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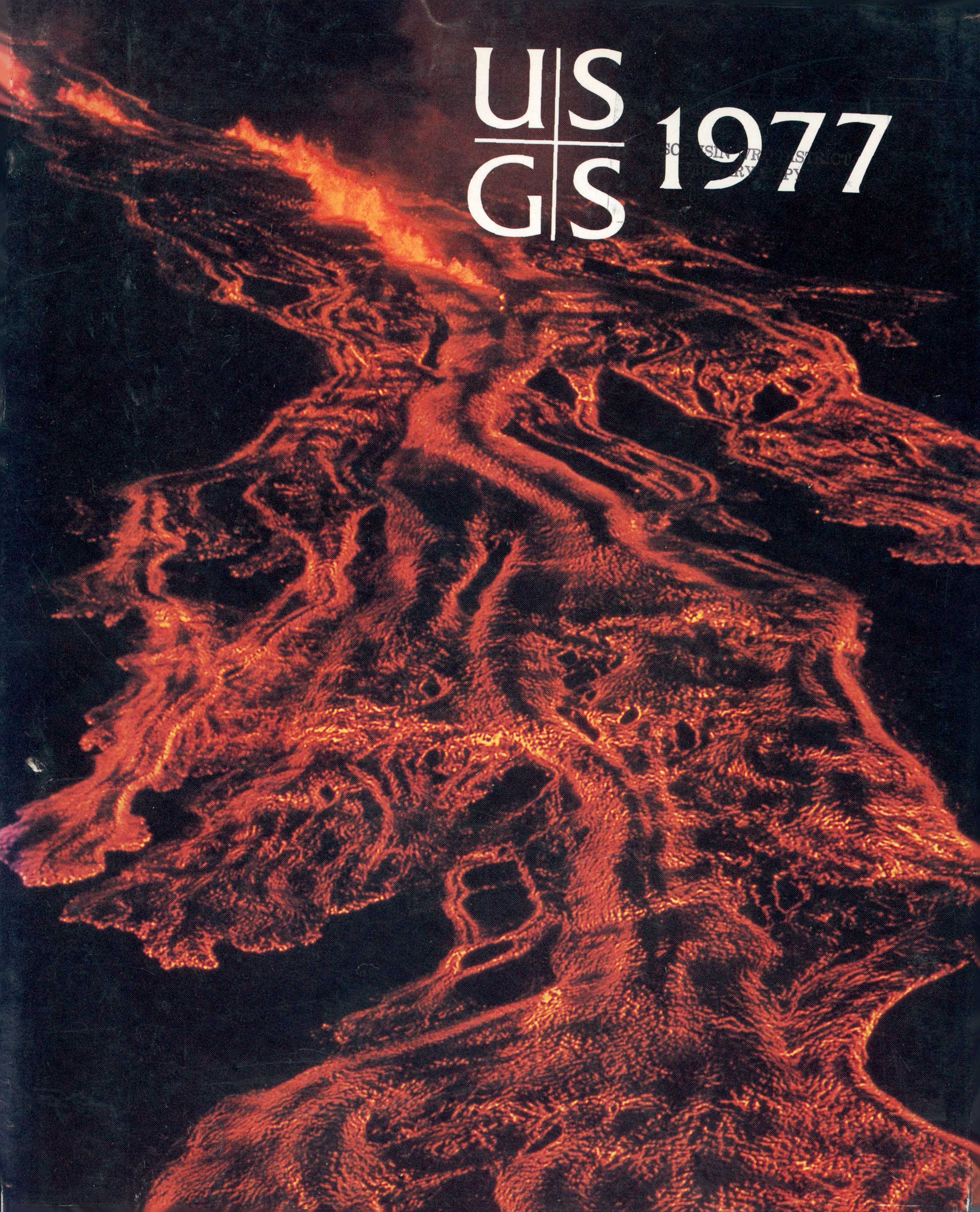

United States Geological Survey Yearbook Fiscal Year 1977

COVER: Aerial view of lava fountains, 50 meters high, spurting in the early morning of July 6, 1975 from fissures near Pohaku Hanalei on the north-east-rift zone of Mauna Loa Volcano, Hawaii, feeding a massive lava flow. The city of Hilo, about 40 kilometers downslope was spared. See pages 36-40 for an article on the monitoring of active volcanoes.
(Photograph by Robin T. Holcomb.)

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

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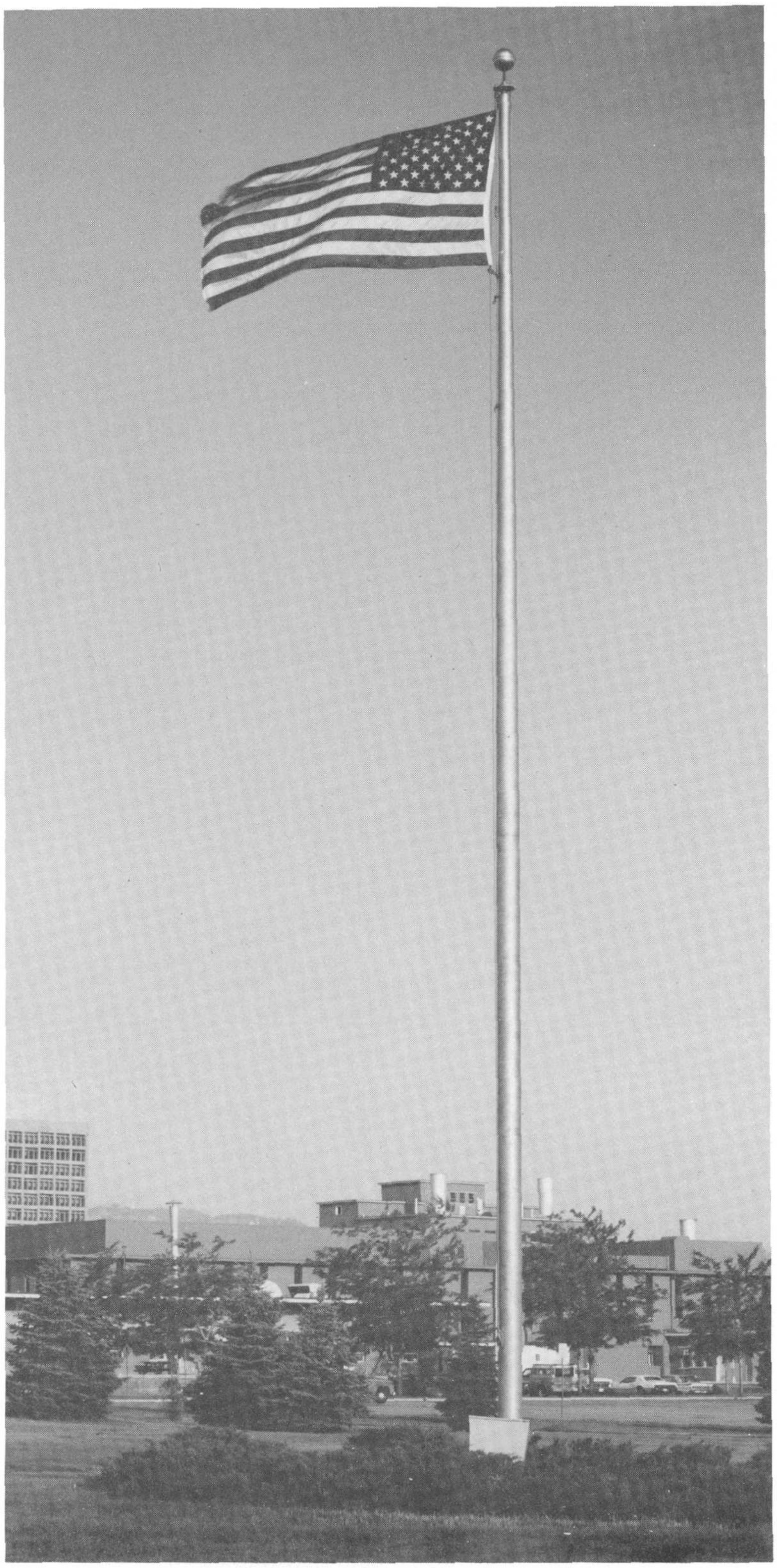
Preface

This Yearbook summarizes the progress made by the United States Geological Survey during fiscal year 1977 in its mandated role—to identify the Nation's land, water, energy, and mineral resources; to classify Federally-owned mineral lands and water power sites; to regulate the exploration and development of energy and mineral resources on Federal and Indian lands; and to explore and appraise the petroleum potential of the National Petroleum Reserve in Alaska.

As a report to Congress and the public, it falls logically into five parts:

- The Year in Review: a look at the major issues and events which affected Survey programs, and some performance highlights.
- Perspectives: a series of concise Earth-science essays which address national issues.
- Missions, Organization, and Budget: a description of the Geological Survey's major duties and assignments and of the organizational and fiscal structures that support its missions.
- A description of the activities and accomplishments of each of the nine operating Divisions and Offices.
- Statistical Tables: summary data which documents program trends, workloads, and significant 1977 accomplishments.

Supplemented by Professional Paper 1050, "Geological Survey Research 1977," the latest in a series of annual reviews of technical results of the Geological Survey's research programs, this Yearbook provides a comprehensive description of the activities of the Federal Government's principal Earth-science agency.



Denver Federal Center. (*Photograph by Dawn Reed.*)

The Year in Review

INTRODUCTION

Fiscal 1977 marked the 98th year the U.S. Geological Survey has endeavored in the unceasing task of providing information about the Earth and its physical resources, and regulating the activities of lessees engaged in extracting petroleum and other minerals from the public domain.

The past year also marked the beginning of a third and challenging mission, drawing upon the Survey's scientific talents, to explore and assess the petroleum potential of a vast 37,000 square miles expanse of Alaska's North Slope known as the National Petroleum Reserve in Alaska.

The first two missions require detailed and continuing investigations of the location, character, and extent of the Nation's land, water, mineral, and energy resources; a continuing National Topographic Mapping Program; the classification of Federal lands for mineral and waterpower potential; and a continuing program of technical review, safety inspection and royalty auditing of the operations of private parties engaged in mineral development on Federal lands to assure standards of safety, environmental protection, resource conservation, and a fair market return to the public for the development of their resources.

WATER RESOURCES

The Geological Survey has the principal responsibility for appraising the source, quantity, quality, and movement of the Nation's water resources. In addition, it is the lead agency for coordinating the activities of all Federal agencies in the acquisition of water data on streams, lakes, reservoirs, estuaries, and ground waters.

Because severe drought conditions prevailed across much of the country in 1977, Congress appropriated an additional $5 million of Federal matching funds for the Federal-State Cooperative Program within the Water Resources Division. These funds were used to provide information and analyses for planners and managers who were concerned with existing and potential water shortages. Stream-flow observations were expanded; evaluations were made of changes in water-use practices; assistance was given to identify supplemental sources of water supply; and determinations were made of changes in lake, reservoir, and ground-water storage.

During 1977, plans were made for extensive, indepth analyses of the Regional Aquifer Systems of the United States. These analyses will contribute to locating and developing adequate supplies of water for urban and rural areas in the event of possible future drought conditions. Twenty such aquifer systems have been identified and studies will begin in 1978.

Because of the national interest in energy and the emphasis on energy shortages, priority was given to hydrologic studies related to coal mining, oil-shale, nuclear energy, and geothermal research. Water quantity and water quality, both on the surface and in the ground, enter the energy equation in a variety of ways. These are discussed under the heading, "Critical National Water Problems," in the chapter which describes the activities of the Water Resources Division.

Plans were formulated to establish a National Water-Use Data System which will indicate the degree of use and the status of development of the Nation's water resources. In the past, detailed information on the occurrence and quality of water resources has been collected and made available but relatively little has been done to describe where, how, and in what quantities water is being used. This information is essential to determine what part of the water resources remains available for future use. Competition among types of uses for the available water in many parts of the country requires that accurate information is provided so that water can be directed toward the area of greatest benefit.

In 1977, some of the first water-quality evaluations were made as a result of measuring water-quality variables at 345 monitoring stations under the National Stream Quality Accounting Network (NASQAN). NASQAN began operation in 1973, having been designated by the President's Council on Environmental Quality as the Nation's primary network for uniform water-quality assessment. It provides data which show geographic patterns of water quality that reflect climate, geology, soil types, agricultural practices, human and animal populations, water pollution, and pollution-control practices, By 1979, the NASQAN network will be expanded to 525 stations.

As part of the Survey's efforts to monitor the quality of the Nation's water, the Water Resources Division Central Laboratories System made over two and one-half million determinations of physical, chemical, and biological characteristics of water from 170,000 samples.

NATIONAL PETROLEUM RESERVE IN ALASKA

On June 1, 1977, the National Petroleum Reserve in Alaska, formerly known as Naval Petroleum Reserve Numbered 4, was transferred from the Department of the Navy to the Department of the Interior in accordance with the Naval Petroleum Reserves Production Act of 1976 (Public Law 94–258, U.S. 94th Congress, April 5, 1976). The Secretary of the Interior charged the Geological Survey with the responsibility for continuing the Navy's 7-year exploration program on the reserve, including:

1. Petroleum exploratory drilling and geological and geophysical investigations to locate, test, and help assess producible oil and gas accumulations on the reserve.
2. Development and continued production of the South Barrow gas field to supply natural gas to the native village of Barrow and other communities and installations near Point Barrow, Alaska.
3. Restoration to an environmentally acceptable state certain areas of the reserve disturbed by previous construction and exploration activities.

The program, originally developed by Navy, involves drilling 26 test wells, collecting 10,000 line miles of seismic and gravity data, and conducting geologic studies to produce a resource appraisal of the petroleum potential of NPRA by the end of fiscal year 1980. Except for continuing production of gas from the South Barrow gas field, no petroleum

◄ "Nicasso Reservoir, principal storage reservoir for the Marin County, California, Municipal Water District's 180,000 customers, as it looked in October 1976. Storage on July 1, 1977, was only 0.3 cubic hectometers (250 acre-feet) of its storage capacity of 28 cubic hectometers (22,500 acre-feet)."

will be produced from the reserve until authorized by Congress.

The Geological Survey established the Office of National Petroleum Reserve in Alaska on November 2, 1976, with headquarters and an operations staff in Anchorage, Alaska. An exploration strategy staff in Menlo Park, California, selects drilling targets, locates seismic surveys, and develops coring and sampling programs. A Liaison Office in Reston, Virginia, interacts with the Department of the Interior and serves as a focal point for budgetary, contractual, and congressional matters.

The Geological Survey negotiated a contract with Husky Oil NPR Operations, Inc., to continue exploratory operations on the reserve. Also, numerous interagency agreements were modified to assure continuing logistical, communications, and operations support for petroleum exploration activities, and an Environmental Impact Statement (begun by the Navy) was completed to address exploration throughout the reserve.

Sites for seven exploratory wells and two Barrow Area development wells to be drilled in 1978 were selected in 1977 to provide the lead time necessary to assure delivery of materials.

ENERGY AND MINERALS

The task of assessing the minerals and energy resources of the Nation's lands continues to shape and direct many of the activities of the Geological Survey.

During fiscal year 1977, the Geologic Division continued mineral resource assessments in Alaska in areas judged to have a high mineral potential. Regional assessments under the Alaskan Mineral Resources Assessment Program continues with the publication of the McCarthy quadrangle folio and the Tanacross quadrangle folio. Resource assessments of 14 additional quadrangles, at a scale of 1:250,000, are underway. These 14 quadrangles and three previously published quadrangles contain approximately 23 percent of the Alaska D–2 lands. Similar regional assessments are also underway in the Alaska D–2 lands at a scale of 1:1,000,000. This program is designed to produce badly needed information on Alaska's mineral resources on lands that may be closed to future minerals and energy development under section D–2 of the Alaska Native Claims Settlement Act. Mineral resource assessment of about one-half of the D–2 land area is now completed.

More than 12.5 million hectares (31 million acres) have been proposed for wilderness status by other Federal agencies since the passage of the Wilderness Act in 1964. As required by Congress, an assessment of the mineral and energy resource potential for each proposed wilderness area is needed before granting wilderness status and concomitant prohibition of mining activity. The Geological Survey, in cooperation with the Bureau of Mines has completed resource surveys on 6.9 hectares (17.0 million acres) of proposed wilderness lands.

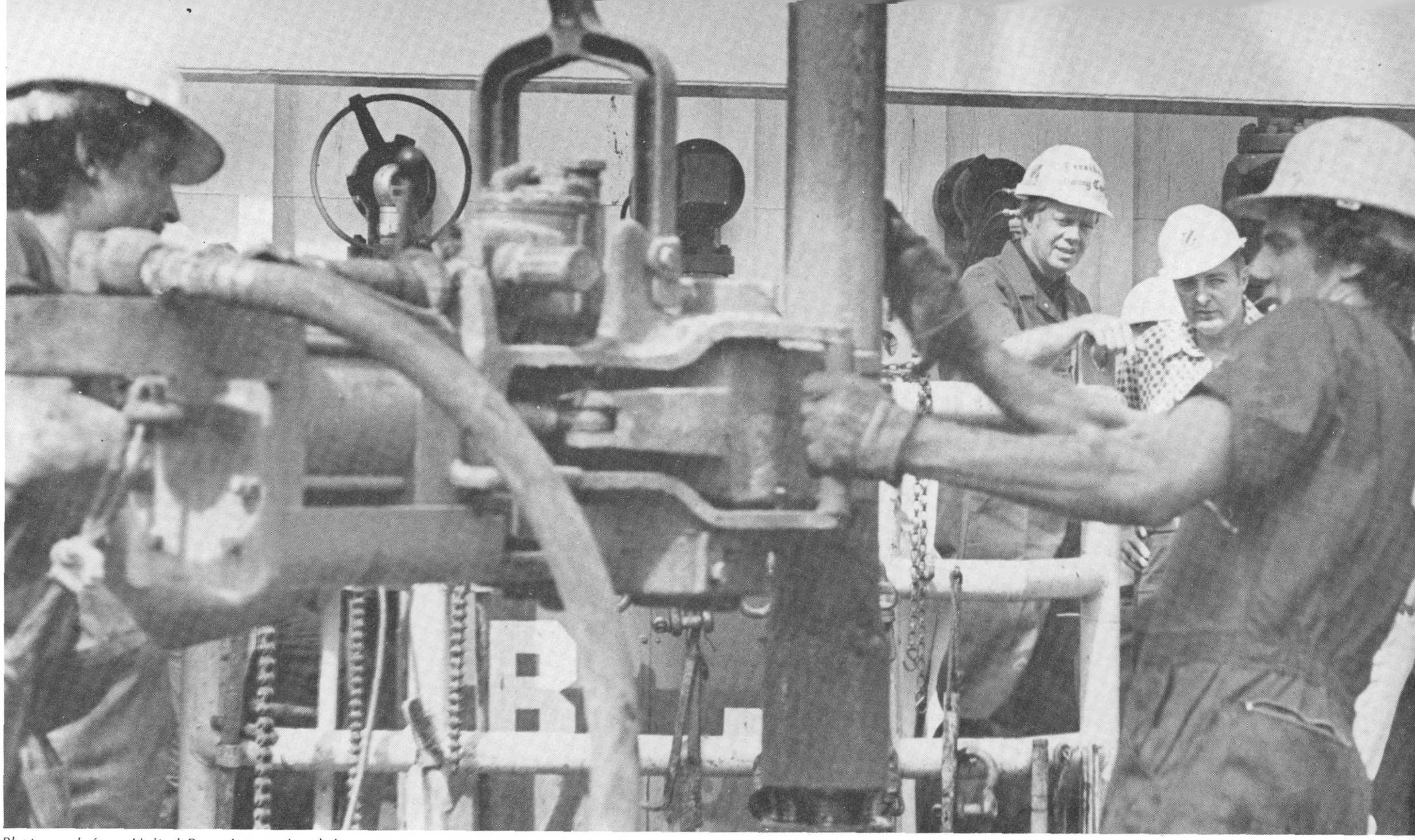
The Geological Survey is cooperating with 15 State Geological Surveys in collecting and analyzing coal and related rocks. Analyses to date, show that coal in the Western Interior Coal Basin (Iowa, Missouri, Oklahoma, Kansas, and Nebraska) and in the Eastern Interior Coal Basin (Illinois, Indiana, and NW Kentucky) contain higher than normal amounts of zinc and cadmium. Analyses also show that coals in the Eastern Interior Coal Basin contain higher than normal amounts of cobalt, chromium, nickel, and vanadium. The Survey also mapped approximately 1,800 square kilometers (695 square miles) of land in Wyoming, Colorado, Kentucky, Virginia, and West Virginia to assess low-sulfur coal resources. An additional 2,300 square kilometers (888 square miles) were re-evaluated for low-sulfur coal resources on Federal lands in Montana and Wyoming.

During fiscal year 1977, oil and gas resource estimates, including field-size distribution, were completed for the Permian Basin in west Texas and New Mexico and offshore Gulf of Mexico, Texas, and Louisiana.

RESOURCE EVALUATION AND LEASE REGULATION

Geological Survey regulatory responsibilities on the Outer Continental Shelf and on Federal and Indian lands are carried out by the Conservation Division.

Six deep Continental Offshore Stratigraphic Test (COST) wells were approved in Federal waters on the Outer Continental Shelf (OCS). These wells were drilled by industry with the stipulation that they share the data with the Department of the Interior. Five were completed and one was being drilled at year's end. Of the two tests drilled in the Atlantic OCS, the first, North Atlantic COST Well No. G–2, was approved in December 1976, drilled to 6,667 meters (21,872 feet), and completed on August 31, 1977; the second, South Atlantic COST Well No. GE–1, was approved in January 1977, drilled to 4,040 meters (13,254 feet) and completed on June 15, 1977. The other four approved deep stratigraphic tests were for the Alaskan OCS. The Lower Cook Inlet COST Well No. 1 test, approved in June 1977 and drilled to 3,776 meters (12,387 feet) was completed on September 24, 1977. Three tests were approved for Alaska's Kodiak Shelf.



Photograph from United Press International, Inc.

President Jimmy Carter observes drilling operations while visiting the Zapata offshore-drilling platform in the Gulf of Mexico during the summer of 1977.

Kodiak Well No. 1, approved in May 1977 and drilled to 2,596 meters (8,517 feet), was completed on July 18, 1977, and the Kodiak Well No. 2, approved in July 1977 and drilled to 3,188 meters (10,460 feet), was completed on September 3, 1977. Kodiak Well No. 3, approved in July 1977, was being drilled at the end of the fiscal year.

Two open-file reports on completed deep stratigraphic tests were released during fiscal year 1977: the Mid-Atlantic COST No. B-2 Open-File Report in November 1976 and the Gulf of Alaska COST Well No. 1 Open-File Report in January 1977. These deep stratigraphic tests provide geologic and engineering data useful to participating companies and to the Federal Government as an aid to evaluating tracts to be offered in future lease sales.

Contracts for the preparation of 510 Coal Resource Occurrence—Coal Development Potential Maps (CRO-CDP) were let to various consulting firms and one university. These maps show thickness of coal beds, the configuration of the top of each bed, thickness of overburden, location of such data points as drill holes or outcrops, and the distribution of the Federal coal resources.

In May 1977, the Geological Survey announced its OCS Platform Verification Program to provide guidelines and standards to reduce the risks and enhance the integrity of the OCS structures to be installed in frontier areas. Also published was a document describing the Geological Survey's Policies, Practices, and Responsibilities for Safety and Environmental Protection in Oil and Gas Operations on the Outer Continental Shelf. This document describes current activities to minimize the potential for pollution from OCS operations. Major elements of other programs outlined in the document will be implemented during 1978.

Three "Notices to Lessees and Operators" (NTL's) streamlining our royalty accounting system were issued. NTL–1 and NTL–1A established use of modernized Federal and Indian lease accounting reports. NTL–5 prescribes product valuation procedures to be applied to royalty accounting of natural gas. A proposed revision of the oil and gas operating regulations significantly strengthening the section on "Noncompliance and Assessment of Liquidated Damages," was published in the *Federal Register*. Drilling for oil and gas on public and Indian lands expanded by 280 new well starts, an increase of nearly 13 percent over fiscal year 1976. Producible well completions likewise increased by 7.4 percent.

Cooperative agreements empowering States to enforce environmental protections and reclamation requirements for surface coal mining on Federal lands were entered into with Colorado, Montana, New Mexico, North Dakota, Utah, and Wyoming.

Reserve inventories were completed in 75 Outer Continental Shelf oil and gas fields bringing the total inventoried to 175 of about 255 fields in the Gulf of Mexico. Within each field, every reservoir was also mapped and the remaining recoverable oil and gas was calculated. Estimates of reserves for other fields were made on a field-wide basis. The first annual estimated reserves of the Gulf of Mexico were released in Open File Report (77–71) and compilation of the first annual estimated reserves of the Pacific Outer Continental Shelf was in progress at the end of the fiscal year.

GEOLOGIC HAZARDS

The Geological Survey is developing methods to delineate and mitigate hazards associated with earthquakes, volcanic eruptions, landslides, ground subsidence, and floods.

Since the discovery of the anomalous land uplift in southern California in late 1975, extensive efforts are being made to define the shape and extent of the uplift, to understand its origin, and to assess its implications for future earthquakes. The uplift extends eastward from Santa Barbara to the Colorado River over an area of about 90,000 square kilometers (35,000 square miles) averaging about 120 kilometers (75 miles) in width. The maximum uplift occurred north of Palm Springs, reaching 45 centimeters (17.7 inches). Precise surveys show that the uplift near Palmdale, California, decreased from about 35 centimeters (13.8 inches) to about 17 centimeters (6.7 inches) between 1974 and 1976. It is likely that the uplift results from accumulating stresses to be released eventually as an earthquake along the San Andreas Fault.

The Geological Survey's Reactor Hazard Research Program continues investigations on the history and nature of recent fault movements to provide a basis for assessing the safety and environmental problems in siting nuclear facilities. Considerable study is focused on surface fault caused by ground-water withdrawal in the Texas Gulf Coast area.

Mauna Loa Volcano, Hawaii, continues to build toward its next eruption. The volcano, which was intensely monitored, continued to inflate with little accompanying seismic activity during the first part of the year, but the rate of inflation slowed later in the year.

On September 13, the flank of Kilauea Volcano erupted with 25–30 meter lava fountains along a 5-kilometer (3-mile) fissure in the Heiheiahulu area. Eighteen days later, the eruption ceased and a rapidly moving lava flow halted within 400 meters (less than a quarter of a mile) of dwellings. The Geological Survey had advised Hawaii County Civil Defense officials of the unstable conditions, and residents were then informed by a press release issued July 29, 1977.

SURVEYING AND MAPPING

In fulfilling responsibility for the National Mapping Program, the Geological Survey prepares and distributes maps in several series, defines mapping standards, coordinates Federal mapping efforts, and provides a central source for cartographic information.

In fiscal year 1977, the Topographic Division produced 304 intermediate-scale maps, including both 1:100,000 scale quadrangle maps and 1:100,000- and 1:50,000-scale county maps. These maps are in heavy demand by Federal and State agencies. For example, the Bureau of Land Management and the Soil Conservation Service utilize these maps to assemble basic map content they need and add their own special information in a tailored edition. As published by the Geological Survey, the maps will show metric units of measurement.

To meet the increasing requirement for cartographic information in digital form suitable for storage, processing, and recall by computers, a Digital Applications team was formed to consider and plan the most efficient methods, including equipment, for handling large volumes of digital cartographic data. As a result of the successful use of the first Gestalt Photo Mapper II—an advanced instrument that simultaneously produces orthophotographs, contour plots, and digital elevation models—a second unit has been ordered.

Design work was completed for the Airborne Profiling of Terrain System, which combines space age inertial positioning and laser ranging as an efficient means of establishing, at the speed of flight, a dense network of ground positions and elevations for topographic mapping, flood-plain studies, and similar applications. Tests of the first prototype of this revolutionary new surveying tool are planned for 1980.

Plans were developed for the systematic conversion of contours to the metric system. The sequence of contour intervals adopted is 1, 2, 5, 10, 20, and 50 meters. The choice of contour interval for a given map depends on the range of topographic relief to be depicted.

Continuing the effort to provide convenient public access to information about maps and mapping, the National Cartographic Information Center established five State-affiliated branch offices, in Arizona, Georgia, New Mexico, South Carolina, and Texas.

LAND INFORMATION AND ANALYSIS

The Geological Survey continued its efforts to interpret and present land-resource information in report and map formats that are readily accessible and understandable to a wide range of Earth-science data users. During fiscal year 1977, the Land Information and Analysis Office published reports and maps and conducted workshops in an effort to convey scientific and engineering data and interpretive information, in readily usable form, to support land resource planners and decisionmakers at all levels of Government and in the private sector.

The Earth Sciences Application Program has been instrumental in developing guidelines and procedures that enable the Survey to effectively carry out its hazard warning responsibilities. The Geological Survey published a statement in the *Federal Register* (April 12, 1977) describing present capabilities and limitations for advance recognition and warning of geologic-related hazards. Efforts are now being made to establish effective warning procedures in cooperation with appropriate local, State, and Federal agency representatives.

The Resource and Land Investigations Program completed a joint project, with the New England River Basins Commission (NERBC), to develop a generalized planning methodology to estimate the onshore impacts of Outer Continental Shelf (OCS) oil and gas development. The results of the study are published as a series of reports, and are being presented during fiscal years 1977 and 1978 at regional workshops partly funded by EPA. The objective is to transfer the state-of-the-art in planning methods to State and local agencies. It is hoped that this technical assistance will aid States to mitigate any adverse onshore effects of OCS development.

Under the Geography Program's nationwide mapping program, land-use and land-cover maps and data were compiled for approximately 1,040,000 square kilometers (400,000 square miles) bringing the total area completed for such mapping to 2,730,000 square kilometers (1,050,000 square miles) since the program began in fiscal year 1975.

The Earth Resources Observation Systems (EROS) Program, through its EROS Data Center (EDC) in Sioux Falls, South Dakota, produced and distributed imagery and data having a value of $2,515,000. Landsat products, while totaling only 18 percent of the data base, accounted for 62 percent of total sales. More than 30 percent of the Landsat product sales were for computer compatible tapes, reflecting the increased capability of industry and Federal and State agencies to digitally process Landsat data. A new digital image processing system being implemented by the Goddard Space Flight Center and EDC will start generating products from Landsat-C data early in 1978 which will be superior to those from Landsats 1 and 2.

The Environmental Impact Analysis Program had lead or joint lead responsibility for the Survey, in the preparation of 16 environmental impact statements and participated in a nonlead capacity in the preparation of 19 statements. Of the 35 EIS's, 32 were energy related. Also, 1,800 impact statements and related documents were reviewed.

ADMINISTRATIVE AND TECHNICAL SUPPORT

Major efforts during the year were directed at improvements in handling the increasing administrative workload in Procurement and Contracts, Financial Management, and Property Management. This development is part of an overall plan for automating administrative systems. Major portions of the data entry and processing activity of the above functions are now automated through the use of computer terminals, both at Headquarters and in the Regional Offices. Information being filed in the Geological Survey's Administrative Data Bases is now more timely, more accurate, and more useful. Consequently recurring and special reports are available not only to administrative managers, but also to managers in the Survey's Program Divisions and in the Department of the Interior.

Three Honeywell Multics time-sharing facilities were brought online to provide nationwide computer access for interactive problem solving. Located in Denver, Colorado; Menlo Park, California; and Reston, Virginia these facilities exploit existing automatic data processing technology to provide methods for scientific computations, data handling, and administrative data processing for the Geological Survey's varied activities.

A record number of maps were reproduced in fiscal 1977 in the Survey's printing plant. More than 20 million copies of over 7,380 different maps were printed including nearly 3,700 reprints of previously published maps. This major thrust in reprinting was accomplished to reduce the unusually large number of maps out of stock.

Results of many Geological Survey activities are not formally published, but are made available to the public and the scientific community through Open-File Reports. A centrally located facility was established in Denver, Colorado, to provide direct-mail sales of microfiche and paper-duplicate copies of Open-File Reports.

Perspectives

"If we are to make full use of the earth's resources and at the same time maintain a viable environment we must understand the natural forces and processes at work in the earth, the rivers, the oceans and the atmosphere. We must know how these forces, processes, and materials interact and how and to what extent we perturb them in our activities. In spite of the warnings we frequently hear, there is nothing inherently wrong in changing the so-called balance of nature. Nature herself does it continually and man has been doing it with good, bad, and indifferent results since the discovery of fire and agriculture. What is dangerous now, with our enormous power to modify the earth and its processes, is to act in ignorance of the consequences."

V. E. McKelvey
in *"Earth Scientists—Front and Center!"*
April 17, 1972

River-Quality Assessment

By Phillip E. Greeson and David A. Rickert [1]

CONCEPT OF RIVER-QUALITY ASSESSMENT

In 1972, the U.S. Geological Survey began a program of river-quality assessments. The objectives of the program are (1) to define the character, interrelationships, and apparent causes of existing river-quality conditions, and (2) to devise and demonstrate the analytical approaches and the tools and methodologies needed for developing water-quality information that will provide a sound technical basis for planners and managers to use in assessing river-quality problems and evaluating management alternatives. Both reconnaissance and intensive river-quality assessments are envisioned under the program. Reconnaissance river-quality assessments concentrate on the first objective by describing the river quality of the basins and by identifying existing and potential river-quality problems. These are the necessary "problem identifiers." Intensive river-quality assessments emphasize the second objective and lead to predictions of river-quality under various optional management strategies. They are the "problem analyzers."

River-quality problems stem basically from two factors—the unique hydrology of a river basin and

◀ The Willamette River, Oregon.
(*Photograph from* the Oregon State Highway Commission.)

[1] Respectively, Hydrologist and Coordinator of River-Quality Assessment Program, U.S. Geological Survey, Reston, Virginia 22092; and Hydrologist and Project Chief of the Willamette River assessment, U.S. Geological Survey, Portland, Oregon 97208.

man's development and use of the land and water resources. In the broadest context, river-quality assessment is a problem-oriented approach for developing information that is appropriate and adequate for sound resource management (fig. 1).

To predict the consequences of any management plan, a fundamental understanding of cause-effect relationships is essential. Assessment, therefore, necessarily extends far beyond the basic data on water's physical, chemical, and biological qualities to the determination of pollution sources and the prevailing hydrologic conditions that cause the observed effect. When, by scientific analysis, cause-effect relationships are defined and verified, assessment becomes a powerful predictive tool by which alternative plans for action can be evaluated. Such evaluations then enable the planner and the decisionmaker to establish priorities rationally. (Rickert, Hines, and McKenzie, 1976a, b.)

For a specific river basin, the process of river-quality assessment involves seven steps: (1) identifying significant problems of major importance in the basin; (2) analyzing the hydrology; (3) deciding upon assessment methods appropriate to each problem; (4) collecting data relevant to each problem by intensive investigations; (5) analyzing the data for cause-effect relationships, formulating and calibrating predictive methods by which changes in river-quality variables can be projected, and verifying the predicted results against observed conditions; (6) forecasting the impacts of various planning alternatives on river quality; and (7) presenting the results of river-quality assessment in a manner that is understandable to planners and decisionmakers.

OVERVIEW OF THE SURVEY'S PROGRAM

On the basis of a recommendation from the Department of the Interior's Advisory Committee on Water Data for Public Use, the Geological Survey began an intensive pilot assessment in January 1973 with a study of the Willamette River basin, Oregon (fig. 2). The Williamette River was selected for several reasons. First, there was an excellent base of background data, particularly on hydrology. Second, social and political attitudes in Oregon reflected a keen interest in environmental quality. This suggested that the people and agencies would welcome the study and that results would be used at the State and local levels. Third, a river-basin management plan already existed, as did several land-use projections. Thus, the study could evaluate existing planning alternatives to provide a realistic test of assessment approaches. Fourth,

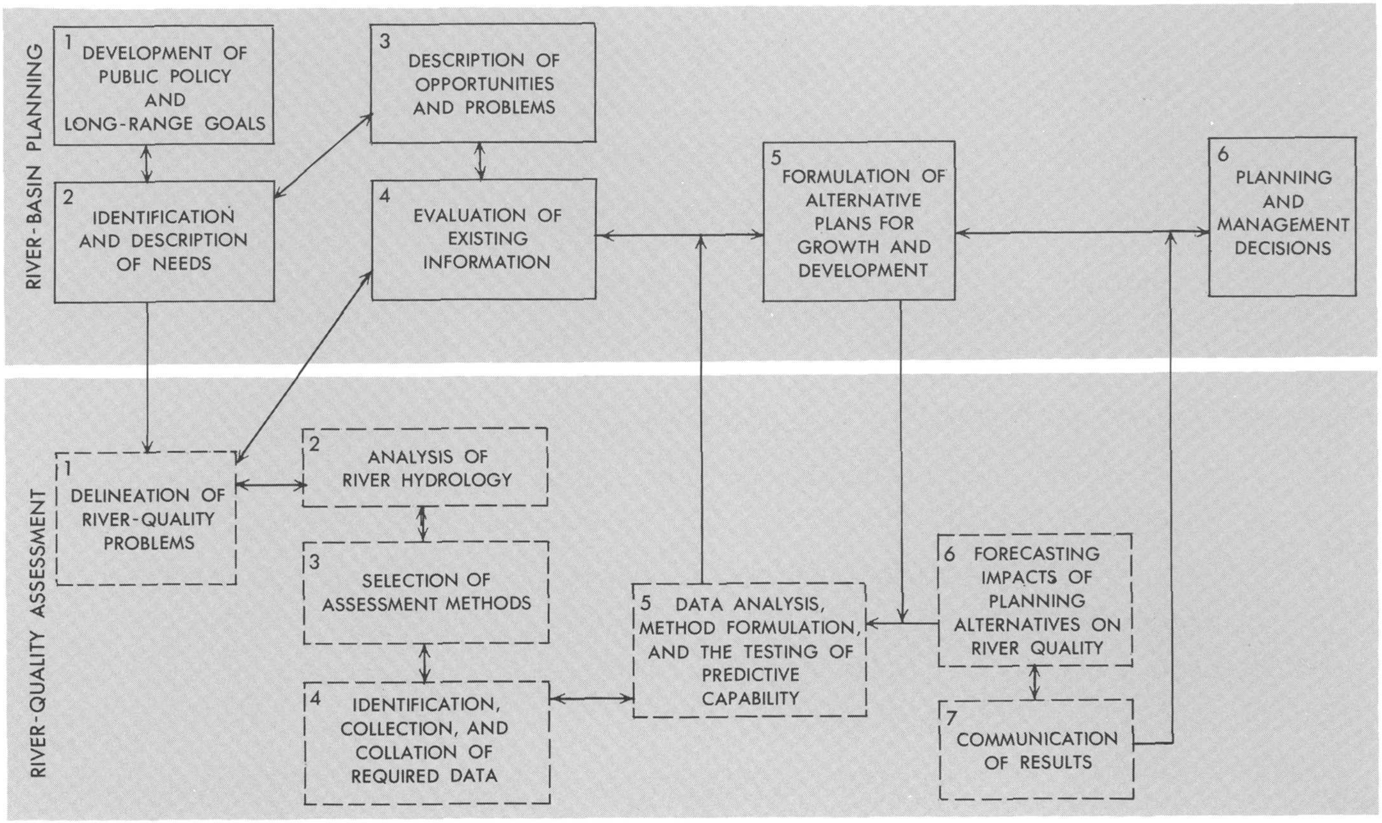


FIGURE 1.—The interrelation of river-quality assessment to river-basin planning. (From Rickert, Hines, and McKenzie, 1976a.)

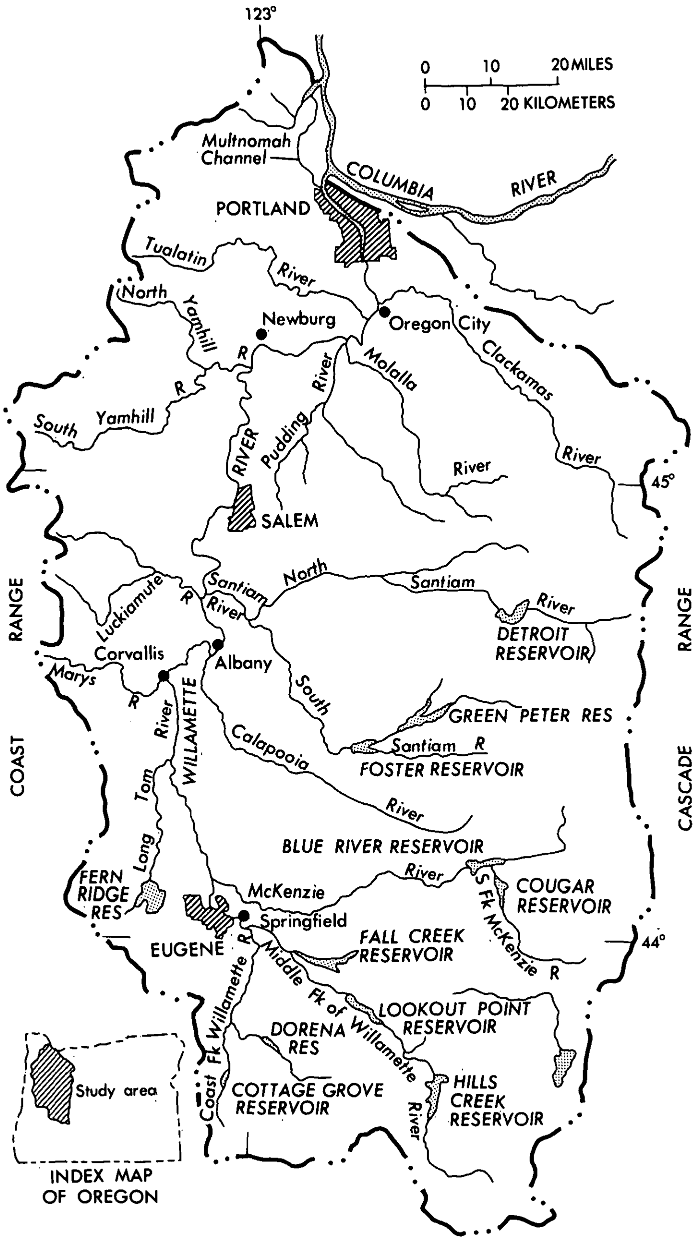


FIGURE 2.—Willamette River basin, Oregon, emphasizing the main stem, principal tributaries, and major reservoirs. (From Rickert, Hines, and McKenzie, 1976a.)

the Willamette is the largest river in the Nation for which all major point-source discharges receive secondary waste-water treatment. Water quality is above the stringent State standards, and the river is considered a national success story. Thus, the study could include appraisal of the factors to which past improvement was attributed, in addition to evaluating the factors that needed to be managed to maintain or improve the quality.

The Willamette River basin, a watershed of nearly 29,800 square kilometers (11,500 square miles), contains the State's three largest cities, Portland, Salem, and Eugene, and approximately 1.4 million people, representing 70 percent of the State's population (1970 census). The basin supports an economy based on timber, agriculture, industry, and recreation, and contains extensive fish and wildlife habitats.

The basin is roughly rectangular, with a north-south length of about 240 kilometers (149 miles) and an east-west width of 120 kilometers (75 miles). Altitudes vary from less than 3 meters (10 feet) near the mouth of the Willamette River to 140 meters (459 feet) on the valley floor near Eugene and to more than 3,050 meters (10,000 feet) in the Cascade Range. Average annual precipitation in the basin is about 1,600 millimeters (63 inches).

The slopes and foothills of the Cascade Range account for more than 60 percent of the basin area. About 62 percent of the basin is timberland, located largely in the tributary basins. Approximately 33 percent of the area is farmland, and the remaining 5 percent is urban and in other uses.

Specific problems addressed during the study were determined in consultation with State, interstate, and Federal agencies. The problems included (1) the need for maintenance of high-level dissolved oxygen in the river and the effects of reservoir release patterns on downstream river quality; (2) algal growth potential; (3) occurrence and distribution of trace metals; and (4) the significance of erosion potential to proposed land and water uses (table 1). The Willamette

TABLE 1.—*Existing or potential river-quality problems of the Willamette River basin, Oregon. (from Rickert, Hines, and McKenzie, 1976a.)*

Problem	Relative importance [1]	Selected for present study
Nonpoint-source pollution	3	
Reservoir-release quality	3	
Dissolved-oxygen depletion	1	x
Algal-problem potential	2	x
Trace-metal occurrence	1	x
Sanitary quality	3	
Accelerated erosion	1	x
Riverbank esthetics	2	

[1] 1 = greatest importance; 3 = least importance.

assessment has been completed and the results have been reported in 10 Geological Survey Circulars (U.S. Geol. Survey Circs. 715). (See references to Hines, Jennings, Rickert, Shearman, and others, 1975–77.)

Before discussing the results of the Willamette study, let us look briefly at the rest of the Survey's river-quality assessment program. In order to develop the approaches and methodologies for some of the basin problems not encountered in the Willamette River study, two additional intensive river-quality assessments were started in April 1975. One is of the Upper Chattahoochee River basin, Georgia, and the other is of the Yampa River basin, in Colorado and

Wyoming. The Upper Chatahoochee River assessment is scheduled for completion in the spring, 1978; reports of the Yampa River assessment are in preparation.

The Upper Chattahoochee River assessment (Cherry, R. N., and others, 1975) is addressing problems related to thermal loading and heat dissipation; wastes from concentrated urban-industrial areas; flow pulsations resulting from hydropower production; and sediment sources, transport characteristics, and deposition. The Upper Chattahoochee River basin study is demonstrating the kinds of information that can be provided as a basis for knowledgeable management decisions regarding basin development and future uses of the river in which the maintenance and improvement of water quality are prime requisites.

The Yampa River (fig. 3) assessment (Steele, T. D., and others, 1976a and b) addresses problems related to resource development for energy production—primarily, the impact on river quality of coal extraction and conversion processes. The study incorporated the concepts of both reconnaissance and intensive assessments. The first phase of the study assessed, prior to development of energy-related activities, the environmental setting of the basin and the current and predicted energy-development plans. Under the second phase of the study, the relative impacts on the basin of various proposed plans for energy-resource development are evaluated. The developed and documented methodologies should be readily transferable to other energy-rich, semiarid regions of the United States.

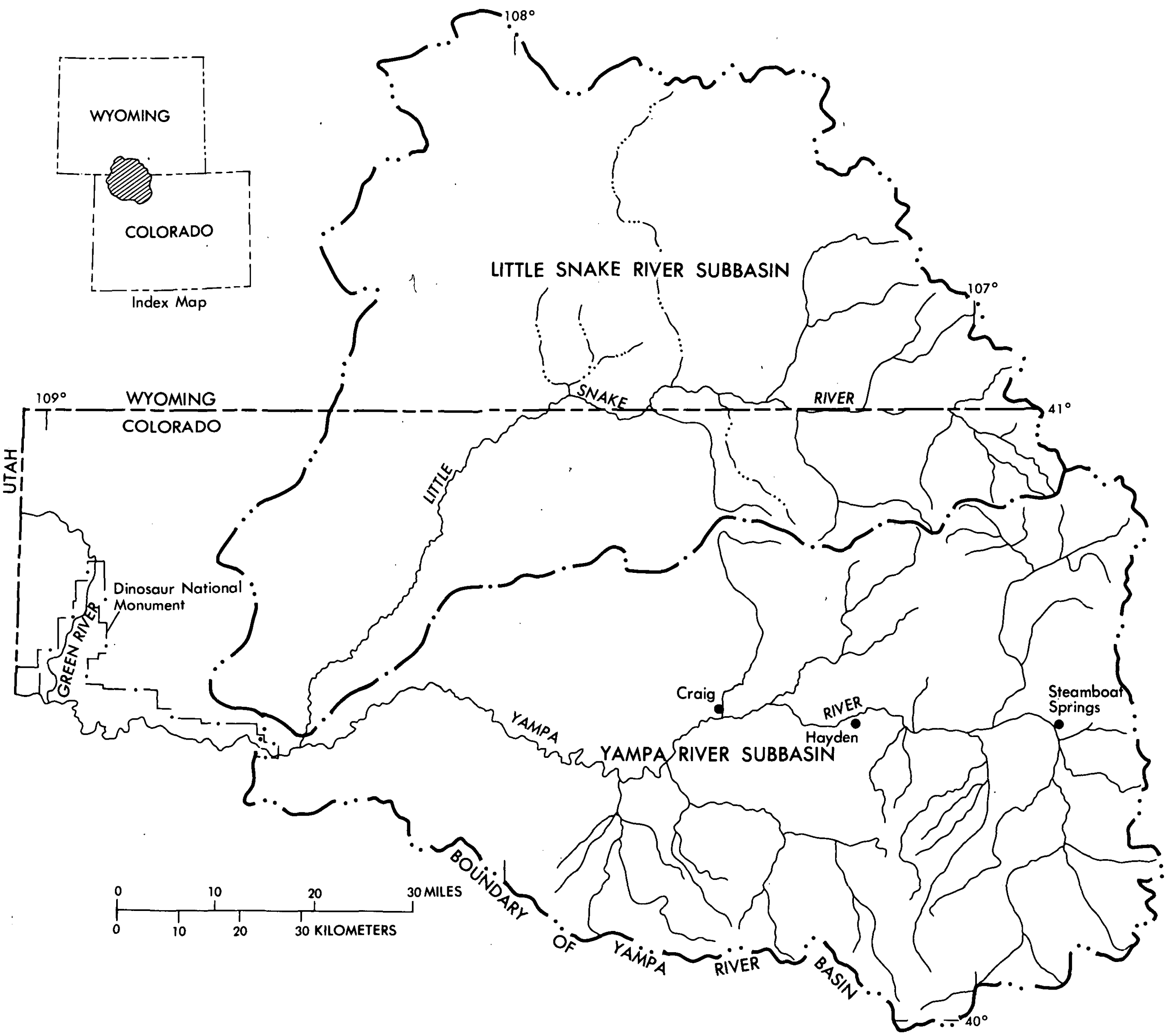


FIGURE 3.—Yampa River basin, Colorado and Wyoming. (From Steele and others, 1976a.)

IMPLICATIONS OF THE WILLAMETTE ASSESSMENT

The following conclusions (Rickert, Hines, and McKenzie, 1976; Greeson, Velz, and Rickert, 1977) are drawn from the Willamette River assessment:

Dissolved-oxygen depletion. Historically, maintenance of high dissolved-oxygen concentration has been the critical quality problem in the Willamette River, especially during summer low flows (fig. 4). In recent years, dissolved-oxygen levels have increased dramatically in the summer. Secondary biological treatment of all point sources of wastes has effectively reduced the discharge of organic, oxygen-demanding waste (biochemical oxygen demand or BOD) and, together with streamflow augmentation from storage reservoirs, has caused the improvement.

The advent of secondary treatment resulted in continuous discharges of effluents at several industrial installations, rather than the previously used program of summer lagooning and winter discharging. Ammonia from certain of these effluents was shown by the study to be the major cause of oxygen depletion in the lower third of the river. Reduction of ammonia loading from a few sources presents a relatively simple alternative for achieving a large improvement in summer dissolved-oxygen levels.

By contrast, it was found that further reduction in the point-source discharge of organic waste beyond that achieved by efficient secondary treatment would produce insignificant improvement in the dissolved-oxygen concentrations. Certain sources however, might require upgrading of their secondary treatment. Only about half of the total basinwide loading of organic, oxygen-demanding substances presently comes from point sources (table 2). The other half represents natural background demand from essentially pristine streams and cannot be reduced by pollution control programs.

TABLE 2.—*Dry-weather 1974 ultimate BOD loading, Willamette River, Oregon. (from Hines, McKenzie, and Rickert, in press.)*

Source	Loading (lb/day)	Percent
Nonpoint	77,100	46
Point		
Municipal	37,600	22
Industrial	54,400	32
Total	169,100	100

Even with basinwide secondary treatment and reasonable limitation on ammonia loading, low-flow augmentation from headwater streams would be necessary to maintain the State's high dissolved-oxygen standards. As basin development continues, reservoir augmentation to the present flow level probably will be needed even with increased treatment removal of oxygen-depleting materials.

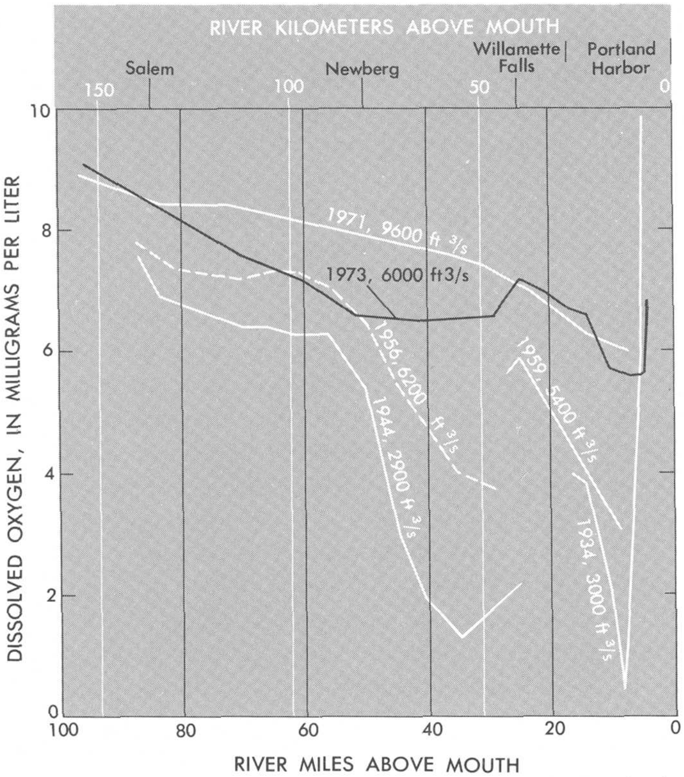


FIGURE 4.—Comparison of 1973 with historical DO (dissolved oxygen) profiles in the Willamette River for the summer low-flow period. (Historical data are adapted from Gleeson, 1972.)

Potential for algal problems. Despite the secondary treatment of point-source discharges, nitrogen and phosphorus concentrations in the Willamette River remain high, creating a potential for algal problems. There are several probable reasons why nuisance growths have not been observed: lack of other essential trace elements, low water temperatures, high summertime turbidities, and short water-detention times. The results and comparisons with other rivers indicate that the primary reason for favorable algal populations in the Willamette River, in spite of high concentrations of nitrogen and phosphorus, was the short detention time of water.

A number of factors discourage the growth of nuisance algae in flowing waters. Perhaps the most important is the constant nutrient influx which prevents depletion of major nutrients to the advantage of bluegreen algae. The key to algal control in the Willamette River appears to be maintenance of present levels of low-flow augmentation, to maintain higher streamflow velocities. The detailed biological studies indicate that arbitrary standards for permissible nitrogen and phosphorus concentrations are not desirable.

Trace-metal occurrence. Many materials discharged into river systems can be toxic to aquatic organisms. Most substances enter the river at subtoxic levels, but many can be concentrated at successive steps in aquatic food chains. Records for the Willamette River basin showed that there was little possibility of problems resulting from industrial organics and pesticides but few data existed on the discharges of trace metals or of their possible accumulation in the water, sediment, and food chains.

To help fill the data void, a study was conducted to determine the concentration and distribution of selected metals in river-bottom sediments in order to establish baseline data for future comparisons and to provide an alert to possible accumulations of metals. The concentrations detected in the study suggest that no metals were present at levels which might represent a potential ecological threat. There were, however, moderate enrichments of zinc, resulting from industrial discharges, and slight enrichments of lead, resulting from urban runoff. The procedures developed in the study could be modified to detect the extent of trace-metal pollution in virtually any river.

Impact of land-use activity on erosion. Great increases in population and industry over the next 50 years are predicted for the Willamette Valley. The potential impacts of the development on the land and the water quality is unknown, but they may be very high. For the study, a photomosaic map and an erosion-potential matrix were developed to delineate the relationships between physiographic factors, types of land use, and resultant erosional and depositional problems. Together, the map and matrix provide a means for making tentative estimates of the erosional impact of human activities on various types of terrain. They can be used elsewhere for land- and water-resource planning and for the design of improved programs for assessing land and river quality.

Implications for the Scientific and Engineering Community

While the results of the pilot study are of particular importance to decisions affecting the Willamette River, certain findings can be extended to the investigative programs of the scientific and engineering communities across the Nation. Some already have been pointed out—such as the importance of low-flow augmentation and the limited impact on the river of further reduction of organic, oxygen-depleting wastes. These can be extended readily to other river-basin appraisals and could influence decisions involving the expenditures of vast sums of money.

Of particular importance to the scientific community is the insight gained as to the types of data needed to conduct a sound river-quality assessment. Short-term, intensive, synoptic studies are needed to provide the types of data required for assessment of problems in the river. As well as defining cause-effect relationships, data from synoptic studies can provide knowledge of critical temporal and spatial changes in river quality, environmental factors, and waste loading, and sufficient data for a given time period to define the range of error in results and predictions.

It was found that mathematical models, if properly formulated and based on sound and adequate data with all the assumptions clearly stated, can be used effectively in the practical assessment of resource-planning alternatives.

There are many problems, however, which are currently difficult or impossible to model in a practical and verifiable manner. Such problems include nutrient-algal growth relationships and trace-metal occurrence. In the pilot study, a qualitative-descriptive approach was used to develop sound planning information. The descriptive studies demonstrated that qualitative approaches can produce adequate and reliable data for assessing key river-quality problems.

The approach of the pilot study and all the methods and techniques developed were intended for widespread application to facilitate the assessment of land and river quality in many basins. Often the demographic and economic uncertainties in a basin may be greater than the river-quality uncertainties, but this only increases the need for careful, thorough scientific assessment of local problems. Such appraisal can provide a starting point for systematic evaluation of the impact of socioeconomic and political options and of technical alternatives on each specific problem. Sound resource planning and management decisions can be made only on the basis of an intensive, coordinated assessment of the entire river basin that is keyed to the local problems and conditions.

Implications for Resource Planning and Management

The need to study each basin individually is one of the broad implications of the study. For instance, a special interrelationship in the Willamette River was revealed between nutrient concentrations and flow as controllers of algal growth. The application of rigid nationwide standards might have resulted in expenditures, unnecessary in this basin, to reduce the loading of nitrogen and phosphorus.

Another broad implication is that wastewater treatment is not the sole means of river-quality enhancement, although it plays an important role. More and more treatment is not necessarily the answer. Other strategies must be considered, for example, low-flow augmentation, industrial processing of wastes, and

Collecting bottom sediment samples with a Peterson Grab.

better control of nonpoint sources of pollution and urban runoff.

Results of the pilot study also indicate that, when expensive management decisions are pending, there is no substitute for carefully interpreted, detailed and intensive data. Routine monitoring or surveillance data, while useful for local management and determining compliance with standards, are seldom adequate for defining the cause-effect relationships that control most river-quality problems.

The cost of conducting the dissolved-oxygen element of the study was approximately $125,000. Although a considerable investment, it was small compared with the amount that might be spent for pollution control in such a river basin over the next 10 to 20 years. In fact, the General Accounting Office (Comptroller General of the United States, 1976) estimated that the results of the study potentially could save tens of millions of Federal, State, and local dollars. Such a study is important as a basis not only for setting planning and management priorities, but also for pointing out potential savings—particularly when little improvement in water quality would be achieved by proposed waste-treatment or other pollution-control programs.

Summary

In 1972, the U.S. Geological Survey began a pilot program of river-quality assessments. The objectives of the program are (1) to define the character, interrelationships, and apparent causes of existing river-quality problems, and (2) to devise and demonstrate the analytical approaches and the tools and methodologies needed for developing water-quality information that will provide a sound technical basis for planners and managers to use in assessing river-quality problems and evaluating management alternatives.

The pilot study on the Willamette River basin, Oregon addressed problems related to (1) the need for maintenance of high-level dissolved oxygen in the river including effects of reservoir release patterns on downstream river quality, (2) algal growth potential, (3) occurrence and distribution of trace metals, and (4) the significance of erosion potential to proposed land and water uses.

Two other pilot assessments were begun in the Upper Chattahoochee River basin, Georgia and in the Yampa River basin, Colorado/Wyoming. The Upper Chattahoochee basin study is addressing problems related to thermal loading and heat dissipation; wastes from concentrated urban-industrial areas; flow pulsations resulting from hydropower production; and sediment sources, transport characteristics, and deposition. The Yampa basin study addressed problems related to resource development for energy production—primarily, the impact on river quality of coal extraction and conversion processes.

The most noteworthy finding of the Willamette assessment was that across-the-board advanced waste treatment is not the most effective way of assuring that the stringent water-quality standards for dissolved oxygen in the river are met. It was found that the elimination of two industrial discharges of oxygen-demanding ammonia would result in a much greater improvement on the Willamette River at considerably less cost than advanced waste treatment.

The Willamette Assessment showed that existing water-quality data generally are inadequate for defining critical cause-effect relationships that control river-quality problems and that intensive, synoptic surveys keyed to local problems and conditions are needed in most river basins to develop an adequate information base for managing key river-quality problems. The study illustrated the fact that rigid standards and regulations are likely to result in unneeded expenditures in some river basins. The study concluded that a proper balance can be attained only through an intensive, coordinated assessment that is keyed to local problems and conditions. △

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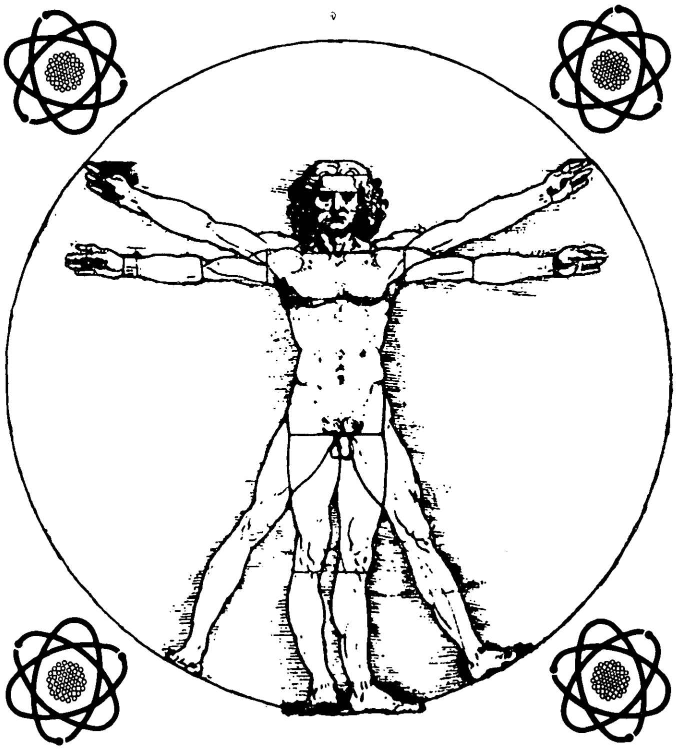
Role of Earth Sciences in the Disposal of Radioactive Waste

By George D. DeBuchananne



"The basic requirement for a safe repository is that the repository and its waste will be isolated from mankind and the biological environment for hundreds of thousands of years."

INTRODUCTION

Since the beginning of the Atomic Age, man has known that disposal of radioactive waste would be a serious problem due to the longevity and toxicity of radioactive waste. It has also been apparent that, as most of the wastes are either in liquid or solid form, disposal is in a large part an earth-science problem that requires an understanding of the fate of these wastes after disposal.

Radioactive wastes are generated at several different times or stages in the uranium fuel cycle. The more important sources of waste result from mining, milling, refining, enrichment, and fabrication of the fuel, the operation of power reactors, the reprocessing of spent reactor fuel elements or assemblies for the recovery and reuse of unused uranium and(or) plutonium, the storage or disposal of spent fuel assemblies if not reprocessed and, to a lesser extent, nuclear research and development. No repositories for the storage or disposal of high-level waste exist today in the United States.

Nearly all operations that produce or use nuclear materials generate radioactive waste. Most of the waste comes from Department of Energy military reactors, commercial nuclear power plants, and Federal and commercial nuclear fuel cycle activities, such as fuel fabrication and reprocessing facilities.

Radioactive wastes can be referred to as high-level, transuranic (Tru), and low-level. For the purpose of this discussion, high-level wastes include fission products wastes that have a high level of penetrating radiation, high rates of heat generation, and a long toxic life. In addition to those high-level wastes generated by the reprocessing of spent reactor fuel, one must reckon with the spent fuel and assemblies themselves if they are to be disposed of without reprocessing for recovery of plutonium and uranium. Tru wastes are described as those solid or solidified wastes that contain long-lived alpha emitters at concentrations greater than 10 nanocuries per gram. They generate little or no heat, and have radiation levels of less than 1,000 millirems[1] per hour after packaging. Transuranic elements also occur in high-level and low-level wastes and in spent fuel. Low-level radioactive wastes are those wastes that have become contaminated through use or origin yet do not fit into the above categories.

Sources of Radioactive Waste

According to the Comptroller General's Report to Congress (1977), the high-level wastes generated by the Department of Energy (DOE) fuel reprocessing plants for the military programs amounted to about 0.27 million cubic meters (74 million gallons) as of January 1977. Most of these wastes have been generated and stored at DOE's Hanford facility in Washington, at their Savannah River facility in South Carolina, and at their Idaho National Engineering Laboratories in Idaho. When solidified, those wastes will be about 0.19 million cubic meters (7 million cubic feet). By the year 2000 it has been estimated that the reprocessing of military wastes could generate an additional 0.11 million cubic meters (4 million cubic feet.) of high-level waste.

The only commercial fuel reprocessing plant that operated in the United States processed 640 metric tons of spent fuel from April 1966 to early 1972, generating about 2.4 thousand cubic meters (640,000 gallons) of high-level liquid waste. Additional commercial high-level waste, in the form of spent reactor

[1] Rem: A unit of measure for the dose of ionizing radiation that gives the same biological effect as 1 roentgen of X rays: 1 rem equals approximately 1 rad for X, gamma, or beta radiation.

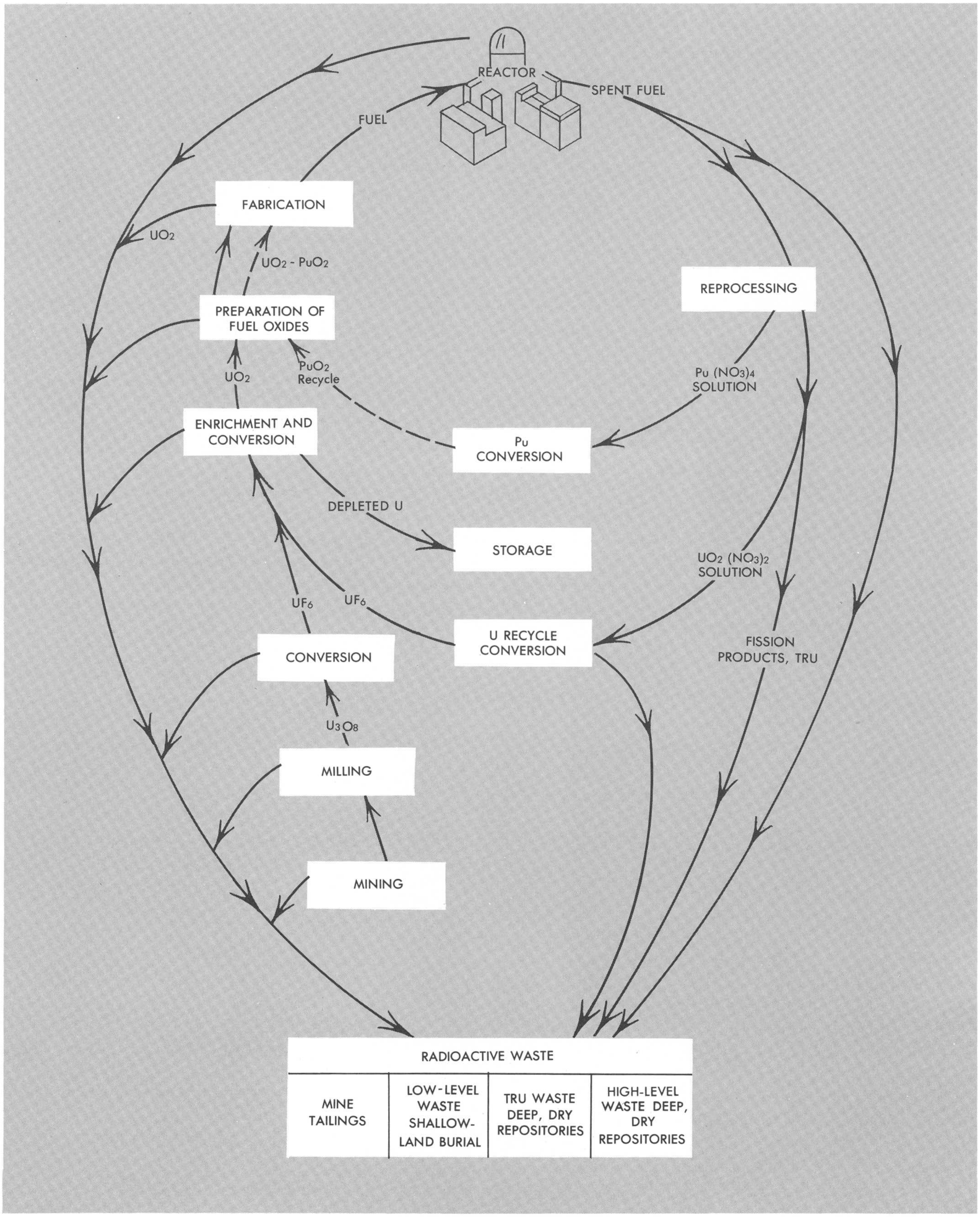


FIGURE 5.—Sources of radioactive waste in the light-water fuel cycle. (Modified from "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle", ERDA–76–43, UC 70, May 1976.)

fuel assemblies, from operating nuclear power reactors is accumulating yearly. This spent reactor fuel will have to be handled as high-level waste if the President's decision to defer commercial reprocessing continues indefinitely.

The Nuclear Regulatory Commission (NRC) (1976) projects that there will be about 500 large nuclear power reactors operating by the year 2000.. NRC estimates that these reactors will generate 127,000 metric tons of spent fuel through the year 2000. If these spent-fuel assemblies are reprocessed and the resulting wastes are solidified, the additional high-level wastes have been estimated to total as much as 6.4 thousand cubic meters (230,000 cubic feet).

In addition to the high-level waste cited above, about 0.37 million cubic meters (13 million cubic feet) of transuranic contaminated solid waste from military and research activities already have been either buried or stored retrievably at five principal DOE shallow-land burial sites. There are no records on the volume of commercial transuranic contaminated waste that has been buried at six State-owned shallow-land burial sites.

DOE's predecessor, the Energy Research and Development Administration (ERDA), estimated that about 0.19 million cubic meters (7 million cubic feet) of transuranic contaminated waste will be generated commercially through the year 2000. In addition, some of the .036 million cubic meters (1.3 million cubic feet) of waste being generated by DOE programs each year are contaminated with transuranic elements.

The Comptroller General Report to the Congress (1976) reports that some 1.17 million cubic meters (42 million cubic feet) of other than high-level radioactive waste (commonly called low-level waste) have been buried at DOE facilities through 1974. The annual volume of DOE generated low-level waste was estimated at about .036 million cubic meters (1.3 million cubic feet) in 1976, but the volume is expected to gradually decrease in the future.

During the period 1962 through 1973, approximately 0.25 million cubic meters (9 million cubic feet) of commercial low-level radioactive wastes have been buried at commercial State-owned shallow land burial sites. Each year the volume of commercial low-level waste buried at commercial sites increases, commensurate with the expected growth of the nuclear power industry. In a study, O'Connell and Holcomb (1974) projected an average annual volume of commercial low-level waste at 0.41 million cubic meters (14.5 million cubic feet) for 1981 to 1990 and 2.2 million cubic meters (78 million cubic feet) for the period 1991 to 2000. By the year 2000 it was estimated that approximately 28 million cubic meters (1 billion cubic feet) of low-level solid waste would accumulate. It should be noted that this 1974 estimate by EPA is about 7 times greater than the 1976 NRC estimate shown in table 3. The difference, in part, is believed to be due to different projected nuclear growth.

Waste Disposal Concept

Table 3 illustrates the possible volume of accumulated waste that would come from a balanced light-water reactor power system by the year 2000 for the no-recycle and uranium-only recycle options.

Since the beginning of the Atomic Era, many disposal concepts have been considered in the management and disposal of high-level radioactive waste. The most promising of these concepts include: (1) transmutation, the conversion of a radioactive nucleus to another isotope by bombarding it with radiation or nuclear particles; (2) extraterrestrial disposal, where waste would be placed in orbit around the sun; (3) ice-sheet disposal, where waste would be placed in the polar regions; (4) sea-floor geologic disposal, where waste would be placed in the rocks underlying the ocean deeps; and (5) deep geologic disposal, where waste would be placed in deep continental geological formations.

These five concepts have all been given serious consideration, and research is still underway on several of these modes of disposal. After more than 30 years of study the proposed disposal in deep continental geological formations appears to show the best possibility for isolating the waste from mankind. The new U.S. Department of Energy is following its predecessors, the Energy Research and Development Administration and the Atomic Energy Commission, in pushing forward the search for a suitable geological environment for a high-level repository.

TABLE 3.—*Cumulative volumes, in cubic meters, of waste inventory in the year 2000*[1]

Type of Waste	Fuel Cycle Option: No Recycle	Fuel Cycle Option: U Recycle
Mill tailings	780,000,000	690,000,000
Spent fuel	55,000[a]	6,000[c]
High-level	[b]	6,500[d]
Transuranic	[b]	76,500[e]
Hulls and hardware (transuranic)	[b]	52,000
Low-level reactor waste (non-transuranic)	3,800,000	3,800,000
Other low-level (non-transuranic)	310,000	300,000
Chemical	179,000	183,000

[a] 400,000 spent-fuel assemblies.
[b] Not produced with No-recycle
[c] 37,000 spent-fuel assemblies in pool storage awaiting processing.
[d] Volume of HLW in 37,000 canisters.
[e] Includes plutonium wastes.
[1] Taken from Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, NuReg-0116 (Suppl. 1 to WASH 1248). Nuclear Regulatory Commission 1976, p. 3–16.

National Waste Disposal Program

According to Zerby (1976) in 1976, ERDA announced a greatly expanded program for the management of nuclear waste and created the National Waste Terminal Storage (NWTS) program. The object of the NWTS program is to provide facilities in various deep geological formations at multiple locations in the United States where commercial radioactive waste can be safely disposed.

The Department of Energy has the responsibility for selecting and constructing Federal repositories for radioactive waste. However, the Nuclear Regulatory Commission, must license such repositories as being safe prior to their construction and use. Furthermore, the U.S. Environmental Protection Agency (EPA) is charged with the responsibility of determining whether or not the license requirements have been satisfied and whether or not a given repository, as operated, is indeed safe.

The basic requirement for a safe repository is that the repository and its waste will be isolated from mankind and the biological environment for hundreds of thousands of years. The single most important hydrogeological consideration in the deep burial of high-level waste is the isolation of the waste from circulating groundwater. If the waste can be so isolated it can be considered to be immobile. Providing complete assurance of immobility for hundreds of thousands of years does not appear possible to many geohydrologists. The basic problem that must be addressed in all considerations of geologic disposal of high-level waste (HLW) can be stated as follows: HLW material which is not in mechanical, thermal, or chemical equilibrium with its natural environment is placed in a complex geologic host with the object of not allowing physical and(or) chemical migration of radionuclides away from the disposal site into the biosphere in hazardous concentrations. It follows that the multi-component physical-chemical system that will develop in and around the repository as a result of waste-rock interaction must be completely understood in order to avoid any unforeseen effects. The effects of natural disturbance on local equilibrium must be considered as well. The major categories of investigation needed to resolve these problems are: (1) investigations of natural and waste-induced processes; (2) characterization of host-rock media; (3) characterization of environments or regions to evaluate their potential for repositories.

The object of these three categories of study is ultimately to assess all possible failure modes. Failure may result from both natural and waste-induced processes, occurring independently or in conjunction with each other. Basic information on the effect of disposal in host media and its geologic regions, data from laboratory studies, and the results of predictive containment and transport models all contribute to a thorough understanding of possible failure.

U.S. GEOLOGICAL SURVEY NUCLEAR WASTE DISPOSAL PROGRAM

High-Level Waste Program

The Survey's ongoing nuclear-waste research program in cooperation with DOE, though limited in scope, is designed to mesh with DOE's National Waste Terminal Storage program which calls for early emphasis on salt formations and later studies of shales, crystalline rocks and other rock types. Geochemical, hydrological, geologic and geophysical work is now underway for salt formations and salt domes. A limited effort has begun to evaluate the suitability of shales and crystalline rocks as host media by a combination of field and laboratory studies.

Investigations of natural and waste-induced processes include:

1. Geochemical interactions of the waste and its host media.
2. Analysis of seismic risk and development of seismic design criteria.
3. Nature and effect of climate changes.

Investigations directed towards the characterization of regions include:

1. Geologic remote-sensing evaluation.
2. Regional and borehole geophysical evaluation.
3. Regional geochemical investigations.
4. Hydrogeological evaluation of salt domes and anticlines.
5. Hydrogeological evaluation of bedded salt deposits.
6. Hydrogeological evaluation of shales.
7. Hydrogeological evaluation of some rock types at the Nevada Test Site.

Low-Level Waste Program

Disposal by burial in shallow trenches of solid other than high-level waste (commonly called low-level waste) containing radionuclides was initiated during World War II at several National laboratories as an expedient method of directly protecting personnel from radiation and of isolating the radionuclides from the hydrosphere and biosphere. At that time, the volume of such low-level waste was small and disposal sites were selected largely as a matter of convenience with only generalized considerations given to long-term containment. Most of the other-than-high-level waste consisted of material that had become radioactive through use in the nuclear laboratories and production facilities. Typical contaminated materials include glassware, containers, rags used to wipe up spills, sweepings, brooms, mops, filters, and various and sundry pieces of laboratory equipment and hardware for which decontamination was uneconomical or impossible.

After the war, the effort to apply nuclear materials to a myriad of peaceful uses resulted in a constantly expanding volume of an increasing variety of waste types to be disposed. Limited evaluation of the available data collected at the earlier burial sites did not indicate any major problems. Also, early studies of ion exchange and other sorption processes in the laboratory helped to foster a belief that in the Earth's subsurface, when all else failed, natural sorption processes could be relied on to adequately delay movement of most radionuclides. Furthermore, the economic attractions of shallow land burial, the ready availability of sites, and the opinion that any problem which might develop would be corrected by engineered remedial techniques, contributed significantly to the conclusion that this method of waste disposal was satisfactory. This philosophy prevailed through the 1950's and 1960's and the burial sites became larger and more numerous, until today there are 11 geographical localities in the United States which are used as burial sites for other-than-high-level radioactive waste materials.

In addition to the Survey-DOE high-level waste program, the Survey-DOE has underway two field investigations of other-than-high-level waste disposal—one in the arid hydrogeologic environment of basaltic rocks of Idaho and the other in the humid environment of folded and fractured calcareous shales and limestone of east Tennessee. The problem in both environments is to describe the micro-hydrogeology of the system so that radiochemical data can be related to field observations in order to predict waste migration. The results to date of the study in Idaho have been very encouraging. Robertson (1974) has field tested a predictive digital waste-transport model and found it to be accurate. This model will be a useful tool for designing a meaningful monitoring system for the Idaho Nuclear Engineering Laboratory area. In the Tennessee program which is just beginning, basic hydrologic field data is being collected so that the hydrogeologic system can be adequately described. The hydrologic data will then be used to develop a digital hydrologic-flow model of the system. After the hydrologic flow model has been verified, it can hopefully be used to design, construct, and verify a model to predict waste-solute transport. The predictive transport model would then be used to select the most desirable locations for observation wells to monitor the waste movement through the fracured calcareous shale.

The Geological Survey's own other-than-high-level radioactive waste program funded by appropriation to the Survey is directed at determining the processes and principles of radioactive waste migration. The program also addresses the problem of determining the availability of and uses of water by the nuclear industry.

These investigations are both theoretical and applied. Theoretical mathematical simulation and laboratory studies related to radioactive waste disposal are already underway at USGS research centers in Reston, Va.; Lakewood, Colo.; and Menlo Park, Calif. Experiments in the laboratory are being conducted with actual materials and solutions collected at the different burial sites. The Survey also has initiated comprehensive field investigations at the several other-than-high-level waste burial sites, with the cooperation of the responsible State agencies in New York, South Carolina, Kentucky, Illinois, and Nevada, respectively. Earlier studies at the Maxey Flats burial site in Kentucky were initiated with funds transferred from EPA's Office of Radiation Programs. These five field investigations in addition to the USGS-DOE studies in Idaho and Tennessee will provide from seven different hydrogeological environments the field data that are essential to establishing hydrogeologic criteria for the siting of shallow-land burial grounds.

It should be noted that, in initiating these studies, the Survey has received both policy and resource support from the Federal regulatory agencies, such as the Nuclear Regulatory Commission and the Environmental Protection Agency as well as the Department of Energy. Other studies not involving radioactive waste concern waste heat discharges into surface waters at nuclear power plants.

In addition to the radioactive waste disposal problems generated by the nuclear industry, there are other water-waste related problems involving municipal, industrial, and agricultural waste which are being studied by the Geological Survey.

UNRESOLVED PROBLEMS OF RADIOACTIVE WASTE DISPOSAL

The problem of high-level waste disposal has been under consideration by earth scientists since 1955 when the National Academy of Science gathered together a group of earth scientists to consider the geologic, biologic, physical, and chemical ramifications of this problem. Since that time considerable effort by scientists at Oak Ridge National Laboratory and at the Battelle Northwest Laboratories has been directed towards considering the feasibility of disposing of liquid high-level waste in deep geologic basins and salt mines, and later in disposing of solidified waste in bedded salt deposits.

More recently, since 1974, in response to growing pressures for a resolution of the problem of disposing of radioactive waste, earth scientists associated with universities, national laboratories, industrial organizations, state geological surveys and the U.S. Geological Survey have begun intensive examinations of the problem.

Because there will always be some residual uncertainty about basic processes of ground-water migration, waste-rock interaction, tectonism, and varying climate, a conservative approach to the development of these repositories is called for. This conservative approach entails clear and detailed statements of geologic criteria, the development of adequate techniques for verifying that a particular site meets the designed criteria, and a plan for long-term monitoring of the repository to insure that the processes that actually occur are those that were anticipated or are at least benign.

The potential hazard from unplanned releases of waste to the biosphere and hydrosphere is real and the risk extends to periods of millions of years. But predictions over time frames of millions of years is beyond the capability of earth scientists. In practice, during an evaluation of the effect of a particular natural event, the fate of the waste will vary with the interaction and timing of other unrelated natural events, and doubt would always remain about the effects of these processes upon the ability of the environment to contain the wastes.

One of the greatest gaps in current knowledge concerns the chemical interaction between the host media and the waste. High-level radioactive wastes generate heat. The highest repository temperatures occur during the first tens or hundreds of years. The effects of this release of thermal energy on geologic media are many and include at least three principal categories: mechanical, mineralogical, and hydrologic. Virtually all thermal effects complicate enormously the task of prediction over the intervals of geologic time required for the isolation of waste. Such complexity increases the uncertainty of geologic estimates and in several instances, current technology is inadequate to yield any prediction at all.

Geophysical techniques, particularly down-hole techniques, are inadequate at this time to adequately explore and describe the mass of rock needed for a repository. The problem of describing the area of a repository is amplified by the necessity of not destroying the integrity of geologic containment by excessive drilling of exploratory holes in the repository area.

Most of the repository sites will be located within the stable part of the North American Continent. However, because of the hazard of high-level waste, seismic risk must be evaluated for any areas considered for siting. Adequate methods for doing this evaluation over very long time periods must also be developed to assure repository siting suitability.

One of the major questions that will have to be asked about any proposed repository for radioactive waste will be the effect of future climate on the hydrologic regime and geomorphic setting. Major climatic oscillations, with periods on the order of tens of thousands of years, have been a feature of global climate for at least the past million years and may be expected to continue. Therefore, existing paleoclimatological data needs to be reviewed from the point of view of nuclear waste disposal.

In order for a repository to be acceptable, the host rock must be essentially impermeable. This raises the question of how to measure permeability in a drill hole with such low permeability or insignificant ground-water flow. A number of such problems as constrained by current technology remain to be solved for high-level waste repositories.

As previously stated, earth scientists recognize that high-level waste must be isolated from circulating ground waters. In the event, at some later date, that such waste is subjected to ground water, it is mandatory to be able to predict rates of flow and pathways of solutes from the repository sites. Ground water in low-permeable crystalline rocks flows principally through fractures. Ground water flow through fractured media is not well understood.

Understanding the thermal effect on the rocks surrounding buried waste is extremely important to management of high-level waste. The rise of temperature and the dissipation of heat from high-level waste must be evaluated. To do this, it is necessary to acquire data on thermal conductivity of rocks and the effects on temperature, pressure, porosity, mineral composition, and water saturation.

The assessment of rock at any potential high-level waste repository involves assessing the potential movement of transuranium elements as well as other radioactive contaminants. There are several aspects of this assessment which need to be fully understood: (1) chemical reactions between the radionuclides and the natural earth materials through which they are being transported are not understood; and (2) the effect of the high-level waste heat on the migration of radionuclides via ground water has not been evaluated.

Many earth scientists are concerned with the reactions that will occur between radionuclides and the naturally occuring earth materials. These reactions are not well understood, particularly for the transuranium and other elements that will be contained in the waste.

Existing programs do not fully address the impact of man's intrusion on the natural environment. Drill holes, mine shafts, and other repository construction activities will introduce additional uncertainties that will have to be evaluated. All repository openings, regardless of depth will have to be sealed by some, as yet unknown, technology which will in effect return the site to near virgin conditions. In addition, little or no effort has been devoted to the problem of monitoring a repository and the surrounding area to detect changes which could ultimately lead to a leak of the containment.

Radioactive waste problems are dynamic, complex, and varied. Therefore, there can be no one simple solution to all problems. The different solutions will have to be imaginative, working primarily within the constraints dictated by the hydrogeologic environment at each proposed disposal site to determine what type and classification of radioactive waste can be contained by the proposed site for the period of time required to protect the biosphere and hydrosphere. The waste should be tailored to the environment since man, as yet, is unable to control many of the natural processes.

Recognizing all of the unresolved earth science problems, will it be possible to isolate radioactive waste from man's environment? Geologic containment is the most reasonable alternative for radioactive waste isolation and safe geologic repositories can be constructed, once these problems are resolved. △

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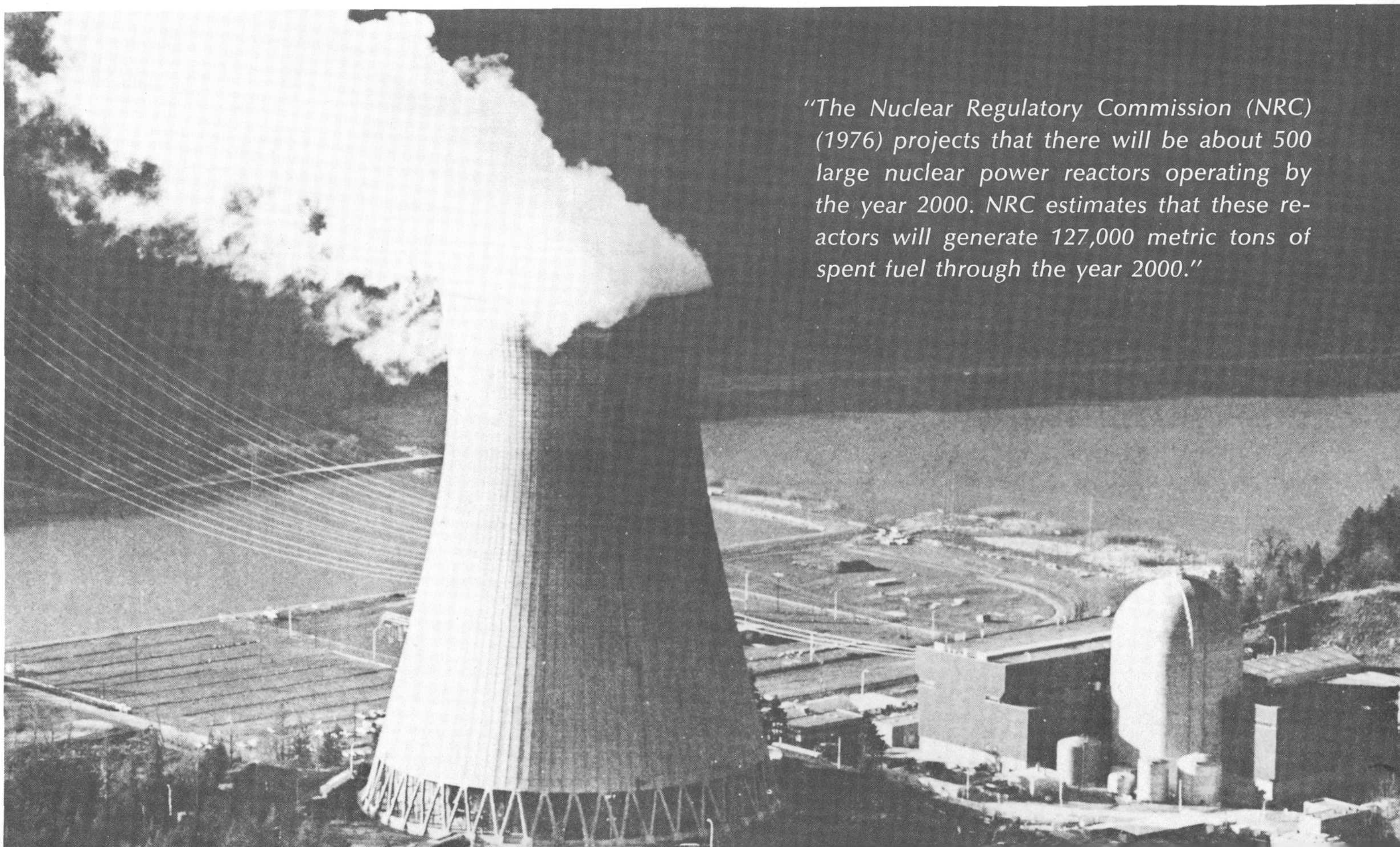


Shut-In Wells on the Outer Continental Shelf

By Charles M. Perrott and Ronald W. Taylor

Shut-in oil and gas wells have been a major concern in the past two or three years to the Congress, the Geological Survey, the industry, and the general public. Thus, a discussion of the background of the problem and what has been done to resolve it is in order.

It was mentioned in the last two Annual Reports that a Congressional subcommittee has held the view that some oil companies deliberately shut-in producible wells and reservoirs (particularly gas wells and reservoirs) until higher prices will make production more profitable. Industry's response was that reserve figures include behind-the-pipe reserves in wells with multiple sands which could not be produced concurrently. Where multiple horizons occur, the productive sands are produced sequentially.

The Survey initiated action on this matter in January 1975 by asking 10 companies that appeared to have the most questionable cases of shut-in wells on leases to start production immediately or submit reasons and data explaining why shut-in status should be permitted. Subsequently, in March 1975, 3 of these 10 companies were required to submit additional data supporting the shut-in status of their wells. As a result of the Survey's review, two companies chose to terminate one lease each in fiscal year 1975. Then, in fiscal year 1976, one other company terminated two leases.

In addition to the above action, in January 1975 the Survey made the reporting of shut-in oil and gas wells on the Outer Continental Shelf (OCS), a continuing project with the establishment of a shut-in well computer data base. Part of the initial problem concerning shut-in wells was caused by confusion and misunderstandings of in-house statistics and records on the part of those not familiar with offshore oil and gas operations. One reason for this was that in 1974 the Survey did not explain just what was included in the statistic, "Shut-in Producible Zone Completions," as reported in our OCS statistics booklet. These figures included all nonproducing completions in all wells that had not been permanently plugged and abandoned without indicating the reason for the nonproducing status. Such statistics were adequate for use in regulatory activities but did not indicate a meaningful shut-in status of the wells and completions included therein. For example, the OCS well status summary as of December 31, 1974, indicated 3,124 shut-in oil completions, 948 shut-in gas completions, and 618 nonproductive wells that had not been plugged and abandoned. There was no further categorization of the shut-in completions nor of the wells that had not been plugged and abandoned; consequently, it was all too easy to reach the erroneous conclusion that there were approximately 4,700 oil and gas wells on the OCS that were capable of being produced but for some unknown reason were not being produced.

In order to properly monitor all OCS oil and gas operations, the Survey initiated a program in January 1975 to identify accurately all shut-in oil and gas completions so as to categorize them by their potential for future utility. Secondary classifications grouped the shut-in completions as to the reason for their shut-in status. The informaion thus obtained could be used to determine if any of these so-called shut-in completions were capable of production and delivery of a product to the market place.

In order to standardize the term "shut-in well", the Geological Survey in 1975 defined a "shut-in well" as any well which at some time in the past was a producing well, is not currently producing, and is physically in such mechanical condition that the former producing interval could be opened for production if any production capability exists. The expanded definition also included any new wells which, in the near-term future, could be producing upon completion of drilling operations or construction of production facilities or pipelines. The term "oil and gas wells" is distinguished from the term "oil and gas *completions* within a well." A "completion" is defined as a perforation, or set of perforations, through which the production of oil and/or gas might be obtained from a single formation. Therefore, a single well borehole passing through several producing zones may contain more than one "completion." A "service well" normally has no production of its own but is utilized to aid the production of other wells.

As part of the January 1975 survey mentioned above concerning the 10 oil and gas companies, all oil and gas operators in the Gulf of Mexico were directed to submit a list of all shut-in completions and to identify each as to its potential for future utility and the reason for the shut-in status. By late March 1975, all operators had responded and identified approximately 5,400 shut-in completions, of which approximately 1,400 had production restoration possibilities, and 400 could be used as a service

TABLE 4.—*Number of completions by production capability as of July 1977*

	Oil	Gas	Other	Total
Actively producing	3,237	2,236	---	5,473
Shut-in with no restoration potential	1,557	636	15	2,208
Shut-in with restoration potential	1,412	816	25	**2,253**
Service (gas injections, water injection, etc.)	----	----	392	392
Drilling status	----	----	626	626
TOTAL				10,952

well at some time in the future. The remaining 3,600 were identified as having no potential for future utility; therefore, they were not shut-in producible zone completions but abandoned completions with no value for oil and/or gas production (usually depleted or watered out). Approximately 1,300 of the shut-in completions were located in wells that were producing from other completions within the well. As an illustration of the significance of this last figure, it should be pointed out that it is often uneconomical and sometimes harmful to the producing completion to attempt a major workover on the other completion of a dually completed well.

The oil and gas wells with indicated reserves were not on production because of mechanical problems, sand and water problems, low flowing pressures, and, in some cases, because the operators were waiting for production equipment and facilities or transportation facilities. Also, some wells completed in a gas cap were shut-in until the final stages of production to conserve reservoir pressure and to prevent loss of possible liquid production. The Geological Survey also had a verification program in conjunction with this 1975 survey; hence the additional check on the 10 companies mentioned above.

Since the shut-in reporting system of 1975 was initiated, it has been updated and improved. Now, for instance, complete shut-in statistics are compiled for the Gulf of Mexico OCS each month. These statistics are based upon a completely revised shut-in reporting system that was begun in March 1977. Any well that has zero production for a reporting month is considered shut-in and the Survey requires that the operator report both the reason for shut-in status and the action required to bring the well back on production. An operator is required to file a separate report when a major well is shut-in for more than 5 days. A major well is defined as one capable of producing 200 barrels of oil or 4 million cubic feet of gas daily.

Statistics for the following tables were taken from the July 1977 monthly well-status summary for the Gulf of Mexico OCS. This area accounts for 95 percent of United States OCS oil production and 99.9 percent of United States OCS gas production. The July statistics are representative of the monthly statistics obtained since the new reporting system was begun.

The following three tables show: (1) the extent of producible shut-in completions (2,253) related to total completions (10,952) in the Gulf of Mexico, (2) the reasons these 2,253 producible shut-in completion are not producing, and (3) the actions required to bring them back on production.

Table 4 categorizes completions by production capability. The "other" category adjacent to the shut-in statistics includes those completions whose hydrocarbon potential has not been determined.

The Geological Survey classifies a well's shut-in status into one of seven major "reasons for shut-in." One of these, weather, usually has an effect only during hurricanes or unusually cold weather. Table 5 lists the restorable shut-in completions in the remaining six categories.

Well-bore related problems account for almost half (49.2 percent) of the restorable shut-in wells. Well-bore problems include such deficiencies as holes in the tubing or casing strings; tubing or perforations sanded up or loaded with water; debris dropped in tubing during remedial work; and subsurface safety valve problems. The next most common reason that a well is shut-in is reservoir-related. Reservoir-related problems account for 34 percent of restorable shut-in wells. Reservoir problems involve low reservoir pressure; high water-oil ratio; reservoir testing; reservoir depletion; and wells completed in gas caps of oil reservoirs shut-in to conserve the reservoir driving mechanism. In addition to reporting the reason for shut-in, operators are now required to indicate the action required to restore the well to production. Table 6 shows the actions required to restore those wells reported shut-in in table 5.

Table 6 indicates that only 10.4 percent of restorable shut-in wells could be restored to production by merely opening the master valve on the Christmas tree (wellhead). Examples of wells in this category include those shut-in for safety violations, those shut-in to prevent flaring of gas from oil wells, those shut-in to conserve reservoir pressure (gas-cap wells), and those shut in to insure safety of operation by avoiding simultaneous drilling and production activities on the same platform. The remaining 89.6 percent of restorable shut-in wells require some kind of remedial work. No completions have been identified as shut-in for reasons other than depletion, mechanical failures, or good operating practice. △

TABLE 5.—*Shut-in oil, gas, and other completions with restoration potential by reason for shut-in*

Reason for Shut-in	Oil	Gas	Other	Total
Reservoir related	486	277	4	767
Well-bore related	794	302	12	1,108
Surface equipment related	20	33	1	54
Pipeline related	13	69	5	87
Platform related	80	115	3	198
Regulatory related (Safety violations, etc.)	19	20	0	39
TOTAL	1,412	816	25	**2;253**

TABLE 6.—*Action required to return restorable shut-in completions to production*

Action	Oil	Gas	Other	Total
Open Surface Valve	131	97	7	235
Surface construction or repairs needed	132	182	2	316
Minor workover required	431	179	11	621
Major workover required	718	358	5	1,081
TOTAL	1,412	816	25	**2,253**

Planetary Exploration and Understanding the Earth

By Michael H. Carr

We are witnessing, in the second half of the twentieth century, a unique event in the history of mankind—the exploration of the solar system. Those of us living in this era are the first to get a close look at those planetary bodies whose movements through the heavens have intrigued Man since his beginning. The event is influencing many of Man's activities, subtly affecting his consciousness of himself and his place in the universe. Through space exploration we have already enhanced our realization of the unique nature of the planet Earth, of its fertility and its isolation in a hostile universe. But aside from the philosophical impact, space exploration is providing specific knowledge about the Earth and the processes that have controlled its evolution. Until the current era of space exploration, geologic processes could be studied only under the restricted set of conditions that prevail here on Earth. There was no way to appreciate what possible evolutionary paths a planet might follow, no way to know how the Earth's history, internal dynamics and surface processes compared with other planets. The mode of the Earth's formation and its early history were particularly difficult to evaluate and almost entirely in the realm of pure speculation. So access to other planetary bodies with better preserved records of their early history and where geologic processes have operated under more varied and extreme conditions is now providing new insights into several areas of gelogy. How these new insights have and will affect our knowledge of the Earth is the main theme of this review of space-age geologic findings.

The exploration of the solar system is well under way. Manned exploration of the Moon between 1969 and 1972 was followed by a period of intense study of the lunar samples and a general global synthesis. The result is that the history of the lunar surface and the general chemical evolution of the Moon are now roughly understood. At the same time a vigorous program for unmanned exploration of the inner solar system was initiated. The Mariner 10 spacecraft to Mercury in 1973 revealed a planet whose surface so closely resembles that of the Moon that similar surface processes can be inferred. This was somewhat surprising because the bulk properties of the two bodies are so different. The Moon consists almost entirely of silicates while Mercury has only a thin veneer of silcates over an iron-rich core, comprising 80 percent of the mass of the planet. Very little is known about Venus because of its thick cloud cover. Two Soviet spacecraft have successfully transmitted pictures from the surface that reveal a rock strewn terrane. Radar images acquired with Earth-based antennae indicate the venusian surface is fairly smooth with vague circular depressions, linear troughs and some large mountains (several hundred kilometers across) that could be enormous volcanoes. Scheduled orbital missions to Venus with cloud penetrating radar in 1978 and possibly 1982 will provide a much better basis for evaluating the geologic evolution of this our closet neighbor and the planet that most resembles the Earth in size and density. Meanwhile, the exploration of Mars is well advanced. The Mariner '71 mission and more recently the Viking missions have revealed an enormously varied surface with huge volcanoes, canyons, large river beds, permafrost features and other indicators of a complex history. Future exploration may include an unmanned rover mission in the 1980's and returned samples in the early 1990's.

Exploration of the outer solar system has just begun. Two Pioneer spacecraft have made close observations of Jupiter and are on their way to Saturn. In addition, two much more sophisticated Voyager spacecraft were launched in 1977 to Jupiter and Saturn with arrivals expected in 1979 and 1981 respectively. Of particular interest to geologists are the large satellites of Jupiter and Saturn which number more than a dozen. These have a combined land area that exceeds the entire land area of the inner solar system so far photographed. Their enormous range in density and surface properties suggest widely different compositions and evolutionary paths. Thus within a very few years, the number of planetary bodies available for observation will have increased from one to about twenty and we will have been able to study the effects of numerous geologic processes on planetary bodies with an extremely wide range of initial chemistry, size, atmospheric composition and distance from the sun.

The Earth's Early History

How will any knowledge that we gain from studying other planetary bodies affect our understanding of the Earth? One of the main benefits will be an improved understanding of the Earth's early history. Almost all evidence of what occurred during the first billion years of the Earth's history has been erased from the surface by subsequent volcanism, mountain building and erosion. Yet during this evolutionary period life began, the forces of mountain building and volcanism were set in motion, and the atmosphere probably assumed approximately its present composition. In the cases of Mars, Mercury and the Moon, the evolution of the surface during the first billion years was dominated by two processes, meteorite impact and flooding by lava. We have been able to reconstruct the impact history of the Moon at least as far back as 4 billion years ago (fig. 6) by correlating absolute ages of lunar samples with the number of impact craters superimposed on the unit sampled. The record previous to that time has been erased by extremely intense bombardment. It is now clear that the impact rate on the Moon was very high 4 billion years ago and declined very rapidly 3.9 billion years ago to a much lower rate which has remained approximately constant ever since. This gives the Moon its characteristic appearance (fig. 7). Surfaces older than 3.9 billion years are very heavily cratered; surfaces younger than 3.9 billion years are very sparsely cratered. Mercury and Mars appear to have similarly experienced an early intense bombardment which rapidly declined to a much lower level at a later date, although for these planets we cannot confidently date the decline. The Earth, being in the same part of the solar system as the Moon, must have experienced an impact history similar to the Moon. Approximately 3.9 billion years ago, much of the Earth's surface probably resembled the lunar highlands with the effects of the high impact rate dominating the landscape. The surface was probably saturated with craters and the rocks shattered and fragmented to depths of several tens of kilometers. After 3.9 billion years ago the appearance must have changed relatively rapidly as the impact rate declined and the effects of processes such as volcanism and erosion became more apparent. Possible major differences are that the Earth's atmosphere would have filtered out the smaller objects and the possible presence of oceans must have considerably modified the effects of large impacts, perhaps resulting in large tidal waves, sedimentary deposits, and the filling of large impact basins.

On the Moon and Mars, and possibly Mercury, extensive lava plains formed after the decline in cratering and, at least on the Moon, there is abundant chemical evidence of planet-wide volcanism before the decline. By analogy there may have been a similar era of early volcanism and lava plains formation on Earth but all the evidence has been erased. After 3.7 billion years ago we enter the time span in which we can read the historical geologic record as pre-

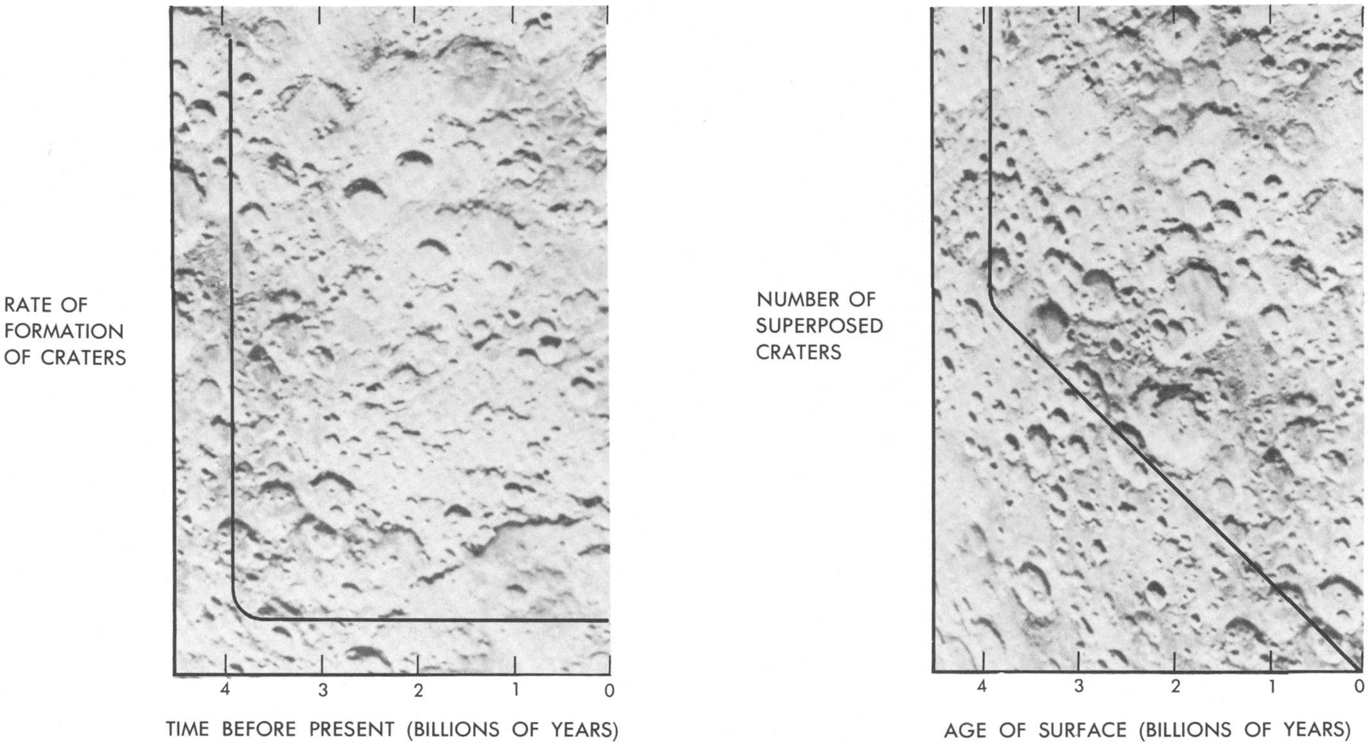


FIGURE 6.—Crater formation on the Moon. The rate of formation of craters on the Moon decreased rapidly 3.9 billion years ago *(left-hand figure)*. Surfaces that formed before that time are saturated with craters, those that formed after are only sparsely cratered, the number of superposed craters depending on the age of the surface *(right-hand figure)*. The Earth has experienced a similar cratering history but most of the evidence has been erased by erosion and other processes such as volcanism and mountain building.

