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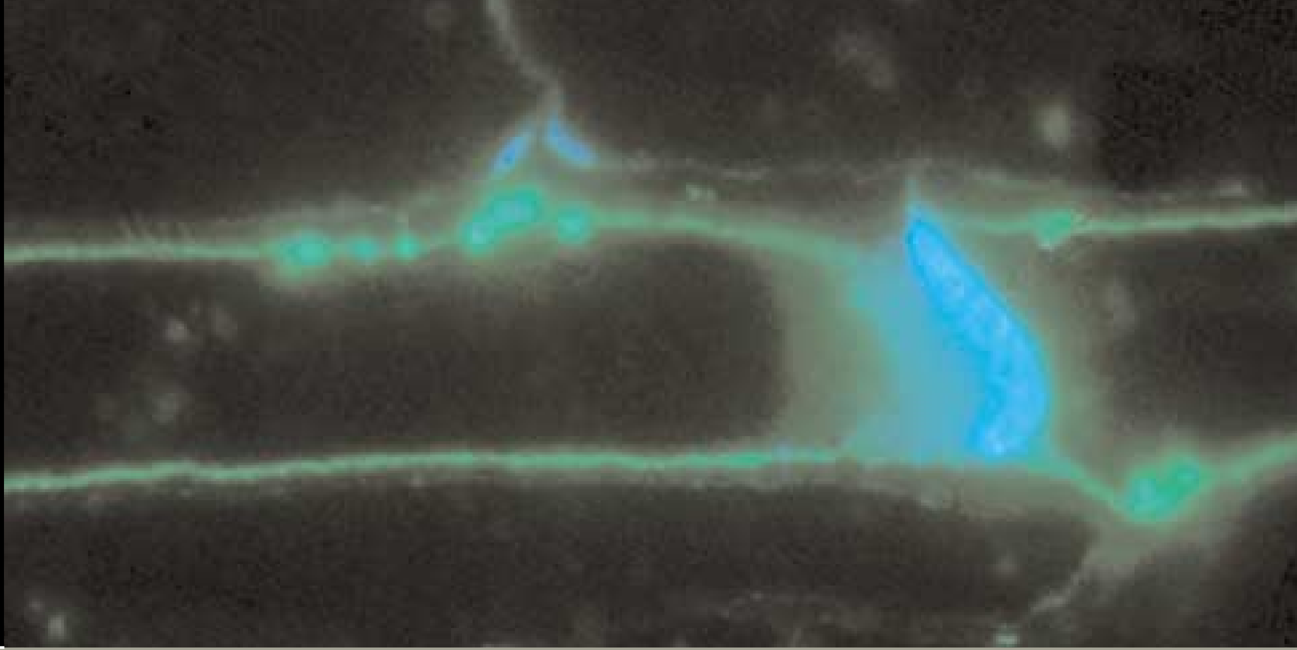

