# USGS 1981 FISCAL YEAR ACTIVITIES

GEOLOGICAL SURVEY CIRCULAR 875

*The Brinkerhoff-Signal Rig 72, under contract to Williams Exploration, is drilling the Granite Creek Well, also identified as Game Hill Unit 1-30, sec. 30, T. 39 N., R. 113 W., Teton County in the Bridger-Teton National Forest, about 30 miles from Jackson Hole, Wyoming. The well was begun on August 3, 1980, and currently is being tested at 19,842 feet. Thus far, Williams Exploration has invested over $15 million on this well. Activity on this well, as on all others on Federal and Indian lands in the overthrust belt of Wyoming, is approved and supervised by the District Oil and Gas Supervisor of the Rock Springs, Wyoming, U.S. Geological Survey District Office. The Environmental Assessment was made jointly by the Geological Survey and the U.S. Forest Service.*

# U.S. Geological Survey Activities, Fiscal Year 1981

## Circular 875

**United States Department of the Interior**
JAMES G. WATT, *Secretary*

**Geological Survey**
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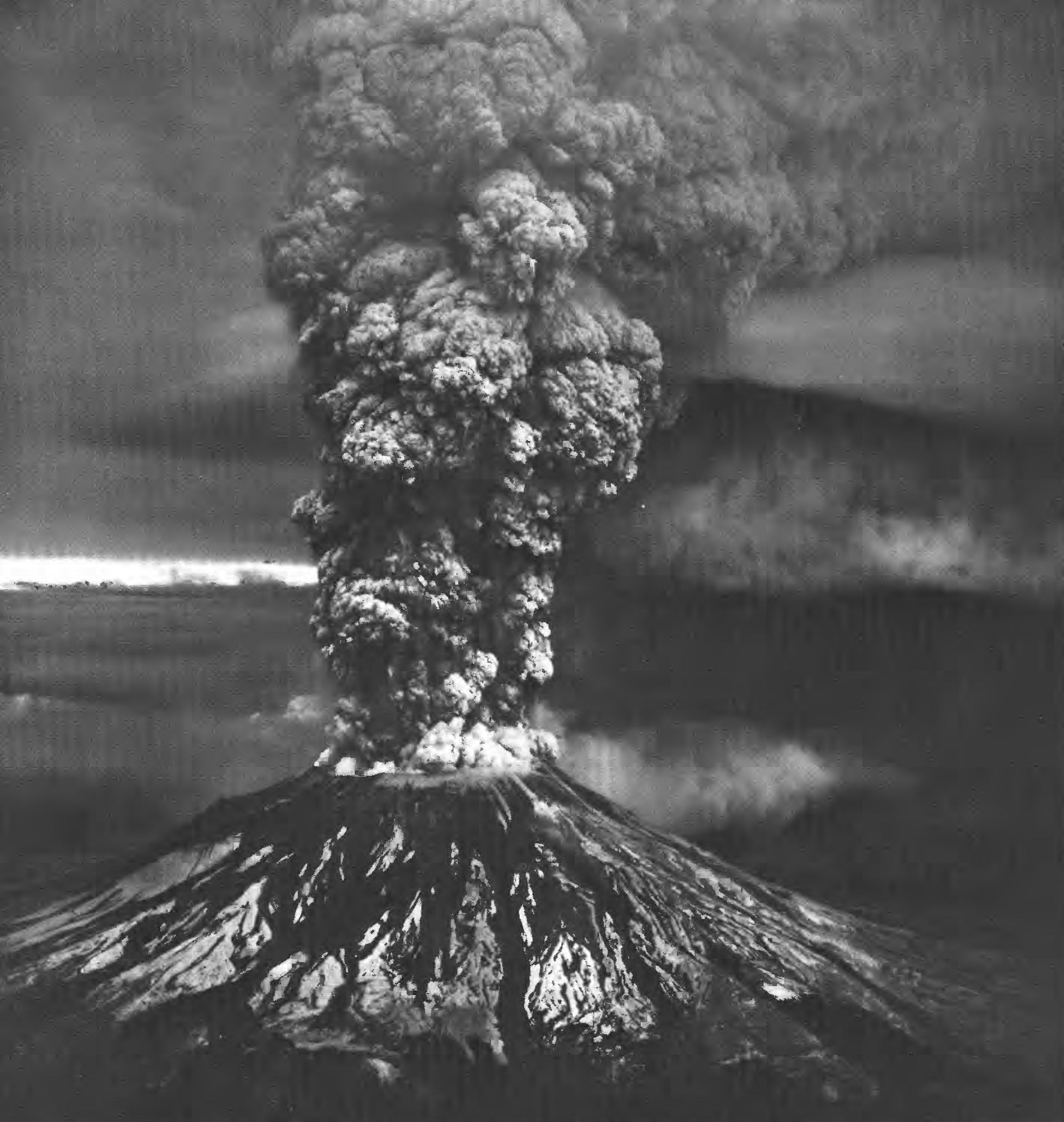
# Preface

The U.S. Geological Survey, a bureau of the Department of the Interior, is the principal agency of the Federal Government devoted to the pursuit of the earth sciences. In addition to its studies of earth science phenomena and the Nation's mineral, water, and land resources, the Geological Survey also classifies the federally owned lands with respect to leasable minerals and waterpower sites and supervises the exploration and development activities of private parties conducted under mineral leases and permits on Federal and Indian lands.

Between 1880 and 1932, the Geological Survey submitted a series of annual reports describing its activities to the Secretary of the Interior for transmittal to the Congress. From 1933 until 1964, the Geological Survey's annual report was included as a part of the *Annual Report of the Secretary of the Interior*, after which highlights of the Survey's activities were reported in the Department of the Interior *Conservation Yearbook* series. In 1975, the Geological Survey resumed the practice of reporting its fiscal year's activities in a separate document. This issue, *U.S. Geological Survey Activities, Fiscal Year 1981* presents a summary of the work performed between October 1, 1980, and September 30, 1981.

The results of the U.S. Geological Survey's activities are voluminous, and no attempt is made here to report them in any detail. Instead, certain selected aspects of the Survey's work are presented which are topical and together form a representative sample of the types of activities in which it is currently engaged. Those desiring to know more about the Geological Survey's activities and the services it offers are referred to the summary "Guide to Publications and Information Services" on page **147** and to the more detailed Geological Survey Circular 777, *A Guide to Obtaining Information from the USGS 1981*. In addition, the technical results of the Survey's research programs are reported annually in the Professional Paper series. Professional Paper 1275, *Geological Survey Research 1981*, containing abstracts of investigations in the earth sciences, is the latest of these annual reports, and supplements the description of program activities contained in this volume.

Dallas L. Peck
Director, U.S. Geological Survey
February 1982



# The Year in Review

Fiscal year 1981 proved to be unusually challenging for the U.S. Geological Survey as it sought to satisfy the established claims upon its capabilities and resources expressed in law, custom, and settled policy, and to position itself to support the incoming administration's announced policies toward the Nation's land, mineral, and water resources, all within the limits of available funds and personnel.

Among the Survey's active concerns at the beginning of the year were a number of programs deriving from recently enacted laws, Secretarial decisions, and other directives concerning the assessment and development of minerals on Federal and Indian lands, both onshore and offshore. The 1979 decision to resume leasing on federally owned coal lands was one such event. Another was the passage of the Outer Continental Shelf Lands Act Amendments in 1978. The Surface Mining Control and Reclamation Act of 1977 applied to all coal lands, public and private, and created a demand for information that the Survey was responsible for providing and, in the case of Federal and Indian lands, for applying. The mineral assessment of public lands nominated for wilderness classification continued under the Wilderness Act of 1964. Lastly, the character and extent of the Survey's functions in Alaska were changing as the oil and gas assessment program in the National Petroleum Reserve was phased out and new responsibilities were assumed under the Alaska National Interest Lands Conservation Act of 1980.

In addition to its responsibilies for resource assessment and management, the Survey had, by fiscal year 1981, been charged with providing information needed to mitigate the effects of geologic hazards. Attention was strongly focused on these hazard-related duties by the sensational eruption of Mount St. Helens on May 18, 1980, 3 weeks after the Survey had issued a warning that permitted State and Federal authorities to take preventative actions that saved many lives. Geologic and hydrologic studies conducted during the past year have provided knowledge that has been valuable in assessing the posteruption effects of volcanic phenomena and in refining prediction techniques.

Many of the Survey's ongoing commitments rapidly began to merge with newer ones as a result of the new administration's pledge to, among other things, increase private access to Federal lands for mineral and energy development, reduce the regulatory role of the Federal Government, accelerate and expand domestic energy and mineral production, and generally reduce funding and staffing of Federal activities other than those related to national defense and certain other specified areas. These new attitudes and policies had direct implications for both the scientific and the regulatory functions of the Survey, and fiscal year 1981 saw the initial stages of a reorientation of Survey programs and investigations to support the goals of the new Administration.

The highlights of fiscal year 1981 activities summarized below reflect the conjunction of the Survey's established functions and responsibilities with those acquired as the result of the 1980 general election.

## Alaskan Transition

When the final six wells were completed during fiscal year 1981, the oil and gas exploration program on the National Petroleum Reserve in Alaska, conducted for the Department of the Interior by the Geological Survey since the program's transfer from the Navy Department in June 1977, was essentially finished. Over the 7 years of the program's life, 28 exploratory wells were drilled and 13,500 line miles of geophysical surveys run on the 37,000-square mile Reserve lying between the Colville River and the Arctic Ocean in a systematic effort to assess its petroleum potential, and, secondarily, to discover commercially producible deposits of oil and gas. Although no commercially significant discoveries were made, the investigations indicated a 50-percent probability that 5.2 billion barrels of recoverable oil and 9.4 trillion cubic feet of gas may be found on the Reserve

The phasing out of the exploration program was succeeded by the first leasing activity on the Reserve. In September 1981, the Secretary of the Interior selected 53 tracts comprising 1.5 million acres from the acreage nominated by the petroleum industry to be offered for lease in December 1981. This sale is to be followed by another of 0.5 million acres in May 1982.

Elsewhere in Alaska, petroleum exploration activity focused on the Continental Shelf beneath the Beaufort Sea, where 34 wells had been drilled on State of Alaska leases at the end of fiscal year 1981 and where the first gravel island on a Federal lease was built by Exxon Corporation during the fiscal year for use in the 1981–1982 winter drilling season. A second lessee, the Shell Oil Corporation, announced its intention to construct a gravel island on its lease. In view of the active interest shown by the petroleum industry in Beaufort Sea leases, the new lease schedule released by the Department in July 1981 advanced the next Federal lease sale No. 71, by 5 months to September 1982. Lease sales 55 and 60, for tracts in the Gulf of Alaska and lower Cook Inlet, respectively, attracted little interest.

The Alaska National Interest Lands Conservation Act, which became law in December 1980, gave the Secretary of the Interior a number of tasks that require support from the Geological Survey. One provision requires that the Secretary study all Federal lands north of 68° latitude, except the National Petroleum Reserve in Alaska, to assess their potential oil and gas resources, make recommendations for the use and management of those resources, review wilderness characteristics, and recommend protective measures for fish and wildlife.

The Act also charges the Secretary to "assess the oil, gas, and other mineral potential of all pubic lands in the State of Alaska in order to expand the data base with respect to the mineral potential of such lands." In effect, this assignment will be carried out by the continuation and expansion of the Survey's Alaska Mineral Resources Assessment Program, which has been under way for several years. In recognition of this need, the Survey was granted an additional $3 million during fiscal year 1981, which permitted a substantial increase in staffing and the acquisition of some additional aeromagnetic data. As a result the amount of mapping increased by 50 percent over what had been programmed initially; more than 70,000 square miles were mapped at 1:250,000 scale in fiscal year 1981.

The Survey participated in two additional specific studies ordered by the Act. The first—the Arctic National Wildlife Refuge Coastal Plain Resource Assessment—calls for an inventory of fish and wildlife and an analysis of the impacts of oil and gas exploration, development, and production and authorizes selected exploratory activity (not to include drilling) on the Wildlife Refuge. Survey effort during fiscal year 1981 concentrated on the preparation of exploration guidelines and an environmental impact statement on exploratory activities. Subsequent exploration plans will be submitted to the Secretary for approval.

The second study, and one for which the Survey was assigned the lead role, called for the Secretaries of Interior, Defense, and Energy to "initiate and carry out a study of the mission, facilities, and administration of the Naval Arctic Research Laboratory at Point Barrow, Alaska."This assignment, a subsection of which will make recommendations for redirecting the United States Arctic research policy, required extensive coordination and discussions between the Survey and other Federal agencies, State and local political entities, scientific organizations, and individual experts. At the end of the fiscal year, the study was in its final stage.

# Mount St. Helens Revisited

By October 1, 1980, when fiscal year 1981 began, activity at Mount St. Helens had tapered off to occasional nonexplosive eruptions, in dramatic contrast to the shattering violence of the May 18, 1980, eruption, which devasted an area of 230 square miles, killed more than 60 people, and caused over a billion dollars worth of damage. In the course of the eruption, Mount St. Helens deposited ash hundreds of miles downwind in Washington, Idaho, and Montana, dumped more than 0.7 cubic mile of debris into the North Fork of the Toutle River (which, in turn, transported enough of it downstream to close the Columbia River to navigation at Portland for a time), and left the volcano's drainage area with a legacy of hydrologic instability that will endure for years to come.

Geological Survey activity at Mount St. Helens during fiscal year 1981 was concerned both with monitoring current activity and with assessing the aftereffects of the catastrophic May 18 eruption. The ad hoc organization hastily put together at Vancouver, Washington, in response to the burst of activity in the spring of 1980, was established formally as the Cascades Volcano Observatory; the observatory staff represents diverse scientific disciplines, appropriate to its task of observing activities at Mount St. Helens and other Cascade Range volcanoes and assessing and reporting on their effects.

To assist the observatory in its mission, additional stations have been added to geophysical and hydrological observation networks in the vicinity of Mount St. Helens, and installation of monitoring networks at three other Cascade volcanoes—Mount Shasta and Lassen Peak in California and Mount Baker in Washington—has begun.

Four flood-warning gaging stations were added during the year to the Survey's 7-station satellite-data relay network in the immediate area of Mount St. Helens. Additional flood-warning stations without telemetry and other stations measuring river systems in the ash-impacted areas, maintained as part of the warning and information-gathering network, bring the total numbers of stations in service to 34.

The six eruptive episodes that have occurred since December 1980 have been characterized by the formation of an irregular mound or dome of extruded lava on the crater floor. Each eruption has added to the size of the dome, which, by the end of fiscal year 1981, was some 2,100 feet long, 1,700 feet wide, and 500 feet high. This series of nonexplosive, dome-building eruptions has been extremely useful to Survey geologists attempting to develop techniques for predicting activity of this sort. Survey scientists, have used data from seismic, ground-deformation, and volcanic gas monitoring to provide reliable forecasts several hours or days, or even weeks, in advance of the last seven eruptions. The current phase of intermittent, largely dome-building activity is expected to continue for many more years, although the possibility of future moderate-size eruptions cannot be dismissed. The probability of another large eruption similar to the one that occured May 18, 1980, is very low.

The effort that went into assessing the effects of the May 18 eruption during fiscal year 1981 will form the basis of numerous reports. The definitive work, *The 1980 Eruptions of Mount St. Helens, Washington*, which should be available in 1982 as Professional Paper 1250, treats all aspects of the volcano's activity both before and after the May 18 eruption. This volume is dedicated to the memory of David A. Johnston, a Survey volcanologist who died in the initial eruption.

Individual studies of the complex changes in the hydrologic regime caused by the eruption seek to determine water-related hazards and predict their impacts and to improve understanding of the processes responsible for these hazards. Included are studies of sediment deposition in river channels, the susceptibility of debris-avalanche dams to failure, the toxicity of leachates, the mechanisms for triggering mudflows, the effects of the eruption on glaciers, and the effect of ashfalls on the rate of snowmelt and snow accumulation on glaciers. The first eight circulars in a series dealing with these effects and others have been issued, and another is currently being prepared.

The profound topographical changes around Mount St. Helens have made it necessary to remap the area affected by the May 18 eruption at 1:24,000 scale. During fiscal year 1981, new data were compiled for 28 7.5-minute quadrangle maps planned for publication in calendar year 1982. Digital elevation data and 7.5-minute orthophotoquads covering this area also were made available in fiscal year 1981. Additional orthophotoquads and digital elevation data for an expanded area are scheduled for completion early in calendar year 1982.

# Streamlining Leasing and Regulatory Procedures

The Reagan administration's commitment to eliminating unnecessary and burdensome regulatory procedures and reporting requirements, together with its announced goal of expanding the size of oil and gas lease offerings on the Outer Continental Shelf, were factors underlying an extended Survey effort in FY 1981 to bring its procedures and directives into line with those objectives.

In issuing his proposed Outer Continental Shelf leasing plan in July 1981, Secretary of Interior James G. Watt announced his intention to offer all or significant portions of entire planning areas for lease at a single sale. These offerings, comprising more than 10 million acres each, are much larger than the 500,000 to 1,500,000 acres offered in past sales and will dictate profound changes in the Survey's preleasing actions, which, in the past, have relied on detailed geologic and geophysical work for tract selection, input for environmental impact statements, assessment of geologic hazards, and prelease determination of economic values for the tracts offered.

During fiscal year 1981, the Survey consulted with other bureaus and offices in the Department on how best to meet the new requirements posed by the large increase in the size of lease offerings without jeopardizing the environment, the interests of adjacent States, and the public resources in question. Although details were still lacking at the fiscal year's end, some general conclusions had been reached. The Geological Survey will prepare geologic maps of entire planning areas prior to sale dates, but postsale economic evaluation will concentrate only on the relatively small portion of the large offering that is bid on at any given sale. Marketplace competition will be used to establish the fair value of the tracts, subject to the Survey's monitoring.

Presale evaluation of offshore geologic hazards, which previously has relied heavily on high-resolution seismic data gathered by the Survey on all tracts offered, now will depend on an evaluation of regional data. Less reliance will be placed on data collected by the Survey, instead, the Survey will analyze data gathered and supplied by the lessees in support of their exploration plans, with the understanding that leases found to contain unacceptable hazards will be subject to cancellation.

Conversion to these streamlined leasing procedures will begin when the Secretary's revised leasing plan is approved and will be completed sometime in 1983.

The basis for the Survey's current efforts to identify and rework burdensome, counterproductive, and unnecessary regulations is Executive Order 12291, signed by President Reagan in February 1981. Much of the Survey's response to that order in fiscal year 1981 has been devoted to changes that will become effective in succeeding years.

Onshore, the rules governing Federal oil and gas leases are being updated to bring them into line with current practice. Regulations enforcing the Connally Act of 1935, which forbids interstate shipment of oil produced in violation of State market demand proration orders—a stipulation made pointless when market demand proration ended in the early 1970's—were eliminated. Another similar regulation dealing with the acquisition and leasing of water wells also was deleted.

Offshore, initial proposals include exempting the mature producing area of the western Gulf of Mexico from the requirement that operators submit development and production plans for approval; eliminating redundancy in environmental reporting; and providing for an extension of a lease period if inordinate delays have occurred in the issuance of permits.

The Geological Survey is also streamlining regulations governing reporting requirements, retaining only those that are truly necessary and identifying the least costly alternatives for its other rules. When the streamlining process has been completed, the application regulatory codes will be up to date and free of unnecessary provisions. A continuing review will be undertaken to insure that they remain so.

# Coal Program

The 10-year pause in Federal coal leasing that began with a moratorium imposed by the Department of the Interior in 1971 to discourage speculative leasing of tracts ended on January 13, 1981, when the first part of the Green River-Hams Fork competitive lease sale was held in Colorado and Wyoming. The second part of the sale was held the following day, and the remaining acreage was leased on April 30, 1981. A second sale was held in Alabama on June 25, and a third sale in the Uinta region of Utah was held on July 30. Altogether, 19 tracts comprising nearly 33,000 acres were leased for approximately $25 million.

The resumption of active leasing by the Federal Government, together with the administration's strong emphasis on increasing coal production on both public and private lands, has important implications for the Survey's coal program. To meet the goals set by the administration for coal usage by 1985, the domestic coal industry will need to produce nearly double the 800 million tons mined in 1980, and the 10 percent share of that total contributed by Federal and Indian land leases also will have to continue to grow.

These prospective large increases in coal production will require additional knowledge about the Nation's coal resources (extent and quality, bed and overburden thicknesses, chemical properties, and other information) if informed decisions are to be made in both the public and the private sectors, about resource development, land-use planning, and evaluation of federally and Indian-owned coal. In addition, the Survey's specific responsibilities for supplying general hydrologic information on all surface-mining areas under the Surface Mining Control and Reclamation Act of 1977 will increase with the growth in surface mining.

The Survey's work in coal hydrology, which has been expanding since its beginning in fiscal year 1974, continued to focus on the Eastern (Appalachian) and Interior coal provinces during fiscal year 1981. By the end of the year, 19 hydrologic reports had been completed on major subbasins in these provinces. These reports and the 41 others planned for fiscal years 1982 or 1983 will summarize all pertinent hydrologic data on the Nation's principal coal lands.

In addition to the Federal coal hydrology program, continuing work under the Federal-State Cooperative Program on 77 projects in 31 States was aimed at evaluating site-specific mining hydrologic problems such as acid mine drainage, subsidence, impacts on local water supplies, excessive sediment in streams and reservoirs, and pollution from coal washing and unloading facilities.

The Survey's coal investigations program continued to identify and delineate Federal coal resources in the northern Great Plains and Rocky Mountain provinces and on low-sulfur beds in the central and southern Appalachian province. The data generated by these investigations are presented mainly in a series of map folios, predominatly at 1:100,000 scale. At the end of fiscal year 1981, work was in progress on 24 folios describing the resources of the western basins and 4 devoted to basins in the Eastern States. Two folios (Denver East and Recluse in Colorado and Wyoming, respectively) were completed. In addition, work was completed on four Wilderness areas in Pennsylvania, Kentucky, Illinois, and Alabama, and fieldwork was completed on one RARE II area in New Mexico. Fieldwork also was completed on five coal-resource assessment studies sponsored by the Bureau of Indian Affairs. In these coal investigations and others, some 47,000 feet of test hole were drilled and geophysically logged.

Data generated by the Survey's coal investigations in fiscal year 1981 were incorporated into the National Coal Resources Data System, as in past years. In return, data from the system were used in preparing the coal folios.

# Royalty Management

The complete overhaul and reorganization of the Survey's royalty management system, which began in fiscal year 1980 and continued through 1981, has been one of the most significant management-improvement initiatives that the Survey has undertaken in recent years. At the fiscal year's end, the Survey began its planned conversion from the early (1950's) decentralized accounting system to an improved interim phase which will be replaced, in 1983, by a highly sophisticated, computer-assisted operation administered through a headquarters organization and five field offices.

The new system centralizes all minerals royalty collection and accounting functions under a Deputy Division Chief for Royalty Management at the Survey's headquarters in Reston. The field organization consists of a national Accounting Center and a Review and Analysis office, both located in Lakewood, Colorado. Four Review and Analysis suboffices are located in Albuquerque, New Mexico; Metairie, Louisiana; Tulsa, Oklahoma; and Lakewood, Colorado. Under the old system, management, accounting, and audit functions were performed separately for onshore and offshore leases at 14 offices in 11 cities. Conversion to the new system is being implemented in phased increments; already, three regional offices have ceased collections. All new or restructured components are scheduled to be in place and operating by early 1984.

Several benefits will derive from the unified policies and standardized procedures of the new royalty management program, including increased income for the U.S. Treasury, the Indians, and the States; timely availability and processing of funds; increased personnel productivity; and a substantially reduced reporting burden on private industry. From the standpoint of internal control, the new system will assure greater security for the proprietary information collected, reduce the potential for fraud and abuse in royalty reporting, and provide better administrative control over activities and funds. The resulting reduction in undercollections, together with prompt payments and same-day deposits into interest-bearing accounts, is expected to add millions of dollars annually to the revenues accruing to the Federal Treasury and to other recipients of royalty payments. These payments, which were less than $425 million in fiscal year 1970, had reached $2.96 billion 10 years later and are expected to exceed $4 billion in calendar year 1981. Thus, as energy costs continue to rise, the Survey faces the next decade with an efficient royalty management program for its mandated revenue collection.

# Water Data Telemetry

The Geological Survey's satellite-data relay network, begun in 1972 to expedite the collection of hydrologic data from remote locations, continued its steady expansion through fiscal year 1981 to include 380 collection sites and one ground-receive station. The ground-receive station, activated in Tacoma, Washington, in February 1981, receives data through geostationary satellite from numerous data-collection sites in the Pacific Northwest, including the flood-warning network surrounding Mount St. Helens. A second ground-receive station, scheduled for installation in Phoenix, Arizona early in 1982, will include support for the 45-station central Arizona flood-warning network operated by the Survey.

Of the 380 data-collection sites in the network, 105 are operated under contract by COMSAT General, and 140 others are operated by the Survey in cooperation with the U.S. Army Corps of Engineers. Twenty new sites in the Upper Missouri River Basin will be added under an agreement with the Corps during fiscal year 1981.

This telemetered data-collection network uses satellites orbiting 23,000 miles above the Earth's equator to relay data gathered at remote sites to processing facilities, brings a real-time reporting capability to hundreds of stations; data gathered at these stations used to be stored on punched tape and were collected at intervals of 4 to 6 weeks. The timely receipt of water data makes it possible not only to sense critical hydrologic events such as floods at their outset but also to monitor instruments daily and to identify sensor problems within hours rather than weeks.

# Acid Rain

Several cooperative studies completed during fiscal year 1981 provided valuable new information about acid rain. For a number of years, the Geological Survey has been collecting information on the chemical composition of precipitation as part of its Federal-State Cooperative Program, most notably in Florida, New York, North Carolina, and Pennsylvania. Survey hydrologists in Colorado and Wisconsin have been investigating the effects of acid precipitation on watersheds having limited buffering capacities. Data obtained from a reconnaissance study of snow chemistry in the Northeastern United States are being used to describe the occurrence and distribution of chemical constitutents in winter precipitation over the Northeastern United States from December 1980 to March 1981.

# Hazardous Wastes

In July 1981, the Survey replaced the Office of Radiohydrology with the Office of Hazardous Waste Hydrology to coordinate research and investigations related to the disposal of all types of hazardous waste, both radioactive and toxic-chemical. This organization change recognizes the fact that the transport of all types of waste through the environment is controlled by the same geologic, hydrologic, and geochemical conditions. The change is expected to improve the Survey's effectiveness in providing the technical information needed to alleviate a critical threat to public health and safety.

Work continued on the Survey's high-level radioactive-waste disposal program, which attempts to identify environments suitable as disposal sites for commercial power-reactor wastes. The geologic and hydrologic characteristics of broad physiographic provinces are used as a basis for screening successively smaller land units where potentially suitable repository sites might be located. The Basin and Range province, lying between the Rocky Mountains and the Sierra Nevada and Cascade Ranges, was selected for a prototype study to determine the feasibility of this method of identifying potential repository sites. A Province Working Group composed of earth scientists from the Geological Survey and the States of Arizona, California, Nevada, Idaho, Oregon, Utah, New Mexico, and Texas has been organized to conduct the screening and to recommend areas suitable for more intensive study.

# Oil and Gas Resource Estimates

The first 5-year review and revision of the Survey's systematic appraisal of undiscovered oil and gas resources of the United States, published in 1975 as Circular 725, was released in February 1981. The product of more than 80 specialists in the 137 petroleum provinces studied, the review disclosed relatively minor changes in the total amount of undiscovered oil estimated to exist in the United States but noted an encouraging increase in the estimate of total gas resources. New appraisals of both oil and gas resulted in substantial differences in a few provinces, where the acquisition of new data permitted more definitive estimates. A comparison of the two appraisals showing amounts estimated at 95- and 5-percent probability and the mean value for total undiscovered recoverable crude oil and natural gas is given below.

| *Commodity* | *1975* | *1981* |
|---|---|---|
| Crude oil, in billions of barrels | | |
| 95 percent (low) | 50 | 60 |
| 5 percent (high) | 127 | 105 |
| Mean | 82 | 83 |
| Natural gas, in trillion cubic feet | | |
| 95 percent (low) | 322 | 475 |
| 5 percent (high) | 655 | 739 |
| Mean | 484 | 594 |

# Digital Cartography

By fiscal year 1981, digital cartography had progressed to the point where this aspect of the Survey's national mapping functions began to take shape. A study conducted by the Office of Science and Technology Policy at the direction of the Office of Management and Budget verified the need for a national digital cartographic data base and recommended that the primary responsibility for the program within the Federal Government rest with the Geological Survey. The study determined further that the demand for digital cartographic products is such that the development of the data base could be financed from revenues resulting from the sale of the products.

This recommendation represents a sharp departure from the Survey's historic approach to product pricing, which previously had recovered only the actual cost of reproduction and distribution, not initial preparation, which was financed by annual appropriations. Because the change requires legislative action, the Secretary of the Interior forwarded to Congress a proposed "Digital Cartography Act of 1981," which was introduced in the Senate on May 21, 1981, as S-1280. The bill as introduced would provide for a gradual shift to full financing of all costs of ditigal cartographic products from sales revenues.

Development of the digital data base proceeded through fiscal year 1981 with plans to incorporate (1) data on boundaries, public land net, streams and water bodies, and transportation features on 1:24,000-scale maps; (2) elevation data largely obtained concurrent with the orthophotoquad program; (3) the planimetric features from the 1:2,000,000-scale sectional maps of the National Atlas; (4) elevation data obtained from the 1:250,000 scale maps series; (5) land use and land cover data; and (6) geographic names.

Progress in fiscal year 1981 was encouraging. Digital elevation models for 2,500 1:24,000-scale quadrangle maps were added to the data base, and boundary and net data for 2,000 quadrangles also were added. Elevation data from the 1:250,000-scale maps are now available for most of the United States. All 21 regional sheets of the National Atlas series were digitized, and editing is continuing.

# Organization and Management Notes

No significant changes were made in the formal organization of the U.S. Geological Survey during fiscal year 1981, which was devoted to consolidating and completing the thoroughgoing changes initiated during the previous year.

On September 30, 1981, in ceremonies held at the National Center in Reston, Virginia, Dallas L. Peck was sworn in as the eleventh Director of the U.S. Geological Survey, succeeding H. William Menard, who resigned the previous January to return to Scripps Institute at La Jolla, California. Peck, who had been the Survey's Chief Geologist for 4 years at the time of his appointment, has spent his entire professional career of 30 years with the Survey.

# Perspectives

## Chemical and Nuclear Wastes—Different Problems with Different Solutions?

**By John B. Robertson**

Although public awareness and concern for nuclear wastes have been evident for decades, we have only recently begun to take notice of a sleeping giant—toxic chemical waste contaminants. We have awakened during the past 2 years with the threats to our ground water from toxic waste sites like the Love Canal, New York, and the Valley of the Drums, Kentucky. It is clear that operating our complex, energy-hungry, industrial society has some undesirable risks and costs, not the least of which are hazardous wastes, which must be effectively dealt with. The waste-management issues are complicated not only by challenging technological questions but also by emotional, political, and ethical concerns. In this essay, I will attempt to place the broad question of hazardous waste management in clearer technical perspective with regard to the nuclear and toxic chemical viewpoints.

With the national attention that nuclear power projects have received, it might appear that nuclear wastes are a much bigger environmental threat than other wastes and that the technical barriers that must be overcome to dispose of the nuclear wastes safely are greater than those for chemical wastes. But are they?

Since the beginning of nuclear development in the 1940's, nuclear wastes have been strictly regulated by one principal Federal agency—first, the Atomic Energy Commission; later, the Energy Research and Development Administration; and currently, the Nuclear Regulatory Commission. (The Department of Energy regulates most nuclear wastes generated by activities of the Federal Government.)

Authority over toxic chemical waste management, however, has been incomplete and scattered through several agencies and regulations. Recently enacted laws such as the Resource Conservation and Recovery Act (1976) and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 ("Superfund") have helped to consolidate and expand Federal control of toxic waste management. In the 1980 U.S. Geological Survey *Yearbook*, Gerald Meyer summarized the evolution and complexity of Federal waste-management programs and their relationship to ground-water contamination problems.

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One fact that becomes clear through all this is that nuclear and chemical waste regulations have developed almost completely independently of each other with differing philosophies, technical approaches, and amounts of money and other resources applied to the problems. Even within the Environmental Protection Agency, for example, two separate groups address the two issues. For some time, the Geological Survey has had interests and activities devoted to earth science aspects of both chemical and radioactive waste disposal. Priority within the Geological Survey research program, in terms of dollars spent, was assigned to efforts dealing with radioactive wastes. Since the 1950's, the Survey has expended approximately five times more money and effort on research on radioactive waste than on toxic chemical waste.

### RELATIVE MAGNITUDE OF CHEMICAL AND NUCLEAR WASTE PROBLEMS

To gain some perspective on the relative magnitude of chemical and nuclear wastes, some comparisons can be made on quantities of wastes accumulated to date and current generation rates, extent of contamination problems resulting from the wastes, numbers of disposal sites, and sources and characteristics of the wastes.

Table 1 lists estimates of some of these characteristics. There are, of course, other important technical characteristics that also could be compared such as relative toxicity, mobility in ground water, and others. However, many of these become rather complex and are outside the expertise of the Geological Survey or beyond the scope of this review. Although admittedly simplified, the information in table 1 does serve to make the point that the volume and complexity of toxic chemical waste and existing contamination problems are much larger than those of nuclear wastes and could lead to the conclu-

Table 1.—*Some characteristics of nuclear wastes compared to those of toxic chemical wastes. Estimated volumes and other data in this table are based primarily on information from the documents listed at the foot of this table.*

| **Characteristics** | **Nuclear wastes** | **Toxic chemical wastes (liquids and solids)** |
|---|---|---|
| Estimated volumes on hand, 1980. | 70 million cubic yards, uranium mill tailings. 2 million cubic yards, all other nuclear waste. | 6 billion cubic yards. |
| Estimated yearly volume generated, 1980. | 1.5 million cubic yards, uranium mill tailings. 300,000 cubic yards, all other nuclear wastes. | 50 to 500 million cubic yards. |
| Number of known disposal or storage sites. | 42 uranium mill tailings sites 20 other major waste sites. Does not include nuclear-power reactors (70) where spent fuel is temporarily stored. | 7,000 to 100,000. Does not include municipal landfills and septic tanks. |
| Estimated area underlain by ground water contaminated beyond potable use. | 10 to 30 square miles | 1,000 to 10,000 square miles. |
| Residential populations affected by condemned groundwater supplies. | None known | More than 2 million. |
| Composition of the wastes. | Fairly well known | Extremely variable; largely unknown. |
| Principal sources of wastes. | Relatively few industrial and institutional activities; well known and regulated. | All sectors of public and industrial activities; poorly known and controlled. |

Gass, T E, 1980, *To What Extent is Ground Water Contaminated?: Water Well Journal*, November 1980, p 26–27

Landa, Edward, 1980, *Isolation of Uranium Mill Tailings and Their Component Radionuclides from the Biosphere—Some Earth-Science Perspectives:* U S Geological Survey Circular 814, 31 p

Pishdadazar, H and Moghissi, A A, 1980, Hazardous Waste Sites in the United States *Nuclear and Chemical Waste Management*, v 1, nos 3 and 4, p 161–309

U S Council on Environmental Quality, 1981, *Contamination of Ground Water by Toxic Organic Chemicals:* 85 p

U S Department of Energy, 1981, *Low-Level Radioactive Waste Policy Act Report—Response to Public Law 96-573*· DOE/NE 0015, 57 p

———1981, *Spent Fuel and Radioactive Waste Inventories and Projections as of December 31, 1980*· DOE/NE-0017, 279 p

U S Environmental Protection Agency, 1980, *Ground-Water Protection.* a Water Quality Management Report, 36 p.

sion that the magnitude of toxic chemical wastes problems is also considerably larger than that of nuclear wastes.

As a case in point, I am aware of only one well used for public drinking water that has been condemned due to radioactive waste contamination (near Argonne, Illinois), even though low-level radioactive wastes have been disposed to the subsurface in a variety of methods and sites since the 1940's. That is not to say that more ground water has not become contaminated with waste radionuclides; there are many instances where it has. Generally, these situations are in areas where no one is using the water and where its quality is well monitored. In contrast, toxic chemical contaminants have caused the condemnation of wells supplying drinking water to millions of residents across the Nation, from large cities to rural households.

Other aspects of table 1 worthy of amplification are the descriptions of types and sources of wastes. Radioactive wastes result from a relatively few well-known and documented sources. Although the physical forms of those wastes cover a broad spectrum—from sludge to paper and rubber gloves to machinery—the radionuclides present in them are generally fairly well known.

**. . . toxic chemical contaminants have caused the condemnation of wells supplying drinking water to millions of residents across the nation, from large cities to rural households.**

Toxic chemical wastes, on the other hand, result from almost every industrial, institutional, and household activity. There has been no central system of comprehensive documentation of toxic waste sources or even disposal sites. After so much publicity on Love Canal-type situations, I am sure that many people believe that these sites and the waste from large chemical companies are the biggest problem.

The Environmental Protection Agency has concluded that the most common toxic contaminants found in ground water are nitrates, heavy metals, and petroleum derivatives. In most areas, the most common sources of contamination are from common household septic systems Another large source of toxic waste contaminants is ordinary municipal waste landfills. Although I do not wish to diminish the concern for large industrial toxic waste-disposal sites, it is important to see them in the proper perspective. In addition to about 6,800 identified hazardous waste-disposal sites in the United States, there are probably 200,000 municipal landfills containing hazardous waste. Depleted pesticide, paint, and solvent containers and used motor oil (loaded with toxic metals and carcinogenic organic compounds) often are discarded in household trash which then contributes to the toxic contamination potential of our local landfills.

Nearly every community has leaky gasoline and oil tanks and pipelines; consequently, nearly every community has ground-water contamination from these sources. Many small businesses and industries common to most communities (dry cleaning and machine shops, for example) often are the source of toxic contaminants such as trichloroethylene in ground water.

The National Water Well Association estimates that only about 1 percent of the area underlain by usable ground water is contaminated from industrial wastes; unfortunately, however, the areas most contaminated are often areas of greatest water demand. Although that estimate includes effects of septic tanks and municipal landfills, it fails to include ground water contaminants from agricultural sources which might easily double the figure.

## WHAT IS THE ROLE OF EARTH SCIENCE?

Over one-half the people in this Nation rely on ground water as their source of drinking water. Understanding the behavior and fate of contaminants in this resource is a highly important technical concern. Among the most important technical aspects of waste disposal are the physical, biological, and chemical processes that affect contaminants beneath the ground surface. The ultimate goal is to minimize the rate at which contaminants migrate from disposal or spill sites, thus keeping contaminated concentrations in ground water and areas of contamination to a minimum. Figure 1 schematically depicts the manner in which contaminants from a variety of sources can enter and migrate in ground-water systems. The major processes which control the occurrence, concentration, migration rate, and fate of contaminants in ground water are described in table 2. It should be clear from table 2 that the processes which control contaminants in ground water are extremely complex and interdependent. Also, it is apparent that, in general, nearly all the same fundamental processes apply to most contaminants, regardless of their source or whether they are radioactively or chemically toxic. One basic difference between nuclear and chemical wastes is important: Nuclear materials all have decay rates that can be accurately calculated, whereas chemical wastes do not. Heavy metal contaminants, such as mercury and lead, have *no* decay rates and some stable organic compounds such as polychlorinated biphenyls (PCB's) are extremely persistent. However, many other toxic organic compounds do decompose with time due to chemical and biochemical breakdown.

**The Environmental Protection Agency has concluded that the most common toxic contaminants found in ground water are nitrates, heavy metals, and petroleum derivatives. In most areas, the most common sources of contamination are household septic systems.**

Other important earth science concerns are geologic and hydrologic factors which can affect the long-term ability of a disposal or storage site to isolate waste produced from the biosphere. These factors would include effects of geologic faulting, earthquakes, volcanism, and erosion. Some radioactive and chemical waste products require isolation periods of hundreds of thousands of years or longer to permit the radioactive wastes to decay to innocuous levels, or disperse, or reduce the chemical wastes to an acceptable concentration level or a harmless form. Therefore, very long-range predictions of infrequent or

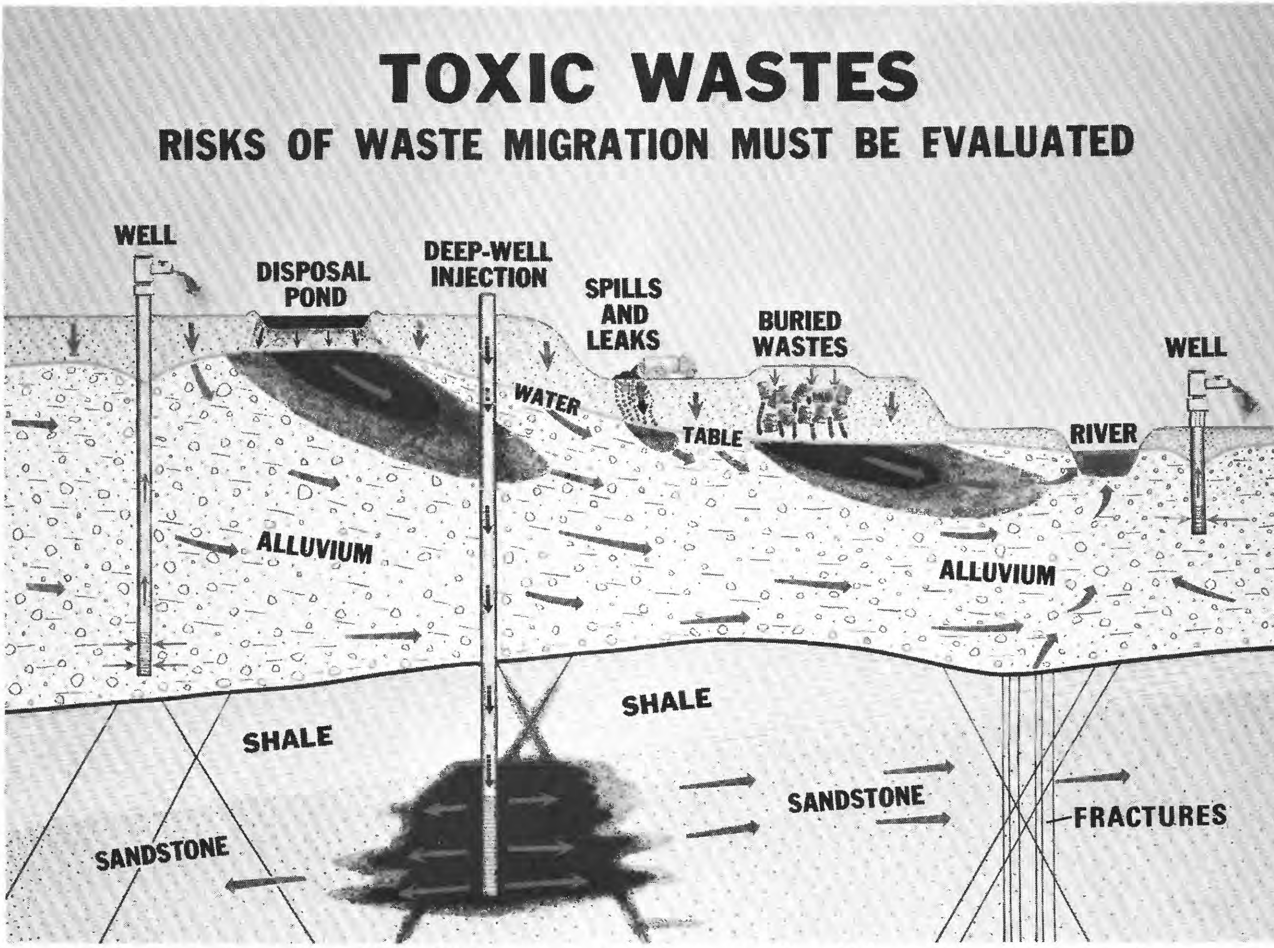



FIGURE 1.—*A schematic profile to illustrate some typical processes by which ground-water resources become contaminated.*

slow geologic processes are required to assure isolation. The technology for making such predictions with confidence has not been developed. However, much progress has been made in the past decade, largely in connection with nuclear waste-disposal studies.

If we had a thorough understanding of all the pertinent processes in a wide spectrum of environments for all the major contaminants, we would be in a good position to make the informed decisions on problems of waste management that are sorely needed. We are not in that position at this time. In fact, we have only barely scratched the surface on some of the subjects, such as biotransformation reactions in the subsurface. Although we have sophisticated mathematical models which simulate many aspects of contaminant movement and reaction in the subsurface, we have not developed the means to adquately measure all the parameters that need to go into these models, nor have we demonstrated that the models provide the right answers on a sufficient number and variety of actual field contamination problems.

## THE CHALLENGES AHEAD: WHERE ARE WE GOING AND WHERE SHOULD WE BE GOING?

As the magnitude of ground-water contamination problems and the disparity in the level of attention devoted to radioactive wastes versus chemical wastes became clearer in recent years, the Geological Survey moved toward treating these problems as one integrated interdisciplinary concern. We believe that these complex technical issues are amenable to solutions but only through a carefully planned and coordinated systematic approach.

The principal scientific questions and challenges remaining are:

- What techniques can most effectively be used to control or reduce existing or potential contamination problems?

Table 2.—*Processes controlling the fate of contaminants in ground water*

| Physical processes | Description of process | Effect of process |
|---|---|---|
| Ground-water flow | Ground water flows through pores and fractures in rocks and soil. | Carries dissolved or suspended contaminants with it. |
| Dispersion | Ground water flows faster in some pores or cracks than in others; when contaminated water meets clean water, they mix. | Reduces concentrations but spreads extent of contaminants. |
| Buoyant effects[1] | Lighter liquids, such as gasoline, tend to float on top of water; denser liquids tend to sink. | Can concentrate zone of contaminants at bottom or top of aquifer depending on density of the waste liquid. |
| Filtration | Porous soils and rocks can physically filter out contaminant particles suspended in ground water. | Reduces concentration of suspended contaminants in ground water. |
| Radioactive decay[2] | Changes the atomic structure of the element. | Reduces concentration of waste elements at predictable rates. |
| Volatilization[1] | Volatile contaminants evaporate from the water table into an unsaturated zone or the atmosphere. | Reduces concentration of volatile contaminants. |
| Thermal effects | Heat from waste affects physical properties of water and chemical properties of wastes. | Variable. |
| **Chemical processes** | **Description of process** | **Effect of process** |
| Adsorption and ion-exchange. | Some dissolved contaminants tend to adhere to mineral surfaces rather than remain in solution. | Reduces concentration and (or) migration rate. |
| Oxidation-reduction reaction. | Changes the molecular structure and ionic properties of contaminants. | Can change toxicity and chemical behavior and mobility of contaminants. |
| Hydrolysis | Reaction with water which changes the molecular and ionic nature of contaminants. | Do. |
| Complexation | Dissolved contaminants join with other dissolved compounds to form new products. | Can increase mobility of contaminants and otherwise change chemical behavior. |
| **Biological processes** | **Description of process** | **Effect of process** |
| Microbiochemical transformations[1] | Bacteria and other microbes in ground water alter or decompose organic (and a few inorganic) contaminants through enzymatic and respiration reactions. | Can reduce concentration of some contaminants; also can create new toxic products. |

[1]These processes are much more important for toxic chemical wastes than for radioactive waste.

[2]Does not apply to toxic chemical wastes.

- What earth science guidelines are needed to properly select, design, operate, close, and monitor future waste-storage and waste-disposal sites?
- What techniques are needed to characterize potential storage and disposal sites and to demonstrate they will meet required performance criteria?

To address some aspects of these questions for radioactive waste, the Survey conducted studies through the former Office of Radiohydrology. Some facets of the toxic chemical waste question have been investigated through a separate program of the Water Resources Division Subsurface Waste Disposal Investigations. In fiscal year 1981, to enhance and broaden coordinated efforts to encompass both toxic chemical and radioactive wastes, the Survey replaced the Office of Radiohydrology with the Office of Hazardous Waste Hydrology and designed a new broadened research program beginning in fiscal year 1982 to provide better and more timely answers to the questions.

This program includes the following elements:

**High-level radioactive wastes**

- To assist the Department of Energy in establishing repository site selection criteria and selecting and characterizing potential sites and the Nuclear Regulatory Commission in developing regulations and in licensing repository sites.
- To conduct our own independent program of research on geochemistry of plutonium and related isotopes in ground water; flow of fluids and radionuclides through porous and fractured materials, including improved mathematical simulation models; thermomechanical properties of rocks; development of geophysical techniques to measure physical and chemical properties of rock masses; and the characterization of long-term geologic processes and events that could disrupt potential repository sites.
- To screen large areas of the nation to identify regions having favorable characteristics for locating potential waste repository sites.

**Low-level radioactive wastes**

- To conduct fundamental research and field investigations into processes controlling leaching and migration of radionuclides from shallow land-disposal sites.
- To develop earth science technical guidelines for the selection and design of future sites and for remedial measures at existing sites where site performance does not appear to be adequate.
- To assist other Federal and State agencies in developing and implementing effective low-level waste-management programs.

**Toxic chemical wastes**

(These activities are planned to be initiated over the next 3 fiscal years in accordance with available funding and personnel.)

- To conduct fundamental research into surface chemistry, biochemistry, and other chemical factors controlling the mobility and fate of organic chemicals and toxic inorganic substances in ground water.
- To conduct intensive interdisciplinary field research of a few selected disposal or contamination sites to characterize the most important earth science processes affecting the fate of contaminants.
- To assist other Federal and State agencies in developing regulations and standards for managing hazardous waste disposal.
- To assess the general extent and magnitude of ground-water contamination across the Nation.
- To screen large regions of the Nation for potentially favorable disposal sites.
- To evaluate the feasibility of using field techniques to improve the quality of contaminated ground water.

Other agencies, such as the Environmental Protection Agency, are conducting related research on important aspects of the problem which will fit additional pieces into the puzzle. Over the next decade or two, some exciting and important advancements in technology are likely to be made if planned programs are implemented properly and carried out.

**The ultimate goal is to minimize the rate at which contaminants migrate from disposal or spill sites thus keeping contaminated concentrations in ground water and areas of contamination to a minimum.**

As scientists, we know we will never find all the answers to problems of hazardous waste management, but every step forward at this stage will provide significant benefits to the public. Our wastes can be managed and related ground-water contamination problems can be reduced greatly if appropriate attention is addressed, not only to the earth science questions, but also to the socio-political concerns. Radioactive wastes and toxic chemical wastes must be viewed in proper perspective to each other. I am not suggesting that we reduce our effort to solve the radioactive waste question, but rather that our attention to the chemical waste problem be evaluated and integrated into one concern for the disposition of hazardous contaminants in our environment. This requires that scientists, legislators, regulators, and the public in general develop a realistic and objective understanding of the relative risks of exposure to these materials and the ultimate importance of waste-disposal practices to our lives and those of future generations.

*John Robertson is a pioneer in the application of computer simulation techniques to studies involving transport of pollutants in ground water. He has authored 35 papers on the behavior and fate of organic contaminants and radionuclides in ground water.*

# Petroleum Exploration in the National Petroleum Reserve in Alaska

by George Gryc

## INTRODUCTION

The completion of Awuna Test Well No. 1 on April 20, 1981, brought to a close the Federal Government's second exploration program (1974-81) in the National Petroleum Reserve in Alaska, formerly Naval Petroleum Reserve No. 4. Twenty-eight test wells—a total of 283,877 feet of borehole—were drilled on 26 "structures." [1] The tests were widely spaced over most of the Reserve and located in several different geologic settings to provide a basis for evaluating the resource of the entire Reserve. In addition, 13,455 line-miles of common-depth-point seismic surveys were completed and interpreted for most of the Reserve. New engineering, operational, and logistics techniques were devised to expedite the work and to minimize its impact on the environment. Each activity site was cleaned and rehabilitated after drilling was completed, and long-abandoned drilling and building sites in and adjacent to the Reserve were cleaned up and revegetated.

Nearly all of the test wells had at least traces, or shows, of oil, gas or both. A new small gasfield (12 billion cubic feet of producible reserve) was discovered 7 miles east of the South Barrow gasfield, and a new, potentially large gasfield was discovered at Walakpa, 14 miles southwest of Barrow. Determining the full extent of this gas accumulation and its potential for commercial development will require further drilling an analysis. Additional propects for gas accumulations in the Barrow area have been defined.

Except for the East Barrow gasfield, which is important to the local economy, no commercial deposits of oil or gas were discovered by this latest exploration program. What, then, has this program contributed to our national energy needs or to the advancement of the knowledge base on which future energy policy and planning decisions can be based?

## HISTORICAL PERSPECTIVE

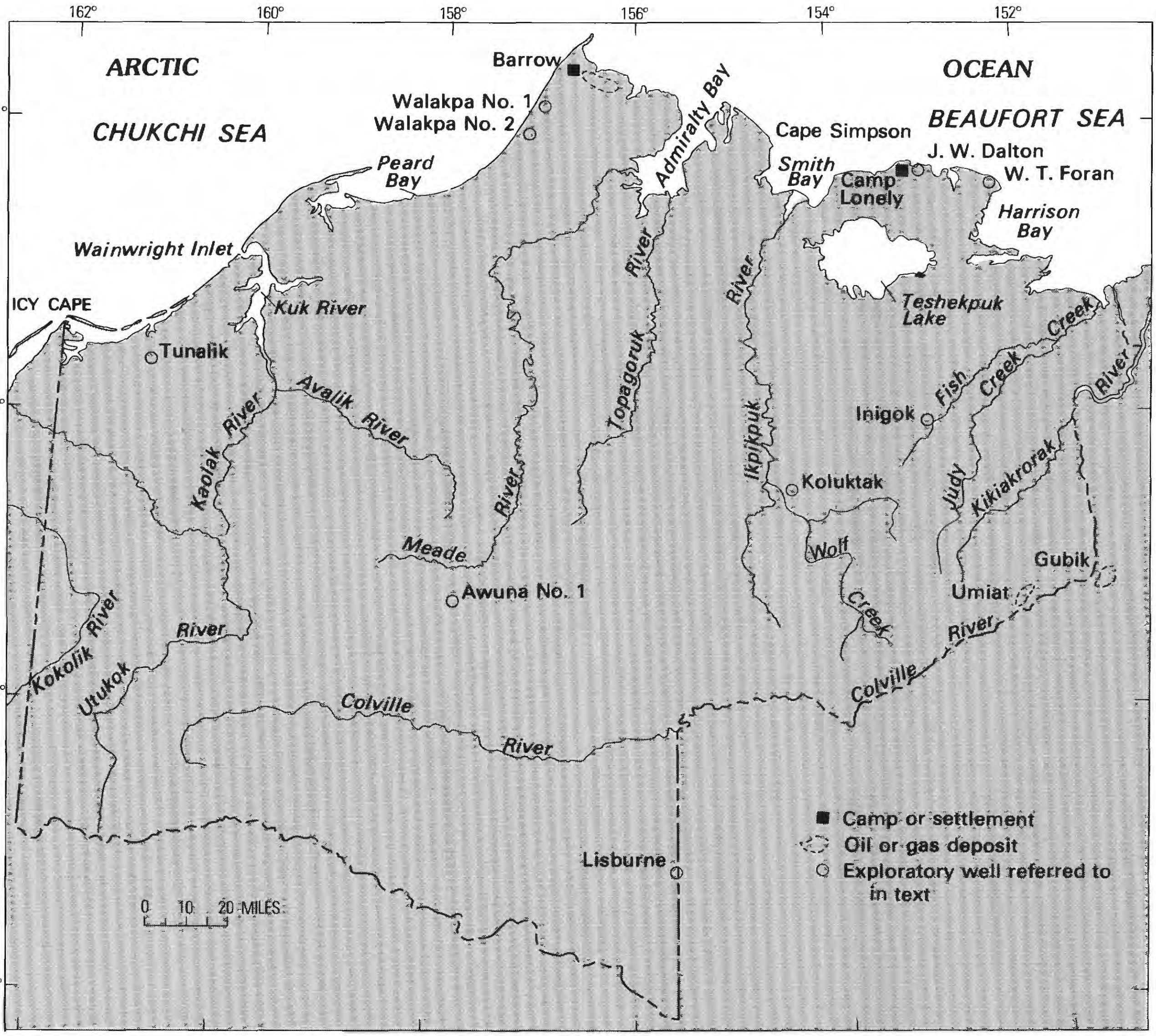
Any assessment of the Federal programs conducted in the National Petroleum Reserve in Alaska, including the one just completed, must be made in the context of the directives, the political setting, and the technology available when the program began. Nearly 60 years have passed since President Warren G. Harding signed an Executive Order on February 27, 1923, setting aside about 37,000 square miles of Northern Alaska as Naval Petroleum Reserve No. 4. The Order reads, in part, "Whereas there are large seepages of petroleum along the Arctic Coast of Alaska, and conditions favorable to the occurrence of valuable petroleum fields on the Arctic Coast and . . . Whereas the future supply of oil for the Navy is at all times a matter of national concern . . . [this order does] hereby set apart [the designated area] as a Naval Petroleum Reserve . . . " Thus, by 1923, the possibility that there were significant hydrocarbon deposits in northern Alaska was already recognized.

The first recorded description of oil seepages was sent to the U.S. Geological Survey by E. de K. Leffingwell in 1906 and published by A. H. Brooks (1909). Probably long before recorded history, the Eskimos harvested tar mats from the seepages and combustible oil shales found along major streams for fuel. What was undoubtedly oil shale was reported and described by W. L. Howard of the Stoney Expedition on his 1886 trip down the Etivluk River (within the area that was to become the National Petroleum Reserve in Alaska) (Stoney, 1900).

Several expedition traversed the Arctic Coast and the Brooks Range before 1900, but their objectives were primarily geographic and contributed little to the geologic knowledge of the region. The first recorded geologic traverse across the Brooks Range and the North Slope was made by W. J. Peters and F. C. Schrader in 1901, and the results were published in 1904 by the U.S. Geological Survey (Schrader, 1904). Schrader named and described the Lisburne limestone formation of Mississippian age and described in considerable detail the Cretaceous rocks and the broad anticlinal structures in the foothills of the North Slope. Both of these rock units and this type of structure have proved to be commercially productive in the Prudhoe Bay district.

From 1906 to 1914, Leffingwell mapped the Arctic Coast east of Barrow and traversed inland in the Canning River region. His classic report (Leffingwell, 1919) is still an important and useful

[1] For specific data on well locations, depths, and discovery results, see chapter beginning on page 128




*Location map showing the National Petroleum Reserve in Alaska.*

reference, especially on the subject of permafrost. Leffingwell described and named the now-famous oil-bearing Sadlerochit sandstone in the Prudhoe Bay field. In 1917, "Sandy" Smith examined the oil seepages along the Arctic Coast and stimulated the interest of the oil industry. In 1921, several applications for prospecting permits were initiated under the old mining laws on claims near Cape Simpson and Peard Bay and along the Meade, Kukpowruk, and Kokolik Rivers. An excellent summary of these early expeditions and geologic studies was presented by Smith and Mertie (1930).

Thus, by 1923, the three main requirements for hydrocarbon accumulations—source rocks (oil shale and other organic sedimentary rocks), reservoir rocks (limestones and sandstones), and traps (anticlinal structures)—were known to be present in the area that was to become the National Petroleum Reserve in Alaska. After the establishment of Naval Petroleum Reserve No. 4, the U.S. Navy recognized that, more complete geologic and geographic information was necessary for wise management and further assessment of the petroleum resources. From 1923 through 1926, the U.S. Geological Survey traversed most of the larger rivers crossing the Reserve and mapped the geology and geography at reconnaissance scales.

The results of these surveys were published by Smith and Mertie (1930), who recorded and described (1) the oil seepages, especially those on the Simpson Penninsula; (2) the widespread occurrence of oil shales as a possible source rock; and (3) the many anticlinal structures in rocks of Cretaceous age, including sandstones that could provide traps and reservoirs for petroleum accumulations. Smith and Mertie studied the Lisburne limestone and discussed the possibility that these rocks were a source or a reservoir or both. They concluded, however, that the Lisburne was complexly broken and faulted in the area of exposure and too deeply buried along the coast to be important as a petroleum source or a reservoir, "unless there are great structural discordances."

We now know that, despite the reservations expressed by Smith and Mertie, there are, indeed, such discordances and that they are perhaps the most significant factors in the complex geologic history of the Prudhoe Bay deposit, the largest oilfield in North America. Smith and Mertie also cautioned would-be prospectors about the area's adverse geographic conditions and the resultant high costs of exploration. The geologic insight and long-range perspective documented by the Smith and Mertie (1930) paper is truly remarkable, considering the limited knowledge available at that time.

Nothing more was done to explore the petroleum potential of the Reserve until 1944, when the Pet-4 program was undertaken by the Navy as a wartime effort. The history of this program and much of the technical data collected were published in a series of U.S. Geological Survey Professional Papers (Robinson and Bergquist, 1956, 1958a, b, c; Patton, 1957; Bowsher and Dutro, 1957; Collins and others, 1958; Collins and Bergquist, 1958a, b, 1959; Reed, 1958; Patton and Matzko, 1959; Spetzman, 1959; Robinson and Collins, 1959; Robinson and Yuster, 1959; Chapman and Sable, 1960; Keller, Morris, and Detterman, 1961; Brewer, 1961; Woolson and others, 1962; Detterman, Bickel and Gryc, 1963; Black, 1964; Bergquist, 1966; Chapman, Detterman and Mangus, 1964; Patton and Tailleur, 1964; Robinson and Brewer, 1964; Brosge, Whittington, and Morris, 1966). A short summary of the exploration stategy of that program was published by Gyrc (1970). From 1945 through 1952, 45 shallow core tests and 36 relatively shallow test wells were drilled, for a total of 169,250 feet of borehole, and about 3,357 line-miles of reflection seismic surveys and 391 line-miles of refraction seismic surveys were completed within and immediately adjacent to the Reserve.

The results of the Pet-4 program include the discovery of one large oilfield at Umiat (70 million barrels of producible high-grade crude oil); one small gas deposit at Barrow (25 million cubic feet of producible gas); one potentially larger gas deposit at Gubik; three prospective gasfields at Meade, Square Lake, and Wolf Creek; and two minor oil accumulations near the seepages at Cape Simpson and Fish Creek. Perhaps the Pet-4 program's greatest contribution was to establish firmly, for the first time, the feasibility and practicality of operating a large-scale oil-exploration program, including geologic and geophysical surveys and studies and test drilling, in the Arctic.

In 1958, Public Land Order 82, which had withdrawn public lands in Alaska from entry in 1943, was cancelled, and these lands became available for lease. Private drilling begun in 1963 outside of the Reserve at first followed up on trends and leads provided by the Pet-4 program but event ually began looking at new prospects to the north and east. In 1968, the discovery of Prudhoe Bay was announced. This field, about 60 miles east of the Reserve initially was estimated to contain a producible reserve of 9.6 billion barrels of crude oil and 26 trillion cubic feet of gas. Additional reserves of oil are now being developed in the Kuparuk field just west of the Prudhoe Bay deposit, and new fields to the east and just offshore also have been discovered, although no reserve figures have been published.

## EXPLORATION OF THE NATIONAL PETROLEUM RESERVE IN ALASKA, 1974–81

Stimulated by the discovery at Prudhoe Bay and seizing the opportunity by the Arab oil embargo of 1974, the Navy proposed and was authorized by Congress to begin another exploration program in Naval Petroleum Reserve No. 4. The plan, entitled "Engineering Plan for Assessment and Evaluation of NPR-4," called for exploring the Reserve systematically, from the northeastern corner to the southwestern corner, completing geophysical surveys, and establishing logistics bases in advance of drilling. Twenty-six test wells and 10,235 line-miles of geophysical surveys were to be completed over a 7-year period, later reduced to 5 years. At an earlier stage in planning, it was suggested also that the Umiat oilfield be produced and a small topping plant be installed to provide fuel for the rest of the program. This proposal was dropped from the final plan.

Between 1974 and 1977, the Navy used private oil-exploration contractors to drill seven wells in the northeastern corner of the Reserve, following the Prudhoe trend and hoping for similar results but with no success. The Navy also drilled four exploration wells in the Barrow area to increase gas reserves for local use and discovered, about 7 miles east of the South Barrow field, the East Barrow deposit, which had an estimated producible reserve of 12 billion cubic feet of gas.

In 1975, the Navy signed a 5-year contract with Husky NPR Operations, Inc., to manage and supervise all aspects of the exploration program. Four of the seven test wells in the northeastern corner of the Reserve were drilled for the Navy under the Husky contract.

The Naval Petroleum Reserves Production Act of April 5, 1976, authorized further development of and actual production and sale of crude oil from Naval Petroleum Reserves Nos. 1, 2, and 3 in California and Wyoming, and redesignated Naval Petroleum Reserve No. 4 as the National Petroleum Reserve in Alaska. Thus, the purpose of these Reserves was redirected from meeting naval requirements to augmenting domesting supplies of crude oil. The Act also mandated continuing the exploration program in the Reserve and required studies of other resources and alternative management systems, all to be completed and submitted to Congress by January 1980. Although the exploration program was not tied directly to the schedules of other studies in the Act, its results obviously would have had considerable influence on further land-use decisions. The Navy's 5-year plan, containing a schedule for the exploration program was stated for completion in 1980.

The Act transferred responsibility for the National Petroleum Reserve in Alaska to the Secretary of the Interior, who in turn assigned to the U.S. Geological Survey three responsibilities: (1) continuation of the exploration program, (2) continuation of operations, maintenance, and production at the Barrow gasfields, and (3) cleanup of debris left over from previous activities in and adjacent to the Reserve. The Navy's 5-year contract with Husky NPR Operations, Inc., as well as other minor contracts, also was transferred to the Geological Survey, in accordance with the Act. The Navy had moved the operational base for the exploration program from Barrow to Camp Lonely, 90 miles east on the Arctic coast. The Barrow gasfield had been operated and maintained for the preceding several years under an interservice agreement with the Office of Naval Research and its contractor for the operation of the Naval Arctic Research Laboratory at Barrow. This arrangement has been continued by the Survey. Until Congress directs otherwise, the Department of Interior will continue to be responsible for supplying gas to the Barrow community.

Thus, when the U.S. Geological Survey took over supervision of the exploration program on June 1, 1977, several constraints were already in place. The program was oriented toward future land-use decisions—national in scope rather than naval—and a timetable was imposed both by the reports that the Act required and by the 5-year contract transferred from the Navy. Further, a base of operations and an overall logistics capability already had been established. Three drill rigs capable of drilling to about 20,000 feet and one capable of reaching somewhat shallower depths were under subcontract. Another drilling rig was contracted for later drilling of shallow (2,500 feet) development wells at the Barrow gasfields. These subcontracts, along with others for services such as transportation, communication, and operation of the Camp Lonely base facility, constituted fixed costs. An additional, and perhaps the most significant, constraint on program planning in the Arctic was the absolute necessity to time activities to the seasons. To maintain a four- or five-well drilling program, each winter's activities had to be planned and coordinated on an extremely tight schedule. Logistics planning had to be completed at least 1 year in advance, and final locations had to be determined about 6 months in advance. Geophysical surveys were shot the winter before drilling was to begin, but interpretations of these surveys were not completed until a few weeks or days before the locations had to be staked. An environmental assessment, including archeologic clearance, had to be completed before work at the site began. An excellent review of this subject and other environmental considerations in the Reserve appeared in the "U.S. Geological Survey Yearbook, Fiscal Year 1978" (Britton, 1978).

Within these planning constraints and with the 1977-78 drilling season more or less already established by the Navy as of June 1, 1977, the Geological Survey reviewed the plan and various exploration strategies in an attempt to meet the objectives of the Naval Petroleum Reserves Production Act. The prime objective was defined as an assessment of oil and gas in the entire Reserve—an area of 37,000 square miles, or more than 23 million acres. An important but secondary objective was the discovery of commercially producible deposits. Thus, all tests were located "on structure" to the extent that it could be determined from the available data. To meet these objectives and to develop an exploration strategy through 1980, the Survey made a "play" analysis. (A "play" is defined as a group or cluster of prospects having similar geological and geophysical characteristics.) Characteristics considered included the presence or absence of source rocks, reservoir beds, and traps; thermal history; the timing of oil generation and migration; and the history of trap formation. Originally, 10 plays were defined, 9 largely on the basis of specific stratigraphic units or of closely related units. The remaining play was a geologic and geographic "belt" that included several formations in a complex structural setting. Potential source rocks are present throughout the Reserve, and traps in the form of closed structures are abundant in the foothills and in the disturbed belt north of the Brooks Range. Closed structures, however, are scarce in the northern part of the Reserve, and trapping mechanisms, if they are present, are controlled by stratigraphy, unconformities, pinch-outs, and the like. These factors were all considered in the play analysis. It was proposed finally that the exploration strategy should call for at least two exploration test wells in each play to provide specific subsurface information and to discover any deposits that might exist within the area of the play; some followup test wells also were included in the strategy. It was concluded that about 20 to 40 test wells would have to be drilled to further refine the play approach, to assess which part of the Reserve had the greatest potential, and to make a more reliable assessment of resources in the entire Reserve. At no time, however, was it believed that 20 or even 40 wells would provide a definitive assessment of the hydrocarbon potential of the National Petroleum Reserve in Alaska.

## HIGHLIGHTS OF DRILLING RESULTS

In all, 28 exploration wells were drilled during the 1974–81 program. All of the technical data gathered from these test wells have been released and can be obtained from the National Geophysical and Solar Terrestrial Data Center, National Oceanic and Atmospheric Administration, 325 Broadway, Boulder, Colorado 80303. All geophysical surveys and data are also available; all technical reports submitted by the prime contractor and by subcontractors either have been or will be released through that office, as well. Annual program summaries for 1977 through 1981 have been published by the U.S. Geological Survey in the Yearbooks.

A review of drilling results is most meaningful if the reviewer has an in-depth knowledge of the regional geology. Although such a discussion is beyond the scope of this essay, a few general comments will illustrate what the program has contributed to the knowledge base and to the understanding of the hydrocarbon potential of the National Petroleum Reserve in Alaska.

Basement rocks (that is, rocks with little or no hydrocarbon potential) rise from a depth of about 10,000 feet at Prudhoe Bay to their shallowest point at Barrow, where basement is at a depth of only 2,300 feet. These basement rocks dip south under the Reserve to a depth of a least 25,000 feet at about the latitude of the Colville River and then are exposed at the surface in the Brooks Range, where they form a trough of sedimentary rocks generally referred to as the Colville trough or geosyncline. All of the area underlain by this thick section of sedimentary rocks is considered a potential province for hydrocarbon accumulation. The Reserve covers about half of the province.

The seven wells drilled by the Navy between 1974 and 1977 explored the extension of the Prudhoe-Barrow trend into the Reserve. Perhaps the W. T. Foran Test Well came the closest to duplicating the geologic setting of Prudhoe Bay. A similar sequence of rocks was penetrated, and good porosity and permeability were present in the Sadlerochit formation, the main producing horizon at Prudhoe Bay. Although the test well produced only water, good oil and gas shows were present at several horizons. The Geological Survey's prime contractor, Husky, drilled nine more tests along the Prudhoe Bay trend, which includes several of what are believed to be the more favorable plays. Furthermore, because the sedimentary section above basement is no more than 10,000 feet thick and near the coast, development of a deposit there would be less expensive than it would be in the deeper and more remote parts of the Reserve. The J. W. Dalton Test Well, on the Arctic coast, also penetrated nearly 800 feet of sandstone and limestone having good porosity and permeability in the Sadlerochit and Lisburne formations, but only heavy residual oil was produced on test. There are good indications that the Dalton and Foran test wells represent older accumulations of oil that have moved basinward as the Arctic Ocean subsided. A Prudhoe Bay–type deposit may be present just offshore of the Reserve.

Several test wells were drilled on the southern flank of the Prudhoe-Barrow trend to test the onlap edges of potential reservoirs of Early Cretaceous and Jurassic age. The Survey test well at Walakpa No. 1, 14 miles southeast of Barrow, penetrated a 20-foot gas sand at a depth of about 2,075 feet. A followup well 5 miles to the south of Walakpa No 1 penetrated 40 feet of the same gas sand. Tests show that each well could produce up to 3 million cubic feet of gas per day. At that rate, however, gas hydrates form and shut off the flow. If this problem can be solved, it may be possible to obtain higher flow rates. Ascertaining the full extent of this deposit will require additional drilling, but a reserve of several hundred billion cubic feet of gas may be present in the Barrow area.

Test wells farther south on the downslope of the Prudhoe-Barrow trend were drilled to test the wedge edge of the Lisburne group of Mississippian and Permian age. Although limestones of this age were penetrated, none had the porosity and permeability required to provide a good reservoir in which oil could have accumulated.

Two wells, Inigok and Tunalik, were drilled in the center of the sedimentary trough to test deep structures and older formations just above basement. The Inigok Test Well encountered hydrogen sulfide gas at 17,570 feet and bottomed at 20,102 feet in rocks of Mississippian age, but only minor shows of gas in Cretaceous rocks were noted. The Tunalik Test Well, in the extreme northwestern corner of the Reserve, encountered high-pressure gas at 12,550 and 14,725 feet in sandstone reservoirs of Early Cretaceous age. The test well bottomed in the Lisburne group at 20,335 feet, a new depth record for Alaska.

The shallow detached structures in rock of Cretaceous age in the central part of the Reserve were not tested in the early stages of this program because they had been drilled extensively in the 1945–53 program. Oil had been discovered at Umiat, and gas had been found at Gubik; thus, some assessment of this play was available. Other potential gas deposits also were encountered, but possible flow rates were not tested because gas in northern Alaska was of little or no economic interest at that time. However, in the latter stages of the 1974–81 program, it was deemed important to test and establish the potential gas reserves of these shallow structures and especially to test the entire Cretaceous sequence. Thus, the deeper horizons on the Umiat structure were tested, a high-pressure gas zone in the Cretaceous was penetrated at 5,340 feet. Tests indicated a depleting reservoir, however, and, after initial tests of up to 6 million cubic feet per day, production dropped sharply. At Awuna Test Well No. 1, highly fractured sandstone beds were drilled at about 8,400 feet in the Fortress Mountain formation of Early Cretaceous age. Tests produced strong blows of gas and a water flow of more than 2,000 barrels per day. From that point to the well's total depth of 11,200 feet, the rocks penetrated were predominantly fractured sandstones having several zones of high-water flow. The Koluktak test well was designed to test the potential of gas sandstone reservoirs equivalent to those at Gubik and Umiat. However, the test was a dry hole, and no further information was acquired on potential flow rates or reserves in this play.

