic rocks which are unfavorable for the occurrence of petroleum.

The quantitative petroleum assessments for the Wilderness Lands in the Western United States represent a part of the total estimate of the remaining undiscovered oil and natural gas for the 38 petroleum provinces, as defined in Survey Circular 860, within which the Wilderness Lands occur. The undiscovered recoverable oil, reported at the 95- and 5-percent probability levels, for the Wilderness Lands in the Western States is estimated to range from 0.555 to 1.490 billion barrels with a mean estimate of 0.834 billion barrels. The undiscovered recoverable natural gas reported at the same probability levels is estimated to range from 5.536 to 16.639 trillion cubic feet with a mean estimate of 9.729 trillion cubic feet. For comparative purposes, the total undiscovered recoverable oil and natural gas resources estimated by the Geological Survey for the 38 western petroleum provinces in which these Wilderness Lands occur are 25 to 45 billion barrels of recoverable oil with a mean estimate of 31 billion barrels and 141 to 256 trillion cubic feet of natural gas with a mean estimate of 183 trillion cubic feet. An estimated percentage range (reported at the 95- and 5-percent probability levels) of the amounts of petroleum resources within these western provinces which may occur within designated and proposed Wilderness Lands is 2.2 to 3.3 percent of the total undiscovered recoverable oil and 3.9 to 6.5 percent of the total undiscovered recoverable gas.

These results have been published as Survey Circular 902. The circular documents the entire study: the methodology, procedures, and digital cartography; a description of the geology and geologic framework for each State, along with an explanation of the interpretative geology and evaluation of the petroleum potential within the locale of each of the wilderness tracts; tables and graphs of the results of the qualitative assessments tabulated by acreages; and the quantitative estimates reported as probability distributions.

A series of maps, one for each Western State, will be published separately as Survey Miscellaneous Investigations Series Maps I–1537 through I–1547. Each map will show, in color and at a scale of 1:1,000,000, the location and Bureau of Land Management tract identification and qualitative petroleum potential of the Wilderness Lands studied, the boundary locations of other major Federal and Indian lands, the boundaries and identification of the petroleum provinces, and other base information (see the figure). A pamphlet will accompany each State map describing the geology of the State and the local geology relative to the position of the wilderness tracts and their petroleum potential.

During the next several years, a similar program is scheduled to complete the petroleum resource assessments of Wilderness Lands in Alaska and other major Federal lands in Alaska and the Western United States.



The petroleum potential of Wilderness Lands in the western portion of Montana.

National Coal Resource Data System

Immediately following the oil embargo of 1973, the United States moved rapidly to increase the use of alternative sources of energy. During the balance of the 1970's, a significant amount of new exploration for coal resources was accomplished under various governmental and industrial programs designed to accelerate development of the Nation's vast reserves of this fuel. In 1974, the U.S. Geological Survey began the development of the National Coal Resources Data System to provide a central repository for all previously acquired public coal data as well as for additional data acquired in the future. It is a user-oriented computerized data system for the inventory and analysis of the Nation's coal resources. The system also is designed to summarize data on coal resources and to make these data accessible to a large audience in a standardized format so that they can be used in formulating and implementing the Nation's energy policy.

The coal resources of the United States are large, and the task to assess them is challenging. Current estimates indicate that there are nearly 4 trillion short tons of coal in the United States; however, less than one-half have been identified by systematic mapping and exploration. The existence of the remainder is extrapolated from current data. In addition, the coal resource information included in existing summaries is often inadequate because of outdated information, lack of uniform standards, insufficient detail, and lack of data. The scope and complexity of the task to create a modern U.S. coal resource assessment are clear from the following facts: coal-bearing rocks underlie approximately 13 percent of the land area in the United States, the strata may contain more than 50 coalbeds or zones at depths of 6,000 or more feet, and the geological structure ranges from regular and flat lying to highly folded and faulted.

The system is designed to be open-ended so that it can accommodate growth in quantity and type of data stored and in facilities to make these data accessible. Presently, the goal of developing a system that can statistically, tabularly, and graphically analyze coal data has been met. The major goal to calculate coal resources according to the approved methods of the Geological Survey has also been attained.

Research and development on the system has also provided tools which can be and are applied to available data for other research and planning needs; for example, capabilities of the data system can be used to study geochemical constituents and the shape, size, and distribution of coal and overburden layers for use in making models of coal occurrence. The system also improves prediction of additional coal resources in unexplored areas and can aid in mine reclamation plans.

Data from the various parts of the system may be integrated to demonstrate the relationship of several different elements; for example, trace element and petrologic data can be overlayed with stratigraphic data to generate prediction models for coal quality variation on a bed or multiple bed basis. These facilities allow integration of quantity and quality data for coal resource assessments. Coal quality data (such as sulfur content) are essential to decision-makers who must assess the environmental impact of coal mining and use. As the data base grows, it is expected to be of considerable value in industry planning for exploration and development of new resources.

The problem of assessing the Nation's coal resources is a multifaceted one with efforts from many contributors aiding in the solution. Coordination between groups within and external to the Geological Survey has been of great value. Substantial contributions have been made by the Information Systems and National Mapping Divisions. To augment the Federal coal-mapping/data-gathering programs, the expertise available in State geological agencies has been used to carry out a large part of the data collection. At this time, the Survey is funding 18 State geological agencies or universities to collect and submit available coal resource-related data for entry into the NCRDS. For the majority of the States, this is a 5-year program. As of September 1983, information on approximately 65,000 drill holes or outcrop observations have been entered into the system.

The U.S. Geological Survey is firmly committed to the continued improvement of the National Coal Resources Data System to serve current and future needs for U.S. coal resource assessment.

Landslide Crisis in Utah

Heavy precipitation in Utah during the 1982–83 winter season, beginning with a major storm in September 1982, produced a near record snowpack in the higher elevations. Rapid melting combined with spring snow and rainstorms triggered damaging debris flows and landslides in unprecedented numbers.

The U.S. Geological Survey responded to requests from the Utah Geological and Mineral Survey and the Federal Emergency Management Agency for geological help in the emergency response to the landsliding. During the period of this emergency, eight geologists and engineers with support staff from the Survey's regional centers in Denver and Menlo Park and from the University of Cincinnati and the Los Angeles County Flood Control District provided various types of technical assistance. This team provided assessments of threats to life and property from different types of landslides between mid-April and mid-June 1983 and evaluated potential problems that could be triggered by future cloudbursts.

The first indications of impending problems materialized with the reactivation of a large (106-million-cubic-foot) landslide near Thistle, Utah. The landslide blocked Spanish Fork Canyon which created a large lake and cut off a major transcontinental railroad line and highway access to central Utah which prevented shipment of coal and other supplies; costs of damage have exceeded $100 million. The Survey responded to a request from the Utah Survey to provide assessments of the landslide conditions at Thistle and a detailed map of the bedrock geology in the vicinity of the landslide. The geologic map, published by the Utah Survey, has been useful in selecting routes for bypass tunnels for the railroad and for estimating tunneling conditions.

Toward the end of May, a week of very warm weather accelerated melting of the snowpack triggering numerous landslides in the Wasatch Mountains and Wasatch Plateau that mobilized into debris flows. North of Salt Lake City, debris flows crashed into the communities of Bountiful and Farmington, destroying homes and forcing the evacuation of hundreds of residents. Geologists from the Geological Survey assisted the Utah Survey in hazard appraisals in areas of population concentration. The lack of fatalities caused by landsliding was due in large part to the well-organized response of the Utah Survey in directing repeated evaluations of hazards in critical areas and to cooperation with appropriate local, State, and Federal emergency management agencies.

Two other potential disasters involved reservoirs in the Wasatch Plateau that could have been breached or partly filled by landslides, releasing a wall of water that would probably have caused extensive damage in communities downstream. One of the reservoirs was partially drained and the other was closely monitored to make certain that the hazard did not become worse. Other problems involved the potential for landslides blocking creeks and forming dams which, if breached, would release a large volume of water and debris in a short time. Still other problems involved landslides that disrupted road systems and water supplies.

After the most pressing emergency situations had abated, the Utah Survey asked the Geological Survey to determine whether additional landslide disasters were in the early stages of formation in other areas of the State and which areas in the State should be photographed for short- and long-term assessment of landslide potential. One major problem was the need to cover 82,000 square miles in a short time with limited funds and manpower. To make the most rapid survey possible, two geologists rode in a light aircraft, one of them plotting areas of landsliding on a 1:100,000-scale topographic map and the other taking pictures of these areas and describing the localities in a tape recorder. At the end of 4 days, a 1:500,000-scale map was prepared showing all the known landslide areas along with an evaluation of which areas seemed to be highest in priority for immediate hazard assessment on the ground and for longer term landslide assessment using vertical aerial photography.

Another major problem was to determine the hazard represented by partly detached landslides that occupied valleys upstream from several communities north of Salt Lake City. The concern was that, during summer rainstorms, these landslides could become debris flows, which would be similar to the destructive ones of May and June. Although geologists and engineers are able to predict the stability of a particular hillside if information on the strength, volume, and geometry of the materials are known, the prediction of mobilization into a debris flow is still a research problem.

Large landslide near Thistle, Utah, blocking U.S. Highway 89 and a major transcontinental railroad line.

(Photograph, courtesy of U.S. Forest Service.)

The problem is even more difficult in making regional predictions of debris flow activity. Five geologists and engineers were assigned the task of designing a method to make such regional predictions.

The clues for solving the problem came from understanding the behavior of debris flows that occurred during the past spring. The volume of the landslide material that mobilized or could be mobilized, the average gradient of the stream channel, and the presence or absence of historic and prehistoric debris flows in a canyon system seemed to be the most important factors, apart from the water needed to mobilize the material. This information was determined for 24 canyons from Salt Lake City north to Willard, and a map was made to show the relative potential for debris flows reaching the mouth of each canyon. For those canyons with very high potential, one of the engineers made recommendations for methods of mitigating the debris flows after they emerged from the canyon mouths and extended into communities below.

The causes and mechanism of the unprecedented landslide activity are being investigated by the Geological Survey. The problem of high ground water triggering reactivation of old landslides is being studied at two landslides on the Wasatch Plateau. The team of scientists is also analyzing the runout patterns of debris flows in areas where flows have not been interupted or influenced by manmade structures to formulate a method to predict runout distances.

Eruption of Kilauea Volcano, Hawaii

Kilauea Volcano began a major eruption on January 3, 1983. It was not unexpected; the weekly forecast of eruption probability issued on December 30, 1982, based on the state of strain of Kilauea's summit area, indicated that the likelihood of an eruption during the period of December 30 to January 5 was nearly double the average long-term probability.

Just past midnight on the morning of January 2, a major earthquake swarm and harmonic tremor set off the seismic alarm that sent the staff of the U.S. Geological Survey's Hawaiian Volcano Observatory rushing to the observatory to see what the monitoring instruments were showing. Three to five small, generally unfelt earthquakes were occurring every minute at shallow depths beneath the upper east flank of Kilauea along a zone of weakness known as the east rift. The earthquakes were accompanied by harmonic tremor on the summit and east rift seismographs, indicating that magma (molten rock) was on the move through underground fractures. After 1:00 a.m. the earthquake swarm increased, and several quakes of magnitude 2.5 to 3.0 were felt by local residents.

Another clue to what was happening underground became evident just after 2:00 a.m. as recording tiltmeters began to show rapid subsidence of the summit of Kilauea, amounting to 7 inches in the next 24 hours. A tiltmeter is an instrument that can measure changes in inclination as small as one part per million. All signs indicated that a major new fracture was forming beneath the surface on the east flank of Kilauea and that magma from beneath the summit of Kilauea was moving into this newly forming, but still hidden, crack. During the day of January 2, the earthquake swarm beneath the flank of Kilauea slowly migrated about 5 miles farther down the east rift zone indicating that the underground fracture was still extending eastward. Geologists in the field moved down the surface of the rift zone hoping to be at the location of any breakout of the fracture to the surface.

They were not disappointed; at 12:31 a.m. on January 3, 24 hours after the underground movement of magma began, lava burst to the surface in a remote area on the flank of Kilauea Volcano near an old crater on the rift zone. The erupting fissures rapidly extended until they were about 5 miles long and produced a line of incandescent lava fountains called a curtain of fire.

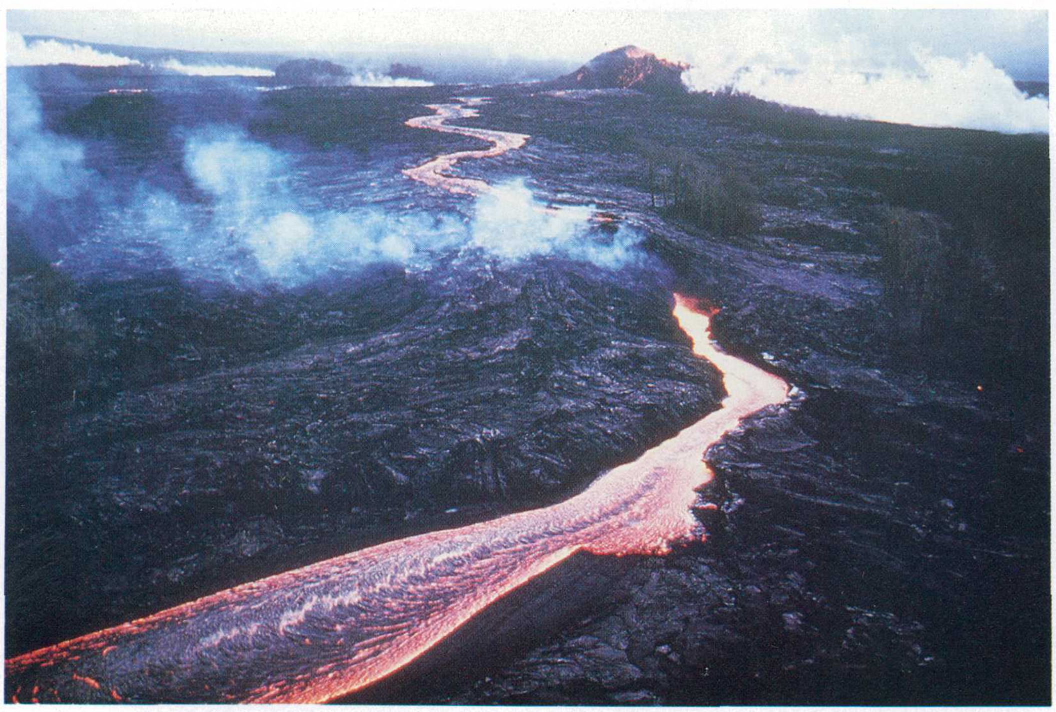
The eruption continued intermittently through mid-January with high rates of lava emission on January 7 that fed a major lava flow. This flow moved 4 miles in 5 hours towards the relatively undeveloped Royal Gardens subdivision of house lots. This first threat to Royal Gardens was perhaps a warning of destruction yet to come.

The eruption paused until late February as the magma reservoir beneath the summit of Kilauea slowly refilled. Evidence for this recharge came from the recording tiltmeters which showed the summit to be slowly swelling upward after its rapid subsidence during January's emission of lava. When enough pressure was regained in the molten rock beneath the summit, the flank eruption was renewed. No new swarms of earthquakes occurred, indicating that the same fracture system was acting as the magma conduit for the eruption.

Five more major eruptive phases have occurred to date (July 27, 1983) late February to early March, late March to early April, mid-June, late June to early July, and late July. Each of these phases has erupted from vents on the fracture system in the roadless and trailless fern forest of the middle east rift zone of Kilauea. They have produced spectacular lava fountains, and four phases also have fed 5- to 6-mile-long lava flows that have invaded the Royal Gardens subdivision. These thick, relatively slow-moving lava flows move through the forest-covered slopes of the south flank of Kilauea at speeds that average 3 feet per minute with surges in speed up to 100 feet per minute. They utterly destroy everything in their path and, so far, have consumed 16 dwellings and covered 330 houselots in the subdivision.

This eruption is already one of the longest lasting rift-zone eruptions in Kilauea's recorded history, and most indications suggest that it is not over.

Lava flows in March, April, June, and July 1983 destroyed 16 dwellings and covered 330 house lots in the Royal Gardens subdivision on the Island of Hawaii. (Aerial photograph by J. D. Griggs)



River of molten lava pours down the south flank of Kilauea Volcano on July 1, 1983. The eruption vents along the east rift zone are visible on the horizon. (Aerial photograph by J. D. Griggs)

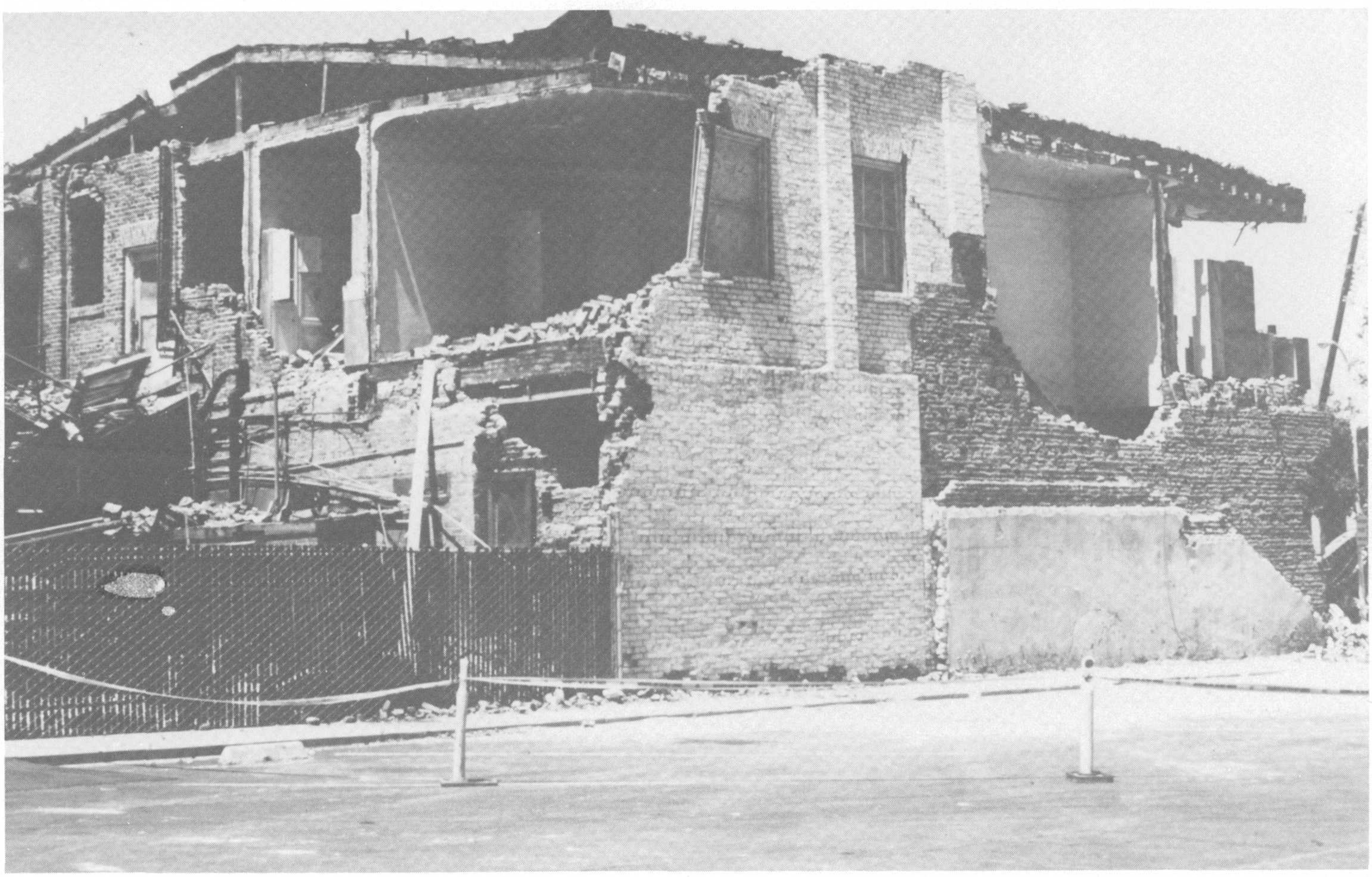
The 1983 Earthquake Sequence Near Coalinga, California

On May 2, 1983, the town of Coalinga, California, was heavily damaged by an earthquake that was centered about 8 miles northeast of town. The earthquake measured 6.5 on the Richter scale and was felt as far away as Las Vegas, Carson City, Los Angeles, and Sacramento. Estimates by the Office of Emergency Services indicate that shaking from the earthquake caused approximately $31 million damage in Coalinga, making this the most damaging earthquake in California since the San Fernando earthquake of 1971. Damage was most severe to older unreinforced masonry buildings (fig. 1) and some older wood framed residences. Newer buildings of nearly all construction types, both within and outside of the downtown area, suffered much less damage. The extensive damage generated by the earthquake in Coalinga reemphasized the seismic vulnerability of older unreinforced masonry structures with the sobering realization that most older California communities contain many such structures. In the event of larger earthquakes along other portions of the San Andreas fault system, the amounts of damage to life and property could approach catastrophic proportions.

Seismic data continuously transmitted via telephone and radio from the Survey's California Seismographic Network together with automatic computer analyses of the incoming data provided accurate locations within minutes of the occurrence of the mainshock and its more than 6,000 aftershocks. Information collected from this network suggests that the Coalinga earthquake sequence was the result of seismogenic failure in a portion of the Earth's crust outlined by previous earthquake sequences. The seismic gap filled in by the Coalinga earthquake sequence and the previous earthquake sequences is illustrated in figure 2.

Precise elevation measurements and analyses of seismic data suggest that the Coalinga mainshock occurred along the

Figure 1.—Damage to older unreinforced masonry building, Coalinga.



Anticline Ridge fault with the result that after the earthquake, the region northeast of the fault was elevated by about 16 inches and the area to the southwest lowered by about 6 inches.

Of the more than 6,000 aftershocks which have occurred in the Coalinga region, six were larger than magnitude 5.0, with five of these on the nearby Nunez fault. Surface rupture along the Nunez fault began on June 11 with a magnitude 5.2 aftershock. Subsequent aftershocks lengthened and enlarged the rupture so that it now extends for about 2 miles and has a maximum vertical displacement of over 23 inches.

Strong-motion instrumentation operated by Survey as part of the U.S. National Strong-Motion Network has provided numerous recordings of the damaging levels of ground shaking generated by the mainshock and subsequent aftershocks. This information, crucial for earthquake-resistant design analyses and description of the nature of seismogenic crustal failure in the region, was recorded on conventional photographic film recorders as well as newly developed computerized recording systems which provide data of exceptional quality, such as the General Earthquake Observation System (GEOS). Such recordings show significant geographic

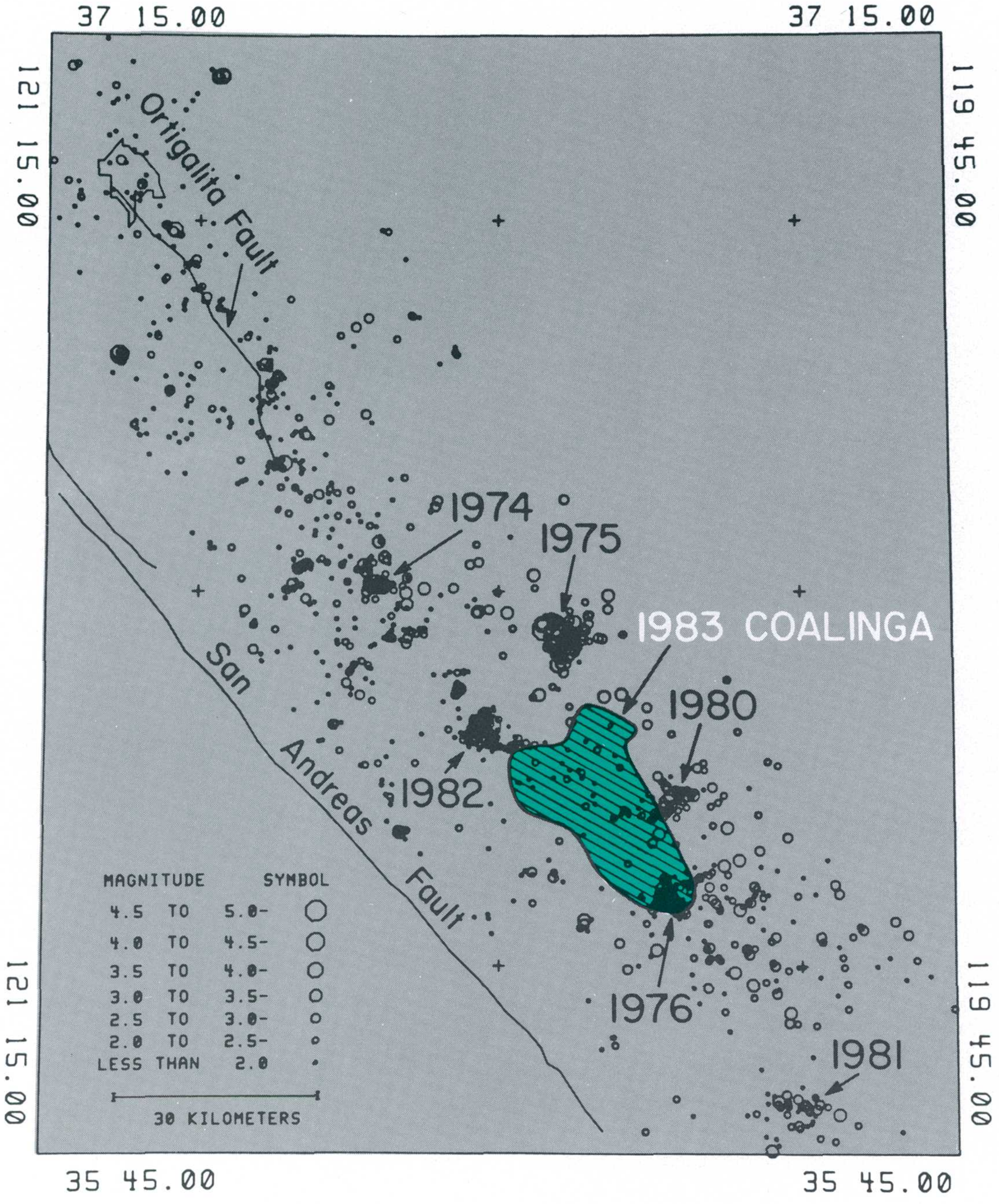


Figure 2.– *Previous earthquake sequences and seismic gap filled in by the Coalinga earthquake sequence.*

variations in the amplitude and frequency content of ground shaking that can be used to study the characteristics of damaging levels of strong ground shaking.