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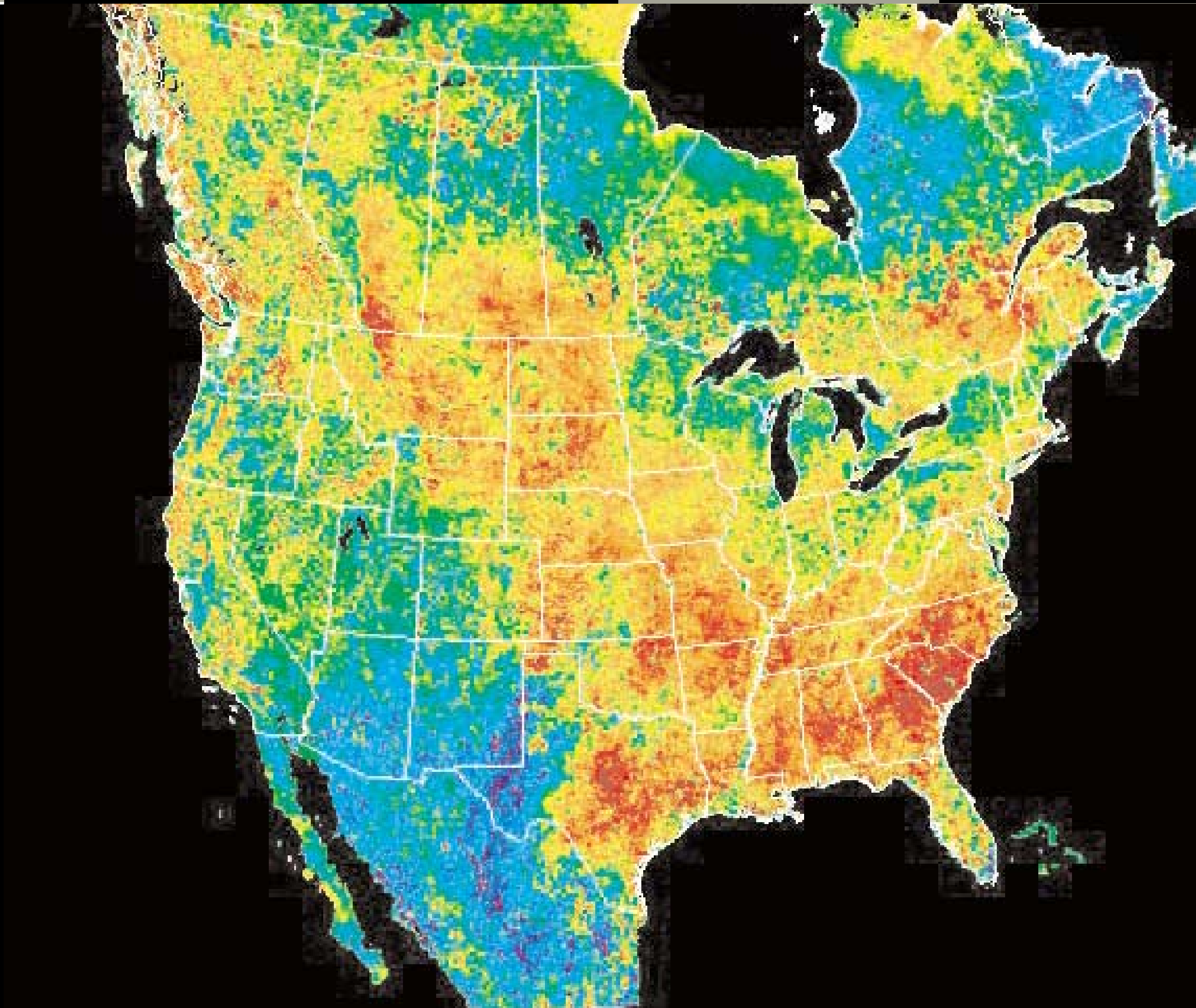