The tenth play is defined as the Disturbed Belt, an area of complexly folded and broken thrust faults along the northern front of the Brooks Range. The structure of these rocks is very difficult to map and interpret. A test drilled at Lisburne on what appeared to be a closed structure encountered only minor hydrocarbon shows. The well penetrated at least five stacked plates and possibly seven plates of the Lisburne formation, further documenting the complex geologic history of this play.

During Congressional hearings for the fiscal year 1981 program, a number of members asked that discovery of commercial deposits be made the prime objective; accordingly, the focus of the program was returned to the shallower prospects along the Prudhoe-Barrow trend. This redirection resulted in the discovery at Walakpa Test Well No. 2 which may prove to be a large gas deposit of considerable interest as an energy source, at least locally. The exploration and development of local sources of energy fuels, here and elsewhere in the United States, are of considerable significance to national fuel requirements.

The Congressional mandate to continue supplying gas to the Barrow community also required drilling additional test and production wells in that area. Six wells were drilled, and four were completed for production.

## A LOOK AHEAD

Although the exploration program just concluded did not find any commercial hydrocarbon deposits, it did provide a new and more sophisticated knowledge base for further assessment and exploration of the Reserve. All geological, geophysical, and geochemical data collected and analyzed systematically over the entire Reserve have been or are being made available to the general public. This set of data may be unique for so large an area in a single petroleum province because it was collected systematically in a relatively short time and was made readily available to the public.

As the exploration progressed, several appraisals of the potential hydrocarbon resources of the Reserve were made. The latest appraisal was made available by the Department of Interior in a press release dated July 17, 1980. The release reads, "The new estimates suggest a 95 percent chance of 0.55 billion barrels of oil in place, a 5 percent chance of 15.8 billion barrels, and a 50 percent probability that 5.2 billions barrels of oil are contained in the Reserve. Revised figures for gas in place show a 95 percent chance of 2.5 trillion cubic feet (tcf), a 5 percent chance of 27.4 tcf, and a 50 percent chance of 9.4 tcf." All these figures were generated by a somewhat complicated, computer-based probability analysis that used as its geologic base the play concept. The 10 original plays were subdivided into 17 separate plays; several factors for each were evaluated quantitatively by a knowledgeable geologic team. Positive information on these factors is limited, however, and wide ranges of values had to be assigned on the basis of geologic judgements. The probability analyses sampled these values statistically. Obviously, as new data are collected, these values will change; thus, the range of values having assigned probability is the most significant and useful information to result from such assessments.

In the Department of Interior Appropriation Act for fiscal year 1982, Congress agreed to terminate Federal exploration and authorized a leasing program in the Reserve to begin in 1982. The leasing of up to 2 million acres without a new environmental impact statement was authorized. A call for lease nominations went out to all interested parties, and nearly all of the 23 million plus acres were nominated. The Geological Survey and the Bureau of Land Management selected 5.8 million of those acres for further study; 1.5 million acres have now been earmarked for lease in December 1981, and another 0.5 million acres will be available for lease in May 1982. Further lease sales will follow, but no schedule has been announced.

The 1974-81 exploration program has shown that vast quantities of oil and gas must have been generated in the Reserve portion of the Colville sedimentary trough. The existence of the Prudhoe Bay field has proved that at least one giant deposit and several other large deposits did accumulate in the eastern part of the trough. Substantial deposits of oil and probably of gas have been discovered by government exploration programs within the Reserve. The existence of deposits large enough to warrant economic development in the Reserve has not been proven or disproven. The government exploration program of 1944-53 led the way for modern oil exploration in the Arctic. The 1974-81 program has gathered a treasure trove of data from which new interpretations of Alaskan geology can be derived.

All of this information is readily available in public files and provides a sound base for making further land-use decisions and resource assessments and for the next stage of exploration by private industry.

*As Chief of the Office of the National Petroleum Reserve in Alaska, George Gryc directed all U.S. Geological Survey programs and activities described in this essay from July 1977 until his departure in October 1981 to become Assistant Director for the Western Region. He has specialized in Alaskan geology and mineralogy since 1943 and is author or coauthor of more than 50 papers in his field.*

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# 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, the investigaton of the "geological structure, mineral resources and products of the national domain." A number of laws and executive orders since have expanded the scope of the Survey's scientific responsibilities, both as to function and geographic extent.

Although established primarily as a scientific agency, the Geological Survey had from its beginning the responsibility for classifying Federal lands as to their mineral and waterpower potential—a function it still discharges. In 1925, it was given the further responsibility for supervising the operations of private parties exploring for and producing minerals from Federal and Indian lands under leases and permits. This responsibility was extended to the Federal portion of the Continental Shelf in 1953.

The Survey's most recently added responsibility has been the management of the oil and gas exploration program on the National Petroleum Reserve in Alaska (NPRA), which was transferred from the Department of the Navy to the Department of the Interior in June 1977 under the Naval Petroleum Reserves Production Act of 1976 (Public Law 94-258). This program, carried out under contract with a private oil exploration company, had been virtually completed by the end of the 1981 fiscal year, and preparations were underway to begin leasing acreage for private oil and gas exploration in fiscal year 1982. Other provisions of the law assign to the Department of the Interior the continuing responsibility for operating the South Barrow gasfield as a source of energy for the village of Barrow and several Federal installations. This responsibility, in turn, was given to the Geological Survey.

In general, then, it may be said that the Geological Survey is charged with two basic missions: scientific and regulatory. The first of these is to collect, organize, interpret, and publish information about energy, mineral, water, and land resources and to develop an understanding of the structure, processes, and history of the Earth and other members of the solar system. The primary focus of these efforts is the United States and its territories, but the reach of the Survey's investigations has extended to the ocean floor and all continents and beyond these to the Moon and the planets. The second of the Survey's missions is to classify Federal lands as to their mineral and waterpower potential and to supervise the activities of lessees who explore for and develop the mineral resources of Federal and Indian lands, including the Outer Continental Shelf.

These two missions are carried out through a variety of functions and activities, including topographic mapping; geologic, geophysical, and geochemical investigations; stream gaging and water resource assessments; research on prediction and mitigation of damage from natural hazards; assistance in applying earth science information to urban development planning; the classification and evaluation of Federal lands; the enforcement of regulations and procedures to assure the safe, orderly, and diligent development of energy and mineral resources on Federal and Indian lands; and the collection of all rents and royalties due from such development.

## Organization

The U.S. Geological Survey is a bureau within the Department of the Interior headquartered in Reston, Virginia. Its work is administered through four major Program Divisions (National Mapping, Geologic, Water Resources, and Conservation) and two Offices (the Office of National Petroleum Reserve in Alaska and the Office of Earth Sciences Applications). These six mission units are serviced by three Support Divisions (Administrative, Computer Center, and Equal Employment Opportunity Office).

Reporting to the Survey's National Center headquarters at Reston is a field organization of more than 200 offices located throughout the United States and Puerto Rico whose work is coordinated by three Assistant Directors in Regional Offices located at Reston, Virginia, Denver, Colorado, and Menlo Park, California. Coordination among the Divisions at the National Center is accomplished through five functional Assistant Directors acting in the areas of administration, program analysis, research, resource programs, and engineering geology.

A chart of the Geological Survey organization may be found on pages **140** and **141** a selective directory of the National Center and field offices begins on page **142**

# Budget

In fiscal year 1981, the U.S. Geological Survey obligated a total of $769.5 million, of which $623.1 million came from direct appropriations and $146.4 million from reimbursements. As shown on the accompanying table, this amount was $12.6 million less than the figure for the previous year and reflected an increase of $46.7 million in "Surveys, Investigations, and Research" and $3.4 million in reimbursements which were substantially offset by a reduction of $62.8 million in funds obligated under "Exploration of National Petroleum Reserve in Alaska."

Figure 1 presents a 10-year perspective of the Geological Survey's obligations by budget activity. The most noteworthy features of the presentation are the curve of NPRA obligations which rose rapidly from 1977 to a peak in 1979 and declined almost as rapidly since that year because of the planned phasedown of the program and the disproportionate rise in funds obligated to regulatory functions as depicted in the twelvefold increase in the budget activity "Conservation of Lands and Minerals."

The Survey relies on outside sources to accomplish an increasing share of its workload, as shown in figure 2. Between 1971 and 1981, payments to grantees and contractors for work performed for the Survey increased twelve fold from $12 million to $158.9 million, while their share of the total budget (less NPRA) rose from 7 percent in 1971 to 24 percent 10 years later. Virtually all funds obligated under the appropriation "Exploration of National Petroleum Reserve in Alaska" were for contractual services.

*U.S. Geological Survey obligations for fiscal years 1980 and 1981, by activity*

[Dollars in millions. Data may differ from those in statistical tables because of rounding]

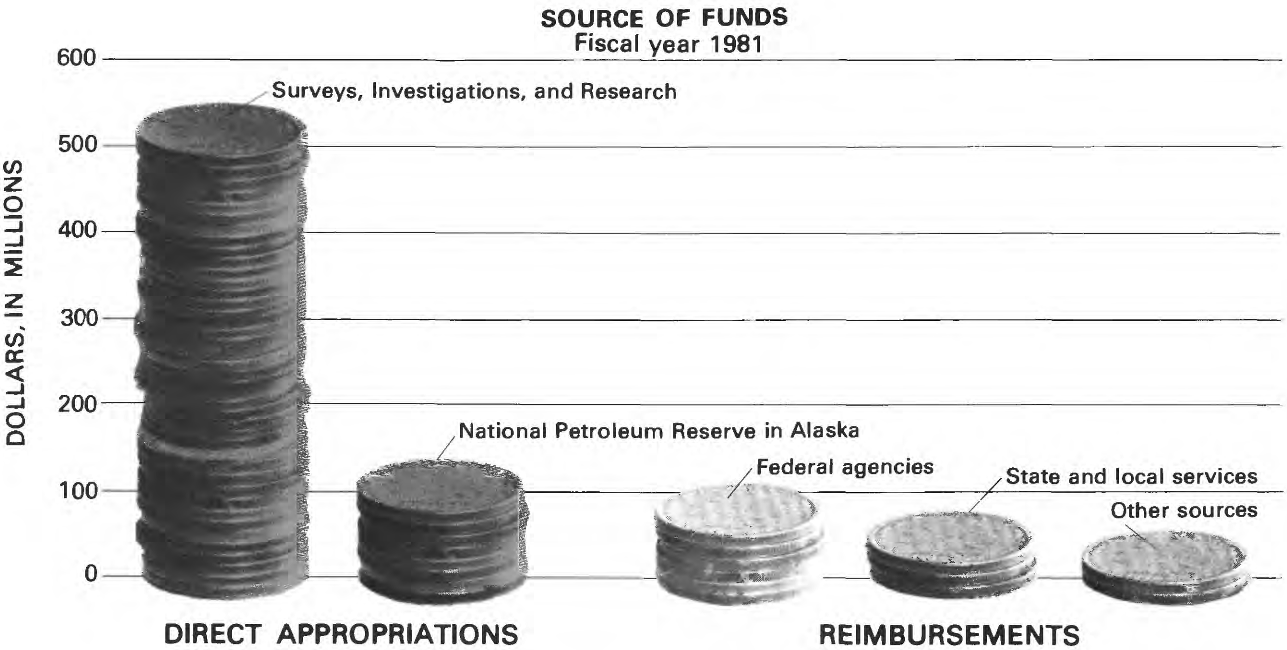
| Activity | Fiscal year 1980 | Fiscal year 1981 |
|---|---|---|
| **National Mapping, Geography, and Surveys** | **82.7** | **89.1** |
| Direct programs | 72.8 | 77.4 |
| Reimbursable programs | 9.9 | 11.7 |
| **Geologic and Mineral Resource Surveys and Mapping** | **193.7** | **208.2** |
| Direct programs | 147.0 | 162.7 |
| Reimbursable programs | 46.7 | 45.5 |
| **Water Resources Investigations** | **184.9** | **194.0** |
| Direct programs | 108.7 | 115.5 |
| Reimbursable programs | 76.2 | 78.5 |
| **Conservation of Lands and Minerals** | **106.4** | **127.0** |
| Direct programs | 105.9 | 125.7 |
| Reimbursable programs | .5 | 1.3 |
| **Office of Earth Sciences Applications** | **23.7** | **23.2** |
| Direct programs | 18.9 | 18.9 |
| Reimbursable programs | 4.8 | 4.3 |
| **General Administration** | **3.8** | **3.9** |
| **Facilities** | **12.3** | **11.9** |
| **Miscellaneous Services to Other Accounts** | **4.9** | **5.3** |
| **National Petroleum Reserve in Alaska** | **169.9** | **107.0** |
| **Total** | **782.1** | **769.5** |
| **Direct programs** | **639.1** | **623.1** |
| **Reimbursable programs** | **143.0** | **146.4** |
| States, counties and municipalities | 46.8 | 48.7 |
| Other Federal agencies | 79.3 | 78.2 |
| Other sources | 16.8 | 19.6 |

### About the Budget

The U.S. Geological Survey receives its funds from two main sources, appropriations made by the Congress and reimbursement for work performed under agreements with Federal agencies, State and local governments, and other entities including licensees and permitees of the Federal Energy Regulatory Commission, 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 its existing programs or works. Work done for State, county, and municipal agencies is almost always done on a cost-sharing basis, and activities so financed are known collectively as the Federal-State Cooperative Program. In fiscal year 1981, the Survey received funds under two appropriations, "Exploration of National Petroleum Reserve in Alaska" (NPRA), which financed work done on the NPRA, and "Surveys, Investigations, and Research," which is the traditional source of funding for all other Survey activities.

Most of the funds received by the Survey, both appropriations and reimbursements, are distributed through budget activities that roughly correspond to its mapping, geologic, hydrologic, information transfer, and regulatory areas of responsibility. Two small budget activities relate to the support functions of "General Administration" and "Facilities."

The sources and distribution of Geological Survey funds for fiscal years 1976 through 1981 are shown in table 1 on page , and special analyses of reimbursements received by source are presented in tables 2 and 3 immediately following. A list of organizations with which the Survey had agreements for reimbursable work in fiscal year 1981 can be found beginning on page



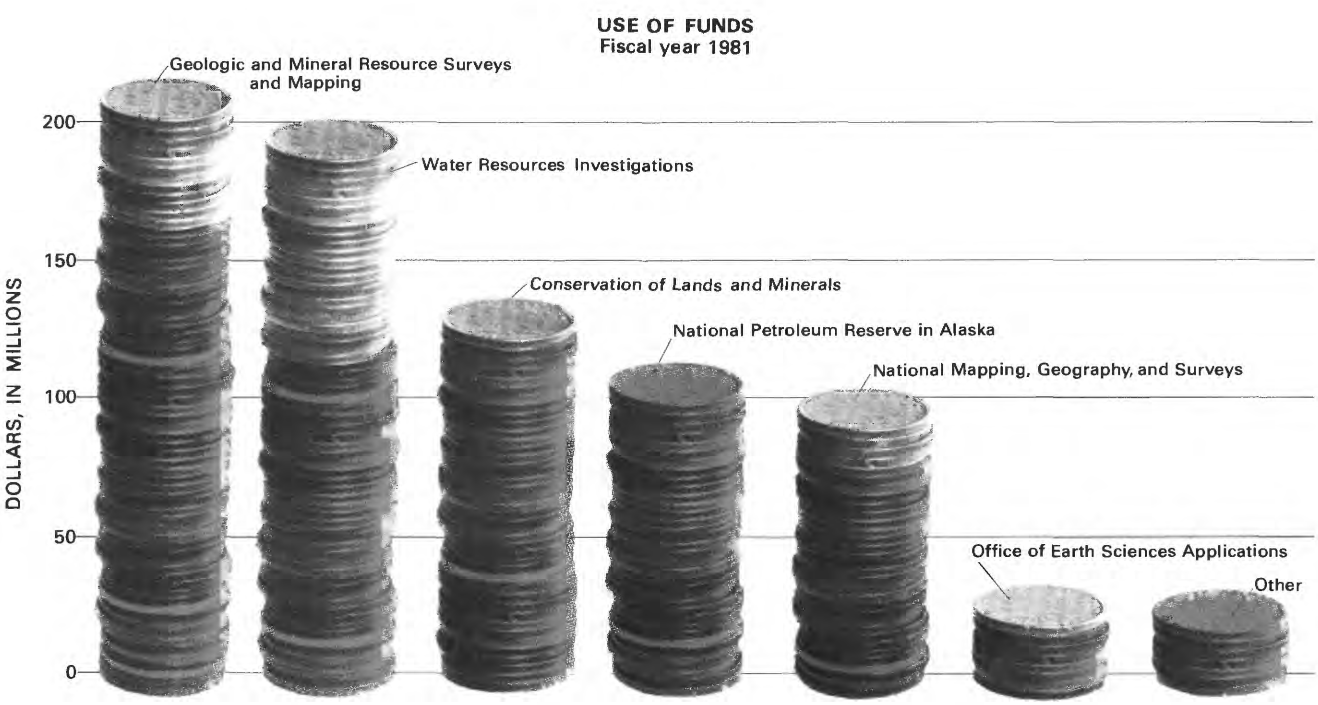
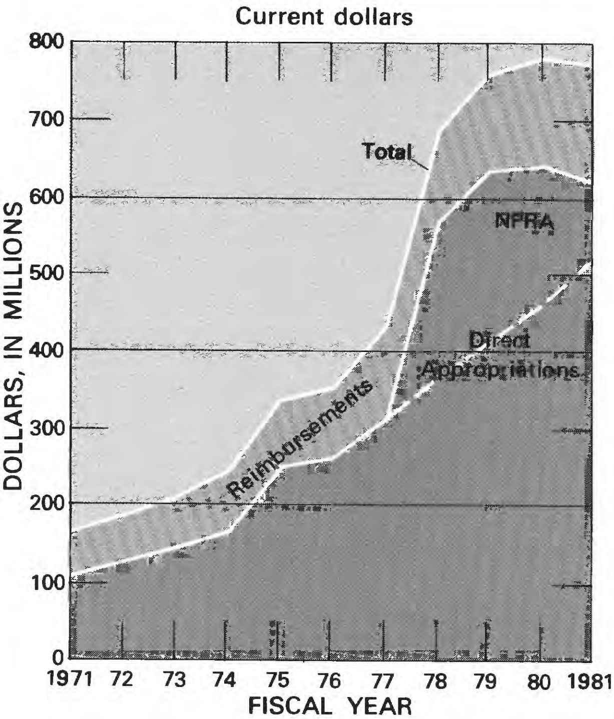




FIGURE 1.—*U.S. Geological Survey budget, fiscal years 1971 to 1981.* ▶


Current dollars
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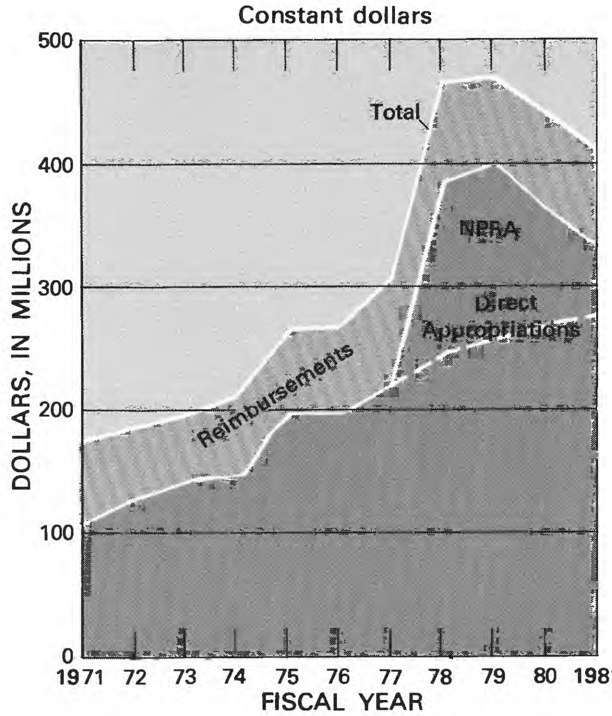
Constant dollars
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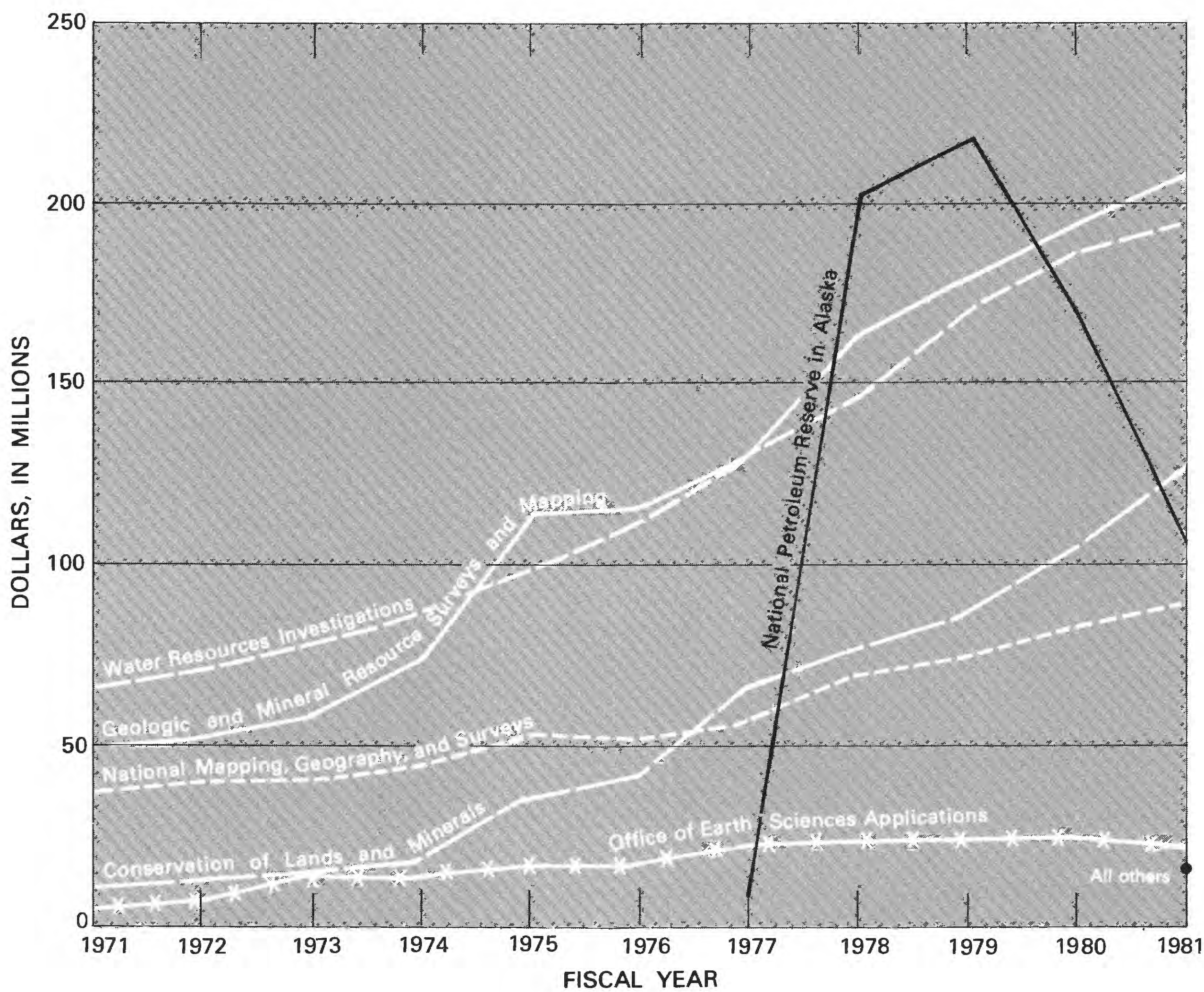
DOLLARS, IN MILLIONS
FISCAL YEAR


National Petroleum Reserve in Alaska
Geologic and Mineral Resource Surveys and Mapping
Water Resources Investigations
National Mapping, Geography, and Surveys
Conservation of Lands and Minerals
Office of Earth Sciences Applications
All others
DOLLARS, IN MILLIONS
FISCAL YEAR

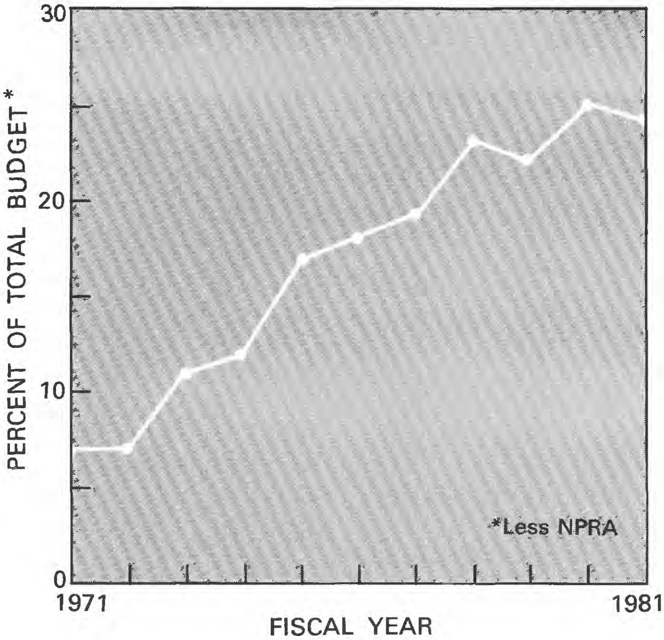



FIGURE 2.—*Budget share of grants and contractual services (less NPRA).*

# Personnel

At the end of fiscal year 1981, the U.S. Geological Survey had 9,436 permanent full-time employees on board, an increase of 127 compared with fiscal year 1980. Of the total, 1,468 were employed at the Reston National Center, with the remaining 7,968 distributed among the three Regions, as shown in figure 3. More than one-half of the Survey's permanent full-time staff are scientists, engineers, and other professionals, and approximately one-fourth are technical specialists. Hydrologists and geologists predominate among the professional group, which includes more than 30 other disciplines including a number from the life and social sciences.

The 10-year perspective of the Survey's permanent full-time personnel strength given in figure 4 shows a slow but steady increase between 1973 and 1978, and a slow irregular trend downward since the latter year. As the figure also shows, the entire increase was identified with the Survey's regulatory functions, which had to do with increasingly rigorous regulatory attitudes and the expanded scope of energy exploration and development on Federal and Indian lands during that period.

In contrast, the Survey's other work has been accomplished with a virtually level full-time work force since 1973; moderate increases in the Geologic Division, the Office of Earth Sciences Applications, and the Support Divisions have been offset by decreases in the National Mapping and Water Resources Divisions. The additional workload on these scientifically oriented components has been supported in part by the rapid expansion in the use of grants and contractual services noted in the preceding discussion of the budget and in part by the extensive use of temporary and part-time personnel.

The number of these other-than-full-time permanent employees has more than doubled since 1973, as evidenced in figure 5, and includes many students and faculty members from colleges and universities and summer hires from various categories. The Survey has profited greatly from its association with the academic community that has resulted from this practice. The expertise of many eminent specialists has become available to the Survey in this manner and has given it great flexibility in solving problems and meeting surges in its 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.

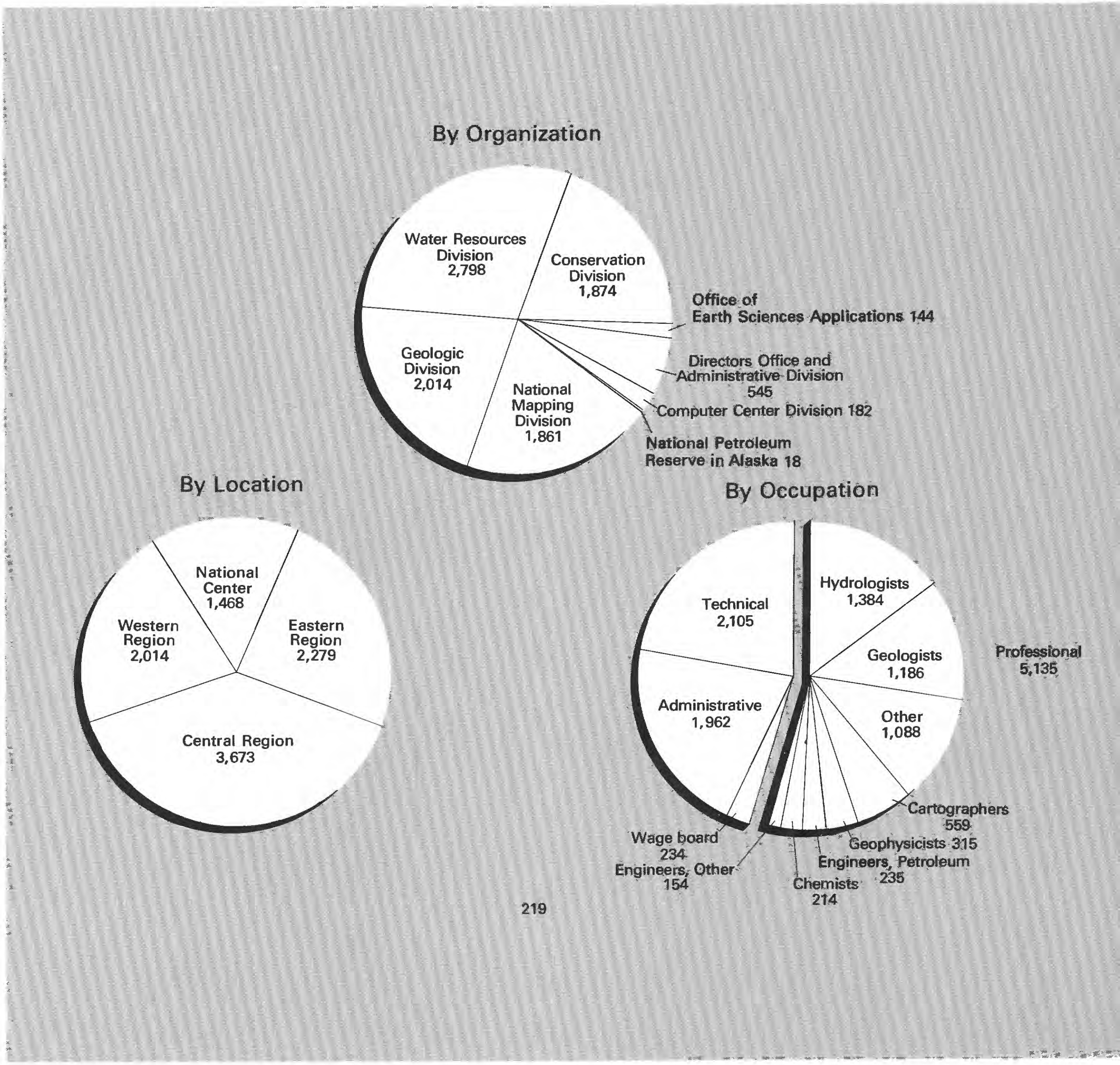



FIGURE 3.—*Permanent full-time U.S. Geological Survey employees, fiscal year 1981.*

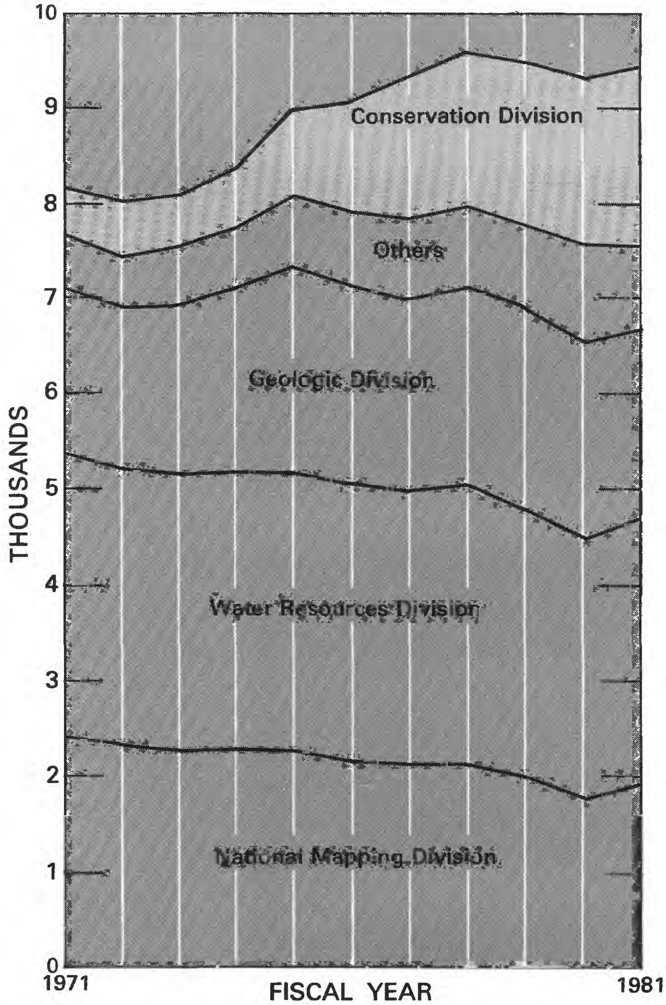
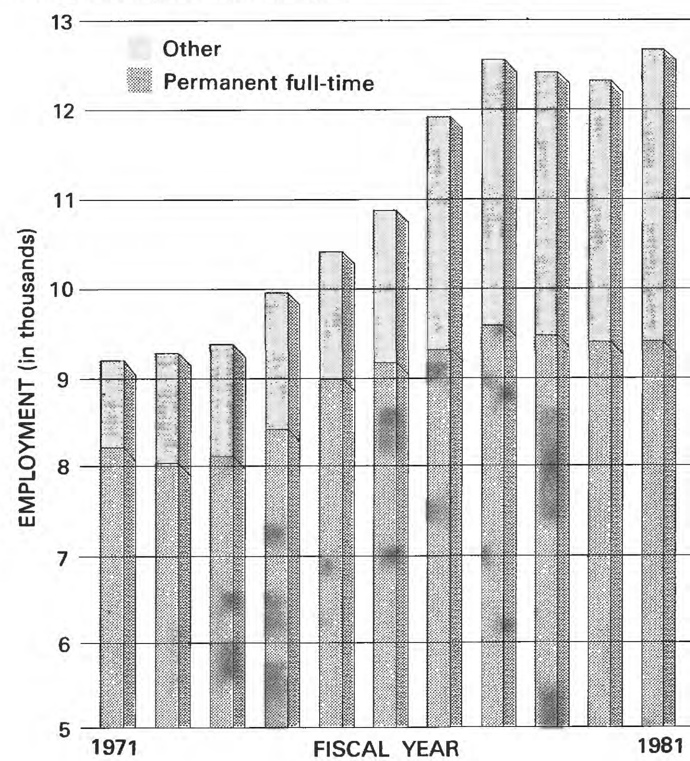



FIGURE 4.—*Permanent full-time U.S. Geological Survey employees, fiscal years 1971 to 1981.*

FIGURE 5.—*U.S. Geological Survey end-of-year employment, fiscal years 1971 to 1981.*



# National Mapping, Geography, and Surveys

## Mission

The National Mapping Division of the U.S. Geological Survey formally began operations in April 1980, combining the former Topographic Division with most elements of the Publications Division and the Survey's Geography Program. The purpose of the consolidation was to form a broad-based mapping organization built on the scientific disciplines of cartography and geography and to incorporate the related physical resources for map printing and distribution. The new Division continues to operate the National Cartographic Information Center and the Public Inquiries Offices maintained by the two predecessor Divisions. Fiscal year 1981 is the first full year of operation of the new organization.

### PRODUCTION CENTERS

Within the National Mapping Division, four regional mapping centers are the principal locations for map production. These centers, at Reston, Virginia, Rolla, Missouri, Denver, Colorado, and Menlo Park, California, also serve as points of contact and coordination for mapping on a regional basis, working with other Federal agencies and coordinating joint mapping activities with the States.

A fifth center, responsible for the printing and distribution of maps, is headquartered at Reston, Virginia. It is responsible for map storage and distribution activities conducted in Arlington, Virginia, Denver, Colorado, and Anchorage, Alaska, as well as the operation of the Survey's printing plant at the National Center in Reston.

### MAJOR ACTIVITIES

The National Mapping Division conducts the National Mapping Program of the United States, which includes the following major activities:

- Quadrangle mapping and revision, including production and revision of 7.5-minute maps at 1:24,000 scale (inch-pound system units) and 1:25,000 scale (metric units) for the conterminous United States, Hawaii, and developing areas in Alaska and maps at 1:63,000 scale (inch-pound system units) and 1:50,000 scale (metric units) for Alaska.
- Small-scale and special mapping, including 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.
- Information and data services, which include acquisition and dissemination of information about the Nation's maps, charts, and aerial and space photographs; geodetic control; cartographic and geographic (spatial) data and other related information; distribution of earth science information to the public; and sale of map and map-related products through more than 2,500 private retailers.
- 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 people; 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 speed the mapping of important areas of the Nation.
- Cartographic and geographic research with particular emphasis on spatial data techniques for studies employing modern geographic analysis with new and improved cartographic concepts and techniques.
- Digital mapping to produce base categories of cartographic data at standard scales, accuracies, and formats suitable for computer-based analysis.

## Budget and Personnel

For fiscal year 1981, National Mapping Division obligations amounted to $89.1 million, an increase of about 8 percent over fiscal year 1980. Included are funds from 38 States, which, together with Federal funds, amounted to $6 million under joint funding agreements for mapping. These joint funding projects mutually benefit the State and national program by ensuring completion of map coverage sooner than would otherwise be possible.

*National Mapping, Geography, and Surveys activity obligations for fiscal years 1980 and 1981, by subactivity*

[Dollars in millions. Data may differ from those in statistical tables because of rounding]

| Subactivity | Fiscal year 1980 | Fiscal year 1981 |
|---|---|---|
| **Primary Quadrangle Mapping** | 47.4 | 44.9 |
| **Map Revision and Orthophotoquads** | 18.3 | 20.0 |
| **Digital Mapping** | 2.3 | 2.0 |
| **Small- and Intermediate-Scale and Special Mapping** | 11.7 | 18.8 |
| **Cartographic and Geographic Information** | 3.0 | 3.4 |
| **Total** | 82.7 | 89.1 |
| **Direct programs** | 72.8 | 77.4 |
| **Reimbursable programs** | 9.9 | 11.7 |
| States, counties, and municipalities | 3.1 | 3.0 |
| Other Federal agencies | 6.2 | 7.6 |
| Other sources | 0.6 | 1.1 |

The National Mapping Program of the Geological Survey is carried out through a combination of in-house and work-share efforts and through contracts. The permanent full-time strength of the Division at the end of fiscal year 1981 was 1,861, encompassing a variety of professional skills including geography, cartography, data processing, engineering, photographic technology, and the physical sciences. An additional 263 employees, many on work-study programs, were on the rolls at the end of the fiscal year

# Quadrangle Mapping, Revision, and Orthophotoquads

During fiscal year 1981, 1,185 new standard topographic maps, covering 68,667 square miles, were published. Most of the maps were in the 7.5-minute 1:24,000-scale series (1:63,360-scale series in Alaska). There are 16 States with complete published topographic map coverage at 1:24,000 scale, and, overall, 77.2 percent of the conterminous United States has been published at this scale. These maps also are used to prepare intermediate- and small-scale and special maps.

As national coverage in the 7.5-minute series increases, the map revision workload grows. The need for revision of individual maps is determined by the amount of change detected when published maps are compared to current aerial photographs. Maps are reviewed cyclically with emphasis on urban areas, coastal areas, airports, major transportation corridors, and other areas of high national interest. During the year, 3,606 7.5-minute maps were reviewed, and 1,332 revised maps were published.

One innovation in the mapping process, the preparation of a provisional map, was initiated to get more new maps to users by shortening the production cycle and reducing the initial costs. This concept would help meet the Survey's objective of having complete map coverage of the conterminous United States by the end of 1988.

A provisional map would be published in colors as is a standard map and would show about the same level of detail. The major difference is that a provisional map would show data compiled in the photogrammetric stage of production; that is, with hand lettering, with some data unclassified by symbol, and with some extraneous data such as crop lines and road scars unedited. User reaction to sample products has been excellent.

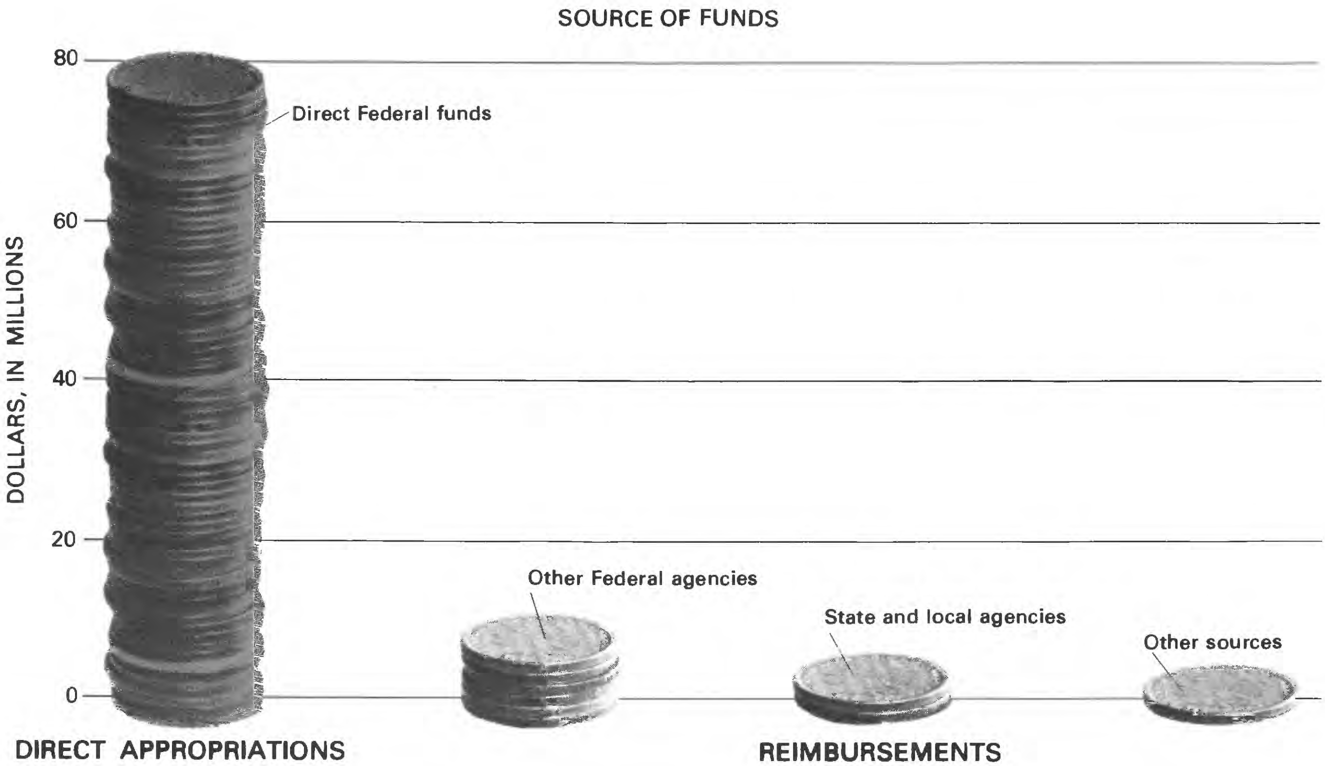
After initial map coverage is complete, the provisional maps will be updated and will receive full cartographic treatment. By that time, digitized map data (data that can be stored in and manipulated by computers) should be available to simplify and expedite the revision and map-finishing processes.

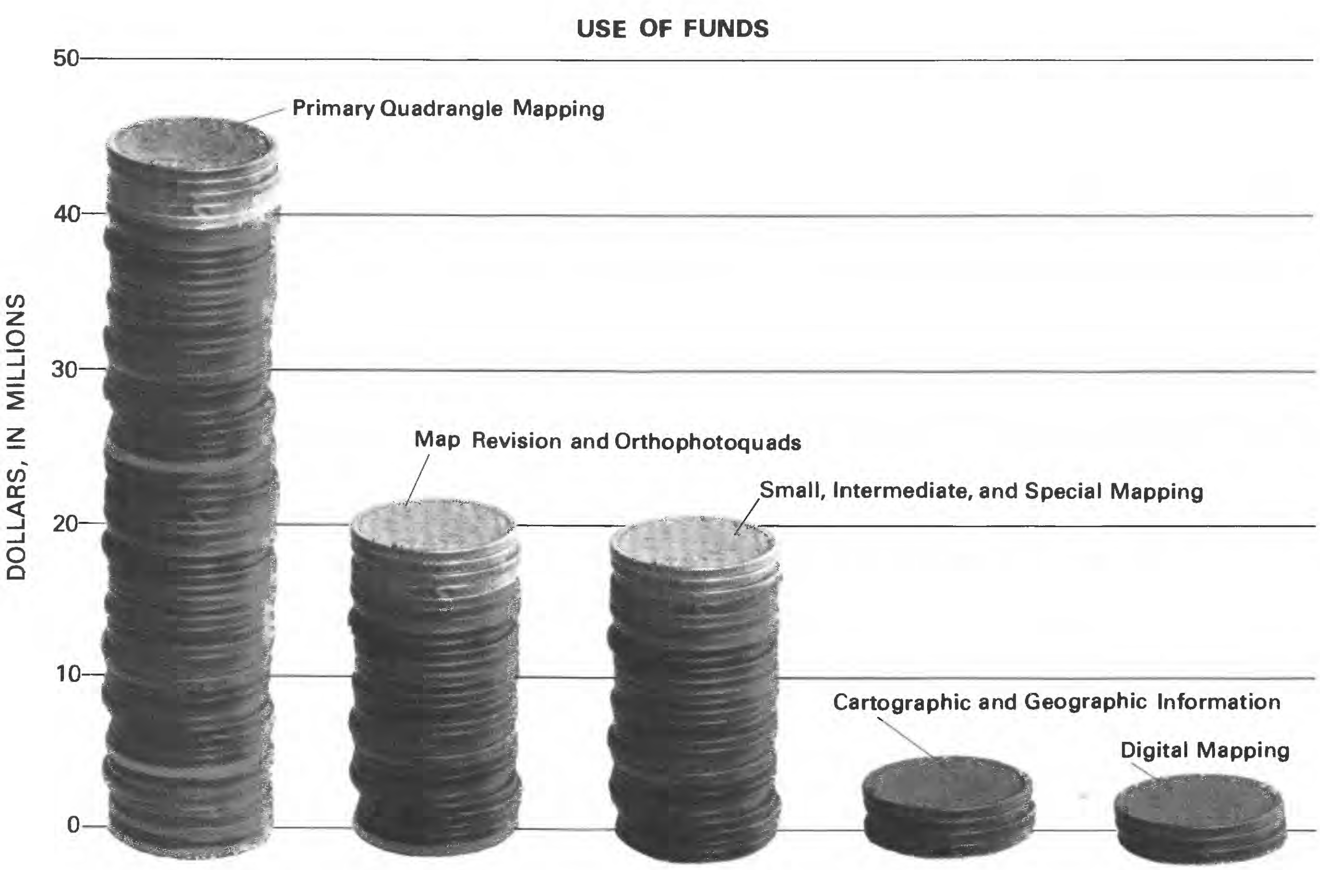
Orthophotographs are produced by processing aerial photographs to correct image displacement caused by camera tilt and terrain variations. Orthophotographs become orthophotoquads when grid and name information are superimposed in a standard quadrangle format and have many applications as map substitutes or as companions to published line maps. In fiscal year 1981, 3,222 orthophotoquads were prepared. Printed copies are available for a limited number, with the remainder available in nonlithographic form (diazo print) on sale by regional mapping centers.

# Intermediate-Scale Mapping

The U.S. Geological Survey publishes an intermediate-scale series of maps at scales of 1:50,000 and 1:100,000 to meet a variety of customer requirements for formats and detail that cannot be met with the 1:24,000- and 1:250,000-scale series.

Intermediate-scale maps have proven to be a valuable multiuse product. These maps have the flexibility of combining layers of map information in a number of ways to produce base maps on


SOURCE OF FUNDS
80
60
40
20
0
DOLLARS, IN MILLIONS
Direct Federal funds
Other Federal agencies
State and local agencies
Other sources
DIRECT APPROPRIATIONS
REIMBURSEMENTS


USE OF FUNDS
50
40
30
20
10
0
DOLLARS, IN MILLIONS
Primary Quadrangle Mapping
Map Revision and Orthophotoquads
Small, Intermediate, and Special Mapping
Cartographic and Geographic Information
Digital Mapping

which agencies such as the Bureau of Land Management can display resource inventories and the Survey can use the resulting products, such as the coal folios, which are a series of maps showing surface features, thickness of coal seams, and overburden, ownership, and other data needed for decisionmaking.

At the end of the fiscal year, intermediate-scale map coverage was available for approximately 65 percent of the conterminous United States. The long-range plan calls for complete 1:100,000-scale topographic quadrangle map coverage of the conterminous United States by the end of the present decade.

Under a joint agreement with the Defense Mapping Agency, the Geological Survey produced 15-minute 1:50,000-scale metric topographic

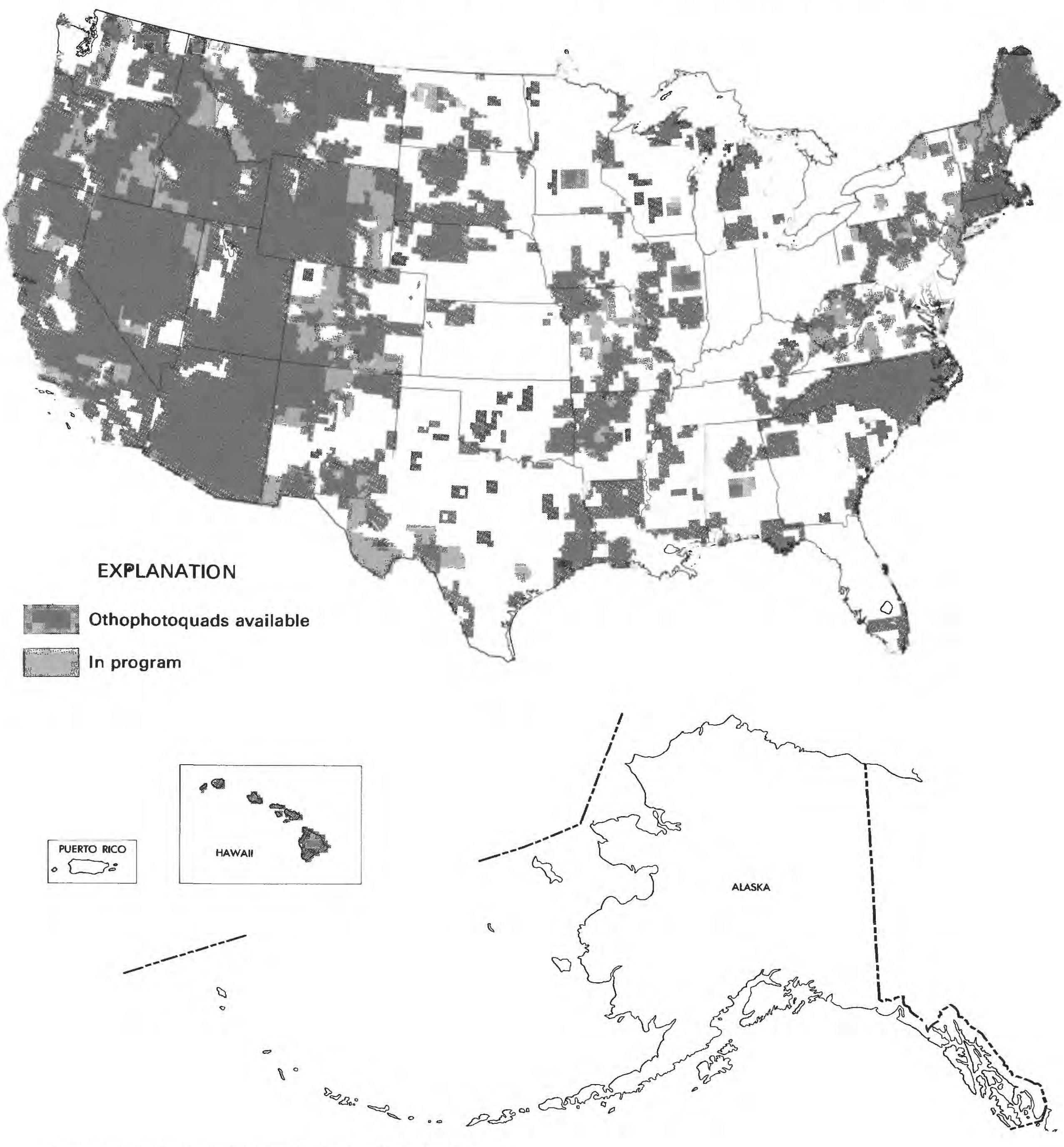



FIGURE 1.—*Status of orthophotoquad production.*

maps. The current program goal is completion of about 1,700 additional 15-minute maps of high-priority areas prepared in accordance with jointly developed specifications and yielding map materials that can be used directly in preparation of other intermediate-scale maps. About 400 of these maps have been published to date.

These intermediate maps embody a number of innovative features, including multiple feature-separation drawings that can be combined in various ways to produce special maps with varying levels of content. Feature symbols have been designed for automated data capture, computer storage, and automated plotter output.

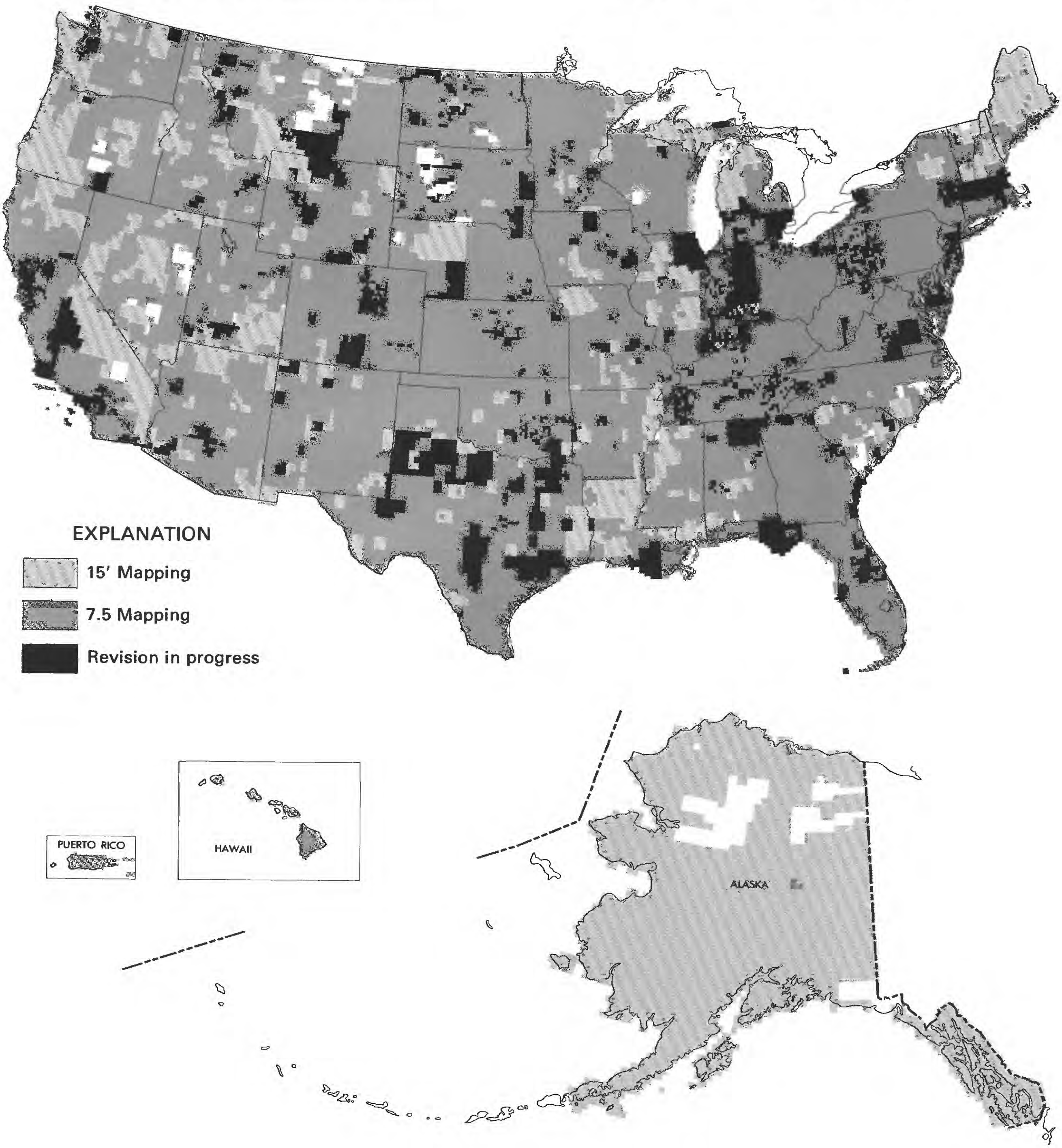



FIGURE 2.—*Status of standard topographic mapping and revision.*

# Small-Scale and Special-Purpose Mapping

The largest scale of complete topographic coverage available for the United States is the 1:250,000-scale map series. These maps are widely used by Federal and State agencies as well as by the U.S. Geological Survey for preparing State base maps, various geologic maps, and special-purpose maps. During the year, 24 revisions were published.

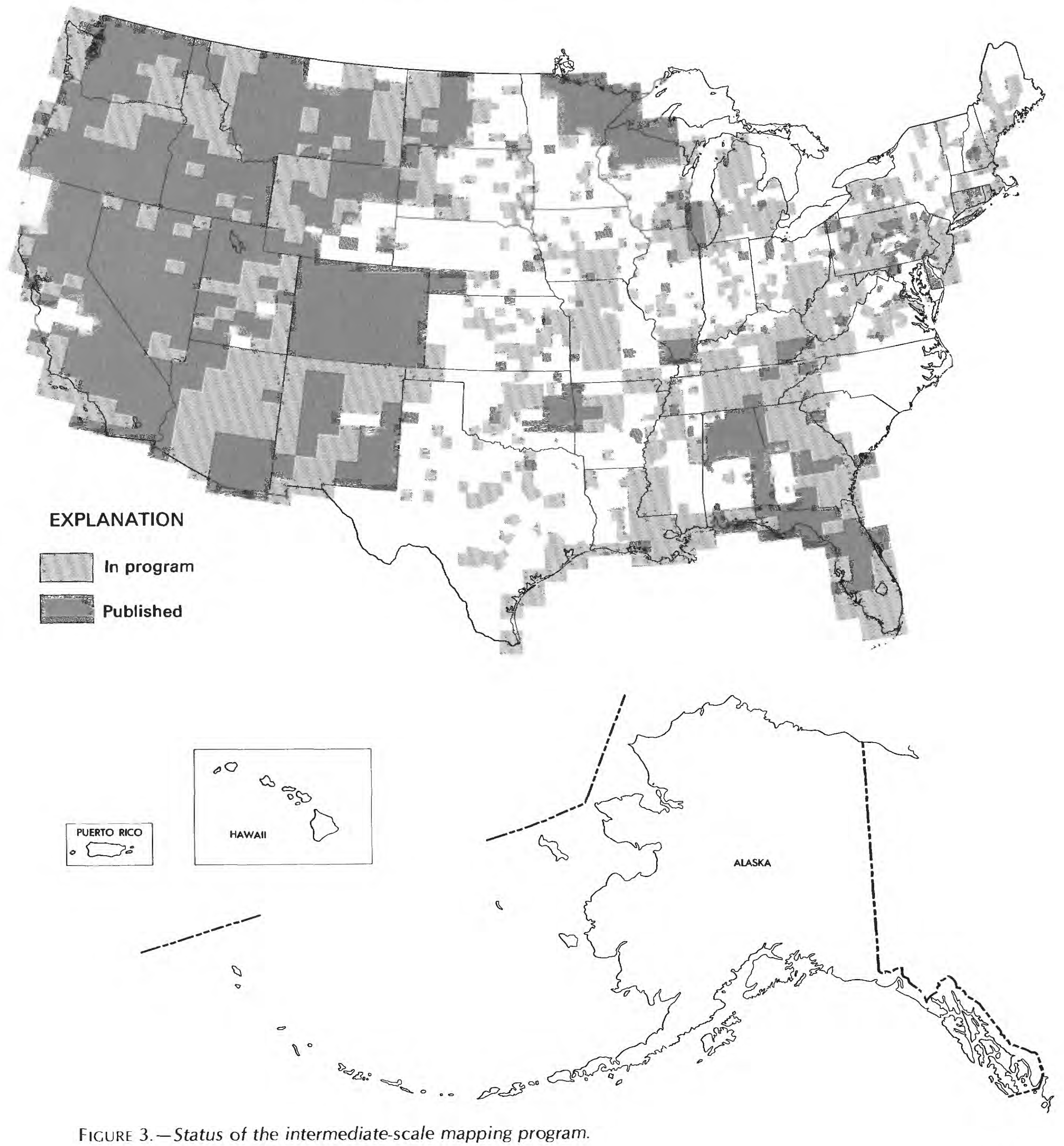



FIGURE 3.—*Status of the intermediate-scale mapping program.*

# Topographic and Bathymetric Mapping

The joint Geological Survey-National Ocean Survey program for producing coastal area maps combining topography of the land with bathymetry of the ocean floor continued to progress during the year. The series includes maps at the Survey's three basic scales: 1:24,000, 1:100,000, and 1:250,000. By the end of the fiscal year, 15 maps at those scales had been published. The maps used by State and Federal agencies are a valuable tool for coastal area planning.

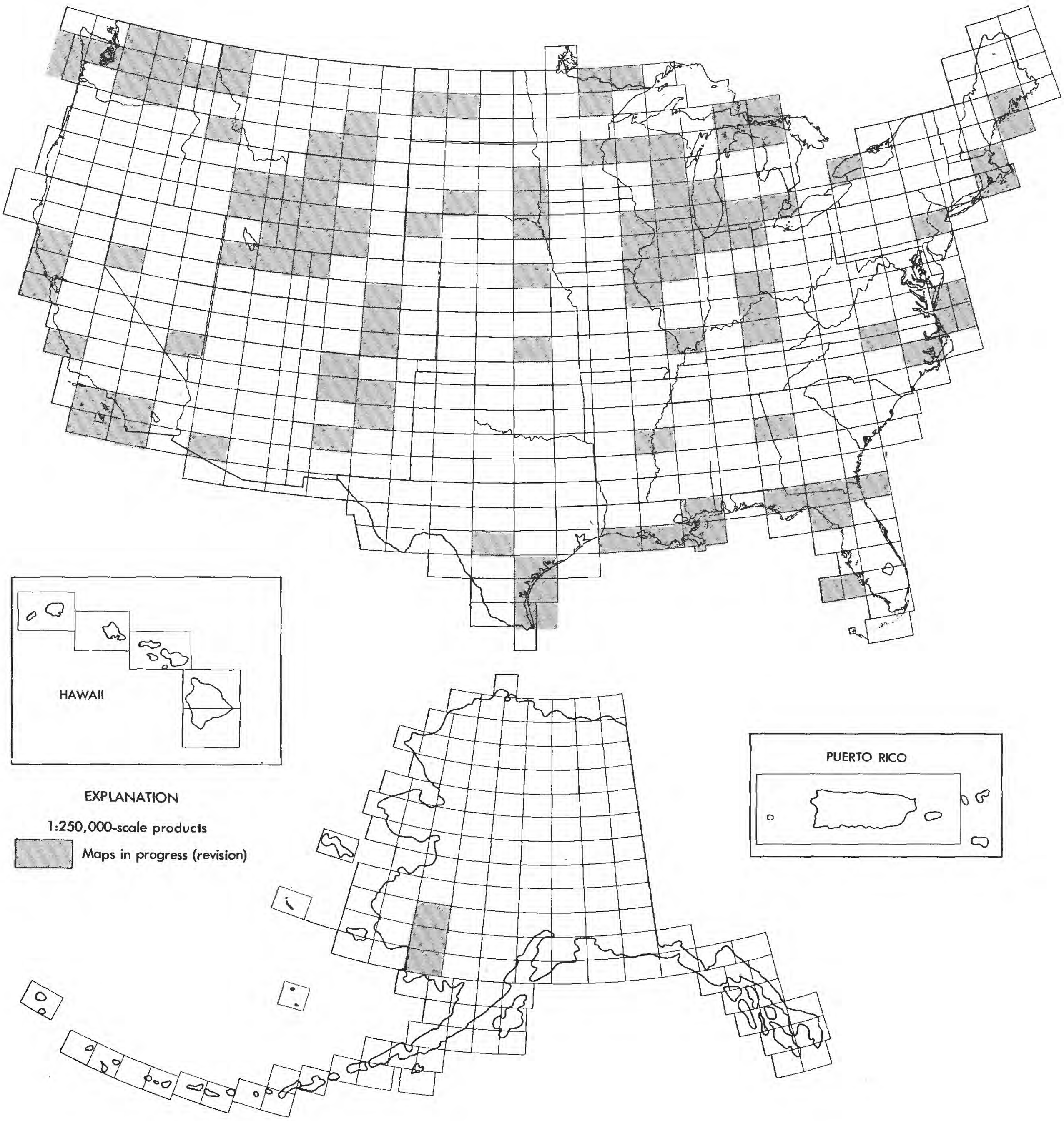



FIGURE 4.—*Status of 1:250,000-scale mapping production.*

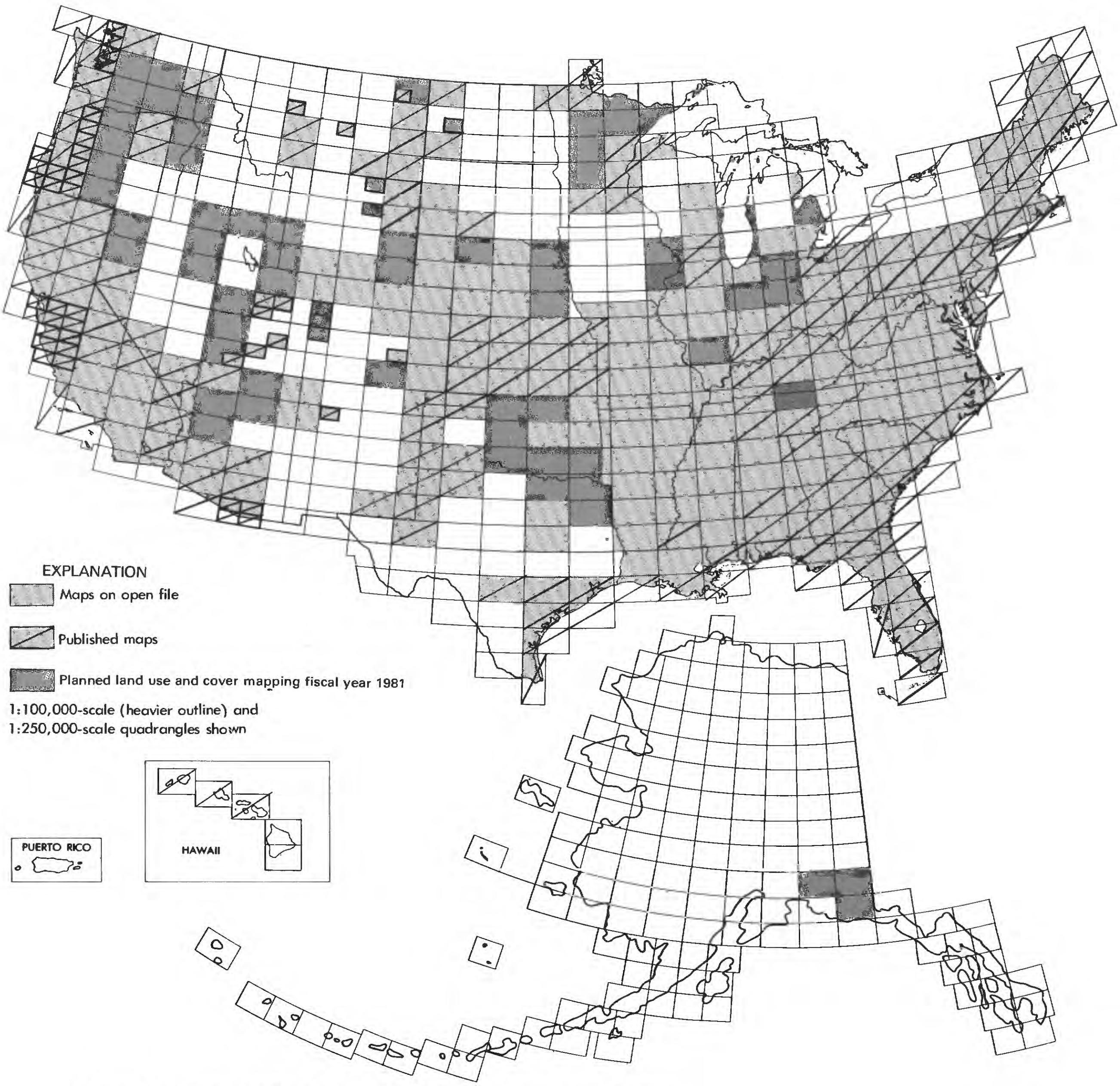



FIGURE 5.—*Status of land use and land cover mapping production.*

# Land Use and Land Cover Mapping

Land use and land cover maps for more than 300,000 square miles of the United States were completed by the end of the fiscal year, bringing total coverage to 1.9 million square miles. At current production rates, coverage will be completed for the entire Nation by 1987. To date 14 States have entered into joint funding agreements with the Survey for land use and land cover map products.

Land use and land cover maps are relatively new base map products of the U.S. Geological Survey. In 1975, the Survey undertook to publish current reliable land use and land cover maps for the entire Nation in standard formats compiled from high-altitude aerial photographs as primary sources. The maps are based on a land use and land cover classification system developed by the Survey that is becoming the standard for the Nation. The maps are at 1:250,000 scale, with

*Mapping production for fiscal year 1981 (in square miles)*

| State | 1:24,000-scale topographic | 1:24,000-scale orthophotoquads | 1:24,000-scale revisions | Intermediate scale |
|---|---|---|---|---|
| Alabama | 1,041 | --- | 1,386 | 6,583 |
| Alaska | 50 | 253 | --- | --- |
| Arizona | 4,196 | --- | --- | 839 |
| Arkansas | 2,547 | 425 | --- | --- |
| California | 1,118 | 3,930 | 6,552 | 11,417 |
| Colorado | 1,903 | 5,066 | 1,450 | 20,088 |
| Connecticut | --- | 296 | --- | 1,294 |
| Delaware | --- | --- | --- | --- |
| District of Columbia | --- | --- | --- | --- |
| Florida | --- | --- | 4,615 | 23,878 |
| Georgia | --- | --- | 1,071 | 14,378 |
| Hawaii | --- | --- | 630 | 3,655 |
| Idaho | 1,714 | 1,229 | 108 | 3,396 |
| Illinois | 3,256 | --- | 2,622 | 1,450 |
| Indiana | --- | --- | 11,970 | --- |
| Iowa | 7,703 | --- | 167 | 1,792 |
| Kansas | 1,335 | --- | 59 | --- |
| Kentucky | --- | 584 | 649 | --- |
| Louisiana | 1,498 | --- | 6,336 | --- |
| Maine | 808 | 715 | --- | --- |
| Maryland | --- | --- | 174 | 85 |
| Massachusetts | --- | 38 | --- | 9 |
| Michigan | --- | --- | 1,026 | --- |
| Minnesota | --- | --- | 1,248 | 7,978 |
| Mississippi | 992 | --- | 63 | 884 |
| Missouri | 1,459 | 329 | 702 | --- |
| Montana | 1,898 | 4,296 | 3,111 | 6,704 |
| Nebraska | 1,485 | --- | 112 | --- |
| Nevada | 3,103 | 2,773 | --- | 5,532 |
| New Hampshire | 250 | 656 | 54 | --- |
| New Jersey | --- | 309 | --- | --- |
| Nex Mexico | 3,478 | 1,692 | 2,522 | 9,132 |
| New York | 868 | 1,620 | 3,410 | 11 |
| North Carolina | 2,006 | 221 | 424 | 281 |
| North Dakota | 3,881 | --- | 1,869 | 14,664 |
| Ohio | --- | --- | 456 | --- |
| Oklahoma | 1,084 | 85 | 121 | --- |
| Oregon | 1,695 | 2,776 | 1,890 | 6,840 |
| Pennsylvania | --- | 1,127 | 113 | 2,274 |
| Rhode Island | --- | --- | --- | --- |
| South Carolina | 124 | 4 | 1,488 | 1,538 |
| South Dakota | 3,308 | --- | --- | 6,744 |
| Tennessee | 20 | 42 | 5,566 | 3,840 |
| Texas | 4,061 | 1,127 | 7,680 | --- |
| Utah | 1,876 | 4,246 | 174 | 26,400 |
| Vermont | 1,036 | 825 | 648 | --- |
| Virginia | --- | 1,550 | 1,416 | 474 |
| Washington | 2,097 | 3,696 | 2,273 | 3,344 |
| West Virginia | --- | 962 | --- | --- |
| Wisconsin | 1,879 | --- | --- | 15,029 |
| Wyoming | 2,360 | 1,353 | 2,125 | 14,216 |
| Guam | --- | --- | --- | --- |
| Puerto Rico | --- | --- | --- | --- |
| Samoa | --- | --- | --- | --- |
| Virgin Islands | --- | --- | --- | --- |

selected areas (that is, those undergoing development, urban areas, and so forth) at 1:100,000 scale.

The land use and land cover maps also are being digitized and placed in a Geographic Information Retrieval and Analysis System. Digital data products include statistical summaries by counties, hydrologic units, and Census county subdivisions and for federally owned land. Analysis of such data to determine land use trends and patterns helps to solve land resource problems. The digital formats are essential for efficient use and multipurpose applications of the information.

# Digital Cartography

Digital cartography involves the collection, storage, manipulation, analysis, and display of spatial data through the use of computers. It is part of the rapidly growing field of computer-assisted spatial data handling. The increasing use of computers for storing and analyzing earth science data has sparked the growth in demand for digital cartographic data. Maps have traditionally played a key role in earth science analysis and as that process becomes automated, so, too, must the map information.

During fiscal year 1981, substantial progress was made in delineating the Survey's role in maintaining a national digital cartographic data base and in planning the structure and initial inputs to that base.

## NEEDS FOR DIGITAL CARTOGRAPHIC DATA—ROLE OF THE GEOLOGICAL SURVEY

If spatial or cartographic information is to be used for computer analyses and computer-aided decisionmaking, then it must be organized into a data base that meets consistent and exacting national standards for widespread public use. Management of such a data base raised several public policy issues that were addressed during the year by the Secretary of the Interior and the Office of Management and Budget: Is there sufficient national need to warrant public investment in such a data base? Which, if any, public agency ought to undertake the project? Is the technology sufficiently understood to allow the program to commence?