Aftershock recordings obtained in the town of Coalinga, which is located in an alluvium-filled valley, and at nearby sites located on bedrock, suggest that certain frequencies of shaking were considerably larger in Coalinga than at bedrock sites less than 2.5 miles away (fig. 3). This increased shaking due to the alluvium beneath Coalinga may have contributed to the significant damage caused by the mainshock.

Additional scientific investigations have provided a preliminary estimate of the rate of offset along the Anticline Ridge fault. Scientists have found an area where the ground surface is upwarped and incised by small creeks. Determination of the age of the upwarped ground surface suggests that there is a 0.2 inch per year uplift rate for the area over about the last 2,500 years. The repeat time for similar earthquakes along the Anticline Ridge fault has been estimated at about one event every 350 years. Similar geologic and tectonic settings for other regions along the west side of San Joaquin Valley suggest that similar earthquakes could also occur in these regions.

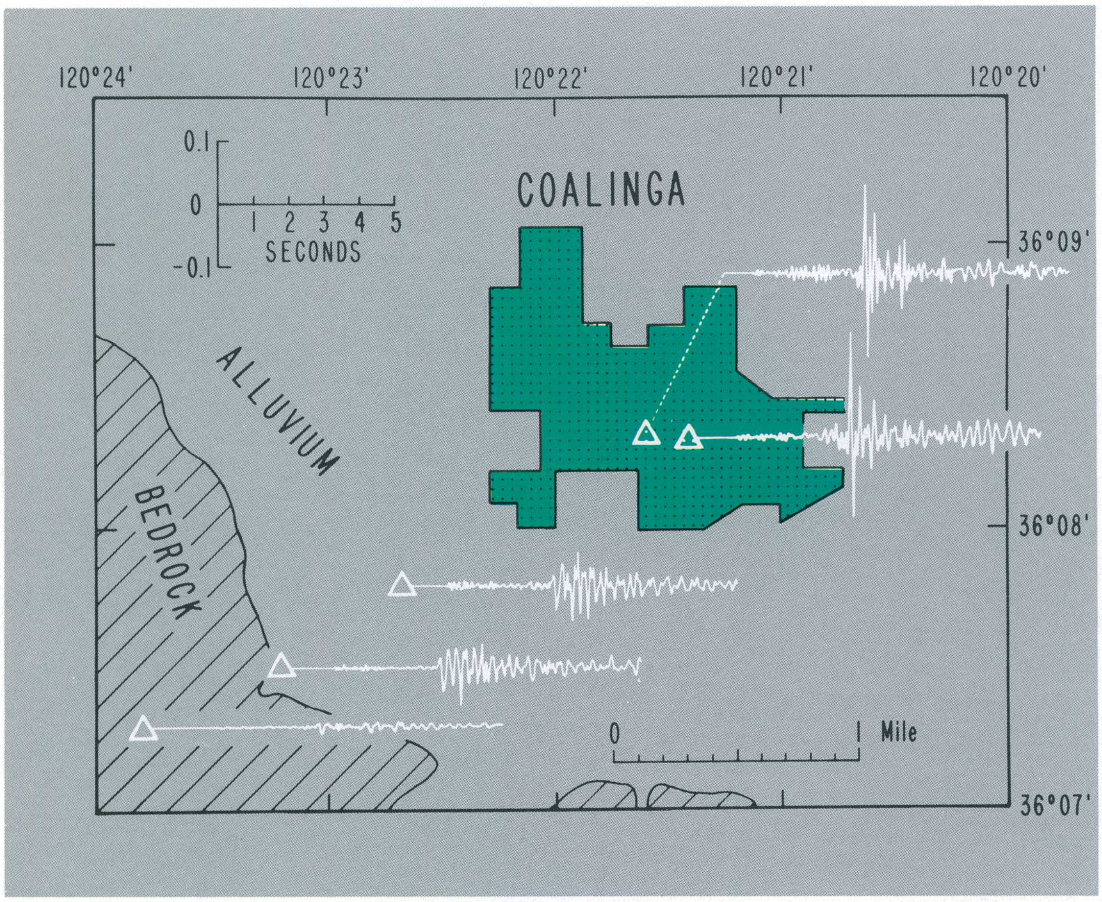


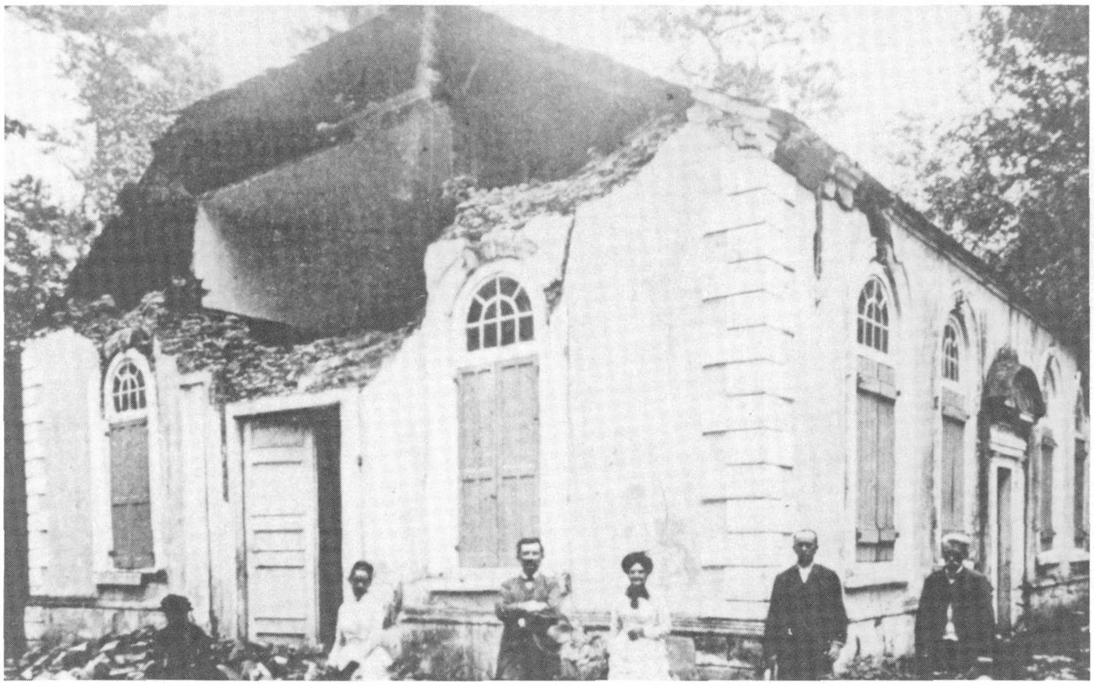
Figure 3. *— East-west components of ground velocity recorded at five GEOS locations from a magnitude 4.3 aftershock*

Earthquakes in the Eastern United States

Earthquakes are about 10 times more common in southern California than they are in the Eastern United States. However, damaging earthquakes do constitute a significant hazard in the Eastern United States. Historic examples of violent eastern earthquakes occurred in Charleston, South Carolina, on August 31, 1886, and in the New Madrid, Missouri, area in the winter of 1811–12. Extensive damage and 60 deaths were caused by the South Carolina event, and widespread dislocation of the ground surface occurred in the Mississippi River Valley area. These earthquakes were felt over much of the Eastern United States as is characteristic of major eastern events. Intensities registering VI and higher on the Modified Mercalli Intensity Scale (MM) were observed across several Eastern States in 1811 and 1886.

For the past decade, the U.S. Geological Survey has focused research on understanding the origins of eastern seismicity. One natural target for these investigations has been the Charleston area which experienced the 1886 event (MM X) and which continues to experience seismicity. A major multidisciplinary research program has significantly increased the understanding of Charleston seismicity and its regional tectonic setting. Results of this study are described in Professional Paper 1313, *Studies Related to the Charleston, South Carolina, Earthquake of 1886*. Because several competing hypotheses exist to explain the specific tectonic origin of Charleston seismicity, resolution of these hypotheses into a workable seismotectonic model remains an important research goal. Although it is recognized that the Charleston area remains a likely area for future large earthquakes, the probability of such events elsewhere along the east coast has also been addressed. Although there is no recent or historic evidence for strong earthquakes elsewhere in the East, the fact that most tectonic elements of the Charleston area are similar to those in other parts of the East allows for the possibility that major earthquakes with long recurrence intervals may occur elsewhere in the region. A full understanding of the cause of 1886 Charleston earthquake within the regional tectonic framework is important to understanding the likelihood of strong earthquakes throughout the East.

In May 1983, a conference, The 1886 Charleston Earthquake and Its Implications for Today, gave scientists and individuals having diverse backgrounds in government, academia, and the private sector an opportunity to discuss what is known and what still needs to be known about the historic Charleston earthquake. The conference participants also discussed ex-



Goose Creek church, Charleston, South Carolina, after earthquake of 1886.

periments for resolving hypotheses about the tectonic origin of the 1886 earthquake and developed measures for reducing the destruction from future earthquakes. They agreed on a plan for continued cooperative research and hazard mitigation measures in the East. First, the recently formed South Carolina Seismic Safety Consortium and the South Carolina Geological Survey were strongly encouraged to continue their efforts to heighten public and governmental awareness and preparedness for possible future Charleston-type earthquakes. Second, the Nuclear Regulatory Commission received technical guidance for formulating future research priorities related to its regulatory function. Third, the U.S. Geological Survey was encouraged to continue its integrated research plan with emphasis on refinement and resolution of the existing seismotectonic models. Continuing cooperative efforts among all the groups concerned with earthquake activity in the area is essential to build public concern and to provide accurate scientific information for dealing with problems related to earthquakes.

Warehouse, Charleston, South Carolina, after earthquake of 1886.

Strategic and Critical Minerals—Potential Supply Problems and New Research Directions

In 1979, civil war in Zaire spurred industry fears of a supply interruption and resulted in an eightfold explosion to as much as $50 per pound in the spot market price of cobalt, a metal that imparts high-temperature strength to ferroalloys and is used extensively in jet engines and for super magnets. The cobalt crisis was short lived, but it indicates how sensitive the world metal market is to threats of supply disruption. Many industrialized nations lack not only cobalt but a wide variety of minerals. Figure 1 shows that the United States is strongly dependent on imports for a large proportion of its mineral needs and that the sources of some of these materials may be vulnerable to political, economic, or even military disruption. Those minerals which are essential to our Nation's economic well being and military security and for which domestic or secure foreign sources are not assured are termed critical and strategic. The United States has not always been an import-dependent nation; indeed, within the last century, the United States was, for a brief time, a world leader in the production of such now-strategic commodities as chromium, nickel, cobalt, and aluminum. However, as industrial demands have multiplied, as domestic deposits have been depleted, and as richer deposits in foreign lands have become developed, the United States steadily moved toward an importer status.

Since the Second World War, a number of major domestic mining districts have closed, and the steady trend of increasing dependence on foreign suppliers shows that the slack has not been taken up by new domestic producers. Among those districts closed are Bunker Hill, Idaho (lead, zinc, silver), Butte, Montana (copper, silver), Keewenaw, Michigan (copper), and Ducktown, Tennessee (sulfur).

The closing of these mines has encouraged a widespread perception among persons outside of the minerals community that the United States is thoroughly explored and that no new mineral deposits remain to be discovered, but recent experience demonstrates that this is far from correct, as a few examples demonstrate:

- Within the last 30 years, the world's largest lead deposit (Viburnum, Missouri) has been discovered and put into intensive operation; it now yields

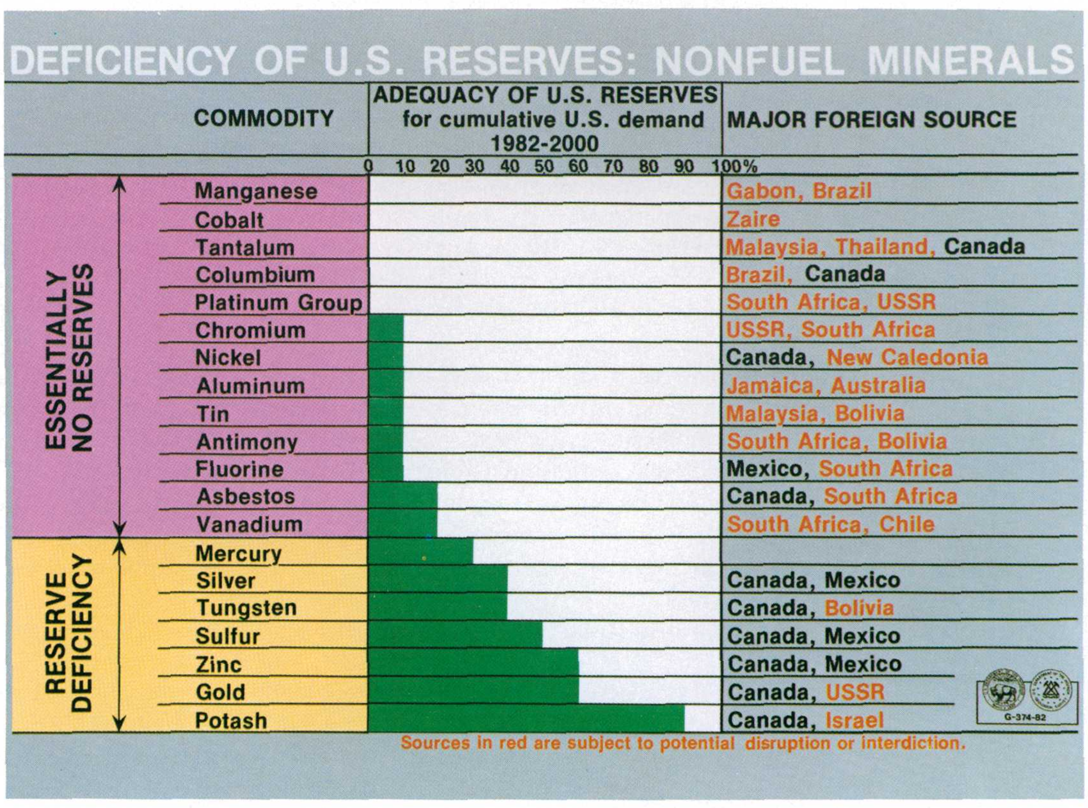


Figure 1.—*U.S. dependency on selected nonfuel minerals.*

about 90 percent of the Nation's lead production. Continued exploration is locating more and more mineralization in this area.

- A dozen or more substantial gold deposits have been discovered in the Great Basin (principally Nevada). These are an unusual, low-grade, large-tonnage type only recently recognized as having economic potential.
- Large deposits of copper and zinc have been discovered at Crandon, Wisconsin, and Bald Mountain, Maine.
- A recently discovered extensive zone of platinum metals in the Stillwater complex of Montana is probably the world's second largest deposit (after the Merensky reef deposit in the Bushveld complex of the Republic of South Africa).
- The Brooks Range in Alaska is the site of two large new, and as yet undeveloped, deposits, Arctic Camp (copper and zinc) and Red Dog (zinc).

Although there has been a continuing flow of new discoveries, the levels of exploration, discovery and development have lessened, reflecting a decline in the health of the industry and a gradual reduction of good exploration targets. Furthermore, despite some success in finding additional ore deposits of the types already known to be present, the platinum find in the Stillwater, Montana, and the nickel find at Brady Glacier, Alaska, are the only major discoveries of minerals high on the strategic and critical list. Chromium, manganese, cobalt, tin, aluminum, tantalum, and many others still are predominantly imported, and some of the supplies may not be dependable in the future. To assure that the Nation is in the best possible position with respect to minerals, the Geological Survey's program of basic mineral research is now focused on strategic and critical minerals. Three main elements comprise this program: systematic local and regional mineral surveys, investigations of the geologic controls on mineralization, and establishment and maintenance of the data base concerning the geologic availability of minerals at home and abroad.

Mineral Surveys

Three general components of regional mineral mapping are included within this program: Conterminous U.S. Mineral Assessment Program (CUSMAP), in which large areas are mapped at a scale of 1 inch equals 4 miles in blocks of about 8,000 square miles each (1 latitude by 2 longitude) (fig. 2). The 48 conterminous States contain about 150 such quadrangles which are favorable for the occurrence of strategic and critical minerals. Eleven of these have been assessed since the program began in 1977, and 12 more quadrangles are in progress. Studies include geologic mapping; geochemical sampling of stream sediments, soils and rocks; and geophysical investigations. This work provides a basis to delineate certain areas as having potential for mineral deposits; because different geologic settings possess different probabilities for the occurrence of different minerals (for example, lead and zinc are often found in dolomitized carbonate rocks, whereas uranium occurs in sandstones), the resulting mineral assessment map may be highly complex with several kinds of potential indicated. Priorities for the study of CUSMAP quadrangles are assigned on the basis of the amount of Federal land to be assessed, the level of previously known mineral potential, the probability that the study will identify significant mineral potential, and interest from States and from other Federal agencies.

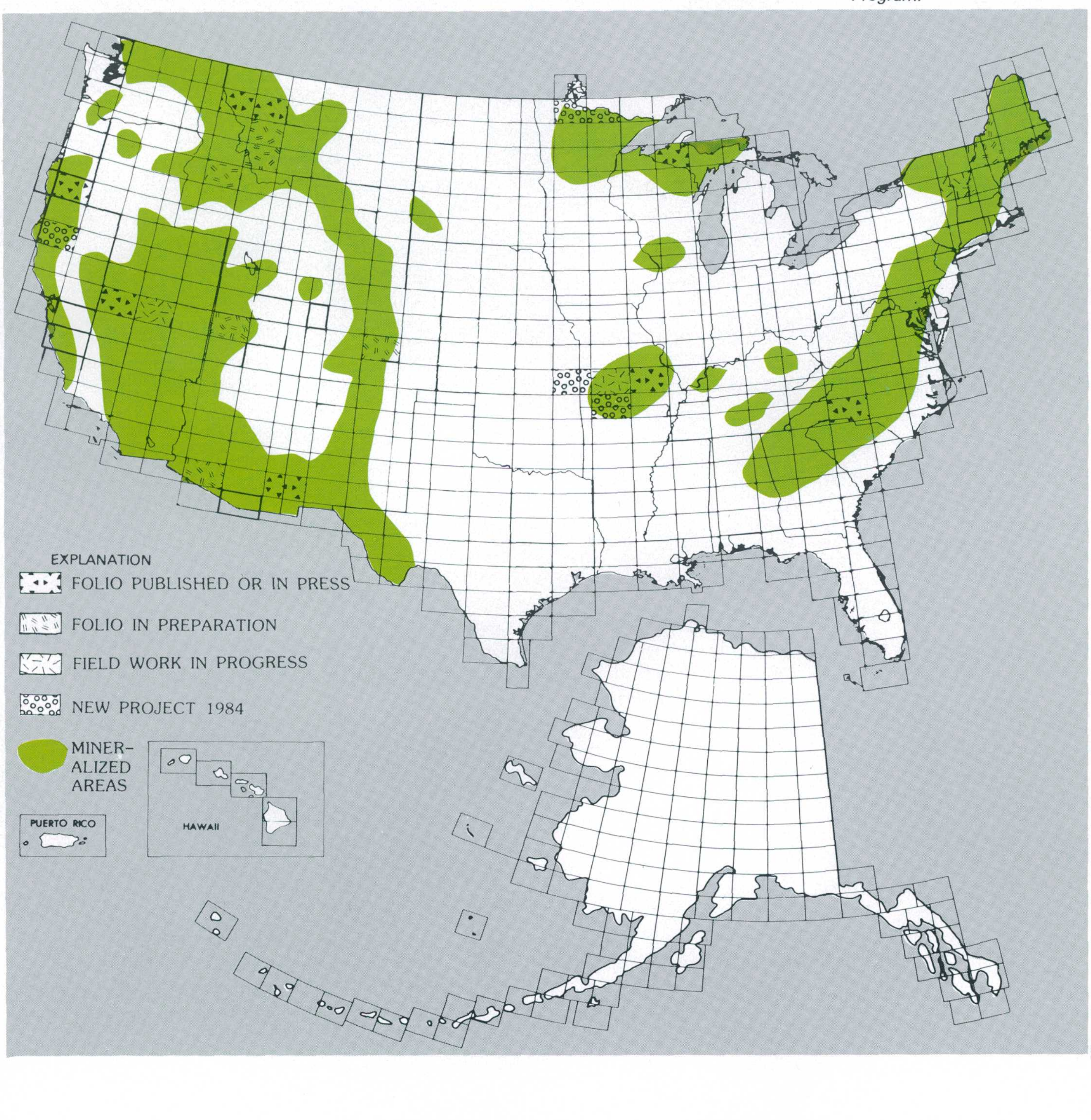
In Alaska, a similar program called Alaska Mineral Resource Assessment Program (AMRAP) is systematically covering the State (fig. 3). Difficulty of access is a severe problem in many parts of Alaska, but, nevertheless, about 41 percent of the quadrangles containing significant mineralization in the State have been mapped and assessed thus far.

Under the provisions of the Wilderness Act of 1964, Public Law 88–577, and the Federal Land Policy and Management Act of 1976, Public Law 94–579, the Geological Survey, in cooperation with the Bureau of Mines, conducts mineral surveys of certain lands designated and considered for incorporation into the National Wilderness Preservation System. Since the passage of the Wilderness Act in 1964, about 800 tracts of Forest Service lands totalling more than 42 million acres have been assessed, and, since 1978, 36 tracts under Bureau of Land Management jurisdiction totalling about 3 million acres have been studied, with emphasis on strategic and critical minerals. Where practical, such tracts have been integrated into the CUSMAP and AMRAP programs, but, in general, the level of detail and amount of time spent per unit area is greater for the wilderness studies than for CUSMAP or AMRAP.

Mineral Deposit Research

Most mineral deposits that are exposed at the surface have been recognized by prospectors, but a large fraction of deposits are either concealed or have only an uneconomic fringe visible. Thus, a key element in the transition from the physical description of the ground, in the form of a geologic map, to the mineral assessment is the ability to recognize the possibility or probability for a given type of mineralization to occur in a given geologic setting. The basic tool for this is the comparison of the tract with similar tracts known to be mineralized so that the geologic clues to mineralization can be recognized and interpreted. Studies of known mineral deposits are key factors in support of the assessment activity. These studies must include detailed field and laboratory investigations of mines and prospects and an interpretive synthesis leading to predictive models for mineral deposits. Use of these models can lead to discovery of new resources in previously unexplored parts of the United States as well as expanding the identified reserves in recognized mining districts.

