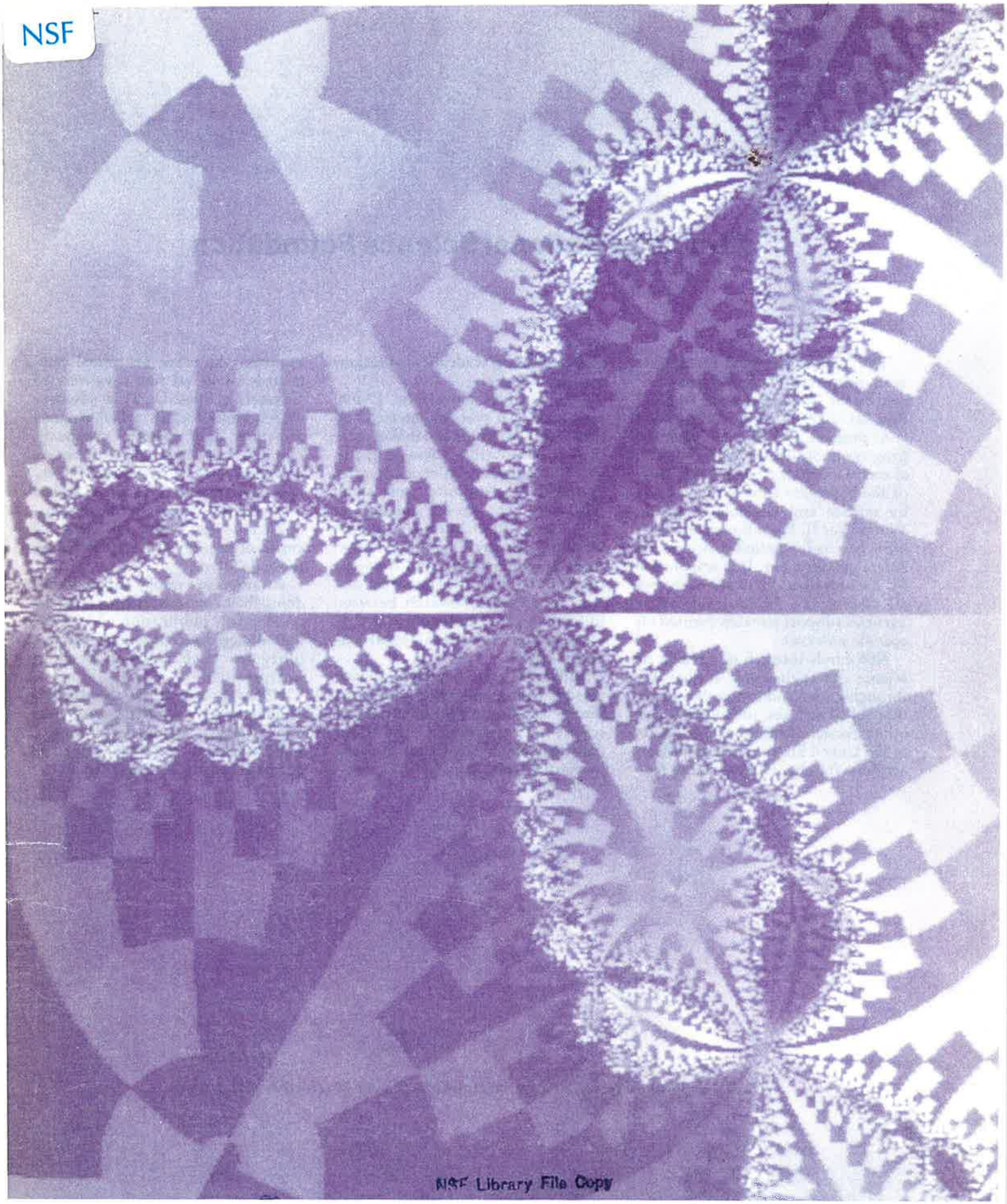
National Science Foundation Annual Report 1983



About the National Science Foundation

The National Science Foundation is an independent federal agency created by the National Science Foundation Act of 1950 (P.L. 81-507). Its aim is to promote and advance scientific progress in the United States. The idea of such a foundation was an outgrowth of the important contributions made by science and technology during World War II. From those first days, NSF has had a unique place in the federal government: It is responsible for the overall health of science across all disciplines. In contrast, other agencies support research focused on specific missions.

NSF funds research in all fields of science and engineering. It does this through grants and contracts to more than 2,000 colleges, universities, and other research institutions in all parts of the United States. The Foundation accounts for about 28 percent of federal support to academic institutions for basic research.

NSF receives more than 27,000 proposals each year for research and graduate fellowships and makes more than 12,000 awards. These go to universities, colleges, academic consortia, nonprofit institutions, and small businesses. The agency operates no laboratories itself but does support National Research Centers, certain oceanographic vessels, and Antarctic research stations. The Foundation also aids cooperative research between universities and industry and U.S. participation in international scientific efforts.

NSF is structured much like a university, with grant-making divisions for the various disciplines and fields of science and engineering. The Foundation's staff is helped by advisors, primarily from the scientific community, who serve on formal committees or as ad hoc reviewers of research proposals. This advisory system, which focuses on both program direction and specific proposals, involves more than 50,000 scientists and engineers a year. NSF staff members who are experts in a certain field or area make final award decisions; applicants get verbatim unsigned copies of peer reviews and can appeal those decisions.

Awardees are wholly responsible for doing their research and preparing the results for publication. Thus the Foundation does not assume responsibility for such findings or their interpretation.

NSF welcomes proposals on behalf of all qualified scientists and engineers and strongly encourages women, minorities, and the handicapped to compete fully in its programs.

Cover: Order and chaos in Newton's method (see chapter 4 for further explanation)

National Science Foundation (U.S.)

Thirty-Third Annual Report for Fiscal Year 1983

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Letter of Transmittal

Washington, D.C.

DEAR MR. PRESIDENT:

I have the honor to transmit herewith the Annual Report for Fiscal Year 1983 of the National Science Foundation, for submission to the Congress as required by the National Science Foundation Act of 1950.

Respectfully,

Edward A. Knapp
Director, National Science Foundation

The Honorable
The President of the United States

Contents

A Vital Enterprise

EDWARD A. KNAPP
Director

These are exciting times to be an American scientist or an American engineer. Never has the pace of innovation and the discovery of new knowledge about the world around us—and within us—seemed faster. We are dazzled almost every day by discoveries that promise to improve the quality of our lives—intellectually, economically, physically, and aesthetically.

The pace of discovery is fast not only in our own country but around the world. Because of this, we find ourselves in a highly competitive international race for excellence in science and technology. We welcome this competition, believing that we have unique ways to train and support scientists and engineers. Before we were challenged, we often took the strengths of our remarkable scientific enterprise for granted. Now we recognize these strengths and are beginning to exploit them to their fullest.

Scientists and engineers—and the society at large—are reaping the benefits of the resulting revitalization of American science and technology. The support of basic science and engineering is strong, and we can look forward to continued strong support in the foreseeable future.

This annual report for 1983 is a sampling of the many NSF-supported accomplishments of the past year. Let me list some of them here:

- *Biology*—NSF support for Postdoctoral Research Fellowships in Plant Biology, begun in 1983, will accelerate molecular and cellular approaches to plant biology by encouraging young, well-trained biological and physical scientists to pursue research careers in plant science. The fellowships will thus fill a gap that now exists in plant research.

  To show the importance of such research, a basic study of photosynthesis last year led to the development of a new diagnostic tool to localize and identify foreign or altered cells in our bodies. This research is an example of how unanticipated benefits can emerge from what began as an esoteric fundamental study. It also reveals how quickly basic research can lead to a marketable product in the fast-growing area of biotechnology (in this case, about six months).
- *Astronomy and Atmospheric Sciences*—Using telescopes at NSF-supported facilities, scientists witnessed the birth of a star—a first for astronomers—and discovered evidence of what may be

the first black hole outside the Milky Way galaxy. Astronomers also found the two fastest-spinning radio pulsars discovered in the past 15 years or so and spotted the first large gas cloud outside a galaxy.

Atmospheric studies yielded new information about small-scale but severe weather systems, atmospheric chemistry, and climate. The probable benefits of this research include immediate improvements in the accuracy of weather forecasts and warnings about such phenomena as lightning; cost-effective and environmentally sound control strategies to deal with acid rain; and ways to protect the ozone layer. Atmospheric scientists also made the surprising discovery that termites are a major source of the world's supply of methane gas. Though only a trace gas, methane seems to be increasing in the atmosphere and contributes to the gradual warming of the atmosphere that we call the greenhouse effect.

- *Physics*—There was important work on the concept of supersymmetry as a key to understanding elementary particles and the basic forces of nature, perhaps even contributing to a grand unified theory about those forces. In other research, physicists worked to develop the atomic clock technique, which lets scientists measure times in a much shorter range than present electronic methods allow. Still another development was use of a supercomputer to obtain the first high-resolution studies of the physics of fluids near a black hole.
- *Chemistry*—One possible benefit of recent membrane research is the use of synthetic vesicles as transport vehicles for drugs in the body. Another team of chemists found that certain compounds produced in white blood cells are key factors in the human immune system. Still other researchers produced a family of organic molecules that bind to metal ions in an unusual way. These "chelating" agents may one day be used in fields ranging from medicine to metallurgy.
- *Engineering*—In 1983, construction began on the first building in the United States to use the new seismic resisting technique of base isolation, founded on the premise that horizontal ground motions can be significantly reduced before they are transmitted to a building. This southern California structure will be the largest in the world built on shock-isolator devices.

  Engineers also developed a mathematical model for an infarcted heart ventricle. The model has not only made it possible to assess the extent of heart attack damage more accurately but has also revealed new information about stress in the region adjacent to the infarcted zone. Significant engineering advances in the field of factory automation include a new feeding machine that helps robots locate and identify pieces, and robot vision systems coupled with pattern recognition algorithms so that a "sighted" robot can select a piece from a supply of random parts, then properly position it for operation.
- *Earth and Ocean Sciences*—The results of NSF-supported research in earth science have helped scientists find and evaluate fuel and mineral resources, predict earthquakes and volcanic eruptions, assess construction sites, and dispose of toxic and radioactive wastes. U.S. oceanographers can now make detailed, real-time maps of the sea floor from a moving survey ship. And direct sampling of the oceanic crust and sediments through drilling operations has confirmed the concept of plate tectonics.
- *Antarctic Research*—During the 1982-83 season, U.S. scientists worked on 85 research projects in the Antarctic, one of science's most challenging frontiers. Among the disciplines represented were astronomy, upper-atmosphere physics, meteorology, glaciology, geology and geophysics, physical and chemical oceanography, and biology. NSF is the lead U.S. agency involved in the international research efforts on this coldest of continents.

Finally, during 1983 we also looked back to NSF's beginnings with publication of *A Patron for Pure Science: The National Science Foundation's Formative Years, 1945-57*, by J. Merton England. This is the first volume of the official NSF history and a valuable study of early U.S. science policy.

These are noteworthy achievements. But with the increased support for basic research in general, and NSF-supported research in particular, come wonderful opportunities for the Foundation. We are reinvigorating what's best about NSF and redirecting those things that can be done better. We are changing the way we do business—developing new programs, improving the way we administer others—as we seek to guard and guide the health of the whole American science enterprise.

For example, I have instituted a new management plan for NSF in which our program officers take responsibility for a broad range of concerns. These include more involvement in our science and technology enterprise by small, chiefly undergraduate colleges and by such groups as female and minority scientists and engineers. We think this move will lead to general improvement of our research capabilities.

We are also pushing hard to strengthen the base for experimental research, and we are now able to respond to the needs of scientific areas that have been suffering neglect. For example, equipment is outmoded at many universities and colleges throughout the country. During times when funding decreased or remained constant, these institutions were forced to choose between equipment and people. Of the two, purchasing equipment was the easiest to delay. Now we are no longer faced with a choice between equipment and people, but a choice between people and equipment on one hand and inadequate research on the other.

Computers, uniquely, make up a class of instrument used in almost every science and engineering discipline today. Much of the strength and vitality of the Nation's science and technology enterprise depends on the access of university researchers to state-of-the-art computers. In 1983, we began a modest activity to increase academic access to advanced computers. We look forward to expanding this activity considerably in the future.

We continue to be concerned about educating tomorrow's scientists and engineers today; our efforts to improve precollege science and mathematics education are expanding. At the other end of the education spectrum, where taking part in research forms the apprenticeship of our scientists and engineers, we want to strengthen the link between excellence in research and excellence in education.

This past year has been rewarding for all of us concerned with the health of American science and engineering. But even as we review the accomplishments of 1983, we look forward to an equally exciting and rewarding 1984.

Astronomical, Atmospheric, Earth, and Ocean Sciences

1

NSF supports geophysical research mainly through these programs. Scientific investigations of the earth, its atmosphere, and the observable universe beyond focus on the how, when, where, and why of significant events and conditions. Researchers then use the knowledge they gain to assess mankind's effect on the environment.

In 1983 support for ground-based and theoretical astronomy came through five grant programs to more than 140 universities, plus backing for five national astronomy centers. Some far-reaching scientific advances:

- Observational work at radio, optical, gamma-ray, ultraviolet, and X-ray frequencies has uncovered a profusion of explosive objects and high-energy, short-term phenomena. Their existence had been unknown before. In addition, observations at radio wavelengths revealed a gaseous interstellar medium rich in more than 60 species of molecules, many of them organic and quite complex.
- More sensitive electronic-array detectors have made it possible to map radiating sources hundreds of times fainter and more distant than anything mapped before.
- Astrophysicists were able to assess many of the effects of such phenomena as mass loss, binary star interactions, magnetic fields, and rotation on the structure and evolution of the stars.

Atmospheric research concentrates on the behavior of the earth's atmosphere and interactions between the atmosphere and the sun. NSF provides the primary backing for atmospheric research to university and private-sector groups in the United States; it also supports the National Center for Atmospheric Research (NCAR) and the Upper Atmosphere Facilities (UAF). NCAR, in Boulder, Colorado, handles large scientific research programs that could not be done easily by a single university. The UAF supports four incoherent-scatter radar facilities in a chain stretching from Greenland through the United States and from Puerto Rico to Peru.

Modern atmospheric studies have yielded new information about small-scale severe weather systems, atmospheric chemistry, and climate. The probable benefits are noteworthy:

- Immediate improvements in the accuracy of forecasts and warnings about such phenomena as lightning.
- Better climate-prediction techniques.
- Cost-effective and environmentally sound control strategies to deal with acid rain.
- Protection of the ozone layer.
- Predictive models for long-term climate change.

Earth science research backed by NSF explores the structure and composition of the continental lithosphere (the earth's outer surface); studies the earth's evolution from its beginning to the present; develops quantitative models for the evolution of sedi-

Table 1
Astronomical, Atmospheric, Earth, and Ocean Sciences
Fiscal Years 1982 and 1983
(Dollars in Millions)

	Fiscal Year 1982		Fiscal Year 1983	
	Number of Awards	Amount	Number of Awards	Amount
Astronomical Scis., Nat'l. Research Centers	212	$59.10	240	$62.72
Atmospheric Sciences, Nat'l. Research Centers	477	70.34	519	75.51
Earth Sciences	540	29.49	624	34.85
Ocean Sciences	747	95.03	710	102.53
U.S. Antarctic Prog.	152	68.50	165	83.20
Arctic Research	78	5.90	68	6.22
Subtotal	2,206	$328.36	2,326	$365.03
Adjustment to Internat'l Awards	--	--	--	-1.03*
Total	**2,206**	**$328.36**	**2,326**	**$364.00**

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.
SOURCE: Fiscal Years 1984 and 1985 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

mentary basins; seeks a better understanding of tectonic processes; and develops a model of convection in the earth's interior. Accompanying the theoretical and technological developments is a growing demand for basic knowledge about the earth, in order to solve practical problems. Advances in this field reflect that relationship between the theoretical and the practical:

- In 1983 the study of plate tectonics moved ahead with the development of tools that permit new kinds of critical observations.
- Seismic reflection profiling has produced a high-resolution probe for deeper parts of the continental crust, thus making new discoveries possible.
- The results of NSF-supported research have helped scientists find and evaluate fuel and mineral resources, predict earthquakes and volcanic eruptions, assess construction sites, and dispose of toxic and radioactive wastes.

Oceanography is a rapidly growing discipline; its boundaries with earth, atmospheric, and biological sciences remain dynamic. Oceanographers can now study global ocean processes by using new techniques and instruments such as satellites, acoustic and optic remote sensing, instrumented buoys, and powerful computers. Ocean coring and drilling techniques developed in recent years now permit direct investigations of climatic processes. Satellites can detect ocean currents by mapping surface waters discolored by suspended sediments of phytoplankton.

Major advances in 1983 continued through interdisciplinary activities such as those aboard the deep-sea research submersible *Alvin*. For example, biologists, chemists, physical oceanographers, and geophysicists using the *Alvin* have investigated hydrothermal systems on the sea floor. U.S. oceanographers can now make detailed, real-time maps of that floor from a moving survey ship. Direct sampling of the oceanic crust and sediments by drilling has confirmed the concept of plate tectonics.

The arctic program managed by NSF supports research in five disciplines: atmospheric, biological, and earth sciences; glaciology, and oceanography. Achievements in arctic research affect our understanding of the earth as a whole.

During 1983 arctic researchers continued to study the general effects of atmospheric structure and makeup on the polar region. They also investigated glaciers and polar marine ecosystems—notably the impact of physical and chemical factors on the population dynamics of important species.

Astronomy

Traditionally, astronomy has been concerned with phenomena that take place over very long time periods. The life of a star, for example, is measured in billions of years. However, new, large-aperture optical and radio telescopes and new types of detectors sensitive to previously inaccessible wavelengths (gamma-rays, X-rays, the ultraviolet, and the infrared) show a profusion of explosive objects and high-energy, short-term phenomena whose existence was hardly expected a few years ago.

The death of one generation of stars as supernovas sends shocks through the gas and dust of the interstellar medium, precipitating the birth of the next generation of stars. We have long known that heavy elements are synthesized by nuclear fusion in stellar cores and dispersed by supernova explosions, enriching later generations of stars. A key factor in both stellar and galactic evolution is the unexpectedly large rate of mass loss through stellar winds. Mass exchange between close binary stars can drastically alter the course of their life cycles and contribute to the formation of gaseous circumstellar disks whose instabilities may lead to nova outbursts.

Many sources of X-rays and gamma-rays are thought to be gas-accreting neutron stars and black holes, collapsed objects marking the demise of massive stars. The origin of high-energy radiation in the centers of galaxies, including our own Milky Way, may be the accretion of whole stars onto supermassive black holes. These voracious hulks could be the residue of a temporary, active phase which the nuclei of most galaxies undergo and which we observe as a quasar.

Collisions and gravitational interactions between galaxies seem to have significant effects on the evolution of galaxies in clusters. Studies of the three-dimensional distribution of galaxies and computer simulations of galaxy formation are revealing fascinating glimpses of the early universe. Of particular interest is how the universe developed from an expanding, uniform mixture of radiation and particles into a cosmos characterized by a seemingly endless hierarchy of clustering.

Common to many of the recent discoveries in these and other areas—and critical to the solution of many remaining problems—is the availability of large instruments and electronic detectors of increasing power, sensitivity, and resolution.

The Foundation supports astronomical research at more than 140 universities, private and federally owned observatories, and industrial firms. It does this through research grants and through contracts for the national observatories. Studies of the composition, structure, and evolution of the sun, the solar system, stars, the interstellar medium, and galaxies all receive funding. NSF also promotes the development of new instrumentation and computing capabilities to aid in these studies.

Finally, astronomers throughout the nation are able to observe in the optical, infrared, and radio portions of the spectrum at these five national astronomy centers supported by NSF: The National Astronomy and Ionosphere Center, Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory, The National Radio Astronomy Observatory, and The National Solar Observatory.

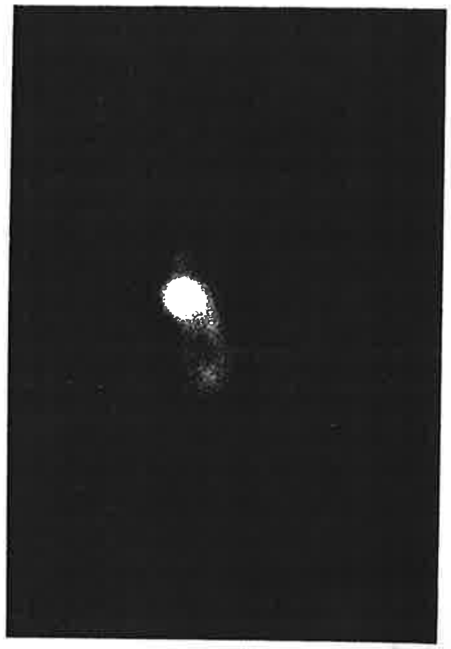
Stellar Birth and Death

New stars are continuously born out of the clouds of gas and dust that stud the plane of our Milky Way galaxy. For several reasons, though, the actual birth of a star is difficult to observe. At optical wavelengths, for example, clouds near the sun obscure our view. In addition, the condensing protostars remain shrouded by infalling dust.

Star formation takes place over a span of about 10,000 years, long by terrestrial standards but short on astronomical time scales. Eventually, the energy released by the collapsing material raises the temperature in the core of an infant star enough to ignite self-sustaining nuclear reactions. At that moment, the star begins to shine, but it remains observable only at infrared and radio wavelengths until radiation pressure and particle winds clear away its dusty cocoon.

This moment of birth has now been witnessed for the first time by John Graham of the Cerro Tololo Inter-American Observatory (CTIO). On a photographic plate taken with Yale University's one-meter optical telescope at CTIO, the newborn star is visible at the tip of a luminous cloud called a Herbig-Haro object. Earlier photographs from other observatories show no trace of the star—aside from a recent plate from the Siding Spring Observatory in Australia. There the star is visible but so faint that it was not noticed.

The endpoint of a star's life is also difficult to observe. When a star exhausts all the nuclear fuel in its core, it collapses to form a small, high-density object. If the star is less than about 1.3 solar masses, it becomes a faint, slowly cooling white dwarf. If it is more massive than this but less than about 2.6 solar masses, it undergoes a supernova explosion, and its core survives as an even smaller and denser object known as a neutron star. If the mass of the star exceeds 2.6 solar masses, the pressure buildup never becomes sufficient to halt the star's collapse and it becomes a center of gravitational attraction so intense that not even light can escape—a black hole.



A star is born. A photograph taken with the four-meter Cerro Tololo telescope shows the first star whose birth has been witnessed optically. As it brightens, the star is lighting up the dust in the gaseous knot out of which it condensed. Scientist Anne Cowley is seen in second photo. Along with British Columbia scientists David Crampton and John Hutchings, she announced the discovery of the first black hole outside the Milky Way galaxy.

A black hole can be observed only by indirect means, such as by its gravitational influence on a companion star or by X-rays emitted by infalling gas around such a star. While some X-ray sources may be black holes, the only way this can be ascertained is to estimate the object's mass based on the orbital motion of a visible companion. The only object in our galaxy that has been thus inferred to be a black hole is the X-ray source Cygnus X-1. The discovery of the first extragalactic candidate was announced by Anne Cowley of the University of Michigan and David Crampton and John Hutchings of the Dominion Astrophysical Observatory in British Columbia. They used the four-meter optical telescope at CTIO in a study of X-ray sources in a small, neighboring galaxy called the Large Magellanic Cloud. The black hole candidate has between 8 and 12 solar masses.

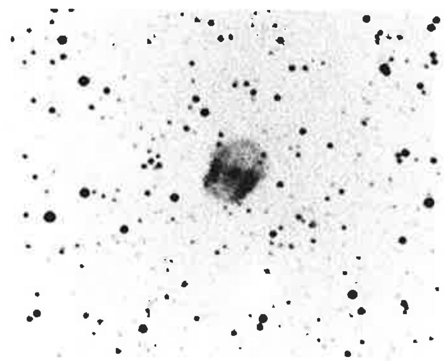
Stellar Cannibalism

Unlike the sun, most stars are members of binary systems, born simultaneously and bound gravitationally, usually in pairs but sometimes in multiples of up to perhaps six. While binary stars have been known for centuries, the differences between the life cycles of single and binary stars are only now being fully appreciated.

Binary components so close together that their orbital period is measured in hours distort one another tidally into elongated spheroids. When the hydrogen fuel in a star's core is exhausted at the end of the star's main-sequence phase of evolution, the interior collapses, releasing so much energy that the outer layers expand to the enormous dimensions of a "red giant" star. If this object is a member of a close binary, gas in its outer layers can gravitate to the companion star—often a small, collapsed object such as a white dwarf or a neutron star. In that case, the gas has too much angular momentum to fall directly onto the smaller star but orbits around it, forming what is called an accretion disk. Sudden instabilities in this disk are thought to produce thermonuclear explosions on the star's surface, causing the brilliant outbursts of novas and other cataclysmic variable stars.

One implication of this scenario is that the mass exchange just described initially operated in the opposite direction. The more massive a star is, the faster it evolves. Since binary components are the same age, the collapsed star must have originally been the more massive and hence passed through the red giant phase first, while its companion was still a main-sequence star. Some of the red giant's mass might then have been transferred to its companion, accelerating the latter's evolution. This stellar cannibalism is so short lived that instances of it are rarely observed. However, astronomers now think that such cannibalism may explain an enigmatic product of stellar evolution: the planetary nebula.

Albert Grauer of the University of Arkansas and Howard Bond of Louisiana State University were using optical telescopes at Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory, and Louisiana State University Observatory when they discovered that the central stars of four planetary nebulas are binaries. These nebulas are luminous shells of gas that have been mysteriously expelled from at least some stars; from earth, the shells appear to be rings or planetlike disks. They dissipate quickly, so the fact that many shells are seen implies that most evolved stars may eject them. Grauer's and Bond's research explains the ejection as a natural consequence of the evolution of close binaries.



Planetary nebula. The close binary system discovered at the heart of the planetary nebula Abell 41 (center of illustration) may be an example of stellar cannibalism. While the red giant star expanded to engulf its main-sequence companion, the latter was actually swallowing gas from the former. The eventual result was the expulsion of the nebular shell. This is an important discovery in stellar research and yet another advance in the oldest science, astronomy.

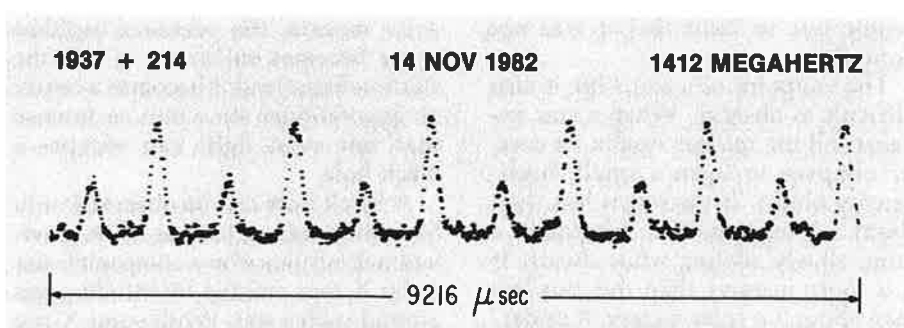
During the cannibal phase, the recipient star may be completely engulfed in the outer layers of its companion and its orbital motion slowed by friction. The swallowed star would then gradually spiral in toward the core of the red giant, much as the orbit of an artificial satellite decays because of atmospheric drag. Energy is transferred to the red giant's outer layers by this process until they are finally expelled, forming a planetary nebula.

This work is an important step in the understanding of stellar evolution.

Two Fast-Spinning Pulsars

Since the discovery of the first radio pulsar in 1967, about 330 such objects have been found; there must be hundreds of thousands in our galaxy alone. These celestial beacons emit short bursts of radio waves periodically from about once a second to hundreds of times a second. For 15 years, the shortest known period was 0.033 second—that of the pulsar in the Crab Nebula. Then, in the course of seven months, astronomers discovered two pulsars having periods near 1 millisecond. This work was done with the 305-meter Arecibo telescope of the National Astronomy and Ionosphere Center (NAIC).

Donald Backer, Shrinivas Kulkarni, and Carl Heiles of the University of California at Berkeley, Michael Davis of NAIC, and Miller Goss of the Kapteyn Laboratorium in the Netherlands have found the first and fastest of these pulsars in the constellation Vulpecula. Designated PSR 1937+214,



A pulsar beat. This tracing shows six cycles of the radio signal from PSR 1937 + 214, a newly found pulsar with a period 20 times shorter than that of the fastest pulsar previously known. The primary and secondary peaks of each pulse cycle are produced by opposite magnetic poles of the rapidly spinning neutron star.

its period is 1.558 milliseconds. Though the object was known before as a radio source, Backer suspected that it was a pulsar, on the basis of its spectrum and other clues. However, only by repeated attempts with modern equipment could the Berkeley team measure the extremely short period and thus confirm the object's identity as a pulsar.

A radio pulsar is believed to be a neutron star, the central remnant of a supernova explosion that marks the evolutionary endpoint of a star of intermediate mass. As they radiate energy away, pulsars must gradually slow down. The fastest spinning pulsars should therefore be the youngest. This does not seem to be the case for PSR 1937+214. Measurements by Joseph Taylor of Princeton University give a very slow rate of "spin-down," which is thought to indicate great age. The explanation may be that this pulsar once rotated slowly but had its spin accelerated by magnetic interaction with a gaseous disk.

Another fast-spinning pulsar, designated PSR 1953+29, was discovered by Valentin Boriakoff of Cornell University and two Italian colleagues, Rosalino Buccheri and Franco Fauci. They were observing gamma-ray sources at radio wavelengths in a search for fast pulsars. The object's period is 6.14 milliseconds. Its unique feature is the fact that it is one of only a handful of radio pulsars known to be binary stars. Though at least half of all stars are binary, interaction with a companion star is believed to limit a pulsar's radio emission.

The astronomers inferred the pulsar's binary nature from a variation in its pulse period. While the observations are not sufficient to yield a mass for the pulsar, and the companion star is not close enough to generate significant gravitational radiation, future study of the system may reveal whether a pulsar can indeed be "spun-up" by a companion star.

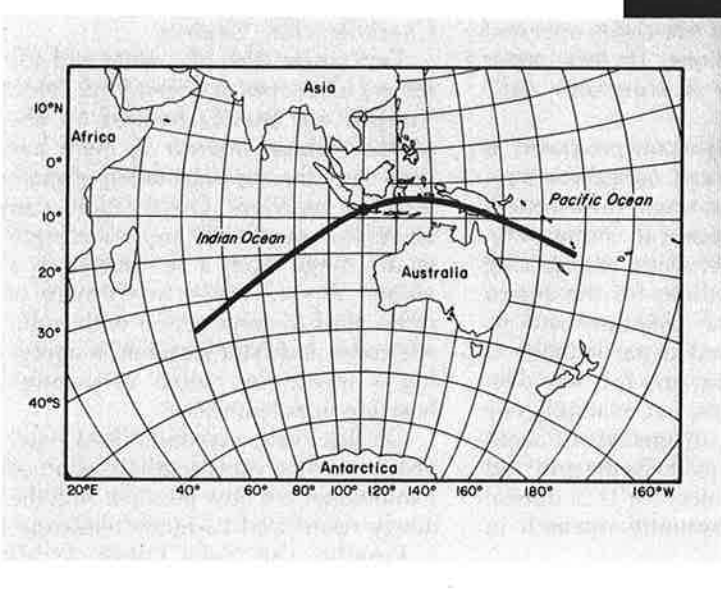
Total Solar Eclipse

NSF activities were national news in Indonesia during the first two weeks of June 1983. The event was the total eclipse of the sun, which took place over the central and eastern portions of the island of Java. NSF sent an expedition consisting of nine scientific teams and more than six tons of equipment to Java for the eclipse.

Preparations for all this began two years ago with advance surveys of conditions, sites, and logistics. After a careful look at all potential sites, a choice was made and the Indonesian government granted NSF's request for a site on the north coast of Java at Tanjung Kodok (Frog Point). A large antenna for television transmission via satellite throughout Indonesia, to Japan, and the rest of the world was installed near this site.

On the day before the eclipse there was a major wind and rainstorm. The winds destroyed most of the souvenir stands that had sprung up around the site and took the roof off a nearby building but left the NSF site and telescopes undamaged.

On eclipse day the science teams, which had been making practice observations all week, began the final countdown. The clouds cleared a few moments before totality, and the total eclipse began. All of the teams obtained excellent data, which were still under analysis at this writing.



Solar eclipse. This photograph was taken on 11 June 1983 by NCAR scientists stationed on the north coast of Java. They used an NCAR-developed camera that suppresses the bright inner corona with a radially graded filter—in order to show the faint, intricate surface structure of the outer corona. Images like this one will help scientists study the interaction between solar magnetic fields and the corona. On the map, the dark swath is the track along which the eclipse was total. The dot marks Java, one of the few places where the phenomenon could be viewed from land. The NCAR team was part of a group of 30 NSF-sponsored researchers participating in the expedition to observe the eclipse.

Intergalactic Gas Cloud

Gas clouds, or nebulas, are common features of the spiral arms of galaxies like our own Milky Way. Composed primarily of neutral hydrogen, they are regions where stars are born when the internal density becomes great enough to cause gravitational collapse. A nebula discovered in the constellation Leo is the first large cloud found well outside any galaxy; previous searches for such objects had not turned up a single one. This cloud was found by accident when Stephen Schneider, George Helou, Edwin Salpeter, and Yervant Terzian at Cornell University were calibrating the NAIC's 305-meter radio telescope during a study of hydrogen gas in other galaxies.

The nebula is about 30 million light-years away and some 300,000 light-years in length—more than three times the size of the Milky Way. The astronomers determined that the cloud is rotating at about 80 kilometers per second. With such a rapid spin, the cloud must have a mass of at least 100 billion solar masses if its gravitational force is to keep it from breaking apart. Its actual mass, however, is about 100 times greater than expected, implying the existence of much unseen matter—perhaps in the form of burned-out stars or black holes. This "missing mass" problem also affects the stability of our own galaxy and the continued expansion of the entire universe.

Astronomers believe that spiral galaxies like our own evolved from rapidly rotating protogalaxies that fragmented into stars, star clusters, and interstellar clouds. Galaxy formation seems to have been confined to an era about 10 to 15 billion years ago. The nebula found by the Cornell team could be a protogalaxy that has so far failed to mature. Similar objects may be as rare as they are because they are usually dispersed or assimilated during collisions with small galaxies. In a quest to resolve such mysteries, the Cornell team has intensified its efforts to locate other intergalactic clouds.

National Astronomy Centers

The *National Astronomy and Ionosphere Center* (*NAIC*) is operated by Cornell University under contract with NSF. The Center supports research programs in radio astronomy, planetary radar astronomy, and atmospheric science. NAIC's principal instrument, located near Arecibo, Puerto Rico, is a 305-meter antenna, the world's largest radio/radar telescope. NAIC also operates two remote sites: a 31-meter antenna, located 11 kilometers north of the observatory and used for interferometry, and the High-Frequency Ionosphere Heating Facility some 17 kilometers north of the main site.

Associated with the Arecibo telescope is a broad spectrum of observing and data processing equipment, including a multitude of receivers, several very powerful radar transmitters, assorted computers, and other instruments.

Kitt Peak National Observatory (*KPNO*), located in the Tucson, Arizona area, is operated under contract with NSF by the Association of Universities for Research in Astronomy, Inc. (AURA). This nonprofit consortium represents 17 universities in the United States. As the nation's main center for optical and infrared astronomy research, KPNO gives U.S. astronomers access to the large telescopes, auxiliary instrumentation, and support services needed for observational and theoretical research in extragalactic, galactic, stellar, and planetary astronomy.

Besides operating 12 telescopes, KPNO offers sites and services on Kitt Peak for six more telescopes operated by other institutions. Its four-meter Mayall reflector is especially well-equipped.

KPNO has important programs in detector development, optical coatings, and diffraction gratings; these benefit the entire astronomical community. Kitt Peak has extensive engineering and technical facilities for the design and fabrication of telescopes and instrumentation, and it participates in development programs for new telescope technologies. For example, one instrument with an aperture of about 15 meters is expected to be the principal ground-based project for U.S. optical and infrared astronomy research in the next decade.

Like KPNO, *Cerro Tololo Inter-American Observatory* (*CTIO*) is run by AURA under contract with the Foundation. This observatory's seven optical and infrared telescopes are the only ones generally available to U.S. scientists for studying the southern skies. They include a four-meter reflector, which is the Southern Hemisphere's largest and a near twin to the KPNO Mayall telescope.

CTIO headquarters are in the coastal town of La Sereña, Chile, some 80 kilometers by road from the mountain site of the telescopes. The latitude of 30 degrees south and the exceptionally good atmospheric conditions over Cerro Tololo furnish ideal conditions for the study of such important Southern Hemisphere objects as the Magellanic Clouds and the central regions of our own galaxy.

Both Kitt Peak and CTIO worked for three years to get more sophisticated detectors in place—systems using the so-called charge-coupled devices or CCDs. By the end of fiscal year 1983, those systems were in service for one CTIO telescope (the 4-meter) and three of the Kitt Peak telescopes. Five CCD data-acquisition and display systems also were in service at the two observatories as FY 1983 ended.

The *National Radio Astronomy Observatory* (*NRAO*) is one of the world's principal centers for radio astronomy. Operated by Associated Universities, Inc., NRAO has telescopes at three sites; its headquarters and a data processing center are in Charlottesville, Virginia.

Two single-dish (91-meter and 43-meter) telescopes at Green Bank, West Virginia are heavily booked by observers, whose interest in them has risen since the implementation of more sensitive receivers. Observations can be made at practically any wavelength in the range from a centimeter to a meter. The 43-meter instrument is often used in conjunction with radio telescopes at distant locations in applying a technique called very-long-baseline interferometry.

On Kitt Peak, a second NRAO site, observations to wavelengths as short as 1 millimeter are now possible with the newly resurfaced 12-meter telescope.

Finally, the Very Large Array

(VLA) near Socorro, New Mexico offers a unique combination of high sensitivity and resolution for radio astronomy observations. Its 27 antennas are routinely used in different location patterns and at four standard-frequency bands for continuum and spectral-line observations.

Workers have finished fitting parts of the VLA and the 43-meter Green Bank telescope with new receivers. Expansion of the VLA wavelength range has begun at this writing, while installation of a second set of intermediate-frequency channels has doubled the system's data rate.

After submitting a proposal to the Foundation for a Very Long Baseline Array, consisting of 10 antennas (25 meters each) stretching from Hawaii to Puerto Rico, NRAO staff started plans for a one-year design study in 1984. This array would dramatically improve resolution over that of any existing ground-based telescope and would open up whole new areas of research in astronomy.

The *National Solar Observatory* (*NSO*) is the world's premier solar observatory. Its Sacramento Peak facility is at an elevation of 2,760 meters in the Lincoln National Forest in New Mexico. Along with NSO's Kitt Peak facility, it enjoys unusually good observing conditions. The Vacuum Tower telescope on Sacramento Peak produces very-high-resolution solar images, revealing the finest details in the solar atmosphere observable from the ground. An impressive array of auxiliary instruments permits extremely accurate measurements of velocity and magnetic fields in the sun's atmosphere.

NSO's McMath Solar Telescope on Kitt Peak is the largest such telescope in the world. Its capabilities include spectroscopic studies of the sun at maximum wavelength resolution. Recent instrumental improvements have extended the high-resolution spectroscopic capability to stars other than the sun. A program of research on solar-type phenomena in other stars is now in place.

Atmospheric Sciences

NSF programs in this area aim to increase our knowledge of the terrestrial atmosphere that extends from the earth's surface to outer space. Seven grant programs—aeronomy, atmospheric chemistry, climate dynamics, meteorology, experimental meteorology, solar-terrestrial research, and the Global Atmospheric Research Program (GARP)—support scientific research on fundamental problems. Atmospheric scientists work to understand the physical bases of climate and weather, natural global cycles of gases and particulates in the earth's atmosphere, and the composition and dynamics of upper atmospheric systems. They also hope to improve our knowledge of the sun and neighboring planets as they relate to earth's upper atmosphere and space environment.

The Foundation also supports the National Center for Atmospheric Research (NCAR) and the Upper Atmospheric Facilities program. NCAR has two major goals: (1) to plan and conduct, in cooperation with the atmospheric sciences community, research programs on selected problems and (2) to develop, maintain, operate, and make available services and facilities required to carry out atmospheric research in universities and at NCAR.

Located in Boulder, Colorado, NCAR is operated by the University Corporation for Atmospheric Research (UCAR), a consortium of 53 institutions with graduate programs in the atmospheric sciences. The Center has an active visitor program in which students and scientists engage in both collaborative and individual research. In 1983 research areas included analyzing and predicting atmospheric behavior, understanding climate and climate change, establishing solar-terrestrial connections, investigating air chemistry, evaluating the environmental and societal impacts of atmospheric problems, and studying convective storms and severe weather.

NCAR also operates state-of-the-art computer facilities for use by atmospheric scientists, along with field facilities that include Doppler radars and instrumented research aircraft. A national computer network and new communications equipment also are in place, making it easier for scientists to use the NCAR computers from their home campuses.

The Upper Atmospheric Facilities program supports the operation of, and scientific research done at, four incoherent-scatter radar facilities. These are located in Sondrestromfjord, Greenland; Millstone Hill, Massachusetts; Arecibo, Puerto Rico; and Jicamarca, Peru. The Greenland radar moved from Chatanika, Alaska during 1982-83 and is now at a much higher magnetic latitude than before.

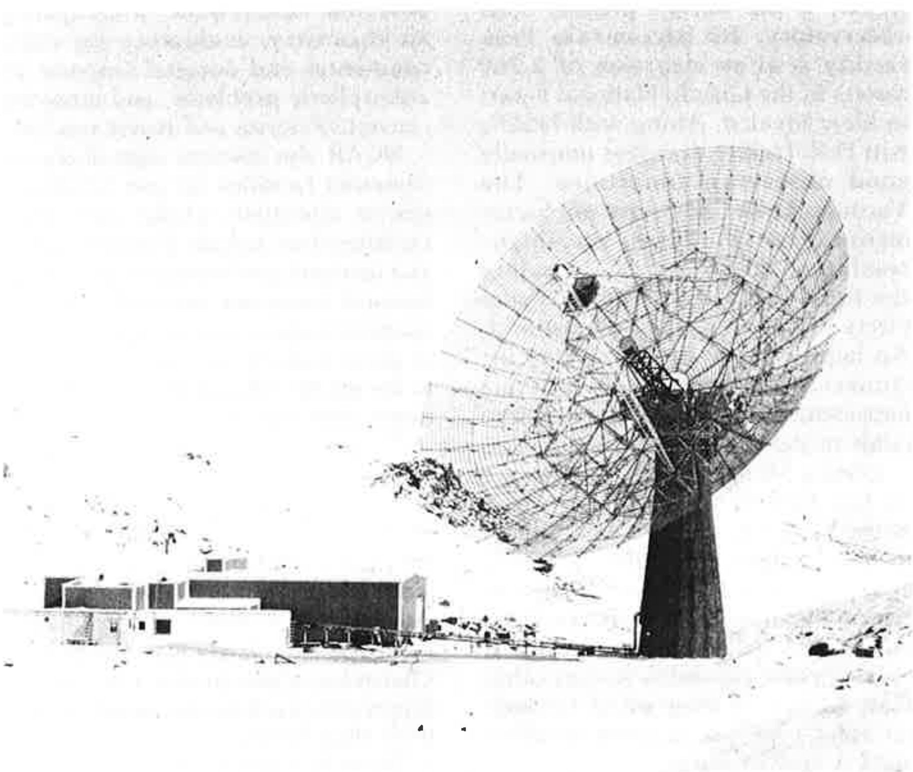
There is a major effort to coordinate the operation of these radars and thus answer questions about global dynamics in the upper atmosphere and ionosphere (which begins about 50 miles up). The facilities are a major form of support for experimental work in aeronomy, or study of the upper atmosphere.

Fiscal year 1983 saw new instrumentation put in service at NCAR and other institutions. Examples are the Portable Automated Mesonet or PAM II system to measure surface meteorological conditions and tunable diode lasers to measure chemicals in the atmosphere.

Lightning Research

The behavior and geographic distribution of lightning continue to puzzle atmospheric scientists. A relatively new tool—a device to locate cloud-to-ground flashes—may solve those problems and give useful operational information on lightning hazards as well.

The device locates lightning flashes that strike the ground by identifying the unique electromagnetic signature produced by each return stroke. Ten



New site. During 1982-83 this incoherent-scatter radar, part of the Upper Atmospheric Facilities program, moved from Alaska to a higher magnetic latitude at Sondrestromfjord, Greenland.

stations using this device are operating in the Mid-Atlantic states, New York, and parts of New England. The network was set up by Richard E. Orville, from the State University of New York at Albany, with support from the NSF, the National Aeronautics and Space Administration (NASA), and a private company. The device itself is the product of basic research on the physics of lightning—work supported by NSF and other federal agencies during the last decade.

The number of lightning flashes that strike the earth's surface is required information in calculating the earth's electrical budget—that is, the amount of charge carried to the earth's surface and the ionosphere. In the past, this quantity was estimated from the number of "thunderstorm days," a thoroughly unsatisfactory measure of lightning frequency. The capability to determine the locations and numbers of lightning flashes, the number of strokes per flash, and their peak electric field strengths will help scientists test various hypotheses about the earth's electrical climate.

Observations with the lightning location network have shown that lightning activity in thunderstorms does not necessarily coincide with the regions of maximum vertical motion, as inferred from radar reflectivity data and cloud-top temperature. Thus radar or infrared satellite imagery alone cannot be considered an unambiguous measure of lightning hazard in thunderstorms. Moreover, at sufficient distance from a storm, especially during the early stages of its growth, radar may not be able to observe the storm at all, whereas the lightning location system can detect flashes far over the horizon at any given radar station.

The northeastern lightning location network has already proved useful in several operational tasks. For example, air traffic controllers at Leesburg, Virginia have observed the beginning of thunderstorms as much as 30 minutes sooner with the lightning display than with radar or satellite data alone. This information can be used to route aircraft around the area much sooner. Some electric power companies use the lightning data to schedule their repair crews quickly and efficiently to restore service after an electrical storm—saving money for both companies and consumers.

Climate Studies on El Niño

Along with the oceanic research described later in this chapter, climatologists also have been studying the El Niño phenomenon. This is the annual warming of ocean waters along the coast of Ecuador and Peru that seems to affect weather in other parts of the world as well. Examples of El Niño climatology work supported by NSF in FY 1983:

- James O'Brien of Florida State University developed a model of the equatorial Pacific Ocean circulation, to find out why the warming spreads in the pattern observed.
- J. M. Wallace and D. L. Hartmann at the University of Washington compared abnormal weather patterns in other parts of the world with those in the equatorial Pacific, to infer cause-effect relationships between atmospheric circulation systems.
- Eric Pitcher from the University of Miami and John Geisler from the University of Utah used NCAR resources to simulate an atmospheric circulation pattern similar to that observed during the winter of 1976-77. They hope that further modeling efforts will clarify why the 1982-83 El Niño produced results different from those in the 1970s.
- Continuing investigations of phenomena such as El Niño may result in better climate forecasts. For instance, Tim Barnett of Scripps Institution of Oceanography used El Niño data in attempting to predict U.S. seasonal weather trends. His 1982-83 forecast of generally high winter temperatures for the United States

showed promising skill, although unsatisfactory precipitation forecasts indicated the need for more work.

The encouraging results of these investigators have prompted climatologists and oceanographers to develop plans for a Tropical Ocean/Global Atmosphere (TOGA) weather experiment. Understanding the complex relationships between ocean and atmosphere may increase the accuracy of future long-range forecasts.

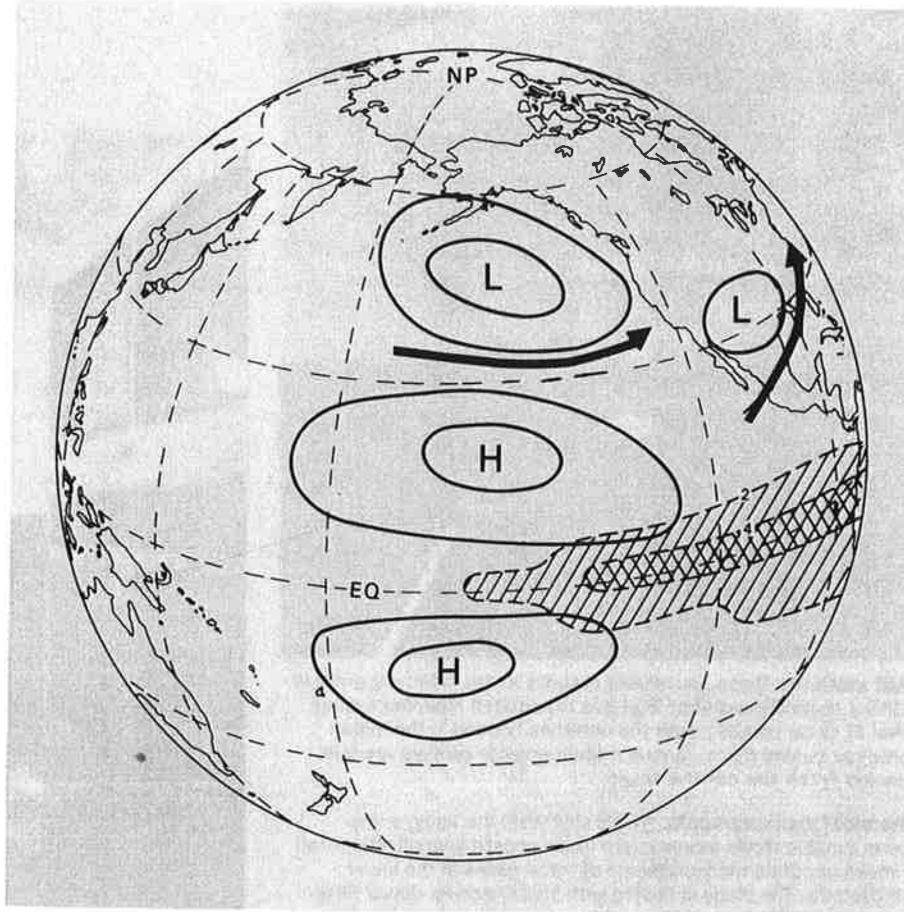
New NCAR Equipment

PAM II. NCAR's automated equipment to gather data on weather has opened up new experimental opportunities for field researchers to investigate many meteorological events and issues, including fog, various kinds of storms, air quality, wind-shear events that threaten aircraft, and weather modification. The Portable Automated Mesonet (PAM) system collects all types of meteorological data and relays them to a central base station. Thousands of bits of information gathered each minute can be simultaneously displayed for immediate use and stored for later processing, analysis, and archiving.

The first PAM system, built seven years ago, has been widely used by scientists across the country. The second-generation version of the system, PAM II, transmits its data to one of the many satellites in the National Environmental Satellite Service, for relay to the NCAR base station. The PAM II solar-powered stations can be placed anywhere. Their number has grown from 30 to 100 at this writing, and PAM's large microprocessor memory allows the device to be programmed in FORTRAN. Eventually PAM II will also include a portable field base mounted in a trailer, to provide data to field researchers.

New Laser System. Trace gases tell us something about the roles that carbon monoxide, sulfur dioxide, and similar gases play in air pollution, acid rain, and other phenomena. Measurements of trace gases in the stratosphere—about 7 to 30 miles above the earth's surface, where temperature increases with altitude and clouds of water are rare—have played an important part in air-chemistry research at NCAR. Now scientists are also learning about the way those gases move in the troposphere, the lowest level of the atmosphere that extends to the stratosphere. (Here clouds form and temperatures generally decrease with altitude.)