These issues were addressed during the year by a joint study directed by the Office of Management and Budget and conducted by the Office of Science and Technology Policy. It verified the national need for a digital cartographic data base and recommended that lead responsibility for the program be centralized within the Federal government in the Geological Survey. The study determined further that there is sufficient demand for digital cartographic products and that the development of the data base could be financed out of revenues resulting from the sale of the products. Finally, the study team established that the technology was sufficiently developed to allow the program to commence.

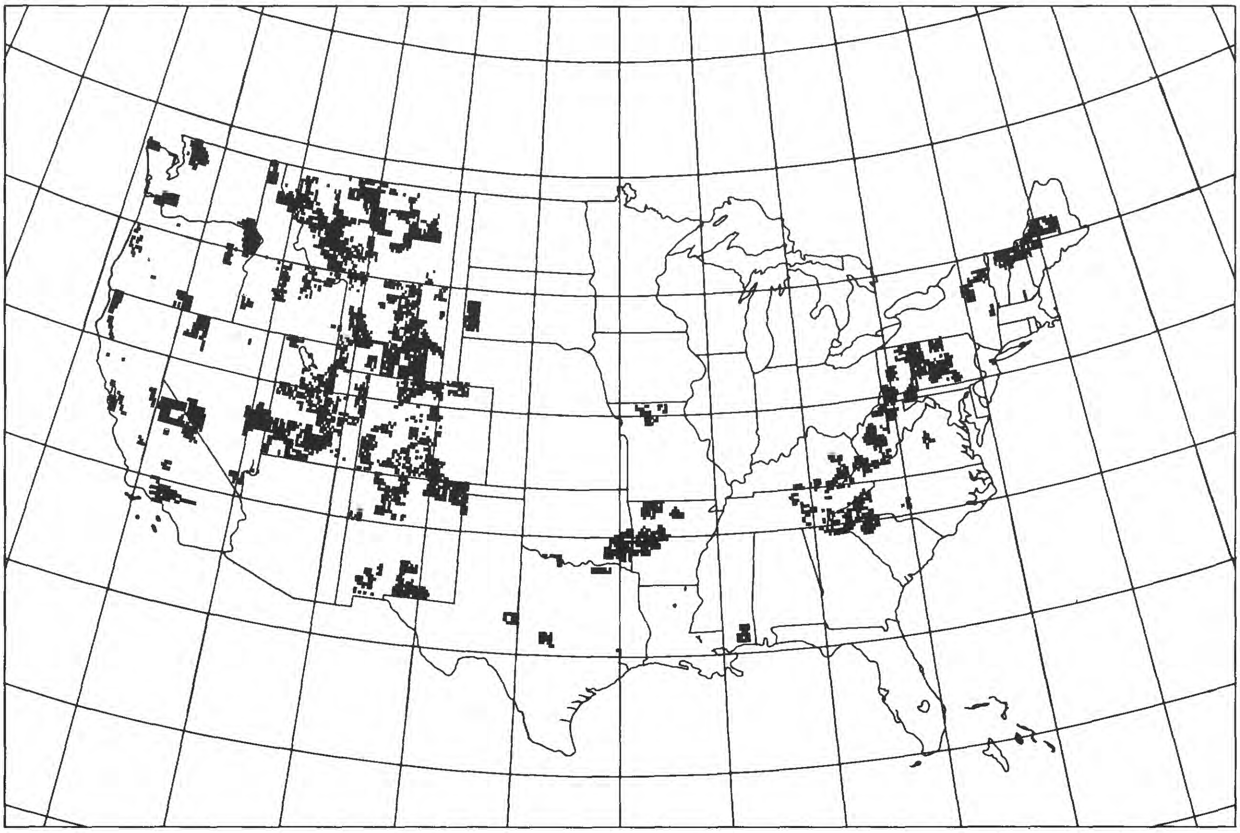
The study's recommendation to finance the program out of revenues from the sale of products rather than through annual appropriations will require legislative action. The Secretary of the Interior forwarded to Congress a proposed Digital Cartography Fund Act of 1981 for legislative consideration. It was introduced on May 21 in the Senate as S. 1280. As introduced, proceeds from the sale of digital data-base products would be collected in a fund established by the Act. The fund would then be used to finance continued operations of the digital cartographic data-base program after an initial capitalization by the Government. After several years of operation, no further annual appropriations would be anticipated.

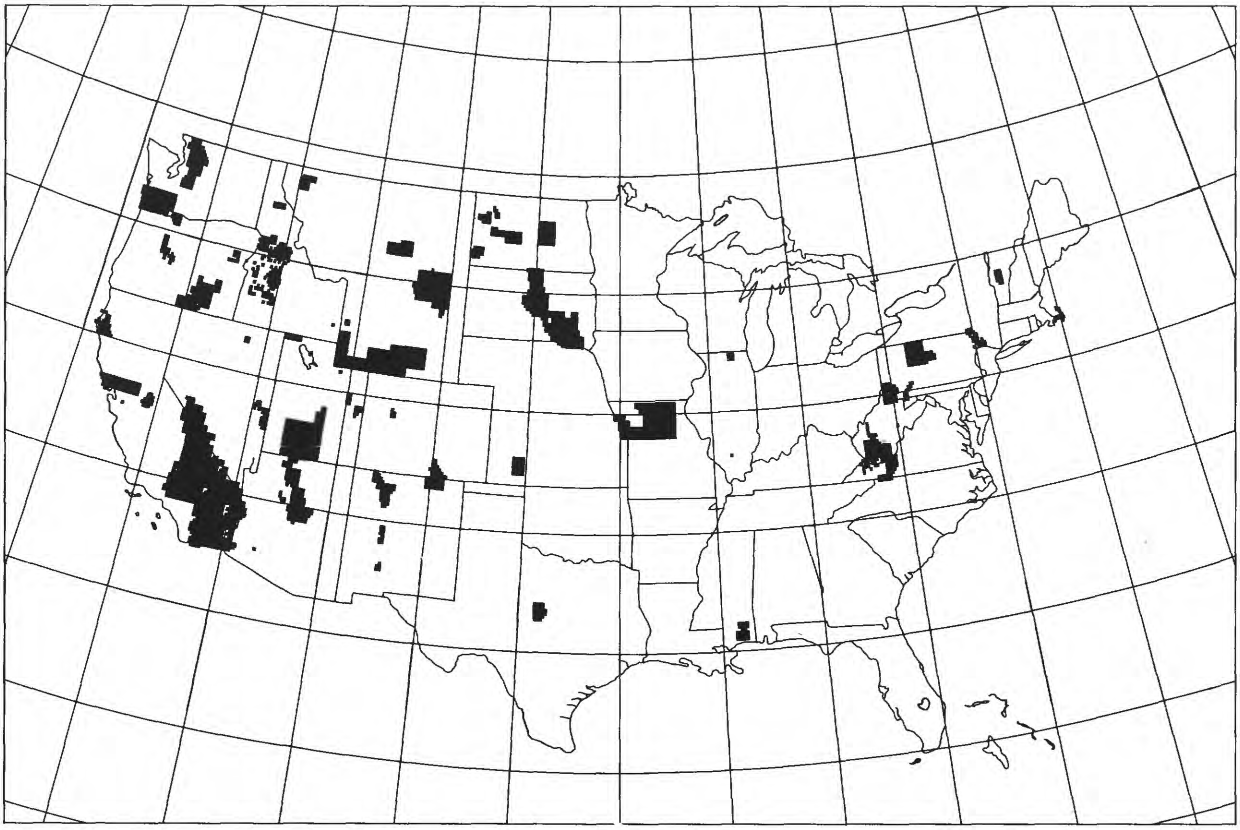
The Digital Cartography Fund Act of 1981 would represent a significant policy change for the Survey regarding the development and provision of earth science information to the public. It would tie a program directly to success in marketing and selling the information and products that result from the program. It also would require a different approach to product pricing. By direction, prices that the Survey now charges for information and products, from aerial photographs to maps and printed reports, are set to cover the cost of reproduction and distribution. There is no requirement to recover costs of initial preparation, which are financed by annual appropriations. Digital cartographic data products would have to be priced to recover not only the cost of reproduction and distribution but also to recover all costs associated with developing and maintaining the data base itself.

## DATA-BASE DEVELOPMENT

Fiscal year 1981 was marked by continued efforts to transfer the Digital Cartography Program from a research orientation into progressive stages of development and production.

Plans call for the data base to consist initially of the boundaries, public land net, streams and water bodies, and transportation features shown on 1:24,000-scale maps; elevation data largely obtained concurrently with the orthophotoquad program; the planimetric features from the 1:2,000,000-scale sectional maps of the *National*





*Atlas of the United States of America;* elevation data obtained from the 1:250,000-scale map series; land use and land cover data; and geographic names. The potential size of the data base is extremely large; with complete coverage of the conterminous United States at 1:24,000 scale requiring nearly 54,000 maps, the data base would eventually contain several trillion bits of spatial data.

In fiscal year 1981, the Survey added 2,500 digital elevation models to the data base for a total of 6,300. Each model covers one 7.5-minute quadrangle. Boundary and land net data from 2,000 quadrangles also were added, bringing the current total to 3,600. Elevation data from the 1:250,000-scale maps currently are available for most of the United States, including Alaska. All 21 sheets of the 1:2,000,000-scale *National Atlas* series were digitized, and editing is continuing.

Many of these products in the data base will soon be available for public sale. The digital files derived from the 1:24,000-scale series produced as part of the initial research effort now are being reviewed for accuracy and adherence to specifications and standards, necessary documentation is being completed, and customer materials are being prepared.

# Research and Development

The research program of the National Mapping Division centers around geographic and cartographic research with particular emphasis on spatial data analysis, applications of remote sensing, and improved cartographic concepts and techniques.

## CORRECTING DIGITAL ELEVATION MODELS

Many of the digital elevation models of the Earth's terrain are collected by automated mapping equipment. This equipment uses overlapping aerial photographs (a stereopair) to calculate an array of point elevations for the area. The equipment is accurate over most types of terrain; however, over flat areas, water bodies in particular, errors can occur. This could result, for example, in lakes with "hills" in them.

To overcome this problem, the boundaries of water bodies are digitized and tagged with their true surface elevations. These areas then are merged with the unedited digital elevation model, and the correct elevation data are placed into the model. The procedure will handle multiple water bodies and islands.

◀ FIGURE 6.—*The status map above shows 7.5-minute quadrangles where digital elevation models have been completed. A digital elevation model is a digitized file of ground positions normally at 30-meter intervals. The status map below shows digital line graph 7.5-minute quadrangles where at least one category, such as transportation, hydrography, or boundaries, has been digitized. A digital line graph is line map information in digital form.*

## MAPSAT

A feasibility study, conducted under contract, indicates that an operational mapping satellite system is an economic and practical possibility This satellite system, called Mapsat, utilizes many characteristics of the current Landsat satellite missions but features improved resolution and stereocoverage. Multicolor image maps at scales as large as 1:50,000 with contours are envisioned as one product of the system.

A primary concern in designing Mapsat was to have a high-resolution capability but, at the same time, to keep data transmission from the satellite as low as possible. These factors run counter to each other because high resolution requires more data transmission. A possible solution to this problem that would be incorporated in Mapsat would have only one of the three proposed spectral bands with high resolution. By combining the bands, it should be possible to achieve a decrease in data rate without a corresponding loss in information. A test combining two lower resolution bands with a higher resolution band yields significant improvement in image quality over the low-resolution image.

## RADAR STUDIES

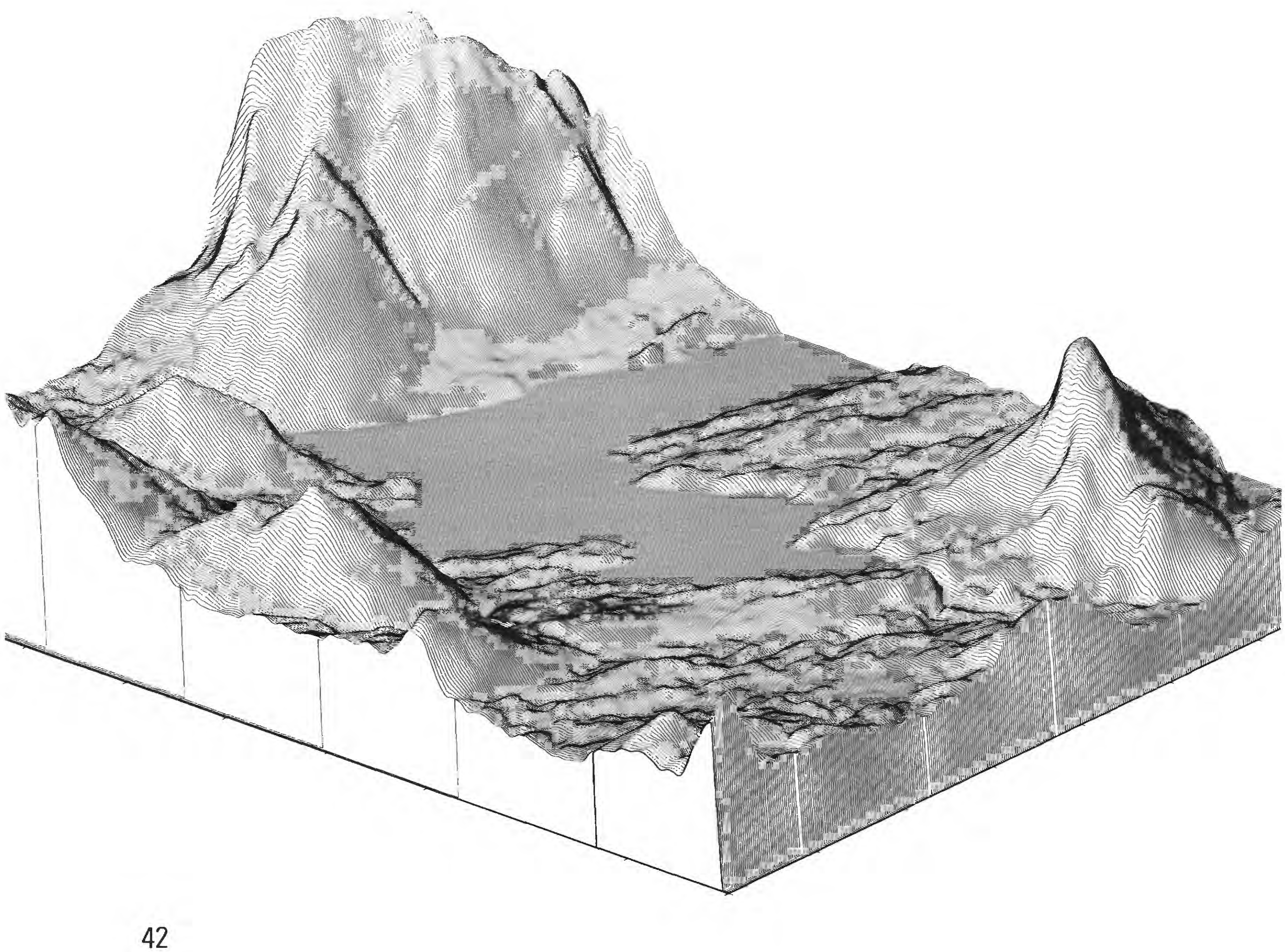
The Survey is evaluating side-looking airborne radar for use in topographic and geologic mapping and geologic resource surveys. The side-looking airborne radar systems contain a transmitter that provides a pulse of radar energy that is emitted from an antenna. The energy pulse travels to the ground, is reflected, and returns to a receiving antenna. This reflected energy then is used to make an image on film, analogous to photographic film using reflected sunlight to make an image. Imaging radar systems such as side-looking airborne radar, have a unique ability to "see" through clouds and rain and, to some extent, vegetation, such as tree tops, to the ground underneath. This combination of characteristics has shown promise in mapping geologic structures, topography, wetlands, and vegetation.

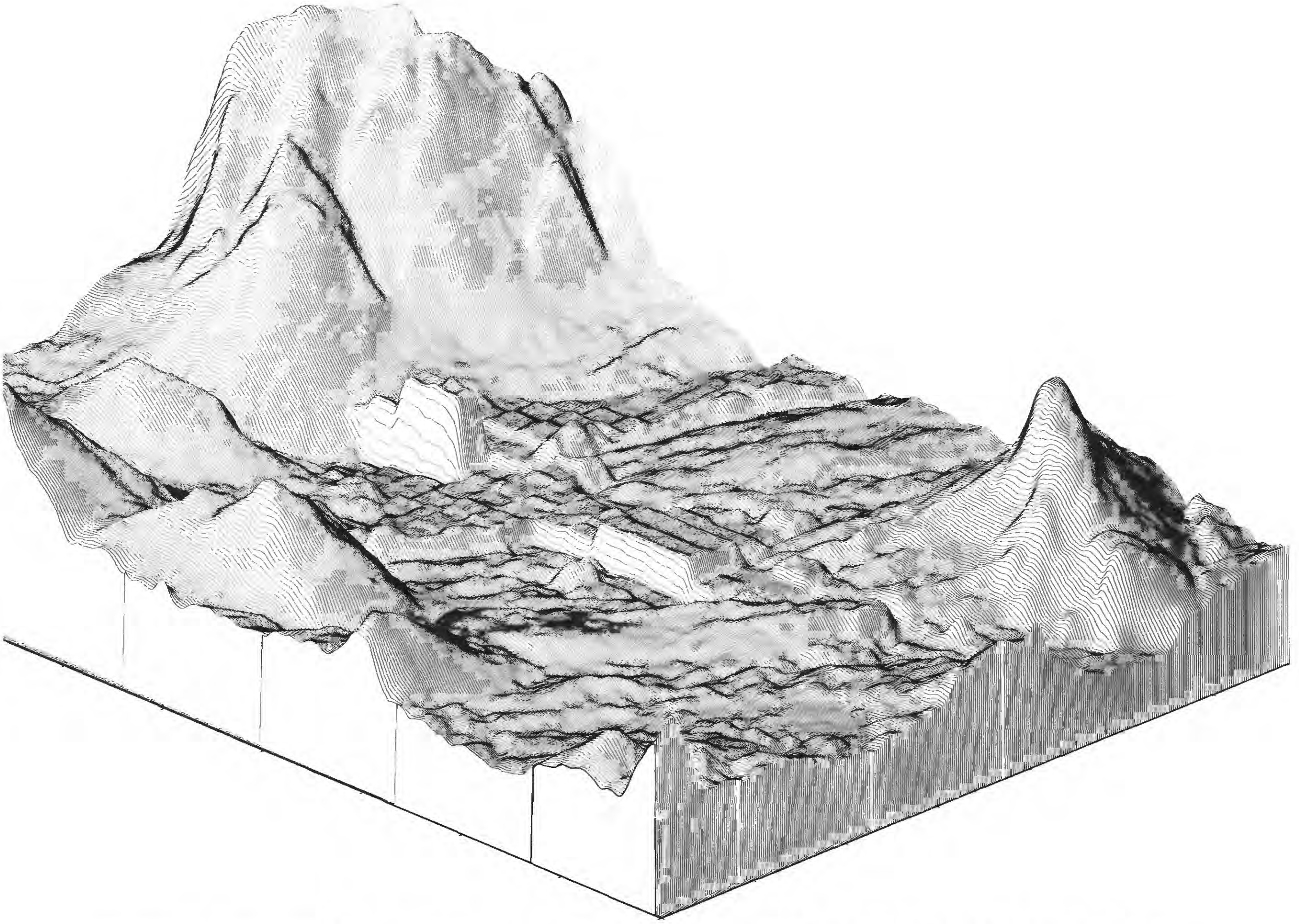
Side-looking airborne radar image mosaics for areas in Montana and Idaho were used to evaluate how well four base mapping categories—hydrography, landforms, transportation, and culture—can be discerned. Natural features such as hydrography and landforms are easiest to identify without using the corresponding line map as a guide. Transportation features intermittently disappear in the imagery, making them difficult to trace. Culture, such as urban areas, images as white patches, and road patterns within urban areas cannot be detected easily. Airports appear as bright spots caused by the high reflectivity of metallic and concrete objects. Urban patterns and airports are not sharply defined because of the low resolution of the sensor.

An inherent problem of side-looking airborne radar imagery is shadows caused by lack of radar return. This problem can be overcome by combining images taken from different directions to help fill the voids. Combinations of images of the same area from different "look" directions are being evaluated. Side-looking airborne radar imagery in the vicinity of Ugashik, Alaska, was used for several experimental printings of these combined images.

To better evaluate the ability of radar to discern terrain, imagery from three areas in Montana was compared to computer-generated shaded-relief imagery developed from digital elevation data. In making the shaded-relief image of the elevation data, the computer simulated the illumination of the Sun to match the illumination characteristics of the radar image. The resulting display has many of the qualities of a radar terrain image and may be superior for geologic interpretation. Although the simulated shaded-relief imagery does not contain surface features such as streams, roads, and towns that appear on radar

FIGURE 7.—*Three-dimensional computer plots of the Little Bigelow Mountain area, Maine, graphically display the effect of editing the digital elevation model. The unedited upper plot shows artifacts in the water area, and the edited lower plot shows the correction from editing.* ▶ ▼





imagery, this may not be a drawback in that this additional detail may be distracting when analyzing geologic structure. Radar imagery must be taken from at least two positions to detect all ground structure, with commensurate additional cost. However, it is quite simple to simulate multiple-look shaded-relief images from digital data. This latter simulation is more geometrically correct and is not subject to the voids often present in radar images.

## LAND USE CHANGE

An experimental 1:250,000-scale land use and land cover map of the greater Pittsburgh region was prepared from aerial photographs acquired in 1969 and 1973, just before and after the 1970 Census. Between 1969 and 1973, land use or land cover was converted from one class to another in 1.21 percent of Allegheny County. An additional 0.36 percent of the county was in the process of changing from one land use or land cover type to another. Besides urban expansion, other significant changes were the result of construction of Interstate Highway I-79 and the resurgence in strip mining for coal as a result of the energy crisis.

## CROPLAND-PASTURE DELINEATION

High-altitude color infrared photographs used to prepare land use and land cover maps were studied to determine whether they could be used to accurately differentiate cropland from pasture in three Louisiana parishes. Photointerpretation and field verification, resulting in an interpretive accuracy level of 74 percent (short of the Survey requirement of 85 percent), suggest that pasture-cropland delineation from such photographs should not be a standard practice.

## LAND COVER PATTERN ANALYSIS

Some success was achieved in discriminating flooded wetland forest from other surrounding forest using imagery from Seasat radar. Analysis of this imagery was most effective in the nearly level sections of the Atlantic and Gulf coastal


FIGURE 8.—*Avon, Montana, is near the center of these comparison images. The upper portion is imaged by side-looking airborne radar; the lower image is a shaded-relief map simulated by a computer using the digital elevation model data base for the area.*

plains. However, in rugged terrain, distortion introduced during the conversion of the reflected radar energy to an image as well as saturation of various parts of the image due to topographic roughness hinders wetland delineation.

Experimentation with the satellite-borne radar continued in the pursuit of gaining better delineation of snow and ice features. The critical gap revealed during the research was the need to have simultaneous field-data collection coordinated with the radar overflight because the boundaries of the snow and ice features are so variable during the season of minimum extent.

# Public Services

Through its National Mapping Division, the U.S. Geological Survey maintains a number of offices and distribution centers throughout the United States to handle inquiries and requests for its maps and publications. Among these are its Public Inquiries Offices, National Cartographic Information Center, and, currently, a traveling exhibit. Survey maps are also sold through a network of authorized dealers, and map information is available from offices affiliated with the National Cartographic Information Center and operated by agencies of State governments in 28 States.

## PUBLIC INQUIRIES OFFICES

U.S. Geological Survey Public Inquiries Offices provide a public focal point for obtaining maps, reports, and other publications of the Survey, as well as providing information on Survey program activities and in giving general assistance to the public in locating Survey earth science information. Locations of the 10 offices are given on page147, "Guide to Information and Publications."

Each office is a Consigned Sales Agent for the Superintendent of Documents and provides over-the-counter and mail-order services for Geological Survey book reports of its geographic area and selected Surveywide technical publications (geology, water resources, and so forth).

Two exceptions are the Reston, Virginia, and Washington, DC, Public Inquiries Offices which provide over-the-counter sales of Survey map and book publications and Surveywide informational referral services for the entire United States.

## NATIONAL CARTOGRAPHIC INFORMATION CENTER

Cartographic and geographic information consists of a wide variety of products and services, virtually the entire range of items that either go into or are produced by the process of compiling and publishing maps. It is the role of the National Cartographic Information Center to make cartographic and geographic data available to the public. The National Cartographic Information Center also makes available information about cartographic and geographic holdings of other public agencies and private organizations.

National Cartographic Information Center offices handled more than 200,000 requests for information and assistance during the year. Key centers are operated by the four mapping centers and two Federal affiliates at the National Space Technology Laboratories, Bay St. Louis, Mississippi, and the Tennessee Valley Authority in Chattanooga, Tennessee.

## NATIONAL MAPPING DIVISION TRAVELING EXHIBIT

A National Mapping Division Traveling Exhibit has been developed and is being circulated to major universities and colleges throughout the United States. The exhibit describes map products and their uses and the services of the National Mapping Division.

An estimated 20,000 people have seen the exhibit to date at Pennsylvania State University, University of Illinois-Champaign, University of Minnesota, Eastern Michigan University, Rhode Island College, and Frostburg State College in Maryland.

The exhibit is scheduled to appear at North Carolina State University, Eastern Illinois University, Western Carolina University, University of New Mexico, Tufts University, University of Michigan, University of Kentucky, Detroit Public Library, Southern Connecticut State College, and Dartmouth University.

## PRIVATE RETAILERS

Currently over 2,500 authorized map dealers, a 20-percent increase over fiscal year 1980, sell Survey maps nationwide, which accounts for one-third of agency map sales. A special effort was undertaken to establish dealerships in areas where studies proved sales would be successful. Map dealerships for special Survey maps were established to sell the Colonial National Historical Park map and the Colorado and Pennsylvania county maps. Customer mail-order requests were filled by the Distribution Branches, with referral lists to dealers for future orders.

# Image Products—Supplements to Maps

The U.S. Geological Survey has recognized a national need for image products as valuable

mapping tools, map supplements, mapping alternatives, and popular sales items. As a result, it is responding to these needs through three programs that provide such products, namely its National High-Altitude Photography, orthophotography, and satellite imagery programs.

# National High-Altitude Photography Program

High-altitude photography has been recognized as a prominent national need within numerous Federal and State agencies for the last decade. Until recently, these Federal agencies have been obtaining this photography independently and with minimal coordination. Since 1978, to better coordinate these Federal and State needs and provide more users with high-altitude photography on a timely basis, the Survey took the lead in developing a national high-altitude photography data base, which has been designed to meet many of the users' major interests and objectives.

The national high-altitude photography data base consists of both black-and-white panchromatic and color infrared 9-inch × 9-inch photographs taken from 40,000 feet above mean ground level. The black-and-white photographs are taken by an aerial camera with a focal length of 6 inches, resulting in a photograph scale of 1:80,000. The color infrared photographs are taken by a second camera with a focal length of 8.25 inches, resulting in a photograph scale of 1:58,000.

In 1980, the first year of operation, 11 Federal agencies pooled their funds and coordinated their priorities to obtain about 600,000 square miles of high-altitude coverage.

At the end of the second year of a planned 6-year program for one-time national coverage, high-quality high-altitude aerial photographs were available for approximately 25 percent of the conterminous United States. About 500,000 square miles are entered into the program each year.

The data-base design incorporated findings of a Soil Conservation Service study to identify the image needs and coverage requirements for the Department of Agriculture. In addition to the Geological Survey and the Soil Conservation Service, the principal Federal users and contributors to this program are the Forest Service and the Economics, Statistics, and Cooperatives Service of the Department of Agriculture, the Defense Mapping Agency, and the Bureau of Land Management, the Bureau of Mines, the Bureau of Indian Affairs, the Office of Surface Mining, the Fish and Wildlife Service, and the National Park Service of the Department of the Interior. Photography obtained under this program is available for purchase by all government agencies and by the public.

The benefits of the National High-Altitude Photography Program include a nationwide aerial photographic data base planned for 1985, elimination of duplicate coverage, reduced costs, and the availability of systematic national coverage. Within the Geological Survey, this data base will make it possible to increase the production of digital elevation models, map revisions, and orthophotoquads and, at the same time, provide a product that will be useful to support natural resources investigations such as geologic interpretations, land use and land cover interpretation, and hydrographic studies.

◀ FIGURE 9.—*The Mokapu quadrangle, Hawaii, orthophotoquad features Kailua and Mokapu Point at a scale of 1:24,000. The area is also covered by a topographic map at the same scale.*

# Orthophotography Program

Orthophotographic products have become increasingly popular as interim mapping aids and map supplements to published line maps. There are three major map products of orthophotography: orthophotographs, orthophotoquads, and orthophotomaps.

Orthophotographs are aerial photographs that have been rectified to eliminate distortions due to camera tilt and to image displacement caused by photographing areas of varying relief on a flat film surface.

Orthophotoquads are monocolor orthophotographs produced in standard quadrangle format with an minimum of cartographic enhancement such as the addition of a few place names. Basic marginal information such as the Universal Transverse Mercator grid, scale, quadrangle name, and survey date are shown. Standard orthohotoquads do not show contour lines. However, a few experimental products showing contour lines have been well received by users. Orthophotoquads are used primarily as map substitutes for unmapped areas; supplements to line maps in planning, inventory, and management; image bases for land use mapping and for photoinspection and photorevision of published maps; and image-base guides for delineating planimetric features for line maps.

Orthophotoquads are produced mainly at 1:24,000 scale and have proven valuable to engineers, surveyors, foresters, and scientists. They are available for virtually all areas of the

United States, except Alaska, that are unmapped at 1:24,000 scale. About 3,200 orthophotoquads (6 percent of the area of the United States) are produced annually.

Orthophotomaps are full-color topographic maps published over a photoimage base. Information such as roads, boundaries, water features, and contours are overprinted on the image base. Orthophotomaps particularly are well-suited to certain areas of the country where standard line maps cannot portray adequately the terrain, such as marshlands, swamplands, and deserts. Orthophotomaps contain some valuable information not found on conventional maps, such as more detailed drainage patterns, vegetation patterns, cultivated areas, urban area buildings and structures, and field lines. All features are shown to scale.

# Satellite Imagery Program

Another activity of the National Mapping Division is to explore and evaluate the present and future applications of remote sensing for its contributions and benefits to mapping. Specifically, three significant projects utilizing Landsat data in mapping were undertaken in 1981.

A satellite image map of Cape Cod and vicinity was compiled at 1:100,000 scale using return beam vidicon imagery. Four return beam vidicom images were mosaicked and fitted to a central base. The black-and-white image map will be used in preparing a geologic map of Cape Cod and in preparing an intermediate-scale planimetric map.

Image maps at 1:500,000 scale were completed of the Berry Islands, The Bahamas. Landsat multispectral scanner images of the Berry Islands were digitally enhanced by the EROS Data Center, Sioux Falls, South Dakota, and photographically enhanced by the Eastern Mapping Center, Reston, Virginia, to emphasize underwater detail. The resulting product, *Berry Islands, The Bahamas*, is being distributed by the Defense Mapping Agency and the Survey.

Utilizing Landsat 3 return beam vidicom images, a 1:250,000-scale quadrangle image map of Ikpikpuk River, Alaska, was prepared as a prototype for conservation and mineral development studies of the area.

# Geographic Names Information System

The Geographic Names Information System, an automated data system containing primary information for places, features, and areas in the United States identified by a proper name, was completed in 1981 and is now fully operational. There are approximately 2 million names contained in the Geographic Names Information System taken mainly from U.S. Geological Survey topographic maps.

The project began in 1976 as an effort to establish uniformity in the use of names and their application throughout the Federal Government. The U.S. Geological Survey worked in conjunction with the U.S. Board on Geographic Names, which maintains a close working relationship with State and local governments and with the public. In addition to establishing uniformity in the use of names, the Geographic Names Information System serves as an index of names found on Federal, State, and private maps. It eliminates duplication and the need for other agencies to organize similar data files, provides a means of integrating data from other systems for multidisciplinary use, standardizes data elements and coded representation, and meets Federal and public information requirements as established by law.

For each entry the Geographic Names Information System provides the official name, feature class, location of the named feature (State, county), geographic coordinates (including source if a linear feature, such as a river), variant names, Survey map sheet code, and elevation (where applicable). With this basic information, the Geographic Names Information System can be used as a quick reference tool, or it can be used as a base for more specialized data.

Because information from this System can be retrieved and manipulated to meet user needs, users may incorporate information into their data base for further application to their own needs. For example, the coordinates of populated places are often incorporated into demographic data bases for use in location analyses.

The Geographic Names Information System lists data for various kinds of features identified by a name. The data include all named natural features and most man-related features, such as places, civil divisions, dams and reservoirs, National and State Parks, and airports. Named streets, roads, and highways will be added later.

Edited alphabetical finding lists are currently available for 28 States and the District of Columbia in spiral-bound book form, microfiche, or magnetic tape. Unedited files are available on magnetic tape and as computer printouts for the entire United States and its territories.

The preparation of a *National Gazetteer of the United States* is now underway. The *National*

*Gazetteer,* a product of the Geographic Names Information System, is to be published in the U.S. Geological Survey's Professional Paper series. Completion of the *National Gazetteer,* which will be on a State-by-State basis, will take approximately 5 years.

## THE WAY IT WAS: GEOGRAPHIC NAMES

There is a story that Nome, Alaska, got its name when a map editor, seeing a prominent cape marked on a draft, wrote the query "Name?" beside it, and the cartographer who prepared the final copy converted the query into "Nome", which also became the name of the settlement established there. Whether this story be true or apocryphal, the question of what to name a feature on a map or how to write the name of a well-known place (Bering or Behring Sea? Woods Hole or Wood's Holl?) can be a vexing one.

Before the 19th century, those Americans who could read and write spelled as they pleased. With the publication of dictionaries and the rise of mass literacy in the 19th century, uniform orthography became important. Schools, newspapers, and magazines all demanded the one best way of spelling every word that appeared in print. How else could the immigrant from abroad learn the language of the new land and the native, newly taught to read, follow the events of the day in the newspaper?

When Thomas C. Mendenhall left the presidency of Rose Polytechnic Institute in 1889 to become Superintendent of the Coast and Geodetic Survey, he found that the Federal Government had no policy for deciding which names to put on its maps and charts. Each agency made up its own. So Mendenhall called together representatives from all the bureaus in Washington that needed decisions about names. This voluntary group was so successful in resolving disputes that President Benjamin Harrison issued an Executive order in 1890 that made it official as the U.S. Board on Geographic Names. The Board functioned outside any one Department until the 1930's, when it was placed in the Interior Department.

Until the Second World War, 90 percent of the Board's decisions on what to call a place or geographic feature or on how to spell its name were domestic. With the spread of American forces all over the world in the 1940's, foreign names came to dominate the Board's work, and this domination continued into the postwar period as the United States took responsibility for preserving world peace. By 1947, when the Board received an organic act from Congress, it had a staff of nearly 100 people.

The increasing need for foreign names for military, intelligence, and diplomatic purposes pressed hard on the Board, which never had more than half a dozen people working on domestic names. So, in 1958, the Secretary of the Interior moved the domestic names people to the Geological Survey, which had had its representative on the Board from the beginning and was a principal user of its decisions. Soon thereafter the foreign names people moved to what later became the Defense Mapping Agency.

The staff of the Domestic Names Committee of the Board is now part of the National Mapping Division of the Survey. As in the 1890's, only half a dozen people carry out the research that goes into the myriad of decisions which must be made. Computers help them keep up with and even expand their activities.

Decisions once made have to be promulgated. In the 1890's the pages of the *National Geographic Magazine* carried the details of what the Board on Geographic Names had decided. Nowadays, domestic names are published in the *Decision List* which is binding on Federal agencies and generally is accepted by other publishers of maps and gazeteers. In an age when uniformity of spelling is essential if documents are to be read by machine, the Board on Geographic Names keeps the United States ahead of most other countries in maintaining a standard set of place names. The Board is probably the oldest organization in the United States that controls language. It continues to mediate between the marvelous inventiveness of the American people with their language and the need of our computers to keep everything straight.

# Geologic and Mineral Resource Surveys and Mapping

## Mission

The Geologic Division conducts programs to assess energy and mineral resources, to identify and to predict geologic hazards, and to investigate the effects of climate. The assessments resulting from these programs are essential to planning for the wise use and management of the Nation's land and mineral and water resources and to mitigating the disastrous effects of geologic hazards.

In the last several years, the U.S. Geological Survey's responsibility in assessing the Nation's resources has increased markedly, especially in the areas of energy—oil and gas, coal, geothermal, and uranium. Large areas designated by Congress for inclusion as Wilderness Areas have required mineral assessments, and additional areas are likely to be designated in the future. Research and investigative efforts have moved into frontier areas such as identifying and assessing mineral resources on the ocean floor and the energy resource potential of offshore areas in the arctic environment. In addition, a major program for earthquake hazard mitigation and prediction is now underway. Geologic hazards related to nuclear reactor siting are being investigated.

In support of these mission programs, extensive basic research is done continually on geologic processes and events. Basic research continues to be a strong part of the Division's programs and provides the capability needed to respond to emerging national problems. The Geologic Division budget is presented to Congress under five subactivities that fulfill the above programs. A brief description of these subactivities follows:

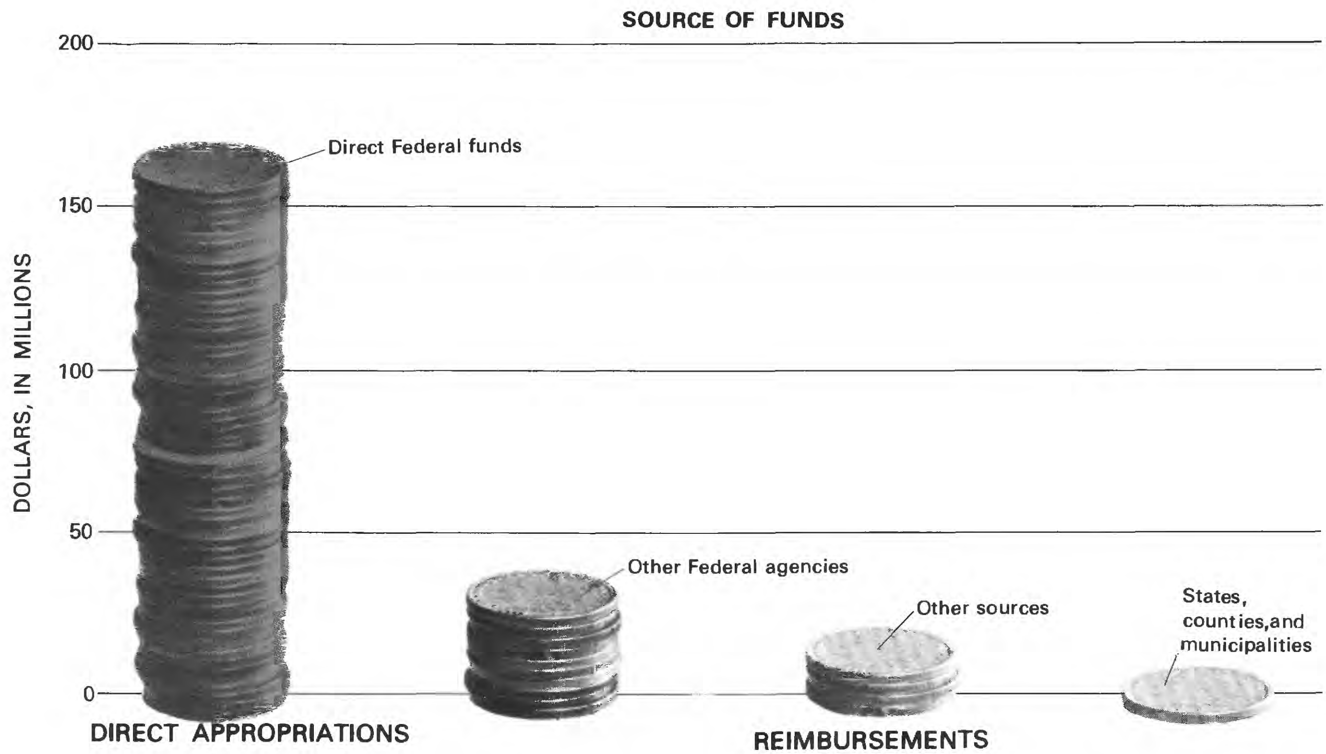
- *Geologic Hazards Surveys* are conducted to acquire data useful in predicting and delineating hazards from earthquakes and volcanoes and to identify engineering problems related to nuclear reactor siting, ground failure, and construction hazards.
- *Land Resource Surveys* are conducted to acquire basic information on the Nation's geologic framework and the processes that have shaped it, to develop an understanding of climate change and its effects on land and water resources, and to measure changes in the strength and direction of the Earth's magnetic field.
- *Mineral Resource Surveys* provide an assessment of the distribution, quantity, and quality of the mineral resources of the United States. During fiscal year 1981, these surveys were concentrated in Alaska, Wilderness Areas, and other public and Indian lands. Multidisciplinary studies of mineralized areas in Idaho, Missouri, Michigan, and Wisconsin were completed, and similar studies are in progress in 11 other States. Research also is conducted on the fundamental geologic processes that result in mineral formation.
- *Energy Geologic Surveys* provide assessments of the distribution, quantity, and quality of the Nation's coal, oil and gas, oil shale, uranium, and thorium, and geothermal resources. Assessments of these resources are continually updated so that information is kept current.
- *Offshore Geologic Surveys* investigate the continental margins of the United States and its territories to assess the potential mineral and energy resources and to identify environmental hazards that must be considered when siting offshore drilling platforms and pipelines.

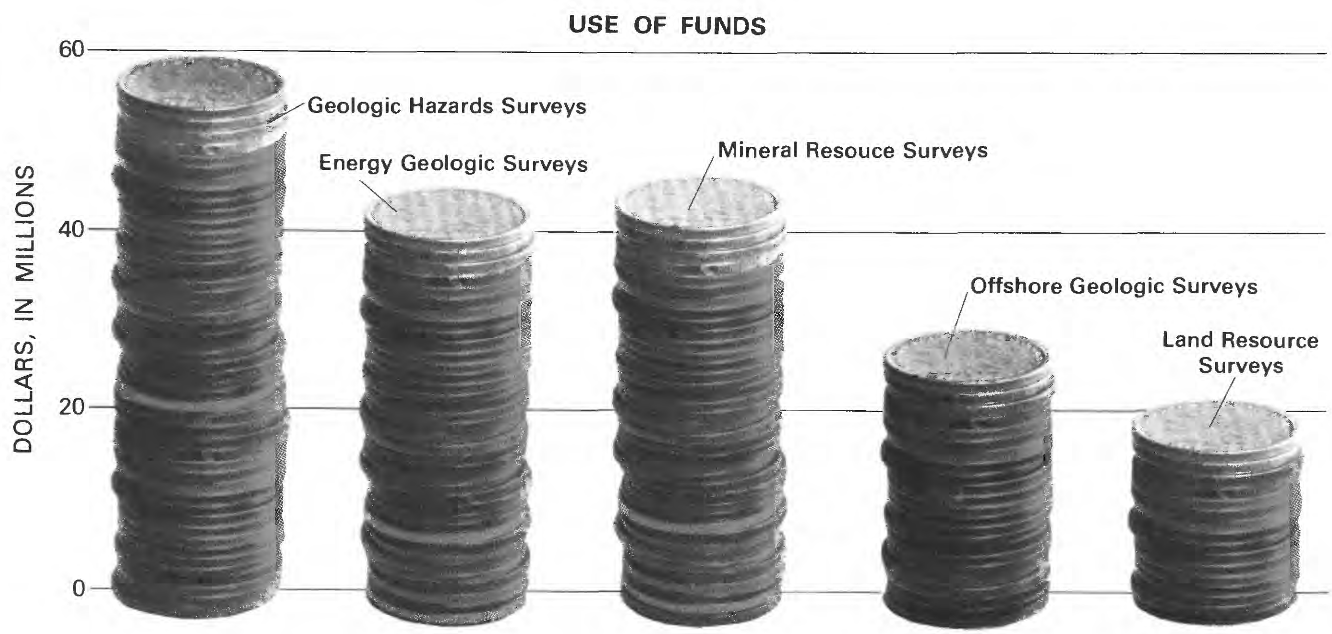
The following articles describe some of the research and assessments done by the Geologic Division in fiscal year 1981. Although they reflect only a small portion of the current programs, these articles represent typical ongoing activities of the Division.

## Budget and Personnel

In fiscal year 1981, obligations of the Geologic and Mineral Resource Surveys and Mapping activity totalled $208.2 million. This amount included $45.5 million in reimbursable programs. About $600,000 in reimbursements came from nine States under cooperative work programs.

At the end of the fiscal year, the Geologic Division has 2,014 permanent full-time employees and 966 employees and 966 employees in other categories.


SOURCE OF FUNDS
200
150
100
50
0
DOLLARS, IN MILLIONS
Direct Federal funds
Other Federal agencies
Other sources
States, counties,and municipalities
DIRECT APPROPRIATIONS
REIMBURSEMENTS


USE OF FUNDS
60
40
20
0
DOLLARS, IN MILLIONS
Geologic Hazards Surveys
Energy Geologic Surveys
Mineral Resouce Surveys
Offshore Geologic Surveys
Land Resource Surveys

*Geologic and Mineral Resource Surveys and Mapping Activity obligations for fiscal years 1980 and 1981, by subactivity and program*

[Dollars in millions. Data may differ from those in statistical tables because of rounding]

| Subactivity and Program* | Fiscal year 1980 | Fiscal year 1981 |
|---|---|---|
| **Geologic Hazards Surveys** | **48.2** | **56.5** |
| Earthquake Hazards Reduction | | |
| Earthquake Hazards Reduction | 37.7 | 38.4 |
| Volcano Hazards | 4.6 | 12.9 |
| Ground Failure and Construction Hazards | 2.0 | 1.8 |
| Reactor Hazards | 3.9 | 3.4 |
| **Land Resource Surveys** | **17.1** | **17.9** |
| Geologic Framework | 13.1 | 13.9 |
| Geomagnetism | 3.0 | 3.0 |
| Climate Change | 1.0 | 1.0 |
| **Mineral Resource Surveys** | **9.9** | **43.0** |
| Alaska | 5.1 | 8.2 |
| Conterminous States | 6.3 | 5.8 |
| Wilderness Mineral Surveys | 10.1 | 9.6 |
| Resource Information and Analysis | 6.3 | 6.6 |
| Development of Assessment Techniques | 11.9 | 12.7 |
| Mineral Discovery Loan Program | 0.2 | 0.1 |
| **Energy Geologic Surveys** | **40.3** | **41.8** |
| Coal Resource Investigations | 12.4 | 12.9 |
| Onshore Oil and Gas Investigations | 8.1 | 8.5 |
| Oil Shale Investigations | 0.8 | 2.4 |
| Uranium-Thorium Investigations | 8.4 | 8.1 |
| Geothermal Investigations | 10.6 | 8.5 |
| World Energy Assessment | .. | 1.4 |
| **Offshore Geologic Surveys** | **25.3** | **26.6** |
| Offshore Oil and Gas Resources | 12.4 | 12.7 |
| Energy-Related Evironmental Investigations | 11.2 | 12.1 |
| Marine Geology Investigations | 1.7 | 1.8 |
| **Other Programs** | **22.9** | **22.4** |
| Office of International Geology | 15.5 | 15.3 |
| Astrogeologic Studies | 4.8 | 4.8 |
| Special Projects and Military Geology | 2.6 | 2.3 |
| **Total** | **193.7** | **208.2** |
| Direct Programs | 147.0 | 162.7 |
| Reimbursable Programs | 46.7 | 45.5 |
| States, counties and Municipalities | 0.6 | 0.6 |
| Other Federal Agencies | 34.8 | 31.7 |
| Other Sources | 11.3 | 13.2 |

*Program data estimated.

# Earthquakes and Risk in California

Seventy-five years ago on April 18, 1906, northern California was struck by the most devastating earthquake in Unites States history. This great earthquake, magnitude 8¼ on the Richter Scale, ruptured the northernmost 270 miles of the 700-mile-long San Andreas fault. The ground along the fault moved an average of more than 12 feet north of San Francisco and about 6 feet to the south. Buildings were damaged in a 50-mile-wide region extending for over 350 miles parallel to the fault break.

San Francisco suffered disasterous losses, primarily from the fire caused by the earthquake. The fire consumed much of the city and left 250,000 people homeless. Over 700 lives were lost as a result of the earthquake, and property damage exceeded $500 million in 1906 dollars. Similar damage in dollar values for the 1970's would result in losses greater than $2 billion.

In the years since the great 1906 earthquake, earth scientists have learned much about the causes of such periodic upheavals of the Earth's surface. Most major earthquakes occur at the boundaries of the several large tectonic plates into which the Earth's crust and the first few miles of the underlying mantle are divided. These plates are in constant motion, overriding, plunging beneath, or simply slipping past one another, as in the case of the North American and Pacific plates which meet in California along the celebrated San Andreas fault zone and move at an average of 1.5 to 2 inches per year. Measurements taken over an extended period of time indicate that this movement is irregular and episodic; segments of the adjoining plates may remain immobile and locked together for years, only to break free in a great lurch that may result in an offset of several feet over a few seconds as the two plates resume their slide-slip movement.

A recent report, *An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake: Findings and Actions Taken*, prepared by the Federal Management Agency with major assistance from the U.S. Geological Survey, concluded that the probability of a catastrophic earthquake occurring in California during the next three decades exceeds one chance in two. Dollar losses in such an event likely would total tens of billions of dollars, and fatalities could be in the thousands.

# THE SEISMIC GAP THEORY

Analysis of the seismic activity of the major plate boundaries around the world has led to the recognition that ruptures along major plate boundaries tend to occur sequentially, affecting limited segments and often leaving intervening portions undisturbed as seismic gaps. With time, however, large earthquakes tend to occur in these seismic gaps before repeated movement occurs on more recently ruptured segments. The locations and magnitudes of more than six major earthquakes have been forecast successfully by this theory since the mid-1960's.

Application of seismic gap theory to the San Andreas fault leads to the identification of four distinct fault segments: two that have ruptured in great earthquakes and two for which there is no historic record of any major earthquakes. These fault segments are shown in figure 1. From north to south, these segments are as follows: *A*, the northern 270 miles of the fault that ruptured in 1906; *B*, the central 100-mile-long segment that adjoins the 1906 break to the south; *C*, the 220-mile-long south-central segment that last ruptured in a magnitude 8.3 earthquake in 1857; and *D*, the southernmost 120 miles of the fault that terminates in the birthplace of the fault in the Imperial Valley. Estimates of the mean slip rate on each segment of the fault, when combined with detailed studies of ancient earthquakes preserved in the geologic record, give rather compatible estimates of long-term recurrence. When combined with the historic record of seismicity and measurements of crustal strain, they give us some estimate of today's short-term risk.

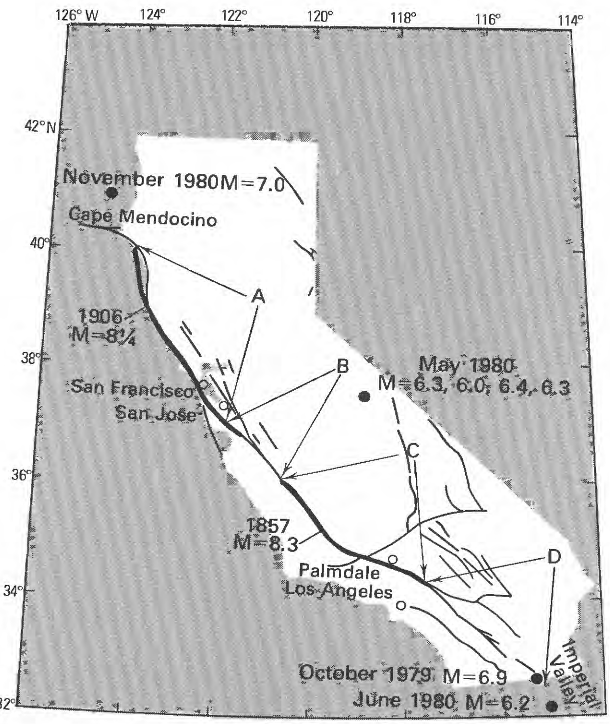


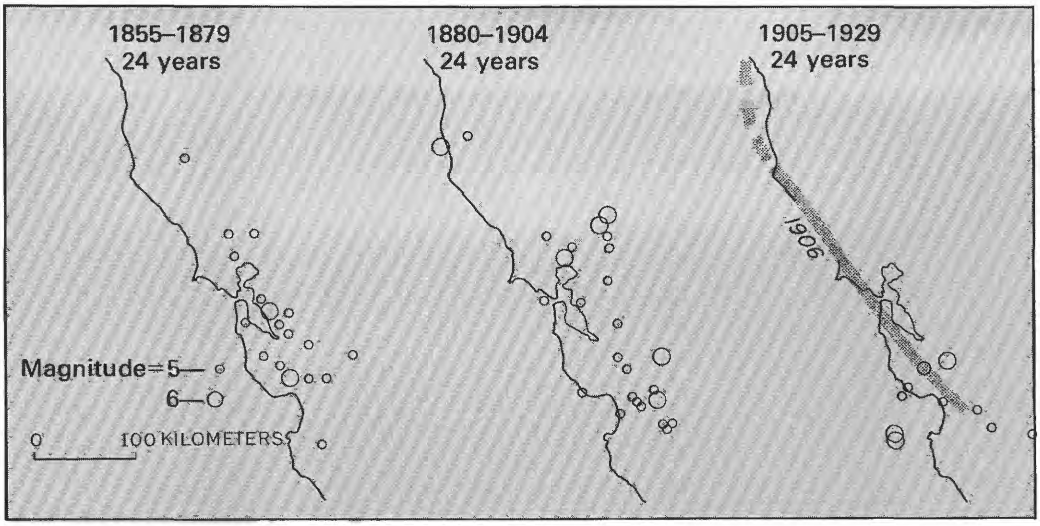

FIGURE 1.—*Seven earthquakes of magnitude 6 or greater have occurred in or near California in the past 2 years, compared with only four in the previous 20 years. The extent of faulting in historic magnitude 8 earthquakes on San Andreas fault shown by heavy lines.*

## Probability of earthquakes on segment A

The recurrence of a magnitude 8 earthquake on the northern *A* segment (fig. 1) of the fault appears to be unlikely within the next several decades. Mean recurrence time, which is determined by dividing the fault displacement expected in a great earthquake by the long-term slip rate of the fault, implies an average return time of roughly 150 years for a 1906-sized event. Contemporary strain data also suggest that approximately another 50 to 100 years will elapse before the crust returns to its pre-1906 strain state, assuming that the current strain rate is maintained throughout the interval. Information pinpointing the time and size of previous major events is critically needed and would permit a significant refinement of these estimates.

If the sequence of events leading to the next great earthquake on the northern sectors of the San Andreas fault follows the same general pattern observed before 1906, then other lines of evidence would similarly suggest that a great earthquake is not imminent. In particular, the occurrence rate of earthquakes of magnitude 5 or greater was significantly higher during the 50-year period before 1906 than it has been since (fig. 2). In fact, no earthquakes as large as magnitude 5 occurred in the entire San Andreas system to the north of San Jose in the first 50 years following the 1906 earthquake (fig. 3). Since about 1956, magnitude 5 earthquakes have begun to reappear within this northern coastal belt of faults, although the present level of activity appears to be well below the 19th century level. Repetition of the same general pattern of seismicity in advance of the next earthquake would imply that several decades characterized by increased frequency of damaging earthquakes should be expected. Similar long-term variations in the earthquake rate have been identified elsewhere in the world, notably in the focal regions of great earthquakes in Japan and in Kamchatka, U.S.S.R.

A significant aspect of this seismic cycle model, as applied to northern coastal California,



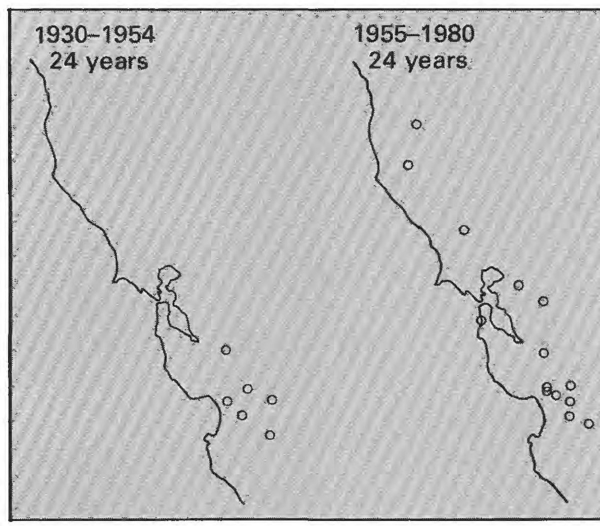




FIGURE 2.—*Seismicity of the San Francisco Bay region from 1855 to 1980. Note the conspicuous decline in number of earthquakes following 1906.*

is that it forecasts that the region will experience magnitude 6 to 7 earthquakes at a frequency comparable to that of the 19th century, or about one per decade, for several decades to perhaps a century before the next great earthquake of magnitude 8 or greater occurs. Such a series of magnitudes 6 to 7 earthquakes locally may pose as serious a hazard as a great earthquake on the San Andreas fault.

## Probability of earthquakes on segment *B*

In contrast to the low but rising probability of a major earthquake on segment *A* of the San Andreas fault, the central sement *B* (fig. 1) of the fault appears to have very low potential for producing a major earthquake in the near future. Among the segments of the San Andreas fault, the central segment is uniquely characterized by the occurrence of numerous small-magnitude (less than 5) earthquakes. This segment is presently moving in rigid block motion, principally by aseismic slip (fault creep). No detectable strain has accumulated in the crust adjacent to the fault since at least the mid-1880's. Either this segment of the fault has maintained itself in a critical equilibrium, on the verge of rupturing in a large earthquake for over a century, or fault creep effectively accomodates the plate motion. Most scientists who have studied this segment favor the latter viewpoint.

## Probability of earthquakes on segment *C*

The short-term risk of a major earthquake on either the south-central segment *C* (fig. 1) or southern segment *D* (fig. 1) of the San Andreas fault is considered to be significantly greater than it is to the north. Estimates place the annual probability of such an event between roughly 2 and 5 percent per year. Several independent lines of evidence contribute to this assessment.

The mean recurrence time for major earthquakes on a portion of the 1857 break has been determined from the record of ancient earthquakes preserved in a marsh at Pallett Creek, near Palmdale, California. The mean frequency of fault offsets is one event every 140 years. At this site, the 124-year interval since the last event in 1857 is approaching the mean time interval between events.

Analysis of long-term earthquake rate variations also suggests that the risk of a major earthquake is high. Observed changes in earthquake frequency follow the same cyclic pattern de-

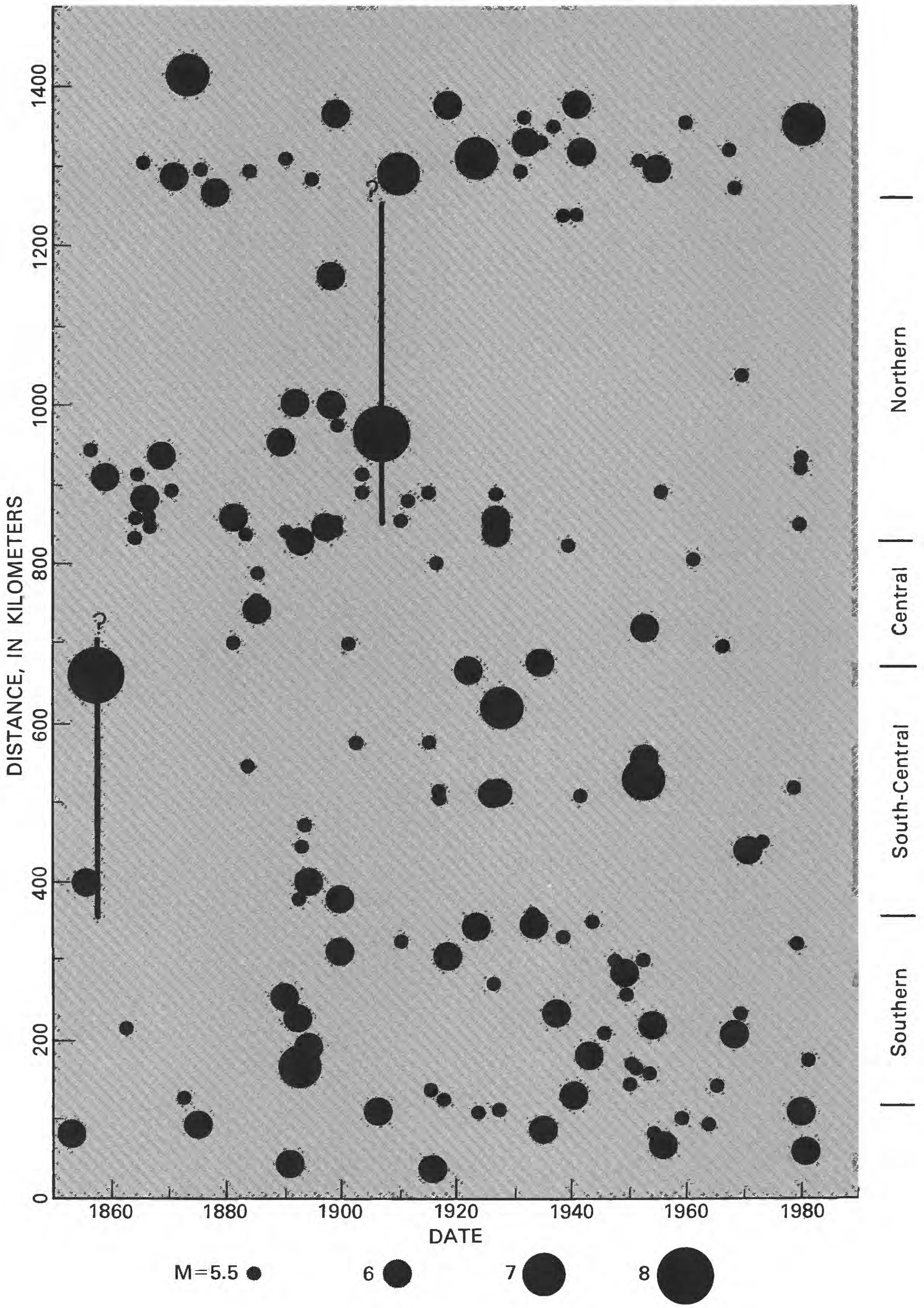



FIGURE 3.—*Space-time diagram of seismicity of the San Andreas fault system from 1850 to present. Extent of surface faulting of 1857 to 1906 earthquakes shown by vertical lines.*

scribed above for the northern San Andreas fault system. In the broad region surrounding the 1857 earthquake, seismicity has apparently increased to a level comparable to that observed along the northern segment preceding the 1906 earthquake since the early part of the 20th century (fig. 3). Thus, the pattern observed along the south-central segment (C, fig. 1) appears to be more advanced in its development by about 50 years than is the northern segment (*A*, fig. 1). This high level of seismicity also can be expected to continue up to the repeat of an 1857-sized event. Each of these lines of evidence suggests that a major earthquake may occur sooner along the south-central segment of the fault than along the northern segment. However, these time estimates can only be given in decades, not months or years.

Frequent surveys of geodetic networks represents one very promising approach to the problem of detecting short-term anomalous crustal movements preceding damaging earthquakes. Data collected since 1973 from five of seven observation networks in southern California suggest that a regional increase in strain may have occurred in 1978–79. This short-term variation in the longer term strain accumulation pattern was most pronounced in the Palmdale network, where the strain field adjusted to bring the fault significantly closer to failure. Although there was no apparent correlation between this regional strain episode and detailed seismicity patterns recorded within the networks, the change coincides with a statewide increase in magnitude 6 and greater earthquake activity. The significance of this coincidence is unknown at present.

### Probability of earthquakes on segment *D*

The earthquake potential of the southernmost fault segment (*D*, fig. 1) is less well defined because no major earthquakes are known from either the historic record or detailed geologic studies. However, the risk here should be considered to be high. This segment of the fault, like the other two segments that have ruptured causing earthquakes, is locked at the surface, has elastic strain accumulating across it, and produces very small earthquakes. It is embedded within the most seismically active area in California, one that has produced magnitude 6 and greater earthquakes at a nearly constant rate during the historic period. Thus, the features believed to be symptomatic of high potential for major earthquakes elsewhere on the San Andreas fault appear to be present here.

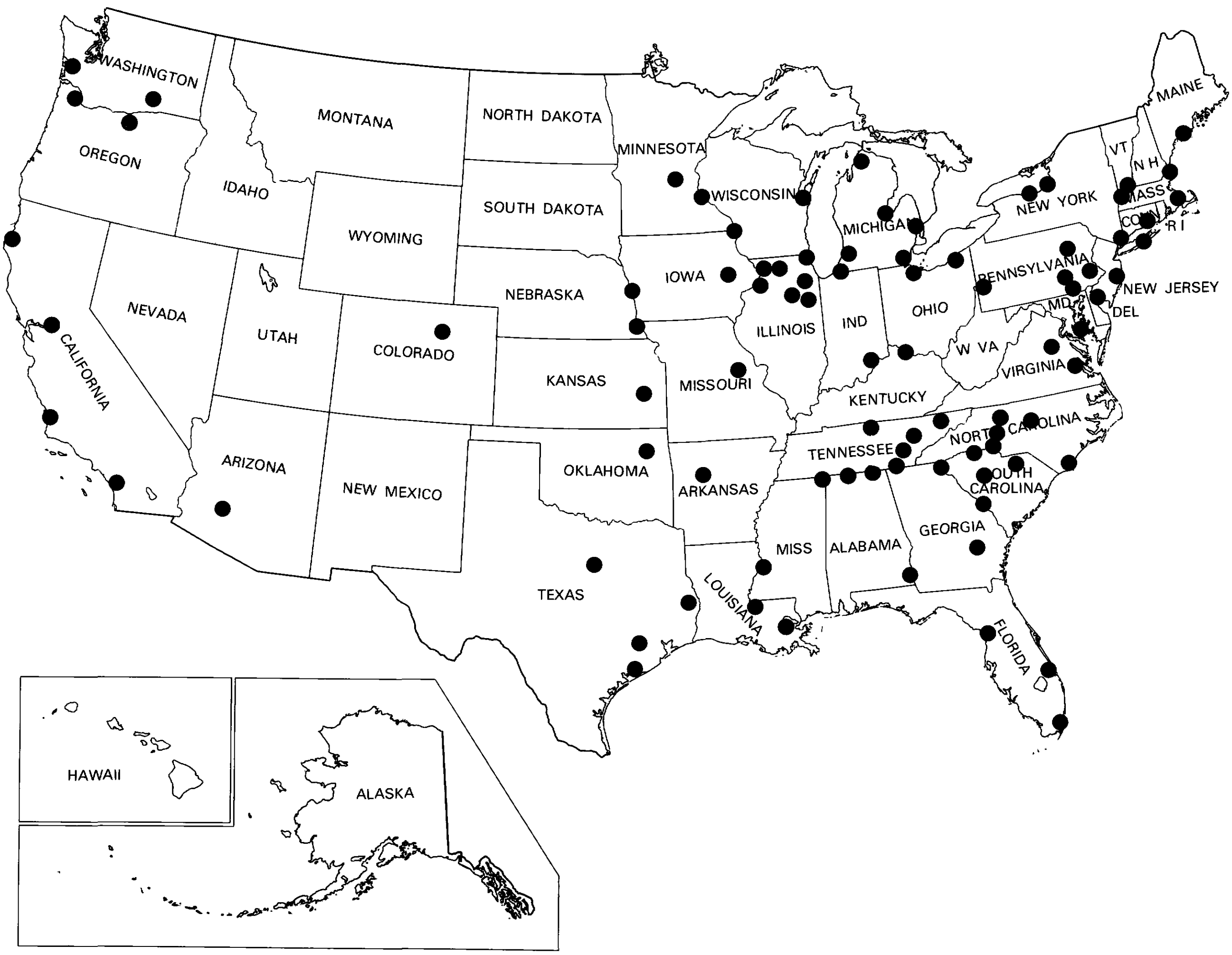
### The Earthquake Hazard Production Program

The U.S. Geological Survey is attempting to refine the estimates of short-term risk given in the preceding paragraphs through the Earthquake Hazard Reduction Program, a program of monitoring and research that includes several scientific disciplines. Instrumental and survey networks that include over 400 telemetered seismographic stations and 25 geodetic networks containing hundreds of survey lines, for example, now cover the San Andreas fault system in its entirety. Because of its scale and fundamental emphasis, this network is most likely to succeed in developing the ability to predict the occurrence of the largest earthquakes in the San Andreas system—the magnitude 7 to 8 events that form the major hazard to human life and property. The instrumented region also includes between 5 and 10 sites where repeated moderate earthquakes have occurred and thus provides a number of opportunities to study the processes accompanying these small but more frequent earthquakes.

# The Reactor Hazards Research Program

## RESEARCH RELATED TO THE SAFE SITING OF NUCLEAR REACTORS

The surge of nuclear powerplant construction that began in the mid-1960's brought into focus the need for a better understanding of faulting, seismic shaking, volcanism, and ground failure so that the hazards from these sources be minimized through plant location or design. In 1973, the Nuclear Regulatory Commission adopted more comprehensive regulations for seismic and geologic siting criteria pertaining to nuclear powerplants. In practice, as these criteria were applied to specific areas, it soon became evident that basic geologic data in many areas were insufficient. The U.S. Geological Survey, having assisted in the development of the criteria and having by then assisted the Nuclear Regulatory Commission (then the Atomic Energy Commission) in the review of many applications for reactor sites, became aware of the need for a research program specifically developed to broaden the




*Location of nuclear powerplants (planned, under construction, or completed) in the conterminous United States.*

base of geologic knowledge and data as applied to nuclear powerplant siting. In the Southeastern United States, the 1886 Charleston, South Carolina, earthquake and its application to engineering design was not well understood. Similarly, in the northwest, information about the 1872 earthquake in Washington was inadequate.

The Reactor Hazards Research Program was established in 1975 to conduct the basic research for these as well as many other areas of limited knowledge.

Through the ensuing years, a diversified research effort of over 40 projects has evolved covering regional tectonics, applied geophysics, seismology, age-dating methods, and geologic processes; brief descriptions of the objectives of these efforts are given below. Priority for areas of research has been determined, in part, by those areas of major power needs—the Pacific coastal states and the eastern and midcontinent industrial and population centers (see map).

## Regional Tectonics

Research projects in regional tectonics are directed towards a more comprehensive understanding of the deformation of the Earth's crust over the past 65 million years and its relation to present-day seismicity. In the Western

United States, research has demonstrated the relation between earthquakes and faults. Because of the particular geologic setting, movement along certain faults can be observed following large earthquakes. In the Eastern United States such an obvious relationship is not evident. There have been large earthquakes, but the evidence as seen at the ground surface by movement along faults, to date has not been observed. The reasons for this basic difference between eastern and western earthquakes are not clear. To probe more deeply into the origin or cause of eastern seismicity, research projects have been developed that provide for the investigation of major geologic structures such as basins and arches within the Atlantic Coastal Plain and a major structural boundary in New England. A common objective of these efforts is to develop fault histories to ascertain rates of deformation and fault behavior through time under varying stress fields. Recent acquisition of data from deep seismic reflection surveys in the Charleston, South Carolina, area and in Virginia along a transect extending from the Blue Ridge Mountains to the Chesapeake Bay and along a shorter segment across the Culpeper Basin is leading to the recognition of additional structural elements that need to be assessed with respect to the potential to generate earthquakes of significance to engineering design of nuclear powerplants in the east.

## Applied Geophysics

In addition to the interpretation of seismic reflection data mentioned above, other geophysical studies include deep magnetic soundings in New England and in the Pudget Lowland of Washington, an aeromagnetic survey of the Foothills fault zone, California, a detailed gravity survey in support of subsidence research in Arizona and Texas, and seismic reflection surveys of the Great Lakes. All such studies assist in extending our knowledge of surface geologic structure to the subsurface, thus adding the third dimension, depth, to our understanding of regional structures and how they relate to siting nuclear facilities.

## Seismology

Research in seismology has included support for seismic networks at Charleston, South Carolina, and the Mojave Desert area, California, and studies in ground motion as applied to engineering design. In addition, a continuing effort is made to update the U.S. earthquake catalog. An integral part of this research is the review and reanalysis of major earthquakes that occurred before modern instruments were available to refine existing data about their intensity and the locations of their epicenters.

The South Carolina seismic network has been in operation continuously since 1974. Although no large earthquakes similar to the 1886 event near Charleston have occurred, numerous smaller events have been recorded. Analyses of these events are being made in conjunction with ongoing geologic mapping and geophysical studies in an effort to understand and evaluate the seismic risk of the area.

## Age-Dating Methods

In regions where faults may be close to nuclear powerplant sites, the geologic siting criteria set forth by the Nuclear Regulatory Commission requires an interpretation of the age of last movement of the fault, particularly where movement may have occurred during the past 35,000 years. To establish the age of fault movement reliable methods of age dating are required.

The Reactor Hazards Research Program includes research in various techniques and is developing new methods of determining geologic age dates. Ages younger than 35,000 years before present can be determined using the carbon-14 dating method provided, of course, that material suitable for sampling are available. For ages from 35,000 years before present to 1,000,000 years before present, other methods are required. Current research applicable to this age span includes fission track, thermoluminesence, soil chronology, paleontology, volcanic ash stratigraphy techniques, and paleomagnetic stratigraphy. All researchers utilizing these various age-dating methods are collaborating and integrating their respective studies with those of field mapping projects. For example, field geologists mapping in Charleston, South Carolina, and the Cape Fear Arch, North Carolina, areas are collecting stratigraphic reference samples for paleontology, amino acid, soil chronology, U series, carbon-14, and paleomagnetic dating. In the Western United States soil and volcanic ash (including ash from the May 1980 eruption of Mount St. Helens) are being collected for soil and volcanic ash chronology, carbon-14, paleomagnetic, and paleontologic dating. The overall results being obtained from this research are as follows: (1) multiple methods of age dating are providing a means of cross-correlating and verification of ages of faulting and fault movement, (2) methods are being refined and both precision and confidence levels increased, and (3) risk assessment or other studies relying upon recurrence intervals of tectonic or volcanic events are being accomplished with greater reliability.

## Geologic Processes

Research in geologic processes has been directed towards subsidence caused by fluid withdrawal and hazards resulting from volcanic eruptions and landsliding.

Research on land subsidence caused by withdrawal of the underlying fluids includes instances where there has been ground failure associated with both the production of large volumes of ground water and solution mining. In the Phoenix, Arizona, region, large fissures have developed and the ground surface over a large area has subsided as a result of many years of ground-water extraction. The degree of ground failure, either as differential subsidence or fissuring, is of significance to large structures which must remain functional, such as nuclear reactor containment vessels.