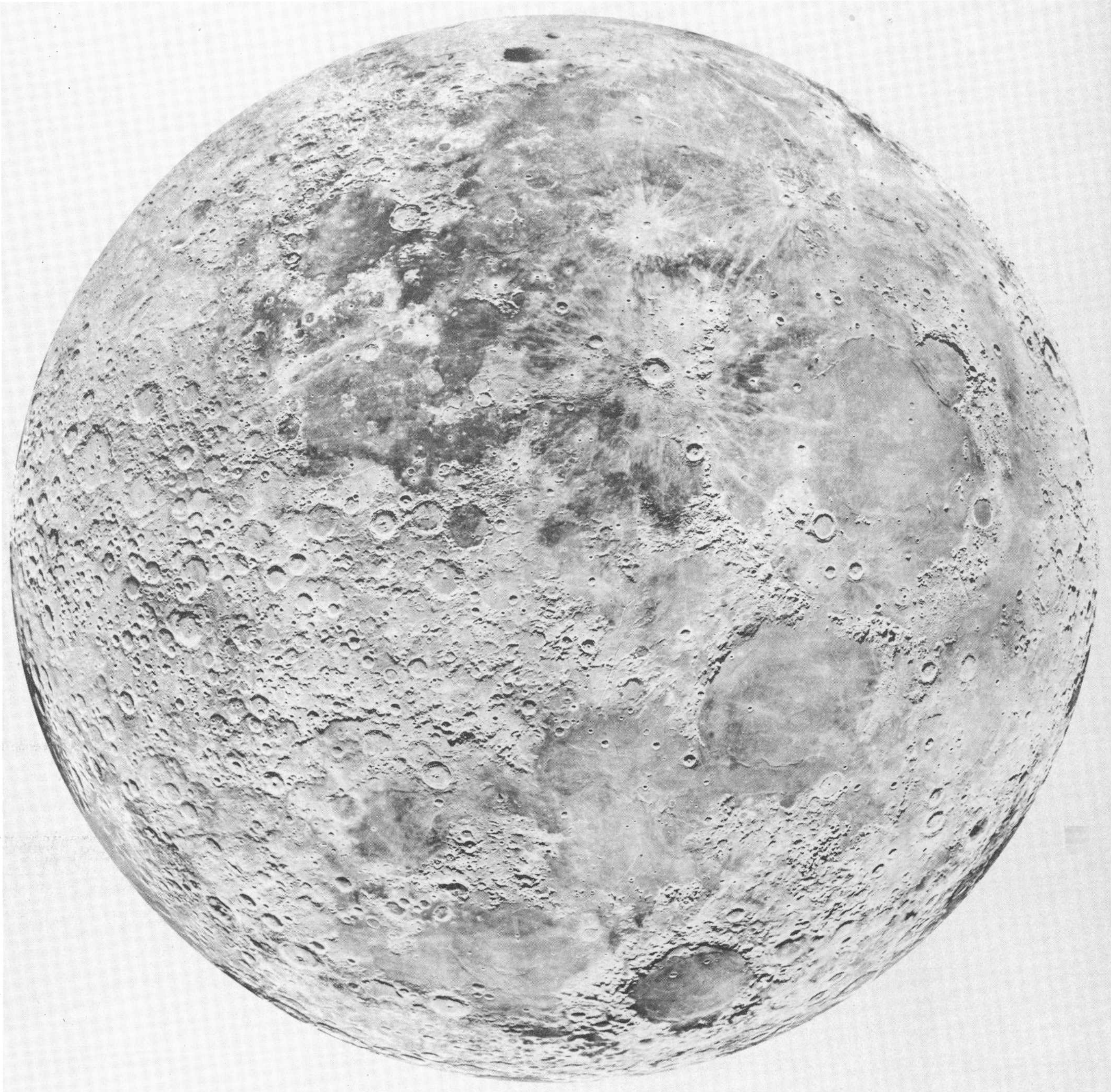


FIGURE 7.—Front side of the Moon. The lunar surface is divided into densely cratered highlands which mostly formed before the decline in the rate of cratering 3.9 billion years ago and the mare which formed after that time. Before 3.9 billion years ago much of the land surface of the Earth probably looked like the lunar highlands, but after that time Earth's appearance changed rapidly as the impact rate declined and the effects of volcanism and mountain building became more apparent.

served on the Earth. From then on we are no longer solely reliant on comparison with other planets to determine the sequence of events.

Geologic Processes

Comparison of the Earth with other planets is still, however, useful for better understanding geologic processes. Unlike any other planet, so far as we know, the geologic framework of the Earth's crust is dominated by plate motion; that is, by the lateral motion of different parts of the rigid crust with respect to each other. These large rigid segments are called plates and the relative motions between them are described as plate tectonics.[1] So pervasive are the

[1] Hamilton, W. B., 1976; "Plate Tectonics and Man," in U.S. Geological Survey Annual Report, Fiscal Year 1976, U.S. Geol. Survey, pp. 39–53.

effects of these plate movements that little or no evidence remains to show what the Earth was like before the onset of plate tectonics or what effects other processes previously had on the evolution of the surface. Comparison with other planets may help in both these areas. Mars has many geologic features in common with the Earth, features such as volcanoes, fracture systems and sedimentary basins. It differs by having no oceans, only a very thin atmosphere, and no plate tectonics. Mars may give some indication of what the Earth was like before the crust broke up into moving plates. For example, centered on the Tharsis region of Mars is a bulge in the Martian crust approximately 7 kilometers (4.3 miles) high and 4,000 kilometers (2,485 miles) across. On top are three enormous volcanoes and radiating from the center as far as 3,000 km (1,864 miles) are numerous fractures (fig. 8). So extensive is the fracture set that it affects almost a complete hemisphere of the planet. Some of the fractures and the volcanoes themselves appear to have been the sources of large volumes of lava which behave like basalt lavas on Earth. The Tharsis region has been studied in great detail. We can assess when the bulge formed, the sequence of fracturing, and the volcanic history. The most plausible hypothesis concerning its origin is that the formation of the bulge was related to separation of the iron-rich core early in the planet's history. The Earth may have similarly developed features like the Tharsis region early in its history. The rise, its radial fractures, and its volcanoes resemble sites of incipient plate break-up on Earth, and we might conclude that Mars tried plate motion but didn't quite make it. Perhaps the rigid crust is too thick, the planet too small, or several regions like Tharsis are required. Whatever the reason, we may have preserved on Mars a configuration similar to that which prevailed on Earth before plate tectonics and we may be observing the effects of a stress system similar to that which on Earth caused the initial break-up into crustal plates. We can therefore study the stresses in a situation where their effects have not been masked by subsequent plate motion.

We can also study other geologic processes in situations uncomplicated by plate motion. The evolution of the Earth's crust is affected both by deep seated processes originating below the mobile plates and by processes related to plate motion. For example, the evolution of Hawaiian type volcanoes is affected both by the processes of rock melting deep within the Earth and by the movement of the Pacific plate upon which the volcanoes sit. On Mars we are able to study similar volcanoes where there is no crustal motion. The comparison is very revealing since the Hawaiian and Martian volcanoes closely resemble each other. Both have gently sloping flanks, large multiple collapse pits at their center and both appear to be built largely of fluid lavas which have left numerous flow features on their flanks. The most obvious difference between the two is size (fig. 9). The Martian shields grow to over 20 kilometers (12 miles) in height and more than 500 kilometers (310 miles) across in contrast to a maximum width of 120 kilometers (75 miles) and height of 10 kilometers (6 miles) for the Hawaiian shields. The difference is readily comprehensible as a consequence of plate tectonics. The Hawaiian shields are at the southeastern end of the Hawaiian-Emperor chain, a long line of extinct volcanoes, many of them submarine, that stretches several thousand kilometers across the Pacific Ocean. The Hawaiian volcanoes are relatively short lived—a few million years at most. They become extinct as movement of the Pacific plate to the northwest carries them away from the deep source of lava, adding another extinct volcano to the chain and causing a new volcano to form over the source. The Martian shields on the other hand are fixed over their source and continue to grow for a long period of time, perhaps billions of years, constrained only by the lava supply and the required pressure to pump it to the surface. The Martian shields therefore grow to enormous sizes compared to their smaller short-lived terrestrial counterparts. Another point of contrast between the Martian and Hawaiian shields is their evolutionary cycle. The Hawaiian shields have an initial shield-building phase in which eruption of very fluid lavas predominates, as exemplified by the Mauna Loa and Kilauea volcanoes. Later the style of volcanism changes from the relatively quiet effusion of predominately basaltic lavas to more explosive activity and more silica-rich lavas, as for example at Mauna Kea. This later volcanic stage appears not to occur on Mars. If it were caused by deep-seated processes, such as chemical changes in the source regions, as has been proposed, then we would expect to see similar effects on Mars and we do not. It is likely therefore, that the late stage of the Hawaiian volcanoes is in some way related to plate motion. Thus comparison with Mars leads us to favor one set of hypotheses regarding the final stages of evolution of the Hawaiian volcanoes, those that attribute the late explosive stage to the effects of plate motion.

Mars also provides a means of studying surface processes in totally different environments from those that prevail on Earth. For example, pictures returned from the Viking mission to Mars reveal a number of spectacular landslides (fig. 10). They resemble many terrestrial slides that have moved as catastrophic avalanches. Because of the threat that they pose, considerable work has been done on the causes of landslides and their precise emplacement mechanism.

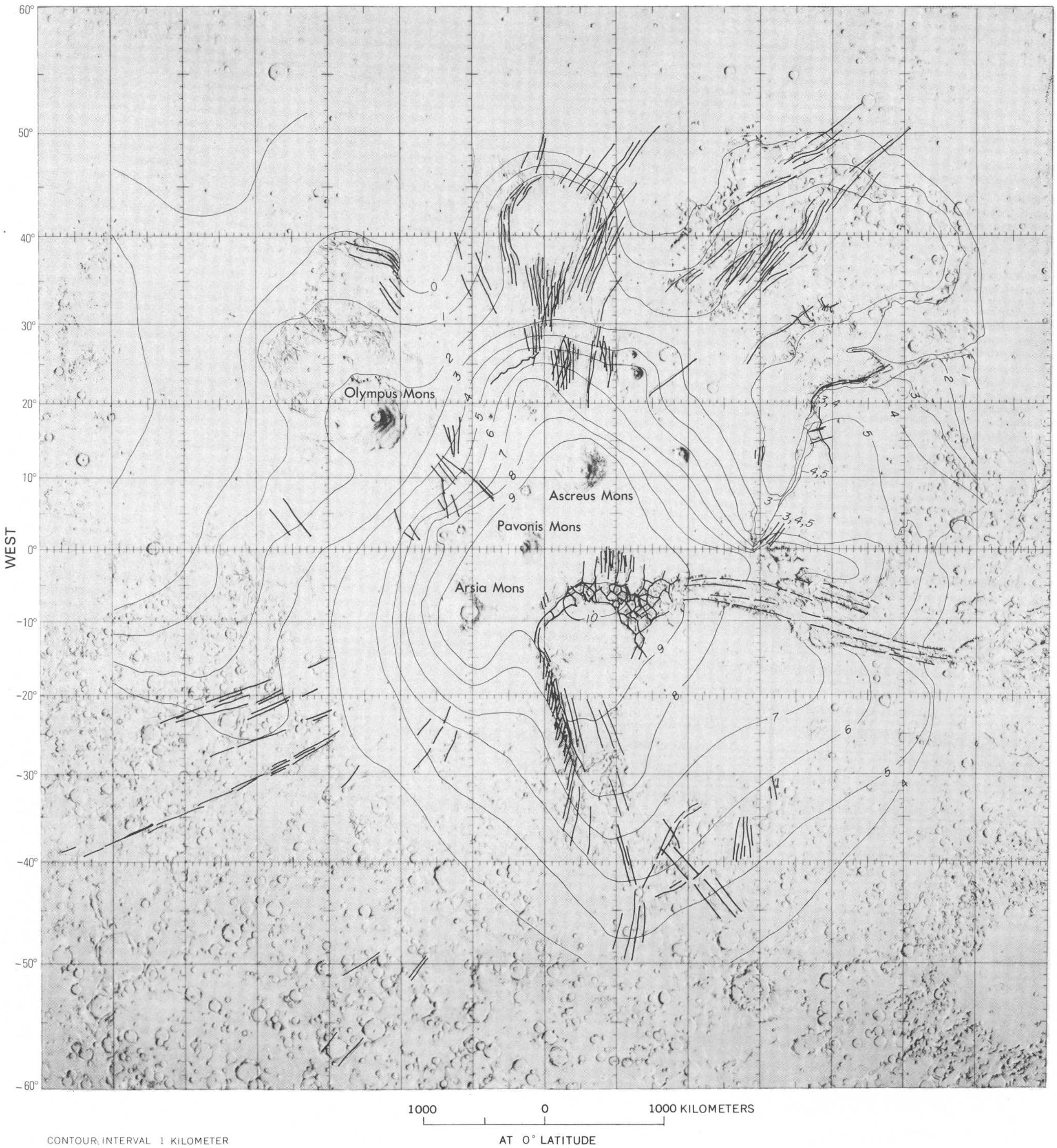


FIGURE 8.—The Tharsis region of Mars. The contours (fine lines) outline a bulge in the Martian crust where the largest known volcanoes of the solar system are located. The dark lines schematically represent the radial fracture system around the bulge. The rigid outer layer, or lithosphere, of Mars is not divided into moving plates like that of the Earth. We therefore see, preserved on the surface, features such as Tharsis that appear to be the result of processes operating deep within the planet. On Earth the effects of such processes are generally masked by the effects of plate motion.

The value of the Martian examples in assessing the relative merit of the different proposals arises from the fact that conditions there are so different from any that prevail on the Earth. For example, movement on a cushion of air has been invoked to explain the large distances over which some catastrophic terrestrial slides can travel. Yet we see on Mars landslides that have travelled many tens of kilometers, much farther than most known terrestrial slides, and they did so in the presence of an extremely thin atmosphere, less than one hundredth that of the Earth. We concluded therefore substantial atmospheric interaction is not necessary to explain the efficient motion of terrestrial landslides.

Mars is similarly a laboratory for the study of erosion and deposition by the wind. Although thin, the Mars atmosphere is capable of erosion, and the transport and deposition of debris. On Earth the effects of wind action tends to be masked by the effects of water. In contrast water appears to have had only a limited effect in sculpting the Martian surface except in very localized areas. Wind action appears however to have been continuous, forming a wide variety of landforms which we can study in detail. Surprisingly little is known of the mechanics of wind action. What factors control erosion rates and the final form of deposition features are poorly understood. Three decades of neglect followed some pioneering quantitative work in the thirties and forties. Recently however, because of the implications

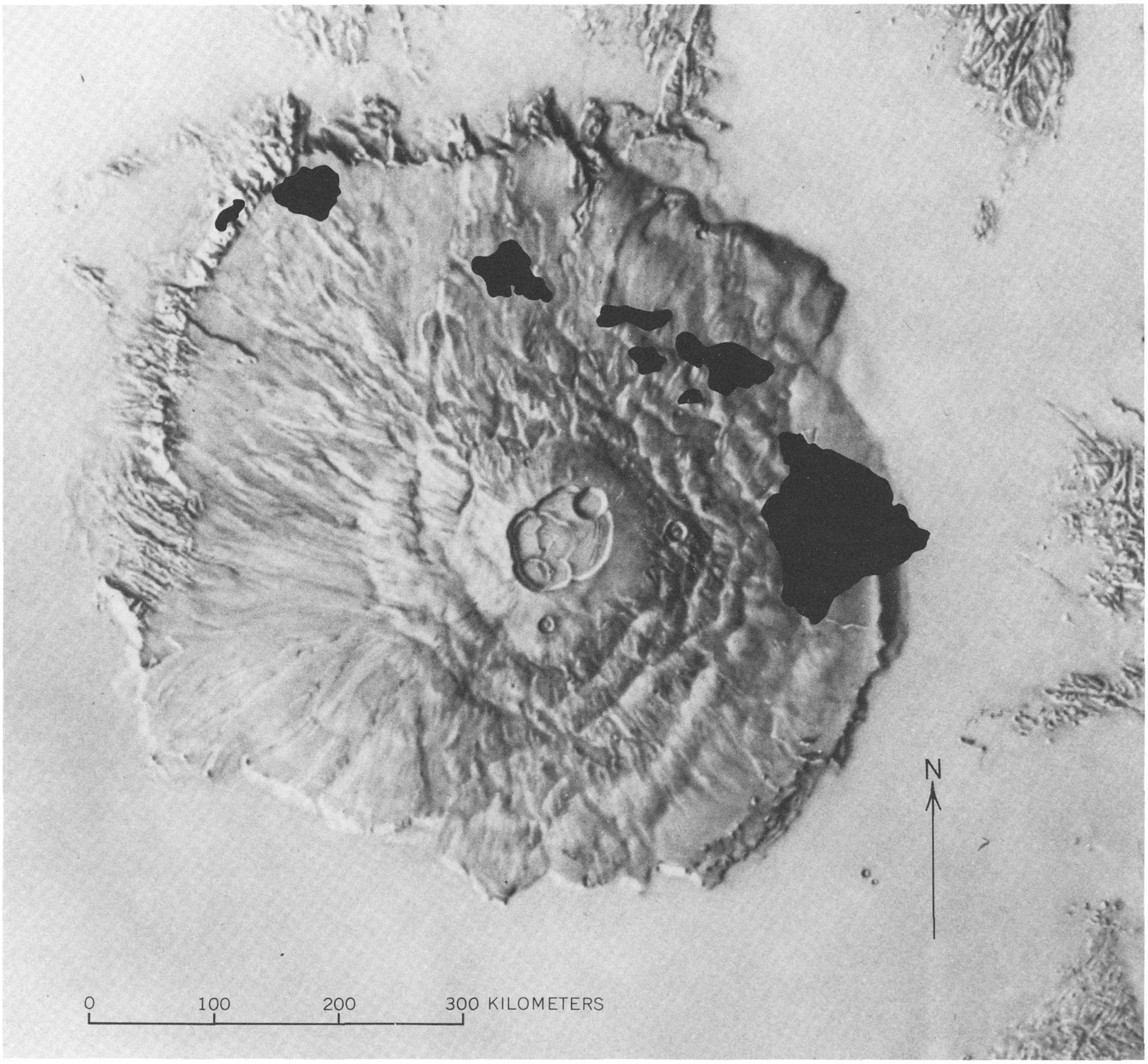


FIGURE 9.—Olympus Mons, the largest shield volcano on Mars, is approximately 500 kilometers (about 310 miles) across and 27 kilometers (about 17 miles) high. The outlines of the Hawaiian Islands are superimposed on the volcano at the same scale. The Hawaiian volcanoes grow to only a limited size because the motion of the Pacific plate to the northwest carries volcanoes away from the magma source. In contrast, the Martian volcanoes remain fixed over their source of magma for hundreds of millions, perhaps billions of years, and grow to immense size.

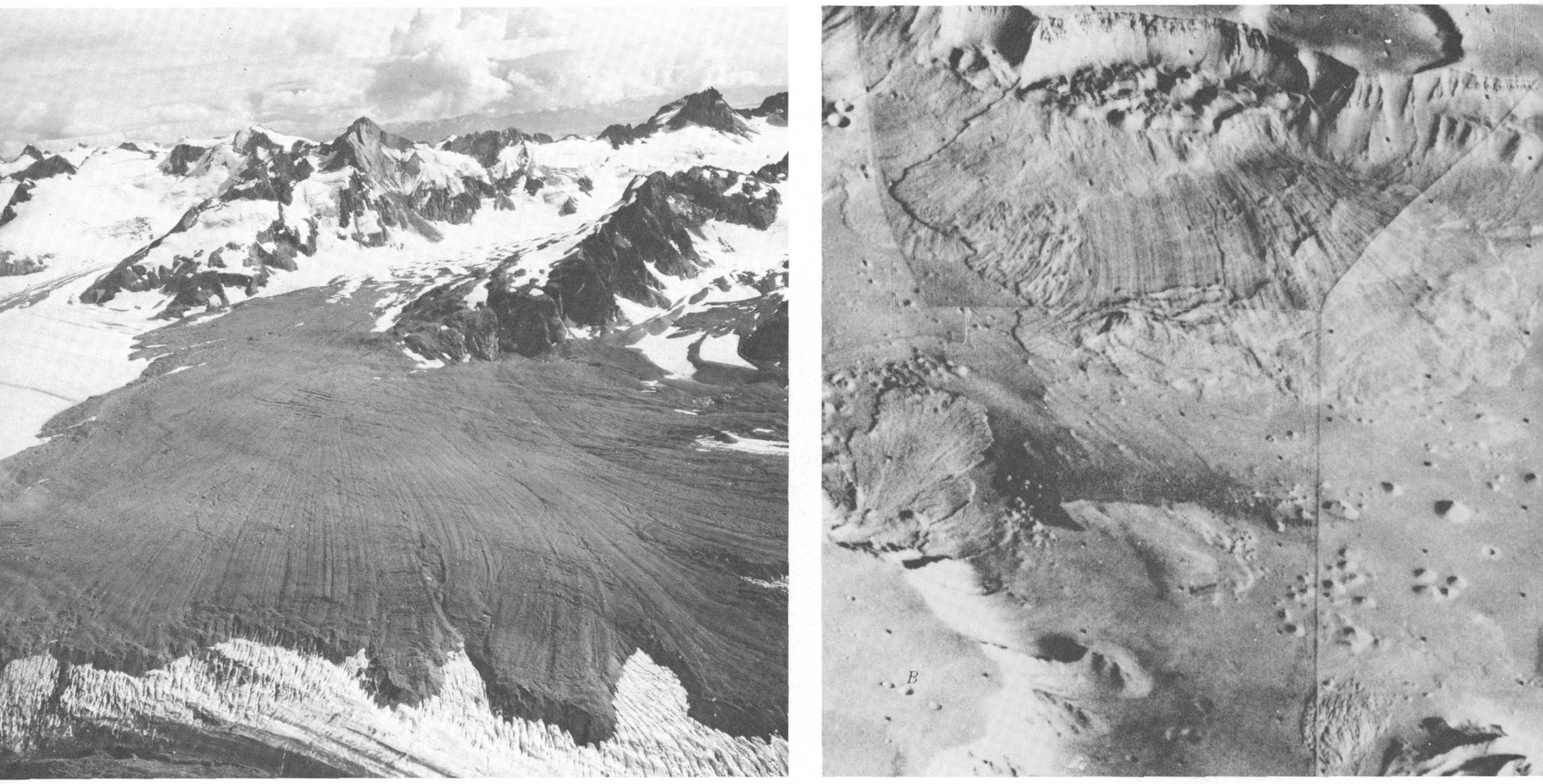


FIGURE 10.—**a.** The Sherman Landslide, Alaska. The landslide formed 27th March 1964 as 30 million cubic meters (a volume equivalent to a 1,000 foot-cube) of rock dropped 600 meters (1,969 feet) and moved laterally 5 kilometers (2.7 miles), partly over the Sherman Glacier. The longitudinal grooves are approximately 8 meters (about 26 feet) wide and average 600 meters (about 2,000 feet) in length. Distal ridges (*foreground*) are 3 to 15 meters (about 1 to 5 feet) high and 15 to 150 meters (about 5 to 50 feet) across. **b.** Landslide in the equatorial canyon of Mars. The canyon is approximately 150 kilometers (about 90 miles) across with walls 2 to 3 kilometers high. Longitudinal striae and the ridges near the toe of the slide are strikingly similar to the Sherman slide.

for Mars, there has been renewed interest in the effects of wind. Several laboratories are conducting wind tunnel experiments and attempts are being made to theoretically model various wind processes. Comparison between Mars and the Earth is particularly useful for such aeolian modelling. The values of the acceleration due to gravity and atmospheric pressure are, for example, very similar in most terrestrial environments but quite different on Mars. The effect of varying these two parameters can thus be assessed by comparing wind features on the two planets. In a related study, Martian dust storms are being analyzed in great detail in order to assess the effects of surface reflectivity, grain size, the brightness of the grains, and temperature gradient in the atmosphere on storm initiation. The results are being applied to dust storms in the Sahara and the southwestern United States. In general there is an increasing recognition of wind as an important erosive agent, particularly where soil has been de-stabilized by over-grazing or over-cultivation, and planetary studies are stimulating the studies needed for a better understanding of those environmental factors most sensitive in initiating erosion.

Cratering is another area where interplanetary comparisons may yield a better understanding. Interest in the Moon in the 1960's resulted in considerable experimental and theoretical work. One uncertain factor, which is difficult to test experimentally, is the effect of g, the acceleration due to gravity. Some of the uncertainties are being resolved by examination of craters on several planetary bodies. The results are somewhat surprising in that the final crater shape is relatively insensitive to gravity: craters on the Earth are very similar to those on Phobos, one of the moons of Mars, on which there is virtually no gravity. It is widely believed that the nickel deposits of Sudbury, Ontario, are in an old impact crater and oil has been found in some probable impact features in the Williston Basin of North Dakota. So better understanding of impact mechanics may well have direct economic implications.

Formation of the Earth

Certainly a major gain of planetary exploration will be an improved understanding of the formation of the Earth. Before acquisition of lunar samples, it was widely believed that the inner planets formed by accumlation of material that corresponded in composition to some meteorites. A type of meteorite called chondrites was generally assumed as representative of the parent material. It was believed that the inner planets formed by cold accretion of chondritic debris and later heated up slowly as a result of radioactive decay of the long-lived isotopes of potassium (K), uranium (U), thorium (Th). That now-obsolete model predicted that the surface of the Moon would be chondritic in composition and that no volcanic activity could have occurred because of the small size of the Moon and the relatively low K, U, and Th content of chondrites. We found, of course, that contrary to the model, the Moon is not made of chondrites and that there is evidence of extensive volcanic activity. Our concepts as to how the Moon formed, and consequently as to how the Earth and other planets formed had, to undergo revision.

Clues as to how planets form come from two main sources: (1) the variation in the bulk density of the planets with increasing distance from the sun and, (2) the chemistry of various obects within the solar system. We have at present good chemical information only on the Earth, the Moon, and meteorites. There are two theories currently in vogue as to how planets form. Both groups of theorists calculate that materials condensed out of different parts of the gaseous disc or nebula that surrounded the early sun. Where the theorists differ is their calculations of the extent to which equilibrium is or is not maintained between material already condensed and the remaining gases. Both agree in proposing that as the solar nebula cooled, different minerals condensed out to form solid grains from which the planets accreted.

In brief, on those planets forming close to the sun, only materials with high condensation temperatures such as CaO, Al_2O_3, $MgSiO_3$, Fe and Ni condensed, whereas toward the outer edge of the solar system almost everything condensed except hydrogen and helium. The net result is that the planets which formed from materials that condensed close to the Sun are rich in refractories whereas those further out are rich in volatiles. In the first or homogeneous accretion model, its proponents hold that accretion of the planets is slow compared with the dissipation of the nebula gases. Equilibrium is maintained between the condensed particles and the remaining gases with the result that planets accumulate from particles that are essentially homogeneous in composition, the composition depending on position within the solar system. In the second or non-homogeneous model, its proponents theorize that accretion of condensed particles into planetary bodies is relatively rapid so that continuous equilibrium between the condensed phases and the remaining materials does not occur. In this view, therefore, the planets are built up with an onion ring structure as successive layers are added. Both formation theories can be reconciled with the observed density distribution of the planets. Discrimination between the two theories requires detailed knowledge of elemental abundance and isotopic ratios on different bodies. Acquisition of data for bodies other than the Earth, Moon and meteorites will be necessary to unambiguously discriminate between the two theories.

Accretion of the condensed grains is likely to have resulted in substantial heating and melting of at least the outer few hundred kilometers of the Earth's crust. Evidence for this is deduced mainly from the Moon but is corroborated to some degree by sparse data from Mars and Mercury. We now know that the Moon has a heavily cratered crust, at least 4 billion years old, made up of coarse-grained, feldspar-rich igneous rocks, that crust must have formed as a consequence of melting during a very early episode of heating. The event occurred too early to be attributed to heating by long lived radio-isotopes. The most likely sources of heat are successive impacts and gravitational compression during the final stages of planet formation. As the proto Moon increased in size, its gravitational field increased and consequently, the impact energy of new material being accreted. In the late stages, accumulation was sufficiently rapid to cause melting in the outer two to four hundred kilometers creating oceans of molten rock from which the lunar crust separated. Accretion must have been rapid otherwise radiation of energy to space would have prevented the required temperature rise. Estimates are that most of the accretion took place in less than 10 million years and perhaps in as few as 10 thousand years. Mars and Mercury also have crusts that apparently formed very early in their history so heating must have occurred in the later stages of their accretion just as it did on the Moon.

We can conclude that the outer part of Earth must also have undergone extensive heating during the final stages of accretion. In the case of the Earth, however, because of its much larger size, heating must have been more intense and probably affected the planet to much greater depths than in the case of the Moon. In the final stages of accretion the outer parts of the Earth are likely to have been molten, and from this molten layer the materials that constitute the crust of the Earth separated. Thus studies of extraterrestrial materials have led directly to a much clearer understanding of the sequence of events during the Earth's formative phases, particularly how the crust formed. Uncertainties still remain, but as we acquire chemical information on other planets, some of these will almost certainly be resolved.

Technique Development

Application of space technology is already taking place on a large scale and may ultimately prove the most significant effect of space exploration on terrestrial geology. Development of image processing techniques and their application to Landsat pictures of the Earth is a prime example. During the early 1960's several digital imaging devices were developed for lunar and planetary exploration. These differ from the more familiar analog home television in that the image is comprised of a large number of discrete elements, each with a specific gray level designated by a number, much like a picture in a newspaper. The Landsat digital devices have several advantages over other devices in terms of signal to noise, weight, reliability and simplicity of operation and so have been flown on almost all planetary probes. They also have several analytical advantages that were not fully foreseen. Because of their digital format, the images can be manipulated in a computer and with each successive mission more sophisticated manipulative techniques were developed. Ways were developed to enhance or suppress surface topography and reflectivity, to emphasize linear features, to detect atmospheric haze or subtle color differences on the ground.

The success of these techniques led to the launching of ERTS and Landsat vehicles and the application of image processing methods to a wide variety of terrestrial problems from evaluating crop yields to estimating pollution levels in lakes. The geologic applications are enormous, and include detection of previously unrecognized structural trends in the Southeast U.S., detection of mineralized areas in Nevada, and geologic reconnaissance of wide areas of the Middle East. A considerable effort is under way to develop comparable techniques at radar wavelengths because of the potential application to Venus, and we can expect a similar feed-back to terrestrial problems.

Another area where numerous terrestrial applications are likely is in the handling of large data arrays. An enormous amount of data has been acquired on the Moon, much of which can be displayed on maps. Examples are remanent magnetism, gravity, elevations, surface ages, aluminum/silicon ratios of the surface, and electron density. Between forty and fifty such data sets exist. Because of the volume of the data, their different formats, and limited accessibility, comparisons between the different data sets were at first extremely difficult. Computer techniques were therefore developed to facilitate comparison and to aid in interpretation. These techniques, built largely upon existing image processing technology, led very quickly to clarification of several aspects of lunar evolution, particularly the history of the magnetic field. The methods are now being applied to terrestrial problems which involve correlation of different types of remote sensing data such as gravity and magnetics. Expectations are that the techniques will have wide application. Other techniques developed in support of the planetary program but now being employed by the U.S. Geological Survey in support of terrestrial geology include photogrammetry of images with unorthodox geometries, photogrammetry of radar images, and cartography of the sea floor by means of sonar.

Summary

In this limited space it is possible to review only briefly the significance of planetary exploration for comprehending our own planet. One of the most significant contributions is a greatly improved understanding of how the Earth formed, and of its early history—the evolution of its surface. These questions cannot be resolved without interplanetary comparisons which provide opportunities to test theories of geologic processes with initial conditions and under environments quite different from any that prevail on the Earth. From a practical viewpoint, the greatest impact may be development of new techniques for acquiring remote sensing data and for facilitating their interpretation. Future geologists may all be planetologists able to call forth non-terrestrial examples for comparison as readily as they now do terrestrial examples. △

Mapping in Support of Domestic Energy Production

By Stephen F. Pousardien and John D. McLaurin

INTRODUCTION

The Nation is still in the midst of an "energy crisis." In fact, the crisis worsens daily as our dependence on imported petroleum increases. Even the much heralded Alaska oil will lessen the problem only slightly and temporarily.

In order to ease the effect of dependence on imported energy, America must develop domestic resources. Pertinent resources are not limited to domestic coal, oil, or other energy sources, but include manpower, technology, and public will. These additional factors must be included because, by definition, a resource is a supply of anything that is available for use or that can supply a need. One other resource that must be available if energy resources are going to be fully developed while the environment is adequately protected, is adequate topographic map coverage.

NEED FOR TOPOGRAPHIC MAPS AND RELATED PRODUCTS

Topographic maps and related products are prerequisites for all phases of energy development and land-use planning. In the early stages of energy exploration and geologic studies, base maps are essential for describing the location of terrain features, the shape of the Earth's surface, and studying the geomorphology of a region. Often the basic topographic shapes of a region provide clues to areas with potential energy resources. Furthermore, base maps are invaluable for planning geologic studies and investigations and determining access routes to the most promising areas. After field studies are completed, base maps become the foundation on which the geologic information is presented.

Once energy resources are located and identified, the basic maps and cartographic data are used to help evaluate the economic feasibility of development, consider alternative means of extraction, and assess the environmental impact of the development. For example, maps and digitized map data are used to study drainage patterns to determine the effect of mining on the local water supply and the relationship of the energy resource to the transportation network, towns, and villages.

Tasks during the resource development phases are monumental. To cite one example, domestic coal production is expected to increase from 670 million tons to 1,270 million tons per year in the 9 years, 1976–1985. This 600 million ton per year increase is not concentrated in one area nor confined to one type of mine operation, but is a mix of eastern and western coal and of deep and surface mining. The Bureau of Mines has calculated that to provide the additional production, the coal mining industry must open 177 new underground mines and 63 new surface mines between 1976 and 1985 for an average of one new mine every 2 weeks. Such activity underscores the requirement for the topographic maps that must be used to plan necessary changes in the transportation network, to estimate the millions of tons of earth to be moved during development, to site processing facilities, and to plan and design support facilities, such as pipelines, waste disposal, and utilities. Maps are also a fundamental resource upon which development plans can be displayed and analyzed. Base maps and other cartographic data are also used to plan land reclamation and evaluate alternative land uses, such as parks, range, forestry, industry, and urban development.

Special maps play important roles in planning national energy strategy. A prime example of this use is a set of small-scale maps depicting energy flow patterns prepared especially for Congressional committees studying energy transportation problems. These maps display such data as energy commodity flow—petroleum from the Gulf region to the north central and northeastern States as an example, quantities of commodity, and modes of transport—rail, highway, pipeline, water, or transmission lines.

The basic map scale used by most governmental agencies with responsibilities in the energy field is 1:24,000. This scale is preferred for general-purpose topographic maps used as basic planning documents. The content of this series is so widely accepted, the Surface Mining Control and Reclamation Act of 1977 requires strip mining permit applications to include maps presenting all information shown on these maps.

ENERGY MAPPING REVIEW

Recognizing the increased emphasis on domestic energy development and the role topographic maps and related products must play in that development, the Survey began a comprehensive review late in 1973 to determine the status of topographic and related mapping for areas with known and potential energy reserves. Areas of the country rich in energy resources were determined through interviews with staff of the various agencies responsible for mineral development and conservation and through a review of published material. Energy resources considered include oil and gas, oil shale, coal, geothermal energy, and nuclear fuels.

The review disclosed several requirements to which the National Mapping Program was not adequately responding; requirements caused by suddenly increased emphasis on domestic energy production. These requirements were for maps in areas not previously mapped, revision of previously published maps, and new and special products.

Effect on the National Mapping Program

The energy crisis surfaced a new set of priorities and requirements for the National Mapping Program. Areas that had been of relatively low priority suddenly became very important. Products that had previously been discussed in an academic light became production requirements. Survey Cartographers acted immediately to satisfy unmet requirements, consistent with capacity and other high priorities. Mapping to complete 1:24,000-scale coverage either in the form of standard topographic maps or orthophotoquads was accelerated for the more important Federal coal lands, especially those in the Northern Great Plains Province. Revision of published 1:24,000-scale maps was greatly expanded for all coal reserve areas, eastern and western, Federal and private, producing and undeveloped reserves.

Bureau of Land Management (BLM) requirements for intermediate-scale base maps to inventory resources for energy development resulted in the initiation during 1976 of a new mapping program. Working jointly, the BLM and the Survey designed a multipurpose series of 1:100,000-scale maps in quadrangle format. The Survey is responsible for various base categories of data such as transportation networks, topography, hydrography, and political boundaries. The BLM overprints other information, such as land ownership and lease status, required for managing Federal leases and planning development of energy resources. This map series is designed so that the base category information can be separated by feature and combined with various overlays of information to produce special maps for special purposes. For example, the same basic map data are reformatted to meet the Soil Conservation Service needs for intermediate-scale county maps and the Defense Mapping Agency requirements for 1:50,000-scale training maps.

Further supporting the mapping requirements for energy exploration and development are the joint topographic/bathymetric maps of the Geological Survey and the National Oceanic and Atmospheric Administration (NOAA). These maps display both the topographic information normally collected by the Survey and the bathymetric information for the water areas collected by NOAA. These products have extensive usefulness in planning offshore activities such as locating drilling platforms and planning pipeline collection networks. Environmentalists, coastal zone planners, and various Federal and State agencies also use these maps to analyze the effect of and to plan for onshore facilities to support offshore oil development.

Other map data and products having widespread application to energy related problems include aerial photographs, map data in digital form, and slope maps.

- Aerial photographs are the basic working tools for map compilation and revision. They are also directly useful in their original form for many purposes. Although black and white panchromatic film is normally used for mapping, other types, such as color and infrared films, are exceptionally useful for particular studies.

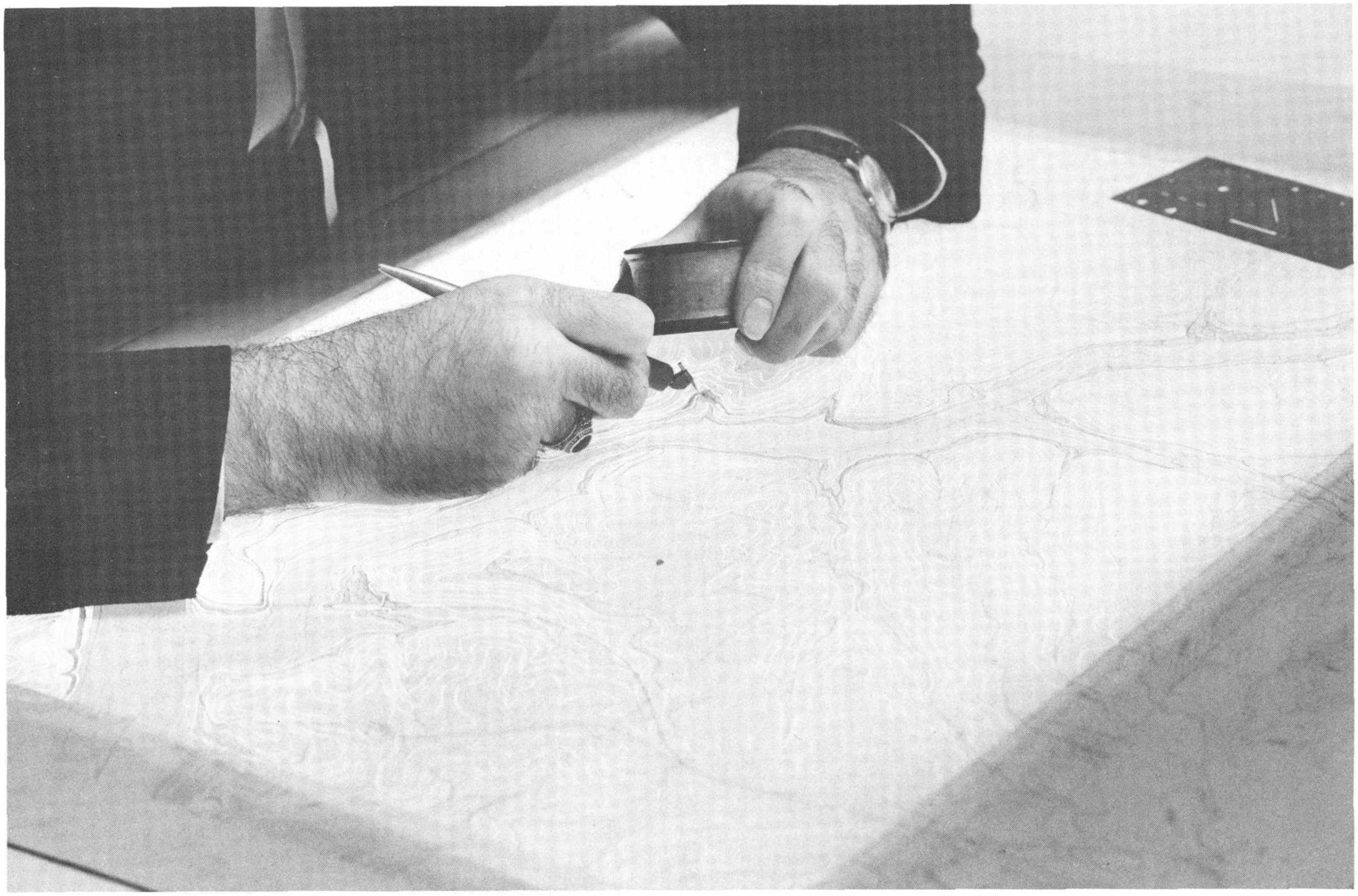
- Digital map data have many uses in analyzing such characteristics as slopes and rainwater runoff and, when combined with digitized resource data, evaluating potential mineral value and calculating overburden. Digital data permit computer analysis in support of management decisions affecting the use of land, water, energy, and mineral resources. For example, the Survey's Geologic and Topographic Divisions are using digitized terrain information and digitized information about the depth and thickness of coal beds in the northern Great Plains to estimate the amount of overburden that must be removed and the costs for developing these coal resources.

- Slope maps are prepared to meet specific requirements for maps that identify different ranges of terrain slope. These maps are derived from the contour data of the published topographic maps.

Considering the already heavy demand for maps the finite production capacity, setting priorities is particularly important. Energy-related priorities are combined with other specific mapping requirements in choosing new mapping, revision, and orthophotoquad projects.

The Geological Survey is responding as quickly as possible to urgent requirements of map users while maintaining enough flexibility in map production, data display, and data storage to meet the requirements of many different organizations from a single set of basic map data. To do so requires development of additional capabilities, particularly in generating digital data; acquisition of new, more efficient equipment and development of advanced techniques for extracting basic map data from various sources. The goal is to have the appropriate map or map data ready for the user in time to solve the specific problem he is addressing.

Maps are one of the fundamental, although often unrecognized, resources of a nation. They are necessary for the solution of many kinds of problems and serve many economic and scientific needs. However, maps are truly a resource only when sufficient time and attention are given to their production well in advance of the date they are needed. △



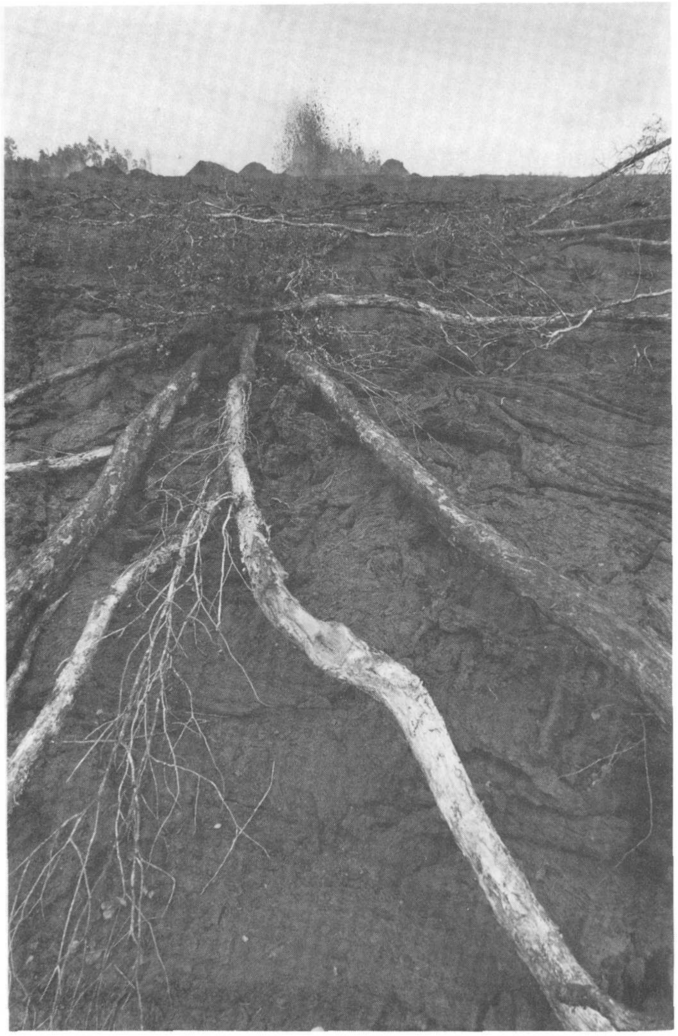


FIGURE 11.—Lava fountains, approximately 100 meters high, play at the vent during the September 1977 eruption of Kilauea Volcano. New lava flows and downed trees in foreground (*Photograph by Boone Morrison*).

Monitoring Active Volcanoes

By Robert I. Tilling

Certainly one of the most spectacular, awesomely beautiful, at times destructive, displays of natural energy is an erupting volcano, belching fume and ash thousands of meters into the atmosphere and pouring out red-hot molten lava in fountains and streams. Countless eruptions in the geologic past have produced volcanic rocks that form much of the Earth's present surface. The gradual disintegration and weathering of these rocks have yielded some of the richest farmlands in the world, and these very fertile soils play a significant role in sustaining our large, and growing, population. Were it not for volcanic activity, the Hawaiian Islands—with their sugar cane and pineapple fields and magnificent landscapes and seascapes—would not exist to support their residents and to charm their visitors. And yet, the actual eruptive processes are catastrophic and can claim life and property.

Eruptions of andesitic volcanoes, which dot the margins of the moving rigid plates of the Earth's crust, are characteristically violently explosive. For example, in 1902 a single explosive eruption of Mount Pelée, Island of Martinque in the Lesser Antilles, virtually destroyed the entire city of St. Pierre, killing some 30,000 persons. On the other hand, eruptions of the Hawaiian volcanoes generally are non-explosive and more benign, posing a threat to property, but rarely to life. For example, lava flows of the 1960 eruption of Kilauea Volcano burned and buried the small village of Kapoho on the eastern tip of the island of Hawaii. Not a single person was injured or killed, however, because warning signals of impending eruptive activity were detected in time to permit safe evacuation of Kapoho residents.

There are presently about 500 known active volcanoes on the Earth, not counting those that lie beneath the sea. Scientists have estimated that at least 200,000 persons have lost their lives as a result of volcanic eruptions during the last 500 years. Little wonder then that people living in the shadow of active or dormant volcanoes have feared eruptive outbreaks in times past and present. Centuries ago, the Romans attributed volcanic and related phenomena (including earthquakes) mainly to the movement of wind, imprisoned inside the Earth, rushing violently out to the surface. The Polynesians believed volcanic activity to be caused by the beautiful but wrathful Pele, Goddess of Volcanoes, whenever she was angered by, or jealous of, actions of other deities or of mortals. Today, scientists know that volcanic eruptions occur when buoyant magma (molten rock) that formed deep in the Earth ascends and ultimately is ejected upon release of gas pressure. More importantly, with precise, sophisticated instruments and refined data analysis, it is now possible to track the subsurface movements of magma by monitoring the earthquakes and ground changes accompanying such movements. Although the present state of knowledge does not permit the prediction of the exact time and place of eruptions, we can detect departures from usual behavior that augur impending activity. Systematic monitoring studies are conducted only on a few active volcanoes—those in Hawaii, and some in Italy, Japan, New Zealand, and Kamchatka (U.S.S.R.). The overwhelming majority of active volcanoes are not monitored, little understood, and, hence, extremely hazardous if in populated regions.

Monitoring Techniques

How do volcanologists study restless, potentially dangerous, active volcanoes? Basically, volcano monitoring involves the recording and analysis of measurable phenomena—ground movements, earthquakes, variations in gas compositions, deviations in local electrical and magnetic fields, etc.—that reflect pressure and stresses induced by the subterranean magma movements. To date, monitoring of earthquakes and ground deformations before, during, and following eruptions has provided the most reliable criteria in predicting activity, although other geochemical and geophysical techniques hold great promise.

Most of the commonly used monitoring methods were largely pioneered and developed by the Hawaiian Volcano Observatory (HVO), established in 1912 by Dr. Thomas Jaggar, Massachusetts Institute of Technology, and operated continuously by the Geological Survey since 1948. The sixty plus years of continuous observations of Kilauea and Mauna Loa, two of the world's most active volcanoes, have fostered fundamental developments in instrumentation and measurement techniques, which are increasingly used in the study of other active volcanoes the world over. Moreover, early major advances in seismic research at HVO contributed significantly to subsequent systematic investigations of earthquake and related crustal processes, now conducted as part of the Geological Survey's Earthquake Hazards Program.

The volcanic plumbing and reservoir system beneath Kilauea can be pictured schematically as a balloon buried under thin layers of sand and plaster. In this baloon model, magma is fed from depths into the reservoir (analogous to air filling a balloon), the internal pressure increases, and the sand-plaster surface layers are pushed upward and outward in order to accommodate the swelling or inflation. The net effects of such inflation include: the steepening of slope of the volcano's surface; increase in horizontal and vertical distances between points on the surface; and, in places, the fracturing of the sand-plaster layers stretched beyond the breaking point (fig. 12). Such rupturing of materials adjusting to magma-movement pressures results in earthquakes. A shrinking or

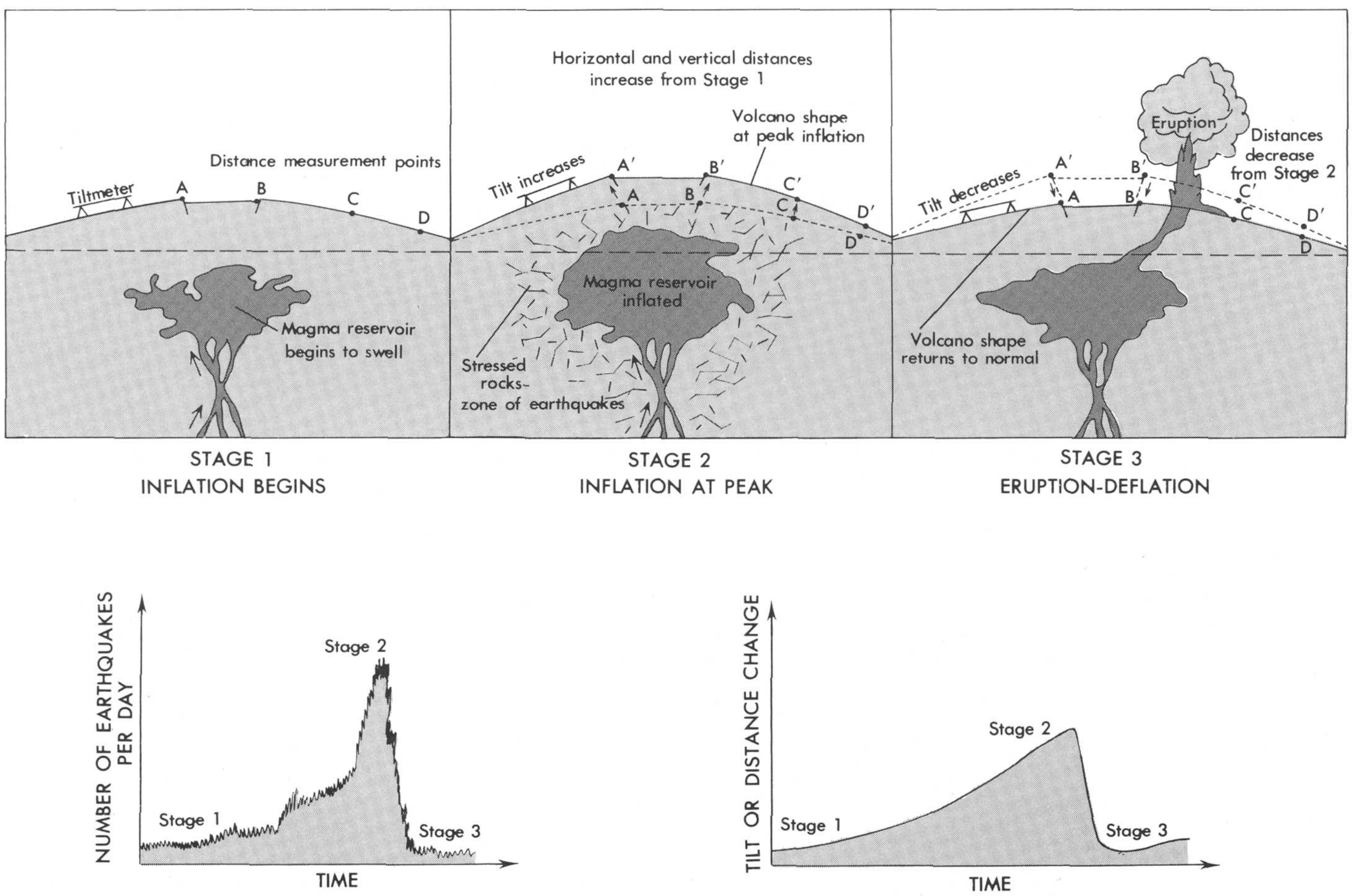


FIGURE 12.—Schematic diagrams of three commonly observed stages in the course of a typical Hawaiian eruption. The lower part of figure shows idealized graphs of earthquake frequency, tilt, and distance changes as a function of time during the three stages. See text for additional discussion. (Modified from illustration by John D. Unger in Earthquake Information Bulletin, 1974, vol. 6, p. 7).

rapidly draining reservoir to feed surface eruptions (analogous to deflating or popping the ballon) would produce the opposite effects: flattening of slopes, reduction in distances between surface points, and decrease in earthquake frequency (fig. 12).

Let us now go from the balloon model to a real volcano. Changes in slope can be measured precisely by various electronic-mechanical "tiltmeters" or field tilt surveying techniques, which can detect the change in slope of a kilometer-long board if raised by the thickness of a dime placed under one end! Similarly, very small changes in horizontal distances and in vertical distances can also be measured respectively by an electronic distance measuring instrument that utilizes a laser beam and by precise levelling surveys. Such changes can be easily detected to a precision of a few parts per million. The notion of one part per million can be dramatized in terms of a very dry martini—1 drop of vermouth per 16 gallons of gin! The frequency, location, and magnitude of earthquakes generated by magma movement can be easily and accurately determined by data from a properly designed seismic network. For example, the Hawaiian Volcano Observatory has recently expanded its seismic networks to 45 stations to better monitor the earthquake activity of Kilauea and Mauna Loa on a round-the-clock basis.

It must be stressed, however, that the continuous monitoring of present-day seismicity and changes in volcano shape alone is not sufficient for predicting eruptions. The proper analysis of monitoring data requires a basic understanding of the prehistoric eruptive record and behavior of a volcano that can only be reconstructed from regional geophysical and geologic studies, and dating and geochemical investigations. Such glimpses into a volcano's prehistoric past are critically important, because its historic data base is much too brief to allow reliable extrapolation of present eruptive behavior and frequency for predictive purposes.

Recent Case Studies

Investigations carried out as part of the Geological Survey's Volcano Hazards Program provide case studies of monitoring two of the world's most active and best understood volcanoes, Mauna Loa and Kilauea on the "Big Island" of Hawaii.

Mauna Loa Volcano last erupted July 5–6, 1975. At that time it had been inactive for a quarter of a century since the June 1950 eruption along its southwest-rift zone. The first hint of change leading up to the 1975 eruption was a marked increase in the number of earthquakes beginning in April 1974, more than a year before the eruption. Inflation or swelling of the summit of Mauna Loa was detected four months later, in August, during the annual "laser beam" remeasurement of horizontal distances across the summit crater. The 1974 set of measurements showed the first significant increases in the horizontal distances of the lines across the summit crater since the inception of the precise distance monitoring program in 1967. The Hawaiian Volcano Observatory immediately issued a press release alerting Hawaii officials and the general public to the possible reawakening of Mauna Loa from its long slumber.

During the next twelve months, both the ground-deformation and seismic networks on Mauna Loa were expanded. Intensified monitoring showed that numbers of earthquakes and the rate of summit inflation increased steadily, reaching a crescendo during the summit eruption that began on July 5 of 1975. The exact timing of the eruption could not be predicted, even though all premonitory indicators pointed toward an eruption any day. Although the earthquake frequency tapered off sharply in the weeks following the July eruption, swelling of the summit resumed, indicating continuing accumulation of magma in Mauna Loa's summit reservoir. Measurements made on six separate occasions over a period of a year and half following the eruption all demonstrated continued swelling. From analysis of the written records of the past historic eruptive behavior and the fact that both the earthquakes and swelling had extended out along the northeast rift, Observatory scientists suggesed that a flank eruption on the northeast rift was likely sometime before the summer of 1978, *if Mauna Loa were to behave as it has for the past 200 years*. This conclusion was conveyed to members of the Hawaiian Congressional delegation and Hawaii Civil Defense officials, announced to the media, and published in a scientific journal.

However, newly observed changes in the geodimeter lines in July of 1977 suggest that Mauna Loa may be departing from previous behavior, and the timetable for the predicted eruption may have to be revised. Inflation of Mauna Loa Volcano has slowed. The northeast-rift zone has contracted slightly, and there has been little seismicity of significance in recent months. According to Observatory scientists, the volcano is not shrinking or deflating. The magma that accumulated in the summit region over a period of more than three years (since April 1974) has not

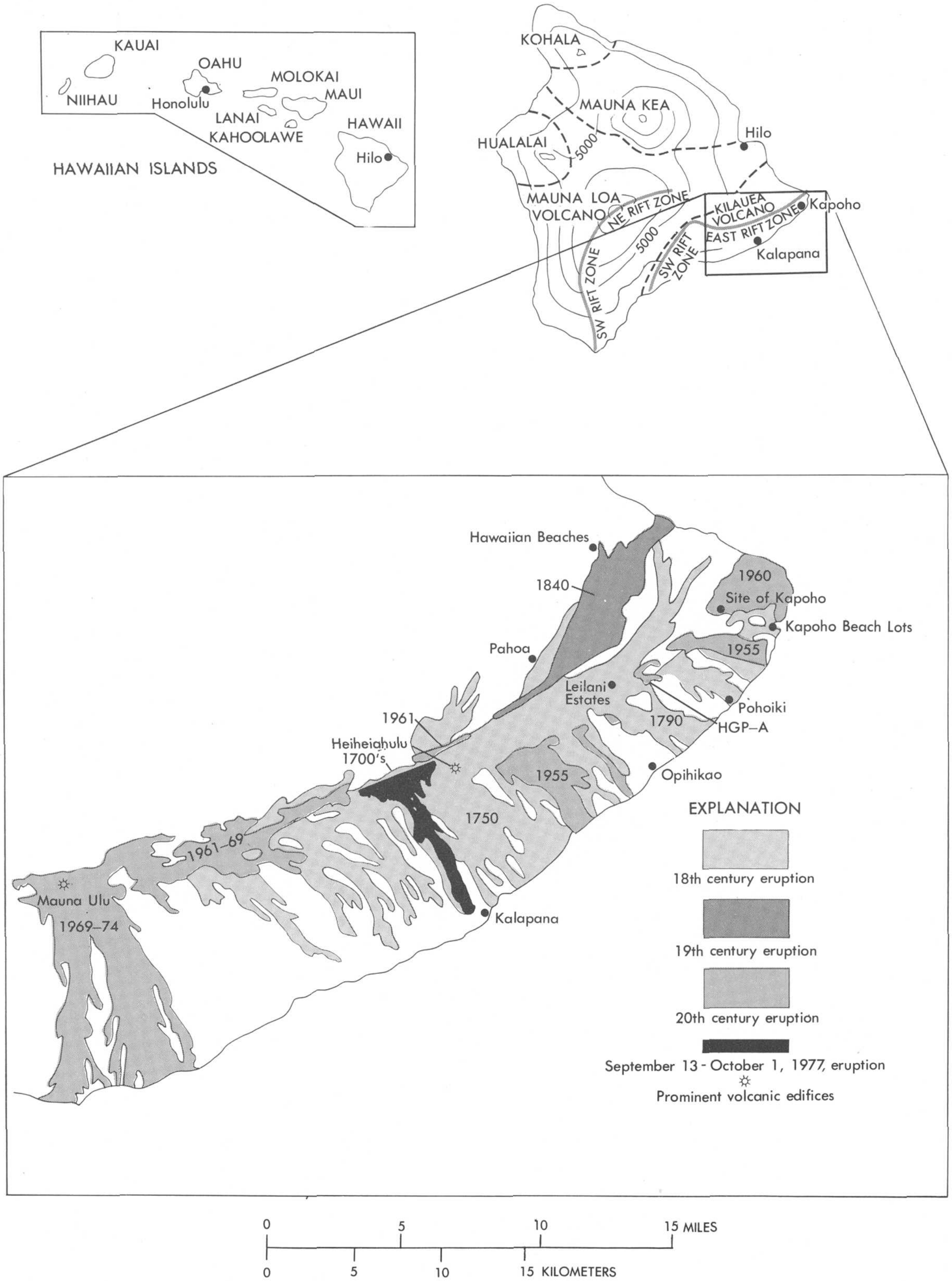


FIGURE 13.—Sketch map showing historic lava flows erupted from Kilauea Volcano's east-rift zone, including those of the Sept. 13–Oct. 1, 1977 eruption. Note the locations of villages and subdivisions relative to these lavas. HGP–A marks the site of a 1,969 meter-deep test hole of the Hawaii Geothermal Project of the University of Hawaii.

drained away. Thus, the potential for an eruption is still very much present. The new data do suggest, however, that the predicted eruption may be farther away in time than before the summer of 1978. A new forecast of the probable time of eruption is not possible until Mauna Loa's swelling and earthquakes resume and analysis can be made of its changing pattern of eruptive behavior.

These recent developments show that the relatively limited time span of intensive monitoring (three years and the short historic record (about 200 years) are simply inadequate to establish statistically reliable probabilities for the exact time and place of the next eruption, even though we know Mauna Loa is still primed for action.

Kilauea has been closely monitored for a longer period of time than for Mauna Loa, but even here we have not achieved the necessary state of knowledge for prediction of eruptive activity. But there have been some notable successes. For example, in the early 1970's, several eruptions were predicted with sufficient certainty 4 to 8 hours in advance, so that Observatory scientists could advise officials of Hawaii Volcanoes National Park to evacuate certain sections. The Park Rangers were able to safely clear park visitors from the actual outbreak areas in ample time! However, there also have been false alarms—when all of the premonitory indicators signalled movement of magma from the summit reservoir, only to have the magma injected below ground into the rift zones without breaking the ground surface.

In the fall of 1976, increased steaming and dying of forest near Heiheiahulu on Kilauea's lower east-rift zone to the north of Kalapana (fig. 13) caused Observatory staff members to increase the monitoring of this area. Although significant changes were observed, they were ascribed largely to continued southward shifting of Kilauea's south flank following the effects of the devastating 7.2-magnitude earthquake of November 29, 1975. Since the summer of 1977, however, changes in the Heiheiahulu area have taken place at an increased rate. Swelling of the general area around the Heiheiahulu cone began. The area underwent uplift, accompanied by additional southward horizontal movement, suggesting the accumulation of magma in this area, but without the occurrence of increased seismicity, which at Kilauea typically accompanies such magma movement. Additional monitoring instruments were installed, even though Observatory records dating back to 1958 show that similar swelling has occurred here before without the advent of eruption.

Because the east-rift zone of Kilauea has long been the locale of recurring lava flows (fig. 13) and eruptive activity could pose a threat to downslope cultivated and populated areas, Hawaii County Civil Defense officials were advised of the unstable conditions. Hawaii residents were informed by a press release issued on July 29, 1977. At 7:30 p.m. (Hawaiian Standard Time), September 13, lava fountains 25–30 meters high spurted along a 5 kilometer-long fissure only a few kilometers uprift (WSW) of the swollen Heiheiahulu area, following an intense earthquake flurry and abrupt deflation that began about 24 hours before. The eruption continued intermittently for the next 18 days along a restricted part of the fissure. Episodes of vigorous fountaining alternated with interludes of relative inactivity or feeble spattering of lava. The final and most voluminous phase of the activity produced a rapidly moving lava flow, which posed a potential threat to the village of Kalapana downslope (fig. 13). Unlike the nearby village of Kapoho destroyed during the 1960 eruption, Kalapana was spared, as the lava fountains stopped on October 1, and the 15 meter-high flow front slowly ground to a halt—only about 400 meters from the nearest dwellings.

Conclusions

Tremendous strides have been made in recent years in intensifying the monitoring of Mauna Loa and Kilauea as part of the Volcano Hazards Program, and our understanding of the typically non-explosive, Hawaiian-type of volcanism has increased markedly. But reliable and specific prediction capability for eruptions in Hawaii still eludes us. The predictive capability is much poorer for explosive andesitic volcanoes, such as those in the Cascade Range of northwestern United States (Mount Rainer, Mount Hood, Mount Lassen, etc.), Alaska, and elsewhere around the Circum-Pacific "Ring of Fire." The explosive Cascade volcanoes, which have only erupted rarely within recorded historic times, are potentially much more destructive and deadly than Hawaiian volcanoes. Should they erupt violently, large population centers in the northwest, such as Seattle and Portland, could be seriously threatened. Clearly, present intensive monitoring of Hawaiian volcanoes must be maintained, and fundamental studies and systematic monitoring of the Cascade volcanoes need to be expanded and accelerated. △

Replenishing Non-Renewable Mineral Resources—A Paradox

By Richard P. Sheldon

In 1922 a joint committee of petroleum geologists from the American Association of Petroleum Geologists and the U.S. Geological Survey estimated that the United States had only 9 billion barrels of oil left in the ground either as reserves or as resources to be discovered (U.S. Geological Survey, 1922). Eleven years later, the 9 billion barrels had been produced and an additional 13 billion barrels had been discovered.

In 1952 the President's Materials Policy Commission estimated the Nation's foreseeable copper resource (as of 1950) to be 25 million tons. Twenty-five years later, 31 million tons of copper had been produced and an additional 57 million tons of reserve had been discovered.

These are two of many examples of carefully reasoned mineral resource predictions by credible highly qualified geologists and engineers that have been overtaken in a few tens of years by additional production and discovery.

Mineral resource estimates ordinarily are requested by national planners when they perceive possible future shortages. The 1922 oil estimate was made during the "John Bull" oil shortage scare, and the 1952 copper estimate was undertaken during the post-World War II period when the United States was thought to be "outgrowing its resource base." The engineers and geologists responsibly furnish these these estimates, usually qualifying them as conservative, particularly in regard to minerals expected to be added by additional discovery. Unfortunately, such qualifiers are quite often dropped by many of those who use the estimates. These estimates generally deepen the concern over impending shortage, but become irrelevant when the period of shortage gives way to a period of adequate or even over supply.

Behavior of these non-renewable mineral resources over time is opposite to what we intuitively expect. Geologists and engineers measure and report resource abundance. The resources they estimate are then depleted at ever increasing rates that foreseeably should exhaust the resource. Concern about shortages grows. Yet when the time approaches when we should have run out of the resource, we find paradoxically—almost alchemically—that we have more than we started with. At best we distrust the forecaster's ability and at worst his motives. What has gone wrong? Are such underestimates going to continue to be made in the future? To answer these questions, the nature and dynamics of resources need to be understood.

Nature of Resources

In Webster's dictionary, a resource is defined as a fresh or additional stock or store of something available at need. Thus, in the short term, we think of resources as a stockpile of inventoried material with immediate availability. If we consider long-term demand, the question of future availability becomes important, so that undeveloped resources, that is mineral resources awaiting discovery in the ground or living resources yet to be born or planted, must be considered. Thus resources have two essential characteristics: (1) a demand, and (2) an availability. Depending on the time frame being considered, the demand and the availability are either immediate or potential.

Resource demand. Potential resources are based on a projection of future demands, a process that carries some risk. For example, in view of the threatening deforestation in France in the late 17th century, the King planted an oak forest near Paris as a reserve to supply, some 200 years hence when the trees matured, oak logs for masts and timbers for warship construction. His foresight created a beautiful forest that still stands, but did little to meet the needs of the modern French Navy.

The changing nature of mineral resource demand and its affect on resources over time can be seen by considering the mineral resources of the State of Montana at two times: a thousand and ten years ago and ten years ago.

On the one hand, the stone-age Indian living in 968 in what was to become Montana had a very small but highly specialized need for stones. Each year he used a few pounds of flint and obsidian for tools, arrowheads, and axe heads, a few pounds of sandstone for mortars, a little salt and mineral dye. Their value at today's prices would be a few cents, or at his prices, a few belts of wampum. The total resources available in his shallow quarries would be worth perhaps a few thousands of dollars in our terms. Of course, he used so little of his mineral resource that their eventual depletion was of little if any concern to him.

On the other hand, the industrial-age Montanan living in 1968 had tremendous needs for minerals, and huge production facilities and mineral resources to meet them. Along with his fellow citizens from the other 49 states, the Montanan used, on the average, 20 tons of minerals a year. The value of the cumulative mineral production of Montana from 1880 up to 1960 was over 4 billion dollars, showing that Montana lives up to its name, the Treasure State. In 1968, Montana contained 52 varieties of significant mineral deposits ranging from asbestos to vermiculite (U.S. Geological Survey, 1968). The most important of these were oil, natural gas, coal, copper, phosphate rock, and chromium. Their reserves at that time were worth 1.17 trillion dollars.

The mineral needs of the stone-age Montanan were low, and his assessed resources were correspondingly low. On the other hand, the mineral needs of the industrial-age Montanan are large and varied, but so are his mineral resources. The difference in mineral needs, supplies and resources between the two ages is staggering. It is no matter that the stone-age Montanan was standing on vast deposits of minerals that were to become highly valuable to Montanans a millenium later. To him they were rocks to walk on, not resources to use. The separation of ages is complete when one realizes that the industrial-age Montanan does not even include among his vast mineral resources the small deposits of flint, obsidian and sandstone used by his predecessor a millenium earlier.

It is clear from considering this example that even though most mineral deposits are permanent and unchanging on the human time frame, mineral resources are temporal and changing. V. E. McKelvey pointed out (1972, p. 20) that, "Defining resources as materials usable by man, a little reflection reveals that whereas it is God who creates minerals and rocks, it is man who creates resources." One can reflect further that a mineral *deposit* can be characterized as nonnewable, but mineral *resources* are another thing entirely. By additional effort by man new mineral resources can be "created," not in the sense of creation by the Almighty, but in the sense that a body of rock is identified for the first time as useable. Within the limits of geologic availability, one can conclude that the character, variety and size of mineral resources depend on the technology that needs them and the technology for developing them.

Resource availability. To be anything other than a wishful thought, resources must be available or potentially so. A mineral deposit that has been found, measured, and determined to be economically mineable at the current price using current mining and extraction technology is available and clearly a resource. If the deposit is known and measured, but no process is known or foreseen by which the material can or could be recovered economically, it is not available for use and is not a resource. However, if it seems to qualified engineers technologically feasible to develop in the future a process to recover the matrial economically, the deposit would be potentially available for use and would be called a sub-economic resource (U.S. Bureau of Mines, and the U.S. Geological Survey, 1976). For example, in 1950, when the 6.2 billion tons of U.S. iron ore reserve included no taconite, the low-grade taconite deposits were subeconomic and were foreseen to be only potentially available. The developing of the technology to drill, mine and concentrate taconite made it economic and, in fact, the preferred ore, which in 1975 made up most of the U.S. iron ore reserve of 17 billion tons.

Another factor of availability is the knowledge of the existence of a deposit. It is obvious that a deposit must be identified to be available and that an undiscovered deposit is unavailable. Exploration and resource geologists can identify areas where undiscovered deposits might occur and then can make a knowledgeable guess about how many deposits exist there, and of these how many might be discoverable. They also can make knowledgeable guesses about the size of such undiscovered deposits. Such deposits can then be considered potentially available; that is we have the potential to discover them with current exploration techniques. Nearly all of our known deposits that now make up our past production and present mineral reserve were once a part of the undiscovered but discoverable resource.

There is no way in which the ultimate amount of the undiscovered resources can be determined even though some portions of the ultimate amount can be estimated. We can predict a discoverable portion of undiscovered resources using well supported *hypotheses* of the occurrence of deposits, as well as an additional discoverable portion using poorly supported *speculations* on the occurrence of deposits. These portions make up the *hypothetical* and *speculative* categories of undiscovered resources used by the Geological Survey and the Bureau of Mines. However, a still further portion of undiscovered ultimate resources cannot be predicted because it is undiscoverable using either current or foreseeable future exploration technology. For example, some rocks of the western United States are mineralized where they are exposed, but in large areas where they are covered by younger lava flows, they cannot be prospected for by anything other than the too-expensive drill or shaft. Geologists can confidently predict that many deposits exist beneath the lava flows but the deposits are not economically discoverable with present or foreseeable future technology and cannot be counted as a part of our resources. A still further portion of undiscovered ultimate resources cannot be predicted because of lack of scientific evidence of the existence of the deposits. Such deposits probably exist but are unsuspected by geologists. A clear hindsight example of such a deposit is the Red Sea metalliferous mud. On February 17, 1965, marine geologists on the oceanographic research vessel, *R. V. Atlantis, II,* were astonished to find that a core of mud taken in the central part of the Red Sea was enriched in zinc, copper, lead, silver, and gold (Degens and Ross, 1969). Subsequent surveys showed that the metalliferous muds in the Red Sea are widespread, fairly thick and contain large quantities of scarce metals. These deposits now are a part of the world's subeconomic resource, but there was no reason whatever before their chance discovery to suspect that they existed. They were totally unconceived and were certainly not visualized as a part of undiscovered resources.

Resource Flow

A common but incorrect way of viewing mineral resources is to regard them as the sum of the known and predicted economic deposits of commodities in current use, and from that to conclude that mineral resources in general are fixed and non-renewable. As seen in the discussion in the previous section, mineral resources consist of known and suspected mineral deposits that are counted as resources by virtue of industrial needs for them and subsequently are categorized according to knowledge of their existence, the economics and technology of their discovery, and the economics and technology of their mining and extraction. These factors change over time, causing the make-up and magnitude of resources to change. Recognizing that resources are so heavily influenced by these temporal economic factors, economists David Brooks and P. W. Andrews pointed out in 1974 that in matters of long-term supply, minerals should be treated not as a fixed stock, but as a flow that responds to demand.

The misconception of resources as a fixed stock answers part of the question raised at the start of this paper, "What has gone wrong with our mineral forecasting?" At a time of concern over threatening shortages of minerals, resource geologists and engineers are asked to join forces and estimate the known mineral resources and predict the unknown mineral resources. They would like to estimate once and for all the total or ultimate resources of the country, but they cannot. Their problem is this—both geologists and engineers, no matter how technically liberal they may be, must stay within the confines both of their data and their technical understanding and methodology. They come up with estimates, but each one is outdated the day it is published, because continuing exploration and study generate new data, and new basic research sparks new ideas of occurrence or recovery. In the past, most estimates have turned out to be too low, which is expectable. Regardless of the liberalism of the estimater, the methodologic conservatism that must be followed insures that the estimate will exclude deposits that are unrecoverable with foreseeable technology as well as deposits that are undiscoverable—as were the mineral deposits beneath basalt flows—or are unpredictable—as were the Red Sea metalliferous muds. Over time with the accumulation of more knowledge, significant amounts of such deposits will become recoverable, discoverable or predictable and add to the total resources.

This is not to say that rocks, minerals, and their natural concentrations are not finite or that geologic availability is not a limiting factor in resource magnitude, but only that the conception and perception of resources at any given time are likely to be limited.

Mineral Supply System

The mineral supply system of the United States yields this flow of most mineral materials from one resource category to another progressively from speculative-undiscovered resources to refined material production. As we have seen, the system is driven by the demands of the industrial-age.

To understand how this supply system works and the factors influencing it, one must look at its components. It is commonly conceived to have three major phases: research, exploration, and exploitation; however, each of these phases is divided into two parts. Research consists of conception and assessment of undiscovered resources; exploration consists of discovery and delineation of mineral deposits; and exploitation consists of extraction and processing of ores. Table 7 shows this breakdown along with the actual activity carried out, the mineral resource category developed, and the institutions with the prime responsibility.

The flow of material is initiated by research organizations in government, academic, and the private sector conducting basic research on geologic processes of rock and mineral formation and distribution. Originally all resources were unconceived, and only by such basic study and thinking was each kind of deposit conceived. Once conceived, the magnitude, location and character of the deposits are speculated

TABLE 7.—*Phases of Mineral Supply System*

Major phases	Detailed phases	Activity		Mineral resource category developed	Prime responsibility
RESEARCH	CONCEPTION	Research in geologic processes, i.e. plate tectonics, formation of mineral deposits, etc.	UNDISCOVERED RESOURCES	SPECULATIVE	Universities, Government, research organizations, private institutes
	ASSESSMENT	Geologic, geophysical, and geochemical mapping, geostatistical analysis		HYPOTHETICAL	Government Industry
EXPLORATION	DISCOVERY	Prospecting	RESERVES	INFERRED	Industry
		Research on prospecting techniques			Government and Industry
	DELINEATION	Exploration		INDICATED AND MEASURED	Industry
		Research on exploration techniques			Industry and Government
EXPLOITATION	EXTRACTION	Mining and land reclamation		Produced raw material	Industry
		Research and development on extraction		Reserves	Industry and Government
	PROCESSING	Beneficiation reduction and refining		Produced refined material	Industry
		Research and development on processing		Reserves	Industry and Government

on and reported as a *speculative* undiscovered resource, generally by government and academic research organizations.

In the next phase, mineral resources are further defined by government resource agencies and to a lesser degree (and mainly for its own purposes) by the exploration sector of industry. They conduct geologic, geophysical, and geochemical mapping of areas of speculative resources. Application of well-supported hypotheses concerning the occurrence of mineral deposits to these regional data allows estimation of *hypothetical undiscovered resources.* In this way the certainty of actual existence of the undiscovered resource is increased to the point that the hypothetical resource estimates have sufficient reliability for national planning in government or exploration planning in industry.

At this point exploration is initiated by industry. The regional maps produced at the assessment stage are used to plan a prospecting program. More detailed field studies are carried out to narrow the target areas, and finally drilling or tunneling is undertaken to search for the deposit. This activity, when successful, develops *reserves* of the *inferred* class. Further detailed exploration improves the accuracy of the reserve estimate by better delineating the extent and shape of the deposit as well as its grade and mineralogy. This activity develops *indicated and measured reserves* which have the degree of certainty necessary for the investment by industry of large amounts of capital needed for exploitation of the deposit.

The mineral supply system consists of a series of sequential steps, each one necessary for the initiation of the succeeding step, and each one designed to improve the effectiveness and economic efficiency of the total system. The demand for minerals drives the resource flow. The overall economic efficiency of this system is set by the technologic level and is improved by research and development at all phases. That is to say, the estimated magnitude of undiscovered resources is increased by improved basic concepts of mineral deposits and mapping and resource assessment of potentially mineralized areas. Reserves are increased by prospecting, which is made more effective by improvement of prospecting, extraction and processing techniques. The increase in resources over time is directly related to the amount of effort put into improving the technology as well as to the amount of exploration effort. That is to say, we replenish, expand and diversify our "non-renewable" mineral resources by technologic advance through research and development effort.

The relationship between mineral resource supply and mineral science and technology can be shown by comparing the growth in value of U.S. annual production of principal raw material mineral commodities (fig. 14) with several indices of the growth of scientific and technologic effort in the minerals area. The first is the cumulative numbers of scientific articles on the geology of North America (fig. 15). The second is the growth of the yearly number of earth scientists in the U.S. (fig. 16). The strength of the geoscience educational system is shown by the growth of the number of degree granting, geoscience departments in the U.S. Universities (fig. 16). Finally, increasing sophistication of geoscience is indicated in part by the fields of specialization, which are in turn measured by the increasing number of National geoscience societies (fig. 17). If the cost to support a geoscientist in terms of salary, administrative and scientific support is taken at $50,000, a conservative figure, nearly 2 billion dollars would have been spent in 1975 to support this geoscience effort. Of course, not all of this geologic effort would be directed at the mineral supply system, but a major portion would be, either directly or indirectly. Also the geologic effort is by no means the whole of the effort going into resource studies as much effort is made by mineral and mining engineers.

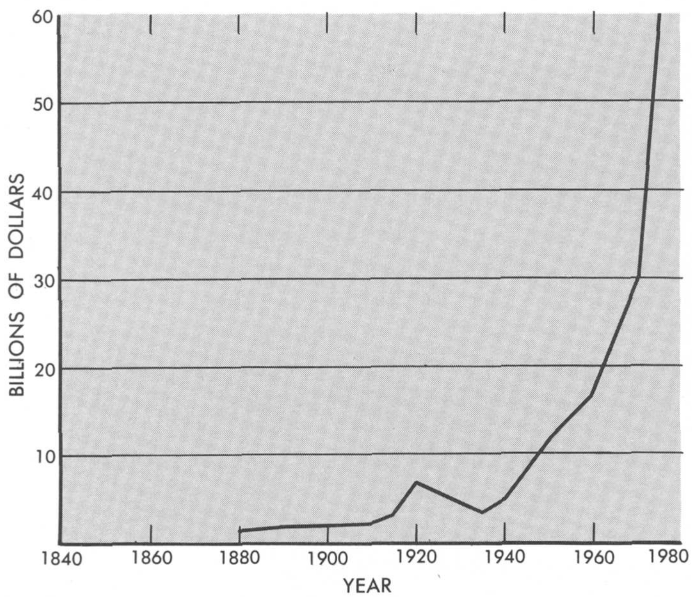


FIGURE 14.—Growth of U.S. annual production of principal raw material mineral commodities. (From U.S. Bureau of Mines, 1975.)

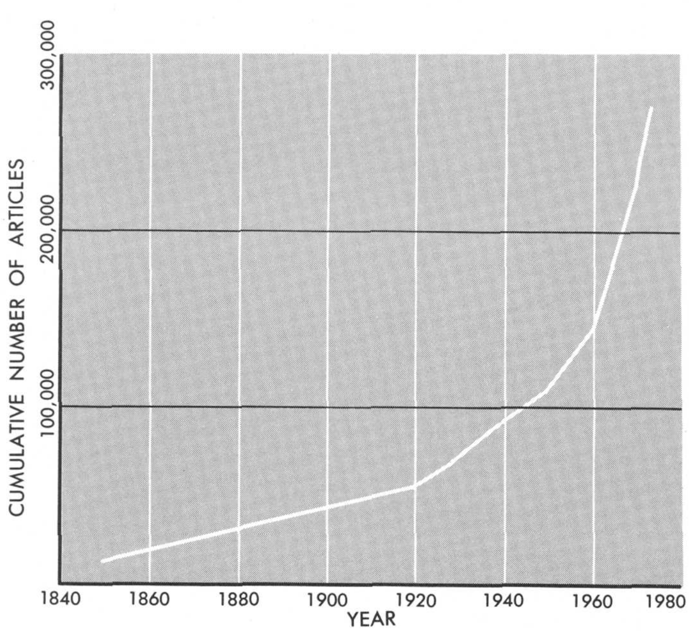


FIGURE 15.—Cumulative number of scientific articles on the geology of North America.

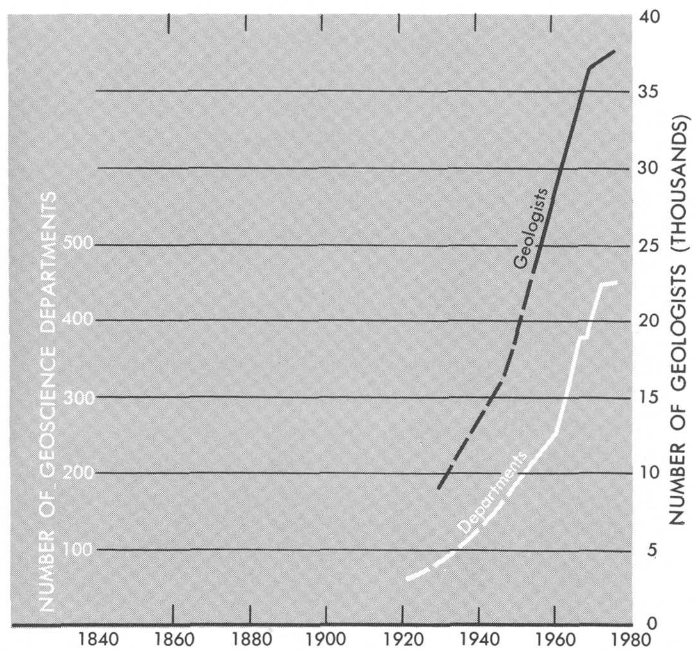


FIGURE 16.—Number of geologists and number of degree-granting geoscience departments.

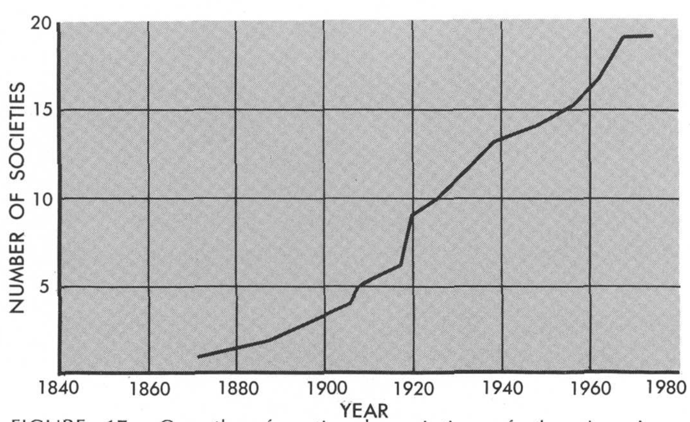


FIGURE 17.—Growth of national societies of the American Geological Institute.

Long-term Mineral Supply

Our mineral resources are replenished by scientific and technologic advance, but how long can this keep up? Even with replenishment, will we eventually outgrow our mineral resource base? Much thought has been given to this question and much diversity of opinion exists. Economic geologist, B. J. Skinner, in an article titled, "A second iron age ahead?" (1976) predicts that the day when "we will have to come to grips with the way in which the earth offers us its riches . . . is less than a century away, perhaps less than a half century. When it dawns we will have to learn to use iron and other abundant metals for all our needs." On the other side, resource economist, J. F. McDivitt (1974) believes that ". . . if the peoples of the world continue to work closely together and to move towards an ever more efficient pattern of resource use, . . . mineral shortages will continue to be only a faint cloud on the world's horizon."

The mineral supply system certainly will have to deal in the long term with serious constraints if it is to keep up with demand. First of all, demand itself has been growing exponentially and, of course, that sort of growth cannot continue. Brooks and Andrews (1974) have suggested that "relative demands (for minerals) decline after a point with increase in per capita income. Indeed . . . the relative growth is sufficiently damped that it was suggested in one study that mineral production will need to grow less fast in the future than it has grown in the recent past, exactly the opposite of most conclusions based on trend analysis." This is the same sort of hopeful sign that in recent years we have witnessed in some population growth in reaction to increased per capita income. Another constraint to the long-term mineral supply system is a threatened shortage of energy. Much of the technologic advance that replenishes mineral resources is energy intensive, so this could be a serious future constraint and in fact, the rise in energy costs in the last years has been severely felt in most parts of the mining industry. Another present major constraint that could increase even more is the accommodation of the mineral supply system to the regulatory controls and costs concerned with environmental pollution and degradation as well as to the public desire to withdraw from mineral entry all public lands judged better used as a wilderness or an ecologic reserve. Another possible constraint is what B. J. Skinner calls the "mineralogical barrier." Scarce metals in the earth's crust, such as copper, lead, nickel, tin, and tungsten, are mostly disseminated within the atomic structure of host minerals that make up common rock. In that way they are accessible to recovery only by chemically breaking down the host minerals, a feat which requires very large amounts of energy. Such scarce metals are now recovered from the geologically rare deposits in which they occur as a principal component. Geologist Skinner believes that such deposits will soon be depleted. Economists Brooks and Andrews argue against this concept by holding that "every bit of evidence we have indicates the existence of mineral resources (at lower grades) that could be mined and, further, that either as their price goes up or as their cost goes down (which is to say, as technology of extraction improves), the volume of mineable material increases significantly—not by a factor of 5 or 10 but by a factor of 100 or 1,000." The arguments on this critical issue could be better focused by additional scientific information on the amounts of mineralized rock available at different grades, because existing data are too limited for definite conclusions. Thus, it is not certain that the geologic availability of lower grade resources to the mineral resource supply system is assured so a potential barrier to the resource system remains.

Whether the mineral resource supply system can overcome these restraints in the long run depends ultimately on the magnitude of those mineral resources that we cannot now assess. They are the resources that we are unable to conceive or for which we are unable to foresee the discovery or recovery techniques. There is no question that the resources we know about are a fixed stock and eventually will run out. But, can they be replaced?

Another way of posing this problem is to ask the question whether or not an equilibrium of mineral use can be established that will last indefinitely or nearly so. If the real world of supply and demand is likened to a model where mineral resources are fixed and demand is dynamic and expanding, minerals will run out. But this model is not like the real world where supply and demand are dynamically interrelated and mineral shortages set off a whole set of changes including higher prices, reduced demand, increased conservation, increased substitution, increased recyclying, increased technologic and scientific research, increased exploration and increased exploitation of lower grades ores. In the real world, mineral use has evolved to overcome such shortages as firewood from depleted forests, or copper from mined out high grade veins, and such evolution will continue to operate as new shortages arise. This is not to say that such minerals as petroleum in conventional fields, and presently economic deposits of mercury, helium, platinum, and other such geologic rarities will not be exhausted eventually. But our technology likely will evolve to accommodate to a lesser or more expensive supply of such minerals, much as it has developed without abundant supplies of the metals praeseodymium, neodymium, promethium, gadolinium, terbium, and the other rare earths, which were they abundant, probably would be used widely.

Mineral economist John E. Tilton in his excellent book, *The Future of Nonfuel Minerals*, concluded:

> In the more distant future—the twenty-first century and beyond—depletion could become a more pressing problem. It is important to stress this possibility, for the consequences to industrial societies could be most severe. At the same time, it should be noted that the arsenal available to mankind for dealing with this threat is not empty. As pointed out above, public policies that support research in minerals and reduce their consumption increase the likelihood that technological progress will continue to offset the adverse effects of depletion. Other policies, such as programs to encourage smaller families, to slow the growth of population, may be desirable for other reasons as well. Finally, even in the absence of such policies, one cannot be certain that depletion will ultimately overwhelm the cost-reducing impact of new technology. For as depletion starts to push mineral prices up, it unleashes forces that stimulate the substitution of cheaper and more abundant materials for the increasingly scarce minerals, encourages the search for new and unconventional sources of supplies, and promotes the development of more cost-reducing technologies. Conceivably, these forces could by themselves keep the specter of depletion at bay indefinitely.

It seems clear that our long-term mineral supply system is much stronger than believed by the analysts who regard mineral resources as a fixed and essentially known and fully conceived stock. At the same time, we have the responsibility of keeping the system healthy, and some steps should be taken to do so. The workings of the mineral resource system in its full complexity needs examination to better understand the factors that affect it. A statistical monitoring series that would give early warning of a weakening in the resource replenishment process in any part of the system should be devised and set up. Finally, adequate research and development should be carried out in order to strengthen weak parts of the mineral supply system. △

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Games Coastal Area Planners Play

OR HOW SIMULATION HELPS PREDICT IMPACTS OF OCS DEVELOPMENT

By J. Ronald Jones, William W. Doyel, and Philip A. Marcus

SAVANNAH.—Why would sixty men and women converge on a metropolitan hotel, pay handsomely for accommodations and most meals just to play games? If the name of the game is "see how they run" onshore to locate support facilities for offshore oil, then gaming or simulation may provide planners and citizens alike with new understandings of the pressures, benefits and costs stemming from the presence of oil development in their communities.

—*The Beaufort Gazette,* Monday, July 25, 1977

A NEW ACTIVITY FOR THE SURVEY?

The newspaper article quoted above is typical of the interest aroused by the experiential workshops being conducted by the Geological Survey with the help of the American Society of Planning Officials. The Savannah workshop was one of a series helping to prepare State and local land-use planners and decision makers for the onshore impacts that may occur as the result of OCS oil and gas development. Why should the Survey's Resource and Land Investigations Program (RALI) even take on this responsibility? And why should unconventional technical assistance techniques such as "gaming" be employed?

First, these exercises are sponsored and managed by the Resource and Land Investigations Program, as the Survey's organization chartered by the Department of the Interior to conduct studies and projects of Department-wide scope and interest. Many of Interior's programs affect, impact, or even impinge upon the total environment of the Nation's coastal zone. An obvious example is the Outer Continental Shelf oil and gas leasing and lease-management program operated jointly by the Bureau of Land Management and the Geological Survey. Perhaps less obvious are the custodianship/land management programs of the National Park Service, of the Fish and Wildlife Service, and of the Bureau of Outdoor Recreation; as well as the scientific information gathering and interpretation activities of the Survey, the Fish and Wildlife Service, and others. The Department, in supporting this workshop series is, in effect, saying . . . while we must proceed in the development of our OCS energy resources to meet critical domestic supply shortages, we also have an obligation (as well as the expertise and the data) to aid the coastal communities, who may be heavily impacted by this OCS development, to plan for and thus mitigate adverse impacts to their communities. Further, the implementation of any component of a National Energy Plan depends, to a great extent, on the support and cooperation of the State and local levels of government.

Second, why "gaming"? Because a heterogeneous group of State and local planners and decisionmakers—with widely varying expertise in planning generally, and in impact assessment methodologies specifically—have to be exposed to a set of highly technical and complex ideas, methods, and data. There are only 2-½ to 3 days for each workshop, and the aim is to send the participants home with new skills and knowledge that will help them do their jobs better. It was and is believed that an information transfer process involving gaming and simulation exercises could and would be most effective (and most enjoyable) if it required, as it does, the active involvement of all participants.

THE RESPONSE OF THE PARTICIPANTS

And gaming does involve the participants. Over and over it was interesting to observe the shocked—even crestfallen—faces of senior planners, department heads, and elected officials when, at each workshop's outset, they were issued pocket calculators—a sure sign of workshop exercises to come! During all six workshops a consistent behavior pattern was observed of participants: (1) shock at being committed to a "working" workshop; (2) anxiety about being able to cope with the computational exercises; (3) anger about the workload and late evening sessions; (4) intensity during the game exercise itself; (5) camaraderie and group cohesiveness resulting from an intense, common experience; and (6) relief and self-satisfaction in having learned valuable facts and procedures useful in their coastal area planning and decisionmaking jobs.

What were we trying to do in so short a time to these unsuspecting planners and decisionmakers? We were trying in each workshop to impart a basic understanding of offshore activities and onshore facilities, their potential impacts; and how to evaluate, set policies, and plan for their development. So we had the participants work their way through a four-part curriculum: (1) a lecture series; (2) small-group computational exercises; (3) a gaming/simulation exercise; and (4) panel and group discussion.

The Lecture Series

The lecture series was intensive, but included periodic interruptions for computational exercises. Participants were exposed to materials related to the following planning and decisionmaking issues:

1. The nature, magnitude, and timing of offshore activities such as exploration, development, and production, which require onshore supporting facilities which, in turn, generate impacts.
2. The types, numbers, timing, and characteristics of onshore facilities such as service bases, platform fabrication yards, pipe-coating yards, and refineries, among others, which may be associated with offshore development.
3. The environmental and socioeconomic effects of various facilities on communities.
4. The planning and decisionmaking methodologies available to State and local officials for setting realistic planning priorities and for identifying work programs to deal with development.

In preparing the lecture series materials, we designed the materials to meet the differing backgrounds of the participants. We therefore presented tightly edited, technically competent material, using understandable and eye-catching graphics to supplement the oral presentations. We found that the more knowledgeable participants quickly assumed roles of "adjunct faculty." We now believe that those who had difficulty with the materials are at least aware of what it is they didn't know.

The Computational Exercises

The small-group computational exercises provided a needed respite from lectures, and afforded the opportunity for participants to work together and thus begin to build the group trust and cohesiveness necessary for the successful operation of the gaming/simulation exercise to follow. Participant groups utilized a step-by-step procedure permitting them to create:

1. Offshore oil and gas development scenarios, involving the number of production platforms needed to develop an oil and gas find, the development of a platform installation schedule, and the calculation of both development drilling and production schedules.
2. Onshore impact scenarios, including projections of added employment and population (for various facilities and types of communities); governmental and school operating costs and revenues; capital costs and revenues; environmental, economic development, demographic, and social impacts; and infrastructure requirements (for example, the need for secondary public services).

Workbooks provided both the computational algorithms and the assumptions behind them. Participants were shown how the assumptions were derived and were encouraged to challenge them, dissemble the algorithms, "plug in" their own assumptions, and generate their own numbers.

The Gaming/Simulation Exercises

The gaming exercise provided an immediate opportunity for the participants to apply the information, knowledge, and techniques from the previous sessions in a realistic but simulated setting that compressed 3 years of events into a 3-hour exercise. The overall object of the game was to lead the participants to decide, on the basis of the best available information and methods, whether and where to site various OCS-related facilities, such as service bases, platform fabrication yards, and refineries. The physical setting was a hypothetical coastal region, comprised of three States and their assorted communities. The participants were assigned roles (seventy in all) ranging from fisherman to governor, from environmentalist to industrialist, from city council member to TV news commentator—and were given time to study their role descriptions along with descriptions of the physical, economic, and political settings for each State and community. Then they were turned loose to interact.

The game was "driven" by the interjection of new facts at about 15-minute intervals via news "releases." New facts ranged from OCS leasing schedule changes to oil and gas find announcements to changes in the political situation in the Middle-East. Workshop faculty members circulated throughout the room especially laid out for the gaming exercise, refereed disputes, and functioned essentially as the judiciary system. No other constraints were explicitly imposed on the participants.

What invariably occurred next was a scene reminiscent of the floor of the New York Stock Exchange on a heavy trading day. Energy levels and intensity were high for all participants, and time passed quickly. The game demanded frequent reference to the information base and to the planning materials about onshore OCS-related facilities requirements and impacts introduced at earlier sessions. Participants were being taught the value of information, and that one never has enough information in the form that one

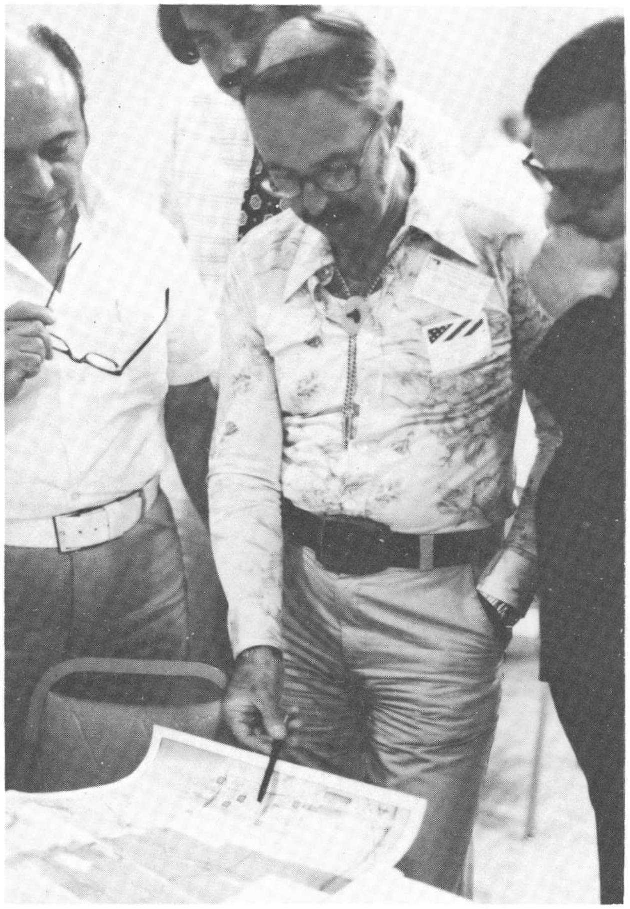
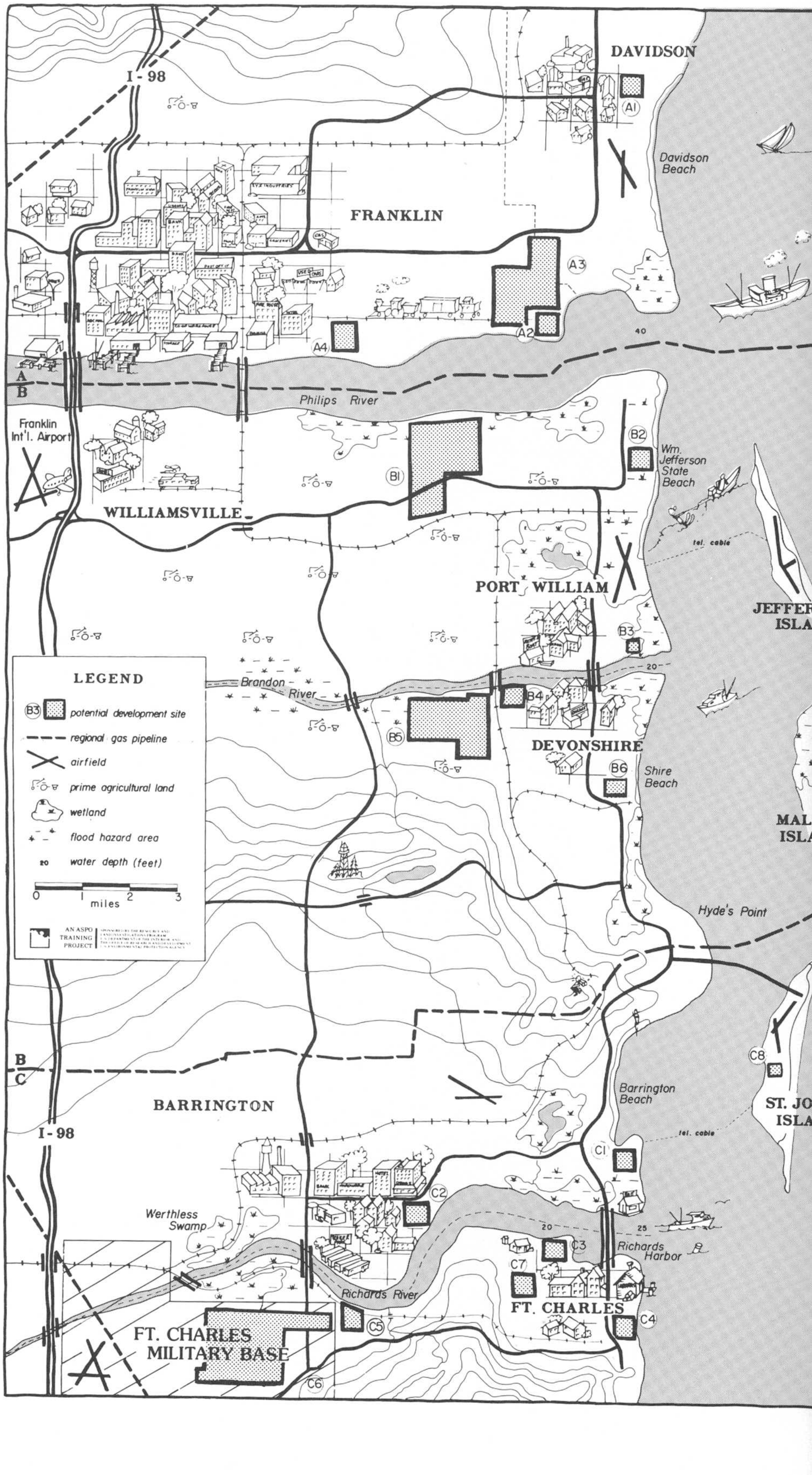


FIGURE 18.—State and local coastal-zone management officials participate in realistic and lively simulation game on the onshore impacts of OCS development, under the direction of American Society of Planning Officials and RALI Program faculty.



prefers when one needs it. This process of making do with partial information is the essence of decisionmaking—as distinguished from the academic idealized planning exercises presented in earlier sessions.

Without prompting, participants assumed their roles, and compromises between disparate groups began to emerge. For example, an announcement of the closing of a military base in an area already suffering high unemployment provoked a temporary coalition between conservationists and elected officials. In another case, a new industry offered to construct a community health services clinic in exchange for local acquiescence to the siting of a pipe-coating yard that would emit considerable noise pollution. In yet another case, property exchanges were negotiated to protect the integrity of a wildlife preserve. And so it went, until time was called and the exercise was critiqued.

The gaming exercise exposed participants to the pressures, uncertainties and conflicts involved in the OCS-related facility siting process. The critique then provided an opportunity to decide as a group whether the objectives of the game had been met, to sort out some of the major events and determine why they had happened, to think about how they would do it "next time," and to evaluate the overall value of the gaming exercise itself.