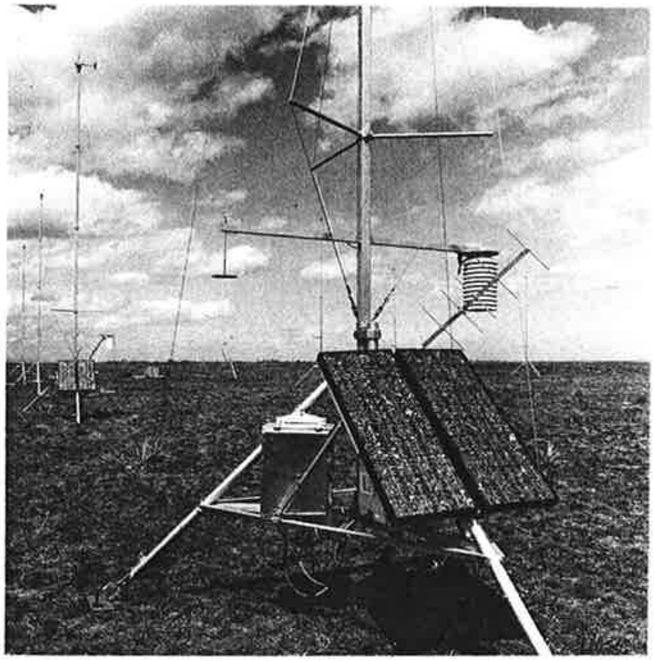
William Mankin and Michael Coffey at NCAR have developed a portable, tunable diode-laser system to make rapid measurements in the troposphere. The desk-sized instrument, which can be flown in an aircraft, uses a lead salt diode that produces a monochromatic beam of infrared light. In contrast with stratospheric measurements, which are average concentrations over large areas, tropospheric measurements must show the movements of gases in small areas. The new laser technique was developed to do just that, and NCAR researchers have found it a valuable measurement tool.



El Niño effects. Drawing shows schematic relationships between equatorial Pacific Ocean temperature anomalies (cross-hatched areas in zero degrees centigrade) and modified upper air-pressure and flow patterns during the winter of 1982-83. The large changes in North Pacific high and low (H and L) pressures were associated with a strong jet-stream (heavy arrow), which steered many storms toward the western coast of the United States. A similar jet along the eastern seaboard caused an unusually strong transport of warm southerly air into the eastern U.S. (Figure modified from one provided by John Horel of Scripps Institution of Oceanography. Data from National Weather Service.)

Methane Sources

Scientists at NCAR have been studying questions of how and to what extent the biosphere controls the chemical composition of the atmosphere. Several studies are focused on methane, commonly called "marsh



PAM stations. These are remote stations in the improved array of NCAR's second-generation Portable Automated Mesonet system (PAM II). Solar panels power the batteries housed in the metal container behind them; various meteorological sensors are suspended from the central mast.

Chemical measurements. NCAR scientists are using a low-power tunable diode-laser system flown aboard a small jet aircraft to make accurate measurements of trace gases in the lower atmosphere. The diode is cooled with liquid neon (in dewar flask, center front). The laser beam used to detect the gases is reflected many times within the sampling cell (long box, rear center), allowing use of a short optical path length. This keeps the instrument compact. Below to the right are signal-processing electronics and to the left are inlets for the air sample.

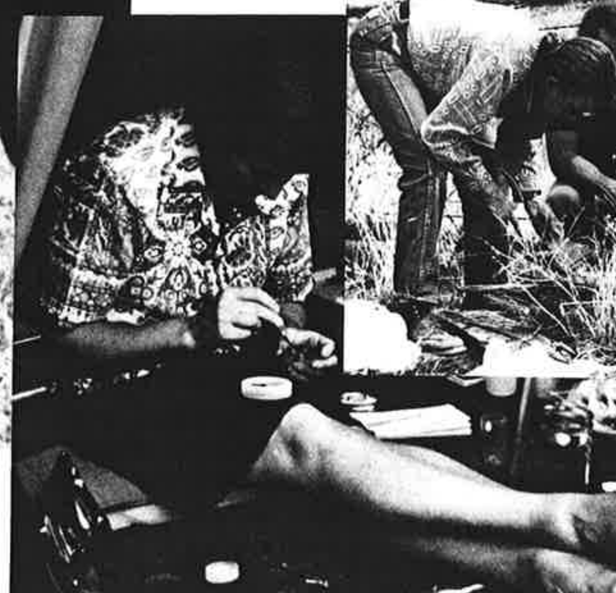
King Air interior. NCAR's King Air is a versatile research aircraft that can be readily adapted for individual flight missions to study the atmospheric boundary layer, air-sea interactions, air chemistry, and cloud physics. Put into service in April 1983, it is equipped with a compact data system that incorporates a dual computer system with an interactive terminal and four on-board video displays.

gas," which enters the atmosphere when natural organic materials decay. This gas appears to be increasing in the atmosphere at an annual rate of about 1.5 percent. Although it is a trace gas, methane has major atmospheric effects. In the lower atmosphere, it reacts to form carbon monoxide and ozone, which absorb solar heat and contribute to the well-known "greenhouse effect" (the gradual warming of the atmosphere caused by an increase of carbon dioxide levels from burning fossil fuels). Further up, in the stratosphere, it decays to form water vapor, further enhancing the greenhouse effect.

In the past, scientists thought that the main sources of methane were swamps, rice paddies, digestive processes in ruminants, geological gas reservoirs, and biomass burning. Patrick Zimmerman, with the help of James Greenberg and Shem Wandiga (a visitor from the University of Nairobi, Kenya), found that a large portion of the methane in the atmosphere may be produced by termites as a byproduct of their anaerobic digestive systems. Termites inhabit two-thirds of the earth's land surface and outweigh humanity by about 10 to 1. They are concentrated most heavily in moist tropical areas. From samples of arboreal termite nests in Guatemala and laboratory colonies at NCAR, scientists have estimated that termites contribute as much as 150 billion of the estimated 350 to 1,000 billion kilograms of methane produced annually by all sources.

In another NCAR study, Ralph Cicerone and James Shetter measured methane emissions from experimental rice fields. Making global extrapolations from their measurements, they found that rice paddies produce only 20 percent as much methane as prior investigations had indicated. In addition, they identified a part of the methane cycle that had not been known before: The gas escapes primarily through the plants themselves rather than bubbling up through the water from sediments. Nitrogen-fertilized plants, they found, produce more methane than nonfertilized ones. Increases in rice cultivation to meet growing world food needs may account partly for the rise in global atmospheric methane.

This kind of work has global implications for the environment, providing valuable data to help us deal with the greenhouse effect.



Sampling termite emissions. NCAR and other scientists study methane emissions from termite nests in Guatemala and in NCAR laboratory colonies. Termites have proved to be one of the world's major methane sources.

Earth Sciences

Earth scientists study the structure, processes, and historical evolution of our planet. Their research helps solve many of our most pressing problems, such as the need for energy and mineral resources, ways to predict and avoid natural disasters, and disposal of hazardous wastes.

Excitement in this field is high as geologists and others test and adapt the concepts of plate tectonics. Scientists are using new instruments and tools to study the deep continental crust and the mantle. These hidden parts of the earth are the key to what moves and deforms the outer crust, and they hold the record of past plate motions and deformations.

Work of note during 1983:

Floods and Climate Changes

Along with their general destructiveness, large floods pose a major technical problem for the engineer and hydrologist. Conventional engineering analyses, for example, fail to deal with flows much larger than previous historical peaks. In addition, although available evidence suggests that climate changes do occur in time scales of thousands of years, the effects of climate cycles or trends are not included in hydrologic analyses of flooding, water resources, or regional planning. There is little agreement as to climate conditions expected in the future and the potential consequences of runoff, erosion rates, and sediment yields under both natural and man-induced changes in climate and landscape.

The major goal of research by James C. Knox at the University of Wisconsin was to evaluate the response of floods and sediment movement to climate changes during the past 10,000 years (the Holocene Period) in the Upper Mississippi Valley. Knox also compared the record of ancient flooding to contemporary floods that occur every year or two in that area.

According to previous estimates by Knox, the contemporary flooding record is two to four times greater than "presettlement" floods; this is a direct result of progression from a natural prairie and forest vegetation to the present agricultural landscape. However, as recorded in more recent sediment data, Holocene floods averaged about 10 percent larger to 40 percent smaller than contemporary floods of the same frequency.

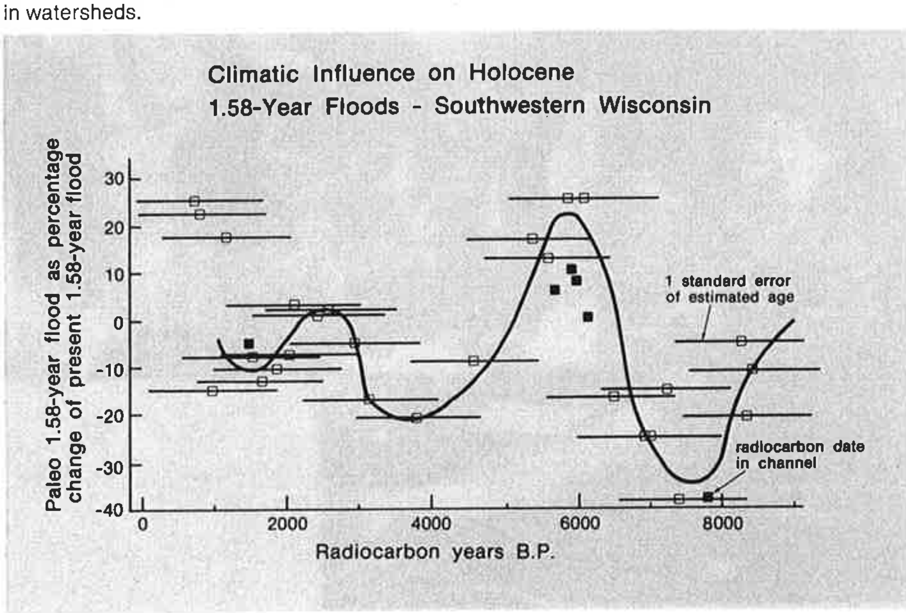
Ancient channel deposits serve as sensitive indicators of river responses to climate change over the past 10,000 years. These deposits indicate that large floods occurred during three separate periods, which alternated with three separate periods of small floods. Further sediment studies show that 8,000-6,000 years ago, westerly weather patterns produced heavy rainfall and coarse deposits in stream tributaries. This influenced flooding during that 2,000-year period, but at the same time, the effects of melting snow and frontal precipitation on flooding were less dominant then. These data, based on absolute dating methods, agree with, and provide better resolution for, existing general climate trends established by fossil pollen studies in the region.

Potential application of this research spans a number of scientific disciplines:

- Information acquired from a study of flood activity before human settlement helps climatologists separate the effects of variables introduced into the environment by man's activities.

- The extreme floods of the Holocene Period revealed in these field studies have had critical effects on terrain, often resulting in major channel widening, floodplain destruction, changes in bank vegetation, or dramatic long-term changes in stream patterns in a short time. Engineers and hydrologists may incorporate data from the study of these floods in their analyses, rather than depending strictly on stream-gauging records that typically date from the 1940s and are influenced by

Comparing floods. Physical properties of relict river channels and their sediments indicate that climatic changes were the principal cause of long-term, nonrandom variations in postglacial floods, which ranged from about 5-25% larger to 15-40% smaller than contemporary floods of the same expected recurrence (once each year or two). The irregular variation in flood magnitudes is closely related to the long-term storage and remobilization of sediments in watersheds.



changes in land use and streamflow regulation.

- For geologists, the study of Holocene paleofloods promises information on the long-term behavior of channel stability—information that will help them develop theories about the evolution of the earth's crust. The study of flood deposits adds another dimension to the geologist's understanding of Holocene events, heretofore exclusively derived from examining glacial, marine, or lake deposits.

Surging Behavior of Variegated Glacier, Alaska

A major unsolved problem in understanding glaciers is the cause of "surges"—periodic episodes of very rapid advance, lasting one to several years. These alternate with intervals of normal behavior lasting for decades. The history of Variegated Glacier, east of Yakutat, Alaska, suggested that a surge was likely to occur in the early 1980s. A research project to monitor the normal behavior of the glacier has been in progress since 1973, involving scientists from the University of Alaska (William Harrison) and the University of Washington (Charles Raymond). In 1980 they were joined by glaciologists from the California Institute of Technology, led by Barclay Kamb. The project thus became jointly supported by NSF's divisions of earth sciences and polar programs.

The long-anticipated surge of Variegated Glacier seems to have started in January 1982. Surface velocities of the ice reached as much as 10 meters a day by midsummer, returned to normal velocities of a meter or two a day during the late summer and fall, then increased again in the spring of 1983 (up to 50 meters a day). The rapid movements resulted in greatly increased discharges of water as well as

Alaska's Variegated Glacier. Photo at bottom left shows the lower middle part of the glacier before that section began to surge. Picture at top left is the same view a year later, during the surge. In third shot, scientist measures the glacier motion with an electronic distance meter, using a laser beam.

a chaotic breakup of the ice surface by crevasses, folds, and faults and thinning of the glacier in lower reaches.

Detailed studies of phenomena accompanying the surge were made possible by the observation network set up during earlier baseline research. Scientists used a variety of techniques, including time-lapse photography, to measure the glacier's movement, placing their instruments at various points: the base of the ice, surface layers, and adjacent valley walls.

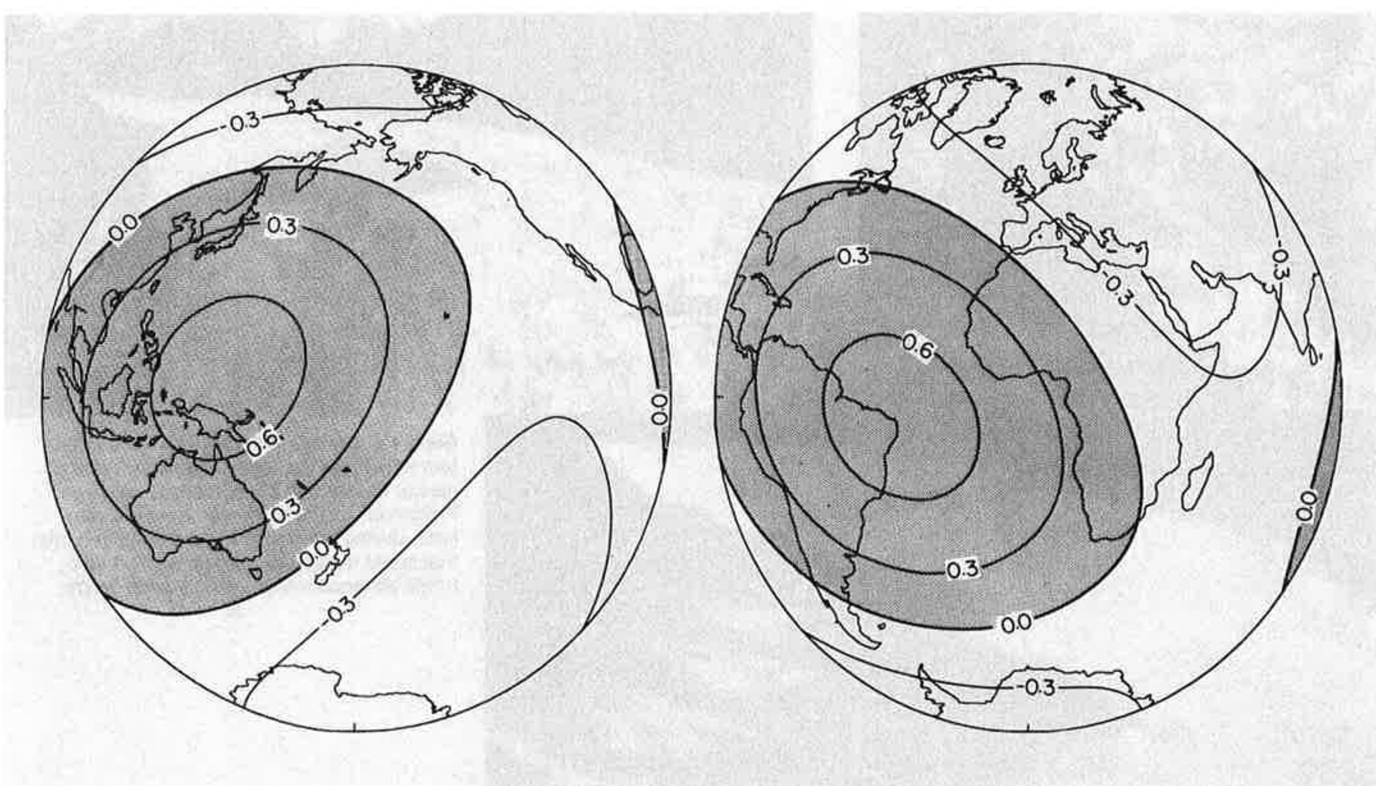
This project provided the most extensive set of data available on the behavior of a surging glacier. Preliminary analysis suggested that surges may be caused by changes in water pressure in the channels beneath the glacier—changes which in turn affect the base of the glacier and cause it to slide. This information tells glaciologists what may have contributed to the rapid collapse of some of the huge ice sheets of the Pleistocene Period.

Understanding the earth's geological history is one aspect of this research; planning for the future is another. Variegated Glacier is in a remote area, and floods from a surge are not hazardous. Other glaciers, however, lie near inhabited regions where a surge could pose a threat to lives and property. If scientists can accurately predict a glacial surge they may be able to prevent future disasters.

The Large-Scale Aspherical Structure of the Earth

Recent developments in the theory of seismic wave propagation have revealed a very large-scale pattern of small frequency shifts in the spectra of long-period seismic events. This pattern has an anomaly that, when modeled, appears to originate at depths of 400 to 650 kilometers in the earth and correlates spatially with subduction zones in the western Pacific Ocean and with the East Pacific Rise. These results are significant because they constitute the first seismological observations of large-scale mantle convection.

At long periods, a recording of an earthquake is dominated by wave packets with energy trapped in the upper 1,000 kilometers of the earth. As they travel away from the earthquake, the wave packets become dispersed and can circle the globe many times before they become unobservable. The velocity of a packet of waves depends on the elastic and structural properties of the earth along the great circle path linking the source of the earthquake and the recording instrument. By comparing the velocities of wave packets for many great circle paths, scientists can detect deviations from spherical symmetry. Researchers at Harvard and the University of California-San Diego have used these deviations to obtain information about



Transition zone anomaly. Certain data have revealed a very large-scale pattern of aspherical structure for the earth. The largest feature of that pattern is an anomaly believed to originate in the earth's transition zone (400-650 km depth). These two drawings show the geographical shape of that zone; regions of positive anomaly are shaded.

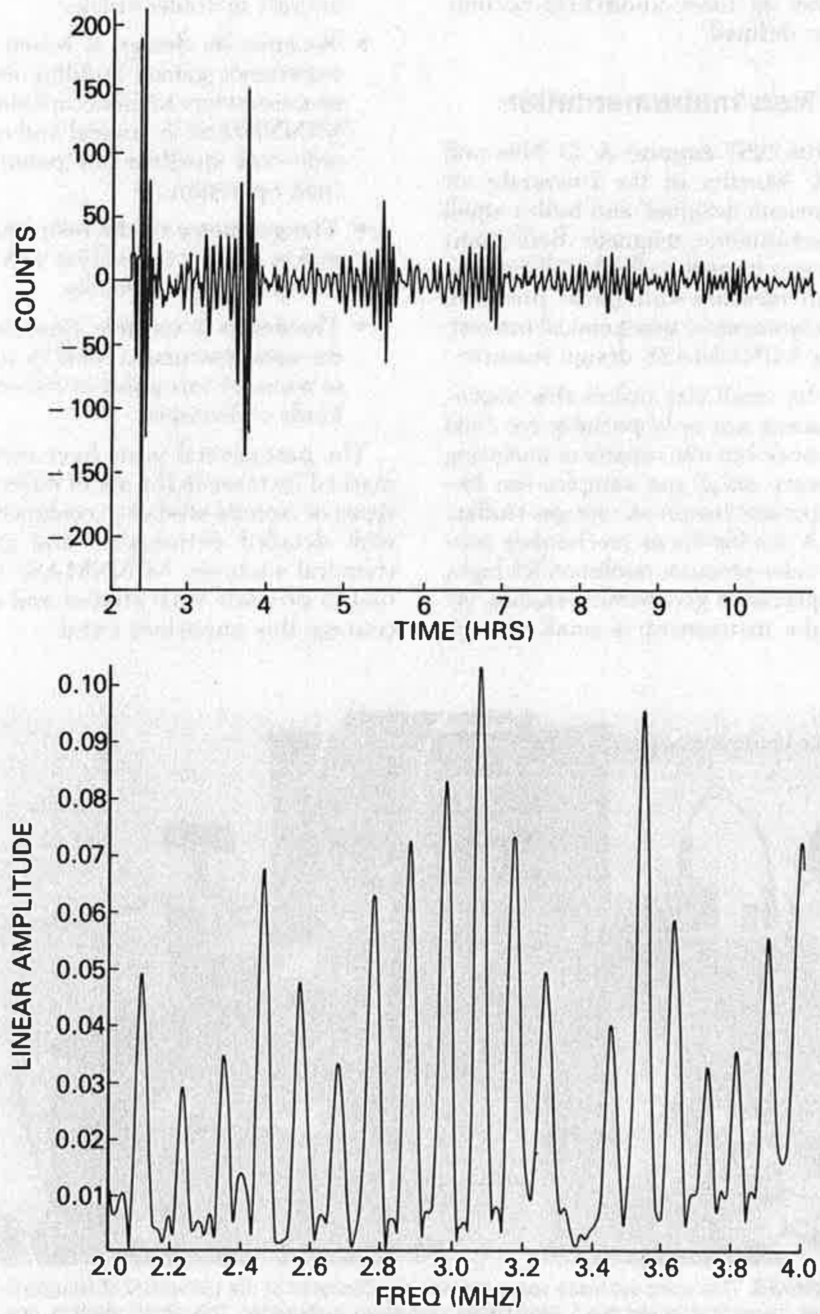
large-scale features at depths in the earth.

In order to describe earthquakes recorded at very long periods (longer than 200 seconds), the seismic spectrum is displayed in terms of a number of discrete peaks, representing standing waves caused by free oscillations of the earth. If the earth were exactly spherically symmetric, the discrete peaks would have identical frequencies, a phenomenon called "degeneracy." Departures from spherical symmetry remove the degeneracy, causing splitting of the spectral peaks. The result is that the frequencies of the peaks appear to be slightly different for different great circle paths.

Measurement of these small frequency shifts allows deduction of the long-wavelength aspherical structure of the earth. In one study at California's Institute of Geophysics and Planetary Physics, nearly 4,000 of these frequency shifts were measured from extremely high-quality data recorded by the IDA (International Deployment of Accelerometers) network. These data revealed a very large-scale pattern of aspherical structure that dominates observations in the 220s to 600s period band. The largest feature of the pattern is an anomaly that is negatively correlated with the ellipticity of the earth—the net effect being that the earth appears to have no ellipticity as far as these standing waves are concerned. Another large feature of the pattern is a large sectorial component; it is of great interest that both these features correlate well with the shape of the residual geoid.

A simple model, which fits the observations very well, places the source of the anomaly in the transition zone of the earth (400 to 650 kilometers in depth). The inferred anomaly predicts a residual geoid of roughly the observed shape but about a factor of five too big in amplitude. The implication of these and other data is that a large compensating anomaly exists deeper inside the earth.

A reasonable interpretation of these results is that we are at last beginning to see a signal related to large-scale convection in the earth. Our understanding of the way the earth works



Earthquakes recorded. Figure at top shows a long-period recording of an earthquake in Mexico at a station in Scotland (part of the International Deployment of Accelerometers or IDA). The wave packet that arrives at 2.4 hours is seen again, attenuated and dispersed, at 5.4 hours after one orbit of the globe. The packet appears still again at 8.4 hours, now so dispersed that it is hard to identify. The wave packets arriving at other times are from energy traveling in the opposite direction around the globe. Figure at bottom is a Fourier amplitude spectrum of a recording of the same Mexican earthquake at an IDA station in Peru. The frequency axis is in millihertz and corresponds to a period range of 250 to 500 seconds. The discrete peaks corresponding to the earth's normal oscillation modes are very obvious. The location of the center frequencies of these peaks is slightly different for different great circle paths joining sources and receivers. Measurements of frequency shifts allow geologists to deduce the long-wavelength asperical structure of the earth.

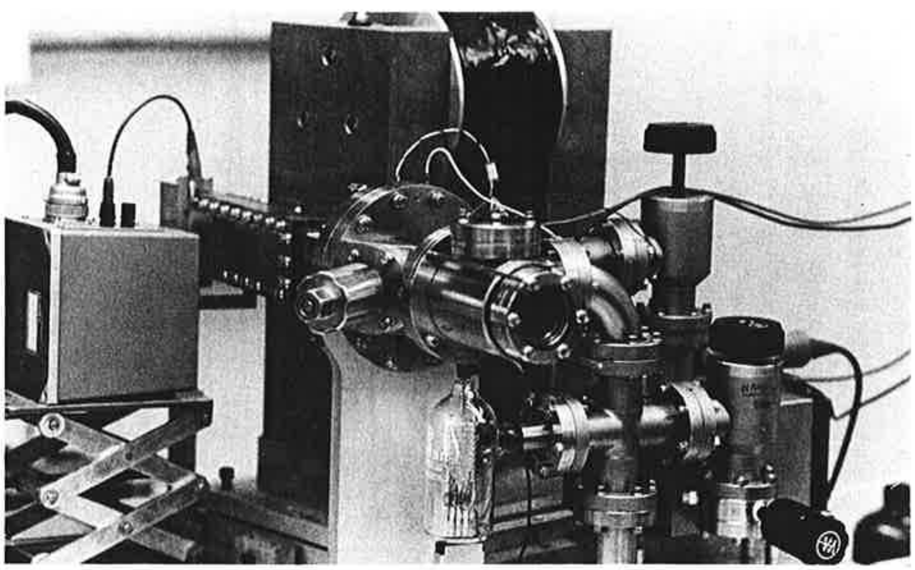
to remove its heat will be greatly improved as these anomalies become better defined.

New Instrumentation

With NSF support A. O. Nier and V. R. Murthy of the University of Minnesota designed and built a small (9.5-centimeter magnetic deflection) mass spectrometer called MINNMASS. It can measure with great precision most isotopes of geochemical interest. Some MINNMASS design features:

- Its small size makes this instrument not only portable for field work but also capable of analyzing very small gas samples—an important feature in rare-gas studies. A double-focus mechanism provides adequate resolution for high-precision geochemical studies, yet the instrument is small enough to be carried aboard ship or on an aircraft or trailer-truck.
- Because its design is based on experience gained building mass spectrometers for space missions, MINNMASS is rugged and reliable—key qualities for potential field operation.
- The geometry of the instrument makes it easy to analyze several isotopes simultaneously.
- The design is versatile. Essentially the same instrument could be used to measure rare gases or different kinds of isotopes.

The past several years have seen a marked increase in the use of different types of isotope studies in conjunction with detailed petrological and geochemical analyses; MINNMASS is a tool to promote such studies and encourage this important trend.



MINNMASS. This compact mass spectrometer was designed at the University of Minnesota. Handles on vertical valves are 5 centimeters (2 inches) in diameter. This small, durable, and versatile piece of equipment can also do sensitive and precise analyses—all of which makes it an extremely valuable tool in geochemical research.

Ocean Sciences

Oceanography is entering an exciting and challenging era. Oceanographers can now study global ocean processes, using new techniques and instruments such as satellites, acoustic and optic remote sensors, instrumented buoys, and powerful computers. The major scientific disciplines involved in this study are biology, physics, chemistry, and geology/geophysics. Researchers in some of these disciplines cooperated on large-scale investigations in 1983, as described later in this report.

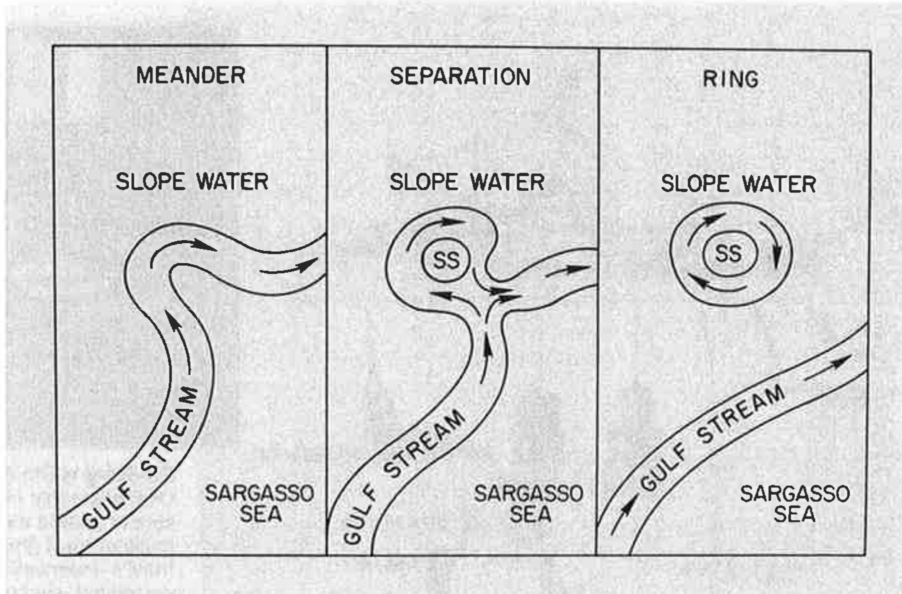
The ocean sciences depend heavily on equipment, and general-purpose research vessels continue to be the backbone of this research. These ocean platforms are supplemented by satellites, remote underwater vehicles, manned submersibles, instrumented buoys, and aircraft. In 1983, NSF supported about 70 percent of the operations of the federally funded academic fleet. The research vessel *Atlantis II* was converted to serve as tender for the deep-submersible *Alvin*. Funding for the conversion came from NSF, the Office of Naval Research, and the National Oceanic and Atmospheric Administration.

Through interdisciplinary activities such as those taking place aboard *Alvin*, scientists expect to continue making significant advances in oceanography in 1984. As a result of 1983 improvements to the *Alvin* system, in 1984 biologists, chemists, physical oceanographers, geologists, and geophysicists will participate in the most ambitious schedule in the submersible's history. The number of dives will increase by 55 over the maximum done before in a single year.

Many ocean research problems are so large and complex that scientists from several countries must work together to solve them. Most international research projects are handled directly by the scientists and institutions involved. Some cooperation involves U.S. bilateral arrangements with other countries such as Mexico, France, and the People's Republic of China. Large-scale, long-term activities such as world climate studies are aided by multilateral organizations, including the Intergovernmental Oceanographic Commission and the International Council of Scientific Unions.

If U.S. oceanographers are to carry out programs in resource zones of other countries, international cooperation will be increasingly important in the future.

During 1983, international law on the status of the oceans changed with the Law of the Sea Treaty. At this writing, more than 100 nations have signed this proposed treaty, but it is not yet official. The United States has not signed. Like many other nations, though, it has set up an Exclusive Economic Zone off its coastal boundaries. This means that the United States, for example, has control over, and exclusive rights to, resources in a 200-mile offshore area. These actions may limit scientists' access to areas under the control of coastal states—and thus inhibit scientific progress in some locations.



How rings form. A Gulf Stream meander in the Sargasso Sea (SS) separates and forms a warm-core ring.

Warm-Core Rings

Over the past three years, NSF has been the principal sponsor for this program, which aims to answer many fascinating questions about the Gulf Stream and its large circular columns of warm water.

The Gulf Stream, which originates in tropical latitudes, was once described as an ocean river, but it is much more complex than that. Its path changes constantly, often meandering into loops, some of which become pinched off into "warm-core" rings with a clockwise circulation. These rings—up to 200 kilometers in diameter and several hundred meters deep—spin away and move into colder, less saline waters between the Stream and the economically important North American continental shelf.

The Warm-Core Rings Program is one of the most comprehensive multidisciplinary projects ever undertaken in ocean sciences. More than 25 principal investigators from 13 research and academic institutions have participated in the program.

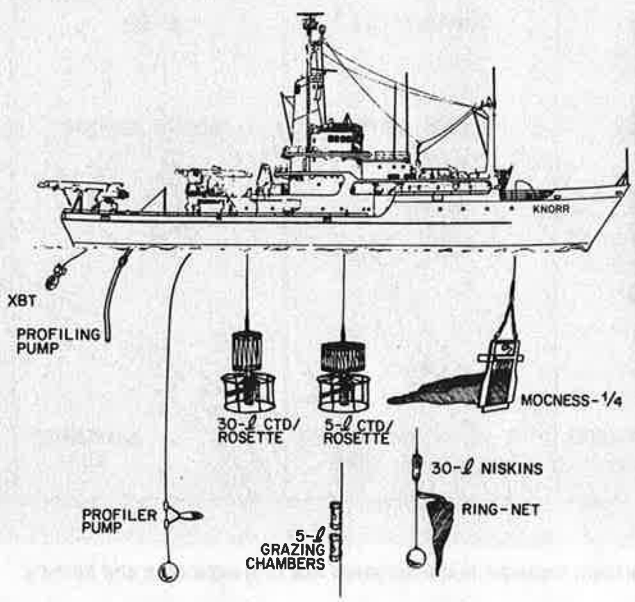
Five research cruises, requiring over 100 days at sea, were mounted over a period of one year. Three research ships of the NSF-supported U.S. academic fleet, *Endeavor*, *Knorr*, and *Oceanus*—as well as ships and aircraft provided by other agencies—followed the development and fate of several rings. The scientists involved used a variety of technologies, including satellite and aircraft remote sensing, to accumulate an exhaustive series of scientific measurements and observations of the biology, physics, and chemistry of the waters.

One of the most significant discoveries is that just as the Gulf Stream is not a simple river, the rings are not isolated tubes. As the rings spin, they draw in "streamers" of surface water that spiral into their center. These streamers are often entrained from shelf and coastal regions.

Undisturbed rings may maintain their identity for more than 9 months, but interaction with each other, the shelf, or the Gulf Stream can result in rapid dissolution. These complex, dynamic systems are found in major current systems throughout the world's oceans, adjacent to highly productive continental shelf regions.

The biological effects of the rings may be complex and diverse. The welling up of nutrient-rich deeper ring water onto the shelf would enhance the productivity of coastal waters. Conversely, it now seems clear that a ring swirling past a major fishing ground such as George's Bank off Cape Cod at a critical time in the spring might literally vacuum up the tiny larvae

Work aboard the *Oceanus*. Along with two other research ships of the NSF-supported U.S. academic fleet, *Oceanus* followed the development of several warm-core rings in the Gulf Stream. This was one of the most comprehensive multidisciplinary projects ever undertaken in ocean sciences, and it produced much information about the rings and the Gulf Stream itself.



Studying warm-core rings. Research assistant from Woods Hole Oceanographic Institution monitors data displayed on a video screen aboard the R/V *Knorr.* She uses information from a huge multinet trawl (the MOCNESS), towed from the ship, to control the trawl's underwater operations. Drawing shows MOCNESS and other equipment used on the *Knorr.* These included pumps for work on plant pigments, two CTD/rosette sampler systems, 5-liter zooplankton grazing chambers, a 30-liter Niskin bottle, and a ring-net. (Note: XBT = expendable bathythermograph; CTD = conductivity/temperature/depth.)

that follow the annual spawning of fish such as cod or haddock.

For years; scientists have speculated on the causes of large fluctuations of major fish stocks on which the economies of many nations depend. The poor survival of fish larvae has usually been blamed on starvation or predation. An alternative hypothesis is that future fish stocks depend more on transient physical phenomena such as these rings, which can be thought of as the oceanic equivalent of a passing hurricane.

Sea-Air Interaction

A constant rain of particles, invisible to the naked eye, has been landing on the oceans for the past 600 million years. Only during the past 20 years, however, have scientists caught and identified these particles, then evaluated their contribution to the ever-thickening sedimentary blanket on the ocean floor. Some of the most sophisticated instruments known to modern science are at work to characterize trace metals such as lead, mercury, and tin, as well as a host of organic species.

Robert Duce of the University of Rhode Island coordinated the efforts of a team of scientists in a program known as SEAREX (Sea-Air Exchange). The scientists—nine from U.S. universities, one from France, and one from Britain—have cooperated in measuring these exchanges. Using solid platforms on land masses and islands in the Pacific, the team assembled instruments on towers to measure wind speed and direction, humidity, particle fluxes, rainfall, and gas composition. Researchers made chemical and physical analyses of particles trapped by special collectors mounted on these towers. Technical snapshots of this kind, from a large array of Pacific islands, are adding to the global picture of dust and aerosol transport to the ocean.

These scientists found that significant quantities of Asian desert dust are transported to the Enewetak Atoll during the spring. This dumping of desert sands into the ocean may account for half of the nonbiological marine sediments in that region of the Pacific.

In other research, William Fitzgerald of the University of Connecticut measured gaseous and particulate mercury at various Pacific Ocean sites. He found that more than 99 percent of the mercury there is in the gaseous phase. This finding has significant implications for the rate at which this metal can be scrubbed from the atmosphere by rainfall, since gases are much less readily scavenged than particles by rainfall.

Scientists also have discovered that mercury forms organic compounds, which may represent half of the vapor phase near land. This discovery, too, will help scientists predict rates of washout and metal transport. The organic component of metal compounds not only influences the rates at which they move from air to sea but can greatly increase their toxicity.

Studies on tin by Meinrat Andreae of Florida State University have shown that organic compounds, specifically methyltin, enhance metal toxicity. The analogous mercury compound, methylmercury, is well known for its high toxicity. Since both methylated compounds are gases, the scrubbing rates by rainfall are expected to be low. Measurements at Enewetak Atoll confirm this prediction for both mercury and lead.

Sea-air exchange towers. Some 15 to 20 meters high, the two towers in photo at left (by David Erickson) are on Ninety-Mile Beach, New Zealand. They are equipped with instruments to collect metal and organic fallout that represents ocean fluxes. Other photo (by Joseph Prospero) shows aerosol sampling gear in the Pacific's Cook Islands; this tower is operated in cooperation with the local meteorological service. Research on interactions between sea and air, such as the exchange of chemicals, helps scientists understand changes in the ocean floor, cleansing of sea waters, and other phenomena.

Research on air-sea exchanges of chemicals is allowing scientists to understand the complex processes that lead to changes in the topography of the ocean floor and cleansing of ocean waters through particle scavenging. Models of oceanwide transport of materials are being improved continuously; these will help us manage and predict our future marine resources.

El Niño

El Niño, "the child" in Spanish, was named by Peruvian fishermen because it normally begins around Christmas along the Peru-Ecuador coast. In 1982 and 1983, this oceanic and atmospheric phenomenon caused widespread temperature changes in ocean waters of the western equatorial Pacific Ocean, resulting in droughts, floods, and altered storm tracks. Severe storms along the U.S. Pacific coast and in the Rocky Mountains left more than 50 people dead and caused more than $1 billion in damages. Floods along the U.S. Gulf Coast resulted in another billion dollars in damages. All this was linked to the strongest El Niño of the century, originating in the western equatorial Pacific Ocean and upsetting weather around the world.

U.S. and Peruvian oceanographers have closely studied these conditions; thus the mechanisms involved in El Niños have been worked out in some detail. Klaus Wyrtki at the University of Hawaii and others postulate that El Niño is caused by a relaxation of southeast trade winds in the central and western Pacific Ocean after a period of strong trade winds. Water and heat accumulated in the central and western Pacific by the preceding period of strong trade winds are redistributed in a rapid, basinwide adjustment. The anomaly propagates in a wavelike fashion eastward on the equator and then poleward along the coast, causing anomalously warm sea-surface temperatures, increased sea level, and a deepened mixed layer.

Sea-level measurements by Wyrtki show that this wavelike response was triggered by a relaxation of the equatorial wind field in June 1982. The wave reached the South American coast in early October, triggering other waves that propagated along the coast. Thomas Royer at the University of Alaska observed the propagation of anomalously warm coastal water as far north as the Gulf of Alaska. And Eric Firing at the University of Hawaii saw definite changes in equatorial current fields as far west as 158 degrees along the equator; these persisted into the summer of 1983.

In addition to being a major climatic event, El Niño has considerable environmental and economic consequences. Richard Barber at Duke University has studied its effects on the Peruvian upwelling area since 1969. During El Niño, water upwelled off the Peruvian coast is warmer and less rich in nutrients than that normally upwelled in this region. The result is a great reduction in plankton and a change of species that are able to grow. Fish that depend on this food source starve or leave the affected area.

The impact of the latest El Niño is not yet documented at this writing, but the 1972 event reduced Peru's booming anchovy fishery from harvests of more than 10 million tons per year—then the world's largest fishery—to less than 2 million tons per year in 1973. Disappearance of the usually abundant anchovetta and other small fish has caused enormous sea bird mortality. In late 1982, ornithologists Ralph and Elizabeth Schreiber, at the Los Angeles County Natural History Museum, found that about 17 million sea birds normally present on Christmas Island, a coral atoll just north of the equator, had fled the island; their nestlings, abandoned, had starved. This was almost the entire bird population of the world's largest coral atoll. However, Ralph Schreiber found in a visit six months later that the birds had begun to return.

El Niño also has pronounced effects on the United States. Joseph Fletcher at the University of Colorado pointed out that the 1982-83 event promoted west-to-east air flow over the United States during the past winter. This caused heavy snows in the western states, unseasonable rains in the southwest, and flooding in California.

At this writing, university scientists from Scripps Institution of Oceanography, the University of Washington, and the University of Alaska are studying effects of the anomalous oceanographic conditions on biota along the West Coast of the United States.

Oceanographers and meteorologists studying the biology and dynamics of the ocean-atmosphere system are combining data collected during the current El Niño to understand this system better, and to learn how its occurrence and effects on short-term climate might be predicted.

Ocean Drilling

The entire margin of the Pacific Ocean, including Japan, western South America, and New Zealand, has experienced pulses of explosive volcanic activity in the geologic past. Some of these eruptions were gigantic—much larger than those experienced within historical times. Evidence for this hypothesis came from an international group of 16 scientists supported by 54 drillers, technicians, and crew on the research drilling vessel *Glomar Challenger*. Their expedition to the ocean basins between New Caledonia and New Zealand in the southwest Pacific ended successfully in January 1983.

The scientists discovered multilayered volcanic ash in sediment cores from deep beneath the ocean. Each ash layer records a major volcanic eruption when vast quantities of volcanic ash were blasted into the atmosphere; the ash finally settled in layers up to three inches thick on the ocean floor. Those layers, each recording a separate event, ultimately became buried among fossils of millions of marine organisms.

The ash layers can be dated according to the known ages of marine organisms found within them. Scientists on the *Challenger* found that many layers were grouped together within certain time intervals. These volcanic pulses in the South Pacific apparently happened at intervals of about 5 million years. One of the largest of these pulses has been occurring during the last 2 million years around the Pacific (Japan, western South America, and New Zealand). This period coincides with the great ice ages, when ice covered much of North America and northern Europe.

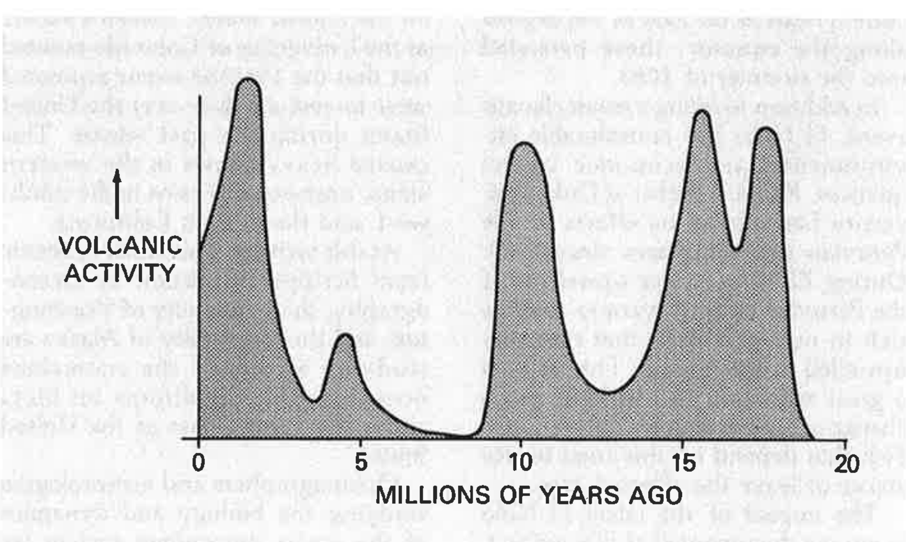
A long-standing theory suggests that increased volcanic activity is related to cooler global climate because volcanic ash in the atmosphere reflects solar radiation. The scientific team on the *Challenger* had new evidence to support this theory.

Periods of increased volcanic activity probably result from intensified movement between the great plates of semirigid material that compose the earth's surface. Such movements also lead to mountain development. New Zealand is located at a collision boundary between two of these plates and hence is both mountainous and highly volcanic. From their *Challenger* work, scientists have been able to show that the uplift of New Zealand's Southern Alps, located along the famous active Alpine Fault, began 6 million years ago. They also found that the rate of uplift increased during the last 2 million years.

Evidence for this mountain-building history came from a drill hole close to the east coast of New Zealand's South Island. Here the researchers were able to date the input of the first muddy sediments carried to the ocean from the uplifting mountains. Before the mountains began to form, only clean white limestone sediments were laid down on the ocean floor. This theory got further support from the scientists' discovery of volcanic ash layers of similar age in other cores drilled near New Zealand. As the mountains were uplifted, volcanic activity increased.

The southwest Pacific expedition set an all-time record for cores recovered. Taken end to end, their total length is 3,700 meters, equal to eight times the height of the Empire State Building. Hundreds of scientists throughout the world have been examining these cores for more clues about the climatic, volcanic, and glacial history of earth and the evolution of life in the deep oceans.

Volcanic pulses. Figure shows periods of intense volcanic activity within the Pacific Ocean over the last 20 million years. These discoveries were made by an international group of oceanographers and drillers working on the research vessel *Glomar Challenger*.



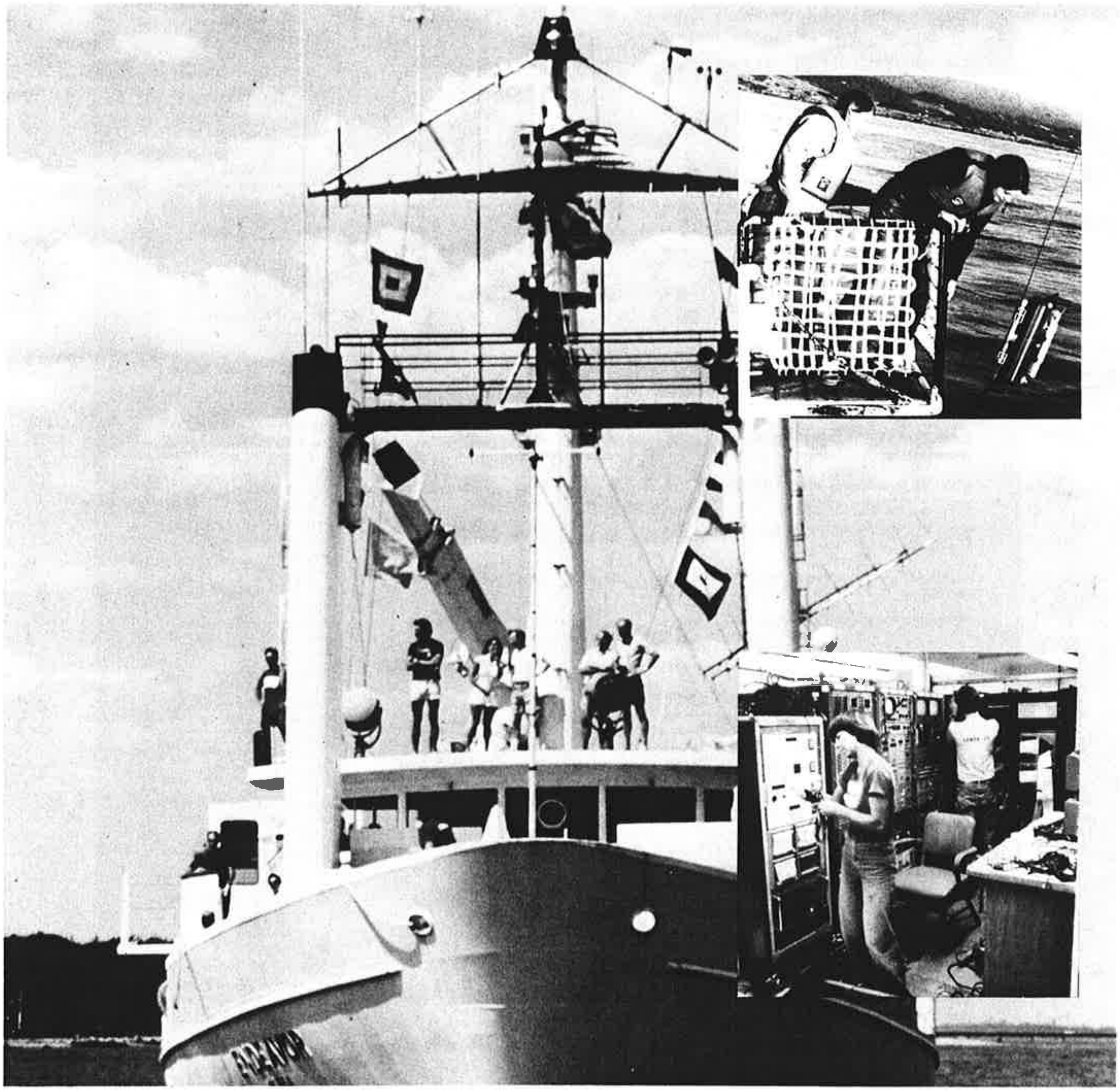
Oceanographic Facilities

In 1983 there were significant improvements in ships of the academic research fleet that NSF funds:

- Modifications to the research vessel (R/V) *Atlantis II* prepared it for service as a support ship for the deep-submersible *Alvin*.
- A modern system called Seabeam, used for precise mapping of seafloor contours, was installed on the ships R/V *Conrad* and R/V *Atlantis II*.
- The R/V *Thomas Washington* acquired an earth-satellite-based navigation system. Similar improvements in navigational accuracy are being considered for other research ships at this writing.
- NSF got a 65-foot former U.S. Coast Guard tug, *Clifford A.*

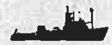
Barnes, and began to convert it for oceanographic research. R/V *Barnes* replaces two outmoded ships.

About half the fleet's ships got upgraded systems, including several new deep-sea winches, to handle instruments. On several vessels, automated data recording systems were installed to help scientists integrate scientific and navigational data. These improvements, together with continuing efforts to acquire and upgrade shipboard equipment of all types, have increased the fleet's versatility and effectiveness. In 1983, it supported 140 research projects requiring about 3,100 days at sea. Cruises ranged from the Arctic to the Antarctic Oceans and from the western Pacific to the eastern Atlantic.



Ships from the U.S. academic research fleet. In photo at left, the *Endeavor* returns to its home port after a six-month trip. At top right, two researchers aboard Oregon State University's *Wecoma* launch a sampling system. Last photo shows laboratory of Texas A&M University's *Gyre*.

VESSELS OPERATED BY UNOLS INSTITUTIONS

SHIPS Operating Institution	Built/ Converted	Scientific Bunks	Length	
ALPHA HELIX University of Alaska	1966	15	41 m	
CAPE HENLOPEN University of Delaware	1975	12	37 m	
•MOANA WAVE University of Hawaii	1973	20	62 m	
COLUMBUS ISELIN University of Miami	1972	15	52 m	
CALANUS University of Miami	1971	6	20 m	
CAPE FLORIDA University of Miami	1981	12	41 m	
ENDEAVOR University of Rhode Island	1976	16	54 m	
VELERO IV University of Southern California	1948	12	34 m	
LONGHORN University of Texas	1971	10	24 m	
•THOMAS G. THOMPSON University of Washington	1965	19	64 m	
CLIFFORD A. BARNES University of Washington	1983 (built '66)	6	20 m	
CAPE HATTERAS Duke/University of North Carolina	1981	12	41 m	
CAYUSE Moss Landing Marine Laboratories	1968	8	24 m	
RIDGELEY WARFIELD The Johns Hopkins University	1967	10	32 m	
•CONRAD Lamont-Doherty Geological Observatory	1962	20	64 m	
WECOMA Oregon State University	1975	16	54 m	
•MELVILLE Scripps Institution of Oceanograhy	1970	29	75 m	
ELLEN B. SCRIPPS Scripps Institution of Oceanography	1965	8	29 m	
•THOMAS WASHINGTON Scripps Institution of Oceanography	1965	19	64 m	
NEW HORIZON Scripps Institution of Oceanography	1978	13	52 m	
BLUE FIN Skidaway Institute of Oceanography	1975 (built '72)	8	22 m	
•GYRE Texas A & M University	1973	20	53 m	
ATLANTIS II Woods Hole Oceanographic Institution	1963	25	64 m	
•KNORR Woods Hole Oceanographic Institution	1969	25	75 m	
OCEANUS Woods Hole Oceanographic Institution	1975	12	54 m	

•Ships marked with an asterisk are owned by the United States Navy. The other ships are owned by the National Science Foundation or the operating institution.