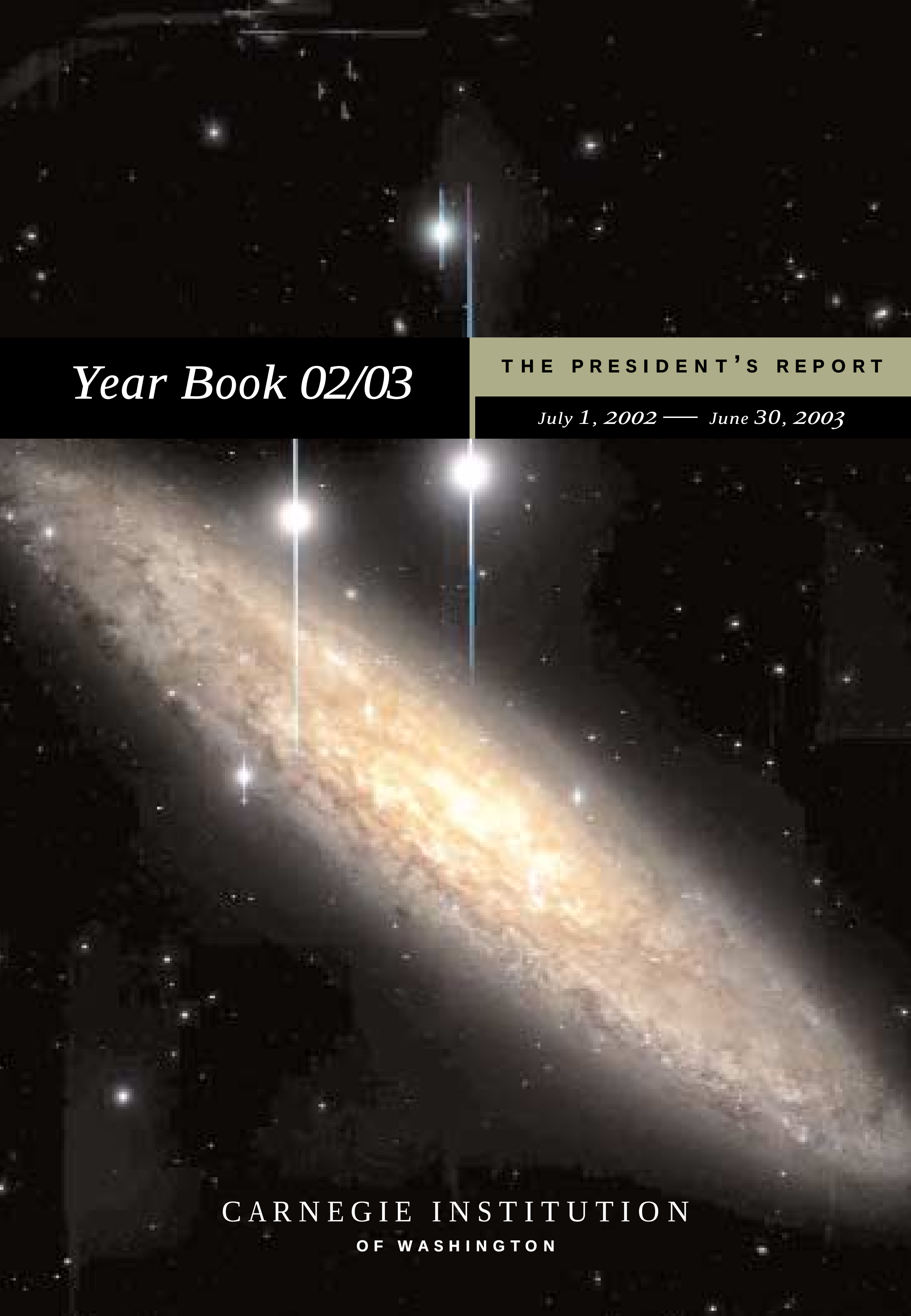

Year Book 02/03

THE PRESIDENT'S REPORT

July 1, 2002 — June 30, 2003

CARNEGIE INSTITUTION
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ABOUT CARNEGIE

. . . TO ENCOURAGE, IN THE BROADEST AND MOST LIBERAL MANNER, INVESTIGATION, RESEARCH, AND DISCOVERY, AND THE APPLICATION OF KNOWLEDGE TO THE IMPROVEMENT OF MANKIND . . .

The Carnegie Institution of Washington was incorporated with these words in 1902 by its founder, Andrew Carnegie. Since then, the institution has remained true to its mission. At six research departments across the country, the scientific staff and a constantly changing roster of students, postdoctoral fellows, and visiting investigators tackle fundamental questions on the frontiers of biology, earth sciences, and astronomy.

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> “CARNEGIE’S EFFORTS STILL SERVE A SPECIAL AND LARGELY DIFFERENT PURPOSE FROM THE MAINSTREAM OF SCIENTIFIC RESEARCH BECAUSE OF THE CRUCIAL CONTRIBUTION THAT INDIVIDUAL SCIENTISTS CAN PROVIDE IN EXPLORING NOVEL, UNEXPECTED ROUTES THAT ARE OFF THE BEATEN PATH.”
>
> ***—Richard A. Meserve***

These pages provide an opportunity each year for the president of the institution to discuss important issues bearing on the institution’s activities, to explore trends, and to take stock of where we stand. This is my first opportunity to make such an offering. I will provide my assessment of the institution and of my near-term aspirations for it. I will then turn to a more fundamental issue—the examination of the continuing significance of the institution’s activities.