Figure 2. — *Status of the Conterminous United States Mineral Assessment Program.*



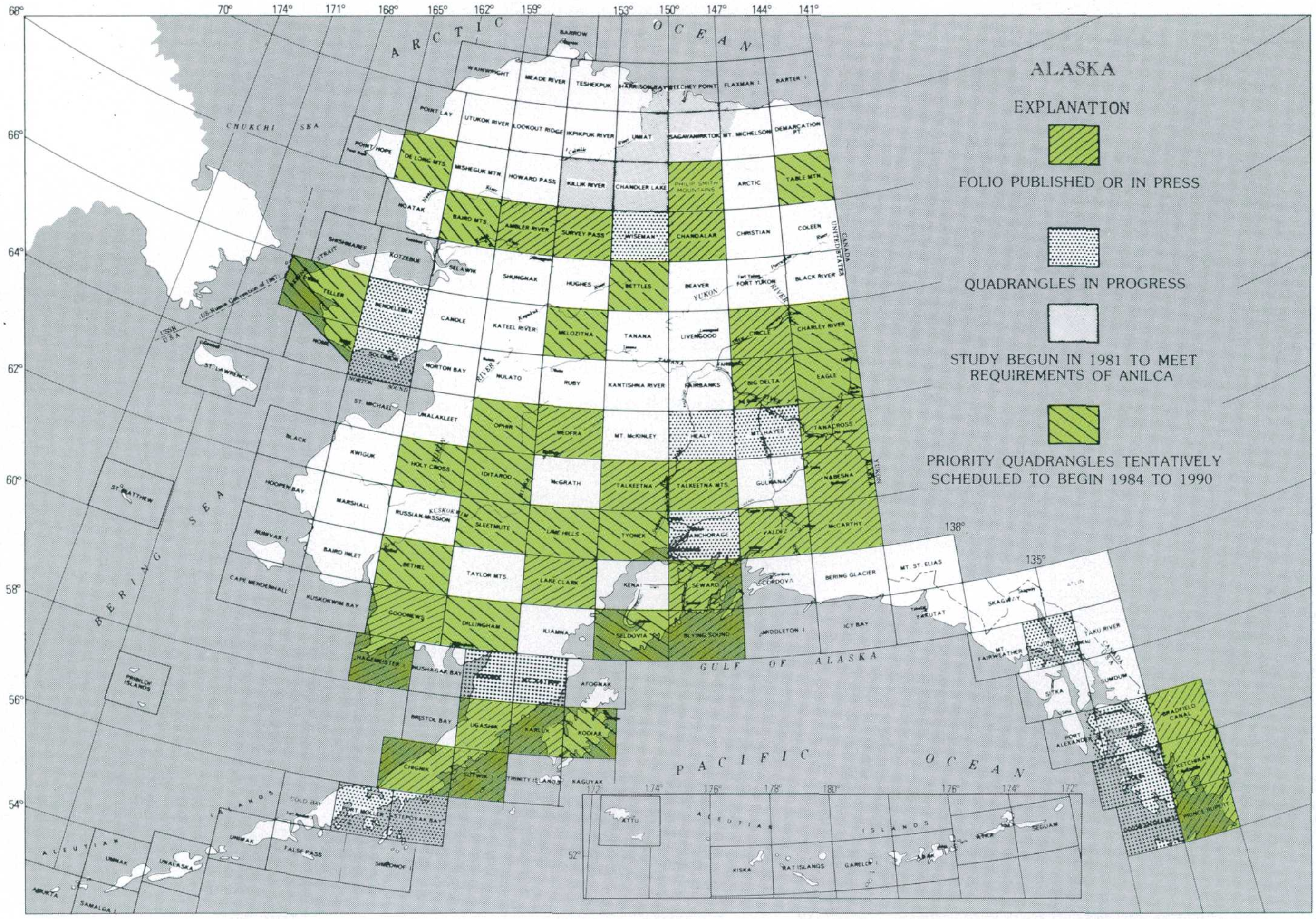


Figure 3. — Status of the Alaska Mineral Resource Assessment Program.

Geologic Availability of Minerals

To keep track of the amount and distribution of mineral resources within the United States and to promote the adequacy and certainty of access to resources from foreign sources, the Geological Survey carries out several mutually complementary activities. Each of the major mineral commodities is assigned to an experienced earth scientist whose duty it is to acquire and maintain a thorough understanding of the national and international resource information for that specific mineral or material. These mineral commodity experts constitute a valuable source of resource information to answer direct inquiries from the private and public sectors. In addition, the amount and distribution of resources by geographic region is compiled and used through a recently revised computerized mineral and geologic data system which possesses over 60,000 entries. To improve our knowledge of foreign supplies and potential supplies, the Geological Survey is cooperating with the State Department and many agencies of foreign governments to develop improved resource information and evaluate worldwide nonfuel mineral resource potential and to keep track of international exploration activities. Survey foreign activites are directed especially toward identification of alternate and more secure sources of the strategic minerals needed by the United States.

In summary, the Geological Survey is attacking the increasingly difficult problem of United States critical minerals import dependency by systematic mineral surveys to identify domestic mineral resource potential, mineral deposit research that can lead to the discovery of new types of deposits in hitherto unexplored parts of the United States and expanding known resources in recognized mining districts, and resource data services in the form of mineral commodity experts and an international computerized mineral resources data base. These activities are continuing programs that constitute a significant part of the Geological Survey's responsibilities as mandated by the Organic Act of 1879. Because of long experience in these activities, the Geological Survey has been able to quickly focus on strategic and critical mineral problems to support the President's National Materials and Minerals Program Plan that was released in April 1982. By these activities, the Geological Survey can help identify new domestic mineral resources and more secure foreign sources, as well as provide resource information to support land and mineral policy decisionmaking.

Climate Change

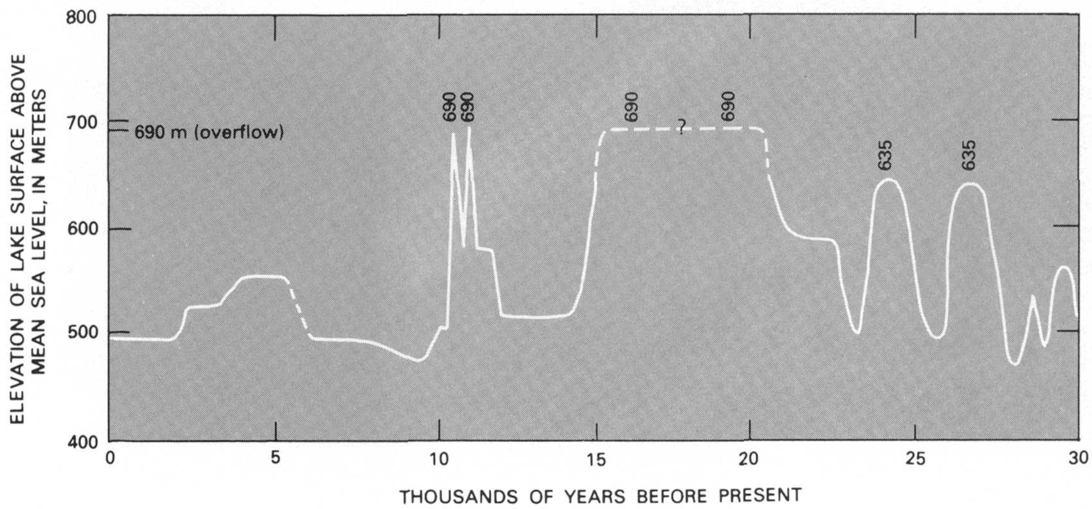
Most people are very much aware of the unusual weather that occurred during the last year. For example, record snows in the Midwest followed by early spring thaws and heavy spring rains caused flooding in a number of places such as Salt Lake City, Utah, and parts of the Southeastern United States. However, different types of geologic studies demonstrate that climate varies over a wide range of time scales from decades to millenia and that the climate changes experienced by modern man represent relatively minor wiggles superimposed on larger scale climatic fluctuations. Geologists are actively involved in the study of ancient climates (or paleoclimates) because much geologic data such as associations of fossils, structure and composition of sediments, and the occurrence of features directly related to glacial processes can provide information on past climates that extends beyond the historical records of man. Such information is essential for understanding current climate and for predicting future climate change.

The water-level fluctuations of ancient Searles Lake, California, shown in the figure, represent one kind of paleoclimate record. Although now dry, Searles Lake was one of about 100 lakes in the Great Basin that extend from the Sierra Nevada of California to the Wasatch Mountains of Utah. These lakes, which were developed in closed basins, are called pluvial lakes (rain lakes) because their water-level changes dramatically with changing climate. During times of cool and wet climate, the pluvial lakes expand, whereas during times of warm and dry climate, they shrink. Through studies of the geology of Searles Valley and cores from ancient Searles Lake, U.S. Geological Survey scientists have been able to reconstruct the history of Searles Lake for the last 30,000 years.

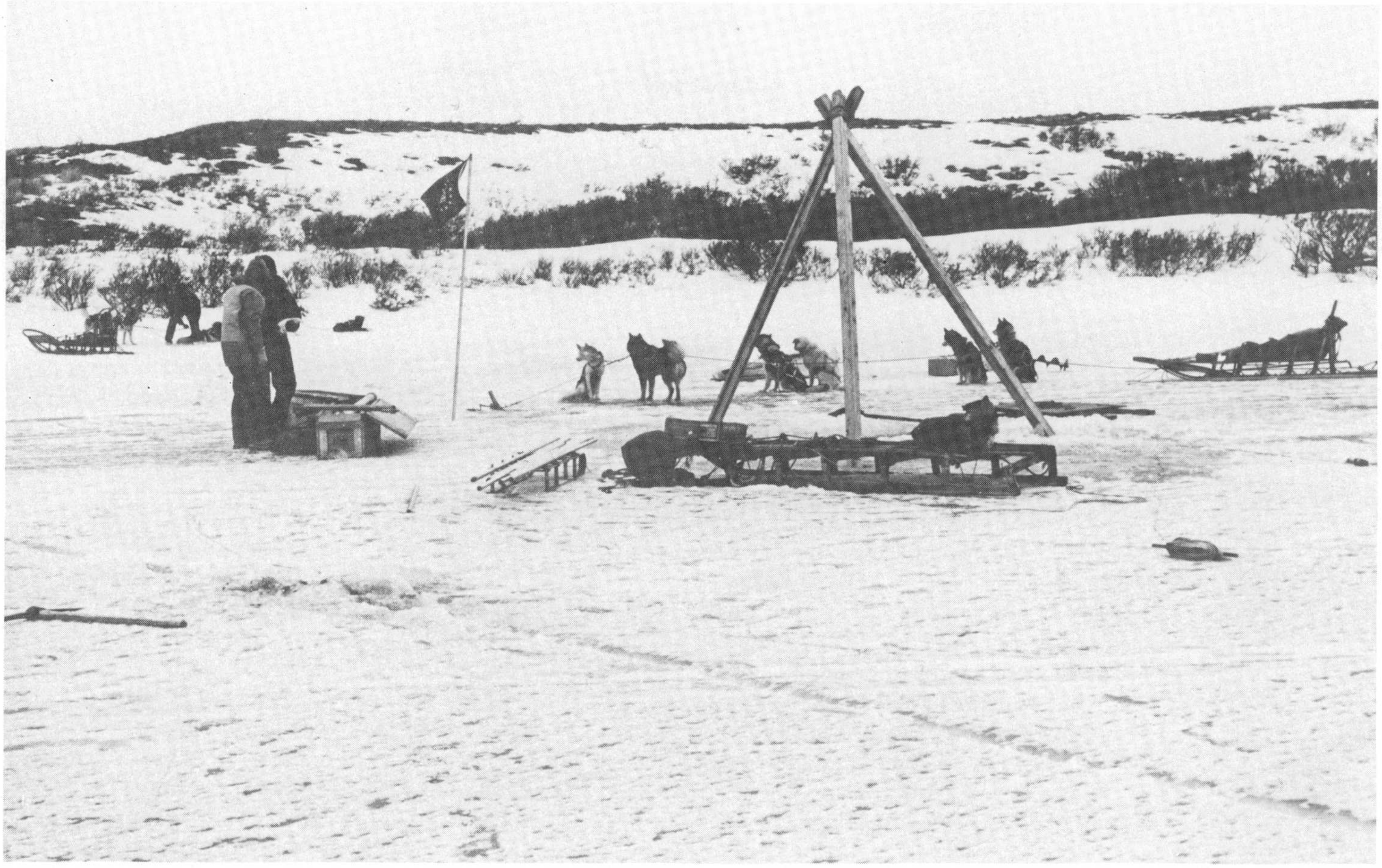
The figure shows that Searles Lake has remained dry or at a relatively low level for the last 10,000 years. In contrast, from 10,000 to 30,000 years before present, the level of ancient Searles Lake was generally much higher, and extreme rapid fluctuations in the level of the lake occurred frequently. Between 15,000 and 20,000 years before present, the lake level rose high enough to flow over the valley rim into the next lower basin. Because changes in the lake level reflect changes in climate, we infer that warm, dry, and relatively stable climates of the past 10,000 years were preceded by a period of cold and wet and more variable climates.

The modern and ancient record of Searles Lake generally matches the history of lake levels determined from many other pluvial lakes in the Great Basin. For example, when Searles Lake was overflowing its basin between 15,000 and 20,000 years before present, Great Salt Lake was greatly expanded and formed part of a huge lake called Lake Bonneville which covered an area of about 19,300 square miles, 17,000 square miles larger than the present Great Salt Lake.

A wide variety of paleoclimate studies indicate that climate has fluctuated regularly in the past; these studies also show that climates as warm as the last



Water-level fluctuations of ancient Searles Lake, California.



10,000 years have only occurred about 5 percent of the time in the last 700,000 years. Therefore, we are currently in a time of abnormally warm and equitable climate, and, unless man's activities change the natural system, we expect to see a change to cooler and more variable climates in the (geologically) near future.

Scientists of the Geological Survey continue to investigate the long-term natural variability of climate because this information is necessary both to assess the influence of man's activities on climate and to predict the consequences of future natural, or man-induced, climate change on the Nation's resources. In addition, as part of the Nation's effort to understand climate and climate change as they relate to national goals and needs, the U.S. Geological Survey provides essential information on paleoclimates to the National Climate Program.

Winter sediment-coring operations on St. Michael Island, Alaska. Analysis of fossils in cores provides data for reconstructing climatic history.

Puerto Rico: A Key to the Caribbean Basin

The U.S. Geological Survey's first major program in the Caribbean basin was aimed at providing economic assistance to the Government of Puerto Rico through an assessment of the mineral resources of the island. Shortly after the program began in 1952, FORMENTO, the Puerto Rican Industrial Development Corporation, and scientists of the Geological Survey realized that basic geologic data upon which to make a mineral resource assessment for Puerto Rico were lacking. The Geological Survey scientists began a program of detailed basic geologic mapping of the island to provide the necessary framework for ongoing and future mineral resource studies.

The change in orientation from an economic mineral resource assessment program to a program combining basic geologic mapping with resource assessment resulted in a detailed study of the entire island and involved a wide range of Geological Survey talent. The 62 detailed (1:20,000 scale) geologic maps produced over the 31-year history of the project have transformed Puerto Rico from one of the geologically least known to one of the most thoroughly known terranes in the world. The recently completed Geologic Map of Puerto Rico (1:100,000 scale) combines the essentials of the original 62 detailed geologic maps with modern interpretations made in light of current geologic theory into a convenient single map. The detailed maps and the regional map form a basis for further studies in metallic and nonmetallic mineral resource assessment and for studies of geologic hazards such as unstable ground and earthquakes.

Puerto Rico, like the other islands of the Greater Antilles, Cuba, Hispaniola, and Jamaica, originally formed along a belt of submarine volcanoes that later were raised above the sea in the form of an island arc. The oldest rocks of the island arc are at least 110 million years old, whereas the youngest volcanic rocks are about 38 million years old. The oldest volcanic rocks consist chiefly of lava flows that in surface exposures often resemble masses of irregularly piled pillows. The pillow lavas, along with glassy brecciated rocks were produced by sudden quenching and fracturing of molten lava by sea water. Evidence that the lavas were formed in part above, or very near, the sea surface comes from the presence of shallow-water clamlike fossils in sandstone and limestone beds interlayered with the volcanic rocks. These older volcanic rocks (fig. 1) characteristically show chemical peculiarities that distinguish them from other island-arc volcanic rocks. They contain relatively little potassium, rubidium, thorium, and uranium and are classified as primitive island arc rocks. The younger volcanic rocks of Puerto Rico formed as lava flows, tuff, and volcanic breccia produced by explosive and quiet eruptions of lava or as debris derived from the erosion of volcanic rocks exposed at the surface. These more evolved island-arc rocks are chemically distinct from those of the primitive island arc because of their greatly increased potassium content in relation to calcium and sodium. Intrusive rocks which gave rise to these younger rocks are known to contain copper deposits, and recent preliminary evidence suggests that they may also contain gold deposits.

Geologists had generally assumed that Puerto Rico and other islands of the Greater Antilles were formed in their present positions or possibly on the western margin of the Caribbean basin near the present position of Panama, Costa Rica, and Nicaragua. Recently completed work on rock magnetism indicates, instead, that Puerto Rico and probably the other islands of the Greater Antilles formed at the latitude of present-day Peru and Ecuador and that they moved into the Caribbean basin at some time in the last 38 million years.

An understanding of the basic geologic framework of Puerto Rico is fundamental to future mineral resource assessment of the island, particularly in regard to predictive resource estimates for copper, gold, and phosphate rock used for fertilizer and to the expected incidence and potential severity of geologic hazards such as earthquakes and landslides.

Figure 1. *—Pillow lavas representative of the older volcanic rocks of Puerto Rico were extruded on the sea floor. Individual pillows are as large as 15 feet in diameter.*

Water Resources Investigations

Mission and Organization

The U.S. Geological Survey has the major responsibility within the Federal Government for assessing the Nation's water resources. It collects basic data and conducts special investigationa to provide background information for planners and managers. Demands for water from a wide variety of users increasingly require that planners at Federal, State, and local levels establish priorities for use. Sound judgment in determining such priorities depends on access to accurate hydrologic information and impartial expertise.

Office of Water Data Coordination

A major responsibility was assigned to the Survey in 1964 when it was designated the lead agency for coordinating water-data acquisition activities of all Federal agencies. Activities include those that produce information on streams, lakes, reservoirs, estuaries, and ground water. This coordination effort minimizes duplication of data collection among Federal agencies and strengthens the data base and its accessibility.

Programs

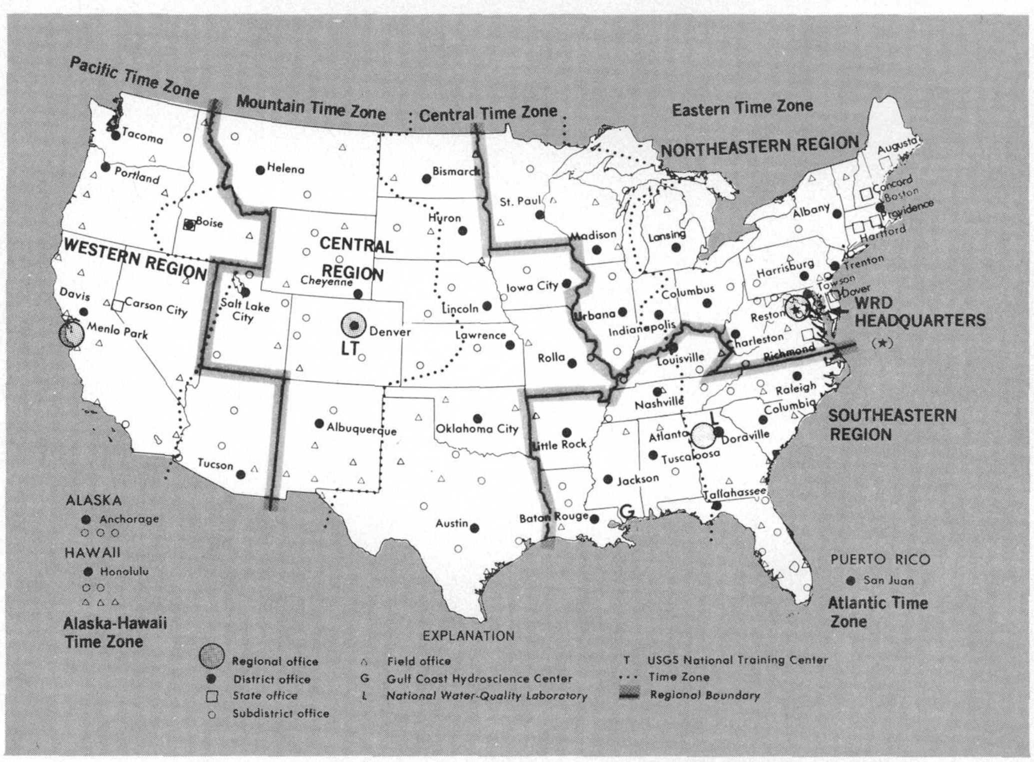
Water Resources Division programs fall into four categories: the Federal Program, the Federal-State Cooperative Program, Assistance to Other Federal Agencies, and the Non-Federal Reimbursable Program.

The Federal Program

The data collection, resource investigation, and research activities of this program are carried out in areas where the Federal interest is paramount. These include bodies of water in the public domain, river basins and aquifers that cross State boundaries, and other areas of international or interstate concern. Activities include operation of surface- and ground-water quantity and quality measurement stations throughout the country, the Survey's Central Laboratories System, hydrologic research and analytical studies, and a variety of supporting services.

The Federal-State Cooperative Program

The Cooperative Program is based on the concept that Federal, State, and local



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.

governments have a mutual interest in evaluating, planning, developing, and managing the Nation's water resources. The immense size of the task of appraising the Nation's water resources precludes accomplishment by Federal efforts only. Similarly, State and local agencies working independently cannot relate to the sizable regional aspects of the hydrologic system. Because many water problems begin at the local level, the Survey has cooperative agreements with all States under which each party funds one-half the cost of financing studies of water resources. Cooperation through this Program provides an economical and comprehensive system for water-resources assessments.

Most projects under the Cooperative Program respond to a recognized problem or define a potential one. In addition to data collection, programs may focus on water use and availability, the impact of man's activities on the hydrologic environment, and energy-related water demands which may strain available water supplies. In emergency situations, such as drought or flood, events are monitored, and the data accumulated under the Cooperative Program prove invaluable.

Assistance to Other Federal Agencies

With funds transferred from other Federal agencies, the Geological Survey performs a wide variety of work related to the specific needs of each agency.

Non-Federal Reimbursable Program

Non-Federal reimbursable funds are unmatched funds received by the Geological Survey from State and local agencies in situations where there is both Federal and State interest in investigation of water resources but where matching Federal funds are either unavailable or are not otherwise applicable to cost sharing.

Budget and Personnel

At the end of fiscal year 1983, the Water Resources Division employed 2,927 full-time personnel. This number included scientists and engineers representing all fields of hydrology and related sciences, technical specialists, and administrative, secretarial, and clerical employees. An additional 1,644 permanent part-time and intermittent employees assisted in the work of the Division.

The $200.8 million obligated in 1983 for water resources investigation activities came from the following sources:

1. Direct Congressional appropriations.
2. Congressional, State, and local appropriations for 50–50 funding in the Federal-State Cooperative Program.
3. Funds transferred from other Federal agencies.
4. Funds transferred from State and local agencies.

Highlights

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

The Federal-State Cooperative Water Resources Program—Some Highlights From 1983

The Federal-State Cooperative Program in fiscal year 1983 continued to concentrate on water-resources investigations of highest priority to the Nation. Hydrologic data collection and interpretive studies were proceeding in every State, Puerto Rico, and several of the territories with focus on such current concerns as ground-water contamination, flood analyses, impacts of toxic wastes, acid precipitation, and stream quality.

During the year, this 50–50 matching program was carried out in working partnership with more than 800 State, regional, and local agencies. Joint funding from all sources totaled about $92 million. Details of the program are arranged at State and local levels by representatives of the Survey and the cooperating agencies. This pooling of interests results in a balanced effort that directs combined resources to hydrologic investigations having the most significance to the cooperating parties. A few of the highlights of 1983 are described below.

Slidell, Louisiana: Backwater and Flow Distribution of Pearl River Floods

Severe flooding on the lower Pearl River in the vicinity of Slidell, Louisiana, occurred in April 1979, 1980, and 1983. Each flood approached or exceeded a 100-year frequency of recurrence. The chance for three such floods happening within a 4-year span is about 1 in 10,000.