In the Houston, Texas, area, subsidence research has been coupled with study of another process—aeseismic or "growth" faulting. The Houston Basin has subsided many feet as a result of the extraction of large volumes of fluids; this subsidence has been expressed at the ground surface as a steplike southeastward ground movement along preexisting faults. The total dislocation has taken place over a period of several decades primarily as a process of slow creep and without detectable seismicity. The faults, therefore, are considered as posing no seismic threat to engineered structures. Differential movement across the faults, however, does pose a threat to buildings. In several greater Houston housing areas, streets have sagged several feet across the scarp, and some homes have been deformed. At the San Jacinto Monument, a small landscaped pool and the access road are subsiding. An area with a similar potential for differential subsidence would not be recommended for use as a nuclear powerplant site. Siting constraints are being determined through these field analyses and will be used as guides for location of plants in more favorable areas.

Landsliding is another aspect of ground failure hazard important in nuclear plant site evaluation. Even such an event as disruption of the cooling-water supply caused by the temporary damming of a river by a massive landslide must be considered. Similar slides have developed in the past and were triggered either by an earthquake or by local slope conditions. The mechanics of landslide processes must be understood; the research of the Reactor Hazards Research Program in this field will help in establishing a more complete understanding of these processes and the variability of critical parameters.

The hazards posed by volcanic activity have been a component of the Reactor Hazards Research Program since its inception. The hazard analyses considered, among other factors, potential ash fall accumulations at various distances from volcanoes of the Cascade Range in the Pacific Northwest. Some of the early results were used in formulating guidelines for reactors at the following locations: Trojan and Pebble Springs, Oregon, and Skagit, Satsop, and Hanford, Washington. The 1980 eruptions of Mount St. Helens provided a unique opportunity to document and further refine concepts of the various hazards. Two effects of the May 18, 1980, eruption that are of particular interest are the apparent anomalous thickness of ash that accumulated at Ritzville, Washington, and the total effect of the ash load in the ensuing flood down the Toutle and Cowlitz Rivers and ultimately into the Columbia River. Enough ash load was deposited in the bed of the Columbia River upstream (south) from the confluence of the Cowlitz River that the navigational channel had to be dredged before the large ships from Portland could traverse the passage. The surge of relatively high-density flood debris apparently was strong enough to flow several miles southward against the normal northward flow of the Columbia River, a situation not considered probable until the eruption and flood proved otherwise. These kinds of effects are now being carefully analyzed and the results will be incorporated in the overall volcanic hazard assessment.

# SUMMARY

The Reactor Hazards Research Program was established in 1975 with the principal goal of providing a more adequate base of geologic and seismologic knowledge that would aid in the siting of nuclear powerplants. To date, numerous maps and texts dealing with tectonic structures, new techniques of age dating, and analyses of ground motion have been published. These publications and regular presentations of the results of investigations and research at national or regional meetings of geologic or seismological professional societies serve as the means of making the data available to ther public.

# Planetary Exploration: The Geology of Saturn's Satellites

A team of U.S. Geological Survey geologists and cartographers, working with the Voyager Imaging Science Team at the Jet Propulstion Laboratory in Pasadena, California, played a major role in planning and executing the National Atmospheric and Space Administration's Voyager spacecraft missions to Saturn and Jupiter. The emphasis of the missions was on the geology and cartography of the moons of the giant planet.

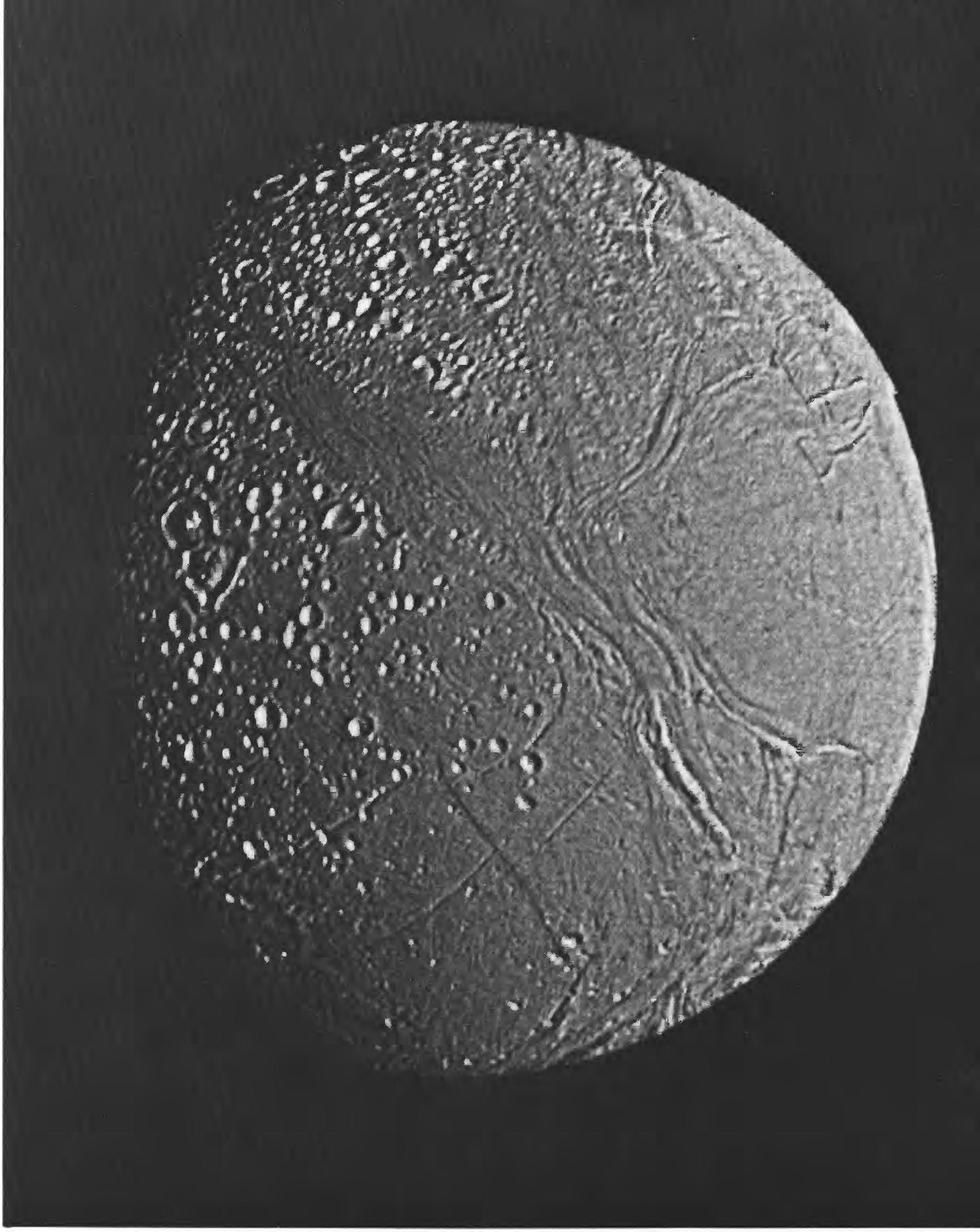
During 1980 and 1981, the primary focus was the Saturnian system. The Voyager 1 spacecraft arrived at Saturn in early November 1980 and imaged at high resolution the moons Mimas, Dione, and Rhea with distant views of Tethys, Enceladus, Iapetus, and Hyperion. Voyager 2's sequence was planned to complement Voyager 1's investigations and yielded high-resolution images of Tethys and Enceladus and far better views of Iapetus and Hyperion than did Voyager 1. In addition, Voyager 2 provided the first photographic information on Phoebe, Saturn's most distant moon. Voyager 1 discovered three small "shepherd" moons; two orbiting along and evidently confining the complex braided F ring and a third orbiting at the edge of the A ring, the outermost of the main sections of Saturn's rings. Although Voyager 1 passed very close to Saturn's largest moon, Titan, a dense cloudy atmosphere prevented imaging of the surface. Hence, most of the information we have about Titan comes from other nonimaging experiments that measured the temperature, pressure, and composition of Titan's atmosphere. Results from those instruments indicate Titan may be the most exotic world in the solar system. The Voyager missions discovered that Titan has a dense cold nitrogen atmosphere in which methane may behave much like water does in the Earth's atmospheric system. The temperature and pressure conditions are close to those required for methane snow, methane rain, and even methane rivers. The surface temperature is near −360° F. In addition, complex photochemical reactions occur as solar radiation strikes Titan's upper atmosphere, thus creating a wide range of hydrocarbon molecules. It has even been speculated that Titan now may resemble chemically the early prebiotic conditions of Earth. The true nature of Titan's surface and its geologic history and processes will remain a mystery until Titan's atmosphere and surface are investigated with some form of landing vehicle and (or) its surface is studied using an imaging radar system similar to that planned for a Venus mission in the near future.

Saturn's 17 known moons can be divided into two general classes. The first class includes eight new or minor satellites discovered since the mid-1960's. These include the three "shepherd" moons mentioned above which orbit along the edge of the A and F rings, two coorbital satellites that share an orbit between the rings and the orbit of Mimas, and three Trojan satellites that occupy stable positions ahead of or behind two of the larger satellites. These bodies are found at the classical Lagrange points 60° ahead of and behind Tethys and 60° ahead of Dione. These objects show irregular shapes, suggesting an origin by fragmentation. Very likely they are remnants of larger bodies and not produced by direct accretion. Their existence indicates an early period of tremendous collisions within the Saturnian system capable of destroying moons in the size range of a few hundred miles in diameter.

The second class of moons includes the nine classical moons which have been known since the 19th century. These include, in order out from Saturn: Mimas and Enceladus, which are 250 and 300 miles in diameter, respectively; Tethys and Dione, which have nearly identical diameters of about 700 miles; Rhea, which is 950 miles in diameter, about one-half of the size of the Earth's Moon; cloudy Titan, which is the size of Mercury or Ganymede (one of Jupiter's moons); Hyperion, which is an object of very irregular shape much like the new or minor satellites but about the size of Mimas and Enceladus; Iapetus, which is at a much greater distance from Saturn and has a diameter nearly identical to that of Rhea; and Phoebe, which is a very dark and distant moon seen for the first time by Voyager 2.

All of the inner moons of Saturn are rotating synchronously and revolving in orbit. Hence, one hemisphere faces Saturn, as our moon's "frontside" faces the Earth. The "leading hemisphere" always faces forward as the body moves in its orbit. Voyager 1 global views of Dione and Rhea show them to have generally bland leading hemispheres, lacking albedo (reflectivity) variations, but to have trailing hemispheres displaying complex interwoven patterns of bright swaths set against a dark background. These patterns occur in a small circular region on each body centered in the trailing hemisphere. Because the moons are

*Surface of Saturn's moon Enceladus viewed from Voyager 2 on August 25, 1981. The small satellite, only 300 miles in diameter, is seen from a height of 69,500 miles.*



in synchronous rotation, as is the Moon about the Earth, they keep the same face towards Saturn and the same faces leading and trailing in orbital motion. E. M. Shoemaker of the U.S. Geological Survey has estimated that the cratering rates, produced primarily by impact of cometary nucleii, differ from the leading hemispheres to the trailing hemispheres of these moons by factors of about 10 to 1. Based on this model, it is likely, then, that the trailing hemispheres have received far fewer impacts and have been "impact gardened" to an order of magnitude less than the leading hemispheres. It is probable, therefore, that the patterns have survived only in the trailing hemisphere and, at one time, laced the entire globes of Dione and Rhea. Detailed inspection of high-resolution images along the extensions of these bright markings suggest that they are formed on fractures. It is probable that fluids escaping along these fractures produced frost deposits on the surface. Images of Dione show that, in its trailing hemisphere, the bright swaths cross over the top of the impact craters, indicating that the loss of internal fluids along the fracture system had to occur well after cessation of heavy bombardment. This was the first evidence for some endogenic or internal activity of these small moons.

Prior to the Voyager encounters with the Saturnian system, it was known that Iapetus was a very bizarre world in that the leading hemisphere was extremely dark and that the trailing hemisphere was very bright. The dark side has an albedo of only a few percent, about that of carbon black or soot. The albedo of the trailing hemisphere, however, is similar to the rest of Saturn's icy moons with a reflectivity of about 50 percent, or about that of dirty snow. One of the models suggested that the leading hemisphere of Iapetus might be dark because dark material was falling in from space and being deposited preferentially on the leading hemisphere. The purported source of this material was postulated to be Phoebe. Ground-based telescopic observations of Phoebe suggested that it had colors like carbonaceous chondrites and dark asteroids and, therefore, also might have a very dark surface.

Although Voyager 1 confirmed that Phoebe is extremely dark, Earth-based telescopic data, which was confirmed by Voyager observations, indicated that the color of Phoebe's surface and Iapetus's dark leading hemisphere are very different. The Voyager images of Iapetus showed that the boundary between the leading and trailing hemispheres was probably too complex to be produced simply by infalling material. Voyager 1 images showed a ring of dark material about 125 miles in diameter extending from the dark hemisphere into the bright hemisphere. The features resembles a moat produced when large craters with central prominences were flooded on the Moon. Voyager 2 images showed that not only is the boundary between the leading and trailing hemispheres angular, but part of that boundary extends deep into the trailing hemisphere. Additionally, Voyager 2 images showed floors of craters covered by the dark material which are located in the center of the trailing hemisphere. The evidence now indicates that some internal process is responsible for the extrusion of dark materials onto the surface of Iapetus which form the dark regions, flooding crater floors, and large basins. The conclusions now are tentative and highly speculative and will have to await a future mission to this strange moon for detailed understanding of its geologic evolution.

Mimas, Enceladus, and Hyperion are the smallest of the classical Saturnian satellites and have diameters between about 150 and 200 miles. By mass, they each are about ten-millionths the mass of the Earth. Prior to the encounters of Voyagers 1 and 2, the suspicion was that these bodies were far too small to have any substantial internal geologic activity. The Voyager images showed these three small objects to have geologic histories that range in diversity over the spectrum of planets we have so far seen in the solar system.

Mimas, an approximately spherical body, is likely an object of cold accretion. An enourmous impact crater found on its leading hemispher is nearly one-half the diameter of the small satellite. Most likely Mimas was subjected to even larger impacts early in its history. Under such an impact, the body would be blasted apart. Because the fragments would have low relative velocities (typically only a few hundred feet per second, comparable to Mimas' escape velocity) compared to Mimas' orbital spread of 15 miles per second, the material would continue orbiting in a tight wreath and slowly reaccrete, thus reforming the moon. Evidently little other geologic activity, except recratering of the surface early in its history, has gone on. Hyperion, in contrast, resembles the new or minor satellites. It is a very irregularly shaped moon, evidently a piece of a larger object that, like Mimas, was intensely battered, but, in this case one large fragment evidently survived. Enceladus, in great contrast to Mimas and Hyperion, was the real surprise of the Voyager 2 encounter. Scientists were suspicious that it might be unusual in that it has an extremely high albedo reflecting nearly 100 percent of the light it recieves from the Sun. Additionally, Enceladus' orbit coincides with the peak intensity of the E ring, a diffuse ring of material well outside the main ring system. Normally, satellites clean out or sweep out material along their orbits; the evidence indicated that Enceladus is a source rather than a sink of material. Finally, C. Yoder of the Jet Propulsion Laboratory realized that there is an orbital resonance between Dione and Enceladus similar to that by which Europa heats Io, the volcanically active moon of Jupiter. Dione causes Enceladus to move through Saturn's gravitational field in such a way that the surface is flexed. Voyager 2 images of Enceladus show that, in fact, it does have an extremely complex geologic history. Terrains vary in their crater populations from cases where craters are nearly shoulder to shoulder to those where craters are absent, at least to the limit of resolution of the Voyager images. A wide array of other terrains that are intermediate in crater density between these two extreme crater densities also can be identified. Complex "ropy" ridges are found on the margins of some of the crater-free plains. Evidently Enceladus has undergone geologic activity, perhaps episodically, throughout its history. Preliminary estimates by A. Cook and R. Terrile of the Voyager Imaging Science Team suggested that tidal energy may well be inadequate to heat a body composed of pure-water ice. One possible explanation is that the interiors of the icy moons may contain more volatile species. Methane and ammonia are likely candidates and are known to be abundant in the atmosphere of Titan. Either one of these materials, if present in substantial quantities within the moons, would lower their melting points by perhaps 180° F. to ranges not far above their surface temperatures. Under such conditions, tidal heating, perhaps assisted by some early radiogenic heating, could easily keep such a tiny icy world geologically active.

# World Energy Resources—The Need to Know Their Quantity and Location

For more than 100 years the U.S. Geological Survey has had the responsibility for assessing mineral resources to provide a basis for informed decisions and policies in both the public and private sector of the United States. The need for reliable data on the extent, location, and quality of these mineral resources has continued to grow with the broadening of our concerns and commerce. The United States requires mineral supplies from countries around the world, as do all technically advanced societies. Not only is a wide variety of minerals in demand, but, the energy minerals, very large quantities are needed.

Fortunately, the United States is very well endowed with mineral wealth and especailly with the energy minerals. We are, and have been throughout the period of the Industrial Revolution, one of the world's principal producers of petroleum, coal, and more recently uranium. Our capacity to produce and discover remains high, but so does our demand. For instance, the demand for petroleum over the past decade has been about three times the rate of domestic reserves additions. The Nation presently is embarked on a major exploratory effort to discover and produce more petroleum. At the same time, we are taking steps to divert petroleum demand to other energy sources, such as coal, and to reduce consumption. However, it is clear that continued cooperation, on as broad a base as possible, with other supplier nations is essential to our economic well being and hence national security.

In decades past, a stable price and supply rendered petroleum readily available to all nations with such reliability that national security was not affected. Now, however, extraordinary prices, political upheavals in the Middle East, changing economic principles in supplier countries, and domestic resource depletion require that we broaden our base of knowledge about the distribution and potential future availability of energy minerals throughout the world. This knowledge is essential to formulating international relations and to maintaining our national security.

From the perspective of the U.S. Government, there is no need for direct assistance for exploration activities conducted by the private sector at this time; however, the U.S. Government does need a broad knowledge of the worldwide regional resource availability as an aid to the conduct of international relations. A case in point is the sudden emergence of Mexico as a major producer of petroleum. In retrospect, the signs of that emergence clearly were evident 10 years ago. But in the absence of a program capable of recognizing the clues and analyzing their significance, the U.S. Government had no base of geologic resource understanding over a period of several years to enable it to respond politically and diplomatically to the changing resource realities.

The principal focus of the U.S. Geological Survey's World Energy Resources Program is on petroleum, but a modest effort to build a base for the worldwide investigation of other energy mineral resources has been initiated. The intent of the program is to provide an understanding of world energy mineral resources for the purposes of policy planning and analysis, including domestic resource assessment, that will be useful to the President, Congress, and other Federal agencies such as the Departments of State, Energy, and Commerce. The initial program objective has been to develop a geologic synthesis of the major petroleum producing regions of the world and, in cooperation with petroleum engineers in other agencies, to assess the present and future producibility of those resources. Secondly, we have initiated studies in frontier areas of the world that offer great promise for future production or are significant areas of international concern (Antarctica, for example). And finally, resource studies have begun in areas of modest resource potential but ones that show geologic promise of at least supplying some measure of local energy mineral needs. The program is coordinated with and depends critically on research activities in the domestic energy resource area. Relations with other Survey international programs also are maintained for best use of available manpower and data sources.

The principal products of the program will be Survey Circulars reporting on our assessment of resource potential in a given country or basin, coupled with a brief discussion of the geology leading to the assessment. Separate publications will include a more detailed presentation of the resource geology which will provide a baseline of information for ongoing analysis. To gain full advantage of the resource investigations, the assessment must be continuing, and, for each area studied, the program will maintain a surveillance of exploration activity as a check on the assessment process. At the completion of the first year of operation, assessments have been completed and are available as Open-File Reports for the following countries or parts of countries: Arabian-Iranian Basin (subdivided by country); West Siberia, Volga Urals, and Middle Caspian Basin, U.S.S.R.; Venezuela; Indonesia; Malaysia-Brunei; world offshore basins; southeast Mexico, Belize, and northern Guatemala; Trinidad; and northeast Mexico.

# Hard Minerals From the Deep Sea: The Role of Spreading Ridges

For more than three decades the sedimentary rocks of the world's continental shelves have been a prolific source of oil and gas. In recent years, due both to advances in marine mineral recovery technology and the increasing cost of locating and producing onshore supplies, there has been a marked growth of interest in the sea floor as a prospective source of nonfuel minerals as well. These hard minerals, such as zinc, copper, and silver and so called because they are formed and concentrated in hard crystalline rocks as distinguished from the softer sedimentary deposits that are the source and habitat of oil, gas, and coal, are presently the focus of extensive commerical and scientific investigation.

Of particular interest to scientists has been the evidence of mineral formation along the great 45,000-mile-long system of oceanic spreading-center-ridges that circles the world and is the site where new crust is being continously formed by the upwelling of molten rock from the underlying mantle (fig. 1). As the new crust is formed, it moves away from the spreading center on both sides of the ridge at varying rates up to 6.3 inches per year. Recent investigations have disclosed the occurrence of mineral-rich submarine hot springs that are a source of potentially valuable minerals along the spreading-center-ridge system. Some areas of the Western United States and Alaska contain sections of oceanic crust that have been transported via plate tectonic movement and incorporated into the continental crust. Studying the current mineralization processes on oceanic spreading ridges will thus enhance our ability to identify these onshore areas and target them for mineral explorations.

In 1979, a detainled photographic and geophysical survey of the Pacific sea floor off Mexico discovered a number of hot springs forming concentrations of zinc, copper, and silver, in ore-grade sulfide-mineral deposits on very young glassy volcanic rocks. The initial work, which used unmanned vehicles, was immediately followed by manned submersible investigation of selected submarine springs, and mineral deposits and hot water samples were recovered. The hydrothermal waters were much hotter (700°–750°F.) than previously observed or suspected. Since the initial discovery, this

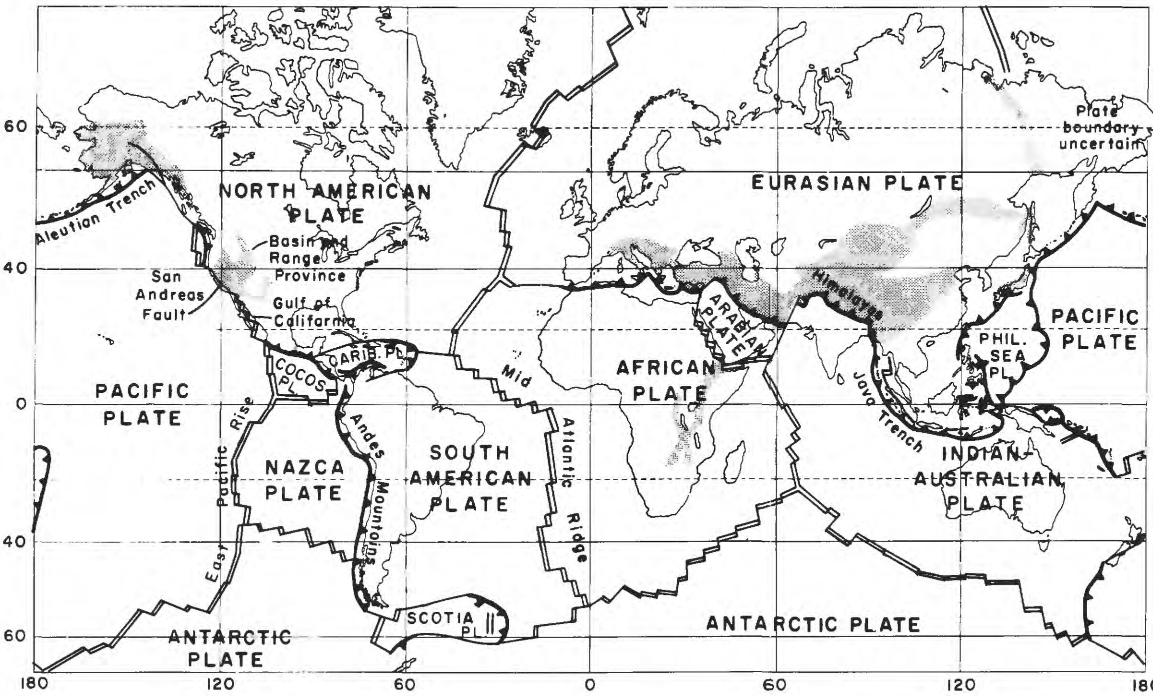



FIGURE 1.—*Map showing the major spreading centers of the world's oceans (double lines), subduction zones (toothed lines), and the larger tectonic plates.*

hydrothermal site at 21° north latitude on the East Pacific Rise has become the focus of investigations of the formation of metallic mineral deposits on the deep-sea floor. Since 1974, Geological Survey scientists have been involved in mapping the geology, crustal generation, and hydrothermal processes of the sea floor at this site.

Submarine hydrothermal activity on the deep-sea floor is known from other sites along the world-encircling oceanic spreading-center-ridge system. Lower temperature hydrothermal vents have been observed during submersible work along the Galapagos Rift System in the equatorial Pacific. Sulfide minerals have been dredged from Guaymas Basin in the Gulf of California, and hot water vents similar to those at 21° north latitude off Mexico have been photographed in the South Pacific on the East Pacific Rise west of Chile (fig. 2). All these occurrences are on oceanic spreading-center ridges where the rate of separation of the plates is greater than 2 inches per year. One-half the length of the spreading-ridge system has separation rates that exceed 2 inches per year. All detailed geophysical, photographic, or submersible studies of small segments of ridge crest having separation rates exceeding 2 inches per year have found active hydrothermal systems or mineral deposits left by these submarine springs. Thus, it is likely that many more areas of actively forming mineral deposits will be found on the deep-ocean floor. The similarity of bottom-dwelling animals at these widely separated hydrothermal sites is additional support for suspecting that hydrothermal systems will be found along most of the world's spreading ridge system.

## Resource Potential and Application to Contential Deposits

The submersible studies of the Galapagos Rift and the East Pacific Rise off Mexico provide the most comprehensive picture of hard mineral deposits formed at spreading centers. The sulfide deposits form small shallow mounds occasionally topped by one or more conical sulfide spires or chimneys. The mounds rest on fine-grained marine sediment (generally siliceous ooze) or directly on pillow lavas of the sea floor. Mounds observed on the East Pacific Rise site are 50 to 100 feet across and 6 feet high. The sulfide chimneys are 3 to 15 feet high.

The mounds and chimneys mark the location of hydrothermal vents that discharge metal-rich fluid at temperatures up to 700°F. onto the sea floor. The chimneys are constructed from sulfide

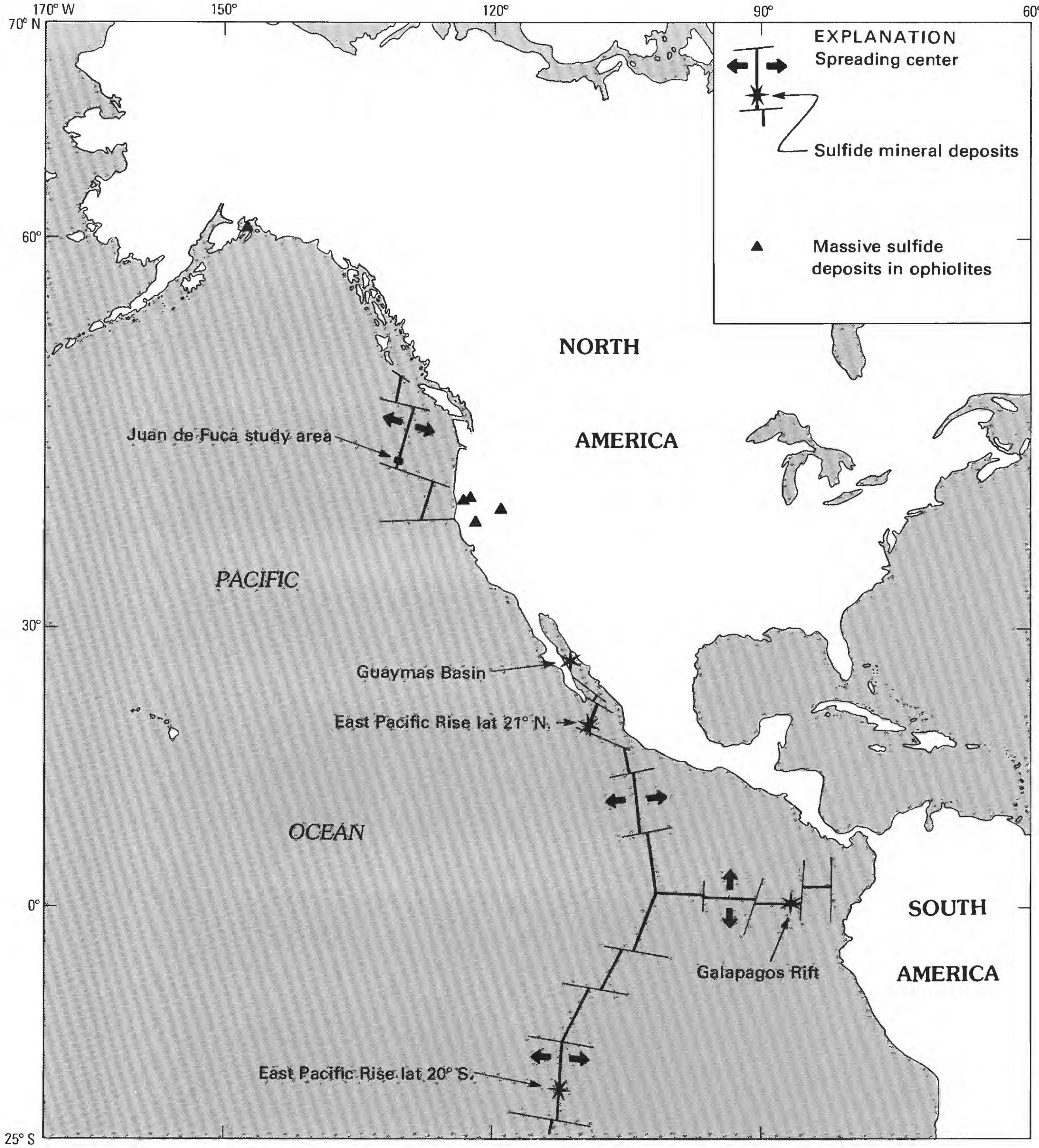



FIGURE 2.—*Map showing the location of known massive sulfide deposits along the Pacific Ocean spreading centers, massive sulfide deposits in ophiolites in the Western United States, and the U.S. Geological Survey study area on the Juan de Fuca spreading center.*

minerals precipitated as the hydrothermal fluid cools during mixing with seawater; the mounds result from direct precipitation from the accumulation of particulate matter expelled through the chimney and from the erosion and collapse of chimney debris. Some vents are currently active and vigorously discharging large volumes of cloudy black (sulfide- rich) or white (sulfate- or silica-rich) fluid. Other vents are inactive and rapidly disintegrating. Many active vent systems are inhabited by exotic communities of worms, crabs, and other organisms evidently supported by abundant sulfur-reducing bacteria in the hot-spring environment.

The mounds and chimneys are composed largely of sulfide minerals, especially zinc, copper, and iron. Parts of the vent deposits contain considerable amounts of anhydrite, barite, amorphous silica, and talc, and some mounds are largely composed of these minerals. Native elements commonly present include gold, silver, and sulfur. Sediment and basalt surfaces near the mounds are coated with deposits of iron and manganese oxide deep-sea sediments on the flanks of oceanic ridges and in nearby basins also are enriched hydrothermally in metals such as iron, manganese, nickel, copper, lead, zinc, arsenic, and mercury.

Analogs of the massive sulfide deposits of the East Pacific Rise are found in ophiolite sequences on land. Onshore ophiolites are layered sequences of volcanic rocks up to 6 miles thick that have lithological, structural, and geophysical characteristics similar to the crust beneath present-day ocean basins. Thus, ophiolites are thought to be fragments of ancient oceanic crust that formed at an oceanic spreading center and subsequently were transported away from the axis of spreading, uplifted, and placed onto the margins of continental land masses.

Sulfide deposits in ophiolite belts of the eastern Mediterranean region, particularly in Cyprus and Oman, have been important production centers for copper, iron, gold, and silver since 2500 B.C. Other large deposits of this type occur in Turkey, the Phillippines, Canada, the United States, and in several other countries. Ophiolitic terranes in the United States with massive sulfide deposits are found in California, Nevada southwestern Oregon, and Alaska. The massive sulfide deposits in ophiolites typically comprise 50,000 to 20 million tons of ore containing 0.5 to 10 percent copper, 0.5 to 3 percent zinc, and a few ounces of gold and silver per ton. In addition, several deposits may have important reserves of cobalt.

Like their counterparts on the East Pacific Rise and other modern oceanic spreading centers, the massive sulfide deposits in ophiolites are associated originally with pillow lavas (so called because of their pillowlike shape) erupted on the sea floor. The deposits contain two types of mineralization: massive (discrete orebodies) and stockwork (vein-type) (fig. 3). Compact massive sulfide occurs in lenses or dish-shaped bodies interlayered with pillow lava or pillow lava fragments. The massive sulfide body is typically underlain by hydrothermally altered pillow lava and a network of interconnected veins or stockwork that extend downward in rootlike fashion into the ophiolite. The stockwork veins represent the channelways followed by ore-bearing hydrothermal fluids as they migrated upward toward the sea floor. The mineralogy of the massive sulfide in ophiolites is dominated by iron sulfide minerals with lesser amounts of copper and zinc minerals. Quartz is the principal accessory mineral in the massive ore.

## FORMATION PROCESSES OF SUBMARINE MASSIVE SULFIDE DEPOSITS

The massive sulfides of the midocean ridges are hydrothermal deposits, that is, the heavy metals and sulfur were carried in dissolved form in deep-seated hot-water fluids and deposited when these fluids discharged as geysers on the sea floor. Chemical measurements of the hot water sampled along the East Pacific Rise site indicate the fluid was originally seawater that had undergone various chemical changes as a result of heating and chemical interaction with volcanic rocks beneath the sea floor.

The great oceanic spreading centers are one of the largest geologic features on Earth and account for the bulk of the Earth's volcanic activity. During the process of sea floor spreading, great amounts of heat are brought up from the mantle of the earth to the sea floor along these zones. Although of great linear extent, the actual zone of active lava production is narrow, usually only 1 mile or less in width. Such a geometry and the fact that the spreading center crests are generally more than 6000 feet below sea level gives rise to cooling of the spreading centers by convecting seawater. Such convection transports about 60 percent of the total heat introduced by sea-floor volcanism. The volcanic rocks on the sea floor are highly permeable to seawater, which is taken into the sea floor and absorbs heat from the top of the magma chamber along the spreading ridge axis. The intense pressures at these depths permits seawater to remain in the liquid state at approximately 800°F. Although boiling cannot occur

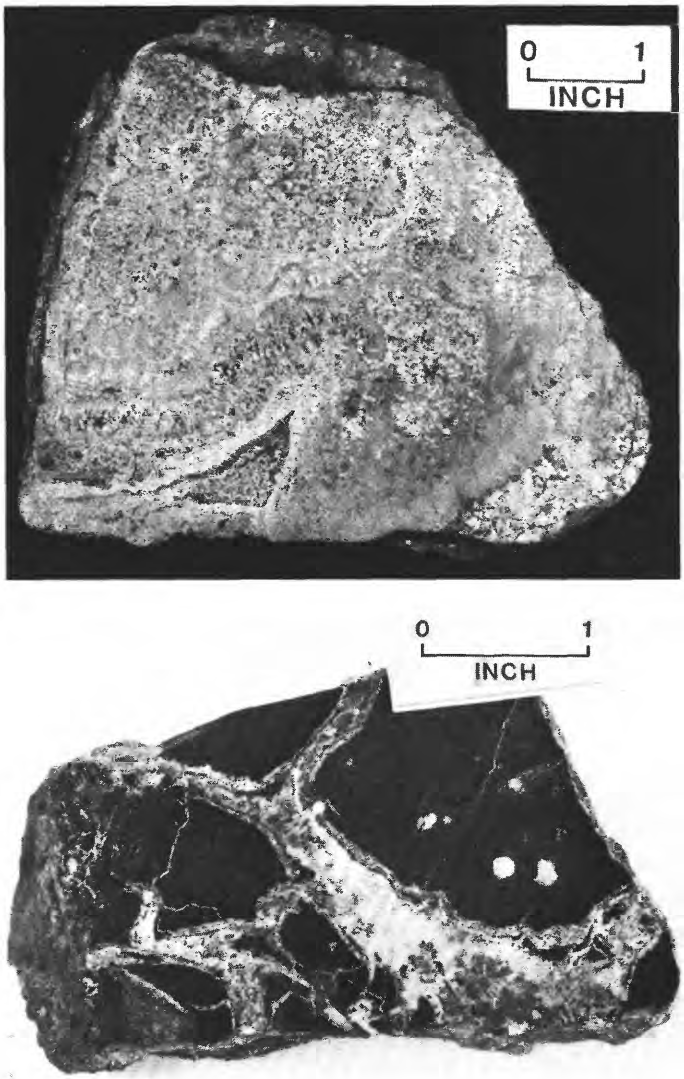



FIGURE 3.—*Example of massive and stockwork sulfide mineralization found in ophiolites. The slab of massive sulfide shown above exhibits a crude layering and consists mainly of iron compounds (light-gray areas) and five minerals (dark-gray spots and layers). The sample shown below exhibits basalt cut by stockwork veins. The veins are composed of iron compounds (bright edges), quartz (white areas), and copper minerals (gray areas). The massive sulfide and veins represent sea-floor and subsea-floor deposition of metals respectively.*

at these great pressures, the sea water with its dissolved minerals, is considerably expanded at the elevated temperatures. Its buoyancy becomes so high that it rises and is discharged onto the sea floor in a manner analogous to coffee in a percolator. Discharge of the ascending fluid is confined to a few localized and narrow channels that give rise to the isolated and rapidly discharging geysers observed on the sea floor.

The concentrations of heavy metals in normal seawater are extremely low, so low, in fact, that simply measuring them accurately has been one of the most difficult problems in marine chemistry during the past 30 years. Seawater at room temperature is slightly alkaline and, thus, has little or no tendency to react with and to dissolve metallic elements in the sea-floor rock.

Experiments conducted by Geological Survey scientists, however, have revealed that seawater changes from alkaline to acidic at temperatures above 575°F., when in contact with volcanic rocks. The acidity, in turn, acts on the rock to leach it of its heavy metals. The metals will remain dissolved as long as the acidity is maintained, and concentrations of the metals from the experiments are of the same magnitude as those found in the sea floor discharges.

Experiments further revealed that if flow rates are sufficiently slow, then acidity would be neutralized via reaction with successive amounts of unaltered volcanic rocks, and the metals would be then lost from solution. Thus, for a sea-floor deposit to form by such a process, the flow rates must be high and must involve large volumes of water compared to the amount of rock altered.

On the sea floor, a dramatic reaction takes place where the hot acidic metal bearing fluid discharges into cold (35°F.) oxygenated alkaline seawater at the sea floor. Mixing one with the other produces a drastic and nearly instantaneous change in the chemical and physical conditions of the fluid, and a black plume is produced (fig. 4). The plume consists of iron, copper, and zinc sulfide minerals that have precipitated on mixing.

## JUAN DE FUCA RIDGE

The Survey is initiating a program to better understand the mineral-forming processes at these spreading-center hydrothermal systems. The program will emphasize comparison of modern submarine hydrothermal deposits with ore deposits in ophiolite sequences exposed in the Western United States and Alaska. The study is designed to improve the ability to locate and define oneland sulfide mineral deposits in ophiolite sequences. The Juan de Fuca Ridge, 250 nautical miles west of the Oregon coast, will be the focal point of the Survey study of modern spreading-center mineralization. The Juan de Fuca Ridge has a separation rate of 2.5 inches per year, and evidence of hydrothermal activity is already known. A series of cruises designed to locate, photograph, and sample fluids and mineral deposits along the Ridge crest was started in 1980.

The most recent of these cruises to the Juan de Fuca Ridge recovered samples from a hydrothermal vent area. The samples had typical values of about 55 percent zinc, 3,200 parts per million copper, 2,500 parts per million lead, and 300 parts per million silver. Deep-sea fauna observed in bottom photographs at the vent areas appear to differ in composition from the communities observed at the Galapagas and East Pacific Rise sites. Continued investigations of the Juan de Fuca deposits will enable the Survey to investigate the connection between presently forming and ancient ore deposits.

# Offshore Hard Mineral Resources within U.S. Jurisdiction

The sea floor surrounding the United States, including Alaska, Hawaii, and the island territories, is the depository for vast quantities of hard mineral resources. These resources attracted growing interest from industry in the 1960's until moratoria on their leasing and exploitation on the Federal Outer Continental Shelf were emplaced, which has limited exploration and evaluation by government and industry. In early 1981, however, policy statements by the incoming Administration indicated the intention to include offshore hard

FIGURE 4.—*Active hydrothermal vent and sulfide-mineral deposits at the East Pacific Rise crest near 21° north latitude showing a black sediment-laden plume rising from the throat of a chimney about 18 inches in height. Behind the plume is the upper three-fourths of the chimney that was knocked over by the submersible* Alvin. *The chimney is flanked by the more typical porous sulfide mounds 6 to 9 feet in height. Note the abundance of deep-sea fish and crabs on the mineral deposits.*

*Table 1.—Resource estimates—Selected hard mineral resources on the continental shelf of the United States*

| Region | Shelf area (thousand square miles) | Sand and gravel (billion cubic yards) | Shell and carbonate (billion cubic yards) | Phosphorite (million tons) | Manganese nodules (million tons) | Heavy mineral sand (million yards) | Precious coral (pounds) | Rock salt (billion tons) |
|---|---|---|---|---|---|---|---|---|
| Atlantic Coast | 150 | 1,085 | 72 | 3,640 | 275 | 1,700 | | 6,600 |
| Gulf Coast | 128 | 352 | 125 | | | | | 12,100 |
| Pacific Coast | 52 | 38 | 3 | 129 | | 2,700 | | |
| Alaska | 840 | [1] | [2] | | | [1] | | |
| Hawaii | 7 | 25 | 3 | [2] | | | 155,000 | |
| Total | 1,177 | 1,500+ | 203 | 3,769 | 275 | 4,400 | 155,000 | 18,700 |

[1] Large. [2] Minor.

minerals mining among multiple uses of Federal lands. The first major expression of this new policy was the release of an Offshore Hard Minerals Task Force report by the Department of the Interior (May 1981). U.S. Geological Survey staff compilations from the report provide preliminary data on selected offshore resources (table 1); some of these include minerals currently imported by the United States (fig. 1).

## FERROMANAGANESE NODULES AND METALLIFEROUS DEPOSITS

Manganese nodules in the Blake Plateau, off South Carolina and Florida were considered subeconomic up to 1978, despite the fact that they make up the largest potential U.S. resource of managanese. In the late 1960's, the nodules were the site of pilot studies by the Deep Sea Ventures Company, which recovered nodules from water approximately 3,000 feet deep using airlift techniques (fig. 2 ).

Renewed interest in the nodules located within the presumed U.S. exclusive economic zone has been spurred by industry requests for leases. Recent analytical studies by the Geological Survey have also shown that the Blake nodules have the highest platinum concentrations (nearly 0.5 part per million) of any oceanic nodules studies to date.

In the Pacific area, Geological Survey scientists edited a cooperative monograph on the prime Pacific nodules sites and have pointed out the economic potential of hydrothermal polymetallic ore deposits located along the Juan de Fuca Ridge. Additional interest centers on cobalt-rich nodules and crusts in seamount areas within the

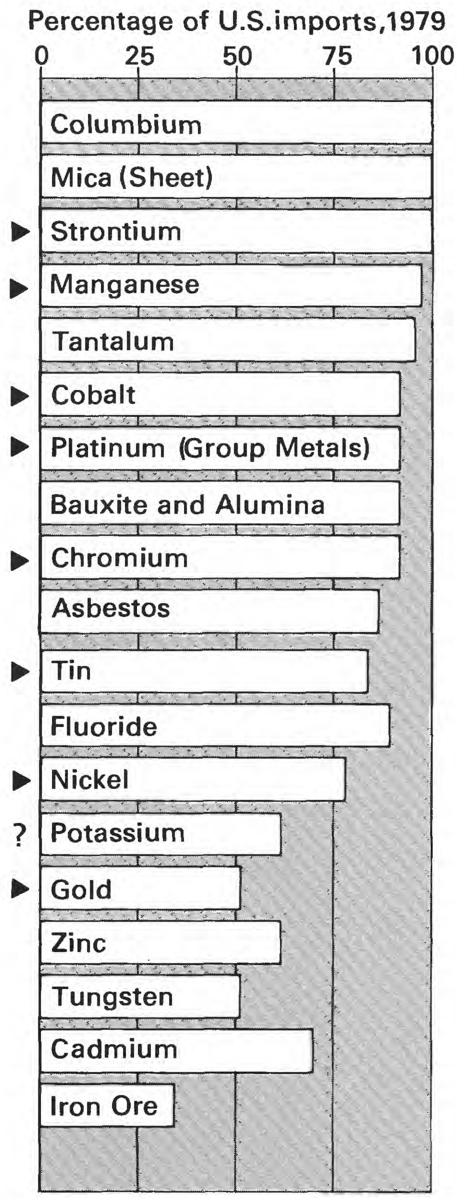



FIGURE 1.—*Percentage of imported (1979) mineral requirements of the United States. Arrows indicate minerals potentially available for sea floor and subsea-floor deposits within U.S. jurisdiction.*

probable U.S. exclusive economic zone around the Hawaiian Islands and other island and coastal areas.

## SAND AND GRAVEL

Aggregate materials for building and other construction are in short supply, or in potential short supply, in several coastal urban areas. In the New York Bight area, onshore reserves of sand and gravel will be depleted within the next 5 to 10 years. A critical situation may develop once existing deposits are depleted because net costs of construction aggregate are closely tied to transportation distance. However, economic models showed that offshore supply could replace onshore sources and recover capital costs in less than 5 years. Sand resources on the Atlantic Continental Shelf of the United States were estimated to be adequate to supply coastal Atlantic States for several thousand years at current annual consumption rates of 150 million to 200 million tons per year (fig. 3).

Other areas where offshore sands and gravels could fill near-term needs include areas off Portland, Oregon, southern California, southern Florida, Hawaii, and the Virgin Islands. Off northern Alaska, material is needed in the construction of artificial islands to serve as oil exploration and development platforms 1 to 3 years after conclusion of lease sales in the Beaufort Sea.

## PHOSPHORITE

New economic studies indicate that phosphorite deposits offshore South Carolina to Georgia may be economically competitive with

FIGURE 2.—*First nodule recovery by airlift from Blake Plateau deposits at a depth of 3,000 feet. (Photograph courtesy Deep Sea Ventures Company.*

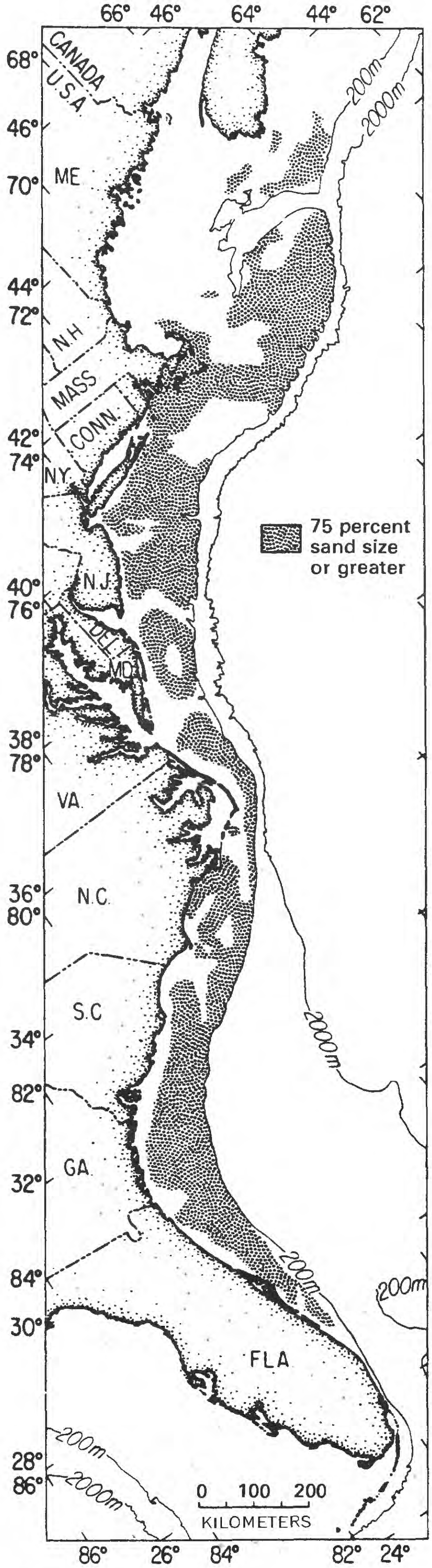



FIGURE 3.—*Distribution of potential sand resources, Atlantic Continental Shelf.*

onshore phosphorite development. Discovery of new phosphorite-rich sediments in Onslow Bay, off North Carolilna, were announced in February 1981. Both deposits appear to be offshore extensions of the Middle Tertiary phosphorite belt to which the established Florida deposits and the Lee Creek Mine in eastern North Carolina belong. Offshore southern California, phosphorite deposits also have economic potential if innovative mining methods can be developed.

## PLACER METALS: GOLD, PLATINUM, TIN, CHROME, AND TITANIUM

Gold and heavy mineral placer deposits occur rather extensively in relict beaches, buried river channels, and reworked Pleistocene gravels bordering northern California, Oregon, and Alaska (fig. 4). The greatest potential for these metals is in the Alaska Outer Continental Shelf where 17 broad target areas were defined earlier, including Norton Sound (gold), Goodnews Bay (platinum), and western Seward Peninsula (gold and tin). In the coastal regions of the Gulf of Alaska, Geological Survey investigators have postulated significant undiscovered recoverable gold resources. Virtually nothing is known about placer distribution and potential beyond the nearshore zone.

Sand deposits containing about 30 million tons of chromite concentrates have been identified on the southern Oregon shelf as products of weathering of basaltic and ultrabasic rocks in the Oregon-Washington area. On the Atlantic Continental Shelf, titanium minerals are typical of the weathered products of granitic rock, but knowledge of areal variability and grade, especially with depth, is very limited.

## OTHER RESOURCES

Huge quantities of rock salt, estimated to be 19 trillion tons and possibly containing significant potassium and bromine, are within easy drilling depth (6,000–7,000 feet) along the shelf and slope of the Gulf of Mexico. Newly discovered diapirs off the Atlantic coast from Georgia to New Jersey may also contain salt. Other bulk nonmetallic deposits of interest include precious coral (Hawaii); limestone and shell deposits in the Atlantic, Gulf, and Pacific continental margins; and bulk materials like special clays and sediment-mineral combinations suitable for ceramic raw materials.

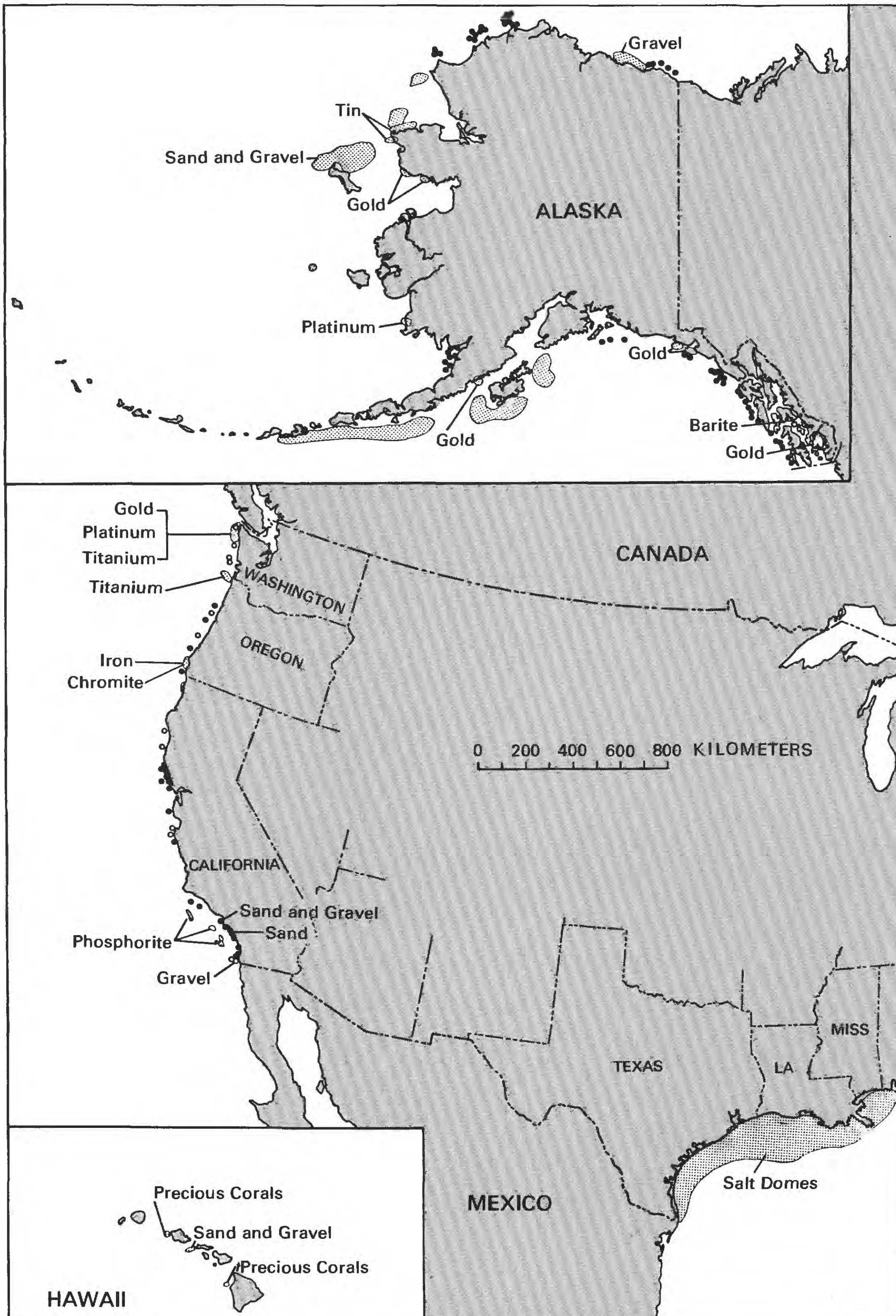



FIGURE 4.—*Distribution of gold and other mineral resources of the Pacific and Alaskan continental coast.*

# International Highlights

U.S. Geological Survey operations in other countries fit, in general, into three categories: technical assistance and participant training, scientific cooperation and research, and representation at international scientific commissions, congresses, and unions. Specific cooperative activities are selected in large part because they support U.S. foreign policy and provide an opportunity to augment objectives of the Survey's programs. The Survey's overseas investigations include studies that bear directly and significantly on its research on natural hazard prediction and mitigation, measurement of the world's known and potential energy resources, exploration and development of scarce minerals, and remote sensing.

## PEOPLES' REPUBLIC OF CHINA

The Survey began to evolve a cooperative research program with its counterpart in the Peoples Republic of China (China) when Director H. William Menard, as a member of a U.S. Government delegation of senior science administrators, visited Beijing in June 1978, and a Science and Technological Cooperation Agreement was signed on January 31, 1979.

Three requirements must be met in the Survey activities planned to be undertaken in cooperation with China:

- The work done must show a clear benefit to the United States.
- The work done must strengthen our ability to achieve the objectives of our domestic programs and not represent a diversion of resources for them.
- The exchanges must be financed from funds currently available.

Three types of activities are being undertaken with China: (1) joint projects to be accomplished under the umbrella Science and Technology Agreement between the United States and China (2) coordination and review of disciplinary areas for mutually beneficial cooperative research programs, and (3) exchange of visiting scholars (carried out under the umbrella Science and Technology Agreement) between the United States and PRC.

### Earthquake studies

Earthquake studies are the most thoroughly developed part of the research program with China. The participating scientists from both countries are experts in seismological instrumentation and field operations, seismological data analysis and interpretation, and other investigations relevant to earthquake prediction. Benefits to the United States from these cooperative earthquake studies are two. First, field operations in China allow the Survey to observe at first hand the effects of large damaging earthquakes and to acquire a large body of information that will augment observations of earthquake damage in the United States. The second advantage offered by cooperation with the Chinese is access to a large and successful earthquake prediction program. China has a very active earthquake prediction program because of the high number of damaging earthquakes, and the consequent great losses of life and property that occur in that country. The most notable of several predicted earthquakes in China was the Haicheng event of 1975; that prediction caused officials to order the city evacuated, saving many thousands of lives. Because of the widespread and frequent earthquake damage in China, the Chinese have devoted a large amount of manpower and much effort to gathering and examining data for earthquake premonitors. The Chinese have compiled a very complete 2,000-year history of seismicity in China, and these historical records plus the current data base are unmatched in the World. The Survey will have access to this information, and the Chinese prediction program allows the Survey to evaluate China's methods, analysis techniques, and prediction successes and failures. The results of this effort are directly applicable to predicting earthquakes in the United States. A brief description of the major components of the earthquake program follows:

#### PREMONITORY PHENOMENA AND TECHNIQUES FOR EARTHQUAKE PREDICTION

The Survey makes field observations of earthquake precursors and analyzes the observations. The work is concentrated on areas near Beijing and in Western Yunnan Province. Current activities are as follows:

- *Beijing seismic network support.*—Several Chinese scientists are to be trained in the United States in the operation of the network system and in the use of special routines and techniques used by the Survey.
- *Magnetic precursors.*—Measurement of precursory charges in the geomagnetic field in seismic areas near Beijing and in western Yunnan Province began with Survey field

work in the fall of 1980. Recording magnetometers will be shipped to China, and a Survey delegation will return to Yunnan in late 1981 to resurvey the magnetic network and discuss Chinese measurements made over the past year.

- *Deformation observations.*—Survey observations of crustal deformation near active faults began in 1981. A laser distance meter will be used in China for increased surveillance of motion on active faults.
- *Seismic observations.*—A Survey delegation discussed the installation of additional seismometers in the existing Chinese network in Yunnan Province in 1980. Agreement was reached on the type of instrument, and six systems have been ordered.
- *Analysis of strain data.*—Chinese and U.S. university scientists, the latter supported by the Survey and the National Academy of Science, analyzed strain data from Chinese observatories. Analysis techniques were developed to permit removal of background "noise" from strain records, and strain events apparently precursory to the disastrous Tangshan earthquake were identified.
- *Haicheng earthquake analysis.*—The Survey is supporting a cooperative effort with Chinese scientists to analyze foreshocks and aftershocks of the Haicheng earthquake of 1975. This event was predicted, and Haicheng evacuated, due to unusual foreshock activity. Analysis of these events and following aftershocks suggested that different faults were involved in the foreshock sequence than in the main shock and aftershocks.

### INTRAPLATE ACTIVE FAULTS AND EARTHQUAKES

The Geological Survey is examing the Tanlu and Red River faults relative to earthquake recurrence on active faults.

Aerial and satellite photographs of the Tanlu fault are being examined by both parties in an effort to find sites along the fault that are suitable for detailed study. Such sites are not readily apparent because cultural activities have obliterated much of the surface expression of the fault.

## Basic Research in Earth Sciences

Basic Research activities are just now being fully negotiated. The negotiators have generally agreed on the title and scope of 20 mutually beneficial projects which, during the next few years, could involve exchanges of approximately 78 scientists for 125 person months. These initial exchanges will focus on such topics as exploration and analysis of uranium deposits, coal, and petroleum basins; relation of volcanism to the origin of metallic deposits; the general nature and occurrence of petroleum in carbonate rocks; geologic and tectonic framework of the Circum-Pacific region; and karst phenomena. Generally, the broader the geographic area of study of geoscience phenomena, the greater the understanding that scientists can gain of their genesis, classification, and economic appraisal of such phenomona. For U.S. geoscientists, China provides unique opportunities to study examples of many of these phenomena.

## INDONESIA

The present program of the U.S. Geological Survey with Indonesia, sponsored by the Agency for International Development, is an example of technical assistance in action. The general objectives are to assist the geoscience Directorates of the Government of Indonesia in making geologic hazard studies, particularly of volcanoes and landslides (see figure), and in publication of geologic maps and reports; in establishing data banks; in regional environmental studies, including land use; and in utilizing remote sensing techniques. Training is provided for Indonesian counterparts to increase the capacity of the Indonesian directorates to gather, assess, and report on geologic conditions and materials that directly affect productivity, health, and safety, as well as to survey, monitor, and report on geologically hazardous areas. This work is important in a country that has many active volcanoes, many of which endanger major population centers. Glowing avalanches of high-density gas, mudflows, and landslides are only some of the possible hazards. Since the program started, 21 Survey specialists have undertaken assignments in Indonesia, including 4 volcanologists, 5 seismologists, 1 data storage and retrieval expert, 1 computer specialist, 5 geologists (land use and landslide specialists), 1 soils scientists (from the Soil Conservation Service) and 1 hydrologist.

## SAUDI ARABIA

The Technical Assistance Agreement between the U.S. Geological Survey and the Saudi Arabian Ministry of Petroleum and Mineral Resources has been extended for 2 years, until 1983. The present program, which began in 1963, is assisting the Ministry to establish and (or) expand capabilities

*Damage to village elementary school caused by landslide movement, southern Cianjur Regency, Java, Indonesia.*

of its earth science organization, the Directorate General of Mineral Resources, and is the Survey's largest and longest continuing technical assistance program.

Studies which are a part of the program have led to the discovery of a deposit containing significant amounts of tungsten and tin at Baid al Jimalah in Saudi Arabia. The deposit is similar to well known tungsten-tin deposits in other parts of the world. Analysis of wadi sediment samples shows that the ore minerals have not been widely dispersed from the mineralized area by surficial processes, and, therefore, similar deposits might escape detection in low-sample-density geochemical surveys. The ore minerals are believed to be genetically related to a lead-zinc-silver deposit 1 mile to the east, which was the scene of mining activity in ancient times. The ancients presumably were interested in the silver, which is not present in anomalous amounts at the tungsten deposit.

The deposit is significant in that it indicates that the Arabian Sheild had evolved by the late Proterozoic era (650 million–700 million years ago) to a stage suitable for formation of specialized granites. Mapping and sampling are in progress to determine the shape, extent, grade, and structure of the deposit and surrounding rocks.

# The Way It Was: Earthquake Hazard Reduction

At 5:12 on the morning of April 18, 1906, G. K. Gilbert of the United States Geological Survey woke up with a start, After a few seconds, he realized that the Earth was shaking underneath him. He quickly got out of bed in the redwood-framed building where he was staying in Berkeley, California, and began to takes notes. "A vigorous earthquake was in progress," he later wrote, and he did not want to miss a thing. As soon as he could, Gilbert left Berkely for San Francisco, there to inspect for himself the damage done by one of the world's most devasting earthquakes and the fire that followed it.

Three days after the earthquake, Governor George C. Pardee appointed a commission to investigate. Of its eight members, half were with the Geological Survey. There were no State funds for the scientists; all the public money went to relieve the homeless and destitute. So the Carnegie Institution of Washington, whose Secretary was the Survey's Director, C. D. Walcott, paid for the research. Three of the Survey's full-time staff and two contributors to its publications helped the commissioners with their fieldwork.

In 1908 and 1910 came the commissions' mammoth final report. The first volume of 450 pages gave an account of what happened. In the second volume, Professor Harry F. Reid of Johns Hopkins, the Survey's special expert on earthquake records, developed his elastic-rebound theory to explain earthquakes. Reid's idea that strain builds up a fault until a sudden movement releases energy into the elastic waves of an earthquake has stood the test of time: *The Report of the Investigation Commission* was reprinted in 1969.

There was a second report on the San Francisco disaster, published by the Geological Survey. Richard L. Humphrey, who directed the Survey's structural materials laboratories and served as secretary of the National Advisory Board on Fuels and Structural Materials, went to San Francisco to study how different materials and methods of making them into buildings had stood up to the earthquake and fire. His report, together with those of an officer of the Army Engineers and the dean of the College of Civil Engineers at Berkeley, came out as Bulletin 324 (1907). Gilbert introduced the volume with an account of the earthquake itself. Research by the Survey thus helped begin what is known as earthquake engineering.

# 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 investigations 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. The increasing pressures associated with developing energy resources in environmentally sound ways are enlarging demands for hydrologic data. Water is an integral element in all energy and environmental problems.

## 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 inter-State 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 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. Cooperation through this Program, under which the Survey matches funds provided by State agencies, provides an economical and comprehensive system for assessing water resources. Many water problems begin at the local level. Recognizing this, the Survey has cooperative agreements with all States under which each party funds one-half the cost of financing studies of water resources.

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 work related to the specific needs of each agency. Examples of work done in cooperation with several of these agencies are as follows:

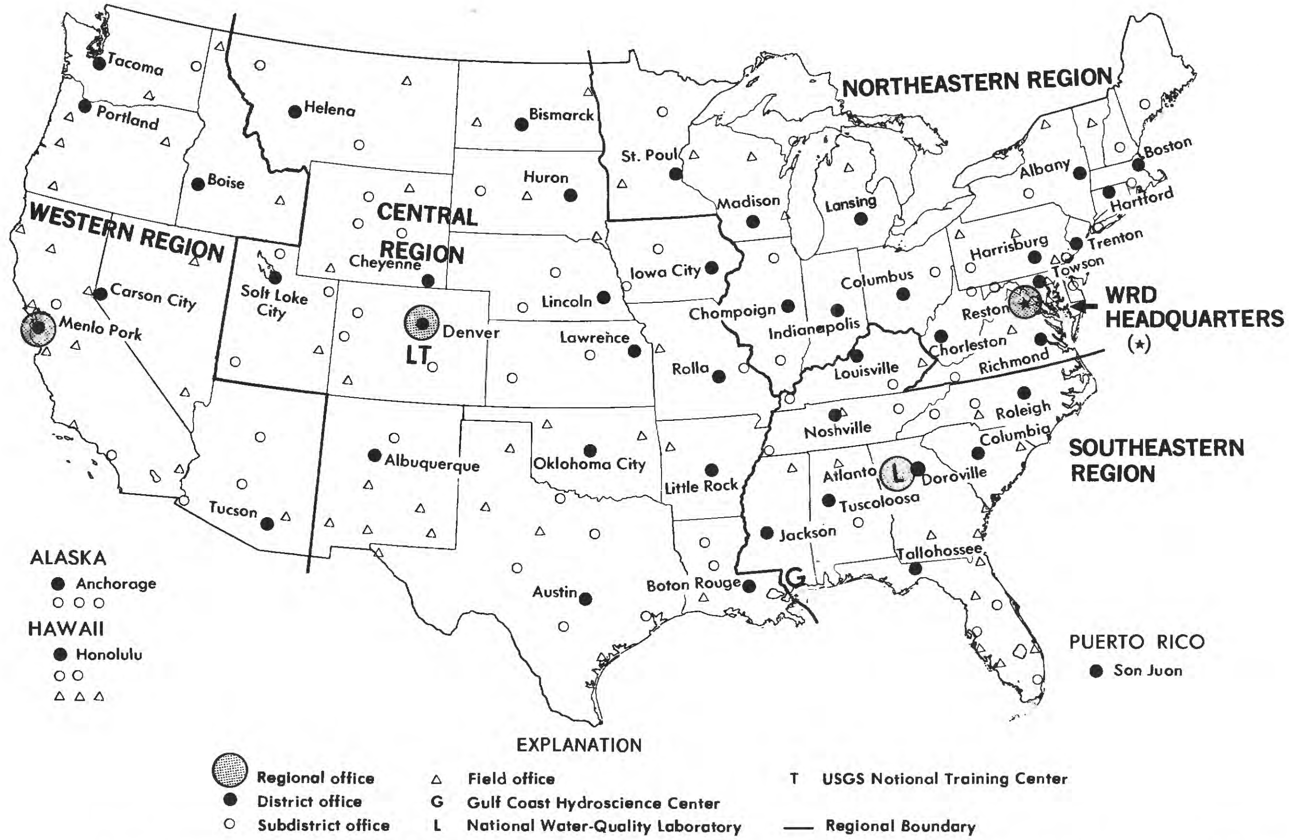
**Department of Agriculture**
Hydrologic studies on small watersheds, sediment studies, stream discharge and quality.

**Department of Defense—Corps of Engineers**
Tidal flows in estuaries, subsidence studies, streamflow data, ground-water studies, sedimentation and water-quality studies.

**Department of Energy**
Hydrologic and water-supply exploration studies at nuclear-explosion sites and at both operating and potential nuclear-waste sites, research in field of radiohydrology related to interaction between radioactive materials and various geohydrologic environments, both above and below ground; hydrologic modeling.

**Department of Housing and Urban Development**
Flood-plain delineation, flood profiles, flood-frequency studies related to flood-insurance programs.

**Department of the Interior:**
*Bureau of Indian Affairs*
Hydrologic data collection, water resources appraisal studies, water-supply investigations on reservations.




*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.*

*Bureau of Land Management*
Collection of hydrologic data, water-supply studies on public lands, effects of coal mining on hydrology.

*Bureau of Mines*
Collection of hydrologic data, hydrologic studies of abandoned coal mines.

*Bureau of Reclamation*
Collection of hydrologic data, ground-water resources, reservoir, and land-subsidence studies.

*Fish and Wildlife Service*
Collection of hydrologic data, ground-water recharge, water supply for fish hatcheries, instream flow evaluations, relation of ground water to lakes.

*National Park Service*
Collection of hydrologic data, water-resources appraisals of National Parks and Monuments, flood-hazard, forest-geomorphology, and ground-water studies.

## 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.

# 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.

# Budget and Personnel

At the end of fiscal year 1981, the Water Resources Division employed 2,790 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 1,874 permanent part-time and intermittent employees assisted in the work of the Division.

The $194.0 million obligated in 1981 for water resources investigation activities came from the following sources:

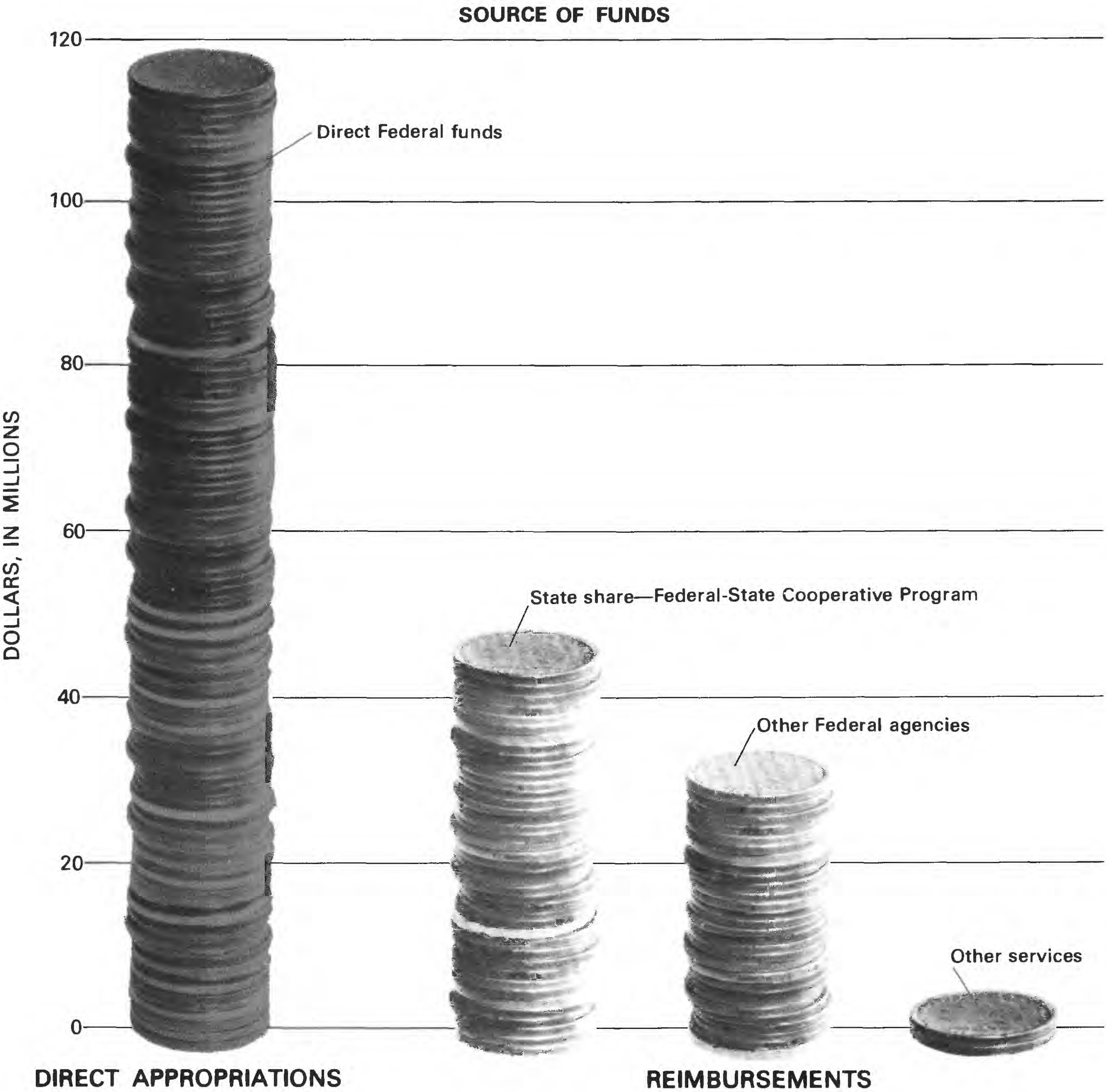
1. Direct Congressional appropriations.
2. Congressional, State, and local appropriations for 50-50 funding in the Federal-State Cooperative Program.
3. Funds transferred from other Federal agencies.
4. Funds transferred from State and local agencies.