THE STATE OF THE INSTITUTION

I find myself fortunate to have succeeded Dr. Maxine Singer as president. She provided a firm hand at the helm for 15 years. During Maxine’s tenure, all of the institution’s diverse activities were strengthened. Today, Carnegie scientists are discovering planets outside our solar system, determining the age and structure of the universe, studying the causes of earthquakes and volcanoes, deepening our understanding of the global carbon cycle, studying the properties of matter at pressures found at the Earth’s core, preparing the tools for identifying extraterrestrial life, discovering plant genes that combat disease and environmental stress, and revolutionizing our understanding of fundamental processes in molecular and developmental biology. Over the course of her tenure, Maxine appointed new directors to the six scientific departments, and she did so wisely. She undertook renovations and new construction throughout the Carnegie enterprise, and she championed the development of two state-of-the-art 6.5-meter telescopes—a remarkably prescient step in light of recent discoveries showing that the universe is far stranger than previously appreciated. And after extensive consultation with the scientific community, she launched Carnegie’s newest department—the Department of Global Ecology. By every measure, the Carnegie Institution is a strong and exciting place as a result of Maxine’s energy and efforts.

Fig. 1. Richard A. Meserve became the institution’s ninth president in April 2003. (Courtesy Jim Johnson.)

Left: Andrew Carnegie would be proud of the diversity of the institution’s research today—from life at extreme conditions (p. 66) to the evolution of galaxies (p. 22).

Fig. 2. The Department of Embryology's new Maxine F. Singer Building is scheduled for completion early in 2005. (Courtesy Bill Kupiec.)

There are a number of important initiatives that were started during Maxine's tenure, however, that remain to be accomplished. A new building is near completion for the Department of Global Ecology, and a new facility—appropriately, the Maxine F. Singer Building—is under construction for the Department of Embryology (Fig. 2). Renovations of various spaces at our Broad Branch Road Campus are also progressing. And to capitalize on the remarkable Magellan telescopes, the development of instrumentation is ongoing.

To complete these initiatives, support fellowships, continue the capacity of the various departments to explore new directions, and build our endowment for the future, our financial resources need to grow. Thus, under Maxine's tenure, the institution launched a major capital campaign, with a goal for contributions of $75 million by the end of 2006. Although significant progress has been achieved in the campaign thanks to the generosity of our trustees and many other donors, a substantial challenge remains. As a result, I conclude that an appropriate early strategy is to complete the projects under way before launching significant new enterprises.

I recognize, however, that opportunities can arise as a result of staff initiatives, and it is important to enable staff to seize special opportunities that come from their work. Maintaining the capacity and flexibility to adapt to such circumstances is an important Carnegie tradition that must be maintained. But because funds are constrained, new initiatives must be examined critically. Exactly such a challenge is revealed in this volume by Wendy Freedman, director of the Observatories, in connection with the next generation of large telescopes.

Much of the financial support for our activities comes from our endowment—about half of total spending came from our endowment between July 1, 2002, and June 30, 2003. Fortunately, the institution has benefited not only from the generosity of our friends, but also from the investment sophistication of our finance committee, under the leadership of David Swensen. As shown by the chart (Fig. 3), the institution's endowment has grown at a time when many other nonprofit organizations have had to slash programs in response to significant losses in their investments. Moreover, in recognition of Carnegie's sound financial stewardship, the institution was awarded the highest debt rating by Moody's (Aaa), putting Carnegie in the top 5% of not-for-profit institutions. The skill of our finance committee in maintaining and growing our endowment is a very significant accomplishment in these difficult economic times. Their efforts have been essential in enabling the institution to contemplate the various initiatives now under way.

In sum, the state of the institution is strong. It is a vibrant and exciting place.

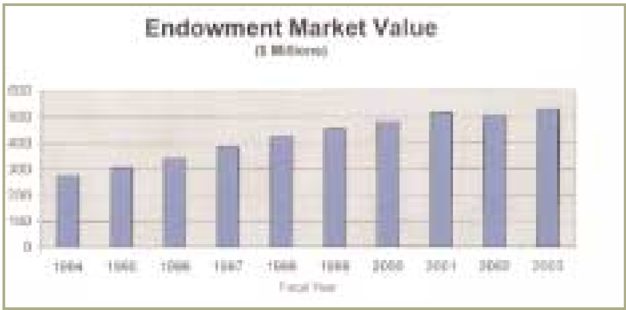

Fig. 3. The market value of the Carnegie Institution's endowment, shown for the last 10 years, has grown as a result of a successful investment strategy and generous contributions. Amounts represent nominal fiscal year-end balances.