PRODUCTS AND BENEFITS FOR COASTAL STATES

Judging from participant response thus far, the workshops disseminate needed information efficiently, and in a manner that will likely affect future planning and decisionmaking in coastal communities anticipating OCS-related impacts. But this is not accidental success. Research and the development of materials began 2 years before the first session and several organizations collaborated in the effort:

The Panel and Group Discussion

For each workshop a panel of individuals who had experienced a particular aspect of industrial impact relevant to the workshop participant was assembled. Panelists were from the region in which the workshops were held and covered such subjects as planning for installation of an offshore drilling platform construction yard in Northhampton County, Virginia, to development of a marine terminal/storage/pipeline complex in Clallam County, Washington.

The participants were then split into three groups to discuss specific problems relating to local reactions and methods used as mitigating and control techniques. One group discussed industrial development; the second, land-use controls; and the third, policy formulation and implementation.

A commonality of problems was apparent in all the discussions, as was the fact that many of the traditional approaches to coping with impacts of industrial development are not as useful in reducing adverse socioeconomic impacts as are some of the more innovative techniques, such as negotiation with industry and contract zoning.

The New England River Basins Commission (NERBC) prepared: (1) the most extensive set of facts ever assembled describing the kinds of onshore facilities likely to be constructed to support OCS oil and gas development operations (NERBC, 1976A); (2) three scenarios for the development of the North Atlantic (Georges Bank) oil and gas resources, along with a procedure for developing such scenarios in other coastal areas (NERBC, 1976B); (3) a planning methodology, incorporating the facts and scenarios described above, designed to aid planners in identifying alternative sites and impacts of various OCS-related facilities (NERBC, 1977A); and (4) various materials and graphics designed to support a nationwide series of workshops.

The American Society of Planning Officials (ASPO) prepared: (1) a source book which describes the state-of-the-art in industrial facility siting methodologies (ASPO, 1977A); (2) an extensive annotated bibliography to the literature, to on-going research, and sources of expertise (ASPO, 1977B); and (3) a set of issue papers which describe the controversies, history, and parties involved in OCS-related activities (ASPO, 1977C).

In addition, ASPO, with the aid of consultants and the RALI Program staff, designed the workshop, the gaming exercise, and the multimedia package of materials given to each participant. Further, by means of direct communication with each coastal State Governor's office, along with the use of APSO's extensive membership list of practicing planners and elected planning officials, we were assured that the participants were, in fact, the people who would actually be called upon to make facility siting decisions as the OCS resources are developed.

The U.S. Environmental Protection Agency, Office of Research and Development, provided funding for ASPO involvement, and participated actively in workshop sessions involving the assessment of environmental impacts.

The Office of Coastal Zone Management of the National Oceanic and Atmospheric Administration, the Bureau of Land Management, and the Conservation Division of the Survey contributed technical assistance and presented valuable materials to the workshop participants.

Finally, the Survey's RALI Program conceived the entire project, funded the NERBC activity, participated in the development of all NERBC and ASPO materials, led individual workshop sessions, and managed and coordinated each project element.

The above listing of sponsors and contributors show the wide range of talents, interests, and resources needed to provide technical assistance such as this to the land-use planning community. Planning is a broad, multifaceted discipline. Planning assistance requires an equally broad basis, perspective, and participation.

The Workshop Schedule

From June through October 1977 six regional workshops were held: Newport, Rhode Island; Ocean City, Maryland; Savannah, Georgia; Otter Crest, Oregon; Biloxi, Mississippi; and Anchorage, Alaska. Each workship used the same basic materials, but was customized to the needs of the region by the selection of pertinent examples and the use of local experts to augment the permanent faculty. Not surprisingly, each gaming exercise produced different siting results. The exercise was not intended to produce a "best" result, but merely to give coastal State officials the opportunity to engage in a hypothetical exercise using best-available information and methods.

A second series of workshops is scheduled for mid-to-late 1978—same locations, and, hopefully, same paticipants. The objectives of the next series are: (1) to acquaint participants with the results of planning assistance studies currently underway; (2) to investigate more exhaustively both existing and developing methods for calculating secondary and tertiary impacts; (3) to give participants a better understanding of the economics of information as it relates to improving their decisionmaking ability; and (4) to conduct a new series of gaming exercises involving small groups—8 to 10 people, real data, and current issues.

CONCLUSIONS

The history of the development of frontier OCS oil and gas areas off the Gulf and Southern California coasts indicates that public resistance to such development is at least partly due to fear of the unknown and to a lack of confidence in studies that purport to assess potential, coastal impacts. This workshop series attempts to present objective facts, to the extent they are knowable, and thus move the debates that will inevitably occur about such development away from issues of data credibility and toward the more profound issues of values and philosophies.

Results of the workshops thus far indicate that coastal area officials are eager and willing to distinguish the objective and subjective elements of the issues, and want to become familiar with the important part that scientific information should play in determining and thus planning for coastal area impacts. Participant evaluations of the workshops indicate that they believe this kind of hypothetical experience to be valuable indeed.

As the Geological Survey and the rest of the Department of the Interior proceed in their roles in the development of oil and gas on the Outer Continental Shelf, coastal communities must continue to find ways to cope with the development that will inevitably occur. Experiences, particularly of various Gulf Coast communities already impacted by OCS development, indicate that the communities that plan ahead experience fewer adverse and more positive impacts. The workshop series described above provides coastal officials with the means to accomplish this planning and is thus supportive of Federal energy policy. △

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Submarine Landslides

By Dwight A. Sangrey and Louis E. Garrison

He had brought a large map representing the sea,
Without the least vestige of land;
And the crew were much pleased when they found it to be
A map they could all understand.

Lewis Carroll

INTRODUCTION

The maps of many sea regions have undergone striking changes in recent years as new tools are provided to brush aside the waters electronically and permit scientists to peer closely at the sea floor itself. Former areas of blank blue paper "without the least vestige of land" have come to show an amazing variety of forms—mountains, plateaus, mesas, troughs, trenches, and canyons—that have been mapped until the major ocean-bottom features are as well known as the major features on land. But nowhere has the sea floor been subjected to such microscopic scrutiny and its shape and consistency so carefully analyzed as in the areas of petroleum production where giant oil platforms and their spider web of pipelines stand at the mercy of the ocean environment. Here, where a small oversight may be very costly, an enormous amount of effort is expended in trying to understand the subtle environmental clues which ultimately may spell the difference between safety and danger, or success and failure of the platforms.

Much has been learned from these experiences. Areas of the sea floor once thought to be essentially immobile are now known to undergo changes at rates that are sometimes startling. In extreme cases, maps of the seafloor may require annual updating to retain their usefulness, and some areas must be resurveyed after each major storm or earthquake.

A wide variety of geological processes are responsible for these dynamic qualities, but none is more spectacular, or bears more potential for damaging offshore platforms than the submarine landslide. In the inventory of sea floor instabilities, it is one of the most difficult to predict, yet its results can be the most disastrous.

In 1969 when Hurricane Camille ripped northward through the Gulf of Mexico, three major oil platforms standing on the Mississippi Delta were victims of her fury. Post-storm investigations revealed, however, that they were not bowled over by the force of Camille's 322-kilometer (200-mile) per hour winds, nor even by the pounding of her more than 15-meter (50-foot) high waves. Rather, it is believed that they were damaged and lost because their foundations were shifted by landsliding triggered by the storm.

There had been earlier records of landslide damage, but these were largely confined to pipelines and telephone cables supported on the sea floor. The classic example was the Grand Banks slump in 1929, when an earthquake-induced sea floor failure caused damage to telephone cables over a distance of several hundred kilometers (fig. 19).

During the "Good Friday Earthquake" which struck the Prince William Sound area of Alaska in 1964, a large portion of the waterfront (more than 98-million cubic yards) at the town of Valdez disappeared into the sea. With it went the docks and warehousing facilities carrying some 30 people to their deaths. Later, investigations shown that a massive submarine landslide had occurred, triggered by the earthquake shaking of soft deltaic sediments. At least 100-million cubic meters (3,531-million cubic feet) of sediments, including the Valdez waterfront, had almost instantaneously moved seaward in this gigantic submarine landslide.

Accompanying many of these submarine landslides are the dangerous tsunamis, or immense ocean waves which spread outward from the slide area and travel at high speeds for great distances. These waves strike land areas with disastrous results. Many cases can be cited, but perhaps the worst on record in human lives lost occurred in the Lisbon earthquake of November 1, 1775, when tsunami waves washed the west coasts of Portugal, Spain, and Morocco and left some 60,000 dead in Lisbon alone.

All landslide phenomena are not so catastrophic, nor are all associated with storms and earthquakes. In quieter modes, small areas of sea floor muds have been observed to move without any obvious force functions other than gravity.

For example, in 1974 a jack-up drilling rig in the Gulf of Mexico suddenly and without warning moved several hundred meters seaward of its original location, shearing conducter pipes and drill string. The drilling rig, sitting on unstable sediments, was caught up in a submarine landslide but was fortunate enough to ride out the slide without overturning. Another

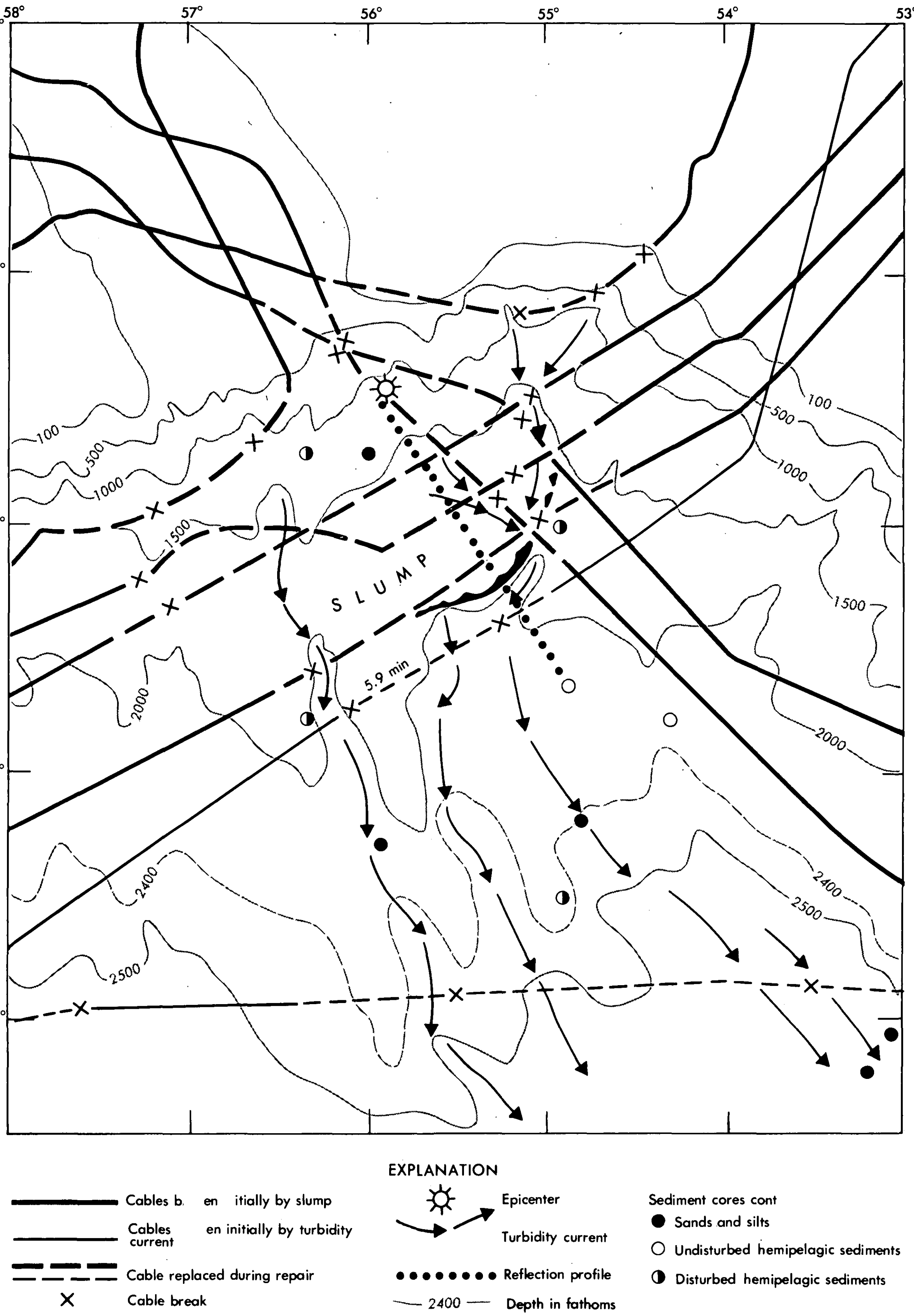


FIGURE 19.—Map showing the Grand Banks slump in 1929. Earthquake-induced submarine landsliding caused cable breaks as noted. (From Heezan and Drake, Bull. AAPG, v48n2p111, 1964).

drilling rig disappeared during Hurricane Camille in 1969, and was later found to be completely buried in slide debris under the sea floor.

Similarly, in certain areas of the Mississippi Delta, repeated pipeline breaks and well-jacket displacements have cost their owners hundreds of thousands of dollars annually in repairs and lost production time. Although the cause was not understood at the time these structures were emplaced; it is now known that the area is honeycombed with small slides that are either in almost constant motion or periodically activate themselves in a burst of movement. Pipelines laid across these features are sheared, and nearby well jackets sometimes bent grotesquely out of alignment when stress accumulation is sufficient.

Submarine slides are an important natural process whereby great masses of sediment move from shallower to deeper locations on the ocean floors. Because of the increasing use of shallow sea floor areas for construction of oil production facilities, it is important to understand the mechanisms of these slides, the factors which create a slide, and the warning signs that point out the danger. In some cases, construction must be done in slide areas, and structures must be designed to withstand their forces. Intensive studies, therefore, must be initiated in order to predict these forces and their effect on the structures.

Offshore landsliding presents a broad range of important implications. The conventional arguments concerning risk of economic loss or loss of life are accentuated by our experiences with such loss and the fact that a single offshore structure (fig. 20) may cost more than $100 million and support a work force of 50 or more people. Another important element is the great risk of environmental damage in failures. Although no landslide-related accident to date has produced environmental damage, the potential exists and, therefore, we must make every effort to minimize the risk.

FIGURE 20.—The offshore production platform must support drilling equipment, a complex of processing machinery and safe living space for large work crews. We must limit the vulnerability of these structures to landslides.

NATURE OF SUBMARINE LANDSLIDES

What is submarine landsliding, and how does it differ from what we see on land?

There is obviously a wide variety of types and causes of sea floor instability and the term "landsliding" is applied very broadly to describe many of these phenomena. Different sea floor materials, different environments, and different forms of loading all influence the kinds of landsliding which can occur. The wide variety of landslide forms is a direct consequence of the infinite mix of these factors. Studies of landsliding must concentrate on understanding the role of each factor individually and in combination. The form and distribution of submarine landslides are the consequence of interaction among many factors.

One of the major difficulties with studies of underwater landsliding is that we cannot "see" the form of the slide in the way that we can on land. This is one of the reasons why the scope and significance of offshort landsliding are just now beginning to be appreciated. As new technology and methods are applied, however, a variety of forms and sizes have been revealed, and distributional patterns are taking shape. While no formal classification system has yet been proposed for underwater landslides, several general types can be described. The particular types are inevitable consequences of combinations of materials, environment, and loading.

To understand landsliding, submarine or terrestrial, it is necessary to describe the features in quantitative terms. In its most simplified form, quantification of a landslide, such as illustrated in figure 21, involves the mechanical balancing of driving forces tending to produce failure or movement against the forces resisting movement. Although it may be triggered by earthquake shaking or by storm waves, gravity acting on the soil mass is the major force which drives a landslide. The shearing resistance or strength acting along the failure surface provides the resistance to movement. As long as resisting forces are greater, the slope remains stable, but when the combination of triggering function and gravity become greater than resistance, failure results and a slide occurs.

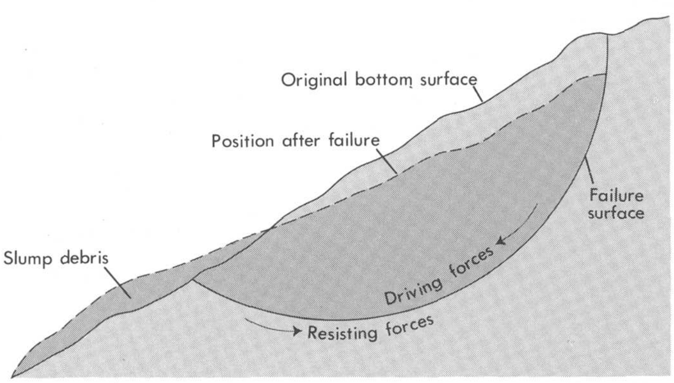


FIGURE 21.—When driving forces are greater than resisting forces, landslides such as this block slump occur. Simplified illustration of force balancing used in quantitative analysis of landsliding.

Block slumps are a common and simple form of submarine landsliding. A downslope cross-section through a block slump would show a relatively undisturbed mass which had rotated or slid with respect to its initial position. Any dislocation of sediment layers within the feature is usually a good indicator of the type and magnitude of movement. On land, a cross-sectional profile can be developed from extensive borings or trenches cut through a landslide. Offshore the seismic profile is used to produce much the same information from which important features of a slide can be defined. For a different perspective, the plan view of the sea-bottom surface can be obtained using side-scan sonar. As illustrated for the block slump (fig. 22), this instrument gives a much clearer view of the size and extent of landslide features.

Research on slope stability concentrates on the various driving and resisting forces acting on a slope. A powerful and frequently-used approach is the analysis of existing failures where slide geometry is known and samples can be obtained for determination of strength and other properties. Block slumping is particularly adaptive to this approach because of the relatively simple form and minimum disturbance of the slide material (figs. 21 & 22).

Block slumping can occur in most continental shelf areas where slope gradients are sufficient and in a wide variety of materials. It is often the initial failure in what becomes a more complex form, such as a flow slide or mudflow. Although movement may occur suddenly, block slumps often move more slowly than other types of landslides. Nevertheless, the damage potential is high because the relative displacement across a failure surface will shear off almost any man-made structure. Structures riding on moving slump blocks are also damaged, and their use impaired, when they rise up or sink with respect to the sea surface.

Flow slides, in contrast to block slumps, are characterized by a disrupted or chaotic accumulation of landslide debris which has flowed downslope from a source area (fig. 23). This type of sliding can be associated with a variety of earth materials, but submarine flow slides usually occur in relatively weak sediments. Flow slides are often associated with a catastrophic loading event, such as an earthquake, and some offshore flow slides cover tens of square kilometers. These factors, coupled with rapid rates of movement,

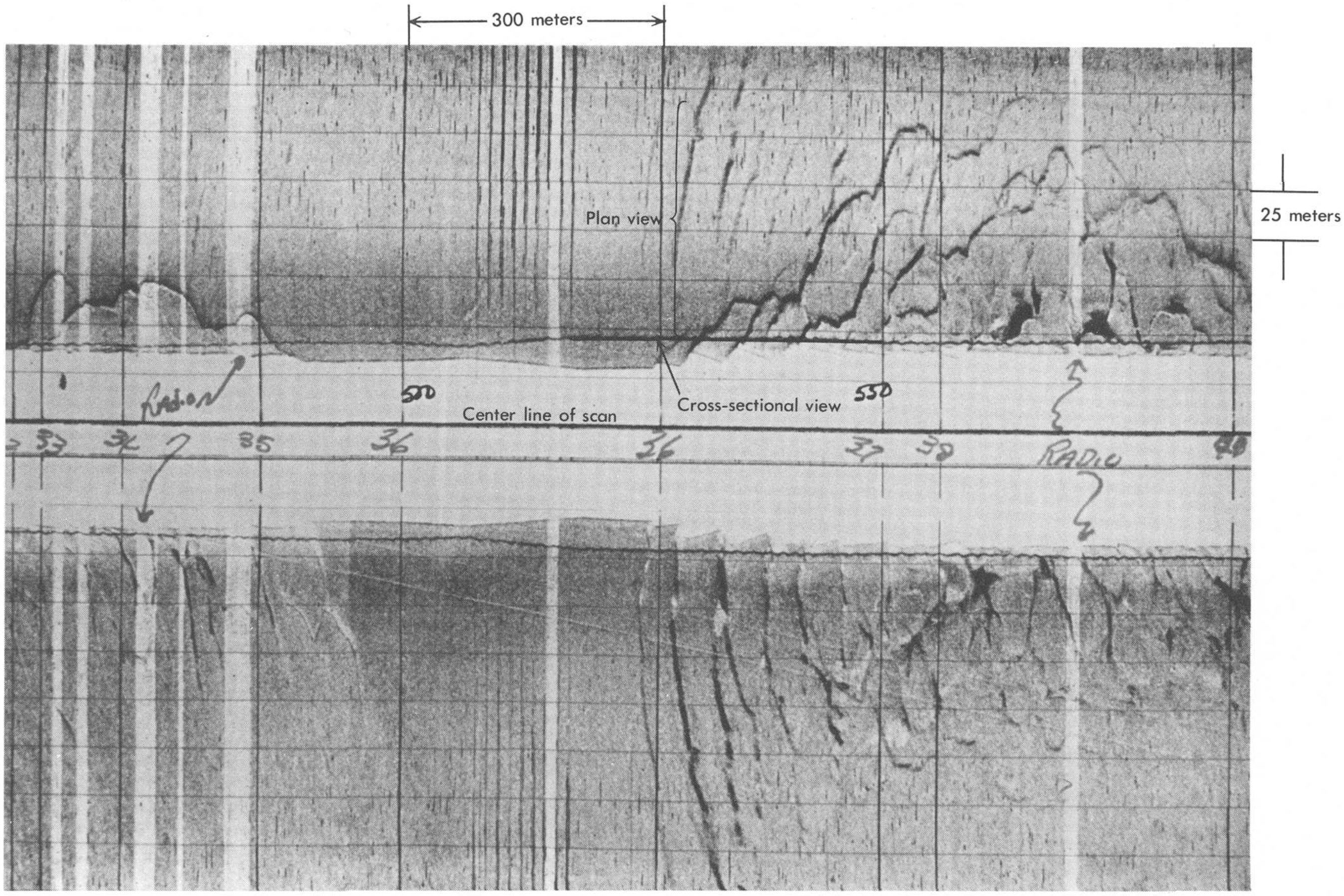


FIGURE 22.—Data from the side-scan sonar is as close as we can come to a look at landslides on the surface of the sea bottom. In this example the characteristics of block slumping are shown.

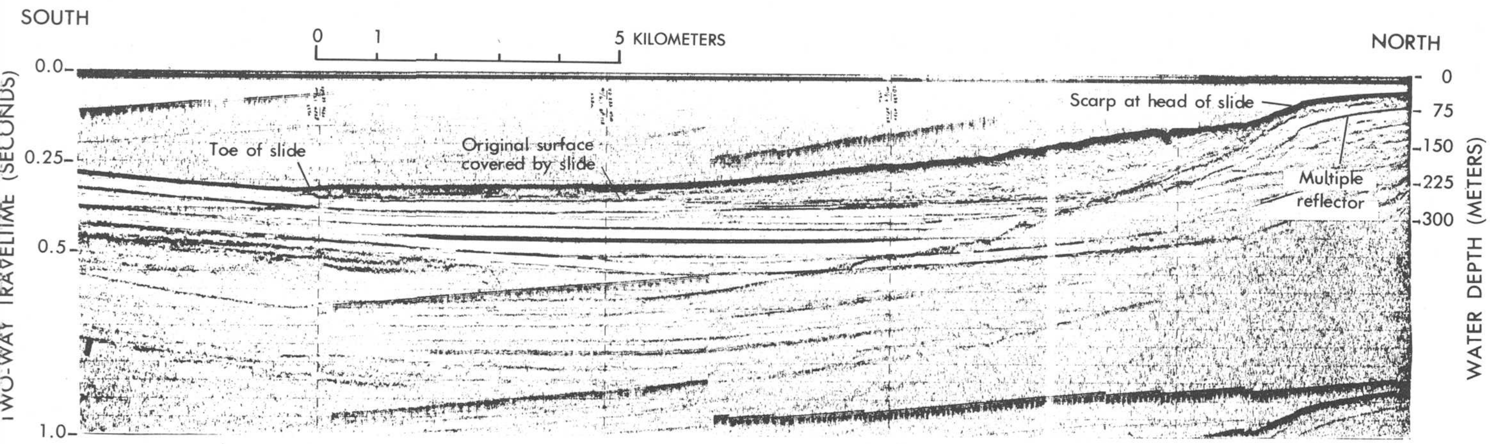


FIGURE 23.—Seismic profile of a flow slide showing its highly disrupted internal structure and the widespread flow of debris associated with this very destructive form of offshore landsliding.

place the flow slides among the most destructive types of offshore bottom-stability problems (fig. 24). The deaths and damage at Valdez during the Alaska earthquake are typical of the violent and unexpected nature of submarine flow slides.

The flow slide is very complex. Original bedding and other sedimentary structure are destroyed by the flow, the slide material is often not available for sampling and testing, and analysis is much more difficult because of this disturbance and the rate at which failure occurs. Because of their wide distribution and extremely high potential to do damage, however, the understanding of flow slides is a high-priority research area.

Mudflows are landslide features best developed in the submarine environment. They are commonly

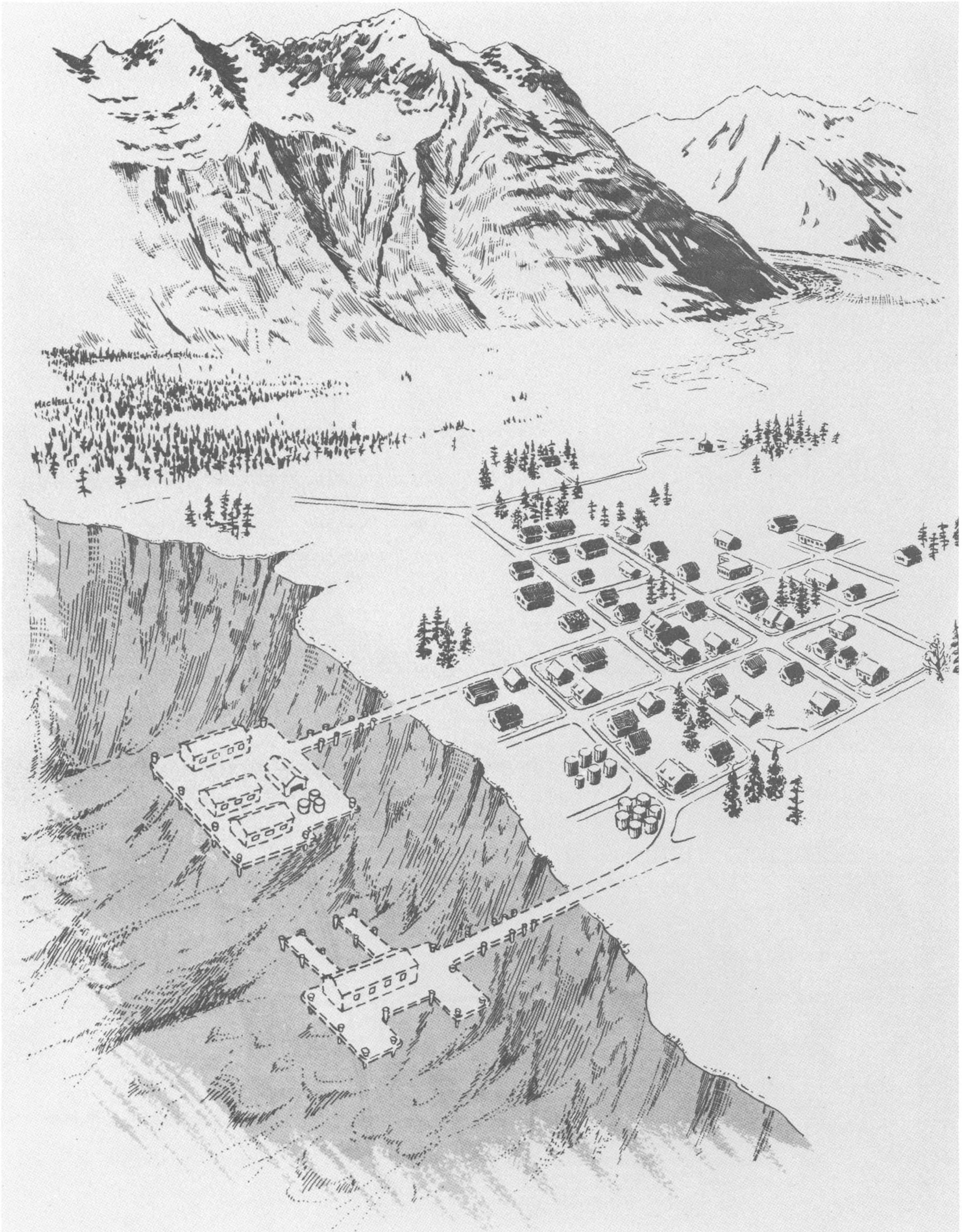


FIGURE 24.—Waterfront area engulfed in submarine flow slide at Valdez during the Alaska earthquake in 1964. (Sketch by David Laneville; from H. W. Coulter and George Migliaccio, U.S. Geol. Survey, Prof. Paper 542–A, 1969).

found in areas of rapid deposition, as around river mouths (fig. 25) where fine grained muds form thick masses of extremely soft and unstable material. The form of a mudflow may be quite complex (fig. 26) and, to date, their mechanics are poorly understood.

The Mississippi River Delta area is an ideal environment for the development of mudflows, and nowhere have they been studied more intensively. Much of this basic research has been done or supported by the Geological Survey, and we can attribute much of

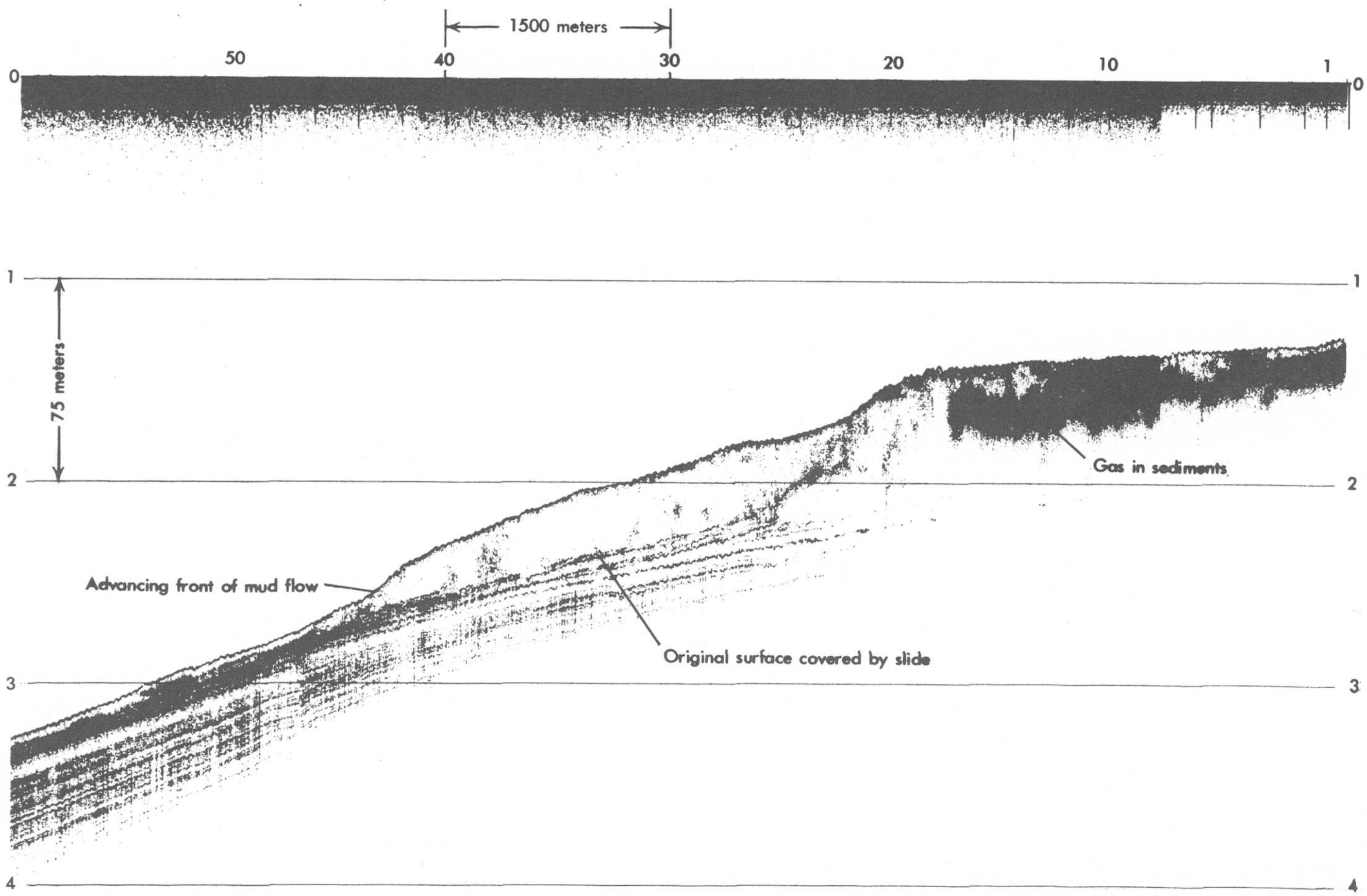


FIGURE 25.—Seismic profile of a typical Mississippi River Delta mudflow. The rates at which these masses slide down the slope remains an important unanswered question.

our present understanding of mudflows to this work. The extensive production of petroleum from the Gulf of Mexico has resulted in a need for better understanding of mudflows and the implications for building safe and reliable facilities. Most of the damage to structures and pipelines in the Mississippi Delta area is now attributed to this type of bottom instability. In an effort to provide better information about these problems, the Geological Survey has produced maps describing the hazards, surficial geology, and other features of the area (fig. 27).

Although the movements of great submarine landslides in today's oceans receive much attention, geological evidence shows that mass sediment failure was even more prevalent at various times in the Earth's past. When the great glaciers attained their last maximum advance about 25,000 to 30,000 years ago, the storage of vast quantities of ice on the continents removed enough water from the world's oceans to lower sea level by an estimated 100–150 meters. Great expanses of our present continental shelves were then land areas, and coastlines lay in regions of modern outer shelves. Rivers dumped their sediment loads on more steeply sloping sea floors and, as these deposits grew in thickness, submarine landslides were frequent.

Recent studies of shelf edge deposits in the Gulf of Mexico show many such fossil slides, now buried beneath thin veneers of later sediments (fig. 28). The present degree of stability of these slide deposits is not known, nor are sufficient data now available to indicate what forces would be required to set them in motion again.

APPLYING NEW TECHNOLOGIES

As man strikes out into new frontiers, he frequently finds that familiar tools and technologies are no longer adequate to meet the new challenges. Offshore geological studies are no exception.

Since early 1973 the Geological Survey has investigated the problem of submarine landslides and other manifestations of sea floor instability. The Mississippi Delta Project, conducted in cooperation with university scientists, industry groups, and other governmental agencies, has taken part in the development of many new tools and technologies.

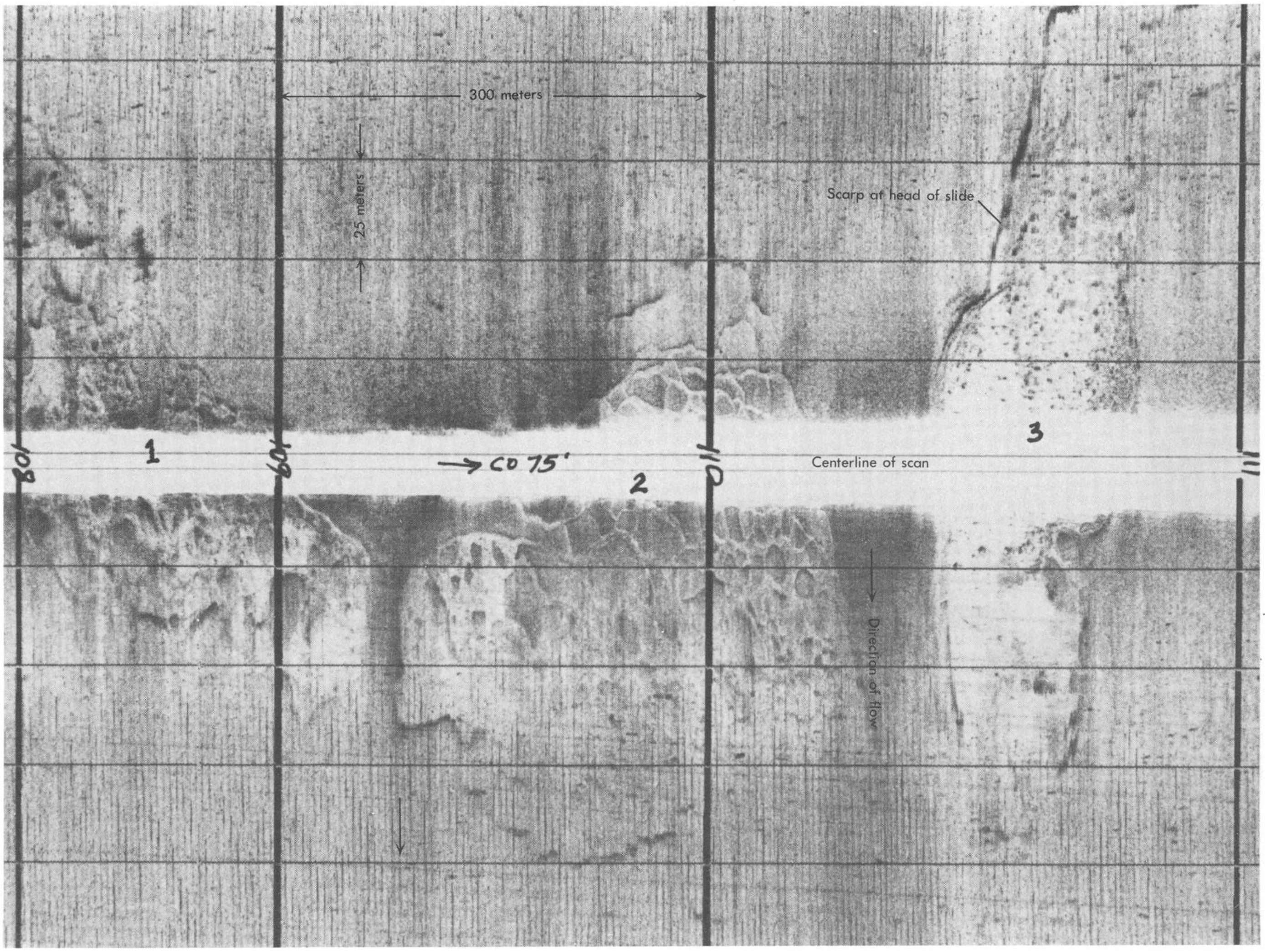


FIGURE 26.—Side-scan sonar records show that the submarine mudflows come in a variety of shapes and sizes. All of them are potentially destructive to facilities built offshore.

Among the new factors being considered and applied to the problems of submarine bottom stability is the role of pore-fluid pressures. Pore pressures are the hydrostatic fluid pressures acting within the void space of porous materials such as soil and rock. It has long been appreciated in geotechnical engineering onshore that the only rational way to evaluate the strength of soil and rock materials is to consider the pore pressure acting within them. Application of this principle offshore has been limited in the past because of the time and expense required to measure pore pressures. During the past 2 years, however, significant strides have been made in the development and testing of pore-pressure measuring systems for use offshore. As part of the Delta Project's SEASWAB experiment in the Gulf of Mexico, the first comprehensive set of pore-pressure measurements from a deepwater offshore location has been collected (fig. 29). These data provide a major breakthrough in our efforts to understand and quantify the destructive mudflow phenomena of the Mississippi Delta area.

The use of sound waves reflected from the sea floor and from sedimentary layers beneath it is constantly being refined to enable us to detect and measure smaller features. High frequency sonar has been adapted to be "flown" above the sea floor as air-borne radar is flown above a land surface, with somewhat analogous results (figs. 22 & 26). Using these radar images, project scientists have made mosaics which yield an almost photographic image of subtle variations in relief and texture of the sea floor. Such images permit geomorphic analyses of submarine features with unprecedented accuracy.

In addition to such new mapping tools, new techniques are being developed to assess the state of stability of marine deposits. Industry has extended the conventional use of sea floor borings for soil samples with the addition of new down-hole tools

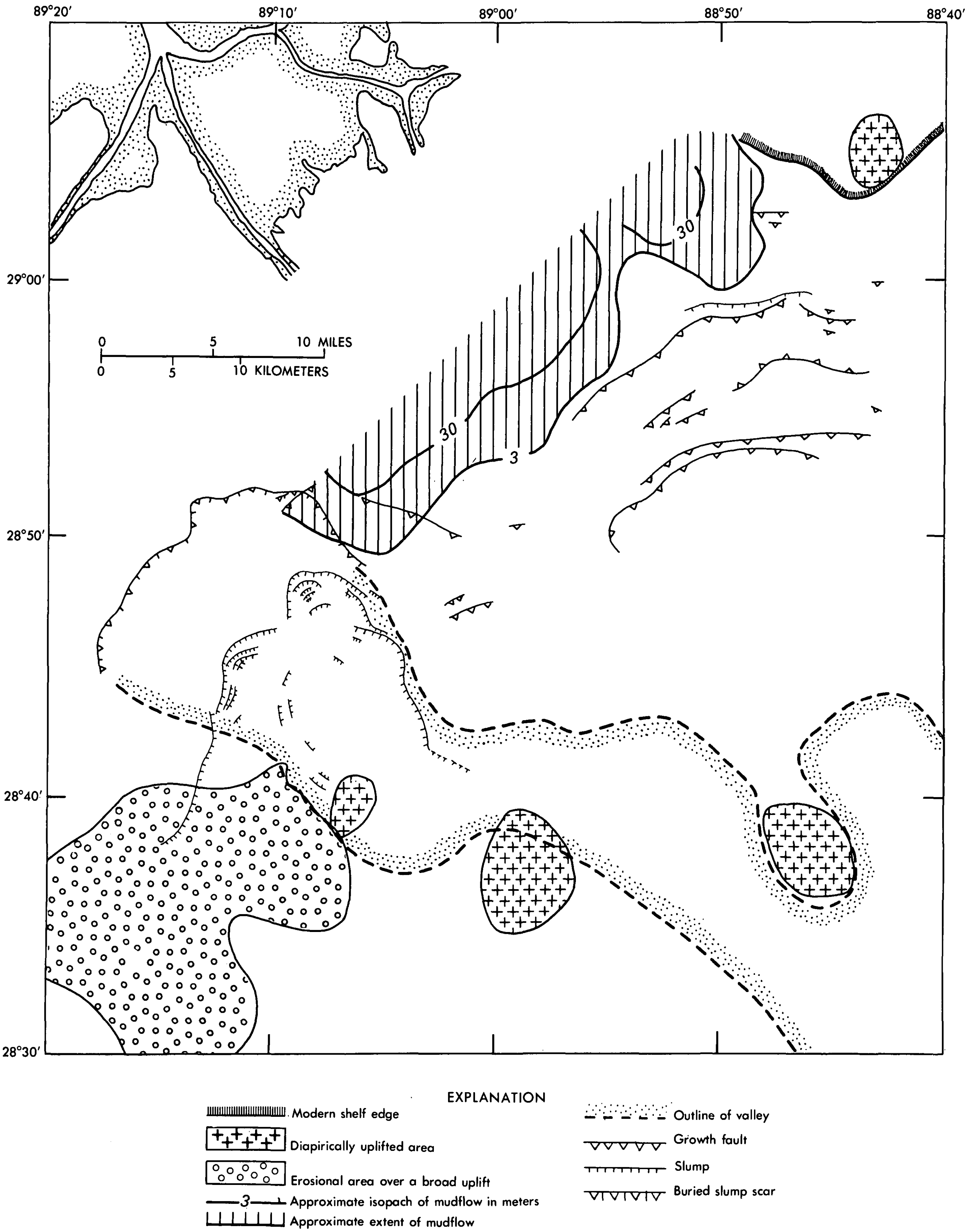


FIGURE 27.—A map of the Mississippi Delta offshore area indicating the location of geological features, particularly mudflows, which constitute a potential hazard for development in these areas.

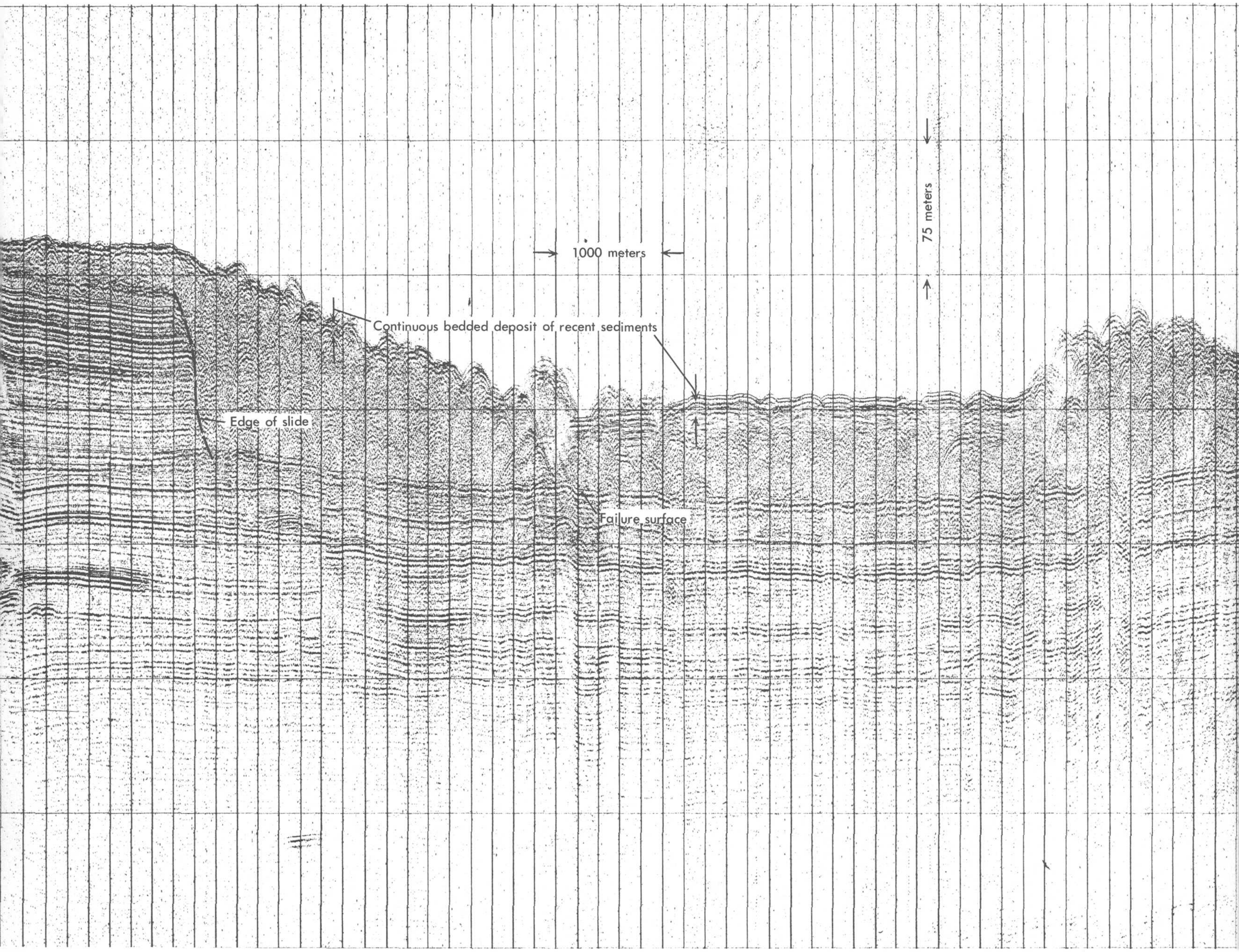


FIGURE 28.—This seismic view across a slide shows that the submarine landslide must be old and immobile. Such slides may be relatively stable or can be reactivated by man's activities.

that measure sediment strengths with minimum disturbance to the material. For gassy sediments, in which all measurements were notoriously unreliable until now, Texas A & M University as a part of the Delta Project has developed a pressurized core barrel which permits sample recovery at down-hole ambient pressures. These samples are opened only in special chambers on land where appropriate testing can be performed under corresponding pressures.

The presence of large amounts of gas in shallow sediments has been recognized for some time, but until the last 2 years little was known about the geochemical mechanisms and environments producing this gas. The significance of gas in landsliding and other bottom-sediment instability was completely unknown. As part of the DELTA Project studies, Louisiana State University now has field and laboratory data which indicate a clear tie between the geochemical environment, gas generation, and sediment strength and stability. We are beginning to understand that an increase in gas content, as tiny bubbles within the soil pores, decreases soil strength and can lead to collapse or landsliding. Much work remains to be done, but the directions for study have been defined.

The influence of wave loading on bottom stability is another area of significant change and growth in

◀ FIGURE 29.—Installation of the USGS-Texas A&M piezometer in South Pass Block 28 as part of the research in the Delta Project. Instruments such as this are required to measure in-situ pore pressures.

understanding of offshore landslides. Only within the last decade has there been any suggestion that surface waves could influence bottom-sediment stability, except through an erosion process near the coastline. We now recognize that wave loading is a major factor in most marine areas and out to depths of water in excess of 100 meters. Louisiana State University has collected field evidence that surface waves cause sympathetic oscillation of soft marine sediments (fig. 30). This motion in turn produces changes in pore pressure, sediment strength, and stability and provides a quantitive explanation of the link between submarine landslide damage and hurricane or storm waves.

Many offshore areas with high priority for study and development lie in close proximity to active plate margin areas which are areas of concentrated earthquake activity. The potential for earthquate loading is, therefore, an important factor in any consideration of bottom stability. Earthquakes affect marine deposits both by increasing the loading due to ground motion and by causing strength decrease in the soils as a result of earthquake shaking and an increase in pore pressures. That earthquakes cause catastrophic submarine landslides is clearly documented but, at present, virtually nothing is known about the size, distribution, or frequency of earthquake-induced landslides in the submarine environment. Some of the first comprehensive studies of this type are presently being done by the U.S. Geological Survey in the Gulf of Alaska. The objective is to evaluate the hazard posed by earthquake-induced landslides and to develop a rational understanding of the problem as a basis for avoiding or controlling damage.

Many other factors significant in submarine landsliding are being identified and studied by an increasing number of scientists in various disciplines. For example, rates of mass movement in various types of sliding are an important problem. Special loading mechanisms such as the impact of sea ice, erosion by submarine currents, tectonic deformation, and internal sea waves are being considered in particular areas. Another very important new problem is the influence of man's activities on submarine slope stability. It is now clear that some bottom instability has been caused by loads imposed by bottom-supported structures. Other activities such as dredging, mining, and soil-structure interaction during earthquakes also have potential for producing landslides.

The conception and utilization of all these new tools and technologies have paralleled the development of a new "scientist" as well. In the complex world of sea floor investigations, this new scientist must integrate data from physical measurements, from oceanographic modelling, from chemical analyses, biological research, and sedimentological study. The interpretations must be compatible with soil engineering practice and should ultimately be translated into a form that can be used by the structural design engineer. The new scientist clearly is not an individual but one of a team. To advance appreciably on these problems requires a group of skilled specialists, each of whom is not only an expert in his own field but has rare talent for grasping the ideas of his colleagues from other disciplines and weaving them firmly into the fabric of his own thinking. Only through the directed efforts of a group of such scientists can we hope to understand and predict the phenomena with which we are dealing. △

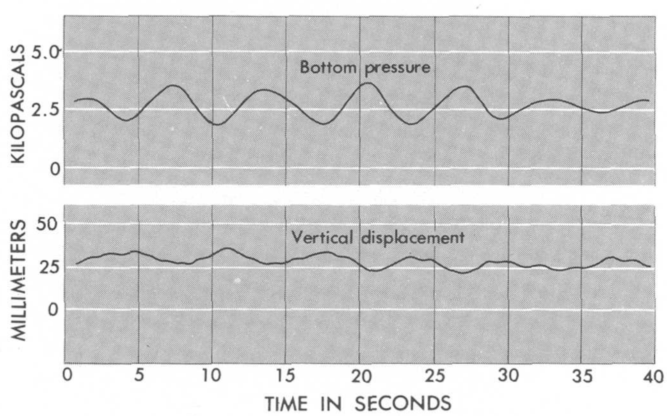
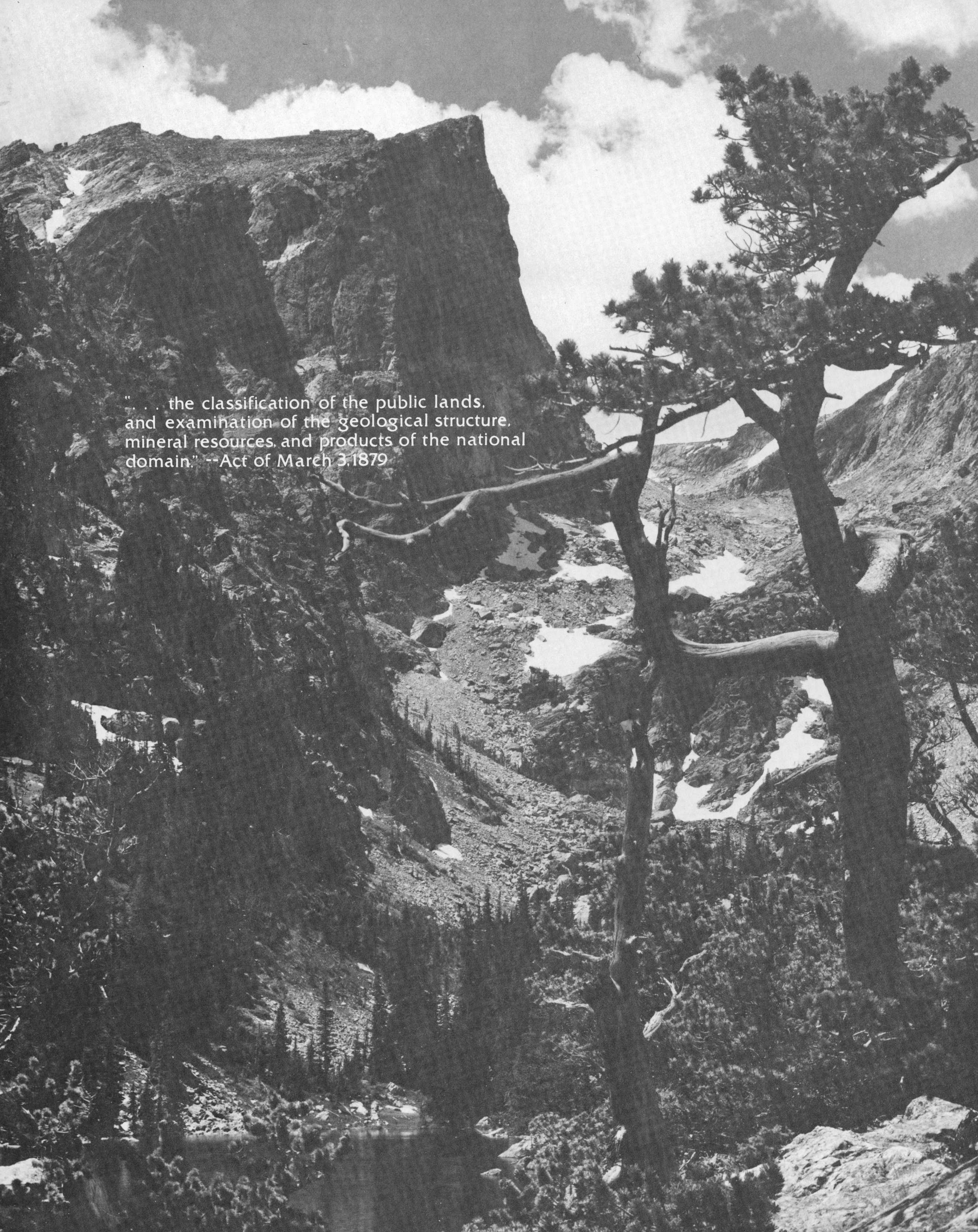


FIGURE 30.—Data collected from the Delta Project SEASWAB experiments showing that surface waves cause bottom displacement and changes on pore pressure, all of which affects submarine landsliding. (Suhayda, J. N., Whelan, T., Coleman, J. M., Booth, J. S., and Garrison, L. E., 1976, Marine sediment instability: Interaction of hydrodynamic forces and bottom sediments: Offshore Technology Conference, OTC Paper No. 2426.)


". . . the classification of the public lands, and examination of the geological structure, mineral resources, and products of the national domain." --Act of March 3, 1879

Missions, Organization, and Budget

For nearly a century, the U.S. Geological Survey has served Federal, State, and local governments, and the public, by collecting, analyzing, and publishing detailed information about the Nation's energy, mineral, land, and water resources. The Geological Survey was created in 1879 to study the geologic structure and mineral resources of the public domain and to provide information to support development of the West. Congressional and Executive direction later expanded the Survey's authorities and responsibilities to include topographic mapping; chemical and physical research, stream-gaging and water supply assessments; supervision of mineral exploration and development activities on Federal and Indian lands; engineering supervision of waterpower permits; and administration of a minerals exploration program.

And, in June 1977, under provisions of the Naval Petroleum Reserves Production Act of 1976, jurisdiction of the Petroleum Reserve in Alaska was transferred from the Department of the Navy to the Department of the Interior. Responsibility for administration of the continuing petroleum exploration program on the Reserve and operation of the South Barrow Gas Field was delegated to the Director of the Survey by the Secretary of the Interior.

Except for operation of the South Barrow Gas Field to supply gas to the village of Barrow and its vicinity, the Geological Survey has not departed from its fact-finding mission described in the brief authorizing legislation of 1879, although program emphasis and balance have changed over the years to meet demands of users of Survey data.

That fact-finding mission has two objectives: First, the Survey is charged with increasing the scientific knowledge of the extent, distribution, character, and origins of the natural resources and of the geologic processes that affect the use of the land so that man may adjust his activities to the constraints imposed by the environment and so that the Earth's resources may be managed wisely. The responsibilities delegated to the Survey for the exploration program on the National Petroleum Reserve in Alaska call for an engineering and geologic evaluation and assessment of the petroleum potential of the Reserve. These studies—to be completed in 1980—are closely allied to this first objective and are needed to assist the Department in an adequate petroleum resource appraisal of the Reserve.

Second, and no less important, are the Survey's regulatory responsibilities—classifying Federal lands and supervising mineral lease development on Federal and Indian lands. By working closely with the Bureau of Land Management and other land-management agencies, the Survey seeks to identify and conserve the Nation's public resources and to supervise their development, so that the public receives its fair share for leased resources, and so that damage to other resource, environmental, and social values is minimized during exploration and development.

Implicit in carrying out the Survey's mission and defined objectives are factual and impartial reporting of investigations, identification of natural constraints on land use and resource development, and analyses of the consequences of alternative policies or actions related to resource development, conservation, and environmental protection.

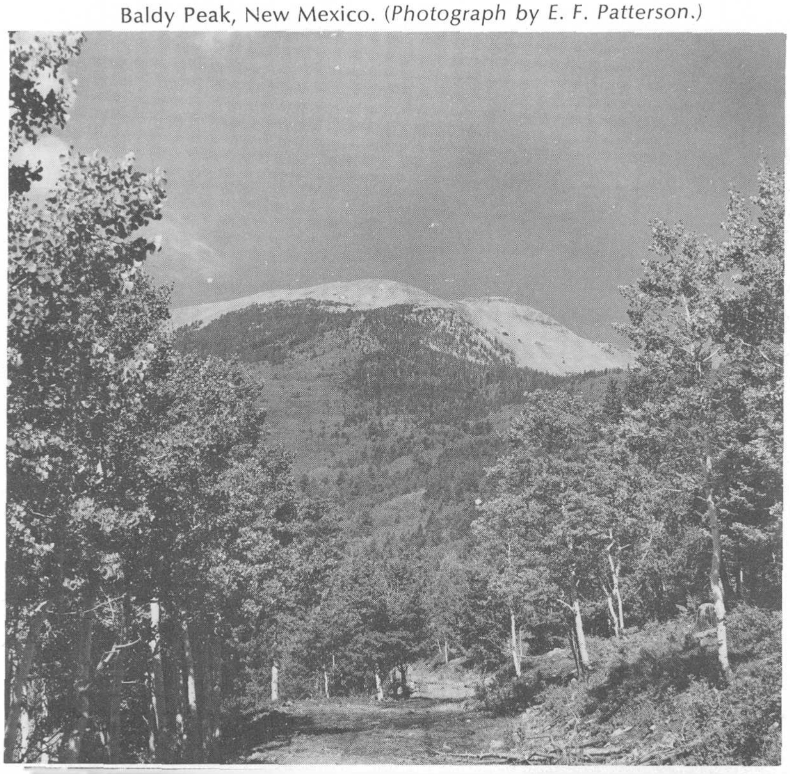
◄ Hallet Peak, Colorado. *(Photograph by David Usher.)*

ORGANIZATION

The scientific and regulatory mission of the Geological Survey (and the operation of the South Barrow Gas Field) are carried out by six organizational units, each of which is responsible for one of the Survey's major programs or budget activities (see organizational chart on pages 186–187 and table 26 in the section entitled "Organizational and Statistical Data").

- The Topographic Division produces maps delineating the physical features of land areas in the United States and its outlying areas and in Antarctica. The Division also collects and distributes information on the availability of aerial photographs and space images, maps and charts, geodetic data, and related cartographic information through the National Cartographic Information Center.
- The Geologic Division conducts research on geologic processes and the Earth's history and thereby provides the information that permits man to adjust intelligently to the Nation's environment and to use the Earth's resources wisely. The Division also determines the composition and structure of the rocks and materials that lie at and beneath the Earth's surface, identifies potential energy and mineral resources (including those of the Outer Continental Shelf), and develops and distributes knowledge about natural hazards such as earthquakes, volcanic eruptions, and land subsidence.
- The Water Resources Division assesses the quantity and quality of the Nation's water supply, develops the knowledge necessary to predict the environmental consequences of alternative plans for developing water resources, coordinates Federal water-data-acquisition activities, collects and distributes information about the availability of water data through the National Water Data Exchange, and develops and distributes information about natural hazards such as floods and land subsidence.
- The Conservation Division classifies the public lands with respect to leasable mineral and water power sites and supervises exploration and development authorized under leases and permits on Federal and Indian lands.
- The Land Information and Analysis Office coordinates and administers interrelated, interdisciplinary programs of the Survey, as well as other units of the Department of the Interior, with the objective of interpreting and displaying resource information in ways that are readily accessible and understandable to a wide range of potential users, particularly land-use planners and decisionmakers.
- The Office of National Petroleum Reserve in Alaska manages the continuing exploration of the Reserve during the interim between the transfer of jurisdiction from the Department of the Navy to the Department of the Interior and the effective date of any legislation for a permanent development and production program, enforces regulations and stipulations which relate to the exploration program, and operates the South Barrow Gas Field to supply gas to the village of Barrow and its vicinity.

Baldy Peak, New Mexico. (*Photograph by E. F. Patterson.*)



The structure of the Geological Survey's budget closely parallels the structure of its organization. Each program Division (Topographic, Geologic, Water Resources, and Conservation), the Land Information and Analysis Office, and the Office of National Petroleum Reserve in Alaska (ONPRA) is responsible for one of the Survey's major budget activities.

A small activity, Alaska Pipeline Related Investigations, is currently administered by the Geologic Division with technical assistance from the Water Resources Division.

Funds for the program Divisions and the Land Information and Analysis Office are appropriated under the heading, "Surveys, Investigations, and Research." Although a small SIR appropriation was made in fiscal year 1977 for transition of the NPRA function to the Department of the Interior, funds related to the exploration activity on the NPRA were appropriated to the President and transferred to the Department of the Interior. In the future, funds for the NPRA will be appropriated under the heading, "Exploration of National Petroleum Reserve in Alaska."

TABLE 8.—*Participation of Survey organizational units in areas of study included in the fiscal year 1977 budget*

Area of Study	Topographic Division	Geologic Division	Water Resources Division	Conservation Division	Land Information and Analysis Office	Office of the Director and Administrative Division	National Petroleum Reserve in Alaska
OCS oil and gas	--	X	--	X	--	--	--
Onshore oil and gas	--	X	--	X	--	--	--
Coal	--	X	X	X	--	--	--
Uranium, geothermal, and oil shale	--	X	X	X	--	--	--
Metallic, nonmetallic, and ocean minerals	--	X	--	X	--	--	--
Multipurpose geologic baselines	--	X	--	--	--	--	--
Earthquakes, volcanoes, and landslides	--	X	--	--	--	--	--
Water-data collection, analysis, and research	--	--	X	X	--	--	--
Topographic mapping programs	X	--	--	--	--	--	--
Earth Resources Observation Systems	--	--	--	--	X	--	--
Land resource decision products	--	--	--	--	X	--	--
General administration	--	--	--	--	--	X	--
National Petroleum Reserve in Alaska	--	--	--	--	--	--	X

DEFINITIONS OF BUDGET TERMS

Some of the terms used to describe the budget of the Geological Survey, which appear frequently throughout the next few chapters, are explained here. Funds appropriated directly to the Survey are categorized under several budget activities or broad functional areas; for example, Topographic Surveys and Mapping or Water Resources Investigations. These activities are further subdivided or categorized as subactivities, programs, and program elements, depending upon the size and complexity of the activity. But the term "program" is used more generally and may refer to the entire budget, a budget activity, or a subactivity—or may denote work supported by funds from a particular source, especially in the case of funds received from reimbursement.

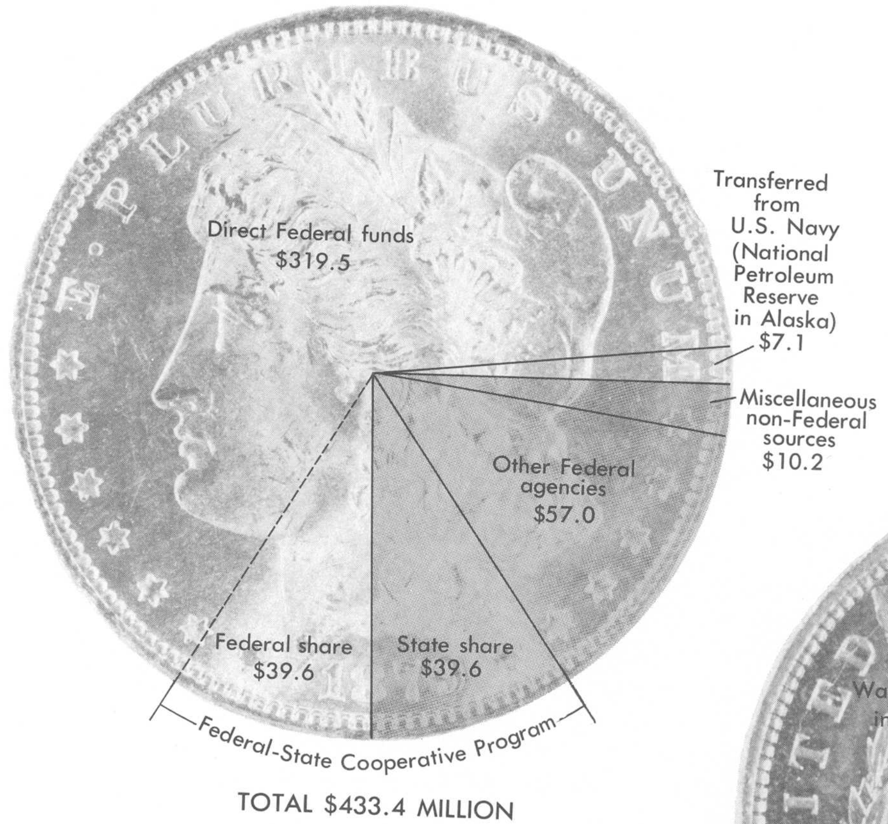
Funds to support programs of the Survey come from two sources: (1) annual appropriations and (2) reimbursement from Federal and non-Federal agencies. Directly appropriated Federal funds support the Survey's directly appropriated programs under each budget activity. Funds from State and local agencies, other Federal agencies, permittees and licensees of the Federal Power Commission, foreign countries, and international organizations pay for various information products and services provided by the Survey's reimbursable programs.

Whereas directly appropriated programs for "Surveys, Investigations, and Research" are aimed at resource investigations and research on problems of nationwide concern, the reimbursable programs enable the Survey to apply its expertise in the Earth Sciences to the specific problems of the funding agencies. The results of these investigations contribute in a very substantial way to the solution of urgent national resources problems and respond directly to the changing needs of the funding agencies and the Survey for Earth Science information. Agencies and organizations with which the Survey had formal agreements for fiscal cooperation in fiscal year 1977 are listed in the section entitled "Organizational and Statistical Data" beginning on page 195.

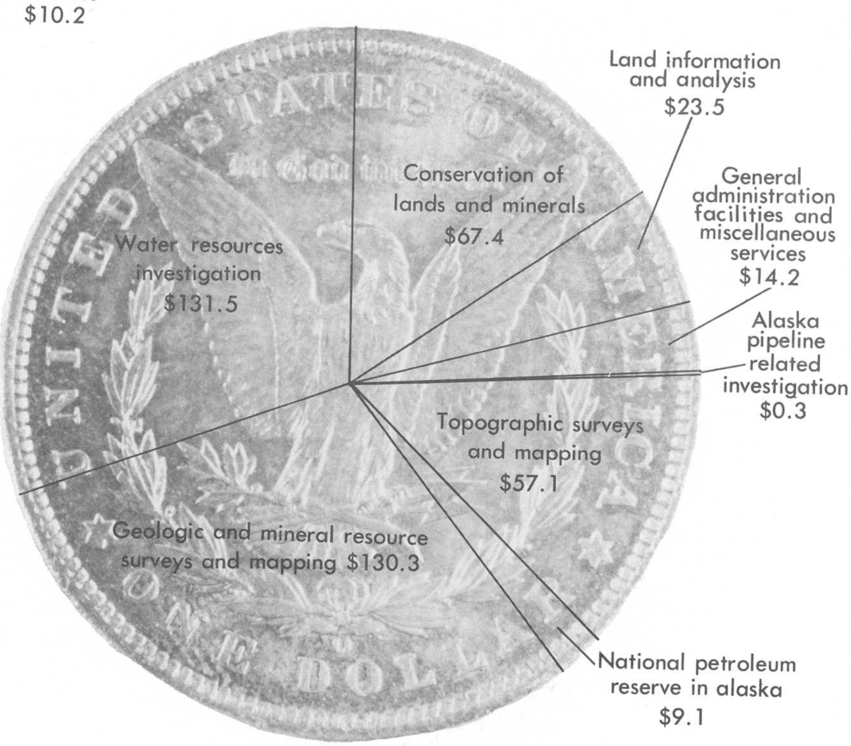
Work done for State, county, or municipal agencies may be performed on a cost-sharing basis. Funding arrangements may vary according to the type of investigation, and the annual appropriations for Surveys, Investigations, and Research stipulated that Federal funds may not be used to finance more than one-half the cost of any topographic mapping or water resource investigation carried on in cooperation with a State or municipality. Within this general 50-percent limitation, each annual appropriation act also specifies the dollar amount of Federal funds that shall be available for cooperative water resource investigations. On the other hand, appropriated funds may be used to pay for more than 50 percent of the cost of other cooperative programs of the Survey. The activities jointly funded by State and local reimbursable program funds (State share) or direct program funds (Federal share) are collectively referred to as the Federal-State Cooperative Program.

Other work related to Surveys, Investigations, and Research done by the Survey for specific Federal agencies and non-Federal organizations is usually performed on a fully reimbursable basis.

U. S. GEOLOGICAL SURVEY BUDGET



SOURCE OF FUNDS



USE OF FUNDS

BUDGET

The total funds obligated by the Geological Survey in fiscal year 1977 amounted to $433 million, an increase of $79 million over fiscal year 1976. Part of the increase, $7 million, reflects transfer of funds from the Department of the Navy for NPRA. Appropriated funds for Surveys, Investigations, and Research in fiscal year 1977 provided about 74 percent of the total funds available to the Survey. Nearly $114 million was provided from Federal, State, and local agencies and from miscellaneous non-Federal sources. The allocation of funds to the Survey's activities funded under the SIR appropriation (Topographic Surveys and Mapping, Geologic and Mineral Resource Surveys and Mapping, Water Resources Investigations, Conservation of Lands and Minerals, and Land Information and Analysis) all increased in fiscal year 1977. The largest increases were for the Conservation of Lands and Minerals activity—67 percent—and Water Resources Investigations activity—20 percent; other increases were more modest. But the overall percentage increase for SIR-funded activities was over 20 percent.

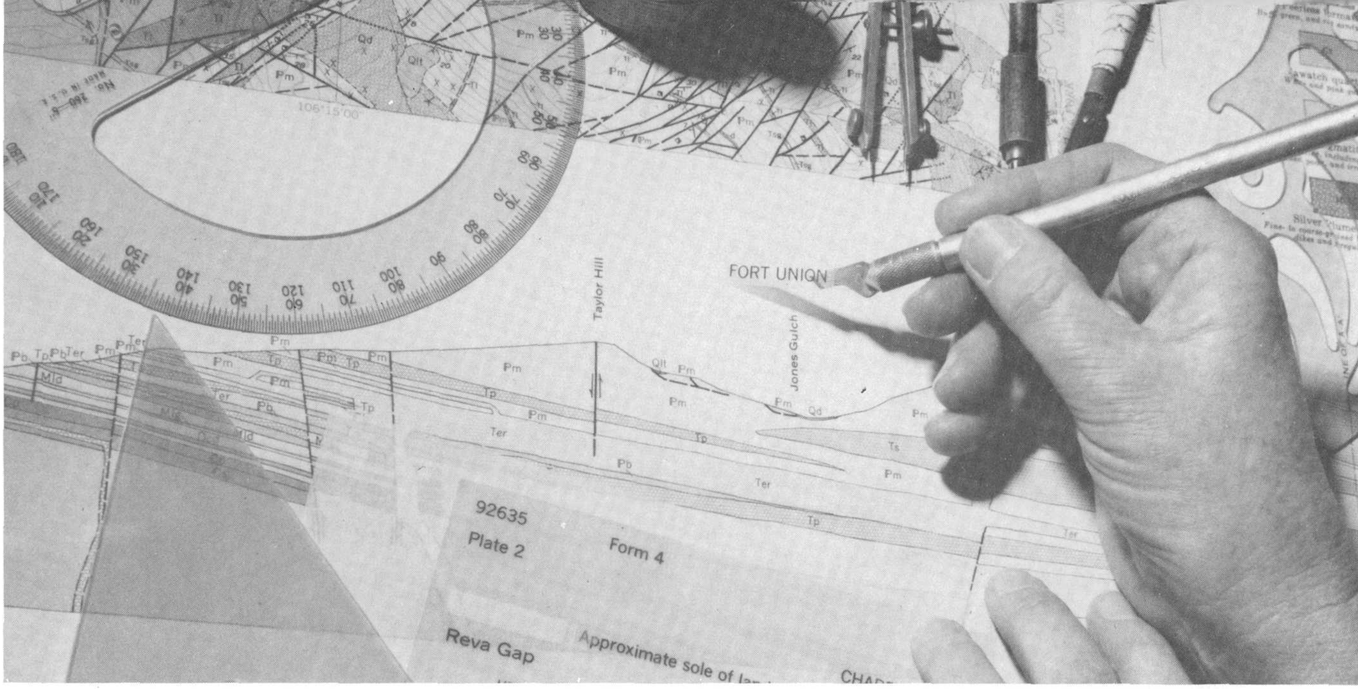


TABLE 9.—*Geological Survey obligations for fiscal years 1976–77 (dollars in thousands)*

[Data in other chapters may differ because of rounding]

Activity	Fiscal year 1976	Transition quarter	Fiscal year 1977
TOTAL	$353,970	$102,858	$433,400
Direct program	264,434	77,570	319,468
Reimbursable program	89,536	25,288	113,932
Alaska Pipeline Related Investigations	287	85	317
Topographic Surveys and Mapping	52,220	13,289	57,073
Direct program	45,354	11,548	50,311
Reimbursable program	6,866	1,741	6,762
Geologic and Mineral Resource Surveys and Mapping	115,554	32,194	130,269
Direct program	92,322	24,829	100,007
Reimbursable program	23,232	7,365	30,262
Water Resources Investigations	112,480	30,716	131,509
Direct program	57,176	15,916	68,555
Reimbursable program	55,304	14,800	62,954
Conservation of Lands and Minerals	41,677	13,381	67,427
Direct program	41,489	13,375	67,239
Reimbursable program	188	6	188
Land Information and Analysis	17,278	8,919	23,476
Direct program	14,908	7,795	17,698
Reimbursable program	2,370	1,124	5,778
General administration	3,398	1,491	3,760
Facilities	9,500	2,530	9,502
Miscellaneous services to other accounts	1,576	253	924
National Petroleum Reserve in Alaska	----	----	9,143
Direct program	----	----	2,079
Allocation Transfer	----	----	7,064

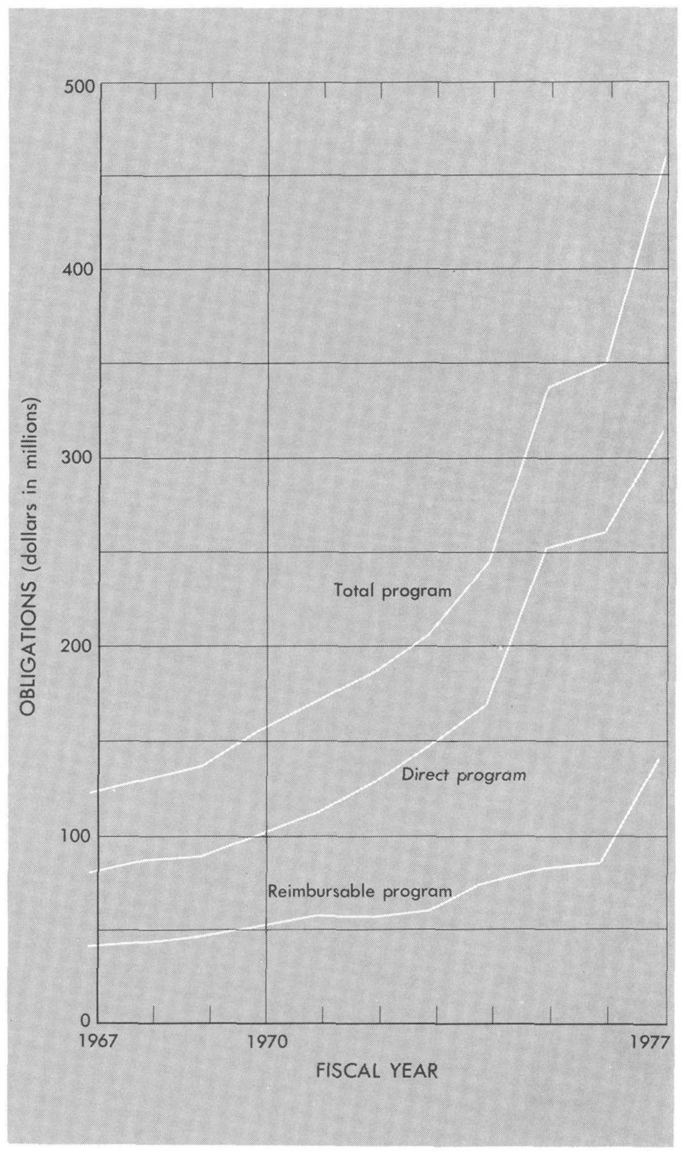


FIGURE 31.—Geological Survey budget, by source of funds, fiscal years 1967–77.

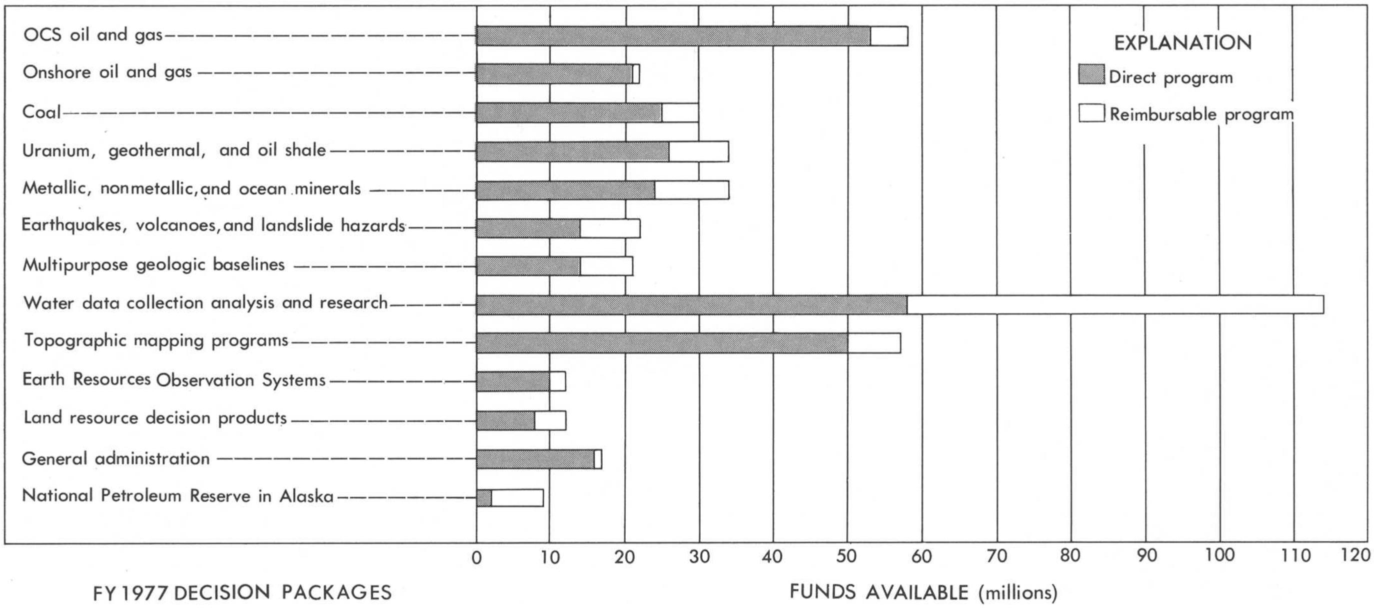


FIGURE 32.—Distribution of Geological Survey obligations for fiscal year 1977, by areas of study.

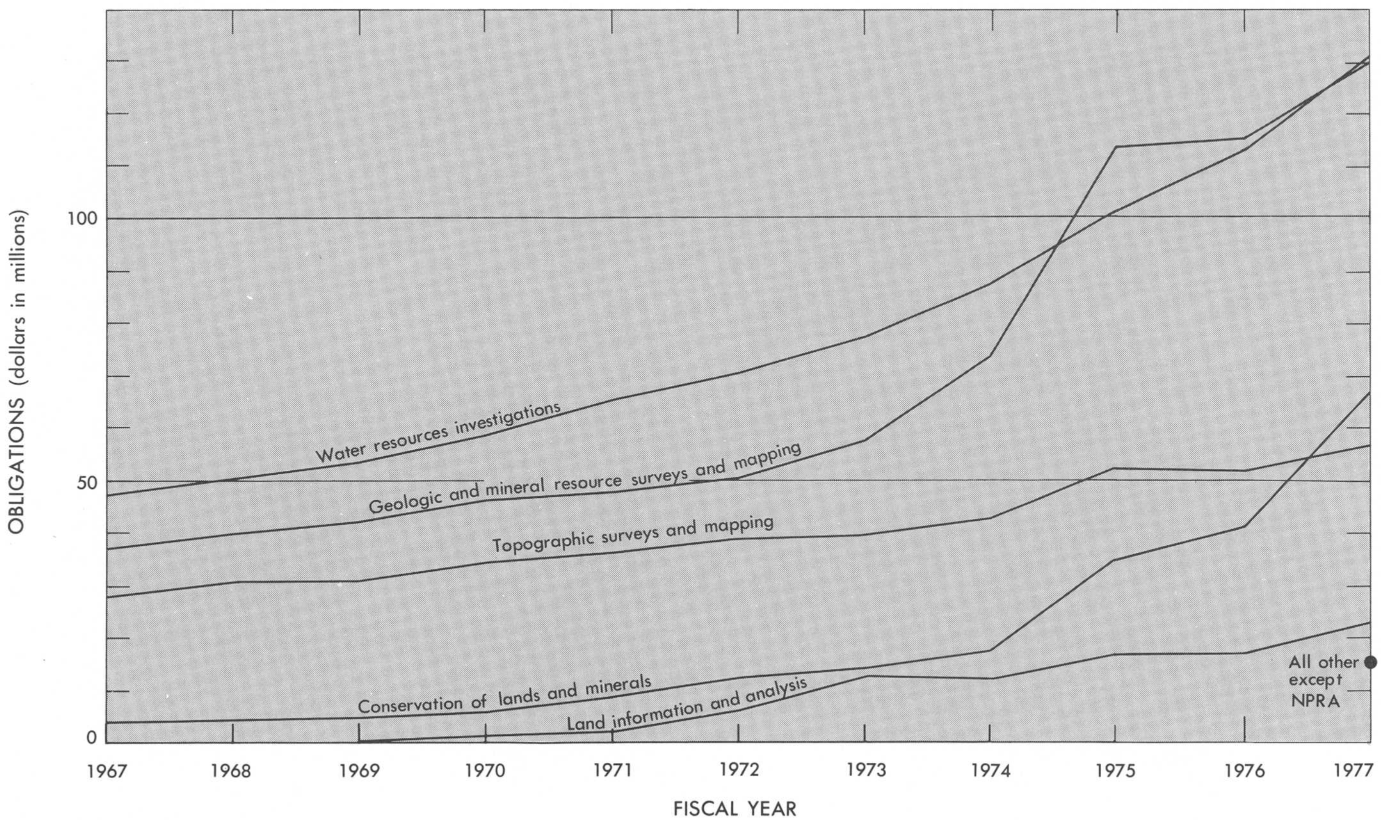


FIGURE 33.—Geological Survey budget by activity, fiscal years 1967–77.

PERSONNEL

While funds available for programs of the Geological Survey have more than tripled since 1968, the number of permanent full-time employees available to implement the programs remained more or less constant through fiscal year 1973 (fig. 34 and table 44). In fiscal years 1974–77, however, 1,237 additional permanent full-time positions were filled, an increase of 15 percent over fiscal year 1973. (See figure 35 for distribution of the 9,326 permanent full-time employees by organizational unit as of the end of fiscal year 1977.) Augmenting the Survey's permanent work force were 2,604 employees on the rolls in other than permanent full-time positions.

Professionalism—denoting employees classified in professional or technical positions as defined by the Civil Service Commission—in programs of the Geological Survey is reflected in the composition of its work force. At the end of fiscal year 1977, the Survey employed 9,326 people on a permanent full-time basis, 50 percent of whom were employed in professional or technical positions (engineering, cartographic, chemical, geologic, geophysics, or hydrologic). The Survey's professional work force provides the Federal Government with a significant resource of scientific and technical expertise in energy, mineral, land, and water resources, the skills needed to fulfill its mission.

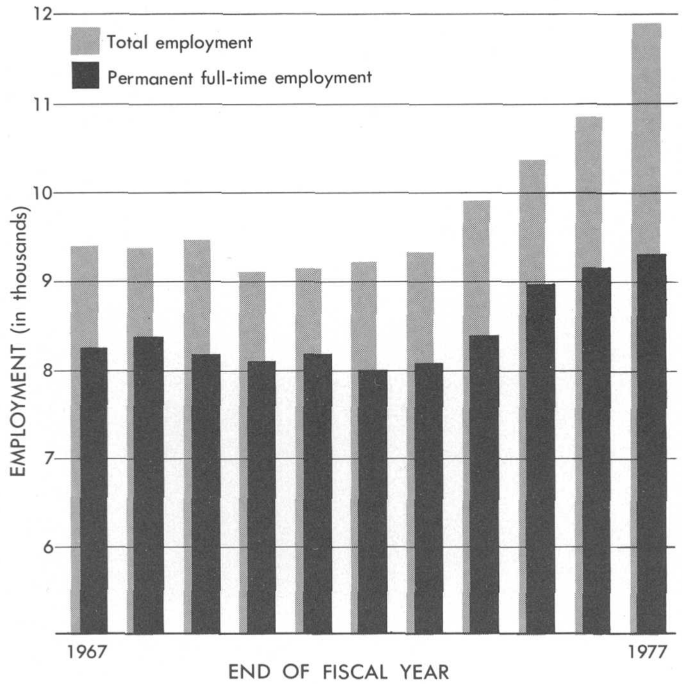


FIGURE 34.—Geological Survey end-of-year employment, fiscal years 1967–77.

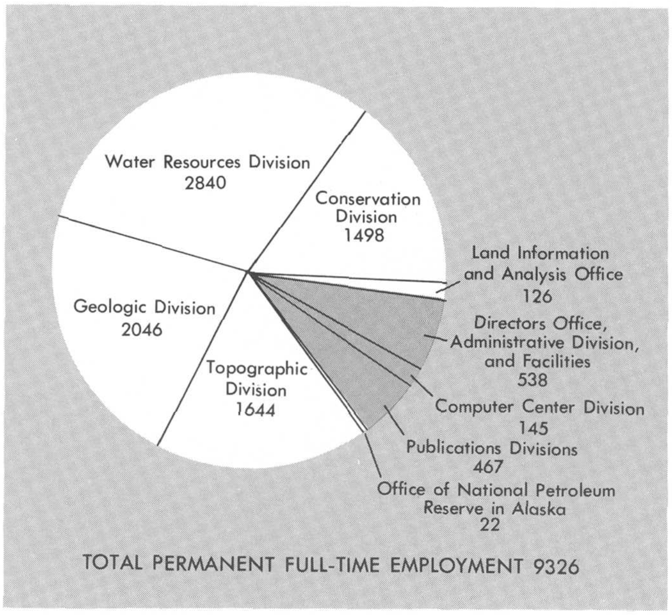
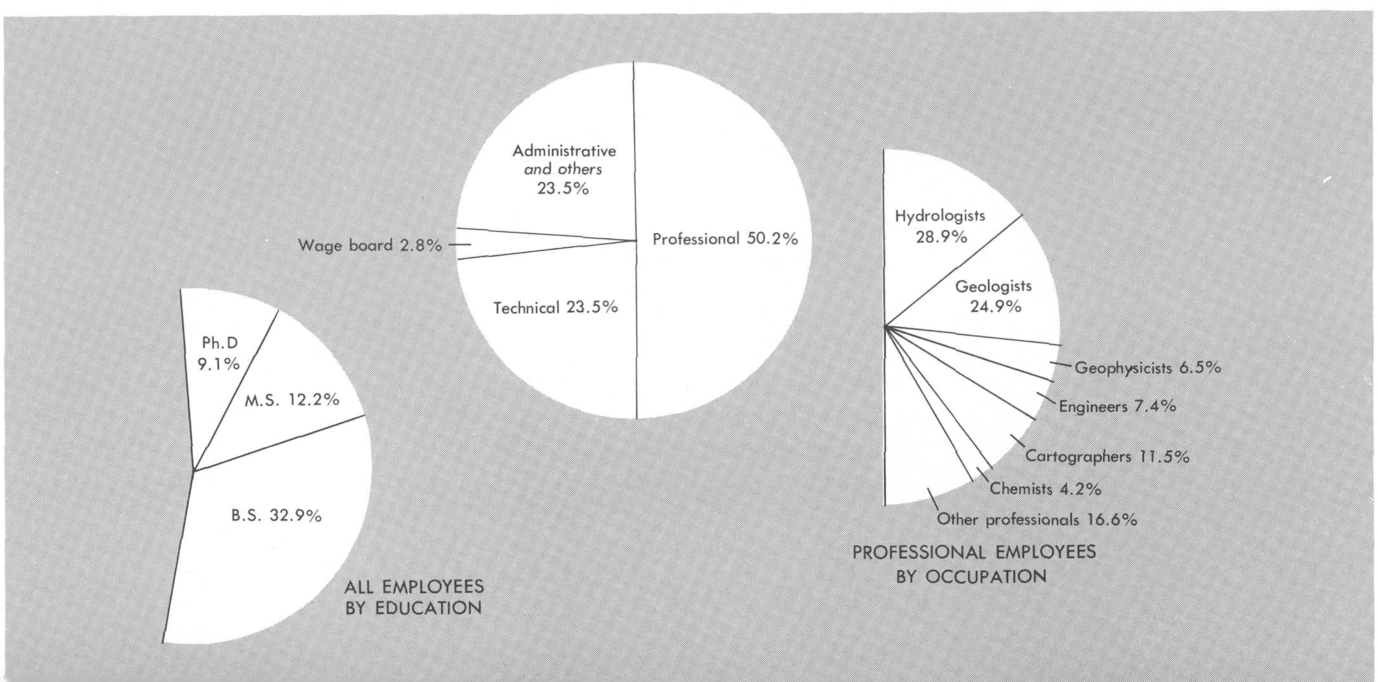
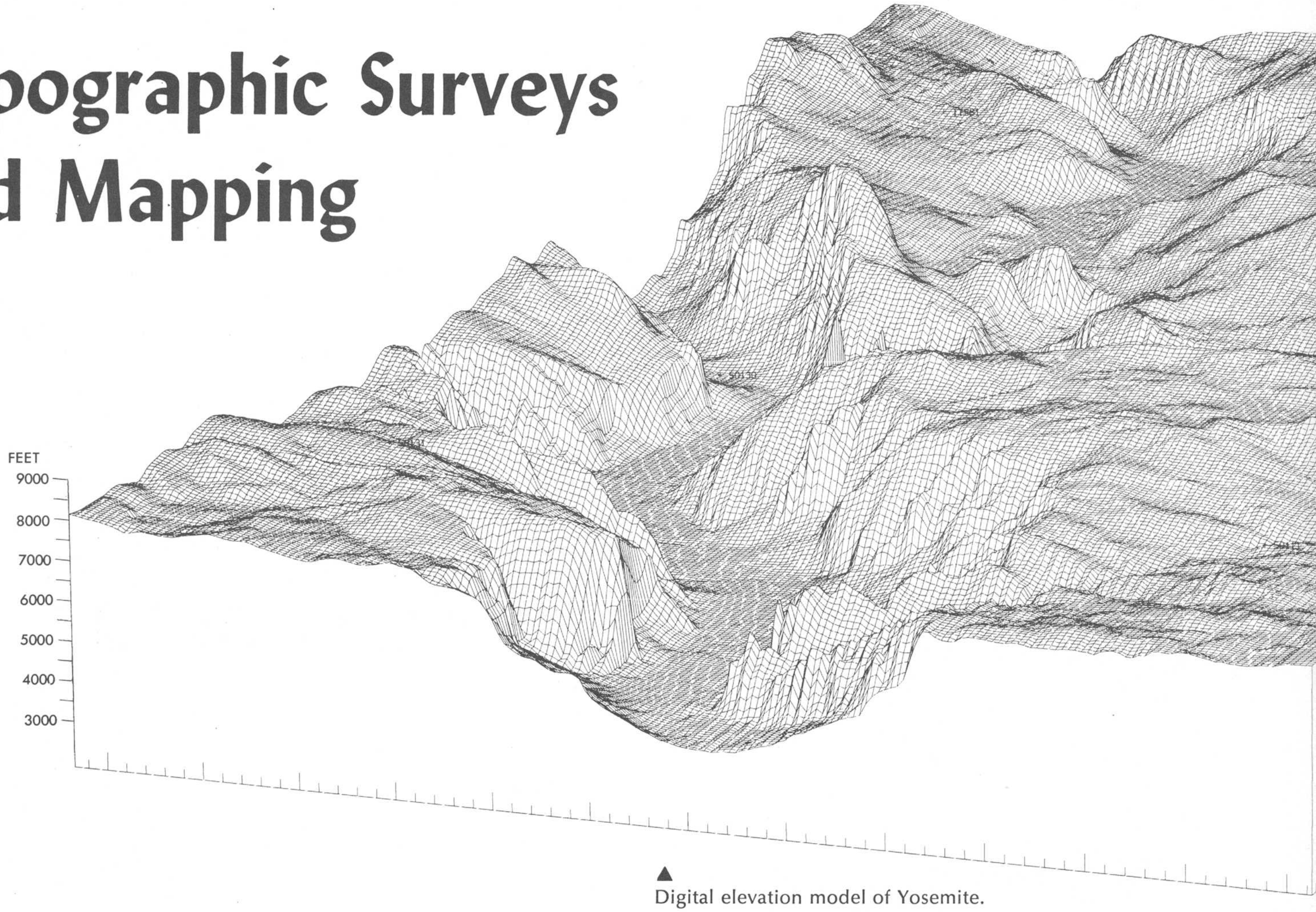


FIGURE 35.—Distribution of permanent full-time Survey employees by organizational units as of the end of fiscal year 1977.

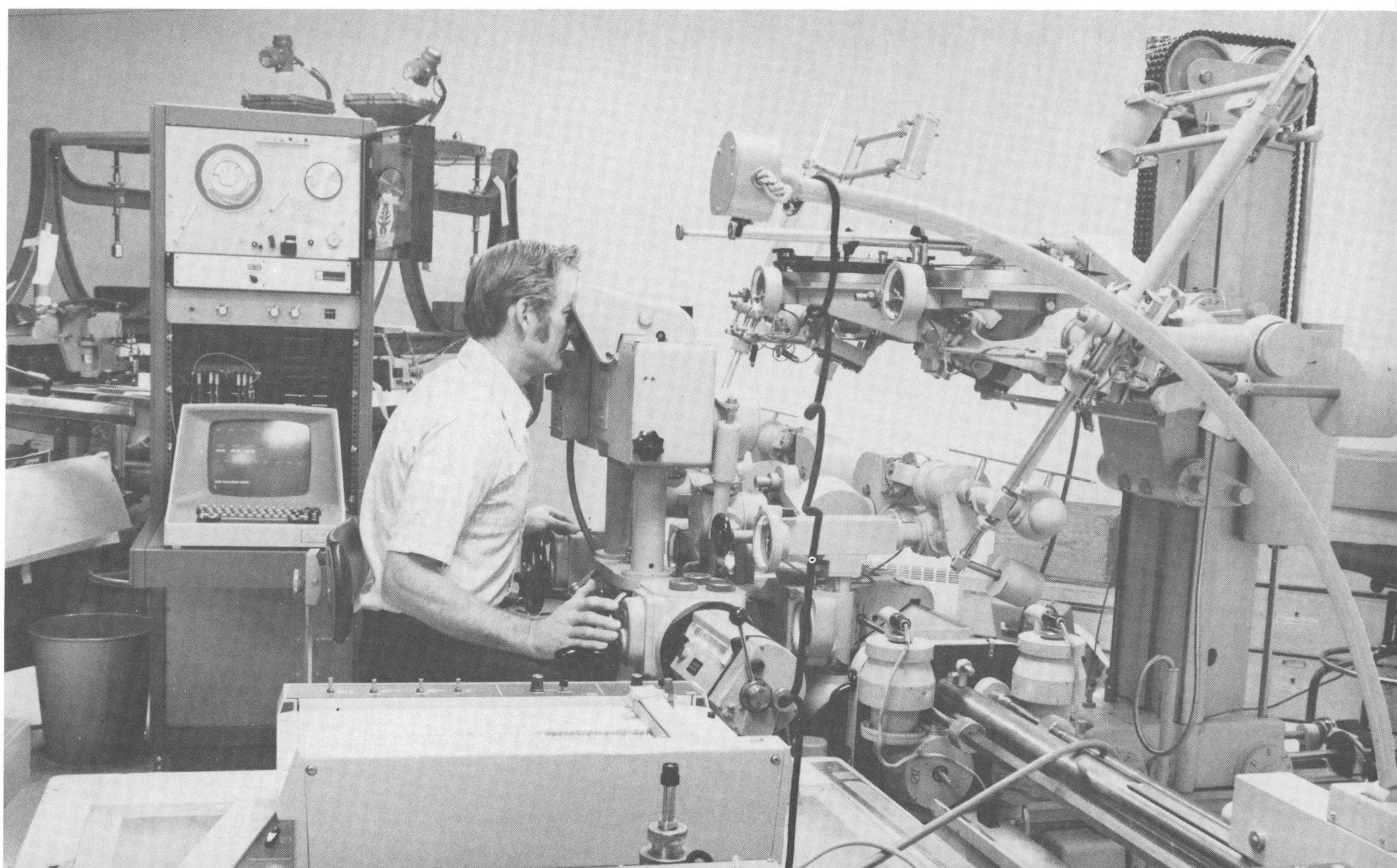
FIGURE 36.—Permanent full-time Survey employees by type.

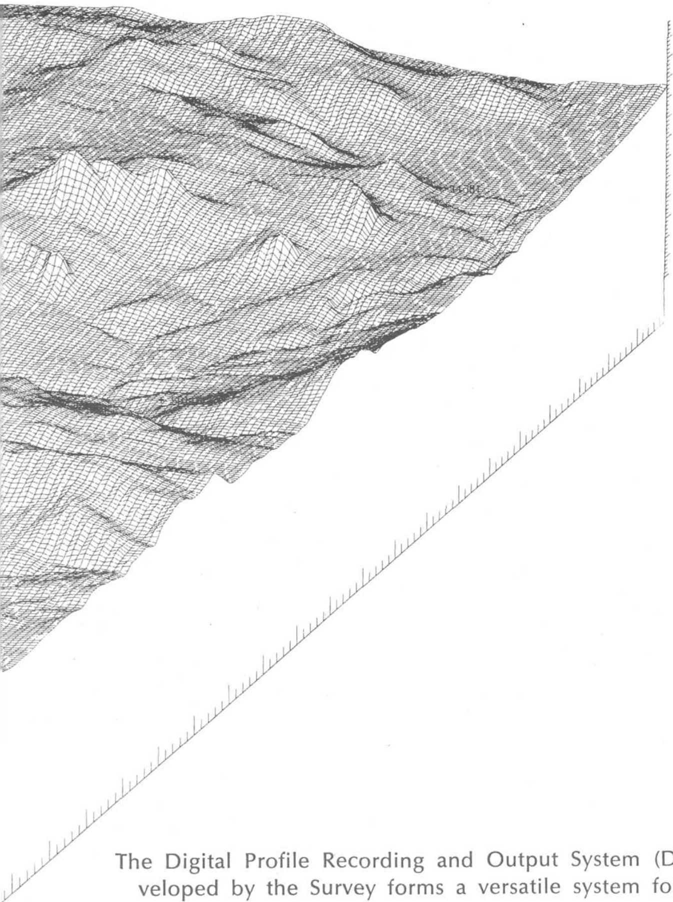


Topographic Surveys and Mapping



▲
Digital elevation model of Yosemite.





The Digital Profile Recording and Output System (DPROS) developed by the Survey forms a versatile system for digitizing and recording terrain profiles from different stereoplotting instruments. The digital profile data are stored on magnetic tape and can be processed into terrain models by a computer. The data can also be used to control an offline orthophotoprinter (p. 80) producing displacement-free photographic images of the terrain.

INTRODUCTION

The National Mapping Program involves the preparation and dissemination of accurate and up-to-date basic cartographic data for the United States in forms that can be readily applied to the new expanding needs of the Nation. Topographic maps, illustrating detailed and precisely referenced information about natural and manmade features on the earth's surface, continue to be the most important product with over 1,300 new 1:24,000-scale topographic maps published during the year ending September 30, 1977 (table 46).

These maps provide fundamental information, both natural and manmade, required by a large number of Federal and State agencies in dealing with most of the important key national issues including the location and evaluation of energy and other resources, examination of environmental impacts and development alternatives and planning and locating a wide variety of public works, commercial, and other facilities. In addition to the 1:24,000-scale topographic maps, the Geological Survey provides other products and services such as orthophotoquads (image maps), intermediate scale (1:100,000 and 1:50,000) planimetric and topographic maps, and a wide variety of basic cartographic data used by other agencies as base materials for special maps they prepare. Fundamental to the value of the basic maps is the need for a continual revision of the data shown on the maps.