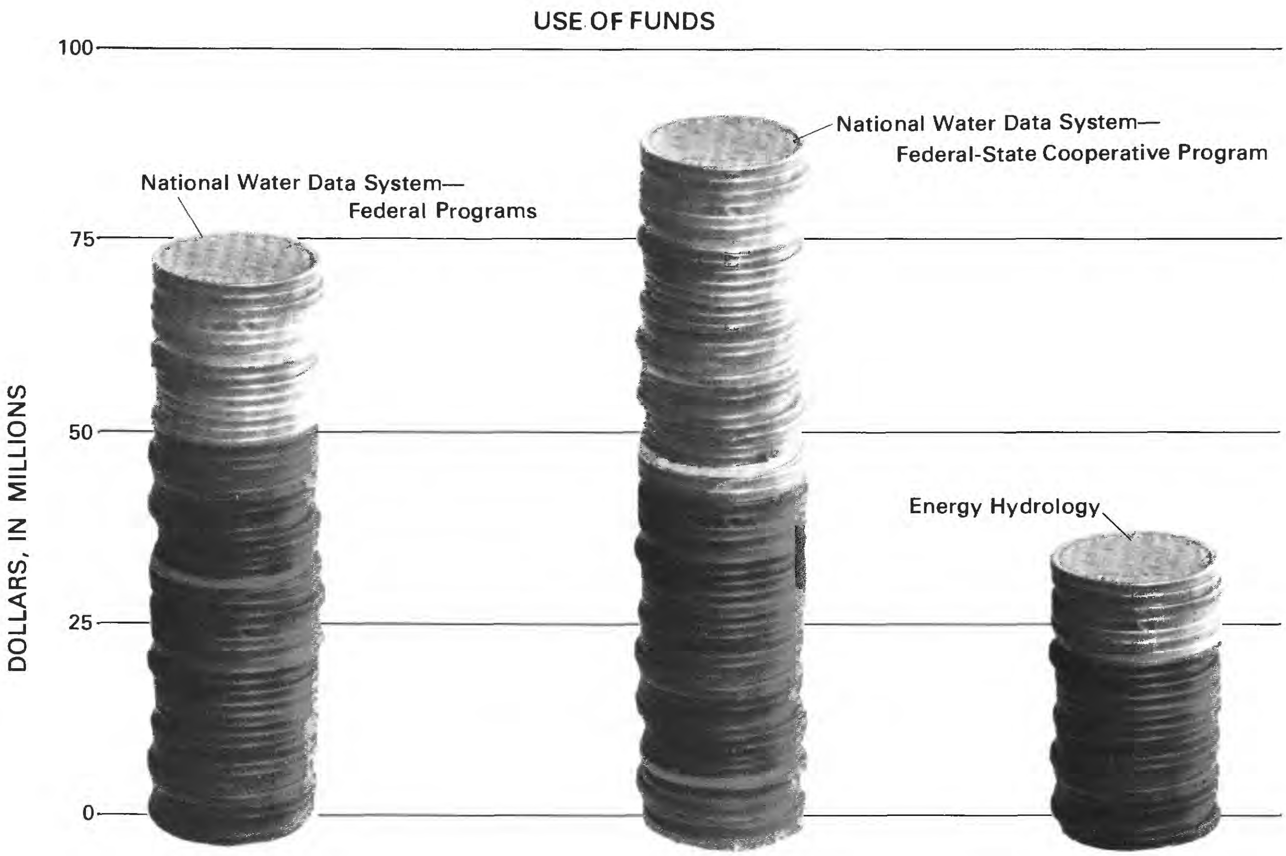
*Water Resources Investigations activity obligations for fiscal years 1980 and 1981, by subactivity*

[Dollars in millions. Data may differ from those in statistical tables because of rounding]

| Subactivity and Program* | Fiscal year 1980 | Fiscal year 1981 |
|---|---|---|
| **National Water Data System—Federal Program** | **70.5** | **72.4** |
| Data Collection and Analysis | 38.6 | 39.0 |
| National Water Data Exchange | 1.2 | 1.3 |
| Regional Aquifer Systems Analysis | 15.5 | 15.8 |
| Coordination of National Water Data Activities | .9 | .9 |
| Core Program Hydrologic Research | 5.7 | 6.0 |
| Improved Instrumentation | 2.0 | 2.0 |
| Ground-Water Recharge | 1.3 | 1.4 |
| Subsurface Waste Storage | 1.4 | 1.5 |
| Flood Hazards Analysis | .4 | .5 |
| National Assessment of Water Supply and Demand | --- | .4 |
| Supporting Services | 3.5 | 3.6 |
| **National Water Data System—Federal-State Cooperative Program** | **80.4** | **87.9** |
| Data Collection and Analysis, Areal Appraisals, and Special Studies | 72.8 | 74.8 |
| Water Use (Cooperative) | 6.4 | 6.8 |
| Coal Hydrology (Cooperative) | 4.8 | 6.3 |
| **Energy Hydrology** | **30.4** | **33.7** |
| Coal Hydrology | 19.7 | 19.6 |
| Nuclear Energy Hydrology | 9.3 | 10.6 |
| Oil Shale Hydrology | 1.4 | 3.4 |
| **Total** | **184.9** | **194.0** |
| **Direct programs** | **108.7** | **115.5** |
| **Reimbursable programs** | **76.2** | **78.5** |
| States, counties, and municipalities | 43.1 | 45.1 |
| Other Federal agencies | 31.3 | 31.3 |
| Other sources | 1.8 | 2.1 |

*Program data estimated


SOURCE OF FUNDS
120
100
80
60
40
20
0
DOLLARS, IN MILLIONS
Direct Federal funds
State share—Federal-State Cooperative Program
Other Federal agencies
Other services
DIRECT APPROPRIATIONS
REIMBURSEMENTS




*See Source of Funds graph on preceding page for explanation of direct and reimbursable tints.*

# One Year Later: How the Mount St. Helens Eruption Transformed Water Resources

Immediately after the eruption of Mount St. Helens, significant hydrologic changes in the environment were evident to all observers. The magnitude of the changes are becoming apparent following a year's scientific investigations conducted by U.S. Geological Survey hydrologists which reveal impressive data related to changes in water quality, drainage basin structure, mudflows, glacier activity, and other significant aspects of the water system in the affected area.

## CONTAMINATION OF WATER

During the eruption, a tremendous amount of vegetation was destroyed or transported to some point of burial or submergence. The Mount St. Helens' forests had been exceptionally lush before the eruption. Burning of the forest plant and soil organic material created a large number of organic compounds that contaminated lakes, rivers, and much of the airfall material. Some of these compounds were found on bottom material deposited in the lower Cowlitz River valley. Much of this vaporized organic material condensed and attached to ash particles and was transported many miles in the ash plume. Some organic material not immediately burned up was buried in the hot debris deposits, was dropped into Spirit Lake, or was transported downstream in the mudflows. The hot wet environment has resulted in the continued formation of additional organic compounds similar to those formed during the initial blast. Many of the contaminants have formed into products similar to those in effluents from paper and pulp mills.

One of the most significant changes in water quality in lakes has been large increases in the concentration of dissolved organic carbon; for example, the organic carbon content of Spirit Lake water increased from 1 to 40 milligrams per liter.

Approximately 50 percent of the dissolved organic materials are high-molecular-weight colored organic acids similar to those from more typical aquatic environments, except for higher content of organic sulfur.

Lakes in the area have been sampled for nutrients (nitrogen and phosphorus), selected metals, organic carbon, and other selected constitutents. Samples of minute plant and animal life were collected and identified to species level where possible. Preliminary results of these studies indicate that the impact of the eruption on lake-water quality ranges from severe at Spirit Lake, located 5 miles from the volcano, to little or no impact for Deadman's Lake, located approximately 13 miles from the volcano.

Studies of the toxicity of the May 18, 1980, volcanic ash leachate to common blue-green algal species have shown that leachate from volcanic ash collected near Richland, Washington, was toxic and caused cellular abnormalities but that leachate from ash collected further east, Moses Lake and Liberty Lake, Washington, was not toxic. The toxicity is associated with the composition of organic material leached.

Alteration of the unweathered debris deposits will proceed by chemical weathering and hydrothermal processes, and the resulting products will alter the chemistry of the water. Detailed analysis of the chemical changes observed in the water draining the debris deposits will be needed in conjuction with an analysis of mineral alteration products to obtain insight into the weathering processes in volcanic deposits of this type.

## MUDFLOWS

One of the major hydrologic hazards associated with volcanoes is flowing slurries of rock debris and water—variously termed lahars, mudflows, or debris flows. A major part of the destruction from the May 18 eruption and of the cost of cleanup was caused by mudflows. It has been known that a major eruption is not a prerequisite for mudflows on volcanoes. On the flanks of Mount Shasta in summer 1977, sudden releases of glacier melt water triggered massive mudflows in four different drainage areas. And on December 25, 1980, heavy rains initiated a catastrophic mudflow on the east side of Mount Hood.

Despite the magnitude of the hazards posed by mudflows, relatively little is known about the exact physical processes that set the dense viscid slurries in motion. Also the flow mechanics of mudflows are not understood well enough to allow the use of mathematical models to predict their size and how far and fast they will move.

Two studies, focusing particularly on Pine Creek and Muddy River, are underway at Mount St. Helens that address these questions. The first study is concerned with the triggering of mudflows on Mount St. Helens, both the flow of May 18 and the smaller flows that are still periodically occurring. Several critical questions are being asked: (1) Where exactly does the water come from?, (2) Where is the rock debris picked up?, and (3) How are the two mixed together into a slurry? To answer these questions, direct observations are being made on the mobilization of small mudflows in the crater and on Shoestring Glacier, which frequently experiences small outburst floods. In addition, still and movie photographs and videotapes of the eruption are presently being analyzed and should provide much useful information. Hypotheses will be tested by calculations based on known time-mass-energy relations at the time of the eruption. Composition and stratigraphy of mudflow deposits also should shed some light on mechanisms of initiation.

The second study is aimed at documenting the flow characteristics and identifying the physical parameters of the large May 18 mudflows and the smaller ongoing events. The following approaches are involved: (1) calculations based on physical evidence of past mudflow dynamics, particularly the use of superelevation of flow at bends to determine flow velocity, (2) determination of particle-size distribution and original-water content of samples of mudflow deposits and laboratory testing of strength and viscosity of reconstituted slurries, and (3) direct measurement of velocity (and velocity distribution), channel width, depth and slope, variation in slurry composition and water content, and hydrograph shape in moving mudflows on an instrumented channel reach, supplemented by movie photographs of events. To date, samples have been collected, superelevation of mudlines are being surveyed, and instrumentation is being installed along the channel below the Shoestring Glacier for the monitoring of active flows. Active mudflows in other localities, should they occur, also will be used to collect data on mudflow characteristics.

## GLACIER ICE AND SNOW

Mount St. Helens, the "Mount Fuji of the United States," had a thick cover of glacier ice and snow in the early morning of May 18, 1980. The cataclysmic eruption removed 70 percent of this frozen water (170 million cubic yards). Some of it melted very quickly, and the water lubricated the mudflows; some of it was hurled through the air, pelting survivors; and some of it was buried in the debris pile where occasional ice blocks persist. Contact of this ice and its melt water with hot ash caused numerous steam explosions which continued for a month or so. An ice block may have caused a delayed explosion in May 1981.

The long narrow Shoestring Glacier was beheaded by the eruption. Scientists from the Geological Survey and the California Institute of Technology had been studying this glacier before the eruption and now could gain new insights about the flow of a glacier by observing how the flow changes in a "grand experiment." Although most of the glaciers were either beheaded or removed completely during the eruption, small glaciers on the south side of the mountain were buried under as much as 6 feet of ash. As a result, these glaciers are now much thicker than normal; the 1979-80 snowpack still lies preserved under the ash cover. Studies of the glaciers on Mount St. Helens will lead to new ways to predict the effects of eruptions on glaciers on other Cascade Range volcanoes and, therefore, the hazards to man downstream.

The ash discharged by the eruptions had an effect on snowmelt over a wide area. Studies by Geological Survey glaciologists showed that a small amount of ash, less than 1 inch, enhances the rate of melt of snow. A coating only about 0.13 inch thick causes the melt rate to double. Thicker coatings of ash tend to suppress melt. These results are useful in predicting runoff for the efficient operation of hydroelectric power or irrigation water reservoirs in areas dusted by volcanic ash.

## SEDIMENT, DEBRIS, AND FLOODING

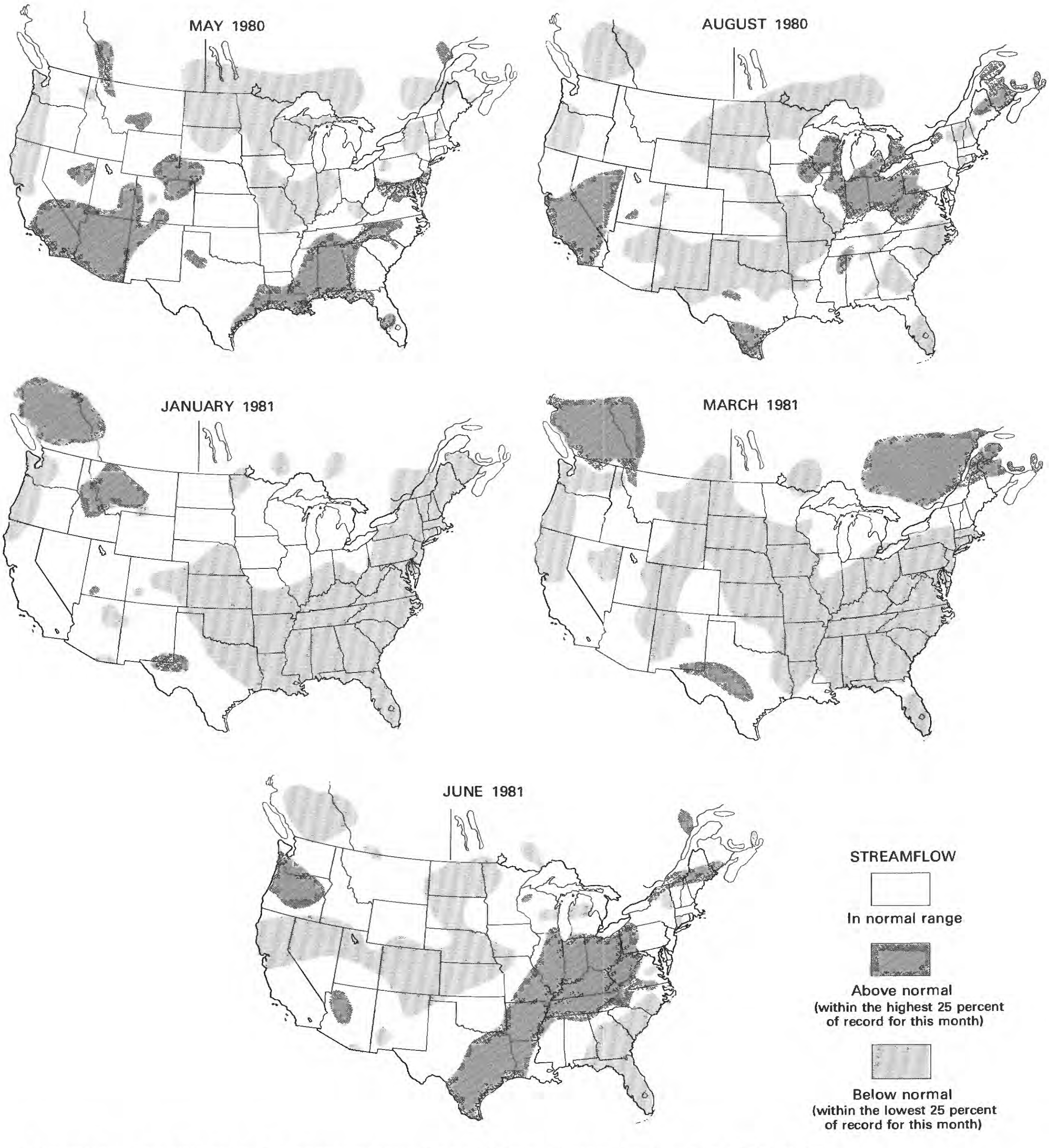
Sediments deposited in the lower Cowlitz River valley during the flooding of May 19, 1980, severely increased the flooding potential. The U.S. Army Corps of Engineers began dredging operations in the lower Cowlitz and Toutle Rivers in July 1980 to increase the amount of flow these streams could transmit without flooding. Personnel of the Geological Survey constructed a digital computer model of the lower Cowlitz and Toutle Rivers to document the progressive changes in flood hazard along these rivers using flood profiles and inundation maps. During the year, the model was updated at about 6-week intervals following field surveys of channel geometry that were made to determine the changes in the channel caused by the combination of dredging and sediment inflow. The flood profiles and inundation maps were available on a continuing basis to those agencies responsible for emergency response to flooding. The field surveys of channel geometry indicated that the May 19 mudflow on the lower Cowlitz deposited approximately 47 million cubic yards of sediment in the Cowlitz River and on its flood plain. Nearly all of that sediment in the main channel of the river was removed by dredging during summer and autumn 1980. The field surveys also indicated that an additional 14 million cubic yards of sediment was deposited in the Cowlitz channel by May 1981. This material was derived from the Toutle River during the 1980-81 winter flows.

The debris avalanche material that filled approximately 17 miles of the North Fork Toutle River valley blocked inflow from tributaries along this reach. Large lakes have formed in Coldwater Canyon Creek and in South Fork Castle Creek. The outlet to Spirit Lake was blocked by the debris avalanche, and this lake continues to increase in size. Projections made by the Geological Survey scientists indicated that Coldwater and South Fork Coldwater Creek Lakes would fill and overtop their debris dams by late 1981 or early 1982. In response to these projections, the Corps of Engineers constructed a spillway at Coldwater Lake to prevent overtopping. In the near future, construction of a spillway at South Fork Castle Creek Lake will begin.

Investigations are underway at Coldwater and South Fork Castle Creek Lakes to determine the extent of water in the debris dams blocking them and its direction and rate of movement. Results will help determine the susceptibility of these dams to failure. A study also is underway to determine whether Spirit Lake will eventually fill and overtop its debris dam. One of the new gaging station sites installed this past year is located in the North Fork Toutle River just below Coldwater Lake. This station, along with lake-stage gages at each lake, will provide an almost instantaneous warning if any of the lakes should break out and also will provide a warning of flooding from a volcanic flow or snow.

# The Drought of 1980-81

The periodic occurrence of serious droughts in the United States represents a major water resources problem not easily resolved by man's intervention. It is obvious that the ever-increasing demand for water for food and fiber, energy conversion, industry, and domestic use will magnify




*Streamflow conditions in the conterminous United States during the drought of 1980–81.*

the effects of future droughts on the Nation's well being. Construction of reservoirs to mitigate the effects of droughts becomes progressively less feasible because of rising costs of land and construction, environmental constraints, and the lack of suitable dam sites.

The drought of 1980–81 may be described as typical. It was unpredictable and, like most droughts, had adverse effects on large segments of the population and the economy. This discussion of the 1980–81 drought serves to highlight drought problems that have general applicability.

What are droughts? When, precisely, did the 1980–81 drought begin and end? What caused the drought and what were its impacts? And, finally, what can we do about droughts?

## WHAT ARE DROUGHTS?

Droughts mean different things to different people—farmers need water for crops, and city managers, for water supply; in fact, everyone needs water for some essential purpose. In general, a drought implies a deficiency of precipitation or water supply over a significant period of time. The magnitude or length of deficiency sufficient to classify an event as a drought is different for different water users and for different "experts" on droughts.

A variety of methods have been proposed for assessing droughts. One common technique accumulates data which represent annual or seasonal deviation from normal precipitation. Wayne C. Palmer of the U.S. Department of Commerce recommended a comprehensive index computed from the magnitude of precipitation deficiency and climatic conditions to reflect a general state of dryness. Hydrologists index droughts through assessment of the percentage of normal streamflow and the status of ground-water levels. Agriculturists developed a "Crop Moisture Index," and there are others. Whichever index is used, the 1980–81 event definitely qualifies as a drought.

## WHEN DID THE 1980–81 DROUGHT BEGIN AND END? AND HOW DID IT DEVELOP?

Pinpointing the onset of a drought is difficult. Given the lack of agreement about what constitutes a drought, it is impossible to be certain when a dry period becomes significant and qualifies as a drought. Even when a drought is in progress, we cannot be certain whether a storm or series of storms ends the drought or provides only a temporary respite.

The 1980–81 drought probably began in May–June 1980. At that time, stream gages in the northern Great Plains and in areas along the Pacific Coast indicated flow rates in the below-normal range, defined as flows within the lowest 25 percent of experience for that month. The Palmer Drought Index also began to indicate conditions of severe drought at that time.

Extreme heat in the summer of 1980, particularly in Texas and the southern Great Plains, rapidly depleted moisture supplies and combined with a persistent absence of normal precipitation across much of the Nation to rapidly expand the area of deficient streamflow. During July and August, the drought area included large parts of the midcontinent, parts of the Pacific Coast, and portions of the Southeast.

The winter of 1980–81 was unusually dry. Precipitation over much of the conterminous United States was light, and ground-water aquifers and surface reservoirs did not refill to normal levels. Warm temperatures over the western mountains, combined with light precipitation, prevented an accumulation of normal snowpacks. Record low measurements were recorded for the Cascades of Oregon and the Rockies of Montana, and spring and summer runoff from snowpacks was forecast to be less than 70 percent of normal for virtually all the West.

The areal extent of the drought reached a maximum in March 1981 when about two-thirds of the conterminous United States recorded streamflows in the below-normal range. Figure 1, taken from the Geological Survey *Water-Resources Review* shows the geographical extent of the area of deficient streamflow. Figure 2, taken from the *Weekly Weather and Crop Bulletin,* published by the National Weather Service and Department of Agriculture, shows the Palmer Index on March 28, 1981. Figures 1 and 2 generally depict the same geographic area affected by drought conditions.

A slow, but relatively steady, reduction in the extent of the drought began in April 1981. Heavy rains in a band from Texas to Ohio changed local concerns from water shortage to floods and to crop fields too wet to plant. Nevertheless, during June 1981, below-normal streamflows still occurred in a wide band from California to Kansas and as far as North Dakota and in another area covering South Carolina, Georgia, Alabama, and Florida.

Was the drought over, or were we in a period of only temporary relief? It was difficult or impossible to tell by autumn. Weather conditions over the forthcoming months would determine whether the drought would continue or end. Long-range climatological forecasting is not yet developed to an extent that much confidence can be placed in any forecasts of the continuance or end of a drought.

The following facts may provide some measure of the extent and intensity of the 1980–81 drought:

- Combined flow for the Nation's "Big Five" rivers—Mississippi, Columbia, St. Lawrence, Ohio, and Missouri—averaged below normal for 6 consecutive months through May 1981. The Big Five rivers account for almost one-half of the stream runoff in the conterminous United States, and their flow records provide a quick useful check on the Nation's water resources.

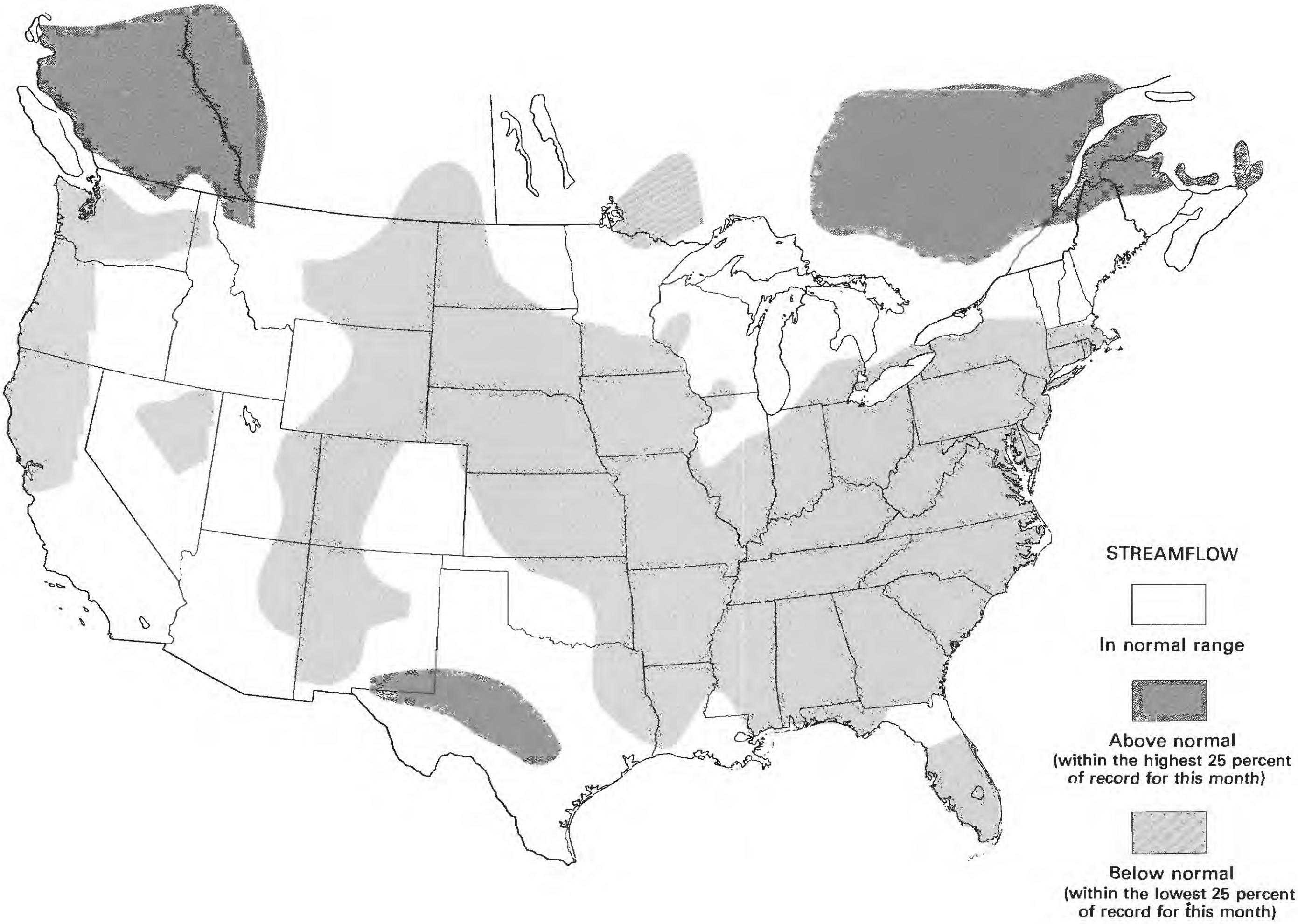



FIGURE 1.—*Status of streamflow conditions in the United States during March 1981. (From U.S. Geological Survey* Water Resources Review.)

- Record low ground-water levels occurred in parts of at least 20 States during January 1981
- Monthly and (or) daily mean flows were the lowest of record for January 1981 in parts of 16 States (mostly in southeastern and northeastern parts of the United States).

## IMPACTS OF DROUGHT

By mid-September 1980, it was evident that water supplies in much of the Northeast were seriously deficient. Drought declarations were issued by the Governors of Pennsylvania, New Jersey, and New York. New York City initiated a vigorous water-conservation campaign. The Delaware River Master proposed significant reductions in diversions by New York City from its Delaware River reservoirs and in the quantity of water required to be released to maintain downstream flows.

Communities in northeastern New Jersey, eastern Pennsylvania, and parts of Connecticut were particularly hard pressed. Some, such as Greenwich, Connecticut, and Hackensack, Jersey City, and Newark, New Jersey, were reported to have less than 30 days' supply remaining at one time. An emergency pipeline was built to deliver 25 million gallons of water per day from Lake Hopatcong to the Rockaway River where it could be utilized by the northeastern New Jersey distribution systems.

In northern New Jersey, arrangements were made to divert 20 million gallons per day from the New York City system through a pipeline to be constructed on the George Washington Bridge.

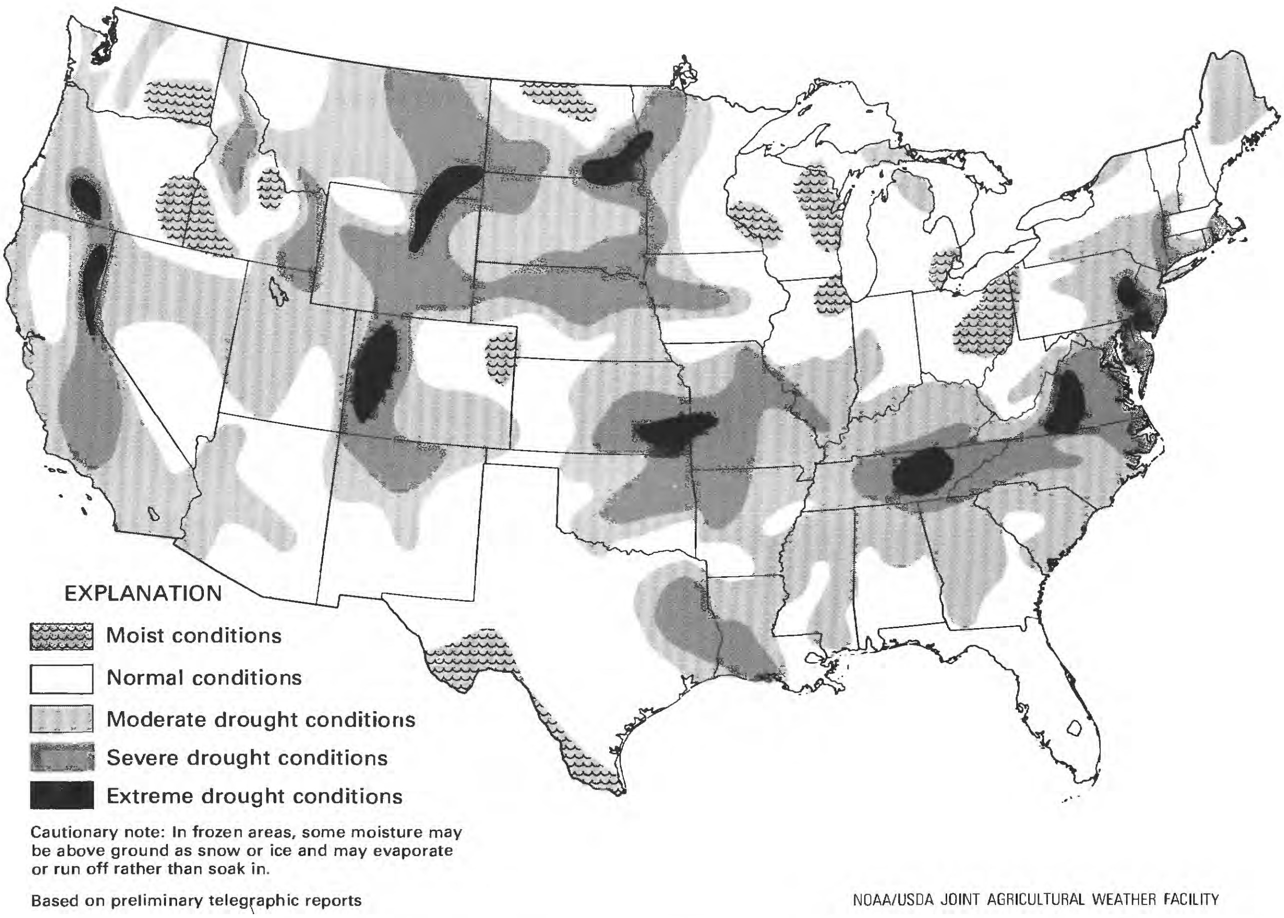



FIGURE 2.—*Palmer Index for the United States for March 28, 1981. (From* Weekly Weather and Crop Bulletin *published by National Weather Service and Department of Agriculture.)*

The water would be delivered to the Hackensack Water Company for distribution in that area.

In October, the salt front in the Delaware Estuary intruded upstream to mile 96.5, a point just 1.5 miles downstream from the Camden, New Jersey, well field posing a possibility of contamination to that source of supply. By November 15, however, the salt front had retreated about 8 miles, relieving the threat of contamination to the Camden water supply.

Starting in early February 1981, rainfall and snowmelt produced some runoff that served to improve water supplies generally, and, by the middle of May, it was possible to rescind the restrictions on New York City diversions. The conservation campaign in New York City had served to reduce consumption by more than 100 million gallons per day.

Another populous area, Norfolk-Virginia Beach, Virginia, also adopted mandatory restrictions during fall 1980, and plans were made to develop emergency ground-water supplies to augment dwindling surface-water sources.

In Florida, sinkholes suddenly appeared as ground-water levels declined. Forest fires became a serious hazard in many parts of the Nation, especially in the Western States and in southern Florida. The Nation's corn crop was down 10 percent, and the peanut crop failed disastrously. The Mississippi River had record low water levels—so serious that barge traffic was stalled.

Although public appeals to conserve water are effective, saving water causes financial losses to water suppliers. In many cases, rates must be raised, ironically penalizing those who conserve.

## Responses to Drought

Communities historically have reacted to water shortages by asking users to conserve water, by seeking new or temporary water supplies, and by regulating water use. Fundamental to the design and implementation of such responses is a better understanding of water-use patterns and of the hydrology of drought, the availability of auxiliary water resources during drought, and an improved ability to predict drought occurrence and severity. At present, drought and drought-related phenomena are among the least understood aspects of hydrology, imposing severe limitations on planning and management measures.

Principal Federal participants in drought evaluation include the National Weather Service, the U.S. Geological Survey, and the Soil Conservation Service. The National Weather Service monitors and assembles data on climatic variables related to droughts. Similarly, the Geological Survey observes and publishes information on the quantity and quality of surface-and ground-water resources, and the Soil Conservation Service has responsibility for coordinating and managing information on soil moisture and western mountain snowpacks.

Monthly information on ground-water levels and streamflow conditions is published by the Geological Survey in a publication entitled *Water Resources Review*. During periods of drought, the Geological Survey expands data-collection activity on streamflow, reservoir, and ground-water levels to provide State and local agencies and private organizations additional information to make water management decisions. During the 1980–81 drought, the Geological Survey responded to numerous requests for information on supplemental water sources, water-quality changes, ground-water levels, and location of saltwater fronts.

## EMERGENCY RESPONSE

Response of Federal agencies to ongoing droughts is intended to supplement the efforts and capabilities of State and local governments. The Federal Emergency Management Agency coordinates Federal assistance and technical guidance in areas experiencing a drought and has compiled a list of Federal agency programs, authorities, functions, and activities that may assist States with water-shortage problems.

# River-Quality Assessments in the Federal-State Cooperative Program

The need for water-quality information nationwide is rapidly increasing. Despite considerable progress in solving complex water problems, stresses affecting the quality of the Nation's waters are multiplying. Any deterioration in the quality of water available for domestic, municipal, industrial, or agricultural uses obivously has an adverse affect on human health and the Nation's economy.

In the 1970's, public awareness and concern about water quality resulted in the passage of a variety of Federal and State laws which provided a legal framework for protection and improvement of water quality. Nevertheless, the scientific and technical information base required for decisionmaking is still inadequate. Challenging problems remain to be solved.

Many leading water-quality specialists believe there is a need for a scientific approach to river-quality management which emphasizes an understanding of the cause-and-effect relations involved, distinct from a legalistic approach. When such relations are defined and verified, a powerful predictive tool is developed which can be used by planners and managers to evaluate alternative courses of action.

In this discussion, "river quality" refers to the physical, chemical, and biological characteristics of water with regard to its suitability for specific uses. A river may be of good quality for one use and bad for another, depending on its characteristics and the selected quality criteria. D. A. Rickert and W. G. Hines, 1975,[1] stated, "The characteristics and criteria for judging quality are based on scientific knowledge and popular perceptions. Popular perceptions, in turn, depend on environmental, economic, and demographic conditions. As these conditions change, perceived purposes and suitabilities of rivers change, and the water resource decisionmaker is often left without adequate scientific information to evaluate alternatives."

To fill this information void, river-quality assessments are designed to determine the quality of rivers from the standpoint of the river system stress and response in time and space and as a function of streamflow. River-quality assessments define major environmental and cultural controls of those characteristics of a river system that decisionmakers perceive as being most important to resource planning and management.

## GEOLOGICAL SURVEY'S RIVER-QUALITY ASSESSMENT PROGRAM

Historically, many agencies have collected water-quality data and prepared river-quality reports. In 1964, in an attempt to eliminate duplication of effort and to develop uniform data standards, the Bureau of the Budget designated

[1] *A Practical Framework for River-Quality Assessment:* U.S. Geological Survey Circular 715-A, 1975.

the Department of the Interior as the lead agency in coordinating Federal activities related to water-data acquisition. Responsibility for this function was assigned by the Department to the U.S. Geological Survey. The Survey established advisory committees to assist it in discharging this responsibility.

In 1971, the Survey's Advisory Committee on Water Data for Public Use recommended that the Geological Survey conduct a river-quality assessment. As a result, in 1973, a prototype assessment was begun in the Willamette River Basin, Oregon. Since then, six other federally funded assessments, which encompassed a wide variety of river-quality problems, have been conducted by the Survey.

The basins studied during the federally funded pilot program were carefully selected from 80 basins which had been nominated for investigation by field offices of the Geological Survey; by other Federal, State, and local agencies; and by the Advisory Committee on Water Data for Public Use. The basins were located in all sections of the country. As a result, considerable interest was aroused in the assessment program as a tool to aid in water resources planning and management.

## RIVER-QUALITY ASSESSMENTS IN THE FEDERAL-STATE COOPERATIVE PROGRAM

The federally funded program resulted in development and demonstration of methodologies for conducting other river-quality assessments. Currently, there are 27 projects in the Federal-State Cooperative Program that satisfy the criteria of river-quality assessments. This Program provides a logical means of providing grassroots identification of problems, a strong meld of Federal and State interests, and an opportunity to further develop techniques that have high potential for transfer to other locations. Typical of the Program assessments under way are (1) Pequea Creek in Pennsylvania, which is concerned with defining the discharge of suspended sediment, nitrogen, phosphorus, and triazine herbicides from selected land use areas, (2) the water-quality assessment and steady-state dissolved oxygen model of the White River in Arkansas, which defines dissolved oxygen dynamics in a stream with numerous large pools, and (3) the Hudson River assessment, a description of which follows.

## THE HUDSON RIVER ASSESSMENT

In the late 1960's and early 1970's, nearly four decades after the introduction of polychlorinated biphenyls (PCB's) into commercial use, scientists began to be aware of widespread PCB dispersion in the environment and the resultant possibility of hazard to health. The discharge of PCB's into the Hudson River from about 1950 to 1977 had resulted in serious degradation of the river as a source of food and drinking water.

In 1976, the Geological Survey, as part of its Federal-State Cooperative Program and in cooperation with the New York State Department of Environmental Conservation and the Board of Water Commissioners of the Town of Waterford, began a study of PCB's in the Hudson River to determine concentration and transport rate of PCB's in the river and to provide a basis for deciding what actions should be taken to reduce the level of contamination.

### History of the Problem

PCB's are actually a group of closely related compounds, the molecular structure of which is illustrated in figure 1. Between 1 and 10 chlorine atoms can be attached in any of the 10 substitution sites (X) on the biphenyl portion, creating over 200 possible compounds. Commercial mixtures contain a number of these compounds whose chlorine content is dependent on the particular manufacturing process used by the producer. At the time of the Hudson River assessment, the only important U.S. producer was Monsanto Chemical Company which marketed PCB's under the trademark of Arochlors until production was discontinued in 1977.

Although PCB's had a variety of uses, their major use was in electrical capacitors and transformers, where their resistance to degradation at high temperatures made them particularly valuable as insulators and coolants. The General Electric Company purchased PCB's for use in manufacturing of electrical equipment at plants in Fort Edward and Hudson Falls. Records indicate that between 1966 and 1974 these two plants accounted for 15 percent of all domestic purchases of PCB's.

Discharge of PCB's from two outfalls on the Hudson River dates back to about 1950, although records of the actual volume discharged are available only for the past 10 years. These records show that the quantity averaged 35 pounds per day in the early 1970's. Discharge was terminated in 1977. Wastes accumulated in a river pool retained by the Old Fort Edward Dam, a 150-year-old stone-and-wood structure used for generation of hydroelectric power. In October 1973, when the dam was removed, massive quantities of PCB-laden sediment that had collected behind the dam were washed downstream. It is estimated that about 650,000 pounds of PCB's are

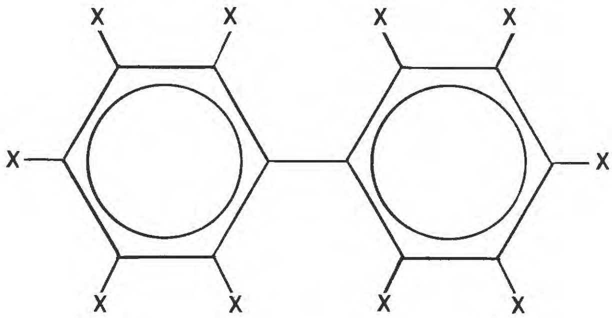


FIGURE 1.—*Structure of polychlorinated biphenyls.*

now present in Hudson River sediments. Concentrations of PCB's in the sediment generally decrease downstream from more than 1,000 parts per million at Fort Edward to less than 10 parts per million in the harbor at New York City. These sediments are believed to be the source of PCB's in the Hudson River water.

## Upper Hudson River

The Hudson River above the head of the tidal estuary at Troy is marked by a series of low-level dams used for navigation and power generation. The 45-mile reach from Troy north to Fort Edward contains eight dams. Samples of river water are being collected by the Geological Survey within this reach at Rogers Island (near Fort Edward), Schuylerville, Stillwater, and Waterford. Locations are shown on figure 2. In addition, background samples are being collected from a bridge at Glens Falls upstream from the contaminated reach. PCB's have not been found at the background station.

Figure 3 shows the relationship between concentration of PCB's and water discharge expressed as a U-shaped curve. The increase at very high discharge is due to resuspension of contaminated sediments in the river water. These high discharges typically occur only during a few days of spring snowmelt, but, during this time, as much as one-third of the total annual PCB transport may occur. Figure 3 indicates that the relation between concentration and discharge during these floods differ from year to year. This variation is partly a reflection of the alternating covering and reexposure of PCB-laden sediments on the river bottom; but the major cause is the variation in source of flood flow, which may be either far upstream, passing over the more contaminated reaches, or further downstream, passing over the less contaminated reaches. Similar results also have been found at Stillwater and Waterford.

The increase in PCB concentration at low discharge is due to a relatively constant source of PCB's seeping from bottom sediment into the overlying water column. In contrast to the periods of very high discharge when PCB's are attached to suspended sediment, the balance of the time they are found mainly in the dissolved phase. Average flux (excluding floods) is calculated to be 2 pounds per day at Rogers Island and 10 pounds per day at Schuylerville, Stillwater, and Waterford, with quantities decreasing by about one-half since 1980. The fact that nearly identical fluxes are observed at the three downstream sites indicates that the most highly contaminated sediments are still upstream from Schuylerville.

## Hudson River Estuary

The 150-mile tidal reach of the Hudson from Troy to the Battery in New York City has suffered the major economic impact of contamination. Commercial fishing for nearly all species has been banned and sport fishing has been curtailed substantially. The New York State Department of Environmental Conservation estimates economic losses may be as high as $25 million annually.

Water samples have been collected from late spring to early fall in the upper two-thirds of the estuary since 1978. Average PCB concentration decreases from 0.25 part per billion near the head of the estuary to 0.1 part per billion 100 miles downstream; average concentration during the same period at Waterford is 0.4 part per billion. The difference between concentrations at Waterford and the head of the estuary is due to dilution by the Mohawk River which contains no PCB's and enters the Hudson just below Waterford. Further decrease in concentration at downstream sites in the estuary is due to dilution by tributaries and perhaps in part to losses by volatilization.

## Drinking Water

Numerous private households, institutions, and communities use the Hudson River as a source of drinking water. Waterford and Poughkeepsie (80 miles south of Troy) are the major users of public supplies. The standard for finished drinking water has been set by the New York State Department of Health at 0.1 part per billion.

Most monitoring has been done at Waterford rather than Poughkeepsie because PCB concentration is known to be higher there than in the estuary. Concentrations in raw and treated water have been measured. Results show that the concentration in treated water rarely exceeds the drinking water standard.

During high discharge, removal is achieved readily simply as a byproduct of the settling processes that remove suspended sediment from the

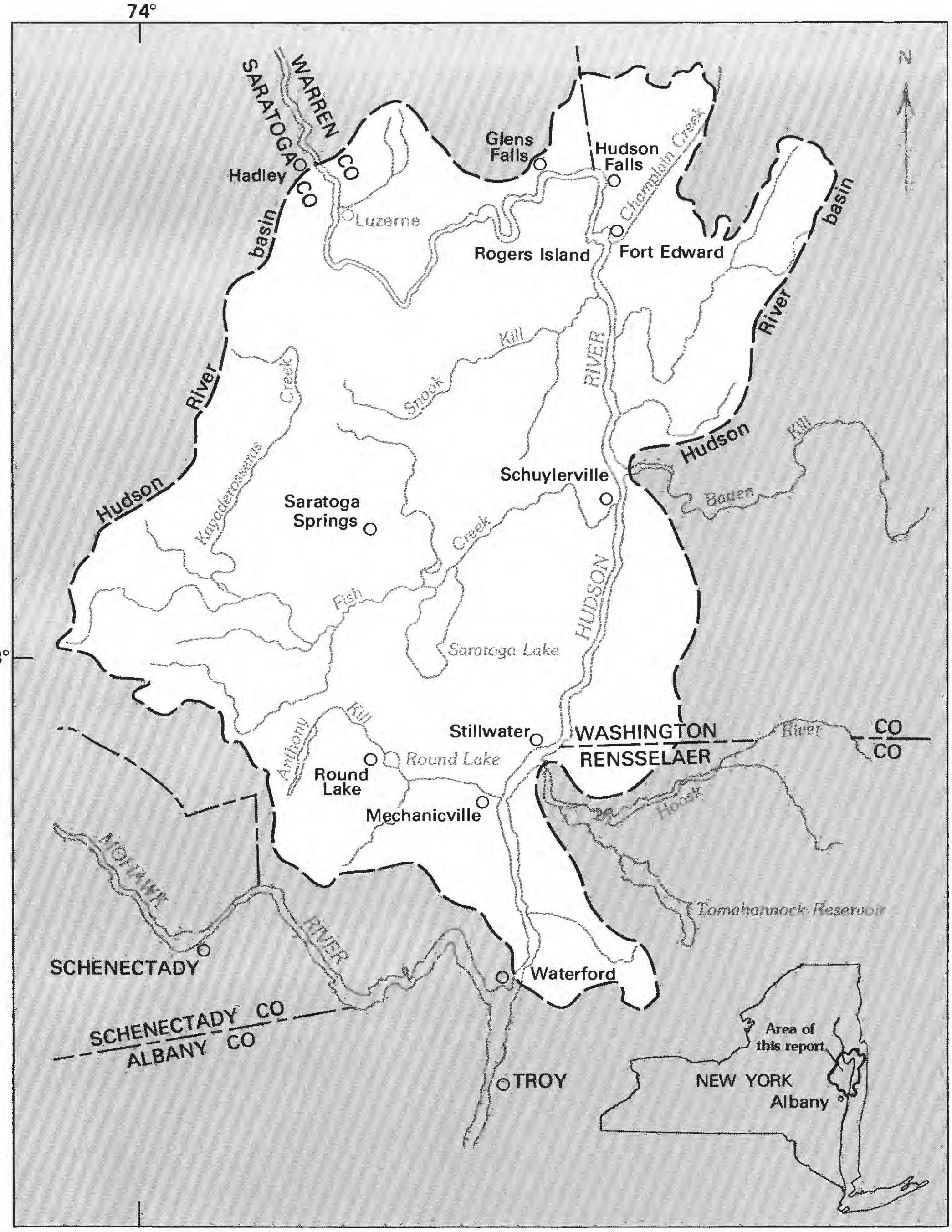



FIGURE 2.—*Map of Upper Hudson River Basin showing major tributaries and location of sampling sites.*

raw water. During the rest of the year, when a significant fraction of the PCB's is present in the dissolved phase, removal is achieved by the combination of settling, coagulation, and charcoal filtration processes used for water purification.

## Cleanup Plan

If PCB transport rates were to remain constant in the future, it would take nearly a century to move the total accumulation of PCB's from the upper river. Even though covering of old contaminated sediments with new uncontaminated sediments and natural degradation of PCB's could shorten the interval, the length of time necessary for the river to clean itself by natural processes is still very long. For this reason, the U.S. Environmental Protection Agency and the New York State Department of Environmental Conservation

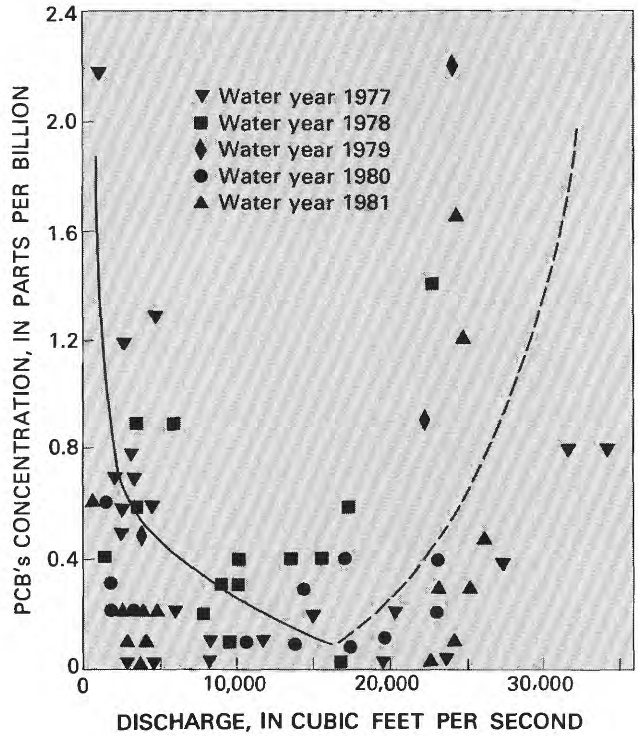



FIGURE 3.—*Results obtained for Hudson River at Schuylerville illustrating U-shaped relation between concentration of polychlorinated biphenyls and river discharge. Dashed line represents "average" conditions during spring snowmelt flood period; solid line is derived from regression relation between concentration and inverse discharge during remainder of year.*

have decided to spend $26.7 million to remove contaminated sediments by dredging.

Dredging for removal is planned to begin in 1982 or 1983 and will be completed in 1 year. Dredging will remove sediments from about 30 "hot spots" above Schuylerville where concentration of PCB's exceeds 50 parts per million. The sediments will be stored in a clay encapsulation site on 250 acres a few miles south of Fort Edward. Removal of these hot spots will decrease total PCB's in sediments of the upper river by nearly one-half and should, therefore, result in a comparable decrease in concentrations and loads transported by the river. Water sampling on the upper Hudson is scheduled to continue through 1986 to compare "before and after" dredging concentrations.

# Acid Rain—What We Know and Don't Know

The phenomenon of "acid rain," or precipitation with low pH values was observed in Europe as early as 1966 and later was noted in the Northeastern United States in 1974. The term pH is used to describe the free hydrogen ion concentration and acidity of water. A pH of 7 is called neutral; pH's above 7 are called basic or alkaline; pH's below 7 are called acidic. The pH of water in equilibruim with atmospheric carbon dioxide ($CO_2$) is 5.6, a value considered to be the normal condition for precipitation in the absence of strong acid-forming materials. The term acid rain applies to preciptiation with a pH of less than 5.6.

It is by no means certain that precipitation is in equilibrium with $CO_2$ all the time. Variations in the pH of precipitation above and below 5.6 may be due in part to departures from equilibrium. Oversaturation with $CO_2$ will lower the pH below 5.6, and undersaturation will raise it. Both conditions may be caused by particular combinations of temperature, barometric pressure, and turbulence in the atmosphere during rainfall, as well as by changes in the concentrations of $CO_2$ in the air from place to place.

Despite the present uncertainties as to the extent and importance of the effects on pH from variations in $CO_2$, which have only partial relation to manmade air-pollution sources, scientists have tentatively ascribed the causes for pH's of less than 5.6 to strong acid-forming gases as opposed to the weak acid-forming gas $CO_2$.

The occurrence of rainfall with a pH of below 5.6 in North America (fig. 1) is centered in the northeast corridor of the United States and through Ontario, Quebec, and the Maritime Provinces of Canada. The occurrence of pH values higher than 5.6 in Montana, North Dakota, Alberta, and Saskatchewan may be caused by dust in the rain which neutralizes the normal acidity.

Acid rain is thought to be caused by acid-forming nitrogen and sulfur oxides emitted from automobiles, coal- and oil-fired powerplants, and many industrial plants (fig. 2). Emissions of nitrogen and sulfur oxides are strongly localized in the upper Midwest, Northeast, Gulf Coast, and Pacific Coast States and in southern Quebec and Ontario and parts of Alberta. These gases pass into the atmosphere where they are carried by prevailing winds and precipitated in rain and snow. These and other acid-forming materials also are produced by many natural processes such as volcanic eruptions and the decomposition of

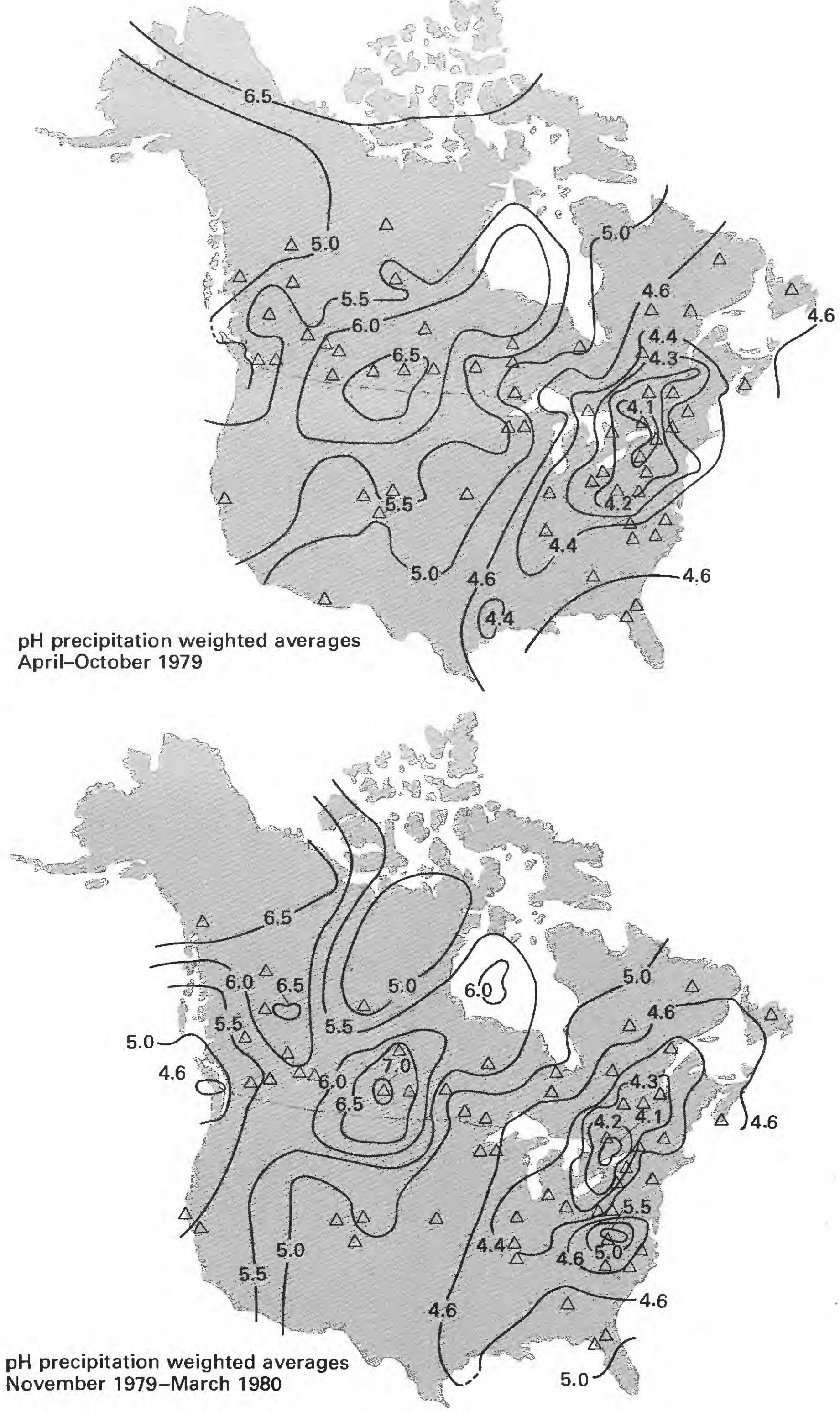



FIGURE 1.—*Occurrence of rainfall in North America with a pH of below 5.6.*

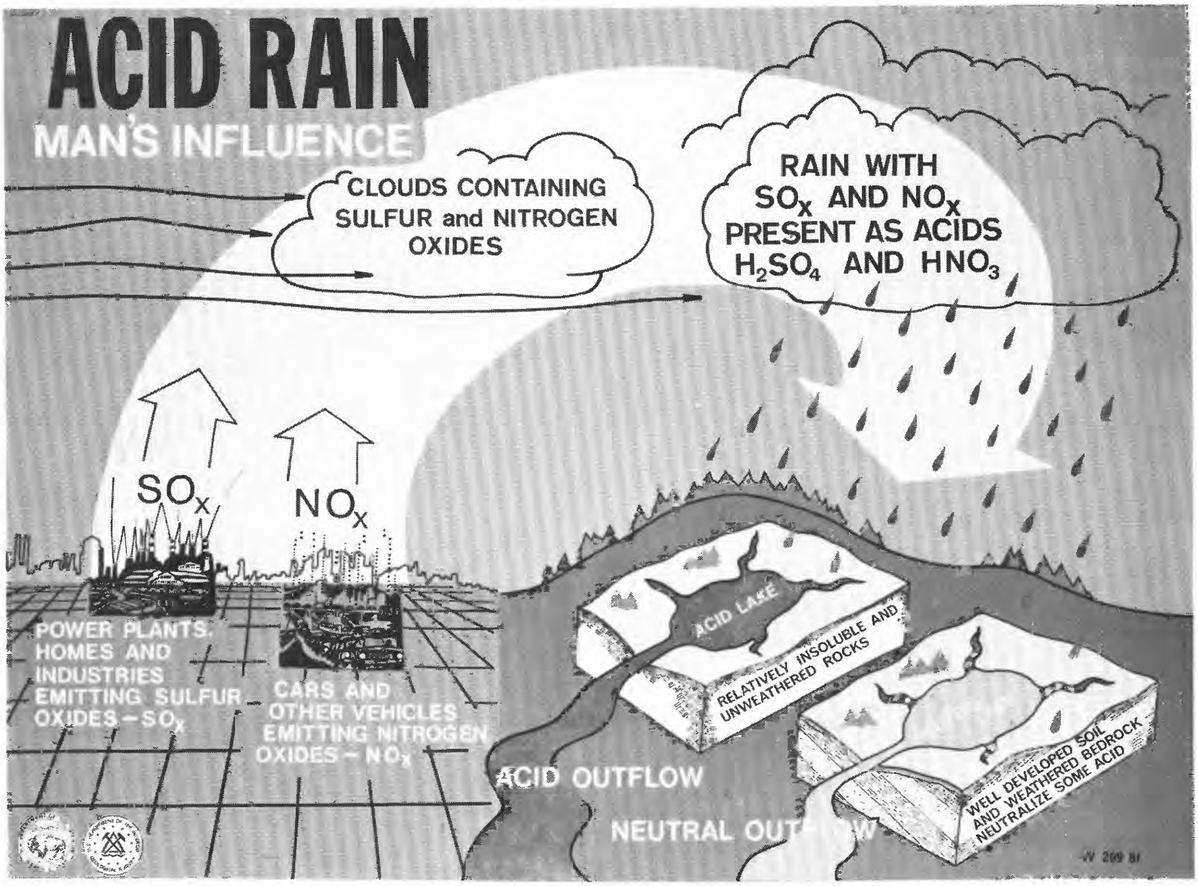



FIGURE 2.—*Schematic of sources and transport of acid-forming gases.*

organic material. Scientists now are attempting to determine the mechanisms that form such naturally produced acid-forming materials and the extent of their occurrence to better assess the extent and severity of man's influence.

Arctic, tropical, and Pacific airstreams tend to converge over the upper Midwest and Northeastern States and the Maritime Provinces of Canada, causing the prevailing pattern of weather fronts and normally high precipitation in this region year-round (fig. 3). In the process, airborne acid-forming materials emitted from the industrial and population centers of this country and Canada are swept into this area to be combined with precipitation to create the acid rain phenomenon. This pattern of airmass movements together with the location of manmade sources explains, in part, the localization of the effect over the northeast corridor and Maritime Provinces and the relative absence of the effect west of the Rocky Mountains. However, acid rain has been observed in the Sierra Nevada and Cascade Ranges of the West and the Rockies as well. There the effect is thought to be due to emissions from very localized population and industrial centers, such as Los Angeles, San Francisco, and Denver.

Recent studies suggest that the acidity of precipitation has been increasing since the mid-1950's and has caused the acidification of several lakes in this country and Canada. The phenomenon apparently has been with us for at least the last 25 years but may have worsened during that period. Studies suggest a steady decrease in pH of precipitation in those most severely impacted areas of the Northeast from about 4.5 in 1955 to about 4.1 in 1975 and the present day (fig. 4). Many scientists are skeptical of the methods used to make this interpretation, and further studies and monitoring are being conducted to verify the trend.

Among the studies conducted recently to detect effects from and trends in the occurrence of acid rain was a statistical analysis of stream-quality data collected over the past decade at the U.S. Geological Survey's remote Hydrologic

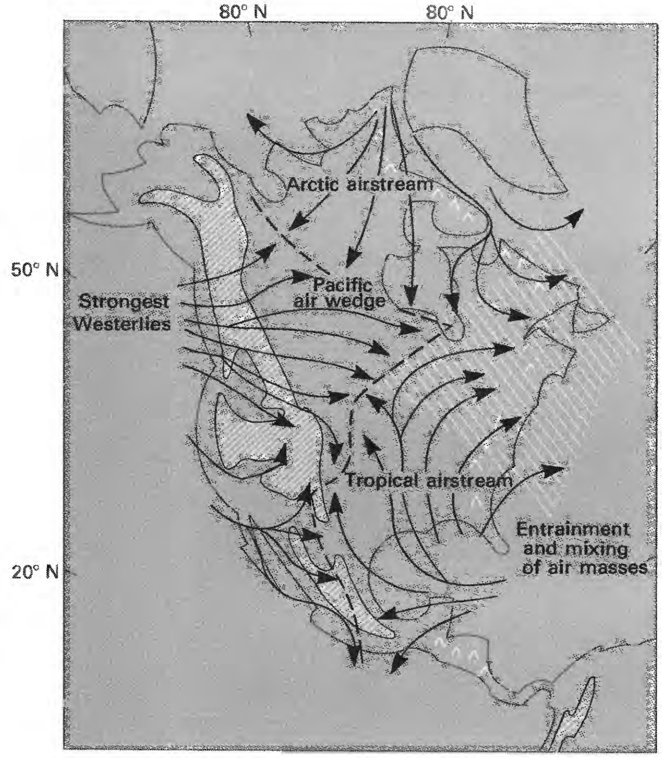



FIGURE 3.—*Schematic representation of the surface flow across North America, illustrating the wedge of Pacific air east of the Cordillera and the downstream entrainment and mixing of airstreams. Based on July resultant surface winds. (From Bryson and Hare, 1974.)*

Bench-Mark Program stations. Analyses of the data show that there have been widespread increases in sulfate concentrations. The extent of the upward trends supports the theory that atmospheric sources (as opposed to land disturbance, which would be more localized) is the primary cause. The major source of sulfate would be sulfur oxides from combustion of fossil fuels.

Concentrations of nitrate showed uptrends also, primarily at stations east of the Mississippi River. The major source of nitrate may be nitrogen oxides from internal combustion engines.

Despite the uptrends in sulfate, however, there is no clear pattern of falling pH or alkalinity levels at the Hydrologic Bench-Mark Program stations. In fact, pH levels are increasing at many stations in the West and in the Gulf Coast States. No explanation for this apparent contradiction is offered, but the existence of this contradiction suggests that further study of the effects of acid rain on stream quality is needed.

Another study recently completed by the Survey using data collected over the 13-year period from 1965 to 1978 at nine precipitation monitoring stations in New York State suggests a mixed pattern of trends in the acidity of precipitation. The pH decreased (increased acidity) by about 0.2 pH units in the western part of the State but increased by about the same amount in the eastern part during the period of the study. The concentrations of sulfate (the ion produced by the strong acid-forming sulfur oxide gases) decreased by 0.25 percent per year, but the concentrations of nitrate (the ion produced by the strong acid-forming nitrogen oxide gases) increased by 4 to 13 percent per year. This suggests a steady shift of predominate sources of acidity from sulfur oxides emitted from fossil-fueled industries and powerplants to nitrogen oxides produced by internal combustion engines, mostly in automobiles. Other evidence suggested that the acidity was being partially neutralized to a variable degree from place to place and time to time, possibly by air-borne particulate material. Neutralization produced an increase of about 0.3 pH units in nonurban areas and 0.7 pH units in urban areas.

A statistical analysis of chemical data from several streams in New York yielded little evidence of temporal trends resulting from acid precipitation except in the Adirondack Mountains where the soils lack significant capacity to neutralize the acidity.

Studies indicate that acids can be neutralized by passage through deep well-developed chemically reactive soils. Where those soils are absent, the acids pass unaltered into streams and lakes. Areas where deep soils are absent are found throughout New England and the Canadian Shield of Ontario, Quebec, and the Maritime Provinces, and it is here that effects from acid rain are most prominent. In the Adirondack Mountains, the pH of selected lakes has decreased since the 1930's (fig. 5). The median pH value of 138 lakes decreased from 6.75 between 1930 and 1934 to 6.51 in 1979; but, more importantly, the percentage of lakes with a pH of below 6 more than tripled from 6.5 to 19.6 percent during this period. Moreover, a comparison of lakes in a different group between 1930 and 1975 showed that the occurrence of lakes with a pH of less than 5 also increased dramatically.

A loss of fish was illustrated dramatically in a comparison of fish populations between the 1930's and 1975 in 40 Adirondack lakes located at high altitudes (fig. 6). The link between reduced pH and loss of fish has not been established completely, but at least two mechanisms are thought to be at work. First, fish eggs and fry are more sensitive to low pH than are adults. Simultaneous occurrences of spawning and a sharply reduced

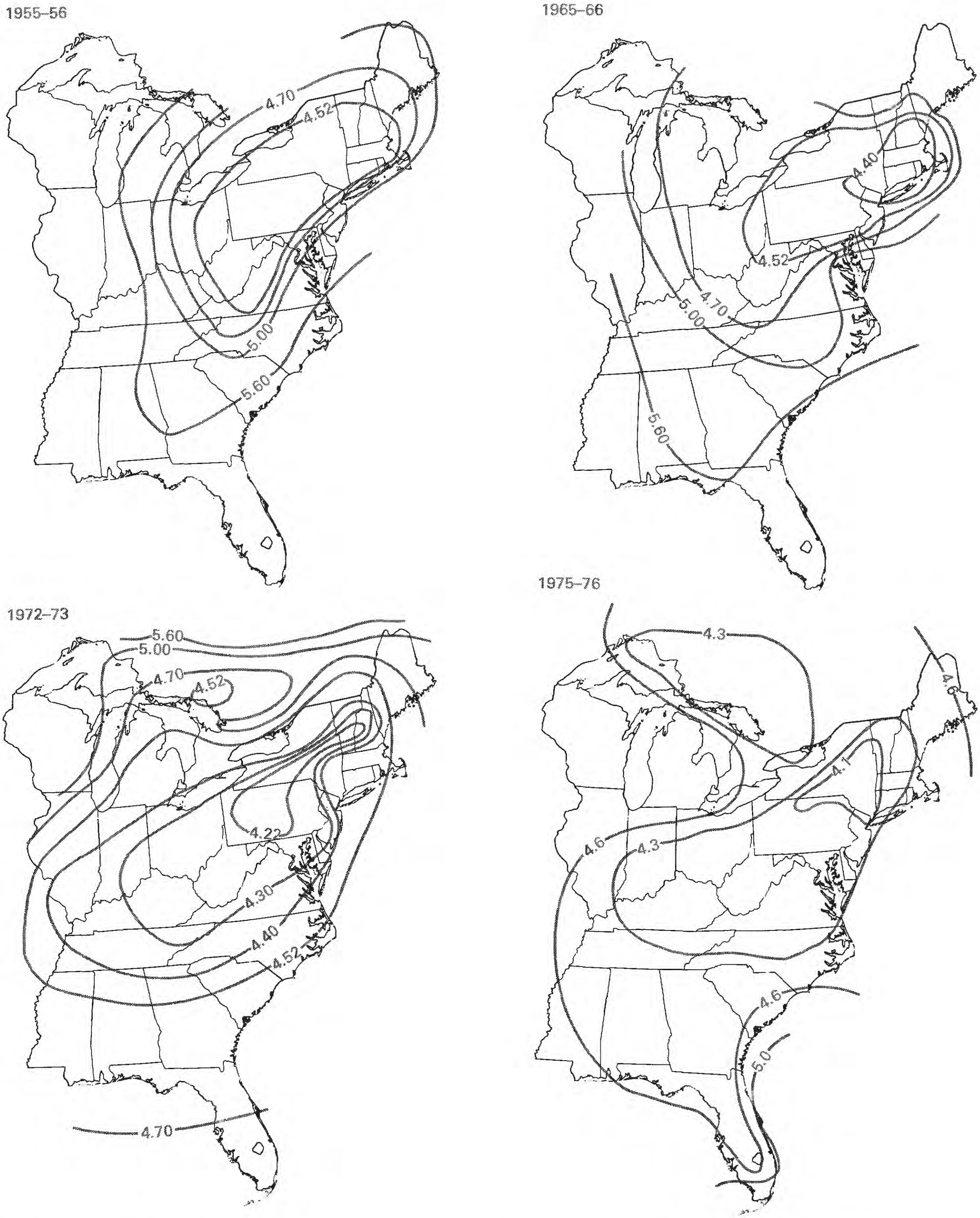



FIGURE 4.—*Isopleths of the weighted annual average pH of precipitation in the Eastern United States in 1955–56, 1965–66, 1972–73, and 1975–76. (U.S. Department of Energy, 1981; modified from Likens and others, 1979)*

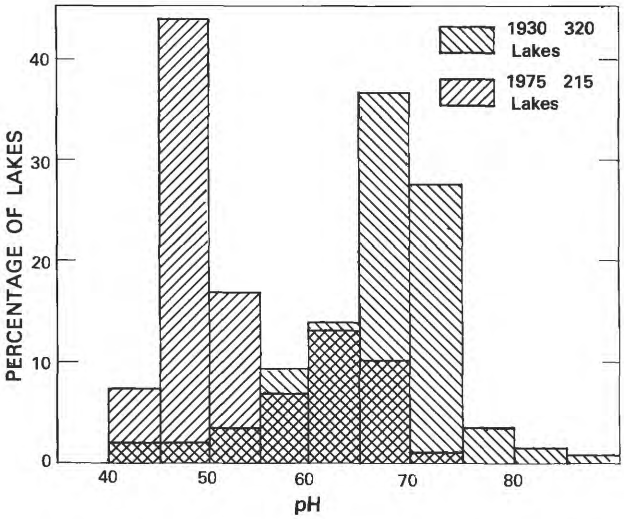



FIGURE 5.—*Comparison of pH values for lakes in the Adirondack Mountains area of New York from 1930 to 1975. (Data from Schofield, 1976.)*

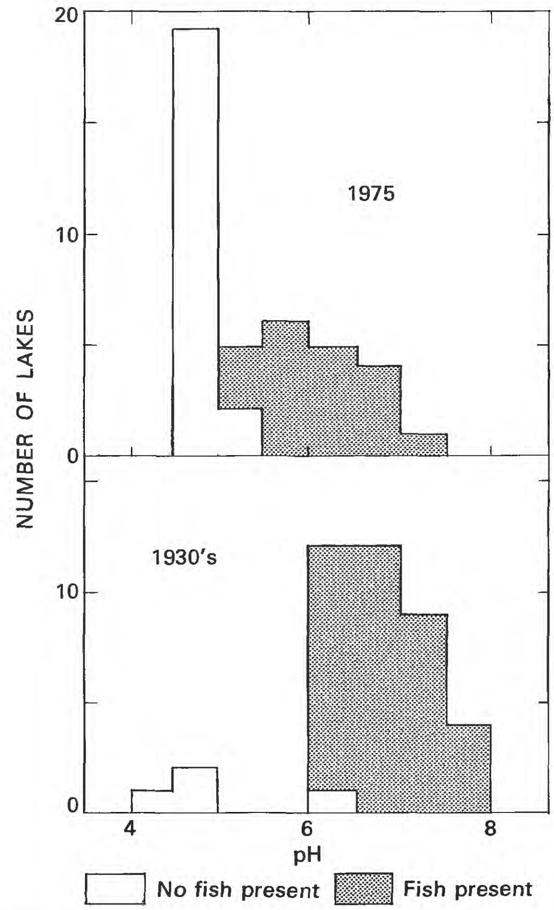



FIGURE 6.—*Frequency distribution of pH and fish population status for 40 high-elevation lakes surveyed in the 1930's and again in 1975 (Schofield, 1976).*

pH during snowmelt runoff, at which time the acid materials accumulated in the snowpack tend to concentrate into a smaller volume of water, cause high mortality of eggs. Second, higher concentrations of dissolved aluminum accompany reduced pH. Aluminum oxides are known to coat fish gills and cause loss of respiratory capacity, increasing stress on the population.

In addition, many scientists think the food supply of the fish may be under stress at reduced pH. Many microscopic organisms which convert land-derived organic material to edible forms cannot survive at pH values less than 5. Because most streams and lakes at higher elevations require land-derived organic matter as the primary food source for higher organisms, the disruption of the organisms that reduce the leaves and debris from the land to edible form could be particularly disastrous to aquatic life. To date, there is only slight evidence for foodchain disruption as a major effect, but studies in this area have been underway only a short time and may yield definitive information in the near future.

The economic damages from acid rain have not been studied thoroughly enough to place dollar amounts on specific instances, but several actual or potential effects have been identified.

- The loss of native fish populations due to cidification of lakes in the United States and Canada means a loss of recreational value in the affected areas and a consequent loss of tourism.
- Any disruption of normal foodchain relations, as is now being speculated as the cause or loss of some fish populations, could extend to terrestrial ecosystems as well. Such disruption could cause losses of valuable plant and animal species.
- Forest productivity may be reduced directly from damage to leaves and indirectly from increased susceptibility to diseases. Moreover increased acidity tends to leach important nutrients such as potassium and calcium from the soil, leading ultimately to reduced fertility.
- Acid precipitation or the interaction of acid-forming gases with dew is causing damage to manmade artifacts such as statues, monuments, and historic structures here and throughout Europe. Corrosion of metals and erosion of concrete and stone may be accelerated, thus threatening damage to buildings, bridges, highways, and homes.