THE CONTINUING NEED FOR CARNEGIE

It is healthy for every organization—perhaps particularly at major turning points—to examine its fundamental goals. From time to time, we should consider whether the underlying charge to the institution is still relevant and whether the institution continues to meet a significant societal need. These goals were framed for us in Andrew Carnegie's 1902 Deed of Trust:

> *"It is proposed to found in the city of Washington, an institution which . . . shall in the broadest and most liberal manner encourage investigation, research and discovery—show the application of knowledge to the improvement of mankind, provide such buildings, laboratories, books, and apparatus, as may be needed; and afford instruction of an advanced character to students properly qualified to profit thereby."*

Carnegie explained further that his "chief purpose" was "to secure if possible for the United States of America leadership in the domain of discovery and the utilization of new forces for the benefit of man."

Carnegie's aim to promote discovery, particularly in the sciences, for the advancement of humankind was a remarkable vision in its time, although perhaps commonplace today. There was no general appreciation at the turn of the 20th century of the significant role that basic science could (and would) play in addressing the wide range of challenges that confront society. Indeed, it is quite remarkable to consider the innovations that were introduced in the 20th century as a result of science. These marvels include modern medicine, modern communications, information technology, lasers, nuclear energy, and much more.[1] Science and technology have perhaps caused a more remarkable change in the lives of humankind in the course of a single century than any other factors in the entire remainder of human history. Thus, from the vantage point of the 21st century, the premise that the enterprise of basic research could yield astonishing fruits is perhaps obvious. But Carnegie's recognition that basic research could lead to advancements for humankind should be seen as a remarkable vision at the time he launched this institution.

The federal role in nurturing science largely evolved after World War II, with the benefit of guidance provided by former Carnegie president Vannevar Bush.[2] Before that time, federal support was limited and was largely focused on agriculture, mainly through the land-grant colleges. Unlike Andrew Carnegie's time, science now receives much of its support from the federal government. In fact, the federal budget for basic science in the 2004 federal fiscal year amounts to over $25 billion.[3] The basic research that is supported in this way is not aimed at an immediate contribution to the mission of the funding agencies, but rather is intended to explore the foundations of nature and thereby to facilitate future advances. Governmental support is justified on the basis that such research does not promise near-term economic returns or even returns that will necessarily accrue to the investor, and hence private-sector investment is likely to be slight. Nonetheless, because the long-term returns—even if not subject to capture by the investor—are substantial, there is a strong justification for investment in the public interest. Andrew Carnegie clearly was ahead of his time in recognizing the need for the nourishment of science as a public good.

In light of federal support available today—support that was largely nonexistent at the time of Carnegie's Deed of Trust—it is appropriate to ask whether Carnegie's vision for an institution supported in part by *private* philanthropy serves any continuing purpose. After all, if the government has assumed the mission that Carnegie envisioned, it is appropriate to question whether this institution is still relevant. Indeed, given the reality that the institu-

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[1] George Constable and Bob Somerville, *A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives* (Washington, D.C.: National Academy of Engineering, 2003).

[2] Vannevar Bush, *Science: the Endless Frontier* (Washington, D.C.: U.S. Government Printing Office, 1945). Reprinted by the National Science Foundation, Washington, D.C., 1990.

[3] American Association for the Advancement of Science, "Trends in Basic Research, FY 1976-2004," in *AAAS Reports VIII-XXVIII*, Washington, D.C., December 2003.

tion's entire endowment is minuscule when compared with even the annual federal expenditures for basic science, it may appropriately be asked whether the Carnegie effort has enough significance to justify the continuing efforts of our trustees and other donors. I believe that this question can be answered with a convincing "YES!"

There is a significant difference between the federal approach and that pursued by the Carnegie Institution. The federal government, in the main, relies on the scientific community *at large* to chart the course for scientific work. Most federal funds are awarded based on proposals from individual scientists (or groups of scientists) that are evaluated through careful peer review by members of the scientific community. It is the scientists themselves who largely define the work that is undertaken, at least within broad programmatic areas. And peer review is aimed at ensuring that proposals promising scientific return are the ones that are supported, thus providing some assurance that it is important work that obtains support.

Andrew Carnegie selected a somewhat different means for scientific support. In defining the aims of the fledgling institution, Carnegie explained that it should "discover the exceptional man in every department of study whenever and wherever found . . . and enable him to make the work for which he seems specially designed his life work." Carnegie thus understood the particular importance of the talented individual; he sought to find such individuals and to provide them with the means to pursue their own visions of productive avenues for advancement.