UNOLS MEMBERS

University of Alaska
University of Delaware
Duke/University of North Carolina
University of Hawaii
The Johns Hopkins University
Columbia University, The Lamont-Doherty Geological Observatory
University of Miami, Rosenstiel School of Marine and Atmospheric Science
University of Michigan, Great Lakes and Marine Waters Center
Oregon State University
University of Rhode Island
University of California-San Diego, Scripps Institution of Oceanography
University System of Georgia, Skidaway Institute of Oceanography
University of Southern California
University of Texas
Texas A&M University
University of Washington
Woods Hole Oceanographic Institution

UNOLS ASSOCIATE MEMBERS

University of Alabama
Bermuda Biological Station
Bigelow Laboratory for Ocean Sciences
Brookhaven National Laboratory
University of California, Santa Barbara
Cape Fear Technical Institute
University of Connecticut
Florida Institute for Oceanography
Florida Institute of Technology
Florida State University.
Harbor Branch Foundation
Hobart & William Smith Colleges
Lehigh University
University of Maine
Marine Science Consortium
University of Maryland
Massachusetts Institute of Technology
Moss Landing Marine Laboratories
University of New Hampshire
New York State University College at Buffalo
New York State University at Stony Brook
North Carolina State University
University of North Carolina at Wilmington
Nova University
Occidental College
Old Dominion University
University of Puerto Rico
San Diego State University
Virginia Institute of Marine Science
Walla Walla College
University of Wisconsin at Madison
University of Wisconsin at Milwaukee

Arctic Research

This NSF program emphasizes support of scientific research that requires an interdisciplinary approach. Rapid industrial development and environmental fragility in the American north have boosted the need for such research in recent years. The Arctic also offers unique opportunities to study many basic scientific questions. Fields of particular interest are the atmospheric and earth sciences, oceanography, glaciology, and biology.

Processes and Resources of the Bering Sea (PROBES)

The Bering Sea is the world's third largest ocean, with an area of more than 2 million square kilometers. Some 45 percent of this area lies over the continental shelf, making this body of water the largest American coastal sea. The area contributes about 4 percent of the world fishery catch, including king and tanner crabs, salmon, yellow-fin sole, halibut, herring, and Alaskan pollock.

Between 1976 and 1983 scientists from nine institutions* did physical, chemical, and biological investigations in the southeast Bering Sea as a part of the PROBES program. During six summers of field experiments, these researchers focused on water circulation and mixing, nutrient dynamics, primary productivity and floating plant life (phytoplankton), and the ecology of the sea's upper trophic, or nutritional, levels.

The program's aim was to explain oceanic processes that contribute to high productivity in the secondary and higher trophic levels of the region's vast continental shelf. Scientists used data on currents, primary production, and herbivore growth in the water column and on the ocean bottom. They wanted to document the circumstances under which Alaskan pollock might emerge from the shelf and also to learn about plant production in the region. The Alaskan pollock was selected because it is a major fishery species, considerable data on it were already available, and its early life history is similar to that of other organisms in the arctic ecosystem.

The researchers found that during cold years, pollock larvae have enough food to survive on the outer but not the middle continental shelf. Because of weak currents on the middle shelf, most larvae cannot drift from where they hatched to outer regions (where their prey is more concentrated) quickly enough to avoid starvation. The varying number of pollock entering the juvenile population each year thus results from the different survival

PROBES work. This satellite imagery of the North Bering-Chukchi Seas is from 12 June 1980, with a temperature enhancement scale of minus 3 degrees C to 12 degrees C. The warm Alaska coastal water appears dark, while the cold Bering Shelf water is light. This and other PROBES findings have given scientists an ecological basis for managing Bering Sea resources.

*The University of Alaska, University of Washington, Florida State University, Bigelow Laboratory for Ocean Sciences, Southwest Fisheries Center of the National Marine Fisheries Service, University of California at Irvine, Louisiana Universities Marine Consortium, Brookhaven National Laboratory, and San Francisco State University.

rates of larvae during warm and cold years on the middle shelf; the rate appears to be constant on the outer shelf.

Another consequence of the middle shelf's weak currents is that the plants not consumed by oceanic herbivores sink to the bottom and support an unusually high number of organisms there. During 1982-83, PROBES researchers made up carbon budgets for the outer and middle shelves and concluded that the middle-shelf carbon flow is balanced. Herbivores and benthic organisms—those at the bottom—consume most of what the middle shelf produces.

On the outer shelf, although a greater number of herbivores graze on phytoplankton, fewer benthic organisms are found; thus not all of the primary production is consumed. In fact, the investigators estimate that nearly half (48 percent) of the algal carbon goes unconsumed; the outer shelf's stronger currents transport it to the continental slope and deposit it there.

Project findings raised questions about the amount of carbon left in the water column of other continental shelves. Carbon models of ecosystems off Peru and the U.S. East Coast and in the Gulf of Mexico indicated that as much as half of the primary production in these areas also was unconsumed. Indeed, PROBES investigators estimate that as much as one billion tons of carbon per year may be buried on continental slopes.

Data such as these contribute to a better understanding of the global carbon cycle and balance. Overall PROBES results provide an ecological basis for managing Bering Sea resources. The information on the carbon cycle is a major ancillary finding.

Biological, Behavioral, and Social Sciences

2

Diversity is a key feature of the research that NSF supports in these areas. Topics of scientific interest range from molecules to entire landscapes, from units of speech to the national electorate; they include desert plants, poverty measures, computer languages, bacteria, fruit flies, and mental images—to name just a few.

Despite this apparently bewildering diversity, there is unity. The scientists who study neurons are linked to those who study social groups through their focus on living matter or its artifacts. Similar to living organisms, the programs and divisions in this NSF directorate change and grow. One manifestation of this change and growth is the different modes of support used by the directorate.

While standard support for research projects is the basic way to foster science, NSF also tailors support to special needs in a field or discipline. Three special initiatives, all at differing levels of maturity in FY 1983, illustrate this flexibility. Postdoctoral fellowships in plant biology began during the year. A long-term ecological research initiative begun in 1980 continued. Support for the Center for Coordination of Research on Social Indicators phased down after a decade of funding.

Until recently, relatively few plant biologists were exploiting new developments in molecular biology, and few molecular biologists had expertise on plants. Even more serious was the lack of students preparing for careers in these areas. New researchers were needed to apply techniques such as recombinant DNA to the plant sciences.

To meet this need, in FY 1983 NSF announced the Postdoctoral Research Fellowships in Plant Biology and got nearly 200 applications in response. Awards were made to 24 exceptionally well-qualified young researchers, including 14 women. The fellows, all within three years of their doctorates, will use their stipends for cross-training. Plant biologists will learn new concepts and methods developed in microbial and animal systems; those already trained in animal and microbial systems will gain insight into the unique characteristics of plants.

Ecosystems scientists have long recognized the need for systematic, long-term, and coordinated investigations. But individual projects often produced incomplete results. Studies suffered from insufficient knowledge of ecosystem variability, unsystematic monitoring of long-term trends, and the conversion of natural ecosystems to uses incompatible with research. And the lack of a coordinated network of sites prevented monitoring and comparing data at different locations.

The proposed solution to this problem was a network of sites designated for long-term ecological research (LTER). The 11 sites chosen in 1980 represented a variety of ecosystems. Each is a regional research facility; together they make up a national resource.

Investigators using the sites are expected to conform to various scientific and environmental restrictions. These include depositing their data in a form usable by future scientists and taking care that their experiments do not interfere with research by others. In exchange, they receive the benefits of interaction with other scientists, access

Table 2
Biological, Behavioral, and Social Sciences
Fiscal Years 1982 and 1983
(Dollars in Millions)

	Fiscal Year 1982		Fiscal Year 1983	
	Number of Awards	Amount	Number of Awards	Amount
Physiology, Cellular and Molecular Biology	1,474	$80.11	1,491	$87.34
Biotic Systems and Resources	711	41.99	716	45.96
Behavioral and Neural Sciences	697	31.74	694	34.02
Social and Economic Scis.	432	17.56	462	20.29
Information Sci. & Tech.	72	5.20	65	5.48
Subtotal	3,386	$176.60	3,428	$193.09
Adjustment to Internat'l Awards	--	--	--	-1.86*
Total	3,386	$176.60	3,428	$191.23

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.

SOURCE: Fiscal Years 1984 and 1985 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

to sites with long-term availability, and well-documented, accessible records.

As hoped, the arrangement has been a magnet for researchers, and data are accumulating rapidly. Most important, LTER research is integrated and cumulative rather than piecemeal. A conference to review the LTER effort took place at NSF during FY 1983. The results presented at that gathering left no doubt that the LTER program represents a milestone in biological research after only three years.

Research on social indicators, the counterpart of economic measures of societal well-being, began with a presidential commission report in 1933 (*Recent Social Trends in the United States*, by the President's Research Committee on Social Trends). During the next two decades, though, this kind of research failed to establish itself as an independent activity, or as the responsibility of either government or the private sector. Then in the tumultuous 1960s there was a rebirth of interest, and by 1970 it was clear that fast-growing conceptual and methodological developments required some direction. The Social Science Research Council, funded by an NSF grant, set up the Center for Coordination of Research on Social Indicators. The Center gave focus and visibility to the study of indicators by sponsoring conferences, workshops, and symposia, as well as providing a clearinghouse for researchers. It distributed working reports, advised researchers on the work of others, and prevented duplication in a fast-moving field.

Partly as a result of these activities, social indicators research is now becoming an established specialty. It has already left its methodological imprint on a number of established disciplines and secured a place in the scientific literature. Government agencies and policy makers in the United States and many western countries use indicator concepts and data in their policies and practices. This includes the National Science Board in its periodic science indicator reports.

Since the Center's purpose has been accomplished, it is scheduled to close soon as of this writing. But important offshoots will continue through the Social Science Research Council and the work of other agencies. An example is the National Center for Atmospheric Research, which will host a 1984 conference on new approaches to social forecasting. This conference is an effort to surmount the conventional boundaries of social science forecasting by including authors, topics, and participants from both the social and natural sciences. Their cross-disciplinary exchange will be of value to participants from fields as diverse as agricultural science, atmospheric science, ecology, economics, evaluation research, and social indicators.

Physiology, Cellular and Molecular Biology

This NSF program backs research into the ways organisms develop, reproduce, regulate their metabolic and physiological activities, and—in physical and chemical terms—how these life processes occur. Equipped with powerful new tools for manipulation and analysis at the genetic and molecular levels, scientists are removing boundaries within the life sciences, and those between the life and physical sciences. Research in the past decade has reduced the time between discovery and application and stimulated new business ventures as well.

Understanding the nature and function of genetic material is central to understanding other biological phenomena. Through the development of such new technology as recombinant DNA, it is now possible to identify, isolate, clone, and manipulate a wide array of genes, including some whose existence was unsuspected. Before recombinant DNA techniques existed, gene structure and function could be inferred only through analysis of a limited number of biological systems. Now the genes of virtually all species and any cell type can be studied.

Other key contemporary techniques include cell fusion, which makes it possible to produce monoclonal antibodies and hybrid plants that cannot cross-fertilize in nature. In addition, thousands of pairs in isolated DNA segments can now be determined with precision by a technique called nucleotide sequencing.

During the past 30 years, much experimental research with plant systems lacked the sophistication applied to microorganisms and animal systems. One reason for this is that tough cell walls and large vacuoles, or cavities, make plant material more difficult to manipulate. These and other obstacles diminished with the use of new techniques. For example, methods to fuse and grow protoplasts, with subsequent regeneration of whole plants, now permit manipulation and analysis at the genetic or molecular level.

Another important milestone was the development of vectors permitting the transfer of recombinant DNA to host plant cells. We can now investigate with keener insight significant plant phenomena such as photosynthesis. And we can develop models to study properties that may be more readily revealed in plants than in microbes or animals.

NSF programs in physiology, cellular and molecular biology give special emphasis to studies with plants because they offer scientific opportunities not readily exploitable before. The new knowledge gained can be applied to improved food, fiber, and fuel production.

In 1983 an important advance in plant biochemistry came from a team headed by Chauncey R. Benedict of Texas A&M University and Henry Yokoyama of the U.S. Department of Agriculture in Pasadena, California. They doubled the production of rubber from guayule by chemically treating that desert shrub in greenhouse experiments. This achievement could be a big step toward providing a domestic source of rubber and freeing this country from dependence on southeast Asian sources. Moreover, the researchers believe the same technique they used on guayule could perhaps be applied to other plants.

Support for Postdoctoral Research Fellowships in Plant Biology, begun in 1983, shows the Foundation's leadership role in that area. These fellowships will accelerate molecular and cellular approaches to plant biology by encouraging young, well-trained biological and physical scientists to pursue research careers in plant science. They will also help reduce the shortage of scientists in a rapidly expanding research area. Twenty-four fellowships were awarded in 1983.

The research accomplishments described below illustrate some new approaches to contemporary biology. These illustrations, however, are only a small part of the rapid progress and opportunity in the life sciences today.

Snake Organs and Kidney Stones

Using tiny units from the kidneys of garter snakes, a scientist is gleaning information that one day could bring relief to millions of persons who suffer from kidney stones and gout. William H. Dantzler, a University of Arizona physiologist, studied the way large amounts of uric acid can be excreted by a snake's kidney without stones being formed. His basic research was funded by the Foundation's Regulatory Biology Program.

Kidney stones are hard mineral deposits formed in the kidney from uric acid and other substances. When large enough, these stones can block the urinary tract and cause excruciating pain. More than 821,000 persons in the United States suffered from kidney stones in 1981, the latest year for which a figure is available. That same year more than 2 million people also suffered from gout, a disease caused by the disturbance of uric acid metabolism.

Kidneys consist of thousands of nephrons, or filtering units, that are responsible for the formation of urine. In snake kidneys the nephrons can readily be separated from fresh tissue and maintained functionally intact for research. In addition, the tube portion of the snake nephron has a highly developed method to transport uric acid across cell walls.

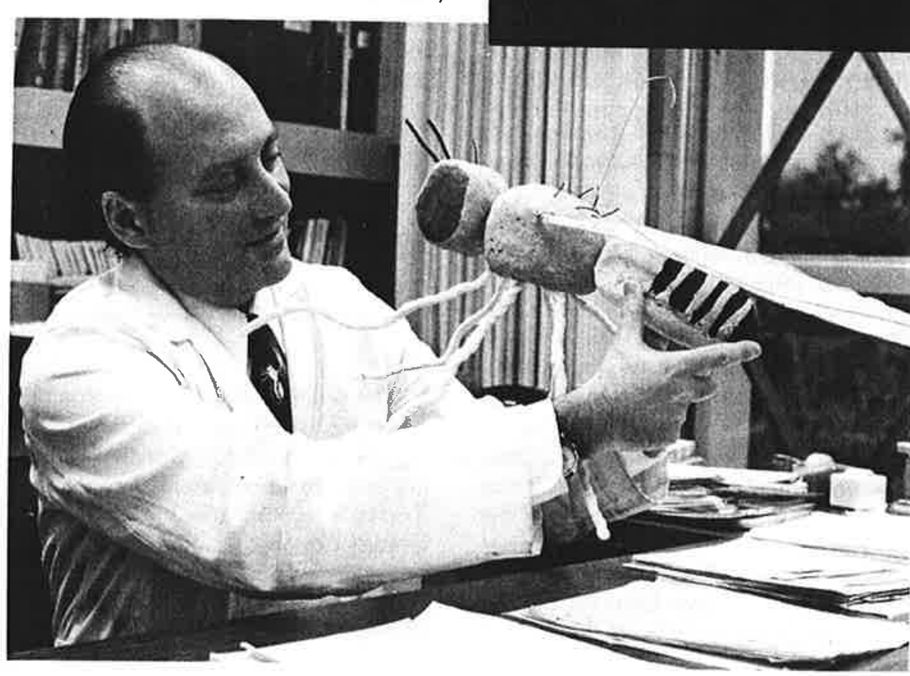
Each end of a tube of cells can be held in a small glass tube and studied in detail as a variety of fluids is passed through them. By studying this transport process, Dantzler learned more about how the kidney regulates the excretion of uric acid. This could lead to better treatment and prevention of both gout and kidney stones.

Genetic Dissection of Learning

What are the physical constraints on behavior? Can they be dissected and elaborated? Answering these questions was the task of Caltech's Seymour Benzer, who has done outstanding work in both physics and biology. His experimental model was the common fruit fly, *Drosophila*, which is complex enough to show behavior patterns and be capable of associative learning, yet simple enough to be one of the best genetically characterized organisms available. Benzer obtained mutants that displayed aberrant behavior and determined that some of the aberrations derive from single gene mutations.

Study of the "dunce" mutant is one of the most exciting and rewarding of those done in Benzer's laboratory. He put the dunces and other flies through a learning process, then tested them for retention. The flies were allowed to react to two odors, one of them accompanied by an electrical shock. When tested, normal flies remembered to avoid the odor associated with the shock, but the dunce

Seymour Benzer and *Drosophila*. His work with the common fruit fly showed that a genetic defect influenced memory in "dunce" mutants of the insects. Research on these fairly simple organisms may lead to more knowledge about learning in higher life forms. (Photo of Benzer by Floyd Clark, Caltech)



flies did not. Appropriate controls and further work with the mutant indicated that the genetic defect did indeed affect memory.

Later studies showed the dunce to be deficient in a specific enzyme that regulates the level of one of the cyclic adenine monophosphates (cAMP), a compound implicated in both gene regulation and changes in neuronal physiology. All dunce mutants isolated showed higher than normal (up to six-fold) levels of this cAMP. The simplest hypothesis at this writing is that aberrant levels of the cAMP cause memory dysfunction. Further work should clarify the process of learning in this relatively simple organism. Scientists can then move closer to answering questions about learning in higher life forms.

Chemical "Cement" Helps Solve a Biological Problem

The outbreak of acquired immune deficiency syndrome (AIDS) has heightened interest in the body's immune system and how it operates. Immunity is extremely complex, involving not only antibodies generated by foreign or invading organisms, but also an independent system maintained by the body and known as "complement." It consists of nine major components. When activated by an antibody, they interact to dissolve or destroy a foreign cell. A full understanding of the entire complement process requires three-dimensional structural detail of the various components and their interactions.

Verne N. Schumaker at the University of California, Los Angeles, has used electron microscopy to clarify the structure of the complement's key first component, composed of two distinct subunits. While it was relatively easy to study the isolated subunits, at first it was not possible to examine them together. Finding that electron microscopy led to separation of the subunits, Schumaker solved the problem by joining them with a cross-linking agent. That agent reacted chemically with both subunits, but did not change the activity of the overall component.

With the two subunits thus "cemented" together, Schumaker got a clear picture of the first component, including the detailed structure of both subunits.

With this structural characterization known, it may now be possible to learn how the first component of the complement system interacts with its other components to destroy a foreign cell in the body. This work has obvious implications for cancer and other research.

Plant Research Aids Medicine

A basic study of photosynthesis—how plants use sunlight to grow—has led to the development of a new class of substances that are useful for medical diagnosis. The first step in photosynthesis in simple plants such as blue-green algae is absorption of light by certain proteins. Alexander N. Glazer, a microbiologist at the University of California, Berkeley, and two collaborators, Lubert Stryer and Vernon Oi of Stanford University, were studying these light gatherers, called phycobiliproteins, and realized that they might have properties useful for medicine.

Purified phycobiliproteins are brilliantly colored molecules, ranging from bright blue to deep red. They surpass most other light-absorbing molecules found in living systems in their intensity of visible light absorption. The investigators found that the pure molecules fluoresce brilliantly, and they exploited this property in their work with reagents (substances used to detect or measure other substances).

Glazer, Stryer, and Oi prepared reagents called conjugates, in which phycobiliproteins were chemically attached to antibodies. The conjugates can be detected at very small concentrations with modern laboratory instruments because of the intense fluorescence of the protein component. The antibody component recognizes a particular cell or part of a cell and attaches the conjugate to it. As a result, conjugates can be designed to recognize specific molecules on the surface of cells or in biological fluids.

These conjugates provide a diagnostic tool to localize and identify foreign or altered cells in the body. Further, since different phycobiliproteins fluoresce in different colors, several analyses can be done simultaneously. Conjugates have already been used successfully to tag and sort various classes of cells.

This research shows how unanticipated benefits can emerge from an esoteric fundamental study. It also reveals how quickly basic research can lead to a marketable product in the fast-growing area of biotechnology. In this instance, technology from basic biological research was transferred to diagnostic medicine in about six months.

Biotic Systems and Resources

The science supported by this NSF division, unlike that of many subdisciplines of biology, draws upon all aspects of biological knowledge. Today's systematic biologist must employ not only traditional approaches but also must be acquainted with ecological relationships and survival strategies and the techniques of biochemistry, genetics, microbiology, mathematics, and computer research. Other sciences may also be essential. For example, in the research reported below on Precambrian paleontology, insights and information from stratigraphy and geochemistry were crucial.

In ecosystem research, physiological ecologists, microbiologists, soil scientists, hydrologists, and atmospheric scientists all may be required to contribute special understanding. The Turkana pastoralist project described below, more inclusive than most ecosystem studies in the past, had anthropologists as co-investigators.

In the past, scientists were reluctant to study long-term ecological phenomena, such as the nutrient investigations cited later, because of difficulties in securing sustained funding. To address that concern, NSF created its Long-Term Ecological Research (LTER) program in 1980, setting up multiinvestigator projects at 11 ecosystem sites across the country. In a May 1983 presentation to NSF and other interested agencies, the principal scientists from these projects discussed commononcerns and findings. This meeting showed the importance of intersite research and interproject coordination as the basis for comparative ecosystem research.

Precambrian Mass Extinction

Rocks older than 570 million years, generally referred to as "Precambrian," lack a conspicuous fossil record. Thus our knowledge of life during the first 85 percent of the earth's history is incomplete. Only in the last three decades have significant numbers of Precambrian fossils been discovered and they are almost exclusively bacteria, structurally simple algae, and protozoans.

Paleontologists such as Andrew Knoll, at Harvard University, have begun to unravel the nearly three billion years of evolutionary history documented by these fossils. Knoll has found that the late Precambrian era, which brackets the time between 570 million and one billion years before the present (B.P.), was a time of great evolutionary change. Working with Gonzalo Vidal of Lund University in Sweden, Knoll examined the late Precambrian fossils of unicellular planktonic organisms and discovered three major periods of organismal change.

A dramatic increase in the morphological diversity of the plankton began about 900 million years ago (M.Y.B.P.). That diversity continued to increase for about 250 million years; this is the earliest known radiation of eukaryotes (cells with a distinct nucleus). Cyst-forming, eukaryotic phytoplankton came to dominate the surface layer of the coastal waters during this period, while prokaryotic (nonnucleated) bacteria held sway over broad areas of the shallow sea floor.

A dramatic extinction episode started about 650 M.Y.B.P., resulting in the loss of almost all of the distinguishable plankton. About 70 percent of the 40 described algal species, and all six of the known protozoans, disappeared. This is the first mass extinction known in the fossil record. Since it coincides with an extensive glaciation event, cooling temperatures may be causally related to this marine extinction.

After a period of low plankton diversity that lasted at least 70 million years, a second and very rapid radiation of morphologically complex planktonic eukaryotes occurred. This reestablished high diversity levels by the time readily fossilized multicelled organisms appeared abundantly in the fossil record—at the beginning of the Cambrian period (about 570 M.Y.B.P.).

Evidence for the late Precambrian mass extinction came from analysis of rocks around the North Atlantic, including sedimentary beds in Greenland and Scandinavia. At this writing Knoll is examining rocks from sites in the United States, Namibia, and Australia. He hopes to determine the extent of the extinction event and to show the relationship between plankton evolution and the widespread glaciations of the late Precambrian.

The Precambrian fossil record, with its associated geochemical and geological records, is important to basic research because it documents the early evolutionary development of the biosphere. Such research sheds light on the physiology, ecology, and evolution of modern bacteria and protozoa. Geologically, it is important because microorganism evolution is directly or indirectly related to the distribution of sedimentary ores such as iron, gold, uranium, and copper. More knowledge of early evolution will improve our ability to prospect for mineral resources found in Precambrian rocks.

Pastoralist Use of a Patchy Ecosystem

The pastoralists of Southern Turkana, Kenya, occupy a semiarid region of about 8,000 square kilometers where vegetation is structurally diverse over short distances and rainfall comes in brief, intense periods. During the rains, there is rapid water recharge of the sandy soil as well as high runoff, causing brief periods of stream flow. Ultimately much of this water is stored deep in the soil. *Acacia* trees, with long roots to tap that deep soilwater, dominate the edges of intermittent stream channels, with shallow-rooted shrubs interspersed. Away from these channels, herbaceous plants are dominant.

The Turkana pastoralists use several species of livestock to improve the tribe s chances of maintaining adequate food supplies during dry seasons and surviving periods of extended drought. Studies of the interaction between these pastoralists and their livestock were done by James E. Ellis and Michael Little and their respective co-workers from Colorado State University and the State University of New York, Binghamton.

The livestock used for food are cattle, sheep, goats, and camels. Each species has its own feeding pattern (grazing, browsing, a combination of both) and liabilities—e.g., the cantankerous disposition of the camels, low milk production in the sheep and goats, and the dependence of cattle on seasonal herbaceous plants. Balancing the use of these different species seems important to the survival of the human population over long periods of time.

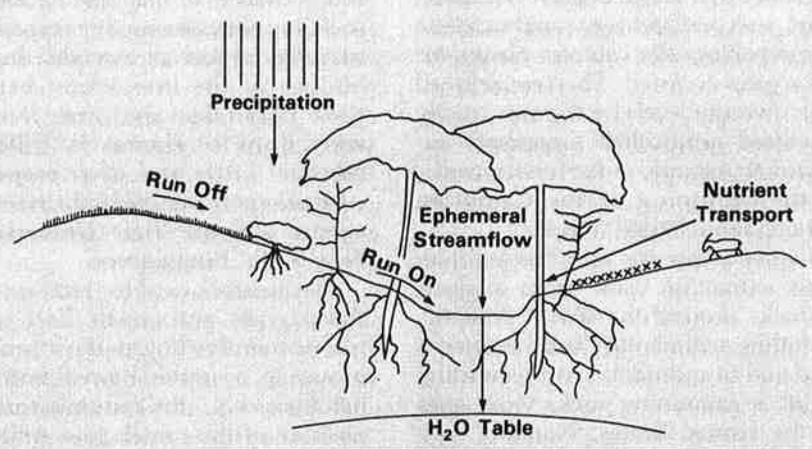
During a wet season, when the herbaceous plants thrive, the Turkana small family groups join into larger communities to share favored, easily accessible grazing areas on moister sites. These communities generally prosper, mainly because of the reproductive success of their cattle and hence high milk production. As the land dries, however, the cattle's grazing supply becomes scarce and poor in quality. The Turkana communities then disperse and the browsers—camels and goats—are used more heavily. Milk, blood, and occasional goat meat sustain the pastoralists during the dry season.

While managing their herds to yield adequate nutrition in the face of highly variable rainfall, the Turkana have not degraded their semiarid environment. They may, in fact, have stabilized it by inadvertently fostering the development of trees, the most stable element of the ecosystem, through the redistribution of nutrients within that nitrogen-poor system.

After grazing and browsing during the day, over an area up to eight kilometers in radius, the livestock are herded back to the village and corraled at night to protect them from nocturnal predators. The corrals, made from small *Acacia* trees, become deposit sites for large amounts of urine and feces derived from their daytime feeding. Ellis and his co-workers postulate that this waste material greatly enhances the nutrient richness of these areas.

The researchers observed dense, circular, even-aged stands of *Acacia* seedlings on abandoned corral sites; such sites are numerous, for corrals are moved frequently. The tribesmen indicated that goats are fed the *Acacia* seed pods during the dry season—the obvious source of the seeds. Thus it appears likely that Turkana livestock management has fostered the development of trees along drainage areas. Survival of the culture in this harsh environment relies on selective use of the vegetation mosaic, which the Turkana have achieved through their livestock management customs.

Kenyan ecosystem. Generalized diagram of the Southern Turkana ecosystem structure shows distribution of vegetation types, use of plants by livestock, and vegetation cover during peak drought periods. This research project revealed a well-balanced use of the area's plant life, notably through creative livestock management by the pastoralist residents. They were thus able to survive in a harsh environment.



	Ground Cover-%	Cattle	Sheep	Goats	Camels	July % of Max. Cover
		% Use				
Herbaceous	72	96	73	38	3	14
Dwarf Shrubs	20	4	25	28	63	70
Medium Shrubs	5					53
		0	2	34	34	
Trees	3					100

xxxxxxx Livestock Corrals

Nitrogen Flux in a Landscape Mosaic

In both dry and well-watered landscapes, the patchiness of vegetation establishes a landscape mosaic. Continuing studies of Maryland's Rhode River Drainage System, which discharges into a subestuary of the Chesapeake Bay, have given information on relationships between the landscape elements of that watershed ecosystem. A prominent aspect of this interaction is the modulation by each unit of the nutrient concentration in the waters of the network of drainage channels.

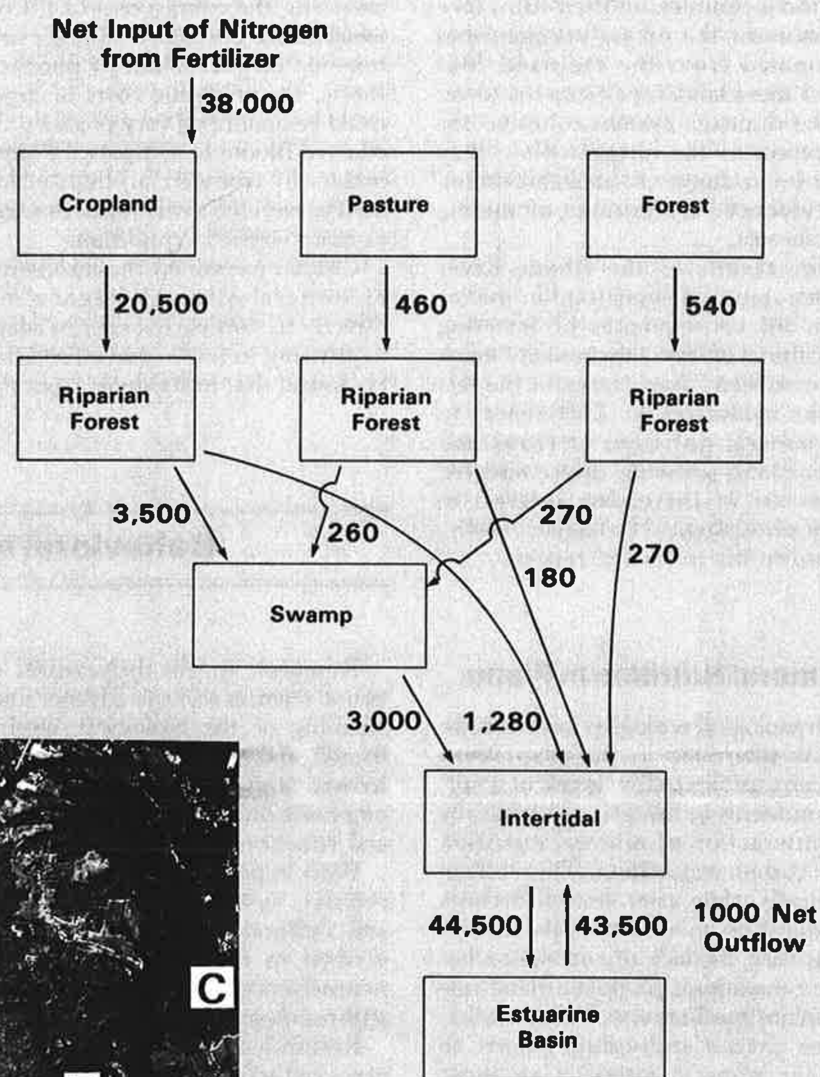
This system, studied by David Correll of the Chesapeake Research Consortium and his co-workers, is small (38 square kilometers) but particularly well-suited to this study because underlying the entire watershed is an impervious clay layer just above sea level. This layer prevents downward seepage, thus assuring that all water movement is horizontal.

The landscape elements include low-elevation uplands bordering the system, and forest-edged drainages, which discharge—in part through a freshwater swamp—into a central complex of tidal waters, marshes, and mudflats. Waters from there ultimately flow through the subestuarine basin into the estuary itself at ebb tide. Excluding the subestuarine basin, freshwater and tidal wetlands occupy about 5 percent of the drainage system area; 61 percent is forested uplands, 16 percent cropland, 12 percent pasture land, and 6 percent residential.

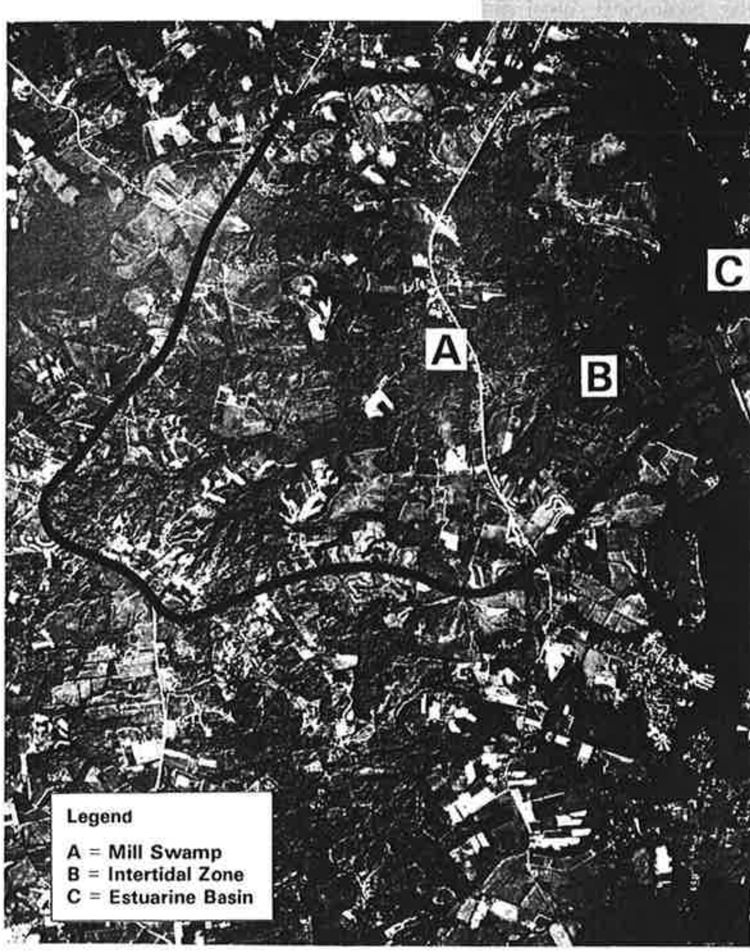
Correll and his team have traced the flux of nitrogen, an important plant nutrient, from each landscape element.

The annual flux from all forested parts of the system is about 500 kilograms and from cropland (mostly planted in maize) 20,000 kilograms. The latter value is 40 times that of the forest, even though the croplands are less than one-quarter the area of the forests. This relatively enormous flux, of course, derives from the application of nitrogen-rich fertilizer. While part of this fertilizer achieves its primary goal of food production, a significant amount serves to enrich still more an already nutrient-rich ecosystem.

The streams draining the cropland are the primary recipients of this enrichment, and the riparian forest bordering these waterways incorporates much of the nitrogen, reducing the flux to about one-quarter of that reaching the streams. In comparison, the flux from the riparian forest on rivers draining less disturbed forested land is about equal to what it receives—i.e., about 540 kilograms. The rooted



Nitrogen balance. Chart illustrates flow of nitrogen among major ecosystem types in Rhode River Watershed. Values are kilograms of nitrogen for the period March 1981 to February 1982. The watershed is 38 square kilometers in extent. Cropland accounts for 16 percent, pasture 12 percent, residential area 6 percent, forests and abandoned fields, 61 percent, freshwater wetlands 3 percent, and tidal wetlands 2 percent.



Landscape mosaic. In Maryland's Rhode River Watershed, pasture, croplands, and undisturbed forest occupy uplands; streams are distinguished by riparian forests following the drainage pattern. Swamps and an extensive intertidal zone buffer the upland from the estuary. This study revealed much about relationships between the landscape elements of this area. Of particular interest was the movement of nitrogen through the ecosystem. That flux showed clearly the effects of agriculture on other parts of the watershed. (See also chart on nitrogen balance.)

and floating plants of the swamp and intertidal complex, in their turn, take up more of the excess nitrogen that originated from the cropland. But while these landscape elements lower in the drainage system continue the reduction of the nitrogen flux, they may be in danger of destabilization, as evidenced by periods of anoxia and die-off.

The results of the Rhode River System study demonstrate in microcosm the consequences of fostering agricultural cultivars that require much more nutrient than plants in the rest of the landscape do. Differences in the mineral nutrition of crops and other plants growing under nutrient stress are of increasing interest to plant physiological ecologists, as discussed in the following report.

Mineral Nutrition in Plants

Physiological ecologists have become keenly interested in the adaptations of plant species to low levels of available nutrients in the soil, and especially the interaction of mineral nutrition with carbon acquisition. This shift in emphasis came after several decades of attention to photosynthesis had made clear the lack of correlation between maximum photosynthetic rate and plant productivity. What mechanisms permit individual plants to survive mineral stress? Can these mechanisms be bred into productive crop species without the loss of high yield, to allow expansion of agriculture to marginal lands without adding fertilizer? The answers to these questions require an understanding of the mechanisms and genetic basis of adaptations to mineral stress in wild plant species.

This problem has been under investigation by Arnold Bloom of the University of California, Davis; F. Stuart Chapin of the University of Alaska; and others backed by NSF. A major advance came when Bloom developed sophisticated instrumentation that could accurately measure mineral uptake by roots.

By monitoring ion concentrations in a nutrient solution before and after its contact with the root system, Bloom was able to construct a precise budget assessing the energy cost of nitrogen metabolism. Combined with the simultaneous measurement of photosynthesis, the energetic costs of growth could be quantified very precisely. This allowed Bloom to compare the mineral budget of commercial, high-yielding barleys with their wild relatives adapted to more stressful conditions.

Chapin examined the mechanisms of mineral-stress tolerance more directly by comparing species adapted to growing in fertile and infertile soils. He found that individuals from these two habitats do not differ in the rate of nutrient uptake, the specifics of nutrient metabolism within the plant, the efficiency with which nutrients are turned into biomass, or the capacity to conserve nutrients by moving them from one organ to another. Instead, adaptation to mineral stress hinges on very low potential growth rates and the allocation of increased resources to root development. Because these two mechanisms may be related, at this writing Chapin is concentrating on allocation decisions within the plant and their effect on growth rate.

Behavioral and Neural Sciences

Research in the behavioral and neural sciences seeks to advance understanding of the biological, environmental, and cultural factors underlying human and animal behavior, with emphasis on nervous system structure and function.

Work is proceeding at the molecular, cellular, system, individual, group, and cultural levels and may be described in three research clusters: neuroscience, cognitive science, and anthropology.

Research in neuroscience describes nerve cell action, the growth and development of the nervous system, and the underlying anatomy, physiology, and biochemistry of that system. Emerging knowledge of brain function and behavior now offers direct insight into the way information is received, processed, and integrated by the nervous system, and how behaviors—from simple reflexes to complex sequences—are generated. (See, for example, the report that follows on reproductive behavior.) Progress in understanding the development of the nervous system, especially at the cellular and molecular level, has been particularly rapid in recent years, as scientists use new techniques to analyze individual nerve cells, their membranes, and patterns of growth.

Cognitive science focuses on the ways human beings obtain, store, retrieve, and use information; properties of language and how it is acquired and used; and human behavior, including developmental processes. Some approaches emphasize an understanding of individual behavior, as in the report that follows on mental imagery. Progress in learning how language is acquired, and how other cognitive behaviors and emotions develop, has been especially rapid. (See the report on infant emotions.)

Anthropology describes the laws or patterns that underlie human societies and populations worldwide. NSF supports research in cultural and physical anthropology, archaeology, and the preservation of (and improved access to) essential research collections. Current work, which integrates the biological, physical, and social sciences, gives perspectives on contemporary civilization across both time and space. With a growing array of new dating techniques, archaeological research extends our knowledge into the distant past. (See the report on the origins of humanity.)

Mental Imagery

Albert Einstein claimed to have received his first insight into relativity theory when he imagined himself chasing a beam of light, "seeing" what would happen as he ran ahead and caught up with it. The German chemist Kekule dreamed of snakes biting their tails and woke up, "as if struck by lightning," realizing that he had discovered the structure of benzene. These and similar anecdotes suggest that mental imagery is a valuable component of creative thinking. Moreover, imagery plays a role in a host of more mundane tasks.

Consider how you would give directions to the train station if stopped by an out-of-town visitor on the street: Would you visualize the roads and count the stoplights in your mind? Or, when faced with a heap of luggage to fit into a car trunk, do you visualize different arrangements, twisting and turning the images to find the best fit?

But what is a mental image? How can one study imagery scientifically? And what would a theory of mental imagery be like? Psychologist Stephen M. Kosslyn has been trying to answer those questions with NSF support. For his work he received the Initiatives in Research Award from the National Academy of Sciences for developing "a comprehensive theory of visual imagery and its representation in the human memory system." The research has also resulted in a 1983 book by Kosslyn called *Ghosts in the Mind's Machine*.

Kosslyn, now at Harvard but previously at Johns Hopkins, began by asking about the properties of mental images. Instead of trying to investigate images directly, his idea was to observe the behavioral consequences of using images in specific ways. In one set of experiments, he and his colleagues demonstrated that images preserve spatial relationships among parts of an object. In a typical experiment, subjects would memorize a picture, shut their eyes and form a mental image of it, and then answer questions about the imaged picture. Kosslyn found that the time to scan across these mental images varied proportionately with the distance scanned, the time increasing linearly as that distance grew. These data make sense if subjects scan across a stored representation that embodies distance.

In another set of experiments, Kosslyn found that smaller images of objects require more time to "inspect" than do larger images. Furthermore, if an image becomes "too large" (i.e., seems to subtend too large a visual angle), it "overflows" and the edges are no longer "visible." These results make sense if imagery occurs in the same brain structures that process input from the eyes. These structures have a limited resolution (which would produce the grain limitations of images) and represent only a limited visual scope.

In other research Kosslyn showed that images are stored in memory as individual units (e.g., for a human form, the stored units correspond to the arms, legs, head, and torso), which are defined by specific perceptual and conceptual principles. These units are activated sequentially and arranged one by one into a single scene or detailed object. Kosslyn has gathered evidence that this "image-generation" process involves activities centered specifically in the left cerebral hemisphere. This finding runs counter to the common wisdom that imagery is a right hemisphere activity.

Kosslyn's goal is to understand imagery well enough to program it into a computer. When the computer is asked to perform specific tasks it should produce the same data as human subjects do, and it should correctly predict human behavior in imagery tasks. In fact, Kosslyn and his colleagues have succeeded in constructing a computer model that not only explains nearly all the known facts about mental imagery but has predicted a host of new phenomena.

This research has helped specify what the brain does during thinking and produced new ways to process information in computers. Among other benefits, Kosslyn's work may lead to useful approaches and tools in education.

Reproductive Behavior in Vertebrates

Research is most fascinating when it challenges the assumptions we hold about ourselves and the world around us. One widespread and long-held belief is that, at least among vertebrate animals, reproduction depends on three functionally associated processes: secretion of gonadal hormones, production of gametes, and sexual behavior. Although this belief is supported mainly by evidence derived from domesticated rodents, many people have assumed that this three-way correlation is true for all sexually reproducing species.

David Crews, at the University of Texas in Austin, is helping to put the study of reproductive behavior and physiology into a broader comparative context. Through a literature survey Crews discovered that the physiological basis of reproductive behavior in both males and females is known for fewer than 50 species, and that not all of these species behave as rodents do. His research with garter snakes and whiptail lizards shows some amazing differences.

Red-sided garter snakes *Thamnophis sitalis* emerge from hibernation in the spring; their mating season begins within a week and lasts for about two months. During this time of vigorous courtship and mating, circulating levels of gonadal steroids in the males are low and sperm production has not yet begun. Gametogenesis will not proceed until after the mating season. In fact, the sperm transferred to females was produced in the preceding year, before hibernation, and stored until the snakes emerged from hibernation. Furthermore, castration does not diminish the sexual behavior of garter snakes, and giving them hormones does not cause that behavior to increase during the mating season or to occur at any other time of year.

These findings emphasize the fact that the garter snake's behavior is dissociated from both gamete production and secretion of hormones. Thus the three-way correlatio is not general to all sexually reproducing animals, and we must revise some time-honored "explanations" that treat gonadal hormones as a necessary precursor to sexual behavior.

A different sort of dissociation between reproductive behavior, gonadal hormones, and gamete production is found in the all-female species of whiptail lizard, *Cnemidophorus uniparens*. They reproduce parthenogenetically (the lizards have only ovaries and produce only eggs, not sperm), yet they exhibit behavior patterns that are remarkably similar to those of closely related species having both males and females. Crews found, for example, that certain malelike actions and postures aid reproduction, serving as neuroendocrine primers just as male sexual behavior does in sexually reproducing species of vertebrates. Furthermore, Crews determined that the same individual lizards alternate between malelike and femalelike behaviors at different stages of their ovarian cycles.

These unisexual lizards clearly illustrate a dissociation between gonadal sex and behavioral sex, in that male or female behavioral roles are not confined to individuals with testes or ovaries. The fact that a single female can exhibit both roles in sequence probably indicates that behavioral sex roles are not an inherent consequence of the gonads.

Finally, it is interesting to think about the ecological and evolutionary forces that cause some species to obey, and others to violate, the principle of the three-way correlation. Perhaps the correlation characterizes species in which males and females live in regular and predictable habitats, and population densities are sufficient to ensure that the sexes encounter each other when mating urges, gamete production, and secretion of gonadal hormones are simultaneously triggered. For species that are dispersed during most of the year, or for species living in relatively changeable and unpredictable habitats, it may be necessary for sperm transfer to occur whenever an opportunity arises, and for females to deposit eggs only when conditions are appropriate. Hence mating would happen without regard for ovulation, and sperm storage would become a mechanism to bridge the gap between sperm transfer and ovulation.

The unisexual lizards, on the other hand, may represent an adaptation to a highly predictable environment in which highly well-adapted females are avoiding the costs of sexual recombination by dispensing with males and fertilization.

This and similar work could result in completely new ideas about the ways we teach and learn biology.

Key Infant Research

In 1983 areas of infant research supported by NSF included the way babies comprehend speech and the range of infant emotions and when they are expressed.

At the University of Washington, Patricia K. Kuhl and Andrew N. Meltzoff found that at 18 to 20 weeks of age, infants could recognize the relationship between what they saw and what they heard when someone was talking to them. In other words, the babies showed some signs of lip reading.

The research team tested 32 normal infants aged 18 to 20 weeks. The experiment involved two adjacent films of a person saying two different vowel sounds in synchrony. The accompanying sound track was synchronized to only one of the speakers and mismatched with the other. Most of the babies were able to detect the audio-video correspondence and looked much longer at the face that matched the sound.

This discovery is important because scientists and others have long thought that the ability to speak and to understand speech was linked almost exclusively to the child's hearing. The Kuhl-Meltzoff research underscores the importance of co-delivering visual and auditory information about speech to hearing infants, or visual and touch information to the deaf.

On a larger scale, studying the ways infants link the auditory, visual, and motor aspects of speech could help us understand how human beings develop language capacities.

In the area of infant emotions, Carroll Izard and his colleagues at the University of Delaware have been studying the faces of infants as they respond to a wide array of emotion-producing stimuli. Their data will help us better understand and communicate with infants.

Izard has developed the Maximally Discriminative Facial Movement Coding System, or MAX. This is an anatomically based, objective system to code each of the separate facial movements that express different emotions. It is based on the assumption that neurological underpinnings of emotions activate organized patterns of facial movements, and that these patterns can be objectively and reliably recognized. The application of MAX has shown that by the time infants are seven to nine months of age, they can produce expressions of interest, joy, surprise, sadness, anger, disgust, fear, and physical distress or pain. The pattern for each of these expressions is distinct and can be reliably identified by careful observers. This system has been adopted in approximately 30 other laboratories in this country and abroad.

In a study of infants 2 to 19 months old who were responding to innoculation, the researchers found that the expression of physical distress was the most prominent response to pain in the early months of life.

By 18 months, though, the predominant response was anger. Brain maturation and individual learning had apparently inhibited the distress signal and released the anger expression. Izard believes that anger has an adaptive advantage as a response to pain by mobilizing energy and organizing responses to cope with a noxious agent.

Another trauma studied is the baby's response to separation from a mother or other principal caregiver, especially around the age of six to eight months. This response has been called "separation anxiety." With the application of MAX, we now know that the typical expression during brief separations is anger more often than sadness.

At this writing, a followup study of children four to six years old is in progress. It will test whether the various emotion-expression styles can predict preschool levels of functioning in such domains as social emotional maturity and cognitive abilities.

There is no way as yet to determine that an infant who expresses sadness actually *experiences* a *feeling* of sadness. But this research on emotional expressions in early development does give us a better understanding of how an infant communicates, and it is a basis to assess normal and abnormal emotional development.

The Origins of Humanity

Scientific and public interest has been sparked in recent years by research into the origins of humanity. This research can explain the underlying processes that guided the transformation of our species from its earliest ancestors to its present form.

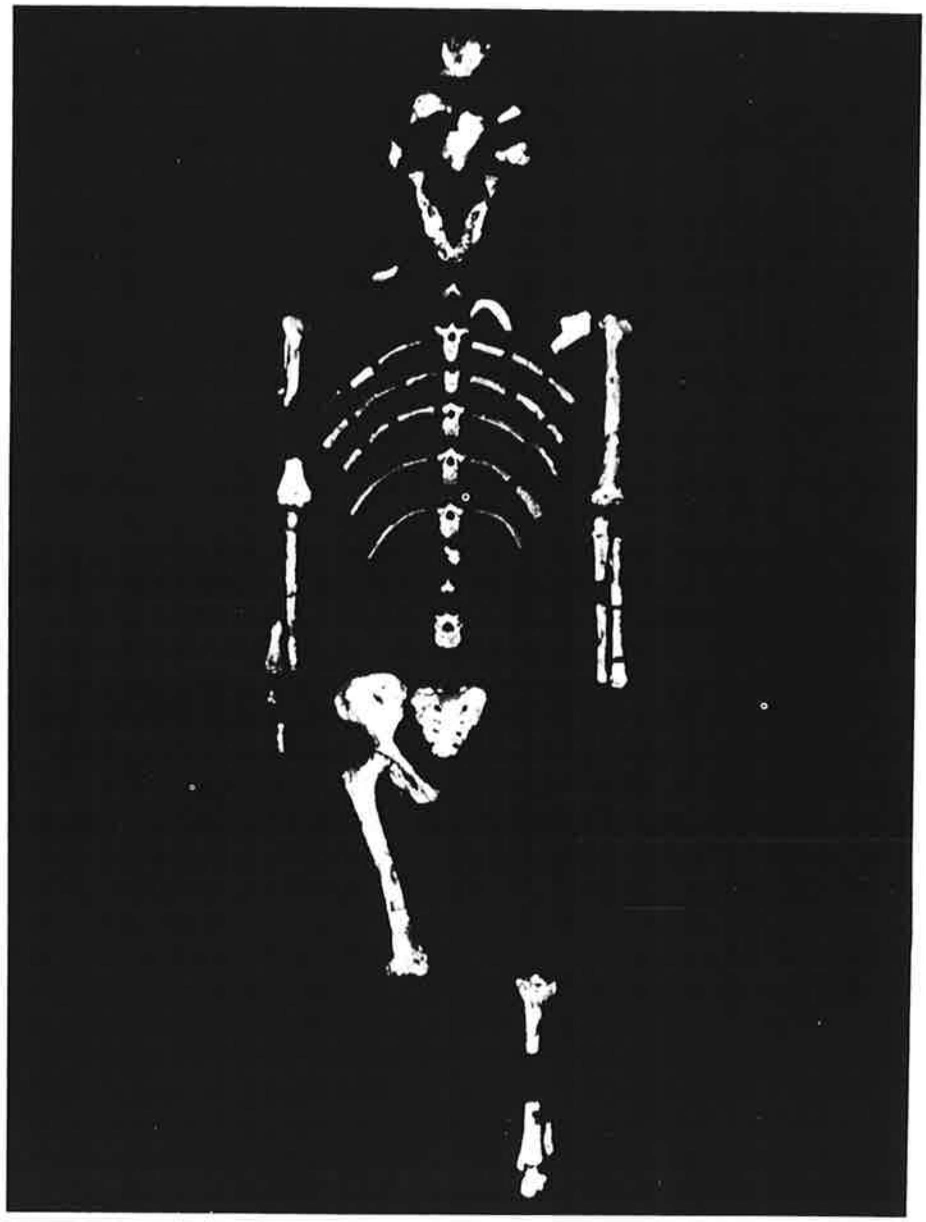
New materials unearthed by teams of investigators have begun to fill the gap that existed in the human fossil record between 2 and 10 million years ago. In addition, we now know much more about past climates, geography, habitats, and the kinds of animals associated with those fossils. These findings have come from work in Pakistan directed by Harvard's David Pilbeam and research in Ethiopia led by Donald Johanson at the Cleveland Museum of Natural History, J. Desmond Clark at the University of California at Berkeley, and others.