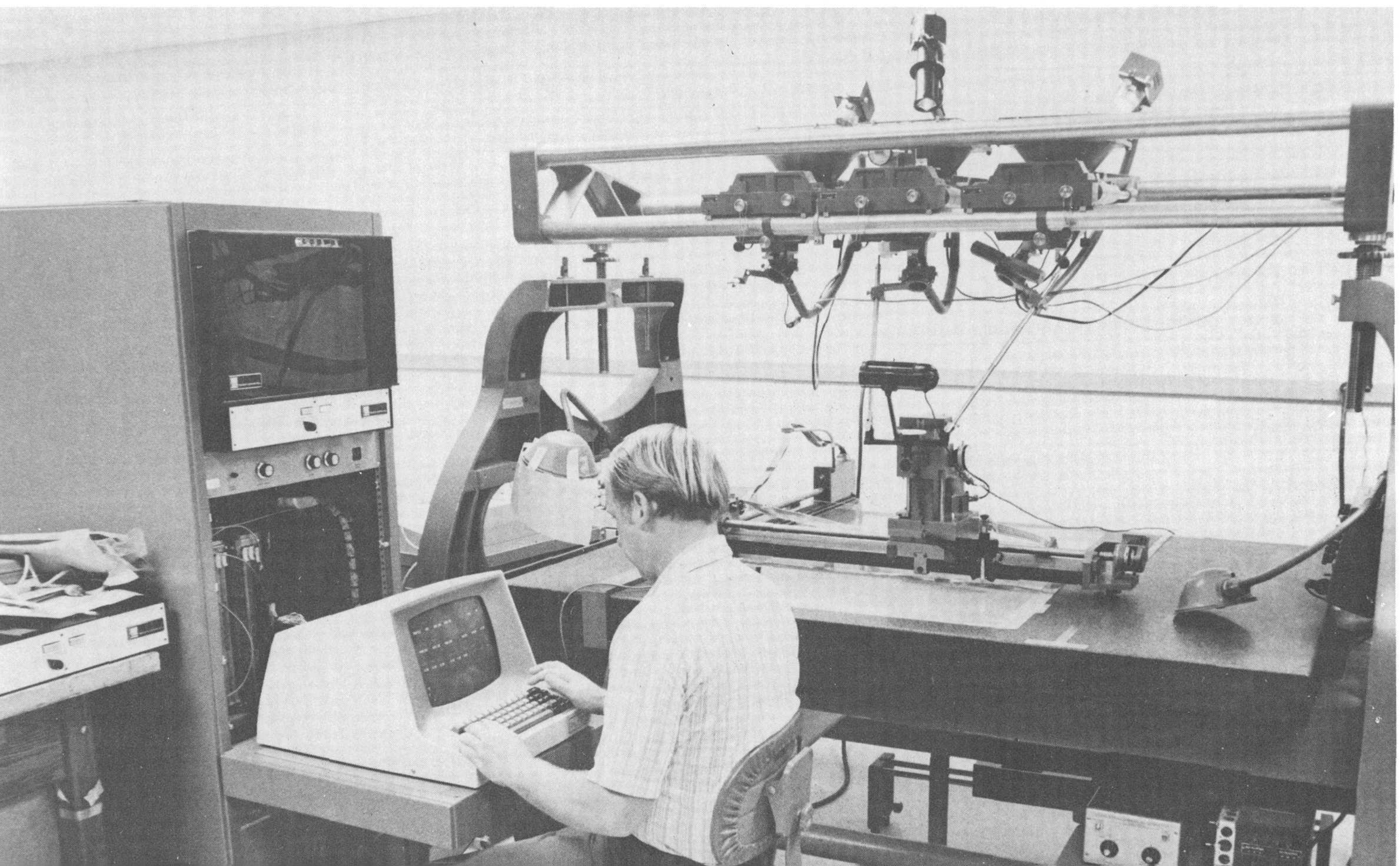


TABLE 10.—*Mapping production for fiscal year 1977 (in square miles)*

	1:24,000-scale topographic	1:24,000-scale orthophotoquads	1:24,000-scale revisions	Intermediate scale
Alabama	1,907	10,238	124	16,388
Alaska	286	-----	4,613	-----
Arizona	3,344	2,821	5,995	7,048
Arkansas	1,147	8,754	2,003	-----
California	2,105	22,640	4,306	23,532
Colorado	1,687	5,916	759	19,164
Connecticut	----	-----	198	2,859
Delaware	----	58	10	978
District of Columbia	----	-----	----	-----
Florida	----	4,875	2,583	5,560
Georgia	1,945	158	1,127	4,271
Hawaii	----	-----	----	4,665
Idaho	1,307	14,904	89	3,451
Illinois	2,595	-----	1,016	4,663
Indiana	----	-----	337	2,713
Iowa	3,792	7,465	2,450	2,310
Kansas	1,009	-----	1,012	2,702
Kentucky	----	1,475	1,316	1,324
Louisiana	1,128	3,072	485	2,051
Maine	332	4,240	----	4,570
Maryland	----	-----	586	2,098
Massachusetts	----	-----	----	635
Michigan	1,197	11,340	2,726	3,060
Minnesota	599	7,384	1,273	24,585
Mississippi	948	4,221	211	7,430
Missouri	2,672	7,985	2,185	689
Montana	3,221	6,707	308	16,205
Nebraska	2,011	-----	2,666	411
Nevada	2,675	13,804	114	9,181
New Hampshire	----	-----	----	-----
New Jersey	----	-----	----	1,265
New Mexico	3,395	10,086	312	25,066
New York	669	-----	55	2,552
North Carolina	2,059	-----	1,608	557
North Dakota	3,363	7,600	1,333	13,976
Ohio	----	171	3,888	2,641
Oklahoma	1,224	30	368	1,946
Oregon	1,684	26,001	547	-----
Pennsylvania	----	-----	1,798	11,314
Rhode Island	----	-----	132	-----
South Carolina	574	-----	137	2,596
South Dakota	3,989	15,863	993	809
Tennessee	----	-----	736	1,902
Texas	6,361	16,320	5,117	17,090
Utah	1,533	2,088	----	4,760
Vermont	88	-----	----	692
Virginia	----	-----	631	1,636
Washington	720	8,610	778	3,240
West Virginia	448	87	7,633	529
Wisconsin	2,683	848	1,255	9,842
Wyoming	1,655	8,393	657	5,742
Guam	----	-----	197	-----
Puerto Rico	----	-----	----	-----
Samoa	----	-----	----	-----
Virgin Islands	----	-----	----	-----

Approximately 1,100 quadrangles are now revised annually and the need for revision continues to grow as more of the basic mapping is completed. Agreement was reached in fiscal year 1977 with the U.S. Forest Service so that they will use their mapping capability to revise maps in the national forests, thus increasing the total number of maps revised yearly in the National Mapping Program.

Fiscal year 1977 saw the initiation of a new effort to provide cartographic data in computer readable form to meet the requirements of a growing number of users. In the years to come, these types of data will become an increasingly important element of the National Mapping Program. A significant aspect of this effort involved the establishment of a full-time research effort and initiation of an equipment modernization program. Also, limited production on a pilot project basis was started in fiscal 1977 to evaluate alternative techniques for producing the digital map related data and to assess user requirements.

An increasing emphasis on intermediate-scale maps was also evident during fiscal year 1977. Agreement was reached between the Geological Survey and the Defense Mapping Agency for the preparation of 1:50,000-scale quadrangle maps as part of the intermediate-scale program to meet military training requirements. The cooperative program with the National Ocean Survey, Department of Commerce, to provide maps in coastal areas that include both topographic and bathymetric information was expanded to include offshore protraction boundaries provided by the Bureau of Land Management. These combination maps will become the standard product in all coastal areas as maps are revised and should provide a single source for much of the data needed in coastal resource management.

Other new roles for the Geological Survey are being suggested—programs for large-scale urban mapping, systematic high-altitude photography, and increased direct assistance to the map user. These apparently diverse requirements should be addressed by the National Mapping Program because of the relationship to standard map products and the mapping process and the need for coordination and standardization.

Coordination of Mapping

The responsibility for coordinating domestic mapping activities is assigned to the Department of the Interior by OMB Circular A–16 and delegated to the Geological Survey. Annual priorities for basic mapping are established based on formal requests of 35 Federal agencies, State Mapping Advisory Committees representing 15 States, and cooperators from 37 States and Puerto Rico. Requests from private individuals and representatives of local governments are also considered. Yearly requests for new and revised topographic mapping—a total of 50,596 requests for 28,303 quadrangles in 1977—far exceed the production capacity and funding level. As such, judgments in the establishment of priorities and selection of projects are important. During the past year, emphasis has been placed on identifying requirements for digital data through interagency pilot projects. These are intended to determine data compatibility and to develop uniform standards.

Special support, from technical assistance to data preparation, is being provided for major national programs of the Department of Housing and Urban Development (Flood Insurance Program), the Soil Conservation Service (Prime Farmlands Program), the National Oceanic and Atmospheric Administration (Coastal Zone Management Program), and the Fish and Wildlife Service (National Wetlands Inventory).

The increased importance of geographically related data to national decisions on energy, economics, and ecology increases the need for map data which are accurate, up-to-date, and compatible with other related information. As an example, geologic, soils, water, land-use, and topographic data must be relatable in order to provide adequate information for surface mining decisions. Continued and improved coordination between data gathering agencies is a necessity for the effective use of these kinds of available data.

Highlights

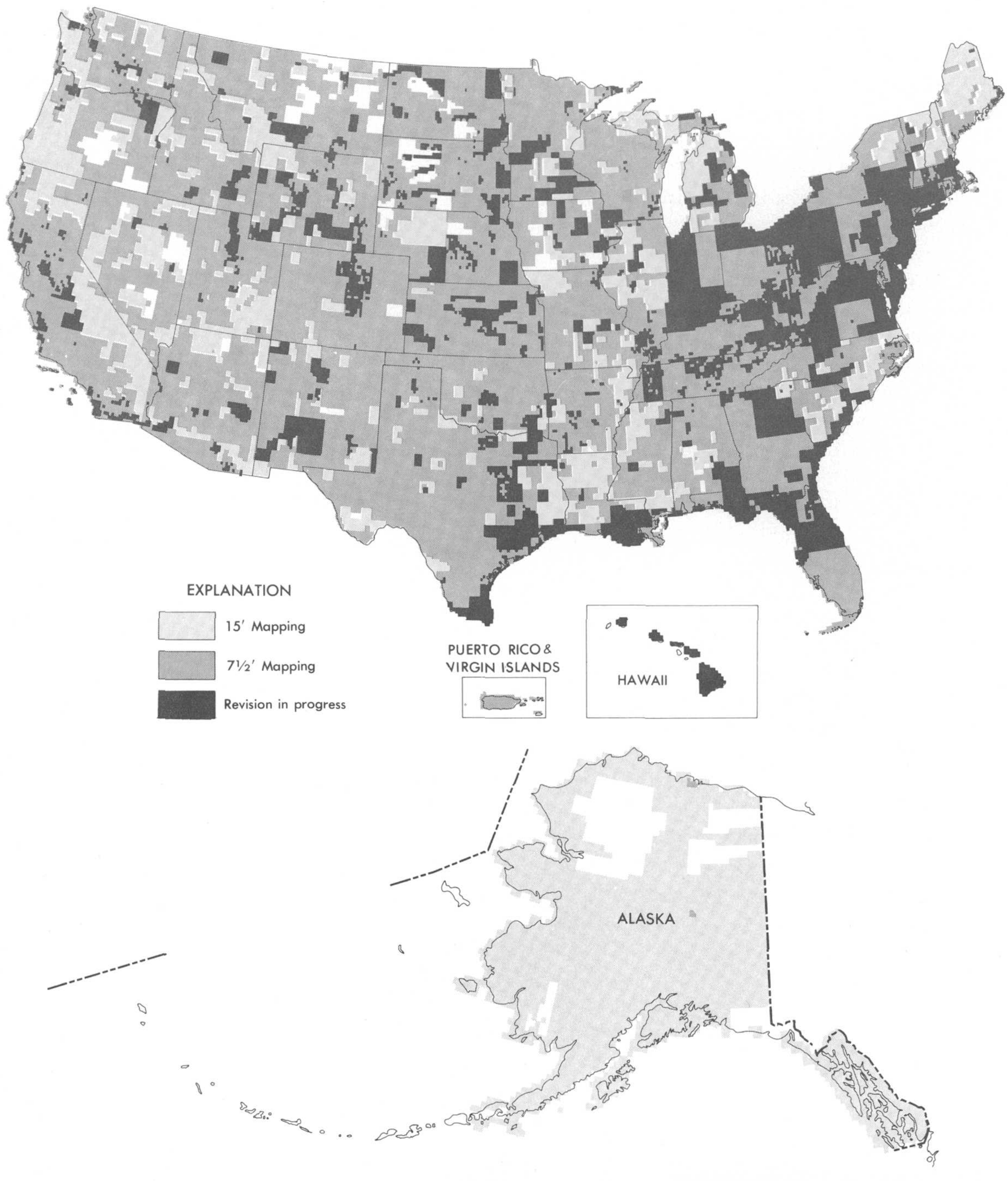
- Establishment of a full-time Digital Applications Team to develop the capability for producing digital cartographic data to meet the requirements of Federal and State agencies. Initial production capability was installed and data generation began on a pilot basis in cooperation with other Federal agencies.
- Agreement with the Forest Service to jointly revise selected 1:24,000-scale maps in national forest areas, thereby, substantially increasing the total number of maps that can be revised nationally.
- Agreements with South Carolina, Arizona, Georgia, and New Mexico to establish State-operated information centers for collecting and distributing cartographic data. The centers are affiliated with the National Cartographic Information Center.
- Agreement with the Fish and Wildlife Service for the Geological Survey to provide two full-time advisers to work with FWS in solving cartographic problems and for the Geological Survey to provide aerial photography and 1:100,000-scale base maps to meet requirements of the National Wetlands Inventory.
- Agreement with the Department of Housing and Urban Development for the Geological Survey to provide information on existing cartographic data and mapping assistance to HUD contractors and grantees prior to their preparation of new maps. The intent is to avoid duplicate mapping.

- Initiation of several metric mapping projects in States which have agreed to convert the 7.5-minute maps to metric products. Specifically, agreement was reached with the Commonwealth of Massachusetts to revise and convert the topographic maps of the entire State to the metric system.
- Completion of 304 intermediate-scale maps to meet special needs of Federal and State agencies. Agreement was reached with Defense Mapping Agency for Geological Survey to produce 1:50,000-scale base maps to meet military training needs.
- Addition of more than 1,088,600 square kilometers (420,300 square miles) of aerial photography to the national aerial photo data base.

FIGURE 38.—Palm Springs, Calif., 1:24,000-scale orthophotoquad. Combined with marginal descriptive information, a high-altitude photograph is differentially rectified to remove positional errors caused by camera tilt and terrain variation. ▶

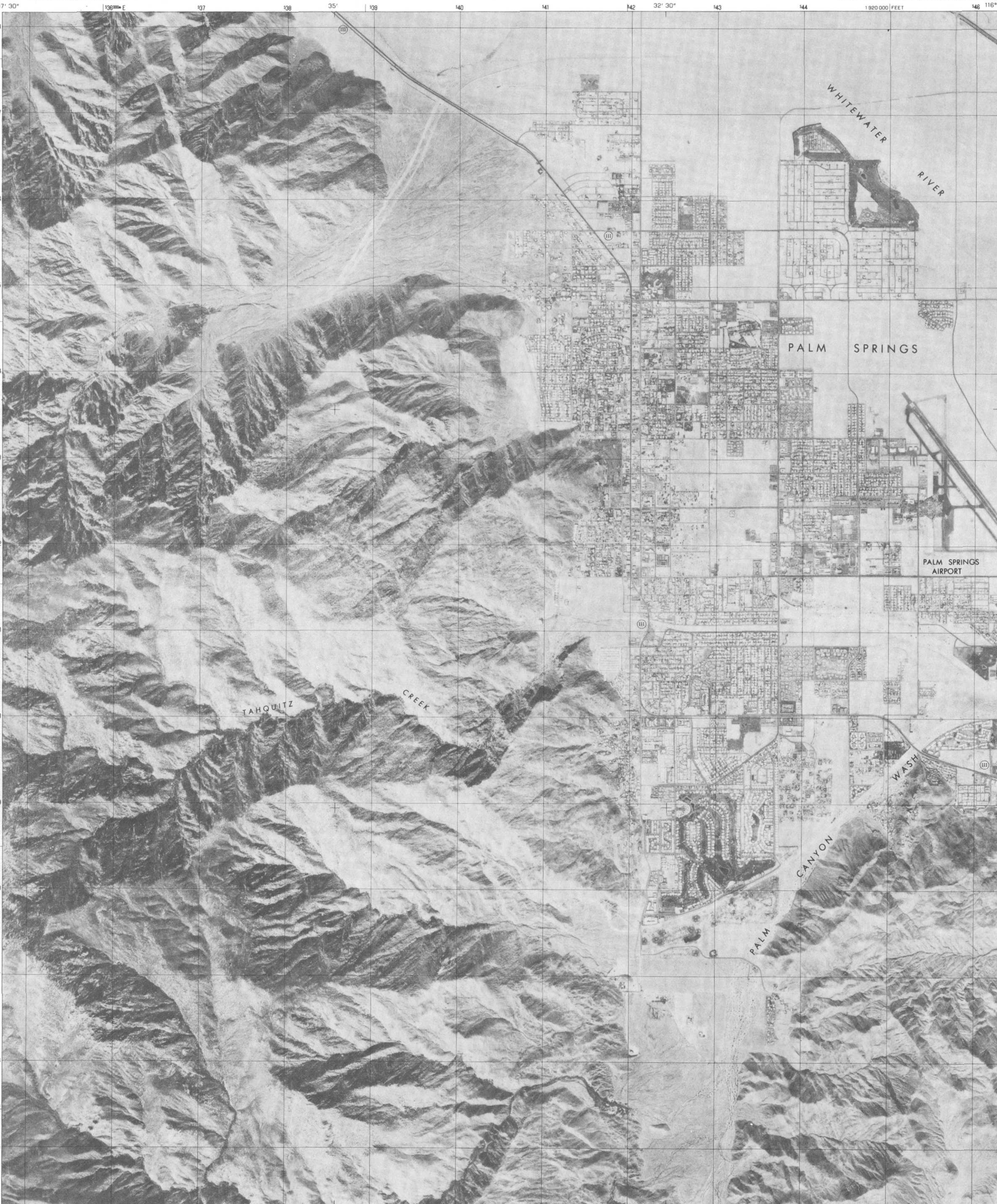
- *Development and installation of equipment to pro*duce digital cartographic data during standard map compilation and orthophoto production, thus providing a capability to produce data not previously available from these instruments.
- Publication of 2,500 new and revised maps, ranging in scale from 1:24,000 to 1:250,000. In addition, about 4,130 orthophotoquads were produced. Initial 1:24,000-scale topographic map coverage of Georgia was completed during fiscal year 1977 as a result of a cooperative effort with the State.

FIGURE 37.—Status of standard topographic mapping and revision.



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PALM SPRINGS QUADRANGLE
CALIFORNIA
7.5 MINUTE SERIES (ORTHOPHOTOQUAD)

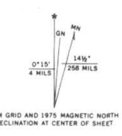


Produced and published by the Geological Survey in cooperation with the Soil Conservation Service

Orthophotograph prepared from 1:80,000-scale aerial photographs taken Oct. 13, 1975

Projection and 10,000-foot grid ticks: California coordinate system, zone 6 (Lambert conformal conic) 1000-metre Universal Transverse Mercator grid, zone 11. 1927 North American datum

Photoimagery transformed by scanning techniques which may produce double or mismatched images; use the mean of image positions for map point



UTM GRID AND 1975 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 — ½ — 0 — 1 MILE
1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET
1 — .5 — 0 — 1 KILOMETRE

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092

QUADRANGLE LOCATION

PRINCIPAL NUMBERED HIGHWAYS

Interstate Route   U. S. Route   State Route

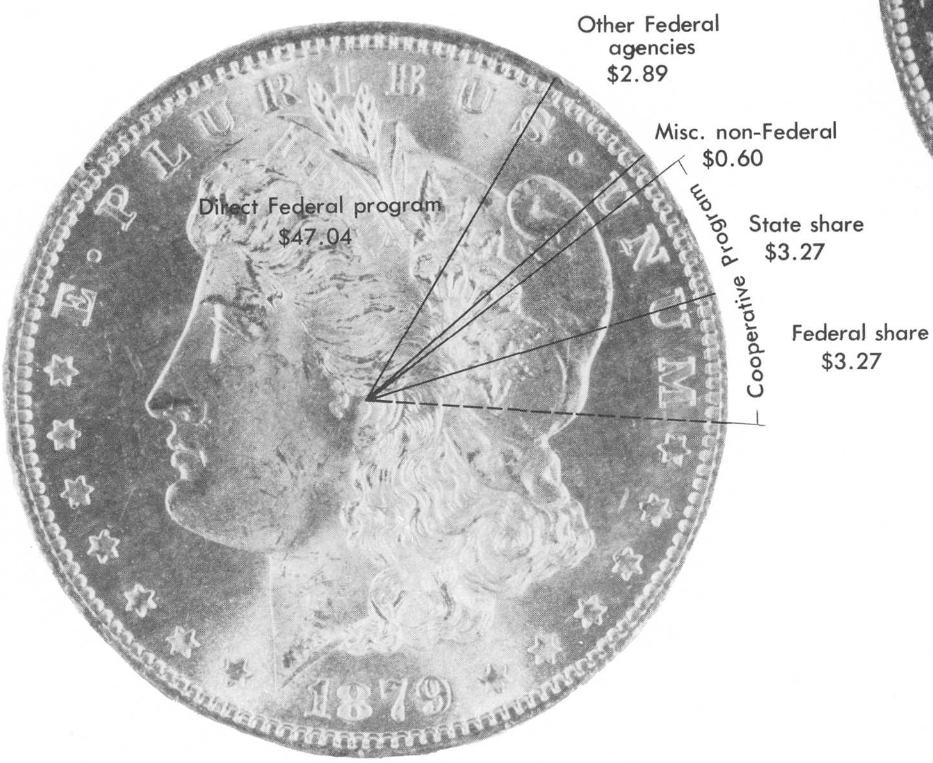
This quadrangle area also covered by SE quarter of Palm Springs 1:62,500-scale topographic map

PALM SPRINGS, CALIF.
N3345—W11630/7.5

1975

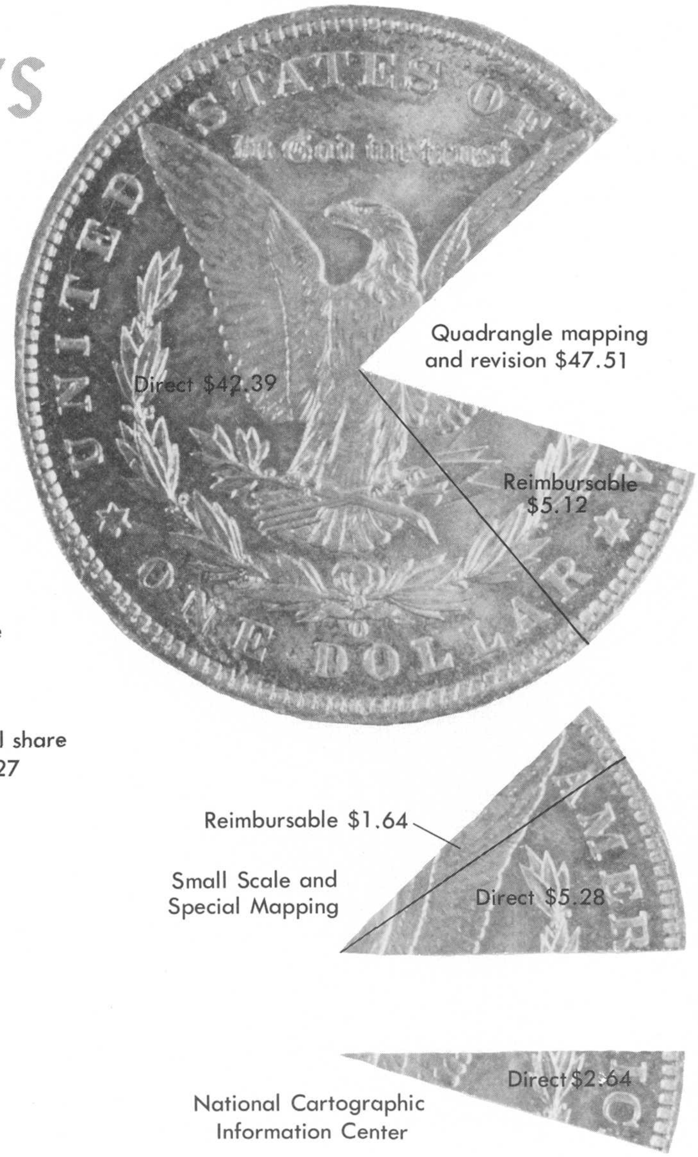
AMS 2651 I SE—SERIES V095

TOPOGRAPHIC SURVEYS AND MAPPING



TOTAL $57.07 MILLION

SOURCE OF FUNDS



USE OF FUNDS

Budget and Personnel

The Topographic Surveys and Mapping budget covers three subactivities:

1. Quadrangle mapping and revision, including the production and revision of the 1:24,000-scale maps (1:63,360 in Alaska) and related activities.
2. Small-scale and Special Mapping, including preparation of other maps and map products from the intermediate scale to the very small scale U.S. base maps.
3. The National Cartographic Information Center for the acquisition and dissemination of information about available cartographic data.

For fiscal year 1977, Topographic Surveys and Mapping obligations amounted to $57.1 million (table 11). Included are funds from 37 States, which, when matched by Federal funds, amounted to $6.5 million for cooperative mapping. These cooperative projects mutually benefit the State and national programs by assuring the completion of map coverage sooner than would otherwise be possible.

The program was carried out through a combination of in-house efforts and contracts. The in-house effort involved 1,644 career employees, many with special training in cartography, data processing, engineering, photographic technology, and the physical sciences. About 225 additional employees, many on

TABLE 11.—*Topographic Surveys and Mapping activity obligations for fiscal years 1976–77, by program (dollars in millions)*

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

Program	Fiscal year 1976	Transition quarter	Fiscal year 1977
TOTAL	$52.22	$13,29	$57.07
Quadrangle Mapping and Revision	43.30	10.46	47.51
Direct programs	38.26	9.40	42.39
Reimbursable programs	5.04	2.15	5.12
States, counties and municipalities	2.93	.70	2.73
Miscellaneous non-Federal	.33	.08	.45
Other Federal agencies	1.78	.28	1.94
Small-scale and Special Mapping	7.19	2.41	6.92
Direct programs	5.36	1.73	5.28
Reimbursable programs	1.83	.68	1.64
States, counties and municipalities	.74	.18	.54
Miscellaneous non-Federal	.17	.05	.15
Other Federal agencies	.92	.45	.95
National Cartographic Information Center	1.76	.42	2.64
Direct programs	1.76	.42	2.64

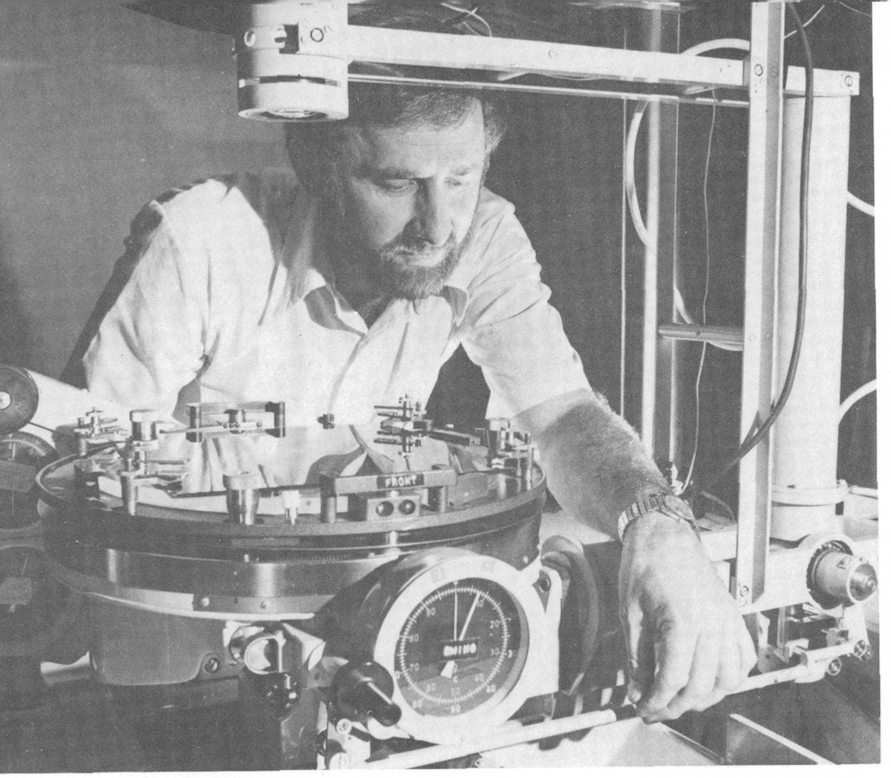
work-study programs, served as temporary aides and professional consultants.

QUADRANGLE MAPPING AND REVISION

Aerial photographs of the land surface are essential to the mapping process. In fiscal year 1977, the Survey contracted for 1,088,600 million square kilometers (420,000 square miles) of aerial photography. Three fourths of the photographs were taken from altitudes higher than 11,700 meters (39,000 feet) for use in photomapping and map revision.

Field control surveys are needed to present map features in correct relationship to each other and to the earth's surface. Horizontal ground control establishes and maintains correct scale, position, and orientation of the map. Vertical control governs the contours and spot elevations which show the shape of the terrain. These data are used to prepare the map base, the framework on which map detail is complied. During fiscal year 1977, 248,500 square kilometers (92,950 square miles) of horizontal control and 115,-700 square kilometers (44,670 square miles) of vertical control were established.

During fiscal year 1977, 1,318 standard topographic maps were published, covering 194,600 square kilometers (72,125 square miles), of the U.S. domain (fig. 37). Most of the maps are in the 7.5-minute series, 1:24,000-scale or 1:63,360 and 1:25,000 in Alaska. In addition to meeting the needs of many users, these are also the basic maps from which smaller scale and special maps are usually derived. As national coverage in the 7.5-minute series increases, the revision mapping workload increases. The need for revision of individual maps is determined based on the amount of change detected in comparing the published maps with current aerial photographs. Maps are reviewed



Digital profile data stored on magnetic tape (p. 73) controls this offline orthophotoprinter for production of displacement-free photographic images.

cyclicly with emphasis on urban, coastal zone, airports, major transportation corridors, and other areas of high national interest. In 1977, 3,987 7.5-minute maps were reviewed and 1,081 were revised.

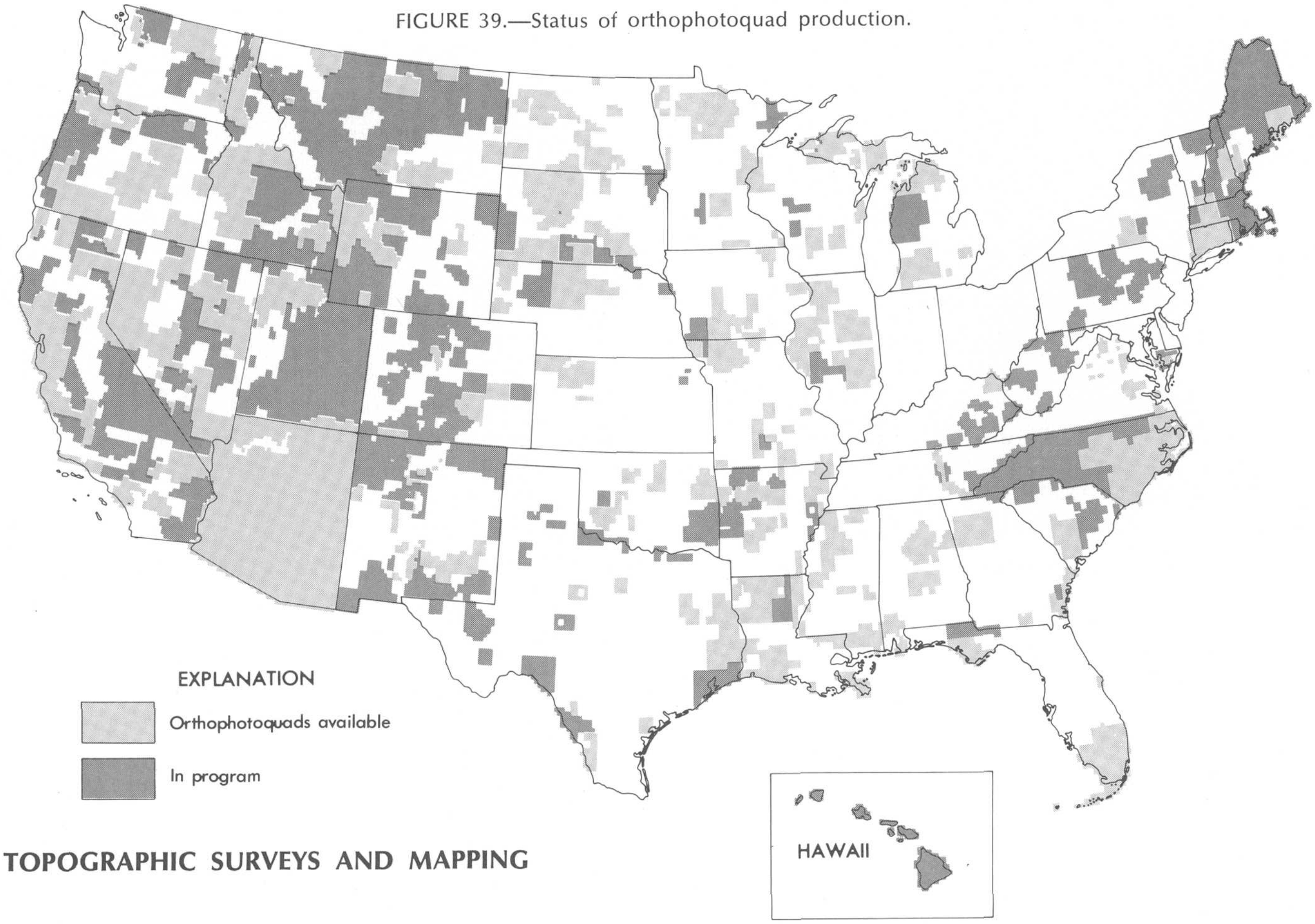
By reprocessing aerial photographs to correct for distortion, orthophotographs are produced. In a standard quadrangle format with grid and name information superimposed, the orthophotograph is called an orthophotoquad and has many applications as a map substitute or as a companion product to an existing map. About 4,100 orthophotoquads were prepared in 1977; printed stock is available for a small percentage of these, with the majority available for reproduction on request (fig. 39). Such orthophotoquads are normally produced in black-and-white, although techniques are being developed for adding color to aid the user in interpreting the imagery.

The orthophotograph may also be combined with the line detail of a topographic map. In some areas where conventional line maps are ineffective in portraying the special character of the terrain, orthophotomaps are substituted for the line maps. About 500 orthophotomaps are in various stages of production; the largest projects cover Florida swamps, Minnesota lake regions, and coastal stretches of Louisiana and Georgia.

SMALL-SCALE AND SPECIAL MAPPING

To meet the need for basic map data at various levels of detail and at scales between 1:24,000 and 1:250,000, the intermediate-scale map series was in-

FIGURE 39.—Status of orthophotoquad production.



troduced in 1975. The user can select the map content from over 20 categories of data and choose county, regional, or 30′ × 60′ quadrangle format. The capability is being developed to provide intermediate-scale map data in digital as well as graphic form. In fiscal year 1977, priority was given to completing 304 intermediate-scale maps for Federal and State agencies.

As part of the intermediate-scale program, the Survey has entered into an agreement with the Defense Mapping Agency for the joint preparation of 1:50,000-scale metric topographic maps for areas of the U.S. to meet military training requirements. Under this agreement, 1,800 maps will be produced throughout the conterminous U.S. within the next five

FIGURE 40.—Status of 1:250,000-scale map revision and digital terrain data.

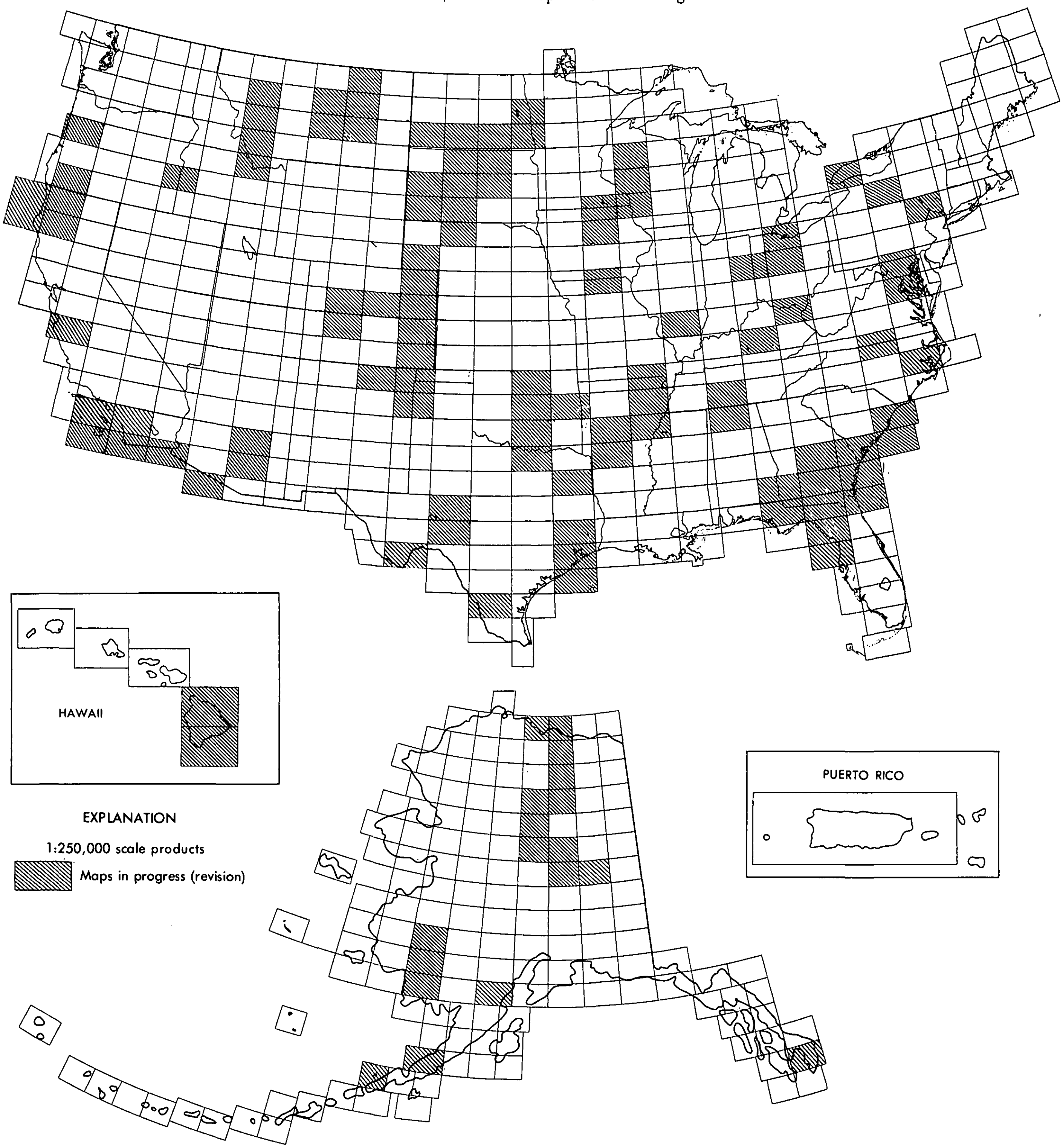
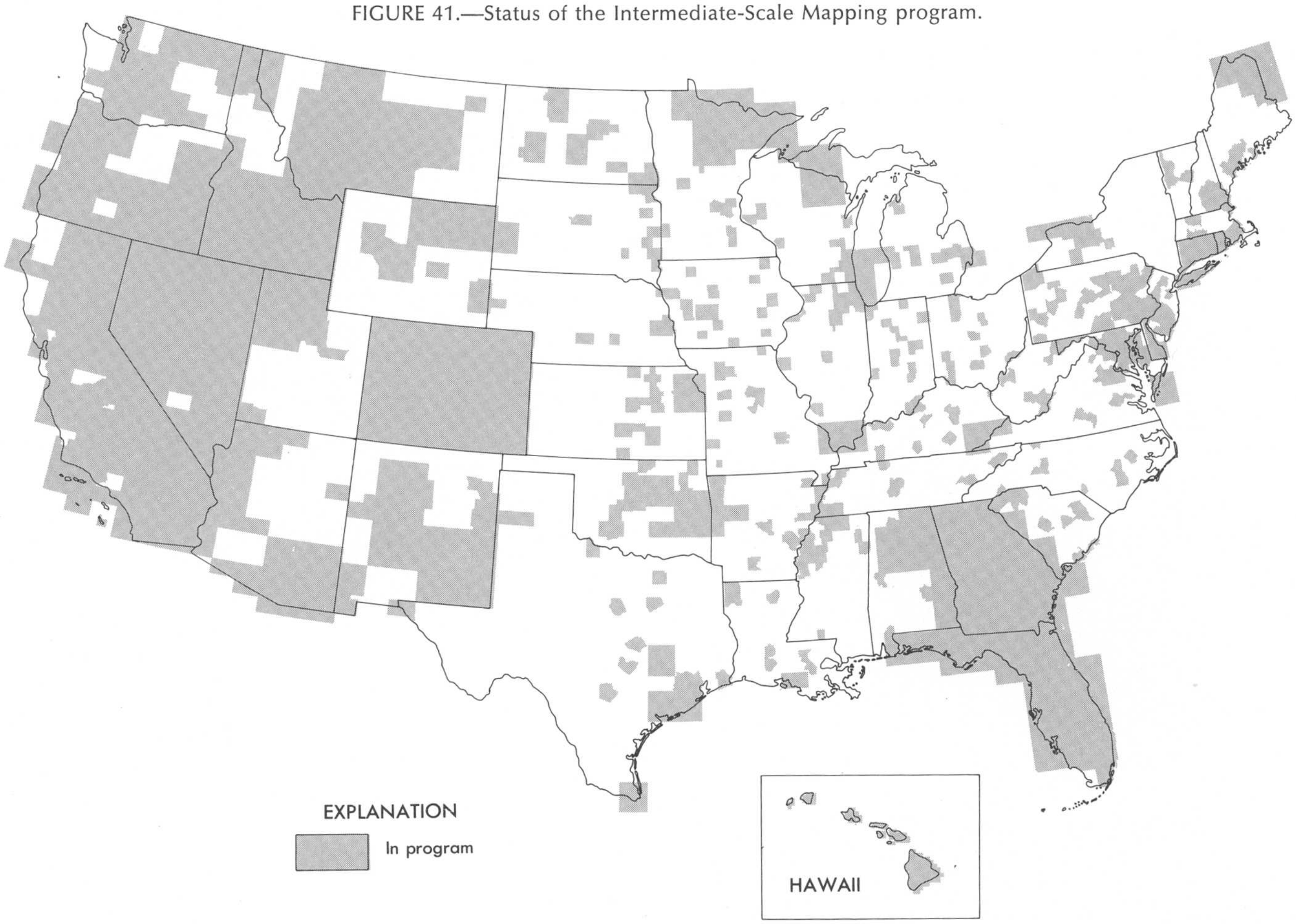


FIGURE 41.—Status of the Intermediate-Scale Mapping program.



years. Both USGS and DMA will be involved initially in the production of these maps with DMA preparing 128 maps and USGS preparing 129 maps during FY 1978. The maps will be prepared in accordance with jointly prepared specifications and can be used directly in the preparation of other intermediate-scale maps as required.

The 1:250,000-scale topographic map series provides the largest scale complete coverage available for the United States and is thus valuable to many Federal and State agencies with regional concerns. The maps are also used by the Survey for preparing State base maps, the 1:1,000,000-scale International Map of the World, various geologic maps, and special-purpose maps such as those produced for the Land Use and Land Cover program.

The 1:250,000-scale maps of Standard Metropolitan Statistical Areas are generally revised every five to seven years. Most other quadrangles in this series are revised every 8 to 10 years. In fiscal year 1977, 31 revisions were completed and 96 more were in production. Terrain data digitized from the contours on the 1:250,000-scale maps are available on magnetic tape from the National Cartographic Information Center (p. 85).

The joint USGS/NOS program for the preparation of topographic-bathymetric maps continues and involves 44 maps at the various scales of 1:24,000, 1:100,000, and 1:250,000. Four of these maps have been published and an additional 40 are in work. In fiscal year 1978, 36 additional maps will be entered into the program.

During 1977, two shaded relief National Park maps were published and one revised map was in work. The Park Service has requested two new maps and seven revised maps for the next fiscal year.

The experimental folded map program has been expanded to include 22 maps at various scales. These maps provide coverage of high-use recreational areas and points of significant interest. Analysis of early user responses indicates the products have been well received, especially in high-use recreational areas.

FIGURE 42.—Hilton Head Island and Parris Island lie in an area ▶ that is being mapped at 1:100,000 scale. On topographic/bathymetric maps such as these, bathymetric data and shoreline information from the National Ocean Survey are combined with USGS topographic data.


Parris Island
Capers Island
Scott
US NAVAL RESERVATION
MARINE RECRUIT DEPOT
BEAUFORT
RIVER
Ballast Cr
PARRIS ISLAND
Old Parris Island Airport
Ribaut Mon
Bermuda Bluff
Longwood
Fort Fremont
INTRACOASTAL WATERWAY
ST
Club Bridge
Creek
Station Cr
St Phillips Island
TRENCHARDS INLET
Moon Creek
Capers Island
Turtle I
Morse Island Cr
Bay Point Island
Daws Island
Daws I
RIVER
RIVER
Corn I
Pinckney Neck
Bobb Island
Pinckney Island
Buzzard
CREEK
WATERWAY
SKULL CREEK
INTRACOASTAL
PORT ROYAL SOUND
Whooping Crane Pond
Hilton Head Airport
Hickory Bluff
Jenkins I
Hilton Head Island
Jarvis Cr
278
Folly Field
Old House Cr
HILTON HEAD ISLAND
Spanish Wells
BROAD CREEK
JOINER BANK
Bass Head
White Ibis Pd
242
ATLANTIC

INTERNATIONAL COOPERATION

Formal agreements and reimbursably funded projects between the Geological Survey and various foreign nations continued during fiscal 1977. Two cartographers remain in Saudi Arabia to provide surveying and mapping support to the Survey's geologic mission as well as to the country. A 1:100,000-scale Landsat image map of the new Federal Capital Territory of Nigeria was compiled for use by the Nigerian Government. Two trainees from Nigeria assisted in the preparation of the map as part of an ongoing program of foreign participant training. Other nations, including Mali, Nepal, and Trinidad and Tobago, also selected members of their mapping agencies for training at Survey facilities.

Fiscal year 1977 marked the 20th consecutive year that the Survey participated in the National Science Foundation's U.S. Antarctic Research Program.

Four Geological Survey cartographers conducted

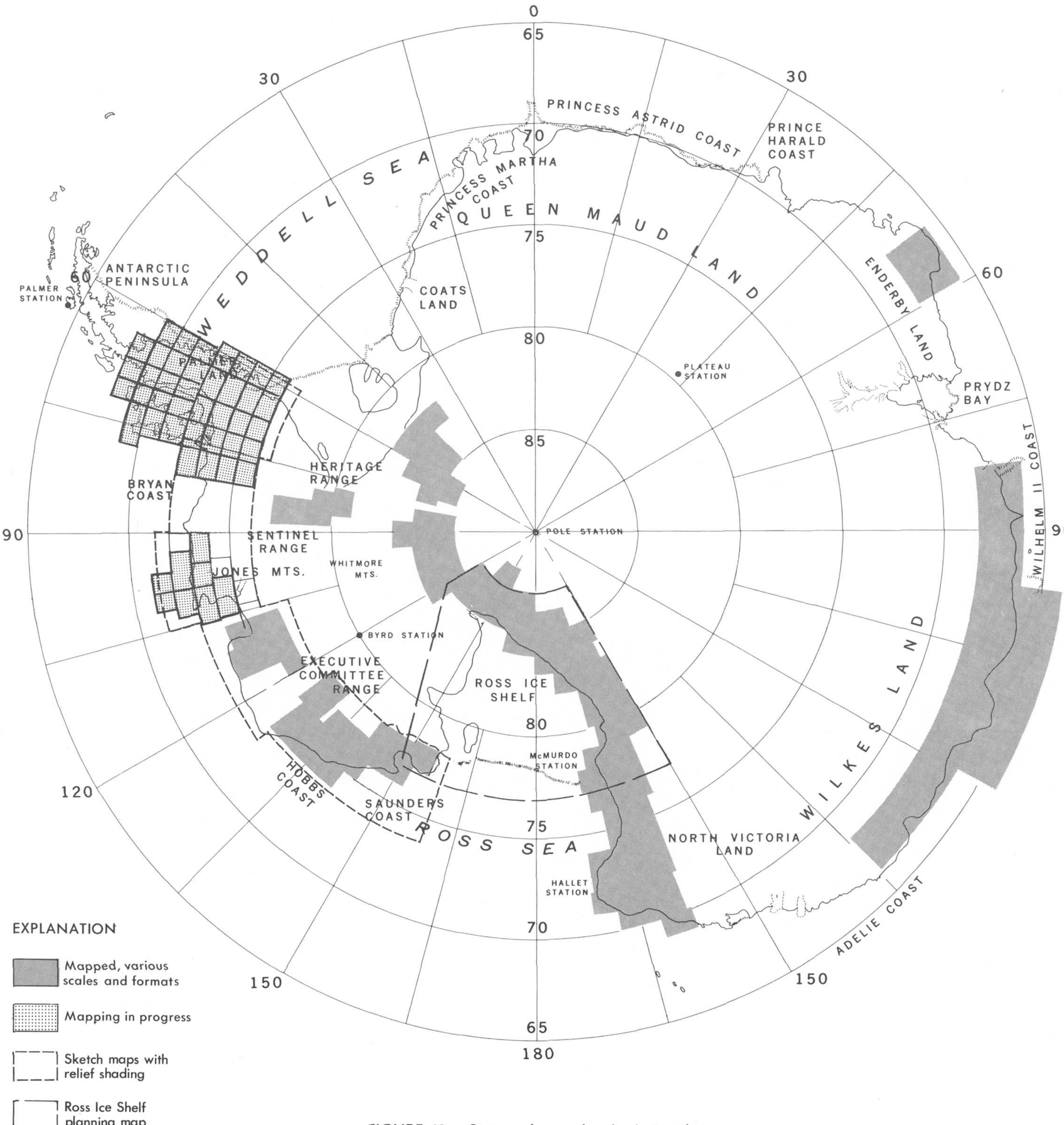


FIGURE 43.—Status of mapping in Antarctica.

ground surveys and operated satellite-tracking and seismological equipment in support of geophysical and glaciological studies.

This year, two 1:250,000-scale topographic maps of the Antarctic were prepared. In the Dry Valleys area eight topographic maps at 1:50,000 scale with 50 meter contour interval were published. These are the first of a new series in Antarctica covering areas of special scientific interest. Each map is formatted so that it covers 2 degrees of longitude and 15 minutes of latitude.

A brochure titled "Maps Published of Antarctica by the U.S. Geological Survey" was prepared and published this past year, containing color samples of different maps of Antarctica with information and a map index for ordering.

The first experimental U.S. Geological Survey map containing cartographic data south of the U.S.-Mexico border was compiled and distributed at the XI PAIGH General Assembly in Quito, Ecuador. This experimental map is the result of an agreement allowing the two nations to exchange cartographic information and coordinate their mapping efforts.

Seminars and workshops on map maintenance and Landsat image mosaicking were conducted by Survey personnel at several locations in Central and South America. Representatives from 15 Latin American countries participated.

THE NATIONAL CARTOGRAPHIC INFORMATION CENTER

In fiscal year 1977, the National Cartographic Information Center continued to expand its program to improve public access to U.S. cartographic data. Activities during the last year centered on negotiating information exchange agreements with other Federal agencies, opening additional offices and affiliates and developing new information and operating systems.

In January, the Second Federal Coordinating Conference was held with representatives of 34 Federal agencies and the States of Florida and Texas. Papers were presented on NCIC's progress since the first NCIC Coordinating Conference in 1974. A series of workshops were held during the conference to discuss recommendations for future NCIC activities.

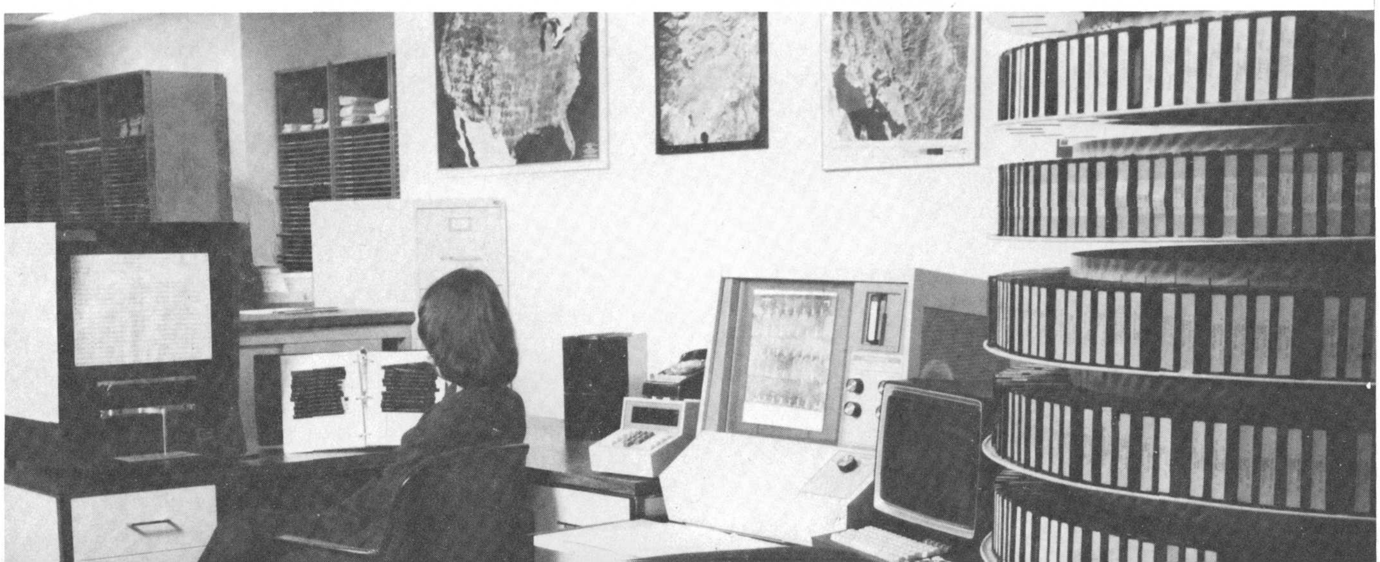
Agreements relating to NCIC were signed in the last year between the Geological Survey and the Department of Housing and Urban Development (HUD) and with the Defense Mapping Agency (DMA). NCIC will help HUD contractors and grantees locate cartographic data they need before starting HUD funded projects. In return, NCIC will be sent descriptions of any data produced during the projects. The DMA agreement provides for the exchange of cartographic products and information (including DMA domestic photographs).

During the fiscal year, a new office was opened at the National Space Technology Laboratories in Bay St. Louis, Mississippi as were four new affiliated State offices in Arizona, South Carolina, Georgia, and New Mexico. The State affiliates expand the services NCIC offers by providing more direct access to information and assistance.

A project to develop a master file of Survey topographic maps produced since the 1800's was completed in the fall. The file was then duplicated on 35mm roll microfilm and arranged alphabetically and chronologically for each State.

Completion of the file marks a large step in NCIC's program to use microfilm to organize the wide array of available cartographic data. As part of another microfilm information system, the second edition of the Aerial Photography Summary Record System (APSRS) was published in April, and the Aerial Photography Unit Record System in September. These systems are used to locate both aerial photography projects and single frames of photography.

To fill the requests for cartographic information the National Cartographic Information Center offices use computer indexing systems to catalog and access data. Microfilm and microfiche files permit viewing of both maps and aerial photographs before orders are placed. ▼



RESEARCH AND DEVELOPMENT

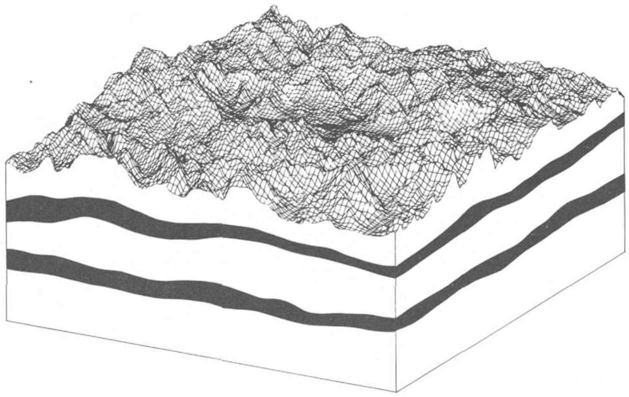
As a means of improving the quality and efficiency of map production and responding promptly to changing and urgent needs, the Survey continually investigates new cartographic instruments, methods, and techniques. Research by the Topographic Division continued particularly in development of computerized instruments and techniques for cartographic problems. These developments promise the means of undertaking tasks that are not practical in conventional cartography and of eventually increasing the productivity of the cartographic work force. Chief among developments in 1977:

- *Camera for Space Shuttle photography.* Design work has been completed for the large-format (23 × 46 cm) cartographic camera to be carried aboard an early Space Shuttle mission. Survey photographic specialists reviewed the camera specifications with NASA and Itek Corporation representatives and recommended technical improvements. After the camera is built by Itek, it will be tested, calibrated, and certified in the Survey's optical laboratory.
- *Mosaicking photographic images on film.* Working with film rather than paper, the Survey has developed an improved method of preparing photomosaics. In the new method the separate film images are not physically joined, as is done with paper prints, but are exposed step-by-step onto a single master film. The method is especially valuable in producing multicolor image maps, such as a Landsat image map for an entire State. Since the multispectral scanner on Landsat obtains simultaneous images in four bands of the visible and near-infrared spectrum, two to four separate master mosaics can be prepared for the area of interest. The separate mosaics are used to make photographic color composites or lithographic pressplates for publication. Practical training on the film-mosaics method was given to cartographers in Central and South America at the request of the Inter American Geodetic Survey and the Government of Chile.
- *Shallow-seas mapping with Landsat imagery.* As part of a continuing investigation of possible applications of Landsat imagery to cartographic problems, experimental editions have demonstrated that small-scale charts of shallow-sea areas can be prepared quickly and accurately. These areas are difficult and expensive to chart by conventional methods. This finding of the Survey's research is of interest to the agencies responsible for nautical charting, particularly the Defense Mapping Agency.

FIGURE 44.—The Ditigal Data Editing System interacts with a computer to integrate textual and graphic data files and to provide for editing, collecting, or reformatting digital data.

- *Digital applications team.* Since a single map or aerial photograph contains millions of bits of information, converting that information to digital form, storing and processing it, combining it with related information as needed, and recalling it in the form needed by a user present a formidable challenge to the practical cartographer. During the year, the Topographic Division formed a Digital Applications Team to consider the problems of digital cartography, design the data bank, select and design equipment, and plan the system for supplying data to users on request. The products supplied may or may not be in visible graphic form. For example, they may consist of digital elevation models recorded on magnetic tape.
- *Geographic names information system.* Geographic names are of interest to everyone and therefore constitute an important element in any cartographic data bank. It is estimated that more than 3,000,000 geographic names are in active use in the United States. An automated information system has been designed, which will eventually encompass all those names together with related information, such as location, size, and kind of feature. The files are organized primarily by State, with complete files now available for Massachusetts, Alaska, and Rhode Island. Another file contains all the formal decisions of the Board on Geographic Names since its founding in 1890.

Digital Cartographic Data Helps Assess the Nation's Coal Resources



Computer readable data speeds up computations.

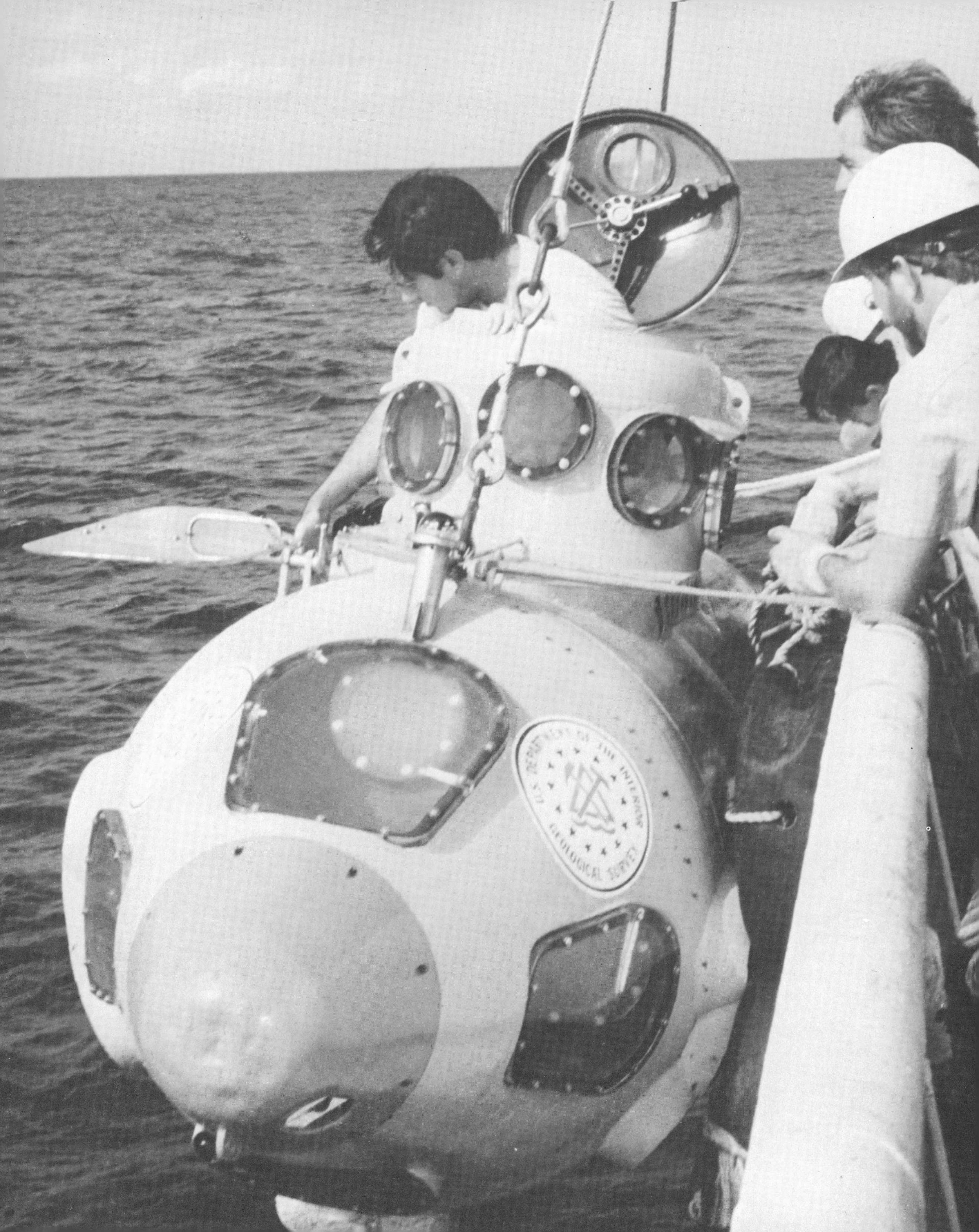
Map information traditionally drawn as lines can now be expressed in numerical terms that are input to computers for analysis and output in either numeric or graphic form. For example, data produced by the Topographic Division's Digital Cartographic Applications Program are now being used to improve the process of evaluating and classifying coal resources of the United States. A major problem in evaluating the development potential of coal resources is measuring the overburden above the coal deposit. This has traditionally been done by manually measuring elevation data from Geological Survey 7.5-minute topographic maps and using drill hole information on the depth to the coal deposits to compute approximations for the overburden.

New equipment procured as part of the Topographic Division's equipment modernization program is now being used to produce a three-dimensional, computer-readable model of the Earth's surface. This digital elevation model is used in the Geologic Division's computer-based National Coal Resources Data System to mathematically compute the overburden. This information is combined with digital files of the political boundaries and public land survey network, also derived by the Topographic Division from 7.5-minute maps, to evaluate the potential for mining known coal deposits on specific parcels of land. When fully developed, this more rapid and accurate method of evaluating and classifying coal resources will be used by the Conservation Division and the Bureau of Land Management in planning for the development of the Nation's coal resources on Federal land.

In fiscal year 1977, the Topographic Division supplied digital data for thirty-three 7.5-minute quadrangles. Ultimately about 8,000 quadrangles of data will be required to cover the Nation's known coal resource lands. △

As established, the files permit ready answers to questions about specific features and also permit assembly of comprehensive lists, such as gazetteers for States, or selective lists, for example, one describing all the streams in six counties. Assembly of complete files for the entire Nation is a long-range project that will take several years.

- *Metric map series.* Designs and specifications are being prepared for the several new series of metric maps, which will eventually replace the current series based on U.S. customary units of measurement. In consultation with the Defense Mapping Agency, specifications for the 1:50,000-scale series have been designed to meet both military and civilian requirements and thus reduce duplication of efforts. Using a similar concept, the design has been standardized for the combined topographic-bathymetric maps of coastal areas being produced jointly with the National Ocean Survey.
- *Automated mapping system.* Production trials of the Gestalt Photo Mapper II (GPM 2) led to several improvements in software to improve performance and in physical conditions to provide a clean-room environment for the photograph scanning and printing elements. The GPM 2 is an advanced system that automatically correlates pairs of aerial photographs and simultaneously produces orthophotographs, contour plots, and digital elevation models. As a result of the successful trials, a second unit of the GPM 2 has been ordered.


U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Geologic and Mineral Resource Surveys and Mapping

INTRODUCTION

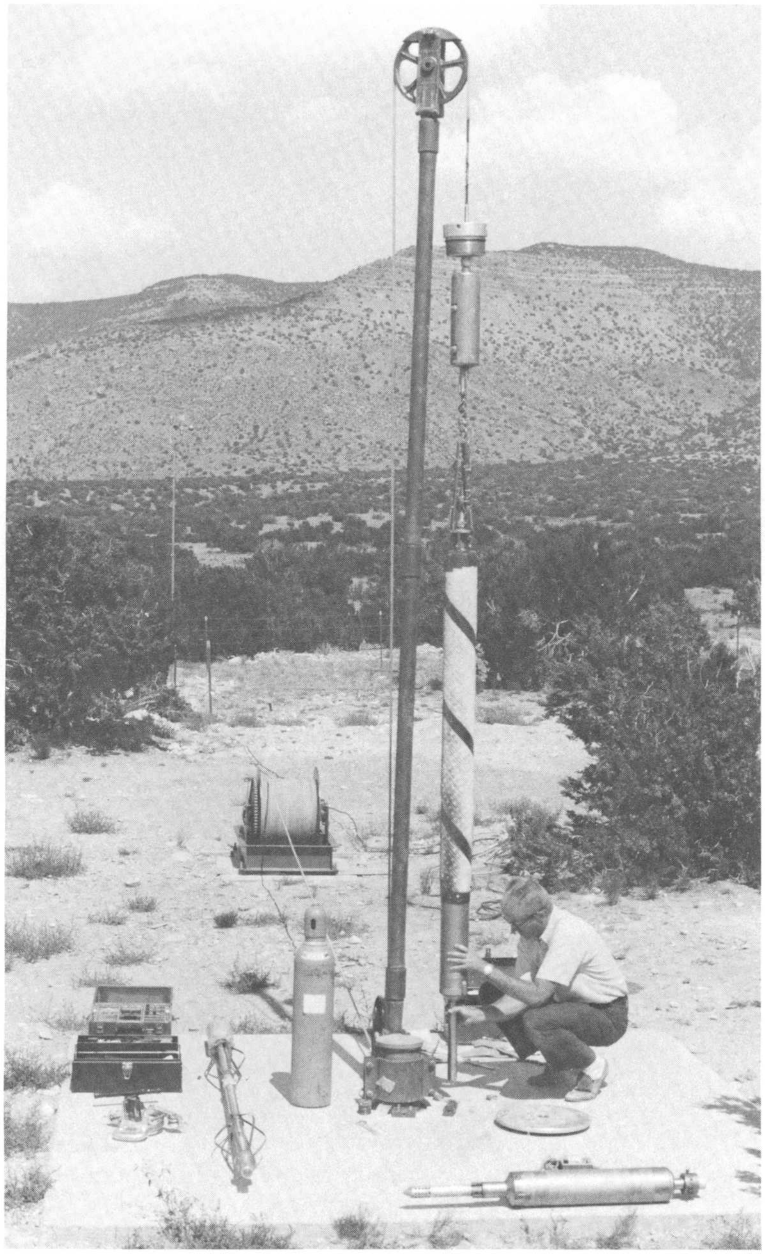
The Geologic Division conducts nation-wide geologic research and investigation programs through continuing research and data collection, as a background for many economic and social decisions. Geologic research is used to determine the structure of the Earth and to develop a better understanding of processes that influence our lives, such as earthquakes, volcanic eruptions, and landslides. Geologic data on the Nation's land, mineral, and energy resources are continually being collected, analyzed, and published to inform the public and provide a rational basis for utilization with minimum damage to the environment of the Earth's surface and atmosphere. The geologic programs are distributed among four main fields of activity; Land Resource Surveys, Mineral Resource Surveys, Energy Resource Surveys, and Offshore Geologic Surveys.

Land Resource Surveys provide geological, geophysical, and geochemical data needed to evaluate the Nation's land resources, the effect of human activity on the land, and the hazards to human life and property posed by natural forces and processes.

Mineral Resource Surveys provide information on the Nation's resources of metallic and nonmetallic minerals. Studies of processes and mineral formation provide a basis for identification of hitherto unknown sources of metallic and nonmetallic minerals. These studies are applied especially to public lands.

Energy Resource Surveys provide current, systematic, and thorough assessments of the Nation's energy resources. Information is established on the location, quantity, and quality of energy resources in the forms of coal, oil and gas, oil shale, uranium and thorium, and geothermal heat.

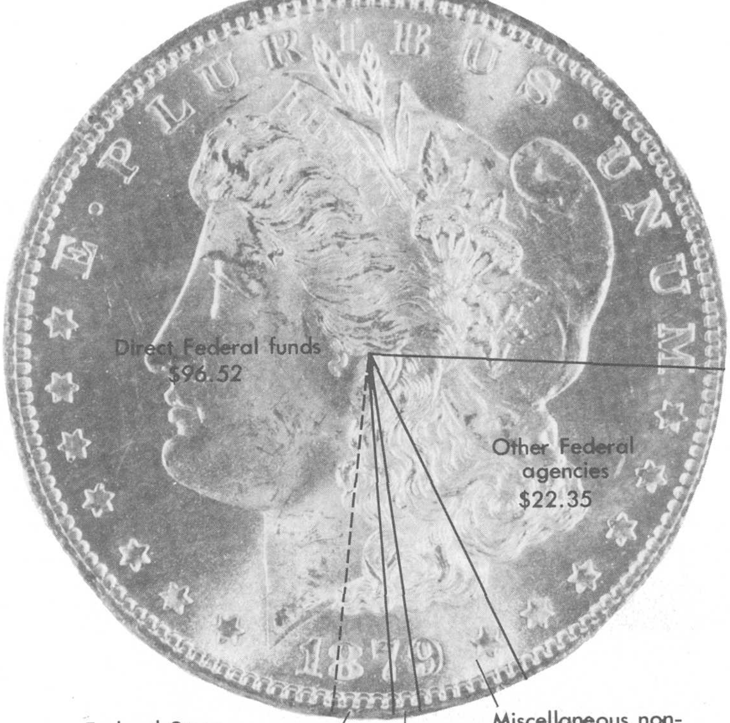
Offshore Geologic Surveys provide an assessment of the potential mineral and energy resources of the continental margins of the United States. Studies are also made to determine the geological and environmental hazards that may effect the siting of offshore drill rigs, production platforms, and pipelines.



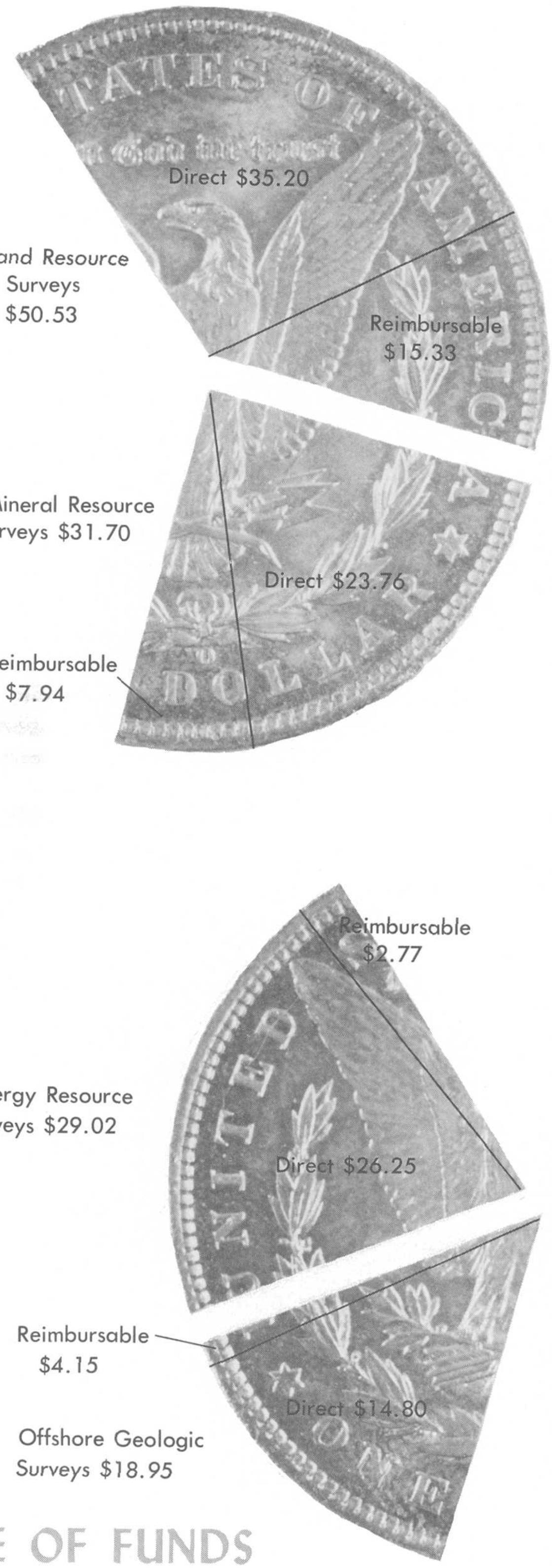
Seismic Research Observatory (SRO) borehole seismometer being prepared for installation. Installed at depths of 100 meters (328 feet), these record seismic events as part of the World-wide Standardized Seismograph Network (WWSSN).

◀ Two-man submarine used to study sea-floor features and collect ocean-bottom samples.

GEOLOGIC AND MINERAL RESOURCE SURVEYS AND MAPPING



SOURCE OF FUNDS



USE OF FUNDS

BUDGET AND PERSONNEL

In fiscal year 1977, obligations of the geologic and mineral resources surveys and mapping activity were $130.2 million. This amount was supplemented by approximately $1.4 million from 31 States and $22.4 million from other Federal agencies and miscellaneous non-Federal sources (table 12).

At the end of fiscal year 1977, the Geologic Division had 2,046 permanent full-time employees and 935 temporary or part-time employees.

TABLE 12.—*Geologic and Mineral Resource Surveys and Mapping activity obligations for fiscal years 1976–77 by program (dollars in millions)*

	Fiscal year 1976	Transition quarter	Fiscal year 1977
Total	**$115.55**	**$32.19**	**$130.20**
Land Resource Surveys	**46.61**	**12.95**	**50.53**
Direct Programs	34.08	9.68	35.20
Earthquake Hazards	11.26	3.78	11.88
Volcano Hazards	.68	.17	.69
Environmental Aspects of Energy	5.23	1.20	6.61
Arctic Environmental Studies	.37	.10	.45
Engineering Geology	1.29	.36	1.29
Regional Mapping and Analysis	15.25	4.07	14.28
Regional Geology / Geophysical Surveys / Geochemical Surveys	9.23	2.49	8.86
Dating and Correlation	4.76	1.26	4.11
Geologic Processes	1.26	.32	1.31
Reimbursable Programs	12.53	3.27	15.33
States, Counties, and Municipalities	1.17	.31	1.08
Miscellaneous non-Federal sources	.20	.06	.26
Other Federal agencies	11.16	2.90	13.99
Mineral Resource Surveys	**26.36**	**6.97**	**31.70**
Direct Programs	19.78	5.32	23.76
Mineral Resource Assessment	6.97	1.89	7.92
Wilderness Areas	1.46	.35	1.35
Alaska	3.48	1.03	4.44
Conterminous States	1.85	.46	1.91
Mineral Discovery Loan Program	.18	.05	.22
Mineral Commodities Assessment	2.02	.55	2.37
Critical Commodities	1.48	.42	1.73
Minerals for Energy Production	.54	.13	.64
Mineral Information System and Analysis	1.66	.69	2.14
Resources Processes Technology	5.23	1.27	5.87
Resource Techniques in Geochemistry and Geophysics	3.90	.92	5.46
Reimbursable Programs	6.58	1.65	7.94
States, Counties and Municipalities	.19	.05	.20
Miscellaneous non-Federal sources	4.74	1.05	6.17
Other Federal agencies	1.65	.55	1.57
Energy Resources Surveys	**23.96**	**6.75**	**29.02**
Direct Programs	23.00	5.86	26.25
Coal	2.31	.51	3.19
Oil and Gas	5.14	1.23	5.59
Oil Shale	1.07	.28	1.02
Uranium and Thorium	4.45	1.07	5.36
Geothermal Energy	8.65	2.55	9.61
Energy Resource Data System	1.38	.22	1.48
Reimbursable Programs	.96	.89	2.77
States, Counties, and Municipalities	.03	----	.03
Miscellaneous non-Federal sources	-----	----	.01
Other Federal agencies	.93	.89	2.73
Offshore Geologic Surveys	**18.62**	**5.52**	**18.95**
Direct Programs	15.47	3.92	14.80
Oil and Gas Resource Appraisal	9.49	2.24	9.23
Environmental Investigations	4.50	1.37	4.25
Marine Geology Investigations	1.48	.35	1.32
Reimbursable Programs	3.15	1.56	4.15
States, Counties, and Municipalities	.08	.03	.09
Miscellaneous non-Federal sources	-----	----	----
Other Federal agencies	3.07	1.53	4.06

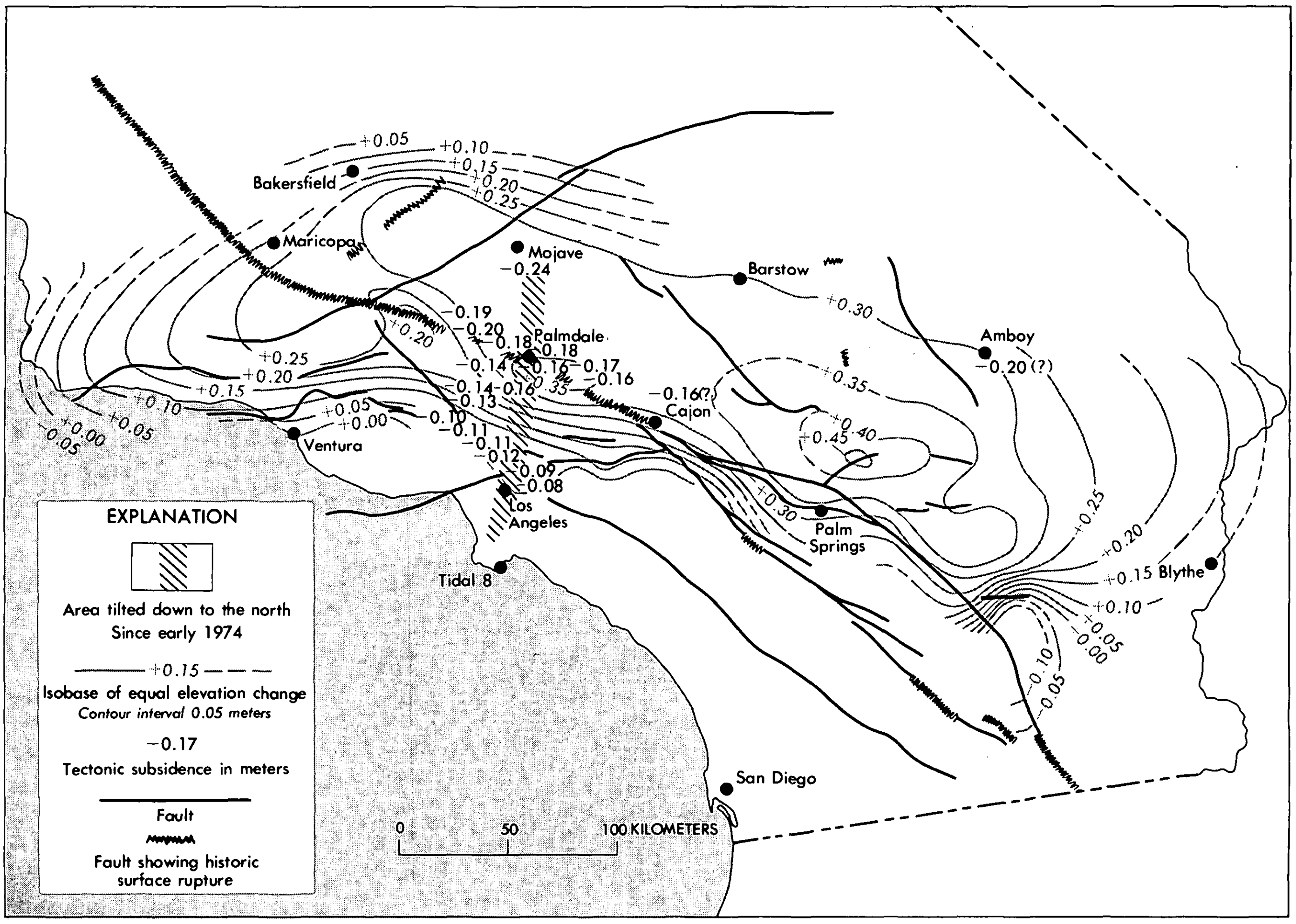
LAND RESOURCE SURVEYS

Earthquake Hazards

The goal of the earthquake hazards reduction program is to mitigate potential casualties, damage, and social and economic disruption caused by earthquakes. Reductions in the potential for hazard can be effected by land-use planning, emergency preparedness, and engineering design and application, all of which can be greatly enhanced if geological and seismological data and analyses are sufficiently refined. The Geological Survey effort comprises research on three major objectives: (1) to delineate and evaluate potentially hazardous areas and processes, (2) to develop the capability to predict the time, place, and magnitudes of earthquakes, and (3) to acquire and disseminate information on earthquake occurrences. Some accomplishments and activities for fiscal year 1977 were:

- Improving and continuing the operation of regional seismic nets in urbanized areas at high seismic risk—central California, southern California, Mississippi Valley, South Carolina, and Puerto Rico.
- Since discovery of the anomalous land uplift in southern California in late 1975, extensive efforts have been underway to define the shape and extent of the uplift, to understand its origin, and to assess its implications for future large earthquakes in this region. The extent of the uplift as of early 1974 was considerably larger than previously suspected, stretching eastward from Santa Barbara to the Colorado River, covering an area of about 90,000 square kilometers (35,000 square miles) mostly along a band bounded on the southwest by the San Andreas Fault (fig. 45). Maximum uplift occurred at a point north of Palm Springs, reaching about 45 centimeters (18 inches). However, uplift near Palmdale decreased

FIGURE 45.—Area of recent uplift in the Transverse Range and adjacent parts of the Mojave Desert in California, during the 1959–74 period. Uplift occurs along the San Andreas Fault.



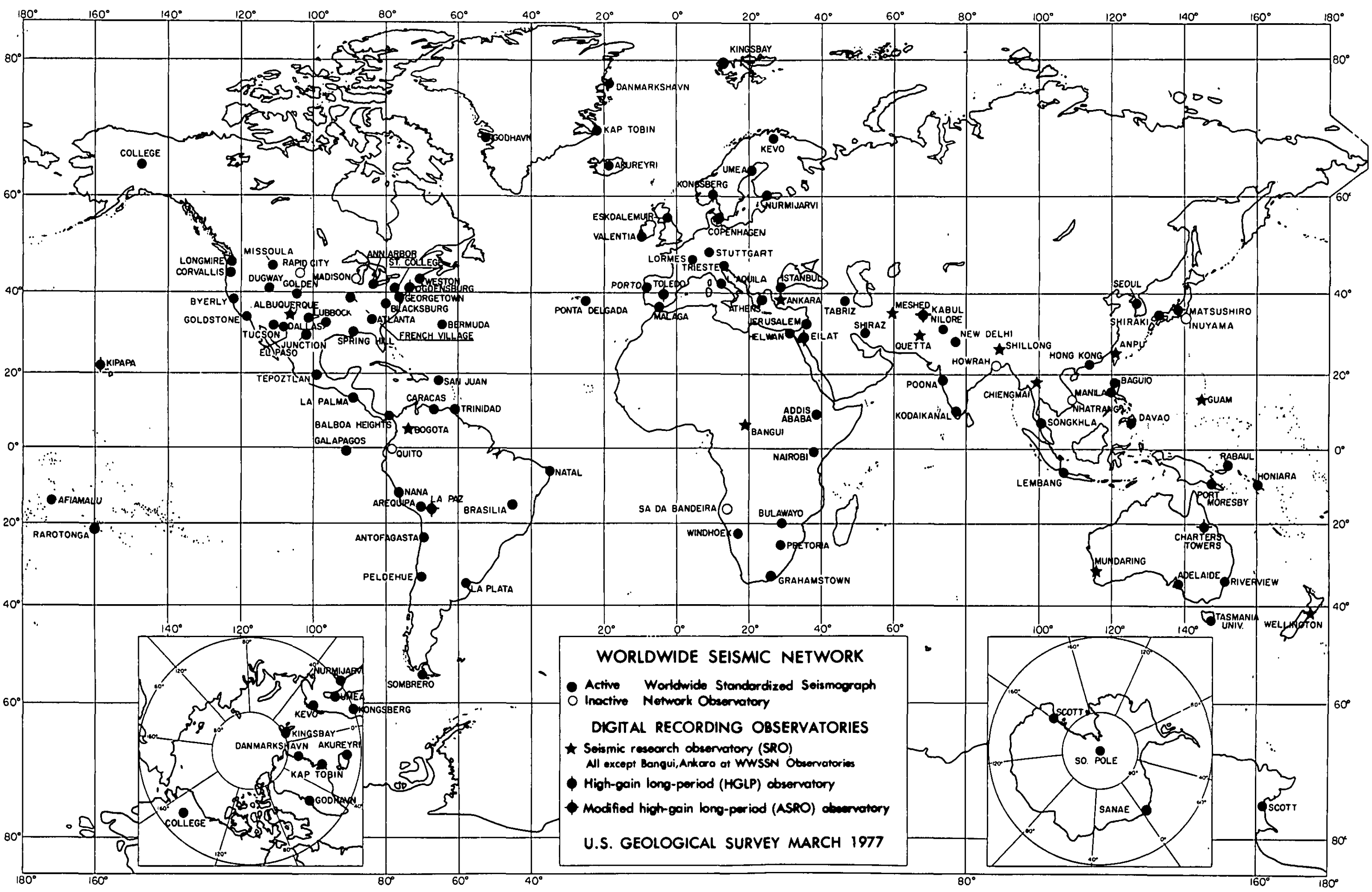
between 1974 and 1976 from about 35 centimeters (14 inches) to about 17 centimeters (7 inches). The origin of the uplift is still poorly understood, but it is likely that the uplift results in some way from the same stresses that store energy to be released as great earthquakes along the San Andreas Fault.

- A system for interpreting tectonic stress from measurements in bore holes has been developed and employed in the seismic regions near Charleston, S.C.; in New Madrid, Mo.; and in California. While this system—based on the hydrofracture technique—will undoubtedly be improved as experience is gained, it offers the first opportunity to measure reasonably directly the fundamental tectonic stresses that cause earthquakes.
- The Worldwide Seismic Network (fig. 46), managed by the Geological Survey, is being upgraded through the installation of 13 Seismic Research Observatory (SRO) photo data systems. Seven are now installed and operating. The highly advanced SRO system combines the noise-free sensitivity of the borehole seismometer with a modern digital recording system, effectively replacing all six seismographs of the older system and adding the capabilities of a gravimeter and two tiltmeters.
- Analyses of older geodetic data identified an early 20th-century episode of crustal uplift and subsequent collapse in southern California having approximately the same location, size, and shape as the present southern California uplift.
- Trench excavations of sedimentary layers disturbed by the San Andreas Fault near Palmdale show geologic evidence that 5 to 8 major fault slip events have occurred there since about 1 A.D.

Volcano Hazards

The principal objective of the Volcano Hazards Program is to mitigate the hazards posed by the active

FIGURE 46.—Worldwide Standardized Seismograph Network Observatories.



volcanoes in Hawaii and in the Cascade Range of Washington, Oregon, and California. Mauna Loa Volcano, Hawaii, continues to build toward its next eruption, Kilauea Volcano displays intermittent activity, and Mount Baker's fumarolic condition is under surveillance. Major accomplishments for fiscal year 1977 activities include:

- Intensive monitoring of Mauna Loa Volcano which early in the year continued to inflate with little accompanying seismic activity, but then slowed its rate of inflation later in the year.
- Precise measurement of a triangle linking Mauna Kea, Mauna Loa, and Hualalai volcanoes showed a significant increase in horizontal distance that reflects the inflation of Mauna Loa.
- Participation with Hawaii State and County officials and other Federal agencies on contingency planning and lava diversion studies in anticipation of a Mauna Loa eruption.
- Initiation of a study to monitor the concentrations of mercury found in the atmosphere and plants around Kilauea Volcano; since people working and living around the volcano may be absorbing harmful amounts of this toxic element.

Environmental Aspects of Energy

The Environmental Aspects of Energy program acquires, interprets, and distributes geologic, hydrologic, geophysical, geochemical, and related information that is essential to the analysis and solution of environmental problems associated with energy-resource development and the planning, siting, and construction of energy facilties.

ENERGY LANDS

The development of coal and oil shale, primarily by large surface mines, has the potential for causing widespread permanent damage to the environment in many areas across the country. The Energy Lands Program establishes basic knowledge of existing environmental conditions in coal and oil-shale resource areas in order to predict possible changes that would be caused by mining coal and oil shale, and then monitor the changes during energy development.

The studies include bedrock, surficial, and engineering-geologic mapping, tests of physical properties, climatic effects on ongoing geologic processes, rates of weathering, erosion, and inventory of ground and surface waters and the effects on aquifers, and inventory of the geochemical setting. Highlights for fiscal year 1977 include:

- Completion of the surficial geology in areas being mined for coal for fourteen 7½-minute quadrangle maps in the Powder River Basin of Wyoming, fourteen 7½-minute quadrangle maps in the San Juan Basin of New Mexico and Colorado, and seven ½°×1° quadrangles in the Williston Basin area of Montana.
- Preparation of an engineering-geologic map of the Buffalo-Sheridan area of Wyoming that shows the effects of coal mining on urban development.
- Preparation of maps showing the availability of water, the occurrence and thickness of coal, and the geologic hazards of the Kaiparowits Plateau area in Utah.
- In conjunction with preparation for evaluating the effects of surface mining, determination that a

Puu Kiái, ("Guardian Hill" in Hawaiian), America's newest topographic feature formed by lava and spatter of the September 1977 eruption on Kilauea's east-rift zone. The new hill is about 240 meters (800 feet) long, 140 meters (450 feet) wide, and 34 meters (110 feet) high. (*Photograph by Boone Morrison.*)

sharp increase in the rate of erosion in the Piceance Basin of Colorado began about 1875.

- Completion of a map of eastern United States locating carbonate-rock deposits suitable for use in flue-gas scrubbers.

REACTOR SAFETY RESEARCH

The operational safety of nuclear power reactors is very sensitive to geologic hazards such as fault movements induced by man's activities, and other failures due to foundation and construction materials. These hazards are evaluated to meet specific needs arising from applications for reactor licenses. Accomplishments during fiscal year 1977 include:

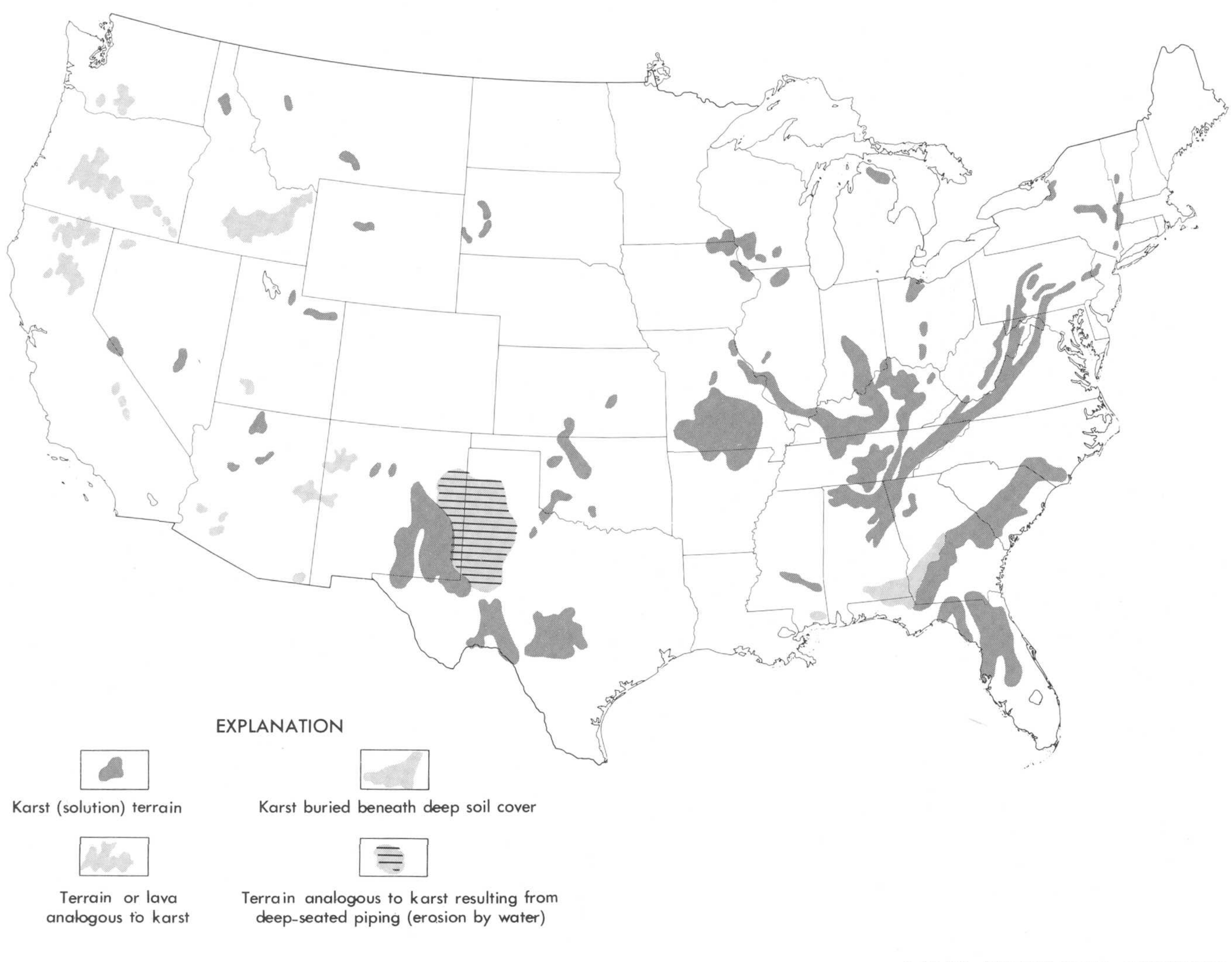
- Determining that the epicenter area of the 1886 Charleston, S.C., earthquake is now exhibiting modest seismic activity along a northwest trend.
- Demonstrating that the ground-water withdrawal in alluvial basins can cause surface faulting.
- Documenting the presence of surface faults that show recent movement in the Texas Gulf Coast area.

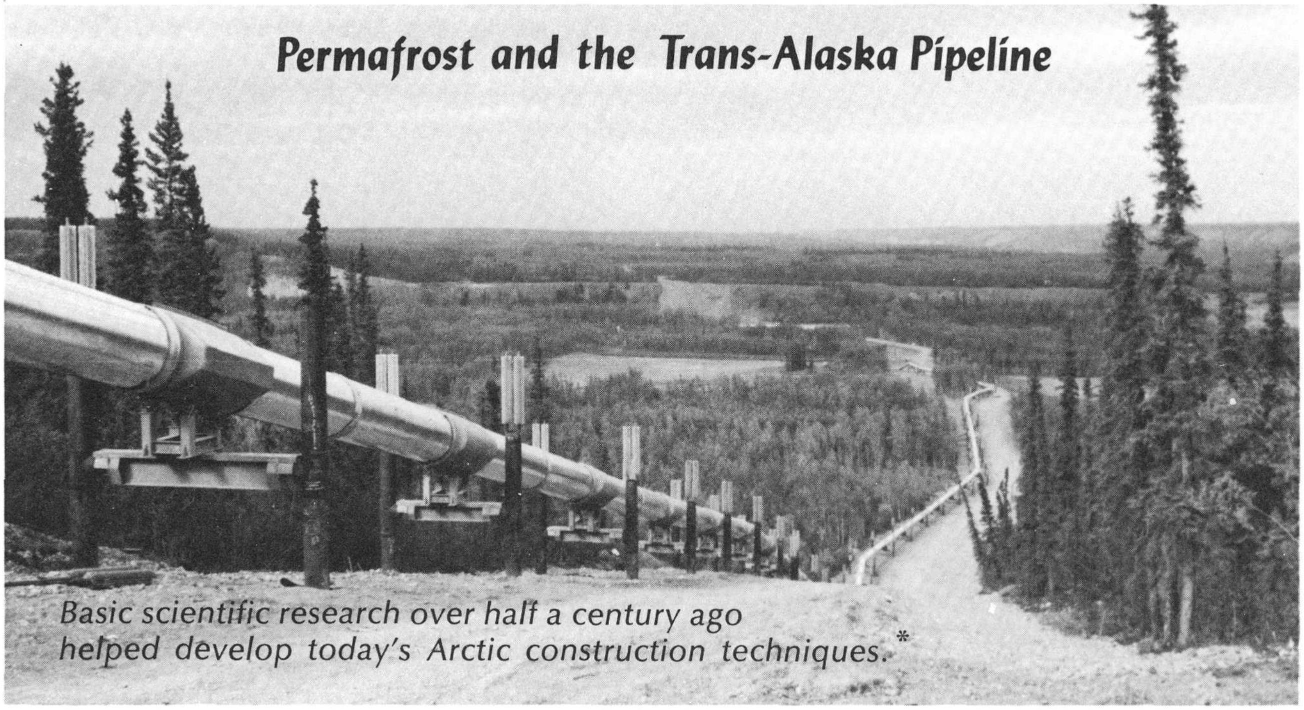
NATIONAL ENVIRONMENTAL OVERVIEW

Maps are being prepared, generally at a scale of 1:7,500,000, which will be useful for understanding environmental problems and for making decisions on land-use and mineral and energy resource development on a national scale. The following maps have been completed in preliminary form:

- Map showing areas of karst (solution) topography and related terrains (fig. 47).
- Map showing areas subject to volcanic hazards.
- Map showing areas of possible landslides.
- Map showing the location of present and proposed nuclear reactor sites.
- Map showing streams with flow rates of 8.5 cubic meters (300 cubic feet) per second.
- Map showing surficial clay, sand, silt, and gravel deposits.

FIGURE 47.—Generalized map of areas of karst (solution) and analogous terrains in the conterminous United States.





** The 1.2-meter- (4-foot-) diameter trans-Alaska hot oil pipeline is elevated above ground, on vertical support members (VSMs), where it crosses terrain underlain by permafrost. Heat tubes inside each steel VSM remove heat from the ground to maintain the frozen condition of the permafrost. Reflectors, which extend above the VSMs, dissipate the heat. Expansion of the pipeline is handled by a trapezoidal zig-zag configuration. The "shoes" under the pipe are teflon coated and allow the pipe to slide laterally on the steel crossmember connecting the VSMs. The outside of the pipe consists of 1.3-centimeter- (0.5-inch-) thick steel covered by 11.4 centimeters (4.5 inches) of fiberglass insulation which is in turn protected by a skin of thin steel.*

Arctic Environmental Studies

The arctic and subarctic regions of Alaska pose special geologic problems for the development of natural resources, transportation systems, and urban areas, primarily because of the unusual environmental conditions of permafrost or perennially frozen ground. Ice-rich permafrost soils undergo a change in volume and a loss in strength when thawed, resulting in severe damage to buildings and other engineering structures. The trans-Alaska oil pipeline (see above) is an example of a major engineering structure that required special design and construction procedures in order to overcome the adverse effects of permafrost soil. Major accomplishments of the program during fiscal year 1977 include:

- Continuing the compilation of engineering-geologic maps of the Arctic Coastal Plain between Prudhoe Bay and the Canadian border, which covers the route of the proposed 314-kilometer (195-mile) long Alaska Arctic Gas Pipeline.
- Continuing the engineering geologic mapping of the Tanana Valley transportation/development corridor between Fairbanks and the Canadian border, which covers the route of the proposed Alcan Gas Pipeline.
- Determining that northeastern Alaska is subject to earthquakes although the region was previously considered to be essentially aseismic. Seismic stations recorded 69 earthquakes of magnitude 1 to 4 in a one-year period.
- Continuing the exchange program with Soviet scientists and engineers concerned with pipelines, permafrost, and environmental protection.

Engineering Geology Studies

Engineering geology is the application of geologic knowledge to civil engineering practices to gain a better understanding of the effects of geologic processes and materials on man's use of the land and on the design and construction of man-made structures.

Permafrost, the perennially frozen ground that is present over extensive areas in the Earth's polar regions, has long been a curiosity for scientists and a headache for engineers.

Members of the U.S. Geological Survey have been studying permafrost (perennially frozen ground) in Alaska since before the turn of the century. In those early years, permafrost was considered only a scientific curiosity. Nevertheless the work done by E. K. Leffingwell in northern Alaska during nine summers and six winters (1906–1914) is a classic example of basic scientific research on permafrost. This research resulted in the "contraction crack" theory which explained the origin and growth of ice-wedge polygons. This research was proved essentially correct many years later by A. H. Lachenbruch.

During World War II, the military experienced serious large-scale engineering problems in Alaska. Differential settlement of the ground surface caused by the thawing of permafrost damaged large buildings, runways, and other structures. The military called on the Survey to help solve these engineering problems. Knowledge of permafrost gained by the early scientific research in Alaska, and in other countries (especially the U.S.S.R.), made it possible for the Survey to make recommendations for the proper design of structures and the proper construction procedures that would minimize the potentially deleterious effects of permafrost.

In 1969, several major oil companies proposed constructing a 4-foot-diameter, 800-mile-long pipeline to carry hot oil from the Prudhoe Bay field in northern Alaska to Valdez, an ice-free seaport in south-central Alaska. The original plan called for the entire pipeline to be buried except for a 45-mile section along the northernmost part of the route. The original estimate of cost for the project was $900 million.

A map prepared by a Survey Geologist, O. J. Ferrians, showing the general distribution and character of permafrost in Alaska, indicated that extensive stretches of the pipeline route were underlain by ice-rich, fine-grained permafrost soils. It was obvious, as a result of past research in Alaska, that the industry plan, if allowed, would result in both economic and environmental disaster. A hot pipeline would cause the ice-rich permafrost soils to thaw. That in turn would cause extensive adverse environmental impacts, extremely serious maintenance problems, and even rupture of the pipe. Because of the seriousness of the problem, the Survey initiated a major effort to resolve these problems by taking a lead role in the preparation of the Environmental Impact Statement and Technical Stipulations covering this project, by engaging in a continual dialogue with industry engineers, and by preparing special reports.

The fact that the pipeline has been constructed with approximately fifty percent of the line elevated aboveground on piles in order to mitigate the permafrost-related engineering problems demonstrates the success of the Survey's role in this project. Costing almost $8 billion, it turned out to be the largest engineering project ever undertaken by private enterprise. △

A major objective is the recognition of geologic features that may be hazards to man's structures and (or) activities. Some accomplishments and activities for fiscal year 1977 are:

- Participating in a program to evaluate foundation failures, landslides, and liquefaction effects resulting from the March 4, 1977, earthquake in Romania.
- Identifying a 15-kilometer (9.3-mile) long scarp near Picacho, Ariz., formed since 1961, which is attributed to faulting caused by ground-water extraction.
- Participating in a review group investigating the causes of the Teton Dam, Idaho, failure in June 1975.
- Continuing studies of the engineering behavior of bedrock and surficial materials in relation to surface and underground mining.
- Investigating, for the World Bank, landslides and slope stability for municipal utilities modernization at La Paz, Bolivia.
- Investigating a massive ancient landslide at a dam and reservoir site in Guatemala.
- Participating in a geologic feasibility study for locating a new capital city for Nigeria.
- Continuing studies related to underground nuclear weapons tests at the Nevada Test Site for the Department of Defense and the Energy Research and Development Administration.
- Continuing investigations of potential media (salt, argillite, igneous rock, and shale) for disposal of radioactive waste for Energy Research and Development Administration.

Regional Mapping and Analysis

The objective of this program is to increase and refine the knowledge of the geologic framework of the Nation. Products of the program are essential to all the other geologic work and are widely used by the Public. The program provides fundamental information by determining the distribution and physical and chemical properties of rocks and other geologic materials, investigating the relative and absolute ages of earth materials, and investigating the processes that are responsible for the formation, modification, and distribution of materials within the Earth and on its surface.

GEOLOGIC MAPPING

The selection of areas to be mapped is guided by relevance to environmental and resource problems, by the needs of other Federal and State agencies, and by the need for geologic information in the area. Through cooperative agreements with several States, the program furnishes Statewide geologic mapping and analysis. Major accomplishments for fiscal year 1977 include:

- Finishing the detailed geologic mapping of the Commonwealth of Kentucky at a scale 1:24,000. This 17-year cooperative program has stimulated the economic development of the State by providing detailed information on clay, coal, limestone, and other mineral deposits, by providing a basis for resource and environmental appraisals. It promises to repay the investment many-fold.
- Completing a new geologic map of Colorado at a scale of 1:500,000.
- Recognizing that the Pacific plate has repeatedly underthrust the North American plate during the early and middle Tertiary time in the Olympic Mountains of Washington (see Geological Survey Annual Report for 1976, p. 39).
- Demonstrating that the indurated calcic soils (caliches) of arid central New Mexico are good markers to establish the presence or absence of faulting.
- Recognizing that the eastern margin of the Blue Ridge may be a zone of post-Triassic tectonic uplift.
- Discovering that the Jurupa Mountains south of Fontana, Calif. have been elevated more than 335 meters (1,100 feet) by relatively recent faulting.

GEOPHYSICAL SURVEYS

Studies of the physical properties of the earth, such as variations in magnetism, paleomagnetism, gravity, electrical properties, and heat flow, provide useful information on the characteristics of rocks beneath the earth surface. The development and improvement of these measurements and a better understanding of what they mean increases the importance of this program. Some of the activities and accomplishments of this program for fiscal year 1977 were:

- Developing a technique to eliminate the distortion in magnetic maps caused by topographic relief. Using this technique satellite data can be used to produce distortion-free magnetic maps of large areas such as the United States.
- Determining from paleomagnetic measurements that a large Mesozoic terrane near McCarthy, Alaska, originated south of its present position with respect to North America. It is an exotic fragment fastened to the continent by plate-tectonic processes.
- Discovering a major crustal feature, the New York-Alabama lineament, by aeromagnetic mapping in the Appalachian basin. It is about 1300 kilometers (800 miles) long and strikes northeast from northeastern Alabama to the Adirondak uplift. The lineament is well defined on a recently completed aeromagnetic map of West Virginia.
- Completing a regional gravity survey of Glacier Bay, Alaska, using radar measurements to correct for thickness of ice. Large gravity highs associated with ultramafic bodies suggest that the bodies extend to great depth. These measurements were made through ice more than 1,200 meters (3,900 feet) thick.