Following the 1980 flood, the U.S. Geological Survey, in cooperation with the Louisiana Department of Transportation and Development, Office of Highways, began a study of backwater and flow distribution of the Interstate Highway I–10 crossing of the Pearl River near Slidell. A finite element model has been developed to simulate flow conditions through the existing bridge opening. The model may also be used to simulate conditions without I–10 in place, with the effects of alternative bridge designs, or with modifications to the existing bridge.

In the vicinity of Slidell, the Pearl River occupies a flood plain about 5 miles wide that is slightly incised below the surrounding land. Just upstream from I–10 at Slidell, the river splits into three distributary channels with the main channel running along the west bank of the flood plain. During floods, streamflow, rather than being concentrated along the main channel that parallels the west bank, shifts to the east side of the flood plain. I–10 embankments and bridge openings cause flow to shift from the west to the east bank farther upstream than it would if the highway were not there. Results of the investigation also show that the I–10 crossing and the resulting shift in flow distribution affect the height as well as the extent of backwater.

Pagan Island, Northern Marianas: Effects of Volcanic Activity on Water Quality

The entire population of Pagan Island, in the Commonwealth of the Northern Mariana Islands, was evacuated to Saipan because of Pagan Volcano's eruption in May 1981. The volcano is a potentially explosive one, and eruptions about 1920 caused the evacuation of the population for several years. The people cannot return home until it is determined that their water supply is no longer contaminated. Under a joint-funding agreement, the U.S. Geological Survey is investigating the quality of water in the vicinity of the villages on Pagan Island.

A field reconnaissance was carried out in March 1983. Members of the party included engineers and chemists from the Water Resources Division and seismologists and volcanologists from the Survey's Geologic Division. Water samples were collected from many sources, and gas and vapor samples were collected at the volcano. Instruments were installed to collect and transmit data on rainfall and seismic events directly to the Honolulu District Office via the GOES satellite. Results of this work will determine whether or not the water supply is potable and may give some indication of trends in volcanic activity.

Sheffield, Illinois: Ground-Water Flow and Tritium Migration From the Sheffield Low-Level Radioactive Waste Site

Sheffield, near Chicago, which was one of six commercial low-level radioactive waste disposal sites in the United States, is being studied by the Geological Survey to develop geohydrologic expertise to be included in criteria for future site selection under the Low-Level Waste Policy Act of 1980. A pebbly-sand unit underlying 67 percent of the site in Illinois extends to a strip-mine pond located about 2,000 feet northeast of the nearest waste trench. As part of a study of the hydrogeology east of the site, a number of test wells were constructed. Seventy-eight nanocuries of tritium per liter were detected in water samples from two of these wells located a few hundred feet east of the boundary of the site. (Nuclear Regulatory Commission regulations allow a maximum permissible concentration of 3,000 nanocuries of tritium per liter for release into water.)

In a cooperative investigation with the Illinois Department of Nuclear Safety, an additional 20 wells have been drilled in an effort to determine the areal extent of the tritium plume, the source of the tritium, and the nature of the release. One migration pathway has been identified along a buried sand-and-gravel-filled channel, and tritium is discharging through seeps to the strip-mine pond. Detailed information obtained from the test wells suggests that other pathways may also be present.

New Mexico: Unexpected Results of Streamflow and Ground-Water Investigations

Results of investigations describing streamflow in the Pecos River, in cooperation with the Pecos River Commission, and ground-water conditions in the Albuquerque-Belen basin, in cooperation with the New Mexico Environmental Improvement Division and the city of Albuquerque, show that previous concepts associated with these hydrologic systems may need to be revised.

Studies of the Pecos River between Artesia and Carlsbad indicate that, in the last several years, base flow has not increased as much as expected after the area was cleared of phreatophytes (salt cedar). Base flow was projected to increase about 1 acre-foot per acre, but analysis of streamflow records reveal only about one-fourth that amount.

In the Albuquerque-Belen basin, reconnaissance investigations of ground-water quality have detected unexpected concentrations of organic chemicals, and one municipal well has been shut down as a result of the sampling program. In addition, water-level measurements have determined that ground-water movement is in a direction away from the Rio Grande toward the eastern border of the basin, and movement of contaminants, therefore, may be in a direction opposite to that originally thought.

Hazardous Waste Hydrology

The safe disposal of hazardous waste provides serious challenges to our Nation, States, and local communities. The great variation in nature and degree of hazard from a wide variety of dangerous substances demands that we employ the most scientific management of which our society is capable. The proper collection, interpretation, and use of earth science information is critical to a program of effective control for such wastes.

With this in mind, the U.S. Geological Survey, through the Office of Hazardous Waste Hydrology, established a program to focus hydrologic and geologic expertise on the earth-science aspects of safe, effective waste disposal and ground-water contamination problems. The comprehensive program is composed of three elements: high-level radioactive waste, low-level radioactive waste, and nonradioactive toxic waste.

High-Level Radioactive Waste

High-level radioactive waste includes spent nuclear-reactor fuel and material derived from reprocessing nuclear fuel. The waste is characterized by high radioactivity and by nuclides with relatively long half-lives, and it generates considerable amounts of heat in its decay. After more than 30 years of nuclear-power development, a suitable permanent repository has yet to be developed for this type of waste. The most viable disposal concept consists of placing the waste in a deep-mined repository as much as a few thousand feet below the surface of the Earth in which the waste is effectively isolated from man's environment for tens of thousands of years.

The principal objective of the Survey high-level waste program is to support the national effort, led by the U.S. Department of Energy, to select and characterize sites where wastes can be effectively isolated in deep geologic environments. Specific program objectives are to provide techniques for (1) evaluating the chemical interaction of nuclear waste with natural fluids and with the rock and mineral framework of ground-water systems, (2) evaluating transport of waste nuclides by ground water, (3) characterizing geologic and hydrologic conditions at sites under consideration by the U.S. Department of Energy, and (4) screening large provinces of the United States for smaller areas having potentially favorable earth-science characteristics for waste disposal.

The earth science problems associated with this endeavor are complex and incompletely understood. The Survey's High-Level Radioactive Waste Program stresses

Earth science investigations of hazardous waste disposal sites provide site-specific geohydrologic data as well as generic information on the effectiveness of investigation techniques, monitoring systems, and so forth. (Photograph by Stephen C. Delaney, U.S. Environmental Protection Agency.)

Careful techniques being developed and tested through programs of the Office of Hazardous Waste Hydrology are employed to collect ground-water samples from a hazardous waste disposal facility and to safeguard the health of hydrologic technicians. (Photograph by Stephen C. Delaney, U.S. Environmental Protection Agency.)

the concept of isolating nuclear wastes by means of relatively independent multiple barriers to waste nuclide migration. A major requirement is to identify environments where such multiple natural barriers are believed to exist. A second major requirement is to identify and understand the critical hydrogeologic properties and processes that are involved in radionuclide migration from a repository to environments of living organisms.

The Comprehensive Nuclear Waste Policy Act of 1982 defines the timetable and responsibility of the Department of Energy in selecting the first and second repositories. As specified in the Act, the Survey program is designed to provide consultation and support to the Department of Energy to accomplish this national mission, which includes selecting the first repository site in 1987 and burial of wastes by 1998.

Low-Level Radioactive Waste

Low-level radioactive waste is produced by hospital, research and industrial facilities, and nonfuel-related activities of nuclear-reactor operation. It is generally much less radioactive than the high-level wastes, as its characterization implies, and does not generate significant amounts of heat in its decay. Disposal in this country is by shallow land burial, although ocean dumping has occurred in the past.

There are six commercial low-level waste sites in the United States. Three are closed, due wholly or in part to environmental concerns, and a fourth closure is being contested in the courts. Provisions of the Low-Level Radioactive Waste Policy Act of 1980 may result in the establishment of as many as eight new commercial sites by 1990. In addition to these commercial sites, the Department of Energy operates six major and a number of minor low-level waste disposal sites for government-generated waste.

Low-level radioactive waste can pose a threat to human health if contaminants migrate from shallow land-burial sites in concentrations exceeding accepted standards. The principal migration pathway is generally ground water. The objective of the Survey program that addresses this problem is to gain a better understanding of the geohydrologic controls on the migration of radionuclides from shallow land-burial sites. To accomplish this objective, the Geological Survey has been conducting field research studies at five commercial and three Department of Energy disposal sites. Basic research complements the field investigations. Final reports on the first phase of field studies at commercial sites were published in 1983. These and other reports on earth science aspects of low-level radioactive waste disposal will be essential information for individual States or multi-State low-level waste compacts as they seek new sites in accordance with requirements of the Low-Level Waste Policy Act of 1980.

Nonradioactive Toxic Waste

The safe cleanup and disposal of toxic chemical wastes from point and nonpoint sources is one of the most critical environmental problems confronting the United States. Point-source contamination from leaks, spills, and disposal of these wastes currently imposes high annual costs on the public and private sectors and can seriously affect human health and safety. The number of toxic substances requiring disposal is increasing, as is the quantity of that waste, the latter at a rate of from 3 to 5 percent annually. In New England and New York alone, more than 1,000 wells are known to be contaminated by organic chemicals, affecting the drinking water of millions of people.

Chemicals used in agriculture have been implicated in nonpoint contamination of shallow aquifers throughout the country. Pesticides currently in use are often different from the organochlorine and organophosphorous pesticides used one or two decades ago. Many of the newer pesticides have low soil affinity and high persistence, which allows them to pass unimpeded through the soil and into the saturated zone of the ground-water system.

In some cases, present technology is inadequate to develop technically sound and practical regulations to protect the public from hazardous chemical contamination in a cost-effective manner. Major technical questions are yet to be answered about the behavior of specific chemicals under different hydrogeologic conditions and about the safety, suitability, and economics of restoration and disposal methods.

The Geological Survey has begun an interdisciplinary program to provide the Na-

Research supported by the Office of Hazardous Waste Hydrology is conducted to obtain a better understanding of contaminant transport from hazardous waste disposal areas to local streams and aquifers. (Photograph by Stephen C. Delaney, U.S. Environmental Protection Agency.)

tion with earth-science information necessary to improve waste-disposal practices and to help solve existing and future ground-water contamination problems. The program uses the data bases and experiences of previous Survey work that are specifically relevant to the problem. It is closely coordinated with related programs of Radioactive-Waste Disposal, Regional Aquifer Systems Analyses projects, the Federal-State Cooperative Program, and studies of glacial deposits in the Eastern United States.

The program includes both field and laboratory investigations. Long-term research programs have been established at locations of known ground-water contamination to determine the behavior of specific contaminants in the ground-water system and to develop techniques with which to study them; these sites are near Bemidji, Minnesota, Pensacola, Florida, and Cape Cod, Massachusetts. This research is complemented by investigations of other field problems related to the reliability of predictive models and monitoring strategies for contamination. Geological Survey scientists have begun an appraisal of national ground-water quality to determine the magnitude and trends of the contamination problem. The appraisal is being closely coordinated with State governments.

Technical information developed within each element of the hazardous-waste program is incorporated into other elements of the program. Other Survey programs such as Regional Aquifer Systems Analyses and core research provide additional technical information and support. An early dividend of this coordination has been major support to the Department of Energy, the U.S. Nuclear Regulatory Commission, and State government agencies in the development of waste-disposal siting criteria. This comprehensive approach to solving earth science related problems of hazardous waste disposal places the U.S. Geological Survey in a position to continue contributing highly useful earth science information on this major national issue.

Cost-Effectiveness of the National Stream-Gaging Program

The U.S. Geological Survey began a nationwide analysis of its stream-gaging program during fiscal year 1983. The purpose of the analysis is to define and document the most cost-effective method of furnishing streamflow information. The analysis is being carried out over a 5-year period with about 20 percent of the program being analyzed each year. The Survey operates about 8,000 continuous-recording gaging stations nationwide that provide streamflow information for a large variety of users. These gaging stations will be evaluated (1) to identify the principal uses of the data and to relate these uses to funding sources, (2) to identify alternate, less costly methods of furnishing needed information, and (3) to define strategies for operating the program to minimize the standard error in streamflow data while staying within the operating budget. The first two steps are designed to ensure that sufficient need exists for operating a gaging station. The third step provides for allocation of financial and manpower resources among the stations that remain in the program after the screening process, so that the program is operated in the most cost-effective manner. An analysis completed for the State of Maine early in fiscal year 1983 will serve as a prototype.

In the first step, the known uses of streamflow data generated at a gaging station are compared against the objectives of the stream-gaging program to ensure sufficient justification exists for Survey involvement at that station. Deficiencies in the existing data-collection program are evaluated to ensure that all information needs are met. The responsiveness of the operation of each station to the types of uses also is evaluated to see that streamflow information is timely. For example, analysis of the data uses for 51 stations in Maine indicated that three stations should be discontinued as soon as is practical and that an additional three stations should be discontinued at the end of short-term projects. Analysis also indicated that, as funds become available, additional stations should be established in the interior of Maine to better define regional hydrology.

The second step of the analysis is used to determine whether sufficient streamflow information can be generated at a station by methods other than operating a continuous-record station. Primarily, two alternate methods are considered, a flow-routing model and a statistical regression model. The flow-routing model uses the traveltime of flow between stations, the storage in the stream channel, and hydrologic routing techniques to transfer daily flows from an upstream station to a downstream one. The statistical regression model correlates daily flows at the station of interest with daily flows at other nearby stations. Once calibrated, both models can be used to estimate daily flows at discontinued stations by using daily flows from operating stations. The accuracy of the estimated streamflow must be suitable for the intended usage for an alternate method to be viable. In the Maine analysis, there was one station where both models provided daily discharges of sufficient accuracy for the intended usage. Both models were calibrated using all existing data, and the recommendation was to continue operating the station until sufficient data were available to verify the models.

The final step is used to determine the best allocation of money and manpower among the stations that remain in the program after the two screening steps. Because there are so many uses made of streamflow data, minimization of the standard error of streamflow data, expressed as percentages, is chosen as the general measure of the program's effectiveness. This part of the analysis defines the uncertainty function for each station in the program, develops the necesary cost information, and determines the number of visits necessary to each station to minimize the uncertainty.

The uncertainty function relates the standard error of streamflow data to the number of visits and measurements made per year or season. Examples of typical uncertainty functions from the Maine study are given in figure 1. These uncertainty functions are computed using a statistical technique that evaluates the accuracy of the streamflow rating curve, the accuracy of transferring flows from nearby stations, and the variability of historical flows at the station. The rating curve at each station is the relationship that enables the hydrologist to convert the

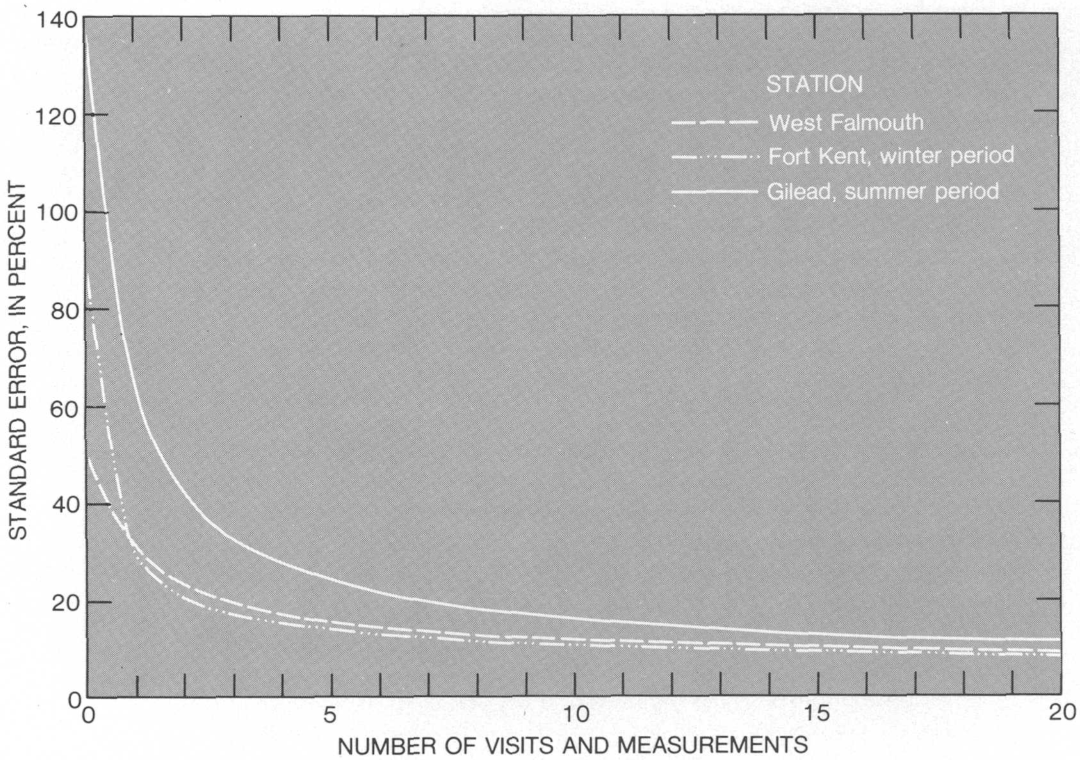


***Figure 1.** — Typical uncertainty functions for three gaging stations in Maine.*

recorded water-surface elevation (gage height or stage) to streamflow. At some sites, additional correlative data are necessary to determine the flow, such as the fall in water surface between sites. When the recorder at the station fails to record the water-surface elevation (or other correlative data), the rating curve cannot be used, and daily flows must be estimated from flows at nearby sites or from historical flows at the station. The uncertainty function includes the variability or standard error of flows estimated in these various ways.

Once the uncertainty functions for each station are known, various costs associated with stream gaging can be determined. Feasible routes are defined for servicing the stations, and each station is assigned to one or more routes. The cost of servicing each station, route costs, and the minimum number of times each station should be visited are determined. The fixed costs of operating each station, including the cost of computing records and their storage and publication, are also determined. This information and the uncertainty functions are input to a computer program that determines the number of times each route is used. The routes selected are those with the largest reduction in uncertainty per dollar of expenditure. By varying the total budget and repeatedly running the program, an uncertainty or average standard error relationship with the budget can be developed. Figure 2 is an example of an uncertainty-cost relationship for Maine. The original Maine stream-gaging program, consisting of 51 stations, operated with an annual budget of $211,000. As a result of the data-use analysis, it was recommended that 6 of the original 51 stations in the Maine stream-gaging program be discontinued. The stream-gaging program analyzed for cost-effectiveness consisted of 45 stations. The current criteria for operating the 45-station program require a budget of $180,300. This is the circle in figure 2 marked "Current Practice." The average standard error of the streamflow records was 17.7 percent. As can be seen in figure 2, this overall level of accuracy could be maintained with a budget of about $170,000 if allocation of resources among the gages was altered. The recommendation was to modify the operation of the program and to use the residual $10,300 to increase receipt of data from the interior of the State. The relationship in figure 2 indicates the reduction in uncertainty that can be achieved by increasing the total budget.

Studies like the one in Maine are scheduled for completion in 17 States during fiscal year 1983. The entire stream-gaging program will be analyzed over the next 5 years as part of the continuing effort of the Geological Survey to evaluate the Na-

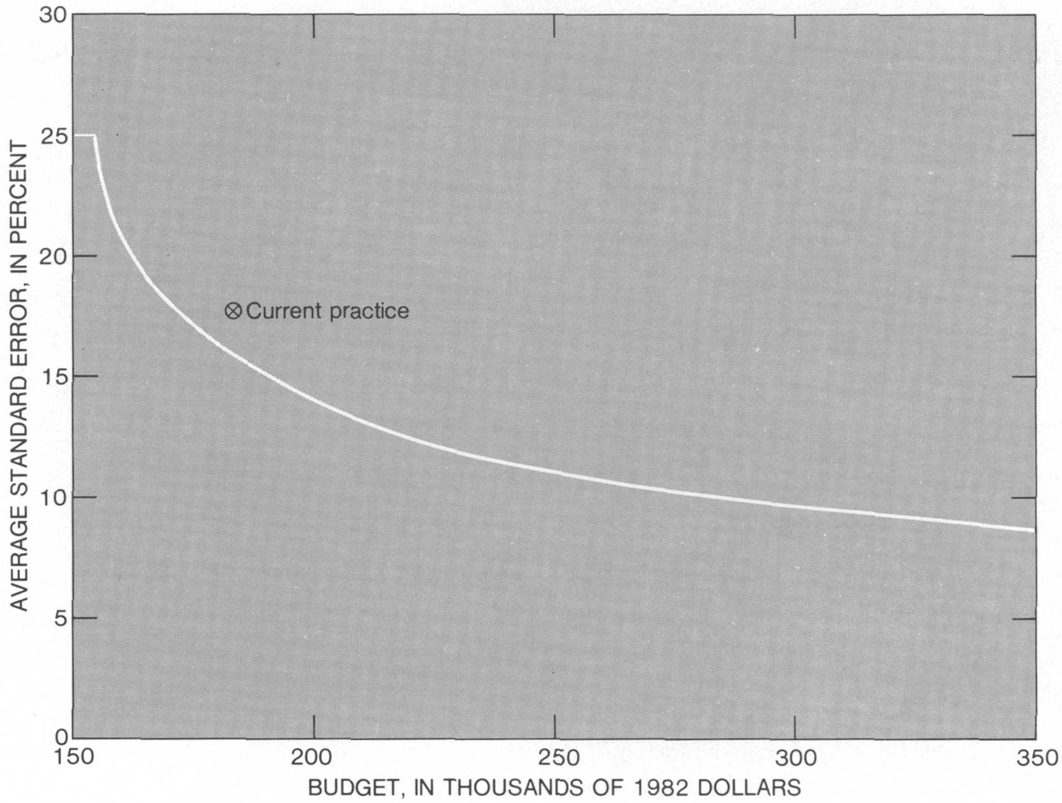


Figure 2. *— The relationship between the average standard error and the total budget for the stream-gaging program for Maine.*

tion's water resources. The national stream-gaging program that results from this analysis will be responsive to the needs of local, State, and Federal agencies and will provide streamflow information in the most cost-effective manner.

Contamination of Ground Water by Coal-Tar Derivatives in St. Louis Park, Minnesota

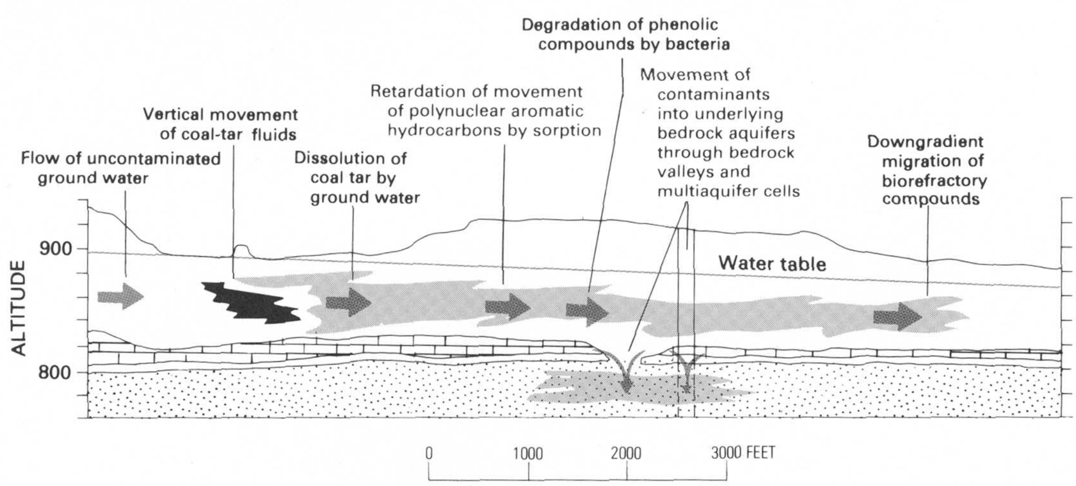
Operation of a coal-tar distillation and wood-preserving facility in St. Louis Park, Minnesota, from 1918 to 1972 resulted in severe ground-water contamination. In 1978, the U.S. Geological Survey began detailed studies of the transport and fate of coal-tar derivatives through ground water in the area. Local, State, and Federal agencies will use the results of the studies to guide management decisions and to design remedial action. The studies were conducted in cooperation with the Minnesota Department of Health, Minnesota Pollution Control Agency, city of St. Louis Park, and the U.S. Environmental Protection Agency.

The problem of most immediate concern to the city and to the State and Federal regulatory agencies is the presence of toxic organic compounds in water withdrawn from some municipal wells. When the first municipal well was drilled in 1932, the Prairie du Chien–Jordan aquifer contained water having a distinct coal-tar taste. The well is 3,500 feet from the plant site. From 1978 to 1981, use of seven more municipal wells in this aquifer was discontinued because the wells yielded water containing trace amounts of coal-tar compounds, including at times and places, the carcinogen benzo(a)pyrene.