We also have learned much about the characteristics of early humans. Current evidence suggests that between 100,000 and 40,000 years ago biological evolution had reached a point where the motor and neural capabilities of early humans were equivalent to ours in the present, and social change had brought people together into larger groups than were typical for our nearest primate relatives. Among the developments that accompanied these social transitions were speech, religious and abstract beliefs, and burial ceremonies.

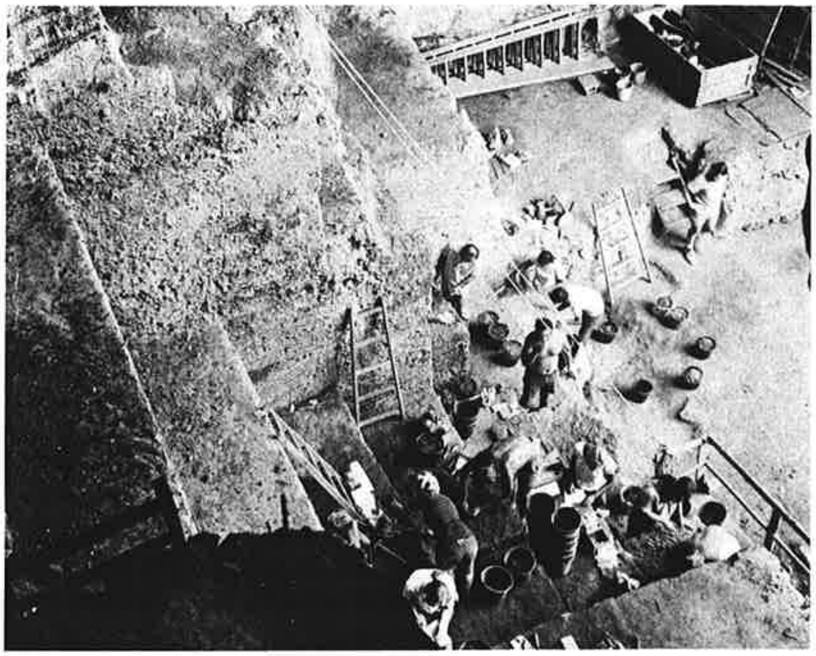
Arthur Jelinek at the University of Arizona has concluded a long-term investigation of the Tabun Cave at Mount Carmel in Israel. Portions of the cave were first excavated by Dorothy A. E. Garrod in the 1930s. The discovery then of Neanderthal remains at Tabun, and of *Homo sapiens* remains nearby, added to the controversy surrounding the Neanderthal's position in human evolution. Was it a dead-end development contemporaneous with *Homo sapiens* or a step in the gradual transition to *Homo sapiens*?

Jelinek reopened the cave in order to apply modern scientific methods to the remains there. The cave had an unusually long span of occupation, which provided a continuous record of changing technology from about 130,000 to 50,000 years ago. Jelinek's interpretation of the cultural materials he found led him to conclude that there was continuous biological evolution from Neanderthal to modern *Homo sapiens*.

New techniques help much of this research. A cornerstone in the work of paleontologists, paleoanthropologists, geologists, ethnoarchaeologists, and others working on these problems is the ability to assign absolute dates to the materials they investigate. Until recently, the range of radiocarbon dating—the archaeologist's most common tool—was limited to 30,000-40,000 years ago, impeding analysis of older materials. Now new radiocarbon facilities, such as the linear accelerator at the University of Arizona and the Van de Graaff facility at the University



Lucy. This fossil find of a nearly complete female, about 28 years of age, was made by Donald Johanson in Hadar, Ethiopia. The date of the fossil is in the range of three million years, and it is the earliest directly in the lineage of *Homo sapiens*. The hip structure indicates this creature walked bipedally.



Excavations at Tabun Cave, Israel. Few aspects of Paleolithic archaeology generate as much discussion as questions on the nature of the Neanderthals and the significance of their material culture. Our knowledge of these transitional (between archaic and modern human) forms is largely derived from excavations in the Levant and Western Europe. Tabun was first explored in the 1930s; an investigation ending some 50 years later found that materials from the cave suggest continuous biological evolution from Neanderthal to modern *Homo sapiens.*

of Rochester, are pushing back the range of radiocarbon dating to include this crucial period of human history. Both machines work by measuring the ratio of carbon isotopes directly instead of counting their radioactive emissions. This permits the use of much smaller samples and provides dates from as long ago as 80,000 years. Other techniques, including potassium-argon dating, allow scientists to assign dates to even earlier periods.

Social and Economic Sciences

The National Science Foundation has been a key force in the development of present-day social and economic science. Over the past two decades its support has been responsible for creating, maintaining, and making accessible major collections of high-quality data, along with the development of increasingly powerful quantitative techniques to analyze those data. Today, these resources are shared by thousands of researchers engaged in theory building and testing across a spectrum of disciplines, and by analysts and decision makers seeking information on public-policy issues.

These major collection efforts, in addition to a number of smaller data projects, were supported in FY 1983: in political science, the National Election Studies; in economics, the Panel Study of Family Income Dynamics; and in sociology, the General Social Survey. A fourth major effort, the National Time-Use Data Series, gives essential information of interest to several disciplines in social and economic science.

Another data program, supported jointly by NSF and the U.S. Bureau of the Census, aims to increase the scientific yield from the vast amounts of social and economic data collected annually by the federal statistical system. Under the aegis of the American Statistical Association (ASA), the program brings established social scientists and promising younger investigators into contact with the large-scale, real-world operations of federal statistical agencies.

Research fellowships awarded under this program enable the federal statistical system to benefit directly from the work of outstanding academic scientists, and the scientists have a chance to continue their research when they return to their universities. The program thus generates both practical, immediate applied research and longer-term academic research of a more fundamental nature.

Some NSF-supported studies illustrating the fruitful interaction of theory and data are described below.

Alternative Ways to Measure Poverty

Timothy Smeeding of the University of Utah joined the Census Bureau in 1982 as a research fellow under the NSF-ASA program noted above. At that time, Congress had just ordered a study of governmental in-kind (noncash) payments. Such payments—for goods and services such as food, housing, and medical care—amounted to a few billion dollars in 1960-61, when the present method of measuring poverty was devised. But by 1980 in-kind transfers consumed more than $72 billion annually. At this writing they are estimated to exceed cash assistance by more than two to one.

Smeeding undertook not just to help the Census Bureau estimate the magnitude and growth of in-kind programs, but to develop a method to value and measure in-kind income and estimate its impact on the official count of the poverty population.

Smeeding's work was designed to permit comparisons among different methods of valuing in-kind benefits and to examine the policy aspects of each approach. Special attention went to the three approaches shown in the table. These approaches—derived from economic theory and developed in conformity with economic principles—are: (1) market value, (2) recipient or cash-equivalent value, and (3) poverty budget share value.

Combinations of these three approaches and three different income concepts resulted in nine alternative estimates of poverty for 1979, as seen in the table. These estimates were then compared with the official poverty estimate based on before-tax money income alone.

The broadest income definition (money income plus in-kind payments for food, housing, and medical care) reduces the poverty rate from 11.1 percent to 6.4 percent, based on the market value approach. The second approach, called recipient or cash-equivalent value, reduces the number of poor substantially but to a lesser extent than market value does. The poverty budget share approach has an even smaller effect, reducing the poverty rate from 11.1 percent to 8.9 percent.

The use of maximum values for in-kind benefits may reduce the number of poor by as much as half for some population subgroups, but the poverty rates for these groups can remain quite high. For example, in 1979 the rate for female householders was 17.6 percent even after in-kind transfer payments for food, housing assistance, and medical care were included at full market value. In addition, regional differences (which can be sizable) and historical trends are not reflected in the study's overall statistics for the nation during one year (1979).

Smeeding's analysis does not imply that redistributive payments are a fundamental solution to the problem of poverty. Cash or in-kind assistance may serve to raise some families above the officially defined poverty level, but evidence is lacking that this supplies the impetus for a sustained climb up the economic ladder. A successful mass exit from poverty depends on a host of factors, social as well as economic, which continue to be the focus of multidisciplinary work. Still, organizations working in this area may find the in-kind research helpful in making comparisons and setting meaningful standards to measure economic well-being.

Number of Poor and Poverty Rates, According to Alternative Income Concepts and Valuation Techniques: 1979

(Numbers in Thousands)

Income concept	Valuation Technique: Market value approach[1]	Recipient or cash-equivalent value approach[2]	Poverty budget share value approach[3]
I. Money income alone:			
Number of poor	23,623	23,623	23,623
Poverty rate (%)	11.1	11.1	11.1
II. Money income plus food and housing:			
Number of poor	19,333	20,218	20,743
Poverty rate (%)	9.4	9.5	9.8
% reduction[4]	-15.6	-14.4	-12.2
III-A. Money income plus food, housing, and medical care (*excluding* institutional care expenditures):			
Number of poor	14,023	18,393	18,866
Poverty rate (%)	6.6	8.7	8.9
% reduction[4]	-40.6	-22.1	-20.1
III-B. Money income plus food, housing, and medical care (*including* institutional care expenditures):			
Number of poor	13,634	17,318	18,866
Poverty rate (%)	6.4	8.2	8.9
% reduction[4]	-42.3	-26.7	-20.1

[1] Equal to the purchase price in the private market of the goods received by the recipient—e.g., the face value of food stamps

[2] The amount of cash that would make the recipient just as well off as the in-kind transfer

[3] The poverty budget share value, which is tied to the current poverty concept, limits the value of food, housing, or medical transfers to the proportions spent on these items by persons at or near the poverty line in 1960-61, when in-kind transfers were minimal.

[4] Percentage of reduction in the number of poor from the 1979 poverty estimate based on money income alone

NOTE: A few months after this annual report was written, the Census Bureau issued new findings and more recent data on this subject. Contact the Bureau for information on its February 1984 study.

An Economic Approach to the Family

During the past three decades the demography of family life has been radically altered in the western world. The mean age at first marriage has increased, divorce rates have shot up, and birth rates have plummeted. The accompanying social transformation has reawakened scientific interest in the family and has prompted a tremendous increase in the collection of time-series and cross-sectional observations on its changing structure. Many panel surveys now track individuals over their life cycle, greatly enriching the standard census data, and large social experiments have investigated the effects of social policies on the family.

This great strengthening of the empirical base for research on the family has been matched by significant methodological advances and improved techniques of quantitative analysis. But it was not until the publication early in this decade of Gary Becker's *A Treatise on the Family* that the systematic development of general theory got a corresponding impetus. In this landmark book, Becker adopted an overarching economic approach to the family, encompassing many apparently dissimilar aspects of family life.

The analysis rests on the three central assumptions of neoclassical economics: maximizing behavior, stable preferences, and equilibria in explicit or implicit markets. Using this apparatus, Becker investigated a number of crucial optimizing decisions: Should a person enter a marriage? How will the family allocate market and household production to its members? How will income be distributed? How will the number of children be determined, and how much will the couple invest in each of them? How will parental time be allocated between careers and child care? These and many related questions can be answered by Becker's analytical framework once a few parameters are known.

In the final chapter of his book, Becker sketched an explanation of changes in family structure over the broad sweep of human history. In this account the shift from the extended family organization to the nuclear family is understood as a response to changing rates of economic growth. With the quickening pace of technological change comes a decrease in the value of the accumulated knowledge of elders. As this process continues and the quality and availability of information improve, individual proficiency becomes more important than family connections. Both of these trends shift training from the family toward the market and the state, with a resultant weakening of traditional ties between kin. At some juncture intergenerational conflicts become more open and parents experience diminishing success in guiding the behavior of their children.

The critical assessment of Becker's important work is still in progress, but there is little doubt that it will affect every science dealing with human behavior. In turn, his central "economic" assumptions already are being confronted with empirical reality. In particular, the predictive capability of the theorems of competitive equilibria are under examination in the context of market failure. These investigations seek to determine the extent to which nonmarket arrangements are superior to the "competitive solution" and are controlling in significant areas of family choice.

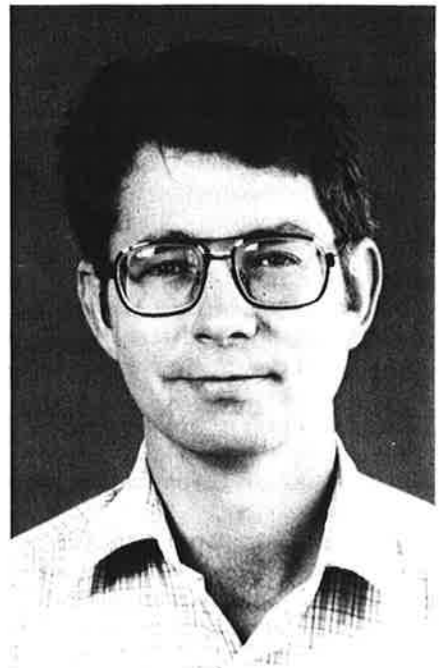
It is too early to say which of Becker's provocative array of hypotheses and deductions will stand up to empirical testing and which ones will be modified or give way to entirely different explanations. Possibly his greatest achievement will be not so much in his substantive conclusions as in the provision of a meaningful and unified system that aids the scientific search for important relationships in family behavior. The rapidly accumulating micro data set of the social sciences is the primary resource in this crucial task.

School and Job Mismatch

The educational credentials associated with some occupations have increased dramatically in recent years. Many factors contribute to this phenomenon—among them developments stemming from technological innovation—but there has been little systematic investigation of trends in the total labor force.

There seems to be an increasing mismatch of schooling requirements to the skill requirements of jobs, leading to a form of underemployment in the American work force. In short, many workers appear to be "overeducated" for their jobs. From a purely vocational perspective, this occupational mismatch or overeducation is viewed as a critical issue of public policy because of both its personal cost for the individual worker and the public cost of vocationally underusing an educated labor force.

Researchers investigating this phenomenon agree that the first step to assess the match of school and work requirements is a detailed look at the educational composition of occupations over time. Clifford Clogg at Pennsylvania State University did such a study of full-time workers; with Teresa Sullivan at the University of Texas-Austin, he developed instruments to assess the prevalence of mismatch. By specifying the distribution of educational credentials within occupations as of 1970, this research determined the average education associated with particular occupations. That was the benchmark used to identify statistically the workers who were substantially overqualified or mismatched.



Clifford Clogg and Teresa Sullivan. Clogg's analysis of data on full-time workers showed increases in the educational requirements for jobs over a decade—especially jobs that did not previously require a college degree (e.g., clerical, sales, service). In this sense, many American workers may be overeducated for their jobs and hence underemployed. Sullivan collaborated with Clogg in developing instruments to measure the prevalence of mismatch between schooling and skill requirements in the workforce. (Sullivan photo by Larry Murphy, University of Texas)

Clogg's work showed annual increases in occupational mismatching between 1969 and 1980, with a net flow of around 600,000 workers into mismatched positions *each year*. Moreover, the increases in mismatching are a problem not only for young workers but older ones as well. This suggests that the supply of educated labor in younger age groups has indirectly affected the demand for educated labor among older age groups as well. Also, increases in mismatching are occurring for black and nonblack workers of both sexes, although men aged 20 to 34 have the most dramatic absolute jump: from 11.5 percent in 1970 to 21.4 percent in 1980 for nonblack males, and from 5.9 percent to 15.9 percent for black males.

These analyses also show that educational upgrading has been most prominent for jobs that did not require a college education before: clerical and sales, crafts, and other service occupations. But the greatest single increase in mismatch is observed for managers, and changes in skill requirements for managerial work are not likely to explain such a dramatic trend. Further analysis indicates that mismatches are *not* the result of changing occupational distributions (i.e., the kinds of jobs available). Rather, rising scholastic attainment and the numbers of people educated at different levels seem to have created this situation. It is noteworthy that the period under study covered several complete business cycles, which included the usual expansionary and recessionary phases. The mismatching phenomenon was common to both phases, although cyclical factors cannot be ruled out as contributing causes in the phenomenon discussed above. At this juncture, the concurrent educational upgrading that resulted in much observed underemployment simply is not well understood.

Ongoing research supported by NSF at this writing includes further refinement of the measures of occupational mismatch, organizational studies of the way employers evaluate educational credentials and assess job requirements, and research on individual decisions to stay in school or enter the labor force.

Information Science and Technology

Information science seeks fundamental knowledge about the ways information is generated, structured, represented, manipulated, and used. This occurs through systematic research on the various forms and properties of information, on systems and technologies that manipulate information, and on the special role of information in society.

One of the most significant problems in this field is the way knowledge is represented in the central nervous system, and how it can be compatibly represented in artificial systems so that people and machines can communicate.

This question involves research in the "bioware" area: looking into the nature of an organism's sensory code, the organization of information into categories, the relationship between knowledge and the structure of language, and the means organisms use to avoid information overload.

Many counterpart problems exist for machine-based information-processing systems. For example, summarizing, abstracting, and indexing are ways to avoid information overload by selectively discarding information. Machines must organize large files efficiently and must classify and recognize patterns in all kinds of data, both written and pictorial. Machine designs must include knowledge-retrieval languages and systems that operate with certain categories of information, draw inferences relevant to user questions, or help the user pose queries. This raises another problem—that of relations between machine-based information systems and the people who use them.

Following are examples of NSF-supported projects in both the bioware and hardware areas. They reflect the information scientist's attempt to cope with the problems listed above.

Classifying and Categorizing Patterns

Even primitive animals and other biological organisms can categorize far more efficiently than any current mechanical system. Recent work on pigeons by Richard Herrnstein at Harvard University suggests that the pattern classification systems used by organisms are universal and simple. In fact, after accounting for the processing requirements of flight control and general physiological functions, there may be as few as several hundred thousand neurons available to a pigeon for categorizing processes.

These results indicate that, while human language may depend on categorization, categorization does not depend on language. It may not even depend on an ability to learn, for instinctive reactions could also be controlled by certain classes of stimuli. To categorize, which is to detect recurrences of stimuli despite their variation, is so enormous an evolutionary advantage that it may be universal among living creatures.

Since categorization is perhaps universal among species, either the underlying physiological structures must be general and elementary or there have been many physiological solutions to the problem of categorizing. The two alternatives are not mutually exclusive.

According to Herrnstein's research, categories that are fairly simple to describe physically do not seem to be significantly easier for animals to distinguish than are categories which are hard to describe physically. For example, pigeons appear to find patches of colored light a more difficult category to form than photographs of trees are. No machines behave this way, and the difference is most likely in the perceptual dimension, which is hard to isolate and even harder to simulate.

An unresolved problem in designing systems to process information is that we do not know the algorithm the pigeon uses to form categories. Yet we can be sure that at least one relatively simple algorithm exists, and that it is highly parallel. A distinguishing characteristic of information processing by organisms is that the tasks biological systems perform best—those related to categorizing, pattern recognition and classification, and learning—are also the ones that use highly parallel procedures. It is important that such algorithms be discovered, and this now seems possible using a combination of theoretical and experimental research.

Understanding Novel Language

Gerald DeJong and David Waltz, of the University of Illinois, are designing mechanisms that will make it possible for machines to understand novel language or terms, an activity human beings can do fairly easily. This means that systems would accept and process material they were never explicitly programmed to handle—i.e., they would contain a set of rules that could be used to generate a meaning for an unanticipated input. Two examples of novel or unanticipated input are:

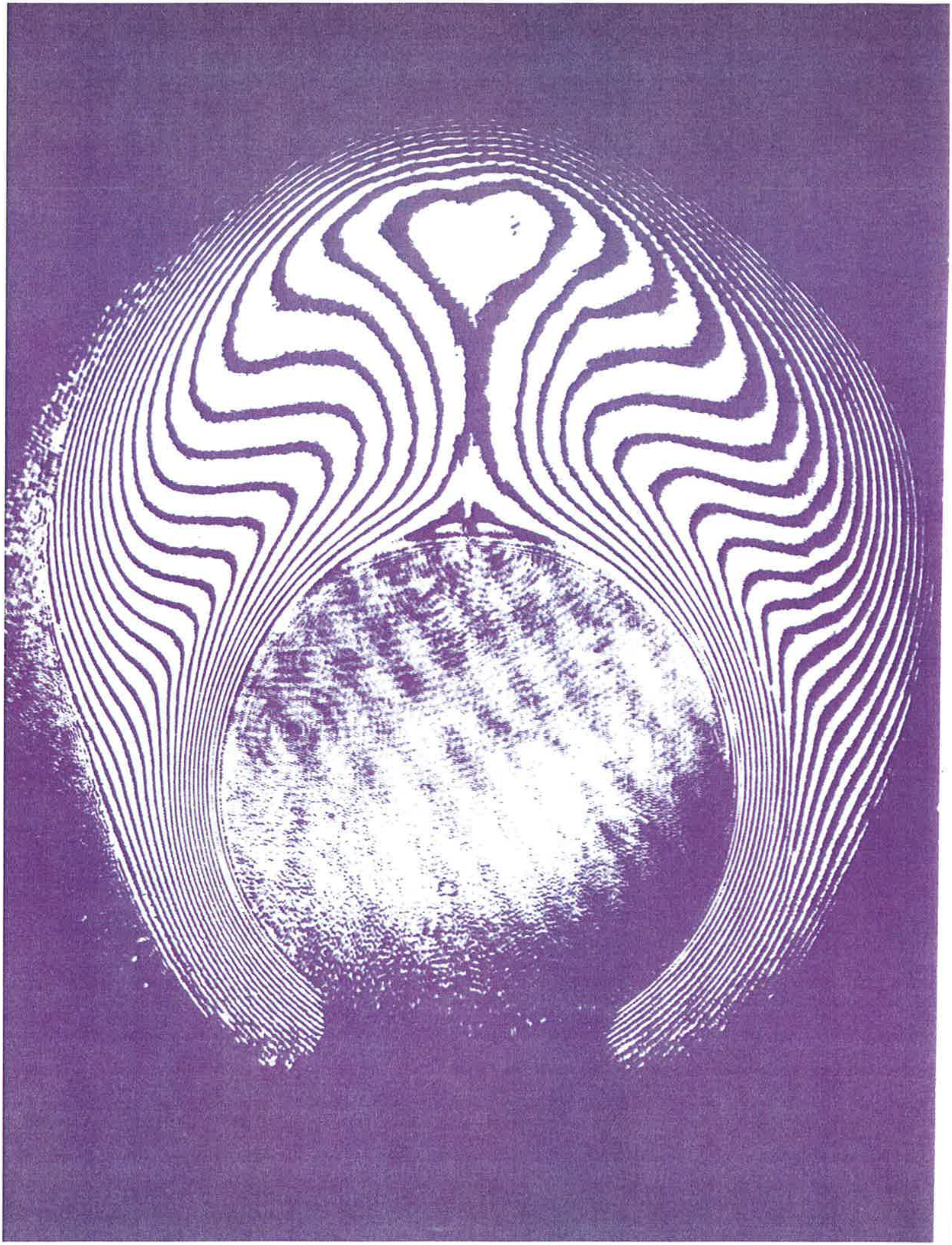
1. *New schemas* describing goal-oriented sequences of actions that may never have been encountered before—for example, hearing about a skyjacking for the first time. Here understanding might consist of determining the purpose and result of the actions, accounting for them as part of the overall schema, and generalizing so that new occurrences can remind the system of the original schema.
2. *Novel metaphors and analogies.* Here the variety of language requiring explanation is staggering. Understanding metaphorical language first requires distinguishing the metaphor from a literal description. Next, information from the "base domain" (the domain in which the language has a literal meaning) must be transferred to the "target domain" (the domain actually being described).

As an example, take the sentence: "John ate up the compliments." Here we would transfer a concept such as ingestion from the eating domain to the communication domain. The system would keep a record of that and any other steps used to understand the metaphor. With this record, the subsequent processing of similar metaphors would be eased.

To deal with schemas, DeJong and Waltz used a new type of machine "learning" called Explanatory Schema Acquisition (ESA); it shows how a system can deal with novel inputs without formally programmed methods. ESA combines the structures normally used to solve problems while considering the potential interaction results. This method allows simple one-trial learning and results in learning from positive results rather than through mistakes.

Metaphors require a somewhat different treatment. For example, hydraulic metaphors often occur in economics (cash *flow*, *draining* of assets, economic *pressure*, etc.). If the language is metaphorical, then the text must be processed according to some internal model. The model used by this research forms verbs into diagrams to be used in a matching process. The diagrams are then compared with possible meanings, using the temporal knowledge of a diagram as well as present context. Once a meaning has been identified, one can either alter the diagram or the meaning of the words for future analyses.

This work shows promise in developing rules to understand a wide range of natural languages. However, the two researchers note that rules can take us only so far: Ultimately the power of systems will depend on the sheer amount of knowledge they possess—knowledge that can be used as the base domain for new metaphors, and schemas that can build still more schemas.



Engineering

3

NSF has become a key source of support for fundamental research in the engineering disciplines. Through this support, the Foundation has worked to strengthen the nation's academic engineering base and the research and educational environment for engineers. Further, NSF programs are designed to encourage more engineers to seek graduate education and to pursue careers in research and teaching.

NSF aids research to advance knowledge of engineering principles and technologies. This research is the basis for broad and timely contributions to technological innovation and industrial productivity, economic growth and competition in world markets, and the nation's defense. Another goal is to stimulate the application of engineering knowledge to solving major problems in our society.

NSF's engineering programs focus on electrical, computer, and systems engineering; chemical and process engineering; civil and environmental engineering; mechanical engineering and applied mechanics; and a fifth area, interdisciplinary research. More and more, developments in technology cut across the traditional science and engineering disciplines, promising new and exciting research opportunities.

To strengthen the research base in engineering, NSF offers special opportunities to full-time engineering faculty who have not received substantial federal funding before. They are eligible for research initiation grants made on a competitive basis and used for theoretical and/or experimental research in all engineering disciplines. A new program called Presidential Young Investigator Awards aids relatively new faculty members over a five-year period. In addition, supplemental grants have been made available to undergraduate engineering students, to increase the pool of people interested in graduate work.

NSF also funds specialized equipment to improve the quality or broaden the scope of an institution's research effort. The institution must make a substantial contribution toward the purchase of the equipment.

Following are some key engineering activities supported by NSF during fiscal year 1983.

Electrical, Computer, and Systems Engineering

Research advances in electrical engineering-based disciplines have fueled the information revolution and changed our lives. Our transformation to an information society, which began three decades ago, is largely due to the integration of an ever increasing number of electronic components on

Table 3
Engineering
Fiscal Years 1982 and 1983
(Dollars in Millions)

	Fiscal Year 1982		Fiscal Year 1983	
	Number of Awards	Amount	Number of Awards	Amount
Elec., Comp., & Systems Eng. ...	510	$25.68	489	$29.53
Chemical and Process Eng.	438	20.27	514	22.56
Civil and Environ. Eng.	425	29.95	449	30.49
Mechanical Eng. & Applied Mechanics	280	17.07	304	19.43
Interdisciplinary Research	17	.31	--	--
Subtotal	1,670	$93.28	1,756	$102.01
Adjustment to Internat'l Awards	--	--	--	-.88*
Total	1,670	$93.28	1,756	101.13

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.

SOURCE: Fiscal Years 1984 and 1985 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

chips the size of fingernails.

The revolution began quietly in 1948 when the transistor was invented at Bell Laboratories. In the early 1950s came the photolithographic process to fabricate transistors on crystalline silicon, and integrated circuit technology was launched. During the 1960s, the design of integrated circuits was largely a manual exercise, but in the next decade computer-aided design systems were introduced. Today Very-Large-Scale Integration (VLSI) Technology can put almost a million devices on a chip. Each advance in VLSI makes possible more powerful computers, which are then used to design and fabricate still more complex VLSI designs.

Historically, improvements in communications and microwave devices have resulted in the need for smaller-feature electronic components. The capacity of any communications system to carry information depends on its frequency; at higher frequencies (smaller wavelengths) more information can be carried. Just as high-density devices make VLSI circuits smaller, the small operating wavelengths in communication engineering make small geometric structures desirable.

Manufacturing, testing, and packaging circuits at dimensions below one micron depend on research advances in semiconductor electronics and microstructures engineering. Improving the performance of devices and circuits has spurred research in such areas as materials growth, fabrication techniques, and the development of new equipment for materials processing and characterization.

The combination of communications with microelectronics and computer technology, supported by systems engineering research, is the basis for advances in robotics and automation research. These areas are critical for better productivity in the industrial, military, and service sectors. Robotics is interdisciplinary and depends on advances in such areas as graphics, computer vision, speech and signal processing, and systems engineering. To program robots for changing environments, research is needed on techniques to design complex systems under uncertain conditions.

Dealing with less structured environments also requires advances in imaging systems and sensor technology, to name just two areas. The variety of sensor devices that make robots respond to their environments includes ultrasonic range sensors, tactile sensors, and vision systems.

An example of a vision system is the research done by the Ohio State University's Welding Research Laboratory, set up with NSF support in 1980. Engineer Richard Richardson has developed a robot control system with a solid-state television camera inside it. This gives the robot's control computer key visual information. In effect, the welding robot can watch—and even correct—what it is doing.

Robotics research is also concerned with mimicking the motion of the natural arm. Because prosthetic research has resulted in an artificial limb that can be controlled by microelectronic devices, cross-fertilization of research between robotics and prosthetics is expected to grow.

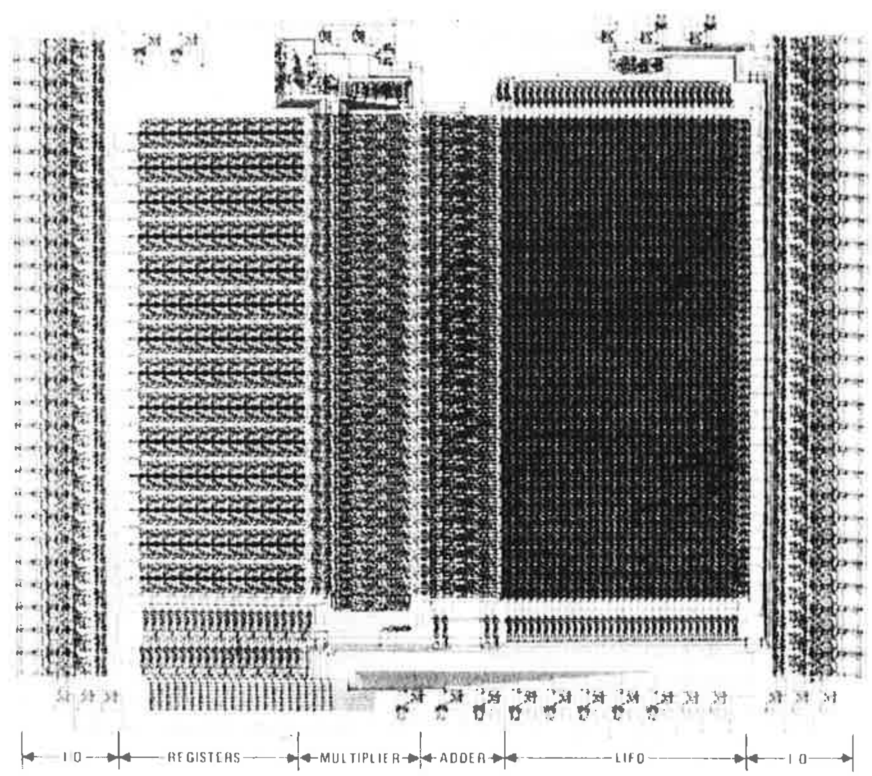
Many industries and government agencies fund electrical engineering research. However, NSF funds are vital for supporting long-range research goals and stimulating new interdisciplinary research.

For electrical, computer, and systems engineering, progress in both basic and applied research increasingly requires multidisciplinary input as well as indepth understanding from two or more traditional subfields. Novel and timely innovation occurs when the research environment encourages interdisciplinary exchange, and NSF is alert to that need.

New Architectures for Advanced Computation

Very-Large-Scale Integration (VLSI) makes it possible to develop inexpensive, novel, and special-purpose com-

MOP chip. University-industry collaborators examined new VLSI architectures that could do matrix manipulations very rapidly. The researchers devised an array processor containing a new architecture. This multiplication-oriented processor (MOP) appears to be useful in many areas of signal processing, especially robotics manipulator control.



puting structures with capabilities far exceeding those of present commercial computers. A university-industry collaborative research group from the University of Southern California (USC) and Hughes Research Laboratory, led by Gary Nudd, set out to identify and investigate computing applications that can exploit parallel-processing computer architectures based on high-density microelectronic technologies. This group has been concerned with matrix operations. Matrix manipulation in real time is limited with the present generation of serial computers; the computational burden is too great and the process takes too long. Researchers must develop ways to speed up computation for matrix manipulation, using parallel architectures to implement recursive and local data-dependent algorithms. A major design task for the Nudd team was specifying the architecture for a multiplication-oriented processor (MOP) and its VLSI implementation. The MOP elements form the array.

The recursive nature of these algorithms, coupled with the local data flow needed to carry them out, suggested to S. Y. Kung at USC the motion analogous to a continuously advancing wave, with data and computational activity flowing through an array of processors. Such a computational wavefront is analogous to one in the field of optics. Kung invented a wavefront language to program this array of processors. Together, this hardware and language make up a form of systolic array processor.

As part of the MOP design, Purdue University's Richard Paul, an expert in robotic controls, realized the value of this VLSI array for a real-time control of a robotic arm. He built a sophisticated and flexible robot with a microprocessor at each joint.

Paul, Nudd, and Kung collaborated on the design, building a prototype of a fast-wavefront-array processor to handle the matrix transformations and communicate data to the microprocessors at the robot joints. All of this will result in real-time sensory control, which opens up a whole new area of robotics research and is a significant step in developing intelligent robots.

Thermionic Integrated Circuits

Jet engine and nuclear reactor instrumentation, well-logging, monitoring of coal gasification, and other applications require active electronic devices and circuits that can operate at temperatures above 300 degrees centigrade. Existing semiconductor silicon integrated circuits are limited to 200 degrees. With special processing of today's commonly used materials, it may be possible to build circuits that can tolerate 300 degrees. Above that, possible solid-state materials are gallium arsenide, gallium phosphide, and silicon carbide, but none of these is feasible yet.

Current research at the University of Arizona, under the direction of Douglas Hamilton and William Kerwin, concerns electron devices called thermionic integrated circuits (TICs) and attempts to satisfy two requirements that cannot be met by conventional solid-state integrated circuits. These devices, essentially ultracompact vacuum tubes, use modern semiconductor processing technology to construct miniature planar cathode-grid arrays. Because of their ambient operational temperature, the cathodes are almost self-heated, thus increasing device efficiency. The researchers have operated TICs at 500 degrees ambient for more than 13,000 hours, and for shorter times at 600 degrees. Potentially these circuits can be operated at 1000 degrees. In addition, they can function normally under intense high radiation. Present indications are that the TIC is more than an order of magnitude better in this regard than the semiconductor integrated circuit.

The University of Arizona research has shown the feasibility of these rather special circuits and devices. At this writing, current research is aimed at developing structures needed to improve circuit performance, modeling techniques, and important amplification properties of the device.

This work also resulted in a five-element device that can be used in a variety of tasks necessary for processing signals efficiently at high temperatures. Although such devices are embryonic, experimental research has shown technological feasibility.

Chemical and Process Engineering

Chemical and separation processes are the backbone of the chemicals industry, which contributes some 8 percent of the U.S. gross national product. The Foundation is the only federal agency with a discipline-oriented program to support research on all aspects of chemical process design. The knowledge resulting from this research contributes to capital and energy savings in the manufacture of broad classes of substances and materials—synthetic fibers, fuel plastics, and pharmaceuticals, to name a few.

Biochemical engineering, closely tied to the rapidly emerging science of recombinant DNA, is also of great interest to industry. But before biotechnology can fulfill its promise, biochemical engineers must build a more substantial knowledge base. Current research in this area includes:

- Designing reactors that discourage recombinant organisms from reverting to their original types.
- Developing less expensive biological techniques to separate and purify products and also improve product quality.
- Boosting productivity with innovations that increase the concentrations of microorganisms in bioreactors.

In addition, researchers are uncovering knowledge needed for nonconventional processing, such as converting renewable resources into more valuable materials and chemicals. At the same time, less-recognized chemical processes continue to be important. For example, separation processes that produce high-purity silica for optical fibers improve our ability to transmit signals in those fibers over great distances. Also growing in importance: the development of basic engineering principles that underlie the chemical and plasma techniques needed to manufacture computer chips. These techniques for making the chips draw on skills developed by chemical engineers and chemists over the past several decades. Finally, advanced instrumentation used to observe catalytic surfaces has renewed interest in understanding catalytic behavior.

Unified Theory of Membrane Transport Phenomena

Transport of material through membranes has many practical engineering applications—isotope separation by gas diffusion through porous barriers; purification of saline water and industrial waste streams; and separations of complex mixtures encountered in petroleum, chemical, and food processing. Membrane transport phenomena are also of great importance in biology and medicine. For over a century, scientists, engineers, and mathematicians have tried to describe membrane transport mathematically. This has not been easy, since the transport system involves many components and membranes with widely differing properties. Although there are many theoretical formulations, covering a wide variety of ideas and approaches, engineers have been unable to determine their strengths and weaknesses or to identify similarities, differences, or even consistency between formulations.

At Brown University Edward Mason, supported by NSF, studied gas transport to explore the motion of aerosol particles in gases compared to the transport process of gas in porous media. If porous media are a collection of particles fixed in space, then these two activities are almost the same, differing only in whether the coordinate system is fixed in the gas or in the particles. The highly developed kinetic theory of gases could be applied to this problem, serving as a model and a way to test the more general theory based on thermodynamics, hydrodynamics, and energy barriers.

Subtle faults and limitations of previous theories were uncovered. Once these troubles were identified, Mason corrected them and developed a more unified fundamental derivation based on statistical thermodynamics. His new theory was not limited to gases; in addition, it included all the previous theories, suitably corrected, as well as special cases.

The theory has improved transport predictions by factors of about two to three. It will make significant contributions to the engineering of membrane systems. Much work remains in this area, but the way for progress is now clearly marked.

Macromolecular Fluid Dynamics

This NSF-supported project is a fundamental study of the fluid dynamics of polymeric liquid solutions and melts. Early work by R. Byron Bird and his colleagues at the University of Wisconsin focused on experimental rheological properties of polymer solutions, as well as the use of classical continuum mechanics without using molecular theory. However, since 1968 the research has made use of nonequilibrium statistical mechanics to predict polymeric flow behavior from polymer structure.

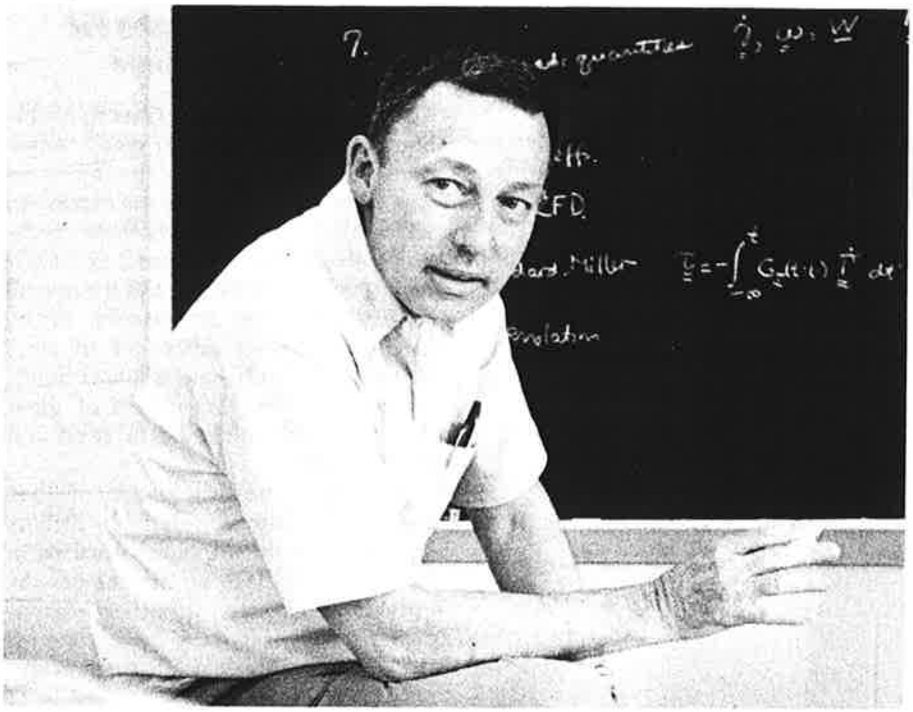
The relatively new field of polymer fluid dynamics has as its object the solution of flow problems for polymer solutions, polymer melts, and two-phase polymeric suspensions. These fluids are all non-Newtonian, i.e., the fluid stress relations are not linear in the velocity gradients. Hence, the classical fluid dynamics (Navier-Stokes) equations are of no value in solving polymer flow problems. The key problem in this field is to establish an expression for the mechanical response of polymer liquids to various kinetic flow gradients. In fluid dynamic terms, what is needed is a constitutive equation for the fluid stress tensor in terms of various kinematic tensors. This is a tremendous challenge in basic physics.

The information about the stress tensor comes from three sources: (1) rheometry—the experimental measurements of fluid viscosity and other rheological properties; (2) continuum mechanics—the formal study of relations between the fluid stress tensor and various kinematic tensors without using molecular theory; and (3) kinetic theory—the use of nonequilibrium statistical mechanics to predict the stress tensor from polymeric structure.

Bird's earlier NSF-supported research concentrated on the first two approaches, and he felt that it was important to inaugurate a major research effort on the kinetic theory of polymeric liquids. Nine years later, the results of this research were published in a book entitled *Dynamics of Polymeric Liquids. Volume II. Kinetics Theory*—the first book dealing with the molecular theory of nonlinear rheological properties of polymers. This book by Bird, Ole Hassager, Robert C. Armstrong, and Charles F. Curtiss is based to a large extent on the work done by several generations of graduate students at the University of Wisconsin, as well as results from workers elsewhere.

Two of the book's most important chapters are based on an earlier article by Curtiss, Bird, and Hassager in "Advances in Chemical Physics 1975." In that article, the Wisconsin researchers developed a totally new phase-space kinetic theory for polymeric liquids, including polymer solutions, melts, and mixtures. This theory shows how to generate the correct expression for the stress tensor and how to account properly for Brownian motion forces. It has provided the broad, unifying framework for much of the later research on the kinetic theory of macromolecules. This basic theory also has led to subsequent demonstrations of its specific utility, e.g., in the rheological properties of polymer melts. Extensive comparisons with experimental data show that the theory gives a much better description of nonlinear flow properties than earlier theories did.

On the horizon is the application of Brownian dynamic simulation to polymeric liquids. The large-scale compu-



R. Byron Bird. He and his colleagues at the University of Wisconsin have done many years of important work in the relatively new field of polymer fluid dynamics. In a journal article, Bird and two co-authors developed a new kinetic theory for polymeric liquids; a book he collaborated on was a first in the field. (Photo by Norman Lenburg)

tational techniques involved enable Bird to study detailed motions of macromolecules and the stretching and orientation of polymer molecules in flow fields, particularly those of interest in polymer processing. Such information on chain dynamics is not obtainable from statistical mechanics or from laboratory experiments. The approach will result in a realistic molecular model and also permit development of improved kinetic theories that can be tested by theoretical assumptions at the molecular level. This engineering research is important for the design of processing systems producing unique, high-strength polymers.

Civil and Environmental Engineering

These programs support a broad spectrum of research, including geotechnical engineering; structural mechanics; hydrology, hydraulics, and water resources; environmental and water quality engineering; and a developing thrust in construction engineering and building research. In addition, NSF is responsible for the part of the President's Earthquake Hazards Reduction Plan that is concerned with research (both basic and applied) and dissemination of results in earthquake engineering research. NSF also supports a small amount of research on the legal, political, and economic effects of measures to mitigate earthquake hazards.

During 1983 the geotechnical centrifuge, under construction at Mountain View, California for several years, neared completion and research using it was to start in 1984. With this centrifuge, engineers can artificially increase the value of gravity in a model of a real-life structure.

Also during 1983, civil engineers increasingly focused on problems related to public works projects. While these problems can only be solved at the community level by the investment of large amounts of money, those costs could be reduced through effective civil engineering research. We need more knowledge on how to operate and upgrade existing facilities, and how to build new ones more efficiently and with a longer and more satisfactory life.

Buildings and other facilities, both public and private, represent a huge investment. Because of this, problems of construction engineering, which has not had an adequate academic research base, are receiving more attention. One such problem is construction productivity, which has not been increasing in this country.

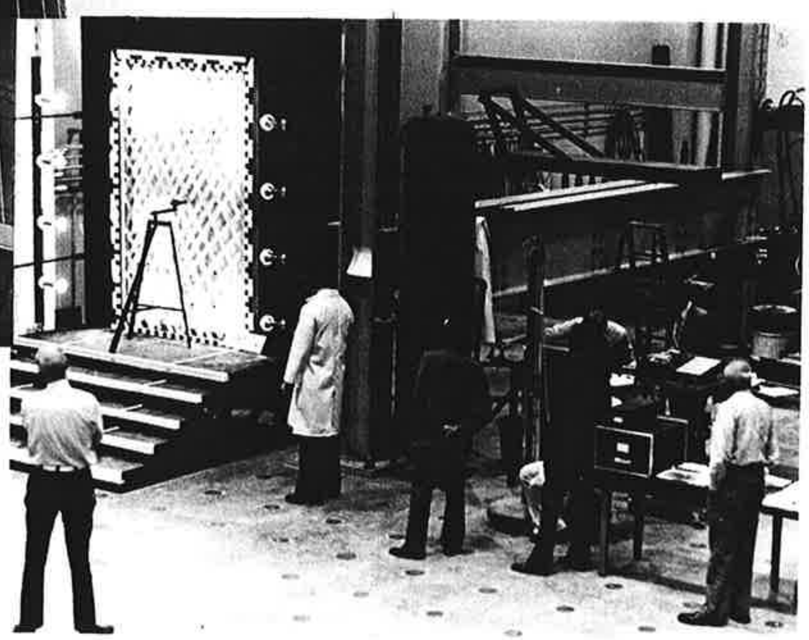
Earthquake engineering research includes studies on the nature and effects of destructive ground motion and tsunamis (tidal waves), and analytical and experimental work on the earthquake resistance of structures. Basic to understanding the effects of earthquakes on buildings is knowledge of strong ground motions that can stress them. During 1983, significant advances in parametric analysis of ground motions helped engineers better understand the influence of large geology discontinuities, such as faults and slips, on strong earthquake motions.

A project to design large-scale simulations of earthquake ground motions was completed in 1983. Its technique of using explosives to simulate those motions is an alternative to modeling and testing full-scale structures.

Other earthquake research found evidence that ocean tides and the moon's gravitational force may combine to set off quakes in certain parts of the world. Previous studies to show this link have focused on large numbers of quakes all over the world; these analyses have not been very successful. But Steven Kilston at the Hughes Aircraft Company and UCLA's Leon Knopoff studied one narrow area of southern California where the San Andreas fault is oriented roughly northwest-southeast. They believe that fault orientation may be a key factor in the statistically significant associations they found between large quakes and various moon phases.

Finally, construction began in 1983 on the first building in the United States to use the new seismic resisting technique of base isolation. This technique is founded on the premise that horizontal ground motions can be significantly reduced before they are transmitted to a building. The structure involved, a court center in southern California, will be the largest in the world built on shock-isolator devices (steel and rubberlike bearings under the building's columns). This type of construction uses information produced by research under NSF's Earthquake Hazard Mitigation Program in recent years.

Houston buildings after Hurricane Alicia. Note window glass broken by wind pressure and windborne debris from the August 1983 hurricane.



Window glass test facility. At Texas Tech University, large windows are tested under simulated wind pressure. Results from these experiments help researchers develop new design approaches for glass.

Rational Designs for Window Glass

In the past, window glass in buildings usually consisted of small, single panes of glass in which the thickness was large compared with the maximum width of the pane. Under these conditions, there was little need to "engineer" such applications, and the overall failure rate was acceptable. Now, however, recent advances in construction methods have allowed builders to use very large sizes of glass that might be subjected to wind and other factors.

In spite of the long history of glass usage in buildings, relatively little is known about the principles involved in loads on the glass or the factors involved in failure. In other words, designs for glass have been done on the basis of empirical information and very limited test results.

The deficiencies of this approach were dramatically illustrated by the John Hancock Building in Boston, in which the glass started to break and fly about before the building was even completed. Although an extreme case, this is but one example of a nationwide problem. Not only do such failures compromise public safety, they hurt the building construction industry directly in lost money.

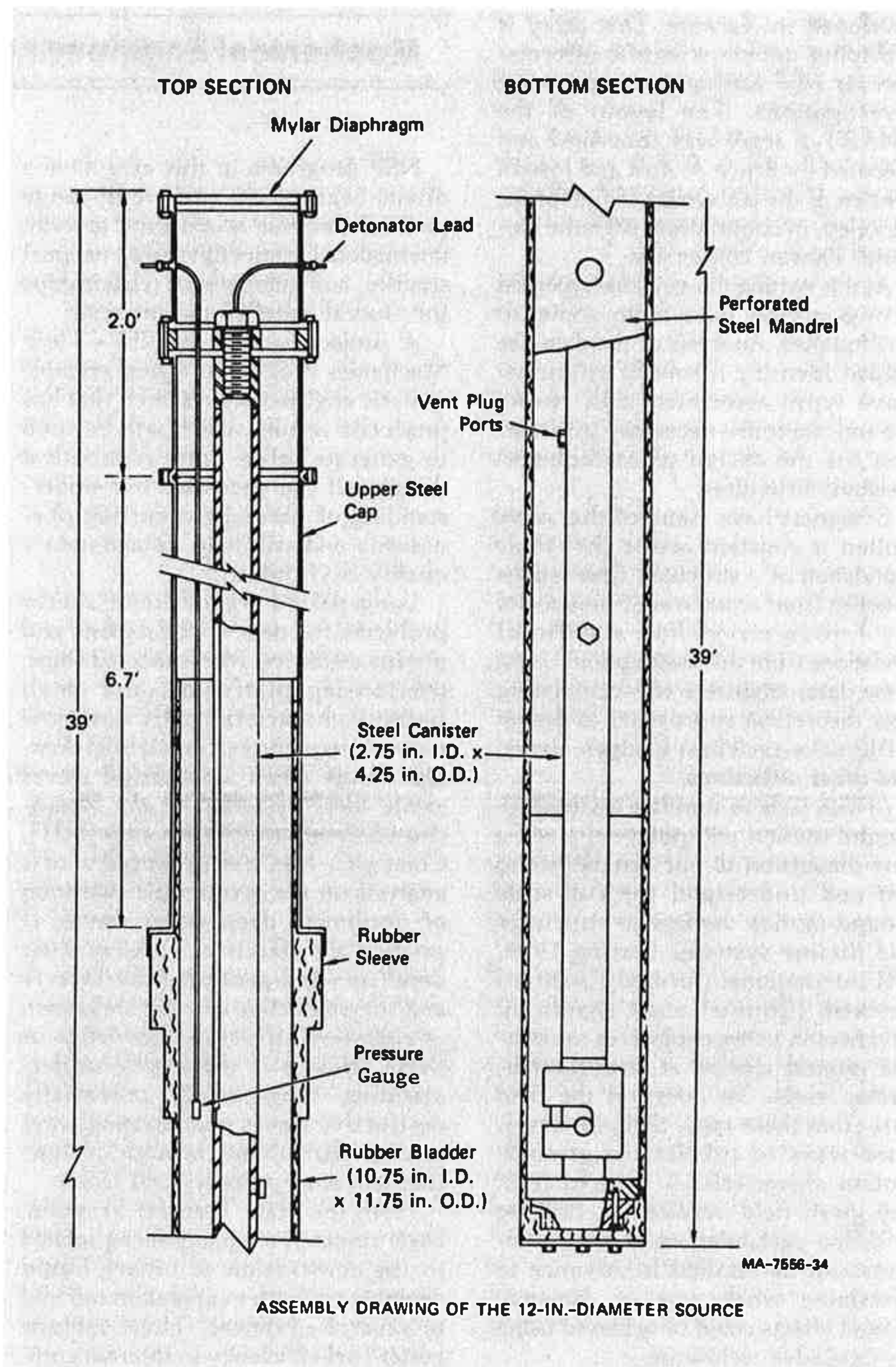
A group of researchers from Texas Tech University, headed by Joseph Minor, began developing design procedures for glass. NSF support aided both phases of this effort—analytical and experimental. After the program began, others became involved: several glass manufacturing companies; architectural and engineering design firms; and the National Research Council of Canada, which had also been doing glass design studies.