GEOCHEMICAL SURVEYS

Geochemical information establishes baseline against which to compare future observations. It is required for pollution control, environmental health research, and energy and mineral resource evaluations. Continuing activities include the development of statistical analystical methods, the compilation of rock analyses, the operation of a geochemical-data system, the investigation of trace elements in the human food chain, and studies of the geochemistry of urban areas. Major accomplishments for fiscal year 1977 include:

- Establishing a program to determine trace-element concentration in areas of coal strip mines.
- Determining pollution levels of trace metals in soils and vegetation around uranium processing plants. For example, selenium and molybdenum are concentrated in vegetation.
- Demonstrating statistical methods for evaluating the trace-element chemistry of marine sediments.

DATING AND CORRELATION—PALEONTOLOGY AND STRATIGRAPHY

Paleontology, the study of fossils, and stratigraphy, the study of sedimentary rocks in which fossils occur are important sources of basic geologic information. Interpretations are developed to determine the age, correlation, and paleoenvironment of sedimentary rocks, to study evolutionary changes of species, and to provide a framework for major events of the geologic past. Paleontologic and stratigraphic information is used as critically necessary background data in other programs throughout the Survey and provides knowledge to respond to future problems that require an understanding of the history of the geologic framework of the Earth. Highlights during fiscal year 1977 include:

- Dating marine and nonmarine Cretaceous age rocks in the Atlantic Coastal Plain using fossil spores and pollen grains.
- Discovering that some major copper deposits of the Wrangell Mountains in Alaska are localized in sedimentary rocks that were deposited above high tide on-shore and in areas of high salt concentrations. This has led to the discovery of other promising copper deposits.
- Refining the age of potential petroleum producing rocks of Paleozoic age of the Appalachian Basin and the Great Basin-Rocky Mountain region.
- Using a newly developed method of freeing radiolarian and other microfossils from chert, siliceous shale, and cherty tuffs. This has enabled Survey geologists to date sedimentary rocks that until now could not be dated directly.

DATING AND CORRELATION—ISOTOPE GEOLOGY

Studies of isotopes provide some of the basic data necessary for understanding Earth history and for solving a variety of problems ranging from mineral exploration to dating faults, predicting earthquakes, storing nuclear wastes, and siting nuclear plants. Major activities and accomplishments during fiscal year 1977 are:

- Began operation of new, highly sensitive equipment for the more precise dating of material less than 40,000 years old. Greater sensitivity of the instrument, which measures the amount of radioactive carbon-14, is achieved by burying the counting chamber 9 meters (30 feet) below the surface of the ground.
- Completed a tandem mass spectrometer (fig. 48) for the measurement of large isotopic ratios in ultrasmall samples.
- Developed a probe using the radioactive isotope Californium-252 to analyze coal, encountered in drill holes, for heat values, and for content of ash, sulfur, and other elements.

GEOLOGIC PROCESSES

Studies of geologic processes are made to support the other programs and because many of these processes bear directly on health and the environment. Current studies include the thermodynamic properties of uranium compounds as related to the solution mining of uranium and the disposal of radioactive wastes, the occurrence and characterization of asbestiform minerals and their application to future public

FIGURE 48.—Survey scientist operating a new tandem mass spectrometer used to measure isotope ratios on ultrasmall samples. This sophisticated spectrometer is equivalent to two normal mass spectrometers.

health legislation, the mechanism of volcanic eruptions, and gas monitoring of volcanoes as a possible means to predict eruptions. Activities and accomplishments for fiscal year 1977 include:

- Determining the eruption history in recent time of the basaltic rocks in the Yakima region of Washington. The basalt flows came from many vents through the period from about 8 to 26 million years ago.
- Establishing a National Center for Thermodynamic Data of Minerals to supply refined data for testing proposed theories of geologic processes.
- Determining the oxidation-reduction conditions in the upper mantle of the Earth. This could increase the understanding of magma genesis and the evolution of the Earth.

MINERAL RESOURCE SURVEYS

Mineral Land Assessments

Areas judged to have high mineral potential are under study in Alaska and the conterminous United States as part of continuing systematic investigations of the mineral resource endowment of the Nation. The Survey also conducts mineral resource assessments of Federal lands administered by other agencies and on lands for which Congressional actions require evaluation of mineral potential before reclassification.

ALASKA

Mineral resource assessments are under investigation in the proposed D–2 lands specified in the Alaska Native Claims Settlement Act and in other areas having high mineral potential. The accumulated information and data are published in folios containing a text and geologic, geochemical, and geophysical maps, interpretive maps based on Landsat photos, and maps showing the location and nature of potential mineral resources. Highlights of the program during fiscal 1977 include:

- Compilation of a map of the State of Alaska at a scale of 1:2,500,000 showing the distribution of rock types known to be associated with certain kinds of metallic mineral deposits.
- Completion of mineral resource assessments at a scale of 1:1,000,000 for approximately half of the the D–2 lands.
- Completion of detailed resource assessment studies of 4 key mines and mining districts within or adjoining proposed D–2 lands.
- Continuation of mineral resource assessments in 17 quadrangles at a scale of 1:250,000.

CONTERMINOUS STATES

Comprehensive studies of the mineral resources of the conterminous States are being conducted at a scale of 1:250,000 in areas with a high proportion of Public land and having a high probability for mineral deposits. These assessments provide information on the existence of present and possible future supplies of valuable mineral resources and gives the Federal, State, and local governments a basis for making decisions on land-use planning. Major accomplishments for fiscal year 1977 include:

- Publishing the "Mineral and Water Resources of Wisconsin" report which describes the locations and extent of water and mineral resources in the State.
- Publishing a reconnaissance geologic and geochemical map of part of the Medford-Coos Bay, Ore., 2° quadrangle. The geochemistry shows anomalous amounts of molybdenum in the area.
- Discoveries of geochemical anomalies in the West End Creek area, Idaho, and in the Wickes district, Montana, have spurred extensive exploration by industry that resulted in locating significant metal resources.
- Discovery of sedimentary phosphate deposits in northern Michigan.

WILDERNESS AREAS

Areas of unspoiled beauty are recognized as a national heritage worthy of preservation, but some of these areas may also host future supplies of critically needed mineral resources. More than 12.5 million hectares (31 million acres) have been proposed for wilderness status. To date, the Survey, in cooperation with the U.S. Bureau of Mines, has completed mineral resource surveys on 6.9 million hectares (17.0 million acres) of land proposed for wilderness. Accomplishments for fiscal year 1977 include:

- Publication of 12 wilderness area mineral assessment reports:
  1. Great Bear Wilderness study area, Montana
  2. Chama-Southern San Juan Wilderness study area, Colorado
  3. Mt. Shasta Wilderness study area, California
  4. Sheep Mountain Wilderness study area and Cucamonga Wilderness, California
  5. North Absaroka Wilderness study area, Montana
  6. Eagle Cap Wilderness, Oregon
  7. La Garita Wilderness, Colorado
  8. Contiguous Uncompahgre Wilderness study area, Colorado
  9. Laramie Peak Wilderness study area, Wyoming
  10. Granite Fiords Wilderness study area, Alaska
  11. Ramsey's Draft Wilderness study area, Virginia
  12. New River Gorge, West Virginia

- Locating significant mineralized resources in three of the designated wilderness areas.
  1. Good gas potential in the Great Bear area in the disturbed belt in Montana.
  2. Good potential for copper and molybdenum in an altered area in the Chama-Southern San Juan area, Colorado.
  3. Potential resources of gold, sliver, copper, molybdenum, nickel, lead, zinc, platinum group metals, uranium, iron, and manganese in the North Absaroka Wilderness study area, Montana.

INDIAN LANDS

Joint Bureau of Mines and Geological Survey mineral resource assessments of Indian lands were continued in fiscal 1977. Assessments based on studies and interpretations of published and unpublished reports, maps, and tribal records of 36 reservations, with a total area of 2,519,978 hectares (6,227,000 acres), were also completed.

Reconnaissance geologic mapping, and geophysical and geochemical studies were completed on the Pine Ridge Indian reservation, South Dakota, with an area of 763,462 hectares (1,886,556 acres). Similar studies are continuing on the Flathead and Fort Belknap reservations in Montana, and the Papago reservation in Arizona—a combined land area of 2,288,131 hectares (5,654,095 acres).

Mineral Commodity Assessment

Mineral commodity specialists collect data worldwide on the geologic occurrences and the current and probable future availability of mineral commodities. They develop new geologic concepts useful in the assessment of and exploration for mineral resources. Information on the location, quantity, quality, and geologic characteristics of deposits of 43 mineral commodities is continually appraised. New techniques in exploration are of particular interest to the mineral commodity specialist as mineral potential is being assessed in new regions and in new geologic settings. Major accomplishments for fiscal year 1977 include:

- Participation of mineral commodity specialists as speakers and panelists at seminars and conferences dealing with the geologic and economic availability of minerals and fuels. This is an important part of the accumulation, interpretation, and dissemination of resource information among Federal and State agencies, the public, and the industrial and academic sectors.
- Publication of a map of known deposits and occurrences of the platinum-group metals in the conterminous States.
- Determination that Pleistocene age sands in the Port Leyden 7½-minute quadrangle in New York contain 28 million metric tons (31 million tons) of titanium minerals and 1.8 million metric tons (2 million tons) of zircon in wedge-shaped bodies up to 85 meters (279 feet) thick.
- Publication of symposium papers entitled "Lithium Resources and Requirements by the year 2000." Potential future demand for lithium for energy-related uses indicates that there is a need to identify large new lithium deposits within the next decade or two.
- Discovering that Salar Uyuni, Bolivia, is potentially the world's largest known lithium deposit and is also a major new source of potassium for use as fertilizer.
- Discovering that uranium is associated with mercury in the Opalite district of Oregon-Nevada. This finding suggests that other opalite-type mercury deposits may contain significant amounts of uranium.

Mineral Resource Information Systems and Analysis

This program provides data on mineral resources needed for national mineral policy decisionmaking and assists the Survey's energy and mineral resource programs. Storage, retrieval, manipulation, and the display of geologic and commodity information for mineral and energy resource evaluation and prediction are continually being improved by new and innovative computer techniques. Highlights for fiscal year 1977 include:

- Successful developing and testing a discovery process model which predicts the size distribution of petroleum deposits to be discovered with a given number of wildcat wells within an exploration play. These predictions will form the basis for calculating reservoir discovery, development, and production costs of future discoveries.
- Developing a quantitive method of integrating data from diverse disciplines such as geology, geochemistry, geophysics, and remote sensing. A recent application of the technique in the Coeur d'Alene district of Idaho identified several potentially favorable exploration target areas.
- Compiling and publishing a generalized geologic map and six mineral distribution maps of South America. These maps show the type and size of deposits of 15 major mineral commodities—copper, lead-zinc, iron, bauxite, nickel, tin, tungsten, chromium, manganese, molybdenum, vanadium, and precious metals.
- Updating the Petroleum Data System which now contains data on more than 70,000 oil and gas fields and reservoirs in the United States and Canada and is available to any user as a commercial timesharing option at nominal cost. The system is being upgraded in two important ways:

  1. The U.S. Bureau of Mines is doing special studies on all large fields, including evaluation of reserves.
  2. All field outlines are being digitized in order to permit graphical display according to selected reservoir parameters included in the statistical file.

- Making publicly available the U.S. Geological Survey's CRIB (Computerized Resource Information Bank) on a world-wide timeshare computer network. The CRIB master file contains 38,386 records of location, size, character, and other data on mineral deposits. Several thousand additional records are in various stages of processing.
- Making fully operational a geothermal resources data base (GEOTHERM) that contains 2,000 records on fields, wells, and analyses from New Zealand, Mexico, Republic of China, and the United States.
- Developing the GARNET (Graphic Analysis of Resources by Numerical Evaluation Techniques) system which is a set of computer programs de-

signed to aid the geologist analyze irregularly spaced, point-located field observations. The GARNET system is a component of the National Coal Resources Data System for the computation of coal resources and the mapping of relevant coal resource information.

Resources Processes

Knowledge is developed and expanded on the fundamental mechanisms by which minerals are deposited in large enough concentrations to become resource material. This knowledge is essential for accurate assessment of, or successful exploration for, mineral deposits. Data obtained from a variety of field and laboratory studies range from documentation of mining districts and mineral belts and the collection of relevant geologic observations, maps, and samples to experimental studies of the physical and chemical properties of minerals and mineralized rock. Major accomplishments for fiscal year 1977 include:

- Results from tests on bentonite samples from Wyoming and Montana provided the Bureau of Land Management and the bentonite producers with criteria for evaluating bentonite deposits on Federal lands.
- Investigations of sulfide deposits of Precambrian age in south-central Colorado which occur largely in metavolcanic rocks and were formed by volcanogenic processes. Their resource potential, which is greater than previously realized, is masked by subsequent metamorphism.
- Investigations of the stratabound copper-silver deposits of the Revett Formation, northwest Montana, formed from metals which were deposited with the sediments and were remobilized and concentrated in lithological and structural traps prior to metamorphism in Precambrian time.

Resource Techniques

Until recently, worldwide efforts to discover mineral deposits have concentrated on those exposed at the surface or those concealed by a thin veneer of surficial material. Most deposits of this sort have been found. Consequently new geochemical and geophysical techniques must be developed for the detection and evaluation of buried mineral deposits and for these concealed deposits to be appraised accurately. Major accomplishments for fiscal year 1977 include:

- Development of new flame atomic absorption technique to aid in the determination of trace elements. Elements that occur in very small amounts are of importance in mineral exploration and assessment and in various environmental investigations.
- Development of a method for direct spectrographic analysis of a fire-assay silver bead to determine platinum, palladium, rhodium, and gold in very low concentrations (parts per billion).
- Development of a simple field test for the identification of alunite and natroalunite, which are potential aluminum resource minerals.
- Discovery of unusually high quantities of copper, zinc, and molybdenum in the White River National Forest, south of Aspen, Colorado. Two areas of potential mineralization are indicated:
  1. Copper-zinc mineralization along Cataract Creek.
  2. Molybdenum mineralization centered west of Hunter Peak.
- Demonstration that regional geochemical sampling using deep-rooted plants (phreatophytes) may be useful in detecting mineral deposits that are covered by as much as 15 meters (49 feet) of overburden.
- Development of techniques to analyze satellite photographs for reflectance properties of vegetation growing over mineralized areas. Comparison with vegetation reflectance of known non-mineralized areas may lead to the discovery of new ore deposits.
- Demonstration, in Clayton Valley, Nevada, that d.c. resistivity soundings can be used to explore for brine bodies that may contain lithium.
- Demonstration that thermal-infrared (heat) images are useful in discriminating geologic units in the uranium area of the Texas Gulf Coast Plain.
- Development of a new technique to produce color composites of Landsat digital data which accurately discriminate altered ground, show variation within altered areas, and can differentiate altered ground from alluvium.

ENERGY RESOURCE SURVEYS

Coal

The Nation's coal resources are being assessed and classified into various categories based on geographic and geologic distribution, physical and chemical characteristics, and mining availability. This assessment involves geologic mapping, evaluation of mining data, stratigraphic and petrographic studies, chemical analyses of samples, geophysical and biochemical investigations, organic and non-organic (mineral) constituent studies, depositional environments, diagenesis, and geologic history of coal. The data obtained from these investigations are entered into the computerized National Coal Resources Data System (NCRDS) which now contains approximately 80,000 records.

Highlights and major accomplishments for fiscal year 1977 include:

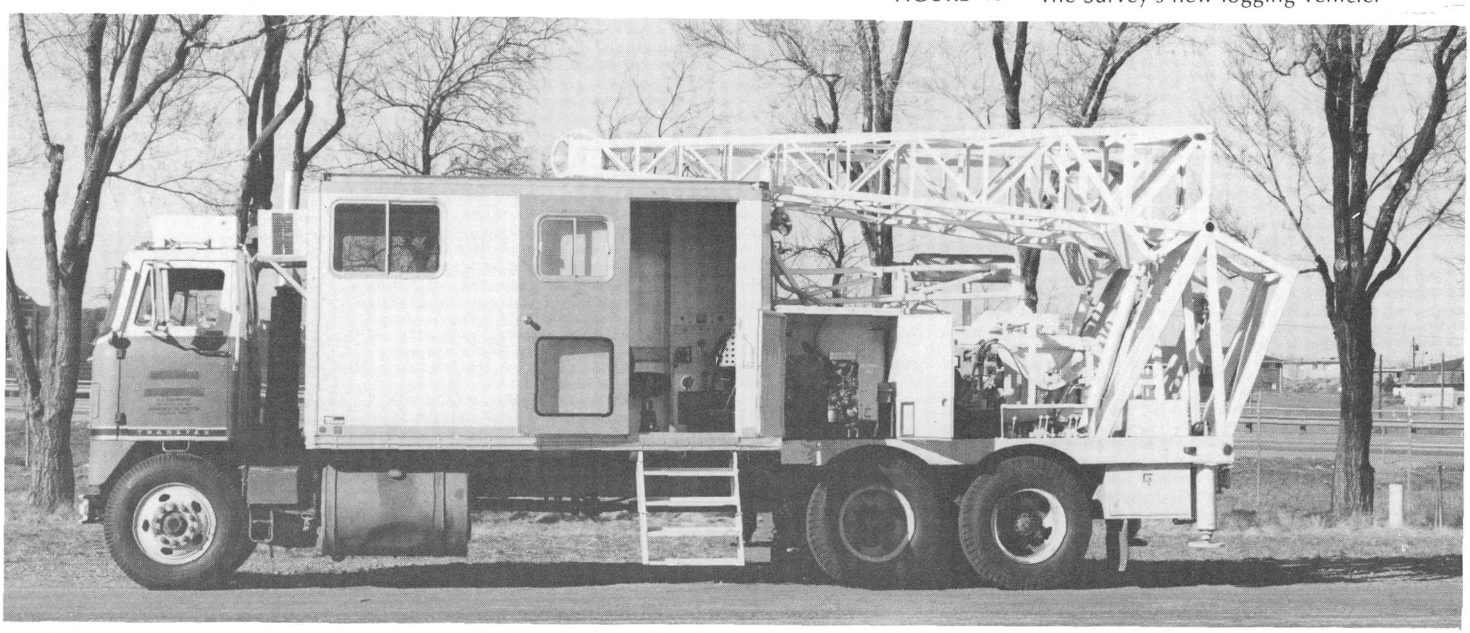
- Geologic mapping and assessing the low-sulfur coal resources in areas totaling about 1,800 square kilometers (695 square miles) in Wyoming, Montana, Colorado, Kentucky, Virginia, and West Virginia. An additional 2,300 square kilometers (888 square miles) of low-sulfur coal on Federal lands in Montana and Wyoming was reevaluated.
- Determining that 137-million metric tons (151 million tons) of coal resources remain in 13 beds within the 356-square kilometer (137-square mile) area proposed for a National Park along the New River Gorge in West Virginia. Approximately 60-million metric tons (66 million tons) of coal resources remain in 12 beds in the smaller 238-square kilometer (92-square mile) area proposed as the Wild and Scenic New River Gorge.
- Preparing four comprehensive reports on the geology, quantity and quality of coal resources, mining methods and potential development, and environmental hazards of mining Federally-owned coal in the Western United States where production is anticipated and for which environmental impact statements will be required.
- Standardizing the Coal Resource Classification System with the U.S. Bureau of Mines.
- Cooperating with 15 State Geological Surveys in collecting 1,300 samples of coal and related rock for chemical analysis. This makes a total of about 5,000 coal samples analyzed during the past several years. These analyses show that coals in the Western and Eastern Interior Coal Basins contain a higher than normal amount of zinc and cadmium and that coals in the Eastern Interior Coal Basin contain a higher than normal amount of cobalt, chromium, nickel, and vanadium.

Oil and Gas

The primary objectives of the Oil and Gas Resource investigations is to document the amount of oil and gas resources that occur in the various petroleum provinces and basins in the United States. To accomplish this objective, improved resource appraisal techniques are developed and geological and geophysical data upon which new and improved resource estimates can be based are collected and interpreted. Resource appraisal studies are also supported by research in exploration technology, which provides up-to-date technical expertise and develops new geological and geophysical insights through topical investigations. Topical studies are aimed at improving techniques in geophysical data interpretation, developing and applying laboratory techniques to identify and evaluate petroleum source rocks, predicting reservoir rock quality through geologic studies and specialized geophysical instruments (borehole gravimeter), and investigating new exploration techniques such as detection of subsurface hydrocarbon accumulation from surface geochemical anomalies. Fiscal year 1977 accomplishments include:

- Publishing a comprehensive report on the Baltimore Canyon investigation of samples and data from the Continental Offshore Stratigraphic Test (COST) B–2 well that was drilled 56.5 kilometers (91 miles) east of Atlantic City, N.J. The report states that this offshore region is more likely to contain gas than liquid hydrocarbons.
- Completing a new logging vehicle designed to be used in making borehole gravity measurements. (see below). Initial results indicate that gravity logs can be used to measure the organic content which is important in measuring the gas potential in black shales.

FIGURE 49.—The Survey's new logging vehicle.



- Completing oil and gas resource estimates, including field size distributions, for the Permian Basin in west Texas and New Mexico and offshore Gulf of Mexico, Texas, and Louisiana.
- Completing a study to delinate some of the tar sands resources in Missouri. Results of this study indicate that past resource estimates may have been too large.
- Completing a one-year reconnaissance study of the tight gas sands in Uinta, Piceance, and Green River Basins and Northern Great Plains areas for the Energy Research and Development Administration.
- Continuing studies of the petroleum potential of the Northern Montana Disturbed Belt. Information from these studies is needed by the U.S. Forest Service to determine which areas are to be withdrawn from minerals leasing. Preliminary study indicates that the region probably contains gas.
- Publishing a report describing the petroleum geology of the National Petroleum Reserve in Alaska (NPRA). The report identifies four separate areas in which oil and gas may be found.

Oil Shale

The ultimate aim is to inventory the oil shale resources of the United States and to understand the geologic setting in which oil shale occurs. Continuing work is concentrated on the Green River Formation of Colorado and Utah, which probably contains the thickest and richest deposits of oil shale in the world. Major accomplishments for fiscal year 1977 include:

- Completing the detailed geologic mapping (1:24,000 scale) of 1,036 square kilometers (400 square miles) in the Piceance Basin, Colorado and Uinta Basin, Utah.
- Completing the stratigraphic measurement of 21 sections for a total of 7,620 meters (25,000 feet).
- Completing the logging of 5 drill cores for a total of 1,524 meters (5,000 feet).
- Evaluating 210 samples for chemical composition, 300 samples for mineral composition, and 255 logs for geophysical data.

Uranium and Thorium

The Uranium and Thorium Investigations program consists of interrelated activities in geology, geochemistry, and geophysics. The overall objective is to improve the knowledge of the nature and distribution of uranium and thorium in the United States. Geologic investigations are concentrated on theories of origin, mining district studies, sedimentary basin analyses, and geologic framework of unmapped areas. Geochemical exploration techniques include gaseous emanation studies and analyses of stream and spring waters and their associated sediment and precipitate. Geophysical exploration techniques include measurement of the physical properties of rocks associated with uranium deposits and research on radiometric equilibrium in uranium ores. Fiscal year 1977 accomplishments and activities include:

- Testing new geophysical logging techniques between widely-spaced drill holes in Texas and Wyoming. This work has revealed anomalies that may be related to uranium mineralization.
- Developing a better geologic understanding, on which to base a uranium resource assessment of the deposits in Triassic age rocks on the Colorado Plateau.
- Discovering that a quartz-pebble conglomerate of Precambrian age in the Black Hills of South Dakota may contain significant amounts of uranium.
- Discovering by geologic reconnaissance that the Seward Peninsula area of Alaska may contain high-grade deposits of uranium, thorium, and rare-earth-elements in igneous rock terranes.
- Establishing new stratigraphic correlations in the Artillery Peak-Date Creek basin district of Arizona that extend the potential for uranium occurrence into new areas.
- Continuing studies in the Camp Smith area of southeastern New York where uranium is associated with massive iron ores of Precambrian age.

Geothermal Energy

A number of areas that have promise as sources of geothermal energy have been identified and other areas of possible geothermal energy are under study. The Geothermal Energy Investigations program is also developing a scientific basis for more accurate assessment and exploration techniques; this effort complements the technologic research program of the Energy Research and Development Administration. Some significant results and accomplishments for fiscal year 1977 include:

- Geologic mapping of the Newberry caldera in central Oregon revealed that silicic rocks are much more abundant than previously recognized, suggesting that the Newberry volcanic system may have a higher geothermal potential than previously believed.
- Investigations of the pressure, volume, temperature, and composition of complex brines led to the development of a method for calculating

the thermophysical, thermochemical, and energy transport properties of geothermal brines. This information promises to be useful for resource assessment, reservoir modeling, and determination of the production characteristics of geothermal wells.

- Studying the water chemistry of springs and wells in the Clear Lake volcanic field of California, in conjunction with geologic mapping and geophysical surveys, indicate that a 200°C (392°F) hot-water geothermal system underlies the area east of the Collayomi fault zone, which is probably the northeast boundary of the Geyser stream field.
- Geologic mapping and petrologic studies in the Coso Range of California have established two relatively recent episodes of volcanism: one occurred from about 4 million to 3 million years ago and the other occurred from approximately 0.5 million years ago to almost the present. This indicates that magma may still exist beneath the Coso Range with a high potential for geothermal energy.
- Electromagnetic measurements, in the eastern Snake River Plain-Yellowstone National Park region, reveal a deep conductive layer extending from Yellowstone National Park, Wyoming, to Raft River, Idaho. These findings should have an impact on geothermal exploration and confirm the geothermal resource estimates in the Western United States published in USGS Circular 776.
- Monitoring of both distant and nearby earthquakes in the Yellowstone National Park area, Wyoming, reveals a low velocity zone beneath the Yellowstone thermal area that may indicate the presence of a partly molten body of rock at depth under the Snake River Plain. This could be the heat source for a geothermal system of large magnitude in southern Idaho.

Energy Resource Data

The Geological Survey continues to build and maintain computer files on energy resource data which are used in preparing up-to-date and accurate resource estimates and to meet the public's need for such data.

The National Coal Resource Data System (NCRDS) can accept and process a wide variety of data related to the quantity and quality of coal resources and the nature of their enclosing rocks. The system has the capability to retrieve coal resource information in the form of charts, maps, and reports to meet Federal and State requirements.

The Petroleum Data System (PDS) contains information on oil and gas fields and pools in the United States. The data cover geologic occurrences, engineering information on reservoirs, and analyses of crude oil, brines, and natural gas. Annual and cumulative production data are given as well as size of field and number of wells. Fields and pools suitable for secondary or tertiary recovery are identified.

Other computer files maintained are:

The United Nations Seabed Data file, which contains a summary of petroleum and selected mineral statistics for 120 foreign countries, including offshore areas.

The Oil Shale Data Storage and Retrieval system which is designed to store data on Fischer assays (organic content) and saline minerals in oil shale.

The Computerized Resources Information Bank (CRIB) which contains the basic information needed to characterize one or more mineral commodities, a mineral deposit, or several related deposits.

The Geothermal Resources Computer File (GEOTHERM) which contains records on location, exploration, evaluation, and use of geothermal energy and resources. Data are included on boreholes, water analyses and heat values.

The Well History Control System (WHCS) which contains basic information on oil and gas wells, including location, production tests, formations penetrated, cores, drill stem tests, depth, and log runs.

The Uranium-Thorium Data Bank which contains data on the physiographic province, rock type, mineralogy, chemistry and precise location of uranium deposits. The data are filed in CRIB.

OFFSHORE GEOLOGIC SURVEYS

Oil and Gas Resource Appraisal

The energy resource potential of offshore sedimentary basins is appraised by geophysical and geological data. For deep-penetration beneath the seafloor the geophysical method of common-depth-point seismic reflection is used and for shallow penetration, high-resolution seismic reflection is used. Seismic refraction, ship-borne gravity and magnetics, and aeromagnetics are also used. Geologic information is obtained from samples collected by sea-floor dredge, shallow core holes, deep stratigraphic test wells, and nearby onshore wells and outcrops. Major accomplishments and activities for fiscal year 1977 include:

- Completing oil and gas resource reports in support of leasing activities along the Atlantic Continental Margin.

- Collecting in the Pacific and Alaskan OCS areas approximately 8,699 kilometers (5,404 miles) of multichannel seismic reflection trackline; 31,807 kilometers (19,764 miles) of single channel seismic reflection; 19,294 kilometers (11,989 miles) of magnetic data; and 23,381 kilometers (14,528 miles) of gravity data, in support of regional geologic and geophysical investigations.
- Preparing a magnetic anomaly map with a 50-gamma contour interval of the entire Atlantic Continental Margin to a depth of 4,000 meters (13,123 feet) from George's Bank (Massachusetts) to Florida.

FIGURE 50.—Survey scientists launching geophysical equipment from the deck of the *R/V Samuel P. Lee.*

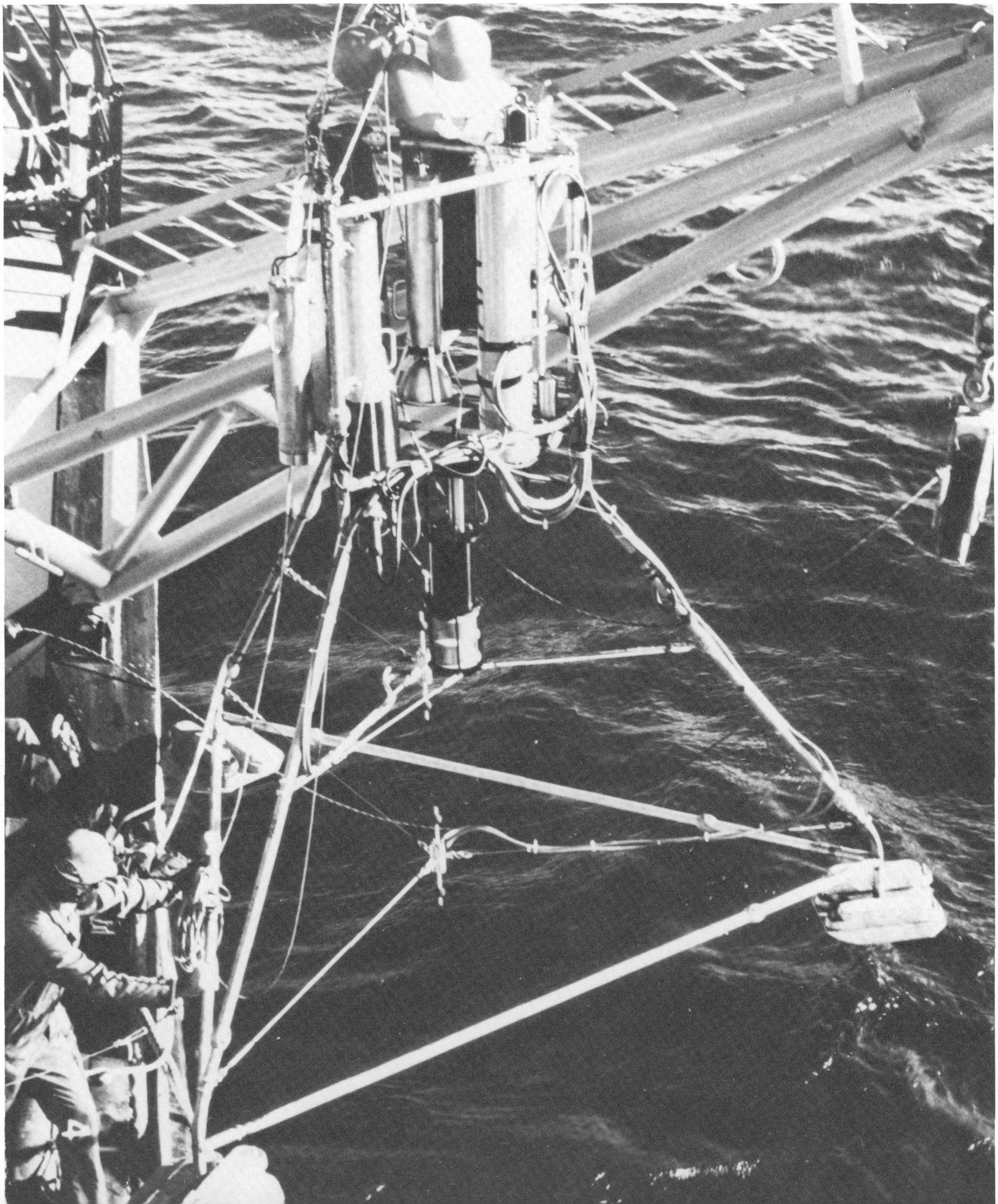
- Mapping the extent and thickness of sedimentary basins underlying the Alaskan continental shelf-using geophysical methods. This work was conducted from the R/V *Samuel P. Lee* (fig. 53). The research vessel is continuing to chart basins of potential oil and gas accumulation in the Gulf of Alaska, Bering Sea, and Beaufort Sea.

FIGURE 51.—Lowering a geoprobe from the *R/V Sea Sounder* ► in Norton Sound, Alaska. Mounted on a tripod, the array of instruments is used to photograph the sea-bottom currents and wave pressures that influence the movements of sediments.

Environmental Investigations

Geologic hazards to offshore structures, including drilling platforms and pipelines, may occur in areas of active faulting, unstable sediments, and excessive underwater erosion. Field studies (see below) which provide this information for leasing decisions and baseline data were conducted in fiscal year 1977 in the north and mid-Atlantic Outer Continental Shelf areas, in the central and western Gulf of Mexico, off the southern California coast and in the Gulf of Alaska and Bering Sea. Activities and highlights for fiscal year 1977 include:

- Discovering that relatively fresh water extends beneath the continental shelf as much as 90 kilometers (56 miles) seaward from the New Jersey coast.



- Deployment of sea-bottom equipment in the north and mid-Atlantic OCS areas and in the northern Bering Sea to measure the effect of ocean waves and currents on sea floor sediments. At the time the tanker Argo Merchant broke up equipment was deployed to monitor the oil and sediment interaction and the oil movement on the sea floor.
- Gathering geophysical data and sea-floor samples in the Pacific and Alaskan OCS areas to identify potential geologic hazards such as submarine slides to offshore oil and gas resource development and to support the Bureau of Land Management's environmental baseline study program.
- Completing a report that summarizes the geologic and oceanographic knowledge of the western Gulf of Mexico.

FIGURE 52.—The Survey carbonate research team assembled a new hand-held coring device that can be used above or below water. It takes core samples of coral used to study potential petroleum reservoir rocks.

Marine Geology Investigations

These investigations focus on obtaining fundamental knowledge of marine and near marine geologic conditions and processes in support of many other programs and investigations. Geochemical studies of deep-sea manganese nodules and development of remote-sensing and deep-water instrumentation are two examples of programs needed as the Nation develops its Outer Continental Shelf areas for mineral and hydrocarbon resources. Other future research activities not directed specifically toward OCS development are research on coastal-zone processes, mineable minerals in the near-shore areas, and engineering properties of the sea-floor sediments. Highlights of the program for fiscal year 1977 include:

- Establishing a data management system to gather data from the other Offshore Geologic Surveys programs and prepare them for computer files.
- Continuing studies of marine geologic processes which act upon coastal and near shore areas in Alaska, Oregon, California, Texas, Puerto Rico, and Massachusetts. The Survey engaged in cooperative programs with Texas, Puerto Rico, and Massachusetts in mapping bays and estuaries.
- Studies in the Mississippi Delta area have related the action of seabottom pressure changes, due to storm waves, to the strengths of sediments around drilling and/or production platform legs.

ASTROGEOLOGY

Exploration of the Moon and planets by the National Aeronautics and Space Administration (NASA) has provided an opportunity and funds to compare geologic materials, geologic processes, and geologic histories of other planets with those of the Earth.

The lunar studies evolved from emphasis on geologic mapping to emphasis on studies of processes and on the synthesis and analysis of a vast amount of geologic, geochemical, and geophysical data collected by the Apollo missions.

The planetary studies are focused mainly on Mars and Mercury. A geologic map of each of these planets is being compiled at a scale of 1:5,000,000. The studies of Martian processes are concerned principally with the histories of wind erosion and water erosion. Mercury, like the Moon offers another perspective on the history of impact cratering and the distribution and source of impacting bodies. Radar techniques have been developed to study the geology and topography of Venus.

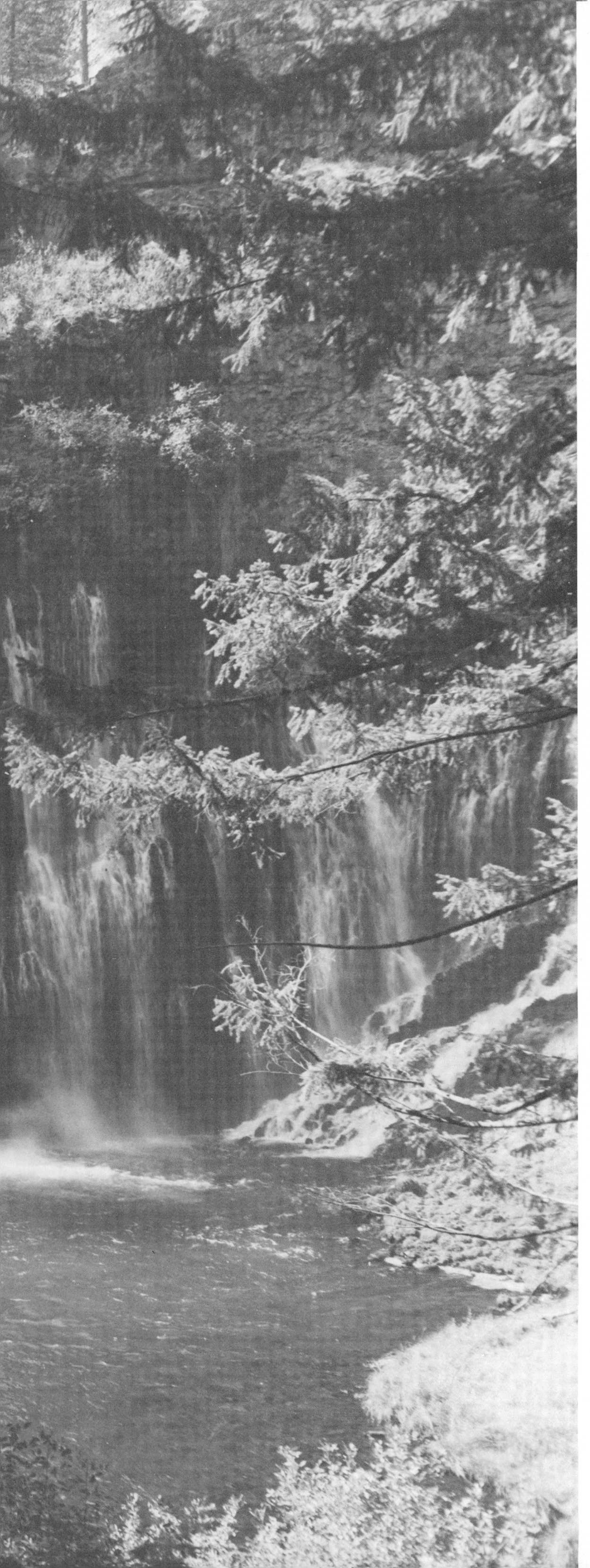
INTERNATIONAL GEOLOGY

The Survey, in cooperation with the Department of State and other Federal agencies, is involved in two categories of international activity—technical assistance and scientific cooperation.

The technical assistance program is designed to aid the developing countries in studies of their mineral resources, and to strengthen their institutions and programs which train earth scientists and engineers. This assistance is requested by the foreign countries, funded by either the foreign government, international organizations, or other United States agencies, with approval by the Department of State, and authorized by the Agency for International Development (AID) under the U.S. Foreign Assistance Act. During fiscal 1977, technical assistance activities were carried out in Argentina, Chile, Mexico, Peru, Egypt, Nigeria, Sahel, Jordan, Saudi Arabia, Yemen, the Trucial area, Philippines and Sri Lanka.

Scientific cooperation with foreign countries provides for joint research and exchange of information on earth resource problems of mutual interest. This cooperation is undertaken partly with funds from other United States agencies and partly as an extension of the Survey's domestic programs. It is carried out with the approval of the Department of State. In fiscal year 1977, scientific cooperation was carried out with Mexico, Germany, Russia, Poland, and Romania. The Survey also participated with other countries in a number of projects in the International Geological Correlations Program, jointly sponsored by United Nations Education, Scientific, and Cultural Organization (UNESCO) and the International Union of Geological Sciences (IUGS). The Survey guided and coordinated the Circum-Pacific Map Project at the request of the Circum-Pacific Council, and in cooperation with the American Association of Petroleum Geologists (AAPG), and the United Nations Coordinating Committee for Offshore Prospecting-East Asia (UNCCOP-EA).

FIGURE 53.— The *R/V Samuel P. Lee*, a 63-meter (208-foot) oceanographic research ship on loan from the U.S. Navy, carries out *geophysical surveys in the Pacific Ocean and Alaskan waters. Its home port is Redwood City, California.*



Water Resources Investigations

INTRODUCTION

In no area of resources management are the problems more complex, or more vital, than those involving the Nation's water. Managing water supplies is a major concern at all levels of government, but the Water Resources Division of the Geological Survey has the principal responsibility at the Federal level for appraising water resources, and for providing basic hydrologic data on both surface and ground water.

The Survey's program, through its numerous cooperative arrangements with State and local governments, is uniquely structured to gather and evaluate water information scientifically. The Water Resources Division presents impartial, factual information and analyses for use by Federal agencies, State and local governments, and other groups charged with managing and developing water resources. The Division provides reports and maps to the public in Federal, State, and local publications and in technical journals. Additional material is made available for public use at selected libraries.

In the Water Resources Division's Federal-State Cooperative Program, 597 State and local agencies provide financial support and services, matching the funds appropriated by Congress. This arrangement assures that the Geological Survey is aware of and can be responsive to water-information needs at all levels of government. It also keeps the Federal Government aware of State and local problems and contributes to a valuable exchange of information. Through a network of offices in all 50 States, as well as in Puerto Rico and Guam (fig. 54), the Water Resources Division works closely with State and local

Burney Falls, Shasta County, California. (*Photograph from* the Department of Water Resources, State of California.)

agencies. The addresses of the Division's District Offices are listed in the chapter on organizational and statistical data.

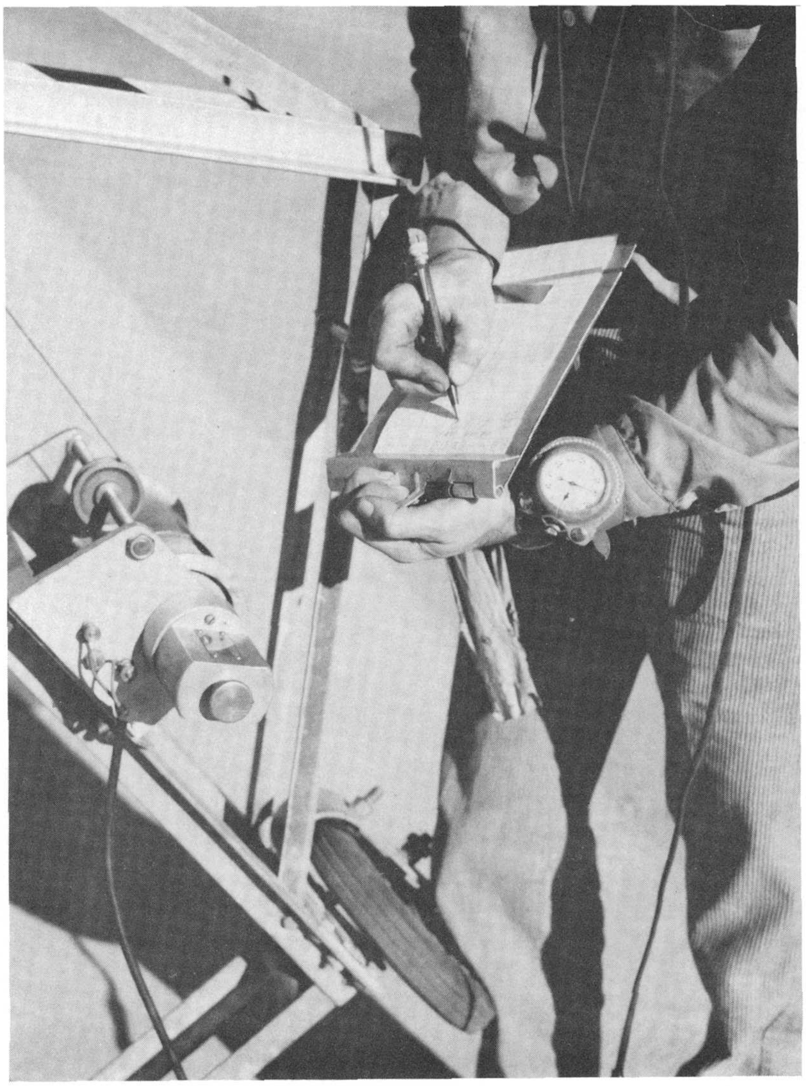
A major responsibility for water data was assigned to the Survey in 1964 when it was designated the lead agency for coordinating water-data-acquisition activities of all Federal agencies, including information on streams, lakes, reservoirs, estuaries, and ground water. This coordination effort has minimized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

HIGHLIGHTS

- In response to Congressional interest, an additional $2 million of Federal-State Cooperative program funds were focused on investigations of hydrologic problems and situations related to coal mining. The program also included activities in other high-priority energy areas such as oil-shale hydrology, nuclear hydrology, and geothermal research, as well as land-use planning, environmental quality, and predictive and impact-assessment hydrology.
- Because of the widespread persistence of drought across the Nation, the Federal-State Cooperative Program concentrated on providing information to assist with planning to ameliorate the effects of existing and potential water shortages. Studies included indentification of supplemental sources of water supply; synoptic sampling of water quality; determination of changes in ground-water, lake, and reservoir storage; expansion of streamflow observations; and evaluation of changes in water-use practices.
- Because surging glaciers can cause destructive outburst floods that disrupt transportation corridors, the Division developed methods to identify and study them in many glaciated areas. Using Landsat images, the research was aimed at ways to predict both the time and intensity of future surges.
- By the end of the year, 8 regional ground-water appraisals had been published as Professional Papers to assist planners in developing and managing ground water. In fiscal year 1978, several more extensive, in-depth analyses of the aquifer systems of the United States will begin.

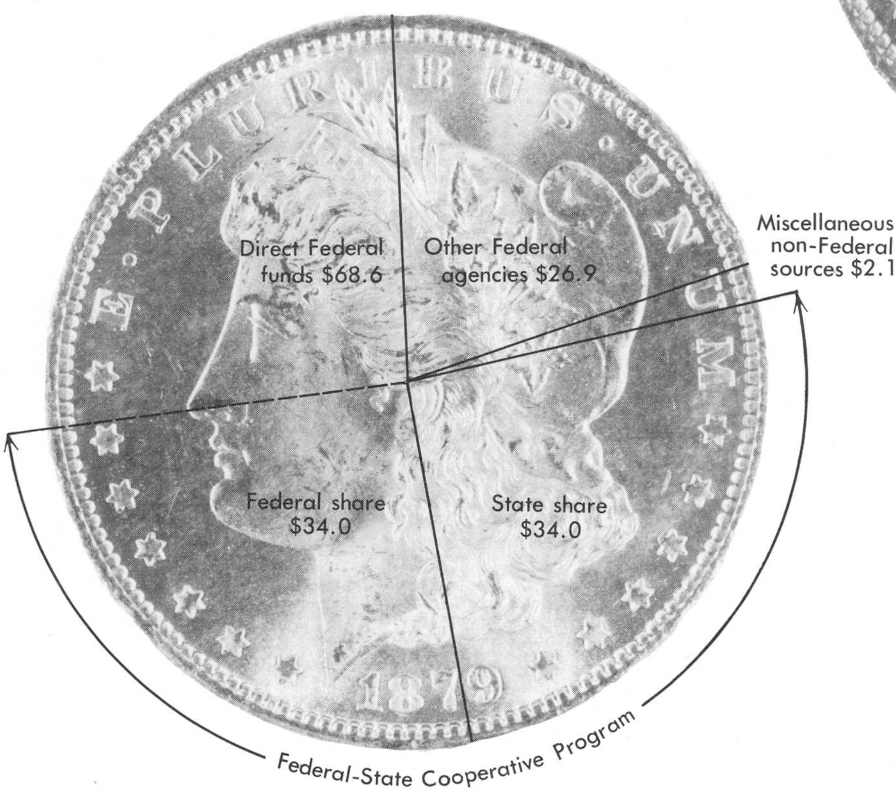
FIGURE 54.—Location of principal offices of the Geological Survey's Water Resources Division in the conterminous United States. Cities named are those where regional and district offices are located. In addition to the subdistrict offices noted on the map, there are two subdistrict offices in Alaska, three in Hawaii, and one on Guam, all included in the western region.

- The second test well of the Madison Limestone Ground-Water Study, located in southeastern Montana, was drilled to a depth of 2,858 meters (9,378 feet). Shut-in pressure of the completed well at the land-surface was 2,300 kilopascals (333 pounds per square inch); however, flow was only 2.8 liters per second (44 gallons per minute). These data, in conjunction with data obtained from a test well drilled the previous year, tend to confirm Division scientists' hypothesis that the Madison will be more productive where it is principally dolomite, rather than limestone.
- Over two and a half-million physical, chemical, and biological characteristics of water were determined in the 170,000 samples analyzed in the Survey's Central Laboratories System. This represents a 400-percent increase in sample analyses since 1970 and reflects intensified efforts to monitor the quality of the Nation's water resources. The Survey's Central Laboratories System is perhaps the largest of its kind in the world.
- Every 5 years the Water Resources Division prepares a water-use report that shows changes in water withdrawal and water consumption, and indicates trends in water use. In 1977, the most recent report, "Estimated Use of Water in the United States, 1975," was published. It revealed that water withdrawn to meet the needs of commerce and industry, farm irrigation, and urban and rural living amounted to an average of about 1,900 gallons per person per day, a 100-gallon increase since 1970, but the smallest percentage increase since assessments began in 1950.
- The four-color series of State Hydrologic Unit Maps (scale 1:500,000) was completed by the Office of Water Data Coordination. Work is now underway to digitize boundaries of the units. To be published as nationwide sheets (scale 1:3.68 million and 1:7.5 million), these editions of the maps will be used in planning activities and for organizing and disseminating data on both a political and a hydrological boundary basis.
- The Water Resources Division used seasonal high-altitude color infra-red aerial photographs of two areas to improve the delineation of hydrologic features, specifically wetlands, on Geological Survey 1:24,000-scale maps. The Division cooperated with the Topographic Division to make experimental wetland maps for the Auburndale, Florida, quadrangle; and in cooperation with the Tennessee Valley Authority, it produced wetland maps which relate the date of photography to stage-duration curves as an aid in the analysis of hydrologic boundaries of wetland classes.



- Flood-frequency curves were prepared for all gaged sites in the United States that have at least 10 years of recorded natural (unregulated) streamflow discharges. They were made available for inspection by district offices throughout the country. This meant that the Program has supplied flood-frequency curves for approximately 11,000 sites on streams and rivers in all 50 States.
- Coastal-zone-management needs led to publication of the "Index to Stations in Coastal Areas," by the Office of Water Data Coordination. A four-volume subsection of the "Catalog of Information on Water Data," the Index covers the Great Lakes area and the Atlantic, Gulf and Pacific Coasts. It provides a ready reference to the availability of water data on streams, lakes reservoirs, estuaries, and ground waters located in coastal counties.

WATER RESOURCES INVESTIGATIONS



TOTAL $131.6 MILLION

SOURCE OF FUNDS

USE OF FUNDS

BUDGET AND PERSONNEL

In 1977 approximately 2,840 full-time personnel carried out the many water-resource studies and data-collection activities of the Water Resources Division. The Division employed 1,495 scientists and engineers representing all fields of hydrology, 935 technical specialists and aides, and about 440 persons who provided administrative, secretarial, and clerical services. An additional 1,100 part-time employees assisted in the collection and analysis of data on water quality and quantity.

The $131.6 million obligated in 1977 for the Water Resources Investigations activity came from four sources:

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

TABLE 13.—*Water Resources Investigations activity obligations for fiscal year 1977, by program (dollars in millions)*[1]

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

Program	Source of funds					Percent change relative to fiscal year 1976
	Federal program [2]	Federal-State Cooperative program [3]	Other Federal agency programs [4]	Non-Federal programs [5]	Total	
Total	$34.6	$68.0	$26.9	$2.1	$131.6	+17
National Water Data System	21.9	68.0	26.9	2.1	118.9	+15
Collection, analysis, and dissemination of streamflow, water-quality, ground-water, and sediment data [6]	12.5	33.0	11.5	1.4	58.4	
Regional and areal resource appraisals	.6	18.5	7.5	.3	26.9	
Studies related to critical water problems	----	8.5	5.0	.1	13.6	
Core program of hydrologic research	5.3	----	----	---	5.3	
Other data collection and applied research	----	8.0	2.9	.3	11.2	
Hydrologic investigations on public lands (soil and moisture conservation)	.2	----	----	---	.2	
Publications and other supporting services	3.3	----	----	---	3.3	
Critical National Water Problems	12.7	----	----	---	12.7	+46
Accelerated energy research and development programs	9.6	----	----	---	9.6	
Coal hydrology	5.7	----	----	---	5.7	
Oil-shale hydrology	2.5	----	----	---	2.5	
Underground heat storage	.1	----	----	---	.1	
Nuclear energy hydrology	1.3	----	----	---	1.3	
Ground-water recharge	1.2	----	----	---	1.2	
Subsurface waste storage	1.3	----	----	---	1.3	
Flood-hazard mapping	.4	----	----	---	.4	
Estuarine and coastal studies	.2	----	----	---	.2	
Percent change relative to fiscal year 1976	+18	+22	+6		+17	

[1] From data available Nov. 11, 1977.

[2] Federal funds excluding those used to match funds from State and local agencies.

[3] Includes Federal funds used to match State and local agency funds on a 50–50 basis.

[4] Funds from 23 other Federal agencies transferred to the Geological Survey, Water Resources Division.

[5] Includes unmatched funds from State and local agencies, funds from permittees and licensees of the Federal Power Commission, and funds from minor miscellaneous sources.

[6] Federal funds include support of coordination of national water data and the National Water Data Exchange.

Federal Program

The water-data-collection, resource-investigation, and research activities of this program support those aspects of the National Water Data System where the Federal interest is paramount. These include bodies of water in the public domain, river basins and aquifers that transcend State boundaries, and other areas of international or inter-State concern.

The Federal Program also supports the operation of surface- and ground-water measurement stations throughout the country as well as sites established to provide data on water quality. The program includes the operation of the National Stream Quality Accounting Network, the Survey's Central Laboratories System, analytical studies, hydrologic research, and a variety of supporting services. Funds for the Federal program in fiscal year 1977 amounted to $34.6 million.

Federal-State Cooperative Program

Most of the activities of the Geological Survey have multiple objectives and serve a broad range of government agencies and private groups in need of objective and credible earth-science information. Consequently, as major users of this information, State, regional, and local agencies have an important role in defining the nature and scope of Survey programs. Accordingly, selected projects judged of mutual benefit to the Federal Government and to State and local governments are funded on a 50-50 basis. For example, in fiscal year 1977, the Geological Survey joined in cooperative water-resource programs with 597 State and local agencies (table 14)—most of the work was conducted by the Survey, but 50 percent of the funds was provided by State and local agencies. The program totaled about $70 million.

Through contact with the "real" world of water conservation, development, and use, the Survey's Water Resources Division has been able to develop a balanced program that anticipates and responds to changing priorities with an interdisciplinary, diversified, problem-oriented approach.

PROGRAM ACTIVITIES

The activities include: collection of long-term multipurpose data (surface water, ground water, and water quality); special interpretive studies of the physical, chemical, and biological characteristics of water resources; and appraisals for environmental-impact evaluation, energy development, coastal-zone management, subsurface waste storage, waste utilization, land-use planning, flood-plain management, and flood-warning systems.

The strength of the Federal-State Cooperative Program lies in (1) coordinated programing for water information that responds to identified and developing needs of people at all levels and relates to the environmental aspects of water use; (2) the acceptability of the water data accumulated through a uniform program in 50 States and several of the territories; and (3) the objective, impartial, non-advocacy position of the Survey in carrying out its work.

In fiscal year 1977, the Federal-State Cooperative Program emphasized information and assistance to State, regional and local agencies responsible for water-management decisions related to the drought. The importance of this work was recognized by Congress which, in May, appropriated an additional $5 million of Federal matching funds for drought-related activities. Another major service was in coal hydrology; here the focus was on water-supply assessments, water-quality problems in mining areas, and water-control measures. High-priority investigations also included work on other energy-related projects such as nuclear hydrology, oil-shale hydrology, and geothermal research, as well as land-use planning, environmental quality, and predictive and impact-assessment hydrology.

TABLE 14.—*State and local agencies with which the Geological Survey had a written agreement for fiscal cooperation (Federal-State Cooperative program) in Water Resources Investigations in fiscal year 1977*

State	Number of agencies				
	State	County	City	Other	Total
Alabama	2	---	---	---	2
Alaska	5	---	2	1	8
Arizona	5	3	4	4	16
Arkansas	3	---	---	---	3
California	6	40	9	23	78
Colorado	5	7	8	12	32
Connecticut	1	---	3	6	10
Delaware	2	---	---	---	2
District of Columbia	1	---	---	---	1
Florida	4	22	22	12	60
Georgia	5	3	2	---	10
Hawaii	2	---	2	---	
American Samoa	---	---	---	1	
Guam	---	---	---	1	7
Trust Territories	---	---	---	1	
Idaho	3	---	---	1	4
Illinois	6	4	1	4	15
Indiana	3	---	3	1	7
Iowa	9	1	3	---	13
Kansas	4	---	1	3	8
Kentucky	3	---	---	---	3
Louisiana	3	---	---	1	4
Maine	5	---	1	1	7
Maryland	3	---	---	---	3
Massachusetts	7	---	---	---	7
Michigan	2	---	---	---	2
Minnesota	5	---	3	1	9
Mississippi	5	2	1	3	11
Missouri	5	1	2	1	9
Montana	7	2	---	1	10
Nebraska	5	---	---	4	9
Nevada	5	---	---	---	5
New Hampshire	2	---	---	1	3
New Jersey	3	3	---	6	12
New Mexico	4	---	3	4	11
New York	7	15	7	8	37
North Carolina	3	1	7	---	11
North Dakota	2	1	---	---	3
Ohio	3	---	3	2	8
Oklahoma	5	---	1	---	6
Oregon	3	7	7	5	22
Pennsylvania	6	1	4	3	14
Puerto Rico	4	---	---	1	7
Virgin Islands	2	---	---	---	
Rhode Island	2	---	1	---	3
South Carolina	4	---	1	---	5
South Dakota	3	---	2	2	7
Tennessee	6	3	5	---	14
Texas	1	1	5	3	10
Utah	2	1	---	1	4
Vermont	1	---	1	---	2
Virginia	3	1	4	1	9
Washington	4	4	6	14	28
West Virginia	4	1	2	---	7
Wisconsin	5	2	2	1	10
Wyoming	6	1	2	---	9
Total	206	127	130	134	597

Examples of reports published during the past year:

- Reaeration-coefficient measurements of ten small streams in Wisconsin using radioactive tracers, with a section on the energy-dissipation model.
- Analog-model analysis of regional three-dimensional flow in the ground-water reservoir of Long Island, New York.
- Ground-water conditions in Utah, spring of 1977.
- Water resources of El Paso County, Colorado.
- Missouri stream- and spring-flow characteristics—low-flow frequency and flow duration.
- Distribution of nitrate in ground water, Redlands, California.
- Theoretical drawdown due to simulated pumpage from the Ohio River alluvial aquifer near Siloam, Kentucky.

Funds Transferred from Other Federal Agencies

Programs for other Federal agencies amounting to $26.9 million in fiscal year 1977, consisted of work carried out by the Geological Survey to provide support of the missions of these agencies. Examples of work performed for other Federal agencies are:

Department of Agriculture	Hydrologic studies on small watersheds; sediment studies; stream discharge and quality.
Department of Housing and Urban Development	Flood-plain delineation, flood profiles, flood frequency related to flood insurance.
Department of Transportation	Stream-discharge and flood-frequency data; hydrologic studies on small watersheds, scour, and bank erosion.
Energy Research and Development Administration	Hydrologic and waer-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 the environment, both above and below ground.
Environmental Protection Agency	Municipal waste-disposal-site studies; study of relationship of ground water to lakes; collection of water-quality information.
National Aeronautics and Space Administration	Applications of remote sensing data collection to problems concerning ground water, estuaries, water temperature, lakes, glaciers, and snow-cover mapping.
Tennessee Valley Authority	Stream-discharge and flood-frequency data; hydrologic studies on watersheds, including sedimentation.
Department of Defense—Corps of Engineers	Tidal flows in estuaries; subsidence studies; streamflow data, ground-water studies, and sedimentation and water-quality studies.

The paragraphs below describe two problems faced by other Federal agencies and the cooperative efforts begun in 1977 by the Water Resources Division to assist in solutions.

Effects of the Proposed Narrows Reservoir on the South Platte River, Colorado

Establishment of the proposed Narrows Reservoir on the South Platte River will affect the ground-water system in the vicinity of the reservoir. First, water will move into the aquifer during the filling of the reservoir. Then, once the reservoir is filled, water will move either into the reservoir from the aquifer during periods of declining reservoir storage, or into the aquifer from the reservoir during periods of increasing reservoir storage. The effects of these gains and losses need to be calculated so that the time required to fill the reservoir initially and the details of operating rules can be determined.

At the request of the U.S. Bureau of Reclamation, the Water Resources Division began a study to determine the time required for the aquifer to adjust to the filling of the reservoir, the bank-storage seepage rates to and from the reservoir, and the changes in ground-water discharge to the river downstream from the proposed dam during the transient reservoir conditions.

A small Price current meter used for measuring stream discharge.

During a drought, it is obvious that the most immediate concern is over the quantity of water available. But the prolonged drought that plagued the Nation during 1977 produced serious, if not as highly publicized, problems of declining water quality. For example, concentrations of dissolved solids and minerals reached record, or near-record, high levels in some streams in North Dakota, South Dakota, Ohio, and Colorado during the past year. Increases in dissolved-solids concentrations can affect the taste of water, produce physiological side effects, and interfere with some sensitive industrial uses, such as steam generation.

Drought conditions create oxygen deficiencies and elevated temperatures in streams. Near-zero concentrations of dissolved oxygen were recorded in some parts of the Mississippi and Minnesota Rivers. This deficiency, in combination with higher than normal water temperatures, led to scattered reports of fish kills, odor problems, algal blooms, and the inability of streams to purify themselves of wastes.

The quality of ground water was also affected; declines in ground-water levels caused by the drought and heavy pumping allowed salt water to invade some coastal area wells in California. The Del Norte County Health Department reported that chloride concentrations at the Klamath townsite increased so dramatically that the town had to resort to use of bottled water to help meet domestic needs.

Perhaps the most critical drought-related problem affecting water quality was the simple lack of water to flush and dilute wastes. In California, for example, the flow of the Russian River declined to the point where sewage discharges from oxidation ponds accounted for 40–50 percent of the total flow of the river and the State was forced to impose restrictions on sewage discharge into the river.

The severe drought of 1977 reaffirmed the necessity to think in terms of water quality as well as water quantity when tackling the problems associated with droughts.

Water Quality in Upper Colorado River, Texas

The Colorado River, between Lake J. B. Thomas and Colorado City, Texas, contains high concentrations of salt resulting from the geologic framework of the area and the activities of man. Recent investigations suggest that controls on disposal of oil-field brines and lowering of ground-water pressure by pumping are reducing the quantities of salt reaching the river. Water Resources Division scientists, in cooperation with the Corps of Engineers, began an investigation in 1977 to delineate the areas of saline inflow and to determine if the quantities of salt reaching the river are decreasing. The decision by the Corps of Engineers whether or not to build salt-control projects in the upper basin will depend in part on the information obtained in this study. If salt concentration is reduced, the quality of water in the E. V. Spance Reservoir, 15 miles upstream from Colorado City, will be greatly improved.

Funds Transferred from State and Local Agencies

In this program the Geological Survey is reimbursed by State and local agencies when there is both Federal interest and State or local interest in an investigation of water resources but where matching Federal funds are inadequate for cost sharing.

ACTIVITIES

National Water-Data System

INTERAGENCY WATER-DATA COORDINATION

During fiscal year 1977 the Survey's Office of Water Data Coordination continued to work closely with a large number of Federal and non-Federal agencies, organizations, and individuals in the planning, design, and documentation of water-data networks and in the development of standards for data acquisition (table 15). This coordination effort is mandated by Office of Management and Budget Circular A–67 and involves approximately 20 Federal agencies and 200 non-Federal agencies that collect water data. It affects about 50 Federal agencies and more than 600 non-Federal agencies that use water data.

TABLE 15.—*Participation in water-data coordination activities with the Geological Survey's Office of Water Data Coordination, fiscal year 1977*

Activity	Participants
Federal	
1. Coordination of Federal water-data programs through the Interagency Advisory Committee on Water Data.	31 Federal agencies.
2. Development of recommended methods for collecting water data; includes Coordinating Council for Water-Data Acquisition Methods (18 Federal agencies).	26 Federal agencies and 162 scientists in 10 working groups.
3. Design and development of national system for handling water data through Federal Interagency Water Data Handling Work Group.	10 Federal agencies.
4. Design of small-watershed network for data on water quality; Working Group on Water-Quality Data Needs for Small Watersheds.	11 Federal agencies.
5. Develop improved communication for interagency coordination, through the Working Group on Improved Communications (Federal).	16 Federal agencies.
6. Field coordination and development annually of 21 regional plans and a Federal plan for water-data acquisition.	28 Federal agencies including 140 field officials.
Non-Federal	
1. Consultation with non-Federal community of data users through the Advisory Committee on Water Data for Public Use.	26 Members.
2. Review and consultation with the Working Group on Recommended Methods for the "National Handbook of Recommended Methods for Water-Data Acquisition."	9 Members.
3. Assessment of river quality through a Working Group on River Quality Assessment of the Advisory Committee on Water Data for Public Use.	10 Members.
4. Develop improved communications for coordination activities through the Working Group on Improved Communications (non-Federal).	9 Members.

In December 1976, the Office of Water Data Coordination sponsored a joint meeting of the Advisory Committee on Water Data for Public Use (the non-Federal committee) and the Interagency Advisory Committee on Water Data (the Federal committee) in Denver, Colorado. This first joint meeting provided a valuable direct exchange of ideas and views.

Included among the Division's publications in 1977 were a variety of reports and studies:

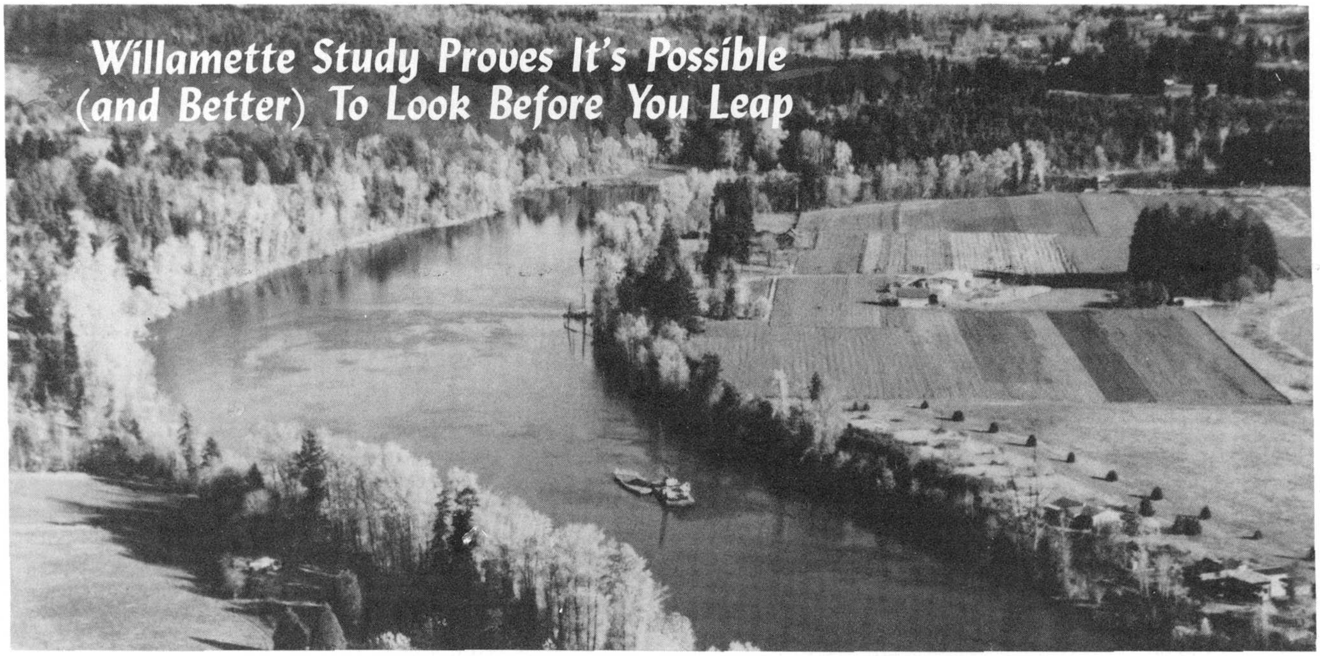
- "Index to Stations in Coastal Areas." A 4-volume catalog (subsection of the 21-volume "Catalog of Information on Water Data") which indexes coastal-zone water-data activities on streamflow and stage, surface-water quality, and ground-water quality (fig. 55).
- Chapter 5, the "Chemical and Physical Quality of Water and Sediment," one of the 10 which will make up the "National Handbook of Recommended Methods for Water-Data Acquisition."
- "Federal Plan for the Acquisition of Water Data—Fiscal Year 1978." Describes water-data activities for 1978 and data needs beyond 1978.
- "Development of a Catalog of Information on Surface Meteorological Data." A joint report of the Interdepartmental Committee on Meteorological Services and the Interagency Advisory Committee on Water Data.
- U.S. Geological Survey Circulars on the Willamette River Basin Assessment. Three additional river-quality assessments are currently in progress: the Chattahoochee River basin of Georgia and Alabama, the Yampa River basin of Colorado and Wyoming, and the Potomac estuary of the District of Columbia, Maryland and Virginia.

The U.S. National Bureau of Standards designated the Coordinating Council for Water-Data Acquisition Methods as the Federal Interagency Metric Panel for Hydrology. This Panel has responsibility for recommending metric units, metric precision and accuracy limits, metric conversion factors, and metric conversion of equipment used for all hydrologic measurements. The 10 technical working groups responsible for drafting chapters for the "National Handbook of Recommended Methods for Water-Data Acquisition" submitted recommendations for metric units and conversion factors to be used in the methods described in their respective chapters. In addition, liaison has been initiated between the United States, Canada, and Mexico to foster coordination of methods and metrication in hydrology.

The final 6 maps of the new, nationwide series of four-color State Hydrologic Unit Maps (scale 1:500,000) were printed. Progress continued during 1977 on national maps of hydrologic units at scales of

1:3.68 million and 1:7.5 million. The Survey's Eastern Mapping Center provided digitized data for all the hydrologic units for each State map within the conterminous United States. This data will be utilized to (1) compute drainage areas for all the hydrologic units, (2) plot hydrologic-unit boundaries on other maps, and (3) locate stations by computer-searching known latitude and longitude coordinates of the hydrologic units and identifying the unit in which any water-data collection site is located. Digitized data will also facilitate exchange of information between existing data bases such as STORET and NAWDEX.

FIGURE 55.—Location of areas covered by Catalog of Information on Water-Data in Coastal Areas.



An intensive river quality assessment of the Willamette River basin in Oregon by the U.S. Geological Survey illustrates "the potential benefits of collecting scientifically sound data and using it to carefully analyze management alternatives" prior to action, according to a 1976 report by the General Accounting Office.* The comment followed publication of findings from the Willamette River assessment, a Geological Survey program designed to demonstrate the benefits of proper water resources planning through the use of sound technical information. The objective of the assessment was to show that it is possible to predict the effects of various management alternatives *before* any action is undertaken.

The most noteworthy finding of the Willamette assessment was that across-the-board advanced waste treatment was not the answer to the problem of meeting stringent water quality standards established for the river. Rather, the elimination of two industrial discharges of oxygen-demanding ammonia would solve the problem.

The Willamette assessment found that existing water quality data generally are inadequate for defining critical cause-effect relationships that control river quality problems and that intensive, synoptic surveys would be required in most river basins to develop an adequate information base for managing key river quality problems.

The study illustrates the fact that rigid standards and regulations are likely to result in unneeded expenditures in some river basins and perhaps undesirable quality in others. It concludes that a proper balance can be obtained only through an intensive, coordinated assessment that is keyed to local problems and conditions.

The General Accounting Office said "the study discovered more effective, efficient and economical means of achieving desirable water quality" and stated this could mean potential savings of tens of millions of Federal, State, and local dollars. △

* *Better Data Collection and Planning Is Needed to Justify Advanced Waste Treatment Construction*, CED–77–12, GAO, Washington, 1976.

COLLECTION, ANALYSIS, AND DISSEMINATION OF BASIC WATER DATA

The collection and analysis of basic water data, such as stream discharge, lake stage, water levels in wells, the chemical and biological characteristics and sediment loads of streams, and water-use statistics are fundamental aspects of water-resource investigations. These kinds of measurements are necessary to determine how much and what kind of water is available where and when. Comparisons can then be made between water used and water needed. Basic water data are essential not only for determining the adequacy of water supplies but also for designing bridges, dams, culverts, and other public works; for planning to prevent or lessen the impact of floods and droughts; for determining the feasibility of water-

TABLE 16.—*Number and type of measurement sites (stations) of the Geological Survey*

Type of station	Federal program	Federal-State Cooperative Program	Other Federal agency programs	Non-Federal program [1]	Total
SURFACE-WATER FLOW OR CONTENTS					
TOTAL	792	12,728	2,483	591	16,594
Continuous discharge	713	4,891	1,827	389	7,820
Partial discharge (high flow and/or low flow)	54	7,395	472	42	7,963
Lake reservoir and contents	25	442	184	160	811
SURFACE-WATER QUALITY					
TOTAL	745	4,216	1,230	39	6,230
Surface-water stations (excluding temperature only)	504	3,510	955	38	5,007
Sediment stations	241	706	275	1	1,223
GROUND WATER					
Sites at which water levels and/or pumpage are collected annually or more frequently				21,400	
Approximate number of sites at which well or spring records are maintained by computer file				650,000	

[1] Includes permittees and licensees of the Federal Power Commission.

power and irrigation projects; and for developing water-pollution control and recreational facilities.

The Survey maintains continuous discharge records at 7,820 stream sites, analyzes water quality at more than 5,000 stream sites, and measures water levels or other parameters periodically in more than 21,000 wells (table 16).

The ground-water site inventory file component of the computerized data-storage system (WATSTORE) now contains records for 650,000 wells and springs. In another year the number of records will be increased to provide data for one million such sites. The system is designed to accommodate up to 209 data elements for each site, including site location and identification, hydrogeologic characteristics, well-construction history, and numerous "one-time-only" measurements, such as discharge temperature. The automation of well inventory records will greatly enhance their value and utility in ground-water surveys and systems modeling.

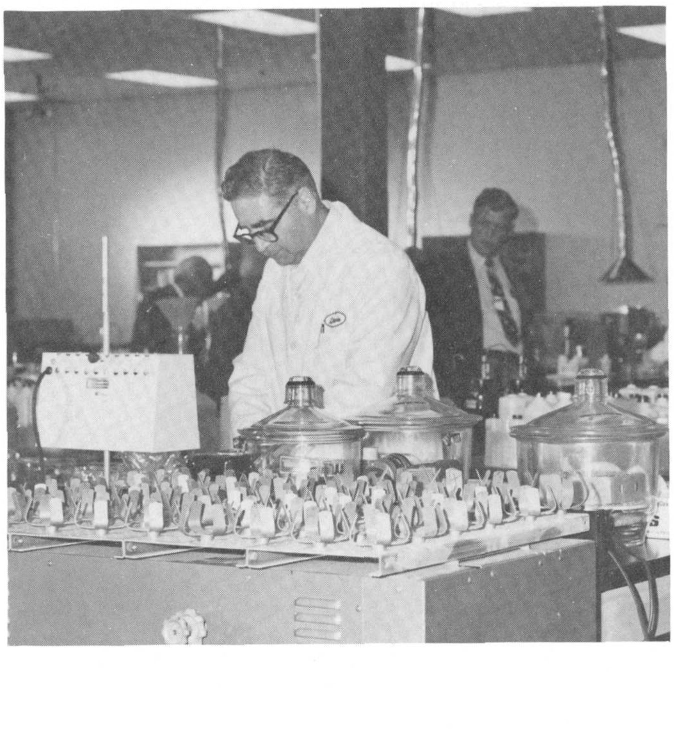
Central Laboratories System

During the past year, the Survey's Central Laboratories System began reorganization of two large, highly complex, automated laboratories in Atlanta and Denver. Services that were once provided by the Albany Central Laboratory in Albany, New York, are now supplied from the other two locations. In 1977 the Central Laboratories System made over two and one-half million determinations of physical, chemical, and biological characteristics of water in more than 170,000 samples. Survey analysts anticipate processing more than 200,000 water samples in 1978.

Among the new devices that have been added to the Central Laboratories System are automated sample changers, equipment for automatically mixing and combining chemicals with samples, instruments that record their own readings, and minicomputers that can compute results and then examine them for possible errors. Analytical results are transmitted directly from the laboratories by way of computer terminals to more than 50 Survey field offices, as well as to a computerized data bank in Reston, Virginia.

The Denver Central Laboratory, constructed in late 1976, is a 4,554-square-meter (49,000-square-foot) laboratory complex in the Denver suburb of Arvada, Colorado. It houses, in addition to the Central Laboratory, numerous other laboratories devoted to methods development, quality assurance, and basic and applied research.

Denver Water-Quality Lab.



National Water Data Storage & Retrieval System (WATSTORE)

Most of the streamflow and stream-quality data that the Survey collects and analyzes are not only published in various Federal and State reports but are also filed in computer storage. WATSTORE, the data storage and retrieval system for the National Water-Data System, now contains approximately 70 percent of the streamflow and water-stage data and 35 percent of the quality of ground- and surface-water data collected by the Federal sector.

Three major files of WATSTORE are now available to non-Survey users: the Daily Values File, Station Header File, and Ground-Water Site-Inventory File. This means that the enormous volume of surface-water and ground-water inventory data collected by the Water Resources Division and other agencies may be accessed directly by users nationwide through their own computer terminals. These three files, plus others in the WATSTORE system, are available through more than 50 terminals located in Survey field offices and through more than 40 terminals located in other Federal or State offices.

In the past year, WATSTORE was augmented by a major revision of the peak-flow data base. This data base contains the annual maximum streamflow (peak discharge) and the annual maximum gage height (stage) values obtained at surface-water sites. By the end of the year, the peak-flow data base contained more than 400,000 annual maximum values. The file is used primarily to compute flood-flow frequency.

National Water Data Exchange (NAWDEX)

The National Water Data Exchange (NAWDEX) was established in 1976 to assist users to identify, locate, and acquire needed water data. The program was expanded in 1977 with the establishment of 52 Local Assistance Centers to provide convenient access to NAWDEX services. These centers are located in 45 States and in Puerto Rico. They include the facilities of 50 Geological Survey district and sub-district offices, the Texas Natural Resources Information System in Austin, Texas, and the Water Resources Research Institute of the Virginia Polytechnic Institute and State University in Blacksburg, Virginia.

NAWDEX provides a nationwide service for indexing and describing the characteristics of data available throughout the Federal and non-Federal sectors of the water-data community. Requests for needed water data are referred to those organizations that can best respond to the requests. All data in the WATSTORE system are also available through the NAWDEX Local Assistance Centers. Two computerized data bases are maintained and accessible to the Local Assistance Centers via computer terminals: (1) a Water Data Sources Directory which identifies more than 300 organizations that collect water data, and (2) a Master Water Data Index which currently identifies and describes the water data available from more than 200,000 sites nationwide. As of July 1977, there were 14 Federal and 43 non-Federal members of NAWDEX.

National Stream Quality Accounting Network (NASQAN)

The National Stream Quality Accounting Network (fig. 56) was established by the Geological Survey to provide a nationally uniform basis for continuously assessing the quality of U.S rivers. At each of NASQAN's 345 monitoring stations virtually the same water-quality variables (more than 50) are measured, with the same frequencies, using the same methods of sampling and analysis. Stations generally are located at the downstream end of 345 water-quality accounting units (subregional drainage basins) which collectively encompass the surface of the Nation. Present plans are to expand the network to 525 stations by 1979.

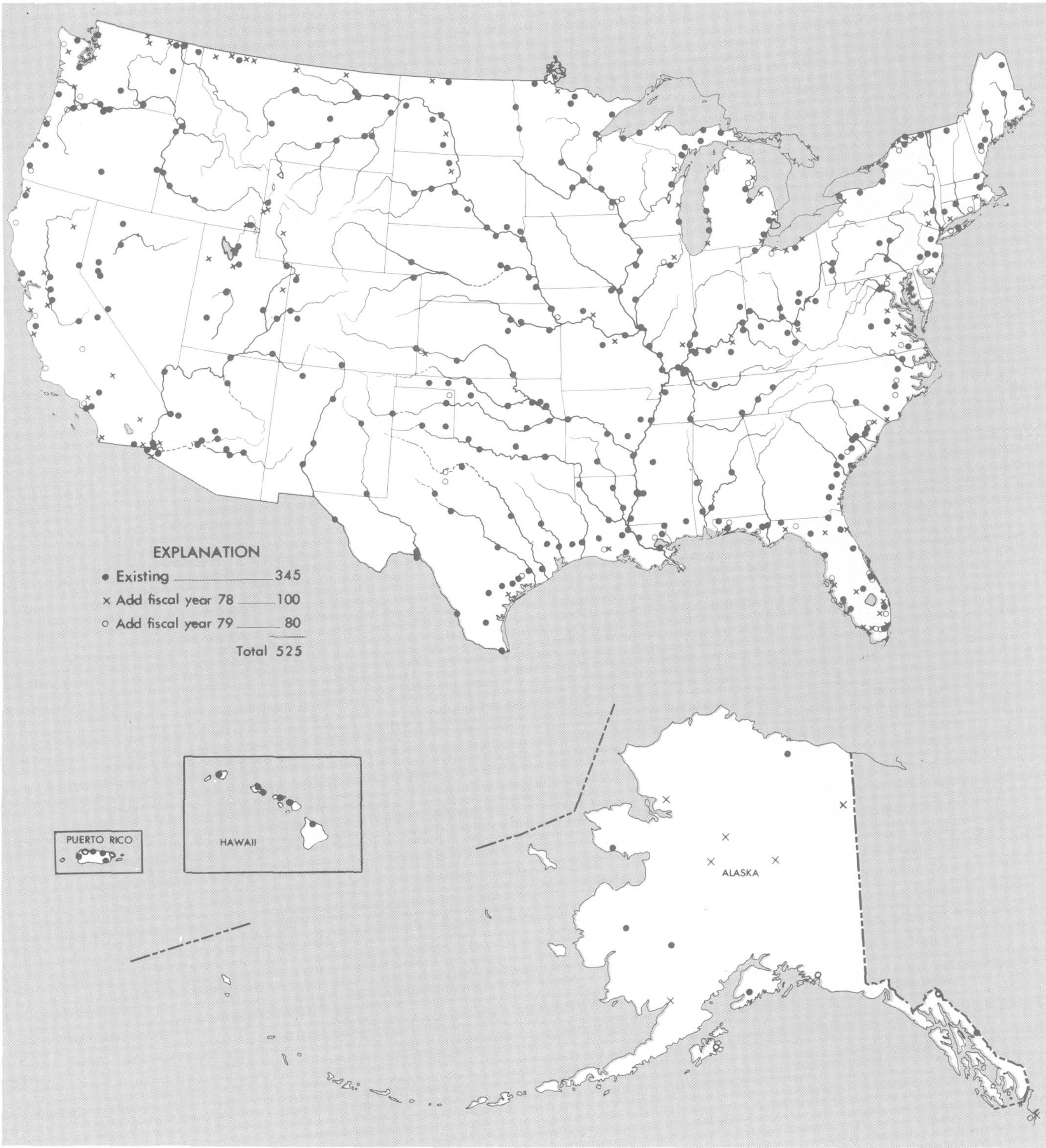
More than 3 years of data are now available from NASQAN. The data show geographic patterns of water quality that reflect climate, geology, soil types, agricultural practices, human and animal populations, water pollution, and pollution-control practices. A preliminary comparison of data from the period 1975 through 1977 suggests that several aspects of water quality improved significantly. Although it is too early to identify trends confidently, the improvements at many locations are concurrent with the implementation of new water-pollution controls.

Many aspects of water quality are determined by natural factors, such as the erodible areas of the Sierra Nevada and the Cascade and Rocky Mountains; the highly mineralized soils in the semiarid and desert regions of the Southwest and Great Plains; and the leached, nutrient-deficient soils of the rainy East, South, and Northwest. Rivers of most of the Midwest and Southwest, for example, are characterized by moderate to high levels of dissolved constituents as well as nutrients, sediment, and biota (floating and attached aquatic plants and indicator bacteria).

Problems caused by high concentrations of nutrients and large densities of aquatic plants are especially common in rivers of the agricultural regions of the Midwest. Many of the rivers in the heavily populated areas of the Midwest and Northeast have high bacteria levels; and parts of the Midwest, Great Plains, and Southwest also show high bacteria counts, often caused by livestock wastes and accentuated during periods of low streamflow.

Chemical quality, except for nutrients, of the rivers of the United States is best, by most standards, in the Northeast, Southeast and Northwest. Waters in these areas generally contain small amounts of dissolved solids and major and minor chemical constituents, are considered soft—except in Florida—and carry relatively small amounts of sediment. Many of these waters, however, carry moderate or high levels of major nutrients derived from cultural activities and have correspondingly high densities of attached and floating plants. High counts of indicator bacteria also show signs of local pollution at some sites.

FIGURE 56.—National Stream Quality Accounting Network.



RESEARCH PROGRAM

The dual objectives of the basic and problem-oriented research program are to provide sufficient understanding of hydrologic systems so that quantitative prediction of response of these systems to either natural or man-made stress can be made, and to support the Division's programs by providing operational and interpretive tools, such as instrumentation for data collection, analytical methods, and mathematical prediction models.

The activities of the research program, managed under 12 separate disciplines (see 1976 Annual Report of the U.S. Geological Survey), are broadly categorized in the areas of surface water, ground water, and quality of water. Research progress in these categories can be subdivided into four stages: development, verification, documentation, and operational.

A sampling of significant research findings:

- Studies of the summer ice pack of the Arctic Ocean indicate very large areas where the ice concentration is as low as 50 percent. This appears to be a significant finding since all earlier estimates put this limit at about 90 percent.
- Experiments indicate that the bromide ion can be used to trace ground-water movement in highly permeable dolomitic rocks. Analysis of the bromide ion by neutron activation allows the detection of very low ionic concentrations. Comparisons with tritium produced essentially identical breakthrough curves.
- The chemical mass transfer program, PHASEQ, was completed and tested in the laboratory and in the field. This program permits an analytical understanding of mineral-water reaction sequences in ground waters and permits correction of carbon–14 dates of ground water for chemical reactions.
- The oilspill resulting from the December 1976 breakup of the tanker, *Argo Merchant*, on Nantucket Shoals, provided an opportunity to verify, apply, and extend an oilspill trajectory model previously developed as part of an oilspill risk analysis for the proposed North Atlantic Outer Continental lease area. Deterministic simulations of the oil slick trajectory, using the observed time series of winds, correlated closely with the observed slick location.
- Models were developed to estimate the rates of water usage in energy conversion and transportation as a function of local meteorological and hydrologic conditions. The analysis considered thermal electric power plants and coal gasification plants using either once-through cooling, cooling ponds, cooling towers, and water utilization in coal slurry pipeline systems.
- Chemical modelling of ground-water chemistry in the Madison aquifer of the western United States may make it possible to predict water chemistry prior to drilling new wells in that region.
- Techniques have been developed to estimate the limits of sediment yields of a stream in order to maintain near "natural" conditions when the drainage area is impacted by construction areas. The transfer value of this technique is high not only in the field of urban hydrology but also with reference to highway construction and surface mining.
- Procedures are being developed for relating the ability of chemical extractants used for sediment metal analysis to the metal extraction ability of bottom-dwelling aquatic deposit feeders. Application could allow relatively quick estimation of bioavailability of sediment-bound metals by chemical extraction as opposed to lengthy bioassay experiments.
- Bioassay experiments conducted in a small flowing California stream indicated that (a) After equilibration with the flowing water containing 110μg/L nitrate (NO_3–N), an algal mass was found to remove about 80 percent of the nitrogen during the day and 50 percent at night. Algal removal of phosphate (PO_4–P), whose initial concentration was 11μg/L, was almost constant over the 24-hour period; and (b) Addition to stream of 104μg/L zinc and 25μg/L cadmium stopped night-time uptake of nitrate although some daytime uptake continued. A halt to algae uptake of silica also resulted, suggesting cessation of diatom growth.

SUPPORTING SERVICES

This program supports the publication of reports and maps and the management of the U.S. Geological Survey National Training Center at Lakewood, Colorado.

The enormous amount of data gained from the water-data-network and the information obtained from special investigations, studies, and analyses are published in Water-Supply Papers, in Professional Papers, in articles in the U.S. Geological Survey Journal of Research, in Hydrologic Investigations Atlases, and in other formats such as circulars, manuals, and open-file reports.

In 1977, the Training Center offered 71 courses in hydrology and related subjects in which 1,300 scientific and technical personnel participated. Students included not only Survey personnel but also representatives of cooperating State agencies and foreign hydrologic organizations. Some training courses were held outside of Denver at locations that provided either a hydrologic setting or laboratory facilities essential to the presentation of the course material. The subject matter of the courses ranged from instructions on the operation of hydrologic instruments to the programming of sophisticated hydrologic computer models. Video tapes of many of the courses are available on a loan basis to field offices throughout the country.

INTERNATIONAL ACTIVITIES

The Agency for International Development, other U.S. Government agencies, and several international organizations sponsor and support selected activities for which the Water Resources Division provides technical assistance. Increasingly, projects are being financed by the countries in which the work is done and whose personnel are trained by the Water Resources Division.

The U.S. National Committee on Scientific Hydrology, which represents the hydrological community of the United States to programs such as UNESCO's International Hydrological Program (IHP) and the World Meteorological Organization's Operational Hydrological Program, assisted with the preparation of the United States contribution to the World Water Conference held in Argentina in March 1977. It also provided a major input to the preliminary draft of activities for the second (1981–1986) phase of UNESCO's IHP as well as assisted with the organization of meetings and preparation of reports which are parts of the current (1975–1980) phase.

The 1977 program of technical assistance included year-long advisory services to Kenya, Saudi Arabia, and Yemen Arab Republic as well as short-term technical missions to eight developing countries. Twenty-four foreign water scientists and technicians received classroom and on-the-job training from the Division.

Critical National Water Problems

COAL HYDROLOGY

Adequate water supply may well be a critical factor limiting the development of coal resources in the Western States. Water enters the energy equation in many ways: the impact of mining on the quantity and quality of the basic resource; the need for water to aid in land restoration after mining; water required to support the increased populations involved in mining and processing coal; water for conversion of the coal to other forms of energy (liquid or gaseous fuels and/or electrical energy); water as a transportation medium for coal being carried to some other location via slurry pipelines.

Survey studies aimed at answering basic questions about water availability and related effects of coal mining range from collection of basic data on water quantity and quality through complex laboratory investigations of gases and organisms in water to analyses of regional aquifer systems such as the Madison aquifer investigation. Now in the second year of a 5-year study, the Madison aquifer has been modeled by digital computer to assess the existing data deficiencies and the sensitivity of the regional analysis to various types of information. This analysis guides data-collection efforts, an important consideration where expensive, deep drilling is required.

As highlighted at the beginning of this chapter, a 2,858-meter (9,378-foot) hole was drilled and tested in southeastern Montana. During 1977, other detailed testing was also done in the first Madison test well which had been completed in Wyoming in October 1976.

OIL-SHALE HYDROLOGY

For the Nation to utilize the tremendous potential of the oil-shale deposits in the Western States, several critical problems must be solved: (1) disposal of the spent shale after processing; (2) availability of water to operate processing plants and to supply the populations necessary to operate them; and (3) disposal of water which may be encountered in both underground and surface mining and which can be highly saline.

One technique, being explored by industry, to minimize the problem of spent shale disposal is to remove a small percent of the shale in place, break the remainder into small pieces with explosives and obtain part of the oil from the oil shale by burning it in place and distilling the vapor produced. This method of development will require that hydrologic models be available which can predict the effects of in-situ techniques on the ground-water system, and vice versa. A complex three-dimensional hydrologic-geochemical model of the Piceance basin, Colorado, is under development by Survey scientists.

Baseline hydrologic data, against which to assess the impacts of development, are being collected on springs, water levels in wells, water quality, sediment loads in streams, and stream discharge. One technique being evaluated as a long-term method of evaluating the impacts of oil-shale development on surface-water quality is to collect and evaluate the benthic (bottom dwelling) invertebrate populations in different aquatic habitats. Any long-term changes in this animal population should be a reflection of long-term changes in water quality at each site.

NUCLEAR HYDROLOGY

One of the most serious problems related to the development of the nuclear industry is the disposal of radioactive wastes. These wastes are classified as high-level if they result from the reprocessing of reactor fuels, and low-level if they are from any other source.[1] Unlike many of man's wastes which degrade more rapidly, many nuclear wastes may remain a threat to the environment for a long time. Some high-level wastes must be safely isolated from the biosphere for a quarter of a million years before the radiation level declines to a point where it can be considered safe. Low-level wastes have been disposed at six commercial field sites in different hydrogeological settings for more than 20 years.

The Geological Survey, in cooperation with the Energy Research and Development Administration, is characterizing several potential regions for the disposal of high-level waste. Studies are in progress in areas of bedded salt in New Mexico, Utah, New York, and Michigan; at salt domes in Louisiana and Texas; and in shales in Colorado, Nevada, and North and South Dakota. Granite and similar crystalline rocks are also being studied on a nationwide basis; investigation of specific sites in granitic rocks of southern Nevada was initiated in 1977.

Low-level waste sites are being investigated in the field to determine the amount and direction of movement of radionuclides under actual field conditions. The radionuclides can move by erosional processes, by ground-water transport, or as gaseous emissions. Geologic materials collected at the field sites are being evaluated in the laboratory to assess their effectiveness in retaining radionuclides by sorption and ion exchange. Studies at the low-level waste sites are designed to gather information and develop geohydrologic criteria for more suitable location of future burial sites.

In connection with both low- and high-level waste field studies, theoretical and laboratory studies are under way to:

- Detect and identify radionuclides by borehole geophysical techniques.
- Use digital modeling techniques to predict ground-water flow and quality.
- Evaluate geochemical kinetics of radionuclides.
- Predict the movement of radionuclides in the unsaturated zone.
- Predict the behavior of transuranic elements in the geologic environment.

[1] Low-level radioactive waste contains such relatively weak concentrations of radioactivity that shielding to prevent personal exposure is not required. High-level radioactive waste is defined as the fission product waste resulting from reprocessing spent fuel to separate uranium and plutonium from the fission products. Under present reprocessing methods, significant amounts of long-lived transuranic elements remain in high-level wastes. The President's decision during 1977 not to reprocess spent reactor fuel rods adds an additional category of waste.

- Predict the transfer of heat in aquifers.
- Improve the use of tracers in studying ground-water movement.

GEOTHERMAL PROGRAM

As part of the Survey's Geothermal Energy Investigations program, the Water Resources Division had 19 ongoing research projects and several supporting activities in 1977. These projects supplement the geological, geochemical, and geophysical studies by the Geologic Division. Some financial support was provided by the Energy Research and Development Administration.

The 19 research projects cover the following studies and investigations:

Type	Number of projects
Development and application of borehole geophysical techniques and shallow- to intermediate-depth test drilling.	2
Analytical and experimental studies of mass and energy transport in geothermal systems.	2
Numerical-modeling studies.	3
Land-subsidence research in geothermal areas.	1
Geochemical studies.	4
Areal and regional hydrologic studies, principally in 6 Western States—Idaho, Oregon, Nevada, Utah, Colorado, and Montana; and also including a large-scale study of the potentially important geopressured-geothermal resource of the Gulf Coast of Louisiana and Texas.	7

In 1977 some significant accomplishments included:

- Testing of a high-temperature acoustic televiewer to a depth of 3,050 meters (10,000 feet) and a temperature of 200°C (392°F) in a borehole and of a high-temperature acoustic-velocity probe in a laboratory. Development of this kind of equipment is particularly important to improve understanding of fractured-rock geothermal reservoirs.
- Determination of rock-water chemical interactions for selected constituents in about 100 springs and geysers in liquid-dominated geothermal systems in the western United States. Eighty-two percent of the waters analyzed exhibit equilibrium with either fluorite or calcite and 41 percent are in equilibrium with both phases. In hot-spring systems having a wide range in calcium and fluoride concentrations, a delicate balance exists among pH, and the solubility of carbon dioxide, calcium fluoride and calcium carbonate. These findings indicate that hot-spring waters are generally in equilibrium with the solids with which they are in contact.
- Modification of a numerical model that describes the movement of steam in a vapor-dominated geothermal system to include the effects of heat

conduction in the overburden, the weight of the steam column, and the effects of condensation when production is terminated.

- Detailed chemical analyses of about 100 formation water samples from 15 oil and gas fields in coastal Texas and Louisiana show that (a) the salinity of water in the geopressured zone ranges from about 20,000 to more than 150,000 mg/L dissolved solids; (b) samples from many gas wells yield low salinities that are not representative of the true salinity of formation water because they are diluted by the condensed water vapor produced with natural gas; and (c) the concentrations of hydrogen sulfide, silica, and mercury are low in geopressured waters and the concentrations of toxic components (boron, ammonia, for example) are moderately high.

UNDERGROUND HEAT STORAGE PROGRAM

The feasibility of repetitively storing large amounts of thermal energy in the form of heated ground water is being evaluated.

Field tests were conducted near Mobile, Alabama, by the Water Resources Institute at Auburn University, Alabama, jointly funded by the Survey and the Energy Research and Development Administration through the Office of Water Research and Technology. The Geological Survey is serving as technical monitor. A large quantity of once-through power plant cooling water from the Alabama River was injected into the aquifer. Although a large quantity of heated water was stored, a not unusual occurrence of progressive but partially reversible aquifer clogging was observed. A second experiment is now under way in which water pumped from a shallower aquifer will be artificially heated and then stored in the aquifer. Two cycles of injection and withdrawal are planned for the second experiment.

Field data from such tests will permit verification of digital aquifer-system models. These models are kindred to models being developed for geothermal studies and waste-heat disposal studies, all of which are complementary.

GROUND-WATER RECHARGE

Studies on ground-water recharge include the use of both spreading basins (shallow ponds) and injection wells. In the semiarid High Plains of Texas and New Mexico, methods are being developed to predict the amount of water that can be returned to aquifers by studying the fundamental principles that control movement of water into aquifers, the rock-water interactions that occur during storage, and the diffusion-dispersion phenomena accompanying water movement after emplacement. In one recent test involving the recharge of about 430,000 m^3 (15,000,000 $ft.^3$) of water, water moved through a 2-meter (6.6 foot) thick clay bed at the rate of about 0.1 meter (4 inches) per day. This rate of movement had been predicted from the lag in barometric pressure change across the bed, based on a recently described method. This prediction was far different from any based on laboratory analyses of cores from the clay bed. Thus, the new method offers great promise for estimating permeability of layers at depth. Other recent tests have demonstrated the utility of polyelectrolyte flocculants (chemicals that cause very fine sediments to settle out of the water) to clarify sediment-laden shallow lake water before recharging it.

Recharge of highly treated sewage by use of spreading basins is being studied on Long Island. Instrumentation is emplaced in a manhole in the center of the basin to study the long-term water quality and clogging effects of such recharge. This instrumentation is also facilitating a study of the movement of viruses into the aquifer during recharge.

MAPPING IN FLOOD-PRONE AREAS

The mapping program in flood-prone areas is directed toward rapid identification of areas subject to inundation. A high priority has been given it in order to meet the flood-plain management and land-use planning needs expressed in recommendations of the Task Force on Federal Flood Control Policy (House Document 465, 89th Congress) and the National Flood Insurance Act of 1968.

In 1977 the Water Resources Division published approximately 200 maps of flood-prone areas. Since the beginning of the program in 1969, nearly 12,700 maps and 1,000 descriptive pamphlets have been published. The maps identify the flood-prone areas in virtually all the developed and developing sections of the country.

Flood-prone-area maps show on a 7.5-minute quadrangle topographic map base (scale 1:24,000; 1 centimeter on the map equals 240 meters) the approximate boundaries of areas having a 1-percent chance of being flooded in any given year. The maps are used extensively to meet local planning needs and to meet objectives of the National Flood Insurance Act of 1968 and the National Disaster Protection Act of 1973. The Water Resources Division field offices stock the flood-prone-area maps which are available for distribution to the public without charge.

In addition to conducting reconnaissance flood mapping, the Geological Survey is one of several agencies conducting flood-insurance studies for the Department of Housing and Urban Development. These studies include flood-profile information and delineation of 100-year floods (floods with a 1-percent chance of occurring in any given year) on city or com-

The 1977 Johnstown Flood, Johnstown, Pa.

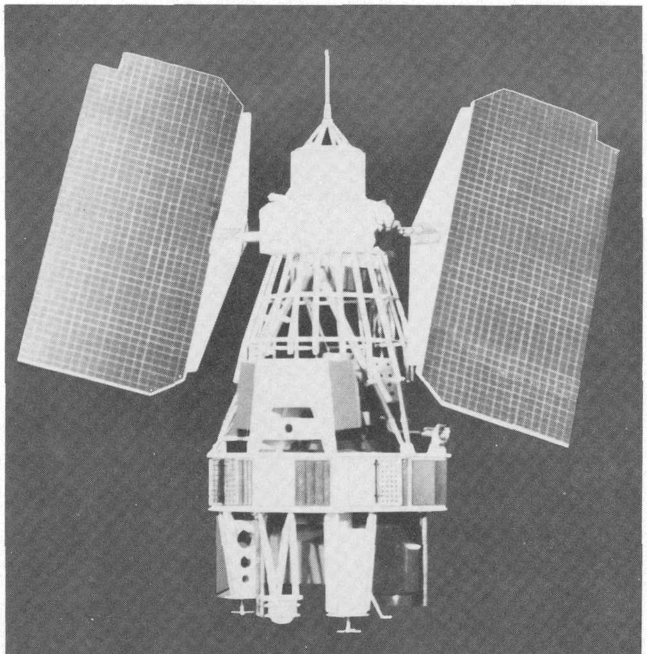
A lifeline across floodwaters. (Johnstown *Tribune-Democrat.*) ▲

Flood waters up to porch level at this home. (Jujulah Corp.) ▶

munity maps of scales such as 1:4,800 (1 centimeter on the map equals 48 meters). Since 1970, such studies have been undertaken by the Survey in about 600 communities.

Documentation of those major floods that occur every year in the United States provides the information required for the judicious management of flood plains. Field investigations of the Johnstown, Pennsylvania, flood of July 1977 were completed; the final report is in preparation. The September 1977 flood in the Kansas City area, Kansas and Missouri, is under investigation. The formal report on the flood caused by the failure of the Teton Dam, Idaho, in June 1976 was completed. In addition, in 1977 the Geological Survey and the National Weather Service (National Oceanic and Atmospheric Administration) began preparation of joint reports on investigations of three disastrous floods: in Maine in February 1976; in Colorado in July 1976; and in the Appalachian areas of Kentucky, Tennessee, Virginia, and West Virginia in April 1977.

The National Water Data Storage and Retrieval System (WATSTORE) maintains a Peak Flow File of flood records for more than 12,000 surface-water sites and contains more than 390,000 peak observations. This file of annual maximum streamflow (peak discharge) values and gage-height (stage) values is available for public use through the Survey's WATSTORE system.



Remote Sensing of Water

Remote sensing is a data-gathering technique that permits measurements, at a distance, of emitted and reflected electromagnetic energy. That energy provides information on the nature of the objects and surfaces from which it radiates. Since World War II this technique has developed rapidly, primarily in response to the increasing need to obtain information about large areas, including information on water-resource evaluation, flood monitoring, and land-use changes.

Water resources are especially amenable to investigation by remote sensors. For example, surface water is perhaps the easiest land-cover category to classify and extract as a map theme, and water has a profound influence on vegetative growth and plant succession which are indicators of hydrologic conditions and change. Water has the highest specific heat of any substance commonly found in nature; therefore wet areas tend to have thermal characteristics which differ from those of adjacent dry areas. These differences, and other dynamic water conditions, such as effluent discharge, generally can be detected using thermal sensors.

Remote sensing is a useful tool that complements rather than replaces conventional techniques. Thus data from ground, air, and space can be combined to provide valuable information that may not be easily obtained from the ground alone.

The Water Resources Division has benefited from the synoptic look provided by remotely-sensed data. It has enabled it to:

- Study dynamic processes such as water circulation in estuaries, snow and ice accumulation and melting, and environmental changes.
- Delineate, inventory, and map hydrologic categories such as wetlands, floods, and drainage basin variables.
- Monitor or assess environmental changes, river basin conditions, and the distribution of water.
- Provide information for water-management decisions such as location of data-collection sites, snow line mapping, and available ground- and surface-water resources.

SUBSURFACE WASTE STORAGE

The objectives of the Survey's subsurface-waste-storage program are to determine the fundamental principles of waste movement into and through the subsurface. An understanding of these principles is necessary to devise protection for fresh-water resources and to predict the long-term impacts of storage and disposal of wastes on water resources from surface and subsurface placement of both liquid and solid wastes. Water and waste managers use the data generated by this program and the resultant knowledge when they assess the degradation of water that is being caused or will be caused by various methods of waste disposal at different sites. They also use it, along with other factors, when they try to decide whether a site and method are or are not acceptable. The data may indicate that other methods must be devised or other sites evaluated.