- Heavy metals which could be toxic to human beings may be leached from soils and rocks by acid precipitation. Although heavy metal concentrations in water supplies are generally well below safe drinking water levels, toxic concentrations of some, such as lead, have been found in water standing in pipes for only a few hours.

In contrast, some economic benefits could be realized. Nitrogen and sulfur, which are the primary sources of the acidity in precipitation are plant nutrients. Studies have shown that the nitrogen in precipitation is a major component of the annual nitrogen budget of forested watersheds in many parts of the United States. Some soils, particularly in tropic latitides, are deficient in sulfur. Acid rain could stimulate productivity in such areas.

It is apparent that resolution of the many unanswered questions about acid precipitation is a major challenge not only to hydrologists but to plant pathologists, soil scientists, bacteriologists, and other specialists. Planners and managers cannot act in an informed manner to alleviate the potential damage from acid rain on the environment until a better understanding of the acid-rain phenomenon has been gained.

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## THE WAY IT WAS: HYDROLOGY AND FDR

In 1927, Franklin D. Roosevelt, a New York lawyer active in Democratic politics, asked the U.S. Geological Survey to study the mineral springs around Warm Springs, Georgia. An attack of polio in 1921 had left Roosevelt crippled. He believed that swimming in the naturally warm water from the springs was helping him and other victims of the disease regain the use of their stricken limbs.

With the scientific skepticism for which the Survey is famous, the Acting Director replied that mineral springs were valuable chiefly for their location. Because people came to them for treatment, resorts were built up around them, but the spring water really did not differ from that which flowed through city water pipes.

Roosevelt was outraged. Like anyone who was healthy until struck down, he dreamed of regaining the use of his damaged legs. He had turned the faded resort of Warm Springs into a health spa run by a newly formed foundation. The Survey's coldly scientific response to his request would not help him build a hospital to treat those who suffered as he had.

After Roosevelt became President in 1933, the Survey began a study, cooperatively with Georgia, of the Pine Mountain area around Warm Springs. The Survey sent D. F. Hewett to work with G. W. Crickmay of the Georgia Geological Survey.

Shortly after they began what became 3 years of fieldwork, Hewett met Roosevelt's visiting expert on warm springs' therapy, Dr. Paul Haertl, managing director of the famous spa at Bad Kissingen in Germany. "Have you examined the shape of the bubbles?" Haertl asked Hewett. Hewett could hardly believe what he heard as Dr. Haertl carefully explained that only square bubbles, such as those in the water at Bad Kissingen, had a therapeutic effect. Hewett, who knew as any other scientist would that all bubbles are round, was flabbergasted by Haertl, whom he compared to P. T. Barnum. But he dutifully examined the bubbles at Warm Springs and showed them to be round.

Hewett and Crickmay published their results in Water-Supply Paper 819 (1937). Their research confirmed the Survey's initial skepticism: there was nothing special about the water from Warm Springs. Water that fell as rain on Pine Mountain descended along a bed of quartzite, then ascended along the fault zone that marked the north edge of Pine Mountain. When it came out at Warm Springs, it had a temperature of 88° F. Otherwise, it was the same as the water from the region's other springs.

Though President Roosevelt was not happy with the Survey's report, he did turn in another direction to find the cure for polio. In 1938, he established the National Foundation for Infantile Paralysis (now the March of Dimes) to sponsor scientific research. This research led in the 1950's to the discovery of vaccines against polio.

# Conservation of Lands and Minerals

## Mission

The Conservation Division performs several functions concerning the leasing, classification, and use of mineral and water resources on Federal and Indian lands, including the Federally owned Outer Continental Shelf. These functions have been delegated to the U.S. Geological Survey by the Secretary of the Interior and are accomplished through three major functions:

- Evaluation of resources, which includes the classification of Federal lands to identify areas containing potentially valuable leasable minerals and areas valuable for waterpower and water-storage purposes. Also included in this mission is the evaluation of mineral resources on tracts of Federal lands that are exchanged, sold, or made available for development and production through a competitive leasing program.
- Supervision of operations associated with the exploration, development, and production of minerals from leased Federal and Indian lands and Outer Continental Shelf lands.
- Collection of rentals and royalties for minerals from Federal and Indian lands.

The scope and complexity of these responsibilities have grown continuously over the past few decades as exploration, development, production, and revenues—particularly from activities related to the energy minerals—have increased and as the Nation's growing consciousness of its environmental responibilities matured into specific policies for protecting its land, air, and water resources. Within a complex framework of law, regulation, and policy, it is the function of the Geological Survey to assure that operations undertaken under Federal and Indian mineral leases support the objectives of sound and orderly resource development, safe and environmentally acceptable procedures, and the receipt of fair value for the resources produced.

As the Federal Government's principal agent in the management of energy and mineral resources development on Federal and Indian lands, the Geological Survey, through its Conservation Division, is confronted with the dual challenge of meeting the increased workload associated with rapidly accelerating industry exploration and development activity, while minimizing the cost to the public of the services provided. In addition, the Survey must strike an appropriate balance between minimizing the constraints to industry activities while providing the public with assurance that its economic and environmental interests are protected.

## Budget and Personnel

In fiscal year 1981, $125.7 million in appropriated funding was required to support the Division's programs. More than one-half of the total was dedicated to the administration of leasing activities on the Outer Continental Shelf, which accounted for $68.9 million. The principal responsibilities addressed included activities necessitated by the Outer Continental Shelf Lands Act Amendments of 1978, while simultaneously accelerating the Outer Continental Shelf leasing program. Several initiatives to streamline the Outer Continental Shelf leasing process resulted in substantially lower expenditures in fiscal year 1981 than might otherwise have been required.

Management of onshore leasing activities on Federal and Indian lands required $43.8 million, of which all but $1.3 million was from directly appropriated funds. Major new initiatives included initiation of activities leading to the first competitive lease sale in the National Petroleum Reserve in Alaska, commitment of additional funding to the management of industry oil and gas evaluation and development activity on Federal and Indian lands, the response to the passage of the Alaska Native Interest Lands Conservation Act, the implementation of additional efforts leading to increased oil shale leasing, and the initiation of efforts to increase nonenergy mineral leasing. The additional costs of these initiatives were partially offset by reductions in the nonenergy minerals and coal resource evaluation programs and termination of the program initiated in fiscal year 1979 to inventory the reserves of coal that are already under lease on Federal lands.

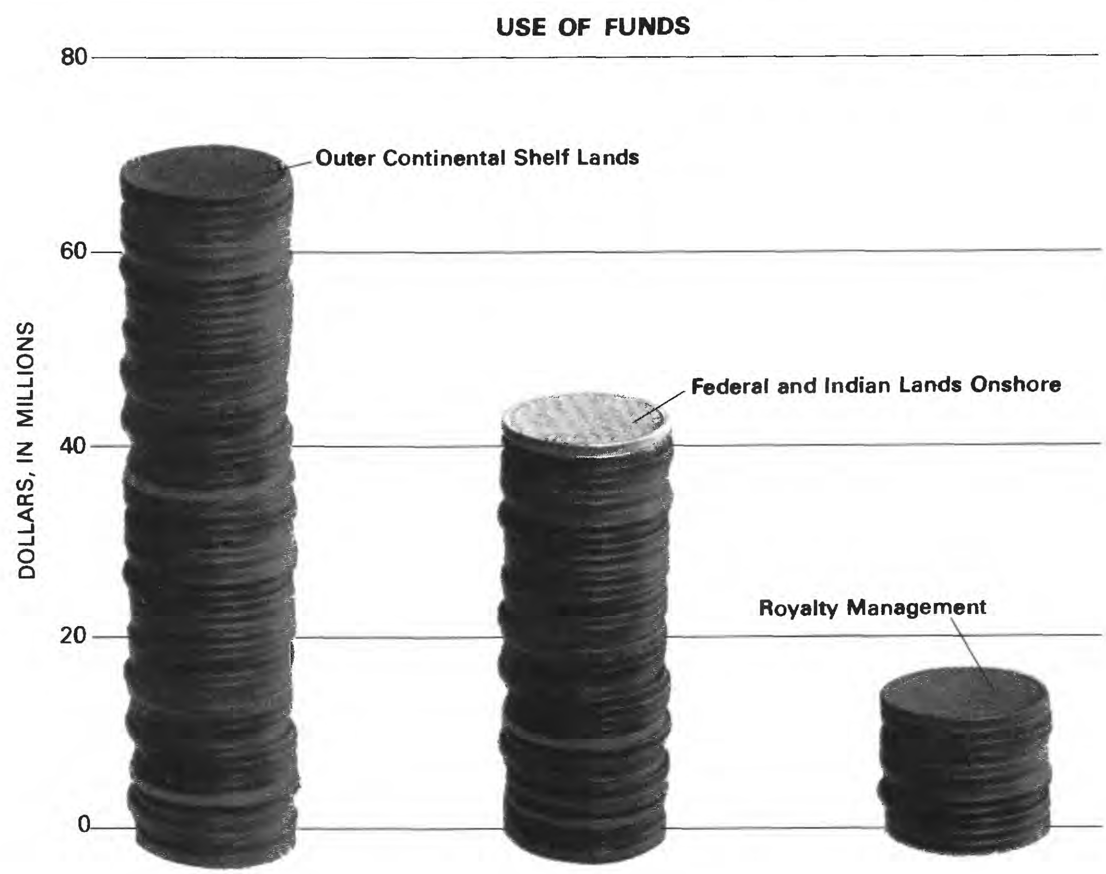
The most significant new initiative for the Conservation Division in fiscal year 1981 was the multiyear effort to design and install an Improved

*Conservation of Lands and Minerals activity obligations for fiscal years 1980 and 1981, by subactivity*

[Dollars in millions. Data may differ from those in statistical tables because of rounding]

| Subactivity and Program * | Fiscal year 1980 | Fiscal year 1981 |
|---|---|---|
| **Outer Continental Shelf Land** | **66.1** | **68.9** |
| Regulatory Program | 31.1 | 31.8 |
| Resource Evaluation Program | 35.0 | 37.1 |
| **Federal and Indian Lands** | **40.3** | **43.6** |
| Oil and Gas | 19.7 | 22.8 |
| Coal | 15.0 | 14.1 |
| Other Energy Resources | 2.8 | 3.8 |
| Nonenergy Minerals | 2.4 | 2.3 |
| Waterpower | .4 | .6 |
| **Royalty Management** | **—** | **14.3** |
| **Total** | **106.4** | **127.0** |
| **Direct program** | **105.9** | **125.7** |
| **Reimbursable program** | **.5** | **1.3** |
| All Federal agencies | .5 | 1.3 |

* Program data estimated

Royalty Management System. By virtue of the significant increase in funding provided by Congress through a supplemental budget, work started in fiscal year 1981 to install a new Audit and Financial System; action leading to the installation of a Production Accounting and Auditing System also was begun. The conversion of existing accounting offices to the new system will begin early in fiscal year 1982 and will continue through mid-1984.

Significant redirection of personnel occurred during the 1981 fiscal year as emphasis changed from resource evaluation toward streamlining, improved royalty management, and acceleration of leasing programs. Actual end-of-year employment for the Division was 1,874 in the fulltime category and 282 in the other-than-permanent categories.

# Royalty Management Program

The Geological Survey has been the collection agent for royalties and rents due from Federal and Indian land mineral leases since 1925. By 1954, a total of $538 million in mineral royalties had been received. From 1955 through 1980, revenues amounted to more than $15 billion of which $3 billion was collected in calendar year 1980 alone. The latter sum included royalties, rents, and windfall profit taxes from producing geothermal, mining, and oil and gas operations. By the end of calendar year 1981, annual revenues will have increased to almost $4 billion, and, by 1990, collections are expected to run as high as $20 billion.

These figures give some idea of the increase in sheer volume of accountable money. In addition, the entire collection-audit-reporting-verification process has been made much more complex in recent years by frequent changes in lease ownership, increases in multicompany joint development of leases, variable royalty schedules, and windfall profit tax legislation that requires royalties to be computed on the basis of complex price indexing and tier categories. Both the General Accounting Office and the Survey considered that the resulting difficulties mandated replacement of the existing largely manual procedures with a computerized and completely new system for speedily accomplishing the tasks of royalty management, along with other improvements in organization and procedures.

These changes now are well underway. By the end of fiscal year 1981, the Conservation Division had begun final testing and installation of the Interim Operating System of its Royalty Management Program. The new system centralizes all minerals royalty collecting and accounting functions under a Deputy Division Chief for Royalty Management. Eventually, automated data processing will replace a major share of the manual tasks associated with the accounting process.

Operational now, this Interim Operating System phases in use of a new reporting format by payors (lessees) during a 19-month period. In turn, an advanced Auditing and Financial System, which will convert accounts from the Interim Operating System, is scheduled to be fully operational by January 1983. Before that, in the summer of 1982, payors will begin reporting production in more sophisticated formats preparatory to installation of the Production Auditing and Accounting System. This system, a final major component of the royalty program, will be operational in early 1984.

The Survey expects to derive several benefits from the new royalty management program, including standardized policies and operating procedures, increased income, timely availability and processing of funds, dramatic increases in personnel productivity, and a substantially reduced regulatory burden on private industry. From the control standpoint, the new system will assure greater security for information collected, will reduce the potential for fraud and abuse in royalty reporting, and will provide a better level of administrative control over activities and funds.

The former royalty accounting system was based on a decentralized accounting scheme and placed the responsibility for account management and auditing in 14 separate offices in 11 cities. Originally, this was done to best maintain accounting files along with production and other lease management information. Each Survey office operated with independent procedures suitable to the region and used largely manual accounting methods which were partially supported by automated systems. But, with the current responsibility to process 300,000 reports involving more than 2 million entries annually, paperwork delays had increased greatly, and check processing had slowed. The Government was frustrated by its inability to ensure timely payment because of inadequate reporting requirements and an enormous records management load.

Under the new system, seven collection and audit field offices have been or are being eliminated, and an enlarged and consolidated accounting center has been established at Lakewood, Colorado. It is expected that 350 employees will staff this center, four review and analysis audit offices, and headquarters. All components of the new system will be operational by 1984.

As finally reorganized, the four review and analysis offices will conduct followup audits of payor accounts. Meanwhile, all 10 offices outside Lakewood will be involved in staged conversions to the various new automated accounting processes already established. The Interim Operating System further updates and expedites procedures so that eventually the thousands of monthly production reports and royalty payments can go directly to a centralized location. By the end of calendar year 1982, it is estimated that approximately 56,000 reports will generate 6 million line entries to account for the Nation's royalty revenues.

Other Survey and Division offices are providing integrated support of the Royalty Management Program, including better onsite lease inspection and improved security for all proprietary data; also in process are long-range planning and assessment and various automatic data processing and management information support services for the program. Chief among the information support services is the coordinated installation of a new computer-assisted microform records management system. This advanced record-handling system will photograph and process working papers and official documents on 35 mm microfilm rolls as well as on microfiche. As required both by law and sound business practice, the Survey's royalty program must store, retrieve, and secure thousands of such records safely and efficiently each day. Accumulated royalty accounting records now involve millions of pieces of paper.

The microform records management system component will be able to routinely file, index, cross reference, and store most of the records that must be accessible for fast accurate reading and copying for both ongoing business and legal and historical reasons. Some few transitory or exceptionally cumbersome records will remain permanently in their original form, and a mandatory destruction schedule will be authorized for other records.

If the predicted rise in royalty collections to $20 billion in 1990 is correct, the Royalty Management Program will ensure that the Geological Survey is prepared to cope properly with the rapid increase of the royalty management workload. The resulting reduction in undercollections, together with prompt payments and same-day deposits into interest-bearing accounts, are expected to add millions of dollars annually to the revenues accruing to recipients of royalty payments.

# Oil and Gas From Onshore Federal and Indian Lands

The number of leases on Federal and Indian lands, the total wells on those leases, and the royalties collected from oil production continued to increase through fiscal year 1981 even though the volume of oil produced has been declining since 1969. Although onshore gas production has continued to increase gradually, royalties stemming from gas well operations have risen sharply since 1975 because of higher market prices. Private companies are attempting to offset the decline in oil production by increasing exploration activities in frontier areas, particularly the western overthrust belt in Utah, Wyoming, Idaho, and Montana. They are also conducting research aimed at increasing the amount of oil and gas recovered from older declining reservoirs. Production from onshore Federal and Indian lands provided roughly 5 percent of the oil and gas produced in the United States during fiscal year 1981.

The U.S. Geological Survey conducts geological investigations, environmental analyses, and other studies related to the many aspects of exploration and development, safety of operations, collection and processing of royalties, and protection of the environment as they pertain to Federal and Indian mineral lease operations. During fiscal year 1981, the Geological Survey approved about 6,400 applications for drilling permits to provide exploration and development wells on Federal leases. More than 6,000 environmental analyses or reviews of the potential impacts of oil and gas development operations on Federal lands also were prepared. In the same period, about 4,000 new wells were started on Federal leases. Approximately 2,200 of those wells were completed for the production of oil and gas or for the injection or disposal of various fluids.

Other sources of oil and gas, such as the "tight" gas sands and tar sands that occur in New Mexico, Colorado, Utah, and Montana, have become more attractive prospects now that present market prices have made drilling and production from these deposits economically feasible. Exploration and development in newer more remote regions provide new challenges. Terrain, especially in wilderness areas, often is rugged; cold winters with deep snows can hamper drilling and supply operations, and the distance from existing pipelines limits delivery of new supplies to the marketplace. Some producible wells completed in these remote areas will likely be shut-in until pipelines or local processing facilities are built to serve them.

The development and use of enhanced recovery processes have been instrumental in the restoration or increase of production from many oil fields originally developed through natural production methods. Such procedures include repressuring of oil reservoirs with gas or water, flooding with chemical solvents, or stimulating with heat to support continued production after other recovery measures become uneconomical. In addition, well-completion techniques and formation stimulation processes constantly are being improved and will continue to add to the supplies of oil and gas produced.

# Mineral Resource Classification

Mineral land classification is one of the main missions of the Geological Survey as stated in Survey's Organic Act. Geological, geophysical, and engineering data are compiled to classify lands that are prospectively valuable for the occurrence of leasable minerals and to outline the boundaries of areas that contain leasable minerals that are presently or potentially economically producible.

## OIL SHALE

During fiscal year 1981, the Geological Survey classified 2.7 million acres of land in western Colorado as prospectively valuable for oil shale. This action provides the Secretary of the Interior with the information needed to remove these lands from withdrawn status, thus making them available for leasing and mineral entry. In addition, two oil shale leasing areas were established—the Roan Plateau Oil Shale Leasing Area comprising 315,000 acres located in Rio Blanco and Garfield Counties and the White River Oil Shale Leasing Area containing 341,000 acres in Rio Blanco County. The White River area, which contains the thickest and richest oil shale deposits in Piceance Creek Basin and rich deposits of dawsonite (sodium aluminum carbonite) and nahcolite (sodium bicarbonate), has multiple mineral development potential. Similar classification actions are expected to follow in Wyoming, Utah, Montana, and Nevada. In cooperation with appropriate State agencies, the Survey is conducting oil shale exploration drilling programs in Montana and Nevada.

## PHOSPHATE

Increasing demand for phosphate, necessary to support the Nation's agricultural needs through the production of fertilizer, has caused increased industry interest in the public phosphate-bearing lands, especially those in Idaho. A cooperative program between the State of Idaho and the Survey is investigating the phosphate potential of large areas in southeastern Idaho. Twelve quadrangle maps were published in fiscal year 1981. These maps, plus five additional ones scheduled for publication in early fiscal year 1982, will complete the series. These maps identify the most geologically promising lands for phosphate development in Idaho.

## SODIUM AND POTASSIUM

The concerns of the Geological Survey with regard to sodium and potassium minerals have been directed to examining and, if need be, to revising the existing classification standards for these minerals. To identify new sodium-bearing lands, the Survey has established 35,875 acres in California as Known Sodium Leasing Areas. These minerals play a key role in glass, ceramic, and chemical manufacturing processes.

## TAR SANDS

America's tar sands are estimated to contain more than 30 billion barrels of oil equivalent. Although this resource is found in 22 States, 90 percent of the Nation's tar sands are located in Utah. In response to the Secretary of the Interior's decision to initiate a tar sand leasing program, the Conservation Division took the first step towards leasing by establishing the following 11 Designated Tar Sand Areas in Utah: P. R. Spring, 274,000 acres; Tar Sand Triangle, 157,000 acres; Asphalt Ridge–Whitrocks and Vicinity, 41,000 acres; Sunnyside and Vicinity 157,000 acres; Circle Cliffs East and West Flanks, 91,000 acres; Hill Creek, 107,000 acres; San Rafael Swell, 130,000 acres; Raven Ridge–Rim Rock and Vicinity, 16,000 acres; Argyle Canyon–Willow Creek, 22,000 acres; Pariette, 22,000 acres; and White Canyon, 10,000 acres. Thirty-three individual deposits containing a total of more than 1 million acres with an estimated potential of 24 billion to 29 billion barrels of oil were classified in the 11 Designated Tar Sand Areas by the end of the fiscal year.

# Leasable Solid Minerals Other Than Coal

During fiscal year 1981, there were 887 Federal and Indian mineral leases comprising 861,000 acres, plus 429 prospecting permits covering nearly 9 million acres under Geological Survey supervision for 33 solid minerals other than coal. More than 90 percent of the acreage and 83 percent of the leases involve the following mineral commodities: (1) uranium, 203 leases comprising nearly 300,000 acres in New Mexico, Wyoming, Washington, and Arizona, (2) potash, 166 leases comprising 235,000 acres in New Mexico, Utah, Nevada, California, and Colorado, (3) phosphate, 279 leases comprising 114,000 acres in Idaho, Montana, Wyoming, Utah, California, and Florida, and (4) sodium, 85 leases comprising 126,000 acres in Wyoming, California, Nevada, Colorado, and Arizona. Other leases, listed in descending order of acreage, are lead-zinc-copper in Missouri; oil shale in Colorado and Utah; copper in Arizona, Oklahoma, and Washington; nickel in Minnesota; sand and gravel in Arizona, Nevada, and California; gilsonite in Utah; gold in Arizona and Washington; fluorspar in Illinois; silica sand in Arizona, Nevada, Oklahoma, California, and Washington; feldspar in Georgia; limestone in Idaho and Virginia; barite in Missouri and Arkansas; asphalt in Oklahoma; chat in Oklahoma; tungsten in Nevada; bentonite in Wyoming; quartz in North Carolina and California; iron ore in Alaska; taconite in Minnesota; wavellite and quartz crystals in Arkansas; granite in Oklahoma; clay in Missouri and Montana; mercury in California; garnet in Idaho; and gypsum in New Mexico.

Combined production of 18 mineral commodities contributed $912 million to the country's gross national product and brought $49 million in royalty revenue to the Federal Government in fiscal year 1981. About 90 percent of the Nation's potash, with a production value of $300 million, was produced from 51 leases in New Mexico, California, Nevada, and Utah during the year. Approximately 30 percent of total domestic sodium compounds production, mostly soda ash, came from 30 leases in Wyoming, California, Nevada, and New Mexico. Production is valued at $267 million. About 70 percent of the Nation's lead was produced from 28 leases in Missouri and was valued at $151 million. Nearly 10 percent of the country's uranium was mined from 14 leases on Indian lands in New Mexico and Washington. Additionally, sizable quantities of phosphate, zinc, and copper were produced from leased properties. Other mineral commodities produced from Federal and Indian lands included sand and gravel, fluorspar, silica sand, feldspar, oil shale, iron ore, barite, gypsum, chat, quartz crystals, and clay. In addition to the leasable minerals, about 20 percent of the Nation's lithium is recovered from brines as a byproduct from sodium leases in Nevada.

# Oil Shale

The Prototype Oil Shale Leasing Program, was established in fiscal year 1971 to encourage industry to develop commercial oil shale mining and processing technology in an environmentally responsible fashion. Four 5,120-acre tracts, two each in Utah and Colorado, containing an oil equivalent of 15 billion barrels of 25-gallon-per-ton oil shale, were leased in 1974 for a total bonus to the U.S. Government of $449 million. Processing and environmental data derived from the prototype program will be used as a basis for Departmental decisions on further leasing of Federal oil shale resources.

Prototype program leases are managed by the Conservation Division's Oil Shale Office in Grand Junction, Colorado. The Oil Shale Office has managed the 20,000 acres of Federal oil shale tracts through comprehensive exploration and baseline environmental data collection, to onsite mining and testing of oil shale retorting technology under the approved detailed development plans. This has required constant analysis and development-plan modification based on data from nearly 900 field sampling points and on advances in oil shale processing and environmental management technologies.

Since 1974, the lessees have expended more than $500 million for lease acquisition and tract development. By the early 1990's, operations on the current four lease tracts are expected to reach a combined production rate of 300,000 barrels per day and ultimately may recover more than 5 billion barrels over the life of the properties. This will yield royalties to the U.S. Government and States of Colorado and Utah estimated at $3 billion to $5 billion over the initial 20 to 30 years of operation. These tracts will host some of the largest mining and processing operations ever achieved in the United States.

On Colorado Tract C-a, in late June of 1981, the Rio Blanco Oil Shale Company ignited its modified in-situ retort No. 1, a 60-foot × 60-foot × 400-foot column of rubblized oil shale developed from a 1,000-foot-deep mine using multiple surface boreholes (fig. 1).

Over its expected operating life of 4 months, this test retort should yield from 15,000 to 25,000 barrels of oil. Planning is also underway for field testing of a Lurgi surface retort that may produce up to 2,000 barrels per day of oil from oil shale removed from the modified in-situ mine and a 36-acre open pit. The lessee is awaiting action on Congressional legislation that would permit off-tract disposal of overburden and processed shale. This would enable open-pit development of the entire tract as envisioned at the time of leasing.

On Colorado Tract C–b, the Cathedral Bluffs Shale Oil Company completed sinking of a service shaft 34 feet in diameter to a depth of 1,750 feet and is installing permanent hoisting equipment and other shaft utilities. Commercial ore handling facilities are being installed in the nearly completed 29-foot-diameter production shaft. From these, and a smaller ventilation-escape shaft 15 feet in diameter (fig. 2), a mulitple level mine will be extended across the tract. Shale oil would be derived through rubblization and ignition of a 290-foot interval of oil shale in a modified in-situ retort chamber. Shale excavated from the mine would be surface retorted according to development-plan modifications submitted for Oil Shale Office review in September 1981.

Joint development by the White River Shale Project of two Utah tracts (U–a and U–b) is expected to commence in early 1982 following Oil Shale Office approval of the detailed development plan submitted in September 1981. So far, development has been enjoined by court action stemming from a contested State-land selection and by conflicting prior mining claims. These issues should be resolved by the time development plans are approved. Development will

FIGURE 1.—*Aerial photograph of Tract C–a Mine Development Area, mine headframe, and Modular Development Phase modified in-situ retort off-gas, water treatment, and oil-collection facilities.*

FIGURE 2.—*Aerial photograph of the Mine Support Area on Tract C–b with concrete headframes over the 29-foot-diameter production shaft and 34-foot-diameter service shaft, each nearly 2,000 feet deep. The taller production shaft headframe is 313 feet high and will be equipped to hoist more than 60,000 tons per day. Ventilation-escape shaft is at far left.*

utilize Superior Oil Company and Union Oil Company surface retort facilities fed with shale mined from room-and-pillar operations beneath both tracts.

# Streamlining of Operating Regulations

One of the basic policies of President Reagan's administration is the reform of the Federal regulatory process, including elimination of excessive and outdated regulations. On February 17, 1981, President Reagan signed Executive Order 12291, thereby beginning the process of identifying unnecessary regulations and streamlining other requirements relating to mineral resources management.

As the major regulatory arm of the U.S. Geological Survey, the Conservation Division inherited the bulk of the requirements for streamlining these rules and regulations. Shortly after Executive Order 12291 was signed, all units of the Division began intensive reviews of their regulations and preparation of lists of rules that could be eliminated.

The most significant onshore streamlining actions were those revising and updating of the

Coal Mining Operating Regulations and the Onshore Oil and Gas Operating Regulations. In addition, the rules governing the formation of unit agreements involving Federal oil and gas leases are being updated to bring them into line with current practices. Regulations implementing the Connally Act of 1935 and those dealing with acquisition and leasing of water wells have not been utilized for many years and are being eliminated as part of the streamlining effort.

Initial priorities of the Outer Continental Shelf regulatory streamlining effort include the following changes to:

- Exempt the areas of the western Gulf of Mexico where considerable exploration and production already has occurred from the requirement that Outer Continental Shelf operators submit development and production plans.
- Provide for reimbursement to lessees and permittees for certain costs of reproducing geological and geophysical data.
- Eliminate redundancy in environmental reporting.
- Eliminate the requirement for segregating the portion of a lease that has been unitized from the portion of the lease outside the unit.
- Delete the requirement to immediately notify the Director of the Survey of the repeated analysis or interpretation of geological or geophysical data.
- Change the deadline for completion of deep stratigraphic test wells and submission of the resulting information from approximately 8 to 2 months prior to the date of a scheduled Outer Continental Shelf lease sale.
- Provide for the granting of a suspension of operations and extension of the lease period as a result of inordinate delays in the issuance of postsale permits and consents from various environmental entities.

The Geological Survey is endeavoring to streamline regulations governing reporting requirements, retaining only those truly necessary ones, and identifying the least costly alternative for each of its other rules. When the streamlining effort is completed in early 1982, the applicable regulatory codes will be current and free of unnecessary provisions. The Geological Survey will continue to review its regulations and rules to eliminate excessive, burdensome, and counterproductive requirements; to eliminate redtape and redundancy; and to minimize cost to industry and the Government. As a result of streamlining, lessees and operators who develop various mineral resources and Federal and Indian leases can be assured that only necessary requirements control their operations.

# Outer Continental Shelf Oil and Gas

The Geological Survey conducted a variety of activities in support of the Department's Outer Continental Shelf oil and gas leasing program. These activities included tract selection analyses and recommendations for four future lease sales and resource evaluations on 1,227 tracts involving seven sales. In the course of these activities, over 100,000 line miles of high-resolution and common-depth geophysical data were acquired and analyzed.

The Survey's Outer Continental Shelf regulatory workload also increased with the expansion of exploratory and production activities by lessees on approximately 2,400 Outer Continental Shelf leases in effect at the end of fiscal year 1981, an increase of 5 percent over the preceding fiscal year. These leases produced 8.5 percent of the Nation's oil and 23.75 percent of the gas in fiscal year 1981. A total of approximately 1,112 new exploratory and development wells were started, and approximately 8,400 inspections were conducted on both a scheduled basis and "random" unannounced basis. Gross royalties of $3.1 billion and net royalties of $2.6 billion are projected to be collected from Outer Continental Shelf production.

Exploration activities included a first for the Outer Continental Shelf areas of Alaska—the construction of a gravel-island drilling site approximately 15 miles northeast of Prudhoe Bay on Beaufort Sea Lease Y-0191. Exxon Corporation, the designated operator for the project, began its 24-hour-per-day construction effort on March 1, 1981. This demanding work schedule enabled construction activities to be completed before the spring breakup hindered transportation on the ice haul road between the construction site and the shore.

The gravel island was laid down on the sea floor in about 18 feet of water, using nearly 350,000 cubic yards of gravel hauled from a State of Alaska open pit located 15 miles from the site. On a good day, trucks could log up to 13,000 truck-miles and could haul as many as 400 loads. Large ice blocks, dubbed "Alaskan ice cubes" by onsite personnel, were sawed out of the ice and removed from the site. Each block measured approximately 5 feet × 5 feet × 8 feet and weighed 2 to 6 tons. Gravel was poured into the resulting holes until the entire area of the pad was gravel filled. The completed pad surface rises about 13.5 feet above the mean higher high water level and measures about 500 feet in diameter.

Despite several arctic storms that halted work, the island was completed on April 9, 1981. A 5-foot berm built around the perimeter of the pad surface increased the height of the island to 18.5 feet above the water line. A stockpile of 35,000 cubic yards of gravel will provide for sandbagging, for reinforcing operations, and for filling any slump areas. Several kinds of instruments have been installed in the island to monitor temperature, displacement, and settlement. Survey personnel have provided onsite monitoring throughout construction operations and will continue to monitor the island during the exploration phase.

During fiscal year 1981, two lease sales, covering areas in the eastern Gulf of Alaska, were held. On October 21, 1980, Federal Lease Sale 55 was held and resulted in the leasing of 37 federally managed tracts covering 213,120 acres. Reoffering Sale 1, which offered 175 tracts passed over in Sale 55, which included two tracts on which bids were rejected, was held June 30, 1981. Only five tracts received bids. The disappointing sale reflects a general lack of interest in reoffered tracts.

On December 18, 1979, in Providence, Rhode Island, 116 tracts over the Georges Bank were offered for lease under Lease Sale No. 42, the first in the North Atlantic leasing area. As a result of that sale, 63 leases were issued covering 358,671 acres, receiving a total high bonus bid of more than $816 million. Litigation against the sale was settled out of court in December 1980.

The Survey established a District Office in Hyannis, Massachusetts, in early 1980 to oversee operations conducted in the Georges Bank area. Exploration plans were filed by Exxon Corporation and Shell Oil Company on December 2, 1980, on Blocks 133 and 410, respectively. The Exxon plan was approved on January 15, 1981, and the Shell plan, after revision, on March 11, 1981. An Application for Permit to Drill was filed by Exxon on January 12, 1981, and by Shell on May 11, 1981. After receipt of concurrence by all affected States, both applications were approved on June 29, 1981.

On July 24, 1981, Exxon began drilling the first well in the North Atlantic area on Block 133 using the semisubmersible drilling rig "Alaskan Star." The well was permitted to a depth of 15,300 feet. On that same date, Shell began the second well in the area on Block 410 using the semisubmersible drilling rig "Saratoga."

The manual procedure to generate these maps for Outer Continental Shelf lease sales is a very cumbersome and repetitive process, requiring many hours of preparation by Geological Survey scientists. Current plans are to increase the size and frequency of Outer Continental Shelf sales which will require the production of many more maps. To speed up the process involved in generating these maps, computerized graphic systems have been developed to assist the scientist by providing the needed base maps and by greatly reducing the numerous manual processing operations leading to the final interpretive map products.

Seismic and geologic data are stored in computer-readable form on tapes and disks. The ability of the computer to generate maps quickly and accurately and to modify and retrieve data easily provides the scientists with an important tool to speed up the map-making process.

Currently, the maps are generated by computers located in Reston, Virginia, and Menlo Park, California. To develop interactive mapping capabilities, efforts are now under way to install complete stand-alone mapping systems on minicomputers in the Outer Continental Shelf region where the lease-sale activities actually occur. These mapping systems will result in even faster generation of computerized maps and will lead to more efficient implementation of Survey programs.

# Automation of Geophysical Mapping

The Geological Survey conducts a variety of activities in support of the Department of the Interior's Outer Continental Shelf oil and gas leasing program, including geohazards analysis and resource evaluations for Outer Continental Shelf lease tracts. In the course of these activities, the Survey acquires and analyzes available geophy sical and geological data and information collected by industry and government.

The process used to analyze these data first requires the drafting of base maps to show geophy sical line locations and geological sample and well locations. When these base maps have been completed, the geophysical and geological data and information are analyzed by geoscientists in a time-consuming manual process that generates subsurface maps of specific geological horizons; that is, the geology at particular depths. Preliminary maps display seismic energy penetration time to a specific geological horizon. After detailing analysis of seismic velocity and well-log velocity data, other maps, including depth maps, are produced.

## THE WAY IT WAS: LAND CLASSIFICATION

In its organic act of 1879, the U.S. Geological Survey was charged by Congress with "the classification of the public lands." Anxious not to tread on the toes of the General Land Office, which disposed of the public domain according to the laws passed by Congress, Clarence King confined the Survey's classification to the information put on maps. And so it remained for 25 years.

In 1904, the Survey built a laboratory for the testing of different kinds of coal at the Louisiana Purchase Exposition in St. Louis. As reliable data on the quality and usefulness of the different American coals came from the Survey's laboratory, the Federal Government, the largest holder of coal lands in the Nation, became interested. Here was the chance to determine how much these lands and the coal they contained were worth. With the public domain passing rapidly into private hands and the outright sale of coal lands lagging, the question arose whether coal was being obtained fraudently. Survey geologists set to work to locate the public lands that contained coal and to determine its quality and value.

The work of classification grew rapidly under the impetus of the conservation movement championed by President Theodore Roosevelt. In 1908, the Survey established the Land Classification Board under A. C. Veatch, who was succeeded by Walter C. Mendenhall, later Director of the Survey. In 1912, the Land Classification Board became a Branch, the equivalent of a present-day Division, joining the Geologic, Water Resources, and Topographic Branches as a full-fledged operating arm of the Survey.

Under Mendenhall, the Land Classification Board was split into two divisions (equivalent to present-day branches): The Division of Mineral Classification had four sections: coal, oil, phosphate, and metals. The Division of Hydrographic Classification had two: water-power and irrigation. Later, a third division classified grazing land for entry under the Enlarged and Stockraising Homestead Acts.

As the Federal Government's capacity increased to manage the public lands scientifically, civil servants such as Director George Otis Smith became more vocal in their opposition to the traditional policy of selling or giving away public lands. Smith also felt that the placer mining law then governing mineral entry did not properly regulate those minerals that were not metals, such as coal, oil, and phosphate. He persuaded successive Secretaries of the Interior to withdraw from entry those lands that contained valuable minerals until Congress changed the laws. He wanted to see the Federal Government keep title to the land and lease the rights to extract the minerals.

From 1908, when the first withdrawal of oil lands in California took place, until 1920, Congress wrestled unsuccessfully with the question of leasing public lands for minerals. Finally, the 66th Congress passed a Mineral Leasing Act, and the Bureau of Mines began supervising the leases granted by the General Land Office according to the Geological Survey's classification. All three agencies were part of the Interior Department.

Secretary of Commerce Herbert Hoover, the strongman of the Harding-Coolidge cabinet, got the Bureau of Mines transferred from Interior to Commerce in 1925.[1] Though he might transfer the agency, he could not transfer its function of supervising mineral leasing on the public domain. The Department of the Interior had learned, from its loss of control of the national forests to Agriculture in 1905, not to permit another Department to take away the management of land. So mineral leasing came to the Geological Survey, joining the other divisions of the Land Classification Board to become the Conservation Branch. It continues as one of the Survey's four operating divisions.

[1] It was returned to Interior in 1934.


*U.S. Geological Survey coal-testing plant in "Mining Gulch" at the Louisiana Purchase Exposition, St. Louis, Missouri, 1904. (Photograph by M. R. Campbell.)*

# Office of Earth Sciences Applications

## Mission

The Office of Earth Sciences Applications was established to improve the application of earth science information in land use and resource planning processes. The public and its elected officials, planners, policy makers, and decisionmakers, increasingly must cope with many issues, such as zoning, permitting, geologic hazard warnings and contingency plans, building site selection, and so forth, that entail technical information at varying levels of complexity and from a diverse range of scientific disciplines. Many times important geologic or hydrologic considerations are not included in the planning process because the information is not available, not known to be available, or not compatible to the needs of the user.

The Office of Earth Sciences Applications addresses the need for an integration of scientific disciplines and communication of earth science information to the public. It manages cooperative projects that assist communities and planners in directly applying earth science information as well as programs that address techniques and methods to improve the utility and dissemination of earth science information. The Office is composed of earth scientists and specialists from a variety of related disciplines such as economics, urban planning, geography, and remote sensing. The major functions of the Office include:

- Developing resource planning methods to enhance the usefulness of earth science information in the planning—decisionmaking process.
- Overseeing compliance with environmental laws, including the preparation and review of environmental impact statements within the Survey.
- Providing earth science information for land resources decisionmaking.
- Collecting, processing, and distributing remotely sensed data and applying remote-sensing technology in support of land resource and environmental analyses.
- Developing visual products and services designed to inform the scientific and nonscientific communities about applications of earth science information.

The task of achieving these objectives is carried on by the following offices:

Resource Planning Analysis Office (RPAO)
Environmental Affairs Office (EAO)
Earth Sciences Assistance Office (ESAO)
Earth Resources Observation Systems Office (EROS)
Visual Information Services Office (VISO)

## Budget and Personnel

Obligations for the Office of Earth Sciences Applications activities during fiscal year 1981 totalled $23.2 million, a decrease of $0.5 million, or 2 percent, below the amount obligated during the preceding year. Reimbursements of $4.3 million supplied 19 percent of funds used during fiscal year 1981.

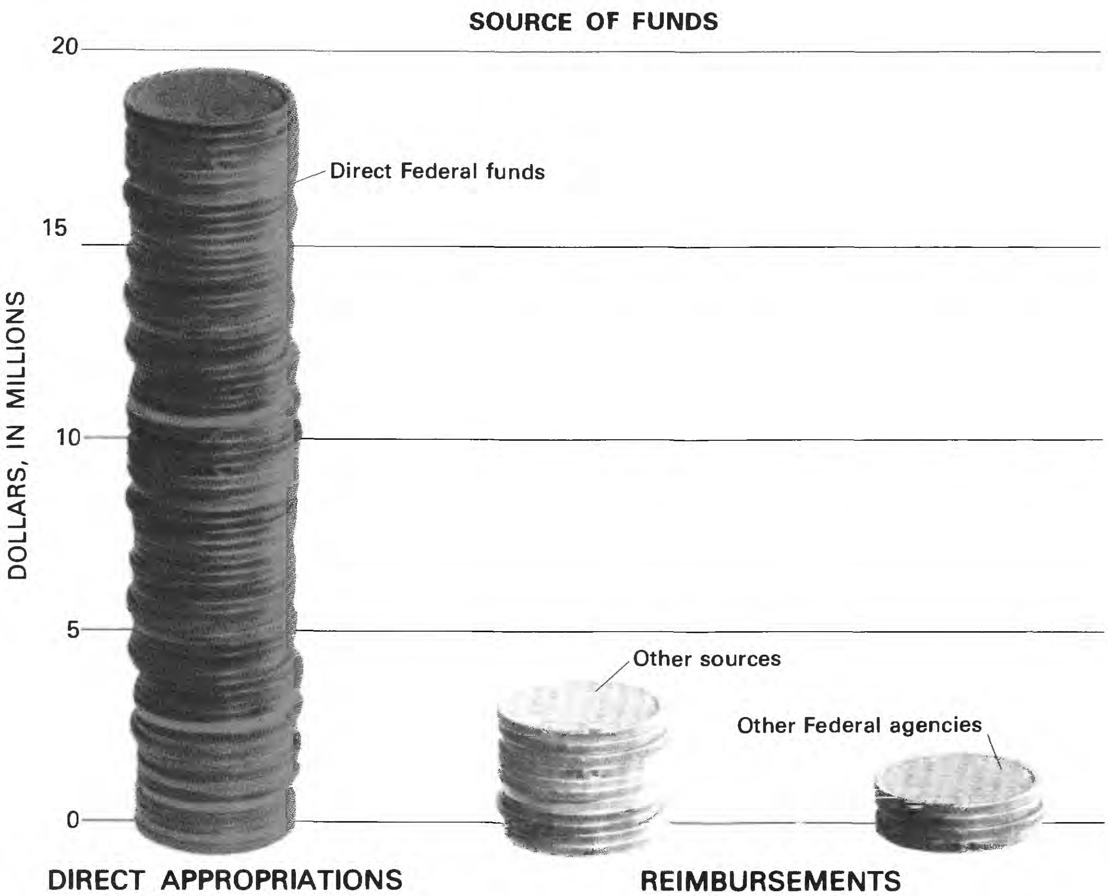
The work of the Office of Earth Sciences Applications is accomplished in part through research grants and contracts to private parties. During fiscal year 1981, $10.2 million, or approximately 44 percent, of the Office of Earth Sciences Applications activity total was obligated for contracts, because contract services were the major source of operational support at the EROS Data Center in Sioux Falls, South Dakota.

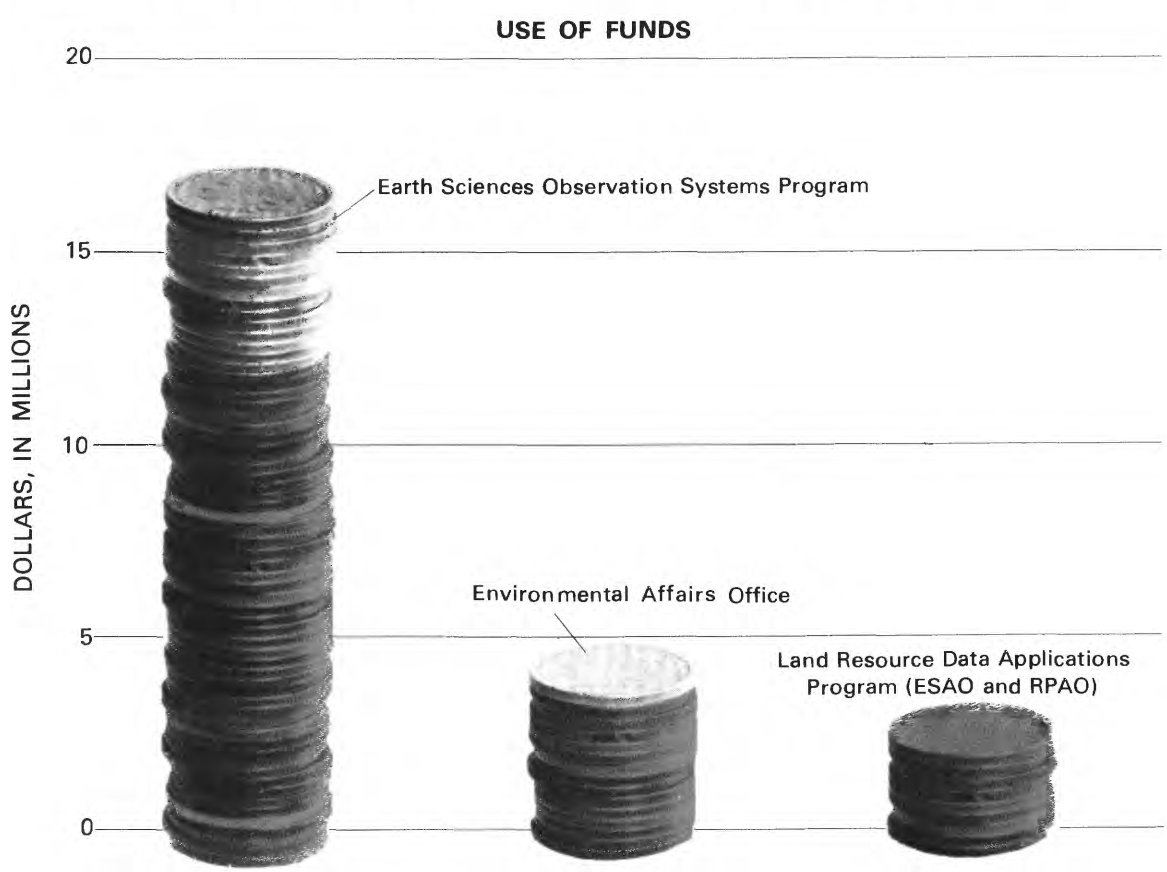
Programs of the Office of Earth Sciences Applications employed 205 full-time permanent personnel in 1981. There were, in addition, 67 temporary or part-time employees.

*Office of Earth Sciences Applications activity obligations for fiscal years 1980 and 1981, by subactivity*

[Dollars in millions. Data may differ from those in the statistical tables because of rounding]

| Subactivity | Fiscal year 1980 | Fiscal year 1981 |
|---|---|---|
| **Earth Resources Observation Systems Office** | 15.3 | 16.5 |
| **Environmental Affairs Office** | 5.9 | 4.1 |
| **Land Resources Data Applications Program (ESAO and RPAO)** | 2.6 | 2.6 |
| **Total** | 23.7 | 23.2 |
| **Direct programs** | 18.9 | 18.9 |
| **Reimbursable programs** | 4.8 | 4.3 |
| Other Federal agencies | 2.0 | 1.2 |
| Other sources | 2.8 | 3.1 |


SOURCE OF FUNDS
DOLLARS, IN MILLIONS
20
15
10
5
0
Direct Federal funds
Other sources
Other Federal agencies
DIRECT APPROPRIATIONS
REIMBURSEMENTS


USE OF FUNDS
DOLLARS, IN MILLIONS
20
15
10
5
0
Earth Sciences Observation Systems Program
Environmental Affairs Office
Land Resource Data Applications Program (ESAO and RPAO)

# The U.S. Geological Survey's Response to Natural Hazards

Geologists generally view the Earth differently than do most others. They study the Earth's history, physical and chemical makeup, and behavior, including such processes as mountain building and land erosion. They look at it from afar using Earth-orbiting satellites and scrutinize its most minute details with electron microscopes. Some geologists mechanically squeeze slabs of rocks to learn more about the behavior of the Earth's crust under the forces of great earthquakes. Others map the land surface and the relations among the various geologic formations to deduce the Earth's past. Geologists then can use such insights and lessens of the past to look into the future and determine how the Earth's natural forces will continue to shape our planet and our lives.

Through geologists' observations, mapping, and probing, we now know that the Earth's landforms, both the spectacular and the unimpressive, are caused by natural processes—processes that dominated the planet's past and will likely control its future. Some of these processes last just for days or even minutes at a time, while others work imperceptibly but continuously to create such majestic forms as the Grand Canyon. Some natural processes, such as volcanic eruptions, earthquakes, flooding, and subsidence, however, are hazardous; and each year considerable time, talent, and money are spent to devise and apply ways of reducing the damage they cause.

Many famous centers of culture and commerce and far more numerous uncelebrated towns and villages have suffered extensive loss from sudden unanticipated natural catastrophes. For example, in 1531, Lisbon, Portugal, lost 30,000 people during an earthquake; in 1970, 20,000 residents in Peru's Yungay Valley were buried by a rapidly moving landslide. And, in one of the most famous natural catastrophes, the entire town of Pompeii, then a flourishing Greco-Roman city, was buried by the ashfall from the A.D. 79 eruption of Mount Vesuvius.

Despite our increasing knowledge about these natural events—why they happen, where they are likely to happen, and how we may better cope with them—the damage they cause has been increasing nationally and globally. Perhaps this mounting toll of damage is due to larger populations and greater accumulation of goods and wealth. Or maybe it is because many of the more hazardous areas happen to be lands promising greatest wealth and growth. It also could be that some of the ways we use our resources and technology to cope with natural hazards and risk are instead causing greater damage. Whatever the reason, losses from geologic and hydrologic hazards will continue to rise unless greater attention is paid to the commanding processes of nature.

There are several ways the U.S. Geological Survey responds to the risks posed by natural hazards and geologic catastrophes. As the Nation's primary geologic and hydrologic research institution, it has a responsibility to investigate the probability, cause, and patterns of earthquakes, volcanic eruptions, subsidence, and other damaging and life-threatening phenomena and to advise the public and governmental officials of its findings. The Survey has been doing this for over a hundred years and, during the past decade, has broadened its response to the threat and occurrence of natural hazards.

An example of this response is the Survey's participation in the San Francisco Bay Area Study, in which scientists conducted the Nation's most comprehensive study of the value of incorporating geologic and hydrologic considerations into the practical decisions of homeowners, public administrators, legislators, building contractors, and anyone with an interest in reducing his vulnerability to natural catastrophes. This study, which produced more than 150 maps and reports, was supplemented by many days of briefings, public testimony, and lectures by scientists to government officials, citizen groups, and school groups. Through such studies and other actions, the Survey has been increasing its efforts to inform the public about the nature of geologic and hydrologic risks; equally important, it is prepared to demonstrate further the benefits of using earth science to help determine how best to live with natural hazards.

In addition to broadening and improving its response to the threat of natural hazards, the Survey has taken two significant steps to respond to the occurrence of a major emergency resulting from geologic events. In 1977, it established a program for warning the public and its officials of geologic catastrophes, and, recently, it initiated a major effort to design formal procedures for a Survey response to geologic and hydrologic emergencies. The Survey's hazard warning program has issued 17 official hazard announcements. The most visible and urgent one of them was the 1980 Mount St. Helens warning.

In late March 1980, University of Washington seismologists working with Survey scientists detected swarms of small and moderate earthquakes near and below Mount St. Helens. From its National Center in Virginia, the Survey contacted and daily briefed interested and responsible Washington State and Federal agencies. Field headquarters were established in Vancouver, Washington, about 45 miles from Mount St. Helens; with the support of the U.S. Forest Service, Survey geologists monitored the volcano's activity and briefed local emergency response officials and news media. After the major volcanic eruption was declared a national disaster, the Survey sent additional staff support to Vancouver to work with the Federal Emergency Management Agency's (FEMA) emergency response team.

Many lessons were learned from the eruption of Mount St. Helens. A large number were scientific and will be invaluable in assessing future eruptions of Mount St. Helens and other similar volcanoes, but the events also highlighted the value of a well-prepared response team. With the cooperation of local, State of Washington, and other Federal agencies, the Geological Survey adequately performed its roles of scientific investigation and counsel, but it continues its efforts to improve its response to similar events in the future. The Survey accordingly is preparing formal emergency response plans that detail the procedures key scientists and administrators are to follow during or in anticipation of geologically related emergencies. These plans will be reviewed by FEMA officials to ensure that they complement other established emergency response plans.

Public officials and citizens can benefit from a clearer understanding of the contribution of geology to reducing public vulnerability to geologic hazards. To better discharge its responsibilities and design a sound effective hazard-warning and preparedness program, the Geological Survey has been consulting with social science researchers who have been studying how the public and public officials respond to various warning systems, messages, and educational programs. Incorporating some of their research results into Survey programs is leading to a more positive hazard warning and education effort; for example, the Survey will cosponsor emergency response and planning workshops for State and local officials. These workshops will be for specific potential geologic hazards. They will not only explain the nature of the hazard and discuss ways to reduce public and private risk but will also focus on the preparation of State and local government emergency response plans. Such advance planning promises to encourage early and effective response to an imminent geologic threat.

The Survey is seeking to meet the new and changing challenges posed by geologic and hydrologic hazards. How well it does respond will depend on the scientific advances it makes, and how well it can translate this knowledge into useful and credible advice. Above all, it will also have to be well prepared and to encourage other agencies and the public to be well prepared also. This will be a future challenge to the U.S. Geological Survey.

Recently, the U.S. Geological Survey received the 1981 Outstanding Planning Program award from the American Planning Association at their national conference in Boston. The award was for the San Francisco Bay Region Environment and Resources Planning Study designed to collect and interpret earth science information for the use of planners and decisionmakers in avoiding hazards, conserving resources, and reducing property damage. The study, begun in 1970, produced over 150 maps and reports on a wide range of topics. Much of the information derived from this study is being used by community governments and organizations in the San Francisco Bay region to give the citizens an extra measure of security from future geological hazards.

# Workshops, Circuit Riders, and County Agents—Experiments in Information Delivery

One of the keys to effective solution of problems involving energy, environment, and land use is a better understanding by all concerned parties of the issues involved and the physical facts surrounding those issues. In an effort to improve the level of knowledge and understanding of resource and land use issues by planners, decisionmaking officials, and the general public, the U.S. Geological Survey is experimenting with a variety of approaches to technical information delivery. In cooperation with numerous Federal, State, and local agencies, universities, and private organizations, the Survey is sponsoring demonstration projects to test and evaluate three of the more promising of these approaches: workshops for local officials, circuit-rider geologists, and the use of County Extension Agents.

## WORKSHOPS

The objective of the earth sciences application workshops project is to increase public awareness of the availability of earth sciences information and its use in helping to resolve land use planning, resource development, and environmental problems. Individual workshops address this objective by (1) identifying earth science problems and opportunities relevant to land use planning in the local area of the workshop, (2) identifying local scientific expertise available to address such problems, and (3) demonstrating selected local applications of earth science data for land use and natural resource planning.

Each workshop is a joint effort involving personnel from various Survey offices, the State geological survey, the State association of professional planners, and earth science and planning professionals from local academic institutions. The workshop attendance consists primarily of local land use planners, elected and appointed governmental officials, educators, and other professionals in engineering, earth sciences, and planning. The workshop itself normally consists of a series of lectures by an expert faculty on selected local planning problems involving earth science considerations. A field trip may follow to illustrate these problems first hand and to show how they have been handled locally. The final session of the workshop involves a practical planning exercise using real earth sciences information for the local area.

Specific local problems that have been addressed in workshops held to date include karst (sinkhole) terrain, slope stability, earthquake hazards, expansive soils, land subsidence resulting from ground-water withdrawals, flood hazards, solid-waste disposal, coastal erosion, and ground-water supplies. In addition, more general topics, such as land capability analysis and general earth science considerations for land use planning, have been addressed in most workshops.

Since the project was initiated in March 1980, workshops have been held in Nashville, Tennessee, Seattle, Washington, Atlanta, Georgia, Houston, Texas, Orlando, Florida, Columbus, Ohio, and Corpus Christi, Texas. Tentative plans for the next year include workshops in Minnesota, Florida, Texas, Maine, Massachusetts, and New Jersey.

## CIRCUIT-RIDER GEOLOGIST

The circuit-rider geologist demonstration project was a 2-year experimental effort, in cooperation with the Division of Geology and Earth Resources of the Washington State Department of Natural Resources, to provide the services of a part-time "circuit-rider" geologist to three counties in the Puget Sound lowland. These counties (Clallam, Island, and Jefferson) were selected on the basis of their proximity to one another and their similarities in geology, stage of development, and kinds of development pressures. The counties also were alike in their generally low level of application of geology to day-to-day land use decisions. A senior staff geologist with the Division of Geology and Earth Resources who was already relatively familiar with the counties was assigned to lead the project.

The Circuit-Rider Project was designed to try to meet the need for geologic assistance in three counties with the idea that, if successful, the concept will be applied elsewhere. Support for expanding the effort could be either from groups of interested counties, from joint county-State financing, or some combination of these approaches.

Services provided by the circuit-rider geologist fell into one or more of five general categories:

- *Geotechnical education.* A general orientation on the applications of earth sciences to the problems of local communities includes the use of geologic data by nongeologists or the use of nongeologic data for geologic purposes.
- *Geotechnical guidance.* This is basically an extension of geotechnical education but with special emphasis on the applications of geology to local problems or questions of policy; for example, indepth discussions with county staff members on such subjects as coastal bluff landslides or longshore sediment transport processes.
- *Site analyses.* These provide for early consideration of geologic and hydrologic factors influencing the siting of utilities such as sanitation, water, and access systems to avoid the need for remedial actions later on.
- *Geologic data source.* Not only must the circuit rider provide needed information to his clients, he must cultivate in them the habit of coming to him when they need assistance.
- *Consultant relations.* The increased use of consultants by developers results in county officials having to analyze geotechnical reports written by or for the very people they are charged with regulating. The circuit rider's role here is to alert local government personnel of problem areas, to aid in assessing the nature of the problems, and to assist in the review of the consultants' findings.

## COUNTY EXTENSION AGENTS

In cooperation with the U.S. Department of Agriculture's (USDA) Science and Education Administration, the Survey has projects underway in Colorado and Pennsylvania to test methods and approaches by which USDA County Extension Agents might assist in making earth sciences information available to primarily nonurban populations. Primary objectives are to demonstrate appropriate and transferable mechanisms and procedures that would increase the effectiveness of the Extension Agent by providing him with improved access to earth sciences information and expertise, and to document a series of case studies (specific onsite examples) as the basis for evaluating the need for and the effect of earth sciences information transfer in attacking local problems.

### Colorado Demonstration Project

The Colorado project is being conducted by the Colorado State University Cooperative Extension Service and addresses the task of providing information that is not readily assessible in meaningful form to those who need it for planning and decisionmaking. Three categories of information are treated:

- *Resources.* A need for authoritative information on mineral and water resources, particularly data and reports relative to water supplies, quality, and flow characteristics, has long existed.
- *Hazards.* Assistance to local governments in identifying and evaluating geological hazards is another area of need. Shrinking and swelling soils, subsidence, slope stability, seismic risk, flooding, and radioactivity are common geologic hazards in Colorado.
- *General.* General earth sciences information aimed at responding to such questions as whether Colorado is subject to volcanic eruptions, if gold mining will become active in the State, how long it will be before oil shale is developed, or what is the condition of the Ogallala aquifer is a third area of need.

The approach being used involves the interaction of an information-transfer team with an advisory panel from the Colorado earth science community. The information-transfer team consists of a County Extension Agent on sabbatical, a graduate student in environmental geology, and an environmental geology professor. The advisory panel includes representatives of the U.S. Geological Survey, the Colorado Geological Survey, and other groups of the Colorado earth science community as appropriate to the problems involved.

The team will identify two or three local problems, such as geological hazards, specialized mapping, and water-flow characteristics, that require earth science input. With the assistance of the advisory panel, the team will then develop for each problem a plan and procedure covering, among other things, (1) identification of the type of information needed by, available to, and usable by Extension Agents, (2) procurement of the information from the earth science community and identification of information gaps, (3) analysis of the significance of the information to the specific problem, (4) transfer of the information in appropriate form to Extension Agents in the field and to the specific individuals or groups faced with the problem, (5) testing the usuability of the information by Extension Agents, and (6) evaluation of the effectiveness of the entire procedure in aiding in the solution of the problem.

### Pennsylvania Demonstration Projects

The Pennsylvania project is being pursued as a joint effort with the Cooperative Extension Service and the College of Earth and Mineral Sciences, both of Pennsylvania State University. Specific project objecives are (1) to disseminate existing earth science information to lay persons and professionals for their use in development of environmentally sound and economical land use plans, (2) to evaluate new and existing earth sciences knowledge as it pertains to citizens, government, and industry, (3) to disseminate information concerning mineral and water resources and geological hazards related to gas and oil well exploration, deep and surface mining, and general earth sciences information, and (4) to develop a workshop that will serve as a source of information on local issues for local government officials and concerned citizens.

This project utilizes an Extension Agent serving four western Pennsylvania counties (Armstrong, Clarion, Indiana, and Jefferson) in the heart of western Pennsylvania's coal area where exploration for natural gas also is increasing. They are confronted with problems such as flooding, ground-water supply and quality, subsidence, slope stability, and environmental pollution. Two general categories of information are being addressed in this project:

- *Availability and quality of water resources.* Coal mining reportedly has contributed to loss of water in many household wells and to pollution of others. Recent drilling of gas wells reportedly has led to pollution of some water supplies with barium and other contaminants. Towns in the area are in need of additional water supplies to support recent growth.

- *Planning of development.* Township and county officials need to know probable areas of future coal development and oil and gas drilling to make a variety of planning decisions relating to new construction, zoning, and so forth. Similarly, areas of geologic hazards, such as landslides, coal mine subsidence, and floods, should be evaluated for this purpose, as should potential problems in disposal of waste products from mineral extraction.

The project Extension Agent will respond to requests for assistance from citizens and local government officials by utilizing the technical support of appropriate agencies to supply answers and assistance. In addition, the Agent will identify onsite problems which can be addressed through educational workshops for specific groups or the general public.

Geological information will be furnished by the faculty of the Geosciences Department of Pennsylvania State University and, as needed, by personnel of the U.S. Geological Survey, the Pennsylvania Geological Survey, or other organizations. Supplementary assistance also will be available through Extension specialists in such disciplines as forest resources, agronomy, engineering, economics, and landscape architecture.

### PRELIMINARY EVALUATION OF RESULTS

The workshop project is evaluated on a continuing basis from questionnaires completed by participants at each workshop. Responses indicate that the workshops have been generally successful in providing participants with usable and useful earth sciences information and application techniques.

A final evaluation of the circuit-rider project currently is in progress. In a report at the end of the first year of the project, the circuit-rider geologist documented a number of activities indicative of the value of his services to the counties involved. In one instance, a site examination indicated that a large concrete or wood retaining wall proposed as a part of a housing rehabilitation program was not required, saving the landowner and the community a significant expense. In another, foundation conditions at an abutment site for a proposed $750,000 bridge were determined to be unstable. The river bank at the site was being undercut, and the bank upstream and downstream showed evidence of recent and currently active sliding. The project was suspended pending further geologic investigations.

The Colorado and Pennsylvania County Extension Agent projects presently are in their early stages. Pennsylvania project personnel report, "A major objective of the project, to set up and improve channels for getting earth sciences information to people at local government levels, has already been accomplished . . . Participants . . . were enthusiastic about the positive effects already derived from project activity in strengthening connections and understanding among the geologist, Cooperative Extension people, and interested parties in the four counties involved."

Although each experimental approach appears to be useful and to provide positive results, no one approach provides a universal mechanism for getting the job done. Numerous other methods for technical information transfer are being used operationally or experimentally in the Survey and elsewhere in government. In all likelihood, many different approaches will continue to be utilized to accommodate the extreme variety of concerns and capabilities of potential users of earth sciences information.

## Spatial Data Research and Applications

Earth scientists and natural resource managers face ever-increasing information needs and multiple data sources as they conduct complex research projects or face complicated management decisions. Thanks to current advances in computer-aided information handling and data processing, geographic data which once appeared only on maps now can be converted, or digitized, into a computer-readable form and then merged with other digitized scientific data to produce new forms of information, such as computer-generated images and maps that enable the user to draw conclusions in a more timely and efficient manner than has been possible.

Divisions of the U.S. Geological Survey currently are developing new applications of spatial data and have established a number of natural resource spatial data bases which possess the unique characteristics of map data in that they are stored and manipulated by locational position. To date, work on these data bases has concentrated primarily on data capture, verification, and file building.

*High-altitude photograph of the San Francisco Bay Region, for which the San Francisco Bay Region Environment and Resources Planning Study was designed. The study, which collected and interpreted earth science information for planners and local decisionmakers, won the 1981 Outstanding Planning Program award from the American Planning Association at their national conference.*

During fiscal year 1981, techniques for merging and integrating disparate digital data sets, such as cartographic, geophysical, geochemical, geologic, hydrologic, and multispectral image data, were investigated and applied in diverse geographic environments. Among these projects were developing a digital geologic data base for the Nabesna Quadrangle, Alaska, mapping forest fuels in Montana, assessing irrigation potential in Oregon, and developing a planning unit data base in Arizona.

## GEOLOGICAL DATA BASE IN ALASKA

To demonstrate the applicability of digital processing techniques to mineral resource investigations, a digital geologic data base was prepared for use in an EROS Data Center advanced course in geologic applications of remote sensing techniques. The Nabesna Quadrangle Area of Alaska was chosen for this demonstration because diverse types of geographically related data are available for this region, it has a known mineral resource potential, and the current Survey mission under the Alaska Mineral Resources Assessment Program (AMRAP) calls for acquiring, analyzing, and interpreting data to evaluate mineral resource potential.

The Nabesna data base included Landsat multispectral scanner data, Defense Mapping Agency topographic data, and AMRAP data sets which include gravity, geochemical (for copper, lead, gold, chromium, and cobalt), geologic, mineral

*Figure 1. Nabesna Quadrangle, Alaska. Stereoscopic pair (1:250,000 scale) of Landsat image data and geochemical copper data, produced by digitally distorting Landsat data as a function of copper anomaly values. The magnitude of the copper anomalies is expressed in the third dimension when viewed stereoscopically.*

occurrence, and land status data. The data base was designed to show its usefulness in analyzing, merging, and integrating many types of data and to provide training course participants with a case example of geologic data base planning and management.

A geologic model for evaluating the potential for porphyry (disseminated, as opposed to concentrated, vein type) deposits of copper in the Nabesna area was developed from the data base. The product was an image that incorporated all of the regional model parameters with the data base to identify areas of highest porphyry copper potential (fig. 1). The resultant areas then were tested against known mineral occurrences.

Field checking of this work took place in August 1981, and a report is being written. Plans are being developed to expand the data base to include adjacent potentially mineralized areas for refining the current porphyry copper model.

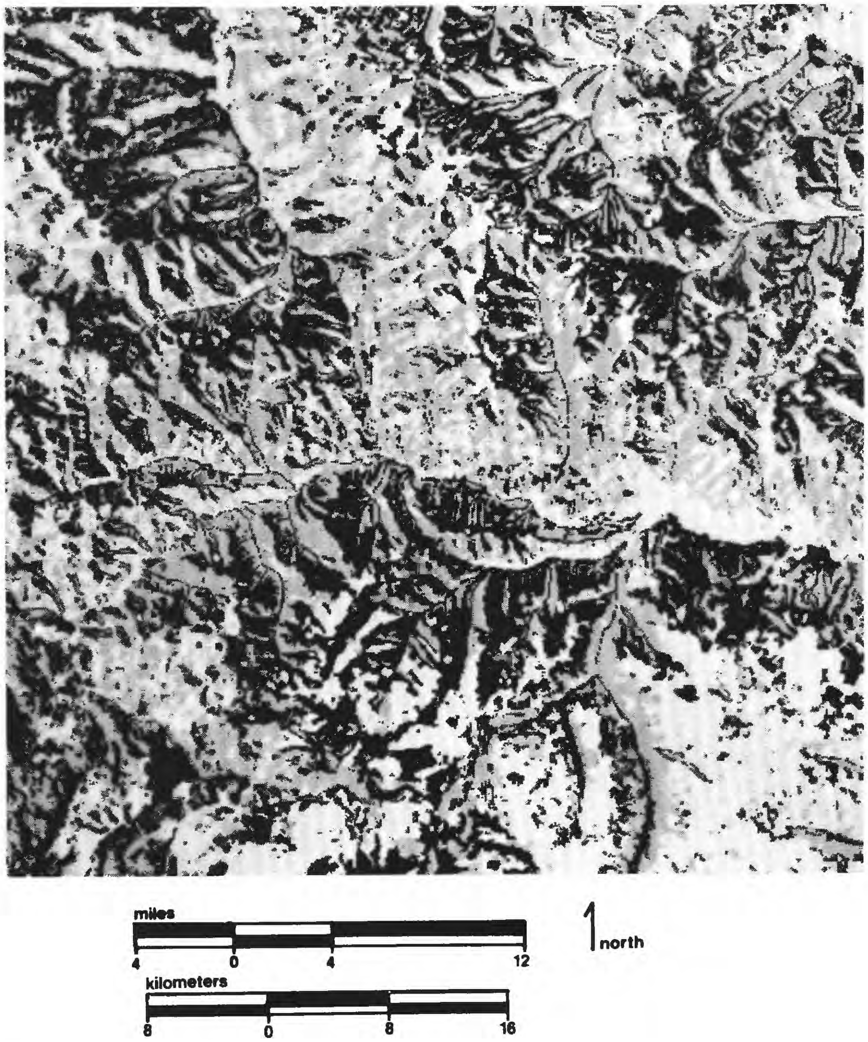



*Figure 2. Map of Howard Creek area, Lolo National Forest, Montana, showing areas of greatest fire potential in black, determined from a fire behavior model that incorporates a fuels–road-network data base with elevation, slope, and aspect data.*

## FOREST FUELS MAPPING IN MONTANA

A digital data base combining forest fuels and terrain information, which was derived from Landsat multispectral data and Survey elevation model data, was developed for a study site in the Lolo National Forest in western Montana. The project was designed to serve as input to a mathematical fire simulation model developed by the U.S. Forest Service, which provides site-specific prediction of wildland fire behavior. Applications of the estimates provided by this model range from realtime site-specific predictions of the probable rate of spread of a flaming front to broad-scale regional planning efforts.

Management and planning tools were improved for the Forest Service by using satellite data in combination with topographic data to determine the identity, location, and fire vulnerability (determined from a timber stand's slope and aspect) of three species. Merging this combined information on a computer with road-network data resulted in a data base for the Forest Service fire behavior model. Figure 2 is a map derived from the data base showing areas of greatest fire potential.

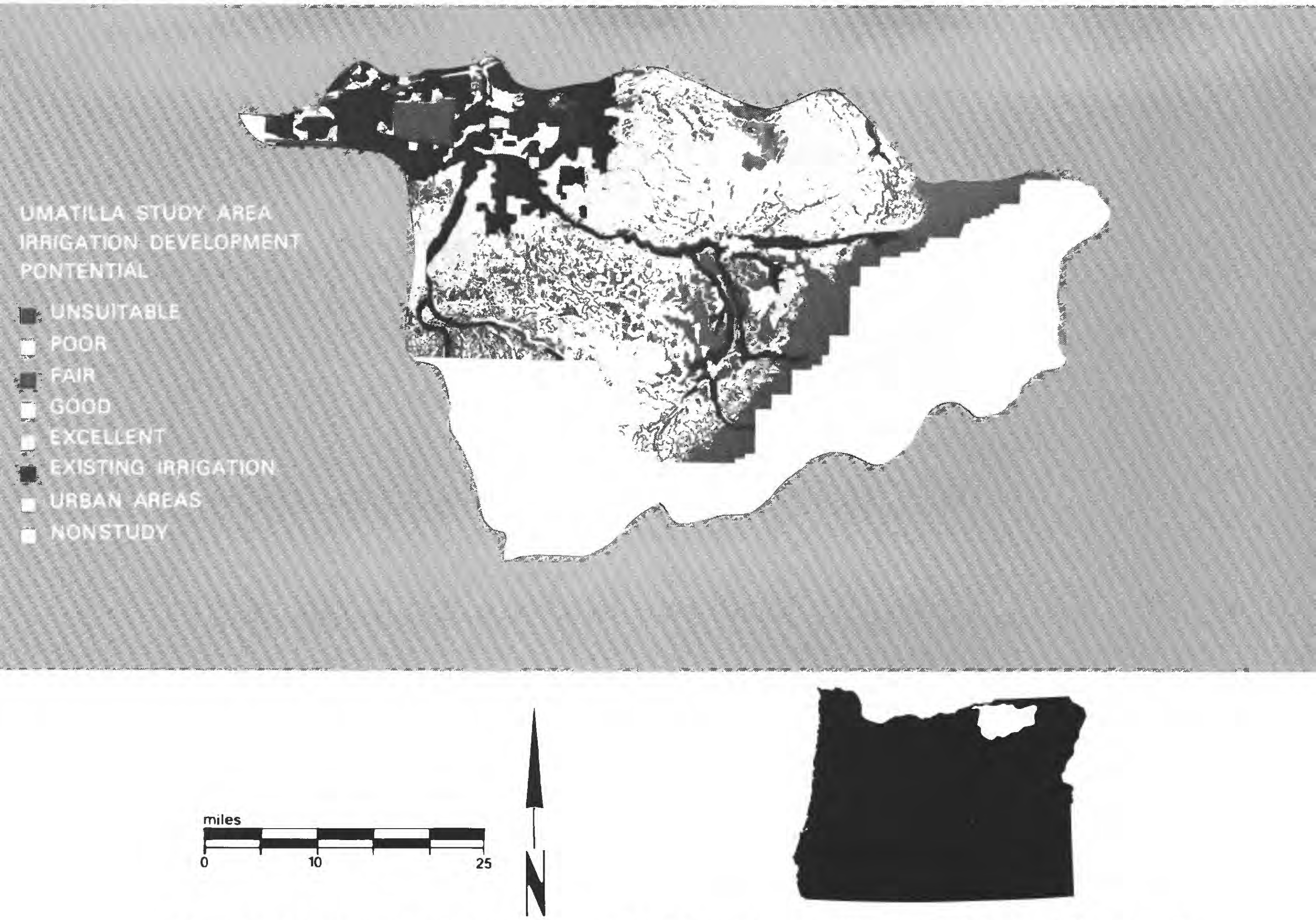



*Figure 3. The Irrigation Development Potential for the northern 1 million acres of the Umatilla Basin of Oregon was determined using a composite mapping procedure and data representing land cover, landownership, soil irrigability, percent slope, and potential energy requirements.*

## IRRIGATION ANALYSIS IN OREGON

In cooperation with the U.S. Army Corps of Engineers, Portland District, Oregon, the Survey conducted a project to develop and test techniques using Landsat with related geographic data to evaluate irrigation agriculture in the 1.6-million-acre Umatilla River Basin in north-central Oregon. Landsat data were interpreted manually to map the growth of irrigation from 1973 to 1979 and analyzed digitally to identify crop types under irrigation in 1979. The crop-type data were then used in conjunction with historical agricultural data and digital topographic and hydrographic data to estimate water and power use for the 1979 irrigation season. The final project task involved production of a composite map of land suitability for irrigation development based on land cover (from Landsat), landownership, soil irrigability, slope gradient, and potential energy cost data. Figure 3 identifies land parcels of various degrees of suitability.