From this project came the Committee on Window Glass Research, an industry-university-government group that coordinates research on window glass under wind pressure. This research focused on loadings to which glass may be subjected and the material behavior and failure mechanisms for glass. There was rapid progress in both these areas, with significant input on loadings from the Canadian engineers and an entirely new design approach developed at Texas Tech University. The latter encompasses fracture theory, stress levels, flaw density, aging effects, and other parameters for glass failure.

Loading predictions and rational design procedures are now available that will assure public safety and prevent economic losses when building with glass. The Committee on Window Glass Research has also produced a reference document for designers that could be the basis for an American National Standards Institute publication.

Earthquake-Induced Ground Motions

Measuring, understanding, and analyzing the destructive ground motions of earthquakes are necessary to mitigate earthquake hazards. Ground motions must be quantified to show the effects of earthquakes on structures. In FY 1983 there was significant progress in measuring those motions and developing new experimental techniques to simulate them *in situ*.



Simulating quake motions with explosives. This technique involves producing earthquake-like ground motion by simultaneous detonation of a planar array of vertical line sources buried in the ground. The key feature of each line source is the internal steel canister in which the explosive is detonated. Ground motion is produced as the explosive products are vented at a controlled rate into an expandable rubber bladder. Thus there is minimal disturbance to areas near the test site. (I.D. = inner diameter, O.D. = outer diameter).

NSF began research programs to install instruments that study earthquake ground motion in the United States and in other areas likely to yield strong-motion data. These areas included California, India, Mexico, Taiwan, and the People's Republic of China. Strong-motion arrays began functioning in FY 1983 and are giving a wealth of data.

Of special note is an innovative instrument array named SMART-1, developed in Taiwan. This array is providing unique scientific information for NSF earthquake engineering investigations. The layout of the SMART-1 array was conceived and executed by Bruce A. Bolt and Joseph Penzien of the University of California, Berkeley, in conjunction with the National Taiwan University.

At this writing the array has recorded strong-motion data from some 20 earthquakes. Analysis of the data has helped identify formerly unknown wave types associated with strong ground motions—necessary information for the design of earthquake-resistant structures.

Designers have assumed that wave motion is constant across the whole foundation of a structure. Correlations obtained from actual wave forms across the Taiwan array show significant deviations from this assumption. Using these data, engineers are formulating new theoretical approaches to design earthquake-resistant bridges, dams, and other structures.

In-situ tests to simulate earthquake ground motion will potentially add a new dimension to our capabilities to test and understand the full-scale ground-motion damage to structures and lifeline systems. During 1983, SRI International (formerly Stanford Research Institute) made significant advances in using explosives to simulate ground motion at strong earthquake levels. To interpret the field data from these tests, SRI also developed ways to predict the ground-motion characteristics induced from any given field installation. Because of this, a particular set of site conditions can be studied in advance to determine what type of dynamic ground effects could be achieved using the explosive technique.

This method opens the possibility of *in-situ* testing of the response of structures to strong ground motion with minimal disturbance of the surroundings.

Mechanical Engineering and Applied Mechanics

NSF programs in this area have a direct bearing on such long-range national concerns as economic growth, international competitiveness, national security, and international relationships for mutual benefits and interests.

A project funded by NSF's Fluid Mechanics Program is a good example of basic engineering research that has produced results which will be used to generate safer, more economical designs. It has increased our understanding of naturally occurring phenomena and will help us maintain a quality environment.

Long-period waves create severe problems for near-shore regions and marine estuaries, where moored ships, tension-leg platforms, and small harbors characteristically have low natural frequencies. Substantial damage occurs when long-period waves excite these systems. At the Massachusetts Institute of Technology (MIT), Chiang C. Mei has produced a new analysis on the asymmetric evolution of nonlinear, deep-water waves. It predicts the effects of varying water depth on wind-generated short waves and the production of what are known as radiation stresses. Knowledge of these stresses is the key to understanding long-period, potentially destructive waves and devising ways to deal with them through designs that will save property and lives.

From the Heat Transfer Program, basic research on phenomena related to the contraction of binary liquid droplets through evaporation can lead to several advances. These include better fuel efficiency in internal combustion engines; cheaper operation of oil-fired burners; enhanced secondary oil recovery; and better quenching, spray-drying, and spray-cooling techniques, including more reliable methods to spray-cool nuclear reactor cores during emergency shutdown.

This research, funded solely by NSF, was directed by Wen-Jei Yang at the University of Michigan, Ann Arbor; he did the work with a group of graduate students and a visiting investigator from Japan.

Basic research funded by the Solid Mechanics Program has produced innovative analytical methods that significantly improve our ability to predict material behavior in basic metal-forming processes. This research has also come up with new techniques to evaluate the extent of damage to heart muscle tissue from a heart attack and to improve treatment methods for heart disease.

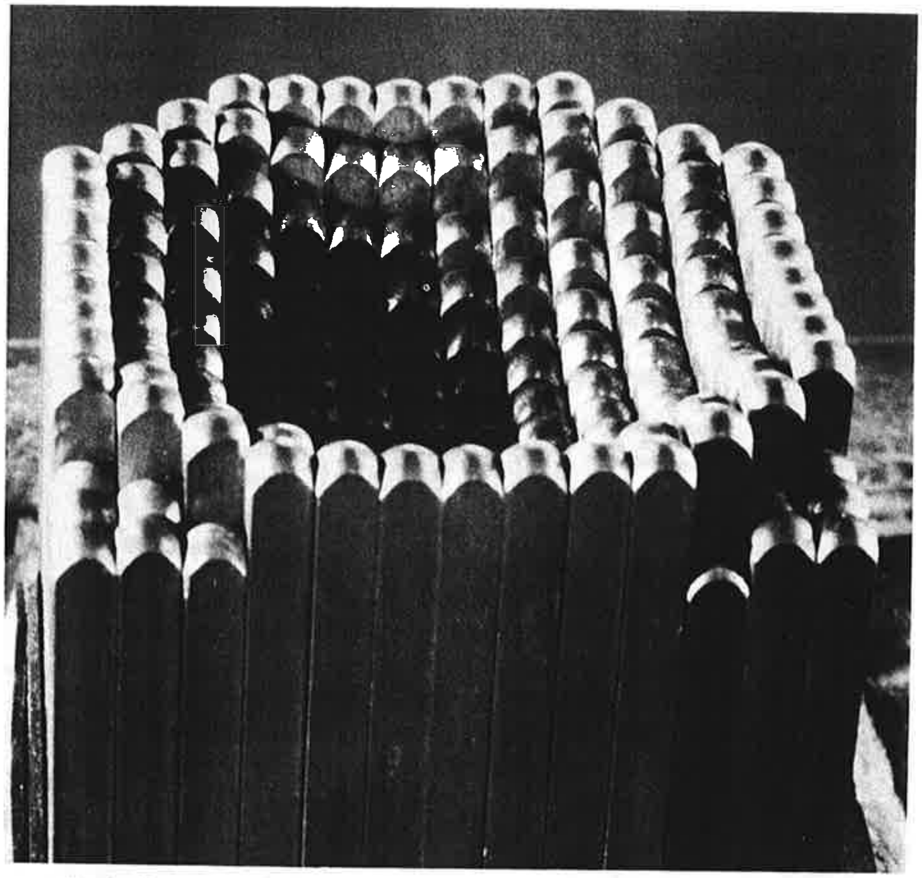
The first project was run by Paul R. Dawson at Cornell University and the second by Brown University's Alan Needleman. In collaboration with Thomas McMahon and Daniel Bogen at Harvard University and Walter Abelman at Boston's Beth Israel Hospital, Needleman developed a mathematical model for an infarcted ventricle. The model has not only made it possible to assess the extent of damage more accurately but has also revealed new information about stress in the region adjacent to the infarcted zone.

Basic research sponsored by NSF's Mechanical Systems Program is essential for the design of new-generation, high-performance, and high-quality machines. Bearing design becomes increasingly critical as shaft speeds and loads increase; to improve efficiency, losses must be reduced and bearing life extended. A multiphase project by Christopher Ettles at Rensselaer Polytechnic Institute is having major impact in this field of tribology. Ettles has been developing three-dimensional models and applying them to various kinds of bearings. He has thus been able to investigate temperature effects, lubrication film configuration, and film stability.

NSF-sponsored Production Research by David Hardt at MIT has resulted in a radically new die for sheet-metal forming—a widely used operation in the automotive, aerospace, and appliance industries, to name but a few. At present, dies are often designed by trial and error and are not only costly but involve long delivery times. Furthermore, these dies may be unable to form parts that will meet manufacturing tolerances. The new die corrects some of those limitations.

Researchers funded through the Production Research Program also have made significant advances in the field of factory automation. Examples:

- A new feeding machine that helps robots locate and identify pieces. Looking to the next generation of robots, those with vision systems, other researchers have coupled those systems with pattern recognition algorithms so that the sighted robot can select a particular part from a supply of random parts, then properly position it for further operations. This new system was demonstrated in a commercially feasible configuration at a major robot exhibition.
- Sensors to detect voltage and current variations. These have been incorporated into the control systems that move the weld gun in automated arc-welding systems (those with and without robots).



Production research. This programmable tool is used to form sheet-metal parts. By an iterative process of trying, computing, resetting the bars, and retrying, it is possible to arrive at the desired tool geometry in a very short time. NSF-sponsored research by David Hardt at MIT resulted in this radically new die, which has fewer limitations than earlier dies. It is expected to benefit the automotive, aerospace, and appliance industries, among others.

Heat Transfer

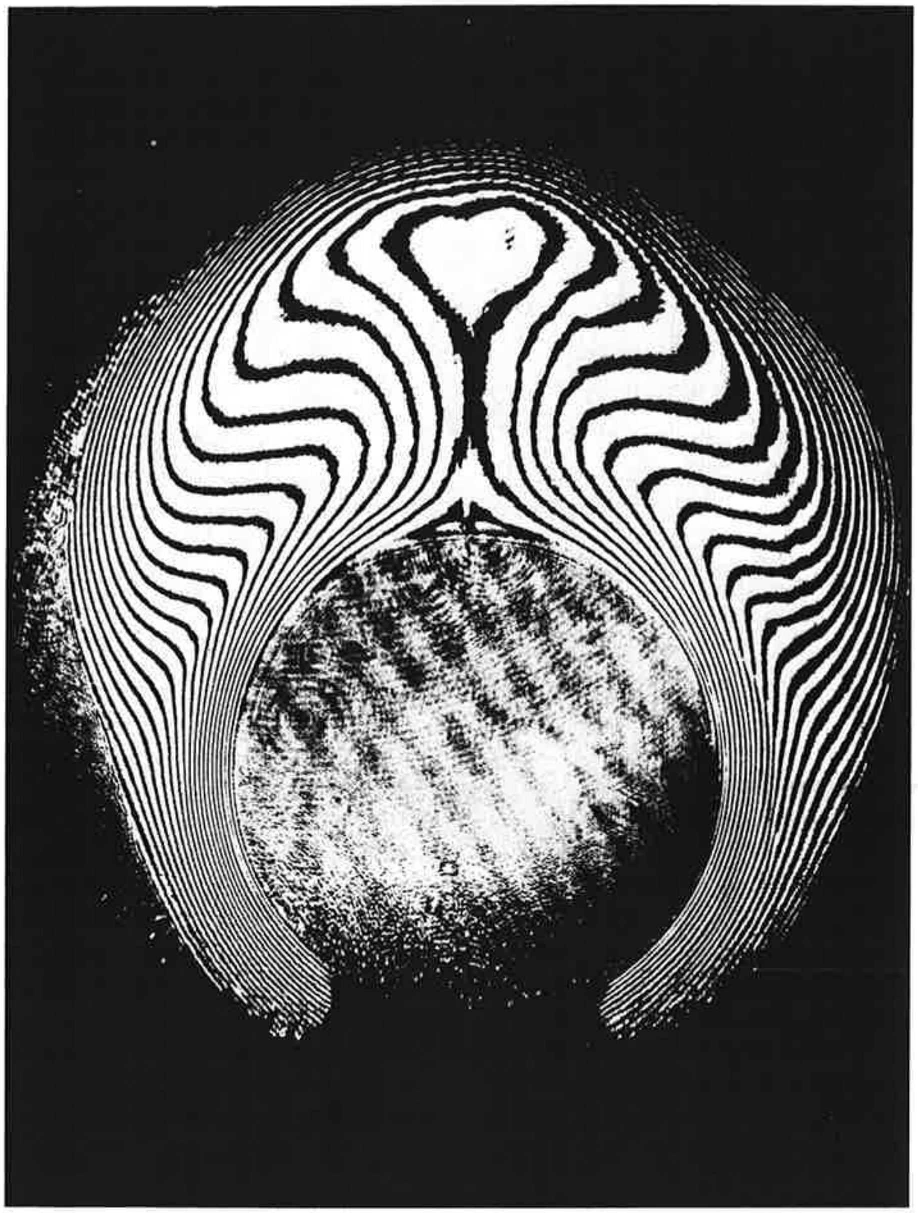
Natural convection in melting and solidification processes is one of the least understood problems in heat transfer, yet it has wide applications. For example, during solidification in metals and alloys, thermal convection strongly affects the processing rates and plays a key role in modifying the solid structure. In the manufacture of semiconductors, certain distribution processes are significantly perturbed by natural convection. Finally, in the freezing of moist soils and the thawing of frozen ground, natural convection is an important factor in controlling the heat transfer rate—a parameter that must be predicted as the ground is increasingly used to store solar energy.

Despite the technological importance of this problem, the effect of natural convection in phase-change processes has not been adequately addressed. To provide more fundamental information on this concern, a group of researchers led by Raymond Viskanta at Purdue University embarked on a theoretical and experimental research program.

At first, the research focus was on the experiments. Measurements with photographic and optical techniques such as shadowgraph and Mach-Zehnder interferometry gave data on the spatial variation of the heat transfer, during phase change, around heated surfaces. Also available for the first time: data on the instantaneous position of the solid-liquid interface, as well as the local heat transfer rates on that interface.

The Purdue study has also tried to develop theoretical models useful in predicting solid-liquid interface positions. Based on a comparison with the experimental data, the research group has achieved some success in its theoretical attempts. By solving the describing equations for natural convection through the use of a digital computer, Viskanta and his associates related the interface position to the melt volume and the instantaneous heat transfer from the heating surface.

To get more accurate results, the team focused on (1) the role of thermal radiation in both a liquid and a semitransparent, melting solid such as n-octadecane, and (2) the melting and solidification of Lipowitz eutectic metal (a metal with the lowest possible melting point). Preliminary findings at this writing indicate that because the Lipowitz metal's constituents are segregated, natural convection is suppressed in the metal during resolidification. This leads to a slower rate of melting and a higher rate of freezing than originally expected. Further, severe temperature fluctuations were found under some conditions; these



Heat transfer. Natural convection in melting and solidification processes is one of the least understood problems in heat transfer, yet it has wide applications—for example, in metallurgy and in the manufacture of semiconductors. At Purdue University, Raymond Viskanta and his team successfully used photographic and optical techniques, including Mach-Zehnder interferometry, to investigate heat transfer. (Photo shows Mach-Zehnder interference fringe patterns that occurred during the melting of n-octadecane around a heated circular tube.) This work may help solve some of the difficulties in working with metals, alloys, and semiconductors.

led to an increased rate of melting of the eutectic.

The work at Purdue University continues at this writing. It should help solve some of the difficulties in work with metals, alloys, and semiconductors.

Predicting Surface Pitting in Gears

Among the important elements in the design of gears are (1) determination of the bending stresses at the root of gear teeth, (2) ensuring resistance to spalling, or chipping, and (3) design against pitting fatigue (failure caused by surface pits that form on gear teeth). The first of these is quite well understood; with more development of a case-hardening procedure, even the second element has become better known. But until the research described here, designing against pitting fatigue was an empirical process.

A university-industry joint project involving faculty and graduate students at Northwestern University and researchers at International Harvester has shed light on this problem. The development of a new analytical model, founded on this basic research, will permit better design of helical and spur gears; designers then will be able to guard against premature failure due to pit formation.

The dividends from this research will be long-lived gear trains that retain precise motion-transmission characteristics longer and thereby yield higher quality, greater cost effectiveness, and more competitive products.

The team doing this work included Herbert Cheng, Toshio Mura, and Leon Keer of Northwestern University and V. K. Sharma, Ted Clark, and G. R. Miller of International Harvester.

This project has also produced interesting results in the area of crack research. Correlations between the morphological experiments at International Harvester with models postulating the appearance of surface cracks around surface defects strongly support the conclusion that cracks begin largely because of asperity contact (contact with roughness or unevenness). Two papers on this subject are imminent at this writing.

Another result is the interaction between asperity-induced surface cracks, which usually occur early in the first half-million cycles of a moving part, and near-surface inclusions (nonmetallic compounds embedded in the mass of a material). A magnetic-particle detection technique lately developed at International Harvester revealed that near-surface inclusions seem to act as bridges, permitting surface cracks to break through a material's "quiescent zone" (beneath the surface) to its high shearing stress region below.

Interdisciplinary Research

NSF's Office of Interdisciplinary Research (OIR) was set up in 1981 to coordinate research efforts involving more than one discipline. Specifically, OIR encourages collaboration between fields, which includes joint funding and joint program activities. Examples are workshops that identify mutual research needs or priorities and cross-program statements for research planning and budgeting.

OIR has been bringing together diverse NSF programs that deal with major research areas such as biotechnology and robotics/automated manufacturing. The results of these efforts have been more collaborative funding and program announcements aimed at critical research in these and other areas.

Through OIR, NSF also supports conferences and review papers to highlight emerging areas of cross-disciplinary research, to determine research needs, and to open communication lines. Examples of these areas are magnetic information technology (MINT), the social impacts of microelectronics, and software psychology.

Magnetic Information Technology (MINT) Workshop

Because all sectors of the economy need to store and retrieve ever-growing volumes of information, the MINT industry is critical to the United States. Annual sales of magnetic devices to meet these needs are growing at about 35 percent a year.

Recognizing the importance of MINT research to industry, OIR put together a university-industry workshop to assess research, personnel, facilities, and other MINT needs. At this workshop, experts from industry and academia expressed concern that the United States can meet the increased demand for MINT. In the near term, according to these experts, the growth of magnetic information capacity will be limited not by industry's ability to manufacture equipment but by the availability of new basic and applied research in all areas of magnetic information technology.

The group identified several MINT research opportunities—for example, in electrical and mechanical engineering, minerals research, and applied physics. Participants also noted that higher information density and faster data storage and retrieval are all required if the capacity of information processing is to keep on growing in the United States.

Microelectronics Conference

Technological change, especially rapid change, affects not only the economic climate of industry but the rest of society as well. In May 1983, at the University of California, Santa Cruz, OIR supported a conference on the social impacts of the microelectronic revolution and the industry it has spawned. Conference participants were from academia, industry, government, and labor, along with others directly affected by the industry. Topics included the effects of microelectronics on industrial structure, labor organization, the workplace, urban development, and community formation.

Much of the conference discussion focused on northern California's Silicon Valley, viewed by many as an industrial utopia and likely to be emulated by other regions of the United States as an example of economic growth. But critical socioeconomic problems have surfaced in Silicon Valley. For instance, production workers cannot afford to live close to their work and must commute from adjoining counties that provide social services without the benefit of the "high-tech" tax base.

Conference participants also discussed the effects of microelectronics on employment and the very nature of work. The discussion included questions such as: "Will the electronic industry create more jobs than will be eliminated by automation?" and "Will automation eliminate service industry jobs, where the work is highly repetitive and mundane?"

No consensus on these questions emerged. However, conference participants did agree that constructive and creative solutions to these emerging societal problems will come from collaborative interdisciplinary research by universities and industry.

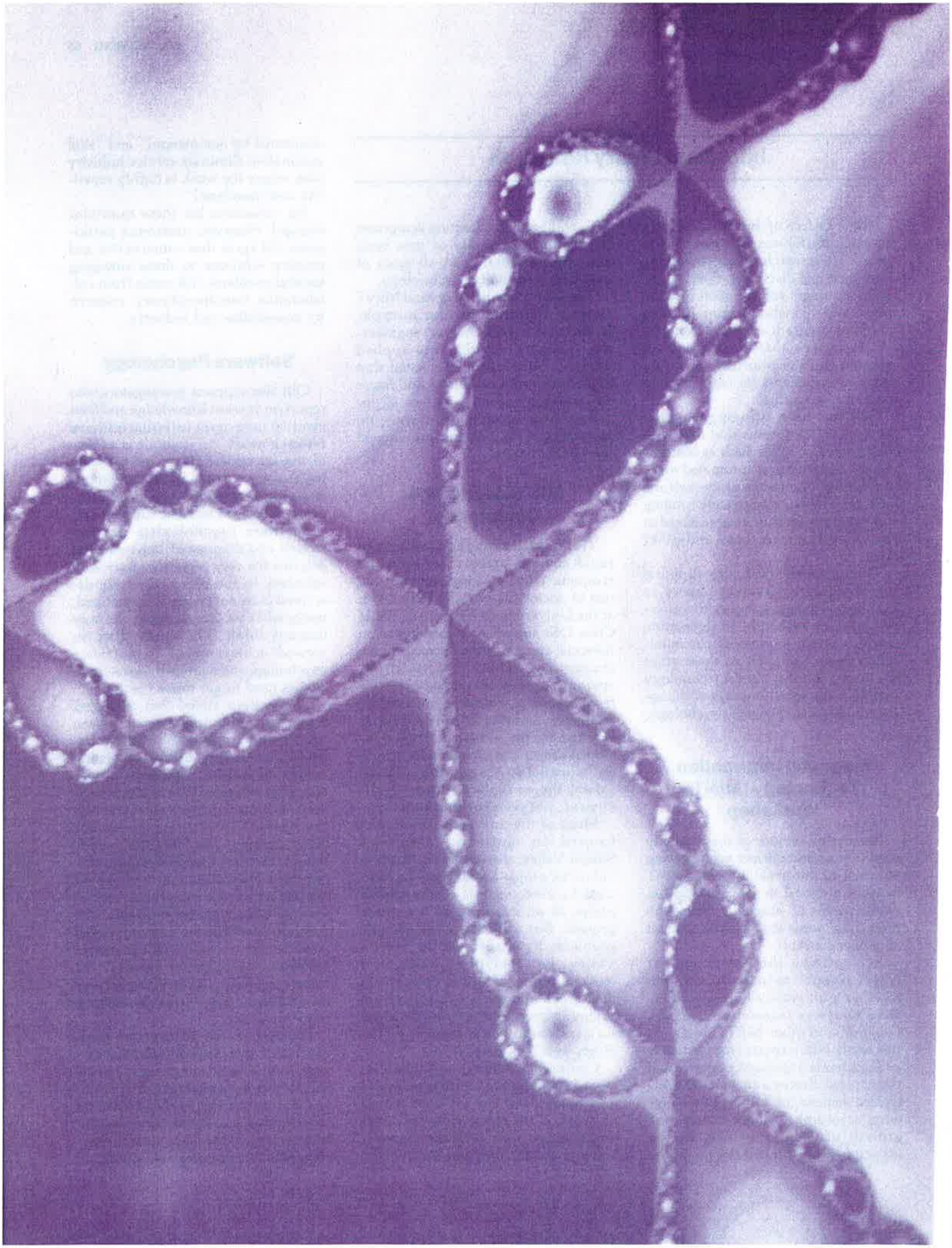
Software Psychology

OIR also supports investigators who report on present knowledge and then identify long-term interdisciplinary research needs. An example is a state-of-the-art review paper on software psychology, written by Ruven Brooks and a team at the ITT Advanced Technology Center in Shelton, Connecticut.

Software psychologists develop models and theories of behavior that describe the way people interact with software. In the paper, the team described how software is developed, using what we know about the way humans think. The study then reviewed achievements in software psychology and analyzed the methodologies used to get those results.

The analysis stated that designing effective communication between people and computers requires behavioral research to develop theoretical models of human cognitive activity in applied settings. This contrasts with research aimed at specific results that can be used to justify a particular design decision. The theoretical models should, however, lead to design principles for certain situations and should explain why those principles work in terms of basic cognitive processes. The authors noted that the research needed must deal with conceptual and mental models, psychological factors, the transfer of skills, the medium of communication, and problem-solving representation.

Looking to the future, the team concluded that interdisciplinary collaboration among computer scientists and software psychologists is needed, so that theories and models are useful to real issues in software development and use and, at the same time, understandable to computer scientists.



Mathematical and Physical Sciences 4

Research in these sciences seeks an orderly development of fundamental principles and concepts that lead to a consistent explanation of the physical laws governing our world. The knowledge thus gained forms the base for progress in other fields of science and in engineering—areas that depend on experimental and theoretical research results obtained by mathematical and physical scientists. Such knowledge is also a key to the nation's future technological and economic growth.

The National Science Foundation supports activities in mathematics, computer research, physics, chemistry, and materials research. These disciplines involve a large body of firmly established experimental research results and general quantitative theories that can accurately predict and explain those findings. Consequently, each discipline has achieved an exceptional ability to exploit existing knowledge and to formulate new concepts.

In spite of this ability, there are still many areas in which understanding is incomplete. This can be attributed in part to the fact that discovery of new knowledge leads to ever increasing intellectual curiosity; satisfying that curiosity often requires—and must await—new tools and materials, new mathematical and computational techniques. Thus many opportunities for discovery arise through advances in instrumentation and the expanding access to specialized experimental facilities for individual and shared use. Some examples of this:

- There is growing use of scientific computation in applied mathematics and statistics and of interactive computing in all areas of mathematics. Indeed, computer experimentation is rapidly becoming a crucial research tool in the mathematical sciences.
- The development of the technology to produce Very-Large-Scale Integrated (VLSI) circuits has reduced the costs of computation and memory units to such an extent that university-based scientists can now become active participants in research on new generations of computer systems.
- Instrumentation development and accelerator research and development are essential to fundamental advances in physics. Instrumentation items required by physicists include accelerator upgrades, large-scale-particle and gravity-wave detectors, computers, and lasers.
- Progress toward understanding the molecular basis of life processes is helped greatly by high-resolution nuclear magnetic resonance (NMR) spectroscopy. Recent advances in NMR allow chemists to determine the structures of complex molecular building blocks of living systems and to study the dynamics of life-sustaining chemical events.
- Materials research increasingly depends on highly sophisticated and costly research instrumentation and on multiinvestigator research collaborations that require the use of shared facilities. Indeed, advances in the development and study of novel, scientifically or technologically important materials (such as multilayered materials, polymer blends and com-

Table 4
Mathematical and Physical Sciences
Fiscal Years 1982 and 1983
(Dollars in Millions)

	Fiscal Year 1982		Fiscal Year 1983	
	Number of Awards	Amount	Number of Awards	Amount
Mathematical Sciences	910	$30.49	927	$34.76
Computer Research	289	25.74	292	29.34
Physics	458	75.32	493	89.14
Chemistry	872	61.36	962	67.63
Materials Research	740	79.93	815	81.08
Subtotal	3,269	$272.84	3,489	$301.95
Adjustment to Internat'l Awards	--	--	--	-1.51*
Total	3,269	$272.84	3,489	$300.44

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.

SOURCE: Fiscal Years 1984 and 1985 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

posites, new organic materials, and liquid crystals) were only possible because of the recent availability of sophisticated preparation and characterization facilities and because of cooperative efforts by materials scientists from diverse disciplines.

The following sections describe some of the areas where major activity is under way in each of the mathematical and physical sciences.

Mathematical Sciences

The mathematical sciences are best defined by the focus of their investigations—those formal, abstract structures that reflect fundamental aspects of the real world and exhibit broad intellectual applicability. Mathematical scientists look for patterns leading to the discovery of new structures, and they model natural phenomena using structures appropriate to the behavior of those phenomena. In so doing, these scientists have developed a natural language to describe the activities and laws of nature and have provided an indispensable undergirding for science and engineering.

Research in the mathematical sciences continues to thrive under an expanding spectrum of stimuli from other fields. Within the disciplines, finite fields and computational complexity and probability and linear programming are providing unexpected synergies. Research concentrating on nonlinear problems has led to progressively sharper models for users of mathematics in other sciences. A more recent development is the growing use of computers for scientific computation in applied mathematics and statistics and of interactive computing in all areas of mathematics.

Activity in the mathematical sciences is organized into these broad classifications:

- Classical Analysis deals with the study of real and complex functions, their approximation, and their interrelations as solutions of ordinary and partial differential equations.
- Modern Analysis centers on the study of classes of functions endowed with special abstract geometric and algebraic properties.
- Geometric Analysis encompasses the study of geometric objects such as curves and surfaces, as well as the use of geometric models in the analysis of nonlinear phenomena.
- Topology deals in a formal and abstract manner with those properties of geometric objects which persist after deformation by stretching, shrinking, and twisting without tearing or cutting.
- Foundations research involves the study of the logical structure and conceptual foundation on which mathematics rests.
- Algebra and Number Theory deals with abstract algebraic structures such as groups, rings, and fields; combinatorial structures; the structure and properties of number systems; and relationships between such structures.
- Applied Mathematics is an activity which brings mathematical methodology to bear on the needs of the empirical sciences. It involves the mathematical modeling and analysis (both theoretical and computational) of complex, real-world phenomena.
- Statistics is the study of methods to collect, organize, and analyze data in order to uncover fundamental mathematical relationships among variables.
- Probability theory deals with phenomena that are random in the sense of combining long-term regularity with short-term unpredictability.

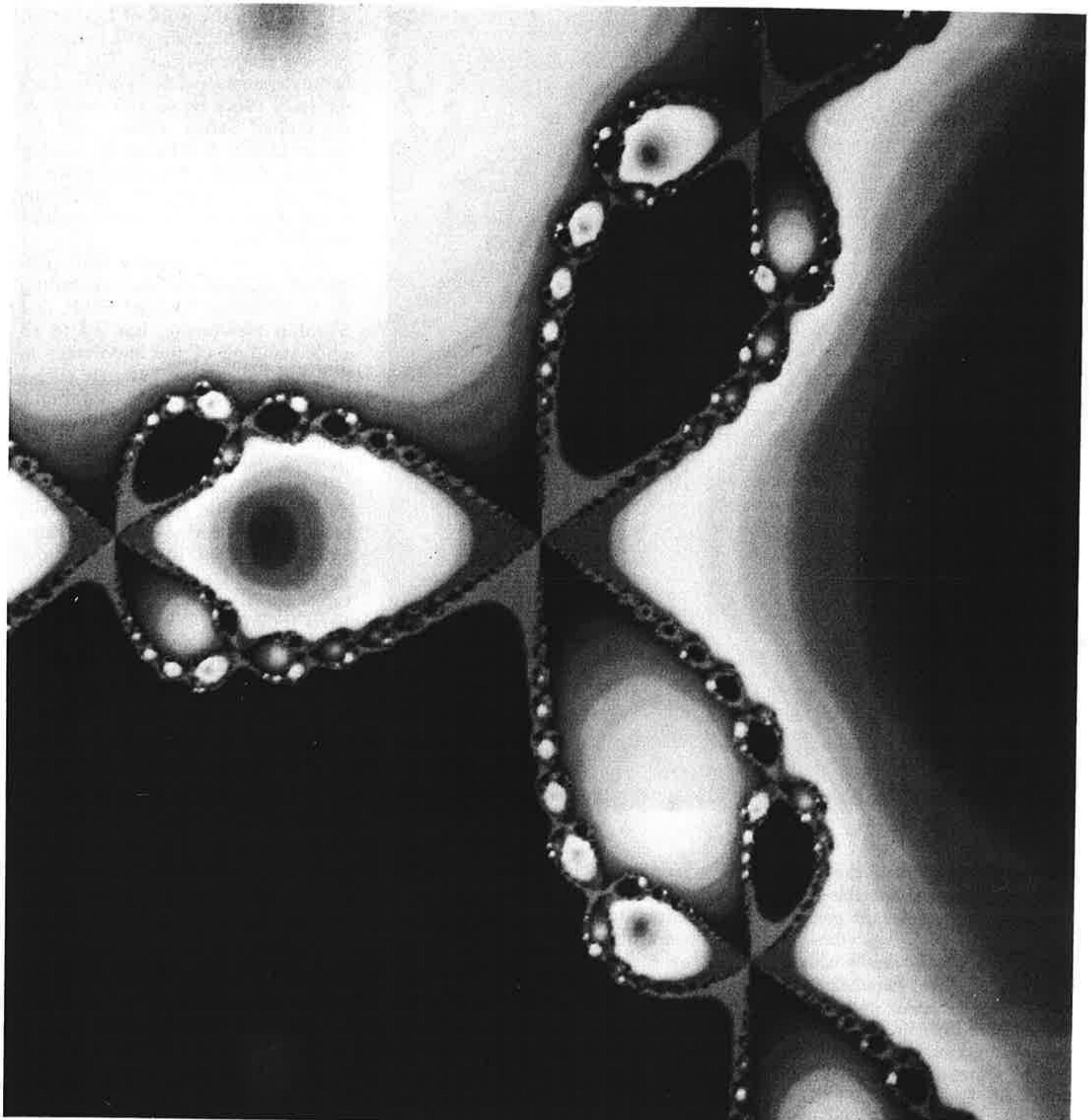
The National Science Foundation's role in support of basic research in the mathematical sciences is pivotal. The Foundation provides virtually all of the federal funding for basic research in algebra, number theory, geometric and modern analysis, topology, and foundations. In classical analysis, NSF accounts for some 90 percent of the funding, with the Departments of Defense and Energy providing the balance. In applied mathematics, probability, and statistics, the Foundation awards approximately 40 percent of the total funds for basic academic research. The programs of NSF, Defense, and Energy are complementary.

The following items describe areas in which major activity is under way. They also illustrate some of the trends within the mathematical sciences today, particularly the disappearance of traditional subdisciplinary boundaries, the interactions taking place with other fields of science, and the rapidly developing role of computation in mathematical and statistical research.

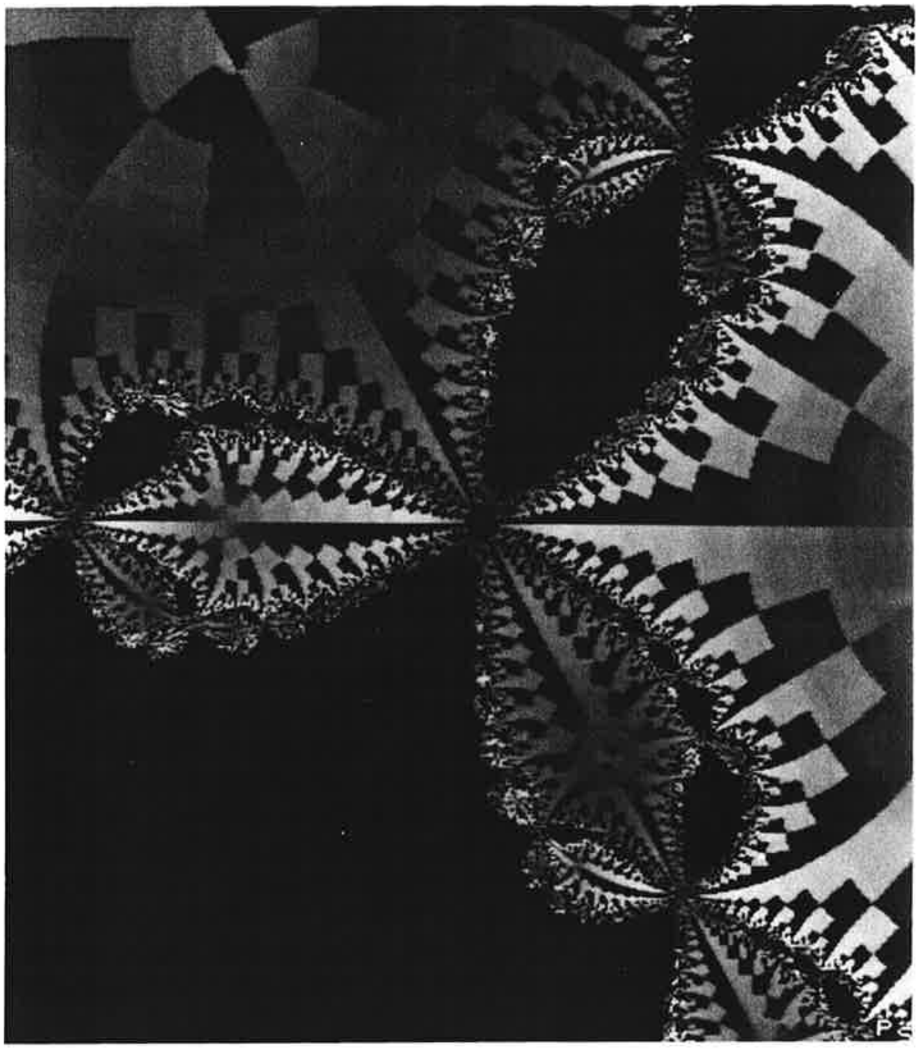
Transition to Turbulence—Chaos

Fluid flows are highly organized and regular at times; at other times they appear to be erratic and random. For instance, the plume rising from the tip of a cigarette usually displays a regular, laminar structure up to a certain height, but above it eddies appear and the smoke pattern is chaotic. In 1883 Osborne Reynolds was the first to examine experimentally the question of the transition of a fluid flow from a laminar regime to a turbulent one. In the case of pipe flows, he found that the transition occurs when a parameter characteristic of the flow (now called the Reynolds number) exceeds a critical value. Since then studies have shown that such a transition to turbulence is a universal feature of fluid flows.

Even though much has been learned about the stability of laminar flows, an understanding of turbulence has eluded mathematicians and physicists for the last century. In the absence of a more comprehensive theory, workers in the area clung to a suggestion made by Lev Landau in 1941. He envisioned the transition to turbulence as an infinite cascade of bifurcations.



Order and chaos in Newton's method. Approximate solutions to nonlinear equations are often found by Newton's method, illustrated here for solving $z^3 = 1$ in the complex plane. Starting from a gray-on-white region, this scheme generates a sequence converging to $z = 1$, while sequences originating in a white-on-gray or black-on-gray region converge to a different cube root of unity. Sequences starting at the common boundary of these regions (a fractal known as the Julia set) fail to converge, but hop around the boundary in an erratic manner best viewed as a random walk. Such coexistence of convergent with chaotic behavior often occurs in dynamical processes associated with iterative computer algorithms and nonlinear models of natural phenomena. The computer pictures here and on the next page were created by Klaus Schmitt and his associates at the University of Utah, supported in part by NSF.



In Landau's picture, the laminar region first becomes unstable at a critical value of the relevant parameter and is replaced by a flow whose configuration varies periodically with time. At a higher critical parameter value, this periodic behavior itself becomes unstable and turns into a quasi-periodic motion with two basic frequencies. Further bifurcations at a sequence of successively higher critical parameter values add more and more frequencies to the time dependence of the flow. These critical values increase to a finite limiting value, at which the time dependence of the flow has acquired infinitely many basic frequencies and has become chaotic. An accompanying illustration describes a Landau-type system used to model population growth for certain kinds of insects.

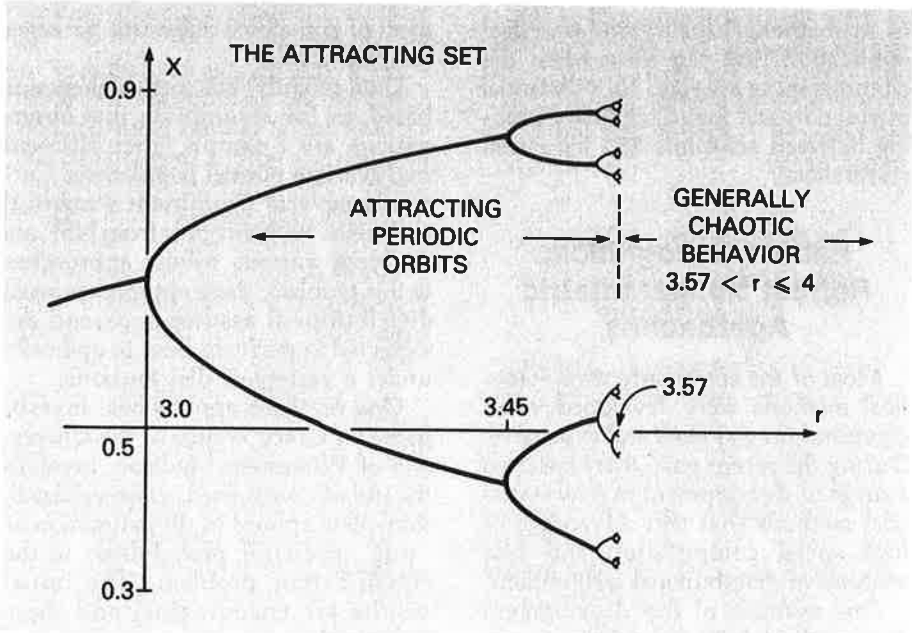
Serious criticisms have been leveled at Landau's picture as a model for the transition to turbulence in fluid flows. Experimental observations suggest that actual turbulent fluid flows are sensitively dependent on initial data, in the sense that two configurations starting from very close initial states can evolve into very different configurations with time. However, Landau's model leads to a turbulent behavior in which nearby states remain close to each other.

While the transition to turbulence in fluid dynamics remains a problem, attempts to provide a theory which agrees with experimental observations have revolutionized our understanding of the passage from periodic to chaotic motion in simpler dynamical systems. The new understanding is based on a geometric theory of dynamical systems, with roots in the work of Lyapunov, Poincaré, and Birkhoff, early twentieth-century mathematicians. The theory has undergone rapid development since the early 1960s by several groups in the United States, France, and the Soviet Union. It is based on viewing the evolution of a dynamical system in terms of a mapping that transforms initial states into the states at some specified later time.

Recent work by many NSF-supported mathematicians, including R. F. Williams, Michael Shub, and Sheldon Newhouse, has led to an understanding of the importance to dynamic behavior of "strange attractors." An attractor is an asymptotic state, such as a stable equilibrium or a limit cycle, which captures all trajectories starting near it. What makes an attractor strange is that its internal motion is chaotic, so that the observed behavior for nearby states is asymptotically random. Strange attractors generally have a much more complicated geometric structure than equilibria (points) or limit cycles (loops); they tend to be fractals, or self-similar geometrical forms.

Strange attractors have been observed in a great variety of models from the natural sciences. In recent NSF-supported research, certain examples have been carefully analyzed by Philip Holmes, Jerrold Marsden, James Yorke, and others. An early and particularly striking example of a natural system with strange attractors was the system of nonlinear differential equations formulated earlier by Saltzman and Lorenz to model atmospheric convection. The existence of a strange attractor in this model can be interpreted as an intrinsic cause for the unpredictability of next week's weather.

The appearance of strange attractors in relatively simple natural models underlies a scenario for the route to turbulence in fluids suggested by Ruelle and Takens in 1971 as an alternative to the Landau picture. In the Ruelle-Takens scenario, increasing the Reynolds-like parameter leads to only a few bifurcations of the quasi-periodic variety, after which the system acquires a strange attractor. This process captures certain dynamic fea-



A view of chaos. Figure represents the initial stages of an infinite cascade of bifurcations on the way to chaos. Lev Landau envisioned the transition to turbulence this way in 1941.

tures which have been observed in fluid flows but are not predicted by the Landau process. On the other hand, both the Landau and the Ruelle-Takens scenarios are relatively removed, in their present formulation, from being an actual physical theory of fluid flow.

This area promises to be one of importance to NSF programs in geometric analysis, applied mathematics, modern analysis, and classical analysis for some time to come.

Dynamical Systems and Coding

Coding theory is an area in which a broad spectrum of applied and theoretical research is actively being pursued. At its present state of development, many problems require either more powerful computational techniques or new approaches in mathematical modeling. Some recent results in ergodic theory* seem to offer significant new insights into certain coding problems. What is particularly nice about the solutions generated by these methods is their computability and potential relevance in constructing practical commercial devices. At the same time they instill mathematical order in complicated engineering constructions. Even more fascinating, a very natural and important invariant in dynamical systems turned out to be the only real obstacle to realizing these codes.

Codes considered here consist of digital information presented as arbitrarily long strings of symbols. In the process of storing and transmitting data, various practical considerations—such as physical restrictions or efforts to minimize errors in the retrieval process—impose constraints on the stored information. More specifically, consider the case of encoding computer data onto a magnetic medium such as a readhead for magnetic tape. There the computer information (the source) consists of arbitrary sequences of 0's and 1's, while the magnetic information (the channel) consists of constrained sequences of pluses and minuses. The problem is to encode arbitrary sequences onto constrained sequences in such a way that one can decode a source sequence from a channel sequence accurately and efficiently.

Certainly, the constraints imply some structural requirements in order to complete this process, but these turn out to be very mild. The only critical feature is a topological variant of a probabilistic notion formulated by Claude E. Shannon: the entropy or information capacity of the system. In this situation, the topological entropy roughly measures the storage capacity of the space. What ergodic theory showed is just what one would hope. An encoding onto constrained data is possible provided that storage capacity permits it.

The mathematical models used in the solution of this problem have been a vast source of examples and information to ergodic theorists for many years. The models, called N-shifts, consist of infinite strings of elements from a finite alphabet and an appropriately chosen map between the strings. The coding problem reduces to finding special maps from certain subsets of N-shifts representing the constrained situation onto complete N-shifts. The topological entropies of the two systems will determine the existence and practical application of the necessary maps.

Brian Marcus of the University of North Carolina made the first breakthrough in the area, determining the existence of such maps when the systems involved had equal entropy. Roy Adler, Don Coppersmith, and Martin Hassner of IBM were able to push these results to more general settings.

As is the case with any good problem, the solution leads to a host of other interesting questions. Although the algorithm for encoding has a large amount of freedom, a blind application can lead to codes that are unacceptable for practical purposes. Careful applications can lead to very efficient codes, some by simple constructions and others requiring extensive computer work. The problem of finding good codes should continue to attract attention. Moreover, in attempting to improve coding efficiency, the codes become more complex, leading to other interesting problems. Finally, since the applications of this work involve aspects of engineering, such as transmission of data with lasers over fiber

*Part of Modern Analysis, ergodic theory is the study of recurrent or predictive behavior in classical, physical, and informational systems that can be suitably modeled either measure-theoretically or topologically.

optic channels, it is likely that engineering requirements will point the way to new mathematical questions.

There is a final chapter to this story which is a bit unusual. These results and applications came from a collection of fortuitous interactions between academia and industry and between mathematicians and other scientists. One key ingredient was the appointment of Brian Marcus as a postdoctoral fellow at IBM and his subsequent collaboration with Roy Adler. Another was the recognition of the practical significance of their work by IBM's Martin Hassner. He was trained as an electrical engineer with interests in coding theory but was also familiar with current developments in ergodic theory. The results show the wealth of mathematical theory and practical application that can arise when the circumstances are right for substantial interaction and interdisciplinary probing between academic and industrial researchers.

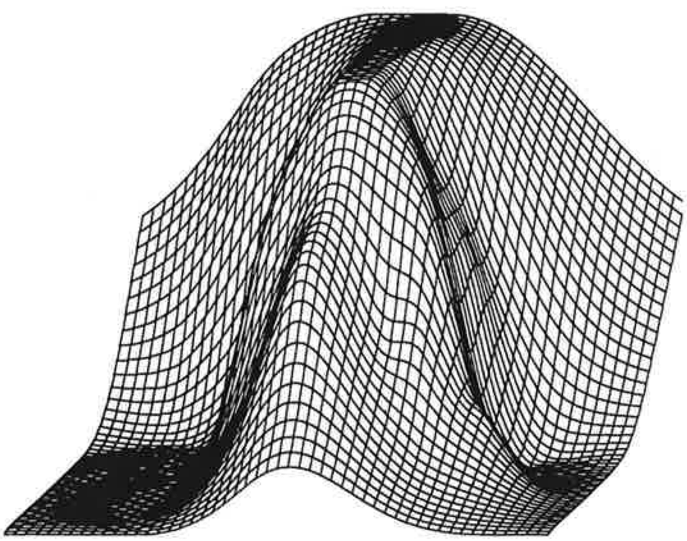
Pattern Recognition: Robust Nonparametric Approaches

Most of the commonly used statistical methods were developed when computation was slow and expensive. During the recent past, there has been a surge of development in new statistical methods that take advantage of high-speed computation and free analyses of distributional assumptions.

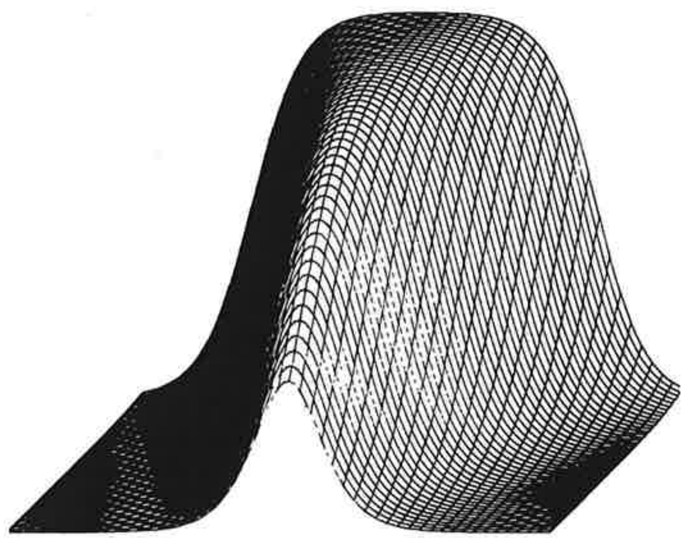
One example of this development is in methodology for pattern recognition, often known as discriminant analysis or classification. This methodology is used in a wide variety of applications such as the analysis of remote sensing data, nondestructive testing for reliability measurements, classification of patients into normal and psychotic groups by using a battery of psychological tests, and the development of automated diagnostic packages for physicians.

Until recently, this methodology was based on the assumption that observations are a sample from different multivariate normal populations. Currently several prominent statistical scientists, with support from NSF, are studying various robust approaches to this problem; those approaches avoid distributional assumptions and are expected to perform close to optimally under a variety of distributions.

One of these approaches, investigated by Grace Wahba at the University of Wisconsin-Madison, involves the use of constrained, cross-validated, thin-plate splines in the estimation of "true" posterior probabilities in the classification problem. The initial results are encouraging, and these investigations have been greatly helped by the recent acquisition of appropriate instrumentation. According to Wahba, this method is relatively computationally intensive and would have been unthinkable a few years ago. It is not particularly difficult or expensive to test these methods on a VAX 11/750 system, however. This system was provided to the University of Wisconsin-



ESTIMATED (POSTERIOR) PROBABILITY SURFACE



TRUE (POSTERIOR) PROBABILITY SURFACE

Recognizing patterns. Statistical scientists are looking into various approaches to classification or pattern recognition problems, especially those involving distributional assumptions. In one approach constrained, cross-validated, thin-plate splines are used to estimate posterior probabilities. This procedure produced the estimate shown in the figure at left; it has much in common with the "true" probabilities seen in the other figure. The work reflects new statistical methods that take advantage of high-speed computation—done here with instrumentation acquired through NSF support. The photo shows Grace Wahba, a professor at the University of Wisconsin, using a terminal attached to the VAX 11/750 system. (Photo by Douglas Bates)

Madison under Scientific Computing Research Equipment for the Mathematical Sciences, a new initiative of the mathematical sciences section.