Legislation prohibiting disposal of waste in streams and by incineration into the air has caused increased disposal on and beneath the land surface. Many chemicals react or are sorbed, degraded, diluted, or dispersed while moving through the unsaturated and saturated soils and aquifers, but many are not sorbed or do not react. Also, the earth materials have limited capacity which may be exceeded. Leachate formed by water percolating through waste, or waste injected into an aquifer, will eventually cause some degradation to some amount of water in an aquifer down-gradient from the disposal point. Although ground-water contamination is limited in area, the impact on ground water is long lasting, and a body of contaminated water tends to expand with time. The chemicals or substances which are not sorbed or do not react are diluted or dispersed as they move with the ground water. However, each year many new points of pollution are created and few are eliminated so that the amount of polluted ground water is increasing from year to year.

The subsurface waste-storage program includes studies ranging from simulation modeling of waste transport in thick unsaturated sediments to determining the velocity of deep ground-water circulation by means of isotope content of the native water. Other studies include: mapping of potential waste-injection aquifers in the Texas and Atlantic Coastal Plains and the Appalachian Basin; determining the impact of injecting treated sewage into saline aquifers in Florida and recharging treated sewage into glacial aquifers in Long Island; investigating the generation and movement of leachate from oil-shale and coal strip-mine wastes; developing predictive models of waste transport in ground water accounting for dispersion, dilution, and other physical and chemical reactions; adapting oilfield borehole-geophysical techniques to water-well research; and in-situ measurement of tectonic stresses and spectrographic identification of wastes.

ESTUARINE AND COASTAL STUDIES

One of the most critical coastal problems facing the Nation today is the health of its estuaries. Concentration of population, industry, and shipping in estuaries and adjacent areas, combined with their location at the lower end of the frequently sewage-laden rivers, has led to serious doubts about their ability to become more than community cesspools. Increasing upstream withdrawals of fresh water for cities, industries, and farms worsen the problem by reducing the inflow to, and thus the flushing of wastes from, estuaries. In most cases, the data on which to document this general degradation, or on which to plan programs for its amelioration, do not exist.

During 1977, an intensive investigation was initiated in the Potomac estuary to provide a scientific base of understanding necessary for designing an estuarine data program.

Studies continued on the biogeochemistry and circulation patterns in San Francisco Bay. Other estuarial studies were conducted in California, North Carolina, South Carolina, and Texas. The continuous withdrawal of fresh water from coastal aquifers and the ensuing problems of salt water encroachment have heightened the need for hydrogeologic data in coastal areas. Numerous areal projects in several coastal States have been carried out to satisfy these needs.

Other investigations in Florida and New York addressed similar data needs for the artificial recharge of coastal aquifers and the disposal of wastes by deep well injections.

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Conservation of Lands and Minerals

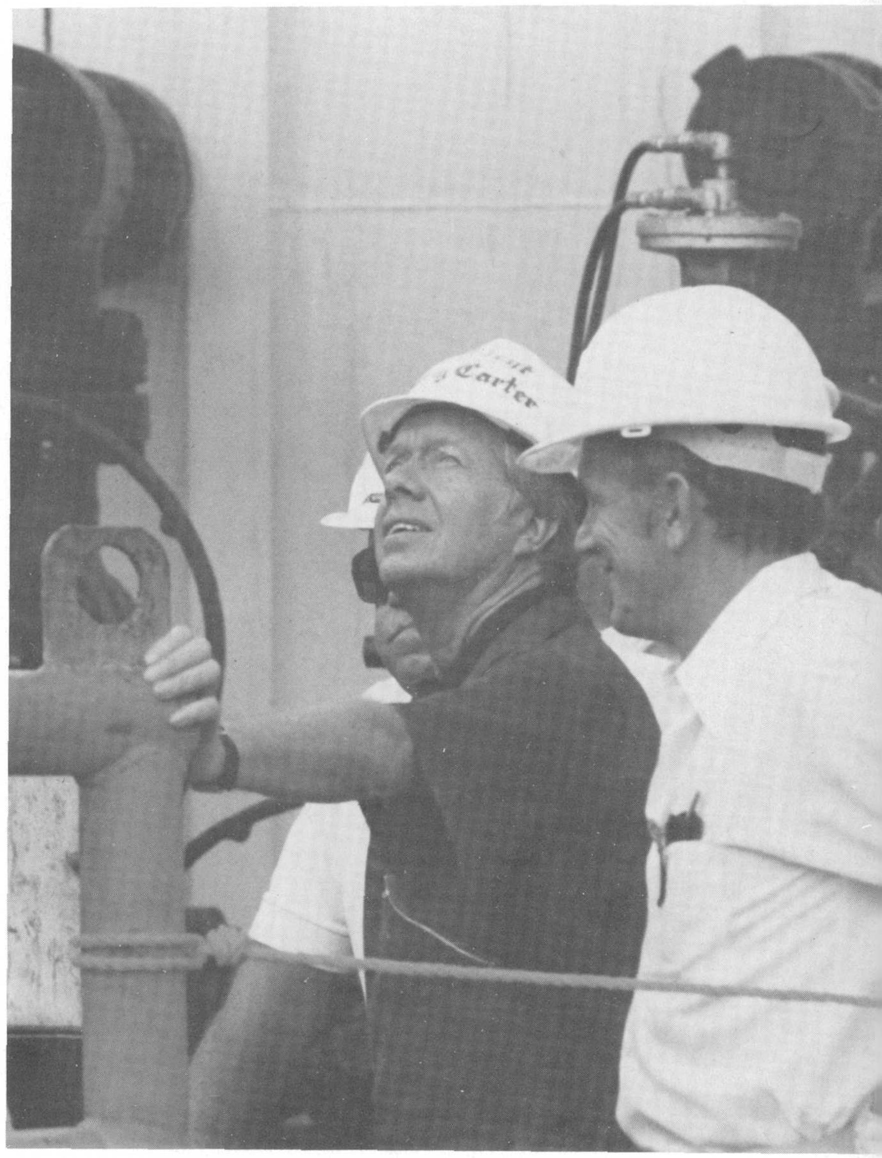
INTRODUCTION

The Conservation Division performs several regulatory functions delegated to the Geological Survey by the Secretary of the Interior under laws governing the leasing, mining and use of mineral and water resources on Federal and Indian lands. These responsibilities are accomplished in two major missions:

- Classification of public lands in terms of their potential for leasable mineral resources and their value for waterpower and water-storage purposes, and evaluation of mineral tracts on public land that are subject to competitive leasing or to sale or exchange.
- Supervision of operations associated with the exploration, development and production of minerals from leased Federal, Indian and Outer Continental Shelf lands, including the collection of royalties and certain rentals which result from mineral production.

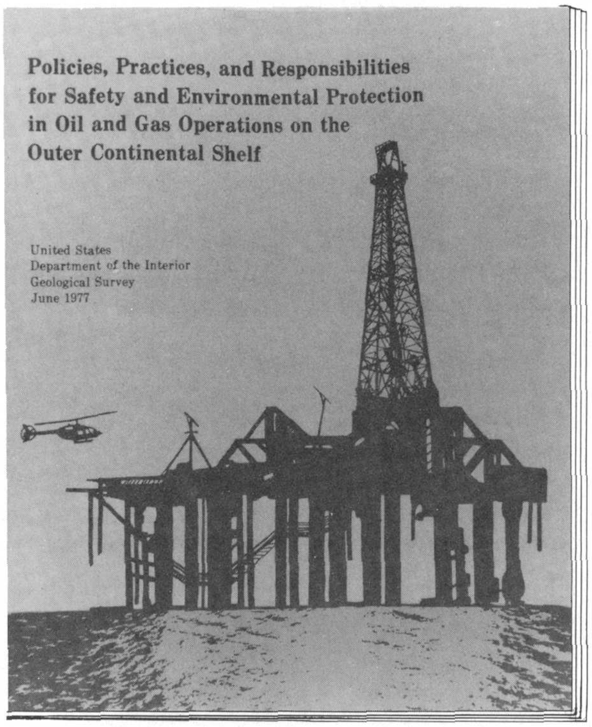
Data acquired by the Geological Survey while carrying out these functions also provides information to support the missions of other Federal agencies who share responsibilities for the sound development of resources and protection of the environmental characteristics found on public lands. These agencies include the Bureau of Land Management (BLM), the Bureau of Indian Affairs (BIA), the National Park Service (NPS), and the Bureau of Reclamation (BR) within the Department of the Interior, as well as the Department of Defense (DOD), the Forest Service (FS), the General Services Administration (GSA), and the Environmental Protection Agency (EPA).

◀ A geophysicist evaluates seismic information to determine whether subsurface geologic structures exist which might contain commercial quantities of oil and gas. This information is used in the economic evaluation of tracts offered in oil and gas lease sales and helps determine whether drilling and production activities can be conducted safely.



President Jimmy Carter and Senator Johnston (La.) observe drilling operations while visiting the Zapata offshore drilling platform in the Gulf of Mexico during the summer of 1977.

USGS Puts It All Together in New Regulations* for Outer Continental Shelf Oil and Gas Operations

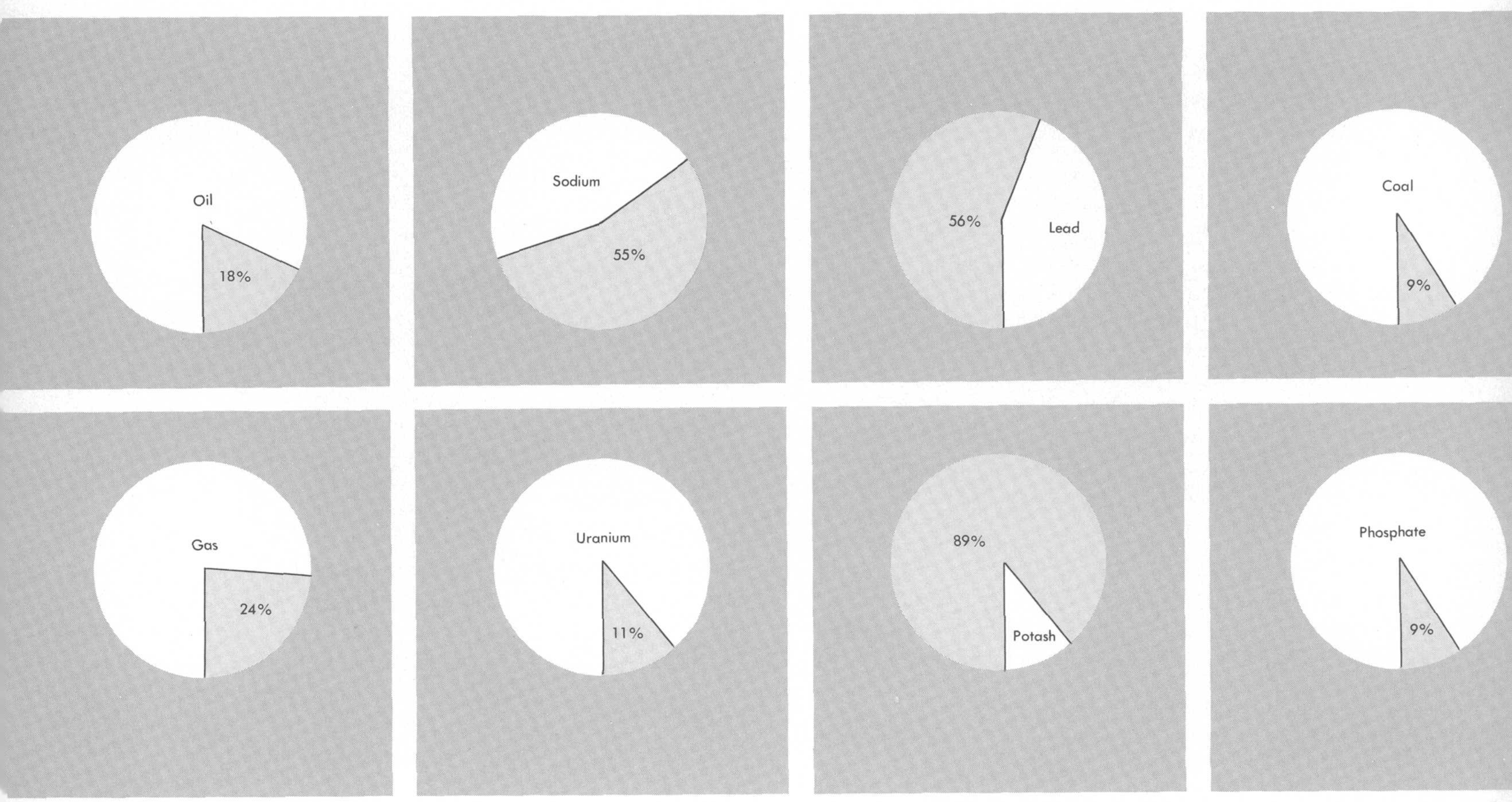

Policies, Practices, and Responsibilities for Safety and Environmental Protection in Oil and Gas Operations on the Outer Continental Shelf

United States
Department of the Interior
Geological Survey
June 1977

An organized and systematic program to assure safe, environmentally sound exploration, development, and production of oil and gas found on the Outer Continental Shelf is described in a recently published Survey document.

This OCS program incorporates many recommendations from recent independent studies of offshore oil and gas production activities by the National Aeronautics and Space Administration, the National Academy of Engineering, the University of Oklahoma, and the Council on Environmental

* *Policies, Practices and Responsibilities for Safety and Environmental Protection in Oil and Gas Operations on the Outer Continental Shelf*, p. 25, U.S. Geological Survey, Washington, 1977. Copies may be obtained free of charge by writing Chief, Conservation Division, U.S. Geological Survey, National Center, Mail Stop 620, Reston, VA 22092.



Quality. Recognizing that the responsibilities of the Geological Survey on the OCS are extensive, specific elements of this program have been designed to assure that all OCS operations are conducted in a way that best emphasizes safety of operations and prevention of environmental damage.

The functional elements of this lease-regulatory program are based on the concept that fundamental responsibility for safe OCS operations lies with each lessee and that it is the role of the Geological Survey to provide oversight of the entire sequence of activities associated with oil and gas production. In a major review of the program, several existing Geological Survey procedures have been revised and new procedures introduced to reflect an increasing emphasis on the responsibilities of each lessee. These new and revised functional elements extend beyond actual lease activities in some instances. New requirements, for example, stipulate that safety equipment comply with standards developed by the Geological Survey and that drilling and production platforms be designed and installed in accordance with new Geological Survey criteria. Even inspection procedures covering actual offshore facilities have been modified through addition of a provision which requries each lessee to perform a prescribed inspection routine at periodic intervals and take specified corrective action for any deficiency. Other major components of the program require lessees to report equipment failures, conduct a design analysis of offshore platform production systems, and perform other related actions with the intention of identifying and eliminating problem areas—and so prevent accidents.

The regulation of OCS oil and gas activities is a continuing process requiring constant review of program components and objectives. As oil and gas production activities become more complex and are undertaken in sometimes hostile new environments—off the Alaskan and Atlantic coasts, for example—this "new direction" in regulatory activity seeks to ensure that offshore oil and gas operations will be carried out in a way that emphasizes safety of operations, with a minimum risk of environmental damage. △

In fiscal year 1977, more than 17.5 percent of domestically produced oil, 24.1 percent of all natural gas and 9.0 percent of the nation's coal were derived from leased public lands onshore and offshore, clearly demonstrating the importance of the Federal land contribution to the nation's supply of petroleum and mineral resources. The production of these minerals has also had a significant impact on the nation's economy. For example, in fiscal year 1977, the value of all commodities produced from leased Federal lands exceeded $8.5 billion, while lease rentals and royalties from the production of minerals and various bonus payments provided more than $1.2 billion in revenue for the Federal Government.

Increased demands for energy and other minerals required amending and revising of public laws governing the operations of the Conservation Division to assure that exploration and development of resources on Federal lands are conducted in a manner that guarantees timely production of minerals while also protecting the environment.

◀ FIGURE 57.—Production from Federal and Indian lands as percentage of total U.S. production in fiscal year 1977.

Highlights

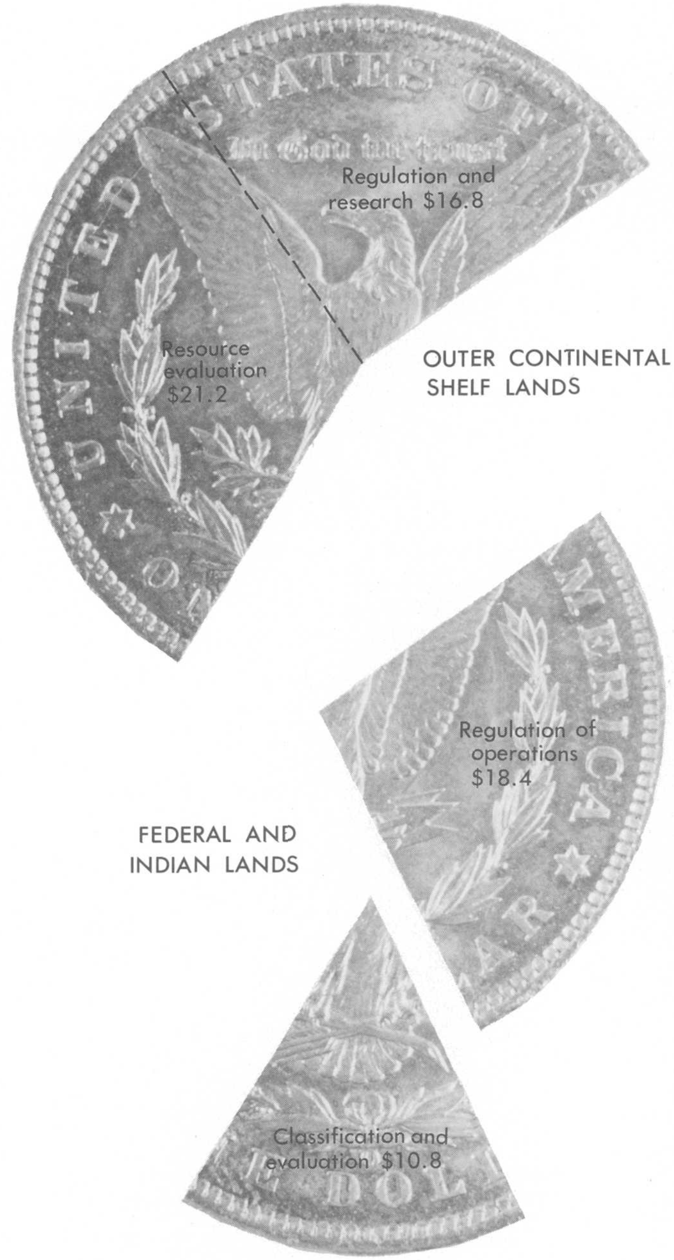
Activities of the Division in carrying out its responsibilities during fiscal year 1977 included:

- Completion of tract evaluations for 2 lease sales covering 0.538 million hectares (1,329,024 million acres) in the Gulf of Mexico and Gulf of Alaska which occurred during this fiscal year.
- Drafting, revision and updating of Outer Continental Shelf Orders (operating regulations) for the Atlantic, Gulf of Mexico and Pacific areas.
- Supervision of operations on 1,993 offshore oil and gas leases covering 3.8 million hectares (9.4 million acres).
- Supervision of operations on 127,810 onshore oil and gas leases covering 41.7 million hectares (103.1 million acres).
- Supervision of operations on 2,523 mineral leases covering 3.6 million hectares (9.0 million acres).
- Collection of $1,200 million in rents and royalties from the leasing of minerals on Federal lands.
- Evaluations of tracts for 14 geothermal lease sales. Subsequently, more than 40,892 hectares were leased in 59 tracts, with a total bonus paid to the Government of $2,693,750.

CONSERVATION OF LANDS AND MINERALS

TOTAL $67.2 MILLION

SOURCE OF FUNDS



USE OF FUNDS

Budget and Personnel

Shortages of some energy commodities during the winter of 1976–77 and policy decisions designed to stimulate greater production and use of coal accounted for marked increases in responsibilities and activities of the Conservation Division during the fiscal year. Appropriation for Division programs to support onshore development of energy and mineral resources on public and Indian lands increased to $29.2 million in fiscal year 1977, an 89.9 percent rise from the previous year.

Program activities related to Outer Continental Shelf energy development represented 56.3 percent of total program funding for the year, or $38.3 million. This represented a 38.8 percent rise over the previous fiscal year budget allocations for this program area, reflecting a continuing Administration

TABLE 17.—*Conservation of Lands and Minerals activity obligations for fiscal years 1976–77 by program (dollars in millions)*
[Data may differ from that in statistical tables because of rounding]

Program	Fiscal year 1976	Transition quarter	Fiscal year 1977
TOTAL	$41.4	$13.4	$67.2
Outer Continental Shelf Lands	26.2	9.2	38.0
Regulation of OCS oil and gas	12.2	3.4	16.3
Research on OCS safety devices	.5	.1	.5
OCS oil and gas tract selection and evaluation	13.5	5.7	21.2
Federal and Indian Lands	15.2	4.2	29.2
Regulation of operations	10.8	3.0	18.4
Oil and gas	7.0	1.9	9.8
Energy minerals (coal and uranium)	1.0	.3	5.6
Oil shale	.4	.1	.8
Geothermal	1.0	.3	.8
Nonenergy minerals	1.4	.4	1.4
Resource classification and evaluation	4.4	1.2	10.8
Oil and gas	.3	.1	.3
Coal	2.2	.6	8.6
Oil shale	.3	.1	.4
Geothermal	1.0	.2	.7
Nonenergy minerals	.2	.1	.3
Water-resource development	.4	.1	.5

[1] Total direct program. Reimbursable program amounted to $189,000, bringing the total program to 67.

policy to expand the leasing and development of offshore energy resources in a timely manner.

The number of full-time Division employees rose 24 percent, from 1,143 in fiscal year 1976 to 1,498 in fiscal year 1977. More than 81 percent of these new positions were filled by professionals, primarily geophysicists, geologists and petroleum and mining engineers. Additional management personnel hired during the same period improved the over-all program direction.

PROGRAMS AND ACTIVITIES

The principal activities of the Conservation Division focus upon two major programs: (1) the classification and evaluation of mineral resources on Federal lands, both onshore and offshore; and (2) the supervision of mineral development and extraction operations occurring on those lands under lease. The evaluation program involves the determination of the present dollar value of Federal mineral tracts being considered for lease, sale or exchange. Although leases for mineral development on Federal lands are offered and issued by the Bureau of Land Management, and those for Indian lands by the Bureau of Indian Affairs for the involved tribes, operating regulations governing the exploration, development, and production of mineral resources from Federal and Indian land leases are implemented and enforced by the Conservation Division of the Geological Survey. This implementation includes supervision of the computation and collection of royalties and certain rental payments from operators of leases, which are transmitted to the Treasury.

Outer Continental Shelf Lands

Federal jurisdiction over coastal waters and the underlying land generally begins 3 miles offshore, where State domain ends, and extends to the limit of the Continental Shelf. The first offshore wells were drilled off California in the 1890's from piers which extended from the shore. Production technology, at that time, was largely based on extensive on-and near-offshore fixed platform experience. In 1938, the Creole Field was tapped in the Gulf of Mexico, marking the oil industry's first move into open waters more than a mile from shore. The first well put down out of sight of land, and drilled from a mobile platform, was located in shallow water roughly 12 miles off the Louisiana Coast in 1947. Between 1954 and 1966, Federal leases were sold to the highest bidder without any concerted effort to assess the true value of the resource prior to sale.

Since about 1970 the geological and geophysical mapping techniques and evaluation procedures utilized have become far more sophisticated. Exploratory wells can now be drilled from fixed, semi-submerged, or floating platforms in more than 1,500 feet of water, with far greater confidence that petroleum resources found in those water depths could be produced. By the end of fiscal year 1977, more than 14,500 wells had been drilled offshore in Federal waters. Total production from these wells reached more than 307 million barrels of oil and 102,037,000 cubic meters (3,603 million cubic feet) of natural gas.

FIGURE 58.—Proposed OCS Planning Schedule *as of August 1977*

SALE AREA	1977					1978											
	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
CI Cook Inlet		N	S														
42 N. Atlantic	F		P		N	S											
43 South Atlantic-Georgia Embayment			F		P		N	S									
45 Gulf of Mexico				F		P		N	S								
65 Eastern Gulf of Mexico						E		H			F	P		N	S		
51 Gulf of Mexico							E		H			F		P		N	S
49 Mid-Atlantic		T						E		H			F			P	
48 Southern California													E		H		
58 Gulf of Mexico			C		D		T							E		H	
54 South Atlantic-Blake Plateau		C				D			T								
Federal/State Beaufort Sea (near shore) Alaska			C		D				T								
55 Gulf of Alaska										C		D			T		
62 Gulf of Mexico														C		D	
46 Kodiak																	
52 North Atlantic																C	
53 Central and Northern California				C							D			T			
60 Cook Inlet																	C
56 South Atlantic-Georgia Embayment																	
59 Mid-Atlantic-																	
66 Gulf of Mexico																	
57 Bering-Norton																	

SALE AREA	1979											
	J	F	M	A	M	J	J	A	S	O	N	D
CI Cook Inlet												
42 N. Atlantic												
43 South Atlantic-Georgia Embayment												
45 Gulf of Mexico												
65 Eastern Gulf of Mexico												
51 Gulf of Mexico												
49 Mid-Atlantic	N	S										
48 Southern California	F		P		N	S						
58 Gulf of Mexico		F		P		N	S					
54 South Atlantic-Blake Plateau	E		H			F		P		N	S	
Federal/State Beaufort Sea (near shore) Alaska			E		H			F			N	S
55 Gulf of Alaska								E		H		
62 Gulf of Mexico		T								E		H
46 Kodiak												E
52 North Atlantic	D			T								E
53 Central and Northern California												
60 Cook Inlet		D			T							
56 South Atlantic-Georgia Embayment			C		D			T				
59 Mid-Atlantic-									C		D	
66 Gulf of Mexico											C	
57 Bering-Norton				C							D	

SALE AREA	1980											
	J	F	M	A	M	J	J	A	S	O	N	D
CI Cook Inlet												
42 N. Atlantic												
43 South Atlantic-Georgia Embayment												
45 Gulf of Mexico												
65 Eastern Gulf of Mexico												
51 Gulf of Mexico												
49 Mid-Atlantic												
48 Southern California												
58 Gulf of Mexico												
54 South Atlantic-Blake Plateau												
Federal/State Beaufort Sea (near shore) Alaska												
55 Gulf of Alaska	F		P		N	S						
62 Gulf of Mexico			F		P		N	S				
46 Kodiak		H			F		P		N	S		
52 North Atlantic		H				F		P		N	S	
53 Central and Northern California				E		H			F		P	
60 Cook Inlet		E				H				F		P
56 South Atlantic-Georgia Embayment						E		H			F	
59 Mid-Atlantic-		T								E		H
66 Gulf of Mexico	D			T							E	
57 Bering-Norton		T										E

SALE AREA	1981											
	J	F	M	A	M	J	J	A	S	O	N	D
CI Cook Inlet												
42 N. Atlantic												
43 South Atlantic-Georgia Embayment												
45 Gulf of Mexico												
65 Eastern Gulf of Mexico												
51 Gulf of Mexico												
49 Mid-Atlantic												
48 Southern California												
58 Gulf of Mexico												
54 South Atlantic-Blake Plateau												
Federal/State Beaufort Sea (near shore) Alaska												
55 Gulf of Alaska												
62 Gulf of Mexico												
46 Kodiak												
52 North Atlantic												
53 Central and Northern California	N	S										
60 Cook Inlet		N	S									
56 South Atlantic-Georgia Embayment	P		N	S								
59 Mid-Atlantic-			F		P		N	S				
66 Gulf of Mexico	H			F		P		N	S			
57 Bering-Norton		H					F		P		N	S

C Call for Nominations
D Nominations Due
T Announcement of Tracts
E Draft Environmental Statement
H Public Hearing
F Final Environmental Statement
P Proposed Notice of Sale
N Notice of Sale
S Sale

Sales are contingent upon a reasonable assumption that technology will be available for exploration and development. A decision whether to hold any of the lease sales listed will not be made until completion of all necessary studies of the environmental impact and the holding of public hearings as a result of the environmental, technical, and economic studies employed in the decision making process; a decision may, in fact, be made not to hold any sale on the schedule.

The Department of the Interior

Rents and royalty payments totaling more than $885 millions from OCS production have been collected for the Government by the Geological Survey.

OCS Resource Evaluation

The offshore resource evaluation activities of the Conservation Division focus upon identifying potential areas for future lease sales, and advising the Bureau of Land Management in their selection of specific tracts to offer for sale. Using geophysical information and available well data, geologists and engineers estimate the amount and value of the oil and gas on each tract to be offered, and analyze the probable costs of producing these resources, thereby arriving at an estimate of the fair market value for each lease. They also identify geologic or other environmental hazards so that exploration, development, and production can be accomplished in an environmentally safe manner. The Division established its present comprehensive offshore resource evaluation program in 1969.

- Six deep Continental Offshore Stratigraphic Test (COST) wells were approved in Federal waters on the Outer Continental Shelf (OCS). These wells were drilled by industry with the stipulation that they share the data with the Department of the Interior. Five were completed and one was being drilled at year's end. Of the two tests drilled in the Atlantic OCS, the first, North Atlantic COST Well #G-2, was approved in December 1976, drilled to 6,668 meters (21,872 feet), and completed on August 31, 1977; the second, South Atlantic COST Well #GE-1, was approved in January 1977, drilled to 4,040 meters (13,254 feet), and completed on June 15, 1977. The other four deep stratigraphic tests were approved for the Alaskan OCS. The Lower Cook Inlet COST Well #1 test, approved in June 1977 and drilled to 3,776 meters (12,387 feet) was completed on September 24, 1977. Three tests were approved on Alaska's Kodiak Shelf. Kodiak Well #1, approved in May 1977 and drilled to 2,596 meters (8,517 feet) was completed on July 18, 1977, and the Kodiak Well #2, approved in July 1977 and drilled to 3,189 meters (10,460 feet), was completed on September 3, 1977. Kodiak Well #3, approved in July 1977 was being drilled at the end of the fiscal year.
- Shallow "off-structure" test drilling approved during fiscal year 1976 was carried out on the Kodiak Shelf off the Alaskan coast. Tests drilled in this program ranged from 150 to 1,200 meters (500 feet to 4,000 feet) in depth and provided valuable data for future offshore lease sales.
- To support tract evaluation, the Division obtained, from private geophysical contractors, more than 60,200 kilometers (37,400 miles) of common-depth-point seismic data helpful in determining the locations of potential hydrocarbon deposits. These firms also supplied 57,300 kilometers (35,600 miles) of high-resolution seismic data to enable geophysicists and geologists to chart the presence and location of shallow geophysical hazards.
- An additional 36,700 kilometers (22,800 miles) of magnetic data and 1,770 kilometers (1,100 miles) of gravity data to support the resource evaluation program also were purchased. Total costs of acquiring all these data reached $7,671,563.
- Tract evaluations were begun during fiscal year 1977 for Sales # 45, 57, and 65 in the Gulf of Mexico, Sales # 42 and 43 on the Atlantic Outer Continental Shelf, Sales # 48 off the Pacific coast, and Sales # 46 and 60 off the Alaskan coast.
- A drainage and development lease sale comprising 61 tracts in the Gulf of Mexico was held on November 16, 1976, in New Orleans, Louisiana. Bids totaling $379 million were offered and accepted for 43 tracts sold.
- A lease sale covering 233 tracts in the Gulf of Mexico was held June 23, 1977, in New Orleans, Louisiana. Bids totaling $1.7 billion were offered and accepted for 124 of these tracts, located offshore Texas, and Louisiana. Additional bids of $43.9 million on 28 tracts were rejected by the government as being insufficient. One tract in this sale brought a bid of more than $77 million.

A large "jack-up" type offshore oil drilling rig.

Supervision of Operations

Following each lease sale by the Bureau of Land Management (BLM), the Geological Survey becomes the agency responsible for supervising oil and gas exploration, development and production activities of the lessees on Outer Continental Shelf lands. This is to ensure that operations are conducted in compliance with Department of the Interior regulations for conservation of the mineral resources and protection of the ocean environment, and that royalties collected for the Government are correct and current. Royalties may be collected either in the form of monies or taken in kind (a portion of the resources produced) for sale to persons other than the producer. Supervision of operations by companies holding offshore leases involves:

- Review and approval of proposed company operating plans;
- Periodic on-site inspection and review of exploration, development and production operations and procedures;
- Computation, collection, and accounting of rents and royalties associated with production of oil and gas from Federal leases.

During fiscal year 1977, Conservation Division personnel were responsible for supervising oil and gas operations on 1,970 leases and test well operations covering more than 3,770,000 hectares (9,312,000 acres) on the Outer Continental Shelf areas of the Alaska, Pacific, Gulf of Mexico and Atlantic coasts. Most of these inspection activities occurred on the Gulf of Mexico, where the largest number of operations are underway.

The Geological Survey reviewed and approved more than 540 exploration and development plans in the Gulf of Mexico in fiscal 1977.

More than 2,655 drilling rig and 2,250 production platform inspections were made during the fiscal year. As a result of these on-site inspections, 683 warnings for improper operations were issued. In addition, production from 1,043 zones beneath 39 platforms was temporarily halted until deficiencies in drilling or production procedures were corrected.

Production of petroleum products from the Outer Continental Shelf totaled more than 307 million barrels of oil and 102 million cubic meters (3,603 billion cubic feet) of gas during the fiscal year and resulted in collection of more than $885 million in rent and royalty payments for the Government.

TABLE 18.—*Status of Outer Continental Shelf Orders at the end of fiscal year 1977*

Order number and title	Gulf of Mexico area	Pacific area	Gulf of Alaska area	Atlantic area OCS
1. Marking of Wells, Platforms, and Fixed Structures	Effective 8/28/69.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
2. Drilling Procedures	Effective 1/1/75.	Effective 5/1/76.	Effective 3/1/76.	Effective 7/1/76.
3. Plugging and Abandonment	Effective 8/28/69.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
4. Suspensions and Determination of Well Producibility	Effective 8/28/69.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
5. Subsurface Safety Devices	Effective 6/5/72.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
6. Completion of Oil and Gas Wells	Effective 8/28/69; being revised.	Effective 6/1/71.	------------	------------
7. Pollution and Waste Disposal	Effective 10/1/76.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
8. Platforms and Structures	Effective 10/1/76.	Effective 6/1/71.	------------	------------
9. Oil and Gas Pipelines	Effective 10/30/70.	Effective 6/1/71.	------------	------------
10. Sulfur Drilling Procedures	Effective 8/28/69.	Effective 6/1/71.	Not Applicable.	Not Applicable.
11. Oil and Gas Production Rates, Prevention of Waste, and Protection of Correlative Rights	Effective 5/1/74.	Effective 5/1/75.	------------	------------
12. Public Inspection of Records	Effective 2/1/75.	Effective 12/1/74.	Effective 3/1/76.	Effective 7/1/76.
13. Production Measurement and Commingling	Effective 10/1/75.	-------	------------	------------
14. Approval of Suspensions of Production	Effective 1/1/77.	-------	------------	------------
U.S. Geological Survey Standard GSS–OCS #1	Effective 2/1/76.	Effective 2/1/76	Effective 2/1/76.	Effective 2/1/76.

TABLE 19.—*Hydrocarbon spills on Outer Continental Shelf, calendar years 1971–76*

[50 barrels equals 6.8 tonnes]

Calendar year	Spills of 50 barrels or more			Spills of less than 50 barrels		
	Number	Barrels spilled	Tonnes spilled	Number	Barrels spilled	Tonnes spilled
1971	11	1,285	174	1,245	1,493	202
1972	2	150	20	1,159	1,032	139
1973	4	[1] 22,175	2,997	1,171	921	124
1974	8	[2] 22,721	3,070	1,129	667	90
1975	2	266	36	1,126	711	96
1976	3	[3] 4,714	637	949	523	71

[1] 9,935 barrels spilled from a ruptured storage tank (1/9/73) and 7,000 barrels spilled from a leaking barge (1/26/73).

[2] 19,850 barrels spilled from a pipeline broken when a ship's anchor dragged on the seabed (4/17/74).

[3] 4,000 barrels spilled from a pipeline tie-in broken by a shrimp trawl drag (12/18/76).

Since 1971, production of oil from existing OCS leases has been decreasing while production of natural gas has been increasing slightly. The use of gas to generate electricity, as a residential heating fuel, and as a feedstock for the production of chemicals, plastics, and synthetics has grown to the point where demand clearly exceeds supply, resulting in several regional shortages and the closing of some industrial plants during the winter of 1976–77. A primary response by Government has been to stimulate further exploration and development on existing leases through an accelerated offshore resource development program. This is particularly important, since from 3 to 10 years are needed on the average to produce additional resources from new lease discoveries. There has been a significant rise in requests for approval of exploration and notices of intent to drill which could lead to the development of still undiscovered resources on all the continental shelf areas.

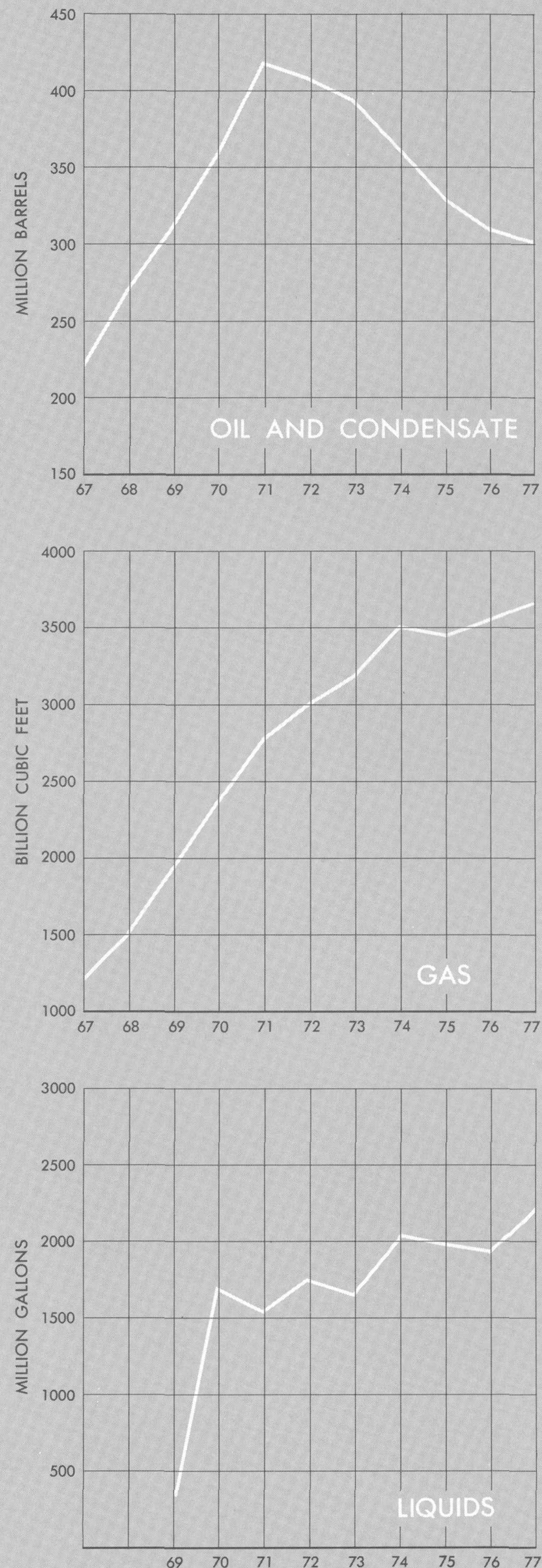
Research and development of enhanced recovery techniques as well as investigation of potential new energy sources like the geopressured zones in the Gulf of Mexico may result in significant new domestic supplies of gas and geothermal energy for the Nation during the coming years.

TABLE 20.—*Fires and explosions on the Outer Continental Shelf, calendar years 1970–76*

Calendar year	Number of events	Injuries	Fatalities
1970	12	31	17
1971	19	16	1
1972	31	9	0
1973	30	9	2
1974	22	15	0
1975	27	11	[1] 10
1976	32	14	0

[1] A tanker collided with a platform. Oil escaping from the tanker ignited and set the ship afire. Six men died in the blaze (8/15/75).

FIGURE 59.—Oil and gas production from Outer Continental ► Shelf lands, calendar years 1967–77.



Federal and Indian Lands

In order to assure that the government retains title to potentially exploitable mineral and water resource development areas on Federal lands, the Survey's Conservation Division staff identify the leasable mineral and waterpower resources and classify the lands.

Field surveys and analyses are conducted on site to compile geologic, engineering and related data. This information is used to:

- Determine the extent and content of leasable minerals on Federal lands.
- Identify existing waterpower and reservoir sites.
- Classify the lands as to their potential for waterpower or mineral development.
- Outline the boundaries of potentially valuable mineral leasing areas.
- Add, modify or eliminate areas withheld from disposal for their mineral or waterpower leasing potential.

Information from these activities, as well as Survey comments and recommended procedures for leasing, are supplied to the Bureau of Land Management and the Bureau of Indian Affairs—the agencies responsible for the sale of mineral resource development leases on Federal and Indian lands respectively.

Following the issuance of mineral leases by BLM and BIA, Conservation Division personnel also supervise, as they do on the Outer Continental Shelf, all activities by lessees associated with mineral exploration, development and production on Federal and Indian lands, again assuring that procedures are conducted in accordance with Federal regulations and environmental policies.

ONSHORE OIL AND GAS

Roughly 6 percent of the Nation's domestic oil and gas supplies is produced from facilities located on Federal and Indian lands in 33 states.

All unleased areas within the boundaries of Known Geologic Structures (KGS) (those structures with producible oil and gas fields) must, by law, be leased competitively. Using information supplied to the Survey by lease operators, including drill core sample data, well logs, production records, and geologic structure maps, Conservation Division personnel make a series of analyses to determine the fair market value of the resources thought to be producible from each unleased tract in a Known Geologic Structure.

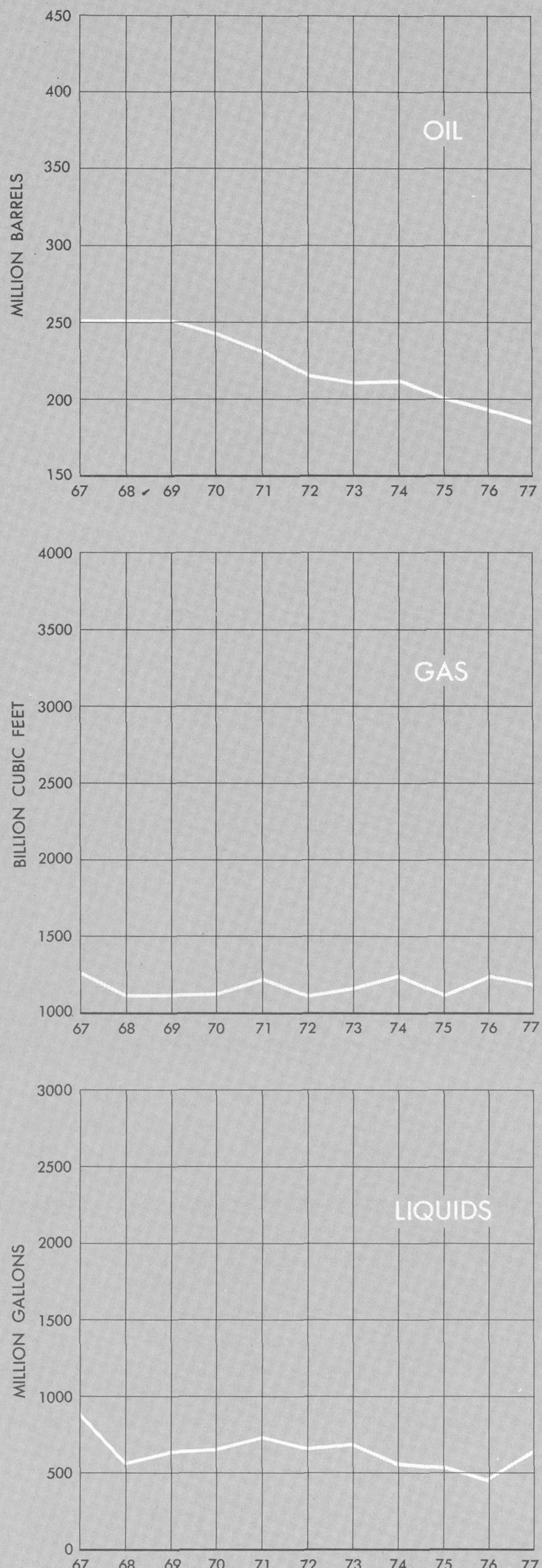


FIGURE 60.—Oil and gas production from Federal and Indian lands, calendar years 1967–77.

TABLE 21.—*Status of Federal land classification, fiscal year 1977*

[Acres in thousands]

Commodity	Mineral lands withdrawn	Classified lands		Prospectively valuable lands [1]	Known leasing areas	
		Nonmineral	Mineral		Undefined	Defined
TOTAL	45,379	38,169	43,016	2,355,408	6,550	29,359
Oil and gas	-----	-----	4	1,476,019	5,928	11,873
Oil shale	14,177	101	-----	14,369	----	-----
Asphaltic minerals	-----	-----	-----	17,946	----	-----
Coal	20,171	33,430	41,975	350,976	----	13,507
Geothermal resources	-----	-----	-----	103,192	----	3,249
Phosphate	1,620	4,638	412	30,599	2	64
Potassium	9,411	-----	-----	88,212	53	378
Sodium	-----	-----	625	268,502	567	288
Sulfur	-----	-----	-----	5,593	----	-----

[1] These figures represent the total acreage for each leasable mineral commodity and, because some acreage contains more than one mineral commodity, do not reflect total acreage prospectively valuable.

When a new oil and gas discovery is made on a Federal lease, the area is designated as an "Undefined Known Geologic Structure." The Bureau of Land Management then halts any additional noncompetitive leasing until the boundaries of the newly discovered petroleum bearing geologic structure can be accurately defined and a legal description of the structure is published in the Federal Register.

The leasing of Indian lands is administered by the Bureau of Indian Affairs on behalf of various tribes or individual Indian allottees. The Bureau of Indian Affairs usually relies on the Geological Survey to parcel tracts to be leased, provide analyses of expected mineral values, supply guidance in the acceptance or rejection of high bids offered by producers, and supervise resulting production in accordance with Federal mineral development and environmental regulations.

The Conservation Division has more than 6.7 million hectares (16½ million acres) of land under classification within Known Geologic Structures. In fiscal 1977, the Bureau of Land Management held 13 lease sales, in which 444 tracts covering 33,096 hectares (81,780 acres) were offered for development.

Regulatory procedures associated with onshore oil and gas development differ from those used in mining and geothermal operations because of the different regulations and technologies involved. All, however, involve the basic components of review and approval of development plans, regulation of exploration, development and production activities, and the collection of appropriate royalties. In oil and gas production, however, the Conservation Division must also approve off-lease storage arrangements, the mixing of various products in transportation systems (commingling of light and heavy crude oil in a pipeline, for example), and plans by various producers to cooperatively develop a single area. The Division also approves methods of production measurement, and the establishment of sales contracts. The Federal Government generally receives ⅛ of produced resources as royalty from onshore production. The cost of shipping government oil to refineries is deducted from the "⅛" as a legitimate cost to the Government, whether royalties are paid in cash or in kind.

At the close of fiscal year 1977, the Conservation Division was administering 13,800 producing oil and gas lease accounts covering 3,684,000 hectares (9,100,000 acres) on Federal and Indian lands. This number was 2 percent higher than the 13,541 active leases under management the previous year.

Production from these onshore leases during fiscal year 1977 totaled 188 million barrels of oil and 32.6 million cubic meters (1,150 billion cubic feet) of natural gas. Income from rents and royalties for these leases totaled $297 million by the close of the fiscal year, an increase of 6 percent, or $18 million over the previous year.

The Survey's Conservation Division processed 16,554 applications for exploratory drilling and producing operations, approved 3,078 new exploration and development wells, prepared 3,066 environmental analyses of proposed operations, and conducted 22,130 on-site inspections of drilling and producing operations.

Because most of the easily discovered oil and gas deposits have been developed, advanced techniques are now required to enhance recovery and maintain production levels from these already developed deposits. Substantial new supplies remain to be found, but these are believed to be smaller in scope, located in remote areas, and more costly to develop and transport to the marketplace than the currently produced reserves. However, partly because of significant increases in the price of oil and gas, the search for new supplies onshore accelerated in 1977.

COAL

More than nine percent of the Nation's 1977 coal production occurred on Federal and Indian land leases, primarily in Arizona, Utah, Wyoming, New Mexico, Colorado, North Dakota and Montana. It is principally in the High Plains that large deposits of coal, generally with a low sulfur content, lie close enough to the surface to be mined economically using surface mining techniques. Surface mining involves the use of large power excavation and earth moving equipment to remove overburden, expose the underlying coal seams, strip away the coal, and replace the surface material and replant vegetation.

In other areas of the West—particularly in the mountain areas, and in most parts of the Eastern United States—the depth of overburden is too great for economical surface mining. Here, underground mining methods must be used.

The Conservation Division maintains a coal resource evaluation program to compile, and if necessary to acquire basic engineering and geologic information. This effort involves systematic test drilling to obtain core samples of coal and overlying rocks and preparing geologic field maps to delineate the quantity, quality, and extent of coal resources. These activities are carried out in order to locate and designate Known Recoverable Coal Resource Areas (KRCRAs) on public lands. During fiscal year 1977, the Conservation Division received geophysical logs and core samples from approximately 1,500 test holes drilled in the States of Colorado, Montana, North Dakota, New Mexico, Utah, and Wyoming. Information from these drilling activities was used in the definition of 10 new KRCRA's covering about 1,700,000 hectares (about 4,200,000 acres) and the addition of about 40,000 hectares (100,000 acres) to 4 existing KRCRA's.

Activities include coal resource evaluations for Federal lands offered for competitive lease. The Survey also reviews data submitted by preference right lease applicants to determine if the commercial quantities requirement has been met. In order to assess the potential commercial value of Federally owned coal resources in lease tracts, the Conservation Division compiles and analyzes all available geologic, engineering, environmental and economic information pertinent to the tracts and considers current industry recovery techniques and costs and the present and foreseeable market demand and pricing pictures. Two products of this analysis are *Coal Resource Occurrence* (CRO) and *Coal Development Potential* (CDP) maps, prepared for use in BLM's and the Department's land use planning. Contracts were issued calling for the acquisition of over 500 CRO/CDP maps over the next 12 month period while interim production of CRO/CDP maps provided coverage for over 50 quadrangles. Coal resource economic evaluations were conducted for 2 sales, and commercial quantities test data for 5 Preference Right Lease Applications were reviewed.

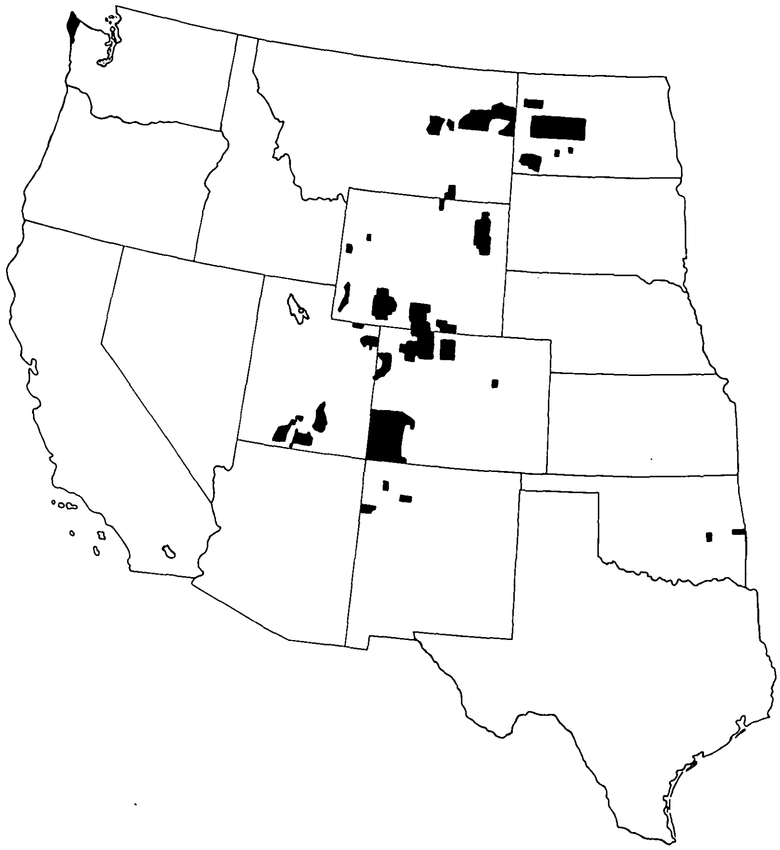


FIGURE 61.—Areas of active coal projects of the Conservation of Lands and Minerals activity on Federal lands during fiscal year 1977.

As of the end of fiscal year 1977 the Secretary of the Interior was conducting a review of the general coal leasing system adopted by the previous administration. It is expected that this system will be modified or totally reconstructed to reflect a deeper concern for the environment, increased public participation, and a more responsive relationship with the affected state and municipal governments. Additional data gathering and analysis, finalization of Departmental policy and possibly additional environmental impact statements will be necessary before any general coal leasing may be resumed.

Existing leases on Federal and Indian lands cover more than 435,042 hectares (1,075,000 acres) and during fiscal year 1977, more than 61,700,000 metric tons (68,000,000 short tons) of coal were produced from 578 coal leases, primarily in Western States. Conservation Division personnel performed 533 on-site inspections of production operations, approved 124

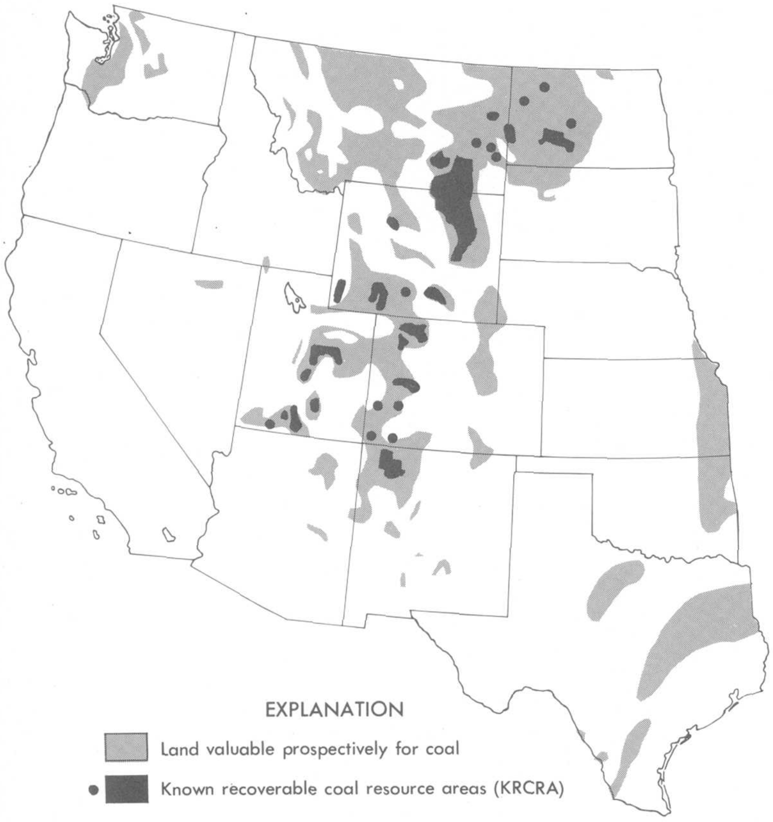


FIGURE 62.—Status of coal classification on Federal and Indian lands in the Western United States.

amendments to mining, exploration and transportation plans, and participated in preparation of 121 environmental impact analyses related to pending mining plans. Royalties from all producing coal lease accounts on Federal and Indian lands totaled $15,526,000 in fiscal year 1977.

GEOTHERMAL RESOURCES

There are several areas in the conterminous United States and Alaska where subsurface geologic formations or the radioactive decay of various minerals creates heat near the earth's surface. This heat, is "stored" in rocks some of which may be permeated by water. In some areas this hot water may be locked underground by impermeable materials, while in other locations it may freely circulate to the surface through series of fissures and porous rock formations. In the latter case, the water may appear naturally as hot springs, or geysers.

The temperature of the water at depths may far exceed the boiling point, but the added pressure at these depths keeps the water from becoming steam. The drilling of a geothermal well, however, allows the water to rise toward the surface, decreases the pressure upon it, and—at the higher "superheated" water temperatures—turns a portion of the water to steam. That steam can drive turbine generators to create electricity. Geothermally heated water or air can also be used directly to heat buildings, dry crops, melt snow and a variety of other applications. Most homes and businesses in Iceland, for example, are heated with geothermal waters.

In order for a geothermal reservoir to have the potential for commercial development as an energy source, it must possess several characteristics including these :

- A minimum reservoir temperature of 170°C (338°F).
- A depth near enough to the surface to permit drilling within current technological limits—roughly 3,050 meters (10,000 ft) or less.
- Adequate permeability of the subsurface rock formations to provide a continuous flow of fluid at a relatively rapid rate.
- Sufficient subsurface water, or a means of pumping back into the Earth the fluids used in production, so that a means of conveying the heat to the surface is available and circulation over a period of many years is assured.

With the passage of the Geothermal Steam Act by the Congress in 1970, the responsibilities of the Geological Survey were broadened to include geothermal resource evaluation, classification of lands with resource potential, and the regulation of Federal geothermal lease operations.

Rules and regulations governing geothermal steam resource development were published in 1973 and a geothermal leasing program was initiated by the Department of the Interior the following year. Between 1974 and the close of the transition quarter, 172 geothermal lease tracts were offered and bids totaling more than $15,495,000 were accepted. By the close of the transition quarter, 120 geothermal exploration plans had been approved and more than 39 exploratory wells had been drilled.

During the past fiscal year, 117 geothermal tracts covering 75,690 hectares (187,000 acres) were offered for lease. 14 sales were held resulting in receipts of $2,693,754.

For leases already under development, 13 exploratory drilling plans were approved and the Survey's Conservation staff performed 75 on-site inspections of drilling operations.

Resource evaluation studies during the past year resulted in the classification of 37,603 hectares (92,917 acres) of land as Known Geothermal Resource Areas (KGRA's), which are subject to competitive leasing.

By the close of fiscal year 1977, a total of 45 geothermal wells had been drilled on public lands in California and Utah. Of this number, 19 wells were considered capable of providing geothermal energy in commercial quantities. Many of these wells are located in northern California, in a large geothermal field known as "The Geysers." The only commercial geothermal electric generating stations currently operating in the United States are located at the Geysers on non-Federal land.

Although all completed wells capable of providing commercial quantities of hot water or steam in other geothermal areas have been capped, pending development of sufficient steam or needed facilities to convert the geothermal resources into other forms of useful energy, it has been estimated that geothermal development could provide at least 1,500 megawatts for use in Western States by 1985.

OIL SHALE

Following establishment of the prototype Oil-Shale Leasing Program by the Department of the Interior in 1971, four tracts were offered for lease by competitive bidding after preparation of an environmental impact analysis covering the resources and the proposed methods of development. These leases for prototype oil shale development in the Green River Formation in Colorado and Utah covered 8,300 hectares (20,400 acres) and resulted in the acceptance of bonus bids totaling nearly $450 million.

The terms of each lease required the lessees to collect two years of environmental baseline data and to file a Detailed Development Plan for review and approval by the Geological Survey before the close of the third lease year. The lessees have completed the environmental baseline programs and have conducted investigations to determine the extent and quality of oil shale resources contained in the lease area. Data and information accumulated have been provided to the U. S. Geological Survey and are available to other agencies and the public.

The Detailed Development Plan for Federal Oil Shale Lease Tract C-b was formally approved on August 30, 1977. The lessees, Ashland Colorado, Inc. and Occidental Oil Shale, Inc., bid more than $117 million for the 5,000 acre tract located in the Piceance Creek basin in Colorado, about 25 miles northwest of Rifle. The approved Plan will result in the development of a more than 300 foot-thick zone of oil shale using the modified in-situ process, an underground recovery technique. According to the plan, a system of shafts and several mine levels will be developed in the underground shale deposit. Approximately 20 percent of the shale will be mined during this development and deposited on the surface and revegetated. The remaining shale in the development zone will be explosively "rubblized" in columns called "retorts," several hundred feet on a side. Each retort will then be ignited at the top, and the oil collected in sumps and pumped to the surface for further processing. Escaping gas is also carried away in special shafts to the surface, where it may be burned to generate power. This method will recover approximately 190 million cubic meters (1.2 billion barrels) of shale oil over the 60 year projected tract life from the 447 million cubic meters (3.0 billion barrels) of in place resource within the indicated zone. The lessees will be required to adhere to the environmental restrictions of the lease and the DDP has been designed to monitor the effect of shale oil production on the environment.

During fiscal year 1977, the Detailed Development Plan for Federal Oil Shale Lease Tract C-a was submitted by Gulf Oil Corporation and Standard Oil Company of Indiana for production of shale oil using modified in situ methods. The lessees bid more than $210 million for the 5,000 acre tract located in the Piceance Creek basin in Colorado about 18 miles southeast of Rangely. The Plan proposes the development of an up to 750 foot-thick zone of oil shale. Development rock removed from the underground mine and hoisted to the surface will be retorted in surface retorts during commercial operations. The in-situ retorts will be rubblized by a method similar to sub-level caving, then ignited and retorted in place.

The lessees of tracts U-a and U-b; Phillips Petroleum Company, Sunoco Energy Development Co., and Sohio Petroleum Company; located in the Uinta Basin of Utah were granted an injunction by the Federal District Court during fiscal year 1977. The injunction was the result of legal conflicts with regard to unpatented pre-1920 oil shale placer mining claims and the State of Utah's in-lieu land selections. A Detailed Development Plan was submitted by the lessees in June of 1976 for development of the tracts by underground room and pillar-mining methods with surface retorting of oil shale. This Plan has not been approved because of the injunction.

There are an estimated recoverable 3.6 billion tons (3.3 billion metric tons) of oil shale containing 30 gallons (114 liters) or more of oil per ton, in the four tracts now under lease. A potential supply of 510 million cubic meters (3.2 billion barrels) of oil might be extracted if the oil shale technology now proposed proves viable upon actual demonstration.

Brine recovery operations from Federal lease land at Searles ▶ Lake, California. Major products of this operation include potash, soda ash, borax, and salt cake.

WATERPOWER CLASSIFICATION

Because potential waterpower and water storage sites are becoming increasingly scarce, their value is growing. Such water sites on Federal lands are classified to preserve the right of the Government to authorize and license development of hydroelectric and water storage projects and to assure that the value of the sites will be properly considered in land use planning and land disposal actions.

More than 5.7 million hectares (14 million acres) of Federal land are presently classified as potential waterpower or water storage sites. During fiscal year 1977, 10,600 hectares (26,300 acres) were classified or reclassified. The Survey's Conservation staff also provided detailed site information for more than 100 water resource planning areas to Federal land management agencies during the fiscal year.

OTHER LEASEABLE MINERALS

Federal and Indian lands contain a variety of leaseable minerals beside oil, gas and coal. Enriched compounds of uranium, used to fuel today's nuclear powered electrical generating stations, are derived from uranium oxide, 9.6 percent of which is mined from Indian land leases in the Western States of New Mexico and Washington.

Other valuable metallic minerals also come from acquired public lands as well as Indian lands. At present, more than 3.7 percent of the nation's domestically produced copper, 31 percent of the zinc, 55 percent of the sodium, and 72 percent of our domestic lead supplies are extracted from leases on such lands. Production of metallic minerals totaled 3,521,316 metric tons, worth $361 million, during fiscal year 1977 and supplied more than $16 million in royalties.

Phosphate and potash deposits are now under more intense development following a dramatic rise in the demand for fertilizers in recent years. More than 88 percent of the nation's domestically produced potash, for example, now comes from Federal leases in New Mexico and California.

Sulfur is another element valuable in the production of certain acids, chemicals, and rubber compounds. Native sulfur is brought up from offshore wells in a manner similar to oil and gas production. Hot brine is pumped into a subsurface formation where it dissolves deposits of sulfur. The mixture is then pumped back to the surface, where separation techniques remove the sulfur for commercial sales.

During fiscal year 1977, the Survey carried out 429 on-site inspections of prospecting permits and leases and determined the appropriate royalties for more than 14,815,000 metric tons of non-energy minerals produced from Federal and Indian lands. These materials had a market value of approximately $537 million and brought $24.6 million in royalty revenue to the Federal government.

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Nikiski village mobil home park

Nikiski air photo

Rig tender dock

Union 76 refinery and pier

Strip-type commercial development

Kenai air photo

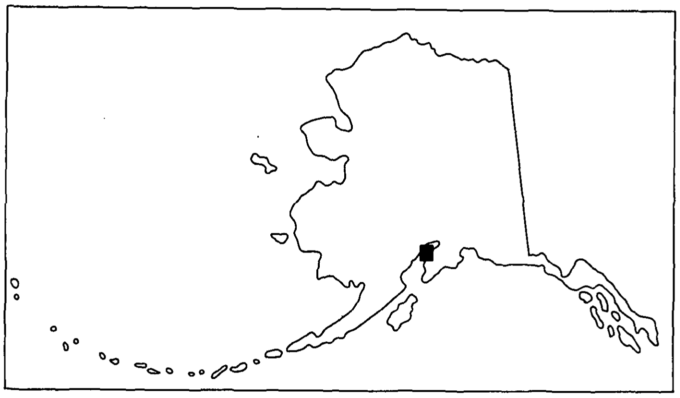
Columbia Ward salmon cannery

Land Information and Analysis

INTRODUCTION

Headlines of local as well as national news items about land resources commonly contain words such as lack, damage, and shortage—in describing deficiencies in some aspect of environmental quality, energy or mineral resources, quantity and quality of water resources, or efficient use of the land. These negative connotations reflect the increasing land-resource and area needs of our society, troubled by limited and diminishing resources. These problems have caused a new interest by officials at all levels of government and by the general public, in the need for information for planning and problem solving—especially for solving problems related to wise use of the Nation's land resources.

Concern about the environment led to enactment of the National Environmental Policy Act of 1969; recent Federal, State, and local land-use legislation; and intensive study of the impact of shortages of energy and mineral resources. As a result, an unprecedented need exists for earth-science and resources information for planning and decisionmaking. For example, determination of the environmental impact resulting from accelerated development of energy resources, particularly the strip mining of Western coal deposits, requires greater knowledge of regional hydrology and of the utility of reclamation methods in restoring mined lands for future use.



◀ A major environmental problem centers on energy development and its associated impacts on land use. In frontier areas, such as the Kenai-Cook Inlet region of Alaska, the magnitude of such impacts from offshore oil and natural gas development is clearly visible.

Much of the earth-science information required to evaluate impacts of alternative uses of the land and to facilitate related planning and decisionmaking is derived from more than one of the Geological Survey's core disciplines—geology, hydrology, cartography, and geography. In the past the Geological Survey responded to the need for such information on a case by case basis, but during recent years it became obvious that a more formally structured approach to conducting multidisciplinary land-resource and environmental studies that require expertise from more than one discipline was necessary. It also became obvious that closer interaction between the compilers and users of the data, land-resource planners and decisionmakers, was necessary to provide the needed data in an understandable and usable form. The Land Information and Analysis Office was established in 1975 to help serve that purpose.

The Land Information and Analysis Office provides scientific and engineering data and interpretive information developed by the Geological Survey and other Bureaus of the Department of the Interior, to support environmental planning and decisionmaking for land use at all levels of government and in the private sector. Explicit in this mission is the translation of scientific and engineering information on activities involving land and other natural resources into readily understandable language and formats so as to encourage its use by elected officials, planners, public interest groups, the legal profession, social scientists, and the general public.

The objectives of the Land Information and Analysis Office are:

- Development and application of multidisciplinary earth-sciences, other natural sciences, and geographic technology in support of land-resources planning and decisionmaking.
- Mapping current land use and land cover.

Sand and gravel, stone and clay are the stuff and substance of which our modern cities are built, but unless careful advanced planning is done, valuable deposits of these resources may be covered over, cut off, or otherwise rendered inaccessible by the relentless outward spread of urban development. Their protection requires a whole suite of coordinated actions: (1) Future needs must be forecast and potential resource sites identified; (2) Measures must be taken to protect the deposits from other preemptive use, although if there is no need for immediate extraction, interim temporary uses could be permitted; (3) Adequate space for processing plants, access roads, and buffer zones should

- Accomplishment of Geological Survey activities directly related to the requirements of the National Environmental Policy Act.
- Collecting, processing, and distributing remotely sensed data, and applying other aspects of space technology in support of land-resources planning and management and environmental impact analysis.

The task of achieving these objectives is carried on by five multidisciplinary programs:

- Earth Sciences Applications (ESA)
- Resource and Land Investigations (RALI)
- Geography
- Earth Resources Observation Systems (EROS)
- Environmental Impact Analysis (EIA)

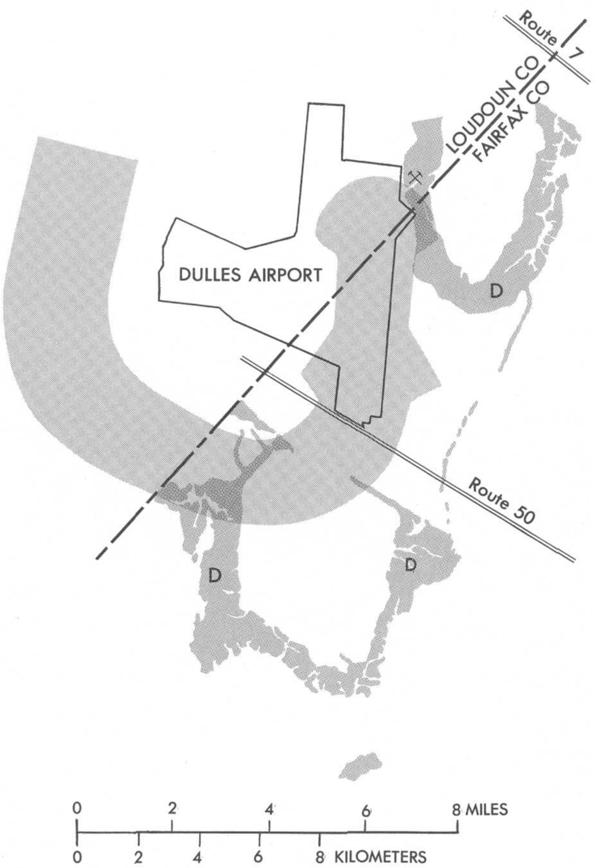
Principal Issues

The principal issues faced by the Land Information and Analysis Office in fiscal year 1977 continued basically to fall within these two dynamically evolving categories.

1. The recent rapid growth of Federal and State legislation responding to concerns such as energy development, coastal-zone management, natural hazards reduction, environmental impact, and water quality has greatly stimulated need for earth-science information to plan and manage land and water resources. Examples are the demands on the research and data-collection activities of the Geological Survey recently required by Federal programs such as the De-

be reserved. In urbanizing areas, companies holding mineral resource land normally will protect their investments by requesting appropriate governmental action, but effective protection of resources remote from presently urbanized areas may depend upon the preparation of land-use plans before requests are received from developers. Measures to assure the protection of mineral resources can be incorporated in land-use plans and regulations.

The quarry seen in the photograph is in Northern Virginia where the Earth Sciences Applications Program is coordinating an urban area study. It is an example of an area where planning for resource protection may be appropriate. In the vicinity of the quarry, the Dulles Airport noise envelope encompasses a nonurbanized part of a rock formation that is valuable as a source of construction aggregate. To ensure the preservation of this resource, and its accessibility in the future, adjacent sites could be set aside now. A decision to preserve the area for future quarrying should be based on analyses of the economic costs and benefits of future quarrying in this area, the costs and benefits of importation of construction materials from other areas, the environmental disruption from extraction and processing, and the value of other preemptive uses of the mineral resource lands. Ultimate reclamation and utilization of the site for noise-free underground facilities, water storage, or waste disposal in a sequential operation might provide maximum benefit. However, regional and local planning and regulatory agencies can provide for and encourage mineral resource preservation and use only when basic information about the resource is available to them at the time that land-use plans are being formulated △



EXPLANATION

Single event noise contour 100 EPNdB[1] Concorde departure

Diabase outcrops

Diabase within 100 EPNdB noise envelope

Quarry

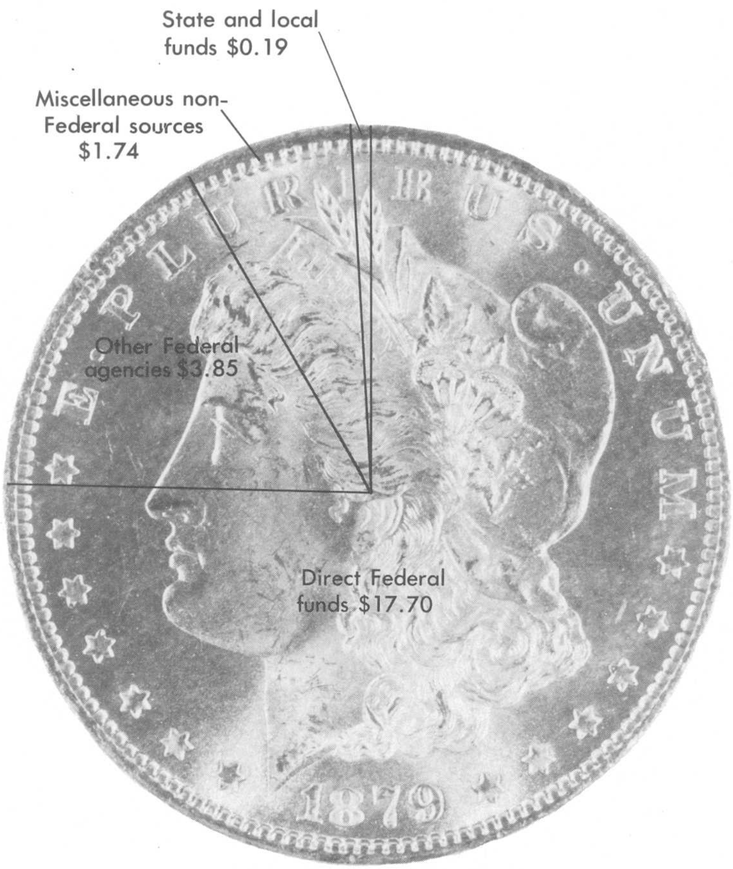
[1]EPNdB—Effective perceived noise level in decibels

partment of Housing and Urban Development's Community Block Grants/Entitlement Grants and Comprehensive Planning Assistance Program, National Flood Insurance Program, and Disaster Relief Act, and EPA Waste Treatment Management Planning Program, the Department of Commerce Coastal Zone Management Program, and related State and local legislation and regulations.

2. The increasing concentration of the Nation's poulation in urban areas and the need for greater and more efficient use of land have focused attention on the opportunities and constraints the Earth poses to growth and development. For example, Chicago is excavating vast underground cavities for storage of storm-water runoff; and cities throughout the United States are placing utilities, communication, and transportation networks in tunnels. These trends, along with the increase in high-density, major structures in urban areas, have escalated the requirements for accurate earth-science data in support of planning and decisionmaking.

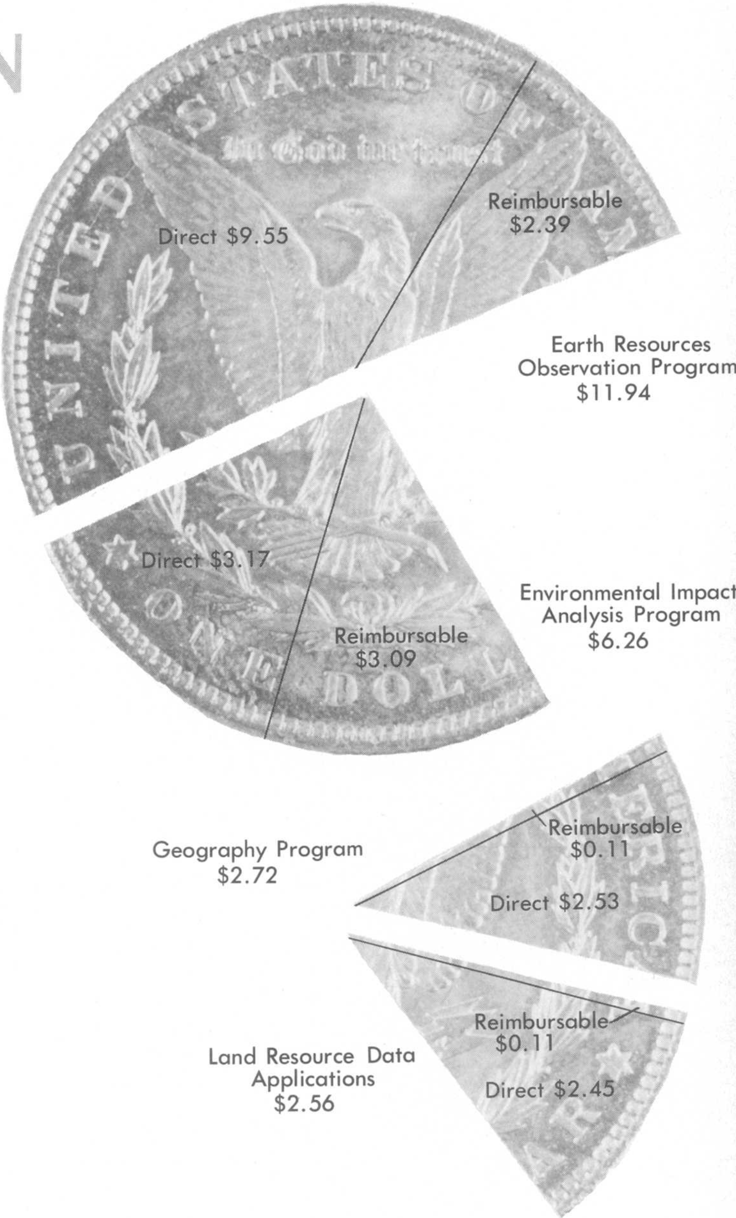
The Survey has already done much to foster the integration of earth-science information into the planning process through urban-area studies and other means. Much research is still needed on data content and interpretation and on application of the results of the Survey's work to a broad spectrum of resource and environmental management.

LAND INFORMATION AND ANALYSIS



TOTAL $23.48 MILLION

SOURCE OF FUNDS



USE OF FUNDS

Budget and Personnel

Obligations for Land Information and Analysis Office activities in fiscal year 1977 amounted to $23.48 million, an increase of 36 percent over fiscal year 1976 (table 22).

Cooperative programs with State agencies were carried on by the Geography program for land-use and land-cover mapping.

The work of the Land Information and Analysis Office is partly accomplished through contracts to private industry and through research grants. Of fiscal year 1977 funds, $7.4 million (31 percent) were expended on contracts. Contract services were the major source of operational support at the EROS Data Center.

The programs of the Land Information and Analysis Office were carried out by 205 full-time career employees in 1977; at the end of the year 126 were assigned to the Office's programs (table 44), and 77 were assigned to other Survey offices in support of the work of the Land Information and Analysis Office. There were also 65 other than full-time employees. In addition, contract support services at the EROS Data Center amounted to 279 man-years. Personnel of the Topographic, Computer Center, and Administrative Divisions are also assigned to the EROS Data Center.

TABLE 22.—*Land Information and Analysis Office obligations for fiscal years 1976–77 (dollars in millions)*

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

Program	Fiscal year 1976	Transition quarter	Fiscal year 1977
Total	$17.28	$8.92	$23.48
Earth Resources Observations Systems program	10.32	5.46	11.94
Direct program	8.16	4.84	9.55
Reimbursable program	2.16	.62	2.39
Miscellaneous non-Federal sources	1.50	.47	1.74
Other Federal agencies	.66	.15	.65
Environmental Impact Analysis program	2.04	1.31	6.26
Direct program	2.04	1.31	3.17
Reimbursable program	-----	----	3.09
Other Federal agencies	-----	----	3.09
Geography program	2.53	.77	2.72
Direct program	2.34	.75	2.53
Reimbursable program	.19	.02	.19
States, counties, and municipalities	.13	.02	.19
Other Federal agencies	.06	----	-----
Land Resource Data Applications program (ESA and RALI)	2.39	1.38	2.56
Direct program	2.37	.90	2.45
Reimbursable program	.02	.48	.11
Other Federal agencies	.02	.48	.11

Highlights

- Publication of "Flood-Prone Areas and Land Use Planning," one of the final interpretive reports stemming from the San Francisco Bay Region Environment and Resource Planning study, describing the development and use of maps of flood-prone areas and other flood-plain information in regional and local land-use planning. Much of the information and many of the techniques presented are applicable in communities throughout the Nation.
- Conduct of a series of regional workshops (partially funded by EPA) to acquaint State and local coastal zone management officials with planning methods and information for assessment of onshore impact of oil and gas exploration and development on the Outer Continental Shelf.
- Compilation of land-use and land-cover maps and data for approximately 1,040,000 square kilometers (400,000 square miles), bringing the total area mapped to 2,730,000 square kilometers (1,050,000 square miles) since the nationwide land-use mapping program started in fiscal year 1975.
- Procurement of the EROS digital image processing system (EDIPS), which will permit processing of much improved imagery products from the Landsat–C satellite data. Installation will be completed in early 1978.
- Participation in a lead or joint-lead responsibility in the preparation of 18 environmental impact statements and participation in a non-lead capacity in the preparation of 20 impact statements, most of which were energy related. Review of 1,800 impact statements and related documents.

- Publication in the *Federal Register* on April 12, 1977, of a description of the Survey's capabilities and limitations for advance recognition and warning of geologic-related hazards and the procedures to be followed in carrying out the responsibilities delegated under the Disaster Relief Act of 1974.

EARTH SCIENCES APPLICATIONS PROGRAM

Program and Activities

The Earth Sciences Applications (ESA) Program was established to direct and coordinate multidisciplinary Geological Survey projects aimed at providing earth-science information for land-resource decisionmaking. The program's objectives are threefold: (1) To interpret, demonstrate, and encourage the use of earth-science information for land-resource decisionmaking through specially designed projects and report products, and through interaction with and technical assistance to users; (2) to stimulate, coordinate, and integrate multidisciplinary land-resource studies in the Survey; and (3) to serve as the focal point within the Survey for multidisciplinary studies in support of the work of other Federal, State, and local agencies.

Urban Area Studies

To accomplish its objectives, the Earth Sciences Applications Program has emphasized projects designed to interpret, and assist in the application of, earth-sciences information bearing on land-use conflicts in selected urban-centered areas of the United States (fig. 64).

These urban area studies are conducted by personnel from the Geologic, Water Resources, and Topographic Divisions supported by allocations of personnel and funds from the Earth Sciences Applications Program. In fiscal year 1977, about $1.6 million were allocated to urban area studies. In addition, these studies were able to build upon about $0.5 million of related research conducted by the other divisions of the Survey in the project areas.

Selected Applications

Fairfax County in Virginia. A preliminary map showing mineral-resources availability in Fairfax County was released early in fiscal year 1977. On the basis of the mineral-resource map and supporting data, the County planning staff has initiated studies of the socioeconomic aspects of sequential development of lands, a practice that allows mineral recovery in known resource areas without foreclosing other potential high-value land uses. These studies ultimately could lead to the development of ordinances to encourage such sequential uses.

A series of interpretive ground-water maps and supporting data have been prepared which indicate that sufficient ground water probably is available in parts of Fairfax County to serve as a significant supplementary source of supply, at least on an intermittent basis during periods of shortage. Because of prevailing near-drought conditions and diminished surface-water availability in the summer of 1977, the County Board of Supervisors requested the Survey to prepare a proposal for a drilling program to verify the preliminary conclusions presented in the maps and accompanying text. The request also expressed Fairfax officials' long-term concerns for adequate water supplies. The proposal was approved, and work started in September 1977 on the program. The potential ground-water resource tentatively defined by Fairfax County project studies may represent a significant alternative for consideration in metropolitan water-supply planning.

Puget Sound area of Washington. A report on the effects of recent volcanic activity at Mount Baker on water quality of Baker Lake was released early in fiscal year 1977. On July 13, 1977, a major snow and ice avalanche occurred in Sherman Crater on Mount Baker, partly filling the East Breach of the crater rim, through which acidic water drains from the crater. Data from a previous ESA study were used by Puget Sound project personnel to assess the hazard potential of a possible damming of the crater water by the avalanche and later sudden release of the accumulated acid water. The evaluation was released to the public by the Mount Baker Information Committee, a group formed by Federal, State, local, and power company officials concerned over possible effects of increased activity of Mount Baker.

As a consequence of the severe drought in the Pacific Northwest, the Washington State Department of Ecology requested additional copies of a recent report relating climatic factors to land-use planning in the Puget Sound basin for the use of State officials in drought response planning. This report, as well as others stemming from Puget Sound project studies, has also been used by the Seattle District, U.S. Army Corps of Engineers, in their regional planning studies.

Colorado Front Range Urban Corridor. A comprehensive report on the causes and effects of the disastrous flood of the Big Thompson River in northern Colorado in August 1976 is being prepared by personnel of the Geologic and Water Resources Divisions, the National Oceanic and Atmospheric Admin-

EXPLANATION

A–Sherman Peak B–Lahar Lookout C–New ice pits opened since avalanche

D–Crater lake, now covered by avalanche, was here

E–Steam plume from a large fumerole that opened last year (one of the indications of increased thermal activity 1976)

F–Avalanche debris G–Black buttes—remnants of old volcanic crater

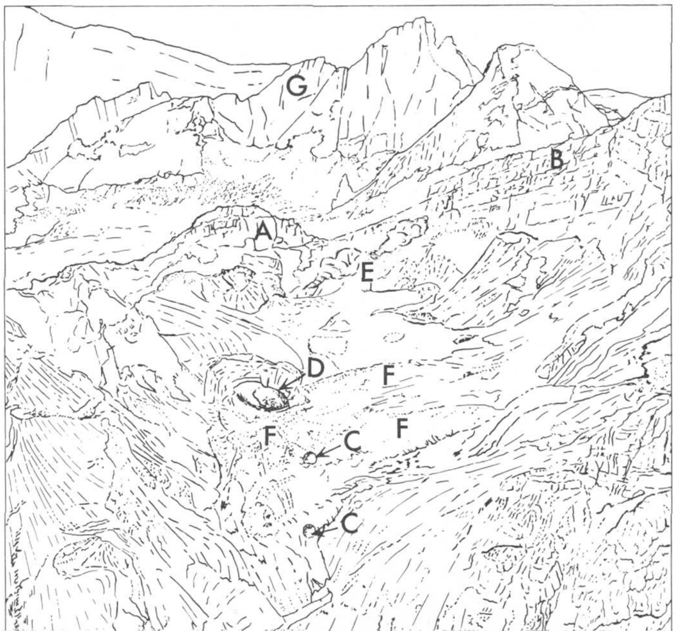
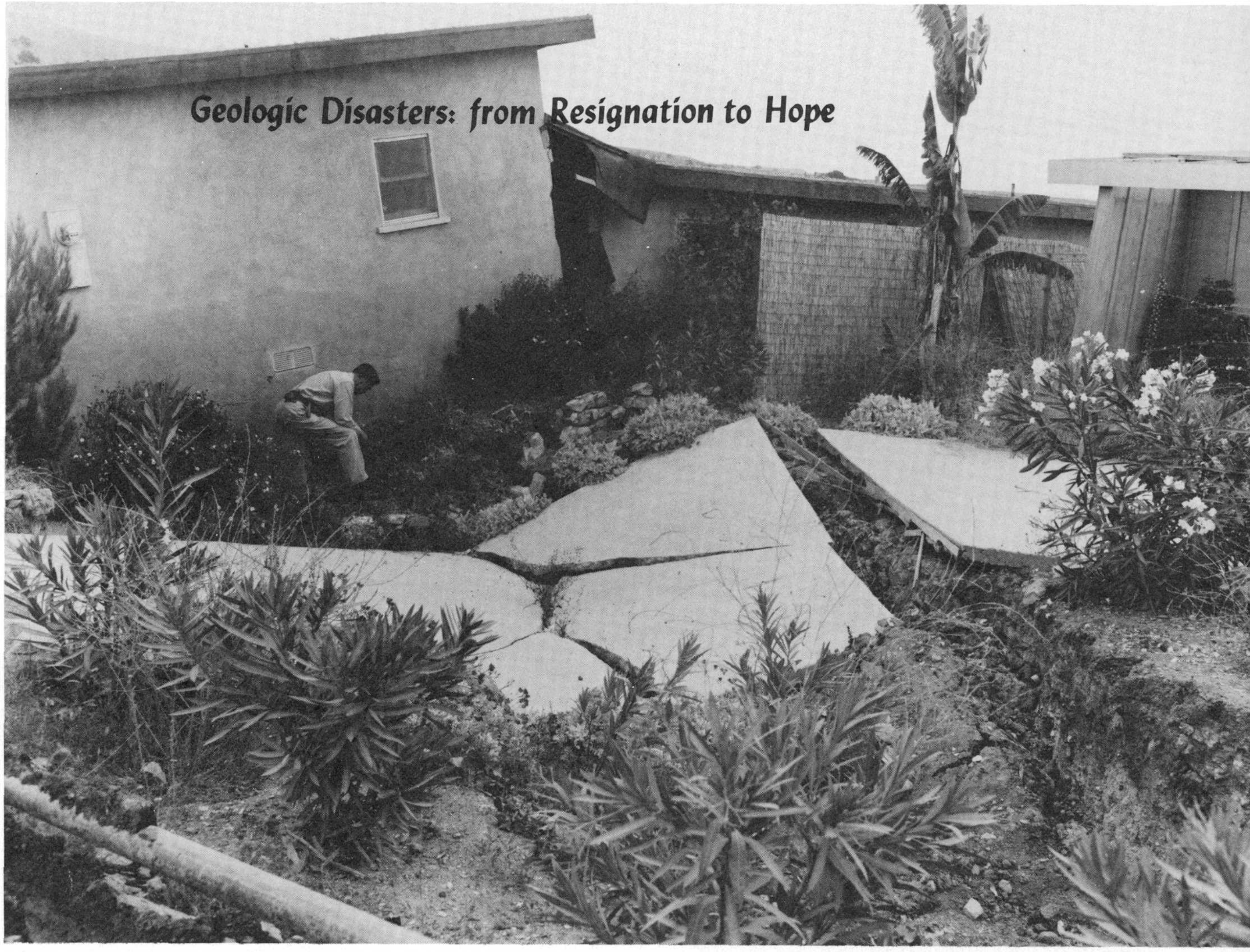


FIGURE 63.—Avalanche in Sherman Crater on Mount Baker, Washington.

Geologic Disasters: from Resignation to Hope



Results of landslide, Palos Verdes, Los Angeles, Calif., 1957. If the high landslide potential of this area had been recognized before construction took place, extensive losses could have been prevented.

istration, and the Colorado Geological Survey. The report will be published in the near future in the Geological Survey Professional Paper series and will describe the weather conditions contributing to the flood, the geologic and hydrologic effects, and the hazards that resulted. In addition, technical assistance will be provided to aid in developing preparedness and mitigation plans.

Geologic-Related Hazards Information

Under the broad responsibilities assigned to the U.S. Geologic Survey in the Organic Act of 1879, the Survey has, for many decades, undertaken studies of earthquakes, volcanoes, and other natural hazards. In recent years, as knowledge of these and related geologic phenomena increased, the Survey developed capabilities for predicting some potentially hazardous events in certain areas. The Survey has the implicit obligation to inform civil authorities and the public of such predictions.

Under the provisions of Public Law 93–288, the "Disaster Relief Act of 1974" (88 Stat. 143), and subsequent delegations of responsibility, the Director, Geological Survey, is directed to ". . . provide technical assistance to State and local governments to insure that timely and effective disaster warning is provided . . . for an earthquake, volcanic eruption, landslide, mudslide, or other geological catastrophe."

After thousands of years of being burned, buried, and buffeted by the assaults of earthquakes, volcanoes, and other geologic upheavals, Man may at long last be acquiring the ability to mitigate if not avoid altogether the consequences of these natural hazards to life and property. This, at least, is the implication of a statement published in the **Federal Register** in April 1977 by the Geological Survey which describes its capabilities and proposed procedures for providing information on geologic-related hazards to Federal, State, and local authorities. The statement also spells out a proposed policy for the issuance of "Notices of Potential Hazards," "Hazard Watches," and "Hazard Warnings" if any geologic processes or conditions are identified that could be hazardous to life or property.

Geologic processes and conditions that could result in harm to people and property include earthquakes, volcanic eruptions, landslides, mudflows, subsidence, faulting, and fissuring of the ground surface, and glacier-related phenomena such as release of glacier-dammed lakes and rapid ice surges or retreats. Under certain conditions, these events may occur suddenly and affect large numbers of people and property over a wide area; in other instances, however, the processes involved occur slowly or affect very limited areas so that few if any people are endangered.

Scientists can now predict some hazardous events with relative accuracy, but continuing research is needed to enable reliable predictions of other types of events to be made. Prediction of the precise location, time, and magnitude of specific earthquakes, for example, cannot generally be made now. On the other hand, continuous monitoring of Kilauea and Mauna Loa volcanoes in Hawaii by an array of instruments and by systematic measurements permits the assessment of the likelihood of impending activity, although predictive capability has not been achieved for volcanoes in Washington, Oregon, and California that have erupted within the last 150 years, or for volcanoes in Alaska.

The time, place, and magnitude of landslides can be predicted only in small, individual landslide areas in which detailed geologic and engineering studies have been conducted. On a larger scale, however, some areas and geologic formations can be identified as being particularly susceptible to landsliding. The Palos Verdes landslide shown in the photograph is in one of these susceptible areas. Glacier-related hazards can, in some cases, be predicted if adequate field measurements and historical data are available. Specific subsidence events caused by ground-water withdrawal can be anticipated in certain areas, such as in parts of Alabama, California, and Texas where studies are underway. Once subsidence involving slow compaction of sediments is initiated, the rate can be measured and, in some cases, the ultimate amount can be estimated.

When and where information is obtained that suggests the development of a hazardous condition, the Geological Survey will attempt to authenticate it, and communicate such information to appropriate State, local, and Federal authorities and to the public. The Survey recognizes that Earth Sciences information, provided in accordance with its expertise, is only the first of many kinds of information needed by State and local governments and the public to avoid or mitigate the effects of geologic hazards. The actual adoption of the most effective mitigation measures by local authorities will result from a cooperative effort by agencies at all governmental levels and by non-governmental organizations and the public. Decisions for adoption of such mitigation measures should be based upon a broad range of Earth Science, engineering, and socioeconomic information. △

As the focal point for multidisciplinary land-resource studies in the Survey, the Earth Sciences Applications Program has been instrumental in developing guidelines and procedures to enable the Survey to carry out its hazard warning responsibilities effectively. On April 12, 1977, a statement was published in the *Federal Register* describing the Geological Survey's capabilities and limitations for advance recognition and warning of geologic-related hazards and the procedures proposed to be followed in carrying out the responsibilities delegated under the Disaster Relief Act of 1974. The *Federal Register* notice was distributed to all Governors, State Geologists, and State emergency-preparedness agencies, as well as to appropriate Federal agencies. Efforts are now underway to establish effective communications procedures for hazards information and warnings in cooperation with designated State and Federal agency representatives.

Tunneling-Feasibility Studies

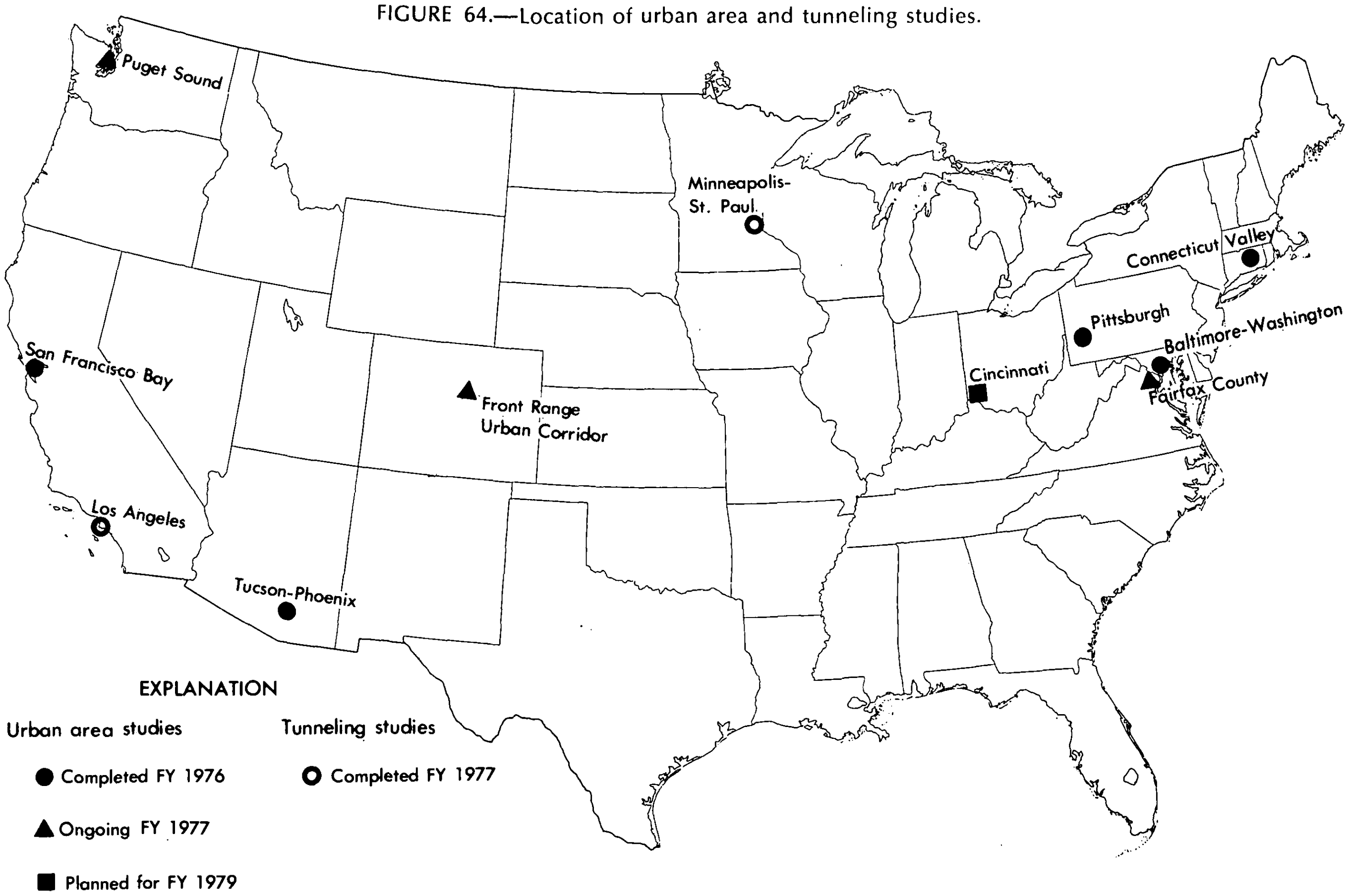
Tunneling-feasibility studies for rapid-transit systems, funded by the Department of Transportation through the Earth Sciences Applications Program, were completed in fiscal year 1977 for the central business districts of Minneapolis-St. Paul, Minn., and Los Angeles, Calif. (fig. 64). The objectives of these two projects were to assess the need for, and the availability of, hydrologic and geologic data relevant to the construction, maintenance, and operation of underground transit systems for the two metropolitan areas. A series of data and interpretive maps for each of the projects is being prepared for publication. Discussions are underway with the Department of Transportation concerning possible follow-on studies of the effects of various geologic and hydrologic conditions on tunneling costs.

Program Highlights and Other Activities

About 50 data and interpretive book reports and maps were prepared during fiscal year 1977 by projects funded through the Earth Sciences Applications Program. Educational and technical assistance activities continued to play a major role in furtherance of program objectives. Among the more significant accomplishments of the program during the year, in addition to those described above, were:

- Publication of "Flood-Prone Areas and Land-Use Planning—Selected Examples from the San Francisco Bay Region, California," one of the final interpretive reports from the San Francisco Bay Region Environment and Resource Planning Study, a project jointly supported by the Geological Survey and the Department of Housing and Urban Development's Office of Policy Development and Research. The report (Prof. Paper 942) describes the development and use of maps of flood-prone areas for the San Francisco Bay region, the application of these maps and other flood-plain information to regional and local land-use planning, and the use, regulation, and management of flood plains. It also describes measures which can prevent or reduce flood loss through control of flood-plain use and protective measures. Much of the information and many of the techniques can be used by planning groups involved in the reduction of flood losses in communities throughout the Nation.
- Approval for publication of "Nature to be commanded . . .," a guide to the use of earth-sciences information for land-use planning. This report illustrates and explains how earth-sciences information has been applied to land- and water-resource planning and decisionmaking in selected example areas across the Nation.
- Participation in a symposium on geology in Federal land-use decisions, sponsored by the American Geological Institute. The symposium, an outgrowth of a series of meetings between geologists of many Federal agencies, explored the present and future role of geologists in Federal land-use decisions. Federal representatives discussed the uses of land-use information services for the land-management, regulatory, and project functions of Federal agencies.

FIGURE 64.—Location of urban area and tunneling studies.



- Presentation of a seminar on earth sciences in planning, in cooperation with the American Institute of Planners and Virginia Polytechnic Institute and State University. The seminar was attended by professional planners from city and county governments, private consultants, and county planning commissioners from Virginia and the Washington, D.C., metropolitan area. Much of the content of lectures and many of the examples presented were from the Baltimore-Washington and Fairfax County urban area studies.

RESOURCE AND LAND INVESTIGATIONS

Program and Activities

The Resource and Land Investigations (RALI) Program was established in 1972 by the Secretary of the Interior to provide ". . . the organizational framework to mobilize more effectively the Department's technological capacity and scientific competence for objective analysis of the alternatives in land use, to provide, with appropriate collaboration by other agencies of government, the knowledge base for efficient and safe land and resource development, and to evaluate the tradeoffs between resource development and environmental protection concerns." The Geological Survey was assigned the role of "lead agency" to manage the RALI program to set about the task of improving technical communication between the collectors and analysts of resource and land information and the planners, managers, and decisionmakers in government, industry, and the public sector.

The Resource and Land Investigations (RALI) Program undertakes projects which address multidisciplinary natural-resources management problems that run through the missions of many Bureaus of the Department. The program's clientele are primarily Federal, State, and local land-use planners, but also others that require a suite of earth-science, biological, and socioeconomic data, methods, and technologies that are not available from any single Departmental bureau.

Program activities involve:

- Product evaluation—in which the utility and reliability of resource planning methods and technologies and the usefulness of information products are tested against real world problems of the planning community. An example of this activity is the ongoing study with the Council of State Governments to find more efficient and accurate ways for States to communicate their natural-resource data needs to Federal data-producing programs.
- Methodology development—where the existing information base is used to generate, analyze, and evaluate alternatives in land and resource planning and decisionmaking. An example of this activity is the joint Resource and Land Investigations Program/Bureau of Indian Affairs/Colville Confederated Tribes study utilizing a high-technology approach to support land-resources management via a computerized geographic information system.

Colville planning meeting.

Investigation of Geologic Hazards—It's The Law in Santa Clara County

Those wishing to build in or near potentially hazardous areas in Santa Clara County, California, may be required to file a geologic site report prior to development of such areas, according to a change made in the *County Ordinance Code* by the Board of Supervisors in 1974. The need for such a report is determined by a designated County official for each proposed development on the basis of County hazard maps. Each report must: (1) be prepared by an engineering geologist registered in the State; (2) be submitted to the County for approval; and (3) specify the remedial measures to be undertaken that will make the development safe. Santa Clara County is one of the largest and fastest growing counties in the San Francisco Bay region. The County, and in particular its areas of greatest geologic hazards, are relatively undeveloped. Most of the geologic hazards have been identified and mapped.

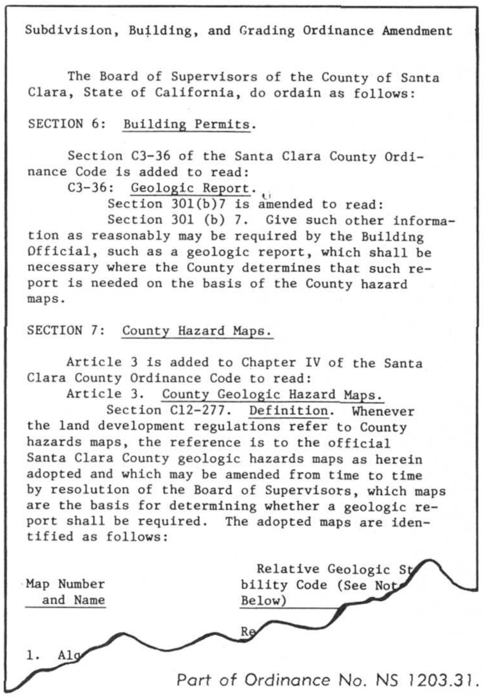
A map of composited geologic hazards based in large part on Geological Survey data, was prepared by the County Planning Department as the official geologic-hazards map for use in the County subdivision, building, and grading ordinances. A portion of the composite map is shown here. Reproducible copies of the map at a scale of one inch equals one mile are available from the County. Ten maps (maps numbered 7a through k in the official ordinance) from the San Francisco Bay Region Environment and Resource Planning Study (an urban area study conducted by the Geological Survey in cooperation with the Development of Housing and Urban Development) were adopted and specifically cited in the ordinance.

Open File Report 76–547 entitled "Use of USGS Earth Science Products by County Planning Agencies in the San Francisco Bay Region, California" contains other examples of applications of USGS information. The County has a state-certified engineering geologist in its Land Development Engineering Department who participated in the development of the ordinance and who has major responsibility for its day-to-day administration. △

- Technology transfer—which includes the packaging of information in usable forms, the conduct of workshops and other educational events, and the provision of short-term technical assistance to the State and local planning community. An example of this activity is the ongoing series of regional workshops with the American Society of Planning Officials to acquaint State and local coastal zone management officials with the planning methods and information base available to help them anticipate more accurately the onshore effects of Outer Continental Shelf (OCS) oil and gas resource development.
- Information dissemination—which includes the compilation of directories, catalogs, and bibliographies to land-resource data, technologies, and sources of expertise.