The Prairie du Chien–Jordan aquifer is the region's major ground-water resource. About 75 percent of ground-water withdrawals in the St. Louis Park and Minneapolis–St. Paul metropolitan areas are from this aquifer. The aquifer has good natural protection from near-surface sources of contamination. In the St. Louis Park area, it is 250 to 500 feet below land surface and is overlain by glacial drift, two bedrock confining beds (Glenwood and basal St. Peter), and two bedrock aquifers (Platteville and St. Peter). Nonetheless, it is now contaminated because materials entered the aquifer through at least five wells that hydraulically connect more than one aquifer (multiaquifer wells). The single major source is a well on the former plant site that was drilled in 1917 to an original depth of 909 feet. When first geophysically logged by the Survey in 1978, the well had filled to a depth of 595 feet. The uppermost 100 feet of the fill was mostly coal tar. Moreover, approximately 150 gallons per minute of contaminated water was moving through the well bore from the St. Peter aquifer into the Prairie du Chien–Jordan aquifer.

Contaminants in the Prairie du Chien–Jordan aquifer have moved at least 2 miles northeast and southeast of the plant site. The direction and rate of contaminant movement changes with time because the bedrock ground-water flow system continually adjusts to hydraulic stresses caused by water withdrawals and flow through multiaquifer wells. Contaminants move rapidly through the Prairie du Chien–Jordan aquifer because the upper part is a carbonate rock with fractures and solution channels. Consequently, the concentration and composition of contaminants in water pumped from the Prairie du Chien–Jordan aquifer through individual industrial and municipal wells fluctuates with time.

Contaminants entered the uppermost bedrock aquifer, the Platteville, directly from the drift and moved at least 4,000 feet from the plant site. Locally, the con-



Section showing major processes controlling the transport through ground water and fate of coal-tar derivatives, St. Louis Park area, Minnesota.

taminants have reached the St. Peter aquifer through the Glenwood confining bed and (or) through bedrock valleys where the confining bed has been removed by erosion.

The greatest mass of contaminants is in the drift near the plant site. Coal-tar derivatives reached the water table by percolation through the unsaturated zone and through ponds that received surface runoff and process water from the plant. Parts of the drift contain an undissolved liquid mixture of many individual coal-tar compounds. Chemical analyses of organic fluid and water from a monitoring well completed in the drift 50 feet below the water table identified more than 200 individual organic substances. The viscous organic fluid is denser than water and has moved slowly downward independent of the direction of ground-water flow. Ground water entering the area of the plant site through the drift is contaminated by partial solution of the organic fluids and by release of compounds sorbed on the drift materials. The contaminated water moves laterally to the east and southeast and downward into the Platteville aquifer. Water in the drift 4,000 feet from the site contains less than 10 milligrams per liter of disolved organic carbon but has a distinct chemical odor and contains a large proportion of coal-tar compounds highly soluble in water.

One major group of coal-tar compounds (phenolic compounds) is being degraded to methane and carbon dioxide by bacteria that metabolize phenolic compounds in the anaerobic (oxygen-free) environment that exists in the aquifer. This finding is of

Vertical aerial photographs of the plant site during plant operation (left) and redevelopment (right).

major scientific importance because it demonstrates the substantial natural capacity of a ground-water system to biologically degrade certain toxic compounds that are very mobile in ground water.

Movement of another major group of coal-tar compounds (polynuclear aromatic hydrocarbons) was found to be greatly retarded by sorption on the drift material. Where ground water contains sufficient oxygen, it seems that some of these compounds are being degraded by aerobic bacteria.

The results of this ongoing project suggest that the ability of the natural systems to assimilate toxic wastes might be successfully exploited in efforts to restore contaminated aquifers.

Fluid samples collected from the drift 50 feet below the water table near the plant site. Organic fluid derived from coal tar (glass on left) is being dissolved and transported by ground water (glass on right).

The Water Resources Division of the U.S. Geological Survey has similar ground-water contamination studies being conducted around the country, several of which are as follows:

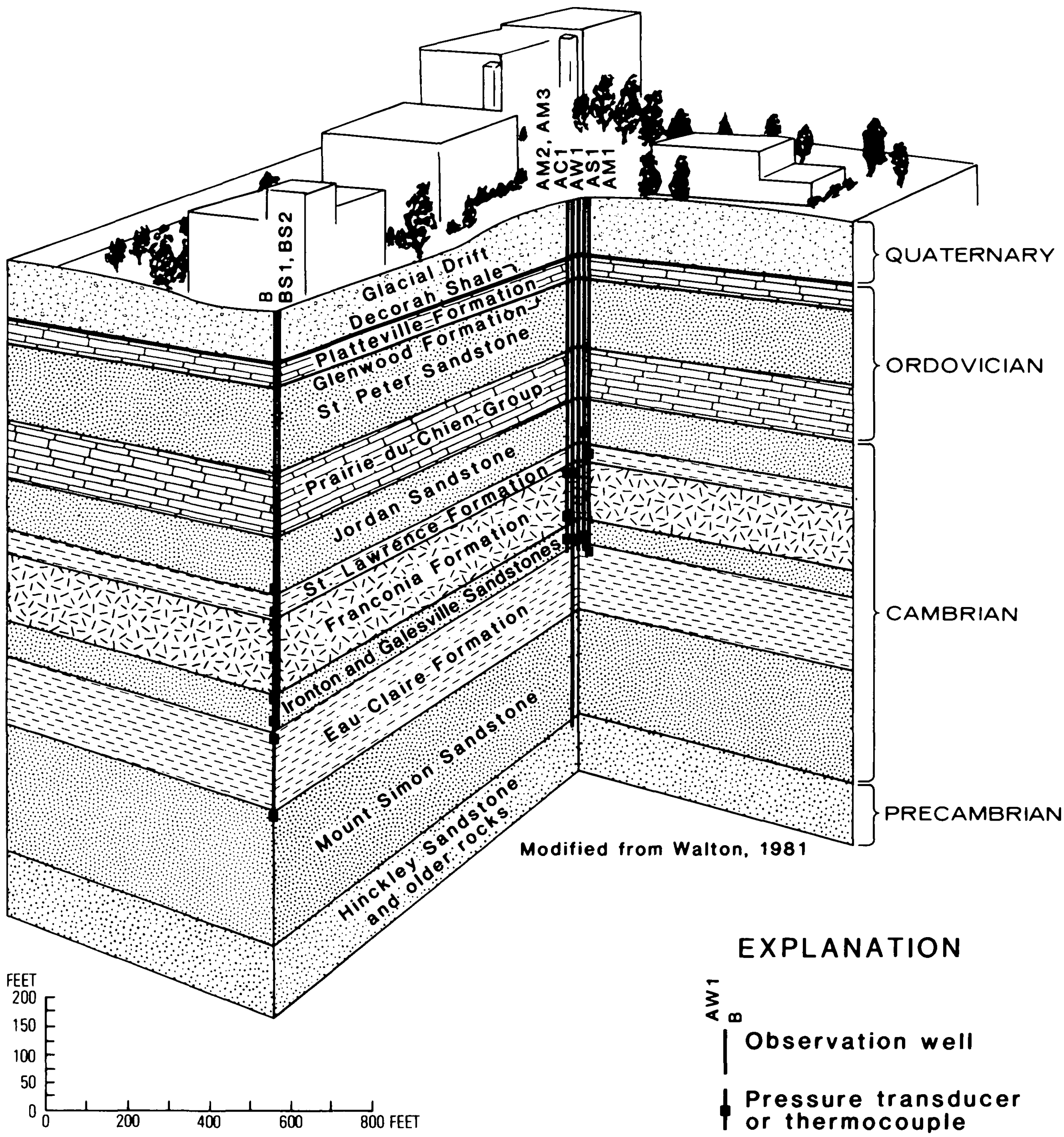
- Bemidji, Minnesota: Contamination from an oil spill;
- Cape Cod, Massachusetts: Contamination from sewage;
- Pensacola, Florida: Contamination associated with the manufacture of wood preservatives; and
- Trenton-Philadelphia-Camden corridor, New Jersey–Pennsylvania: Contamination from industrial solvents and petroleum byproducts.

Aquifer Thermal Energy Storage

In May 1980, the University of Minnesota and the U.S. Geological Survey began a project to evaluate the storage of high-temperature water in the deep Franconia-Ironton-Galesville sandstone aquifer (hereafter called "the aquifer") and later recovering the hot water for space heating. High-temperature water (302°F.) generated during the cooling of the University's electrical generation facilities will supply heat for storage at about 800 feet below the surface. Figure 1 shows the Aquifer Thermal Energy Storage (ATES) system which uses two wells 860 feet apart. Water is pumped from one of the wells in the aquifer through a heat exchanger where heat is added or removed. The water is then returned to the aquifer through the other well. Experimental testing of the ATES system consists of a series of hot-water injection, storage, and withdrawal cycles. Each cycle is 24 days long, and each injection, storage, and withdrawal step of the cycle takes 8 days.

The U.S. Geological Survey designed the data-collection network, collected and analyzed the data to describe the hydrologic properties of the aquifer, and con-

Figure 1.—Block diagram of the Aquifer Thermal Energy Storage site, University of Minnesota, St. Paul.



structed a ground-water-flow and thermal-energy-transport model for evaluating the efficiency of the ATES system.

A comprehensive network for data collection, data storage, and data reduction has been designed to monitor temperature and pressure changes during the ATES test cycles.

Temperature and pressure measurements are combined in observation-well tests at approximate distances of either 20 or 40 feet away from the production wells (fig. 1). All pressure and temperature data are transmitted from the observation wells by way of buried cables to a central data logger where measurements are viewed independently or stored on computer magnetic tape for later analysis.

Two computer models have been constructed to simulate the movement of ground water and heat. The computer code for the models, developed under contract to the Geological Survey, has been used for calculating the effects of liquid-waste disposal in deep saline aquifers. The code has been successfully used to model storage of warm (130°F.) water in a shallow unconfined aquifer in Alabama but never for high-temperature water in a deep confined aquifer, such as in Minnesota.

Application of the calibrated model will consist of simulating various combinations of heat injection, storage, and withdrawal periods and various pumping-injection rates and analyzing the effects of the combinations on efficiency of the ATES system. One measure of system efficiency is the ratio of heat recovered to heat injected, which can be expressed as a percentage. The higher the percentage, the more efficient the ATES system.

Preliminary model simulations indicate that, under the condition of injecting 300°F. water for five 1-year cycles, the least-efficient operation would be injection of hot water for 8 months and withdrawal of hot water for 4 months; both periods have the same injection-withdrawal rate of 300 gallons per minute. This operation would be only 39-percent efficient at the end of the 5-year period.

The most efficient operation that has been simulated describes injection and withdrawal of hot water for equal 6-month periods but with a withdrawal rate of 600 gallons per minute, which is twice the injection rate of 300 gallons per minute. Under these conditions, 84 percent of the stored thermal energy would be removed at the end of 5 years.

Although it may appear that the best operation of the ATES system is the one that is most efficient in terms of heat recovered, other analyses indicate that the most efficient operation may not be the most economical. The economic efficiency of the ATES system is a function of the minimum temperature requirements for use of recovered water.

Preliminary models indicate that, under conditions of injecting 300°F. water with a minimum withdrawal temperature requirement of 110°F., the maximum system efficiency at the end of five 1-year cycles would be 84 percent, based on 6-month injection and withdrawal periods with a withdrawal rate of 600 gallons per minute and an injection rate of 300 gallons per minute. If the minimum withdrawal temperature required is 140°F., the maximum system efficiency at the end of five 1-year cycles would be 61 percent based on 8 months of injection and 4 months of withdrawal, again with a withdrawal rate of 600 gallons per minute and an injection rate of 300 gallons per minute.

The model simulations are encouraging and indicate that the ATES system is a viable means for conserving a valuable resource that presently is being wasted.

Regional Ground-Water Flow in the Floridan Aquifer System

The Floridan aquifer system is one of the major sources of ground-water supplies in the United States. This highly productive aquifer system underlies all of Florida, southeastern Georgia, and small parts of adjoining Alabama and South Carolina, for a total area of about 100,000 square miles. A total of about 3 billion gallons of water per day is withdrawn from the aquifer, and, in many areas, the Floridan is the sole source of fresh water.

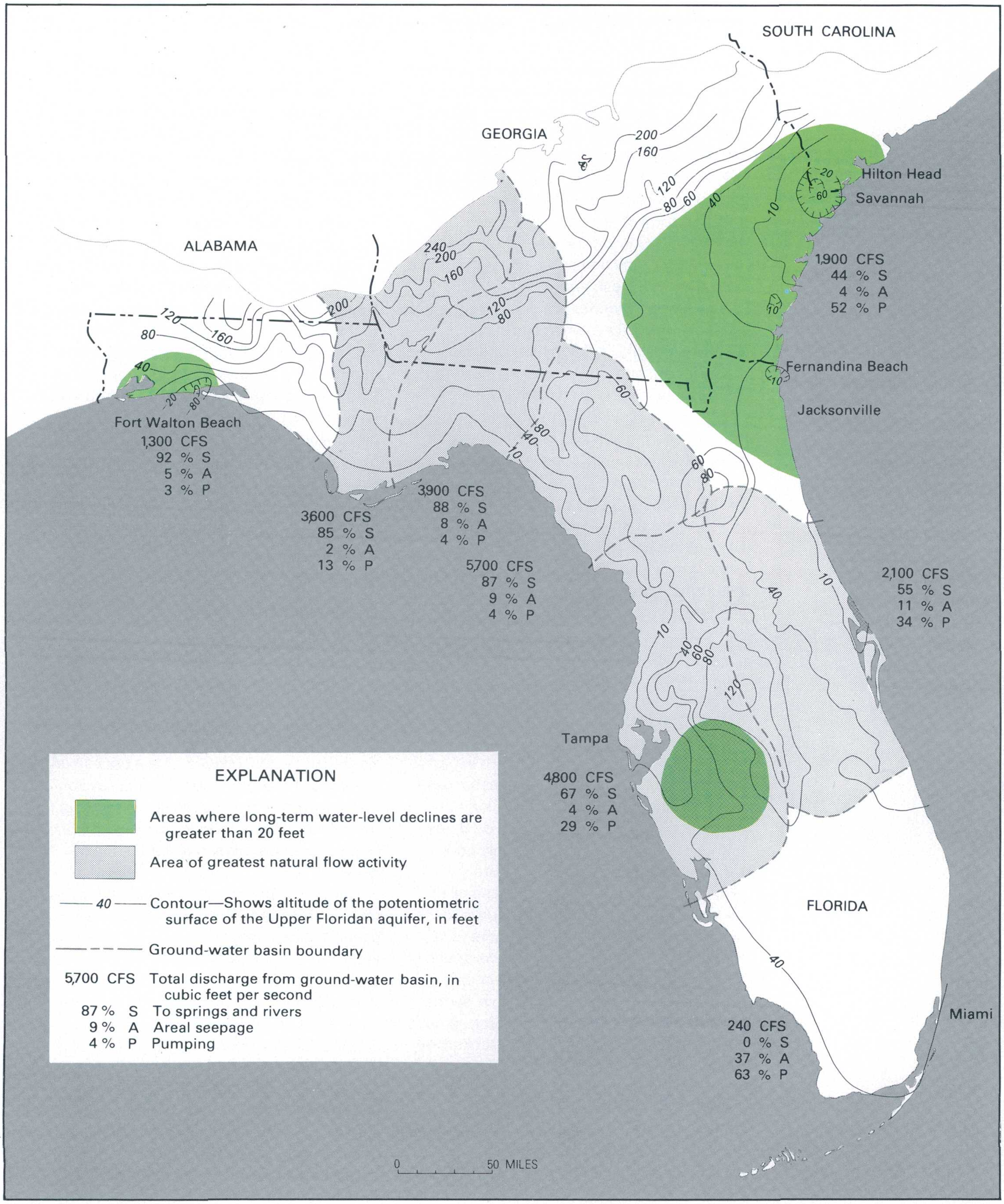
The Floridan aquifer provides public water supplies for many cities including Daytona Beach, Jacksonville, Orlando, Tallahassee, and St. Petersburg in Florida and Brunswick and Savannah in Georgia. The amount of water withdrawn for irrigation and industrial use is greater than that withdrawn for public supply. Although pumping of ground water has caused extensive local declines of ground-water levels, more than one-half the aquifer area has not yet had significant declines in water levels. Despite the enormous amount of untapped water in the Floridan, the water ia not always locally available for use.

This aquifer system is a sequence of hydraulically connected carbonate rocks (principally limestone with some dolomite) that vary in thickness from a featheredge where they crop out to more than 1,500 feet where the aquifer is confined. In parts of southern Georgia and northwestern and central Florida, the rocks of the Floridan outcrop are covered by a thin layer of soil. In these areas, the Floridan usually contains one aquifer. In parts of coastal Georgia, the Florida panhandle, and all of southern Florida, the Floridan aquifer rocks are covered (or confined) by hundreds of feet of clay and sand, and, in these areas, two aquifers generally are separated by rock that has low to extremely low permeability. Most of the natural recharge, flow, and discharge occurs where the rocks crop out or where the aquifer is thinly covered. The large springs of northwest-central Florida occur in the outcrop areas.

From 1978 to 1982, the U.S. Geological Survey conducted a regional assessment of the Floridan aquifer system by studying and summarizing previous studies, collecting new data in selected areas, and using computers to model and simulate ground-water flow. The Floridan study was one of 15 comprising the Survey's Regional Aquifer Systems Analysis Program, which is commonly known as the RASA program. In the early 1930's, Victor Stringfield, a Survey geologist, published a Water-Supply Paper, *Artesian Water in the Florida Peninsula*. In it, he identified for the first time a regional flow system in the carbonate rocks of Florida. His potentiometric surface map of the Floridan aquifer showed the natural recharge areas (intakes to the aquifer), discharge areas (outlets), and the general direction of ground-water movement from the recharge to discharge areas. A major potential recharge area was shown in central Florida. Major discharge areas were shown in the coastal areas of Florida and Georgia.

In the early 1940's, Stringfield, H. H. Cooper, and M. A. Warren documented a widespread decline of water levels, or artesian pressure, along the Georgia-northeastern Florida coast. The areal decline was caused by large ground-water withdrawals from the Floridan aquifer at the coastal cities of Savannah and Brunswick, Georgia, and Fernandina Beach and Jacksonville, Florida. Pumping, which began in the late 1800's, caused "cones of depression" to form in the potentiometric surface around these cities. However, by the 1940's, these cones had coalesced to form a troughlike depression (in the potentiometric surface) extending from Jacksonville, Florida, to near Hilton Head, South Carolina, a distance of 150 miles.

Since this early work of Stringfield, other maps of the potentiometric surface have been prepared. However, to do a rigorous analysis of the flow system, an aquifer-wide map based on simultaneous measurements throughout the four-State area was needed. To meet this need, the Survey, during a 12-day period in May 1980, measured the depth to water level, or artesian pressure, in more than 2,700 wells tapping the upper Floridan aquifer. The resulting potentiometric-surface map, as prepared by R. H. Johnston and several coworkers, is shown in the accompanying illustration. Most of the major features of the regional flow system can be demonstrated from this map; for example, con-



Regional ground-water flow in the Floridan aquifer; Johnston and Bush, 1982

Ground-water levels in the upper Floridan aquifer in 1980; also shown is the ground-water discharge (natural and pumping) in 1980.

tour lines that are distorted or uneven indicate appreciable discharge to springs and rivers and are characteristic of areas such as northwest-central Florida where the aquifer is at or close to land surface, and relatively smooth contour lines are characteristic of areas such as southern Florida and indicate that the aquifer is more deeply buried and thus is insulated from surface stresses.

The change in the potentiometric surface caused by pumping depends on the rate and duration of the pumping and the hydrogeologic setting. Regional long-term declines in water levels greater than 20 feet are shown on the illustration (stippled areas). As of 1980, about 640 million gallons per day, mostly for industrial use, were being withdrawn from the coastal strip of southeastern Georgia–northeastern Florida. As a result, the troughlike depression of the 1940's in coastal Georgia and northeastern Florida has spread inland to become the largest area of significant water-level change in the Floridan aquifer system. Although this water-level depression is relatively shallow, it is widespread because the permeable limestone is overlain by several hundred feet of clay that slows down the recharge rate. Thus, the area over which the recharge occurs must be large.

In west-central Florida, about 900 million gallons a day is pumped from the Floridan aquifer. The phosphate industry and irrigation account for the major part of that pumpage. As a result, a regional depression exists in the potentiometric surface southeast of Tampa. Although the pumping rate is greater in the west-central area of Florida than it is in the area of southeastern Georgia–northeastern Florida, the area of influence is smaller because the thin layers of sand and clay overlaying the Floridan aquifer permit the aquifer to be readily recharged.

In the Fort Walton Beach area of panhandle Florida, pumping of about 15 million gallons per day has caused a regional depression in the potentiometric surface. This relatively low pumping rate has caused a regional depression because, in this area, the ability of the Floridan aquifer to transmit water to the center of pumping is about 100 times less than that in west-central Florida or in southeastern Georgia–northeastern Florida. Steep cones of depression in water levels due to pumping are characteristic in areas where an aquifer's ability to transmit water is low.

To estimate rates of recharge and discharge and to determine how these rates are affected by various pumping conditions, a computer simulation of the Floridan's flow system was developed by bringing together everything that was known about the Floridan's hydraulics and hydrogeology. This computer simulation of the regional flow system showed that before ground-water development began about 21,000 cubic feet per second were discharged from the Floridan aquifer. Of that amount, about 19,000 cubic feet per second, or 90 percent of the discharge, flowed to springs or discharged to rivers. The remainder discharged as areal seepage in coastal areas. Because discharge from the flow system balanced recharge to the system, simulated predevelopment recharge was also about 21,000 cubic feet per second. The average predevelopment recharge rate was about 4 inches per year over the area where recharge occurred, and the average predevelopment rate of areal seepage was about 0.6 inch per year over the area where areal seepage occurred.

As previously mentioned, most of the natural flow (large-discharge springs and highest rates of recharge) is in areas where the aquifer is at or close to land surface (areas shown by hatch marks on the accompanying map). Only about 13 percent of the regional predevelopment discharge occurred where the aquifer is hundreds of feet below the land surface, although that part of the aquifer system includes about 50 percent of the total area of the aquifer.