The two figures accompanying this text indicate the effectiveness of Wahba's approach in a simulation study in which there is one sample of 70 observations from one distribution and a second sample of 70 observations from a second distribution; the issue is to classify a potential new observation as coming from the first or second distribution. The estimated (posterior) probability surface is obtained without knowledge of the true surface and the similarity of the two surfaces shows that the method does indeed work.

Wahba's results are very promising developments that need perfecting for use on higher-dimensional data and larger numbers of observations, situations commonly found in satellite data, medical data, and many other settings.

Computer Research

Computer research is the study of computers, computing, and information processing. Its universe of study consists of strategies and algorithms for solving problems, methods of representing and transforming information, programs to carry out computation procedures, and machines to execute programs. The central unity of this research arises from the concept of computational complexity as a measure of the feasibility of finding a solution to a given problem. It seeks to understand the irreducible limits of complexity in given problems and discover the best ways to find feasible solutions.

Unlike the physical sciences, which deal with the intrinsic properties of physical matter, computer research studies the intrinsic properties of problem-solving procedures and computing systems. It is therefore necessary to discover their underlying concepts and laws, test their validity, and examine their implications for design.

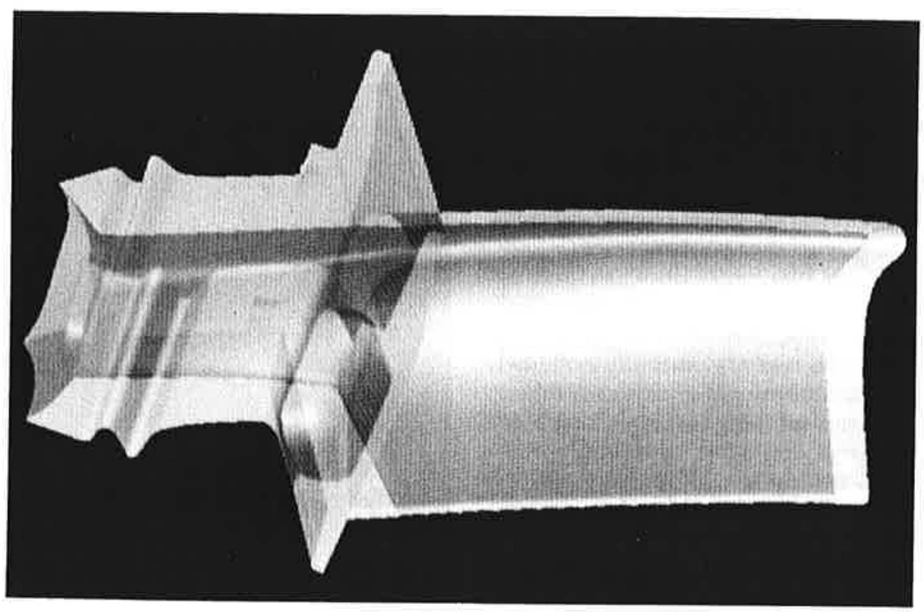
Computer research continues to be one of the most exciting and creative areas within the mathematical and physical sciences. It interacts strongly with technological development and thus accumulates an ever-increasing repertoire of important research topics. As a result of these technological developments and the accompanying reduced cost of components, it is now possible for university researchers—for the first time since the earliest work in the 1950s—to become active participants in research on new-generation computer systems. These new systems will in turn spur research on their appropriate use and their limitations. The result of such activities is a rich intellectual environment that has stimulated a great deal of creative activity among academic researchers.

Basic research into the properties of problem-solving procedures, feasible methods, and optimal algorithms often precedes a technological development that makes an application practical. "Knowledge engineering" is one example of this. For years scientists have studied methods to represent information and organize sets of rules to work with it. Only recently has the reduced cost of large, fast memories made possible some realistic applications. In these the collected knowledge that experts use in well-understood subject areas is encapsulated into so-called "knowledge-based expert systems." Sample applications are found in certain types of medical diagnosis, the analysis of oil and gas wells, and in studying the synthesis of certain classes of chemicals.

Computer graphics has long been a key research area. Currently, the cost of high-quality graphics display is declining. This, together with higher-speed processors, is allowing dramatic advances in the quality of pictorial display. Significant applications are found in computer-aided design and in the generation of films and television commercials.

Data transmission has been studied, and indeed used, for many years. Now satellite technology and other advances in high-speed digital transmission

CAD/CAM. Computer-aided design (CAD) and computer-aided manufacturing (CAM) use interactive computer graphics techniques to aid product design and couple that design to the manufacturing process. This example of computer graphics, from the University of Utah, shows a turbine blade. The picture has been generated from a mathematical model; the same model can be used to generate machine control instructions for the manufacture of the blade.



permit the nearly instantaneous transmission of data and messages between computers; they also make possible access to remote computational facilities. This development makes clear the need for secure access algorithms in operating systems and for other algorithms to protect the data that are transmitted.

Thus basic research, before the enabling technology is available, can lead to significant applications. The excitement to the researcher, however, is more in the discovery of a new organization, a new structure, a new resolution of a previous limitation. This intellectual excitement is abundant in computer research.

Concurrent Programming Languages

The concurrent execution of tasks to speed up the total performance of a job is a common technique in many environments. A computer program is traditionally a single stream of instructions executed in sequence. Some of these instructions can be used to start a separate process that can be done concurrently with the main stream of instructions.

As an example, most computers use one processor to control the input of data, another to control the output of results, and a central processor to carry out the computation. Once a signal from the central processor begins an input or output activity, the corresponding subprocessor controls that activity independently. To begin a second subactivity, the central processor must wait for a completion signal from the subprocessor and is thus temporarily excluded from communicating with that subprocessor.

When two processors perform as equals, rather than in a master-slave relationship, there will be periods in which the two are *mutually* excluded from communicating with each other.

Computer designers have long been interested in using additional processors within a computer system to increase the potential for concurrency. Not only is there a need to provide for mutual exclusion, but synchronization mechanisms must be designed so that programs will exhibit reproducible behavior. Each set of design choices carries with it tradeoffs between the cost of assuring reproducible behavior, the degree of protection from program error, and the programming cost.

Under an NSF grant, P. Brinch Hansen of the University of Southern California developed one of the first programming languages describing ways to manage concurrently executing processors. In experiments with this language, called CONCURRENT PASCAL, several operating systems and a real-time process control system have been developed.

J. A. Feldman at the University of Rochester chose a different set of techniques to develop PLITS (Programming Language In The Sky). This was the first attempt to rely on message passing as the sole means for interprocessor interaction. Similarly, G. R. Andrews at the University of Arizona came up with a programming language, SR (Synchronizing Resources), using a different set of techniques for synchronization and mutual exclusion.

First computer programmer. Augusta Ada Byron, Countess of Lovelace and daughter of the poet Lord Byron, is considered by most scholars to be the first computer programmer. (She devised programs for an early mechanical computer.) Today "Ada" is a trademark for a standard computer language used by the U.S. Department of Defense. (Picture courtesy of the Science Museum, London, England)

These kinds of investigations, supported by NSF and others, have built a community of understanding as to the costs and advantages of each selection of techniques. The Department of Defense's standard programming language for imbedded systems, Ada, is in part a product of that understanding, which continues to grow.

Symbolic and Algebraic Manipulation

As early as 1844 Augusta Ada Byron, the poet's daughter and generally considered to be the first computer programmer, pointed out that a computer could "arrange and combine its numerical quantities exactly as if they were letters or any other general symbols; and in fact it might bring out its results in algebraic notation, were provisions made accordingly." Today there are three main reasons to use symbolic techniques in scientific computation:

1. In some cases a considerable amount of computer resources can be saved by simplifying an expression algebraically before evaluating it numerically.
2. The results are exact, while numerical results have errors due to approximation and roundoff.
3. An answer expressed in algebraic form conveys more scientific insight than the same answer expressed numerically. For example, 3pi is more meaningful than 9.424777962.

Early researchers in computer science observed that computers make excellent symbol manipulators and began efforts in this area. But they met two difficulties. First, as one did algebraic operations on even simple expressions, the size of the resulting expression could grow exceedingly large. This meant that large and expensive computers were necessary, limiting the potential user base and inhibiting classroom use. Second, even though mathematicians had been performing and teaching symbolic and algebraic manipulation for several hundred years, they found it difficult to describe to the computer exactly how it was done.

Anthony Hearn, formerly with the University of Utah and later with the Rand Corporation, developed a computer software system, called REDUCE, for performing symbolic and algebraic manipulations on digital computers. REDUCE was written in a language called LISP, available only on very large computing systems.

To make symbolic computation feasible over a broad range of computing equipment, Martin Griss, a colleague of Hearn's at the University of Utah, developed a LISP programming system called Portable Standard LISP (PSL); it can be used easily on several different machines with very widely varying characteristics. At this writing, the system is available on computers from six different manufacturers; PSL and REDUCE can be used on mini-computers as well as on large mainframe machines.

Another NSF grantee, David Stoutemyer of the University of Hawaii, has investigated the possibility of a hand-held symbolic calculator.

Thus, because of parallel developments—advances in the design and use of symbolic and algebraic systems, the rapid decline in the cost of computers, and the increased abilities of small computers—the availability of equipment no longer prohibits the widespread use of symbolic and algebraic techniques in computer science. Similar progress has been made in other key areas, such as differential equations and polynomial factoring. Now the stage is set for greater exploitation of this area. Symbolic and algebraic manipulation can fill the key role that the early scholars saw for it in their vision of computer science research.

Physics

In its search for fundamental laws governing matter and energy, the science of physics operates over a scale that encompasses both the most elementary and minuscule constituents of matter and the largest aggregation imaginable. Physicists seek to incorporate phenomena on both scales into a unified theory, one based on detailed knowledge of the fundamental forces that act on components of the micro- and macroworlds.

The Foundation supports research in elementary particle physics; intermediate and low-energy nuclear physics; atomic, molecular, and plasma physics; gravitational physics; and theoretical physics. The first of these focuses on the most elementary forms of matter, particles that fall into three families: leptons, quarks, and the gauge particles (carriers of the forces of nature, including photons, intermediate-vector bosons, and gluons).

Particle physics is experiencing a substantial success rate. This includes discovery of the W and Z particles, culminating 75 years of research on the weak interaction and offering very strong evidence for recent theories unifying the weak and electromagnetic interactions. Physicists have found a fourth quark (called charm) and also produced a fifth quark (called beauty). A new lepton (the tau) has been found, and scientists have observed indirect evidence to support the existence of gluons. Recent studies have uncovered candidates for bound states of two gluons (glueballs).

In nuclear science the quark-gluon theory is gaining acceptance in describing the interaction between nucleons at very short distances, while the older meson exchange theories still prevail for longer distances. New accelerators under construction and being proposed will provide the tools needed to explore a broader region of nuclear structure and dynamics, as well as the transition region between meson exchange and quark-gluon theories at high nuclear densities.

In atomic, molecular, and plasma physics there have been dramatic advances in photon sources, both in laser technology and in the brightness and accessibility of synchrotron radiation sources. Ion sources, mass spectrometry, and high-vacuum technology—along with facilities developed originally for other disciplines—are making it possible for physicists to do new experiments in atomic collisions and plasma physics over a broader energy range.

During the past decade outstanding experimental groups began to migrate into gravitational research, bringing new and powerful technologies from other fields in order to detect gravitational radiation. The experimental work is expected to intensify during the coming decade as new tools are applied to this exciting possibility. Computer simulations are progressing toward realistic and unique estimates for the production of gravitational radiation by astronomical sources. Mathematical studies are exploring new exact solutions to Einstein's equations, applying modern techniques from differential geometry, group theory, topology, and complex variable theory. There is a developing collaboration between gravitational and particle theorists in formulating a quantum theory of gravitation.

In theoretical physics two of the four fundamental forces of nature, the weak and electromagnetic forces, were united into a single force through the use of gauge particle theories. Attempts to add a third (the strong) force, producing a Grand Unified Theory (GUT), have led to the profound prediction that the pillar of stability of the universe, the proton, is unstable. Theorists hope to join the gravitational force to the other three, and they are exploring the possibility that the very high energies where the forces become unified can be probed by looking for astrophysical evidence of the events that occurred just after the Big Bang.

Substantial progress has been made on a theory of strong interactions, called quantum chromodynamics (QCD), in which the force between quarks is carried by gluons. Progress is also evident in work with nuclear models and methods that predict, for example, the energy levels of heavy nuclei and the behavior of heavy-ion collisions.

Following are some physics achievements supported by NSF during FY 1983.

Supersymmetry

The concept of broken symmetry has come to play a dominant role in current attempts to understand the elementary particles and the basic forces. This concept was behind the theory that unified the electromagnetic force with the weak force responsible for many elementary particle processes. That Nobel Prize-winning theory was developed through the work of NSF-supported physicists Sheldon Glashow and Steven Weinberg and the Pakistani physicist Abdus Salam. It predicted the W and Z particles recently discovered in history-making experiments in Europe.

A perceived symmetry between the weak and electromagnetic forces had led the theoretical physicists to the conclusion that the weak force must be mediated by the W and Z particles, just as the electromagnetic force is mediated by the photon. The broken nature of this symmetry allows the W and Z particles to be very heavy, even though the photon, to which the symmetry relates them, is without mass.

The notion of broken symmetry is also behind recent efforts to unify the strong nuclear force with the weak and electromagnetic forces in a "grand unified theory." Grand unified theories predict the magnetic monopoles discussed in last year's NSF Annual Report. That report explained that a monopole colliding with a proton or neutron is expected to cause that particle to disintegrate into lighter ones. Scientists have searched for this phenomenon experimentally during the past year.

Intense interest has now developed in a different possible broken symmetry known as supersymmetry. Leading contributions to this theory were made some years ago by Daniel Freedman, Peter Van Nieuwenhuizen, and B. Zumino, all of them NSF-supported, although Zumino was in Europe at the time of his pioneering work. Recently Edward Witten, also backed by NSF, led the way in discovering that supersymmetry can help to explain why the weak force has very great strength compared to the force of gravity. Inspired by this discovery, many theorists are engaged in further study of supersymmetry and the possibility that it may help us to unify *all* the forces, including gravity.

Supersymmetry predicts a rich spectrum of new particles that would be the superpartners of those we already know. These new particles may be among the exciting discoveries made by the high-energy accelerators of the future. Indeed, even if the details of supersymmetry are not correct, nearly all of the current views in elementary particle physics predict exciting new phenomena that are beyond the reach of accelerators now operating. But they would be accessible to the accelerators of the next two decades.

Atomic Clocks for Nuclear Times

In the last few years, there has been a flowering of research effort at the intersection of three traditionally separate research fields in physics: atomic, molecular, and nuclear physics. Under study are X-rays emitted as a result of electronic transitions in the inner shells of atoms *during the time* a nuclear reaction is taking place.

Much of the recent experimental work involving proton-excited X-ray spectroscopy at low energies has been done in the laboratory of Walter Meyerhof at the Stanford University tandem Van de Graaff accelerator. Collaborative complementary work involving uranium-uranium collisions at high energies has been done at Gesellschaft für Schwerionenforschung (GSI) in Darmstadt, West Germany with the heavy-ion linear accelerator facility there.

These two types of experiments are both sensitive to time-delay effects in atomic scattering due to the formation of a compound nucleus in a nuclear reaction. If no nuclear reaction were to take place, the projectile (proton or uranium ion, respectively) would fly by the target nucleus in a typical time of 10^{-21} seconds or less. But under certain conditions a nuclear compound state may be formed. In it the two nuclei will orbit each other for a time much longer than 10^{-21} seconds.

In some of the Stanford experiments, this orbit time was 10^{-16} seconds—much shorter than one can detect by conventional electronic methods. During this time *both* the nuclei and the atomic electrons can form "quasimolecules" (hence the connection with molecular physics). The nuclei coalesce to form a compound state, with nuclear forces holding the system together temporarily. At the same time, the electronic structures of projectile and target merge and emit X-rays; these are characteristic of neither projectile nor target but of a quasimolecular system with an atomic number equal to the *sum* of projectile and target numbers.

In a sense, the atomic phenomena can be used as a "clock" to time the nuclear interaction. The effects of the strong forces in the nuclear quasimolecule on the dynamics of the electrons brought into the collision along with the nuclei are detectable in their effects on the emitted X-ray spectrum. To bring theory and experiment into agreement, a fully quantum-mechanical treatment of the X-ray emission process must be used. Interference effects between the ingoing and outgoing parts of the atomic collision must be carefully taken into account in order to explain the data.

Meyerhof calls this field the study of "sticky nuclei." At this writing, several different types of experiments are under way at laboratories in the United States, West Germany, and Switzerland. The atomic clock technique is very important because it lets one measure times in a much shorter range than present electronic methods allow.

Linac Dedicated

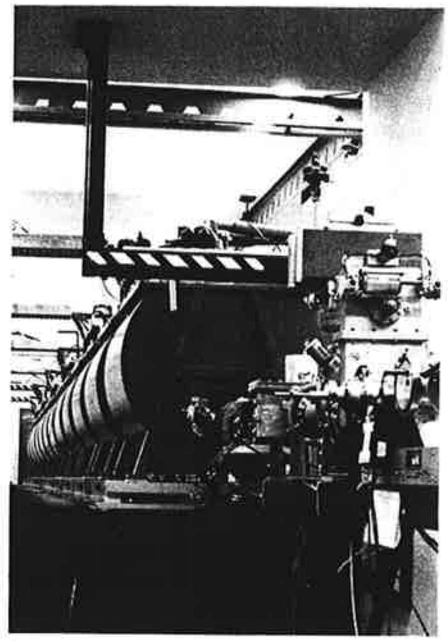
Nuclear physicists gained an important, and relatively inexpensive, new research tool on April 14, 1983. On that date the State University of New York at Stony Brook dedicated its superconducting heavy-ion linear accelerator (Linac). This is the first university-based Linac using superconductivity technology and one of the first in an emerging new generation of higher-energy nuclear accelerators that are expected to yield a better understanding of the basic structure of matter. They may even lead to the discovery of new "superheavy" nuclei.

The Linac was custom built by a team from Stony Brook and the California Institute of Technology. Inventing state-of-the-art technology enroute, the team transformed an old 8-MeV (million-electron-volt) accelerator into a 25-MeV unit that can accelerate heavy nuclei to energies up to 500 MeV. The new machine expands the worldwide capacity of heavy-ion nuclear research by perhaps 20 percent.

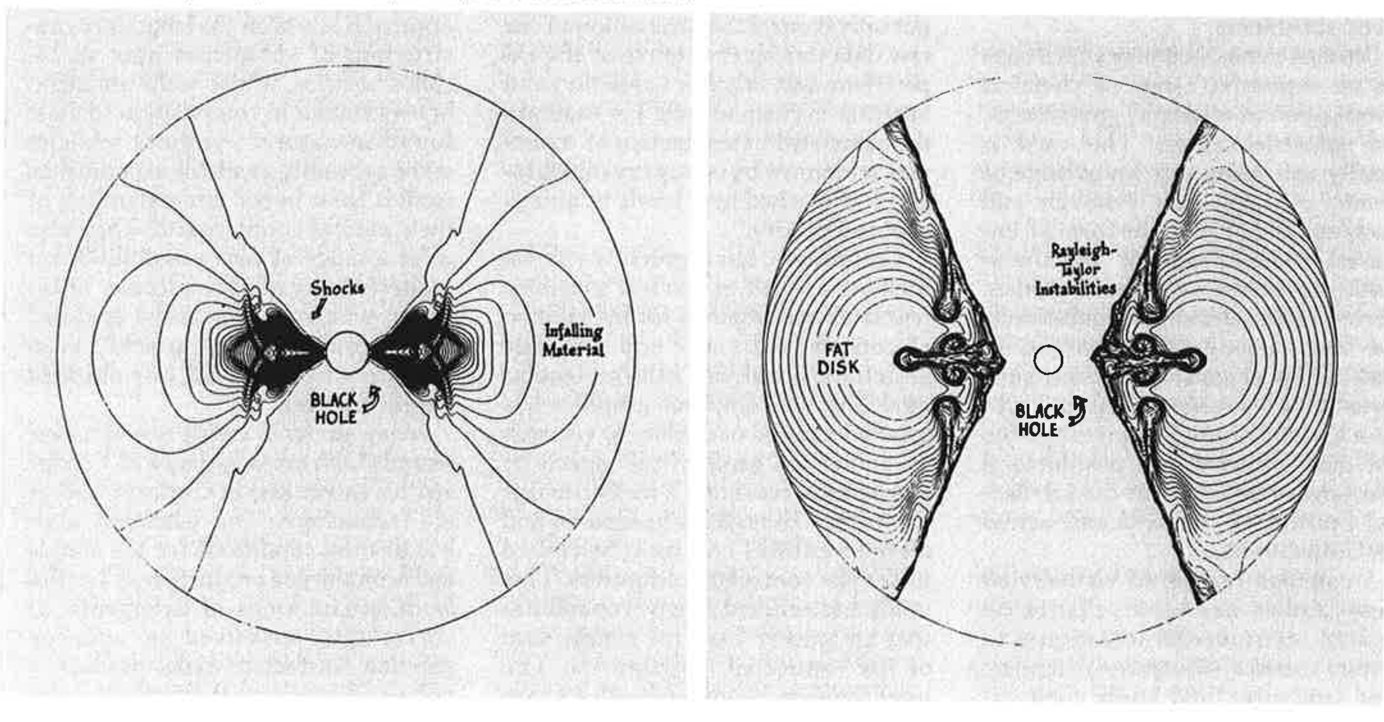
Researchers using the Linac will direct a beam of heavy ions from the University's old Van de Graaff accelerator through superconducting "booster" resonator cavities. The energy of the nuclei will be successively stepped up as they pass through each cavity. When they leave the booster, the nuclei will be traveling at speeds of some 19,000 miles per second—10 percent of the speed of light. They will then be directed into one of several target areas, where they will collide with targets made from nuclei of different elements.

Computer Simulation of Gravitational Dynamics

Most researchers believe that the only source that can power the active galactic nuclei of quasars and certain galaxies is gas accreting onto a supermassive black hole (which has a mass one hundred million times that of the sun). As this gas spirals in toward the hole, it forms an orbiting disk. If the disk cannot efficiently radiate the heat generated internally by viscous processes, a "fat" disk develops—one in which the disk is as thick as it is wide. In such inflated disks, pressure forces from the high temperatures within balance the combination of gravitational and centrifugal forces.



SUNY's Linac. Dedicated in 1983, this is the first university-based, heavy-ion linear accelerator using superconductivity technology. High-energy nuclear accelerators such as this one are expected to yield more information about the basic structure of matter.



Simulating black hole physics. Art at left is a computer simulation of the density contours of a gas following into a black hole, shown as the gas near the hole. The shocks are slowing down the infalling material, allowing it to form a hot pressure-supported disk. Second drawing shows a fat disk with a hot bubble in pressure equilibrium at its core after it is well into the nonlinear Rayleigh-Taylor instability. Fingers of the cool outer gas are penetrating into the core, exchanging position with the hot material there. These simulations do not reflect complex factors such as magnetic fields, turbulence, and viscosity, yet they produce results similar to those of analyses and laboratory experiments. This attests to the utility—and power—of supercomputers in this research area.

It is possible to construct analytic models of stationary fat disks. However, to study the dynamics of fat disks one must turn to numerical methods. Recently there has been important new progress on this problem by John Hawley and Larry Smarr of the University of Illinois, in collaboration with James Wilson of Lawrence Livermore National Laboratory (a U.S. Department of Energy facility). In a project sponsored by NSF, they have perfected a general relativistic hydrodynamics code. With it, they can study axisymmetric rotating flows around black holes. By running the finite-differenced equations on a supercomputer, they were able to obtain the first high-resolution studies of the physics of fluids near a black hole.

Clearly these numerical experiments are only the beginning of a long research program. Still, the impressive resolution of the flow, and its agreement with the analytic solutions and laboratory experiments that apply, show the power of using supercomputers to simulate black hole physics.

Chemistry

Chemistry is often referred to as "the central science," flanked conceptually and experimentally by physics, biology, and materials science. Quantitative chemical theories, derived from physics, have progressed steadily to higher levels of accuracy as computational methods have improved. At another border, bio-inorganic and bio-organic chemists have begun to understand the reactions of biological macromolecules in as much detail as was once possible only for much simpler synthetic substances.

Between these disciplinary interfaces lies an expansive range of chemical investigation in academic, government, and industrial centers. This work is rapidly increasing our knowledge of atomic and molecular behavior and reaching the public in the form of improved drugs, diagnostic and therapeutic procedures, structural materials, fabrics, foods, electronic components, and fuels, among other benefits. In 1983 NSF's chemistry division supported the basic research programs of more than 800 principal investigators and their students and postdoctoral associates—research over the intellectual breadth of the field and across the United States.

A common feature of virtually all these studies has been reliance on modern instrumental techniques to identify chemical substances, determine their structures, and study their inherent physical and chemical properties. Major advances have been made in the power and ease of such methods in recent years, resulting largely from the application of dedicated small computers to their operation. Because computers have been successfully interfaced to these instruments, they can exercise considerable control over them. Experiments not even contemplated a decade ago can now be performed automatically and routinely with great speed. The data systems not only control the acquisition of the raw data during the course of the experiment, but in many cases they can interpret the data as well. For example, the automated determination of molecular structures by X-ray crystallography has reached new levels in molecular complexity.

Computers have given a special impetus as well to nuclear magnetic resonance spectrometry for the solution of complicated static and dynamic structural problems. Intermolecular modeling via computer graphics has greatly increased our ability to visualize the important geometrical aspects of biochemical reactions. Finally, instruments once thought to be separate and distinct entities can now be linked under the control of computers. This union has resulted in new capabilities that are greater than the simple sum of the connected instruments. The most common example of such a union is the connection of an apparatus (such as chromatograph) for separating components of a mixture with an instrument (a mass spectrometer) that makes physical measurements on the substances as they are being separated.

These advances have opened many new frontiers of chemical research and, importantly, have given chemists more time to be innovative and to make maximum use of their creativity. NSF has encouraged much of the current expansion of such capabilities through its program of grants for new instrumentation, to both chemistry departments and individual investigators.

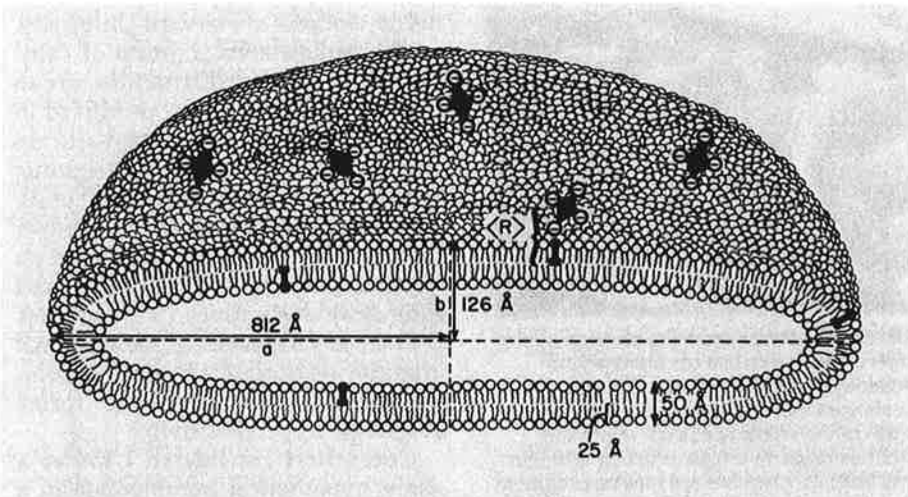
Several achievements highlight the diversity and vitality of FY 1983 projects supported by NSF's chemistry division. Some examples follow.

Synthetic Microcontainers

Living cells are intricately compartmentalized by a network of thin membranes. The diverse biochemical processes of a cell are thus kept from interfering with one another. Natural membranes are selectively permeable, however, to allow the interactions of substances between compartments and between cells—interactions necessary to the life of the organism.

Membrane research is an active field of modern chemistry. One fruitful approach has been the laboratory construction of submicroscopic sacks, called vesicles, whose walls are membranes similar in composition to those found in nature. Synthetic vesicles serve as readily available experimental models for a better understanding of their natural counterparts. They also offer a range of new possibilities for sequestering various molecules of interest, which may be either enclosed in the vesicular cavity, attached to an interior or exterior wall, or embedded within the wall.

Major strides in vesicle research have recently been taken by Janos H. Fendler and his co-workers at Clarkson College of Technology. The Clarkson team has devised conditions for the simple and reproducible production of vesicles from special kinds of detergents, or surfactants, dissolved in aqueous solution. Surfactant molecules have a polar end-structure that attracts water



Potential transporter? One possible benefit of recent membrane research is the use of synthetic vesicles (submicroscopic sacs) as transport vehicles for drugs in the body. In this type of vesicle the molecules have heads that attract water and tails (usually two) that shun it.

molecules and one or more (commonly two) long nonpolar tails that shun water but physically attract each other. Fendler has shown that some surfactant molecules may be made to aggregate into tiny vesicles by the controlled application of ultrasonic radiation (sonication).

These vesicles, like those produced in living cells, have significant stability. For many purposes, however, improved structural integrity would be highly advantageous. Fendler's group has been able to impart extra stability by chemically (covalently) cross-linking adjacent nonpolar tail groups once the vesicle has been assembled as usual by sonication. The result is a polymerized vesicle whose lifetime under ordinary conditions can be measured in months or years. By proper choices of surfactant starting materials and conditions of polymerization, the products can be made with chosen degrees of rigidity and permeability.

These developments have set the stage for a host of exciting potential applications. Vesicles can act as powerful catalysts by bringing reactants into much closer proximity than if they were dissolved homogeneously. Vesicles with appropriate selective permeability should be able to "swallow" precious components from solutions, for subsequent separation and liberation.

One of the most far-reaching possibilities is the use of synthetic vesicles as transport vehicles for drugs in the body. Vesicles may be able to carry drugs to the precise sites where they are needed and release them, rapidly or slowly, on arrival.

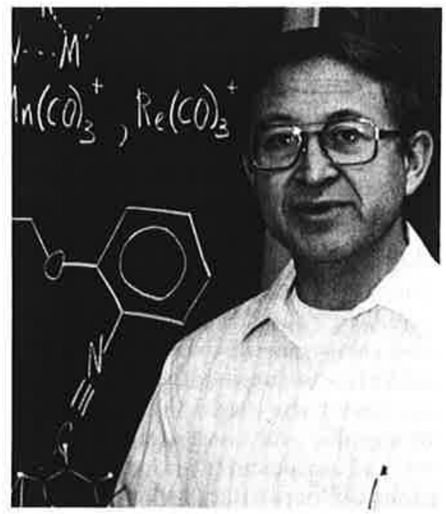
Fundamental and applied research on vesicles is likely to be an important enterprise for years to come.

Agents to Snare Metal Ions

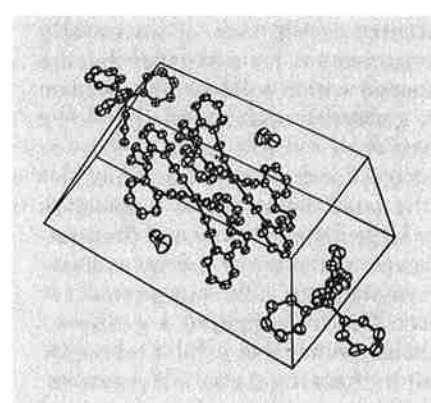
Important ingredients in detergents, water softeners, and certain medicines are organic molecules called "chelating" agents. These agents have a special type of geometry that allows them to bind strongly to positively charged metal ions. Chelating agents typically contain oxygen or nitrogen atoms in their structures, and because the electrical charge of these atoms is opposite to that of the metal ions, the agents can wrap around and strongly bind the ions. In the case of water softeners and detergents, the metal ions present in "hard water" can be chelated to prevent formation of the scum sometimes found in sinks and bathtubs. In medicinal applications, chelating agents wrap around poisonous metal ions so that those ions can be eliminated from the body without causing harm.

Robert J. Angelici and his co-workers at Iowa State University have prepared examples of a new family of chelating agents that bind to metal ions through carbon atoms, instead of through oxygen or nitrogen atoms. The carbon atoms are part of a relatively uncommon unit called an isonitrile group.

Angelici and his co-workers have isolated stable compounds that contain platinum, palladium, or rhenium attached to the isonitrile chelating agents. In collaboration with Robert A. Jacobson, also at Iowa State University,



Chelating agents. At Iowa State University, chemist Robert Angelici (see photo) and his team produced a family of organic molecules that bind, or chelate, to metal ions through carbon atoms, rather than through oxygen or nitrogen atoms (as is more common). Figure shows the structure of a rhodium ion bound through carbon to the organic molecule, as determined by X-ray crystallography. Chelating agents have a variety of possible applications in fields ranging from medicine to metallurgy.



Angelici has obtained an X-ray "picture" of a rhodium ion surrounded and tightly bound by the isonitrile groups of the chelating agent.

The important feature of these isonitrile chelating agents is their preference for binding only to certain metals, such as platinum, rhodium, rhenium, and palladium. This preference suggests that they could be useful as agents to extract these rare metals from their ores, which often consist of a complex mixture of many different metals. The varied industrial applications of these metals include jewelry manufacturing, protection against many forms of corrosion, and uses as catalysts in a broad range of chemical processes. These isonitrile chelating agents also may prove useful for recovering certain precious metals from spent reaction mixtures.

From Light to Electricity

Phthalocyanines are materials similar to the natural dyestuff of chlorophyll. Their deep color, which indicates a strong absorption of visible light, has resulted in a widespread applicability. They have been used for decades in photographic and xerographic emulsions, and as dyestuffs for natural and synthetic fibers in clothing. They strongly absorb light in a region of the visible spectrum where the solar flux on earth is high. However, the previous use of phthalocyanines as materials for converting light energy to electrical energy has been disappointing because of their low conversion efficiencies.

Studies by Neal R. Armstrong at the University of Arizona have shown that one reason for the low conversion efficiency is the lack of an orderly arrangement of the molecules that are contained within solid phthalocyanine. It is generally understood that for a material to exhibit high photo- or electrical conductivity, the molecules in the solid must orient themselves over large distances to avoid dissipating most of the input energy as heat.

Armstrong's NSF-supported research has investigated a group of phthalocyanines that exhibit molecular order by forming stacks like pancakes. Thin films of silicon, aluminum, and

Photoconductors: Scanning electron micrograph shows a thin film of chlorogallium phthalocyanine. Phthalocyanines are substances that strongly absorb light in a region of the visible spectrum where the solar flux on earth is high. Working with thin films like this, chemists are making progress on ways to use such substances to convert light energy to electrical energy. (White line = 5 microns)

especially gallium phthalocyanines form other stacked conformations and tend to show high photoconductivities. For example, when these substances are deposited as a thin film (1/100,000 of a centimeter thickness), they behave as almost perfect insulators in the dark. But they are almost perfect metallic conductors when illuminated with light at near the same intensity and color distribution as sunlight. These new materials routinely exhibit efficiencies of between 3 and 10 percent—an exciting improvement over the previous efficiency range of 0.001 to 0.1 percent.

There has been continuing work to refine the procedures for depositing phthalocyanine thin films so that their efficiency in solar power conversion can be optimized. More importantly, however, other studies have explored the molecular mechanisms of the photoelectrochemical response, to gain an understanding of the chemical and physical factors that are essential in optimizing performance.

Synthesis of the Leukotrienes

The laboratory synthesis of complex organic molecules that originate in living systems has been a field of increasingly productive and useful research. An outstanding example under NSF sponsorship is the preparation of leukotrienes by Elias J. Corey and his co-workers at Harvard University.

The leukotrienes, a group of compounds of elongated structure, are so named because they are produced in white blood cells (leukocytes) and are characterized by three contiguous carbon-carbon double-bond (ene) units. Leukotriene A (LTA) is the group's first member biosynthetically. Corey's work has established that LTA and four close derivatives (leukotrienes B-E) are key mediators of the abnormal immune responses of persons who suffer from asthma and other forms of allergic hypersensitivity.

Corey first considered LTA as a likely hypothetical intermediate in a biochemical reaction connecting two relatively stable related substances observed in Stockholm by Bengt Samuelsson. The Harvard investigators synthesized the compound and confirmed their hypothesis by showing its chemical behavior to be the same as that of a short-lived intermediate in the biochemical conversion—one that could be trapped by adding methyl alcohol.

Samuelsson then speculated that LTA might actually be an intermediate in the body's production of one or more of the so-called slow-releasing substances (SRS's) that had been strongly implicated in human allergic hypersensitivity but never isolated, owing to their very low concentrations and high reactivities *in vivo*. Corey's group proceeded to synthesize a group of candidate SRS structures for the SRS's, through carefully controlled reactions of LTA at the oxygen-containing three-membered ring (oxirane) site with derivatives of the amino acid cysteine and with water. Four of these structures, christened leukotrienes B-E, were found to reproduce SRS biological activity.

Corey's syntheses of the leukotrienes were notable for their control of the geometric identity or configuration of the oxirane and double-bond structural features. Proper configurations are essential to the compounds' biological activity. This was established by the further preparation of several analogs or isomers of altered geometry; these proved ineffectual in producing an allergic reaction.

The preparative accessibility of the

Elias J. Corey. The Harvard chemist and his coworkers have found that five leukotrienes (long-chain compounds produced in white blood cells) are key factors in the human immune system.

leukotrienes has opened a door to the study of asthma, anaphylactic shock (sometimes quickly fatal), and other immune disorders. Rapid growth in understanding immune pathology at the molecular level can now be anticipated, and there is a realistic hope that the treatment and perhaps prevention of such diseases will be correspondingly advanced. The contributions of Corey and other synthetic organic chemists to this field will continue; there is a bright prospect that structural analogs of the natural leukotrienes can now be prepared. Those analogs may regulate the abnormal body's response to immune challenges within normal limits.

Materials Research

Materials research, a field of great diversity, is concerned with the fundamental science underlying the preparation, characterization, and use of materials. It spans the range from theoretical physics to materials engineering, from the study of simple atomic arrangements to the design of complex metal alloys, from temperatures approaching absolute zero to those near 3000°K. Materials investigated include solids, glasses, and liquids—more specifically, metallic alloys, liquid crystals, ionic crystals, semiconductors, organic polymers, and many composite and polyphase mixtures. Properties of interest include electronic, optical, magnetic, and mechanical behavior; crystal structure and bonding; phase stability; reactivity; and thermodynamics.

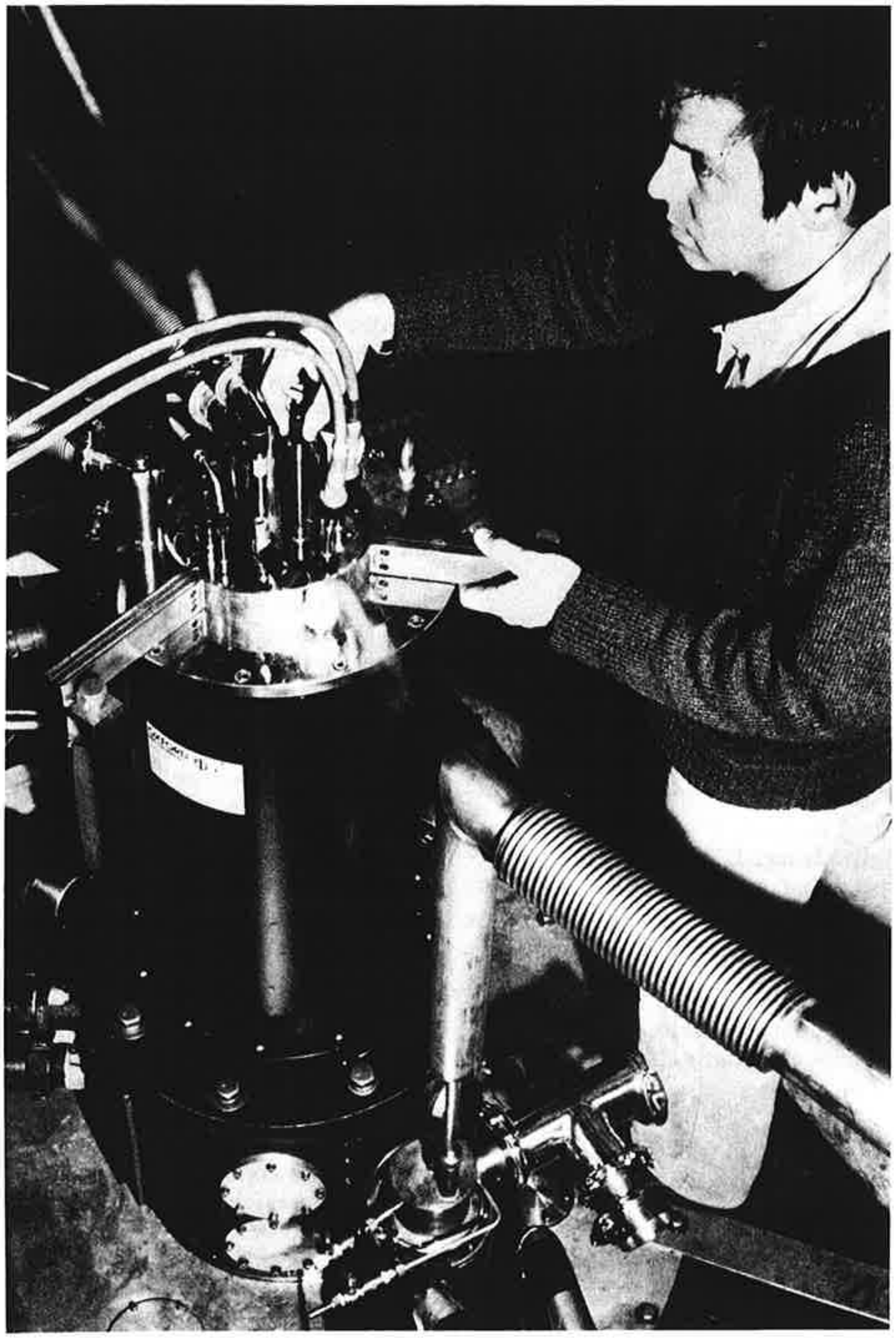
Because of this diversity, materials research relies heavily on, and profits from, interactions among different disciplines: physics, chemistry, metallurgy, ceramics, polymer science, and engineering (chemical, mechanical, and electrical). Materials research has also become an equipment-intensive activity, requiring sophisticated instrumentation.

NSF fosters materials research through a variety of funding modes. These include regular project support in the areas mentioned above; funding to acquire and develop sophisticated instrumentation; grants to 14 universities for materials research laboratories; and national user facilities at six sites around the country.*

Key advances in materials research can be tied to recent developments in the fabrication of novel materials, plus the availability of new analytical techniques. First, the ability to tailor materials systems with precise control over geometry, size and shape, and composition down to the atomic level has resulted in new, ideal materials in which unexpected physical phenomena are observed. For example, some remarkable discoveries of electron behavior would not have been possible without new and advanced techniques in the area of thin-film growth. Daniel C. Tsui of Princeton University and Horst L. Stormer and Arthur C. Gossard of Bell Laboratories have made measurements of conductivity due to electrons confined to two-dimensional layers at very low temperatures and in very high magnetic fields. These measurements have shown that the conductivity becomes quantized, or restricted to discrete values, under these extreme conditions.

Second, researchers are giving more attention to the complex materials systems used in advanced electronic devices. There are new discoveries in the areas of crystal structure and stability of interfaces between the radically dissimilar materials used in these devices. The effects of chemical reactions, structural defects, and other

*Cornell High Energy Synchrotron Source and the Synchrotron Radiation Center at Wisconsin; the National Magnet Laboratory at MIT; the Center for Small-Angle Scattering Research at Oak Ridge National Laboratory; the Center for High Resolution Electron Microscopy at Arizona State; and the Surface Science Center at Montana State.



Magnet lab. An ultra-low-temperature refrigerator is shown mounted in the bore of the high-field hybrid magnet at MIT's Francis Bitter National Magnet Laboratory, a national user facility supported by NSF. Also shown is a visiting scientist from Finland, who is one of a group of experimentalists using the apparatus to study the Quantum Hall Effect.

factors on electronic behavior are under study at many universities. The rich array of possible new materials is attracting many researchers to this burgeoning field, a development that should contribute to the future reliability of electronic devices.

Third, scientists are developing and refining sophisticated experimental techniques to study the structure and properties of materials under unusual conditions. Investigation into theories of phase transitions in two dimensions have benefited from the availability of advanced facilities. For example, Robert Birgeneau of MIT studied the arrangement of krypton atoms adsorbed on graphite as a function of temperature and pressure. Working at the Stanford Synchrotron Radiation Laboratory, he discovered that cooling at higher temperatures produces the predicted commensurate solid, but an anomalous liquid phase appears at lower temperatures. The notion that melting occurs on cooling obviously tests modern theories of phase transitions.

Fourth, powerful new computing tools are becoming available for theoretical analysis and modeling. These tools extend the complexity and scope of electronic structure calculations; they permit difficult problems to be tackled with such methods as many-body theory, Monte Carlo simulations, and renormalization group techniques. As a result, there are some interesting new connections between seemingly disparate physical phenomena. An example is the numerical simulation of microscopic quantum systems by Douglas Scalapino of the University of California at Santa Barbara; his work gives impetus to the design of new chemical structures. Other theoreticians are developing ways to deal with a variety of random systems such as the structure of glasses, the electronic states of amorphous semiconductors, and unusual phase transitions in polymers.

Underlying each of these developments is the interplay between materials synthesis and theoretical analysis. Close interaction between experimentalists and theoreticians is an essential feature of major advances. Furthermore, the developments taking place in research involving thin films and interfaces complement new discoveries in bulk materials and lead to more understanding of their mechanical, structural, electronic, optical, and magnetic properties.

Electron Tunneling

Quantum mechanics predicts that electrons can tunnel from one metal to another metal separated from the first by a thin (less than 100 angstroms) insulating barrier. Scientists have long recognized that the current-voltage (CV) characteristics are critically dependent on whether the metals are normal or superconductors and on the properties of the barrier. For normal conductors, the CV characteristic shows subtle changes reflecting vibrations associated with surface-adsorbed molecules. This tunneling spectroscopy has furthered our understanding of such activities as physisorption, chemisorption, and corrosion.

For superconductors, the CV characteristic changes drastically, reflecting the radically different density of electron states. This has led not only to a vastly improved understanding of superconductivity but also to a great variety of extremely sensitive detectors and very fast computer elements.

One of the major drawbacks of earlier tunnel-junction research was the fact that the barrier had to be a rigid oxide insulating layer, rather than a simple vacuum gap, to avoid problems with mechanical vibrations. Recent technical advances have overcome this drawback:

- In 1983 Calvin Quate, of the Center for Materials Research at Stanford University, built a vacuum tunneling microscope that can operate at cryogenic temperatures and permits study of the electron motion at the surface of superconductors. This microscope was based on the design of four researchers at IBM Zurich Research Laboratory (G. Bining, H. Rohrer, C. Gerber, and E. Weibel).
- Paul Hansma, at the University of California at Santa Barbara, succeeded in fabricating the first squeezable tunnel junctions. Their design provides mechanical flexibility to control the current in vacuum tunneling and will enable the study of superconductivity and surface phenomena without the presence of a perturbing oxide barrier. Robert Silsbee of Cornell developed a capacitive coupling technique to explore the properties of tunneling electrons between small metal particles.

There is considerable experimental and theoretical interest in these developments. They hold promise for new avenues of research in areas that include not only superconductivity but microscopy of adsorbed molecules, crystal growth, and the general interaction of low-energy electrons with matter.

Inside the Spinodal

Many years ago, physicist J. Willard Gibbs distinguished between two kinds of phase transformations in physical systems: those initiated by composition fluctuations that are large in degree and small in spatial extent (classical nucleation) and those small in degree and large in extent (spinodal decomposition). In many alloy systems, at a given composition the homogeneous solid solution is thermodynamically less stable than solutions with either slightly higher or slightly lower solute concentrations. Under these circumstances, the solid may decompose into two components having the same crystal structure but different lattice parameters and compositions.

This spinodal decomposition can produce modulated microstructures on a very fine scale and is of considerable practical as well as scientific interest. Renewed research excitement in this field has come from theoreticians interacting with experimentalists using advanced instrumentation.

Lyle Schwartz of Northwestern University has investigated the structure and strength of the iron-chromium system. He used small-angle neutron scattering measurements (available at the National Center for Small-Angle Scattering Research) and Mossbauer spectroscopy to determine the extent of composition fluctuations. Schwartz found characteristic lengths comparable to those observed directly by Sidney Brenner of U.S. Steel Corporation and William Soffa of the University of Pittsburgh. Brenner and Soffa were using their field ion microscope while working on an industry-university cooperative research project. But the increase in mechanical strength is two orders of magnitude greater than a value predicted by John Cahn at the National Bureau of Standards and James Langer at the University of California, Santa Barbara.

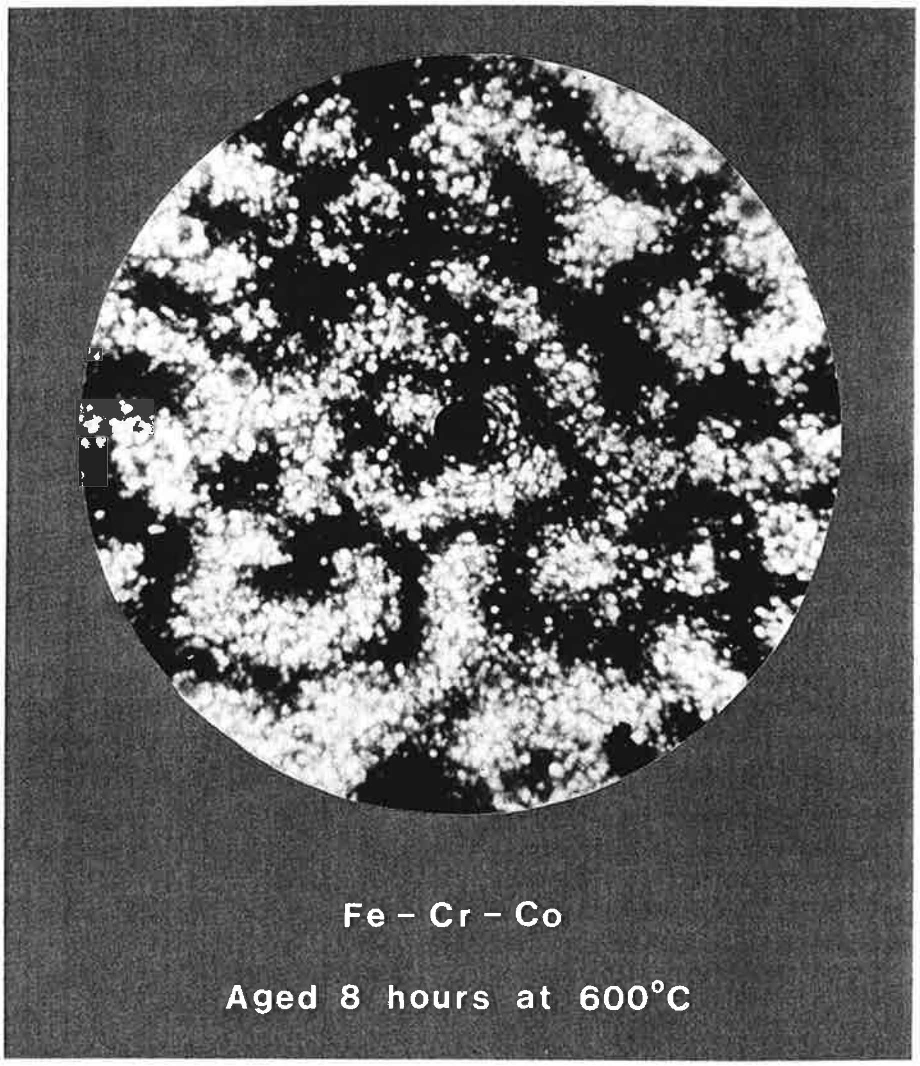
G. B. Stephenson and A. L. Bienenstock of Stanford University, along with Wolfgang Haller of the National Bureau of Standards, used the scattering of high-intensity X-ray synchrotron radiation for their studies of spinodal decomposition in a barium silicate glass. They too found decomposition characteristics different from those predicted by existing theories. Stephenson, an NSF postdoctoral fellow at Rice University at this writing, extended the theory to include the strain energy between glasses of different composition. By assuming stress relief through viscous flow, he got better agreement with the experimental data.