Accomplishments

- Completion of a joint project with the Energy Research and Development Administration (Argonne National Laboratory) to develop methods for integrated mining, reclamation, and regional land-use planning.
- Initiation of an interagency agreement with the Argonne National Laboratory to conduct six regional workshops to transfer the results of the joint project (see above) to working planners, mining engineers, and concerned public officials.
- Completion of a joint project with the New England River Basins Commission (NERBC) to develop a generalized planning methodology to estimate the onshore impacts from the development of Outer Continental Shelf (OCS) oil and gas resources.
- Sponsorship of a series of 12 regional workshops for coastal State and local planners (2 to be held at each of 6 coastal locations, at 1-year intervals in Atlantic City, N. J.; Ocean City, Md.; Savannah, Ga.; Otter Rock, Ore.; Biloxi, Miss.; and Fairbanks, Alaska) with the objective of transferring the state-of-the-art planning



Subdivision, Building, and Grading Ordinance Amendment

The Board of Supervisors of the County of Santa Clara, State of California, do ordain as follows:

SECTION 6: Building Permits.

Section C3-36 of the Santa Clara County Ordinance Code is added to read:
C3-36: Geologic Report.
Section 301(b)7 is amended to read:
Section 301 (b) 7. Give such other information as reasonably may be required by the Building Official, such as a geologic report, which shall be necessary where the County determines that such report is needed on the basis of the County hazard maps.

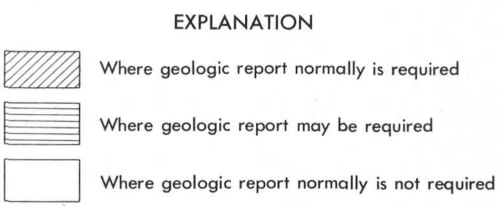
SECTION 7: County Hazard Maps.

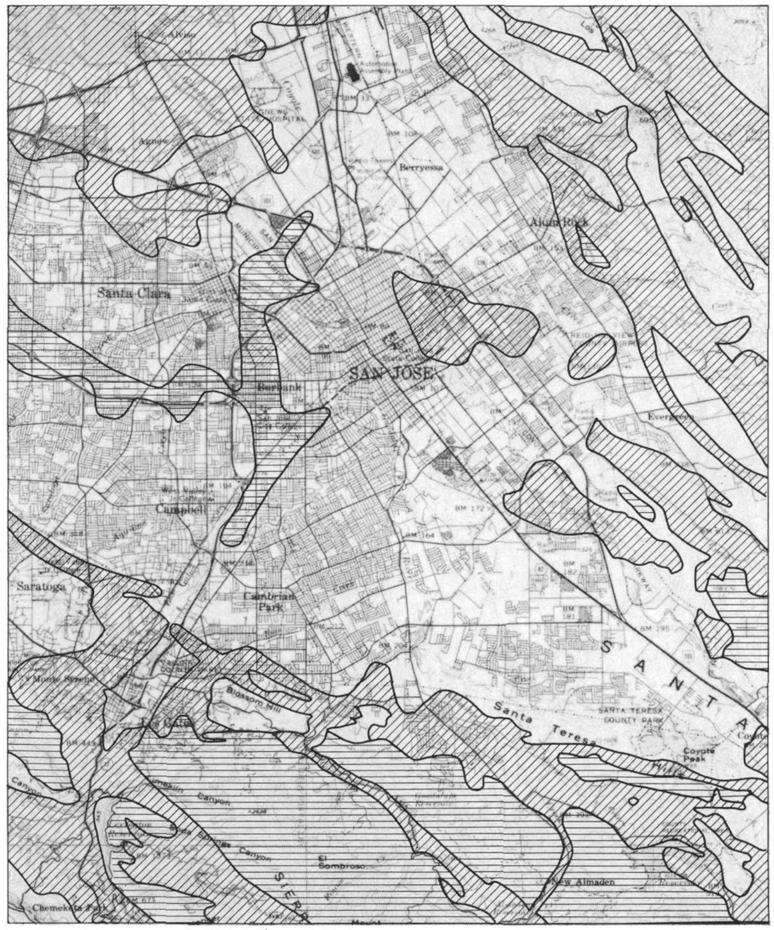
Article 3 is added to Chapter IV of the Santa Clara County Ordinance Code to read:
Article 3. County Geologic Hazard Maps.
Section C12-277. Definition. Whenever the land development regulations refer to County hazards maps, the reference is to the official Santa Clara County geologic hazards maps as herein adopted and which may be amended from time to time by resolution of the Board of Supervisors, which maps are the basis for determining whether a geologic report shall be required. The adopted maps are identified as follows:

Map Number and Name | Relative Geologic St[a]bility Code (See No[te] Below)

1. Al[...]

Part of Ordinance No. NS 1203.31.





Part of official Geologic Hazards Map, from Santa Clara County Seismic Safety Plan (Santa Clara Planning Department, 1975). Scale, 1:250,000.

methods for estimating the onshore impacts of OCS oil and gas development. (Workshops are partly funded by EPA and are managed by the American Society of Planning Officials.)

- Completion of the South Florida Environmental Study with the publication of Geological Survey Professional Paper 1011, "The Environment of South Florida: A Summary Report." The report summarizes and interprets the results of 51 technical studies prepared by seven Federal, State, and local agencies and presents the information in a form suitable for analysis by planners and land-use decisionmakers.
- Initiation of an agreement with the Council of State Governments to assess the extent to which the various land record systems of the State of Wisconsin are amenable to automation and consolidation, and publication of "Natural Resource Data Needs Recommendations" by the Council of State Governments.
- Completion of Critical Areas and State Land Inventory Systems Projects, begun originally in cooperation with the Office of Land Use and Water Planning of the Department of the Interior.

In little more than 4 years, the program and its cooperators, grantees, and contractors have published, released, or have in preparation, more than 70 reports, maps, inventories, or directories. The distribution of publications resulting from one supported activity, the Council of State Governments' Task Force on Natural Resource and Land-Use Information, had exceeded 30,000 copies by the end of fiscal year 1977. The program has also sponsored or co-sponsored 1 national symposium and 14 regional or national workshops designed to transfer technical knowledge to State and local resource planners. Additional workshops are scheduled in fiscal year 1978 on topics including mined-area reclamation, coastal zone planning, and natural-resource information systems.

GEOGRAPHY PROGRAM

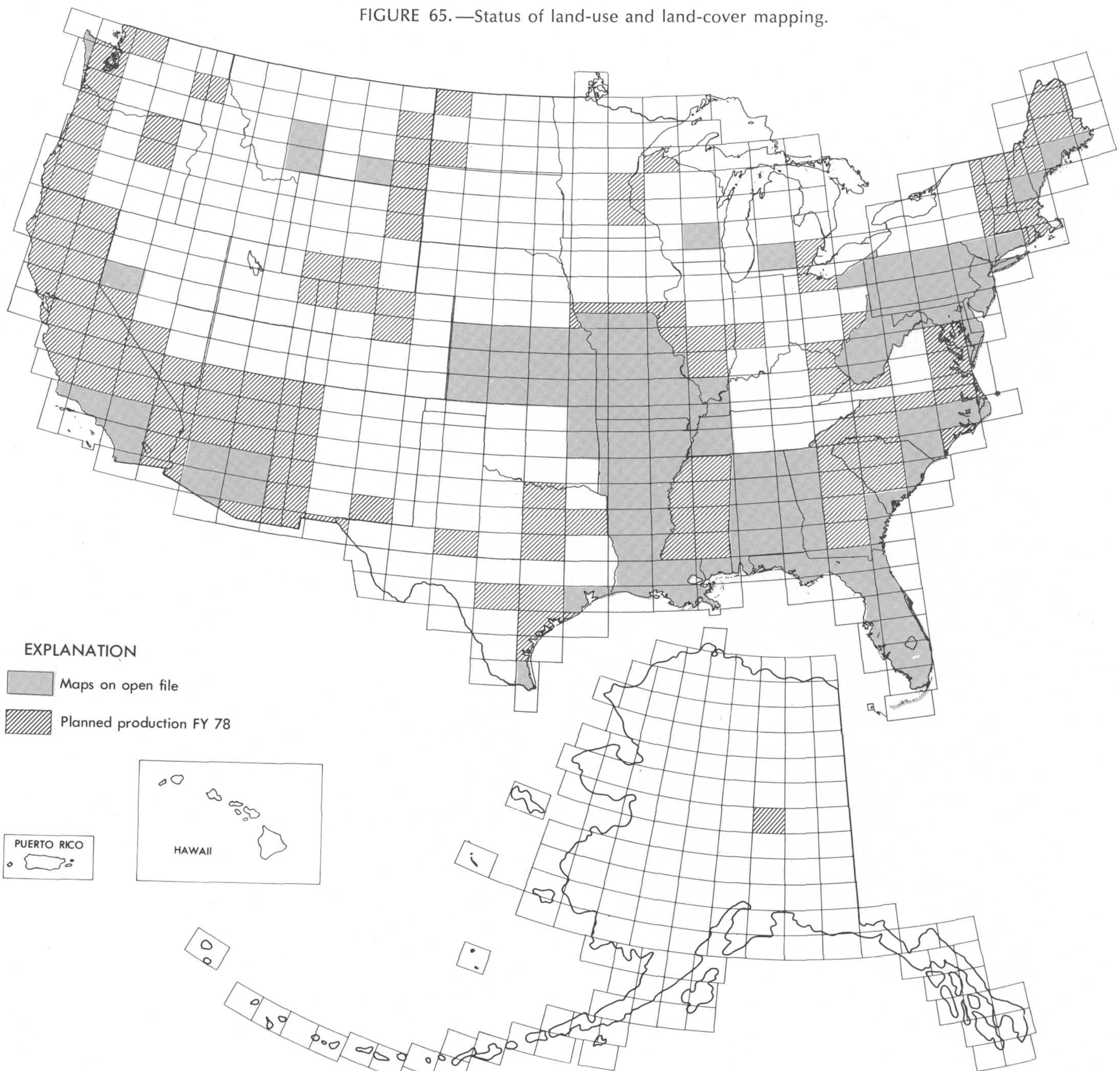
Programs and Activities

The Geography Program links and integrates social science information and the techniques of geographic analysis with earth-science information collected by the Geological Survey. Activities include:

- Mapping land use and land cover on a nationwide basis.
- Developing and demonstrating land-use and land-cover mapping techniques, using remotely sensed data and a geographic-information system.
- Conducting field investigations and participating in multidisciplinary studies that contribute to solutions of planning and technical problems arising from interactions of land-use practices and environmental factors.
- Contributing to the National Atlas project.

Planning and implementing programs designed to promote wise use of the land depend in part on a knowledge of the present distribution of, and temporal changes in, different types of land use and land cover and on a knowledge of where urbanization and other types of development are occurring. The

FIGURE 65.—Status of land-use and land-cover mapping.



location, area, and percentages of various types of land use and land cover are among the types of statistical data used by Federal and State legislators and local officials to determine land-use policy, to project demands for different types of land use, to predict where future development pressures will occur, and to formulate plans for regional development. Current land-use and land-cover data also support Federal and State planning for developing energy resources, managing public lands, siting facilities, developing recreational areas, managing water resources, and assessing potential and actual natural disaster damages.

National Land-Use and Land-Cover Mapping and Data Compilation

In fiscal year 1977, the Geography Program continued the nationwide land-use and land-cover mapping and data-compilation effort, established by the Geological Survey in fiscal year 1975 as the Land Use Data and Analysis program and designed to alleviate or remedy many of the shortcomings of various types of existing data. Maps of current land use and land cover for the entire Nation are being compiled at a scale of 1:250,000, and at a scale of 1:100,000 where such new intermediate-scale base maps are available (see fig. 65). Additional maps of Federally-owned lands, political units, Census county subdivisions, and hydrologic units are being prepared in overlay format in order to relate to the current land-use and land-cover data on these areal units.

The classification system being employed to map land use and land cover places primary reliance on remotely sensed data as the principal type of source material used in mapping. The system was developed after consultation with many Federal and State agencies, and it incorporates common terminology and can accommodate land-use and land-cover data gathered in greater detail.

A computerized geographic-information system has been developed to store and retrieve the data compiled under the national land-use and land-cover mapping program and related research projects. The system includes: (1) entry of digitized land-use and land-cover maps and other related data; (2) editing and updating of the data base; and (3) retrieval, manipulation, and automated plotting of the data for area measurement, comparative analysis with other data, and other analytic applications. Statistical summaries are prepared that present land-use and land-cover data for counties, watersheds, Census county subdivisions, and Federally-owned land.

Experimental and demonstration land-use and land-cover maps are produced to test various techniques of mapping, methods of detecting change, applications of remotely sensed data, regional applications, classification variation, computer applications, and combinations of map scale and minimum mapping unit.

The Geography Program has provided technical assistance to users of Geological Survey land-use and land-cover data and maps, and to those who desire to use the data in conjunction with computer software developed by the Geography Program or who need the data converted to use with other systems. For example, the Geography Program is cooperating with and assisting the U.S. Fish and Wildlife Service, the Bureau of Outdoor Recreation, the Bureau of Land Management, the Environmental Protection Agency, the Soil Conservation Service, the Forest Service, the Appalachian Regional Commission, the Ozarks Regional Commission, the Pacific Northwest Regional Commission, and many State and local agencies to utilize the Geological Survey's land-use and land-cover data in their resource management and planning.

Accomplishments

Accomplishments of the Geography Program during fiscal year 1977 included:

- Compilation of land-use and land-cover maps and data for approximately 1,040,000 square kilometers (400,000 square miles) during the year, the third year of the national land-use mapping effort, bringing the total area completed for such mapping to 2,730,000 square kilometers (1,050,000 square miles). As in the first two years of the program, the emphasis continued on mapping coastal areas, energy-production areas, other areas for which such mapping was desired by other Survey units and other Federal agencies, and areas for which cooperative agreements for land-use and land-cover maps had been made. Land-use and associated maps for 81 quadrangles were released to the open file in fiscal year 1977, bringing the total released to 153.
- Completion of research on the compatibility of land-use and land-cover pattern on Geological Survey maps of the Chattahoochee River basin in Georgia. These area measurements are being compared with field samples of river pollutants and sediments by the Survey's Water Resources Division.
- Completion of research on the compatibility of Geological Survey data files on land use and land cover with U.S. Bureau of the Census data on population in the Jacksonville, Florida, area.

- Mapping was completed under cooperative agreements for the States of West Virginia, Alabama, and Missouri. Arkansas, Louisiana, Kansas, Florida, Pennsylvania, and the Atlanta Metropolitan Region were previously mapped under cooperative agreements.
- Training seminars on map compilation were conducted for personnel from the States of Kansas, Pennsylvania, and Missouri.
- Land-use and land-cover data for forty-three 1:250,000- scale quadrangles covering 760,000 square kilometers (295,000 square miles), and data from 258 associated maps comprising a total of 3,470 meters (11,385 feet) of map polygon boundary lines, were digitized through a contract for automated laser line-following digitizing and entered into the Geography Program information system.
- Completion of a series of sixteen 1-day seminars jointly sponsored by the Geography Program, LIA, and the Topographic Division, which involved Survey personnel and members of the Commission on Geographical Data Sensing and Processing of the International Geographic Union, on the status, and trends in handling digital spatial data in the U.S. Geological Survey.
- Completion of a 3-year joint demonstration with the National Aeronautics and Space Administration (NASA), the EROS Program, and on behalf of the Pacific Northwest Regional Commission, of the use of Landsat digital data in land-resource management.
- Establishment of a 3-year Applications System Verification Test (ASVT), with NASA, for assessing the utility of Landsat digital data for updating maps in the Geological Survey's national land-use and land-cover program.
- Completion of the first phases of experiments in North Dakota, Kansas, and Nevada, testing the use of digital land-cover monitoring techniques in regions of diverse environments for unique patterns of land-cover change.
- Establishment of a Geography Program resident facility at NASA Ames Research Center, enlarging the Survey's capabilities to conduct continuing research and quasi-operational tasks using large capacity computers and digital data from Landsat satellites.
- Release to the National Technical Information Service (NTIS) of the first magnetic tape product (derived by machine processing of 1973 Landsat digital data) containing land-cover information of the Washington urban area, including the District of Columbia, and parts of Maryland and Virginia.
- Statistical summaries of land use and land cover tabulated by associated map sets were completed for the State of Kansas.
- Preparation of initial versions of vegetation/land-cover maps of the 100,000 square kilometers (38,000 square miles) of the National Petroleum Reserve in Alaska (NPRA) in support of Department of the Interior land-use studies and environmental assessment of that area.
- Demonstration of a laser-exposing technique for making plates for lithoprinting color, for a land-use and land-cover map in digital format and with accompanying area statistics.
- Establishment of a Geography Program post at the Institute for Behavioral Science, University of Colorado, for the study of institutional responses to the information available on environmental hazards.
- Completion of research reports on the effect of land-use and land-cover conditions on the local climatic patterns around urban areas.
- Completion of an analysis of changes in land use and land cover in southern Idaho during past periods of phosphate mining.
- Initiation of research at the request of the Bureau of Outdoor Recreation to inventory sites favorable for recreational development as shown on Geological Survey maps of land use and land cover for barrier islands and beaches along the Atlantic and Gulf coasts and for selected urban areas.
- Publication of Professional Paper 1059, "GIRAS: A Geographic Information Retrieval and Analysis System for Handling Land Use and Land Cover Data," which details the design and development of the computer-based information system being used in the national land-use and land-cover mapping and data-compilation program.

EARTH RESOURCES OBSERVATION SYSTEMS PROGRAM

Program and Activities

The Earth Resources Observation Systems (EROS) program, administered by the Geological Survey for the Department of the Interior, develops techniques to obtain and to analyze remotely sensed data and promotes the use of these techniques in fulfilling the resource and environmental inventory and management responsibilities of the Department. This objective is accomplished in cooperation with the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and other Federal agencies.

Program personnel work closely with representatives of the Department's bureaus and offices to coordinate and jointly sponsor applications of remote-sensing technology. Much of the research, which has resulted in the demonstration of numerous new applications, has been made possible by the experimental data acquired through the NASA's Landsat and Skylab programs and their aerial remote-sensing research program. Other research draws on data collected by other systems, such as the environmental satellites of NOAA and aerial remote-sensing activities sponsored by Department of the Interior bureaus and other Federal and State agencies.

EROS Data Center

The EROS Data Center in Sioux Falls, S. Dak., maintains an extensive archive of satellite imagery and aerial and space photographs of the Earth, processes and distributes photographic and digital products, and provides extensive user training and technical assistance in the use of remotely sensed data. The Data Center's archive is a major component of the Survey's National Cartographic Information Center.

TRAINING AND ASSISTANCE

A major function of the EROS Data Center is to communicate the results of remote-sensing research to potential users. Technical training programs, ranging in length from a few days to one month, stress the use of remotely sensed data to particular applications such as forest inventories or mineral exploration.

During fiscal year 1977, the Data Center held training courses and workshops for 650 participants. In addition to 17 discipline-oriented courses and 1 technical symposium, 3 new courses in digital techniques were included in the training program. At the request of the Bureau of Land Management, computer methods of enhancing and analyzing imagery data from the 2-million-acre Denali test site in Alaska were demonstrated to Bureau representatives who are cooperating with NASA in the establishment of an operational information system.

The 8th and 9th International Workshops given at the Data Center and 2 similar courses given in Buenos Aires were attended by 120 foreign participants. EROS Data Center staff also cooperated with Water Resources Division of the Survey and NASA in conducting 2 workshops on the use of Landsat and Geostationary Orbiting Earth Satellite (GOES) data collection platforms in Bolivia and Chile.

Orientation courses were presented to participants in the National Petroleum Reserve of Alaska environmental assessment project; to Bureau of Mines personnel concerning strip mine monitoring; and to members of the Mining Enforcement Safety Administration concerning ground stability in surface and underground mines.

DATA ANALYSIS LABORATORY

Begun as an adjunct to formal training courses, the Data Analysis Laboratory (DAL) has become a focal point for demonstrating and developing new remote-sensing techniques. Sophisticated instruments such as the Interactive Digital Image Manipulation System (IDMS), densitometers, additive color viewers, zoom transferscopes, and stereoviewers are available to users with technical guidance from experienced machine operators and resource scientists. There were about 600 visitors to the DAL in 1977 participating in such activities as:

- Compositing data from Landsat, aeromagnetic, gravity, and topographic sources to aid in interpreting geological anomalies (Geologic Division, Geological Survey).
- Experimentation with the use of portable IDIMS terminals in remote desert areas that are under study (Bureau of Land Management).
- Use of IDIMS in mapping phreatophytes (water-loving plants) along the Colorado River to determine the feasibility of an operational resources inventory (Bureau of Reclamation).
- Combining radar and Landsat data as an experiment in image enhancement (EROS).

APPLICATIONS ASSISTANCE FACILITIES

User assistance and training are conducted also at Applications Assistance Facilities (AAF's) in Mississippi, Fairbanks, Alaska, Phoenix, Ariz., and the Canal Zone.

In accordance with plans made in 1972, the Phoenix AAF was transferred to the Arizona Resources Information System, in the State government, and the Menlo Park EROS function was combined with the Western Region National Cartographic Information Center (NCIC). The AAF's and NCIC regional offices maintain browse files and microfilm of aircraft and satellite imagery and have terminals to the main computer complex at Sioux Falls. A new inquiry, ordering, and accounting system has permitted more efficient processing of inquiries and purchasing of imagery through the regional centers.

DATA PRODUCTION AND DISSEMINATION

The EROS Data Center produces and distributes materials from data collected by satellites and aircraft. Dollar volume of these products sold in fiscal year 1977 amounted to $2,515,000 (table 23). Landsat products, while totalling only 18 percent of the data base, accounted for $1,674,000, or 62 percent of the total sales. Sales of digitally enhanced scenes totalled $137,000 and computer compatible tapes $371,000, more than 30 percent of total Landsat sales, reflecting the increased trend toward digital processing of Landsat data. Foreign users and industry are the principal purchasers of Landsat data, accounting for 32 percent and 27 percent, respectively, of the total sales. The Federal government is the next largest purchaser at about 24 percent. Academia, private individuals, and State and local agencies account for the remainder.

TABLE 23. —*Sale of data from satellites and aircraft in fiscal year 1977*

Landsat imagery	$1,303,000		
CCT's	371,000		
Total Landsat		$1,674,000	
Manned satellites		52,000	
Total value of space products			$1,726,000
NASA aircraft	$ 366,000		
USGS aircraft	423,000		
Total value of aircraft products			789,000
Total value of air and space products			$2,515,000

DIGITAL IMAGE PROCESSING SYSTEM

The digital image processing system being implemented by Goddard Space Flight Center and the EROS Data Center will provide products from Landsat-C data in 1978 which will be superior to those which have been available from Landsats 1 and 2. To simulate products of this new system, images from Landsats 1 and 2 were computer enhanced (fig. 66), on a special order basis, by means of a laser-beam film recorder controlled by a digitally modified computer compatible tape. Terrain brightness and feature edges were enhanced, striping was reduced, and distortions were removed. About 175 scenes were enhanced in this way; image quality approximates that which will be routinely available when the production system becomes operational next year.

Status of Landsat Satellites

Landsat-1, although designed to last only 1 year, began its sixth year in orbit in July 1977. Even though both of its tape recorders and band 4 of its multispectral scanner are no longer functioning, the satellite is still transmitting useful data to ground stations in the United States, Canada, Brazil, and Italy. Canada opened a second receiving station in 1977, Iran has one nearly completed, and several other countries are planning to build receiving stations.

Eighty-five research studies, reflecting the broad range of disciplines using Landsat-1 data, were summarized in Professional Paper 929 entitled, "ERTS–1, A New Window on Our Planet," and published in 1976. This award-winning publication is being reprinted after having sold out in 6 months and is now being translated into Japanese by Professor H. Takeuchi of Tokyo University for the Asakura Publishing Company.

Landsat-2, launched in January 1975, has lost one of its two tape recorders but is otherwise performing well. The format of the data from the two Landsats is identical, permitting interchangeable use.

Landsat-C is to be launched early in 1978 into an orbit at the same altitude so it will also have the same data format, assuring continuity to users. The sensors will be virtually the same as those on Landsats 1 and 2 except that a thermal band is being added to the multispectral scanner, and the Return Beam Vidicon camera system, little used on Landsats 1 and 2, is being modified to improve the resolution by a factor of ten.

COVERAGE OF TRUST TERRITORIES

To determine its usefulness in mapping shallow seas and analyzing changes due to major storms, Landsat-2 coverage was acquired of parts of the Trust Territories of the western Pacific, which are administered by the Department of the Interior. Because only one of the four tape recorders on Landsats 1 and 2 is still working, coverage of areas out of range of ground stations, such as the Trust Territories, had to be obtained on a priority basis by special arrangement with Goddard Space Flight Center.

W. T. PECORA MEMORIAL SYMPOSIUM

Two hundred and twenty-five participants attended the second W. T. Pecora Memorial Symposium on mapping with remotely sensed data, sponsored by the American Society of Photogrammetry, at Sioux Falls, S. Dak., in October 1976.

In October 1977, the third Pecora Symposium, on applications of satellite data to petroleum and mineral exploration, was sponsored by the American Society of Petroleum Geologists. More than 600 participants from 30 nations attended.

Proceedings of the first Pecora Symposium were published by the Survey as Professional Paper 1015.

Accomplishments

- Approval for publication for approximately 30 manuscripts concerning agriculture and vegetation, activities of the EROS Data Center, geology, luminescene studies, floods, urban change detection, wetlands and wildlife habitat, and two maps.

FIGURE 66.—A Landsat-2 image (band 5) of New Orleans, La., which has been computer enhanced at the EROS Data Center.

- Participation in planning of future satellites, such as Landsats C and D, Seasat, and the Space Shuttle, by communicating to NASA the particular data requirements of scientists of the Survey and other bureaus in the Department.
- Visits of nearly 19,000 people to the EROS Data Center to become acquainted with applications of remotely sensed data.
- Continued training and demonstration of new applications in the field of remote sensing.

ENVIRONMENTAL IMPACT ANALYSIS PROGRAM

Program and Activities

The Environmental Impact Analysis (EIA) Program provides an integrated Geological Survey response to the requirements of the National Environmental Policy Act (NEPA) through:

- Direction, coordination, and expertise in the preparation of environmental impact statements (EIS) for which the Survey has lead or joint-lead responsibility.
- Scientific and technical support of the preparation of statements for which the Survey has contributing responsibility.
- Technical analyses and review of statements and related documents prepared by other agencies.
- Manuals, guidelines, and training courses on the preparation and review of statements.
- Environmental research.

NEPA requires that a Federal agency contemplating a major action that could significantly affect the quality of the environment must prepare a detailed statement of the possible environmental impacts. The Act further requires that statements must be reviewed by other Federal agencies having pertinent jurisdiction or expertise. In final form, the statement plays an essential role in an agency's decisionmaking process.

The Geological Survey becomes involved as a lead agency in the preparation of statements through the Conservation Division's regulation of mineral-resource exploration, development, extraction, and reclamation operations on Federal lands. The Survey becomes involved as a participating agency, in a nonlead role, both through its regulatory function, as described above, and through its special expertise in the areas of geology, hydrology, and mining and petroleum engineering.

In accordance with guidelines set by the Council on Environmental Quality (CEQ), Federal agencies submit environmental impact statements to the Department of the Interior for review. The statements are assigned by the Department to one or more bureaus, primarily on the basis of legal jurisdiction or special expertise.

The principal objectives of the Environmental Impact Analysis Program are to:

- Provide a core group of multidisciplinary specialists to assure the continuity of quality standards through acquired expertise in the preparation and review of EIS's and thorough associated research and training.
- Reduce the time necessary for preparation and review of EIS's while providing thorough and complete coverage of required subject material.

The Environmental Impact Analysis Program is organized functionally into three branches: (1) the Preparation Branch which coordinates, reviews, and provides expertise to the work of task forces preparing EIS's; (2) the Review Branch which provides technical analysis and review of EIS's and related documents prepared by Federal agencies; and (3) the Research and Training Branch which promotes and conducts environmental research and provides guidance and training in task force management and EIS preparation.

In fiscal year 1977, new guidelines on five specific aspects of EIS preparation were compiled and existing guidelines and manuals were updated for task force leaders and members. A study concerned with developing methodologies for delineating, measuring, and monitoring environmental impacts of phosphate strip mining in southeastern Idaho was prepared and is in final processing prior to publication.

The EIS process has, in the past, resulted in extremely lengthy documents. During fiscal year 1976, research was begun, aimed at reducing the large size of EIS's. A fundamental objective of the research is to reduce the bulk but still maintain the standards of quality and thoroughness necessary for decisionmakers. Preparation of a prototype site-specific EIS demonstrating reduction of bulk and maintenance of quality was started during the year.

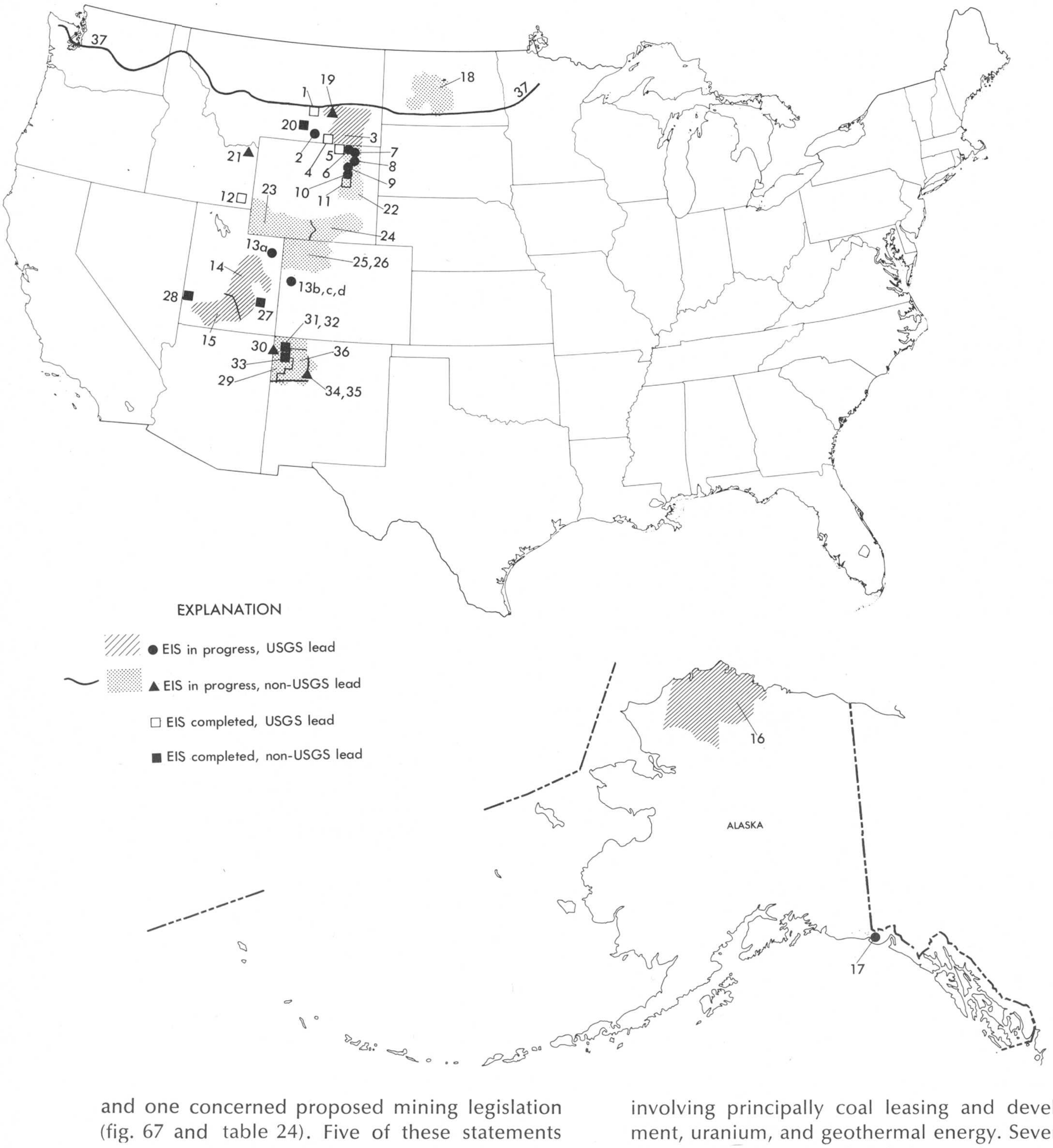
During fiscal year 1977, the EIA Program initiated studies of the application of a computer simulation model in the EIS process for measuring environmental changes or impacts that would result from Federal actions. With the assistance of the State of Montana and the U.S. Bureau of Land Management, a project was begun to investigate the impact of coal development in Montana on demography, land and water use, and environmental residuals. The model output is in the form of graphic simulations of various impacts of given sets of events between the years 1970 and 2000, the most important of which is simulation of the adverse affects of boomtown growth on industrial productivity and the social structure of the region.

Accomplishments

During fiscal year 1977, the Survey:

- Took lead or joint-lead responsibility for the preparation of 18 EIS's. Sixteen EIS's concerned the development of onshore coal, uranium, and oil and gas. One concerned critical minerals,

FIGURE 67.—Locations for which environmental impact statements (EIS's) were in progress or completed during fiscal year 1977.
[Locality numbers are keyed to table 24.]



and one concerned proposed mining legislation (fig. 67 and table 24). Five of these statements were completed during the year.

- Participated in a non-lead capacity in the preparation of 20 EIS's for which other Federal agencies had the lead responsibility (fig. 67 and table 24). Eighteen of these EIS's were energy related, involving principally coal leasing and development, uranium, and geothermal energy. Seven of these EIS's were completed during the year.
- Reviewed and commented on 1,800 EIS's and related documents.
- Initiated studies of the application of systems dynamics modeling in the EIS process.

TABLE 24.—*Environmental impact statements completed or in progress during fiscal year 1977*

[Locality numbers are keyed to fig. 67]

Title	State	Locality number	Project description
GEOLOGICAL SURVEY LEAD OR JOINT-LEAD RESPONSIBILITY			
Westmoreland coal mine [1]	Montana	1	Determine impacts of proposed mining and reclamation plan in the Crow-ceded area in south-central Montana.
Crow Shell (Young's Creek) coal mine	do	2	Evaluate impacts of mine and transportation system on Crow Indian Reservation.
Northern Powder River regional coal leasing and mining	do	3	Evaluate individual and cumulative regional impacts of leasing and mining in south-central Montana.
Decker Coal Mines [1]	do	4	State of Montana and U.S.G.S. project to determine impact of proposed mining and reclamation plan.
Eagle Butte coal mine [1]	Wyoming	5	Determine impacts of Amax Coal Co.'s proposed mine north of Gillette.
East Gillette coal mine	do	6	Determine impacts of Kerr-McGee Co.'s proposed mine north of Gillette.
Caballo coal mine	do	7	Determine impacts of Carter Oil Co.'s proposed mine southeast of Gillette.
Pronghorn coal mine	do	8	Evaluate impacts of Mobil Oil-Consolidation Coal Co.'s mining and reclamation plan southeast of Gillette.
Coal Creek coal mine	do	9	Determine impacts of Atlantic Richfield Co.'s proposed mining and reclamation plan south of Gillette.
Rochelle coal mine	do	10	Evaluate impacts of Peabody Coal Co.'s project in eastern Powder River basin.
Bear Creek uranium mine and mill [1]	do	11	Determine impacts of Rocky Mountain Energy Co.'s mining and milling operation in the national grasslands south of Gillette [2]
Phosphate leasing and development [1]	Idaho	12	Determine separate and collective impacts of 16 mining plans on Federal leaseholds in southeastern Idaho.
Oil-shale tract leasing	Colorado-Utah	13	Evaluate impacts of leasing 4 tracts for in-situ production of shale oil.
Central Utah regional coal leasing and development	Utah	14	Evaluate individual and cumulative regional impacts of leasing and mining.
Southern Utah regional coal leasing and development	do	15	Evaluate individual and cumulative regional impacts of leasing and mining.
National Petroleum Reserve in Alaska	Alaska	16	Evaluate impacts of alternative plans for development, production, transportation, and distribution of petroleum resources in the reserve.
Samovar Hills exploratory drilling	do	17	Determine impacts of Texaco Oil Co.'s proposed oil and gas exploratory drilling program.
Mining law reform [3]	Nationwide	--	Determine impacts of proposed legislation to reform the mining law of 1872.

See footnotes at end of table.

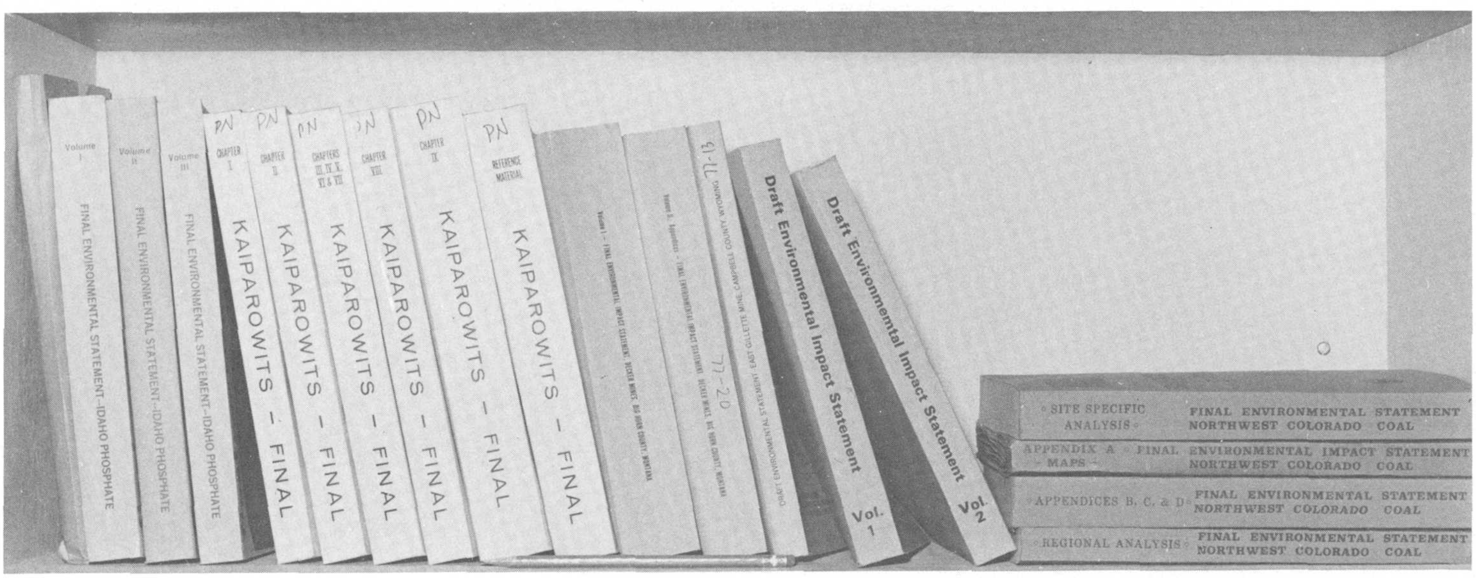
TABLE 24.—*Environmental impact statements completed or in progress during fiscal year 1977*—Continued

GEOLOGICAL SURVEY PARTICIPATION

Project	State	Locality number	Lead agency
West-central North Dakota regional coal leasing and development	North Dakota	18	Bureau of Land Management.
Colstrip No. 3 and No. 4 power transmission line	Montana	19	Bonneville Power Administration.
Westmoreland coal leasing [1]	do	20	Bureau of Indian Affairs.
Targhee (Island Park) geothermal	Idaho	21	Forest Service.
Eastern Powder River coal leasing supplement	Wyoming	22	Bureau of Land Management.
Southwest Wyoming regional coal leasing and development	do	23	Do.
South-central Wyoming regional coal leasing and development	do	24	Do.
Regional coal leasing and development [1]	Northwest Colorado	25	Do.
Northwest Colorado coal leasing supplement	Colorado	26	Do.
Emery coal mine and power-generation plant [1]	Utah	27	Do.
Alunite mining and processing [1]	do	28	Do.
Northwest New Mexico uranium study	New Mexico	29	Bureau of Indian Affairs.
Navajo-Hopi land dispute	do	30	Do.
El Paso coal mine and gasification plant [1]	do	31	Bureau of Reclamation.
Exxon uranium exploration leasing [1]	do	32	Bureau of Indian Affairs.
Navajo-Consolidated coal mine supplement [1]	do	33	Do.
United Nuclear Dalton Pass	do	34	Tennessee Valley Authority.
Mobile Oil Crown Point	do	35	Do.
Star Lake-Bisti regional coal leasing and development	do	36	Bureau of Land Management.
Northern Tier Pipeline	Northern U.S.	37	Do.

[1] Completed.
[2] Joint-lead responsibility with Nuclear Regulatory Agency and Forest Service.
[3] Not shown on fig. 67.

- Provided technical information, gathered by other Survey programs, to the U.S. Forest Service for 7 EIS's on geothermal energy resources and to the Bureau of Land Management for 8 EIS's on leasing of the U.S. Outer Continental Shelf.
- Presented training seminars for personnel assigned to task forces.
- Initiated a prototype site-specific EIS to demonstrate ways to reduce the size of environmental impact statements.
- Prepared guidelines on five specific aspects of EIS preparation to assist task forces in the writing of EIS statements.
- Prepared a research paper concerned with impact monitoring methodologies in EIS preparation.
- Initiated an environmental study on the National Petroleum Reserve in Alaska to evaluate impacts of alternative plans for development, production, transportation, and distribution of petroleum resources in the Reserve.



National Petroleum Reserve in Alaska

INTRODUCTION

On June 1, 1977, the National Petroleum Reserve in Alaska, formerly known as Naval Petroleum Reserve Numbered 4, was transferred from the Department of the Navy to the Department of the Interior in accordance with the Naval Petroleum Reserves Production Act of 1976 (Public Law 94–258, U.S. 94th Congress, April 5, 1976). The Secretary of the Interior charged the Geological Survey with the responsibility for continuing the Navy's 7-year petroleum exploration program on the Reserve. Specific tasks for the Geological Survey include:

1. Petroleum exploration by means of drilling and geological and geophysical investigations to locate, measure and test producible oil and gas accumulations on the Reserve, and to build an information base to assess the petroleum potential of this region.
2. Development and continued production of the South Barrow gas field, or other such fields as may be necessary, to supply natural gas at reasonable and equitable rates to the native village of Barrow and other communities and installations at or near Point Barrow, Alaska, including Department of Defense and agencies of the U.S. Government.
3. Restoration to an environmentally acceptable state of certain areas of the Reserve disturbed by previous construction and exploration.

The exploration program originally proposed by the U.S. Navy is to be completed during fiscal year 1980. This program provided for drilling twenty-six test wells, conducting 10,000 line-miles of seismic and gravity surveys, and collecting geologic data to produce a reasonable resource appraisal of the petroleum potential of NPRA. Except for continuing the operation of South Barrow gas field or other such field to supply gas in the vicinity of Barrow, the legislation prohibits production from the Reserve and all development leading to production of petroleum until authorized by Congress.

The exploration program is closely coordinated with other studies on the Reserve. The legislation requires a Presidential study to determine the best overall procedure to be used in the development, production, transportation, and distribution of the petroleum resource on the Reserve, including alternative procedures (Section 105 (b) (1)). In addition, an Interior-established task force study is to determine the values of and best uses for the lands contained in the Reserve, taking into consideration the native, scenic, historical, recreational, fish and wildlife and wilderness values, mineral potential other than petroleum, and other values of such lands (Section 105 (c) (1)).

◀ Drilling at South Harrison Bay No. 1 on the North Slope, at −40°F. *(Photograph by Valentine Zadnik.)*

HIGHLIGHTS

- Completion by the Navy, with the assistance of the Geological Survey, of an Environmental Impact Statement in May 1977 analyzing exploration activities throughout the Reserve.
- Establishment of the Office of National Petroleum Reserve in Alaska and recruitment of staff.
- Modification of the contract with Husky Oil NPR Operations, Inc., for exploratory operations on the Reserve.
- Negotiation of interagency agreements for continuing logistical, communications, and operational support for petroleum exploration activities.
- Selection of eight exploratory drilling sites, one Barrow area gas-exploration drilling site, and two Barrow area gas-development drilling sites.
- Location of 2,081 miles of seismic lines.
- Cooperation and coordination with other agencies and groups involved in related activities on the Reserve.

BUDGET AND PERSONNEL

The Survey received an appropriation of $1,848,000 during fiscal year 1977 for expenses during the transition period and for organizing and staffing a newly established Office of National Petroleum Reserve in Alaska (ONPRA). The U.S. Navy budget for Naval Petroleum Reserve Numbered 4 for fiscal year 1977 was $100,492,000. Of this amount, $7,169,633 unobligated funds and $32,017,733 obligated funds were transferred to ONPRA on June 1, 1977, to continue the exploration effort through the remainder of the fiscal year and to support continuing logistical requirements. Additionally, the Office of Naval Research transferred $240,000 to ONPRA to continue the operation of the South Barrow Gas Field.

At the time of transfer of the Reserve, five full-time positions were transferred to the Geological Survey from the Department of the Navy. At the end of fiscal year 1977, ONPRA was allocated 32 permanent full-time positions and four part-time positions.

HISTORY

President Harding, on February 27, 1923, signed an Executive Order creating Naval Petroleum Reserve Numbered 4 after early Geological Survey explorers described oil seeps along the northern coast of Alaska. The Reserve was established as a potential source of petroleum during an emergency or crisis. Roughly, the boundary of the Reserve extends south from Icy Cape to the crest of the Brooks Range, east along the divide to longitude 155°37′, north to the Colville River and then along the river to the Arctic Ocean (fig. 68). The Reserve encompasses 23,680,000 acres and occupies more than half of the North Slope of Alaska. During the several years following the formation of the Reserve, exploration activities consisted primarily of field geological studies conducted by the Geological Survey. This work established the general framework of the geology of the area. World War II brought attention to the need for vast quantities of fuel required for mechanized weapons and in 1944 (Reed, 1958) the Navy undertook an exploration program which continued until 1953. This program included drilling of 36 test wells and collection of 3,400 line-miles of seismic surveys. Several small oil and gas accumulations were discovered but only the South Barrow gas field was developed because of its proximity to the native villages and Government installations near Barrow. During this period, the Geological Survey conducted extensive studies on the Reserve and published most of the technical data. Geological studies continued on the Reserve and in adjacent areas from 1953 to the present with emphasis on regional resource appraisal, surficial geology and pipeline related investigations.

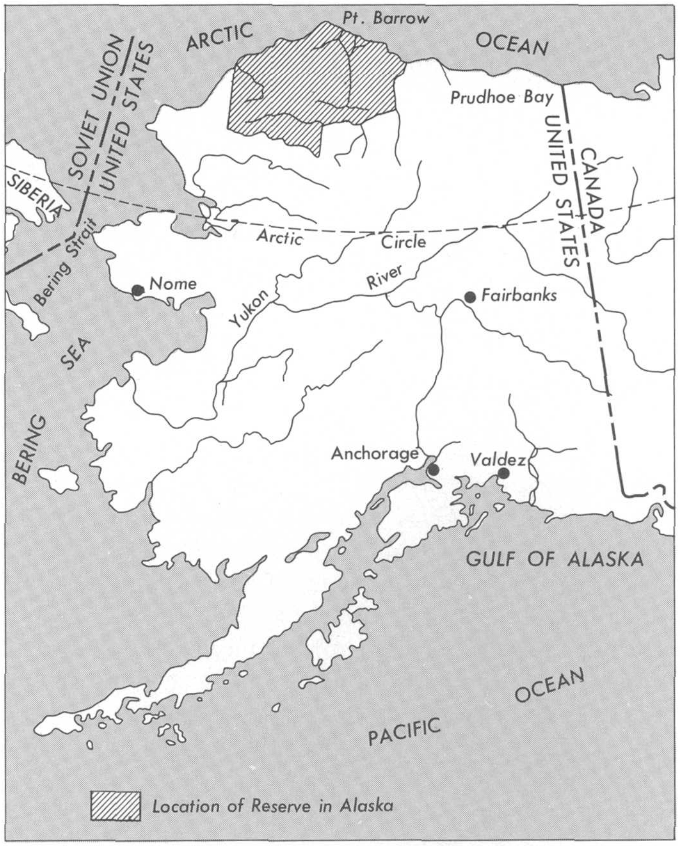
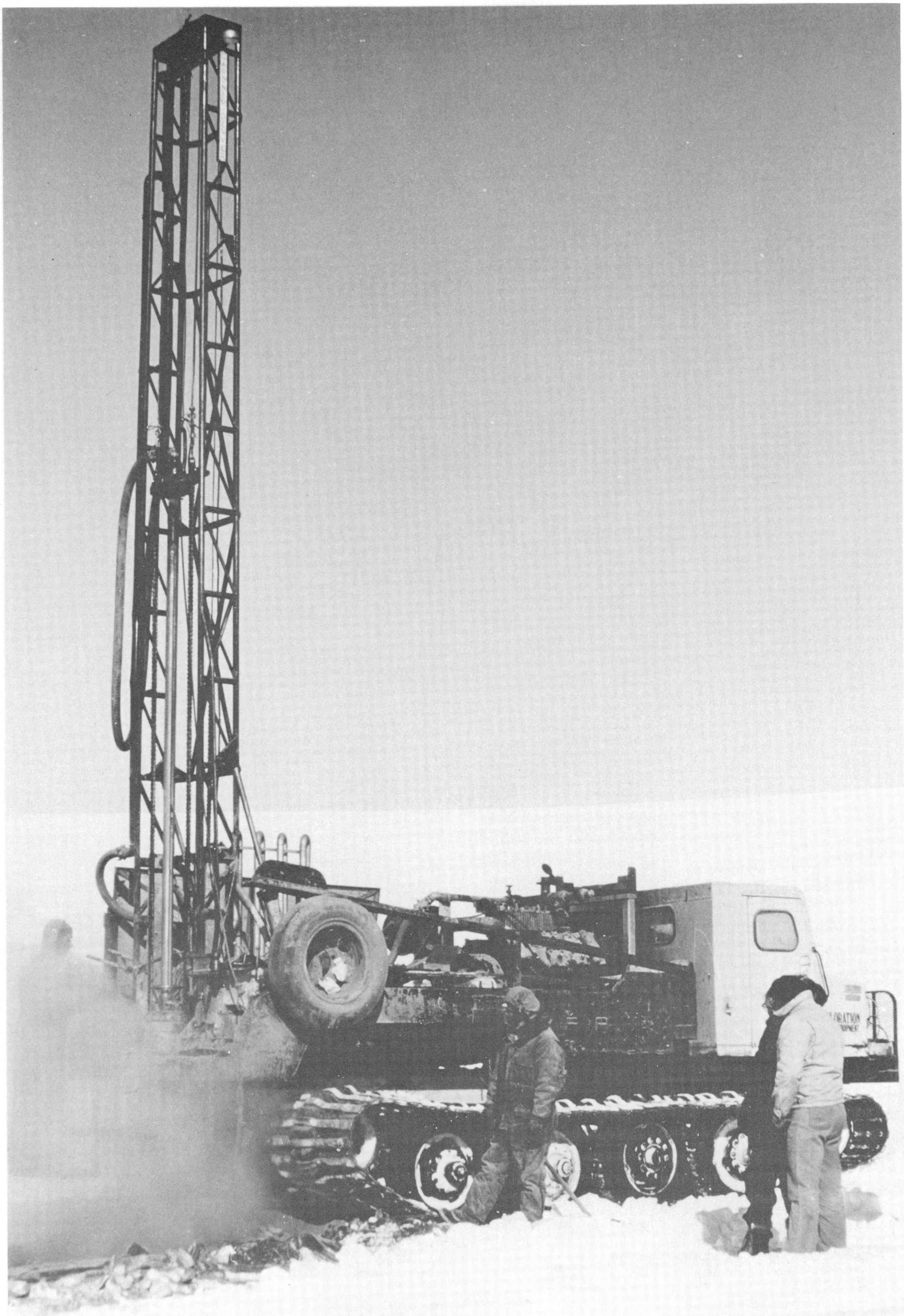


FIGURE 68.—Location map of the National Petroleum Reserve in Alaska. More than 100 miles north of the Arctic Circle, the National Petroleum Reserve in Alaska encompasses a 37,000-square-mile area approximately the size of Indiana. Most of the Reserve is above the Brooks Range in the nearly uninhabited "North Slope." Its largest village, Barrow, protrudes into the Arctic Ocean and is inhabited by the 2,000 northernmost citizens of the North American Continent.

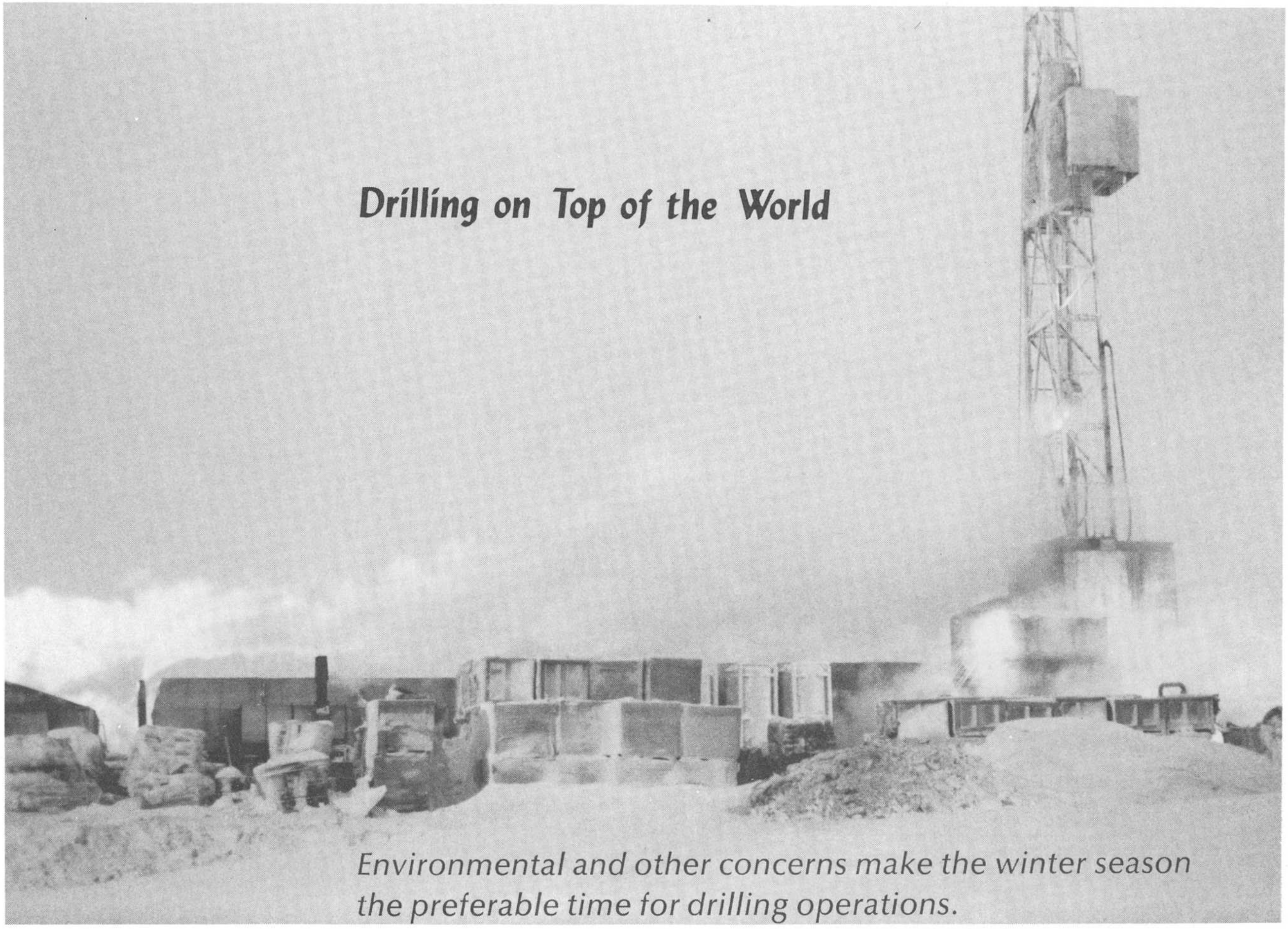
Although the total objectives of the early Navy exploration effort were not met by the time it was recessed, it was successful in yielding valuable technical data concerning Arctic operations. These served as the basis for later industry petroleum exploration activities in Northern Alaska, and for construction of major Government facilities.

As a result of the oil embargo of late 1973, Congress directed the Navy to resume exploration on the Reserve. The Navy commenced a 7-year program of acquiring and interpreting 10,000 line-miles of seismic and gravity data, and began a proposed 26 well exploratory drilling program.

Drilling seismic shot hole in the central part of NPRA at −29°C(−20°F). *(Photograph by Irvin Tailleur.)* ▶



Drilling on Top of the World



Environmental and other concerns make the winter season the preferable time for drilling operations.

Photograph by Valentine Zadnik.

The Navy prepared an Environmental Impact Statement for what was known as Zone A, located in the northeast sector of the Reserve, because this sector was thought to have the highest probability of containing producible oil and gas. The Navy drilling program had two major objectives: (1) exploration of a possible extension of the Prudhoe Bay trend along the northeast edge of the Reserve, and (2) discovery of additional gas deposits in the Barrow area to ensure an adequate supply to meet increasing demand. The first objective resulted in no new discoveries of oil or gas and the results strongly suggest that the Prudhoe Bay geologic model does not extend into the Reserve. However, several shows of oil and gas were noted in some of the recent tests. The second objective resulted in the completion of a successful gas well in a new field east of the South Barrow gas field. The South Barrow gas field is currently the sole sources of gas for the village of Barrow. To the date of the transfer of the Reserve, the recent Navy exploration program expended $167 million, collected 7,600 line miles of seismic and gravity data throughout the Reserve, drilled seven exploratory wells in the northeast part of the Reserve, and constructed a semi-permanent support camp at Lonely, Alaska.

PROGRAM AND ACTIVITIES

Early in 1976, in anticipation of the transfer of the Reserve to the Department of the Interior, the Geological Survey established liaison with the Navy and its contractors and began reviewing and evaluating geological and geophysical data held by the Navy. A planning group was established to affect a smooth transition and to study ways to best continue the Navy exploration program. The petroleum potential of the Reserve was studied more fully and in June 1977 a special report, "The Petroleum Geology and Hydrocarbon Potential of Naval Petroleum Reserve

Distance, darkness, and the ravages of some of the world's worst weather boost the cost of drilling an exploratory oil well to between $10 and $30 million on the National Petroleum Reserve in Alaska, a 37,000 square-mile tract of land lying between the Brooks Range and the Arctic Ocean. Supplies come either by barge through the Bering Strait during the brief summer retreat of the Arctic ice or by year-round airlift. Because there is a 1-year lead-time for shipment of bulk materials and equipment from Seattle, planning and design of wells and purchase of materials must begin 18 months in advance of actual drilling. Environmental and other concerns make the winter season the preferable time for drilling and seismic operations. But this is also a period of extreme cold, high winds, and near total darkness. Protection of the sensitive arctic vegetation and the large distances between base camp, drill sites, and seismic crews require extensive use of aircraft for supply and crew rotation. To keep ground-bearing pressure to a minimum, overland transport is by terra-tired vehicles, rolligons, or tracked vehicles over previously staked winter trails and ice roads. Wherever possible, cross country routes use lake ice and bay ice—again to minimize damage to the tundra.

The permanently frozen ground (permafrost) requires special methods for all construction work and for water supply and disposal. At each drill site (approximately 9 acres), all facilities such as housing, maintenance shops, drilling equipment, and fuel and material storage facilities are placed on a 4- and 5-foot thick sand or gravel pad to insulate the permafrost. Except for the drilling rig and associated equipment which are placed on timber piles embedded in the permafrost, all structures are supported about 12 inches above the pad by timber blocks to retard heat transfer from structures into the pad and underlying permafrost. Each drill site has a landing strip constructed of gravel or prepared on lake ice. In the case of deep wells, which require 150 to 300 drilling days to complete, drilling may be conducted year-round or divided into two winter seasons with a recess during the summer months. For year-round drilling, construction of an all-weather airstrip capable of handling C-130 Hercules aircraft and an all-weather road between the airstrip and pad must be constructed.

The 500,000 to 600,000 gallons of fuel required to drill a medium-depth well (12,000 feet) must be supplied to the site by rolligon in 85 to 100 trips or by C-130 aircraft in 100 flights. More than twice this amount of fuel is required for a deep well (20,000 feet). Fuel storage on-site is about 70,000 gallons, a 10-day supply, to ensure that adequate fuel is available during bad flying weather.

Project headquarters staff in Anchorage and field personnel communicate primarily by telephone, utilizing a satellite and a transportation ground station located at the base camp at Lonely. The base camp at Lonely on the Arctic Ocean is the main offloading point for the barges and is the main source of supply for individual drilling sites. The semi-permanent camp will accommodate approximately 80 workers. △

No. 4, Northern Alaska" (U.S. Geological Survey Open-File Report 77–475), was released.

On November 2, 1976, the Office of National Petroleum Reserve in Alaska was established with headquarters in Anchorage, Alaska. An operations staff, located in Anchorage, manages the development and production activities of the South Barrow gas field and supervises day-to-day petroleum exploration activities of the contract operator, Husky Oil NPR Operations, Inc. An exploration strategy staff established in Menlo Park, California, maintains close liaison with the technical staff of the contractor and subcontractors, located largely in Houston, Texas. This strategy staff also arranges for special technical support from units within the Geological Survey at the Western Field Center or from outside consultants. The group formulates exploration strategy, selects drilling targets, designates coring and sampling intervals, locates seismic shot lines, and performs geologic field studies. An ONPRA Liaison Office located at the USGS National Center in Reston, Va., interacts with Department of the Interior offices and serves as a focus for budgetary, contractual, and congressional matters.

The exploration program in fiscal year 1978 includes three major and interacting elements: drilling, geophysical investigations, and geologic studies. In addition to continued exploration for gas in the Barrow area, the planned drilling program provides for the drilling of four medium depth test wells (wells which can be completed in one winter drilling season) and two deep test wells (wells which require more than one winter drilling season), and the construction of two drilling pads for the fiscal year 1979 drilling season. The goal of the exploration drilling program is to sample, with test wells, a sufficient number of different geologic structures within NPRA, identifiable from geophysical data, to provide a resource appraisal of the Reserve which will assist Congress in determining the best use of the land within the Reserve. The fiscal year 1978 program represents an expansion to areas of the Reserve outside of Zone A to test apparent structural traps in areas where regional geologic trends and seismic data suggest possible favorable stratigraphic relationships or new intervals that have not previously been drilled in northern Alaska. Emphasis will be placed on evaluation of data acquired in the drilling of wildcat wells, to be used for guidance of the future program of exploration and resource evaluation. Laboratory geochemical studies are planned to identify the type and amount of organic material in rocks from the wells and to determine thermal history and source rock potential of these rocks. Similar studies will be carried out on outcrop samples. Studies of selected rock units to determine their depositional environment, reservoir potential, structure, and stratigraphic relationships also will be carried out in the field and will utilize past and future well data. Table 25 summarizes the exploration wells recently drilled by the Navy and the wells planned by the Survey during fiscal year 1978.

TABLE 25.—*Exploration wells recently drilled by the Navy and exploration wells planned by the Survey during fiscal year 1978*

Name	Location	Date spudded [1]	Date completed	Total depth	Deepest horizon penetrated	Status
Cape Halkett No. 1	18 mi ESE of Lonely	3/24/75	5/23/75	9,900 ft.	Argillite basement (Devonian or older)	Dry; plugged and abandoned.
East Teshekpuk No. 1	25 mi S of Lonely	3/12/76	5/11/76	10,664 ft.	Granite basement	Dry; plugged and abandoned.
South Harrison Bay No. 1	50 mi SE of Barrow	11/21/76	1/27/77	11,290 ft.	Lisburne Group (Mississippian)	Poor oil and gas shows; plugged and abandoned.
Atigaru Point No. 1	44 mi SE of Lonely	1/12/77	3/10/77	11,535 ft.	Argillite basement (Devonian or older)	Poor oil and gas shows; plugged and abandoned.
West Fish Creek No. 1	51 mi SE of Lonely	2/14/77	4/21/77	11,427 ft.	Kayak shale (Mississippian)	Poor oil and gas shows; plugged and abandoned.
South Simpson No. 1	41 mi WSW of Lonely	3/9/77	4/18/77	8,805 ft.	Argillite basement (Devonian or older)	Plugged and abandoned.
W. T. Foran No. 1	23 mi ESE of Lonely	3/7/77	4/16/77	8,864 ft.	Argillite basement (Devonian or older)	Oil and gas shows; plugged and abandoned.
Inigok Test Well No. 1	60 mi S of Lonely			19,775 ft. (projected)	Argillite basement (projected)	
Tunalik Test Well No. 1	22 mi SE of Icy Cape			19,980 ft. (projected)	Argillite basement (projected)	
Kugrua Test Well No. 1	33 mi E of Wainwright			12,200 ft. (projected)	Argillite basement (projected)	
South Meade Test Well No. 1	45 mi S of Barrow	(being planned)		9,825 ft. (projected)	Argillite basement (projected)	
Drew Point Test Well No. 1	14 mi W of Lonely			8,300 ft. (projected)	Argillite basement (projected)	
North Kilikpuk Test Well No. 1	37 mi SE of Lonely			7,250 ft. (projected)	Kuparuk River sandstone (projected)	

[1] Drilling began.

"Shooter" and recorder vehicles on seismic shot line in central part of NPRA, February 1977. *(Photograph by Irvin Tailleur.)*

Photograph by Irvin Tailleur.

Summer field work by USGS geologists in the Southern Foothills augments geophysical studies and exploration drilling.

Geophysical investigations will be conducted in three separate areas of the Reserve: (1) 651 line miles of detail, high resolution seismic data in the Barrow area; (2) 393 line miles of less-detailed seismic data in the Umiat area; and (3) 1,037 line miles of reconnaissance seismic data (widely spaced) in the Southern Foothills. The reconnaissance and semi-reconnaissance data will be used to help locate drilling sites for future exploratory wells. The high resolution seismic data will aid in continuing exploration for gas in the Barrow area.

Engineering geology investigations will provide information on the source of suitable construction materials, selection of sites for airfields, road and drilling pads, definition of permafrost problems, and possible effects of exploration activities on the environment.

In the Barrow area during fiscal year 1978, three wells will be drilled; two confirmation wells in the recent East Barrow gas discovery and one exploratory well in an adjacent untested structure. In addition, operation and maintenance of the South Barrow gas field will be continued to ensure an uninterrupted supply of gas to users in the Barrow area.

The environmental restoration of areas disturbed during previous construction and petroleum exploration activities will be continued in close coordination with the Bureau of Land Management, which has the responsibility of managing the surface of NPRA. Approximately two million dollars are planned for this activity.

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U.S. 94th Congress, April 5, 1976, Naval Petroleum Reserve Production Act of 1976: U.S. Public Law 94–258.

▲ Computer operator answers an inquiry from a remote user about mounting a magnetic tape.

▼ The public map-sales counter in the Central Region Branch of Distribution, in Denver, served about 28,000 customers in fiscal 1977. Self-service shelves in the background contain the most popular Colorado topographic maps.

Program Support Activities

INTRODUCTION

Essential Survey managerial, administrative, and technical services are furnished by:

- *The Office of the Director,* through the Director, the Associate Director, the Assistant Directors, and their respective staffs (excluding the Land Information and Analysis Office) provides executive direction, coordinates interagency and intrabureau activities, and guides program development.
- *The Administrative Division* supplies the Survey's programs with budgetary, financial, procurement, personnel, and other administrative services and manages the Survey's National Center in Reston, Virginia.
- *The Computer Center Division* operates a nationwide computing system and provides Survey scientists with a wide range of automatic data-processing services.
- *The Publications Division* edits the Survey's scientific and technical publications, as well as its nontechnical booklets; prepares geologic, hydrologic, and other thematic maps for printing; prints maps, distributes maps, books, and monographs; and answers inquiries from the public about the Survey's work and reports.

Although the Geological Survey Library is operated and funded for the most part by the Geologic Division, it is also described in this section because it provides service to the research activities of all Survey programs.

Program support activities are financed by direct appropriations ("General Administration" and "Facilities" budget activities, table 26), assessments on direct and reimbursable program funds of other budget activities (table 26), and reimbursements from other agencies ("Miscellaneous services to other accounts," table 26).

GENERAL ADMINISTRATION

General administrative expenses include the executive direction and coordination of Survey programs by the Director's Office and the provision of financial, procurement, personnel, and other administrative services by the Administrative Division.

During fiscal year 1977, general administrative expenses (table 43) amounted to $14.0 million. These expenses were funded from three sources: (1) the "General administration" budget activity, about $3.8 million; (2) assessments on the directly appropriated activities, $7.0 million; and (3) assessments on the reimbursable programs, $3.2 million. No assessments are made on cooperative funds from State and local governments. Despite the Geological Survey's larger budget, greater number of employees and increased use of grants and contracts, general administrative expenses continued to represent only about 3.2 percent of the total Survey budget and have increased less than one-half of one percent over the past 5 years.

AUTOMATED SYSTEMS

The Administrative Division has installed several new automated systems:

- *The Procurement Management Information System* maintains an inventory by fiscal year of all procurements processed in the Administrative Division's Procurement and Contract functions in both the Headquarters and Regional Offices. Video terminal data entry minimizes the clerical workload and increases the timeliness and accuracy of the data captured for the system. Reports on the number and dollar amount of these procurements are produced from the system to inform officials of procurement activities. Work is already underway to expand the system to provide additional reports and input to the new Departmental Procurement Information System.

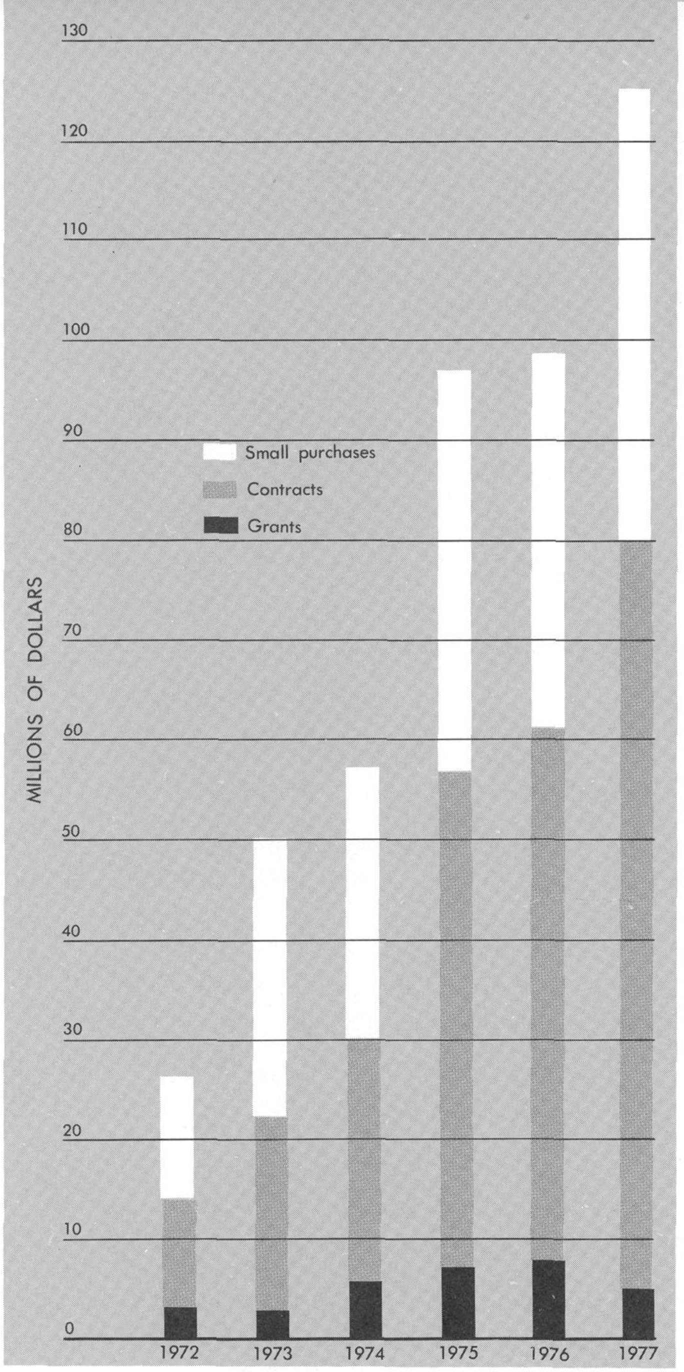


FIGURE 69.—Geological Survey expenditures on grants, contracts, and small purchases, fiscal years 1972–77. Does not include contracts for National Petroleum Reserve in Alaska.

- *The Property Management System* maintains and provides Headquarters and Regional Offices with accurate records on the identity, location, custody, cost, and disposition of all Survey-owned property. Daily data entry through a network of video terminals ensures a current and accurate informational data base from which internal and external reports are produced. Outputs from this system are distributed to the Divisions as well as to the Department of the Interior and General Services Administration. One advantage of this system is that microfilm and microfiche are now used instead of paper in the production of two master reports. That alone results in the elimination of 230,000 paper files.
- *The Financial Management System* processes payments, accounting, and payroll data through the use of remote computer terminals. This system has improved input quality and has reduced the time lag between receipt of bills and payments to vendors. An increased workload has been managed without corresponding increases in staff.

  A separate but related project is the conversion of computer-generated reports from hard copy to microfiche in order to streamline processing and to store financial records more efficiently. Ultimately, the majority of the one-half million documents handled annually will be on microfiche rather than paper.

PROCUREMENT AND CONTRACTING ACTIVITIES

Procurement and contracting activities continued to increase in volume and complexity (fig. 69). Procurements last year ranged from off-the-shelf scientific instruments to complex research and development and systems design, as well as a wide variety of professional and nonprofessional services.

In response to the increased level of Geological Survey procurements, two publications were issued: (1) "Writers Guide for Specifications, Work Statements, and Purchase Descriptions" and (2) "Small Purchase Training Guide."

A manual providing easy incorporation of standard provisions, clauses, and articles into the procurement documents for all types of Geological Survey contracts and solicitations, was drafted. The manual will have a detailed overview of each clause and article, describing its advantages, limitations, applications, and citing pertinent legislation and regulations.

COMPUTER TECHNOLOGY

Scientific research within the Geological Survey is supported by a nationwide system of computer facilities managed by the Computer Center Division.

The primary location of batch computing work is Reston, Virginia, and consists of two IBM 370/155 computers. Together, these computers provide high-speed magnetic core memory for 8 million characters of information and online magnetic disk storage for 8.9 billion characters of information. During fiscal year 1977, more than 1,100 users from 101 remote locations submitted approximately 370,000 jobs to these computers. Most of the terminals used to access the batch system are operated by the Program Divisions.

Three new large-scale time-sharing facilities were brought online during fiscal year 1977. Located in Denver, Colorado; Menlo Park, California; and Reston, Virginia, these new computing facilities utilize Honeywell Multics (Multiplexed Information and Computing Service) computers. Each Multics system provides high-speed magnetic core memory for 2 million characters of information, bulk-store memory (faster than disk) storage for 8 million characters of information, and 1.2 billion characters of disk storage. These facilities allow the scientist to access the computer from a typewriter-like terminal and work interactively with the computer for problem-solving.

Approximately 1,400 users are registered on one or more of the three systems and are currently averaging more than 20,000 interactive sessions per month.

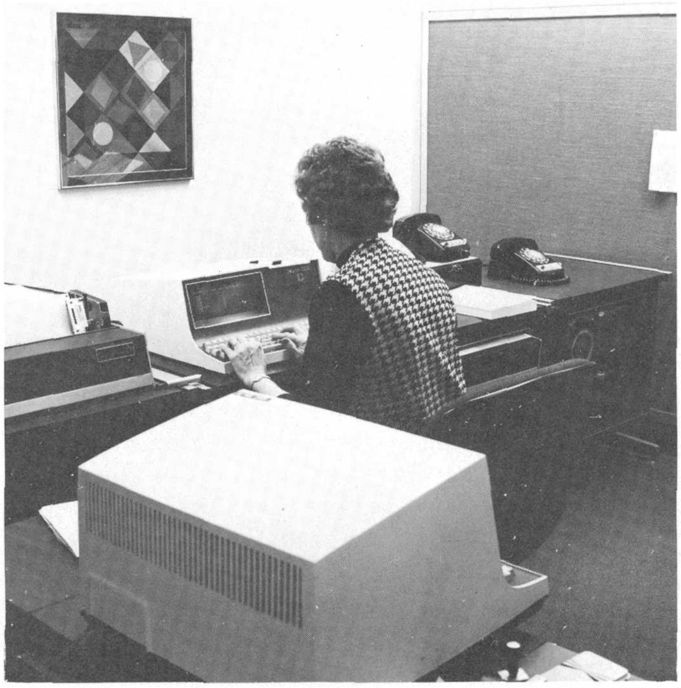
In addition, the Survey operates a number of other large computers:

- Burroughs Corporation Model B–6700 computer at the Earth Resources Observation Systems Data Center in Sioux Falls, South Dakota.
- Systems Engineering Laboratories, Inc., Model 86 computer at the Mid-Continent Mapping Center, Rolla, Missouri.
- Digital Equipment Corporation Model 11/20 and Model 11/45 computers at Flagstaff, Arizona.

The Geological Survey has obtained many mini-computers and mini-computer type devices to support local field and laboratory investigations. These computers are dedicated to a specific local requirement and operate in real time.

Some examples of computer applications in operations or under development during 1977 are listed:

- Development of geologic data bases dealing with mineral resources, energy resources, and geochemical analyses.
- Operation of a real-time seismic monitoring and earthquake detection network.
- Maintenance of the National Water Data Storage and Retrieval System including ground-water data.
- Simulation of surface-water and ground-water behavior in areas expected to be mined for coal and oil shale.
- Production of automated cartographic methods to prepare maps from spatial digital data.
- Use of Generalized Uncertainty Economic Simulation System (GUESS) for analysis of lease sale tracts.
- Tracking of Bureau of Land Management and Geological Survey activities leading to OCS lease sales as an aid to interbureau and interdivisional program coordination.



Automated Property Management System.

- Development of Property Management System to provide Headquarters and Regional Administrative Offices with a current inventory of USGS controlled property.
- Provision of custom enhancements to Landsat pictures with areas of special geologic interests.
- Development of program to optimize and enhance the inquiry, order, and account transaction processing system for EROS data.
- Development of a method of tracking oil spills from satellite-obtained data.

Highlights of computer support activities included:

- Installation of three Honeywell Multics timesharing computers at the Denver facility in November 1976, the Menlo Park facility in December 1976, and the Reston facility in January 1977.
- An intensive training program conducted at all three time-sharing facilities. Over 300 man-days of instructions in the use of the new time-sharing computers were provided by Honeywell and in-house instructors to Survey employees.
- Acquisition of TYMNET data communications service, a commercial service that provides low-cost access to the Honeywell computers from any location in the U.S.
- Establishment of procedures to allow outside user access to some of the information files maintained on Survey computers.

GEOLOGICAL SURVEY LIBRARY

The Geological Survey Library is one of the largest Earth-Science libraries in the world. The main library is located at the Survey's National Center in Reston, Virginia; branches are located at major research centers in Denver, Colorado; Menlo Park, California; and Flagstaff, Arizona. These libraries collectively contain more than 2 million items, including books, monographs, serial and periodical issues, pamphlets, single-sheet maps, photographs and negatives, aerial photographs, microforms, well logs, field record notebooks, and related materials. Although these holdings are intended primarily to support the research activities of the Geological Survey, the library also serves other Government agencies, State geological surveys, academic institutions, and research organizations throughout the country.

Computerized search service has been extended to the Denver and Menlo Park libraries, both of which now are equipped and staffed to handle search requests from Geological Survey personnel. Negotiations are underway to access other geoscience-oriented data bases, including *GeoArchives*, produced in England. Computerized files such as *Geo-Ref*, *Geo-Archives*, and *Tulsa* provide the Survey's reference librarians with superior bibliographic tools for more efficient exploitation of the library's wealth of primary source literature.

The Reston library is investigationg current techniques used to produce computer-generated book catalogs. An appropriate software program used in conjunction with the magnetic tape record of the library's cataloging output will enable the library staff to discontinue the manual processing and editing of catalog cards. It is expected that the fourth supplement to the *Catalog of the U.S. Geological Survey Library* will be a computer-generated product.

A manual has been written for cataloging maps by means of the Ohio College Library Center (OCLC) on-line system. Library catalogers are now devising guidelines that will satisfy the Survey library's requirements for map cataloging while being compatible with the OCLC procedures set forth in the manual. Present planning continues to emphasize cooperative cataloging by those repositories with significant holdings of Earth-Science maps.

The demand for library services continued unabated, highlighted by the large number of requests received from both Survey and non-Survey users for energy, environmental, and mineral resources information. Statistics on library acquisition, circulation, and lending/borrowing activities will be found in table 54.

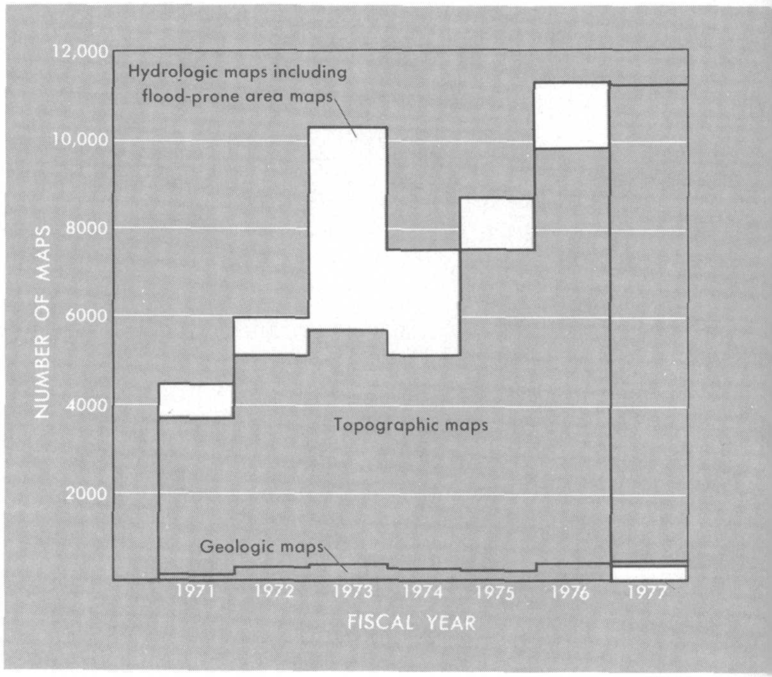
PUBLICATIONS PROGRAM

Results of research and investigations conducted by the Geological Survey are made available to the public through increasingly diverse information services and publications.

The number of reports approved for publication by the Geological Survey continues to increase. About 60 percent of the 3,737 reports prepared in fiscal year 1977 were designated for publication in professional journals and monographs outside the Survey; about 23 percent were placed in open file; and the remainder were scheduled for publication by the Survey (table 45). The Survey also produced over 11,300 topographic, hydrologic, and geologic maps in fiscal year 1977 (fig. 70 and table 46).

The Publications Division edits the Survey's scientific and technical publications (including professional papers, bulletins, water-supply papers, and circulars) which are printed by or through the Government Printing Office. The Division also prepares nontechnical booklets designed to communicate many of the Survey programs to the public in a clear and understandable manner. In addition to providing reproduction manuscripts for geologic, hydrologic, and other thematic maps, the Division prints and distributes all Survey maps. The majority of maps are reproduced in the Survey's modern printing plant in Reston, Virginia, although in recent years a substantial number of maps have been printed by commer-

FIGURE 70.—Number of maps produced, fiscal years 1970–77.



cial firms under contract. The Eastern Distribution Center and all nine Public Inquires Offices distribute books to the public as agents of the Superintendent of Documents. The Public Inquiries Offices also provide a "grass roots" communication network to the public by answering a broad range of inquiries dealing with the Survey's work and reports.

Highlights of the Publications Division's program in fiscal year 1977 included:

- Printing of 23.5 million copies of 7,719 different maps.
- Distribution of 8.7 million copies of maps of which 5.7 million copies were sold for $5.0 million.
- Transmittal of 183 technical manuscripts to the Government Printing Office for printing.
- Distribution of 326,659 copies of technical reports of which 64,518 copies were sold for $174,603.

Guide to Publications

Throughout this report, reference has been made to information services and publications of the Geological Survey. This section describes how and where the public may acquire information and obtain products.

To buy Survey book publications; to buy maps of areas east of the Mississippi; or to request Survey circulars, catalogs, pamphlets, and leaflets (limited quantities free), write or visit:

U.S. Geological Survey
Branch of Distribution
1200 S. Eads Street
Arlington, Virginia 22202

Include check payable to U.S. Geological Survey.

To buy maps of areas west of the Mississippi; or to request Survey catalogs, pamphlets, and leaflets (limited quantities free), write or visit:

U.S. Geological Survey
Branch of Disrtibution
Box 25286, Bldg. 41, Federal Center
Denver, Colorado 80225

Include check payable to U.S. Geological Survey.

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

U.S. Geological Survey
Distribution Section
310 First Avenue
Fairbanks, Alaska 99701

Include check payable to U.S. Geological Survey.

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

U.S. Geological Survey
Mailing List Unit, 329 National Center
12201 Sunrise Valley Drive
Reston, Virginia 22092

To start a subscription to the "Journal of Research of the U.S. Geological Survey," the "Earthquake Information Bulletin," or the "Preliminary Determination of Epicenters," write:

Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

"Journal of Research": $18.90 per year (plus $4.75 for foreign mailing)

"Earthquake Information Bulletin": $3.00 per year (plus 75¢ for foreign mailing)

"Preliminary Determination of Epicenters": $4.35 per year (plus $1.10 for foreign mailing)

Include check payable to Superintendent of Documents.

To buy books and maps of local areas and general interest, visit the Public Inquiries Office in the following states:

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

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

504 Customhouse, 555 Battery Street
San Francisco, California 94111

Colorado:
1012 Federal Bldg., 1961 Stout Street
Denver, Colorado 80294

Texas:
1-C-45, Federal Bldg., 1100 Commerce St.
Dallas, Texas 75242

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

Virginia:
1-C-402, National Center, 12201 Sunrise Valley Drive
Reston, Virginia 22092

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

Washington, D.C.:
1028 General Services Bldg., 19th and F Streets, NW
Washington, D.C. 20244

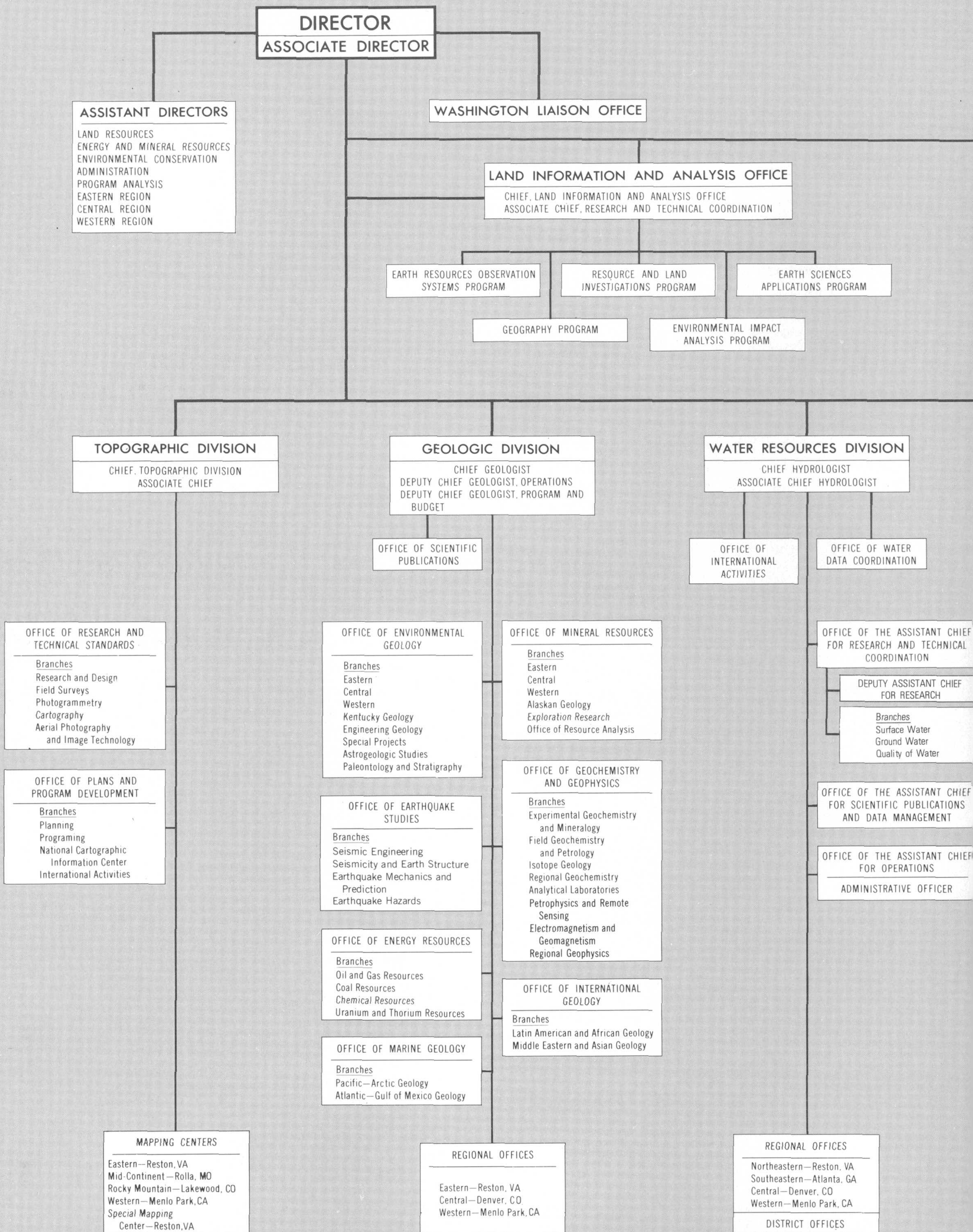
To obtain information on cartographic data, write of visit:

U.S. Geological Survey
National Cartographic Information Center
507 National Center
12201 Sunrise Valley Drive
Reston, Virginia 22092

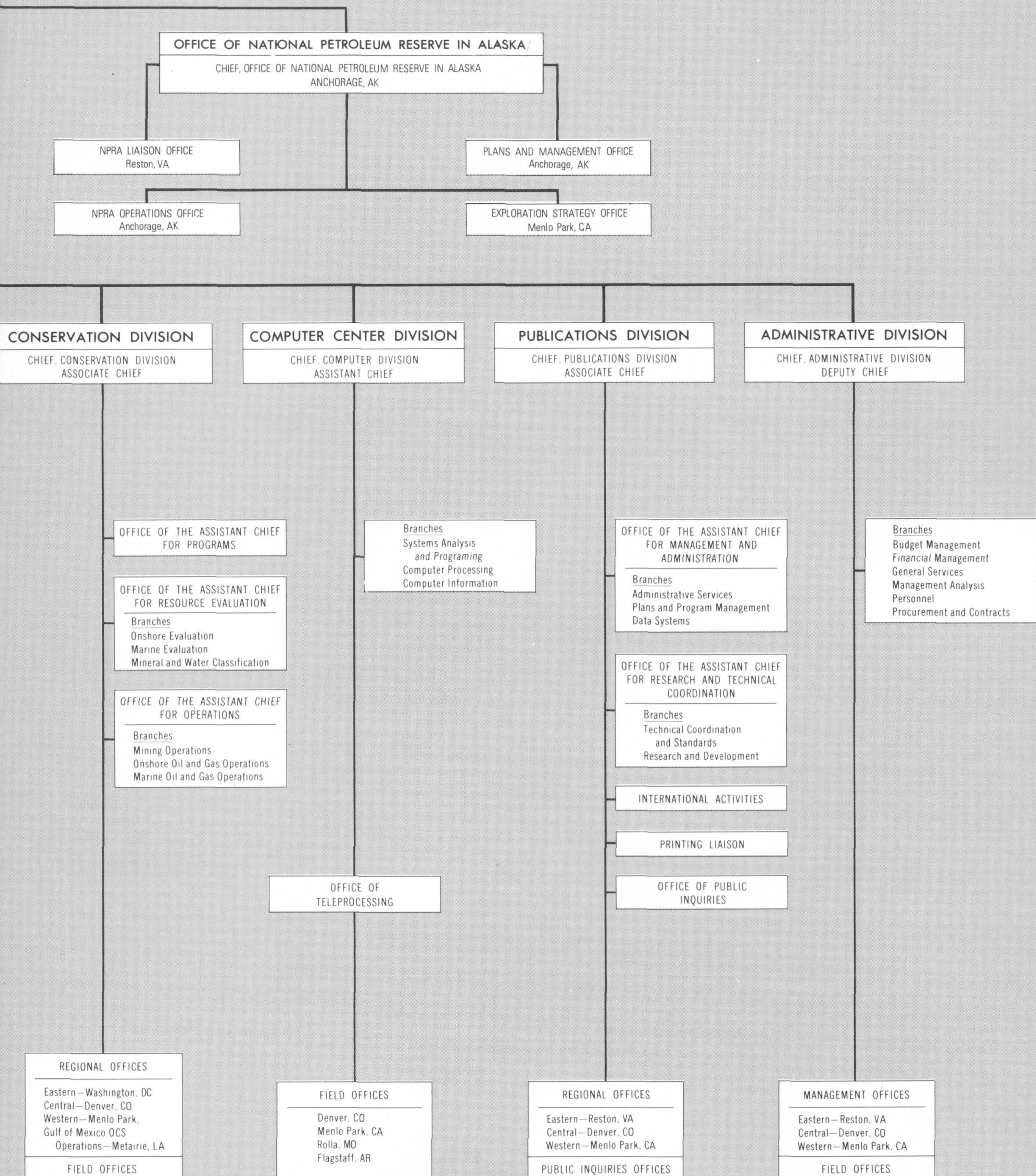
To obtain information on satellite and space photography, write or visit:

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

U.S. Geological Survey Chart of Organization



Organizational and Statistical Data



U.S. Geological Survey Offices

HEADQUARTERS OFFICES

12201 Sunrise Valley Drive
National Center, Reston, VA 22092

OFFICE OF THE DIRECTOR

Official	Name	Telephone number	Address
Director	V. E. McKelvey	(703) 860–7411	National Center, STOP 101
Associate Director	W. A. Radlinski	(703 860–7412	National Center, STOP 102
Washington Liaison Officer	George W. Whetstone	(202) 343–3888	National Center, STOP 103 Rm. 7343, Interior Bldg., Washington, DC 20240
Assistant Director—Land Resources	James R. Balsley	(703) 860–7488	National Center, STOP 104
Assistant Director—Energy and Mineral Resources	Montis R. Klepper	(703) 860–7481	National Center, STOP 171
Assistant Director—Environmental Conservation	Henry W. Coulter	(703) 860–7491	National Center, STOP 106
Assistant Director—Administration	Edmund J. Grant	(703) 860–7201	National Center, STOP 201
Assistant Director—Program Analysis	Dale D. Bajema	(703) 860–7435	National Center, STOP 105
Assistant Director—Eastern Region	William B. Overstreet	(703) 860–7414	National Center, STOP 109
Assistant Director—Central Region	Robert E. Evans	(303) 234–4630	Denver Federal Center, Box 25046, STOP 101, Denver, CO 80225
Assistant Director—Western Region	George E. Robinson, Acting	(415) 323–8111	345 Middlefield Rd., Menlo Park, CA 94025
Information Officer	Frank H. Forrester	(703) 860–7444	National Center, STOP 119

TOPOGRAPHIC DIVISION

Official	Name	Telephone number	Address
Chief	Rupert B. Southard, Acting	(703) 860–6231	National Center, STOP 516
Associate Chief	Rupert B. Southard	(703) 860–6232	National Center, STOP 516
Office of Research and Technical Standards, Chief	Roy R. Mullen	(703) 860–6291	National Center, STOP 519
Office of Plans and Program Development, Chief	Doyle G. Frederick	(703) 860–6281	National Center, STOP 514
National Cartographic Information Center, Chief	Gary W. North, Jr.	(703) 860–6187	National Center, STOP 507
Special Mapping Center, Chief	Roy E. Fordham	(703) 860–7760	National Center, STOP 560, 1925 Newton Square East, Reston, VA 22090

GEOLOGIC DIVISION

Official	Name	Telephone number	Address
Chief Geologist	Dallas L. Peck	(703) 860–6531	National Center, STOP 910
Deputy Chief Geologist, Operations	Robert E. Davis	(703) 860–6532	National Center, STOP 910
Deputy Chief Geologist, Program and Budget	Donald H. Dow	(703) 860–6544	National Center, STOP 910
Office of Scientific Publications, Chief	Walter P. Ketterer, Acting	(703) 860–6575	National Center, STOP 904
Office of Environmental Geology, Chief	John C. Reed, Jr.	(703) 860–6411	National Center, STOP 908
Office of Earthquake Studies, Chief	Robert M. Hamilton	(703) 860–6471	National Center, STOP 905
Office of Energy Resources, Chief	Charles Masters	(703) 860–6431	National Center, STOP 915
Office of Marine Geology, Chief	Charles Masters, Acting	(703) 860–6431	National Center, STOP 915
Office of Mineral Resources, Chief	George E. Becraft	(703) 860–6562	National Center, STOP 913
Office of Geochemistry and Geophysics, Chief	Robert 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	Joseph S. Cragwall, Jr.	(703) 860–6921	National Center, STOP 409
Associate Chief Hydrologist	O. Milton Hackett	(703) 860–6921	National Center, STOP 408
Assistant Chief Hydrologist, Scientific Publications and Data Management	Solomon M. Lang, Acting	(703) 860–6877	National Center, STOP 440
Assistant Chief Hydrologist, Operations	Thomas J. Buchanan	(703) 860–6801	National Center, STOP 441

WATER RESOURCES DIVISION—Continued

Official	Name	Telephone number	Address
Assistant Chief Hydrologist, Research and Technical Coordination	John D. Bredehoeft, Acting	(703) 860-6971	National Center, STOP 414
Office of Water Data Coordination, Chief	R. H. Langford	(703) 860-6931	National Center, STOP 417
Office of International Activities, Chief	James R. Jones	(703) 860-6548	National Center, STOP 470

CONSERVATION DIVISION

Official	Name	Telephone number	Address
Chief	Russell G. Wayland, Acting	(703) 860-7524	National Center, STOP 600
Associate Chief	Vacant	(703) 860-7524	National Center, STOP 600
Assistant Chief, Resources Evaluation	Robert L. Rioux	(703) 860-7571	National Center, STOP 640
Assistant Chief, Operations	John Duletsky	(703) 860-7515	National Center, STOP 620
Assistant Chief, Programs	Harold L. Pumphrey	(703) 860-7581	National Center, STOP 630

LAND INFORMATION AND ANALYSIS OFFICE

Official	Name	Telephone number	Address
Chief	James R. Balsley	(703) 860-7488	National Center, STOP 104
Associate Chief, Research and Technical Coordination	Philip Cohen	(703) 860-7471	National Center, STOP 703
Earth Resources Observation Systems Program, Chief	John M. DeNoyer	(703) 860-7881	National Center, STOP 730
Geography Program, Chief	James R. Anderson	(703) 860-6344	National Center, STOP 710
Resource and Land Investigations Program, Chief	J. Ronald Jones	(703) 860-6717	National Center, STOP 750
Environmental Impact Analysis Program, Chief	Daniel B. Krinsley	(703) 860-7455	National Center, STOP 760
Earth Sciences Applications Program, Chief	Donald R. Nichols	(703) 860-6961	National Center, STOP 720

OFFICE OF NATIONAL PETROLEUM RESERVE IN ALASKA

Official	Name	Telephone number	Address
Chief	George Gryc	(907) 276-7422	*2525 'C' Street - Suite 400 Anchorage, AK 99503
Liaison Officer	Valentine Zadnik	(703) 860-6208	National Center, STOP 151

COMPUTER CENTER DIVISION

Official	Name	Telephone number	Address
Chief	Carl E. Diesen	(703) 860-7106	National Center, STOP 801
Assistant Chief	Charles H. Tyler	(703) 860-7109	National Center, STOP 801
Office of Teleprocessing	Ralph N. Eicher	(703) 860-7119	National Center, STOP 805

PUBLICATIONS DIVISION

Official	Name	Telephone number	Address
Chief	Harry D. Wilson, Jr.	(703) 860-7181	National Center, STOP 341
Associate Chief	Melvin E. Hanes	(703) 860-7181	National Center, STOP 341
Assistant Chief, Management and Administration	Van M. Rayburn	(703) 860-7181	National Center, STOP 341
Assistant Chief, Research and Technical Coordination	Bernard J. Thien	(703) 860-7183	National Center, STOP 341
Office of Public Inquiries	Robbie S. Ritchey	(703) 860-7185	National Center, STOP 341
Printing Liaison Officer	Jesse R. Upperco	(703) 860-7622	National Center, STOP 330
International Activities	A. L. Dilonardo	(703) 860-7186	National Center, STOP 341

ADMINISTRATIVE DIVISION

Official	Name	Telephone number	Address
Chief	Edmund J. Grant	(703) 860-7201	National Center, STOP 201
Deputy Chief	Lewis Menen	(703) 860-7203	National Center, STOP 202
Personnel Officer	Maxine C. Millard	(703) 860-6127	National Center, STOP 215
Contracts Officer	William Burk	(703) 860-7261	National Center, STOP 205

* Office of National Petroleum Reserve in Alaska is headquartered in Anchorage, Alaska.