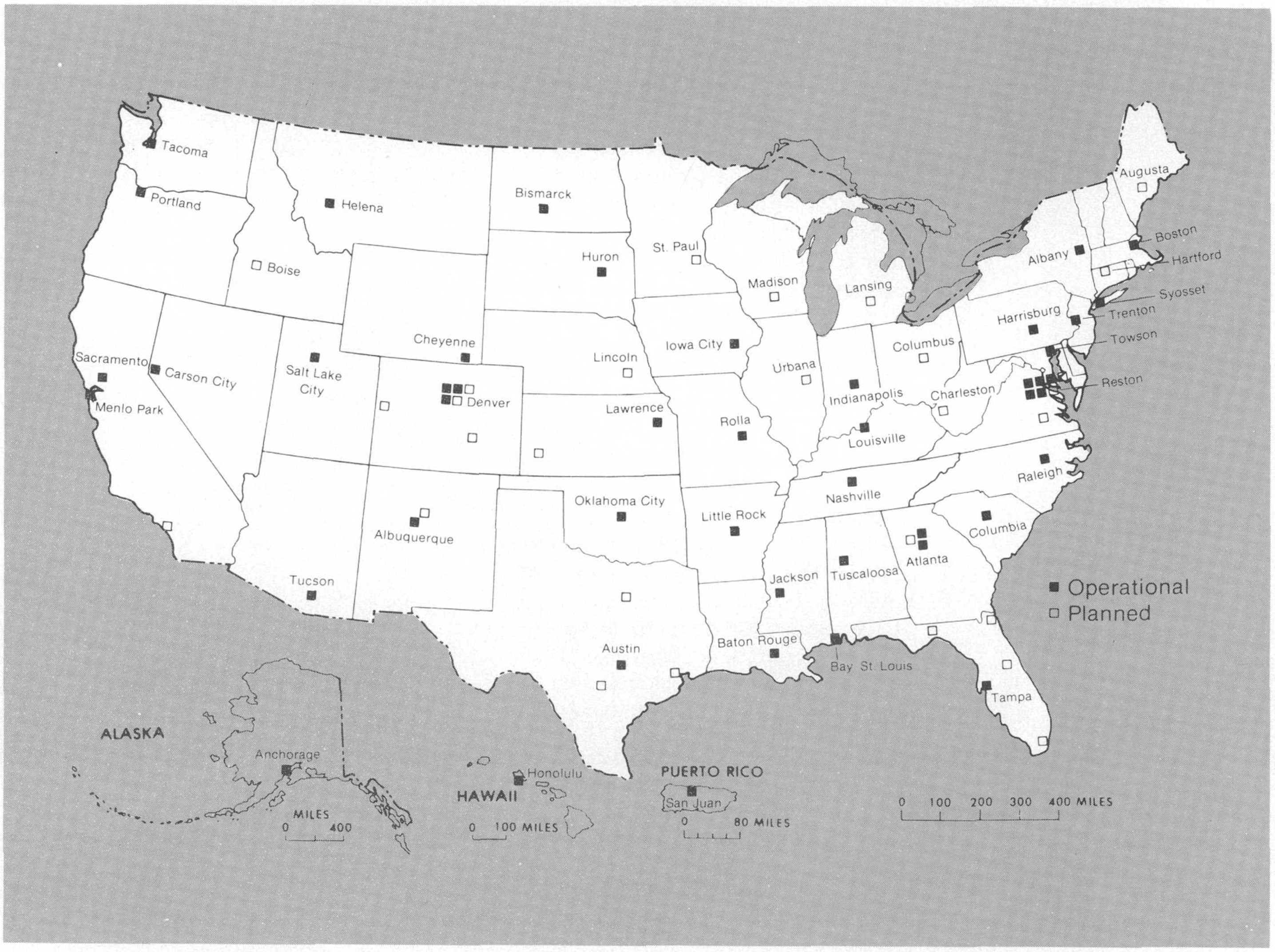
Of today's total Floridan aquifer discharge of about 23,500 cubic feet per second, about 75 percent is discharge to springs and rivers, 7 percent is areal seepage, and 18 percent is pumpage. Ground-water development has reduced spring flow and discharge to rivers by less than 5 percent, and discharge by areal seepage in coastal areas has been reduced by about 30 percent. Of the amount pumped, about 20 percent is salvaged from spring flow and discharge to rivers, and 20 percent is from reduced areal seepage in coastal areas. The remaining 60 percent of the pumpage is from additional recharge that is induced bacause pumping has lowered water levels in the aquifer.

Today's average recharge rate is about 4 inches per year, and the average rate of areal seepage over the discharge areas is about 0.5 inch per year. These averages are virtually unchanged from predevelopment values because ground-water development has enlarged the area over which recharge occurs and has shrunk the area where loss by areal seepage occurs.

In summary, the major part of the flow system today is largely unchanged from predevelopment conditions. Large-discharge springs are still the dominant feature of the system. Although pumping has caused recharge rates to increase locally, the greatest recharge still occurs near the springs. Even after development, ground-water flow remains sluggish in areas where the aquifer is deeply buried relative to flow in areas where the aquifer is close to the land surface.

Similar ground-water studies are being conducted by the Water Resources Division of the U.S. Geological Survey within its Regional Aquifer System Analysis Program. They are as follows:

- Alluvial Basins: In parts of Nevada and Utah;
- Atlantic Coastal Plain: In parts of New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and North Carolina;
- Central Midwest: In parts of Arkansas, Colorado, Kansas, Missouri, Nebraska, New Mexico, Oklahoma, South Dakota, and Texas;
- Central Valley: In California;
- Columbia Plateau: In parts of Washington, Oregon, and Idaho;
- High Plains: In parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming;
- Northeast Glacial Valleys: In the New England States, New York, and the glaciated parts of New Jersey, Pennsylvania, and northeastern Ohio;
- Northern Great Plains: In parts of Montana, North and South Dakota, and Wyoming;
- Northern Midwest: In parts of Illinois, Iowa, Minnesota, Missouri, and Wisconsin;
- Oahu, Hawaii;
- Snake River Plain: In part of Idaho;
- Southeastern Carbonates: In Florida and parts of Georgia, Alabama and South Carolina;
- Southeastern Coastal Plain: In parts of South Carolina, Georgia, Alabama, and Mississippi;
- Southwest Alluvial Basins: In parts of Arizona, New Mexico, Colorado, and Texas;
- Upper Colorado: In parts of Colorado, Utah, New Mexico, and Wyoming; and
- West Gulf Coastal Plain: In parts of Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Missouri, Tennessee, and Texas.



The Distributed Information System

Location of offices of the U.S. Geological Survey's Water Resources Division where the Distributed Information System computer network for hydrology is operational or planned. Connected to each other via telecommunications, the network provides state-of-the-art technology to Survey scientists working on water-resources investigations.

The Water Resources Division of the U.S. Geological Survey is installing a nationwide network of 75 minicomputers to support research, hydrologic simulations, the national hydrologic data base, and management activities. Applications programs and proprietary software for computer graphics, data base management, statistical analysis, and data entry are installed on every system. These minicomputers are located in each District and Regional Office, in many project and subdistrict offices, and in the Reston, Virginia, headquarters. A state-of-the-art data communications network, which connects more than 1,000 terminals with the minicomputers, provides excellent support for Geological Survey scientists and cooperating State and local agencies in every State.

International Activities

Mission

Although the primary responsibility of the U.S. Geological Survey is to conduct investigations within the limits of the United States and its territories, international activities have been an important component of U.S. Geological Survey operations for more than four decades. Such activities have included technical assistance to other countries and international organizations, scientific cooperation with earth resources agencies abroad, exchange of scientists and training of participants, representation of the Survey or the U.S. Government in international commissions and associations, and assessment of mineral and energy resources of foreign countries. During l983, the Survey was involved in a wide range of activities in each of these categories.

In undertaking international activities, the Survey has four principal objectives:

- To help achieve domestic research objectives through the comparative study of scientific phenomena abroad and in the United States.
- To contribute toward foreign policy objectives and to provide support for the international programs of other Federal agencies.
- To obtain information about existing and potential foreign resources of interest to the United States.
- To develop and maintain contacts with counterpart institutions and programs to facilitate scientific cooperation and exchange.

Major Programs and Activities

During 1983, Survey technical assistance was extended to 25 nations under bilateral assistance programs and to several regional or worldwide organizations (see table).

International scientific activities conducted by the U.S. Geological Survey in 1983, listed by country or region

Technical Assistance Activities	
Bangladesh	Mineral resources exploration; modernization of Bangladesh Geological Survey.
Brazil	Natural gas utilization studies.
Costa Rica	Coal resources project development.
Egypt	Technology transfer and manpower development; remote sensing.
El Salvador	Earthquake hazards reduction.
Guatemala	Do.
Indonesia	Land use; hazards mitigation; volcanic research; coal and mineral resources assessment.
Jordan	Seismic systems; ground water resources; geothermal resources.
Kenya	Regional remote sensing facility; landsat imagery.
Malawi	Project development in coal laboratories and stratigraphic-geophysical studies.
Morocco	Landsat image base-map compilation.
Pakistan	Coal resources project development.
Panama	Earthquake hazards reduction.
Paraguay	Hydrologic hazards related to floods.
Peru	Mineral resources assessment; flood hazards in Cuzco.
Philippines	Coal and mineral resources project development; publications assistance.
Portugal	Geothermal resources; seismic hazards-San Miguel Island, Azores.
Romania	Earthquake detection equipment.
Saudi Arabia	Geologic mapping and mineral resource assessment; hydrologic studies.
Somalia	Institutional development; mineral resources surveys.
Syria	Remote sensing.

International scientific activities conducted by the U.S. Geological Survey in 1983, listed by country or region—**Continued**

Technical Assistance Activities	
Thailand	Remote sensing; oil shale and lignite research; geologic workshops and natural gas symposium.
Tunisia	Remote sensing; Landsat mosaic compilation.
Venezuela	Hydrology and water resources of Orinoco Basin.
Yemen	Earthquake investigations.
East Africa	Remote sensing for cartographic and geologic applications.
Latin America	Earthquake disaster mitigation in Andean region.
Southeast Asia	Earthquake engineering and hazards mitigation; engineering seismology and geology; phosphate research.
Worldwide	Global seismic network; geologic and hydrologic training programs; conventional energy resources identifications.

Scientific Cooperative Activities	
Antarctica	Topographic mapping.
Australia	Lacustrine geologic studies; isotopic analyses.
Bolivia	Tin resources surveys.
Brazil	Mineral and energy resources assessments; river sediment studies.
Canada	Strategic minerals inventory; sea-floor mineral exploration; borehole geophysics.
Chile	Aeromagnetic surveys.
Colombia	Mineral resources assessment; geochemical data processing.
Dominican Republic	Geothermal resources assessment; offshore shelf studies.
France	Remote sensing; marine geology.
Germany	Strategic minerals inventory; marine seismic studies of continental margins.
Hungary	Seismic stratigraphy, reflection seismic, electromagnetic, mineralogic, paleomagnetic and paleoenvironmental studies.
Iceland	Volcano and geothermal studies.
Japan	Joint panels on earthquake prediction, marine geology, and marine mining.
Mexico	Volcano and geothermal studies; geochemical and geophysical exploration; mineral and metallogenic map analyses; regional structure and stratigraphic studies; tectonostratigraphic terrane studies.
Oman	Sulfide deposit studies.
Pakistan	Isotopic study of zircon.
People's Republic of China	Earthquake studies; remote sensing; coal basin studies; petroleum geology of carbonate rocks; circum-Pacific geologic and tectonic framework; karst genesis and classification; surface-water hydrology.
Peru	Landslide hazards-Tablachaca Dam.
South Africa	Strategic minerals inventory.
South Korea	Offshore petroleum resources and geothermal resources assessments.
Sweden	Nuclear waste disposal.
United Kingdom	Coal resources and environmental studies.
U.S.S.R	Joint committee on earthquake prediction.
Yugoslavia	Crustal structure research; seismic studies; subsidence research; geochemical surveys.
Pacific region	South Pacific cruise; hydrocarbon resources studies; oceanic crusts studies; chromite resources.
Southeast-East Asia	Sea-floor geologic mapping; petroleum geology research.
Worldwide	International Strategic Mineral Inventory; The World Energy Resources Program.

The largest assistance programs were with the Saudi Arabian Ministry of Petroleum and Mineral Resources (regional geologic mapping, mineral surveys, and institutional development) and with the Saudi Arabian Ministry of Agriculture and Water (surface and ground water hydrology), both financed by the Kingdom of Saudi Arabia. Assistance to several countries involved coal resource assessments and earthquake hazard mitigations, each sponsored for the large part by the Agency for International Development.

Scientific cooperation is conducted under cooperative agreements with counterpart organizations in other countries to help achieve common research objectives and to support foreign policy of the United States. The financing for such cooperative activities is jointly from funds appropriated for Survey research and funds or other financial resources made available by the cooperating country or organization. During 1983, such cooperation was carried out with 24 countries and several regional organizations (see table). The largest bilateral cooperative efforts, in terms of the numbers of scientists involved, were in Antarctica (sponsored by the National Science Foundation), China, Colombia, and Mexico. Another major undertaking was the hydrocarbon resources study in the Southwest Pacific in cooperation with Australia, New Zealand, and other countries of that region, sponsored in part by the Agency for International Development. The Survey continued to coordinate the preparation of maps under the Circum-Pacific Map Project on behalf of the Circum-Pacific Council for Energy and Mineral Resources, which now involves about 35 countries.

Exchange of scientists and training of participants are two activities that are performed by the Survey to support bilateral scientific cooperation and technical assistance programs. The reciprocal exchanges provide the opportunities for global consulation and study by scientists of many countries and those of the U.S. Geological Survey. Training of participants is scheduled or arranged under foreign assistance programs using funds transferred to the Survey. Seventy-seven research scientists from 23 countries spent a total of 290 man-months at Survey facilities in 1983, studying or consulting on most all subjects of which the Survey has expertise. Arrangments often include training at other institutions, such as colleges and universities and private companies. The Survey conducted five training courses for foreign participants in 1983: Hydrologic Techniques, Advanced Remote Sensing Applications, Principles of Data Processing, and two International Remote Sensing workshops. Approximately 60 participants attended these courses.

In 1983, as many as 100 Survey employees represented the United States in meetings of international organizations and commissions and served on councils and committees of scientific commissions and international scientific unions.

The Geological Survey has frequently been called upon for information about known and potential resources abroad. To provide such information, the Survey has gradually broadened the scope of its efforts to collect and evaluate such information in cooperation with other agencies and countries. During 1983, cooperation was continued with the Department of State and the Bureau of Mines in the Resources Attache Program whereby reporting officers are stationed in selected U.S. embassies abroad to assemble data on resources indigenous to the country or region. A world energy resources assessment program also was continued, resulting in new provisional estimates of oil and gas resources worldwide. The Geological Survey cooperated with the Bureau of Mines and with mineral resource agencies of Canada, the Federal Republic of Germany, South Africa, and Australia to conduct an international strategic minerals inventory, which focused on the compilation of data for chromium, cobalt, manganese, phosphate, platinum, tin, titanium, nickel, and rare earths worldwide.

Authority and Coordination

Authority and responsibility for Survey international activities derive in part from specific legislation and in part from agreements to permit the achievement of mandated research objectives. Technical assistance and partipant training are provided on behalf of the Department of State, the Agency for International Development, and the Trade Development Program as authorized under the Foreign Assistance Act. International scientific cooperation is authorized by the Secretary of Interior to supplement domestic research objectives and to provide expertise for reimbursable programs commited by other agencies or requested by other countries. Exchange of scientists is commonly arranged on behalf of the International Communications Agency. Representational activities are carried out either on behalf of the Department of State or as an extension of scientific cooperation. Assessments of mineral and energy resources in other countries are partly in response to commitments of the Survey and partly to support programs of other Federal agencies.

All Divisions of the Survey participate in international programs. Projects are staffed on a rotational basis by personnel from domestic operations. Each Division has a designated representative or office for its international activities, and overall coordination is maintained through the International Activities Committee, which serves under the Executive Committee. The Office of International Geology in the Geologic Division provides logistical and administrative support for all Survey international activities, but technical management of each project is exercised by the appropriate Division.

Highlights

Saudi Arabia

In 1983, the agreement between the Ministry of Petroleum and Mineral Resources of Saudi Arabia and the Geological Survey was extended for another 2-year period, the seventh such extension for the program. Geologic mapping at a scale of 1:100,000, now complete in the southern part of the Arabian Shield, has been extended northward. Geologic maps are being recompiled at scale of 1:250,000 (1.5° × 1° quadrangle) for multicolor publication by the Ministry with the ultimate goal to show the geology of the entire Arabian Shield in this format. Resource evaluations applying mineralogy, geochemistry, geochronology, and isotope dating continued for a variety of mineral prospects in shield rocks and Cenozoic volcanics. Detailed studies on gold were conducted at the Mahd adh Dhahab mine, which was reactivated this year.

During the past several years, the Survey produced geodetically controlled duotone Landsat image mosaics at scales of 1:250,000 and 1:500,000 as bases for compilation of geographic and geologic maps (fig. 1). A new series of four-color image maps is in the process of being developed; two quadrangles at a scale of 1:500,000 will be printed this year, and experimental printing of four-color image maps at a scale of 1:250,000 will be done in 1984. The program to prepare topographic maps in the vicinity of Jiddah at a scale of 1:25,000 was completed in June 1983; the 14 maps in the series will be printed by the Geological Survey in December.

Under the agreement with the Ministry of Agriculture and Water, the Survey has emphasized studies in the occurrence and quality of ground and surface water. Compilation is proceeding on a comprehensive atlas of water resources, including the history of water development.

Indonesia

The Survey's program of technical assistance to Indonesia, principally in the mitigation of geologic hazards, under auspices of the Agency for International Development, was terminated in 1983 after 4.5 years during which 30 scientists on short-term consultancies completed 14 man-years of studies at a cost of about $2.4 million. In 1983, 15 consultants conducted 50 man-months of research on hazards associated with the volcanoes of Java and Sumatra. The program culminates this year with Survey representation at the Krakatau symposium commemorating the 100th anniversary of that major volcanic eruption.

Venezuela

The Survey is assisting the Venezuelan Ministry of Environmental and Renewable Natural Resources on the implementation of stream gaging and water-quality sampling programs for the Orinoco river and its tributaries. Too little is known at this time about the varied flow and sediment-discharge characteristics of this major river to allow Venezuela to plan effectively for future hydroelectric and navigation development. The proposed techniques of study are those developed by the Geological Survey for other large rivers, such as the Mississippi and the Amazon.

Morocco

The Survey, in cooperation with the Defense Mapping Agency, is preparing 13

Landsat multispectral (bands 4, 5, 7) image maps at the scale of 1:250,000 which will provide base maps for an area in Morocco and Western Sahara that is largely unmapped. The coverage will be extremely useful to Morocco in geologic investigations, energy and mineral exploration, and natural resource programs. The maps will be printed in the conventional color-infrared image format.

People's Republic of China

Under the Earth Sciences Protocol signed in 1980 between the Chinese Ministry of Geology and Mineral Resources and the U.S. Geological Survey, some 20 projects have now been defined covering a wide variety of geoscience subjects. In May 1983, the Director, Chief Geologist, and eight other scientific administrators visited China to gain an understanding of the scope and nature of activities in the Chinese geoscience community.

During this year, exchange studies involved 35 Geological Survey scientists on five projects. Remote sensing techniques involving study of the regional structure, surface and subsurface stratigraphy and sedimentology, and evolutionary history were applied to petroleum exploration in the Qaidam (Chaidamu) Basin in China and the Uinta Basin in Utah. This computer-processed Landsat data was compared to geology in the field for selected areas. Identification of the coal-forming environments and the application of computer-based data systems for exploration and assessment of coal resources were the important objectives of a project that in-

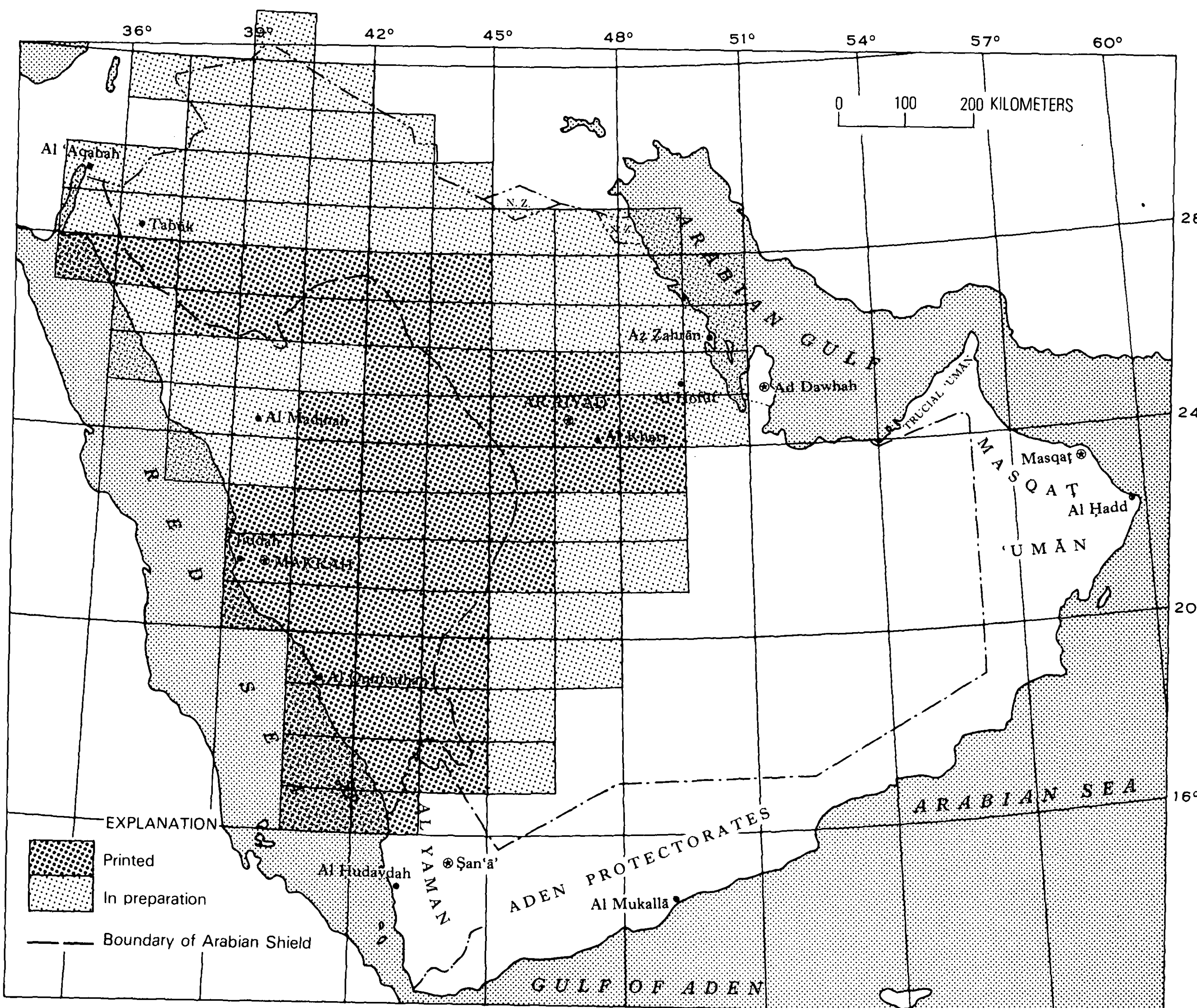


Figure 1.—*Status of 1:250,000-scale Landsat image maps in Saudi Arabia.*

volved comprehensive studies in one or two selected coal basins in each country. The petroleum geology of carbonate rocks was studied in reef sequences of the Permian Basin of western Texas and the Nanpanjiang Basin in southern China, emphasizing types and distribution of sedimentary facies, diagenesis, and hydrocarbon generation and migration. Geologic and tectonic framework studies compared key structural characteristics and tectonic evolutionary history of Meso-Cenozoic time in selected areas of eastern China and the Western United States. Genesis, classification, and distribution of karst is being defined as a future research effort.

South Pacific

Australia, New Zealand, and the United States are cooperating on a program of marine geoscientific research in the South Pacific region in association with, and under coordination by, the United Nations Committee for the Coordination of Joint Prospecting for Mineral Resources in the South Pacific Offshore Areas. The Survey ship, R/V *Samuel P. Lee*, made a three-leg cruise during April, May, and June 1982 in the offshore waters of the Kingdom of Tonga, Vanuatu, and the Solomon Islands to collect scientific data on the geology amenable to hydrocarbon resources (fig. 2). Interpretation of these data during 1983 resulted in the delineation of several sedimentary platforms or basins and defined several significant stratigraphic and structural features capable of trapping oil and gas. A preliminary evaluation of the petroleum potential of this region will be made after an examination of the results of laboratory analyses of samples and a detailed interpretation of the multichannel seismic reflection profiles. A comprehensive evaluation will be made following interpretation of additional data to be collected on a 1984 cruise of the *Lee* in the same waters.