Analysis identified an annual irrigation expansion of over 10,000 acres per year. Also, for 1979, irrigation water use was estimated at 212,000 acre-feet for the 125,000 acres of irrigation, and irrigation power use at approximately 300 million kilowatthours of electricity. The water and power estimates, along with the composite map of land suitability for future irrigation development, provided the Corps of Engineers with a sound basis for evaluating expanding irrigation agriculture while monitoring its impact on other essential uses of Columbia River Basin land and water resources.

## LAND RESOURCE DATA BASE IN ARIZONA

Because the Federal Land Policy and Management Act of 1976 requires the Bureau of Land Management to maintain an inventory of resources on public lands, this agency requires a low-cost, quick, and accurate method of inventorying vegetation on millions of acres of arid public land in the southwest United States.

A Geological Survey project, in cooperation with the Bureau of Land Management, was carried out to develop a digital data base for the latter's Grandwash Planning Unit in northern Arizona. The objective of the project was to demonstrate the flexibility of a digital data base to produce map overlays that could be incorporated directly into the Bureau's planning process.

The initial data set developed during the analytic phase of the project contained a set of tables describing the vegetation and terrain conditions throughout the area and a digital data base containing Landsat spectral classes; elevation, slope, and aspect of the terrain in the project area; and vegetation information for sample areas within the project area. This data base then was merged with the digitized Grandwash Planning Unit administrative boundary and all roads within it.

Using criteria applied by Land Management field personnel, the digital data base was manipulated to produce a set of map overlays showing the location of areas suitable for performing specific management activities. For example, to locate potential areas for allocating firewood permits, all sites within the Grandwash Planning Unit identified as firewood spectral class, which were at elevations between 5,000 and 6,000 feet, having less than 10 percent slope, and within 0.25 miles of a road, were located and produced at the same scale as the base map. These sites appear on figure 4 and indicate potential areas where firewood permits could be allocated. Other map overlays produced from this data base are being used to plan various management activities including firewood collection, wildlife reestablishment (Bighorn Desert Sheep and antelope), and range improvement.

The spatially referenced digital data base provides the Bureau of Land Management with an information source that can be updated and revised easily, manipulated to produce planning information rapidly and economically, and used to produce various scales of map overlays that are cartographically accurate and statistically reliable.

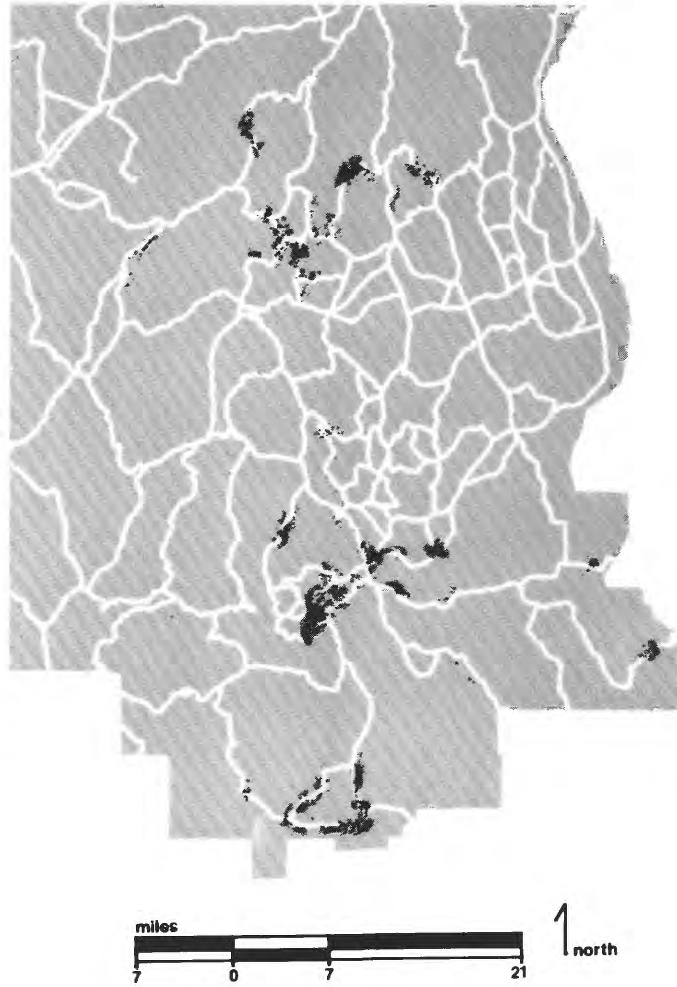



*Figure 4. Map of Grandwash Planning Unit, northern Arizona, showing potential firewood collection areas in black, as determined by locating all tree stands between 5,000 and 6,000 feet, having less than 10 percent slope, and located within 0.25 miles of a road.*

# Water Conservation for Municipal Water Supplies

The problem of maintaining an adequate water supply to meet the increasing demand for water has been the subject of renewed concern as a result of drought conditions in many parts of the United States this year. In fiscal year 1979 the U.S. Geological Survey, in cooperation with the New England River Basins Commission (NERBC), began to research the issue of urban water conservation and established a methodology for designing a water conservation plan. During 1980 and 1981, the Survey and NERBC presented the methodology for water suppliers in the text *Before the Well Runs Dry: A Handbook for Designing a Water Conservation Plan.* The handbook was designed and distributed through a series of workshops for water suppliers and public officials held in the New England States.

The handbook addresses supply and demand aspects of water conservation planning. The water supplier is advised to consider his supply options for maintaining or increasing supply through such programs as leak detection and repair, evaporation suppression, and watershed management. To reduce demand, the water supplier is asked to consider regulation, education, and pricing for conservation. With each of these programs, the water supplier is apprised of the political, social, and financial impacts he needs to consider when implementing the water conservation plan so that the final plan is a comprehensive one meeting the water conservation goals of the community while assuring the necessary operating revenue and community support to make it work.

Interest in the methodology for designing a water conservation plan has led to the design of a second series of workshops in cooperation with the Missouri River Basin Commission. Four workshops were held during June and August 1981 in Nebraska, Missouri, South Dakota, and Montana. These water conservation workshops addressed the water supply problems of Western communities and presented the material from the handbook in a group exercise format.

# Decision Information Display System

The Decision Information Display System (DIDS) is a computerized map-oriented decision support system that displays national statistics in shades of color on a map of the area of interest. It is operated by the Executive Office of the President in cooperation with a Steering Committee of abou 25 Federal agencies, including the U.S. Geological Survey. The prototype DIDS contains over 15,000 statistical data sets covering the full spectrum of domestic (and some foreign) areas of interest, such as census, energy, housing, employment, production, and income. It is used by the White House, Congress, and the cooperating agencies for the analysis and display of domestic issues and trends. The system will become fully operational in fiscal year 1982.

The Geological Survey has placed some coal data and over 1,000 water-related data sets into DIDS, including Survey water-use data covering a 25-year period and data derived from the Second National Water Assessment. In addition, the Environmental Protection Agency has placed some Survey stream-quality data into DIDS.

The Survey has supplied DIDS with the base map used for the display of world data and is redesigning the DIDS color palette. The Geological Survey has contributed to development of the prototype system and is in the process of acquiring a DIDS remote terminal system, which will be linked to the White House computer. In fiscal year 1982, the Survey will expand its efforts to supply earth science data and to provide technological support related to the production and display of thematic maps by computer.

# Landsat 3 RBV Image Shows Increase in Oil and Gas Fields in Southeast New Mexico

Onshore oil and gas leases on Federal and Indian lands are supervised by the U.S. Geological Survey and involve well approvals, field inspections, and the collection of royalties. The Geological Survey conducts geological investigations, environmental analyses, and other studies related to the many aspects of exploration, development, and protection of these lands. Landsat 3 RBV (Return Beam Vidicon) imagery, with its synoptic and temporal coverage, provides a rapid, cheap, and accurate means of inventory and assessment of exploration activity directed toward these nonrenewable resources. The increased availability of Landsat 3 RBV imagery gives scientists and energy resource managers an important data base for accurate assessment and monitoring of oil and gas exploration and development. Regional maps of active oil and gas fields can be inspected adequately and revised using RBV imagery, thus reducing the need for expensive aircraft flying programs to only those areas where definitive revision is warranted.

A Landsat 3 RBV image acquired on October 15, 1978, was analyzed for its usefulness in monitoring oil and gas exploration. The resolution of 100 feet and the broad waveband enables relatively easy discrimination and analysis of surface features. The Ogallala Formation is flat-lying and forms the Mescalero Ridge (caprock), a broad terrace that is easily distinguished by tonal difference from the brighter surrounding Mescalero Sands and by the fact that it forms a prominent escarpment. The Ogallala Formation also appears darker than the underlying older rocks, and, consequently, any cultural feature, specifically drilling activity, which disturbs the surface, stands out in marked contrast to the darker surface of the Ogallala.

The 1976 *Geologic Atlas of Texas,* Hobbs sheet, was obtained for specific location and number of oil and gas wells. The *Atlas* was compiled from maps made in 1954 by the Army Map Service using 1954 aerial photographs which showed a total of 1,131 oil and gas wells over an area of approximately 2,250 square miles. These data were overlayed on the Survey topographic map of Hobbs, New Mexico, which was compiled in 1954 from 1954 aerial photographs and revised in 1973 from 1972 aerial photographs. An additional 208 wells were observed, making the total 1,339 (fig. 1). The information plotted then was overlayed on the Landsat 3 RBV image for transfer of the October 15, 1978, data.

An additional 3,365 oil and gas wells were mapped from the 1978 image and the majority of the 1,339 previously mapped wells were confirmed. Thus, analysis of the RBV image showed an increase of about 250 percent over the 1973 total (fig. 2). However, many wells are less than 100 feet apart and may appear as a single site when there are actually two or more. Discrimination between oil and gas wells versus service wells, stratigraphic tests, core tests, and wells drilled for carbon dioxide is virtually impossible from an altitude of approximately 600 miles. The RBV image shows all well data and generally does not permit a distinction between types, although spacing of the wells may permit one to infer their probable purpose. In spite of these limitations, well data obtained from 1:250,000-scale RBV images provide substantial information for monitoring exploration activity. Standard products are available at the 1:125,000 scale which would provide a more accurate data base without losing resolution or geometric quality. Certainly, however, the RBV data can be used to identify areas where change has occurred and where lower altitude aircraft photography should be taken to provide additional details.

Landsat 3 RBV data may play a significant role in all phases of oil and gas exploration as well as future development. The location of support facilities, such as access roads, pump stations, pipe lines, waste disposal sites, utilities, and refineries, also may be planned more efficiently based on the synoptic coverage and resolving capability afforded by spaceborne sensors, and the environmental impacts of these activities can be monitored effectively.

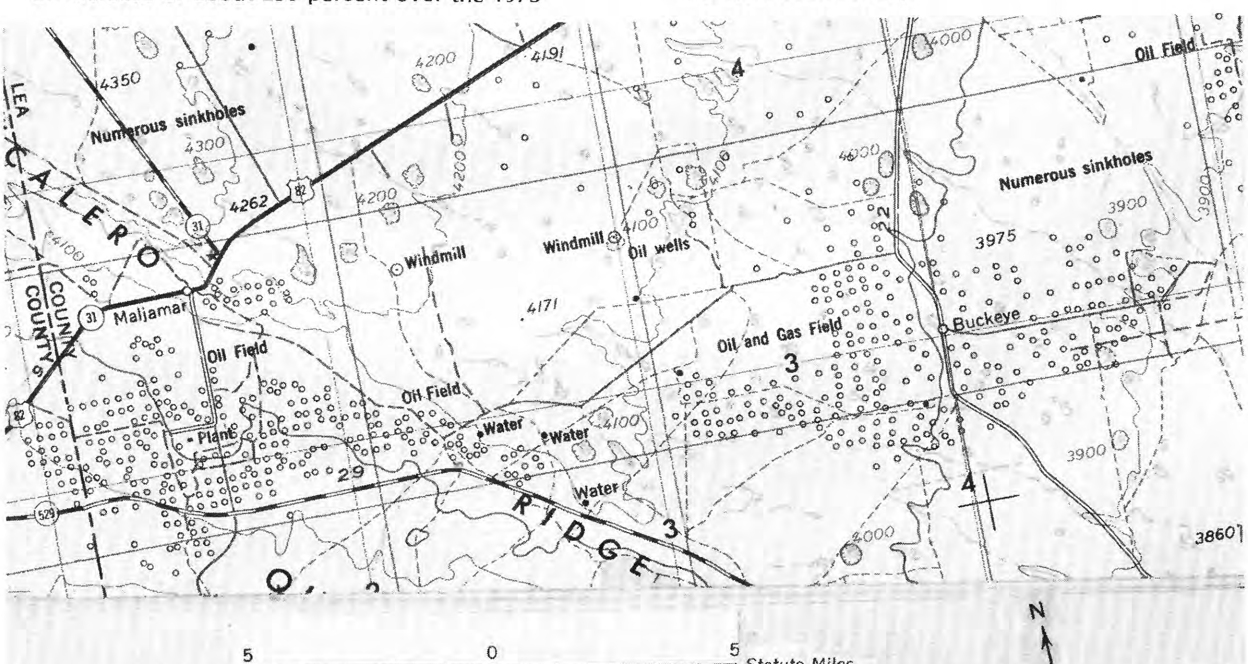



FIGURE 1.—*Enlargement of part of a U.S. Geological Survey [1° × 2°] 1:250,000-scale topographic map of Hobbs, New Mexico. Small circles are symbols representing number and location of oil and gas wells (1,339 total).*

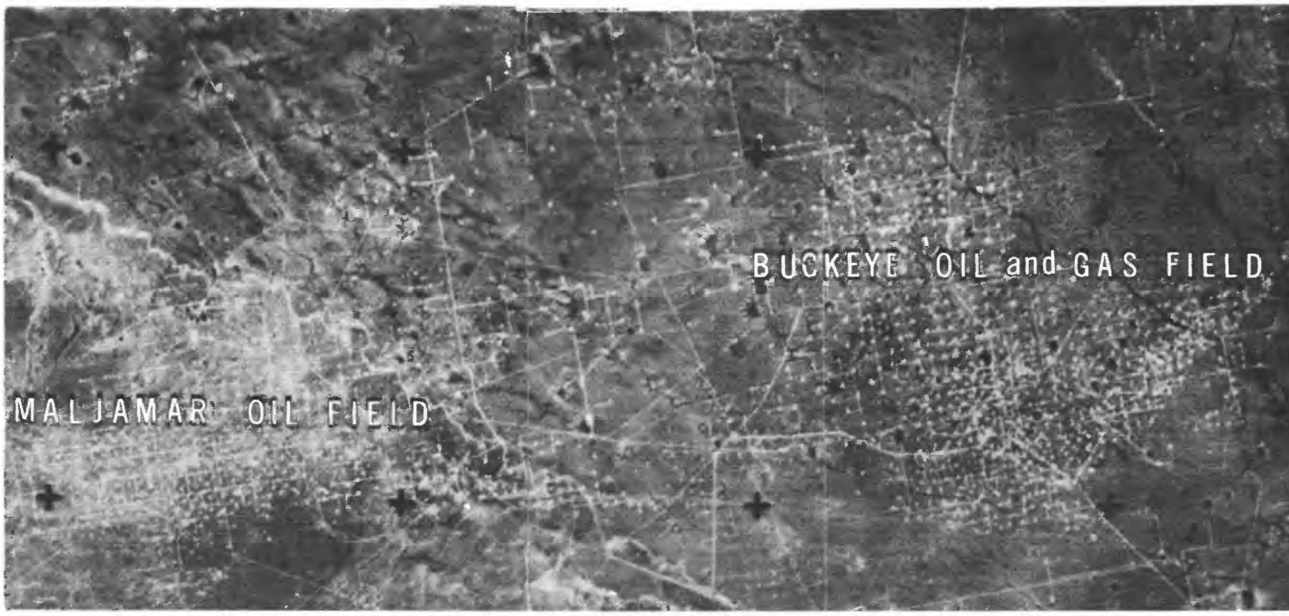



FIGURE 2.—*Enlargement of part of 1978 Landsat 3 RBV image which shows an addition of 3,365 oil and gas wells. The high contrast (brightness) of disturbed drilling locations against dark Ogallala, New Mexico, caprock enable an accurate statistical count of exploration activity.*

# Mapping and Earth Imagery

The Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota, acquired over 150,000 satellite images of the Earth and over 180,000 aircraft photographs of the United States this year, raising the total archive to almost 6.8 million frames. Sales of satellite data amounted to over $2.5 million, a 4-percent increase over last year, and aerial photograph sales came to over $1.4 million, a 56-percent increase. Twenty-four remote-sensing technology training courses were conducted for 451 participants.

At the EROS Data Center, Landsat digital data are converted to photographic images or duplicated on computer-compatible tapes. Modifications were made to the EROS Digital Image Processing System to provide increased flexibility of data formats available to users and to improve data delivery time.

Black-and-white and color infrared photographic coverage from the National High Altitude Photography Program is being cataloged and archived at the EROS Data Center for reproduction and dissemination to users. User demand for this data continues to increase.

*This 324-foot-wide and 100-foot-deep sinkhole in Winter Park, Florida, collapsed on May 8 and 9, 1981. The collapse was caused in part by the prevailing drought. Economic loss is estimated to exceed $2 million. The losses include a house, several cars, portions of several business establishments, streets, and the city swimming pool. View to the south. (Photography by A. S. Navoy.)*

# National Petroleum Reserve in Alaska

## Mission

In fiscal year 1981, the U.S. Geological Survey completed the operational phase of the petroleum exploration program in the National Petroleum Reserve in Alaska, which was begun by the Department of the Navy in 1974 and transferred to the Department of the Interior in June 1977 under the Naval Petroleum Production Act of 1976. Under the Act, the Survey was assigned to explore and evaluate the petroleum resources of the Reserve by drilling and conducting geological investigations, to build an information base to assist Congress in determining the best use of land within the Reserve, to continue developing and producing natural gas in the Barrow area for the native village of Barrow and other communities and Federal Government installations in the vicinity, and to continue the environmental rehabilitation of parts of the Reserve disturbed by previous exploration and construction activities.

During fiscal year 1981, six exploration wells were completed, including one that had been started in the previous year and suspended during the summer months of 1980. At the completion of drilling, all contractor equipment, including drilling rigs, was demobilized from the Reserve, and all materials, equipment, and supplies were removed from the Reserve, surplused, or transferred to Barrow to be used in operating and maintaining the Barrow gasfields, a continuing responsibility of the Department. One geophysical party acquired 590 line-miles of seismic data under a geophysical program designed to study the shallow Cretaceous sandstones at Umiat, which are known to contain oil, and the deeper Jurassic sandstones penetrated by the North Inigok and Walakpa wells. Seismic data were collected in those areas of the Reserve where the petroleum industry had expressed interest in early leasing. The Survey continued to operate the South Barrow gasfield. Construction continued on surface facilities at the East Barrow gasfield, located approximately 7 miles east of the South Barrow field, in preparation for production from three East Barrow wells during the winter of 1981-82. Husky Oil NPR Operations, Inc., continued as the contractor for drilling. Geophysical Services, Inc., was the contractor for the collection and processing of field seismic data, and Tetra Tech, Inc., provided technical services, including interpretation of seismic data.

## Budget and Personnel

Obligations for drilling and related activities within the National Petroleum Reserve in Alaska in fiscal year 1981 totaled $107.0 million, all against the appropriation "Exploration of the National Petroleum Reserve in Alaska." Of this total, $105.5 million was devoted to continuing the evaluation and assessment of the Reserve, and $1.5 million went for operating the South Barrow gasfield. The Environmental Restoration Program, which consisted of the normal cleanup of current exploration drilling sites and the rehabilitation of areas of the Reserve disturbed during previous petroleum exploration and construction activities, was continued with funds included in the program termination costs.

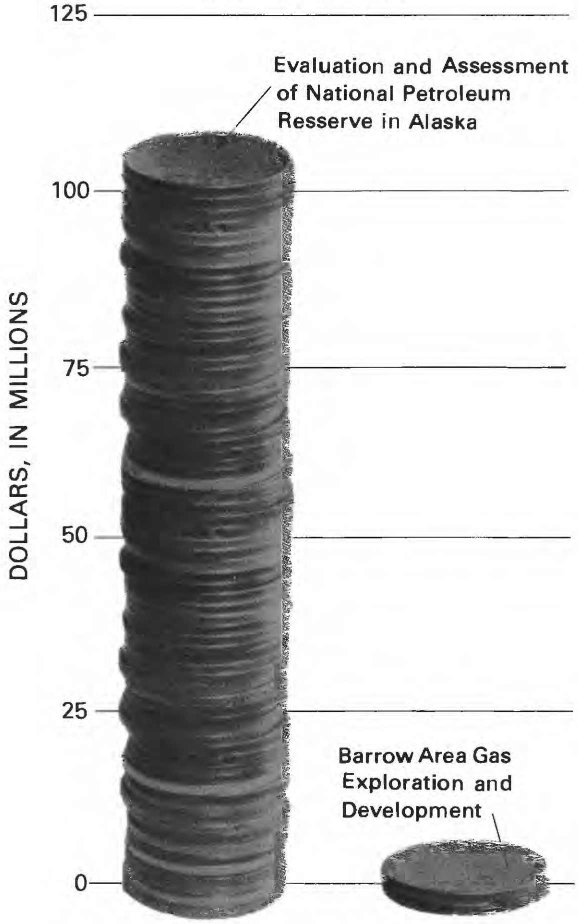
The Office of the National Petroleum Reserve in Alaska ended fiscal year 1981 with 18 permanent full-time employees and 4 employees in other categories.

*National Petroleum Reserve in Alaska obligations for fiscal years 1980 and 1981, by activity*

[Dollars in millions. Data may differ from that in statistical tables because of rounding]

| Activity | Fiscal year 1980 | Fiscal year 1981 |
|---|---|---|
| **Evaluation and Assessment of National Petroleum Reserve in Alaska** | **138.6** | **105.5** |
| **Barrow Area Gas Exploration and Development** | **28.4** | **1.5** |
| **Environmental Restoration** | **2.8** | **—** |
| **Total** | **169.8** | **107.0** |

USE OF FUNDS




DIRECT APPROPRIATIONS

# Status of Exploratory Drilling

Awuna Test Well No. 1, located approximately 152 miles south-southwest of Barrow in the central part of the Reserve, was started on March 1, 1980, to test for potential accumulations of oil and gas on one of the highest structural positions along the prominent Carbon Creek-Awuna anticline, which extends across much of the Reserve. The well, designed to test sands of the Torok and Fortress Mountain formations of Cretaceous age, was suspended for the summer on May 8, 1980, at a depth of 5,300 feet before the potential reservoir horizons were encountered. It was reentered on December 5, 1980, and drilled to a total depth of 11,200 feet. The Torok consisted mainly of shale and some thin, nonporous sands, many of them with gas shows. The upper part of the Fortress Mountain formation was more sandy than the Torok, but the sands were fine grained and generally exhibited poor porosity. Gas shows were indicated in many of the sands. Very minor amounts of asphaltic material were found in the lower part of the well. Very high pressures and lost circulation slowed the penetration rate, and drilling was terminated well short of the projected total depth.

Walakpa Test Well No. 2, located 4 miles south-southwest of Walakpa Test Well No. 1, was drilled to a total depth of 4,360 feet and was temporarily abandoned on February 15, 1981, following testing. The well was designed to test the Jurassic "Simpson" sand near its updip truncation and Lower Cretaceous sand (the "Walakpa" sand), which tested gas in the Walakpa No. 1 well. The Lower Cretaceous "Walakpa" sand, found 536 feet lower than it was in the No. 1 well, was cored from 2,611 to 2,640 feet; fine-grained sand having poor to good porosity and a show of hydrocarbons was recovered. A drill-stem test of the sand recovered gas at the rate of 2.4 million cubic feet per day. The "Simpson" interval was siltstone, as it was in the Walakpa No. 1 well.

North Inigok Test Well No. 1 was completed as a dry hole on April 4, 1981. The well was spudded on February 13, 1981, at a location 20 miles north-northeast of the Inigok No. 1 well and drilled to a total depth of 10,170 feet in the Triassic Shublik Formation. Gas shows, as logged by the well-site geologist, were encountered only in the lowermost Torok formation; a single show was indicated in the Jurassic siltstone. Surprisingly, a drill-stem test of the Jurassic zone produced gas at an estimated rate of 30,000 cubic feet per day. The gas was quite rich and analyzed 73 percent methane, 12.8 percent ethane, 7.3 percent propane, 3.2 percent butane, and 3.7 percent pentanes and heavier hydrocarbons. Such an analysis has important implications for a possible oil-column downdip and for reservoirs elsewhere in the Kingak formation of Jurassic age.

Kuyanak Test Well No. 1 was spudded on February 13, 1981, and completed on March 31, 1981, to a total depth of 6,690 feet. Located 22 miles southeast of Walakpa No. 2, the Kuyanak well was drilled primarily to explore for the "Simpson" sandstone within the Jurassic Kingak shale. This sand had been found in wells having good reservoir characteristics to the southeast, south, and southwest. A secondary objective was the Sag River sandstone of Triassic age. Drilling was begun in rock of Cretaceous age and terminated in argillite basement. A sand correlated as the "Walakpa" sand was found at 5,092 feet and cored from 5,093 to 5,186 feet. There were no hydrocarbon shows in the sand, but good porosity and permeability were measured. The

*Summary of exploration drilling in the National Petroleum Reserve in Alaska by the Department of the Navy and the U.S. Geological Survey from 1975 to 1981*

[Department of the Navy transferred responsibility to U.S. Geological Survey in June 1977]

| Name | Location | Date spudded | Date completed | Total depth in feet | Deepest horizon attained | Remarks |
|---|---|---|---|---|---|---|
| Cape Halkett No. 1 | 18 miles ESE of Lonely | 3-24-77 | 6-1-75 | 9,900 | Argillite basement (Devonian or older) | Dry; plugged and abandoned. |
| East Teshekpuk No. 1 | 25 miles S of Lonely | 3-12-76 | 5-11-76 | 10,664 | Granite basement | Do. |
| South Harrison Bay No. 1 | 50 miles SE of Barrow | 11-21-76 | 2-8-77 | 11,290 | Lisburne Group (Pennsylvanian). | Poor oil shows; plugged and abandoned. |
| Atigaru Point No. 1 | 44 miles SE of Lonely | 1-12-77 | 3-18-77 | 11,535 | Argillite basement (Devonian or older). | Do. |
| West Fish Creek No. 1 | 51 miles SE of Lonely | 2-14-77 | 4-27-77 | 11,427 | Kayak shale (Mississippian). | Do. |
| South Simpson No. 1 | 41 miles WSW of Lonely. | 3-9-77 | 4-30-77 | 8,795 | Argillite basement (Devonian or older). | Dry; plugged and abandoned. |
| W. T. Foran No. 1 | 23 miles ESE of Lonely | 3-7-77 | 4-24-77 | 8,864 | Argillite basement (Devonian or older). | Oil and gas shows; plugged and abandoned. |
| Drew Point Test Well No. 1 | 14 miles W of Lonely | 1-13-78 | 3-13-78 | 7,946 | Argillite basement (Devonian or older). | Poor oil and gas shows; plugged and abandoned. |
| South Meade Test Well No. 1 | 45 miles S of Barrow | 2-7-78[1] | 1-22-79 | 9,945 | Argillite? basement (Devonian or older). | Do. |
| Kugrua Test Well No. 1 | 67 miles SW of Barrow | 2-12-78 | 5-29-78 | 12,588 | Lisburne Group (Pennsylvanian). | Dry; plugged and abandoned. |
| North Kalikpik Test Well No. 1 | 37 miles SE of Lonely | 2-27-78 | 4-14-78 | 7,395 | Kingak shale (Jurassic) | Poor oil and gas shows; plugged and abandoned. |
| Inigok Test Well No. 1 | 60 miles S of Lonely | 6-7-78 | 5-22-79 | 20,102 | Kekiktuk formation? (Mississippian). | Encountered hydrogen sulfide and sulfur at 17,570 feet; poor gas shows; plugged and abandoned. |
| Tunalik Test Well No. 1 | 22 miles SE of Icy Cape. | 11-10-78 | 1-7-80 | 20,335 | Lisburne Group (Mississippian). | Gas test; plugged and abandoned. |
| Ikpikpuk Test Well No. 1 | 42 miles SW of Lonely | 11-28-78<br>1-7-80 | 2-28-80 | 15,481 | Kekiktuk formation (Mississppian). | Shows; plugged and abandoned. |
| Peard Test Well No. 1 | 25 miles NE of Wainwright. | 1-26-79 | 4-13-79 | 10,225 | Argillite basement (Devonian or older). | Poor gas shows; plugged and abandoned. |
| East Simpson Test Well No. 1 | 55 miles SE of Barrow | 2-19-79 | 4-10-79 | 7,739 | Argillite basement (Devonian or older). | Oil and gas shows; plugged and abandoned. |
| J. W. Dalton Test Well No. 1 | 3 miles E of Lonely | 5-7-79 | 8-1-79 | 9,367 | Argillite Basement (Devonian or older). | Oil and gas shows; some heavy oil recovered during testing; plugged and abandoned. |
| Lisburne Test Well No. 1 | 1 mile NW of Umiat | 6-11-79 | 6-2-80 | 17,000 | Lisburne Group (Mississippian). | Shows of gas; plugged and abandoned. |
| Seabee Test Well No. 1 | 1 mile NW of Umiat | 7-1-79 | 4-15-80 | 15,611 | "Pebble shale" (Late Jurassic?-Early Cretaceous). | Gas test; plugged and abandoned. |
| Walakpa Test Well No. 1 | 15 miles S of Barrow | 12-25-79 | 2-7-80 | 3,666 | Argillite basement (Devonian or older). | Shows of gas; plugged and abandoned. |
| East Simpson Test Well No. 2 | 50 miles SE of Barrow | 1-29-80 | 3-15-80 | 7,505 | Argillite basement (Devonian or older). | Poor shows; plugged and abandoned. |

*Summary of exploration drilling in the National Petroleum Reserve in Alaska by the Department of the Navy and the U.S. Geological Survey from 1975 to 1981*—Continued

[Department of the Navy transferred responsibility to U.S. Geological Survey in June 1977]

| Name | Location | Date spudded | Date completed | Total depth in feet | Deepest horizon attained | Remarks |
|---|---|---|---|---|---|---|
| West Dease Test Well No. 1 | 28 miles SE of Barrow | 2-19-80 | 3-26-80 | 4,170 | Argillite basement (Devonian or older). | Do. |
| Awuna Test Well No. 1 | 152 miles S of Barrow | 3-1-80[2] | 4-20-81 | 11,200 | Fortress Mountain formation (Cretaceous). | Many gas shows; plugged and abandoned. |
| Walakpa Test Well No. 2 | 16 miles S of Barrow | 1-3-81 | 2-15-81 | 4,360 | Argillite basement (Devonian or older). | Temporarily abandoned (gas well—Walakpa sand). |
| North Inigok Test Well No. 1 | 20 miles SE of Teshekpuk Lake. | 2-13-81 | 4-4-81 | 10,170 | Shublik formation (Triassic). | Shows of gas; plugged and abandoned. |
| Kuyanak test Well No. 1 | 30 miles SE of Barrow | 2-13-81 | 3-31-81 | 6,690 | Argillite basement (Devonian or older). | Minor gas and oil shows; plugged and abandoned. |
| Tulageak Test Well No. 1 | 24 miles ESE of Barrow. | 2-26-81 | 3-23-81 | 4,015 | Argillite basement (Devonian or older). | Few poor oil shows; plugged and abandoned. |
| Koluktak Test Well No. 1 | 75 miles S of Smith Bay. | 3-24-81 | 4-19-81 | 5,882 | Torok formation (Cretaceous). | Gas shows and minor oil shows; plugged and abandoned. |

[1] Reentered 12-4-78.
[2] Reentered 12-5-80.

"Walakpa" sand thus occurs more than 2,500 feet structurally low to the Walakpa No. 2 well and possibly indicates a continuous sand having good reservoir characteristics below a proven gas column. An equivalent of the "Simpson" sand occurs in the Kuyanak well from 5,378 to 5,656 feet and consists mostly of siltstone and minor gas shows near the top. The "Simpson" sand play lies to the south of this well. Equivalents of the Jurassic "Barrow" and Triassic Sag River sands of the East Barrow field were cored. The equivalent of the Sag River sand indicated a minor gas show.

Tulageak Test Well No. 1, located on the Beaufort Sea coast 24 miles east-southeast of Barrow, was spudded on February 26, 1981, and completed to a total depth of 4,015 feet on March 23, 1981. The well was drilled to test a combination structural-stratigraphic prospect and encountered basement at 3,947 feet. Argillite was drilled and cored from this point to the total 4,015-foot depth. Only one hydrocarbon show was found.

Koluktak Test Well No. 1, located 39 miles southwest of the Inigok No. 1 well, was spudded on March 24, 1981, and completed as a dry hole on April 19, 1981, after a total depth of 5,882 feet had been reached. The primary objective of the well was the Nanushuk Group sands, which had good gas and oil shows in several of the older wells drilled during the Pet-4 program. Koluktak No. 1 drilled a Nanushuk sequence from the surface to about 4,200 feet. The upper two-thirds of this section was predominantly sandstone; some thin shale, siltstone, limestone, and coal beds; many minor gas shows; and a few oil shows. The lower third was much more shaley and had only a few gas shows. The top of the Torok was estimated at about 4,200 feet, and, from this point to total depth, shale and minor amounts of sandstone and siltstone were drilled. Only one minor gas show was indicated in this interval. The imminence of spring breakup precluded any testing.

# Barrow Area Gas Activities

The Geological Survey continued to operate and maintain the South Barrow gasfield, which supplies gas to the village of Barrow as well as to Federal installations in the Barrow area. Construction continued on production facilities at the newer East Barrow gasfield, which will double the amount of natural gas available to the Barrow area.

No new gas wells were drilled during fiscal year 1981. The status of the Barrow gas wells is indicated on the accompanying table.

*Summary of drilling in the Barrow area of the National Petroleum Reserve in Alaska by the Department of the Navy and the U.S. Geological Survey from 1964 to 1980*

[Department of the Navy transferred responsibility to U.S. Geological Survey in June 1977]

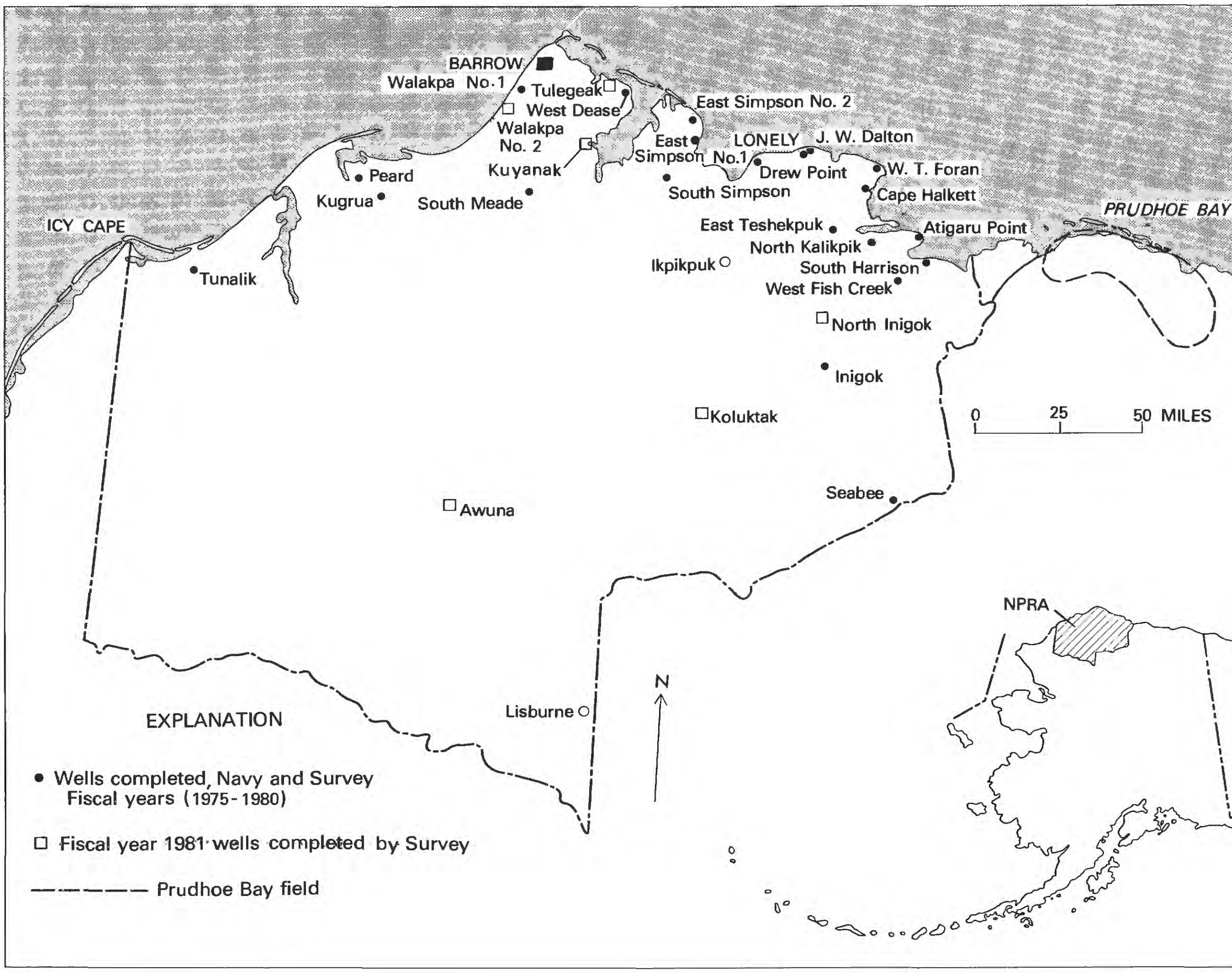
| Name | Location | Date spudded | Date completed | Total depth in feet | Deepest horizon attained | Remarks |
|---|---|---|---|---|---|---|
| South Barrow No. 6 | 4.75 miles SE of Barrow. | 2-28-64 | 3-24-64 | 2,363 | Barrow sand (Jurassic) | Gas well |
| South Barrow No. 7 | 5 miles SE of Barrow | 3-4-68 | 4-2-68 | 2,351 | do | Do. |
| South Barrow No. 8 | 5 miles SE of Barrow | 4-4-69 | 5-1-64 | 2,359 | do | Do. |
| South Barrow No. 9 | 4.25 miles SE of Barrow. | 3-19-70 | 4-15-70 | 2,450 | do | Gas well; 7.8 mmcf/d. |
| South Barrow No. 10 | 4.75 miles SE of Barrow. | 3-7-73 | 3-24-73 | 2,349 | do | Gas well |
| South Barrow No. 11 | 5 miles SE of Barrow | 2-10-74 | 3-5-74 | 2,350 | do | Do. |
| South Barrow No. 12 | 11 miles SE of Barrow | 3-10-74 | 5-4-74 | 2,283 | Shublik formation (Triassic). | Dry; suspended |
| Iko No. 1 | 16 miles Se of Barrow | 2-1-75 | 3-11-75 | 2,731 | Argillite basement (Devonian or older). | Suspended as marginal gas discovery. |
| South Barrow No. 13 | 5 miles SE of Barrow | 12-17-76 | 1-16-77 | 2,535 | do | Shows of gas; suspended as marginal gas well. |
| South Barrow No. 14 | 12 miles ESE of Barrow. | 1-28-77 | 3-3-77 | 2,257 | Sag River sand (Triassic). | Completed as a gas well; Upper and Lower Barrow sand. |
| South Barrow No. 16 | 6 miles E of Barrow | 1-28-78 | 2-18-78 | 2,400 | Argillite basement (Devonian or older). | Dry; plugged and abandoned. |
| South Barrow No. 17 | 13 miles ESE of Barrow. | 3-2-78 | 4-13-78 | 2,382 | do | Suspended; edge well; produces water with gas. |
| South Barrow No. 19 | 11 miles ESE of Barrow. | 4-17-78 | 5-17-78 | 2,300 | do | Completed as a gas well; Lower Barrow sand. |
| South Barrow No. 20 | 11 miles ESE of Barrow. | 4-7-80 | 5-10-80 | 2,356 | do | Shows of gas and oil; suspended as marginal oil producer. |
| South Barrow No. 15 | 10 miles ESE of Barrow. | 8-23-80 | 9-18-80 | 2,278 | Jurassic | Completed as a gas well; Upper Barrow sand. |
| South Barrow No. 18 | 12 miles ESE of Barrow. | 9-22-80 | 10-14-80 | 2,135 | do | Completed as a gas well; Lower Barrow sand. |

# Environmental Rehabilitation on NPRA

The Geological Survey environmental rehabilitation program at the National Petroleum Reserve in Alaska consists of two parts—the collection and consolidation of litter and debris left from earlier construction and oil-exploration activities and the cleanup and revegetation of current drilling sites.

Early oil-exploration and construction activities were carried out with little regard for environmental protection or the effects of drilling operations on the tundra environment. Fuel drums, abandoned equipment and supplies, and other kinds of exploration and construction litter were left at many sites. During fiscal year 1981, the Geological Survey collected over 380 tons of debris and waste materials from numerous old sites on the Reserve, including 8,000 old barrels. These materials were consolidated and stockpiled at several collection points on the Reserve.

Rehabilitation of current drill sites consists of initial recontouring and revegetation of drilling sites and a second reseeding the following year. During fiscal year 1981, initial rehabilitation work was performed at six sites, and followup reseeding and refertilizing were completed at other sites as necessary. Both cleanup and rehabilitation activities are accomplished by contract personnel.




*Location map showing wells drilled in the National Petroleum Reserve in Alaska. Solid circles indicate wells completed by the Department of the Navy and the U.S. Geological Survey from fiscal year 1975 through fiscal year 1980. Open squares indicate wells completed by the U.S. Geological Survey in fiscal year 1981.*

# Program Support Divisions

## Administrative Division

### GENERAL ADMINISTRATION

The cost of executive direction and coordination of the U.S. Geological Survey programs and administrative services provided by the Administrative Division is funded by sources collectively referred to as "General Administrative Expenses." During fiscal year 1981, these expenses totaled $21.1 million and amounted to 3 percent of the total budget. This funding was derived from the following sources: the general administration budget activity, $3.9 million; assessment on directly appropriated activities, $11.9 million; and assessments on reimbursable programs, $5.3 million. No assessments were made on cooperative funds from State and local governments.

### ADMINISTRATIVE MANAGEMENT

The management and service activities of the Administrative Division are directed from the Survey's National Center in Reston, Virginia and from the three Regional Centers at Reston, Eastern, Denver, Colorado, Central, and Menlo Park, California, Western, as well as at field offices located at Atlanta, Georgia, Rolla, Missouri, Flagstaff, Arizona, and Anchorage, Alaska. The field offices provide support to Survey installations and personnel in immediate or nearby areas. Highlights associated with the Division's experience in facilities, Automatic Data Processing systems improvements, and personnel management are described in the following text.

#### EROS Solar Energy Hot Water Heating System

The EROS Data Center (EDC) at Sioux Falls, South Dakota, solar energy hot-water heating system has been in operation since January 1980. Typically, the system provides all the EDC's hot water needs on a sunny summer day and half of the hot water needs on a sunny winter day. On a normal production day, the EDC uses 10,000 gallons of 120°F. hot water. The EDC is purchasing considerably less energy with the solar system and backup electric boilers than with the originally installed oil-fired boilers. In addition to the savings produced by the solar energy system, savings come from the greater efficiency of the electric boilers over the fuel oil boilers.

As the largest operational flat-field solar energy system in the North-Central United States, the EDC demonstration project has received considerable attention. Through presentations at energy management seminars, participation in solar energy conferences, and working with the State energy offices, the EDC system was recommended by the South Dakota State Energy Office for instrumentation and monitoring under a 3-year contract with the Department of Energy.

The system will be extensively instrumented and the data will be fed back to a central computer where the energy contribution by the solar system will be calculated. Because individual loops of the system will be monitored, improvements can be made where heat loss areas are found.

The results, as well as suggested improvements, will be documented and made available to the EROS Data Center and to the general public. These results will be useful when evaluating the feasibility and application of future solar energy systems in both public and private sectors.

#### Automatic Data Processing

The Administrative Division's concerted effort to seek opportunities to streamline administrative processes and to improve the delivery of administrative services resulted in several significant accomplishments during fiscal year 1981. In particular, special emphasis was placed on identifying areas where greater utilization of advanced technologies could be made to increase the efficiency of administrative operations and on undertaking projects aimed at implementing the technologies. Highlights of some of the projects undertaken in 1981 follow.

#### ATTACHED RESOURCES COMPUTER SYSTEM

The Automated Data Processing Network was adopted and installed in 1976 to simplify and reduce the processing time for the 160,000 procurement and property transactions executed by the Survey each year. The network was significantly modified and improved during fiscal year 1981 with the installation of an Attached Resources Computer System at the National Center. The addition of the Attached Resources Computer System increases the amount of processing time available for accomplishing many different tasks; for example, data entry, data manipulation, and data transmission from field offices to the Network System. ARC permits these tasks to be completed simultaneously rather than in sequential order. The Denver and Menlo Park elements of the Network also were upgraded with the installation of faster processing minicomputers. The net effects of the enhancements made to the Network include improving the processing time for procurement and personal property transactions, improving the currency of information available to Survey managers, and increasing the capacity for developing new management information systems for other areas of administrative operations.

## MANAGEMENT INFORMATION SYSTEMS

Utilizing the enhanced Network System, two new management information systems have recently been implemented. The first is a new Personnel Data Collection System that was installed at the National Center and in the Eastern Region. This system was designed to reduce the time and costs of processing personnel actions. To date, the system has accounted for a reduction in data entry time of 57 percent, processing time reduced from 3 days to 1, contractor keypunch costs reduced by 85 percent, data entry errors reduced by 67 percent and personnel supplemental payroll checks being issued has been cut by 50 percent. Because of the successful introduction of this system, it will soon be installed in the other five Survey Personnel offices.

The second system, an automated remote data collection process, has been installed to provide an easier method of entering information into the Automated Regional Locator System. This Regional Locator System permits more efficient ways to identify employees at their exact work sites at the Survey's 392 locations across the Nation.

### Commitment Accounting System

Two major studies have been completed this year which will lead to the development of a new commitment accounting system and a streamlined system for processing personnel actions. The new commitment accounting system will provide managers with reports showing an estimate of funds reserved for requisitions in process and, hence, a more realistic insight of funds availability. This system will maintain an up-to-date status for fund balances through the electronic collection of commitment data and an ongoing reconciliation of accounts with the existing Bureau accounting system.

Each Division within the Survey will receive formal training on the use of the system and will, consequently, be better able to reconcile the status of its funds.

### Alternative Work Schedules

In March 1981, the Administrative Division completed an 18-month evaluation of the Survey's experiments with alternative work schedules. These experiments, which involved about 800 Survey employees in four field office installations and one National Center organization, were made possible by the Federal Employees Flexible and Compressed Work Schedules Act. This law allowed all Federal agencies in the Executive Branch to experiment with a variety of alternative work schedules. The law also mandated that the Office of Personnel Management (OPM) monitor the experiments to determine if alternative work schedules could be used successfully by Federal agencies.

The five Survey organizations selected to participate in the experiments were the Computer Center Division, Reston, Virginia, the Rolla Field Center, Rolla, Missouri, the Denver Central Laboratory, Arvada, Colorado, the Flagstaff Field Center, Flagstaff, Arizona, and the Branch of Marine Geology, Redwood City, California. The Rolla and Flagstaff Field Centers and the Computer Center Division tested a form of flexible work schedule. The Denver Central Laboratory and the Branch of Marine Geology experimented with a form of compressed work schedule (4-day week).

Throughout the 18-month data collection period, the Survey supplied information about its own experiences with alternative work schedules to the OPM and also conducted its own evaluation. The purpose of the Survey's evaluation was to determine what impact the new work schedules had on operations, management tasks, service to the public, transportation, building operations, and employee use of leisure time. Analysis of the data collected through employee questionnaires, customer service surveys, data record forms, and onsite interviews indicated that all the experiments were successful, and that the alternative work schedules had a positive effect on each of the organizations. In each of the experimenting organizations, there was an increase in productivity, a reduction in the use of annual leave and overtime and improved employee morale.

Decisions about permanent use of the new work schedule alternatives in the Survey will be made after consideration of legislation by Congress in spring 1982.

### Employee Awards

During Fiscal Year 1981, Geological Survey employees distinguished themselves by outstanding performance or submission of ideas to improve the economy, efficiency, and (or) effectiveness of Government operations. Approximately 1,100 employees or groups of employees received cash awards totalling $426,000 for their contributions. An additional 210 were recognized with quality step increases for a level of performance meriting faster-than-normal pay increases.

Among the 70 groups of employees who were recognized for their outstanding collective efforts were two which earned the highest awards ever given by the Geological Survey. One group of six scientists received $13,000 for their work before, during, and after the eruption of Mount St. Helens. The work of this group in gathering, assembling, and interpreting data and coordinating with other concerned agencies helped to save many lives when the major eruption occurred on May 18, 1980. In addition to these scientists, 102 other employees were recognized for extraordinary efforts ranging from logistical support to mapping to stream measurement in the wake of the eruptions.

A second group of 11 geologists and engineers received $13,000 for their work in gathering and evaluating the tonnage of Federally owned coal illegally mined in 20 case areas in Alabama. The value of this coal totalled $7,465,000. In addition to this assessment, the group developed new procedures that can be used as a deterrent to future leasable mineral trespass, an achievement of great significance to the national interest.

Besides the use of cash awards to recognize significant achievements, the Survey presented 82 honorary awards to employees for distinguished, meritorious, or superior career achievements. Finally, the Survey was especially honored that Cynthia Dusel-Bacon, a geologist from Menlo Park, was selected as one of 10 Outstanding Handicapped Federal Employees in the country in 1981.

# Computer Center Division

The Computer Center Division operates a nationwide system for computer facilities and terminals to provide automatic data processing and computer-assisted communication services for the U.S. Geological Survey. Fiscal year 1981 witnessed a number of developments in the application of Automatic Data Processing technology and information science to the work of the Geological Survey. Among these were small computer technology, reorganization of information systems, data communications, automatic data processing security, teleconferencing and office automation, and array processing.

## SMALL COMPUTER TECHNOLOGY

During fiscal year 1981, the Computer Center Division evaluated the potential application of small computer or "microcomputer" technology to the various data processing activities of the Survey. In response to the considerable amount of interest shown by the user community in microcomputing, several steps were taken to make this technology more readily available for user evaluation:

- A Microcomputer Technology Team was established to function as the focal point for all activities related to small computer technology. This action, in turn, led to the formation of the Survey Microcomputing Users Group, which serves as an interdivisional forum for planning and discussing overall microcomputer activity throughout the Survey.
- A series of tasks was initiated to evaluate the software for microcomputers. Various software packages are being compared to determine which is the most efficient. Where possible, the packages are being compared with similar ones used on larger "mainframe' computers. The results will be documented as Software Evaluation Reports and made available to the user community. These reports will serve as starting points for those users who are considering the application of microcomputers but need assistance in software selection.
- Means were established whereby microcomputers and associated machinery, such as printers and graphics-output devices, could be acquired and made available to the Survey user community.

## REORGANIZATION OF INFORMATION SYSTEMS

Although microcomputer technology played an increasing role in data processing activities during fiscal year 1981, the Computer Center Division assisted other Divisions in their efforts to reorganize two large information systems, the National Coal Resource Data System (NCRDS) and the Improved Royalty Management Program.

- In the case of the NCRDS, the task was to unify two sets of similar data previously collected and stored in two separate computer systems. The NCRDS Project Management Task Team was formed to manage the system life activities of the two systems, and a unified approach to processing, storing and disseminating the NCRDS and related data was adopted. A single task group was formed, and a recommendation was made to process the data on one computer.
- In support of the Improved Royalty Management Program, the Computer Center Division assisted in developing feasibility studies for proposals and technical evaluations and obtaining contract support for this large project.

## DATA COMMUNICATIONS

To assist their work, scientists require data processing techniques that allow computerized data to be transferred between distant places. To support this requirement, the Division continued to expand and upgrade its data communications capabilities:

- The Survey's use of TYMNET, a communications network that provides easy access to distant computers, was increased approximately 25 percent over the level of the preceding year.
- The Advanced Research Projects Agency Network (ARPANET) was installed for Survey use in June 1981. This communications network provides fast data transfers between Survey computer sites as well as access to non-Survey computers.
- Port Sharing Devices (PSD's) were installed in Reston, Virginia, Denver, Colorado, Menlo Park, California, and Flagstaff, Arizona. These devices will permit greater use of existing computer resources.
- In conjunction with the PSD's, plans were initiated to install a Survey communications network to provide high-speed linkage between Reston, Denver, and Menlo Park.
- Plans for communications connecting the Washington Computer Center to the National Center computers were initiated.

## AUTOMATIC DATA PROCESSING SECURITY

In compliance with existing directives, an Automatic Data Processing (ADP) Security Officer was selected in February 1981. This individual's functions include oversight and management facilities security, security design components in information systems, and security of the data bases supported by those information systems. In April 1981, the first Security Newsletter was published to promote the goals of the ADP Security Program by providing a central source of information, current guidelines, and regulations dealing with the field of ADP security.

## TELECONFERENCING

The Division continued its developmental work in teleconferencing and office automation systems during fiscal year 1981. A system was initiated to allow Multics (Multiplexed Information and Computing Service) users from Menlo Park, Denver, and Reston to attend meetings held through computers. The system encourages the use of computers for conferencing by providing an easy method for field offices to access a central computer. An office automation system was developed for use on the Multics computers to help personnel become more effective in carrying out day-to-day office functions involving electronic mail, word processing, teleconferencing, online calendars, information storage, and retrieval capabilities.

## ARRAY PROCESSING

A Floating Point Systems AP–120B array processor became operational at the Flagstaff Computation Branch during fiscal year 1981. The array processor is connected to a PDP–11/45 computer system that users can access by using a terminal and telephone. The internal organization of the array processor is particularly well suited for performing large numbers of repetitive multiplications and additions required in digital signal processing, matrix arithmetic, statistical analysis, geophysical data processing, simulation, modeling, and image processing. The structure allows for other functions to be performed on the data simultaneously with arithmetic operations, which permits much faster execution than on a typical general purpose computer where operations occur sequentially. The AP–120B is well supplied with software. Over 235 mathematical subroutines cover a wide variety of arithmetic operations including data transfer and control, vector and matrix operations, and signal processing.

# Equal Employment Opportunity Office

In 1981, the U.S. Geological Survey developed and implemented an effective results-oriented Affirmative Action Program.. Underrepresentation analysis was conducted for 46 occupations, 44 of which were subsequently targeted for affirmative recruitment and hiring with 23 geographical or functional organizational components. The Affirmative Action Program was developed within the existing operational structure consistent with line and budgetary authority. Affirmative Action Program goals were established for designated divisional organizational components to ensure maximum line management involvement and accountability. This is in marked contrast to previous Affirmative Action Programs which were developed at the Assistant Regional Director's level without regard to divisional lines of authority for goal attainment.

The fiscal year 1981 accomplishments have been analyzed from two perspectives: the actual "bottom line" change for each occupation as the Equal Employment Opportunity Office will receive and evaluate the Geological Survey's progress and the applicant flow as it relates to the goals of the Federal Equal Opportunity Recruitment Program.

In summary, the overall accomplishments are encouraging and are reflective of the commitment of the Survey to the improvement of its equal employment opportunity posture. Quarterly progress reviews with managers and Division Chiefs using accomplishment reports data will enable effective assessment of progress and will facilitate the immediate identification of areas requiring correction and attention.

The commitment of top-level management is reflected by the positive achievements in the fiscal year 1981 goals. The close coordination and cooperation between the Personnel and Equal Employment Opportunity Offices and the accepted shared responsibility for equal employment opportunity progress is perhaps the most fundamental strength of the Survey's Affirmative Action Program.

The major objective of the Equal Employment Opportunity Program Complaints System for fiscal year 1981 was to adequately process individual and class complaints of discrimination and address systemic discrimination issues which can negatively affect the credibility of the Geological Survey's equal employment opportunity effort. Complaints of discrimination against the Survey have risen from a total of 8 in 1978 to 30 in 1981. The greatest individual increase has been in female complaints of sex discrimination. The increase can be attributed, in part, to the system's high visibility and is indicative of the Survey's commitment to equal employment opportunity.

*Ruins such as these of the Hibernia Bank building in San Francisco after the 1906 earthquake prompted U.S. Geological Survey geologist G. K. Gilbert to stress the value of engineering to avoid such catastrophic results in the future.*

# DIRECTOR
## ASSOCIATE DIRECTOR

### ASSISTANT DIRECTORS
- Administration
- Programs
- Research
- Resource Programs
- Engineering Geology
- Eastern Region
- Central Region
- Western Region

### STAFF OFFICES
- Washington Liaison
- Equal Opportunity
- Congressional Liaison
- Public Affairs

### OFFICE OF NATIONAL PETROLEUM RESERVE IN ALASKA
CHIEF, OFFICE OF NATIONAL PETROLEUM RESERVE IN ALASKA
Anchorage, AK

- NPRA LIAISON OFFICE, Reston, VA
- NPRA OPERATIONS OFFICE, Anchorage, AK
- EXPLORATION STRATEGY OFFICE, Menlo Park, CA

### OFFICE OF EARTH SCIENCES APPLICATIONS
CHIEF, OFFICE OF EARTH SCIENCES APPLICATIONS
ASSOCIATE CHIEF

- RESOURCE PLANNING ANALYSIS OFFICE
- VISUAL INFORMATION SERVICES OFFICE
- EARTH RESOURCES OBSERVATION SYSTEMS OFFICE
  - EROS DATA CENTER, Sioux Falls, SD
- ENVIRONMENTAL AFFAIRS OFFICE
- EARTH SCIENCES ASSISTANCE OFFICE

### NATIONAL MAPPING DIVISION
CHIEF, NATIONAL MAPPING DIVISION
ASSOCIATE CHIEF

- ASSISTANT DIVISION CHIEF FOR RESEARCH
  - Offices
    - Geographic Research
    - Cartographic Research
    - Systems and Techniques Development
- ASSISTANT DIVISION CHIEF FOR PLANS AND OPERATIONS
  - Offices
    - Program Management
    - Plans and Coordination
    - International Activities
- ASSISTANT DIVISION CHIEF FOR INFORMATION AND DATA SERVICES
  - Offices
    - Product Distribution Policy
    - Publications Liaison and Review
    - National Cartographic and Geographic Information Service
  - PUBLIC INQUIRIES OFFICES
- FIELD CENTERS
  - Eastern Mapping—Reston, VA
  - Mid Continent Mapping—Rolla, MO
  - Printing and Distribution—Reston, VA
  - Rocky Mountain Mapping—Denver, CO
  - Western Mapping—Menlo Park, CA

### GEOLOGIC DIVISION
CHIEF GEOLOGIST
ASSOCIATE CHIEF GEOLOGIST

- OFFICE OF SCIENTIFIC PUBLICATIONS
- OFFICE OF REGIONAL GEOLOGY
  - Branches
    - Eastern
    - Central
    - Western
    - Engineering Geology
    - Special Projects
    - Astrogeologic Studies
    - Paleontology and Stratigraphy
- OFFICE OF MINERAL RESOURCES
  - Branches
    - Eastern
    - Central
    - Western
    - Alaskan Geology
    - Exploration Research
    - Office of Resource Analysis
- OFFICE OF EARTHQUAKE STUDIES
  - Branches
    - Seismic Engineering
    - Global Seismology
    - Seismology
    - Ground Motion and Faulting
    - Earthquake Tectonics and Risk
    - Tectonophysics
    - Network Operations
- OFFICE OF GEOCHEMISTRY AND GEOPHYSICS
  - Branches
    - Experimental Geochemistry and Mineralogy
    - Field Geochemistry and Petrology
    - Isotope Geology
    - Regional Geochemistry
    - Analytical Laboratories
    - Petrophysics and Remote Sensing
    - Electromagnetism and Geomagnetism
    - Regional Geophysics
- OFFICE OF ENERGY RESOURCES
  - Branches
    - Oil and Gas Resources
    - Coal Resources
    - Sedimentary Mineral Resources
    - Uranium and Thorium Resources
- OFFICE OF INTERNATIONAL GEOLOGY
  - Branches
    - Latin American and African Geology
    - Middle Eastern and Asian Geology
- OFFICE OF MARINE GEOLOGY
  - Branches
    - Pacific—Arctic Geology
    - Atlantic—Gulf of Mexico Geology
- REGIONAL OFFICES
  - Eastern—Reston, VA
  - Central—Denver, CO
  - Western—Menlo Park, CA

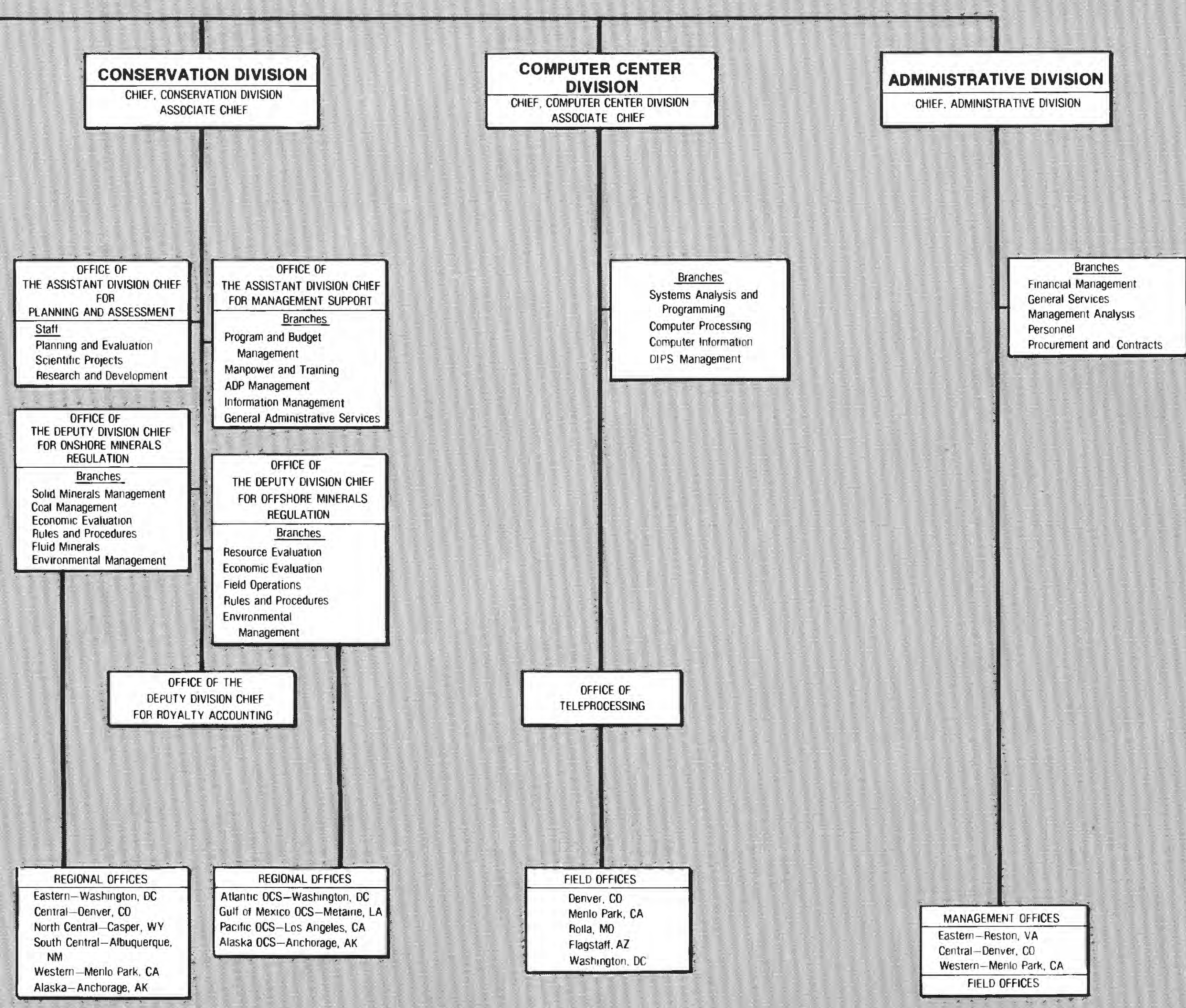
### WATER RESOURCES DIVISION
CHIEF HYDROLOGIST
ASSOCIATE CHIEF HYDROLOGIST

- OFFICE OF INTERNATIONAL HYDROLOGY
- OFFICE OF WATER DATA COORDINATION
- OFFICE OF THE ASSISTANT CHIEF FOR RESEARCH AND TECHNICAL COORDINATION
  - DEPUTY ASSISTANT CHIEF FOR RESEARCH
  - Branches
    - Surface Water
    - Ground Water
    - Quality of Water
- OFFICE OF THE ASSISTANT CHIEF FOR SCIENTIFIC PUBLICATIONS AND DATA MANAGEMENT
- OFFICE OF THE ASSISTANT CHIEF FOR OPERATIONS
  - ADMINISTRATIVE OFFICER
- REGIONAL OFFICES
  - Northeastern—Reston, VA
  - Southeastern—Atlanta, GA
  - Central—Denver, CO
  - Western—Menlo Park, CA
  - DISTRICT OFFICES

# ORGANIZATIONAL AND STATISTICAL DATA

## U.S. Geological Survey Chart of Organization

### As of September 30, 1981



# U.S. Geological Survey Offices
## Headquarters Offices

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

As of September 30, 1981

### Office of the Director

| Official | Name | Telephone number | Address |
|---|---|---|---|
| Director | Dallas L. Peck | (703) 860-7411 | National Center, STOP 101 |
| Associate Director | Doyle G. Frederick | (703) 860-7412 | National Center, STOP 102 |
| Special Assistant (Washington Liaison) and Deputy Ethics Counselor | Jane H. Wallace | (202) 343-3888 | Rm. 7343, Interior Bldg., Washington, DC 20240 |
| Assistant Director for Research | Robert L. Wesson | (703) 860-7488 | National Center, STOP 104 |
| Assistant Director for Resource Programs | Eddie R. Wyatt (Acting) | (703) 860-7481 | National Center, STOP 171 |
| Assistant Director for Engineering Geology | James F. Devine | (703) 860-7491 | National Center, STOP 106 |
| Assistant Director for Administration | Edmund J. Grant | (703) 860-7201 | National Center, STOP 201 |
| Assistant Director for Programs | Dale Bajema | (703) 860-7435 | National Center, STOP 105 |
| Assistant Director—Eastern Region | Betty M. Miller | (703) 860-7414 | National Center, STOP 109 |
| Assistant Director—Central Region | Robert E. Evans | (303) 234-4630 | Box 25046, STOP 101, Denver Federal Center, Denver, CO 80225 |
| Assistant Director—Western Region | John R. Swinnarton (Acting) | (415) 323-8111 | 345 Middlefield Road Menlo Park, CA 94025 |
| Congressional Liaison Officer | Talmadge W. Reed | (703) 860-6438 | National Center, STOP 112 |
| Chief, Public Affairs Office | Donovan B. Kelly | (703) 860-7444 | National Center, STOP 119 |
| Staff Assistant (Special Issues) | John N. Fischer, Jr. | (703) 860-7413 | National Center, STOP 121 |
| Special Assistant to the Director | William W. Barnwell | (907) 271-4398 | 218 E. St., Anchorage, AK 99501 |

### National Mapping Division

| Official | Name | Telephone number | Address |
|---|---|---|---|
| Chief | Rupert B. Southard | (703) 860-6231 | National Center, STOP 516 |
| Associate Chief | Roy R. Mullen | (703) 860-6232 | National Center, STOP 516 |
| Assistant Division Chief for Research | Lowell E. Starr, (Acting) | (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 (Acting) | (703) 860-7181 | National Center, STOP 508 |

### Geologic Division

| Official | Name | Telephone number | Address |
|---|---|---|---|
| Chief Geologist | Robert E. Davis (Acting) | (703) 860-6531 | National Center, STOP 911 |
| Associate Chief Geologist | William C. Prinz (Acting) | (703) 860-6532 | National Center, STOP 911 |
| Deputy Chief Geologist, Operations | Penelope M. Hanshaw | (703) 860-7429 | National Center, STOP 911 |
| Deputy Chief Geologist, Program and Budget | David A. Seyler | (703) 860-6544 | National Center, STOP 910 |
| Office of Scientific Publications, Chief | John M. Aaron (Acting) | (703) 860-6575 | National Center, STOP 904 |
| Office of Environmental Geology, Chief | Douglas M. Morton | (703) 860-6411 | National Center, STOP 908 |
| Office of Earthquake Studies, Chief | John R. Filson | (703) 860-6471 | National Center, STOP 905 |
| Office of Energy Resources, Chief | Linn Hoover (Acting) | (703) 860-6431 | National Center, STOP 915 |
| Office of Marine Geology, Chief | Terence N. Edgar | (703) 860-7291 | National Center, STOP 915 |
| Office of Mineral Resources, Chief | A. Thomas Ovenshine | (703) 860-6561 | National Center, STOP 913 |
| Office of Geochemistry and Geophysics, Chief | Robert I. Tilling | (703) 860-6584 | National Center, STOP 906 |
| Office of International Geology, Chief | John A. Reinemund | (703) 860-6418 | National Center, STOP 917 |

### Water Resources Division

| Official | Name | Telephone number | Address |
|---|---|---|---|
| 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 | Robert J. Dingman | (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 | Leslie B. Laird | (703) 860-6971 | National Center, STOP 414 |
| Office of Water Data Coordination, Chief | Porter E. Ward | (703) 860-6931 | National Center, STOP 417 |
| Office of International Activities, Chief | Della Laura | (703) 860-6548 | National Center, STOP 470 |

### Conservation Division

| Official | Name | Telephone number | Address |
|---|---|---|---|
| Chief | Andrew V. Bailey (Acting) | (703) 860-7581 | National Center, STOP 610 |
| Associate Chief | Hillary A. Oden | (703) 860-7581 | National Center, STOP 610 |
| Deputy Division Chief, Offshore Minerals Regulation | Robert L. Rioux | (703) 860-6141 | National Center, STOP 640 |
| Deputy Division Chief, Onshore Minerals Regulation | John J. Dragonetti | (703) 860-7533 | National Center, STOP 650 |
| Deputy Division Chief, Royalty Management | J. Ronald Jones | (703) 860-7511 | National Center, STOP 660 |
| Assistant Division Chief, Management Support | James V. Fare | (703) 860-6486 | National Center, STOP 630 |
| Assistant Division Chief, Planning and Assessments | Junius Walker | (703) 860-7591 | National Center, STOP 620 |

| Office | Name | Telephone number | Address |
|---|---|---|---|
| **Office of Earth Sciences Applications** | | | |
| Chief | Gene A Thorley | (703) 860-7471 | National Center, STOP 703 |
| Associate Chief | James R Burns (Acting) | (703) 860-7811 | National Center, STOP 703 |
| Earth Resources Observations Systems Office, Chief | John W Salisbury | (703) 860-7881 | National Center, STOP 730 |
| Resource Planning Analysis Office, Chief | Dennis R Hood | (703) 860-6717 | National Center, STOP 750 |
| Environmental Affairs Office, Chief | James R Burns | (703) 860-7455 | National Center, STOP 760 |
| Earth Sciences Assistance Office, Chief | Jerry C Stephens | (703) 860-6961 | National Center, STOP 720 |
| Visual Information Services Office, Chief | Theresa M Sousa | (703) 860-6162 | National Center, STOP 790 |
| **Office of National Petroleum Reserve in Alaska** | | | |
| Chief | George Gryc | (907) 276-7422 | *2525 "C" St, Suite 400 Anchorage, AK 99503 |
| Technical Officer | Valentine Zadnik | (703) 860-6208 | National Center, STOP 151 |
| Program Officer | (Vacant) | (703) 860-6208 | National Center, STOP 151 |
| **Computer Center Division** | | | |
| Chief | Carl E Diesen | (703) 860-7106 | National Center, STOP 801 |
| Associate Chief | R Michael Gall | (703) 860-7108 | National Center, STOP 801 |
| Office of Teleprocessing | Ralph N Eicher | (703) 860-7119 | National Center, STOP 805 |
| **Administrative Division** | | | |
| Chief | Edmund J. Grant | (703) 860-7201 | National Center, STOP 201 |
| Administrative Operations Officer | George F Hargrove, Jr | (703) 860-7204 | National Center, STOP 203 |
| Personnel Officer | Maxine C Millard | (703) 860-6127 | National Center, STOP 215 |
| Contracts Officer | Paul A Dennett (Acting) | (703) 860-7261 | National Center, STOP 205 |
| Finance Officer | Posey B Howell, Jr | (703) 860-6181 | National Center, STOP 270 |
| General Services Officer | Robert E Rogers | (703) 860-7206 | National Center, STOP 207 |
| Management Analysis Officer | William F Grossman, Jr | (703) 860-7211 | National Center, STOP 206 |