SELECTED FIELD OFFICES

TOPOGRAPHIC DIVISION

REGIONAL MAPPING CENTERS

Mapping Center	Chief	Telephone number	Address
Eastern	Peter F. Bermel	(703) 860–6352	National Center, STOP 567
Midcontinent	Lawrence H. Borgerding	(314) 364–3680 ext. 111	1400 Independence Rd., Rolla, MO 65401
Rocky Mountain	Albert E. Letey	(303) 234–2351	Box 25046, STOP 510, Denver Federal Center, Denver, CO 80225
Western	John R. Swinnerton	(415) 323–8111, ext. 2411	345 Middlefield Rd., Menlo Park, CA 94025

GEOLOGIC DIVISION

REGIONAL OFFICES

Region	Regional Geologist	Telephone number	Address
Eastern	Eugene H. Roseboom, Jr.	(703) 860–6631	National Center, STOP 953
Central	William R. Keefer	(303) 234–3625	Box 25046, STOP 911, Denver Federal Center Denver, CO 80225
Western	Joseph I. Ziony	(415) 323–8111	345 Middlefield Rd., Menlo Park, CA 94025

WATER RESOURCES DIVISION

REGIONAL OFFICES

Region	Regional Hydrologist	Telephone number	Address
Northeastern	Francis T. Schaefer, Acting	(703) 860–6985	National Center, STOP 433
Southeastern	Leslie B. Laird	(404) 881–4395	1459 Peachtree St. NE., Suite 200, Atlanta, GA 30392
Central	Alfred Clebsch, Jr.	(303) 234–3661	Box 25046, STOP 406, Denver Federal Center, Denver, CO 80225
Western	William H. Robinson	(415) 323–8111 ext. 2337	345 Middlefield Rd., Menlo Park, CA 94025

DISTRICT OFFICES

State	District Chief	Telephone number	Address
Alabama	William J. Powell	(205) 752–8104	P.O. Box V, 202 Oil and Gas Board Bldg. University of Alabama University, AL 35486
Alaska	Harry Hulsing	(907) 277–5526	218 E St. Anchorage, AK 99501
Arizona	Robert D. MacNish	(602) 792–6671	Federal Bldg. 301 W. Congress St. Tucson, AZ 85701
Arkansas	Richard T. Sniegocki	(501) 378–5246	2301 Federal Office Bldg. 700 W. Capital Ave. Little Rock, AR 72201
California	Lee R. Peterson	(415) 323–8111 ext. 2326	855 Oak Grove Ave. Menlo Park, CA 94025
Colorado	James E. Biesecker	(303) 234–5092	Box 25046, STOP 415 Denver Federal Center Denver, CO 80225
Connecticut	David McCartney	(203) 244–2528	135 High St. Room 235 Hartford, CT 06103

State	District Chief	Telephone number	Address
Delaware	Walter F. White, Jr.	(301) 828–1535	See Maryland District Office
District of Columbia	Walter F. White, Jr.	(301) 828–1535	See Maryland District Office
Florida	Clyde S. Conover	(904) 386–1118	325 John Knox Rd., Suite F-240 Tallahassee, FL 32303
Georgia	John R. George	(404) 221–4858	6481 Peachtree Industrial Blvd., Suite B Doraville, GA 30360
Hawaii	Benjamin L. Jones	(808) 546–8331	P.O. Box 50166 300 Ala Moana Blvd. Honolulu, HI 96850
Idaho	Edwin E. Harris	(208) 384–1750	Box 036 Federal Bldg. Room 365 550 W. Fort St. Boise, ID 83724
Illinois	Lawrence A. Martens	(217) 359–3918	P.O. Box 1026 605 N. Neil St. Champaign, IL 61820
Indiana	Dennis K. Stewart	(317) 269–7101	1819 N. Meridian St. Indianapolis, IN 46202
Iowa	Sulo W. Wiitala	(319) 338–0581 ext. 521	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	Philip A. Emery	(502) 582–5241	572 Federal Bldg. 600 Federal Pl. Louisville, KY 40202
Louisiana	Albert N. Cameron	(504) 389–0281	P.O. Box 66492 6554 Florida Blvd. Baton Rouge, LA 70896
Maine	John A. Baker	(617) 223–2822	See Massachusetts District Office
Maryland	Walter F. White, Jr.	(301) 828–1535	208 Carroll Bldg. 8600 La Salle Rd. Towson, MD 21204
Massachusetts	John A. Baker	(617) 223–2822	150 Causeway St. Suite 1001 Boston, MA 02114
Michigan	T. Ray Cummings	(517) 372–1910 ext. 561	2400 Science Parkway Red Cedar Research Park Okemos, MI 48864
Minnesota	Donald R. Albin	(612) 725–7841	1033 Post Office Bldg. St. Paul, MN 55101
Mississippi	Lamar E. Carroon	(601) 969–4600	430 Bounds St. Jackson, MS 39206
Missouri	Donald L. Coffin	(314) 364–3680 ext. 185	1400 Independence Rd. M.S. 200 Rolla, MO 65401
Montana	George M. Pike	(406) 449–5263	P.O. Box 1696 421 Federal Bldg. Helena, MT 59601
Nebraska	Kenneth A. Mac Kichen	(402) 471–5082	406 Federal Bldg. and U.S. Courthouse 100 Centennial Mall North Lincoln, NE 68508
Nevada	Frank T. Hidaka	(702) 882–1388	227 Federal Bldg. 705 N. Plaza St. Carson City, NV 89701
New Hampshire	John A. Baker	(617) 223–2822	See Massachusetts District Office
New Jersey	Harold Meisler	(609) 989–2162	P.O. Box 1238 420 Federal Bldg. 402 E. State St. Trenton, NJ 08607

WATER RESOURCES DIVISION / DISTRICT OFFICES—Continued

State	District Chief	Telephone number	Address
New Mexico	William E. Hale	(505) 766–2246	P. O. Box 26659 Western Bank Bldg. Room 809 505 Marquette N.W. Albuquerque, NM 87125
New York	Robert J. Dingman	(518) 472–3107	P. O. Box 1350 343 U. S. Post Office and Courthouse Bldg. Albany, NY 12201
North Carolina	Ralph C. Heath	(919) 755–4510	P. O. Box 2857 Room 432 Century Postal Station Raleigh, NC 27602
North Dakota	Walter R. Scott	(701) 255–4011 ext. 227	P. O. Box 778 Room 332 New Federal Bldg. 3d St. and Rosser Ave. Bismarck, ND 58501
Ohio	David E. Click	(614) 469–5553	975 West Third Ave. Columbus, OH 43212
Oklahoma	James H. Irwin	(405) 231–4256	201 N.W. 3d St., Rm. 621 Oklahoma City, OK 73102
Oregon	Stanley F. Kapustka	(503) 234–3361 ext. 4776	P.O. Box 3202 830 N.E. Holladay St. Portland, OR 97232
Pennsylvania	Norman H. Beamer	(717) 782–3466	P.O. Box 1107, 4th Floor, Federal Bldg. 228 Walnut St. Harrisburg, PA 17108
Puerto Rico	Ernest D. Cobb	(809) 783–4660	P. O. Box 34168, Bldg. 652 Ft. Buchanan, PR 00934
Rhode Island	John A. Baker	(617) 223–2822	See Massachusetts District Office
South Carolina	John S. Stallings	(803) 765–5966	2001 Assembly St. Suite 200 Columbia, SC 29201
South Dakota	John E. Powell	(605) 352–8651 ext. 258	P. O. Box 1412 200-4th St. S.W. Room 308 Huron, SD 57350
Tennessee	Stanley P. Sauer	(615) 251–5424	A-413 Federal Bldg. U.S. Courthouse Nashville, TN 37203
Texas	I. Dale Yost	(512) 397–5766	649 Federal Bldg. 300 E. 8th St. Austin, TX 78701
Utah	Theodore Arnow	(801) 524–5663	8002 Federal Bldg. 125 S. State St. Salt Lake City, UT 84138
Vermont	John A. Baker	(617) 223–2822	See Massachusetts District Office
Virginia	William E. Forrest	(804) 782–2427	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, WV 25301
Wisconsin	William W. Barnwell	(608) 262–2488	1815 University Ave. Room 200 Madison, WI 53706
Wyoming	Samuel W. West	(307) 778–2220 ext. 2153	P. O. Box 1125 2120 Capitol Ave. Room 5017 Cheyenne, WY 82001

CONSERVATION DIVISION

REGIONAL OFFICES

Region	Conservation Manager	Telephone number	Address
Eastern	George Brown	(202) 254–3137	1725 K St., NW., Suite 204 Washington, DC 20006
Central	George H. Horn	(303) 234–2855	Box 25046, STOP 609, Denver, Federal Center, Denver, CO 80225
Gulf of Mexico Outer Continental Shelf Operations	A. Dewey Acuff	(504) 837–4720, ext. 9381	P.O. Box 7944, 434 Imperial Office Bldg., 3301 N. Causeway Blvd., Metairie, LA 70010
Western	Hillary A. Oden	(415) 323–8111, ext. 2093	345 Middlefield Rd., Menlo Park, CA 94025

LAND INFORMATION AND ANALYSIS OFFICE

EARTH RESOURCES OBSERVATION SYSTEMS DATA CENTER

Location	Official in charge	Telephone number	Address
South Dakota	Allen H. Watkins	(605) 594–6123	EROS Data Center, Sioux Falls, SD 57198

NATIONAL PETROLEUM RESERVE IN ALASKA

DISTRICT OFFICES

Office	Chief	Telephone number	Address
NPRA Operations Office	Max Brewer	(907) 276–7422	2525 'C' Street - Suite 400 Anchorage, AK 99503
Plans and Management Office	Earle Ausman	(907) 276–7422	2525 'C' Street - Suite 400 Anchorage, AK 99503
Exploration Strategy Office	Irvin Tailleur, Acting	(415) 323–2915	345 Middlefield Rd., Menlo Park, CA 94025

PUBLICATIONS DIVISION

REGIONAL OFFICES

Region	Official in charge	Telephone number	Address
Eastern	Lewis D. Brown	(703) 860–6761	National Center, STOP 328
Central	John L. Heller	(303) 234–4974	Box 25046, STOP 303, Denver Federal Center, Denver, CO 80225
Western	Fred Kunkel	(415) 323–8111, ext. 2537	345 Middlefield Rd., Menlo Park, CA 94025

PUBLIC INQUIRIES OFFICES

Location	Official in charge	Telephone number	Address
Alaska	Margaret I. Erwin	(907) 277–0577	108 Skyline Bldg., 508 2d Ave., Anchorage, AK 99501
California:			
Los Angeles	Lucy E. Birdsall	(213) 688–2850	7638 Federal Bldg., 300 N. Los Angeles St., Los Angeles, CA 90012
San Francisco	Jean V. Molleskog	(415) 556–5627	504 Custom House, 555 Battery St., San Francisco, CA 94411

PUBLIC INQUIRIES OFFICES—Continued

Location	Official in charge	Telephone number	Address
Colorado	Alice M. Coleman	(303) 837–4169	1012 Federal 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	Jimmie L. Wilkinson	(214) 749–3230	1C45 Federal Bldg., 1100 Commerce St., Dallas, TX 75242
Utah	Wendy R. Hassibe	(801) 524–5652	8105 Federal Bldg., 125 S. State St., Salt Lake City, UT 84138
Virginia	A. Ernestine Jones	(703) 860–6167	1C402 National Center, STOP 302, 12201 Sunrise Valley Dr., Reston, VA 22092
Washington	Eula M. Thune	(509) 456–2524	678 U.S. Courthouse, W. 920 Riverside Ave., Spokane, WA 99201

BRANCH OF DISTRIBUTION OFFICES

Location	Official in charge	Telephone number	Address
Alaska	Natalie Cornforth	(907) 452–1951	310 First Ave., Fairbanks, AK 99701
Colorado	Dwight F. Canfield	(303) 234–3832	Box 25286, STOP 306, Denver Federal Center, Denver, CO 80225
Virginia	George V. DeMeglio	(703) 557–2781	1200 S. Eads St., Arlington, VA 22202

ADMINISTRATIVE DIVISION

REGIONAL MANAGEMENT OFFICES

Region	Regional Management Officer	Telephone number	Address
Eastern	Roy Heinbuch	(703) 860–7691	National Center, STOP 290
Central	Thomas J. Lyons	(303) 234–3736	Box 25046, STOP 202, Denver Federal Center, Denver, CO 80225
Western	Avery W. Rogers	(415) 323–2211	345 Middlefield Rd., Menlo Park, CA 94025

COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for financial cooperation in fiscal year 1977, cosigned by responsible officials of the Geological Survey and the cooperating agency. Agencies with whom the Geological Survey had research contracts and to whom it supplied funds for such research are not listed. Parent agencies are listed separately from their subdivisions where separate cooperative agreements for different projects were made with the parent agency and with a subdivision of the parent agency.]

FEDERAL COOPERATORS

Department of the Army:
- Corps of Engineers
- Jefferson Proving Ground
- Rocky Mountain Arsenal
- White Sands Missile Range

Department of Commerce:
- Bureau of the Census
- Coastal Plains Regional Commission
- Economic Development Administration
- National Bureau of Standards
- National Oceanic and Atmospheric Administration
  - Environmental Research Laboratories
  - National Ocean Survey
  - National Weather Service

Civil Service Commission

Council on Environmental Quality

Department of Agriculture:
- Agricultural Research Service
- Forest Service
- Soil Conservation Service
- Statistical Reporting Service

Department of the Air Force:
- AFWL/PRP Kirtland AFB
- Air Force Academy
- Headquarters (AFTAC/AC)
- Pease Air Force Base
- Vandenburg Air Force Base

Department of Defense:
- Advanced Research Projects Agency
- Civil Preparedness Agency
- Defense Mapping Agency
- Defense Nuclear Agency
- U.S. Arms Control and Disarmament Agency

Department of Housing and Urban Development

Department of the Interior:
- Alaska Power Administration
- Bonneville Power Administration
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Reclamation
- Fish and Wildlife Service
- National Park Service
- Office of Library and Information Services
- Office of the Secretary
- Water Resources Council

Department of the Navy:
- Civil Engineering Laboratory, Naval Construction Battalion Center
- Marine Corps, Camp Pendleton
- Naval Facilities Engineering Command
- Naval Oceanographic Office
- Naval Petroleum and Oil Shale Reserves
- Naval Weapons Center, China Lake
- Public Works Center

Department of State:
- Agency for International Development
- Bureau of Intelligence and Research
- International Boundary and Water Commission

Department of Transportation:
- Federal Highway Administration
- Office of the Secretary
- St. Lawrence Seaway Development Corporation

Department of the Treasury:
- U.S. Customs Service

Department of Energy:
- Albuquerque Operations Office
- Argonne National Laboratories
- Chicago Operations Office
- Division of Geothermal Energy
- Division of Oil, Gas, and Shale
- Division of Petroleum, Natural Gas, and In-situ Technology
- Fossil Energy
- Grand Junction Office
- Idaho Operations Office
- Laramie Energy Research Center
- Los Alamos Science Laboratory
- Morgantown Energy Research Center
- Nevada Operations Office
- Oak Ridge Operations Office
- Office of International Program Support
- Richland Operations Office
- San Francisco Operations Office
- Savannah River Operations Office

Environmental Protection Agency:
- Cincinnati Research Center
- Corvallis Environmental Research Laboratory
- Enforcement Division
- Office of Energy, Minerals, and Industry
- Office of Radiation Programs
- Office of Research and Development
- Office of Water Programs
- St. Anthony Falls Hydraulic Laboratory
- Upper Mississippi River Basin Commission

Federal Power Commission

General Services Administration

National Aeronautics and Space Administration

National Science Foundation

Navajo-Hopi Relocation Commission

Northeast River Basin Commission

Nuclear Regulatory Commission

Ohio River Basin Commission

Tennessee Valley Authority

STATE, COUNTY, AND LOCAL COOPERATORS

Alabama:
- Alabama Highway Department
- Commission of Jefferson County
- Geological Survey of Alabama

Alaska:
- Alaska Department of Fish and Game
- Alaska Department of Highways
- Alaska Department of Natural Resources
- Alaska Geological and Geophysical Survey
- Alaska Pipeline Coordination Office
- City of Anchorage
- City of Seward
- Department of Environmental Conservation
- Fairbanks North Star Borough
- Kenai Borough

Arizona:
- Arizona Game and Fish Department
- Arizona Highway Department
- Arizona Water Commission
- City of Flagstaff
- City of Safford
- City of Tucson
- Department of Health Services
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Maricopa County Municipal Water Conservation District No. 1
- Pima County Board of Supervisors
- Salt River Valley Water User's Association
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Company
- University of Arizona

Arkansas:
- Arkansas Department of Pollution Control and Ecology
- Arkansas Division of Soil and Water Resources
- Arkansas Geological Commission
- Arkansas State Highway Commission

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Antelope Valley-East Kern Water
- Association of Monterey Bay Area Governments
- California Department of Conservation, Division of Mines and Geology
- California Department of Transportation
- California Department of Water Resources
- California Water Resources Control Board
- Carpenteria County Water District
- Casitas Municipal Water District
- City and County of San Francisco, Hetch Hetchy Water and Power
- City of Lompoc
- City of Merced
- City of Modesto, Public Works Department
- City of San Diego
- City of San Rafael
- City of Santa Barbara, Public Works Department
- Coachella Valley County Water District
- Contra Costa County Flood Control and Water Conservation District
- County of Madera, Flood Control and Water Conservation Agency
- County of Modoc, Public Works Department
- County of San Diego, Department of Sanitation and Flood Control
- County of San Mateo, Engineer and Road Commissioner
- Desert Water Agency

California—Continued
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Goleta County Water District
- Humboldt County, Department of Public Works
- Imperial County Department of Public Works
- Imperial Irrigation District
- Indian Wells Valley County Water District
- Kern County Water Agency
- Lake County Flood Control and Water Conservation District
- Livermore Amador Valley Water Management Agency
- Los Angeles County Flood Control District
- Los Angeles Department of Water and Power
- Madera Irrigation District
- Marin County Department of Public Works
- Marin Municipal Water District
- Merced Irrigation District
- Metropolitan Water District of Southern California
- Mojave Water Agency
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Napa County Flood Control and Water Conservation District
- North Marin County Water District
- Orange County Environmental Management Agency
- Orange County Water District
- Oroville-Wyandotte Irrigation District
- Pacheco Pass Water District
- Paradise Irrigation District
- Riverside County Flood Control and Water Conservation District
- Sacramento County Department of Public Works
- San Benito County Water Conservation and Flood Control District
- San Bernardino County Flood Control District
- San Bernardino Valley Municipal Water District
- San Francisco Water Department
- San Luis Obispo County:
  - Engineering Department
- Santa Barbara County Water Agency
- Santa Clara Valley Water District
- Santa Cruz County Flood Control and Water Conservation District
- Santa Margarita and San Luis Rey Watershed Planning Agencies
- Santa Maria Valley Water Conservation District
- Santa Ynez River Water Conservation District
- Siskiyou County Flood Control and Water Conservation District
- Solano Irrigation District
- Terra Bella Irrigation District
- Tulare County Flood Control District
- Turlock Irrigation District
- United Water Conservation District
- University of California:
  - Division of Environmental Studies (Davis)
  - School of Forestry and Conservation
- Ventura County Flood Control District, Riverside County
- Western Municipal Water District
- Woodbridge Irrigation District
- Yolo County Flood Control and Water Conservation District

Colorado:
- Arkansas River Compact Administration
- Boulder City-County Department of Health
- City and County of Denver, Board of Water Commissioners
- City of Aspen
- City of Aurora, Department of Public Utilities
- City of Colorado Springs:
  - Department of Public Utilities
  - Office of the City Manager
- City of Fort Collins

Colorado–Continued
- City of Pueblo
- Colorado City Water and Sanitation District
- Colorado Department of Local Affairs
- Colorado Department of Natural Resources:
  - Division of Water Resources
  - Division of Wildlife
  - Geological Survey
- Colorado Department of Public Health, Water Pollution Control Commission
- Colorado River Water Conservation District
- Colorado State University, Department of Earth Resources
- Colorado Water Conservation Board
- County of Jefferson
- Denver Regional Council of Governments
- Eagle County Commissioners
- El Paso County:
  - Board of Commissioners
  - Water Association
- Jefferson County Health Department
- Kiowa-Bijou Groundwater Management District
- Metro Denver Sewage Disposal District No. 1
- North West Colorado Council of Governments
- Park County Board of County Commissioners
- Pikes Peak Area Council of Governments
- Pitkin County Board of County Commissioners
- Pueblo Area Council of Governments
- Rio Grande Water Conservation District
- Routt County Health Department
- Southeastern Colorado Water Conservancy District
- Southern Ute Indian Tribe
- Southwestern Water Conservation District
- State of Colorado, Department of Highways
- Urban Drainage and Flood Control District

Connecticut:
- City of Hartford, Department of Public Works
- City of Torrington
- Department of Environmental Protection
- Town of Fairfield
- Town of Farmington
- Town of Manchester
- Town of Newton
- Town of South Windsor
- Town of Wilton

Delaware:
- Delaware Geological Survey, University of Delaware
- Department of Highways and Transportation, Division of Highways
- Department of Natural Resources and Environmental Control
- New Castle County, Public Works Department

Florida:
- Brevard County
- Broward County
- Broward County Air and Water Pollution Control Board
- City of Bradenton
- City of Clearwater
- City of Cocoa
- City of Deerfield Beach
- City of Fort Lauderdale
- City of Gainesville
- City of Hallandale
- City of Hollywood
- City of Jacksonville
- City of Juno Beach
- City of Lake Worth
- City of Miami-Dade Water and Sewer Authority and the City of Miami Beach
- City of Pensacola
- City of Perry

Florida–Continued
- City of Pompano Beach
- City of Riviera Beach
- City of St. Petersburg
- City of Sarasota
- City of Tallahassee
- City of Tampa
- City of West Palm Beach
- Clay County Development Authority
- Collier County
- Englewood Water District
- Escambia County
- Florida Bureau of Water Resources Management
- Florida Department of Natural Resources:
  - Bureau of Geology
  - Division of Parks and Recreation
- Florida Department of Transportation
- Florida Keys Aqueduct Authority
- Hendry County
- Hillsborough County
- Lake County
- Lee County
- Loxahatchee River Environmental Control District
- Manasota Basin Board
- Manatee County, Board of County Commissioners
- Marion County
- Martin County
- Metropolitan Dade County
- Monroe County
- Northwest Florida Water Management District
- Orange County
- Palm Beach County
- Pinellas County
- Polk County
- Reedy Creek Improvement District
- Sarasota County
- Seminole County
- South Florida Water Management District
- Southwest Water Management District
- St. Johns River Water Management
- Sumter County Recreation and Water Conservation and Control Authority
- Suwanee River Authority
- Suwanee River Water Management District
- Village of Tequesta
- Volusia County
- Walton County
- Winderemere Water and Navigational Control District
- Winter Haven Lake Region

Georgia:
- Chatham County
- City of Brunswick
- City of Valdosta
- Dekalb County
- Department of Natural Resources:
  - Environmental Protection Division
  - Geologic and Water Resources Division
- Department of Transportation

Hawaii:
- City and County of Honolulu
- Honolulu Board of Water Supply
- Maui County, Department of Public Works
- State Department of Health
- State Department of Land and Natural Resources
- State Department of Transportation

Idaho:
- Idaho Department of Health and Welfare
- Idaho Department of Transportation
- Idaho Department of Water Resources

Illinois:
- Bloomington and Normal Sanitary District
- City of Springfield
- Cook County, Forest Preserve District
- DuPage County Highway Department
- Environmental Protection Agency
- Fountain Head Drainage District
- Illinois Division of Transportation:
  - Division of Highways
  - Division of Waterways
- Illinois Institute for Environmental Quality
- Kane County Highway Department
- Lake County Highway Department
- McHenry County Regional Planning Commission
- Sanitary District of Bloom Township
- State Department of Registration and Education, Illinois State Geological Survey and State Water Survey
- State Department of Transportation
- The Metropolitan Sanitary District of Greater Chicago
- University of Illinois at Urbana-Champaign, Environmental Studies Program

Indiana:
- City of Indianapolis
- City of Logansport
- Indiana Board of Health
- Indiana Department of Natural Resources
- Indiana Highway Commission
- Ohio River Valley, Water Sanitation Commission
- Town of Carmel

Iowa:
- City of Cedar Rapids
- City of Des Moines
- City of Fort Dodge
- Iowa Department of Transportation, Highway Research Board
- Iowa Geological Survey
- Iowa Natural Resources Council
- Iowa State University
- University of Iowa:
  - Institute of Hydraulic Research
  - University Physical Plant

Kansas:
- City of Wichita
- Kansas Department of Transportation
- Kansas State Department of Health
- Kansas State Water Resources Board
- Kansas-Oklahoma Arkansas River Commission
- State Geological Survey of Kansas
- State Highway Commission of Kansas

Kentucky:
- Department of Natural Resources and Environmental Protection
- Kentucky Department of Transportation
- Kentucky Geological Survey, University of Kentucky
- University of Kentucky, Division of Research and Planning

Louisiana:
- Capital Area Ground Water Conservation Commission
- Louisiana Department of Highways
- Louisiana Department of Public Works

Maine:
- Androscoggin Valley Regional Planning Commission
- Cobbossee Watershed District
- Department of Environmental Protection
- Greater Portland Council of Governments
- Maine Department of Transportation

Maine–Continued
- Maine Public Utilities Commission
- South Kennebec Regional Planning Commission
- Town of Wilton

Maryland:
- City of Baltimore, Bureau of Engineering, Water Supply Division
- Maryland Department of Health and Mental Hygiene
- Maryland Department of Transportation, The State Highway Administration
- Maryland Geological Survey
- Maryland National Capital Park and Planning Commission
- Montgomery County, Department of Environmental Protection
- Washington Suburban Sanitary Commission

Massachusetts:
- Department of Public Works:
  - Division of Research and Materials
  - Division of Highways
- Metropolitan District Commission
- State Water Resources Commission:
  - Division of Water Pollution Control
  - Division of Water Resources

Michigan:
- Albion Township
- Branch County
- Calhoun Soil Conservation District
- City of Albion
- City of Ann Arbor
- City of Battle Creek
- City of Coldwater
- City of Jackson
- City of Lansing
- City of Mason
- City of Saline
- City of St. Johns
- City of St. Louis
- City of Ypsilanti
- Department of Agriculture
- Department of Natural Resources, Geological Survey Division
- Department of State Highways and Transportation
- Genesee County Drain Commission
- Imlay City
- Kalamazoo Metropolitan Planning Commission
- Kent County Airport
- Macomb County Road Commission
- Oakland County:
  - Department of Public Works
  - Drain Commission
- Tri-County Regional Planning Commission
- Van Buren Road Commission
- Washtenaw County Metropolitan Planning Commission
- Ypsilanti Township

Minnesota:
- City of Lakeville
- Douglas County, Wisconsin Soil and Water Conservation District
- Metropolitan Council of the Twin Cities Area
- Metropolitan Waste Control Commission
- Minnesota Department of Highways
- Minnesota Department of Natural Resources, Division of Waters
- Minnesota State Planning Agency

Mississippi:
- City of Jackson
- City of West Point
- Harrison County Board of Supervisors
- Harrison County Development Commission
- Jackson County Board of Supervisors

Mississippi—Continued
- Jackson County Port Authority
- Mississippi Air and Water Pollution Control Commission
- Mississippi Board of Water Commissioners
- Mississippi Geological Survey
- Mississippi Marine Resources Council
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pat Harrison Waterway District
- Pearl River Valley Water Supply District

Missouri:
- City of Springfield
- City of Springfield, Utilities
- Department of Conservation
- Department of Highways
- Department of Natural Resources:
  - Division of Environmental Quality, Clean Water Commission
  - Division of Geology and Land Survey
- Little River Drainage District
- Missouri State Highway Commission
- Ozark Gateway Regional Planning Commission
- St. Louis County

Montana:
- Department of Natural Resources and Conservation
- Lewis and Clark County, Board of County Commissioners
- Missoula County Commissioners
- Montana Bureau of Mines and Geology
- Montana Department of Health and Environmental Sciences
- Montana Department of Highways
- Montana State Fish and Game Department
- Montana State University
- Rowell County Commissioners

Nebraska:
- Blue River Association of Ground Water Conservation Districts
- Clay County Ground Water Conservation District
- Filmore County Ground Water Conservation District
- Hamilton County Ground Water Conservation District
- Kansas-Nebraska Big Blue River Compact Administration
- Lower Elkhorn Natural Resources District
- Lower Platte South Natural Resources District
- Nebraska Department of Roads
- Nebraska Department of Water Resources
- Nebraska Natural Resources Commission
- Seward County Ground Water Conservation District
- University of Nebraska, Conservation and Survey Division
- Upper Big Blue Natural Resources District
- York County Ground Water Conservation District

Nevada:
- Carson City Engineering and Building Department
- Nevada Bureau of Mines and Geology
- Nevada Department of Conservation and Natural Resources
- Nevada Environmental Protection Service
- Nevada State Highway Department

New Hampshire:
- New Hampshire Department of Resources and Economic Development
- New Hampshire Water Resources Board
- New Hampshire Water Supply and Pollution Control Commission
- Strafford-Rockingham Regional Council

New Jersey:
- Bergen County
- Camden County Board of Freeholders

New Jersey—Continued
- Delaware River Basin Commission
- Delaware Valley Regional Planning Commission
- Morris County Municipal Utilities Authority
- New Jersey Department of Agriculture
- New Jersey Department of Environmental Protection
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Rutgers State University
- Township of Cranford

New Mexico:
- City of Albuquerque
- City of Las Cruces
- Costilla Creek Compact Commission
- Interstate Stream Commission
- New Mexico Bureau of Mines and Mineral Resources
- New Mexico State Engineer
- New Mexico State Highway Department
- Pecos River Commission
- Rio Grande Compact Commission

New York:
- Board of Hudson River-Black River Regulating District
- Central New York State Parks Commission
- City of Albany
- City of Auburn
- City of New York:
  - Board of Water Supply
  - Environmental Protection Administration
- County of Chautauqua
- County of Cortland
- County of Duchess Civil Defense
- County of Nassau, Department of Public Works
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Putnam, Highway Department
- County of Rockland Drainage Agency
- County of Suffolk:
  - Department of Environmental Control
  - Water Authority
- County of Ulster, Ulster County Legislature
- County of Westchester, Department of Public Works
- Department of Transportation
- Monroe County Water Authority
- New York State Department of Environmental Conservation
- New York State Education Department, Museum and Science Service
- New York State Environmental Conservation Research, Inc.
- New York State Museum and Science Service
- Oswegatchie-Cranberry Reservoir Commission
- Power Authority of the State of New York
- Town of Brighton
- Town of Clarkstown
- Town of Warwick
- Village of Nyack

North Carolina:
- Board of Transportation
- City of Asheville, Public Works Department
- City of Burlington
- City of Charlotte
- City of Durham, Department of Water Resources
- City of Greensboro
- City of Winston-Salem
- State Department of Natural and Economic Resources:
  - Division of Environmental Management
  - Division of Resource Planning and Evaluation
- State Water Commission

North Dakota:
- North Dakota Geological Survey
- Oliver County Board of County Commissioners
- State Water Commission

Ohio:
- City of Canton
- City of Columbus, Department of Public Service
- City of Toledo
- Miami Conservancy District
- Ohio Department of Natural Resources
- Ohio Department of Transportation
- Ohio Department of Transportation, Division of Highways
- Ohio Environmental Protection Agency
- Three Rivers Watershed District

Oklahoma:
- City of Oklahoma City, Water Department
- Oklahoma Department of Highways
- Oklahoma Geologic Survey
- Oklahoma State Health Department
- Oklahoma Water Resources Board
- State Pollution Control Coordinating Board

Oregon:
- Burnt River Irrigation District
- City of Corvallis
- City of Eugene, Water and Electric Board
- City of Lakeside, Lakeside Water District
- City of Medford, Public Works Department
- City of McMinnville, Water and Light Department
- City of Portland:
  - Bureau of Water Works
  - Department of Public Utilities
- Columbia Region Association of Governments
- Confederated Tribes of the Umatilla Indian Reservation
- Confederated Tribes of the Warm Springs Reservation
- Coos Bay-North Bend Water Board
- Coos County, Board of Commissioners
- Department of Fish and Wildlife
- Douglas County, Department of Public Works
- Lane County
- Multnomah County, Board of County Commissioners
- Oregon State Highway Commission
- Oregon State Water Resources Department
- Rogue Valley Council of Governments

Pennsylvania:
- Chester County Commissioners
- Chester County Health Department
- Chester County Water Resources Authority
- City of Bethlehem
- City of Easton
- City of Harrisburg
- City of Philadelphia, Water Department
- Delaware River Basin Commission
- Delaware Valley Regional Planning Commission
- Department of Agriculture, Soil Conservation Service
- Department of Transportation, Federal Highway Administration
- Letort Regional Authority
- Pennsylvania Department of Environmental Resources:
  - Bureau of Surface Mine Reclamation
  - Bureau of Topographic and Geologic Survey
  - Bureau of Water Quality Management
  - State Soil and Water Conservation Commission
  - Pennsylvania Department of Transportation
  - Susquehanna River Basin Commission

Rhode Island:
- City of Providence
- Coastal Resources, Graduate School, Universtiy of Rhode Island

Rhode Island—Continued
- State Department of Natural Resources
- State Water Resources Board

South Carolina:
- Commissioners of Public Works, Spartanburg Water Works
- State Health and Environmental Control
- State Highway Department
- State Public Service Authority
- State Water Resources Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Sioux Falls
- City of Watertown
- East Dakota Conservancy Subdistrict
- South Dakota Department of Natural Resource Development
- South Dakota Department of Transportation

Tennessee:
- City of Franklin
- City of Lawrenceburg
- City of Manchester
- City of Memphis, Board of Light, Gas, and Water Commissioners
- Lincoln County Public Utilities Board
- Metropolitan Government of Nashville and Davidson County, Department of Public Works
- Murfreesboro Water and Sewer Department
- Tennessee Department of Conservation:
  - Division of Geology
  - Division of Water Resources
- Tennessee Department of Public Health, Division of Water Quality Control
- Tennessee Department of Transportation
- Tennessee Wildlife Resources Agency

Texas:
- City of Austin
- City of Dallas, Public Works Department
- City of Fort Worth
- City of Houston
- County of Dallas
- Pecos River Commission
- Sabine River Compact Administration
- State Department of Highways and Public Transportation
- Texas Water Development Board

Utah:
- Bear River Commission
- Salt Lake County
- State Department of Natural Resources:
  - Division of Water Resources
  - Division of Water Rights
  - Division of Wildlife Resources
- Utah Geological and Mineral Survey

Vermont:
- State Department of Water Resources
- Town of Springfield

Virginia:
- City of Newport News, Department of Public Utilities
- City of Roanoke
- City of Staunton
- County of Fairfax
- Southeastern Public Services Authority of Virginia
- Virginia Department of Conservation and Economic Development, Division of Mineral Resources
- Virginia Department of Highways
- Virginia State Water Control Board

STATE, COUNTY, AND LOCAL COOPERATORS—Continued

Washington:
- City of Everett
- City of Seattle:
  - Department of Lighting
  - Water Department
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works
- Department of Natural Resources
- Lewis County Board of Commissioners
- Lower Elwah Tribal Council
- Makah Tribal Council
- Municipality of Metrolopitan Seattle
- Nisqually Indian Tribe
- Pacific County Board of County Commissioners
- Port Gamble Tribal Council
- Quileute Tribal Council
- Quinault Resource Development Project
- Spokane County
- State of Washington, Department of Ecology
- Suquamish Tribal Council
- Swinomish Tribal Senate
- Tulalip Tribe Board of Directors
- Washington State Department of Fisheries
- Washington State Department of Game
- Washington State Department of Highways
- Yakima Tribal Council

West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission

West Virginia—Continued
- West Virginia Department of Highways
- West Virginia Department of Natural Resources, Division of Water Resources
- West Virginia Geological and Economic Survey

Wisconsin:
- City of Madison Engineering Department
- City of Middleton Department of Public Works
- Dane County Regional Planning Commission
- Douglas County Soil and Water Conservation District
- Horsehead Lake Protection and Rehabilitation District No. 1
- Southeastern Wisconsin Regional Planning Commission
- State Board of Soil and Water Conservation Districts
- State Department of Natural Resources
- State Department of Transportation:
  - Bridge Section
  - Division of Highways
- The University of Wisconsin-Extension, Geological and Natural History Survey

Wyoming:
- City of Cheyenne, Board of Public Utilities
- City of Riverton
- Geological Survey of Wyoming
- State Highway Commission of Wyoming
- Teton County 208 Planning Agency
- Wyoming Department of Economic Planning and Development
- Wyoming Department of Environmental Quality
- Wyoming State Department of Agriculture
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

American Samoa:
- Department of Public Works

Appalachian Regional Commission

Coastal Plains Regional Commission

Government of Algeria

Government of Saudi Arabia

Guam:
- Environmental Protection Agency

Ozarks Regional Commission

The Federal Power Commission:
- Permittees and licensees

Puerto Rico:
- North Metropolitan 208 Area Wide Planning Commission
- Puerto Rico Aqueduct and Sewer Authority
- Puerto Rico Department of Natural Resources
- Puerto Rico Environmental Quality Board

Trust Territory of the Pacific Islands

United Nations

Virgin Islands:
- College of Virgin Islands
- Department of Public Works
- Planning Office

Budgetary and Statistical Data

[Data in these tables may differ slightly from data in the individual division chapters because of rounding]

TABLE 26.—*Geological Survey budget, by activity and sources of funds, fiscal year 1972–77*

[In thousands of dollars, details may not add to totals because of rounding]

Budget activity	1972	1973	1974	1975	1976	Transition quarter	1977
Total	**$188,996**	**$211,944**	**$249,437**	**$338,764**	**$353,970**	**$102,858**	**$433,400**
Direct program	130,951	149,971	171,983	253,605	264,434	77,570	319,468
Reimbursable program	58,045	61,973	77,454	85,159	89,536	25,288	113,932
States, counties, and municipalities	25,857	28,011	32,443	35,124	35,006	8,956	39,622
Miscellaneous non-Federal sources	3,383	3,620	4,695	6,399	7,923	1,991	10,230
Other Federal agencies	28,805	30,342	40,316	43,636	46,607	14,341	57,016
National Petroleum Reserve in Alaska	-------	-------	-------	-------	-------	-------	9,143
Direct Program	-------	-------	-------	-------	-------	-------	2,079
Allocation Transfer	-------	-------	-------	-------	-------	-------	7,064
Alaska Pipeline Related Investigations	**1,401**	**1,239**	**890**	**344**	**287**	**85**	**317**
Direct program	1,339	1,239	890	344	287	85	317
Reimbursable program	62	-------	-------	-------	-------	-------	-------
Other Federal agencies	62	-------	-------	-------	-------	-------	-------
Topographic Surveys and Mapping	**38,737**	**40,271**	**43,664**	**52,597**	**52,220**	**13,289**	**57,073**
Direct program	34,545	35,172	37,161	45,350	45,354	11,548	50,311
Reimbursable program	4,192	5,099	6,503	7,247	6,866	1,741	6,762
States, counties and municipalities	3,204	3,719	4,942	4,995	3,675	882	3,268
Miscellaneous non-Federal sources	357	600	643	594	501	133	601
Other Federal agencies	631	780	918	1,658	2,690	726	2,893
Geologic and Mineral Resource Surveys and Mapping [1]	**51,529**	**57,979**	**73,563**	**114,477**	**115,554**	**32,194**	**130,269**
Direct program	34,244	42,895	49,877	89,018	92,322	24,829	100,007
Reimbursable program	17,285	15,084	23,686	25,459	23,232	7,365	30,262
States, counties, and municipalities	1,359	1,556	1,681	1,550	1,467	383	1,403
Miscellaneous non-Federal sources	2,317	2,306	2,684	3,751	4,936	1,120	6,439
Other Federal agencies	13,609	11,222	19,321	20,158	16,829	5,862	22,420
Water Resources Investigations [2]	**71,324**	**78,103**	**88,352**	**101,437**	**112,480**	**30,716**	**131,509**
Direct program	37,446	40,185	45,433	53,420	57,176	15,916	68,555
Reimbursable program	33,878	37,918	42,919	48,017	55,304	14,800	62,954
States, counties, and municipalities	21,294	22,736	25,820	28,546	29,735	7,672	34,761
Miscellaneous non-Federal sources	679	664	721	901	940	260	1,331
Other Federal agencies	11,905	14,518	16,378	18,570	24,629	6,868	26,862
Conservation of Lands and Minerals [3]	**13,467**	**14,748**	**18,213**	**36,082**	**41,677**	**13,386**	**67,427**
Direct program	13,441	14,700	18,172	36,032	41,489	13,375	67,239
Reimbursable program	26	48	41	50	188	6	188
Miscellaneous non-Federal sources	1	3	-------	4	1	-------	16
Other Federal agencies	25	45	41	46	187	6	172
Land Information and Analysis [4]	**7,289**	**13,125**	**13,003**	**16,994**	**17,278**	**8,919**	**23,476**
Direct program	6,714	11,876	11,458	15,461	14,908	7,795	17,698
Rembursable program	575	1,249	1,545	1,533	2,370	1,124	5,778
States, counties, and municipalities	-------	-------	-------	33	130	19	190
Miscellaneous non-Federal sources	-------	-------	593	1,093	1,496	469	1,741
Other Federal agencies	575	1,249	952	407	744	636	3,847

See footnotes at end of table.

TABLE 26.—*Geological Survey budget, by activity and sources of funds, fiscal years 1972–77*—Continued

Budget activity	1972	1973	1974	1975	1976	Transition quarter	1977
General Administration [5]	**3,187**	**3,217**	**3,517**	**3,671**	**3,398**	**1,491**	**3,760**
Direct program	3,187	3,217	3,517	3,671	3,398	1,491	3,760
Facilities	35	687	5,475	10,309	9,500	2,530	9,502
Direct program	35	687	5,475	10,309	9,500	2,530	9,502
Miscellaneous services to other accounts	**2,027**	**2,575**	**2,760**	**2,853**	**1,576**	**253**	**924**
Reimbursable program	2,027	2,575	2,760	2,853	1,576	253	924
Miscellaneous non-Federal sources	29	47	54	56	49	10	102
Other Federal agencies	1,998	2,528	2,706	2,797	1,527	243	822

[1] Funds include: Mineral Discovery Loan Program activity for fiscal years 1972–75; and parts of Geothermal Investigations, Minerals Policy, and Arctic Environmental Studies components of the Special Resource and Environmental Projects activity for fiscal years 1972–75. Funds exclude the Land Resource Analysis program for fiscal years 1973–75.

[2] Funds exclude Employee Compensation Payments subactivity for fiscal years 1972–75.

[3] Funds include parts of Geothermal Investigations component of the Special Resource and Environmental Projects activity for fiscal years 1972–75.

[4] Budget activity funds are reconstructed for fiscal years 1972–75 and include: Earth Resources Observation System activity for fiscal years 1972–75; Urban Area Studies and Energy Impact Evaluation components of the Special Resource and Environmental Projects activity for fiscal years 1972–75; Land Resources Analysis program of the Geologic and Mineral Resource Surveys and Mapping activity for fiscal years 1974–75; and the Land Use Data and Analysis activity for fiscal year 1975.

[5] Funds include Employee Compensation Payments subactivity of the Water Resources Investigations activity for fiscal years 1972–75.

TABLE 27.—*Geological Survey Federal-State Cooperative Program funds, by State, fiscal years 1972–77*

[In thousands of dollars]

State	1972	1973	1974	1975	1976	Transition quarter	1977
Total [1]	**$50,651**	**$55,633**	**$65,256**	**$70,151**	**$69,252**	**$117,482**	**$79,195**
Total State share [2]	25,857	28,011	32,443	35,124	35,019	8,986	39,638
Alabama	839	928	1,094	1,212	1,124	171	1,232
State share	461	514	554	623	550	87	606
Alaska	619	838	897	1,162	782	202	1,141
State share	330	399	410	410	407	101	561
Arizona	1,021	1,001	1,144	1,248	1,255	335	1,393
State share	540	510	576	646	639	177	700
Arkansas	506	596	857	887	811	190	1,061
State share	250	288	455	410	371	94	495
California	3,893	4,115	4,789	4,690	4,825	1,271	5,278
State share	1,936	2,053	2,280	2,337	2,473	675	2,685
Colorado	995	1,128	1,484	2,445	2,199	662	3,040
State share	507	575	837	1,324	1,196	349	1,558
Connecticut	617	687	814	1,069	858	241	897
State share	304	292	374	523	415	108	434
Delaware	111	121	130	194	213	54	225
State share	75	81	74	106	116	30	121
District of Columbia	2	3	3	3	3	1	4
State share	1	1	1	1	2	-------	2
Florida	3,398	3,643	5,083	5,575	5,763	1,481	6,500
State share	1,719	1,858	2,552	2,781	2,851	735	3,238
Georgia	799	2,008	3,239	3,083	2,510	552	2,462
State share	437	1,041	1,611	1,531	1,243	275	1,214
Hawaii	622	653	691	697	896	191	811
State share	314	337	339	341	501	101	417
Idaho	619	675	718	749	852	223	952
State share	307	344	353	366	417	111	465

See footnotes at end of table.

TABLE 27.—*Geological Survey Federal-State Cooperative Program funds, by State, fiscal years 1972–77*—Continued

State	1972	1973	1974	1975	1976	Transition quarter	1977
Illinois	653	646	544	645	848	208	1,109
State share	341	333	277	323	459	120	592
Indiana	994	1,107	1,363	1,288	1,519	366	2,053
State share	491	590	678	632	779	182	1,014
Iowa	517	525	608	617	822	241	978
State share	255	259	299	302	405	121	481
Kansas	1,362	1,358	1,402	1,424	1,525	442	1,619
State share	675	676	686	716	752	220	798
Kentucky	2,033	2,212	2,451	2,728	2,828	717	2,957
State share	1,008	1,039	1,122	1,229	1,300	327	1,404
Louisiana	1,212	1,240	1,900	1,740	1,694	440	2,620
State share	655	674	980	902	862	227	1,315
Maine	163	168	175	248	313	89	335
State share	89	91	96	127	181	50	180
Maryland	620	695	851	1,011	1,016	243	1,164
State share	321	356	435	530	517	125	596
Massachusetts	1,159	1,379	1,346	1,618	1,627	368	1,544
State share	614	625	656	810	779	191	755
Michigan	859	947	930	1,054	1,078	252	1,101
State share	417	425	436	505	521	123	541
Minnesota	1,369	1,420	1,903	1,639	1,191	320	1,078
State share	681	727	966	817	625	198	564
Mississippi	592	593	645	743	646	170	713
State share	357	340	325	415	316	85	349
Missouri	792	732	657	678	642	207	813
State share	413	375	322	337	316	105	413
Montana	401	402	505	587	596	146	1,330
State share	221	223	255	287	301	76	673
Nebraska	553	588	705	731	785	187	957
State share	274	298	344	358	396	95	469
Nevada	578	640	689	846	922	244	1,049
State share	271	288	304	332	367	103	408
New Hampshire	100	139	177	172	230	63	248
State share	50	67	97	73	99	28	103
New Jersey	822	856	1,051	977	1,090	276	1,269
State share	418	433	530	501	565	143	642
New Mexico	963	1,107	1,332	1,439	1,510	338	1,537
State share	509	601	662	714	768	175	778
New York	2,224	2,395	2,796	2,977	2,822	727	3,008
State share	1,111	1,229	1,415	1,585	1,615	407	1,573
North Carolina	946	1,038	1,586	1,885	1,462	379	1,833
State share	457	492	771	942	724	197	908
North Dakota	714	899	763	998	990	246	892
State share	361	461	369	489	489	125	437
Ohio	990	1,028	978	1,093	1,255	336	1,570
State share	518	520	481	563	671	175	824
Oklahoma	614	634	702	748	786	196	860
State share	333	340	344	368	386	98	421
Oregon	727	828	896	902	899	287	1,200
State share	372	432	439	443	449	163	624

See footnotes at end of table.

TABLE 27.—*Geological Survey Federal-State Cooperative Program funds, by State, fiscal years 1972–77*—Continued

State	1972	1973	1974	1975	1976	Transition quarter	1977
Pennsylvania	2,167	2,047	2,357	2,415	2,510	554	2,716
State share	1,092	1,042	1,195	1,209	1,269	284	1,364
Rhode Island	92	90	97	110	124	31	127
State share	50	50	52	54	60	16	63
South Carolina	403	574	546	574	557	142	603
State share	212	301	279	284	272	71	296
South Dakota	424	423	471	515	528	146	568
State share	236	230	227	251	259	73	278
Tennessee	538	589	851	952	1,035	280	1,265
State share	294	321	422	470	508	139	620
Texas	3,717	3,794	4,046	4,261	4,351	1,102	4,655
State share	1,925	1,949	2,027	2,100	2,148	550	2,371
Utah	967	1,069	1,068	1,361	1,314	334	1,631
State share	486	530	534	838	745	186	810
Vermont	125	129	144	130	138	28	134
State share	64	66	73	64	68	14	70
Virginia	797	793	905	858	737	142	672
State share	420	421	466	442	378	78	345
Washington	1,800	1,988	2,121	2,208	2,115	509	3,277
State share	881	962	1,037	1,104	1,066	265	1,656
West Virginia	482	620	946	775	716	175	804
State share	263	332	521	448	418	105	459
Wisconsin	1,285	1,354	1,563	1,706	1,874	552	1,825
State share	619	638	775	883	999	297	996
Wyoming	589	612	698	853	754	167	907
State share	316	310	328	514	397	86	393
American Samoa	72	64	63	70	40	9	60
State share	36	32	31	32	20	4	30
Guam	36	43	62	65	68	18	70
State share	18	21	31	32	33	9	33
Puerto Rico	1,042	1,347	1,303	1,293	1,016	185	843
State share	494	557	682	585	463	84	396
Trust Territories	105	125	117	170	170	44	173
State share	52	62	58	84	84	22	84
Virgin Islands	12	([3])	([3])	33	18	2	32
State share	6	([3])	([3])	31	9	1	16

[1] Includes Federal funds from direct program.
[2] Includes reimbursable program funds from States, counties, and municipalities.
[3] Included with Puerto Rico funds.

TABLE 28.—*Geological Survey reimbursable program funds from other Federal agencies, by agency, fiscal years 1972–77*

[In thousands of dollars]

Agency	1972	1973	1974	1975	1976	Transition quarter	1977
Total	**$28.805**	**$30,342**	**$40,316**	**$43,636**	**$46,607**	**$14,347**	**$57,289**
Appalachian Regional Commission	------	------	189	179	------	-------	------
Department of Agriculture	268	273	356	891	2,008	605	2,130
Department of Commerce	85	73	([1])	154	2,205	36	334
National Oceanic and Atmospheric Administration	------	------	2,001	434	1,513	772	1,947
Department of Defense	9,123	8,443	13,351	11,247	11,965	3,195	12,308
Department of Housing and Urban Development	1,202	2,095	3,581	3,069	4,624	1,873	6,003

See footnotes at end of table.

TABLE 28.—*Geological Survey reimbursable program funds from other Federal agencies, by agency, fiscal years 1972–77*—Continued

State	1972	1973	1974	1975	1976	Transition quarter	1977
Department of the Interior	1,714	2,208	2,312	9,361	6,290	2,362	12,186
Bonneville Power Administration	101	118	136	105	130	32	141
Bureau of Indian Affairs	------	149	340	697	759	277	915
Bureau of Land Management	205	207	251	5,114	3,682	1,467	9,011
Bureau of Mines	80	------	------	1,735	148	-------	200
Bureau of Reclamation	656	855	676	721	790	267	1,199
Bureau of Sports Fisheries	11	------	------	------	------	-------	------
Fish and Wildlife Service	101	256	380	372	205	45	178
National Park Service	508	459	529	617	576	230	542
Office of Saline Water	31	156	------	------	------	-------	------
Office of the Secretary	------	------	------	------	------	44	------
Office of Territories	21	8	------	------	------	-------	------
Department of State	2,789	2,756	2,177	1,698	949	221	1,075
Department of Transportation	------	------	------	4	470	240	313
Department of Energy[2]	3,112	3,011	4,029	3,854	4,704	1,926	8,573
Environmental Protection Agency	627	916	1,127	1,389	1,921	777	1,947
National Aeronautics and Space Administration	6,017	6,507	5,672	3,449	3,584	1,051	2,648
National Science Foundation	906	333	1,375	1,928	1,650	40	2,712
Nuclear Regulatory Commission	------	------	------	1,195	1,439	427	1,758
Ozarks Regional Commission	------	------	60	49	------	-------	------
Tennessee Valley Authority	198	255	212	252	216	70	297
Miscellaneous Federal Agencies	766	944	1,168	1,686	1,542	499	1,964
Miscellaneous services to Other accounts	1,998	2,528	2,706	2,797	1,527	253	822

[1] Included in miscellaneous Federal agencies.
[2] Prior to October 1, 1977, shown as Energy Research and Development and Federal Energy Administration. Includes Atomic Energy Commission funds for fiscal years 1972–74. See also funds from Nuclear Regulatory Commission in fiscal year 1975.

TABLE 29.—*Topographic Surveys and Mapping direct program funds, by subactivity, fiscal years 1972–77*
[In thousands of dollars]

Subactivity	1972	1973	1974	1975	1976	Transition quarter	1977
Total direct program	**$34,545**	**$35,172**	**$37,161**	**$45,350**	**$45,354**	**$11,548**	**$50,311**
Quadrangle Mapping and Revision[1]	32.710	33,433	35,046	41,148	38,266	9,396	42,390
Small Scale and Special Mapping	1,835	1,739	2,115	2,661	5,358	1,730	5,278
National Cartographic Information Center[2]	(300)	(675)	(1,043)	1,541	1,730	422	2,643

[1] Funds are reconstructed for fiscal year 1972 and include the Map Revision and Maintenance subactivity.
[2] National Cartographic Information Center funds included in the Quadrangle Mapping and Revision subactivity prior to fiscal year 1975.

TABLE 30.—*Topographic Surveys and Mapping Federal-State Cooperative Program funds, by State, fiscal years 1972–77*
[In thousands of dollars]

State	1972	1973	1974	1975	1976	Transition quarter	1977
Total[1]	**$6,408**	**$7,438**	**$9,884**	**$9,990**	**$7,350**	**$1,764**	**$6,568**
Total State share[2]	3,204	3,719	4,942	4,995	3,675	882	3,284
Alabama	50	50	40	62	48	------	30
State share	25	25	20	31	24	------	15
Arkansas	46	54	58	72	74	28	66
State share	23	27	29	36	37	14	33

See footnotes at end of table.

TABLE 30.—*Topographic Surveys and Mapping Federal-State Cooperative Program funds, by State, fiscal years 1972–77*—Continued

State	1972	1973	1974	1975	1976	Transition quarter	1977
California	186	186	198	252	206	66	194
State share	93	93	99	126	103	33	97
Colorado	------	------	4	830	420	158	666
State share	------	------	2	415	210	79	333
Connecticut	40	40	120	124	110	56	110
State share	20	20	60	62	55	28	55
Florida	580	512	578	454	450	76	450
State share	290	286	289	227	225	38	225
Georgia	56	1,219	2,294	1,992	1,340	244	590
State share	28	609	1,147	996	670	122	295
Illinois	150	120	30	70	70	8	70
State share	75	60	15	35	35	4	35
Indiana	136	134	136	136	108	2	160
State share	68	67	68	68	54	1	80
Iowa	------	------	------	------	176	64	200
State share	------	------	------	------	88	32	100
Kansas	266	248	286	268	266	104	100
State share	133	124	143	134	133	52	50
Kentucky	210	182	278	254	204	60	272
State share	105	91	139	127	102	30	136
Louisiana	60	50	152	120	90	22	90
State share	30	25	76	60	45	11	45
Maine	40	40	40	40	40	20	40
State share	20	20	20	20	20	10	20
Maryland	20	22	20	20	30	2	20
State share	10	11	10	10	15	1	10
Massachusetts	200	196	190	250	250	6	250
State share	100	98	95	125	125	3	125
Michigan	100	100	100	100	100	------	100
State share	50	50	50	50	50	------	50
Minnesota	734	708	1,092	840	246	------	------
State share	367	354	546	420	123	------	------
Missouri	184	130	134	134	110	44	110
State share	92	65	67	67	55	22	55
Nevada	40	40	58	54	58	32	70
State share	20	20	29	27	29	16	35
New Mexico	------	------	------	16	16	------	------
State share	------	------	------	8	8	------	------
New York	380	234	366	226	------	12	------
State share	190	117	183	113	------	6	------
North Carolina	220	172	670	890	502	124	660
State share	110	86	335	445	251	62	330
North Dakota	112	242	88	222	198	10	90
State share	56	121	44	111	99	5	45
Ohio	150	150	150	150	150	38	150
State share	75	75	75	75	75	19	75
Oklahoma	126	112	110	110	110	36	110
State share	63	56	55	55	55	18	55
Oregon	60	78	44	92	32	24	70
State share	30	39	22	46	16	12	35

See footnotes at end of table.

TABLE 30.—*Topographic Surveys and Mapping Federal-State Cooperative Program funds, by State, fiscal years 1972–77*—Continued

State	1972	1973	1974	1975	1976	Transition quarter	1977
Pennsylvania	550	326	392	312	224	32	250
State share	275	163	196	156	112	16	125
South Carolina	------	120	------	36	------	------	------
State share	------	60	------	18	------	------	------
South Dakota	50	50	50	50	50	28	50
State share	25	25	25	25	25	14	25
Tennessee	12	38	50	44	16	------	16
State share	6	19	25	22	8	------	8
Texas	694	742	726	686	682	170	700
State share	347	371	363	343	341	85	350
Utah	72	114	120	100	100	40	100
State share	36	57	60	50	50	20	50
Vermont	20	20	40	34	20	------	------
State share	10	10	20	17	10	------	------
Virginia	166	132	232	218	188	14	190
State share	83	66	116	109	94	7	95
Washington	32	32	34	6	28	6	16
State share	16	16	17	3	14	3	8
West Virginia	206	298	506	228	142	26	156
State share	103	149	253	114	71	13	78
Wisconsin	400	402	412	414	410	208	412
State share	200	201	206	207	205	104	206
Wyoming	10	10	10	10	10	4	10
State share	5	5	5	5	5	2	5
Puerto Rico	50	76	76	74	76	------	------
State share	25	38	38	37	38	------	------

[1] Includes Federal funds from direct program.
[2] Includes reimbursable program funds from States, counties, and municipalities.

TABLE 31.—*Topographic Surveys and Mapping reimbursable program funds from other Federal agencies, by agency, fiscal years 1972–77*

[In thousands of dollars]

Agency	1972	1973	1974	1975	1976	Transition quarter	1977
Total	**$631**	**$780**	**$918**	**$1,658**	**$2,690**	**$726**	**$2,893**
Department of Agriculture	------	------	95	326	1,256	433	1,468
Department of Commerce	------	------	------	------	187	-------	121
Department of Defense	------	35	92	183	151	42	271
Department of the Interior	21	68	238	441	284	78	544
Bureau of Indian Affairs	------	60	165	198	209	20	179
Bureau of Land Management	------	------	73	243	74	58	325
Bureau of Reclamation	------	------	------	------	1	-------	10
Fish and Wildlife Service	------	------	------	------	------	-------	17
National Park Service	------	------	------	------	------	-------	13
Office of Territories	21	8	------	------	------	-------	------
Department of Transportation	------	------	------	4	257	30	65
National Aeronautics and Space Administration	138	207	235	97	132	-------	33
National Science Foundation	256	198	46	257	111	5	94
Miscellaneous Federal Agencies	216	272	212	350	312	138	297

TABLE 32.—*Geologic and Mineral Resource Surveys and Mapping direct program funds, by subactivity, fiscal years 1972–77*

[In thousands of dollars]

Subactivity	1972	1973	1974	1975	1976	Transition quarter	1977
Total direct program	**$34,244**	**$42,895**	**$49,877**	**$89,018**	**$92,322**	**$24,829**	**$100,007**
Land Resource Surveys [1]	15,154	19,246	23,077	33,385	34,077	9,681	35,202
Mineral Resource Surveys [2]	13,524	14,026	14,971	18,017	19,775	5,316	23,757
Energy Resource Surveys	3,144	5,197	6,696	22,376	23,080	5,863	26,250
Offshore Geologic Surveys	2,422	4,426	5,133	15,240	15,470	3,969	14,798

[1] Funds adjusted for fiscal years 1972–73 to include geologic mapping in support of Mineral Resource Surveys.

[2] Funds adjusted for fiscal years 1972–73 to exclude geologic mapping and to include the Mineral Discovery Loan Program activity for fiscal years 1972–73.

TABLE 33.—*Geologic and Mineral Resource Surveys and Mapping Federal-State Cooperative funds, by State, fiscal years 1972–77*

[In thousands of dollars]

State	1972	1973	1974	1975	1976	Transition quarter	1977
Total [1]	**$2,941**	**$4,270**	**$4,254**	**$4,541**	**$3,910**	**$917**	**$3,487**
State share [2]	1,359	1,556	1,681	1,550	1,479	413	1,403
Alabama	------	10	10	15	------	------	-------
State share	------	10	5	5	------	------	-------
Alaska	160	332	238	476	------	------	-------
State share	80	135	93	75	------	------	-------
Arkansas	51	85	125	165	110	------	107
State share	25	36	27	27	27	------	27
California	71	79	362	57	99	35	47
State share	33	22	80	21	66	35	47
Colorado	42	50	------	------	------	------	-------
State share	20	30	------	------	------	------	-------
Connecticut	141	235	208	258	200	62	144
State share	69	69	75	75	75	16	60
Georgia	2	------	6	10	------	------	-------
State share	1	------	3	5	------	------	-------
Hawaii	------	------	------	------	------	------	-------
State share	------	------	------	------	------	------	-------
Idaho	------	------	------	------	------	------	-------
State share	------	------	------	------	------	------	-------
Iowa	------	------	16	------	------	------	-------
State share	------	------	8	------	------	------	-------
Kansas	------	------	------	------	------	------	-------
State share	------	------	------	------	------	------	-------
Kentucky	1,158	1,332	1,454	1,599	1,643	413	1,682
State share	575	600	630	675	718	176	778
Maryland	20	27	14	19	------	------	-------
State share	10	10	7	9	------	------	-------
Massachusetts	417	633	563	581	630	180	509
State share	205	205	228	205	205	97	184
Michigan	153	216	178	158	148	45	128
State share	65	65	65	65	65	20	65
Minnesota	------	------	------	------	------	------	-------
State share	------	------	------	------	------	------	-------
Nevada	192	249	254	384	396	87	413
State share	80	90	90	105	110	25	97
New Hampshire	25	31	59	50	53	13	45
State share	13	13	39	13	13	3	7
New Mexico	------	20	40	11	18	2	6
State share	------	10	20	------	18	2	6

See footnotes at end of table.

TABLE 33.—*Geologic and Mineral Resource Surveys and Mapping Federal-State Cooperative funds, by State, fiscal years 1972–77*—Continued

State	1972	1973	1974	1975	1976	Transition quarter	1977
New York	------	------	20	21	------	------	18
State share	------	------	10	10	------	------	18
North Carolina	35	99	40	18	------	------	6
State share	6	12	6	18	------	------	6
Pennsylvania	15	30	10	------	------	------	-------
State share	8	15	5	------	------	------	-------
South Carolina	------	------	------	5	------	------	-------
State share	------	------	------	5	------	------	-------
Texas	------	3	------	------	------	------	-------
State share	------	3	------	------	------	------	-------
Utah	11	18	7	6	37	8	6
State share	3	7	7	4	4	5	3
Washington	58	122	67	134	81	7	42
State share	20	30	20	30	35	3	16
West Virginia	------	20	20	21	3	17	1
State share	------	10	10	10	3	17	1
Wisconsin	55	82	76	68	121	8	18
State share	8	8	8	8	8	2	6
Wyoming	15	27	26	11	35	------	107
State share	2	2	2	2	2	------	1
Puerto Rico	320	570	461	474	336	40	208
State share	136	174	243	183	130	12	81
Virgin Islands	------	------	------	------	------	------	-------
State share	------	------	------	------	------	------	-------

[1] Includes Federal funds from direct program.
[2] Includes reimbursable program funds from States, counties, and municipalities

TABLE 34.—*Geologic and Mineral Resource Surveys and Mapping reimbursable program funds from other Federal agencies, by agency, fiscal years 1972–77*

[In thousands of dollars]

Agency	1972	1973	1974	1975	1976	Transition quarter	1977
Total	**$13,609**	**$11,222**	**$19,321**	**$20,158**	**$16,828**	**$5,862**	**$22,420**
Appalachian Regional Commission	------	------	189	179	------	------	------
Department of Defense	3,219	1,431	5,670	2,648	2,443	739	1,902
Department of Housing and Urban Development	281	294	224	817	------	------	------
Department of the Interior	134	156	------	5,719	2,330	1,209	3,957
Office of the Secretary	------	------	------	------	------	44	------
Bureau of Indian Affairs	------	------	------	243	370	144	467
Bureau of Land Management	------	------	------	3,741	1,851	915	3,192
Bureau of Mines	80	------	------	1,735	109	------	138
Bureau of Reclamation	23	------	------	------	------	71	149
National Park Service	------	------	------	------	------	35	11
Office of Saline Water	31	156	------	------	------	------	------
Department of Commerce	------	------	------	------	342	------	176
National Oceanic and Atmospheric Administration	------	------	2,001	434	1,513	772	1,947
Department of State	1,987	1,975	1,510	1,056	359	73	477
Department of Energy[1]	2,090	2,134	3,125	2,895	3,401	1,480	6,396
National Aeronautics and Space Administration	5,038	4,708	4,745	2,938	2,800	977	2,433
National Science Foundation	650	135	1,329	1,604	1,538	35	2,618
Nuclear Regulatory Commission	------	------	------	1,195	1,439	427	1,758
Miscellaneous Federal Agencies	210	389	528	673	663	150	756

[1] Prior to October 1, 1977, shown as Energy Research and Development and Federal Energy Administration. Includes Atomic Energy Commission funds for fiscal years 1972–74. See also funds from Nuclear Regulatory Commission in fiscal year 1975.

TABLE 35.—*Water Resources Investigations direct program funds, by subactivity, fiscal years 1972–77*

[In thousands of dollars]

Subactivity	1972	1973	1974	1975	1976	Transition quarter	1977
Total direct program [1]	**$37,446**	**$40,185**	**$45,433**	**$53,420**	**$57,176**	**$15,916**	**$68,555**
National Water Data System	34,849	37,523	42,993	48,191	48,494	12,816	55,826
Federal program	14,841	16,334	17,695	21,183	20,487	5,724	21,809
Federal-State program [2]	20,008	21,189	25,298	27,008	28,007	7,092	34,017
Critical National water problems	2,597	2,662	2,440	5,229	8,682	3,100	12,729

[1] Direct program funds exclude the Employee Compensation Payments subactivity for fiscal years 1972–77.

[2] Federal share of Federal-State Cooperative Program.

TABLE 36.—*Water Resources Investigations, Federal-State Cooperative Program funds, by State, fiscal years 1972–77*

[In thousands of dollars]

State	1972	1973	1974	1975	1976	Transition quarter	1977
Total [1]	**$41,302**	**$43,925**	**$51,118**	**$55,554**	**$57,742**	**$14,763**	**$68,778**
State share [2]	21,294	22,736	25,820	28,546	29,735	7,672	34,761
Alabama	789	868	1,044	1,135	1,042	165	1,112
State share	436	479	529	587	509	84	546
Alaska	459	506	659	686	782	202	1,141
State share	250	264	317	335	407	101	561
Arizona	1,021	1,001	1,144	1,248	1,255	335	1,393
State share	540	510	576	646	639	177	700
Arkansas	409	457	674	650	627	162	888
State share	202	225	399	347	307	80	435
California	3,636	3,850	4,229	4,381	4,520	1,170	5,037
State share	1,810	1,938	2,101	2,190	2,304	607	2,541
Colorado	953	1,078	1,480	1,615	1,779	504	2,374
State share	487	545	835	909	986	270	1,225
Connecticut	436	412	486	687	548	123	643
State share	215	203	239	386	285	64	319
Delaware	111	121	130	194	213	54	225
State share	75	81	74	106	116	30	121
District of Columbia	2	3	3	3	3	1	4
State share	1	1	1	1	2	0	2
Florida	2,818	3,071	4,505	5,055	5,257	1,405	6,050
State share	1,429	1,572	2,263	2,521	2,593	697	3,013
Georgia	741	790	939	1,081	1,170	308	1,872
State share	408	432	461	530	573	153	919
Hawaii	622	653	691	697	896	191	811
State share	314	337	339	341	501	101	417
Idaho	619	675	718	749	852	223	952
State share	307	344	353	366	417	111	465
Illinois	503	526	514	575	778	200	1,039
State share	266	273	262	288	424	116	557
Indiana	858	973	1,227	1,152	1,411	364	1,893
State share	423	523	610	564	725	181	934
Iowa	517	525	592	617	646	177	778
State share	255	259	291	302	317	89	381
Kansas	1,096	1,110	1,116	1,156	1,259	338	1,519
State share	542	552	543	582	619	168	748

See footnotes at end of table.

TABLE 36.—*Water Resources Investigations, Federal-State Cooperative Program funds, by State, fiscal years 1972–77*—Continued

State	1972	1973	1974	1975	1976	Transition quarter	1977
Kentucky	665	698	719	875	981	244	1,003
State share	328	348	353	427	480	121	490
Louisiana	1,152	1,190	1,748	1,620	1,604	418	2,530
State share	625	649	904	842	817	216	1,270
Maine	123	128	135	208	273	69	295
State share	69	71	76	107	161	40	160
Maryland	580	646	817	972	986	241	1,144
State share	301	335	418	511	502	124	586
Massachusetts	542	550	593	787	747	182	785
State share	309	322	333	480	449	91	446
Michigan	606	631	652	796	830	207	873
State share	302	310	321	390	406	103	426
Minnesota	635	712	811	799	945	320	1,078
State share	314	373	420	397	502	198	564
Mississippi	592	593	645	743	646	170	713
State share	357	340	325	415	316	85	349
Missouri	608	602	523	544	532	131	503
State share	321	310	255	270	261	67	249
Montana	401	402	505	587	596	146	1,330
State share	221	223	255	287	301	76	673
Nebraska	553	588	705	731	785	187	957
State share	274	298	344	358	396	95	469
Nevada	346	351	377	408	468	125	566
State share	171	178	185	200	228	62	276
New Hampshire	75	108	118	122	177	50	203
State share	37	54	58	60	86	25	96
New Jersey	822	856	1,051	977	1,090	276	1,269
State share	418	433	530	501	565	143	642
New Mexico	963	1,087	1,292	1,412	1,476	336	1,531
State share	509	591	642	706	742	173	772
New York	1,844	2,161	2,410	2,730	2,822	715	2,990
State share	921	1,112	1,222	1,462	1,615	401	2,550
North Carolina	691	767	876	977	960	255	1,095
State share	341	394	430	479	473	135	536
North Dakota	602	657	675	776	792	236	802
State share	305	340	325	378	390	120	392
Ohio	840	878	828	943	1,105	298	1,420
State share	443	445	406	488	596	156	749
Oklahoma	488	522	592	638	676	160	750
State share	270	284	289	313	331	80	366
Oregon	667	750	852	810	867	263	1,130
State share	342	393	417	397	433	151	589
Pennsylvania	1,602	1,691	1,955	2,103	2,186	522	2,466
State share	809	864	994	1,053	1,107	268	1,239
Rhode Island	92	90	97	110	124	31	127
State share	50	50	52	54	60	16	63
South Carolina	403	454	546	533	557	142	603
State share	212	241	279	261	272	71	296
South Dakota	374	373	421	465	478	118	518
State share	211	205	202	226	234	59	253

See footnotes at end of table.

TABLE 36.—*Water Resources Investigations, Federal-State Cooperative Program funds, by State, fiscal years 1972–77*—Continued

State	1972	1973	1974	1975	1976	Transition quarter	1977
Tennessee	526	551	801	908	1,019	280	1,249
State share	288	302	397	448	500	139	612
Texas	3,023	3,049	3,320	3,575	3,669	932	3,955
State share	1,578	1,575	1,664	1,757	1,807	465	2,021
Utah	884	937	941	1,255	1,177	286	1,525
State share	447	466	467	784	691	161	757
Vermont	105	109	104	96	118	28	134
State share	54	56	53	47	58	14	70
Virginia	631	661	673	640	549	128	482
State share	337	355	350	333	284	71	250
Washington	1,710	1,834	2,020	2,068	2,006	496	3,219
State share	845	916	1,000	1,074	1,017	259	1,632
West Virginia	276	302	420	526	511	132	647
State share	160	173	258	324	314	75	380
Wisconsin	830	870	1,075	1,224	1,343	336	1,395
State share	411	429	561	668	786	191	784
Wyoming	564	575	662	832	709	163	790
State share	309	303	321	507	390	84	387
American Samoa	72	64	63	70	40	9	60
State share	36	32	31	32	20	4	30
Guam	36	43	62	65	68	18	70
State share	18	21	31	32	33	9	33
Puerto Rico	672	701	766	745	604	145	635
State share	333	345	401	365	295	72	315
Trust Territories	105	125	117	170	170	44	173
State share	52	62	58	84	84	22	84
Virgin Islands	12	([3])	([3])	33	18	2	32
State share	6	------	------	31	9	1	16

[1] Includes Federal funds from direct program.
[2] Includes reimbursable program funds from States, counties, and municipalities.
[3] Included with Puerto Rico funds.

TABLE 37.—*Water Resources Investigations reimbursable program funds from other Federal agencies, by agency, fiscal years 1972–77*

[In thousands of dollars]

Agency	1972	1973	1974	1975	1976	Transition quarter	1977
Total	**$11,905**	**$14,518**	**$16,378**	**$18,570**	**$24,631**	**$6,868**	**$26,862**
Department of Agriculture	268	273	261	565	753	172	662
Department of Commerce	85	73	([1])	154	1,733	36	37
Department of Defense	5,879	6,953	7,554	8,391	9,367	2,414	10,135
Department of Housing and Urban Development	921	1,801	3,018	2,252	4,624	1,873	6,003
Department of the Interior	1,497	1,984	2,026	3,190	3,668	1,035	4,597
Bonneville Power Administration	101	118	101	105	130	32	141
Bureau of Indian Affairs	------	89	175	256	179	113	269
Bureau of Land Management	154	207	178	1,130	1,749	494	2,406
Bureau of Mines	------	------	------	------	39	------	62
Bureau of Reclamation	633	855	676	721	790	196	1,040
Fish and Wildlife Service	101	256	367	361	205	45	161
National Park Service	508	459	529	617	576	155	518

See footnotes at end of table.

TABLE 37.—*Water Resources Investigations reimbursable program funds from other Federal agencies, by agency, fiscal years 1972–77*—Continued

Agency	1972	1973	1974	1975	1976	Transition quarter	1977
Department of State	802	781	667	642	589	148	598
Department of Transportation	------	------	------	47	214	31	242
Environmental Protection Agency	627	916	1,127	1,389	1,921	571	1,847
Department of Energy [2]	1,022	877	904	959	1,142	446	2,177
National Aeronautics and Space Administration	266	343	284	235	213	14	60
National Science Foundation	------	------	------	67	------	------	------
Tennessee Valley Authority	198	255	212	252	216	70	297
Miscellaneous Federal agencies	340	262	325	494	191	58	207

[1] Included with miscellaneous Federal agencies funds.
[2] Prior to October 1, 1977, shown as Energy Research and Development. Includes Atomic Energy Commission funds for fiscal years 1972–74.

TABLE 38.—*Conservation of Lands and Minerals direct program funds, by subactivity, fiscal years 1972–77*
[In thousands of dollars]

Subactivity	1972	1973	1974	1975	1976	Transition quarter	1977
Total direct program	**$13,441**	**$14,700**	**$18,172**	**$36,032**	**$41,489**	**$13,347**	**$67,239**
Outer Continental Shelf Lands	7,626	8,114	10,957	23,196	26,194	9,119	37,970
Federal and Indian Lands	5,815	6,586	7,215	12,836	15,295	4,255	29,269

TABLE 39.—*Conservation of Lands and Minerals reimbursable program funds from other Federal agencies, fiscal years 1972–77*
[In thousands of dollars]

Agency	1972	1973	1974	1975	1976	Transition quarter [1]	1977
Total	**$25**	**$45**	**$41**	**$46**	**$186**	**$6**	**$172**
Department of Defense	25	24	25	25	25	------	------
Miscellaneous Federal agencies	---	21	16	21	161	6	172

TABLE 40.—*Land Information and Analysis direct program funds, by subactivity, fiscal years 1972–77*
[In thousands of dollars]

Subactivity	1972	1973	1974	1975	1976	Transition quarter	1977
Total direct program	**$6,714**	**$11,876**	**$11,458**	**$15,461**	**$14,908**	**$7,795**	**$17,698**
Earth Sciences Applications	970	1,519	1,580	1,600	1,629	407	1,433
Resource and Land Investigations	------	------	916	959	740	491	1,021
Geography	------	------	------	2,013	2,341	747	2,527
Earth Resources Observation Systems	5,744	10,357	8,962	8,284	8,158	4,840	9,545
Environmental Impact Analysis	------	------	------	2,605	2,040	1,310	3,172

TABLE 41.—*Land Information and Analysis reimbursable program funds from other Federal agencies, by agency, fiscal years 1972–77*

[In thousands of dollars]

Agency	1972	1973	1974	1975	1976	Transition quarter	1977
Total	**$575**	**$1,249**	**$952**	**$407**	**$744**	**$636**	**$3,848**
Department of Defense	----	------	10	----	----	------	------
Department of Housing and Urban Development	----	------	339	----	----	------	------
Department of the Interior	----	------	48	11	15	40	3,088
Bureau of Land Management	----	------	----	----	8	------	3,088
Bureau of Mines	----	------	----	----	3	------	------
Bonneville Power Administration	----	------	35	----	----	------	------
Fish and Wildlife Service	----	------	13	11	4	------	------
National Park Service	----	------	----	----	----	40	----
Department of Transportation	----	------	----	----	----	179	6
Environmental Protection Agency	----	------	----	----	----	206	100
National Aeronautics and Space Administration	575	1,249	408	179	443	60	122
Ozarks Regional Commission	----	------	60	49	31	------	------
Miscellaneous Federal agencies	----	------	87	168	255	151	532

TABLE 42.—*Land Information and Analysis Federal-State Cooperative Program funds, by State, fiscal years 1972–77*

[In thousands of dollars]

State	1972	1973	1974	1975	1976	Transition quarter	1977
Total[1]	------	------	------	**$66**	**$250**	**$38**	**$362**
Total State share[2]	------	------	------	33	130	19	190
Alabama	------	------	------	--	34	6	90
State share	------	------	------	--	17	3	45
Florida	------	------	------	66	56	--	--
State share	------	------	------	33	33	--	--
Missouri	------	------	------	--	---	32	200
State share	------	------	------	--	---	16	109
North Carolina	------	------	------	--	---	--	72
State share	------	------	------	--	---	--	36
Pennsylvania	------	------	------	--	100	--	--
State share	------	------	------	--	50	--	--
West Virginia	------	------	------	--	60	--	--
State share	------	------	------	--	30	--	--

[1] Includes Federal funds from direct program.
[2] Includes reimbursable funds from States, counties, and municipalities.

TABLE 43.—*Program support funds, by activity, fiscal years 1972–77*

[In thousands of dollars]

Program support activity	1972	1973	1974	1975	1976	Transition quarter	1977
General Administrative Expenses[1]	**$6,422**	**$7,173**	**$8,197**	**$10,806**	**$11,451**	**$3,675**	**$13,982**
General Administration[2]	3,187	3,217	3,517	3,671	3,398	1,492	3,760
Direct program assessments[3]	1,669	2,352	2,770	5,126	5,766	1,466	7,015
Reimbursable program assessment[4]	1,566	1,604	1,910	2,009	2,287	717	3,207

See footnotes at end of table.

TABLE 43.—*Program support funds, by activity, fiscal years 1972–77*—Continued

Program support activity	1972	1973	1974	1975	1976	Transition quarter	1977
Electronic data processing and related services [5]	4,862	6,168	6,987	8,425	7,432	1,922	12,728
Funded by Survey programs [6]	3,351	4,177	4,828	6,129	6,700	1,908	12,631
Funded by miscellaneous accounts [7]	1,511	1,991	2,159	2,296	732	14	97
Publication services	10,667	11,656	11,932	13,004	15,468	3,705	15,412
Funded by Survey programs [6]	10,297	11,147	11,432	12,488	14,662	3,469	14,719
Funded by miscellaneous accounts [7]	370	509	500	516	806	236	693

[1] Obligations of the Director's Office for executive direction and of the Administration Division for management services.

[2] Direct program funds of the General Administration budget activity. Obligations reconstructed for fiscal years 1972–75 to include Employee Compensation Payments.

[3] Assessments made on direct program funds of other budget activities.

[4] Assessments made on reimbursable program funds of other budget activities. No assessments are made on cooperative funds from State and local governments.

[5] Obligations of the Computer Center Division.

[6] Obligations charged to Survey program activities.

[7] Obligations charged to the Miscellaneous Services to Other Accounts activity for reimbursable work done for other agencies.

TABLE 44.—*Geological Survey end-of-year employment, by organizational unit, fiscal years 1972–77*

Organizational unit	1972	1973	1974	1975	1976 [2]	1977 [3]
Total	**9,224**	**9,387**	**9,921**	**10,435**	**11,868**	**11,930**
Permanent employment	8,002	8,089	8,357	8,999	9,049	9,326
Other than permanent employment	1,222	1,298	1,564	1,436	2,819	2,604
Topographic Division	2,045	2,020	1,956	1,877	1,859	1,870
Permanent employment	1,828	1,758	1,762	1,719	1,664	1,644
Other than permanent employment	217	262	194	158	195	226
Geologic Division	2,060	2,147	2,406	2,572	3,170	2,981
Permanent employment	1,706	1,766	1,888	2,135	2,089	2,046
Other than permanent employment	354	381	518	437	1,081	935
Water Resources Division	3,409	3,419	3,611	3,610	4,131	3,946
Permanent employment	2,876	2,900	2,910	2,957	2,895	2,840
Other than permanent employment	533	519	701	653	1,236	1,106
Conservation Division	549	568	647	990	1,242	1,586
Permanent employment	529	547	612	926	1,143	1,498
Other than permanent employment	20	21	35	64	99	88
Land Information and Analysis Office	51	72	85	114	175	191
Permanent employment	39	52	68	89	116	126
Other than permanent employment	12	20	17	25	59	65
National Petroleum Reserve in Alaska	------	------	------	------	------	25
Permanent employment	------	------	------	------	------	22
Other than permanent employment	------	------	------	------	------	3
Director's Office	64	57	64	66	71	76
Permanent employment	51	55	62	57	59	63
Other than permanent employment	13	2	2	9	12	13
Administrative Division	360	382	408	441	468	508
Permanent employment	326	341	366	398	403	424
Other than permanent employment	34	41	42	43	65	84
Facilities [1]	------	------	15	30	51	58
Permanent employment	------	------	15	30	37	37
Other than permanent employment	------	------	------	------	14	21
Computer Center Division	170	174	182	198	154	174
Permanent employment	150	153	159	178	125	145
Other than permanent employment	20	21	23	20	29	29
Publications Division	516	548	547	537	527	501
Permanent employment	497	517	515	510	498	467
Other than permanent employment	19	31	32	27	29	34

[1] Administrative Division personnel assigned to the operation of the Survey's Headquarter facilities.

[2] Includes 20 Bureau clerical pool in fiscal year 1976—count date at end of transition quarter.

[3] Includes 14 Bureau clerical pool in fiscal year 1977.

TABLE 45.—*Number of Geological Survey reports approved for publication, by organizational unit, fiscal years 1972–77*

Organizational unit	1972	1973	1974	1975	1976	Transition quarter	1977
Total	**2,351**	**2,548**	**2,755**	**2,888**	**3,418**	**883**	**3,735**
Book reports [1]	163	147	155	144	146	29	179
Journal of Research articles [2]	106	107	90	85	101	19	93
Open-file reports	447	380	440	570	781	215	851
Basic data reports	196	255	230	256	207	44	102
Outside publications	1,439	1,659	1,840	1,833	2,183	576	2,531
Topographic Division	42	53	53	33	36	6	41
Book reports	------	------	------	------	------	------	------
Journal of Research articles	------	2	1	------	------	------	3
Open-file reports	------	------	------	------	------	------	------
Outside publications	42	51	52	33	36	6	38
Geologic Division	1,329	1,419	1,546	1,811	2,209	578	2,527
Book reports	102	91	96	90	101	16	108
Journal of Research articles	78	79	69	70	62	14	62
Open-file reports	258	216	245	379	499	145	581
Outside publications	891	1,033	1,136	1,272	1,547	403	1,776
Water Resources Division	875	953	1,002	926	1,061	245	943
Book reports	59	54	56	50	42	11	42
Journal of Research articles	28	26	20	15	38	5	23
Open-file reports	180	149	181	152	264	55	215
Basic data reports	196	255	230	256	207	44	102
Outside publications	412	469	515	453	510	130	561
Conservation Division	15	17	18	44	28	15	78
Book reports	1	------	2	1	------	1	1
Journal of Research articles	------	------	------	------	------	------	------
Open-file reports	8	13	11	32	13	10	48
Outside publications	6	4	5	11	15	4	28
Director's Office [3]	90	106	136	74	84	39	146
Book reports	1	2	1	3	3	1	5
Journal of Research	------	------	------	------	1	------	6
Open-file reports	1	2	3	7	5	5	7
Outside publications	88	102	132	64	75	33	128

[1] Book reports include U.S. Geological Survey Professional Papers, Bulletins, Water-Supply Papers, Circulars, and other report series.

[2] Before January 1973, articles were published as part of the annual "Geological Survey Research" Professional Paper.

[3] Includes reports of the Land Information and Analysis Office, Administrative Division, Computer Center Division, and Publications Division.

TABLE 46.—*Number of maps produced by the Geological Survey, by organizational unit, fiscal years 1972–77*

Organizational unit	1972	1973	1974	1975	1976	Transition quarter	1977
Total [1]	**6,094**	**10,304**	**7,361**	**8,722**	**9,099**	**2,310**	**11,354**
Topographic Division	4,817	5,313	4,938	7,288	7,339	2,080	10,508
Quadrangle maps	4,641	5,117	4,780	7,087	6,757	1,970	10,012
New standard quadrangles	2,544	2,347	2,052	2,016	1,405	237	1,318
Orthophotoquads	------	49	15	2,869	3,197	730	4,127
Revisions	1,223	1,118	966	923	656	165	1,081
Reprints	874	1,603	1,747	1,279	1,499	838	3,486
Small scale and special maps	112	148	121	171	582	114	496
1:250,000 series	26	57	50	52	37	5	31
Antarctica	------	5	------	4	6	------	------
State bases	8	2	------	2	34	1	14
Other	20	25	8	24	112	6	1
Reprints	58	59	63	80	73	54	117
Intermediate scale	------	------	------	9	259	32	304
Topographic maps indexes	64	48	37	30	61	16	29
Geologic Division [2]	315	320	215	229	285	71	384

See footnotes at end of table.

TABLE 46.—*Number of maps produced by the Geological Survey, by organizational unit, fiscal years 1972–77*—Continued

Organizational unit	1972	1973	1974	1975	1976	Transition quarter	1977
Water Resources Division [3]	952	4,650	2,192	1,198	1,358	109	361
Hydrologic maps	47	84	52	58	653	70	60
Flood-prone area maps	905	4,566	2,140	1,140	705	39	301
Conservation Division [4]	10	8	9	5	14	------	14
Director's office [4]	------	13	7	2	103	46	87

[1] Additional maps are produced for inclusion in book reports.
[2] Geologic and geophysical maps.
[3] Includes hydrologic unit maps.
[4] Miscellaneous maps and charts.

TABLE 47.—*Oil and gas operations on the Outer Continental Shelf lands, calendar years 1972–77*

Activity	1972	1973	1974	1975	1976	1977
Number of exploration permits issued	254	350	400	486	422	450
Lease sales:						
Number of sales	2	6	5	4	4	2
Tracts offered:						
Number	210	276	1,006	1,374	536	358
Area (acres in thousands)	971	1,515	5,006	7,248	2,818	1,843
Tracts sold:						
Number	178	187	356	321	246	255
Area (acres in thousands)	826	1,033	1,762	1,680	1,278	1,351
Percentage of tracts sold	84.8	67.8	35.4	23.4	45.9	71.2
Bonus (dollars in thousands)	$2,251,348	$3,082,463	$5,022,861	$1,088,133	$2,242,896	$1,568,630
Status of leases:						
Total number of leases supervised	1,023	1,266	1,590	1,792	1,996	2,200
Total area (acres in thousands)	4,339	5,614	7,247	8,321	9,432	10,550
Number of producing leases	698	726	748	790	833	900
Area (acres in thousands)	2,915	3,039	3,147	3,253	3,477	3,700
Percentage	68.2	57.3	47.0	44.0	41.7	40.9
Number of non-producing leases	325	540	842	1,002	1,163	1,300
Area (acres in thousands)	1,424	2,575	4,100	5,069	5,956	6,850
Percentage	31.8	42.7	53.0	56.0	58.3	59.1
Lease operations:						
Number of platforms	1,963	2,016	2,059	2,084	2,100	2,200
Number of new well starts	847	820	816	892	1,041	1,150
Number of new wells completed	338	420	310	392	432	546
Number of new zones completed	496	600	398	515	530	706
Oil zones	306	304	226	225	264	360
Gas zones	180	288	155	277	258	340
Service zones	10	8	17	13	8	6
Total number of completed wells	6,032	6,421	6,218	6,104	6,770	7,290
Total number of completed zones	9,716	10,187	8,750	9,074	13,407	10,822
Oil zones	6,740	6,868	4,418	4,519	6,760	4,431
Gas zones	2,680	2,987	2,403	2,765	3,648	3,045
Service zones	296	332	416	325	333	379
Other zones [1]	---------	---------	1,513	1,465	2,666	2,967
Miles of pipeline under supervision (estimated)	6,000	6,450	6,700	7,150	7,400	10,203 [2]
Production:						
Oil and condensate (barrels in millions)	412	395	361	330	317	307
Percentage of domestic production	11.9	11.8	11.2	10.8	10.8	10.6
Gas (cubic feet in billions)	3,038	3,212	3,515	3,459	3,596	3,603
Percentage of domestic production	13.5	14.0	16.0	17.2	18.1	18.4
Gasoline and LPG (gallons in millions)	1,737	1,635	2,032	1,983	1,924	2,188
Percentage of domestic production	6.5	6.1	7.9	7.9	8.0	8.6

[1] New classification since 1974.
[2] Includes DOI and DOT jurisdictional pipelines.

TABLE 48.—*Revenues from leases on Outer Continental Shelf lands, calendar years 1972–77*

[Dollars in thousands]

	1972	1973	1974	1975	1976	1977 (estimated)
Total revenue	**$2.624,958**	**$3,494,981**	**$5,598,758**	**$1,723,758**	**$2,967,861**	**$2,259,215**
Bonuses	2,251,347	3,082,462	5,022,861	1,088,133	2,242,899	1,356,000
Minimum royalties	2,020	2,391	2,048	2,086	2,128	2,150
Rentals	7,985	8,949	13,533	17,522	23,371	29,200
Number of accounts	(529)	(647)	(1,036)	(1,203)	(1,430)	(1,200)
Shut-in-gas payments	50	53	32	40	38	40
Totals:						
Royalties	363,556	401,126	560,284 [1]	615,545	699,425	871,825
Production value	(2,229,179)	(2,486,865)	(3,570,054) [1]	(3,924,915)	(4,395,905)	(5,454,385)
Number of accounts	(912)	(1,158)	(2,260) [1]	(2,468)	(2,850)	(3,250)
Oil and condensate:						
Royalties	247,689	271,491	384,367	399,527	412,303	440,000
Production value	(1,453,968)	(1,620,732)	(2,398,794)	(2,428,849)	(2,533,410)	(2,648,000)
Gas:						
Royalties	105,892	118,245	142,257	195,198	268,090	404,000
Production value	(663,648)	(736,878)	(881,634)	(1,205,678)	(1,652,843)	(2,494,000)
Gasoline and LPG:						
Royalties	6,525	7,768	19,797	16,376	19,656	27,825
Production value	(89,214)	(105,437)	(254,744)	(216,043)	(246,449)	(312,385)
Salt:						
Royalties	11	11	10	8 [2]	(3) [2]	(2) [2]
Production value	(65)	(69)	(62)	(54)	(20)	--------
Sulfur:						
Royalties	3,439	3,611	3,853	3,738	(1,652)	(2) [3]
Production value	(22,287)	(23,749)	(34,820)	(69,738)	(36,777)	--------

[1] Includes $3,950,000 of lost oil and gas.

[2] Productive salt leases transferred to Louisiana by Supreme Court decree of June 16, 1975.

[3] All currently producing sulfur leases have been turned over to the State of Louisiana by Supreme Court decree of June 16, 1975.

TABLE 49.—*Oil, gas, and geothermal operations on Federal and Indian lands, calendar years 1972–77*

Activity	1972	1973	1974	1975	1976	1977 (estimated)
Competitive oil and gas lease sales on Federal lands only:						
Tracts offered:						
Number of tracts	464	339	421	420	480	320
Area acres	130,546	86,681	98,064	102,397	96,900	69,300
Tracts sold:						
Number of tracts	279	311	295	356	356	294
Area acres	88,326	89,315	65,247	112,401	74,616	64,400
Percentage of tracts sold	60.1	91.7	70.1	84.8	74.2	91.9
Bonus (dollars in thousands)	$1,118	$2,203	$2,296	8,203	$4,934	$7,038
Status of oil and gas leases:						
Total number of leases supervised	113,158	115,761	123,652	125,720	125,817	129,000
Total area (acres in thousands)	75,213	79,116	89,829	93,717	93,682	106,500
Number of producing leases	11,640	11,953	12,386	12,961	13,541	13,800
Area (acres in thousands)	5,741	5,902	6,349	6,564	6,794	9,100
Percentage	10.3	10.3	10.0	10.3	10.8	10.7
Number of non-producing leases	101,518	103,808	111,266	112,759	112,276	115,200
Area (acres in thousands)	69,472	73,214	83,480	84,153	86,888	97,400
Percentage	89.7	89.7	90.0	89.7	89.2	89.3
Oil and gas lease operations:						
Number of new well starts	1,956	1,848	2,312	2,277	2,032	2,448
Number of new wells completed	1,045	1,132	1,280	1,569	1,525	1,652
Number of new zones completed	1,081	1,172	1,341	1,646	1,391	1,692
Oil zones	660	507	701	923	789	862
Gas zones	374	601	579	606	542	736
Service zones	47	64	61	117	60	94

TABLE 49.—*Oil, gas, and geothermal operations on Federal and Indian lands, calendar years 1972–77*—Continued

Activity	1972	1973	1974	1975	1976	1977 (estimated)
Oil and gas lease operations—Continued:						
Total number of completed wells	37,441	38,199	38,372	38,218	37,835	38,529
Total number of completed zones	39,159	39,991	40,251	40,292	39,470	39,950
Oil zones	23,282	23,139	22,791	21,868	21,101	21,091
Gas zones	10,421	11,083	11,487	12,272	12,211	12,800
Service zones	5,456	5,769	5,973	6,152	6,158	6,268
Oil and gas production:						
Oil and condensate (barrels in millions)	217	208	208	200	195	188
Percentage of domestic production	6.3	6.2	6.4	6.3	6.7	6.6
Gas (cubic feet in billions)	1,124	1,153	1,234	1,111	1,209	1,150
Percentage of domestic production	5.0	5.1	5.6	5.3	6.1	5.8
Gasoline and LPG (gallons in millions)	641	669	567	521	461	577
Percentage of domestic production	2.4	2.5	2.2	2.1	1.9	2.2
Status of geothermal leases:						
Total number of leases in effect	------	------	------	552	915	1,032
Total area (acres in thousands)	------	------	------	1,270	1,760	2,017

TABLE 50.—*Royalties from oil and gas leases on Federal and Indian lands, calendar years 1972–77*

[Dollars in thousands]

Commodity	1972	1973	1974	1975	1976	1977 (estimated)
Total royalties	**$115,204**	**$34,568**	**$219,630**	**$243,345**	**$279,066**	**$297,150**
Total production value	(918,360)	(1,074,758)	(1,728,536)	(1,915,768)	(2,156,497)	(2,327,185)
Oil and condensate:						
Royalties	87,594	100,963	176,566	193,608	200,864	191,000
Production value	(678,085)	(783,149)	(1,349,656)	(1,459,088)	(1,499,835)	(1,435,000)
Gas:						
Royalties	25,905	31,263	39,798	47,508	74,616	99,900
Production Value	(206,625)	(248,768)	(315,490)	(374,785)	(593,659)	(791,000)
Gasoline and LPG:						
Royalties	1,686	2,323	3,238	3,789	3,132	4,600
Production value	(33,226)	(42,398)	(62,758)	(76,632)	(60,636)	(93,685)
All others:						
Royalties	19	19	28	440	454	750
Production value	(424)	(443)	(632)	(5,263)	(2,367)	(7,500)

TABLE 51.—*Mining operations on Federal and Indian lands, by activity and by commodity, fiscal years 1972–77*

Activity and commodity	1972	1973	1974	1975	1976	Transition quarter	1977 (estimated)
Total number of leases supervised	**2,647**	**2,579**	**2,488**	**2,479**	**2,557**	**2,575**	**2,591**
Total area (acres in thousands)	**5,924**	**7,566**	**7,830**	**7,977**	**9,096**	**9,167**	**9,223**
Total number of producible mines	**343**	**338**	**377**	**435**	**450**	**450**	**460**
Total commodity production (tons in thousands)	**39,004**	**42,028**	**54,978**	**76,113**	**81,554**	**21,000**	**99,217**
Coal:							
Number of leases supervised	560	561	563	565	570	573	578
Area (acres in thousands)	934	1,038	977	1,023	1,057	1,060	1,075
Production (tons in thousands)	18,966	24,247	32,139	43,590	52,491	14,000	68,000
Percentage of domestic production	3.2	4.1	5.4	7.2	7.9	8.5	9.0
Phosphate:							
Number of leases supervised	226	219	194	194	279	280	279
Area (acres in thousands)	136	131	100	100	114	114	114
Production (tons in thousands)	3,124	3,156	6,258	5,772	6,937	1,500	5,125
Percentage of domestic production	7.7	7.4	14.0	11.8	13.9	12.0	9.0

TABLE 51.—*Mining operations on Federal and Indian lands, by activity and by commodity, fiscal years 1972–77*—Continued

Activity and commodity	1972	1973	1974	1975	1976	Transition quarter	1977 (estimated)
Potash:							
Number of leases supervised	164	163	158	161	163	163	160
Area (acres in thousands)	249	246	238	237	237	237	231
Production (tons in thousands) [1]	3,345	3,442	3,551	3,302	3,576	1,000	4,890
Percentage of domestic production	72.0	75.5	79.2	87.8	81.3	83.0	89.0
Sodium:							
Number of leases supervised	87	84	84	84	89	90	90
Area (acres in thousands)	133	132	132	132	136	138	133
Production (tons in thousands)	2,606	2,336	2,092	2,826	3,311	950	2,527
Percentage of domestic production	66.5	50.5	45.4	58.9	69.2	79.4	55.0
Oil shale:							
Number of leases supervised	--------	--------	4	4	4	4	4
Area (acres in thousands)	--------	--------	20.4	20.4	20.4	20.4	20.4
Production (tons in thousands)	--------	--------	--------	--------	--------	--------	------
Other:							
Number of leases supervised	1,610	1,552	1,485	1,471	1,452	1,465	1,480
Area (acres in thousands)	4,472	6,019	6,363	6,465	7,532	7,598	7,650
Production (tons in thousands)	10,963	8,847	10,938	20,623	15,239	3,550	18,675

[1] Converted to refined tons, 1977 estimated in part.

TABLE 52.—*Revenues from mining leases on Federal and Indian lands, by commodity, fiscal years 1972–77*

[Dollars in thousands; details may not add to totals because of rounding]

Commodity	1972	1973	1974	1975	1976	Transition quarter	1977 [2]
Total revenue	**$14,841**	**$16,484**	**$470,464**	**$31,596**	**$36,479**	**$11,012**	**$52,531**
Bonuses	------	34	449,192[1]	4	50	12	50
Total royalties	14,841	16,450	21,272	31,560	36,429	11,000	52,481
Total production value	(301,665)	(335,282)	(463,811)	(681,281)	(813,221)	(240,000)	(1,059,553)
Coal:							
Royalties	3,119	4,044	5,535	8,335	10,949	3,000	15,526
Production value	(78,256)	(93,307)	(140,307)	(224,947)	(337,312)	(97,000)	(510,857)
Phosphate:							
Royalties	811	842	1,618	1,538	1,868	500	1,591
Production value	(9,674)	(11,314)	(31,158)	(28,383)	(25,769)	(6,000)	(20,424)
Potash:							
Royalties	3,104	3,270	3,962	5,565	6,321	1,800	6,279
Production value	(72,227)	(75,872)	(96,897)	(132,518)	(144,693)	(40,000)	(148,751)
Sodium:							
Royalties	2,531	2,547	2,439	5,046	7,364	2,600	7,016
Production value	(59,728)	(58,179)	(56,240)	(109,590)	(155,612)	(51,000)	(143,387)
Copper:							
Royalties	153	158	563	1,331	1,328	328	2,831
Production value	(2,995)	(2,691)	(6,087)	(7,140)	(7,347)	(1,750)	(31,925)
Fluorspar:							
Royalties	70	86	31	------	11	5	1
Production value	(698)	(865)	(322)	------	(180)	(100)	(12)
Lead and zinc:							
Royalties	1,695	2,192	3,241	5,109	3,677	950	5,652
Production value	(42,195)	(54,640)	(75,319)	(115,340)	(81,564)	(22,000)	(125,265)
Limestone:							
Royalties	3	4	6	10	------	------	------
Production value	(20)	(54)	(86)	(83)	------	------	------
Sand and gravel:							
Royalties	886	623	633	842	505	125	188
Production value	(9,713)	(6,846)	(7,430)	(18,774)	(12,431)	(3,200)	(1,534)

See footnotes at end of table.

TABLE 52.—*Revenues from mining leases on Federal and Indian lands, by commodity, fiscal years 1972–77*—Continued

Commodity	1972	1973	1974	1975	1976	Transition quarter	1977 [2]
Silica—pumice:							
Royalties	------	1	------	------	------	------	13
Production value	------	(14)	------	------	------	------	(1,197)
Uranium:							
Royalties	2,205	2,303	2,224	2,664	3,191	800	11,955
Production value	(18,394)	(18,822)	(22,014)	(16,938)	(23,912)	(6,000)	(45,322)
Zinc:							
Royalties	214	336	936	1,006	1,001	350	1,388
Production value	(5,219)	(8,207)	(22,806)	(24,413)	(22,240)	(8,000)	(30,258)
Other:							
Royalties	50	42	84	56	214	542	41
Production value	(2,546)	(4,490)	(5,146)	(3,155)	(2,161)	(4,950)	(621)

[1] Includes bonuses of $448,797,000 from four competitive oil-shale lease sales.
[2] *1977 estimated in part.*

TABLE 53.—*Information products ordered from the EROS Data Center, fiscal years 1975–77*
[Dollars in thousands; dollar amounts may not add to total because of rounding]

Product	1975		1976		Transition quarter		1977	
	Images	Value	Images	Value	Images	Value	Images	Value
Totals	**414,084**	**$1,610**	**407,395**	**$2,589**	**104,414**	**$718**	**325,992**	**$2,515**
Landsat images	195,125	760	246,449	1,238	50,804	274	130,100	1,083
Landsat computer-compatible data tapes	879	169	2,289	404	1,010	178	1,887	371
Gemini, Apollo, and Skylab images and photographs	28,049	113	9,664	86	1,405	15	3,534	52
Aerial photographs	190,031	567	148,993	735	51,195	221	190,471	789
Miscellaneous Landsat special products	------	-----	------	125	------	30	------	220

TABLE 54.—*U.S. Geological Survey Library operating statistics, fiscal years 1972–77* [1]
[N.A., not applicable]

Activity	1972	1973	1974	1975	1976	Transition quarter	1977	Estimated total holdings
Library acquisitions:								
Total items	**94,445**	**84,208**	**91,047**	**136,106**	**116,927**	**25,077**	**170,960**	**2,246,964**
Bound and unbound issues of periodicals and serials	50,322	45,499	48,095	49,775	58,360	14,890	60,122	718,372
Books and monographs	7,693	7,183	11,600	12,891	11,796	1,666	11,731	340,193
Pamphlets and reprints	2,660	2,425	2,901	2,798	6,927	1,863	7,197	365,987
Single-sheet maps	19,817	20,653	19,439	21,777	20,873	3,102	14,045	388,020
Photographs, negatives, slides and transparencies	12,558	7,121	7,818	3,485	15,387	3,222	8,261	226,870
Aerial photographs	1,100	1,019	812	45,000	1,888	125	3,111	57,124
Field record notebooks and related materials	295	308	382	380	1,104	209	362	13,675
Microforms	-----	-----	-----	------	592	-----	66,131	136,723
New serial titles (number of titles)	959	650	434	657	631	204	358	N.A.

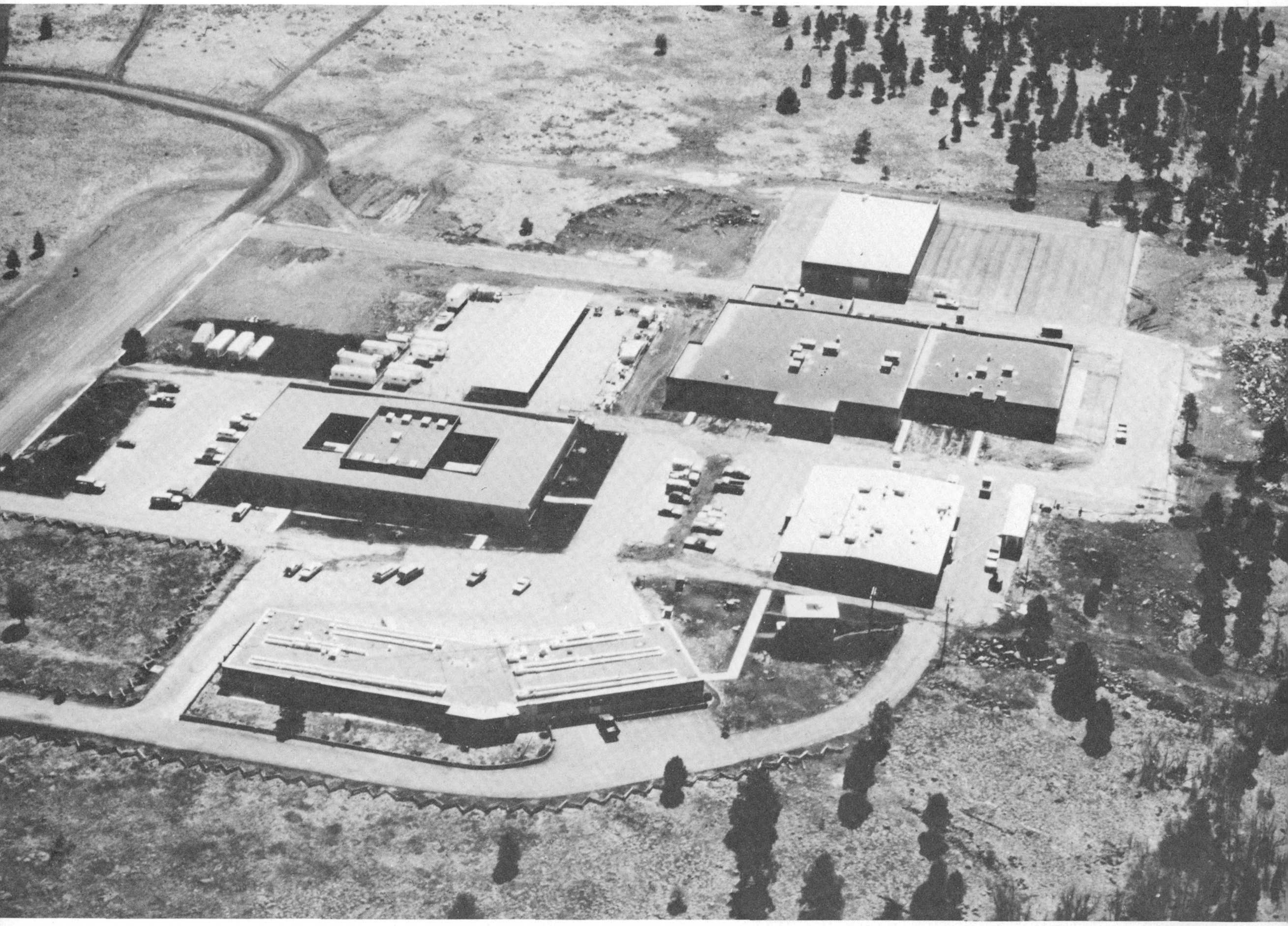
See footnotes at end of table.

TABLE 54.—*U.S. Geological Survey Library operating statistics, fiscal years 1972–77* [1]—Continued

Activity	1972	1973	1974	1975	1976	Transition quarter	1977	Estimated total holdings
Library circulation:								
Total items	**69,302** [2]	**66,327** [2]	**61,656** [2]	**80,991** [2]	**95,814** [2]	**24,575** [2]	**112,766**	N.A.
Books and periodicals	66,627	63,980	59,402	76,658	87,611	23,058	80,855	N.A.
Maps	2,675	2,347	2,254	4,333	8,203	1,517	6,736	N.A.
Other (slides, aerial photos, well logs, microforms, and negatives	-----	-----	-----	----	-----	-----	25,175	N.A.
Interlibrary loans:								
Total items	**19,156**	**16,308**	**15,252**	**20,356**	**18,977**	**4,767**	**19,705**	N.A.
Items loaned	16,138	13,818	13,073	16,965	15,144	3,407	15,123	N.A.
Items borrowed	3,018	2,490	2,179	3,391	3,833	1,360	4,582	N.A.
Reference queries	13,093	11,358	14,047	14,774	17,765	3,836	28,507	N.A.

[1] Statistics include the operations of the Survey's main library in Reston, Va., and branch libraries in Denver, Colo., Menlo Park, Calif., and Flagstaff, Ariz.

[2] Does not include slides, aerial photos, well logs, microforms, or negatives.



Geological Survey Flagstaff Field Center. *(Photograph by Gordon Swann.)*


U.S. GEOLOGICAL SURVEY
250 DOLLARS FINE FOR DISTURBING THIS MARK
ELEVATION
ABOVE SEA
CUMBERLAND
1897
FEET

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.