Circum-Pacific Map Project

Innovative approaches are used to relate the known energy and mineral resources to major geologic features of the Pacific basin under a cooperative effort by participating geoscientists from 35 countries. This effort, the Circum-Pacific Map Project, is an activity of the Circum-Pacific Council for Energy and Mineral Resources; project coordination and cartography are the responsibility of U.S. Geological Survey, and the maps are published by the American Association of Petroleum Geologists. Data are compiled by the appropriate panel representatives on five 1:10,000,000-scale equal-area maps, four of which

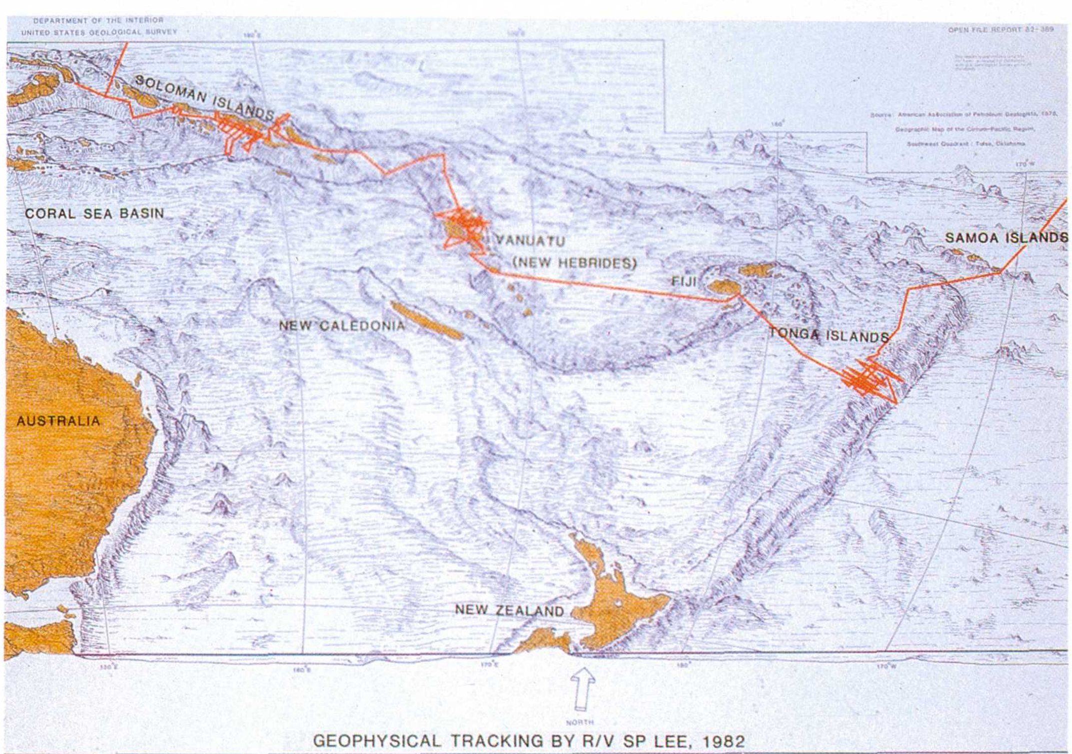


Figure 2. *— Scientific cruise of R/V* Samuel P. Lee.

represent quadrants of the Pacific, and the other, Antarctica. Twenty-one of 47 planned maps have been published since the project began 11 years ago. During 1983, activities centered on the completion of the first three map series, Plate Tectonics, Geologic, and Mineral Resources; publication of the next two map series, Energy Resources and Geodynamics, will commence in 1984.

Antarctica

The Survey, in cooperation with the National Science Foundation, compiles and publishes base maps of selected areas in Antarctica in support of the scientific research projects of the United States Antarctic Research Program. Maps of Antarctica are subdivisions of the International Map of the World system and use symbols approved by the Scientific Committee on Antarctica Research. Available maps include topography at a scale 1:50,000; shaded relief at scales of 1:250,000 and 1:500,000, some of which cover coastal areas of Wilkes Land and Enderby Land; base maps at a scale of 1:1,000,000 produced in accordance with specifications of the International Map of the World; sketch maps with shaded relief at a scale of 1:500,000; and Landsat satellite image maps at scales of 1:500,000 and 1:1,000,000.

In 1982–83, for the 25th year, the National Mapping Division of the Survey again provided a field team to establish Antarctic mapping control. This team worked jointly with two cartographers from the New Zealand Department of Lands and Survey to establish horizontal and vertical control using conventional angulation and electronic distance measuring equipment as well as Navy navigation satellite doppler receivers. For the 11th consecutive year, two Survey employees wintered-over at the Amundsen-Scott South Pole station; round-the-clock overflights of U.S. Navy navigation satellites were tracked, and the seismic station, a vital link in the Worldwide Standardized Seismograph Network, was maintained. A Survey photonavigator assisted the Navy flight crews in obtaining new aerial photograph coverage over a portion of the dry valley area of Antarctica. The Geological Survey continues to maintain the U.S. Antarctic Cartographic Library, which contains international holdings of cartographic materials including aerial film, aerial photographs, and Antarctic maps.

Mexico

Survey and Mexican scientists cooperated on a number of geological mapping and mineral research projects in 1983. A hydrothermally altered zone that appears to have excellent potential for mineral deposits has been delineated in the La Purisima-San Ignacio area. A classical porphry copper-type zone of hydrothermal alteration was discovered in the vicinity of Sonora where sampling, analysis, and evaluation of the potential for production of copper continues. Copper and manganese ores near La Paz and Todos Santos may have formed in association with subaqueous basin-floor discharges of hot springs. On Magdalena Island, magnesite and malachite mineralizations were found in a metamorphased ophiolite sequence in the basement terrane. A sea floor origin analagous to the modern Red Sea geothermal system may be the model for the copper deposit in the Baja. Also in 1983, monitoring studies continued on El Chichon volcano which erupted in 1982.

Information Systems Division

Mission

The Information Systems Division provides guidance 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 Survey on all matters relating to Bureau information technology and automated data processing (ADP) services. It provides for the coordination and growth of information systems and guidelines for data standardization, data administration, and data base management. The Division is responsible for telecommunications management. It supports production systems and conducts ADP research into better ways to use technology to solve mission-related problems.

Budget and Personnel

The Information Systems Division had a budget of $22.6 million for fiscal year 1983. Other Survey Divisions and Department of Interior and Federal agency users provided funding.

As a Department of the Interior General Purpose Computer Center, the Division computing facilities were available to other Interior offices and bureaus as well as to all Survey divisions.

Division staffing consists of 168 full-time employees, primarily computer specialists, computer analysts, mathematicians, systems programmers, computer scientists, and technicians. The staff is augmented by part-time and intermittent employees who greatly assisted in fulfilling the mission of the Division. These employees served customers from the five ADP Service Center sites nationwide: National Center, Reston, Virginia, Washington, D.C., Menlo Park, California, Denver, Colorado, and Flagstaff, Arizona.

Accomplishments

Use Assistance Centers

The Information Systems Division established a user support section at each of its five ADP Service Centers to provide assistance for the full range of services supported by the sites. These services include solving user computer problems, supporting the use of proprietary software packages, analyzing user requirements for computer support, and designing and programming new systems.

Digital Private Automatic Branch Exchange

The Division is developing a Request for Proposals (RFP) to get replacement telephone systems for Reston and Menlo Park. The systems will provide touchtone service and extensive support to digitized voice and data communications. Use of the new systems should result in a significant cost savings and provide the Survey with improved voice and data communications capabilities for the next decade.

Communications Network Management Services

Developing an RFP for a nationwide network dedicated to Survey activities was a major activity this fiscal year. The new network will include a feature for linking all Survey computers as host computing resources and will provide access to these resources for all local and remote location users. The design of the network allows for expansion and will allow new technology to be installed and used throughout the entire life of the contract. This service will replace many fragmented communications facilities and will result in a unified approach to communications within the Survey. Within the next several years, this service should provide the capability to merge digitized voice and data over common communications lines resulting in significant opportunities to reduce expenses.

Tymnet Improvements

Tymnet, a nationwide communication network used by the Survey, was augmented to provide interim communications support to the Water Resources Division Distributed Information System minicomputers. The significant improvements include additional host computer connections and take advantage of the technology that was acquired with the minicomputers. Also, special Tymnet user names were established for each Division or organization to provide usage statistics that will enable the Divison to improve data communications facilities at remote Survey offices.

Large Scale Optical Disk Storage

The amount of scientific data that the Survey digitizes and stores is increasing. Laser optical disk technology provides a method to more efficiently store needed data and preserve it with a high degree of reliability and a lower storage cost. The Information Systems Division, in conjunction with the National Mapping Division, established a program to test the technology and plans to design and implement an earth science digital data library using optical disk mass storage capability.

Optimum Use of Mainframe Computer Capacity

The Division began the rearrangement of its mainframe computers to make more cost effective and efficient use of its resources. The Multics computer sites are being consolidated; the system in Menlo Park was shutdown, and the system at the National Center will be phased out in fiscal year 1984 and its workload shifted, as was Menlo Park's workload, to the Multics system in Denver.

An Amdahl V8 mainframe computer was purchased to assist in combining the Washington ADP Service Center workload with that of the National Center. The computer will replace two Itel computers at the Washington ADP Service Center and reduce operating costs.

Acquisition Support

During fiscal year 1983, the Division continued to support the other Survey Divisions in acquiring ADP resources. The efforts included requirements definition, documentation preparation, regulatory approvals acquisition, technical evaluation of proposed resources, contract administration functions, and management of the bureau ADP reutilization program.

ADP acquisition specialists were added to the staffs in Menlo Park and Denver to provide additional support to the field centers. Over 3,100 requests for equipment, software, and services with expenditures exceeding $40 million have been processed this fiscal year. Programs supported were the Water Resources Distributed Information System, Earthquake Studies, Digitized Mapping Information, administrative support functions, merging of General Purpose Computer Centers, Public Inquiries System, Marine Geology research, and office automation projects.

Increased Support for Minicomputers

The Reston ADP Service Center created the Multics-Minicomputer Technical Support Section to better serve the users of minicomputers within the Survey and installed several minicomputers belonging to other divisions. It also began to install the communications equipment required to link the nationwide network of minicomputers and mainframe computers.

Major Activities

Information Systems Division personnel provided major leadership and support for two bureauwide activities:

Information Systems Council

The Information Systems Council is made up of Division and regional policy-level representatives who meet monthly to review and recommend ADP technical policy, to coordinate ADP technology within the Survey and with the Department of Interior, and to provide guidelines for major information programs and systems of the Survey.

The Council began two studies this year: an evaluation of telecommunications in the Survey and an analysis of the current and anticipated use of mainframe computers by the Survey. The evaluation of telecommunications is significant because data and voice communications costs will become an increasingly larger component of future Survey budgets. An analysis of mainframe computer use was prompted by the rapid growth of the use of small computers throughout the Survey.

The Council also began a program to increase the ADP procurement authority of the Central Region Procurement and Contracts Section from $10,000 to $50,000 and is investigating ways to ease the acquisition and use of technology at all field sites.

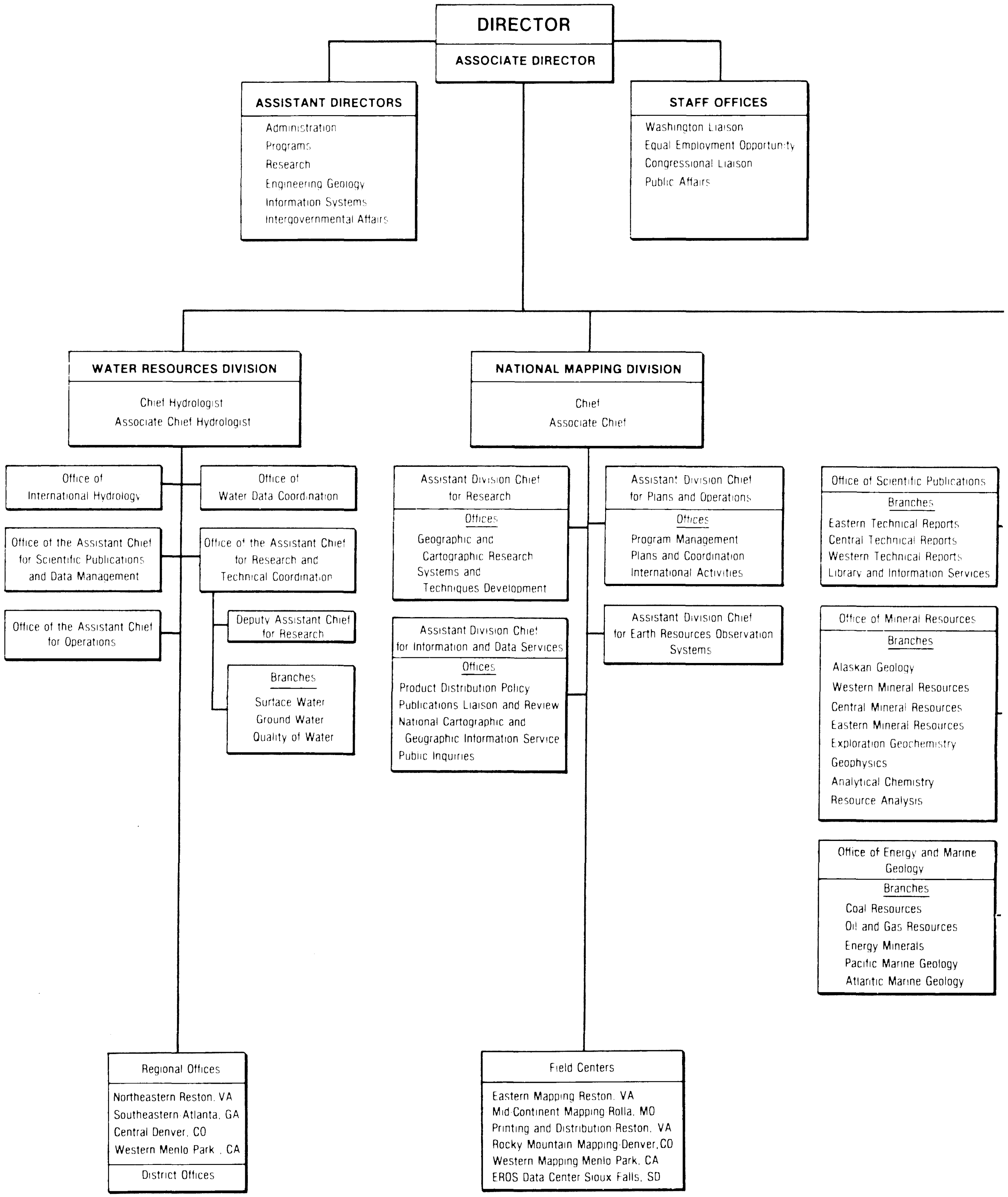
Earth Science Information Network and Centers

The Survey and the Information Systems Council established the Earth Science Information Network to improve dissemination of earth science information. The emphasis of the network is to link public access points to provide more consistent and systematic information access and delivery.

The initial focus will be on the National Cartographic Information Centers (NCIC) and the Public Inquiries Offices (PIO). The Information Systems Division provided the NCIC and PIO offices with microcomputers linked to computerized reference sources describing the Geological Survey's earth science information and products. The network provides the offices with timely news releases from the Public Affairs Office and has the capability to obtain information from non-Survey sources, where necessary, to provide coverage of a particular earth science discipline or geographic area.

The Council is considering establishing one or more Earth Science Information Centers which could provide a more technical information service for the scientific community within the Department of Interior. The centers would be staffed with scientific personnel from each of the line Divisions and would have available the complete set of reference tools being developed and implemented for the existing public access points.

Computer specialist conducts tests to verify performance of new computer system.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Assistant Division Chief for Earth Resources Observation Systems
Field Centers
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ORGANIZATION OF THE GEOLOGICAL SURVEY

U.S. Department of the Interior

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Associate Chief Geologist
Assistant Chief Geologist for Program

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Office of Regional Geology

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- Central Regional Geology
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- Isotope Geology
- Paleontology and Stratigraphy
- Astrogeology

Office of Earthquakes, Volcanoes and Engineering

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- Engineering Seismology and Geology
- Seismology
- Engineering Geology and Tectonics
- Global Seismology and Geomagnetism
- Igneous and Geothermal Processes

Assistant Chief Geologists

- Eastern Region
- Central Region
- Western Region

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Associate Chief

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- Systems Policy and Management
- Data Administration
- Acquisition Management and Support
- Operational Support Services

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- Washington, D.C.
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- Reston, VA

ADMINISTRATIVE DIVISION

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Deputy Chief

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- General Services
- Management Analysis
- Personnel
- Procurement and Contracts

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- Eastern-Reston, VA
- Central-Denver, CO
- Western-Menlo Park, CA

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Associate Chief	Roy R. Mullen	(703) 860-6232	National Center, STOP 516
Assistant Division Chief for Research	Lowell E. Starr	(703) 860-6291	National Center, STOP 519
Assistant Division Chief for Plans and Operations	Peter F. Bermel	(703) 860-6281	National Center, STOP 514
Assistant Division Chief for Information and Data Services	Gary W. North	(703) 860-7181	National Center, STOP 508
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Deputy Chief Geologist for Scientific Personnel	Penelope M. Hanshaw	(703) 860-7429	National Center, STOP 911
Policy and Budget Officer	Norman E. Gunderson	(703) 860-6544	National Center, STOP 910
Office of Scientific Publications, Chief	John M. Aaron	(703) 860-6575	National Center, STOP 904
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Office of Mineral Resources, Chief	Thomas Ovenshine	(703) 860-6561	National Center, STOP 913
Office of International Geology, Chief	John A. Reinemund	(703) 860-6418	National Center, STOP 917
Water Resources Division			
Chief Hydrologist	Philip Cohen	(703) 860-6921	National Center, STOP 409
Associate Chief Hydrologist	R. Hal Langford	(703) 860-6921	National Center, STOP 408
Assistant Chief Hydrologist, Scientific Publications and Data Management	James E. Biesecker	(703) 860-6877	National Center, STOP 440
Assistant Chief Hydrologist, Operations	Thomas J. Buchanan	(703) 860-6801	National Center, STOP 441
Assistant Chief Hydrologist, Research and Technical Coordination	Gordon D. Bennett	(703) 860-6971	National Center, STOP 414
Deputy Assistant Chief Hydrologist, Research	Roger G. Wolff	(703) 860-6971	National Center, STOP 413
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Branch of Water Information Transfer, Chief	Gary D. Cobb	(703) 860-6802	National Center, STOP 440
Branch of Ground Water, Acting Chief	Eugene G. Patten, Jr.	(703) 860-6904	National Center, STOP 411
Branch of Quality of Water, Chief	R. J. Pickering	(703) 860-6834	National Center, STOP 412

Office	Name	Telephone Number	Address
Branch of Surface Water, Chief	Marshall E. Moss	(703) 860-6837	National Center, STOP 415
Office of Water Data Coordination, Chief	Porter E. Ward	(703) 860-6931	National Center, STOP 417
Office of International Hydrology, Chief	Della Laura	(703) 860-6547	National Center, STOP 470
Office of Computer Technology, Chief	J. Ronald Jones	(703) 860-6877	National Center, STOP 440
Office of Scientific Information, Chief	John E. Moore	(703) 860-6878	National Center, STOP 440
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Information Systems Division

Chief	R. Michael Gall	(703) 860-7108	National Center, STOP 801
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Office of Acquisition Management and Support	Virginia L. Thomas	(703) 860-7242	National Center, STOP 805
Office of Program Support Services	Rollin F. Nelson	(703) 860-7103	National Center, STOP 802
Office of Operational Systems Support	James S. Bregman	(202) 343-7981	Interior Building, Room 1443

Administrative Division

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Selected Field Offices

National Mapping Division

Regional Centers

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Rocky Mountain	John D. McLaurin	(303) 234-2351	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	Charles D. Kuhler	(703) 860-6761	National Center, STOP 580

Public Inquiries Office

Alaska	Elizabeth C. Behrendt	(907) 277-0577	108 Skyline Bldg., 508 2d Ave., Anchorage, AK 99501
California:			
Los Angeles	Lucy E. Birdsall	(213) 688-2850	7638 Fed. Bldg., 300 N. Los Angeles St., Los Angeles, CA 90012
Menlo Park	Bruce S. Deam	(415) 323-8111	345 Middlefield Rd., STOP 33, Bldg. 3, Rm. 122, 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) 837-4169	169 Fed. Bldg., 1961 Stout St., Denver, CO 80294
District of Columbia	Bruce A. Hubbard	(202) 343-8073	1028 GSA Bldg., 19th and F Sts., NW., Washington, DC 20244
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

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Washington	Jean E. Flechel	(509) 456-2524	678 U.S. Courthouse, W. 920 Riverside Ave., Spokane, WA 99201

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Western	Dwight F. Canfield	(303) 234-3832	Box 25285, STOP 306, Denver Federal Center, Denver, CO 80225
Eastern	George V. DeMeglio	(703) 557-2781	1200 S. Eads St., Arlington, VA 22202

Earth Resources Observation Systems Data Center

South Dakota	Allen H. Watkins	(605) 594-7123	EROS Data Center, Sioux Falls, SD 57198

Geologic Division

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Central	Harry A. Tourtelot	(303) 234-3625	Box 25046, STOP 911, Denver Federal Center, Denver, CO 80225
Western	G. Brent Dalrymple	(415) 323-2214	345 Middlefield Rd., STOP 19, Menlo Park, CA 94025

Water Resources Division

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Central	Alfred Clebsch, Jr.	(303) 234-3661	Box 25046, STOP 406, Denver Federal Center, Denver, CO 80225
Western	John D. Bredehoeft	(415) 323-8111, ext. 2337	345 Middlefield Road, STOP 66, Menlo Park, CA 94025

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Alaska	Philip A. Emery	(907) 271-4138	733 W. 4th Ave., Suite 400, Anchorage, AK 99501
Arizona	Robert D. Mac-Nish	(602) 792-6671	Federal Bldg., 301 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	Timothy J. Durbin	(916) 484-4606	Room W-2235 Federal Bldg., 2800 Cottage Way, Sacramento, CA 95825
Colorado	James F. Blakey	(303) 234-5092	Box 25046, STOP 415, Denver Federal Center, Denver, CO 80225

Connecticut (See Massachusetts)

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District of Columbia (See Maryland)			
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Georgia	Jeffrey T. Armbruster	(404) 221-4848	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 6610, 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, 1400 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	(505) 582-5241	572 Federal Bldg., 600 Federal Pl., Louisville, KY 40202
Louisiana	Darwin D. Knochenmus	(504) 390-0281	P.O. Box 66492, 6554 Florida Blvd., Baton Rouge, LA 70896
Maine (See Massachusetts)			
Maryland	Herbert J. Freiberger	(301) 828-1535	208 Carroll Bldg., 8600 La Salle Rd., Towson, MD 21204
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	George M. Pike	(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. and U.S. Courthouse, 100 Centennial Mall, North, Lincoln, NE 68508
Nevada (See Idaho)			
New Hampshire (See Massachusetts)			
New Jersey	Donald E. Vaupel	(609) 989-2162	430 Federal Bldg., 402 E. State Street, Trenton, NJ 08608
New Mexico	James F. Daniel	(505) 766-2246	Western Bank Bldg., Rm. 720, 505 Marquette, NW., Albuquerque, NM 87102
New York	Lawrence A. Martens	(518) 472-3107	P.O. 1350, 343 U.S. Post Office and Courthouse Bldg., Albany, NY 12201
North Carolina	James F. Turner	(919) 755-4510	P.O. Box 2857, Rm. 436, Century Postal Station, Raleigh, NC 27602

Office	Name	Telephone Number	Address
North Dakota	L. Grady Moore	(701) 255-4011, ext. 601	821 East Interstate Ave., Bismarck, ND 58501
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Oklahoma	James H. Irwin	(405) 231-4256	Rm. 621, 215 Dean A. McGee Ave., Oklahoma City, OK 73102
Oregon	Edward L. Bolke (Acting)	(503) 231-2009	847 NE 19th Ave., Suite 300, Portland, OR 97232
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 (See Massachusetts)			
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. 258	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) 397-5766	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
Vermont (See Massachusetts)			
Virginia (See Maryland)			
Washington	Leslie B. Laird	(206) 593-6510	1201 Pacific Ave., Suite 600, Tacoma, WA 98402
West Virginia	David H. Appel	(304) 347-5130	3416 Federal Bldg. and U.S. Courthouse, 500 Quarrier St., E., Charleston, WV 25301
Wisconsin	Vernon W. Norman	(608) 262-2488	1815 University Ave., Madison, WI 53705
Wyoming	Richard M. Bloyd, Jr.	(307) 772-2153	P.O. Box 1125, 2120 Capital Ave., Rm. 4007, Cheyenne, WY 82003

Administrative Division

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Western	Avery W. Rogers	(415) 323-2211	345 Middlefield Rd., STOP 11, 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 1983, the Survey produced over 5,265 new and revised topographic, hydrologic, and geologic maps; printed 13,162,500 copies of 5,265 different maps; distributed 7,417,093 copies of maps; and sold 5,610,855 copies for $7,093,548. The number of reports approved for publication by the Geological Survey decreased—4,383 reports prepared in fiscal year 1983 with 63 percent designated for publication in professional journals and monographs outside the Survey with the remainder scheduled for publication by the Survey. In addition, 182,632 copies of technical reports were distributed of which 22,426 copies were sold for $129,281 and 997 open-file reports were released of which 37,204 copies were sold for $282,650.