This research has stimulated a thorough reevaluation of the theory of structure, strength, and other properties of spinodal alloys. Still more exploitation of the extraordinary properties of these materials is expected to follow from better and more detailed understanding.

Interfaces in Electronic Materials

Since the purification and growth of high-quality silicon crystals made the first transistors possible, materials science has played a key role in the evolution of semiconductor technology. Today this participation is even more critical as high-speed circuitry and Very-Large-Scale integration demand the use of new semiconductor compounds, new processing techniques of greater precision, and new materials systems for insulation and interconnection.

The interfaces between different materials are extremely important in device performance; they influence such factors as contact resistance and electrical breakdown, for example. Processing history, heating times, and temperature all cause changes in the structure of the interface and directly influence a device's operational characteristics. Materials scientists, phys-



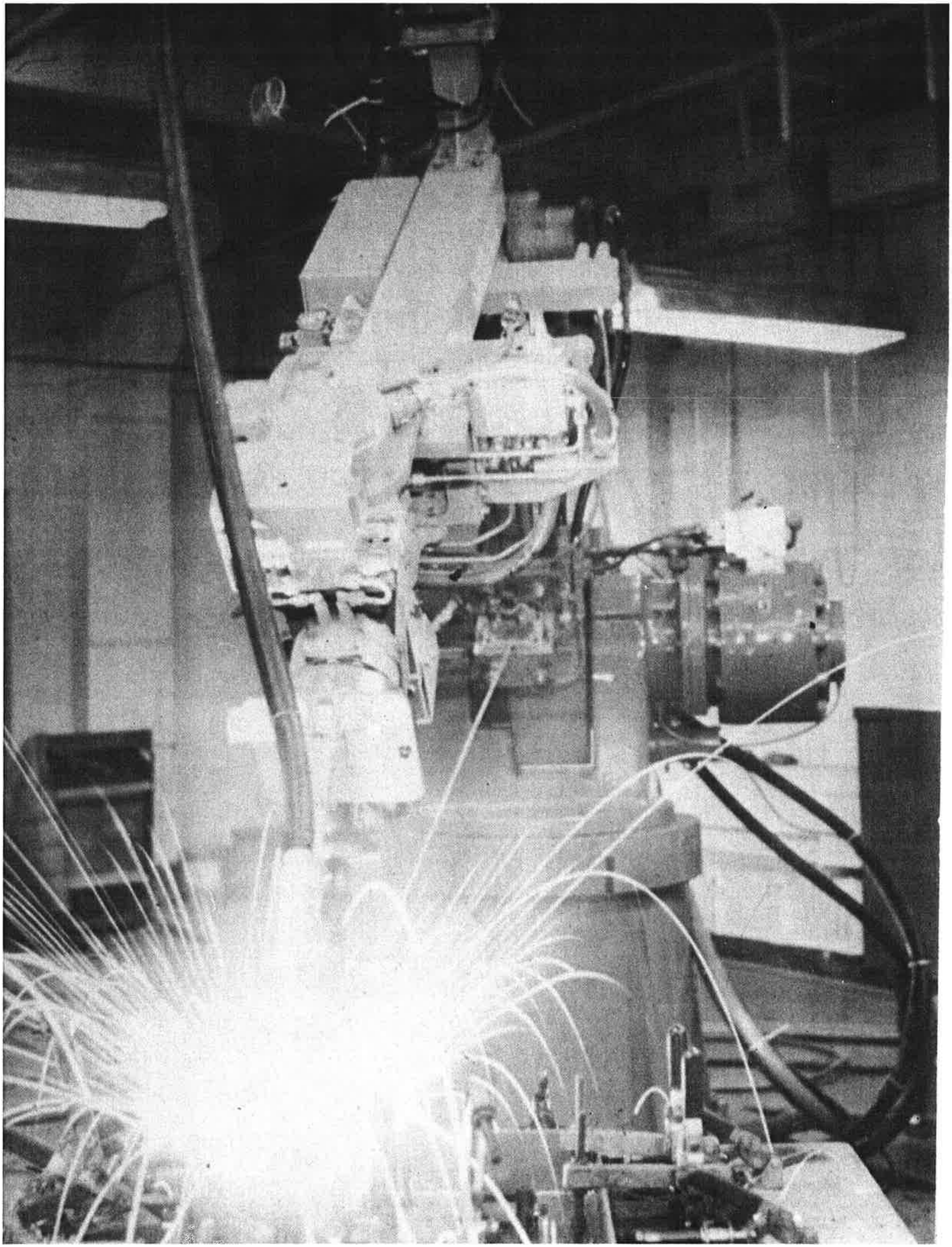
Atomic segregation and magnetic behavior. This micrograph shows the distribution of iron atoms (white dots) during the spinodal decomposition of an iron-chromium cobalt alloy. After eight hours at 600 degrees centigrade, just below the spinodal decomposition temperature, the alloy develops iron-rich fluctuations approximately 10 to 20 atoms across. The difficulty of reversing the direction of magnetization within these islands is due to their small size, elongated shape, and isolation from one another by chromium-cobalt rich veins. This produces a significant increase in the magnetic hardness of these alloys. A university-industry cooperative research project between the University of Pittsburgh and U.S. Steel, this research has showed much about the subtle effects of microstructure on an atomic scale on the magnetic behavior of materials.

icists, and electrical engineers are working cooperatively on these problems, taking advantage of many new analytical techniques.

One advance that has permitted measurement of the atomic structure at the interface is the ability to prepare systems with extremely thin cross-sections, so that thin films and interfaces can be viewed "edge-on" in an electron microscope. Robert Sinclair of Stanford University developed this technique to study the silicon-silica interface in thermally oxidized single-crystal silicon and found that the interface remained atomically flat. In another application, John Spence of Arizona State University, working with colleagues at Oxford University in England, determined atomic positions at the smooth silicon-nickel silicide interface.

Smooth, atomically flat interfaces did not prevail for gold-gallium arsenide interfaces studied by Lloyd Bauer and Arthur Milnes at Carnegie-Mellon University. Instead they found that chemical reactions proceeded in a highly heterogeneous manner and the interface became microscopically pitted by those reactions.

The discoveries of these researchers show the importance of detailed knowledge about microstructure and defect structure in order to appreciate the electrical and electro-optic behavior of semiconductor materials. That knowledge leads to better performance in electronic devices.



Scientific, Technological, and International Affairs

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Through these programs the Foundation's work reaches many potential users of research results across the United States—among them representatives of state and local governments, small business and industrial researchers and planners, academic scientists, groups of private citizens, and decision makers in federal agencies, Congress, and the White House. These activities also link American scientists and engineers with colleagues doing research in foreign countries. Overall program goals are:

- To carry out research that cuts across scientific disciplines and strengthens the scientific and technological (S&T) enterprise, both nationally and internationally.
- To collect and analyze data on the national S&T enterprise and to study key public-policy issues in science and technology.
- To serve NSF and other government decision makers who face complex problems dealing with science and technology and must deal with the impact of those problems on the future of our country.

Industrial Science and Technological Innovation

These NSF programs stimulate private investment in research that can lead to new technology. They encourage collaboration between academic and industrial scientists, support high-risk research by small S&T firms,

Table 5
Scientific, Technological, and International Affairs
Fiscal Years 1982 and 1983
(Dollars in Millions)

	Fiscal Year 1982		Fiscal Year 1983	
	Number of Awards	Amount	Number of Awards	Amount
Industrial S & T Innovation	210	$12.90	50	$14.51
Internat'l Coop. Sci.	363	11.58	86	4.65
Policy Research and Analysis	81	3.90	93	4.27
Science Resources Studies	41	3.14	49	3.65
Research Initiation and Improvement	101	8.80	131	11.77
Subtotal	796	$40.32	409	$38.85
Adjustment to Internat'l Awards	--	--	--	5.28*
Total	**796**	**$40.32**	**409**	**$44.13**

*Actual obligations incurred under the Scientific, Technological, and International Affairs activity.

SOURCE: Fiscal Years 1984 and 1985 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Research Initiation and Improvement

The nation's science and engineering enterprise faces many problems that cut across disciplines. The Foundation has responded with programs designed to:

- Increase opportunities for women, minority, and physically handicapped researchers, and for faculty from undergraduate institutions, to participate more fully in science and engineering fields.
- Foster the development and use of scientific and technical resources that meet the needs of state and local governments.
- Help identify ethical and value issues that arise in the conduct of science and technology and improve our understanding of these issues.

Some of these activities are described below.

Research Participation in Undergraduate Institutions

Lack of modern instrumentation, including relatively low-cost standard equipment, often seriously handicaps faculty in academic institutions primarily engaged in undergraduate education. Not only do the quantity and quality of research suffer, but undergraduate students headed toward careers in the sciences and engineering may get inadequate training.

Recognizing this need, in 1979 NSF began to help two- and four-year colleges acquire research instrumentation. In 1983, the Foundation made 85 awards for equipment, with the average amount being $23,000 and the maximum $35,000. Although grants for chemistry and biology instruments predominated, other NSF-supported disciplines were also represented:

- *Charles Borders*, a chemist at the College of Wooster, and four of his students have used NSF support to purchase an amino acid analyzer; with it they are studying the development of new reagents for the chemical modification of proteins. This instrument provides the sensitivity and reproducibility needed to do their experiments.
- *Jay Pasachoff* at the Williams College Hopkins Observatory studied the 1983 total solar eclipse in Java with a heliostat system funded by NSF. His research focused on why the solar corona heat reached approximately two million degrees. The equipment can also be used to study volcanic eruptions, another "natural experiment" astronomers can exploit to increase their understanding of astronomical and physical phenomena.
- *Margaret Merritt*, a chemist at Wellesley College, returned to an academic career after 10 years at an industrial laboratory. Using a liquid chromatography system bought with NSF funds, she is pursuing several difficult investigations that may yield both general and clinical biomedical applications of phospholipids chemistry.
- *Jon Keeley*, Occidental College, is using two biological incubators to study seed germination in common chaparral herbs. He is particularly interested in differing germination and colonization rates before and after fire in an area. His work to date documents the influence of several environmental factors on seed germination.

Because of the key role that undergraduate institutions play in training for research careers, the Foundation in 1983 set up a new and expanded program to support research at these institutions. The new Research in Undergraduate Institutions (RUI) program, which incorporates the former support for research instrumentation in two- and four-year colleges, includes instrumentation awards as described above, along with other research support. NSF will announce details of the new program during fiscal year 1984.

Research Participation by Women

NSF completed the second full year of the Visiting Professorships for Women (VPW) program in 1983. This is an effort to encourage women to develop research careers and thereby strengthen the nation's science and engineering enterprise. Awards mean greater visibility for successful female scientists and engineers, who are able to do high-level research at major institutions. They also serve as models for future women researchers and the community at large through teaching and counseling.

In 1983, NSF made 32 of these awards, averaging $61,000 each. As their host institutions, the awardees selected a cross-section of universities throughout the United States. Examples:

- *Melanie Lenard*, a computer scientist from Boston University, will spend a year at UCLA. There she will design and develop key software tools for those who use computers to help them make decisions. Lenard will also teach an introductory course in information systems and present seminars on her research results and on career opportunities for women in computer and information science.
- *Susan J. Kohler*, a chemist at Mt. Holyoke in Massachusetts, will spend a year at the Joint Institution for Laboratory Astrophysics, University of Colorado. There she will do research in laser-induced chemistry, teach a graduate course in nuclear magnetic resonance (NMR) spectroscopy, and lecture on her research in NMR spectroscopy and laser chemistry.
- *Carolyn Ritz-Gold*, a biochemist, will be a visiting professor at San Francisco State University, where she will study the conversion of chemical energy to useful mechanical work in muscle fibers. Her

Caroline Whitbeck. She is a visiting professor at the Center for Policy Alternatives, Massachusetts Institute of Technology. Her research involves factors that influence science and technology decisions. This work is integrally related to Whitbeck's teaching responsibilities in technology and policy courses at MIT.

Susan D. Waaland. At the University of California at Davis, Waaland is studying the cellular parameters that control localized growth in cells of the red alga *Griffithsia pacifica*. She is also a guest lecturer in undergraduate courses in plant physiology and phycology and will teach a course on "Development of Algae and Fungi." Waaland is from the University of Washington.

Laurie L. Brown. Brown is spending a year as visiting professor at the New Mexico Institute of Mining and Technology, where she is investigating recent tectonic rotations in the Rio Grande Rift. She is also teaching a course on paleomagnetism at the Institute. Dr. Brown's home institution is the University of Massachusetts, Amherst.

work may yield new insights into this type of energy conversion. Ritz-Gold will also teach undergraduate biochemistry and work in community programs encouraging talented minority youth to pursue careers in mathematics, science, and engineering.

- *Kristina B. Katsaros*, an atmospheric scientist with the University of Washington, will be a visiting professor at California's Naval Postgraduate School, where she will study vapor and droplet flux between the sea and the atmosphere. Her experimental work is at a field facility on San Nicholas Island off the California coast. Katsaros will also teach a course in radiative transfer in the marine atmospheric boundary layer, and she will hold seminars and colloquia on microwave sensing of the atmosphere and oceans from space.

Research Participation by Minorities

NSF works to increase the number of minority scientists and engineers doing research by providing (1) support for individual minority researchers, and (2) awards to predominantly minority institutions.

Minority Research Initiation (MRI) grants support research by members of ethnic and racial minorities that are underrepresented in science and engineering careers. NSF made 16 MRI grants averaging $125,000 each in fiscal year 1983. For example:

- *Scott W. Williams*, SUNY—Buffalo, will focus on two areas of abstract mathematics: box products and co-absolutes. He will examine covering properties in box products and co-absolutes of linearly ordered spaces and their products.
- *Sigrid McAfee*, Rutgers University, will examine the electrical properties of charge carriers by observing deep electronic levels of certain alloys. She will also develop a computer-controlled data-acquisition system to characterize defect parameters such as concentration, spatial profile, and activation energy.
- *Osvaldo Rosario-Lopez*, University of Puerto Rico—Rio Piedras, will develop techniques to characterize concentrations of organic matter associated with air particulates. The project will advance analytical techniques to explore the organic makeup of air pollutants.

Research Improvement in Minority Institutions (RIMI) grants help to increase the research capabilities of predominantly minority colleges and universities that have graduate science programs or any engineering programs. This kind of support carries out the intent of the President's Executive Order 12320 by helping historically black colleges and universities strengthen their abilities to participate in federally sponsored programs.

The Foundation awarded eight three-year RIMI grants averaging $250,000 each in fiscal year 1983. Examples:

- Investigators at Tuskegee Institute, Alabama, will develop hybridoma monoclonal antibody techniques to produce immortal cells by fusing them with tumor cells and cloning the hybrids. This technology—and the resulting immunological reagents—can benefit immunologists, cell biologists, cytogeneticists, and developmental biologists.
- A project at the University of Puerto Rico—Mayaguez will set up a research instrumentation facility to aid graduate training programs in western Puerto Rico. RIMI support will help the university acquire a Fourier transform

MRI and RIMI participants. Biologist Viola Griego, now at Wichita State University, was aided by NSF's minority research initiation (MRI) program while at Oregon State University. She is shown in front of an Oregon State instrument used to transfer bacterial cultures and viruses so that contamination is avoided. In second photo, two professors and two graduate students at North Carolina A&T State University use their biology department's ecological energetics lab. Equipment for that lab was purchased through a RIMI grant.

infrared spectrophotometer system and a computerized gas chromatograph/mass spectrometer system.

- Work at City College, City University of New York, will strengthen and expand laser spectroscopic techniques and studies of the structure and dynamics of molecules on surfaces.
- A project at North Carolina A&T State University, Greensboro, will focus on research in environmental and plant sciences. One study, for example, will evaluate the effects of food protein content and nonnutritive content on the bioenergetic functions of two freshwater invertebrate herbivores.

Strengthening the Science Resource Base

NSF's Intergovernmental Science and Technology program fosters the development and use of scientific and technical resources that respond to the needs addressed by state and local governments. Current efforts are designed to emphasize the replication of successful institutional arrangements, focus on critical issues of common concern to state and local governments, and strengthen the resource base for scientific and engineering research itself.

Activities supported by this program have created effective information and policy advisory systems at the state and local level. Some of these governments have been helped in organizing their resources to promote R&D-based jobs and economic development. Two examples of projects initially launched with NSF aid:

- *The Governor's Office of Policy and Planning* of the Commonwealth of Pennsylvania made significant progress in revitalizing its scientific and technical programs and creating new ones where needed. The state has expanded and refocused the Pennsylvania Technology Applications Program at Pennsylvania State University. The Ben Franklin Partnership Challenge Grant Program was set up to promote the creation of Advanced Technology Centers throughout the commonwealth, and the Pennsylvania School of the Sciences was established for summer instruction at the high school level.
- *The Indianapolis Center for Advanced Research* (ICFAR) brings together the City of Indianapolis Chamber of Commerce, Purdue University, and Indiana University. NSF seed money of $125,000 allowed ICFAR to embark upon an Energy Conservation/Sludge Incineration project. This initial investment led to a $159,000 research grant from the Environmental Protection Agency resulting in energy savings of $600,000 per year. In addition, the city avoided a $2

million expenditure to improve the incinerator. Replication of the sludge incineration model in other communities throughout the country has produced similar savings.

Ethical Issues and Occupational Hazards

In cooperation with the National Endowment for the Humanities, NSF supports a program to study issues involving ethics and values in science and technology (EVIST). These projects, whose results are widely published, analyze topics of general concern and contribute to informed public and professional discussion. In 1983, NSF made 33 EVIST awards averaging $30,000 each; the National Endowment contributed about 70 percent in additional support to these awards.

EVIST work has begun to make a substantial contribution toward an understanding of ethical issues in managing job hazards. Questions range from the most general to the most specific—for example, is there adequate moral justification to allow different hazard exposures for workers and the general public? What standards should be set to protect those who handle radioactive wastes?

Underlying these questions are value issues. Should we value worker privacy and equal opportunity more highly than protection from risks to health? How can we reconcile employers' duties to preserve equal opportunity and provide a safe workplace if there is evidence that some groups are more susceptible than others to toxic effects? What weight should we give to the evidence? How can we best evaluate differing scientific opinions?

These current EVIST projects concentrate on such questions:

- Groups at the Hastings Institute in New York, under the direction of Willard Gaylin, and at Boston University, under Michael Baram, are studying ethical issues arising from occupational health technologies such as biological monitoring to determine levels of lead in the blood.
- Dorothy Nelkin's group at Cornell University is looking at worker views on risks in the workplace.
- Vicente Navarro of the Johns Hopkins School of Hygiene and Public Health is comparing risk management in the United States, Canada, Great Britain, Sweden, Italy, and Spain.
- A team led by Nicholas Ashford at the Massachusetts Institute of Technology is making a historical and ethical assessment of various attempts to control health and safety hazards.
- Roger Kasperson of Clark University is leading a team to study the ethical issues raised by different levels of protection for the general public and for workers facing occupational hazards.

Early results from these studies have been circulated widely in professional, business, occupational health, and environmental journals, as well as in testimony before congressional committees and at professional meetings. The Foundation also supported a forum in April 1983, at the Hastings Institute in New York; there EVIST researchers discussed their work with representatives from labor, industry, government, and public groups. A report on this meeting is available from the Foundation.

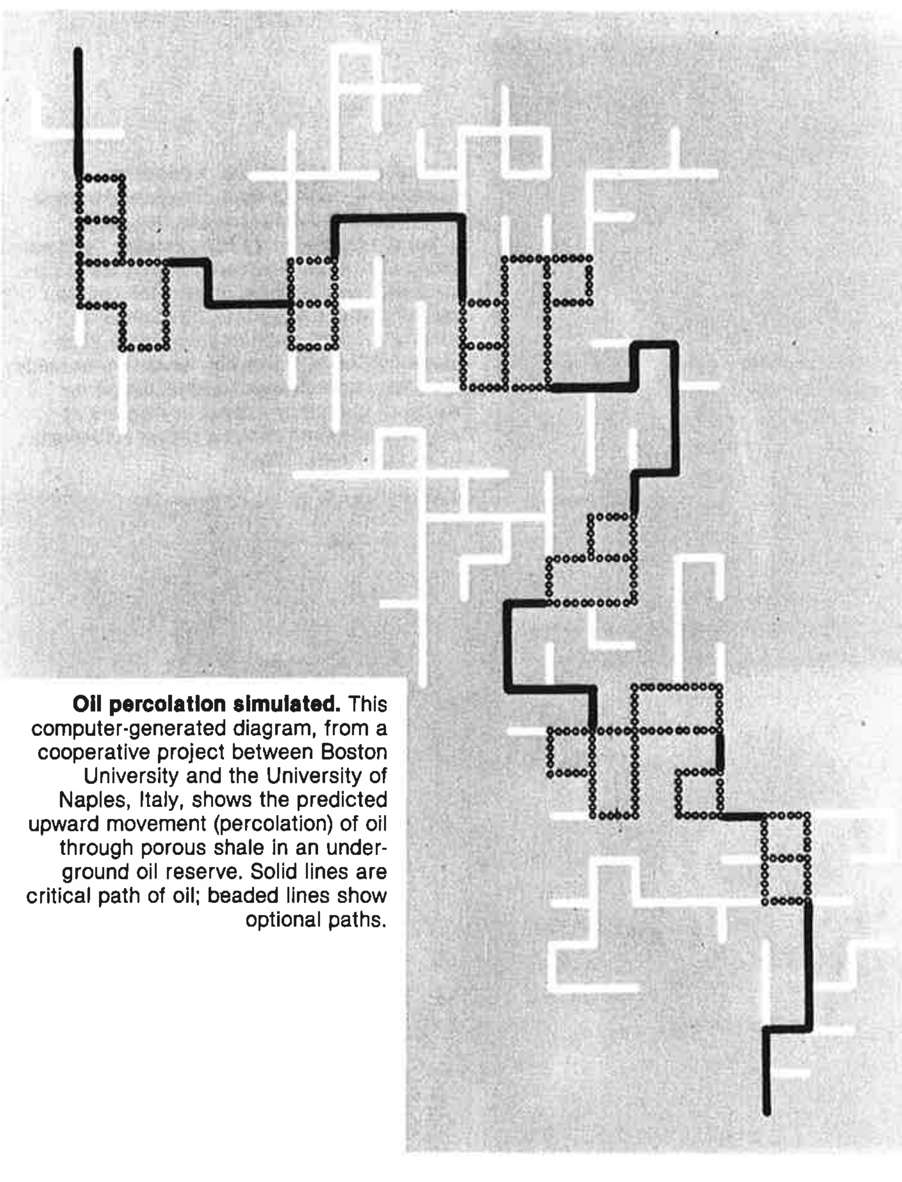
Risk assessment. With a network of international collaborators, physician Vicente Navarro, at the Johns Hopkins University School of Hygiene and Public Health, has been looking at risk management for workers in six countries. Second photo is from the United Brotherhood of Carpenters and Joiners of America; workers such as these were interviewed by Cornell's Dorothy Nelkin in her study on worker views of occupational dangers. Results of that study appear in *Workers at Risk*, by Nelkin and Michael Brown (University of Chicago Press, 1984).

International Scientific Cooperative Activities

Under bilateral agreements with other countries, the Foundation manages some 30 cross-disciplinary programs for cooperation in science and engineering. The United States and the other country share the costs, with the exception of India and Pakistan, where U.S.-owned special foreign currency pays some costs of the partner country.

NSF's bilateral partners fall into three groups: (1) the industrial, market-economy countries of Western Europe, East Asia, and Oceania; (2) China and the centrally controlled, industrial areas of Eastern Europe; and (3) the less industrial countries of Africa, Asia, and Latin America.

Governments can promote the international exchange of scientific knowledge in several ways. Formal arrangements often ease access by scientists from one country to the national laboratories of another. Since building strong personal ties among tomorrow's scientists is important to all nations, governments can help today's younger scientists overcome the difficulties of spending substantial time in research and study abroad. The great expense of some kinds of research equipment and facilities has also led countries to share their use and costs.



Oil percolation simulated. This computer-generated diagram, from a cooperative project between Boston University and the University of Naples, Italy, shows the predicted upward movement (percolation) of oil through porous shale in an underground oil reserve. Solid lines are critical path of oil; beaded lines show optional paths.

Building Models

Scientists and engineers build models—often in the form of mathematical equations—to mirror the real world. Probably the most familiar mathematical models include insurance actuarial tables and the models that fuel oil companies use to predict when customers' oil tanks need filling. Other models are enormously useful in science, industry, and public policy.

In recent years, theoretical models have become much more elaborate, predicting complex changes in human population, food supply, and climate; the behavior of airplanes in flight; or phenomena affecting energy, the environment, health, or industrial production. The successful use of such complex models requires high-speed computers.

At some stage, the scientist who develops a model must be able to test its accuracy, usually in a laboratory where direct measurements can verify its predictions. Sometimes a model developed in another part of the world can be checked in the United States. More often, models are developed here because of advanced U.S. software capabilities and verified elsewhere, since the United States sometimes lacks suitable laboratory facilities, field conditions, or skill in applications. Some examples of NSF-supported model building through international scientific cooperation:

- Computer scientists at the University of California, Berkeley, developed traffic models to understand and predict the flow of information in cable networks. To get access to the data they needed to verify and refine these models, the scientists cooperated with colleagues at the University of Bologna, Italy. Both countries gained valuable information from this joint effort, and the results should be useful to communications system designers everywhere.

- The Technical University of Budapest, Hungary, has much experience with devices for the computerized control of industrial processes. Scientists there worked with colleagues at the University of Minnesota who design mathematical models of control devices. Together, they narrowed the gap between theory and practice in microprocessor control—a potential boon to manufacturing industries in both countries.
- British architects have extensive practical knowledge of applied building design; their U.S. counterparts have expertise in modeling, simulation, information, and management systems. A valuable exchange of all this knowledge came out of a workshop organized by the Georgia Institute of Technology and the University of Reading, United Kingdom. Both sides got more understanding of how to use computerized techniques to design better buildings.
- Map makers of Australia and the United States held a workshop on computer-based geographic information systems that handle the voluminous data needed for policy decisions on the environment, natural resources, urban development, transportation, and human services. Those attending the workshop concluded that greater use of computer graphics and automated cartography should be stressed as a first effort in bringing theory and practice together.
- Water, that common substance of such vital importance, still presents scientific riddles after centuries of intensive study. Scientists at the University of Puerto Rico at Rio Piedras and the Argentine Institute for Liquid Physics and Biological Systems built computerized models of both rigid and flexible water molecules. The models successfully predicted many properties of solutions containing sodium and calcium ions, giving us a better understanding of biological and biochemical processes.

Policy Research and Analysis

The Foundation supports research and analysis on public-policy issues that have science and technology content, and it appraises the impact of research on industrial development and the general welfare. NSF is thus a key source of knowledge and information for decision makers in federal agencies and others who set policy in this country.

Areas of study include the contribution and impact of science and technology on the economy and society; patterns of international competitiveness, technology transfer, and international monetary transactions; ways to assess and manage technological risks; and relationships among S&T policies and environmental, safety, and natural resources issues. Two examples follow.

Alternatives to Regulation

An NSF-supported study by Michael S. Baram discusses ways to cope with risk other than through regulation. Historically, our society has dealt with risk to health, safety, and the environment through various management approaches as well as government regulation. For example, common law or class actions have focused on a variety of environmental risks. Other alternatives, such as self-regulation or compensatory remedies, are more limited in scope. The latter include workers' compensation and the federal insurance program for extraordinary nuclear occurrences.

Baram's study explains why nonregulatory options succeed in some respects and fail in others and how they can become more effective. Under current federal policy to reduce regulatory burdens, an agency would regulate only after full consideration of other options. Baram explores both new options and new roles for the regulator. He identifies many problems in the area of regulatory reform and stresses the need for a more coherent approach to deal with risk.

Central to any federal move toward regulation alternatives is the extent to which an agency, constrained by specific federal statutes, can legally use those alternatives. Before Baram's study, only a few court decisions had dealt with this issue.

Baram found that deliberate attempts by agencies to eschew regulation and rely on alternatives are likely to be challenged in the courts. The resulting cases raise questions different from those in which an agency is challenged because it has simply failed (or decided not) to take regulatory action. Limited case law indicates that an agency's deliberate use of an alternative to regulation may be construed by a court as the functional equivalent of rule making; it is thereby subject to certain requirements under the Administrative Procedures Act. Finally, the legal issue of most importance is whether the agency has discretion not to regulate but to rely on alternatives instead.

In choosing alternatives, some of the criteria to be considered are:

- Efficacy in reducing existing risks and preventing new ones.
- Cost and time effectiveness.
- Special resources (such as experts and other trained personnel and funds) needed to deploy the alternative.
- Satisfaction of those affected.
- Special limitations and effects of the alternative considered.
- Implications of using the alternative again.

These are some interim results from an ongoing project. Baram's final report is expected to extend our knowledge and understanding of this research topic.

Technology and International Competition

NSF policy studies have assessed the influence of technology on the international competitive status of several American industries: automobiles, machine tools, pharmaceuticals, and the fibers, textiles, and apparel complex. These studies show that slow technological change has contributed much to the decline in U.S. international competitiveness. Both government measures and business practices have held up needed changes. For example:

Machine tools. Failure to keep pace with technological change, especially in computerized manufacturing, and continuing reluctance to exploit international markets fully are the main reasons for this industry's decline on both domestic and international fronts.

Pharmaceuticals. Research and development, the foundation of competition in this industry, have not kept up with the great expansion of research by foreign-owned firms.

Automobiles. The Japanese advantage over U.S. firms, whose market share is declining, can be attributed more to Japanese willingness to adopt new management practices than to superiority in equipment technology. Also, the greater competitiveness of Japanese vehicle design than that of standard American cars since World War II arises from the perfection of radically different product technology.

Fibers, textiles, and apparel. This industry could increase its international competitiveness, and some segments are benefiting from applied technology. Still, the apparel industry lags behind some foreign competitors, and there are few signs that applied technology will change much in the next decade.

NSF also supports research on U.S. trade policy. This includes studies of recent efforts to limit imports of certain products because U.S. firms cannot compete with foreign manufacturers. The research suggests that such trade policies are not particularly cost effective and in fact may benefit foreign firms. For example, a look at the voluntary export restraints on autos found about a 3 percent rise in import prices but no increase in quality. Moreover, only 5,000 to 11,000 out of some 200,000 auto workers on indefinite layoff got jobs because of the restraints.

Other NSF-backed studies show that U.S. industrial sectors with rapid export growth in one period do not show such growth at other times. Nor is early and slow export growth necessarily the "kiss of death" later. Rapid growth may come from temporary advantages in technology or early entry into an imperfectly competitive market. Also, most of the recent loss of U.S. output in traditional manufacturing sectors (auto, steel) has been due to contraction of domestic markets, not to imports.

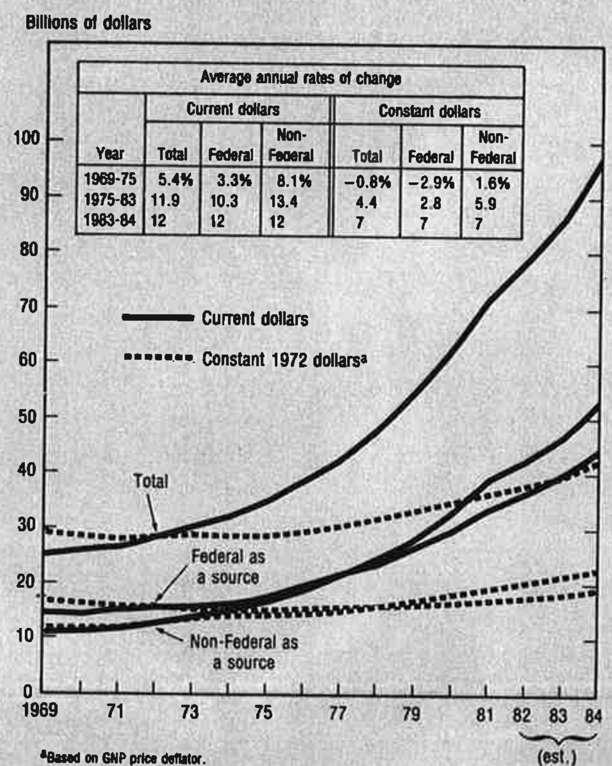
Science Resources Studies

Society and government cannot function effectively without reliable information. The Foundation performs an indispensable service through surveys and analyses of the nation's scientific and technical resources. Publication of the information collected and analyzed helps officials in federal, state, and local governments, in educational institutions, and in industry as they develop science policy and allocate science resources.

During 1983 the Foundation, in some 30 reports and summaries, continued its comprehensive national overviews of personnel and the funding of activities. Some reports of special interest:

- *Science Indicators—1982*, the 15th annual report of the National Science Board, focuses on key policy questions, presents quantitative indicators of scientific and technological activity, and describes advances in several areas. These include prime numbers, plant diseases, cognitive development in early childhood, and ocean floor exploration.
- *National Patterns of Science and Technology Resources*, the fourth volume of a series, notes that total U.S. expenditures for research and development (R&D) should increase in 1984 to $97 billion. R&D outlays have gone up in real constant-dollar terms each year since 1975, averaging about 4 percent annually through 1983. The real growth from 1983 to 1984 should be 7 percent, well above this average. National R&D expenditures as a share of the gross national product went up slightly each year between 1977 and 1983, from 2.2 to 2.6 percent, compared with a peak of 3.0 percent in 1964. In 1984 the ratio is expected to reach 2.7 percent. These increases reflect 1984 federal budget emphases and the expectation of better economic conditions, which should improve the climate for corporate investment in future markets.
- *Science and Engineering Personnel—A National Overview* is a summary of current supply and use patterns for all U.S. scientists and engineers. It also looks at the dynamics of the labor market for this critical population.

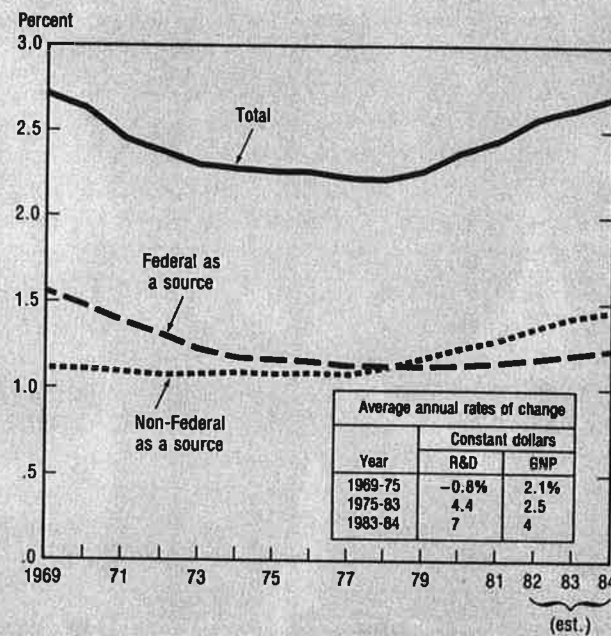
Chart 1. National R&D expenditures



Average annual rates of change						
	Current dollars			Constant dollars		
Year	Total	Federal	Non-Federal	Total	Federal	Non-Federal
1969-75	5.4%	3.3%	8.1%	−0.8%	−2.9%	1.6%
1975-83	11.9	10.3	13.4	4.4	2.8	5.9
1983-84	12	12	12	7	7	7

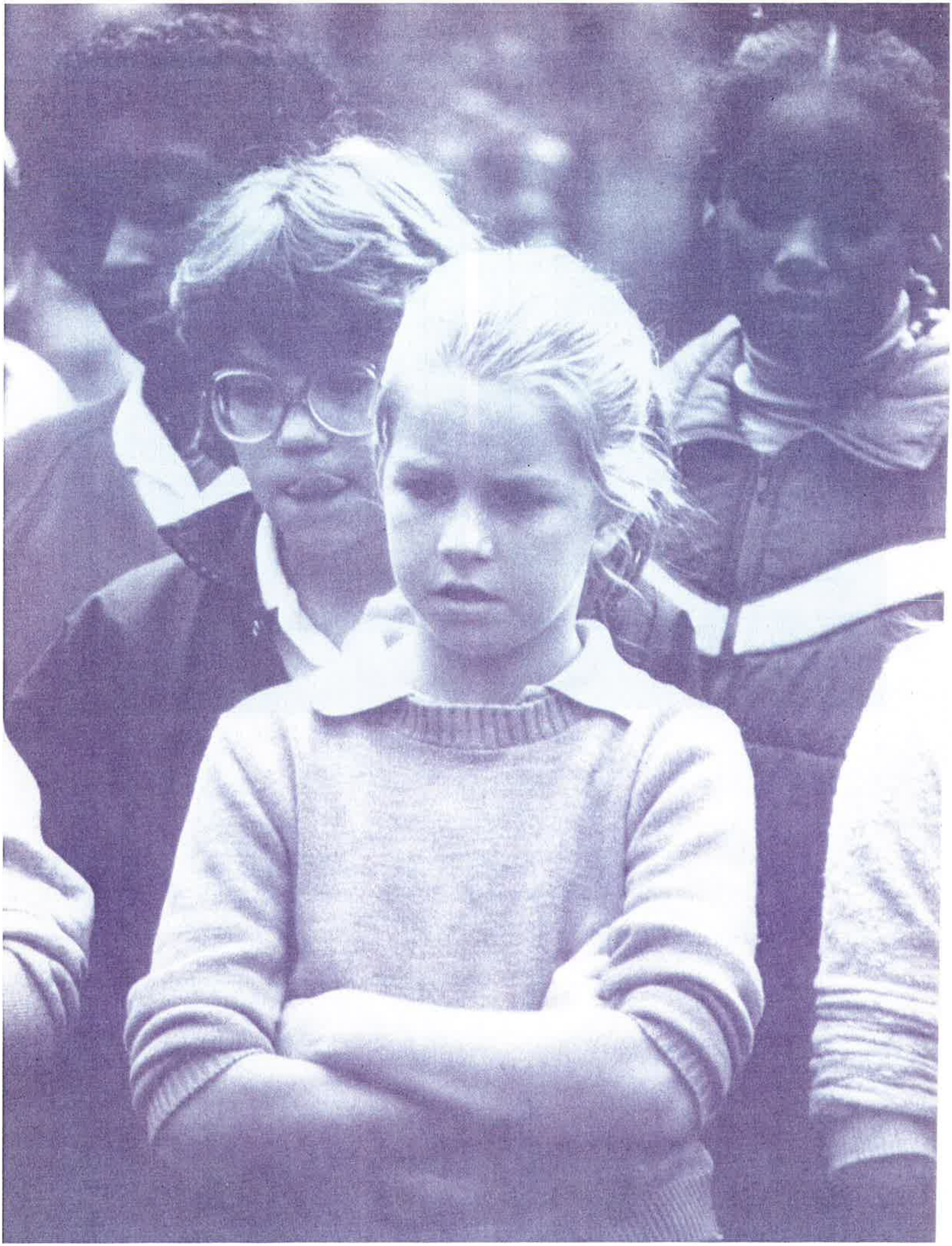
[a]Based on GNP price deflator.
SOURCE: National Science Foundation

Chart 2. R&D/GNP



Average annual rates of change		
	Constant dollars	
Year	R&D	GNP
1969-75	−0.8%	2.1%
1975-83	4.4	2.5
1983-84	7	4

SOURCE: National Science Foundation and Department of Commerce.



Scientific and Engineering Personnel and Education

6

In this age of rapid technological advance, America's industrial growth, economic well-being, and national security depend more and more on the availability of skilled technical personnel at all levels. Responding to this need, NSF works toward greater scientific literacy and a strong science and engineering work force.

In FY 1983 the Foundation's educational efforts focused on support to graduate students and new programs to enhance the status of teachers and provide improved materials at the precollege level. In addition, the National Science Board's Commission on Precollege Education in Mathematics, Science, and Technology ended its 18-month investigation and published a final report on September 13, 1983.

Finally, many education projects continued under earlier NSF funding. Examples:

- Grants to colleges and universities to upgrade science education techniques, mostly at the precollege and undergraduate levels.
- Production of the "3-2-1 Contact" series by the Children's Television Workshop. Featuring a new cast, a second series of programs began in the fall of 1983. At this writing, "3-2-1" is the second most popular children's program on public TV.

Graduate Fellowships

Since 1952 the Foundation has offered graduate fellowships each year to some of the nation's most promising and talented students. Winners of these fellowships may pursue their studies at any appropriate college or university in the United States or abroad. In recent years there has been an emphasis on awards to minority students, to enhance their opportunities for science and technology careers, and on awards in fields that are critical to the continued health of American science.

In FY 1983, 500 individuals were offered three-year graduate fellowships and 1,113 continued their fellowships from previous years. In the FY 1983 competition, another 1,297 persons received Honorable Mention. This NSF citation serves as a very high endorsement and quite often helps students get support from other sources.

Following are four examples of work by those awarded fellowships in FY 1983:

- *Linda T. Foster*, in computer science at Carnegie-Mellon University, has been working toward a career in artificial intelligence. Her graduate study builds on an undergraduate major in cognitive science.
- *Allan H. Harvey*, in chemical engineering at the University of California, Berkeley, prepares for a research career in industry. He

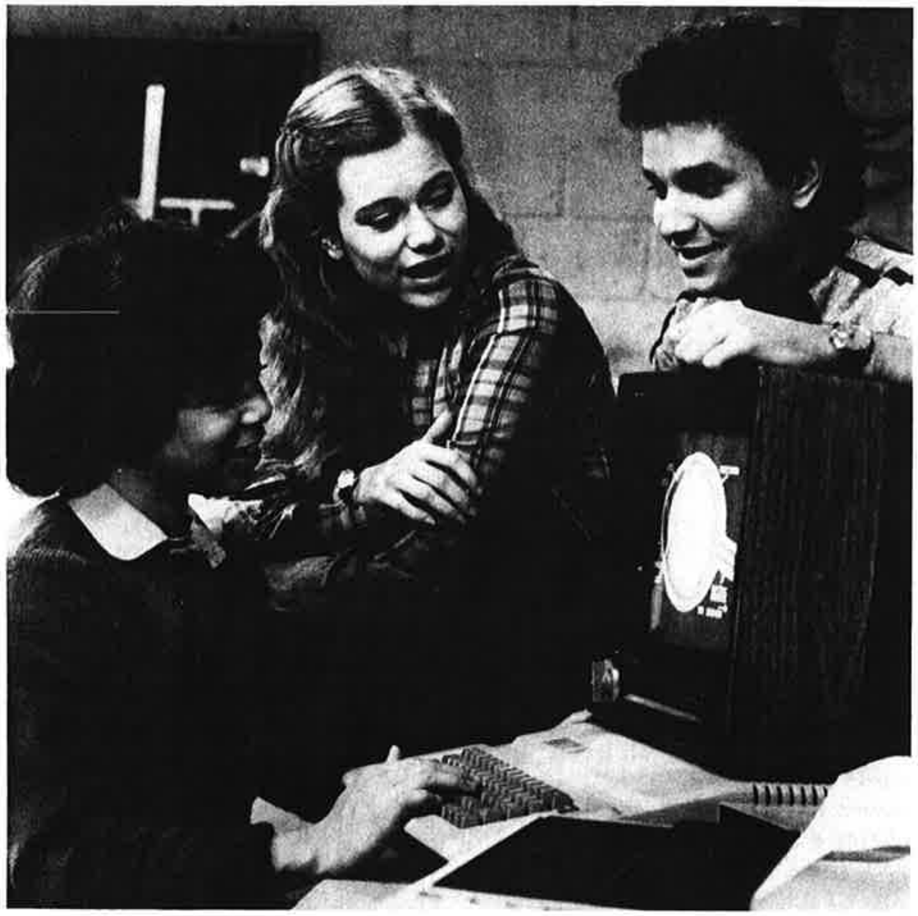
Table 6
Scientific and Engineering Personnel and Education
Fiscal Year 1983
(Dollars in Millions)

	Fiscal Year 1983	
	Number of Awards	Amount
Graduate Research Fellowships	1,390	$14.98
Precollege Sci. and Math Education	106	1.11
Total	1,496	$16.09

SOURCE: Fiscal Year 1985 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

"3-2-1 Contact." Photo at right shows the hosts for this popular TV series — Judy Leak, Kelly Pino, and Frank Gomez — learning about computer graphics. Above, Judy studies sound frequencies.

Pedro E. Hernandez. A second-year Graduate Fellow in organic chemistry at the University of Pennsylvania, he is doing research on the synthesis of certain biologically active molecules. Hernandez also has been elected president of the Chemistry Graduate Students Association. (Photo by Anthony B. Wood)



was salutatorian of his high school class in Rolla, Missouri and did undergraduate research both during the school year and as a summer intern.

- *Caren L. Hix*, at Duke University, focuses her study of pharmacology on the central nervous system. As an undergraduate she was named the outstanding chemistry major at her college by the local chapter of the American Chemical Society.
- *David B. Warlass* specializes in international economics and finance at MIT. His particular interest: analyzing commercial trade policies between modern economic powers and developing economies.

Precollege Education

Quality education in science is an American necessity—whether it leads to a scientific career or simply to a life of informed citizenship in the modern world. Either way, it must begin at an early age when students' curiosity and motivation are taking shape. Answering the demand for qualified men and women trained in the sciences and mathematics is a task for educators at all levels, but especially our elementary and secondary school teachers. How good they are, and how good their teaching materials and resources, ultimately will determine the nation's future economic and technological strength.

In fiscal year 1983 the National Science Foundation established three new activities to improve precollege education in science and mathematics:

1. *Presidential Awards for Excellence in Science and Mathematics Teaching*—104 secondary school teachers (2 from each state, the District of Columbia, and Puerto Rico) received the first of these annual awards in a White

House ceremony on October 19, 1983.

This program was first announced by the President's Science Advisor in January 1983 as a way to give national recognition to outstanding math and science teachers in the nation's secondary schools. A $5,000 grant from NSF goes to the awardee's school, for instructional programs that the awardee directs.

The Foundation searched for candidates in conjunction with the Department of Education and state and local school officials, through a consortium of scientific and professional societies and teachers' groups.*

Teachers were nominated at the state level, and final selections came from a panel of scientists, mathematicians, and teachers.

2. *Honors Workshops for Precollege Teachers of Science and Mathematics*—The basic goal of this program is to motivate, and increase the ability of, mathematics and science teachers from kindergarten through grade 12. During the program's first year, NSF expected to offer workshop opportunities to some 700 teachers.

Award-winning teachers. President Reagan is shown with 4 of the 104 secondary school teachers who received Presidential Awards for Excellence in Science and Mathematics Teaching. These awards were presented at the White House on October 19, 1983. The four awardees seen here (on front row) are Jo Anne Rife of Harrison, Arkansas; Edna Hyke Corbett of Portsmouth, Virginia; Thomas (Tony) Sedgwick of Tacoma, Washington; and Akehiko Takahashi of Wentzville, Missouri. Behind them are White House Science Advisor George Keyworth (left) and NSF Director Edward Knapp.

More winners. Puerto Rico's winners of Presidential Excellence awards are shown at left visiting the Smithsonian Institution's Air and Space Museum in Washington, D.C. They are Jose L. Garrido and Luz V. Conception de Gaspar. District of Columbia awardees, in other photo, are Doris Broome Deboe (left) and Katie Walker.

*Among them: the American Association of Physics Teachers, the American Chemical Society, the National Association of Biology Teachers, the National Council of Teachers of Mathematics, and the National Science Teachers Association. The American Association for the Advancement of Science and the National Academy of Sciences also participated.

To reach its goal, the program will:

- Recognize and honor excellent teachers and help them renew and update their skills.
- Analyze educational methods and practices from the perspective of the best classroom teachers.
- Extend the benefits of teaching workshops to entire school systems.

Projects will reflect an awareness of the needs and potential of the diverse teacher and student populations in the United States—for example, the needs of women, minorities, the physically handicapped, and those who are exceptionally gifted and talented. Workshops may include special seminars, symposia, and teacher involvement in research and coursework (including laboratory experience in industrial settings and other field-based study).

Workshops may vary in length according to the type of activity and the participants. They can take place during the academic year, in summer, or both.

3. *Materials Development for Precollege Science and Mathematics* (K-12)—This is an effort to strengthen teacher abilities in math and science and improve general teaching skills. Projects will enlist the best scientists and science educators to develop and publicize new or better instruction materials. As with the Honors Workshops, projects will reflect an awareness of the nation's diverse teacher and student populations.

The nationwide competition for support covers these areas:

Models and Demonstrations of programs for the continuing education of teachers. These can focus on scientific and technical content or on new technologies—such as computers and telecommunications—to improve math and science teaching.

Materials Development (teaching aids, computer programs, software, television materials, etc.) to improve the quality and efficiency of science and mathematics teaching.

Analysis of the entire educational system for precollege math and science, to monitor and understand its needs and achievements.

Applied Research to understand how teaching and learning processes can be more effective.

Dissemination of ideas and materials to sustain high-quality teaching and help local systems plan and improve their services.

All materials development projects must relate to issues of national rather than limited and local significance, and their results and products must be applicable beyond the immediate locale where they were developed.

Commission on Precollege Education in Mathematics, Science, and Technology

*Educating Americans for the 21st Century** was released to the National Science Board and the American people on September 13, 1983. This was the final report of the 20-member Commission, created by the Board in April 1982.

The Commission found that "The Nation that dramatically and boldly led the world into the age of technology is failing to provide its own children with the intellectual tools needed for the 21st century." The report stated that our educational system must indeed teach the "basics." However, for the 21st century the basics include communication, greater skills at solving problems, and scientific and technological literacy—"the thinking tools that allow us to understand the technological world around us."

The Commission made recommendations that touch nearly every sector of our society, including many persons and institutions not traditionally concerned about elementary and secondary education. It called for "a strong and lasting national commitment to quality mathematics, science, and technology for all students...."

This was the first report on the status of modern U.S. education that:

1. Set a target date (1995) for major improvement of our schools.
2. Described in detail how to reach this goal.
3. Told how much all this might cost and who should pay for what.

The report asked the federal government to invest some $956 million in the first year alone—and to maintain a continuing investment for several years—to improve elementary and secondary science, mathematics, and technology education. The Commission did not consider this excessive, especially in light of the much larger investments asked of state and local

*Subtitled *A plan of action for improving mathematics, science, and technology education for all American elementary and secondary students so that their achievement is the best in the world by 1995.*

Commission on Precollege Education. William Coleman (in center of photo) and Cecily Cannan Selby (to his left) co-chaired the National Science Board's Commission on Precollege Education. At Coleman's right is Board chairman Lewis M. Branscomb.

A model center. These students are all from the Fernbank Science Center in Atlanta. The National Science Board's Commission on Precollege Education in Math, Science, and Technology has identified Fernbank as a model of innovative education in the technical fields. (Photos by Pat Olmert)

systems. Following are more detailed suggestions.

Model Programs: Citing many outstanding programs and centers of excellence, the Commission recommended that 2,000 model programs (1,000 elementary and 1,000 secondary) be established to serve as catalysts for change. The recommended federal investment would be $276 million per year for a three-year period.

Teacher Training: The report put a high priority on retraining elementary teachers and secondary math and science teachers in the next five years, with a federal share of $349 million per year.

Teacher Conditions: School systems were asked to improve the overall school environment (which should include more classroom discipline, for example); recognize and reward good teachers; give salary and status benefits to instructors who opt to stay in the classroom setting; and relieve teachers of responsibilities not directly related to their profession.

Standards: These include rigorous—but fair—standards for teachers; higher standards for grade promotion and high school graduation; and tougher college admission requirements in math and science.