## Selected Field Offices

### National Mapping Division

#### Regional Centers

| | | | |
|---|---|---|---|
| Eastern | Roy E Fordham | (703) 860-6352 | National Center, STOP 567 |
| Mid-Continent | Lawrence H Borgerding | (314) 341-0880 | 1400 Independence Road, Rolla, MO 65401 |
| Rocky Mountain | John D. McLaurin | (303) 234-2351 | Box 25046, STOP 510, Denver, 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 Offices** | | | |
| Alaska | Elizabeth C Behrendt | (907) 277-0577 | 108 Skyline Bldg., 508 2d Ave, Anchorage, AK 99503 |
| 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, ext 2817 | 345 Middlefield Rd., STOP 33, Bldg 3, Rm 122, Menlo Park, CA 94025 |
| San Fransico | Patricia A Shiffer | (415) 556-5627 | 504 Customhouse, 555 Battery St, San Fransico, 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 Mabey | (801) 524-5652 | 8105 Fed Bldg, 125 S State St, Salt Lake City, UT 84138 |

* Office of National Petroleum Reserve in Alaska is headquartered in Anchorage, Alaska

## Selected Field Offices—Continued

| Office | Name | Telephone number | Address |
|---|---|---|---|
| **Public Inquiries Offices—Continued** | | | |
| Virginia | A Ernestine Jones | (703) 860-6167 | 1C402 National Center,<br>STOP 503, 12201 Sunrise Valley Dr,<br>Reston, VA 22092 |
| Washington | Jean E Flechel | (509) 456-2524 | 678 U S. Courthouse<br>W 920 Riverside Ave,<br>Spokane, WA 99201 |
| **Distribution Branch Offices** | | | |
| Alaska | Natalie Cornforth | (907) 456-7535 | 101 12th Ave, Box 12<br>Fairbanks, AK 99701 |
| Western | Dwight F Canfield | (303) 234-3832 | Box 25286, STOP 306,<br>Denver Federal Center<br>Denver, CO 80225 |
| Eastern | George V DeMeglio | (703) 557-2781 | 1200 S Eads St,<br>Arlington, VA 22202 |
| **Geological Division** | | | |
| **Regional Offices** | | | |
| Eastern | Avery A Drake, Jr | (703) 860-6631 | National Center, STOP 953 |
| Central | Richard F Mast | (303) 234-3625 | Box 25046, STOP 911,<br>Denver Federal Center<br>Denver, CO 80225 |
| Western | G Brent Dalrymple | (415) 323-8111 | 345 Middlefield Rd,<br>Menlo Park, CA 94025 |
| **Water Resources Division** | | | |
| **Regional Offices** | | | |
| Northeastern | James E Biesecker | (703) 860-6985 | National Center, STOP 433 |
| Southeastern | James L Cook | (404) 221-5174 | Richard B Russell Federal Bldg,<br>75 Spring St., SW, Suite 77,<br>Atlanta, GA 30303 |
| Central | Alfred Clebsch, Jr | (303) 234-3661 | Box 25046, STOP 406,<br>Denver Federal Center<br>Denver, CO 80225 |
| Western | John D Bredehoeft | (415) 323-8111,<br>ext 2337 | 345 Middlefield Road, MS66,<br>Menlo Park, CA 94025 |
| **District Offices** | | | |
| Alabama | Charles A Pascale | (205) 752-8104 | P O Box V, 202 Oil and Gas Board Bldg,<br>University of Alabama,<br>University, AL 35486 |
| Alaska | Philip Emery | (907) 271-4138 | 733 W 4th Ave, Suite 400,<br>Anchorage, AK 99501 |
| Arizona | Robert D. Mac-Nish | (602) 792-6671 | Federal Bldg,<br>301 W Congress St,<br>Tucson, AZ 85701 |
| Arkansas | Ector E Gann | (501) 378-6391 | 2301 Federal Office Bldg.,<br>700 W Capital Ave,<br>Little Rock, AR 72201 |
| California | Timothy Durbin | (415) 323-8111,<br>ext 2326 | 855 Oak Grove Ave,<br>Menlo Park, CA 94025 |
| Colorado | James F Blakey | (303) 234-5092 | Box 25046, STOP 415,<br>Denver Federal Center,<br>Denver, CO 80225 |
| Connecticut | David McCartney | (203) 244-2528 | 135 High St, Rm 235,<br>Hartford, CT 06103 |
| Delaware | Herbert J Freiberger | (301) 828-1535 | See Maryland District Office |
| District of Columbia | Herbert J Freiberger | (301) 828-1535 | See Maryland District Office |
| Florida | I H Kantrowitz | (904) 386-7145 | 325 John Knox Rd.,<br>Suite F-240,<br>Tallahassee, FL 32303 |
| Georgia | Jeffrey T Armbruster | (404) 221-4858 | 6481 Peachtree Industrial Blvd, Suite B,<br>Doraville, GA 30360 |
| Hawaii | Benjamin L Jones | (808) 546-8331 | P O Box 50166, Rm 6110,<br>300 Ala Moana Blvd,<br>Honolulu, HI 96850 |
| Idaho | Ernest F Hubbard, Jr | (208) 334-1750 | Box 036, Federal Bldg,<br>Rm 365, 550 W Fort St,<br>Boise, ID 83724 |

## Selected Field Offices—Continued

| Office | Name | Telephone number | Address |
|---|---|---|---|
| **Water Resources—Continued** | | | |
| **District Offices—Continued** | | | |
| Illinois | Larry G Toler | (217) 398-5353 | Champaign County Bank Plaza, 102 E Main St, 4th Floor, Urbana, IL 61301 |
| Indiana | Dennis K. Stewart | (317) 269-7101 | 1819 N Meridian St, Indianapolis, IN 46202 |
| Iowa | Donald K Leifeste | (319) 337-4191 | P O Box 1230, 400 S Clinton St, Iowa City, IA 52240 |
| Kansas | Joseph S. Rosenshein | (913) 864-4321 | 1950 Ave A, Campus West, University of Kansas, Lawrence, KS 66045 |
| Kentucky | Alfred Knight | (502) 582-5241 | 572 Federal Bldg, 600 Federal Pl, Louisville, KY 40202 |
| Louisiana | Darwin Knockenmus | (504) 390-0281 | P O. Box 66492, 6554 Florida Blvd, Baton Rouge, LA 70896 |
| Maine | Ivan C James II | (617) 223-2822 | See Massachusetts District Office |
| Maryland | Herbert J Freiberger | (301) 828-1535 | 208 Carrol Bldg, 8600 La Salle Rd., Towson, MD 21204 |
| Massachusetts | Ivan C James II | (617) 223-2822 | 150 Causeway St., Suite 1001, 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 | 1033 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 39201 |
| Missouri | Horace G Jeffery (Acting) | (314) 341-0824 | 1400 Independence Rd, STOP 200, Rolla, MO 65401 |
| Montana | George M Pike | (406) 449-5263 | Federal Bldg., 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 | Vacant | (702) 882-1388 | Federal Bldg, Rm 229, 705 N Plaza St, Carson City, NV 89701 |
| New Hampshire | Ivan C James II | (617) 223-2822 | See Massachusetts District Office |
| New Jersey | Donald E Vaupel | (609) 989-2162 | 430 Federal Bldg., 402 E State St., Trenton, NJ 08608 |
| New Mexico | James F Daniel | (505) 766-2246 | P.O Box 26659, Western Bank Bldg, Rm 809, 505 Marquette, NW., Albuquerque, NM 87125 |
| New York | Lawrence A Martins | (518) 472-3107 | P O 1350, 343 U S Post Office and Courthouse Bldg, Albany, NY 12201 |
| North Carolina | Elver J McClelland | (919) 755-4510 | P O. Box 2857, Rm 436, Century Postal Station Raleigh, NC 27602 |
| North Dakota | Grady Moore | (701) 255-4011, ext 601 | 821 East Interstate Ave, Rm 332, New Fed Bldg., 3d St and Rosser Ave, Bismark, ND 58501 |
| Ohio | Steven M Hindall | (614) 469-5553 | 975 West Third Ave, Columbus, OH 43212 |
| Oklahoma | James H. Irwin | (405) 231-4256 | Rm 621, 215 Dean A. MeGee St, Oklahoma City, OK 73102 |
| Oregon | Stanley F Kapustka | (503) 231-2009, ext 4776 | P O Box 3202, 830 NE Holladay St, Portland, OR 97232 |
| Pennsylvania | David E Click | (717) 782-3468 | P O Box 1107, 4th Floor, Federal Bldg, 228 Walnut St., Harrisburg, PA 17108 |

## Selected Field Offices—Continued

| Office | Name | Telephone number | Address |
|---|---|---|---|
| **Water Resources Division—Continued** | | | |
| **District Offices—Continued** | | | |
| Puerto Rico | Ferdinand Quinones-Marquez | (809) 783-4660 | GSA Center, Bldg 652, Ft Buchanan, PR 00936 |
| Rhode Island | Ivan C James II | (617) 223-2822 | See Massachusetts District Office |
| South Carolina | Rodney N Cherry | (803) 765-5966 | Strom Thurmond Federal Bldg, 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 | Arthur Putnam | (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. 17th St, S, Salt Lake City, UT 84104 |
| Vermont | Ivan C James II | (617) 223-2822 | See Massachusetts District Office |
| Virginia | William E Forrest | (804) 771-2427 | 200 W. Grace St, Rm 304, Richmond, VA 23220 |
| Washington | Charles R Collier | (206) 593-6510 | 1201 Pacific Ave., Suite 600, Tacoma, WA 98402 |
| West Virginia | David H Appel | (304) 343-6181, ext 310 | 3017 Federal Bldg and U S. Courthouse, 500 Quarrier St., E, Charleston, W VA 25301 |
| Wisconsin | Vernon Norman | (608) 262-2488 | 1815 University Ave, Rm 200, Madison, WI 53706 |
| Wyoming | William W Dudley, Jr | (307) 778-2220, ext 2153 | P O Box 1125, 2120 Capitol Ave, Rm 5017, Cheyenne, WY 82001 |
| **Conservation Division** | | | |
| **Regional Offices** | | | |
| Eastern/Atlantic OCS | George F. Brown | (202) 254-3137 | 1725 K St, NW, Suite 204, Washington, DC 20006 |
| Central | John B. Trippe | (303) 234-2855 | Box 25046, STOP 609, Denver Federal Center, Bldg 85, Denver, CO 80225 |
| North Central | Dwayne E Hull | (303) 265-5550, ext 5746 | 100 East B St., Rm 4130, Casper, WY 82601 |
| South Central | James W. Sutherland | (505) 766-2841 | P O Box 26124, 505 Marquette, NW #815 Albuquerque, NM 87125 |
| Gulf of Mexico Outer Continental Shelf (OCS) Operations | Lowell G Hammons | (504) 837-4720, ext. 9381 | P O Box 7944, 434 Imperial Office Bldg, 3301 N Causeway Blvd, Metairie, LA 70010 |
| Pacific OCS | Reid T Stone (Acting) | (213) 688-6875 | 130 Federal Bldg, 1340 West 6th St., Los Angeles, CA 90017 |
| Alaska/Alaska OCS | Joseph M. Jones | (907) 271-4304 | 800 "A" St., Suite 201, Anchorage, AK 99501 |
| **Office of Earth Sciences Applications** | | | |
| **Earth Resources Observetion Systems Data Center** | | | |
| South Dakota | Allen H Watkins | (605) 594-6123 | EROS Data Center, Sioux Falls, SD 57198 |
| **National Petroleum Reserve in Alaska** | | | |
| **District Offices** | | | |
| NPRA Operations Office | Max Brewer | (907) 276-7422 | 2525 "C" St, Suite 400, Anchorage, AK 99503 |
| Exploration Strategy Office | Arthur Bowsher | (415) 323-2917 | 345 Middlefield Rd, Menlo Park, CA 94025 |
| **Administrative Division** | | | |
| **Regional Management Offices** | | | |
| Eastern | Roy Heinbuch | (703) 860-7691 | National Center, STOP 290 |
| Central | Jack J Stassi | (303) 234-3736 | Box 25046, STOP 201, Denver Federal Center, Denver, CO 80225 |
| 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 A complete listing of these services and publications with instructions on how to obtain them is given in Geological Circular 777, *A Guide to Obtaining Information from the USGS 1981*, available free upon request from U S Geological Survey, Distribution Branch, 604 S Pickett St, Alexandria, Va 22304 A summary listing of services and publications offered appears below

**To buy Survey book publications or to request Survey circulars, catalogs, pamphlets, and leaflets (limited quantities free), write or visit:**

U.S Geological Survey
Distribution Branch Text Products Section
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

**To buy maps of areas west of the Mississippi River and to request Survey catalogs, pamphlets, and leaflets (limited quantities free), write or visit:**

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

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

Missouri
Midcontinent Mapping Center
National Cartographic Information Center
1400 Independence Rd
Rolla, MO 65401

Tennessee
Tennessee Valley Authority
200 Haney Bldg
311 Broad St
Chattanooga, TN 37401

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 photography, write or visit.**

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

**To obtain assistance in locating sources of water data, indentifying 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 area, and geologic maps and mapping, write:**

U S Geological Survey
Geologic Inquiries Group
907 National Center
12201 Sunrise Valley Dr
Reston, VA 22091

## 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 1981 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
c—Conservation Division
e—Office of Earth Sciences Applications
g—Geological Division
n—National Mapping Division
w—Water Resources Division

### Federal Cooperators

**Appalachian Regional Commission (e)**
**Central Intelligence Agency (g)**
**Council on Environmental Quality (e)**

**Department of Agriculture:**
- Economics, Statistics, and Cooperatives Service (n)
- Forest Service (e, n, w)
- Graduate School (w)
- Science and Education Administration (e, w)
- Soil Conservation Service (g, n, w)

**Department of the Air Force:**
- AFWL/PRP Kirtland Air Force Base (w)
- Air Force Academy (w)
- Bolling Air Force Base (g)
- Hanscom Air Force Base (g)
- Headquarters, AFTAC/AC (g)
- Vandenberg Air Force Base (w)
- Wurtsmith Air Force Base (w)

**Department of the Army:**
- Corps of Engineers (e, g, n, w)
- Fort Belvoir (n)
- Fort Carson Military Reservation (w)
- Rocky Mountain Arsenal (w)
- Mobility Equipment Research and Development Command (g)

**Department of Commerce:**
- Coastal Plains Regional Action Planning Commission (e, g)
- Four Corners Regional Action Planning Commission (e)
- National Bureau of Standards (g)
- National Oceanic and Atmospheric Administration
  - National Marine Fisheries Service (w)
  - National Ocean Survey (n)
  - National Weather Service (g, w)
  - Office of Sea Grants (e)
- Old West Regional Action Planning Commission (e)
- Ozarks Regional Action Planning Commission (e)
- Pacific Northwest Regional Action Planning Commission (e)
- Southwest Border Regional Action Planning Commission (e)

**Department of Defense Agencies:**
- Defense Advanced Research Projects Agency (g)
- Defense Mapping Agency (n)
- Defense Nuclear Agency (g)
- Defense Intelligence Agency (g)

**Department of Energy:**
- Albuquerque Operations Office (g, w)
- Argonne National Laboratory (c)
- Batelle National Laboratory (c)

**Department of Energy—Continued**
- Bonneville Power Administration (w)
- Brookhaven National Laboratory (c)
- Chicago Operations Office (w)
- Energy Programs Division (e)
- Grand Junction Office (g)
- Idaho Operations Office (g, w)
- Lawrence Livermore Laboratory (g)
- Los Alamos Science Laboratory (g, w)
- Morgantown Energy Technology Center (g)
- Nevada Operations Office (g, w)
- Oak Ridge Operations Office (g, w)
- Office of Energy Research (g)
- Office of International Affairs (g)
- Richland Operations Office (c, g, w)
- San Francisco Operations (g, w)

**Department of Health, Education, and Welfare (w)**

**Department of Housing and Urban Development (w)**

**Department of the Interior:**
- Alaska State Office, Natural Gas Pipeline (g)
- Bureau of Indian Affairs (e, g, n, w)
- Bureau of Land Management (e, g, n, w)
- Bureau of Mines (e, g, n, w)
- Heritage Conservation and Recreation Service (e)
- National Park Service (e, g, n, w)
- Office of the Secretary (e, g)
- Office of Surface Mining Reclamation and Enforcement (e, g, n, w)
- Trans-Alaska Pipeline (e)
- U S Fish and Wildlife Service (e, g, n, w)
- Water and Power Resources Service (g, w)

**Department of the Navy:**
- Naval Explosive Ordance Disposal Test Center (g)
- Naval Oceanographic Office (n, w)
- Naval Weapons Center, China Lake (g, w)
- U S Marine Corps, Camp Pendleton (w)

**Department of State:**
- Agency of International Development (g, w)
- Bureau of International Organization Affairs (e)
- 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)

**Department of Treasury:**
- U S Customs Service (n)

**Environmental Protection Agency: (n)**
- Corvallis Environmental Research Laboratory (w)
- Office of Energy, Minerals and Industry (g, w)
- Office of Monitoring and Technical Support (w)
- Office of Research and Development (c)

**Federal Emergency Management Agency (e, g)**

**General Services Administration (w)**

**Great Lakes Basin Commission (e)**

**Missouri River Basin Commission (e, w)**

**National Academy of Sciences Marine Board (c)**

**National Aeronautics and Space Administration (e, g, w, n)**

**National Science Foundation (e, g, n)**

**New England River Basins Commission (e)**

**Nuclear Regulatory Commisssion (g, w)**

**Tennessee Valley Authority (n, w)**

**United States Arms Control and Disarmament Agency (g)**

**Water Resources Council (n, w)**

## State, County, and Local Cooperators

**Alabama:**

Alabama Highway Department (w)
Geological Survey of Alabama (c, n, w)
Jefferson County Commission (w)

**Alaska**

Alaska Department of Fish and Game (w)
Alaska Department of Natural Resources (w)
  Division of Forests, Lands, and Water Management (w)
  Division of Geological and Geophysical Surveys (w)
  Division of Policy Development and Planning ( w)
Alaska Department of Transportation and Public Facilities (w)
Alaska Power Authority (w)
City and Borough of Juneau (w)
City of Craig (w)
Department of Environmental Conservation (w)
Fairbanks North Star Borough (w)
Kenai Peninsula Borough (w)
Municipality of Anchorage (w)
Matanuska Susitna Borough (w)

**Arizona:**

Arizona Bureau of Geology and Mineral Technology (e)
Arizona Department of Health Services (w)
Arizona Department of Water Resources (w)
Arizona Game and Fish Department (w)
City of Flagstaff (w)
City of Safford (w)
City of Tucson (w)
Flood Control District of Maricopa County (w)
Gila Valley Irrigation District (w)
Maricopa County Municipal Water Conservation District No 1 (w)
Metropolitan Water District of Southern California (w)
Pima County Board of Supervisors (w)
Salt River Valley Water Users' Association (w)
San Carlos Irrigation and Drainage District (w)
Show Low Irrigation Company (w)
University of Arizona (w)

**Arkansas:**

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

**California:**

Alameda County Flood Control and Water Conservation District,
  Zone 7 (w)

## State, County, and Local Cooperators—Continued

**California**—Continued

Antelope Valley-East Kern Water Agency (w)
California Department of Conservation (g)
  Division of Mines and Geology (g)
California Department of Fish and Game, Region 2 (w)
California Department of Boating and Waterways (w)
California Department of Transportation, District 3 (w)
California Department of Water Resources (n, w)
California Regional Water Quality Control Board (w)
  Central Coast Region (w)
  Colorado River Basin Region (w)
  Lahontan Region (w)
  North Coast Region (w)
  San Francisco Bay Region (w)
  Santa Ana Region (w)
California Water Resources Control Board (w)
Carpinteria County Water District (w)
Casitas Municipal Water District (w)
City and County of San Francisco (w)
  Hetch Hetchy Water and Power (w)
City of Los Angeles (w)
City of Merced (w)
City of Modesto (w)
  Public Works Department (w)
City of Santa Barbara (w)
  Public Works Department (w)
City of San Diego (w)
City of Thousand Oaks (w)
Coachella Valley County Water District (w)
Contra Costa County Flood Control and Water
  Conservation District (w)
County of Modoc (w)
  Public Works Department (w)
County of San Diego (w)
  Department of Public Works (w)
  Planning and Land Use (w)
County of San Joaquin (w)
  Flood Control and Water Conservation District (w)
County of San Mateo (w)
  Department of Public Works (w)
  Planning Department (w)
Crestline-Lake Arrowhead Water Agency (w)
Desert Water Agency (w)
East Bay Municipal Utility District (w)
East Bay Regional Park District (w)
Fresno County, Department of Resources and Development (w)
Fresno Metropolitan Flood Control District (w)
Georgetown Divide Public Utility District (w)
Goleta County Water District (w)
Humboldt Bay Municipal Water District (w)
Imperial County Department of Public Works (w)
Imperial Irrigation District (w)
Indian Planning Consortium—Central California (w)
Indian Wells Valley County Water District (w)
Kern County Water Agency (w)
Kings River Conservation District (w)
Lake County Planning Department (w)
Los Angeles County Flood Control District (w)
Los Angeles Department of Water and Power (w)
Madera County Flood Control and Water Conservation Agency (w)
Madera Irrigation District (w)
Marin County Department of Public Works (w)
Marin Municipal Water District (w)
Mendocino County Department of Public Health (w)
Merced Irrigation District (w)
Mojave Water Agency (w)

**California**—Continued

Montecito Water District (w)
Monterey County Flood Control and Water Conservation District (w)
Monterey Peninsula Water Management District (w)
Napa County Flood Control and Water Conservation District (w)
Orange County Environmental Management Agency (w)
Oroville-Wyandotte Irrigation District (w)
Pacheco Pass Water District (w)
Rancho California Water District (w)
Paradise Irrigation District (w)
Placer County Water Agency (w)
Riverside County Flood Control and Water Conservation District (w)
Sacramento Regional County Sanitation District, Department of Public Works (w)
San Benito County Water Conservation and Flood Control District (w)
San Bernadino Valley Municipal Water District (w)
San Francisco Water Department (w)
San Luis Obispo County (w)
  Engineering Department (w)
Santa Barbara County Flood Control and Water Conservation District (w)
Santa Barbara County Water Agency (w)
Santa Clara Valley Water District (w)
Santa Cruz City (w)
  County Community Resources Center, Zone 4 (w)
Santa Cruz County (w)
  Flood Control and Water Conservation District (w)
Santa Maria Valley Water Conservation District (w)
Santa Rosa Band of Mission Indians (w)
Siskiyou County Flood Control and Water Conservation District (w)
Sonoma County Planning Department (w)
Soquel Creek County Water District (w)
South San Joaquin County (w)
Terra Bella Irrigation District (w)
Tulare County Flood Control District (w)
Turlock Irrigation District (w)
United Water Conservation District (w)
University of California (w)
  Division of Environmental Studies (Davis) (w)
  Los Alamos Scientific Laboratory (c)
  School of Forestry and Conservation (Berkeley) (w)
  University of California (Santa Barbara) (c)
Ventura County Public Works Agency (w)
Western Municipal Water District (w)
Woodbridge Irrigation District (w)
Yolo County Flood Control and Water Conservation District (w)

**Colorado:**

Adams County Board of Commissioners (w)
Arapahoe County (w)
Arkansas River Compact Administration (w)
Central Yuma Ground Water Management District (w)
Chapel Hills Water and Sanitation District (w)
Cherokee Water District (w)
City and County of Denver (w)
City of Aspen (w)
City of Aurora (w)
City of Colorado Springs (w)
  Department of Public Utilities (w)
  Office of the City Manager (w)
City of Glenwood Springs (w)
City of Idaho Springs (w)

State, County, and Local Cooperators—Continued

**Colorado**—Continued

City of Northglenn (w)
City of Pueblo (w)
Colorado Department of Health (w)
  Water Pollution Control Division (w)
Colorado Department of Highways (w)
Colorado Department of Local Affairs (n)
Colorado Divsion of Water Resources (w)
  Office of the State Engineer (w)
Colorado Division of Wildlife, Department of Natural Resources (w)
Colorado Geological Survey (w)
Colorado River Water Conservation District (w)
Colorado Water Conservation Board (w)
Copper Mountain Water and Sanitation District (w)
Denver Regional Council of Governments (w)
Eagle County Commissioners (w)
Elbert County Planning Department (w)
El Paso County (w)
  Water Users Association (w)
Frenchman Ground Water Management District (w)
Larimer—Weld Regional Council of Governments (w)
Marks Butte Ground Water Management District (w)
Metropolitan Denver Sewage Disposal District No 1 (w)
Mineral County Commissioners (w)
Northern Colorado Water Conservation District (w)
Pitkin County Board of County Commissioners (w)
Pueblo Area Council of Goverments (w)
Pueblo Civil Defense Agency (w)
Purgatoire River Water Conservancy District (w)
Rio Grande Water Conservation District (w)
Sand Hills Ground Water Management District (w)
St Vrain and Left Hand Water Conservancy District (w)
Southeastern Colorado Water Conservancy District (w)
Southwestern Water Conservation District (w)
Trinchera Conservancy District (w)
Uncompahgre Valley Water Users (w)
Upper Arkansas River Water Conservancy District (w)
Urban Drainage and Flood Control District (w)
White River Soil Conservation District (w)

**Connecticut:**

City of New Britain (w)
City of Torrington (w)
Connecticut Department of Environmental Protection (e, g, n, w)
Midstate Regional Planning Agency (w)
New Haven Water Co (w)
Northwest Regional Planning Agency (w)
Town of Enfield (w)
Town of Fairfield (w)
Town of Manchester (w)
Town of Meriden (w)
Town of Norwalk (w)
Town of Simsbury (w)
Town of Southbury (w)
Town of Windsor (w)
Town of Woodbury (w)
University of Connecticut (w)

**Delaware:**

Delaware Geological Survey (n, w)
Department of Natural Resources and Environmental Control (w)
New Castle County, Public Works Department (w)

**District of Columbia:**

Department of Environmental Services (w)

**Florida:**

Big Cypress Basin Board (w)
Brevard County (w)
  Board of County Commissioners (w)
Broward County (w)
  Environmental Quality Control Board (w)
  Water Management Division (w)
City of Boca Raton (w)
City of Bradenton (w)
City of Cape Coral (w)
City of Clearwater (w)
City of Cocoa (w)
City of Fort Lauderdale (w)
City of Fort Walton Beach (w)
City of Gainesville (w)
City of Hallandale (w)
City of Hollywood (w)
City of Pensacola (w)
City of Perry (w)
City of Pompano Beach (w).
  Water and Sewer Department (w)
City of Quincy (w)
City of St Petersburg (w)
City of Sarasota (w)
City of Tallahassee (w)
City of Tampa (w)
City of Winter Park (w)
Collier County (w)
Consolidated City of Jacksonville (w)
  Department of Health and Environmental Services (w)
  Department of Public Works (w)
Coordinating Council on the Restoration of Kissimmee River Valley and Taylor Creek-Nubbins Slough Basin (w)
Englewood Water District (w)
Escambia County (w)
  Board of County Commissioners (w)
  County Utilities Department (w)
Flagler County (w)
Florida Bureau of Water Resources Management (w)
  Florida Department of Environmental Regulation (w)
Florida Department of Natural Resources (n)
Florida Department of Transportation (w)
Florida Division of Recreation and Parks (w)
Florida Keys Aqueduct Authority (w)
Hillsborough County (w)
Jacksonville Electric Authority (w)
Jupiter Inlet District (w)
Lake County (w).
  Board of County Commissioners (w)
  Pollution Control Department (w)
  Water Authority (w)
Lee County (w)
  Board of County Commissioners (w)
Leon County Public Works (w)
Manatee County Board of County Commissioners (w)
Marion County Board of County Commissioners (w)
Metropolitan Dade County (w)
  Department of Environmental Resources Management (w)
  Planning Department (w)
  Public Works Department (w)
Miami-Dade Water and Sewer Authority (w)
Northwest Florida Water Management District (w)
Old Plantation Water Control District (w)

State, County, and Local Cooperators—Continued

**Florida**—Continued

Orange County Board of County Commissioners (w)
Palm Beach County Board of County Commissioners (w)
Pinellas County Board of County Commissioners (w)
Polk County Board of County Commissioners (w)
Reedy Creek Improvement District (w)
St Johns County (w)
St Johns River Water Management District (w)
Sarasota County (w)
South Florida Water Management District (w)
Southwest Florida Water Management District (w)
Sumter County Recreation and Water Conservation and Control Authority (w)
Suwannee River Authority (w)
Suwannee River Water Management District (w)
Town of Highland Beach (w)
Town of Juno Beach (w)
Volusia County (w)
Walton County (w)
West Coast Regional Water Supply Authority (w)
Winter Haven Lake Region (w)

**Georgia:**

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

**Hawaii:**

City and County of Honolulu (w)
  Board of Water Supply (w)
  Department of Public Works (w)
State Department of Health (w)
State Department of Land and Natural Resources (w)
  Division of Water and Land Development (w)
State Department of Transportation (n, w)

**Idaho:**

Butte Soil Conservation District (w)
Idaho Department of Fish and Game (w)
Idaho Department of Health and Welfare (w)
  Bureau of Water Quality (w)
Idaho Department of Transportation, Division of Highways (w)
Idaho Department of Water Resources (w)
Idaho Water District No 1 (w)
Idaho Water Resources Board (w)
Shoshone-Bannock Tribes (w)

**Illinois:**

Bloomington and Normal Sanitary District (w)
City of Springfield (w)
Cook County (w).
  Forest Preserve District (w)
Illinois Department of Conservation (w)
Illinois Environmental Protection Agency (w)

**Illinois**—Continued

Illinois Institute of Natural Resources (w)
  State Water Survey Division (w)
Illinois State Geological Survey (e, n)
McHenry County Regional Planning Commission (w)
Metropolitan Sanitary District of Greater Chicago (w)
Northeastern Illinois Planning Commission (w)
State Department of Transportation (w)
  Division of Highways (n, w)
  Division of Water Resources (n, w)

**Indiana:**

City of Fort Wayne (w)
City of Indianapolis (w)
Indiana State Board of Health (w)
Indiana Department of Natural Resources (n, w)
Indiana Geological Survey (e)
Indiana Department of Highways (w)
Indiana University School of Public and Environmental Affairs (e)
Town of Carmel (w)

**Iowa:**

City of Ames (w)
City of Cedar Rapids (w)
City of Charles City (w)
City of Clear Lake (w)
City of Des Moines (w)
City of Fort Dodge (w)
City of Harlan (w)
City of Iowa City (w)
City of Marshalltown (w)
City of Sioux City (w)
City of Waterloo (w)
Des Moines Water Works (w)
Iowa Department of Transportation (n, w)
  Highway Division (w)
  Highway Research Board (w)
Iowa Geological Survey (e, n, w)
Iowa Natural Resources Council (w)
Iowa State University (w)
  Department of Agricultural Engineering (w)
  Iowa Agricultural Experiment Station (w)
Ottumwa Water Works (w)
  Sewage Disposal Plant (w)
University of Iowa (w)
  Institute of Hydraulic Research (w)
  University Physical Plant (w)
West-Central Iowa Rural Water Association (w)

**Kansas:**

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

State, County, and Local Cooperators—Continued

**Kentucky:**

City of Louisville (w)
Kentucky Department of Commerce (w)
  Division of Research and Planning (w)
Kentucky Department for Natural Resources and Environmental Protection (w)
  Division of Conservation (w)
  Division of Water (w)
Kentucky Department of Transportation (w)
  Division of Design (w)
Kentucky State Geological Survey, University of Kentucky (e, n, w)
Water Quality Advisory Board (w)

**Louisiana:**

Baton Rouge City-Parish Government (w)
Capital Area Ground Conservation Commission (w)
Louisiana Department of Natural Resources (w)
  Office of Conservation (w)
  Office of Environmental Affairs (w)
Louisiana Office of Highways (w)
  Department of Transportation and Development (w)
Louisiana Office of Public Works (n, w)
  Department of Transportation and Development (w)
Sabine River Compact Administration (w) (see also **Texas**)
Louisiana State Planning Office (n)

**Maine:**

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

**Maryland:**

Anne Arundel County (w)
Baltimore County (w)
  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 (w)
Howard County (w)
Maryland Department of Health and Mental Hygiene (w)
Maryland Department of Transportation (w)
  The State Highway Administration (w)
Maryland Energy Administration (w)
Maryland Geological Survey (e, n, w)
Maryland Water Resources Administration (w)
Montgomery County (w)
St. Mary's County (w)
Town of Poolesville (w)
Upper Potomac River Commission (w)
Washington Suburban Sanitary Commission (w)

## State, County, and Local Cooperators—Continued

**Massachusetts:**

- Barnstable County (w)
- Cape Cod Planning and Economic Development Commission (w)
- Department of Public Works (g, n, w)
  - Division of Research and Materials (w)
- Metropolitan District Commission (w)
- State Water Resources Commission (w)
  - Division of Water Pollution Control (w)
  - Division of Water Resources (w)
- Town of Falmouth (w)
- University of Massachusetts (e)

**Michigan:**

- Branch County (w)
- City of Ann Arbor (w)
- City of Battle Creek (w)
- City of Clare (w)
- City of Coldwater, Board of Public Utilities (w)
- City of Flint (w)
- City of Jackson )w)
- City of Kalamazoo, Department of Public Utilities (w)
- City of Lansing, Board of Water and Light (w)
- City of Mason (w)
- City of Portage (w)
- City of St Johns (w)
- City of Ypsilanti (w)
- Department of Agriculture (w).
  - Soil and Water Conservation Division (w)
- Department of Natural Resources (e, n, w)
  - Bureau of Management Services (w)
  - Geological Survey Division (e, w)
- Department of Transportation (w)
- Dickinson County Board of Road Commissioners (w)
- East-Central Michigan Planning and Development Region (w)
- Genesee County Drain Commission (w)
- Huron-Clinton Metropolitan Authority (w)
- Imlay City (w)
- Kent County Airport (w)
- Macomb County (w)
- Oakland County Drain Commission (w)
- Otsego County Road Commission (w)
- University of Michigan (e)
- Van Buren County Road Commission (w)

**Minnesota:**

- City of St Louis Park (w)
- Coon Creek Watershed District (w)
- Elm Creek Conservation Commission (w)
- Metropolitan Council of the Twin Cities Area (w)
- Metropolitan Waste Control Commission (w)
- Minnesota Department of Health (w)
  - Division of Environmental Health (w)
- Minnesota Department of Natural Resources (w)
- Minnesota Department of Transportation (w)
- Minnesota Geological Survey (w)
- Minnesota Pollution Control Agency (w)
- Minnesota State Planning Agency (e)
- Red Clay Project (w)

**Mississippi:**

- City of Jackson (w)
- Department of Natural Resources (w)
  - Bureau of Geology and Energy Resources (w)
  - Bureau of Land and Water Resources (w)
  - Bureau of Pollution Control (w)

## State, County, and Local Cooperators—Continued

**Mississippi**—Continued

- Harrison County (w)
  - Board of Supervisors (w)
  - Development Commission (w)
- Jackson County (w).
  - Board of Supervisors (w)
  - Port Authority (w)
- Mississippi Research and Development Center (n, w)
- Mississippi State Highway Department (w)
- Pat Harrison Waterway District (w)
- Pearl River Valley Water Supply District (w)

**Missouri:**

- City of Springfield (w)
  - Sanitary Services Department (w)
- Department of Natural Resources (w)
  - Division of Environmental Quality, Laboratory Services Program, (w)
  - Division of Geology and Land Survey (n, w)
- Little River Drainage District (w)
- Missouri Department of Conservation (w)
- Missouri Highway and Transportation Commission (w)
- St Louis County (w)
  - Department of Highways and Traffic (w)

**Montana:**

- Department of Natural Resources and Conservation (w)
- Montana Bureau of Mines and Geology (c, w)
- Montana Department of Health and Environmental Sciences (w)
- Montana Department of Highways (w)
- Montana Fish, Wildlife, and Parks (w)
- Montana State University (w)
- Wyoming State Engineer (w) (see *also* **Wyoming**)

**Nebraska:**

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

**Nevada:**

- Carson City Department of Public Works (w)
- Clark County, Department of Comprehensive Planning (w)
- Desert Research Institute (w)
- Douglas County, Department of Planning (w)
- Nevada Bureau of Mines and Geology (g, n, w)
- Nevada Department of Conservation and Natural Resources (w)
  - Division of Environmental Protection (w)
  - Division of Water Resources (w)
- Nevada Department of Transportation (w)
- Washoe County (w)

**New Hampshire:**

- New Hampshire Water Resources Board (w)

## State, County, and Local Cooperators—Continued

**New Jersey:**

Bergen County (w)
Camden County (w)
  Board of Chosen Freeholders (w)
Delaware River Basin Commission (w) (see *also* **Pennsylvania**)
Morris County Municipal Utilities Authority (w)
New Jersey Department of Agriculture (w)
  State Soil Conservation Committee (w)
New Jersey Department of Environmental Protection (w)
  Bureau of Fisheries (w)
  Division of Fish, Game, and Shell Fisheries (w)
  Division of Water Resources (w)
North Jersey District Water Supply Commission (w)
Passaic Valley Water Commission (w)
Somerset County (w)
  Board of Chosen Freeholders (w)
Township of Bridgewater (w)
  Environmental Commission (w)
Township of Crantord (w)
West Windsor Township (w)
  Environmental Commission (w)

**New Mexico:**

Albuquerque Metropolitan Arroyo Flood Control Authority (w)
City of Albuquerque (w)
Costilla Creek Compact Commission (w)
Elephant Butte Irrigation District (w)
New Mexico Bureau of Economic Development (e)
New Mexico Bureau of Mines and Mineral Resources (c, w)
New Mexico Environmental Improvement Division (w)
New Mexico Natural Resources Department (w)
New Mexico State Highway Department (w)
Pecos River Commission (w)
Pueblo Indians of Zuni (w)
Rio Grande Compact Commission (w)

**New York:**

Central New York State Park and Recreation Commission (w)
City of Albany (w)
  Department of Water and Water Supply (w)
City of Auburn (w)
City of New York (w).
  Department of Environmental Protection (w)
City of Rochester (w)
  Department of Public Works (w)
County of Chautauqua (w)
  Department of Planning and Development (w)
County of Cortland (w)
County of Duchess (w)
County of Monroe (w).
  Water Authority (w)
County of Nassau (w)
  Department of Public Works (w)
County of Onondaga (w)
  Department of Public Works (w)
  Water Authority (w)
County of Oswego Planning Board (w)
County of Putnam (w)
County of Rockland (w)
  Drainage Agency (w)
County of Suffolk (w):
  Department of Health Sciences (w)
  Water Authority (w)
County of Ulster (w)
County of Westchester (w)
  Department of Public Works (w)



## State, County, and Local Cooperators—Continued

**New York**—Continued

Hudson River-Black River Regulating District (w)
Irondequoit Bay Pure Waters District (w)
Long Island Regional Planning Board (w)
New York State College of Agriculture and Life Sciences (w)
New York State Department of Education (w)
  Museum and Science Service (w)
New York State Department of Environmental Conservation (w) (see *also* **Pennsylvania**)
  Bureau of Standards and Compliance (w)
  Division of Water (w)
New York State Energy, Research and Development Authority (w)
New York State Department of Health (w)
  Division of Sanitary Engineering (w)
New York State Department of Transportation (w)
  Bridge Planning and Railroads Bureau (n, w)
New York State Geological Survey (e)
Oswegatchie River-Cranberry Reservoir Commission (w)
Power Authority of the State of New York (w)
State University of New York at Albany (e, w)
State University of New York at Buffalo (e)
Susquehanna River Basin Commission (w) (see *also* **Pennsylvania**)
Town of Brookhaven (w)
Town of Clarkstown (w)
Town of Warwick (w)
Unversity of Virginia (w) (see *also* **Virginia**)
  Department of Environmental Sciences (w)
Village of Nyack (w)

**North Carolina:**

Agricultural Research Service (w)
City of Burlington (w)
City of Cary (w)
City of Charlotte (w)
City of Durham (w)
  Department of Water Resources (w)
City of Greensboro (w)
City of Raleigh (w)
City of Rocky Mount (w)
State Board of Transportation, Division of Highways (w)
State Department of Natural Resources and Community Development (n, w)

**North Dakota**

North Dakota Geological Survey (w)
North Dakota State University (e)
Oliver County Board of Commissioners (w)
State Department of Health (w)
State Water Commission (n, w)

**Ohio:**

City of Canton (w)
  Water Department (w)
City of Columbus (w)
  Department of Public Service (w)
  Division of Water (w)
Cuyahoga County (w)
Geauga County (w)
Miami Conservancy District (w)
Northeast Ohio Areawide Coordinating Agency (w)
Ohio Department of Natural Resources (w)
  Division of Geological Survey (w, g)
  Division of Reclamation (w)
  Division of Water (w)

**Ohio**—Continued

Ohio Department of Transportation (n, w)
  Division of Highways (w)
Ohio Environmental Protection Agency (w)

**Oklahoma:**

Central Master Conservancy District (w)
Cherokee Indian Tribe (w)
City of Ada (w)
City of Altus (w)
City of Claremore (w)
City of Edmond (w)
City of Guthrie (w)
City of Lawton (w)
City of Oklahoma City (w)
City of Sapulpa (w)
City of Tulsa (w)
Foss Reservoir Master Conservancy District
Fort Cobb Reservoir Master Conservancy District (w)
Lugert-Altus Irrigation District (w)
Oklahoma Conservation Commission (w)
Oklahoma Department of Highways (n)
Oklahoma Department of Transportation (w)
Oklahoma Geological Survey (w)
Oklahoma State Health Department (w)
Oklahoma Water Resources Board (w)

**Oregon:**

Burnt River Irrigation District (w)
City of Corvallis (w)
City of Eugene (w).
  Water and Electric Board (w)
City of Lakeside (w).
  Lakeside Water District (w)
City of McMinnville (w).
  Water and Light Department (w)
City of Medford (w)
  Public Works Department (w)
City of Portland (w).
  Department of Public Utilities (w)
  Department of Public Works (w)
City of Reedsport (w)
City of Salem (w)
Confederated Tribes of Umatilla Indian Reservation (w)
Confederated Tribes of Warm Springs Indian Reservation (w)
Coos Bay-North Bend Water Board (w)
Coos County (w)
  Board of Commissioners (w)
Douglas County (w).
  Department of Public Works (w)
Lane Council of Governments (w)
Lane County (w)
  Office of the Chief Administrator (w)
Mid-Willamette Valley Council of Governments (w)
Multnomah County (w)
  Board of Commissioners (w)
Oregon Department of Environmental Quality (w)
Oregon Department of Fish and Wildlife (w)
Oregon Department of Geology and Minerals (w, n)
Oregon State Highway Division (w)
Oregon Water Resources Department (w)
Rogue Valley Council of Governments (w)
Wasco County (w)
  Planning Office (w)

State, County, and Local Cooperators—Continued

**Pennsylvania:**

Allegheny County (w)
  Department of Planning and Development (w)
Chester County (w).
  Board of Commissioners (w)
  Health Department (w)
  Water Resources Authority (w)
City of Bethlehem (w)
City of Harrisburg (w)
  Department of Public Works (w)
City of Philadelphia (w)
  Water Department (w)
Delaware River Basin Commission (w) (see *also* **New Jersey**)
Delaware Valley Regional Planning Commission (w)
Green County Commissioners (w)
Letort Regional Authority (w)
New York State Department of Environmental Conservation (w) (see *also* **New York**)
Pennsylvania Department of Environmental Resources (w).
  Bureau of Surface Mine Reclamation (w)
  Bureau of Topographic and Geologic Survey (n, w)
  Bureau of Water Quality Management (w)
  Office of Resources Management (w)
Pennsylvania Department of Transportation (w)
Pennsylvania Fish Commission (w)
Slippery Rock State College (w)
Susquehanna River Basin Commission (w) (see *also* **New York**)
Warminster Township (w)

**Rhode Island:**

City of Providence (w).
  Department of Public Works (w)
State Department of Environmental Management (w)
  Division of Land Resources (w)
  Division of Water Resources (w)
State Water Resources Board (w)
Statewide Planning Program (w)
University of Rhode Island Center for Ocean Management Studies (e)

**South Carolina:**

City of Lancaster (w)
City of Myrtle Beach (w)
City of North Myrtle Beach (w)
Commissioners of Public Works (w)
  Spartanburg Water Works (w)
Grand Strand Water and Sewer Authority (w)
State Department of Highways and Public Transportation (w)
State Geological Survey (w)
State Health and Environmental Control (w)
State Water Resources Commission (w)

**South Dakota:**

Black Hills Conservancy Subdistrict (w)
City of Sioux Falls (e, w)
City of Watertown (w)
East Dakota Conservancy Subdistrict (w)
South Dakota Department of Transportation (n)
South Dakota Department of Water and Natural Resources (w)
  Division of Geological Survey (w)
  Division of Water Rights (w)
South Dakota School of Mines and Technology (w)

## State, County, and Local Cooperators—Continued

**Tennessee:**

City of Frankline (w)
City of Lawrenceburg (w)
City of Memphis (w)
  Light, Gas and Water Division (w)
  Public Works Division (w)
  Water Division (w)
Lincoln County Board of Public Utilities (w)
Metropolitan Government of Nashville and Davidson County (w)
  Department of Public Works (w)
Murfreesboro Water and Sewer Department (w)
Shelby County (w)
Tennessee Department of Conservation (e, w)
  Division of Geology (e, n, w)
  Division of Water Resources (w)
Tennessee Department of Public Health (w)
  Division of Water Quality Control (w)
Tennessee Department of Transportation (w)
  Bureau of Highways (w)
  Bureau of Planning and Programming (w)
  Office of Research and Planning (w)
University of Tennessee (w)

**Texas:**

Athens Municipal Water Authority (w)
Bexar-Medina-Atacosa Counties Water Improvement District No 1 (w)
Bistone Municipal Water Supply District (w)
Brazos River Authority (w)
City of Abilene (w)
City of Alice (w)
City of Arlington (w)
City of Austin (w)
City of Brady (w)
City of Cleburne (w)
City of Clyde (w)
City of Corpus Christi (w)
City of Dallas (w)
City of El Paso (w)
City of Garland (w)
City of Gainesville (w)
City of Graham (w)
City of Houston (w)
City of Nacogdoches (w)
City of San Angelo (w)
City of San Antonio (w)
  Engineering Department (w)
  Public Service Board (w)
  Water Board (w)
City of Wichita Falls (w)
Colorado River Municipal Water District (w)
County of Dallas (w)
County of Orange (w)
County of Wood (w)
Edwards Underground Water District (w)
Franklin County Water District (w)
Greenbelt Municipal and Industrial Water Authority (w)
Guadalupe-Blanco River Authority (w)
Harris County Flood Control District (w)
Harris-Galveston Coastal Subsidence District (w)
Lavaca-Navidad River Authority (w)
Lower Colorado River Authority (w)
Lower Neches Valley Authority (w)
Mackenzie Municipal Water Authority (w)
North Central Texas Municipal Water Authority (w)



## State, County, and Local Cooperators—Continued

**Texas**—Continued

Northeast Texas Municipal Water District (w)
Nueces River Authority (w)
Palo Pinto County Municipal Water District No 1 (w)
Pecos River Commission (w)
Reeves County Water Improvement District No 1 (w)
Sabine River Authority of Texas (w)
Sabine River Compact Administration (w) (see *also* **Louisiana**)
San Antonio City Water Board (w)
San Antonia River Authority (w)
San Jacinto River Authority (w)
Tarrant County (w)
Texas A & M (e)
Texas Department of Water Resources (n, w)
The University of Texas at Austin (w)
Titus County Fresh Water Supply District No 1 (w)
Tom Green County Water Control and Development District No 1 (w)
Trinity River Authority (w)
Upper Guadalupe River Authority (w)
Upper Neches Municipal Water Authority (w)
Upper Trinity Base Water Quality Compact (w)
West Central Texas Municipal Water District (w)
Wichita County Water Improvement District No 2 (w)

**Utah:**

Bear River Commission (w)
Salt Lake County (w)
  Board of County Commissioners (w)
  Department of Water Quality and Water Pollution Control (w)
State Department of Natural Resources (w)
  Division of Water Resources (w)
  Division of Water Rights (w)
  Division of Wildlife Resources (w)
  Utah Geological and Mineral Survey (c, g, n, w)

**Vermont:**

Agency of Environmental Conservation (n)
State Department of Water Resources (w)
Town of Springfield (w)

**Virginia:**

City of Alexandria (w)
  Department of Transportation and Environmental Services (w)
City of Newport News (w)
  Department of Public Utilities (w)
City of Roanoke (w)
  Utilities and Operations (w)
City of Staunton (w)
County of James City (w)
Southeastern Public Service Authority of Virginia (w)
University of Virginia (w) (see *also* **New York**)
  Department of Environmental Sciences (w)
Virginia Department of Conservation and Economic Development
  Division of Mineral Resources (n)
Virginia Department of Highways and Transportation (w)
Virginia Polytechnic Institute and State University (e)
Virginia State University (e)
Virginia State Water Control Board (w)

**Washington:**

City of Bellevue, Public Works Department (w)
City of Everett (w)

## State, County, and Local Cooperators—Continued

**Washington**—Continued

- City of Seattle (w)
  - Department of Lighting (w)
  - Water Department (w)
- City of Tacoma (w)
  - Department of Public Utilities (w)
  - Department of Public Works (w)
- Chelan County (w)
- Clallam County Board of Commissioners (w)
- Clark County (w)
  - Department of Public Works (w)
  - Public Utility District (w)
- Cowlitz County Public Utility District (w)
- Hoh Indian Tribe (w)
- Intercounty River Improvement (w)
- Island County Planning Department (w)
- King County Department of Public Works (w)
- Lewis County Board of Commissioners (w)
- Makah Tribal Council (w)
- Muckleshoot Indian Tribe (w)
- Municipality of Metropolitan Seattle (w)
- Nisqually Indian Community Council (w)
- Pend Oreille County Public Utility District No 1 (w)
- Pierce County Board of Commissioners (w)
- Quinault Indian Business Council (w)
- San Juan County Board of Commissioners (w)
- Shoalwater Bay Tribal Council (w)
- Skagit County (w)
- State of Washington (w)
  - Department of Ecology (w)
  - Department of Natural Resources (g)
- Town of Fircrest (w)
- Tulalip Tribal Board of Directors (w)
- University of Washington, Fisheries Research Institute (w)
- Walla Walla County Board of Commissioners (w)
- Washington Public Power Supply Service (w)
- Washington State Department of Ecology (w)
- Washington State Department of Fisheries (w)
- Washington State Department of Natural Resources (n)
- Washington State Department of Transportation (w)
- Washington State University (w)
  - Department of Agricultural Engineering (w)
- Whatcom County Board of Commissioners (w)
- Yakima Tribal Council (w)

**West Virginia:**

- City of Buckhannon (w)
- City of Morgantown (w)
  - Water Commission (w)
- Upshur County (w)
- West Virginia Department of Highways (w)
- West Virginia Department of Natural Resources (w)
  - Division of Forestry (w)
  - Division of Water Resources (w)
- West Virginia Geological and Economical Survey (n, w)

**Wisconsin:**

- Brown County Regional Planning (w)
- City of Middletown (w)
- Dane County (w)
  - Department of Public Works (w)
  - Regional Planning Commission (w)
- Madison Metropolitan Sewage District (w)
- Madison Water Utility (w)



**Wisconsin**—Continued

- Sokaogon Chippewa (Mole Lake) Community of Wisconsin (w)
- Southeastern Wisconsin Regional Planning Commission (w)
- State Department of Natural Resources (g, n, w)
- State Department of Transportation (n, w)
  - Bridge Section (w)
  - Division of Highways (w)
- Town of Schleswig (w)
- University of Wisconsin—Extension Geological and Natural History Survey (n, w)
- Village of Oregon (w)

**Wyoming:**

- Cheyenne Board of Public Utilities (w)
- University of Wyoming (e)
  - Water Resources Research Institute and Institute for Policy Research (e)
- Wyoming Department of Agriculture (w)
  - Wyoming Conservation Commission (w)
- Wyoming Department of Economic Planning and Development (w)
- Wyoming Department of Environmental Quality (w)
- Wyoming Game and Fish Department (w)
- Wyoming Highway Department (w)
- Wyoming State Engineer (n, w) (see *also* **Montana**)

## Other Cooperators and Contributors

**Government of American Samoa (w)**

**Government of Guam (w)**

**Government of the Northern Mariana Islands (w)**

**Government of Peru (g)**

**Government of Saudi Arabia (w, 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 (w, g)
- 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 Territory of the Pacific Islands (w)**

**United Nations:**

- United National Development Program (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

[Data in these tables may differ slightly from data in the individual division chapters because of rounding; and totals may sometimes not add because of rounding]

TABLE 1.—*Geological Survey budget for fiscal years 1976 to 1981, by activity and sources of funds*

[In thousands of dollars]

| Budget activity | 1976 | Transition quarter | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|
| **Total** | **$353,970** | **$102,858** | **$433,403** | **$698,272** | **$764,718** | **$782,136** | **$783,656** |
| Direct program | 264,434 | 77,570 | 319,460 | 576,393 | 634,886 | 639,143 | 623,057 |
| Reimbursable program | 89,536 | 25,288 | 113,943 | 121,879 | 129,832 | 142,993 | 146,700 |
| States, counties, and municipalities | 35,006 | 8,956 | 39,621 | 40,784 | 44,124 | 46,849 | 48,700 |
| Miscellaneous non-Federal sources | 7,923 | 1,991 | 10,229 | 12,825 | 15,789 | 16,817 | 19,605 |
| Other Federal agencies | 46,607 | 14,341 | 64,093 | 68,270 | 69,919 | 79,327 | 78,395 |
| **Alaska Pipeline Related Investigations** | **287** | **85** | **317** | **272** | ------ | ------ | ------ |
| Direct program | 287 | 85 | 317 | 272 | ------ | ------ | ------ |
| Reimbursable program | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| Other Federal agencies | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| **National Mapping, Geography and Surveys** | **52,220** | **13,289** | **57,073** | **69,520** | **74,566** | **82,683** | **89,177** |
| Direct program | 43,354 | 11,548 | 50,311 | 61,356 | 65,584 | 72,759 | 77,449 |
| Reimbursable program | 6,866 | 1,741 | 6,762 | 8,164 | 8,982 | 9,924 | 11,727 |
| States, counties, and municipalities | 3,675 | 882 | 3,268 | 3,320 | 3,371 | 3,083 | 2,985 |
| Miscellaneous non-Federal sources | 501 | 133 | 601 | 499 | 597 | 610 | 1,095 |
| Other Federal agencies | 2,690 | 726 | 2,893 | 4,345 | 5,014 | 6,231 | 7,648 |
| **Geologic and Mineral Resource Surveys and Mapping**[1] | **115,554** | **32,194** | **130,269** | **163,193** | **178,556** | **193,652** | **208,287** |
| Direct program | 92,322 | 24,829 | 100,007 | 123,830 | 134,846 | 146,963 | 162,756 |
| Reimbursable program | 23,232 | 7,365 | 30,262 | 39,363 | 43,710 | 46,689 | 45,531 |
| States, counties, and municipalities | 1,467 | 383 | 1,403 | 956 | 584 | 640 | 758 |
| Miscellaneous non-Federal sources | 4,936 | 1,120 | 6,439 | 8,510 | 10,914 | 11,258 | 13,192 |
| Other Federal agencies | 16,829 | 5,862 | 22,420 | 29,897 | 32,212 | 34,791 | 31,761 |
| **Water Resources Investigations**[2] | **112,480** | **30,716** | **131,509** | **146,014** | **168,598** | **184,871** | **194,016** |
| Direct program | 57,176 | 15,916 | 68,555 | [3] 78,487 | 96,847 | 108,664 | 115,458 |
| Reimbursable program | 55,304 | 14,800 | 62,954 | 67,527 | 71,751 | 76,207 | 78,558 |
| States, counties, and municipalities | 29,735 | 7,672 | 34,761 | 36,457 | 40,156 | 43,126 | 45,138 |
| Miscellaneous non-Federal sources | 940 | 260 | 1,331 | 1,429 | 1,673 | 1,778 | 2,088 |
| Other Federal Agencies | 24,629 | 6,868 | 26,862 | 29,641 | 29,922 | 31,303 | 31,332 |
| **Conservation of Lands and Minerals** | **41,677** | **13,386** | **67,427** | **77,409** | **85,484** | **106,395** | **127,001** |
| Direct program | 41,489 | 13,375 | 67,239 | 77,299 | 85,362 | 105,928 | 125,739 |
| Reimbursable program | 188 | 6 | 188 | 110 | 122 | 467 | 1,262 |
| Miscellaneous non-Federal sources | 1 | ------ | 16 | 9 | ------ | 12 | 29 |
| Other Federal agencies | 187 | 6 | 172 | 101 | 122 | 455 | 1,233 |
| **Office of Earth Science Applications** | **17,278** | **8,919** | **23,476** | **23,226** | **23,965** | **23,734** | **23,205** |
| Direct program | 14,908 | 7,795 | 17,698 | 18,132 | 19,959 | 18,935 | 18,849 |
| Reimbursable program | 2,370 | 6,124 | 5,778 | 5,094 | 4,006 | 4,799 | 4,356 |
| States, counties, and municipalities | 130 | 19 | 189 | 51 | 13 | ------ | ------ |
| Miscellaneous non-Federal sources | 1,496 | 469 | 1,741 | 2,153 | 2,333 | 2,808 | 3,139 |
| Other Federal agencies | 744 | 636 | 3,848 | 2,890 | 1,660 | 1,991 | 1,217 |
| **National Petroleum Reserve in Alaska** | ------ | ------ | **9,154** | **202,704** | **216,886** | **169,845** | **107,001** |
| Direct program | ------ | ------ | 2,079 | 202,598 | 216,886 | 169,845 | 107,001 |
| Allocation transfer | ------ | ------ | 7,063 | 106 | ------ | ------ | ------ |
| Reimbursable program (Federal) | ------ | ------ | 12 | ------ | ------ | ------ | ------ |
| **General Administration**[4] | **3,398** | **1,491** | **3,760** | **3,650** | **3,661** | **3,776** | **3,896** |
| Direct program | 3,398 | 1,491 | 3,760 | 3,650 | 3,661 | 3,776 | 3,896 |
| **Facilities** | **9,500** | **2,530** | **9,494** | **10,769** | **11,741** | **12,273** | **11,909** |
| Direct program | 9,500 | 2,530 | 9,494 | 10,769 | 11,741 | 12,273 | 11,909 |

See footnotes at end of table.

TABLE 1.—*Geological Survey budget for fiscal years 1976 to 1981, by activity and sources of funds*—Continued

| Budget activity | 1976 | Transition quarter | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|
| **Miscellaneous services to other accounts** | **$1,576** | **$253** | **$924** | **$1,515** | **$1,261** | **$4,907** | **$5,266** |
| Reimbursable program | 1,576 | 253 | 924 | 1,515 | 1,261 | 4,907 | 5,266 |
| Miscellaneous non-Federal sources | 49 | 10 | 102 | 225 | 272 | 351 | 62 |
| Other Federal agencies | 1,527 | 243 | 822 | 1,290 | 989 | 4,556 | 5,204 |

[1] Funds exclude the Land Resource Analysis program for fiscal year 1976.
[2] Excludes Employee Compensation Payments subactivity for fiscal years 1975 to 1976. [3] Funds for the Airborne Positioning System, appropriated to Water Resources Investigations are included as obligations of Topographic Surveys and Mapping ($2,172 thousand).
[4] Funds include Employee Compensation Payments subactivity of the Water Resources Investigations activity for 1976.

TABLE 2.—*Geological Survey Federal-State Cooperative Program funds for fiscal years 1976 to 1981, by State*

[In thousands of dollars]

| State | 1976 | Transition quarter | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|
| **Total[1]** | **$69,252** | **$17,482** | **$79,163** | **$80,598** | **$86,962** | **$91,090** | **$94,716** |
| Total State share[2] | 35,007 | 8,956 | 39,622 | 40,784 | 44,123 | 46,849 | 48,745 |
| **Alabama** | **1,124** | **171** | **1,234** | **1,074** | **1,075** | **1,134** | **1,304** |
| State share | 550 | 87 | 607 | 532 | 537 | 569 | 641 |
| **Alaska** | **782** | **202** | **1,141** | **1,275** | **1,421** | **1,675** | **1,998** |
| State share | 407 | 101 | 561 | 654 | 753 | 903 | 1,157 |
| **Arizona** | **1,255** | **335** | **1,393** | **1,552** | **1,721** | **2,229** | **2,030** |
| State share | 639 | 177 | 700 | 783 | 878 | 1,165 | 1,081 |
| **Arkansas** | **811** | **190** | **1,033** | **1,118** | **1,315** | **1,224** | **1,300** |
| State share | 371 | 94 | 481 | 543 | 695 | 639 | 692 |
| **California** | **4,825** | **1,271** | **5,336** | **6,079** | **6,003** | **5,768** | **6,035** |
| State share | 2,473 | 675 | 2,714 | 3,091 | 3,135 | 2,963 | 3,082 |
| **Colorado** | **2,199** | **662** | **3,052** | **3,036** | **3,581** | **3,244** | **2,892** |
| State share | 1,196 | 349 | 1,564 | 1,561 | 1,784 | 1,598 | 1,531 |
| **Connecticut** | **858** | **241** | **871** | **864** | **1,242** | **1,164** | **1,271** |
| State share | 415 | 108 | 421 | 411 | 576 | 678 | 578 |
| **Delaware** | **213** | **54** | **225** | **192** | **157** | **127** | **235** |
| State share | 116 | 30 | 121 | 109 | 92 | 64 | 136 |
| **District of Columbia** | **3** | **1** | **4** | **4** | **4** | **4** | **4** |
| State share | 2 | ------ | 2 | 2 | 2 | 2 | 2 |
| **Florida** | **5,763** | **1,481** | **6,428** | **7,219** | **7,415** | **8,118** | **8,120** |
| State share | 2,851 | 735 | 3,202 | 3,667 | 3,819 | 4,428 | 4,227 |
| **Georgia** | **2,510** | **552** | **2,452** | **1,706** | **1,919** | **2,129** | **2,228** |
| State share | 1,243 | 275 | 1,209 | 866 | 942 | 1,174 | 1,131 |
| **Hawaii** | **896** | **191** | **897** | **1,000** | **1,294** | **1,368** | **1,693** |
| State share | 501 | 101 | 460 | 518 | 646 | 699 | 806 |
| **Idaho** | **852** | **223** | **952** | **1,131** | **1,024** | **1,234** | **1,447** |
| State share | 417 | 111 | 465 | 611 | 480 | 617 | 721 |
| **Illinois** | **848** | **208** | **1,109** | **1,092** | **1,324** | **1,299** | **1,717** |
| State share | 459 | 120 | 592 | 575 | 718 | 717 | 914 |
| **Indiana** | **1,519** | **366** | **1,987** | **2,006** | **2,210** | **1,893** | **1,774** |
| State share | 779 | 182 | 981 | 1,078 | 1,107 | 1,058 | 941 |
| **Iowa** | **822** | **241** | **1,004** | **1,031** | **1,060** | **1,102** | **1,109** |
| State share | 405 | 121 | 494 | 521 | 531 | 646 | 557 |
| **Kansas** | **1,525** | **442** | **1,721** | **2,237** | **2,378** | **2,295** | **2,386** |
| State share | 752 | 220 | 849 | 1,113 | 1,163 | 1,237 | 1,179 |
| **Kentucky** | **2,828** | **717** | **3,015** | **2,407** | **1,425** | **1,242** | **1,277** |
| State share | 1,300 | 297 | 1,433 | 1,018 | 709 | 665 | 629 |
| **Louisiana** | **1,694** | **440** | **2,628** | **1,856** | **2,027** | **2,146** | **2,577** |
| State share | 862 | 227 | 1,319 | 929 | 1,015 | 1,148 | 1,427 |

See footnotes at end of table.

TABLE 2.—*Geological Survey Federal-State Cooperative Program funds for fiscal years 1976 to 1981, by State*—Continued

| State | 1976 | Transition quarter | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|
| **Maine** | **$ 313** | **$ 89** | **$ 333** | **$ 382** | **$ 566** | **$ 689** | **$ 761** |
| State share | 181 | 50 | 179 | 191 | 290 | 369 | 389 |
| **Maryland** | **1,016** | **243** | **1,176** | **1,174** | **1,393** | **1,559** | **1,555** |
| State share | 517 | 125 | 602 | 605 | 706 | 805 | 777 |
| **Massachusetts** | **1,627** | **368** | **1,402** | **1,593** | **1,837** | **1,461** | **1,972** |
| State share | 779 | 191 | 684 | 801 | 847 | 903 | 1,054 |
| **Michigan** | **1,078** | **252** | **1,101** | **1,203** | **1,497** | **1,280** | **1,611** |
| State share | 521 | 123 | 541 | 596 | 761 | 700 | 799 |
| **Minnesota** | **1,191** | **320** | **1,082** | **1,759** | **2,330** | **1,614** | **1,467** |
| State share | 625 | 198 | 566 | 949 | 1,249 | 938 | 804 |
| **Mississippi** | **646** | **170** | **713** | **754** | **747** | **817** | **878** |
| State share | 316 | 85 | 349 | 407 | 374 | 413 | 432 |
| **Missouri** | **642** | **207** | **827** | **635** | **713** | **763** | **878** |
| State share | 316 | 105 | 420 | 316 | 341 | 446 | 489 |
| **Montana** | **596** | **146** | **1,330** | **676** | **734** | **800** | **915** |
| State share | 301 | 76 | 673 | 338 | 402 | 417 | 463 |
| **Nebraska** | **785** | **187** | **957** | **1,048** | **1,175** | **1,176** | **1,199** |
| State share | 396 | 95 | 469 | 522 | 579 | 582 | 589 |
| **Nevada** | **922** | **244** | **1,063** | **1,440** | **1,488** | **1,151** | **1,661** |
| State share | 367 | 103 | 415 | 456 | 535 | 676 | 724 |
| **New Hampshire** | **230** | **63** | **248** | **187** | **150** | **176** | **160** |
| State share | 99 | 28 | 103 | 92 | 68 | 88 | 79 |
| **New Jersey** | **1,090** | **276** | **1,269** | **1,437** | **1,427** | **1,404** | **1,433** |
| State share | 565 | 143 | 642 | 851 | 800 | 723 | 736 |
| **New Mexico** | **1,510** | **338** | **1,537** | **1,621** | **1,841** | **1,841** | **1,910** |
| State share | 768 | 175 | 778 | 838 | 942 | 939 | 972 |
| **New York** | **2,822** | **727** | **3,008** | **3,363** | **3,871** | **4,083** | **4,689** |
| State share | 1,615 | 407 | 1,573 | 1,893 | 2,377 | 2,363 | 2,747 |
| **North Carolina** | **1,462** | **379** | **1,805** | **1,713** | **1,633** | **1,523** | **2,025** |
| State share | 724 | 197 | 894 | 858 | 817 | 910 | 1,010 |
| **North Dakota** | **990** | **246** | **834** | **1,023** | **1,029** | **1,101** | **1,177** |
| State share | 489 | 125 | 408 | 505 | 498 | 572 | 579 |
| **Ohio** | **1,255** | **336** | **1,598** | **1,799** | **1,962** | **1,885** | **2,211** |
| State share | 671 | 175 | 838 | 973 | 1,075 | 1,093 | 1,104 |
| **Oklahoma** | **786** | **196** | **846** | **936** | **1,131** | **1,078** | **1,248** |
| State share | 386 | 98 | 414 | 462 | 577 | 582 | 615 |
| **Oregon** | **899** | **287** | **1,230** | **1,214** | **1,391** | **1,551** | **1,683** |
| State share | 449 | 163 | 639 | 610 | 674 | 817 | 855 |
| **Pennsylvania** | **2,510** | **554** | **2,718** | **2,688** | **2,847** | **2,766** | **2,911** |
| State share | 1,269 | 284 | 1,365 | 1,366 | 1,301 | 1,470 | 1,530 |
| **Rhode Island** | **124** | **31** | **145** | **160** | **233** | **260** | **271** |
| State share | 60 | 16 | 72 | 80 | 117 | 130 | 135 |
| **South Carolina** | **557** | **142** | **603** | **625** | **832** | **967** | **949** |
| State share | 272 | 71 | 296 | 329 | 363 | 506 | 476 |
| **South Dakota** | **528** | **146** | **562** | **662** | **766** | **1,048** | **1,120** |
| State share | 259 | 73 | 275 | 331 | 382 | 546 | 551 |
| **Tennessee** | **1,035** | **280** | **1,255** | **1,383** | **1,509** | **1,612** | **1,704** |
| State share | 508 | 139 | 615 | 686 | 729 | 804 | 860 |
| **Texas** | **4,351** | **1,102** | **4,621** | **4,525** | **4,588** | **4,276** | **4,396** |
| State share | 2,148 | 550 | 2,354 | 2,244 | 2,299 | 2,140 | 2,214 |
| **Utah** | **1,314** | **334** | **1,631** | **1,451** | **1,657** | **1,955** | **1,972** |
| State share | 745 | 186 | 810 | 726 | 842 | 1,094 | 999 |
| **Vermont** | **138** | **28** | **134** | **142** | **166** | **173** | **248** |
| State share | 68 | 14 | 70 | 70 | 81 | 90 | 124 |
| **Virginia** | **737** | **142** | **768** | **778** | **897** | **813** | **886** |
| State share | 378 | 78 | 393 | 397 | 548 | 477 | 441 |
| **Washington** | **2,115** | **509** | **3,271** | **2,537** | **2,859** | **2,782** | **2,977** |
| State share | 1,066 | 265 | 1,653 | 1,243 | 1,378 | 1,453 | 1,525 |

See footnotes at end of table.

TABLE 2.—*Geological Survey Federal-State Cooperative Program funds for fiscal years 1976 to 1981 by State*—Continued

| State | 1976 | Transition quarter | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|
| **West Virginia** | **$ 716** | **$ 175** | **$ 830** | **$ 688** | **$ 752** | **$ 694** | **$ 837** |
| State share | 418 | 105 | 472 | 388 | 402 | 369 | 453 |
| **Wisconsin** | **1,874** | **552** | **1,703** | **1,883** | **1,969** | **1,953** | **2,319** |
| State share | 999 | 297 | 935 | 1,026 | 1,022 | 1,074 | 1,137 |
| **Wyoming** | **754** | **167** | **903** | **901** | **819** | **859** | **1,061** |
| State share | 397 | 86 | 391 | 381 | 412 | 437 | 545 |
| **American Samoa** | **40** | **9** | **60** | **64** | **47** | **50** | **100** |
| State share | 20 | 4 | 30 | 32 | 23 | 25 | 50 |
| **Guam** | **68** | **18** | **70** | **85** | **104** | **123** | **143** |
| State share | 33 | 9 | 33 | 47 | 56 | 80 | 100 |
| **Northern Marianas** | ------ | ------ | ------ | **18** | **40** | **42** | **50** |
| State share | ------ | ------ | ------ | 9 | 21 | 21 | 25 |
| **Puerto Rico** | **1,016** | **185** | **843** | **922** | **1,083** | **1,344** | **1,716** |
| State share | 451 | 84 | 396 | 459 | 518 | 691 | 773 |
| **Trust Territories** | **170** | **44** | **173** | **180** | **184** | **196** | **166** |
| State share | 84 | 22 | 84 | 90 | 92 | 98 | 83 |
| **Virgin Islands** | **18** | **2** | **32** | **70** | **94** | **78** | **60** |
| State share | 9 | 1 | 16 | 35 | 43 | 39 | 30 |

[1] Includes Federal Funds from direct program.
[2] Includes reimbursable program funds from States, counties, and municipalities.

TABLE 3.—*Geological Survey reimbursable program funds from other Federal agencies for fiscal years 1976 to 1981, by agency*

[In thousands of dollars]

| Agency | 1976 | Transition quarter | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|
| **Total** | **$46,607** | **$14,347** | **$57,017** | **$68,164** | **$69,919** | **$79,326** | **$78,395** |
| Appalachian Regional Commission | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| Department of Agriculture | 2,008 | 605 | 2,130 | 2,727 | 2,619 | 3,878 | 3,567 |
| Department of Commerce | 2,205 | 36 | 334 | 183 | 141 | 276 | ------ |
| National Oceanic and Atmospheric Administration | 1,513 | 772 | 1,947 | 1,708 | 1,464 | 2,388 | 823 |
| Ozarks Regional Commission | ------ | ------ | ------ | ------ | ------ | 76 | ------ |
| Department of Defense | 11,965 | 3,195 | 12,308 | 15,655 | 16,760 | 17,447 | 18,490 |
| Department of Energy[1] | 4,704 | 1,926 | 8,573 | 14,980 | 15,338 | 14,406 | 10,885 |
| Bonneville Power Administration | (130) | (32) | (141) | (138) | (48) | (61) | (81) |
| Department of Housing and Urban Development | 4,624 | 1,873 | 6,003 | 3,789 | 1,967 | 302 | 188 |
| Department of the Interior | 6,290 | 2,362 | 12,186 | 16,528 | 17,746 | 22,926 | 22,553 |
| Bureau of Indian Affairs | 759 | 277 | 915 | 2,385 | 4,345 | 9,295 | 3,999 |
| Bureau of Land Management | 3,682 | 1,467 | 9,011 | 10,791 | 9,712 | 7,807 | 13,800 |
| Bureau of Mines | 148 | ------ | 200 | 108 | 240 | 297 | 299 |
| Bureau of Reclamation | 790 | 267 | 1,199 | 1,871 | 1,975 | 2,257 | 2,231 |
| National Park Service | 576 | 230 | 542 | 791 | 771 | 818 | 1,121 |
| Office of the Secretary | ------ | 44 | ------ | ------ | 82 | 203 | 154 |
| Office of Surface Mining | ------ | ------ | ------ | 135 | 21 | 1,563 | 469 |
| U.S. Fish and Wildlife Service | 205 | 45 | 178 | 447 | 600 | 686 | 480 |
| Department of State | 949 | 221 | 1,075 | 1,010 | 1,455 | 2,449 | 2,272 |
| Department of Transportation | 470 | 240 | 313 | 193 | 149 | 291 | 273 |
| Environmental Protection Agency | 1,921 | 777 | 2,137 | 3,074 | 2,873 | 2,645 | 1,259 |
| National Aeronautics and Space Administration | 3,584 | 1,051 | 2,648 | 2,763 | 4,033 | 2,793 | 5,065 |
| National Science Foundation | 1,650 | 40 | 2,712 | 848 | 896 | 1,211 | 2,001 |
| Nuclear Regulatory Commission | 1,439 | 427 | 1,758 | 1,318 | 1,583 | 1,325 | 1,781 |
| Tennessee Valley Authority | 216 | 70 | 297 | 216 | 261 | 243 | 317 |
| Miscellaneous Federal agencies | 1,542 | 499 | 1,774 | 1,882 | 1,645 | 2,105 | 7,935 |
| Miscellaneous services to other accounts | 1,527 | 253 | 822 | 1,290 | 989 | 4,556 | 986 |

[1] Shown as Energy Research and Development and Federal Energy Administration prior to October 1, 1977



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