To buy Survey book publications or to request Survey circulars, catalogs, pamphlets, and leaflets (limited quantities free), write or visit:
U.S. Geological Survey
Eastern Distribution Branch
604 S. Pickett St.
Alexandria, VA 22304

To buy maps of areas east of the Mississippi River, write or visit:
U.S. Geological Survey
Eastern Distribution Branch
1200 S. Eads St.
Arlington, VA 22202

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Western Distribution Branch
Box 25286, Bldg. 41, Federal Center
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 obtain information on the availability of microfiche or paper-duplicate copies of open-file reports, write:
U.S. Geological Survey
Open-File Services Section
Box 25425, Federal Center
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
Mailing List Unit
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 or reports and maps, visit the U.S. Geological Survey Public Inquiries Offices at the following addresses:

Alaska:
108 Skyline Bldg.
508 2d Avenue
Anchorage, AK 99501

California:
7638 Federal Bldg.
300 N. Los Angeles St.
Los Angeles, CA 99012

122 Bldg. 3
345 Middlefield Rd.
Menlo Park, CA 94025

504 Customhouse
555 Battery St.
San Francisco, CA 94111

Colorado:
169 Federal Bldg.
1961 Stout St.
Denver, CO 80294

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1100 Commerce St.
Dallas, TX 75242

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

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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.
19th and F Sts., N.W.
Washington, DC 20244

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

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.
Reston, VA 22092

To obtain information on 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
Water Information Group
420 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 1983. 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—Geological 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); Geological Survey of Alabama (n,w); Jefferson County Commission (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), Transportation and Public Facilities (w), Alaska Power Authority (g,w); Anchorage, Municipality of—Department of Health and Environmental Protection (w), Department of Planning (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); Sandpoint, City of (w)

American Samoa: (See Hawaii)

Arizona:

Arizona Department of—Game and Fish (w), Health Sciences, Bureau of Water Quality Control (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); Navajo County Parks Commission (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)

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

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District of Columbia:

Department of Environmental Services (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); 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), 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); Hernando, County of (w); Highland Beach, Town of (w); Hillsborough County (w); Hollywood, City of (w); Jacksonville, Consolidated City of—Department of Health and Environmental Services (w), Department of Public Works (w); Jacksonville Electric Authority (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); 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); Pasco, County of (w); Pensacola, City of (w); Perry, City of (w); Pinellas County, County Courthouse (w); Pinellas Park Water Management District (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 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 South Florida (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 (w); Guam, Government of (w); Hawaii Department of—Health (w), Land and Natural Resources, Division of Water and Land Development (w), Transportation (n,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 Palau (w)

Idaho:

Big Lost River Irrigation District (w); Idaho Department of—Health and Welfare, Bureau of Water Quality (w), Lands (n), Water Resources (w); Idaho Water Resources Board (w); Oakley Canal Company (w); Salmon River Can.la Company (w); Teton County, Board of Commissioners (w); The Shoshone Bannock Tribes, Fort Hall Indian Reservation (w); Water District No. 01, Idaho Falls (w); Water District No. 31, DuBois (w); Water District No. 33, Howe (w); Water District No. 37, Shoshone (w); Water District No. 37-N, Carey (w); Water District No. 65-K, Lake Fork (w)

Illinois:

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

Indiana:

Carmel, Town of (w); Elkhart, City of, Water Works (w); Indiana Geological Survey (n); 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); Purdue University (g)

Iowa:

Cedar Rapids, City of (w); Charles City, City of (w); Clear Lake, City of (w); Des Moines, City of (w); Des Moines Water Works (w); Fort Dodge, City of (w); Iowa Department of—Transportation—Highway Division (w); Iowa Geological Survey (n, w); Iowa State University (w); Marshalltown, City of (w); Sewage Disposal Plant (w); Sioux City, City of (w); University of Iowa, University Physical Plant (w); Waterloo, City of (w); West-Central Iowa Rural Water Association (w)

Kansas:

Arkansas River Compact Administration (w); Harvey, County of (w); Hays, City of (w); Kansas Department of—Health and Environment (w), Transportation (n, w); Kansas Geological Survey (w); Kansas State Board of Agriculture, Division of Water Resources (w); Kansas Water Office (w); Kansas-Oklahoma-Arkansas River Commission (w); Southwest Kansas GWMD No. 3 (w); Western Kansas GWMD No. 1 (w); Wichita, City of, Flood Control Maintenance (w)

Kentucky:

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

Louisiana:

Baton Rouge City-Parish Government (w); Capital-Area Groundwater Conservation Commission (w); Louisiana Department of—Natural Resources—Geological Survey (g,w); Office of Environmental Affairs, Water Pollution Control Division (w); Transportation and Development—Office of Highways (w), Office of Public Works (n,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); 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); 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); Falmouth, Town of (w); Massachusetts Department of Public Works (n)—Division of Highways (w), Division of Research and Materials (w); Massachusetts State Water Resources Commission—Division of Water Pollution Control (w), Division of Water Resources (w); Metropolitan District Commission, Water Division (w)

Michigan:

Ann Arbor, City of (w); Battle Creek, City of (w); Branch County (w); Clare, City of (w); Coldwater, City of, Board of Public Utilities (w); Dickinson County, Board of Commissioners (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); 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); 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 Flood Control Commission (w); Carnelian-Marine Watershed District (w); Coon Creek Watershed District (w); Eagan, City of (w); Elm Creek Conservation Commission (w); Iron Range Resources Rehabilitation 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 Watershed District (w); St. Louis Park, City of (w); University of Minnesota (w); Wesmin Resource, Conservation and Development Association (w)

Mississippi:

Harrison County—Board of Supervisors (w), Development Commission (w); Jackson, City of (w); Jackson County—Board of Supervisors (w), Port Authority (w); Mississippi Department of—Highways (w), Natural Resources—Bureau of Geology (w), Bureau of Land and Water Resources (w), Bureau of Pollution Control (w); Mississippi Research and Development Center (n, w); Natchez, City of (w); Pat Harrison Waterway 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), Sanitary Services Department (w); St. Louis County, Department of Highways and Transportation (w)

Montana:

Chippewa Cree Tribal Council (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 State University (w); State of Montana (w); Salish and Kootenai Tribes of Flathead Reservation (w); Wyoming State Engineer (w)

Nebraska:

Central Platte Natural Resources District (w); Kansas-Nebraska Big Blue River Compact Administration (w); Lincoln, City of (w); Little Blue Natural Resources District (w); Lower Platte Natural Resources District (w); Lower Republican Natural Resources District (w); Nebraska Department of—Environmental Control (w), Water Resources (w); Nebraska Natural Resources Commission (w); Tri-Basin Natural Resources District (w); Twin Platte Natural Resources District (w); University of Nebraska, Conservation and Survey Division (w); Upper Loup Natural Resources District (w)

Nevada:

California Regional Water Quality Control Board, Lahontan Region (w); Carson City, Department of Public Works (w); Churchill County (w); Douglas County, Department of Planning (w); Fallon, City of (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); Reno, City of (w); Washoe County, Council of Governments (w)

New Hampshire:
Nashua Regional Planning Commission (w); New Hampshire Water Resources Board (w)

New Jersey:
Bergen, County of (w); Camden County, Board of Chosen Freeholders (w); Cranford, Township of (w); Logan, Township of (w); Morris County, Municipal Utilities Authority (w); New Jersey Department of Environmental Protection, Division of Water Resources (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:
Alamogardo, City of (w); Albuquerque, City of (w); Albuquerque Metropolitan Arroyo Flood Control Authority (w); Costilla Creek Compact Commission (w); Las Cruces, City of (w); New Mexico Bureau of Mines and Mineral Resources (w); New Mexico Environmental Improvement Division (w); New Mexico Department of Highways (w); Office of State Engineer (w); Pecos River Commission (w); Pueblo of Zuni (w); Santa Fe Metropolitan Water Board (w)

New York:
Albany, City of, Department of Water and Water Supply (w); Auburn, City of (w); Brookhaven, Town of (w); Chautauqua, County of, Department of Planning and Development (w); Cornell University—Department of Natural Resources (w), Department of Utilities (w); Cortland, County of, Planning Department (w); Erie County, Division of Environmental Control, Department of Environment and Planning (w); Hudson–Black River Regulating District (w); Kirkwood, Town of (w); Kiryas Joel, Village of (w); Long Island Regional Planning Board (w); Monroe, County of—Engineering Department (w), Water Authority (w); Nassau, County of, Department of Public Works (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— Education (w), Health, Division of Environmental Health (w), Environmental Conservation—Bureau of Monitoring and Assessment, Resource Monitoring Section (w), Bureau of Water Research (w), Division of Air (w), Division of Water (w), Hydrologic Services Section, PCB Project Unit (w), Water Research Bureau (w); Transportation, Bridge and Construction Bureau (w); New York State Power Authority (w); Nyack, Village of, Board of Water Commissioners (w); Onondaga, County of—Department of Drainage (w), Environmental Management Council (w), Water Authority (w); Oswego, County of, Planning Board (w); Rochester, City of, Department of Public Works (w); Rockland, County of, Drainage Agency (w); Seneca Nation of Indians (w); Shelter Island, Town of (w); Suffolk, County of—Department of Health Sciences (w), Water Authority (w); Susquehanna River Basin Commission (w); Temporary State Commission on Tug Hill (w); Ulster, County of, County Legislators (w); University of the State of New York, Regents Research Inc. (w); University of Virginia, Department of Environmental Sciences (w); Westchester, County of—Department of Health (w), Department of Public Works (w)

North Carolina:
Cary, City of (w); Charlotte, City of (w); Durham, City of, Department of Water Resources (w); Greensboro, City of (w); North Carolina State Department of—Human Resources (w), Natural Resources and Community Development (n,w), Transportation, Division of Highways (w); North Carolina Agricultural Research Service (w); Raleigh, City of (w); Rocky Mount, City of (w)

North Dakota:
Burleigh County, 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 (n, w); University of North Dakota (w)

Northern Mariana Islands: (See Hawaii)

Ohio:
Canton, City of, Water Department (w); Columbus, City of—Department of Public Service (w), Division of Water (w); Miami Conservancy District (w); Northeast Ohio Areawide Coordinating Agency (w); Ohio Department of—Natural Resources—Division of Geological Survey (g,w), Division of Oil (w), Division of Reclamation (w), Division of Water (w); Transportation (w); Ohio Environmental Protection Agency (w); Seneca Soil and Water District (w)

Oklahoma:
Ada, City of (w); Altus, City of (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 Conservation Commission (w); Oklahoma Department of—Highways (n), Transportation (w); Oklahoma Geological Survey, University of Oklahoma (w); Oklahoma Water Resources Board (w); Sapulpa, City of (w); Tulsa, City of (w)

Oregon:
Benton County Emergency Services (w); Burnt River Irrigaton 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); Oregon Department of—Environmental Quality (w), Fish and Wildlife (w), Geology and Mineral Industries (g,n), Water Resources (w); Oregon State Highway Division (w); Oregon State University (w); Portland, City of, Department of Finance and Administration (w); Rajneeshpuram, City of (w); Salem, City of (w); Wasco County People's Utility District (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); Letort Regional Authority (w); Millcreek, Township of (w); New York State Department of Environmental Conservation (w); Oley Township (w); Philadelphia, City of, Water Department (w); Pennsylvania Department of—Environmental Resources—Mining and Reclamation Bureau (w), Office of Resources Management (w), Soil Wastes and Management Bureau (w), State Parks Bureau (w), Topographic and Geologic Survey Bureau (n,w), Water Quality Management Bureau (w); Pennsylvania State University (g); Susquehanna River Basin Commission (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), Transportation and Public Works (w); Puerto Rico Electric Power Authority (w); Puerto Rico Environmental Quality Board (w); Puerto Rico Industrial Development Company (w); Puerto Rico Land Authority (w); Puerto Rico Mineral Resources Development Corporation (g); Puerto Rico Planning Board (w); Puerto Rico Sugar Corporation (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); Grand Strand Water and Sewer Authority (w); Hilton Head Island, Public Service District No. 1 (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); Lower James Conservancy Subdistrict (w); South Dakota Department of—Transporation (n); Water and Natural Resources—Geological Survey Division (w), Water Rights Division (w); Watertown, City of (w)

Tennessee:
Franklin, City of (w); Lawrenceburg, City of (w); Lincoln County, Board of Public Utilities (w); Memphis, City of—Light, Gas, and Water Division (w), Public Works Division (w), Water Division (w); Metropolitan Government of Nashville and Davidson County, Department of Public Works (w); Shelby, County of (w); Tennessee Department of—Conservation, Geology Division (n,w), Health and Environment (w); Transportation, Bureau of Highways (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); Brady, City of (w); Brazos River Authority (w); Cleburne, City of (w); Clyde, City of (w); Coastal Bend Council of Governments (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–Ft. 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); Graham, 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); Sabine River Authority of Texas (w); Sabine River Compact Administration (w); San Angelo, City of (w); San Antonio, City of—Engineering Department (w), Public Service Board (w); San Antonio River Authority (w); San Jacinto River Authority (w); Tarrant, County of, Water Control and Improvement District No. 1 (w); Texas Bureau of Economic Geology (g); Texas Department of Water Resources (n,w); Titus, County of, Fresh Water Supply District No. 1 (w); Tom Green, County of, Water Control and Improvement 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); Velasco Drainage District (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); 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), Water Resources Division (w), Water Rights Division (w), Wildlife Resources Division (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); James City, County of, Department of Public Works (w); Newport News, City of, Department of Public Utilities (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 Development, Division of Mineral Resources (n), Highways and Transportation (w); Virginia State Water Control Board (w)

Virgin Islands:
Department of Public Works (w); Planning Office (w); Virgin Islands, College of (w)

Washington:
Bellevue, City of, Public Works Department (w); Chelan, County of, Public Utility District No. 1 (w); Cowlitz, County of, Board of County Commissioners (w); Everett, City of (w); Fircrest, Town of (w); Hoh Indian Tribe (w); Island, County of, Board of County 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); Pend Oreille, County of, Public Utility District No. 1 (w); Puyallup Indian Nation (w); Quinault Indian Business Committee (w); San Juan County Board of County Commissioners (w); Seattle, City of—Department of Lighting (w), Water Department (w); Skagit, County of (w); Snohomish County (w); Stillaguamish Indian Tribe (w); Tacoma, City of—Public Utilities Department (w), Public Works Department (w); Tulalip Tribal Board of Directors (w); University of Washington (w); Yakima Tribal Council (w); Washington Public Power Supply System (w); Washington Department of—Ecology (w), Fisheries (w), Natural Resources (g,n), Transportation (w)

West Virginia:
Morgantown, City of, Water Commission (w); West Virginia Department of—Highways (w), Natural Resources—Division of Reclamation (w), Division of Water Resources (w); West Virginia Geological and Economic Survey (w)

Wisconsin:
Brown County Planning Commission (w); Dane, County of—Department of Public Works (w), Regional Planning Commission (w); Forest County Potawatomi Community (w); Green Bay Metropolitan Sewerage District (w); Green Lake Sanitary District (w); Lac du Flambeau Indian Reservation (w); Madison Metropolitan Sewage District (w); Madison Water Utility (w); Menominee Indian Tribe of Wisconsin (w); Middleton, City of (w); Southeastern Wisconsin Regional Planning Commission (w); University of Wisconsin, Extension, Geological and Natural History Survey (n,w); University of Wisconsin, Milwaukee (w); Wisconsin Department of—Natural Resources (n,w), Transportation (n)—Bridge Section (w), Division of Highways (w)

Wyoming:
Buffalo, City 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 (n,w); Forest Service (w); Graduate School (w); Agricultural Research Service (w); Soil Conservation Service (g,n,w)

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); Wright-Patterson Air Force Base (n); Wurtsmith Air Force Base (w)

Department of the Army:
Armament Research and Development Command (w); Avionics R and D Activity (g); Coastal Engineering Research Center (g); Corps of Engineers (g,w); Fort Belvoir (n); Fort Bliss (w); Fort Carson Military Reservation (w); Mobility Equipment Research and Development Command (g); Research Office, Triangle Park, N.C. (g); Waterways Experiment Station (g); White Sands Missile Range (w)

Department of Commerce:
Coastal Plains Regional Action Planning Commission (g); National Bureau of Standards (g); National Ocean Survey (n); National Oceanic and Atmospheric Administration, National Marine (w); Fisheries Service (n,w); National Weather Service (g,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); Nuclear Regulatory Commission (g,w); Bonneville Power Administration (w); Chicago Operations Office (w); Idaho Operations Office (w); Lawrence Livermore Laboratory (g); Nevada Oberations Office (g,w); Oak Ridge Operations Office (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,w); Minerals Management Service (g,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 Justice (w)

Department of the Navy:
Naval Explosive Ordnance Disposal Test Center (g); Naval Oceanographic Office (g,n); Naval Weapons Center, China Lake (g,n,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,w); St. Lawrence Seaway Development Corporation (w); U.S. Coast Guard (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 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)

Missouri Basin States Association (w)

National Aeronautics and Space Administration (g,w)

National Science Foundation (g,n,w)

Tennessee Valley Authority (n,w)

Veterans Administration (g,w)

Other Cooperators and Contributors

Government of American Samoa (w)

Government of Guam (w)

Government of Peru (g)

Government of Saudi Arabia (g,n,w)

Government of Venezuela (w)

People's Republic of China (g)

Puerto Rico:
Puerto Rico Aqueduct and Sewer Authority (w); Puerto Rico Department of Agriculture (w); Puerto Rico Department of Health (w); Puerto Rico Department of Natural Resources (g,w); Puerto Rico Department of Transportation and Public Works (w); Puerto Rico Electric Power Authority (w); Puerto Rico Environmental Quality Board (w); Puerto Rico Industrial Development Company (w); Puerto Rico Land Authority (w); Puerto Rico Mineral Resources Development Corporation (g); Puerto Rico Planning Board (w); Puerto Rico Sugar Corporation (w)

Trust Territories 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 Palau (w)

United Nations:
United Nations Development Program (g,w); UNESCO (w); World Meteorological Organization (w)

Virgin Islands:
College of the Virgin Islands (w); Virgin Islands Department of Public Works (w); Virgin Islands Planning Office (w)

Budgetary and Statistical Data

TABLE 1.—Geological Survey budget for fiscal years 1978 to 1983, by activity and sources of funds[1]

(Dollars in thousands; totals may not add due to rounding.)

Budget activity	1978	1979	1980	1981	1982	1983
Total	**$698,272**	**$764,718**	**$782,136**	**$769,757**	**$661,842**	**$556,054**
Direct program	576,393	634,886	639,143	623,057	509,983	396,909
Reimbursable program	121,879	129,832	142,993	146,700	151,859	159,145
States, counties, and municipalities	40,784	44,124	46,849	48,700	50,418	51,972
Miscellaneous non-Federal sources	12,825	15,789	16,817	19,605	24,376	21,215
Other Federal agencies	68,270	69,919	79,327	78,395	77,065	85,958
Alaska Pipeline Related Investigations	**317**	**272**	------	------	------	------
Direct program	317	272	------	------	------	------
Reimbursable program	------	------	------	------	------	------
Other Federal agencies	------	------	------	------	------	------
National Mapping, Geography, and Surveys	**69,520**	**74,566**	**82,683**	**89,177**	**88,133**	**91,611**
Direct program	61,356	65,584	72,759	77,449	77,687	81,138
Reimbursable program	8,164	8,982	9,924	11,727	10,446	10,473
States, counties, and municipalities	3,320	3,371	3,083	2,985	3,000	2,700
Miscellaneous non-Federal sources	499	597	610	1,095	1,100	1,204
Other Federal agencies	4,345	5,014	6,231	7,648	6,346	6,569
Geologic and Mineral Resource Surveys and Mapping	**163,193**	**178,556**	**193,652**	**208,287**	**212,355**	**206,517**
Direct program	123,830	134,846	146,963	162,756	163,731	159,190
Reimbursable program	39,363	43,710	46,689	45,531	48,624	47,327
States, counties, and municipalities	956	584	640	758	480	490
Miscellaneous non-Federal sources	8,510	10,914	11,258	13,192	16,844	14,293
Other Federal agencies	29,897	32,212	34,791	31,761	31,300	32,544
Water Resources Investigations	**146,014**	**168,598**	**184,871**	**194,016**	**190,096**	**199,697**
Direct program	[2]78,487	96,847	108,664	115,458	108,637	115,096
Reimbursable program	67,527	71,751	76,207	78,558	81,459	84,601
States, counties, and municipalities	36,457	40,156	43,126	45,238	46,938	48,782
Miscellaneous non-Federal sources	1,429	1,673	1,778	2,088	2,679	3,914
Other Federal agencies	29,641	29,922	31,303	31,332	31,842	31,905
Conservation of Lands and Minerals	**77,409**	**85,484**	**106,395**	**127,001**	**130,468**	------
Direct program	77,399	85,362	105,928	25,739	129,868	------
Reimbursable program	110	122	467	1,262	600	------
Miscellaneous non-Federal sources	9	------	12	29	210	------
Other Federal agencies	101	122	455	1,233	390	------
Office of Earth Sciences Applications	**23,226**	**23,965**	**23,734**	**23,205**	**20,853**	**18,452**
Direct program	18,132	19,959	18,935	18,849	14,359	11,132
Reimbursable program	5,094	4,006	4,799	4,356	6,494	7,320
States, counties, and municipalities	51	13	------	------	------	------
Miscellaneous non-Federal sources	2,153	2,333	2,808	3,139	3,482	1,728
Other Federal agencies	2,890	1,600	1,991	1,217	3,012	5,592
National Petroleum Reserve in Alaska	**202,704**	**216,886**	**169,845**	**107,001**	**2,196**	------
Direct Program	202,598	216,886	169,845	107,001	2,196	------
Allocation transfer	106	------	------	------	------	------
Reimbursable program (Federal)	------	------	------	------	------	------
General Administration	**3,650**	**3,661**	**3,776**	**3,896**	**3,407**	**16,313**
Direct program	3,650	3,661	3,776	3,896	3,407	14,931
Reimbursable program (Federal)	------	------	------	------	------	1,382
Facilities	**10,769**	**11,741**	**12,273**	**11,909**	**10,098**	**9,167**
Direct program	10,769	11,741	12,273	11,909	10,098	9,022
Reimbursable program	------	------	------	------	------	145
Miscellaneous services to other accounts	**1,515**	**1,261**	**4,907**	**5,266**	**4,236**	**7,897**
Reimbursable program	1,515	1,261	4,907	5,266	4,236	7,897
Miscellaneous non-Federal sources	225	272	351	62	61	76
Other Federal agencies	1,290	989	4,556	5,204	4,175	7,821
Barrow Area Gas Operation	------	------	------	------	------	**6,400**
Direct program	------	------	------	------	------	6,400

[1]Includes 1982 appropriation for Minerals Management Service.

[2]Funds for the Airborne Positioning System, appropriated to Water Resources Investigations are included as obligations of Topographic Surveys and Mapping ($2,172 thousand).

TABLE 2. *—Geological Survey reimbursable program funds from other Federal agencies for fiscal years 1978 to 1983, by agency*
(Dollars in thousands)

Agency	1978	1979	1980	1981	1982	1983
Total	**$68,164**	**$69,919**	**$79,326**	**$78,395**	**$76,675**	**$85,958**
Department of Agriculture	2,727	2,619	3,878	3,567	2,675	2,774
Department of Commerce	183	141	276	------	------	111
National Oceanic and Atmospheric Administration	1,708	1,464	2,388	823	1,781	5,750
Ozarks Regional Commission	------	------	76	------	------	------
Department of Defense	15,655	16,760	17,447	18,490	21,459	25,429
Department of Energy	14,980	15,338	14,406	10,885	10,529	5,858
Bonneville Power Administration	138	48	61	81	75	103
Department of Housing and Urban Development	3,789	1,967	302	188	------	------
Department of the Interior	16,528	17,746	22,926	22,553	20,328	23,955
Bureau of Indian Affairs	2,385	4,345	9,295	3,999	5,001	4,796
Bureau of Land Management	10,791	9,712	7,807	13,800	10,551	7,150
Bureau of Mines	108	240	297	299	275	200
Bureau of Reclamation	1,871	1,975	2,257	2,231	1,800	3,411
Minerals Management Service	------	------	------	------	------	5,284
National Park Service	791	771	818	1,121	1,015	1,957
Office of the Secretary	------	82	203	154	100	223
Office of Surface Mining	135	21	1,563	469	1,176	606
U.S. Fish and Wildlife Service	447	600	686	480	410	328
Department of State	1,010	1,455	2,449	2,272	3,445	573
Department of Transportation	193	149	291	273	500	483
Environmental Protection Agency	3,074	2,873	2,645	1,259	675	883
National Aeronautics and Space Administration	2,763	4,033	2,793	5,065	3,885	3,716
National Science Foundation	848	896	1,211	2,001	1,958	1,300
Nuclear Regulatory Commission	1,318	1,583	1,325	1,781	1,544	2,272
Tennessee Valley Authority	216	261	243	317	290	151
Miscellaneous Federal agencies	1,882	1,645	2,105	3,717	3,431	4,882
Miscellaneous services to other accounts	1,290	989	4,556	5,204	4,175	7,821

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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.