Other Recommendations:

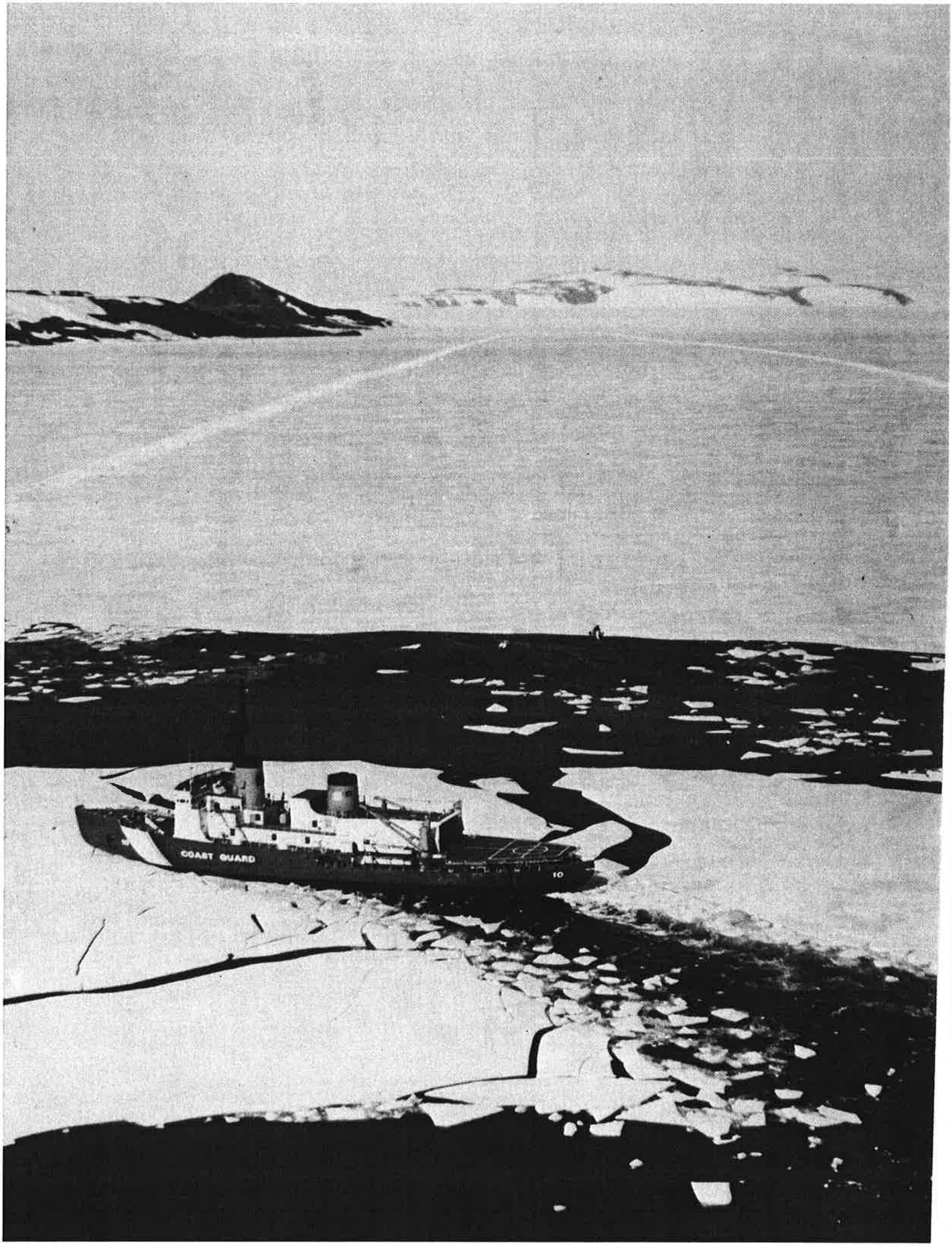
- A renewed commitment to full and equal opportunity for all, coupled with efforts to wipe out the effects of prejudice and discrimination in this area. Said the Commission: "Excellence and elitism are not synonymous."
- A National Education Council, appointed by and reporting directly to the President, to monitor activity and progress at the national level; and Governors' Councils to monitor and act on state educational issues.
- Partnerships involving school boards, business, government, and academia in each community—to solve local education problems.
- Longer school days and/or years to achieve new student training levels.
- Strategies to measure progress in reaching the action plan's goals.

The Commission also urged greater use of new information technologies (e.g., learning about, through, and with computers) and support for informal education (through museums, clubs, the media, etc.), as well as a more consistent and coherent curriculum for grades K-12.

In developing their report, commissioners visited successful math and science programs all over the country and met with hundreds of people from all government levels, the scientific and education communities, and business and industry. The Commission also convened a number of conferences to help determine the curricula revisions needed for students to meet the demands of a technological age. Reports from these conferences and other studies are in a companion document to the final report.

Commission's 8-Point Strategy

1. **Build a strong and lasting national commitment to quality mathematics, science, and technology education for all students.**
2. **Provide earlier and increased exposure to these fields.**
3. **Set up a national system to measure student achievement and participation.**
4. **Retrain current teachers, reward excellent ones, and find ways to attract new instructors of the highest quality and the strongest commitment.**
5. **Improve the quality and usefulness of the courses taught.**
6. **Create exemplary programs—landmarks of excellence—in every community to foster a new standard of academic excellence.**
7. **Use all available resources, including the new information technologies and informal education.**
8. **Develop a procedure to spell out the costs of improvements and how to pay for them.**


COAST GUARD
10

Antarctic Research

7

Antarctica and its surrounding oceans are a natural laboratory for the study of solar-terrestrial interactions, atmospheric and oceanic contents and circulation, present and former climates, geologic history, and the adaptations of life forms to the antarctic environment. Basic research is defining Antarctica's potential for both renewable and nonrenewable resources. It also provides basic information needed to plan for resource management and environmental protection.

NSF funds the total U.S. scientific presence in Antarctica, including logistics support, under a special budget appropriation. University scientists, grantees of the Foundation, perform most of the research. At this writing, 12 other countries also have researchers on the continent.

Research Highlights

During the 1982-83 season, U.S. scientists worked on 85 research projects in the Antarctic. Disciplines represented were astronomy, upper atmosphere physics, meteorology, glaciology, geology and geophysics, physical and chemical oceanography, biology, and medical research. Following are some highlights.

The Moon and Mars in Antarctica

Since 1969 almost 6,000 pieces of meteorites have been collected in Antarctica, doubling the total number available worldwide for scientific study. The samples are estimated to represent several hundred separate meteorite falls. Most were found during organized searches in areas where mountains have halted the flow of the ice sheet and where ablation of the surface ice has exposed the meteorites at the new surface.

Scientists have found a bonanza in these specimens, which include new and rare meteorites; the large collection enables better assessment of the abundance of meteorite types. The advanced terrestrial age of some pieces reveals that they were abundant millions of years ago. The clean state of the samples, collected aseptically from the antarctic deep freeze, allows studies that were difficult or impossible before. These studies are essential to space science because meteorites include the oldest solar system materials available for research, and they reflect a wide range of parent bodies.

Two types of meteorites (three specimens) apparently came from locations other than the asteroid belt, where most other meteorites seem to have originated. One, found in the Allan Hills of southern Victoria Land, is almost certainly a moon rock.

To test the theory that this fragment came from the moon, 20 groups of scientists from five countries received samples of the 31.4-gram specimen. They studied mineral, chemical, and gas content; cosmic-ray exposure; petrology; and other properties. Then they compared their results with similar analyses of lunar samples brought to earth by the manned spacecraft missions. The evidence was overwhelming that the sample, identified as ALHA-81005, is not from the asteroid belt and is from the moon.

What part of the moon the fragment came from, its age, how long it was in space and how long on the antarctic ice sheet, and the way it was ejected from the moon are still unanswered questions. However, early analysis suggests that it came from the lunar highlands and that it remained encased in Antarctica's ice for 100,000 to 600,000 years before American explorers picked it up.

Two other antarctic meteorites may be from Mars. Significant abundances of trapped argon, krypton, and xenon have been measured in the stony meteorite Elephant Moraine 79001. The relative abundances of elements and the high ratios of argon-40 to argon-36 and of xenon-129 to xenon-132 more closely resemble Viking data for the martian atmosphere than data for gas typically found in meteorites. These findings support earlier suggestions, made on the basis of geochemical evidence, that this specimen and related rare meteorites may have come from the red planet.

Lightning Disturbance of Radio Signals

Lightning's most familiar effect on radio is static, created at close range and heard on AM stations. It also affects long-range radio waves, particularly at very low frequencies. Lightning, in fact, is a prime source of very-low-frequency (VLF) wave energy in the magnetosphere, generating waves that travel along the earth's magnetic field lines from one hemisphere to the other and back. The waves disperse in frequency as they travel, and what started as a crack arrives at the opposite hemisphere as a one- to two-second gliding tone called a whistler.

When whistlers perturb energetic electrons trapped in a field line, the electrons sometimes descend to an altitude of 100 kilometers or less. There they interact with the upper atmosphere to increase ionization, which modifies the signals sent by communication and navigation transmitters. This process is called the Trimpi effect, named for a Stanford University scientist who discovered it at Eights Station, Antarctica, in 1963.

The Trimpi effect has become a key method of studying the way natural and manmade waves injected into the magnetosphere induce electron precipitation events. Antarctica is ideal for such work; the observable spectrum is uncrowded, and stations are located at high geomagnetic latitudes.

Research based on observations at Palmer and Siple Stations by Stanford's D.L. Carpenter and others has given us more information on waves. For example, well-defined Trimpi events have been detected at frequencies between 12.9 and 780 kilohertz on signals originating from an Omega navigation transmitter in Argentina. Such information, collected from several ground stations, helps determine the spatial distribution of ionospheric disturbances caused by individual whistlers.

Whistlers also can trigger or suppress background radio "noise" in the magnetosphere. Analysis of data collected earlier from four antarctic stations has revealed that whistler-induced suppression is far more common than researchers had suspected—for example, at the South Pole in 1981 noise suppression took place on 20 percent of all winter days. The VLF research transmitter at Siple Station also has been found to attenuate noise, creating a quiet band in the magnetosphere. The evidence is that the noise is suppressed when whistlers or the manmade signals interact with the particles believed to produce the noise.

Satellite-borne receivers have shown yet another phenomenon: Narrowband signals from the Siple transmitter were seen to broaden significantly as they passed through the magnetosphere. Precipitating electrons again appear to be the cause.

Basic knowledge of these characteristics will aid our understanding of wave-particle interactions in the ionosphere and the low-altitude magnetosphere. Among the expected results: better long-range radio communication.

Marine Fossils on a Mountain Range

Antarctic scientists discovered a wide variety of tiny marine fossils scattered atop the Transantarctic Mountains between 7,000 and 9,000 feet above sea level. This finding may change many concepts about the glacial history of that continent.

The surprise finding by Ohio State University researchers included a wide variety of life forms ranging in age from 2 million to about 70 million years. The ancient marine life fossils were extracted by Peter N. Webb from samples of glacial deposits collected by John H. Mercer. The Transantarctic Mountains, the largest range in Antarctica, stretch some 1,900 miles between East and West Antarctica.

The microfossils included delicately preserved diatoms, radiolaria, silicoflagellates, nannoplankton, and foraminifera—all tiny organisms, some of which can be seen by the unaided eye. The youngest of these fossils could have been formed when the deposits were laid down, but the oldest were already fossilized when they were picked up—possibly by a glacier passing over older sediments in an interior basin. How marine fossil-bearing sediments managed to get scattered atop the mountains over a distance of about 1,000 miles is under evaluation.

Studies of the new collections will play a major role in determining the size and frequency of antarctic ice-sheet fluctuations during the Cenozoic Era—about 65 million years ago. They also will help scientists to decipher world climate in the past 65 million years and to explain global fluctuation of sea level during that time.

The new findings also can help explain the northward movement of very cold marine waters and southward movement of relatively warm waters during the many glacial-interglacial fluctuations. Interplay of waters with contrasting physical and chemical characteristics has a strong bearing on biological productivity and deposition of organic material.

The scientists think that seaways may have crossed Antarctica at various times in the past 60 million years, connecting the southern Atlantic, Pacific, and Indian Oceans. This would have provided important marine migration routes. Now researchers can perhaps delineate the distribution of major sedimentary basins and former seaways in Antarctica.

Ice-Sheet Elevations by Satellite

Polar-orbiting satellites are increasing the data available to antarctic investigators. One experiment showed the feasibility of mapping ice-surface elevations using a satellite called Seasat; investigators on that project believe they have come up with the most accurate representation to date of any major ice area in Antarctica. Thirty-seven orbits, selected from 450 overflights of the short-lived satellite, yielded 27,327 elevation measurements; these were used to produce contours that agree with elevations already established using older methods.

The ease of establishing the elevations with satellites has made it feasible for scientists to do repeated ice-sheet mapping, using successors to Seasat. Glaciologists can now learn more about how the world's major ice sheets respond to and affect changes in global climate.

Before satellites, researchers used airplanes to determine ice-sheet elevation and thickness; a 10-year international program completed in the 1970s covered just over half the continent. Before such specially equipped airplanes were available, scientists could collect data only along isolated traverses on the ice surface.

Facilities in the Antarctic

The United States conducted its 1982-83 research in Antarctica at the four year-round stations described below, and also at temporary camps and aboard research ships.

McMurdo Station, on Ross Island, is a logistics hub for the program, operated year-round. There scientists maintain biological and geological laboratories in addition to specialized research facilities for cosmic-ray observations, satellite tracking, and meteorology. During the austral summer an outfitting center at the station equips research teams for helicopter expeditions to Victoria Land, the Ross Ice Shelf, and sites on Ross Island. Long-range, ski-equipped airplanes transport research and support personnel, and sometimes helicopters, to inland stations and remote field camps. One of these planes is equipped for atmospheric sampling and can also be used for radio-echo sounding of ice thickness, aerial photography, and other scientific observations. Surface vehicles are used for work near camps, and helicopters are available for wider excursions.

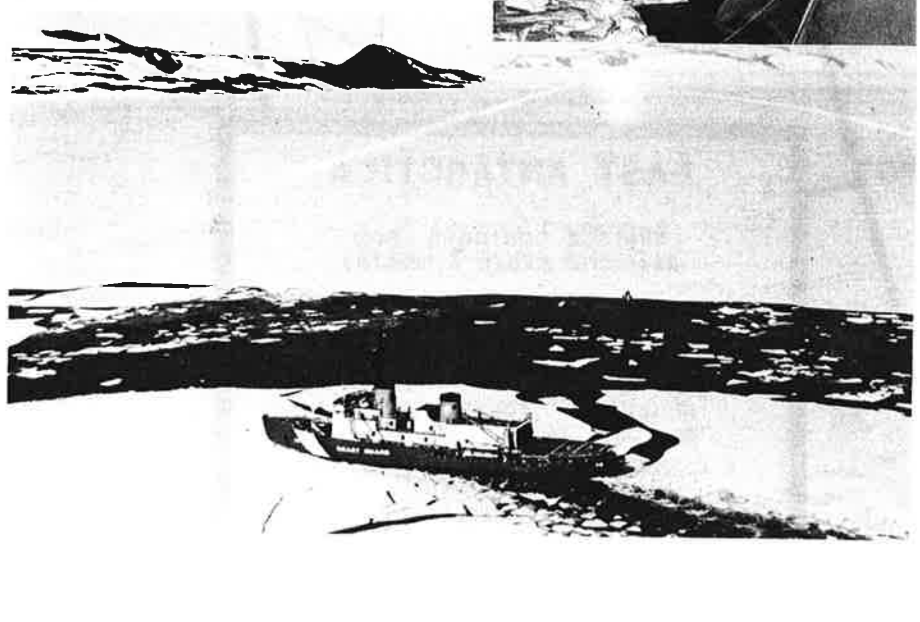
Amundsen-Scott South Pole Station, a year-round station at the geographic pole, is equipped for solar astronomy, meteorology, upper atmosphere studies, satellite tracking, glaciology (including ice-core drilling), and medical research. At a clean-air facility, located upwind of the main station, researchers collect air samples to monitor world background levels of atmospheric constituents.

Siple Station is a specialized research facility in Ellsworth Land that supports studies of the ionosphere and the magnetosphere. Major equipment includes a 42-kilometer horizontal dipole antenna (extended from half that length in 1983) that receives and transmits very-low-frequency radio signals. Because of the ice thickness here (1 kilometer), the antenna behaves as though it were suspended that height above the ground. This station has operated year-round since 1973 but will be closed for 2 years beginning in January 1984. This will extend its useful life for important experiments in 1986 and 1987.

Palmer Station, on Anvers Island off the west coast of the Antarctic Peninsula, is ideally situated for marine research. It has a large biological laboratory that includes sea-water aquariums. Other research areas: upper atmosphere physics, meteorology, and terrestrial biology. Palmer is operated year-round; in the summer small work boats take researchers to nearby islands.

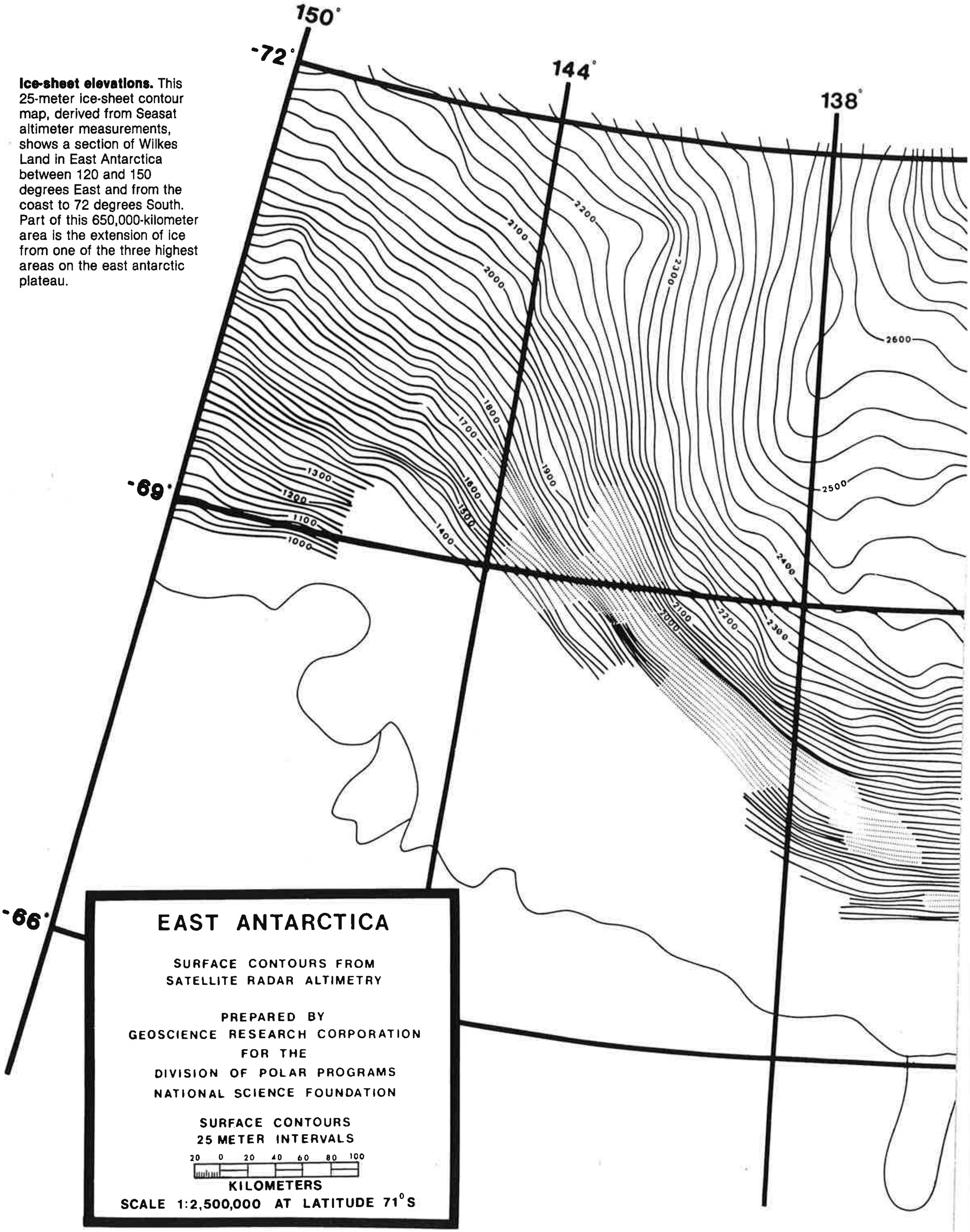
The research ship *Hero* operated

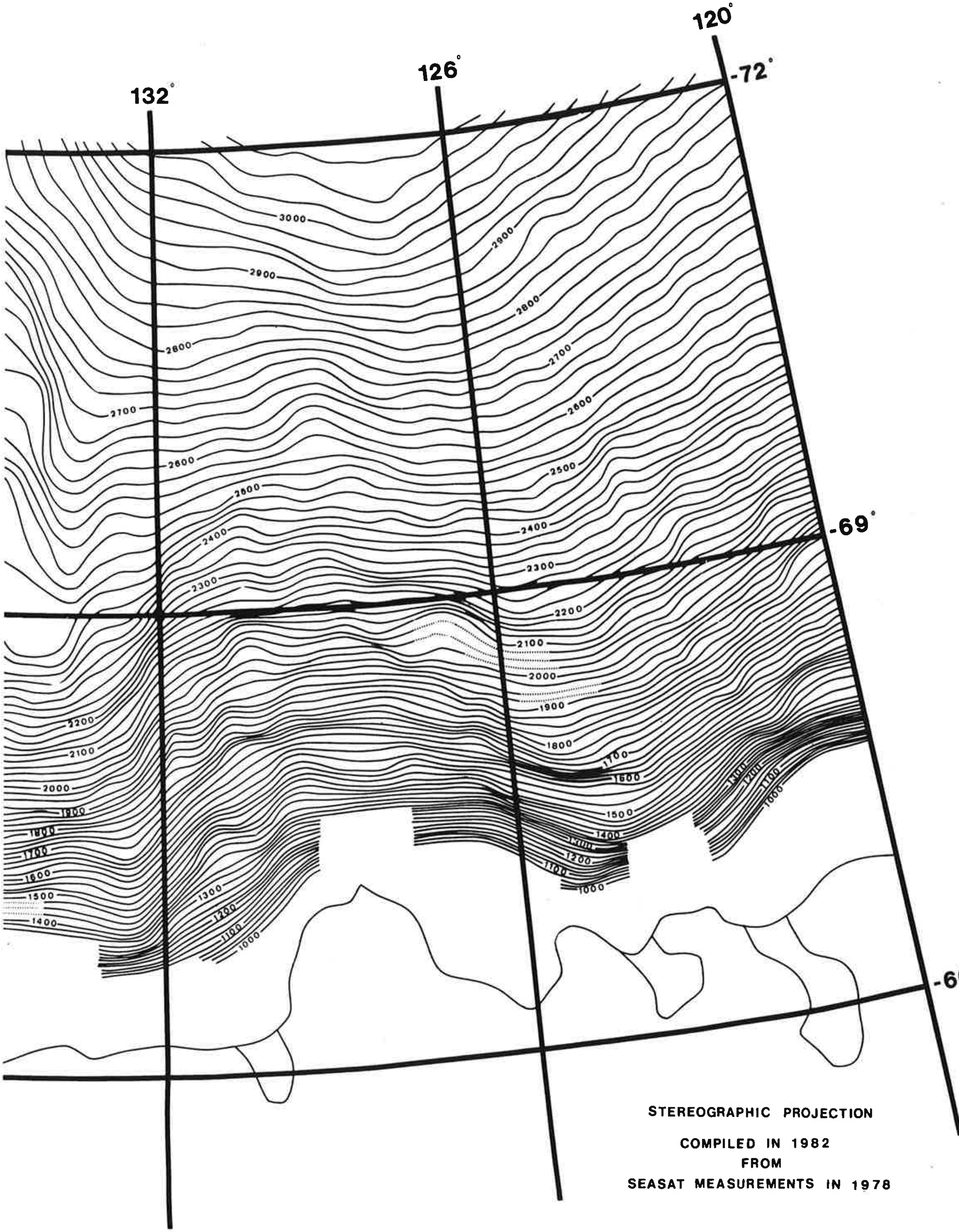
Helicopter lands near small field camp. Helicopters transport scientists and equipment from McMurdo Station to nearby areas in southern Victoria Land and on Ross Island. They also support research parties when large field camps are set up in remote areas of Antarctica. In the foreground is a Scott tent, used by U.S. scientists in Antarctica because it is stable in high winds and can be put up quickly. (Photo by Russ Kinne)



Antarctic circumnavigation. The U.S. Coast Guard icebreaker *Polar Star* is near McMurdo Station. This 122-meter ship can open the 20-mile channel in McMurdo Sound ice much more quickly than older icebreakers did. Along with other Coast Guard vessels of this type that deploy to Antarctica, the *Polar Star* also supports science in the Ross Sea, along the west antarctic coast, and near the Antarctic Peninsula. During the 1982-83 field season the *Star* circumnavigated Antarctica. (U.S. Navy photo by Dana B. Babin)

Ice-sheet elevations. This 25-meter ice-sheet contour map, derived from Seasat altimeter measurements, shows a section of Wilkes Land in East Antarctica between 120 and 150 degrees East and from the coast to 72 degrees South. Part of this 650,000-kilometer area is the extension of ice from one of the three highest areas on the east antarctic plateau.




120°
126°
132°
-72°
-69°
-66°
3000
2900
2800
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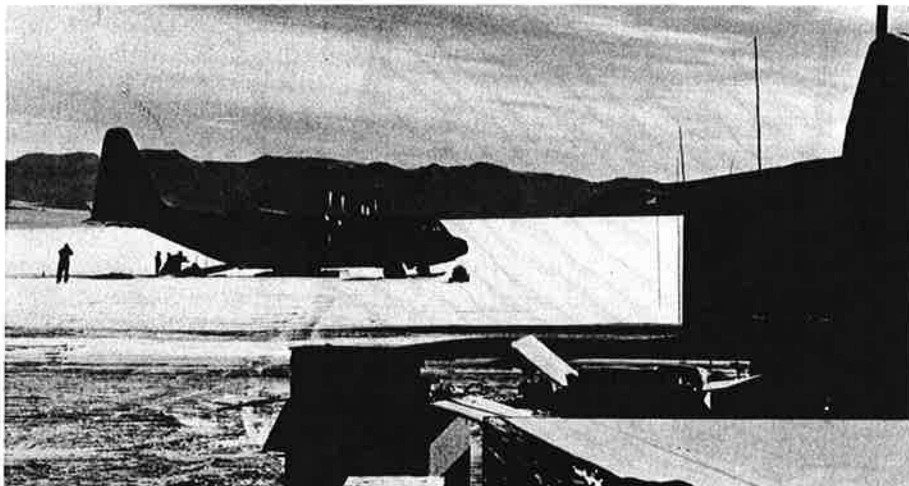
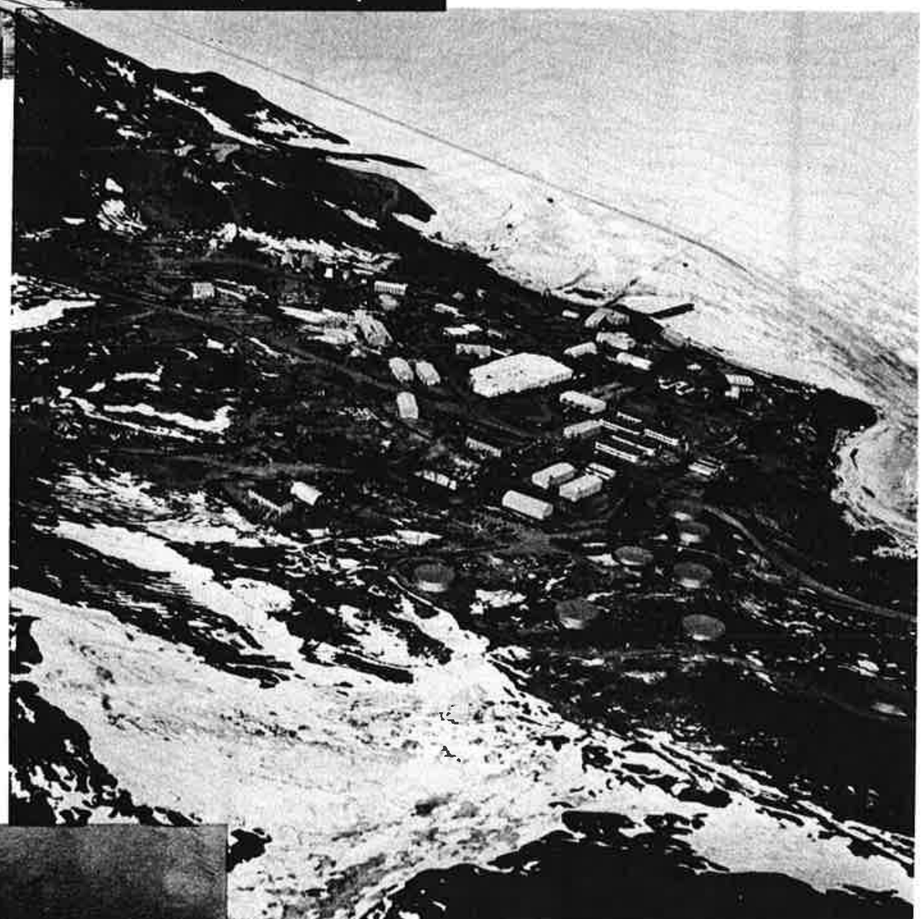
STEREOGRAPHIC PROJECTION
COMPILED IN 1982
FROM
SEASAT MEASUREMENTS IN 1978

along the Antarctic Peninsula during the 1982-83 summer in conjunction with Palmer Station. The wooden, ice-strengthened trawler served both marine biologists and onshore parties from other disciplines. It was also a transport between the Antarctic Peninsula and South America.

Coast Guard icebreakers of various sizes escort ships in McMurdo Sound and support marine research throughout the antarctic region in the summer.



Access to remote research sites. A ski-equipped Hercules airplane lands near a field camp in the Transantarctic Mountains. Often called the "workhorses of the Antarctic," these planes bring personnel and supplies from New Zealand and transport them to inland stations. Because of these airplanes, U.S. scientists can reach and study many remote areas that would otherwise be inaccessible. (U.S. Navy photo by Frank Bair, Jr.)



McMurdo Station on Ross Island. The original station at this site was built during 1955-56; with many additions over the years, McMurdo today is the primary logistics facility for airborne resupply of inland stations and for field science projects. During the austral summer some 800 people reside here; the winter population is about 100. Research in geology, glaciology, biology, ocean science, and atmospheric science is done at the station, on Ross Island, or in nearby southern Victoria Land. (Photo by Russ Kinne)

Antarctic life. A Weddell seal emerges for air through a slush-filled hole in the ice of McMurdo Sound, Antarctica. (U.S. Navy photo by B. M. Anderson)

The icebreakers are equipped for physical, chemical, and biological oceanography; one, the *Glacier*, has a winch for bottom coring.

One of the larger research ships of the U.S. academic fleet, usually the 75-meter *Melville*, is deployed to antarctic waters as available (generally every other year) to support oceanic research.

Antarctic Treaty Activities

Under the Antarctic Treaty, which reserves the continent for peaceful purposes, nations cooperate in research and logistics. At periodic meetings they have agreed on standards for operations, environmental protection, and use of renewable resources.

The U.S. antarctic program works within the framework and objectives of the treaty. Cooperative research, logistics, and support projects with a number of Antarctic Treaty nations were completed during 1983, as in past years.

For two months in early 1983, the program provided the Coast Guard icebreaker *Polar Star* to an observer team from the U.S. Department of State. The ship circumnavigated Antarctica, calling at 14 non-U.S. research stations. The Antarctic Treaty provides that each party involved may designate observers who have complete access to all areas of Antarctica, including stations and installations; it is the only international treaty that guarantees this right of open, onsite inspection.

The team inspected the 14 facilities for compliance with treaty provisions, which include preserving the environment and prohibiting military activities, nuclear explosions, and radioactive waste disposal. As with six other inspection tours since the treaty took effect in 1961, the mission found no evidence of violations of either the letter or spirit of the treaty.

Scientists aboard the *Polar Star* took advantage of the circumnavigation to record distributions of marine mammals and birds. They also made chemical oceanography measurements, did microbial studies, and collected daily air samples to analyze carbon dioxide levels.

During 1983, the Antarctic Treaty nations made further progress on developing a mineral resources regime. This will ensure that mineral resource activities are consistent with the aims of protecting the antarctic environment and preserving international cooperation and harmony. The international Commission on the Conservation of Antarctic Marine Living Resources and its scientific committee, set up in 1982, are developing ways to manage living resources. The Antarctic Treaty nations met in September to discuss specially protected areas, telecommunications, and other matters.

The People's Republic of China acceded to the treaty in June 1983, followed by India in August. This brought the number of treaty nations to 28. India and Brazil were both admitted to consultative status in September 1983. With the 12 original signatory nations, previously joined by Poland and the Federal Republic of Germany, the number of nations that participate in treaty consultative meetings thus grew to 16.

Other Activities

8

NSF Planning and Evaluation

NSF regularly develops, collects, and uses information to set priorities, plan programs, identify staff and support needs, and deal with major policy issues. To supplement extensive analyses done by its own staff, NSF also supports a few extramural studies. Highlights of 1983 work:

- The Committee on Science, Engineering, and Public Policy of the National Academy of Sciences did briefings for top federal policy-making officials on research opportunities in selected areas of science.
- The National Academy of Sciences published "An Assessment of Research—Doctorate Programs in the U.S." in five volumes (mathematics and physical sciences, humanities, engineering, biological sciences, and behavioral sciences).
- The Association of American Universities conducted a project to identify, assess, and publish alternative ways to meet university equipment needs. AAU studied debt financing, better procurement and management practices, ways to increase support from the private sector, the impact of institutional and state regulations, opportunities for changes in federal regulations, and future modes of direct federal investments.

Other subjects of extramural research in 1983:

- Prudent practices to dispose of chemicals from laboratories.
- Experience of women researchers in postdoctoral positions.
- Ways to improve the targeted distribution of research solicitations and program announcements to the academic community.

Policy issues in the funding and performance of scientific activities are of continuing concern to NSF. Examples of issues that NSF looks into: the allocation of support among research areas; how science and engineering relate to achieving national goals; better ways to support science and engineering; the economic and social consequences of that support; ways to develop the nation's technology potential; opportunities for, and constraints on, developing technical fields.

An important planning function is staff support to certain committees and groups of the National Science Board, NSF's policy-making body. These include the Planning and Policy Committee, the Committee on Minorities and Women in Science, and working groups dealing with such issues as engineering research and education; precollege education in mathematics, science, and technology; university-industry research relationships; capital facilities planning; and creativity in research.

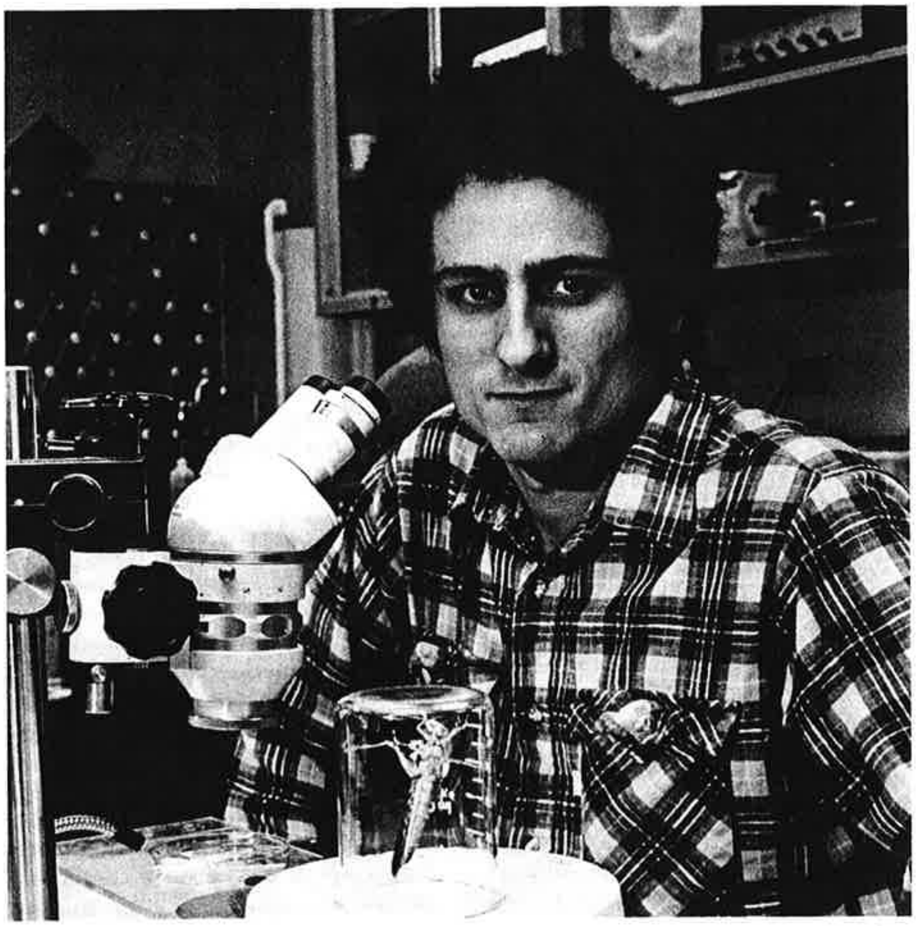
Evaluation studies brief the NSF Director on the effectiveness of major Foundation programs and the integrity of the agency's award process. They form the basis of his oversight responsibilities in these areas and the groundwork for budgetary or policy decisions. In 1983, for example, the National Academy of Sciences finished an evaluation of NSF's chemistry division a study suggested by the U.S. Senate Appropriations Committee.

Alan T. Waterman Award

This award recognizes an outstanding young person in the forefront of science. In addition to a medal, the recipient receives a grant of up to $50,000 a year for a maximum of three years. Candidates must be U.S. citizens 35 years of age or younger, or not more than five years beyond receipt of the doctoral degree on December 31 of the year they are nominated. Emphasis is placed on a candidate's record of completed, high-quality, innovative research—work that shows outstanding ability and exceptional promise for significant achievements in the future.

Two mathematicians, two physicists, one paleobiologist, one chemist, and two biologists have received this Award. The eighth recipient is Corey S. Goodman, a Stanford University neurobiologist. He was honored in 1983 for defining, for the first time, the sequence of developmental changes that occur during the life of a certain population of nerve cells.

Goodman's research focuses on the embryonic development of the nervous system—specifically the cellular and molecular mechanisms that underlie the development of that system's diverse and precise cellular pattern. Over the past five years, Goodman has been seeking answers to two broad and highly related questions: How do individual nerve cells acquire their unique identities (cell differentiation)? What guides the growing processes of the neurons so that they find and



Waterman Awardee. Corey Goodman is the 1983 winner of NSF's Waterman Award. He defined, for the first time, the sequence of developmental changes that occur during the life of a certain population of nerve cells.

interact with their appropriate targets, be they other neurons or muscle cells?

More recently, Goodman has extended this work to study the way growing nerve fibers identify the course they should take and their targets. The achievement of being able to watch neural development on a cell-by-cell basis—coupled with the possibility of doing physiological experiments on the same cells—holds much promise for understanding the overall development of the nervous system.

Special Science and Technology Reports

Publishing these reports involves not only NSF but also the White House Office of Science and Technology Policy (OSTP), other federal R&D agencies, the National Academy of Sciences, and individual experts in various fields. Current studies:

- *Annual Science and Technology Report to the Congress, 1982*—A comprehensive statement of the Administration's science and technology policy, sent by the President to the Congress in September 1983. NSF and OSTP wrote it.
- *Emerging Issues in Science and Technology, 1982*—Nine working papers commissioned by NSF to help OSTP compile the *Annual Science and Technology Report to the Congress, 1982.* The papers explore the Administration's science and technology policies and strategies to carry them out.
- *Five-Year Outlook on Science and Technology, 1982*—A summary of trends and probable future developments in eight selected areas of science and engineering, put together by the National Academy of Sciences at NSF s request.

Appendix A

National Science Board Members and NSF Staff (Fiscal Year 1983)

NATIONAL SCIENCE BOARD

Terms Expire May 10, 1984

Lewis M. Branscomb (*Chairman*, National Science Board), Vice President and Chief Scientist, International Business Machines, Inc., Armonk, New York
Eugene H. Cota-Robles, *Provost*, Crown College, *Professor of Biology*, University of California, Santa Cruz, California
Ernestine Friedl, *Dean of Arts and Sciences and Trinity College*, and *Professor of Anthropology*, Duke University, Durham, North Carolina
Michael Kasha, *Distinguished Professor of Physical Chemistry*, Institute of Molecular Biophysics, Florida State University, Tallahassee, Florida
Walter E. Massey, *Director*, Argonne National Laboratory, Argonne, Illinois
David V. Ragone, *President*, Case Western Reserve University, Cleveland, Ohio
Edwin E. Salpeter, *J. G. White Professor of Physical Sciences*, Newman Laboratory of Nuclear Studies, Cornell University, Ithaca, New York
Charles P. Slichter, *Professor of Physics*, Department of Physics, University of Illinois, Urbana, Illinois

Terms Expire May 10, 1986

Jay Vern Beck, *Professor Emeritus of Microbiology*, Brigham Young University, Provo, Utah
Peter T. Flawn, *President*, University of Texas, Austin, Texas
Mary L. Good (*Vice Chairman*, National Science Board), *Vice President, Director of Research*, United Oil Products, Inc., Corporate Research Center, Des Plaines, Illinois
Peter D. Lax, *Professor of Mathematics*, Courant Institute of Mathematical Sciences, New York University, New York, New York
Homer A. Neal, *Provost*, State University of New York at Stony Brook, Stony Brook, New York
Mary Jane Osborn, *Professor and Head*, Department of Microbiology, University of Connecticut School of Medicine, Farmington, Connecticut
Donald B. Rice, Jr., *President*, The Rand Corporation, Santa Monica, California
Stuart A. Rice, *Dean of the Division of Physical Sciences*, James Franck Institute, University of Chicago, Chicago, Illinois

Terms Expire May 10, 1988

Robert F. Gilkeson, *Chairman of the Executive Committee*, Philadelphia Electric Company, Philadelphia, Pennsylvania
Charles E. Hess, *Dean*, College of Agricultural and Environmental Sciences, University of California at Davis, Davis, California
William F. Miller, *President and Chief Executive Officer*, SRI International, Menlo Park, California
John H. Moore, *Associate Director and Senior Fellow*, The Hoover Institution, Stanford University, Stanford, California
William A. Nierenberg, *Director*, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California
Norman C. Rasmussen, *Professor of Nuclear Engineering*, Massachusetts Institute of Technology, Cambridge, Massachusetts
Roland W. Schmitt, *Senior Vice President*, Corporate Research and Development, General Electric Company, Schenectady, New York

(One Vacancy)

Member Ex Officio

Edward A. Knapp (*Chairman*, Executive Committee), *Director*, National Science Foundation

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Margaret L. Windus, *Executive Officer*, National Science Board, National Science Foundation

NATIONAL SCIENCE FOUNDATION STAFF
(as of September 30, 1983)*

Director, Edward A. Knapp
Deputy Director (Acting), Richard S. Nicholson
Executive Assistant to the Director, Richard S. Nicholson
Director, Office of Equal Opportunity, Perry W. Hooks
General Counsel, Charles Herz
Director (Acting), Office of Government and Public Programs, Thomas Ubois
Director, Office of Planning and Resources Management, M. Kent Wilson
- *Director, Division of Budget and Program Analysis*, L. Vaughn Blankenship
- *Director, Division of Planning and Policy Analysis*, Irwin M. Pikus

Director, Office of Audit and Oversight, Jerome H. Fregeau
Director, Office of Small Business Research and Development, William B. Cole, Jr.
Director, Office of Small and Disadvantaged Business Utilization, William B. Cole, Jr.
Director, Office of Scientific and Engineering Personnel and Education, Walter L. Gillespie
Assistant Director for Mathematical and Physical Sciences (Acting), Marcel Bardon
- *Deputy Assistant Director for Mathematical and Physical Sciences (Acting)*, Edward F. Hayes
- *Director, Division of Chemistry*, Edward F. Hayes
- *Director, Division of Materials Research*, Lewis H. Nosanow
- *Director, Division of Mathematical and Computer Sciences*, Ettore F. Infante
- *Director, Division of Physics*, Marcel Bardon

Assistant Director for Engineering (Acting), Carl W. Hall
- *Deputy Assistant Director for Engineering*, Carl W. Hall
- *Director, Division of Chemical and Process Engineering*, Marshall M. Lih
- *Director, Division of Civil and Environmental Engineering*, William S. Butcher
- *Director, Division of Electrical, Computer, and Systems Engineering*, Thelma A. Estrin
- *Director, Division of Mechanical Engineering and Applied Mechanics*, John A. Weese

Assistant Director for Biological, Behavioral, and Social Sciences (Acting), Robert Rabin

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*Major organizational and/or personnel changes affected some of these listings at or near the beginning of fiscal year 1984 (October 1). See the current NSF organization chart for correct listings.

Deputy Assistant Director for Biological, Behavioral, and Social Sciences, Robert Rabin
Director, Division of Behavioral and Neural Sciences, Richard T. Louttit
Director, Division of Biotic Systems and Resources, John L. Brooks
Director, Division of Information Science and Technology, Edward C. Weiss
Director, Division of Physiology, Cellular and Molecular Biology, James H. Brown
Director, Division of Social and Economic Sciences (Acting), James H. Blackman

Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences (Acting), Albert L. Bridgewater
Deputy Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences, Albert L. Bridgewater
Director, Division of Astronomical Sciences, Laura P. Bautz
Director, Division of Atmospheric Sciences, Eugene W. Bierly
Director, Division of Earth Sciences, James F. Hays
Director, Division of Ocean Sciences, M. Grant Gross
Director, Division of Polar Programs, Edward P. Todd

Assistant Director for Scientific, Technological, and International Affairs, Richard J. Green
Deputy Assistant Director for Scientific, Technological, and International Affairs, Peter E. Wilkniss
Director, Division of Industrial Science and Technological Innovation, Donald Senich
Director, Division of International Programs, Bodo Bartocha
Director, Division of Policy Research and Analysis (Acting), Peter W. House
Director, Division of Research Initiation and Improvement, Alexander J. Morin
Director, Division of Science Resources Studies, Charles E. Falk

Assistant Director for Administration, Thomas Ubois
Deputy Assistant Director for Administration, Kurt G. Sandved
Director, Division of Financial Management, Kenneth B. Foster
Director, Division of Grants and Contracts, Gaylord L. Ellis
Director, Division of Information Systems, Constance K. McLindon
Director, Division of Personnel and Management, Geoffrey M. Fenstermacher
Director, Division of Administrative Services, Troy T. Robinson

Appendix B

Financial Report for Fiscal Year 1983
(in thousands of dollars)

Research and Related Activities Appropriation

Fund Availability

Fiscal year 1983 appropriation	$1,061,300	
Unobligated balance available, start of year	2,347	
Adjustments to prior year accounts	4,048	
Fiscal year 1983 availability		$1,067,695

Obligations

Astronomical, Atmospheric, Earth, and Ocean Sciences:		
Astronomical Sciences	$62,719	
Atmospheric Sciences	75,515	
Earth Sciences	34,848	
Ocean Sciences	102,529	
Arctic Research Program	6,218	
Subtotal		281,829
International Awards		-1,031*
Subtotal, Astronomical, Atmospheric, Earth, and Ocean Sciences		$280,798
U.S. Antarctic Program		$83,196
Biological, Behavioral, and Social Sciences:		
Physiology, Cellular and Molecular Biology	$87,344	
Biotic Systems and Resources	45,958	
Behavioral and Neural Sciences	34,021	
Social and Economic Sciences	20,290	
Information Science and Technology	5,478	
Subtotal		193,091
International Awards		-1,857*
Subtotal, Biological, Behavioral, and Social Sciences		$191,234
Engineering:		
Electrical, Computer, and Systems Engineering	$29,531	
Chemical and Process Engineering	22,560	
Civil and Environmental Engineering	30,489	
Mechanical Engineering and Applied Mechanics	19,431	
Subtotal		102,011
International Awards		-880*
Subtotal, Engineering		$101,131

Mathematical and Physical Sciences:		
Mathematical Sciences	$34,756	
Computer Research	29,339	
Physics	89,144	
Chemistry	67,628	
Materials Research	81,080	
Subtotal		301,947
International Awards		-1,511*
Subtotal, Mathematical and Physical Sciences		$300,436
Scientific, Technological, and International Affairs:		
Industrial Science and Technological Innovation	$14,507	
International Cooperative Scientific Activities	4,651	
Policy Research and Analysis	4,271	
Science Resources Studies	3,650	
Research Initiation and Improvement	11,769	
Subtotal		38,848
International Awards		5,279*
Subtotal, Scientific, Technological, and International Affairs		$44,127
Program Development and Management		$65,697
Subtotal, obligations		$1,066,619
Unobligated balance available, end of year		$704
Unobligated balance lapsing		$372
Total, fiscal year 1983 availability for Research and Related Activities		$1,067,695

Science and Engineering Education Activities Appropriation

Fund Availability

Fiscal year 1983 availability (appropriation)		$30,000

Obligations

Graduate Research Fellowships	$14,979	
Precollege Science and Mathematics Education	1,108	
Subtotal, obligations		$16,087
Unobligated balance available, end of year		$13,913
Total, fiscal year 1983 availability for Science and Engineering Education Activities		$30,000

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.

SOURCES: Fiscal Year 1985 Supplementary Budget Schedules, Fiscal Year 1985 Budget to Congress and NSF accounting records

Special Foreign Currency Appropriation

Fund Availability

Fiscal year 1983 appropriation	$2,200	
Unobligated balance available, start of year	918	
Adjustments to prior year accounts	27	
Fiscal year 1983 availability		$3,145

Obligations

Research and Related Activities	$3,085
Unobligated balance available, end of year	14
Unobligated balance lapsing	46
Total, fiscal year 1983 availability for Special Foreign Currency Program	$3,145

Trust Funds/Donations

Fund Availability

Unobligated balance available, start of year	$1,853	
Receipts from nonfederal sources	10,020	
Adjustments to prior year accounts	3	
Fiscal year 1983 availability		$11,876

Obligations

Ocean Drilling Programs	$8,064	
Gifts and Donations	7	
Subtotal, obligations		$8,071
Unobligated balance available, end of year		$3,805
Total, fiscal year 1983 availability for Trust Funds/Donations		$11,876

Appendix C

Patents and Inventions Resulting from Activities Supported by The National Science Foundation

During fiscal year 1983, the Foundation received 121 invention disclosures. These resulted in dedication to the public through publication in 3 cases, retention of principal patent rights by the grantee or inventor in 37 instances, and transfer to other government agencies in 6 cases. NSF received licenses under 64 patent applications filed by grantees and contractors who had been allowed to retain principal rights in their inventions.

The Foundation published a revised patent regulation on May 2, 1983 (*Federal Register*, vol. 48, no. 85, pp. 19860-65, to be codified as part 650 of title 45, *Code of Federal Regulations*). This regulation implements the February 18, 1983 Presidential Memorandum entitled "Government Patent Policy"; it allows all NSF awardees normally to retain the principal patent rights to their NSF-supported inventions.

The following U.S. patents issued from research supported by the National Science Foundation in FY 1983:

Number	Title	Institution
4,332,719	Method and Apparatus for Isolating Protein from Glandless Cottonseed	Texas A&M University
4,338,581	Room Acoustics Simulator	University of California (UC)
4,344,035	Method and Apparatus for Determination of Changes in the Surface Charge of Materials	BioResearch, Inc.
4,350,607	Detector and Dosimeter for Neutrons and Other Radiation	Yale University
4,350,677	Reagent for Optimizing Agglutination	Massachusetts Institute of Technology (MIT)
4,357,422	Method of Enhancing Interferon Production	MIT
4,361,026	Method and Apparatus for Sensing Fluids Using Surface Acoustic Waves	UC
4,363,747	Metallocarborane Precursor and Catalyst	UC
4,365,005	Method of Forming a Laminated Ribbon Structure and a Ribbon Structure Formed Thereby	MIT
4,369,363	Optical Pulse Detector and Encoder	MIT
4,370,242	Device for and a Method to Separate Orientable or Deformable Particles	UC
4,370,418	Liquid Level Control by Subsurface Draw-Off	UC
4,376,647	Process for Treating Sulfide-Bearing Ores	University of Utah
4,376,823	Method of Increasing the Antibiotic Yield of Producing Organisms	Wisconsin Alumni Association
4,385,119	Magnetic Bacteria and Products Derived Therefrom	BioMagnetech Corporation
4,387,088	NBS-Acidic Phallotoxins and Their Use in the Fluorescence Staining of F-Actin	Cornell Research Foundation
4,393,327	Electric Spark-Type Light Source for Producing Light for Spectroscopic Analysis	Wisconsin Alumni Research Foundation
4,395,312	Method and Apparatus for the Analysis of Solution Adjacent to an Electrode	Ohio State University Research Foundation
Re. 31,287	Asynchronous Logic Array	MIT

Appendix D

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