I have taken the opportunity to visit the various departments and to engage the scientific staff in discussions about their work. These discussions yielded a near-unanimous common theme in every department—an appreciation for the special freedom that Carnegie provides for novel research ventures. This is the special role that, I believe, continues to justify Carnegie's existence.

As noted by Allan Spradling, director of our Department of Embryology:

> *"Mainstream scientific progress occurs regularly in many locations. However, the same is not the case for truly novel discoveries. Such exceptional ideas may result from developing a new technique or novel instrument, and always demands a substantial period of time with no guarantee of success to pursue something that by definition appears unlikely to work or even to be important. Sadly, the patient, long-term support needed to sustain such ventures is usually lacking today in our corporate R&D departments, in our national granting system, and even in most universities and research institutes, where the focus swings with the latest and most visible problems. Why risk getting nowhere, when the incremental advances of the mainstream are there for the taking?"*

The Carnegie philosophy, with its emphasis on supporting the exceptional individual, still has power because of the unique role of unconventional thinking in yielding startling scientific advances. This is not to deny the importance of the pursuit of predictable advances; filling in the interstices of knowledge is necessary to allow the full benefits of science to be realized. And such efforts are particularly likely to garner federal support because of the inherent conservatism of peer review: good marks are given to research proposals that have a high likelihood of success.

The Carnegie philosophy, by contrast, seeks to identify exceptional individuals with the courage and capacity to break new ground, to trust in their judgment, and to give them the freedom to pursue their scientific instincts. Carnegie's efforts still serve a special and largely different purpose from the mainstream of scientific research because of the crucial contribution that individual scientists can provide in exploring novel, unexpected routes that are off the beaten path.

Perhaps the strength of the Carnegie idea is reflected best in efforts by others to emulate it. The National Institutes of Health, recognizing the conservatism inherent in its funding decisions, has sought to provide at least some funds for the support of exceptional individuals.[4] Moreover, the Howard Hughes Medical Institute (HHMI) seeks to ensure adequate support of exceptional individuals and even is creating a new campus with a focus that in many respects will mirror the research at Carnegie's Department of Embryology: the new HHMI facility will support scientists who propose creative investigations with a "high degree of scientific risk-taking."[5] The existence of efforts to re-create the Carnegie paradigm constitutes a validation of the continuing power of the Carnegie idea.

Indeed, far more frequently than might be expected, faith in the individual has served to open scientific vistas that otherwise would be closed. One of the most significant examples of the power of this idea is reflected in the work of Barbara McClintock and her work on "jumping genes." For much of her career, her efforts were largely unappreciated by her scientific contemporaries. But the world she opened up ultimately was seen to justify the award of a Nobel Prize.

Indeed, the continuing power of the Carnegie idea is reflected in every department of the institution. One example is provided by the Department of Embryology. The National Academy of Sciences provides a molecular biology award each year to recognize important, novel research by one or two young scientists. Five different Carnegie staff members have received this award for work done in the department over the last 30 years. This remarkable record is no doubt in part the result of the vitality of the research at the department and of skill in selecting brilliant new recruits. But it is also in part the result of the remarkable freedom that is provided to Carnegie scientists to do new and different things, thereby enabling them to distinguish themselves at an early age. In this case, both nature and nurture are reflected in the Carnegie record.

I believe that perhaps the best measure of the continuing value of the Carnegie idea is derived by assessing the activities in which our scientists engage. Although each of the contributions to this Year Book by the directors serves to highlight only some of our important accomplishments, a sampling serves to provide strong validation of the Carnegie concept.

Scientists at the Department of Terrestrial Magnetism (DTM) lead the world in the identification of extrasolar planets. Of the hundred or so such planets that have been found, more than half have been identified by the team led by DTM staff member Paul Butler and his U.C.-Berkeley colleague Geoff Marcy. This accomplishment complements theoretical work on planet formation by Alan Boss (Fig. 4), observational research on that subject by Alycia Weinberger, and the investigations into characterizing Earth-like planets by Sara Seager.

Fig. 4. The Department of Terrestrial Magnetism's Alan Boss constructs models of planetary formation. This model shows the equatorial density for a protoplanetary disk after 373 years. A multiple-Jupiter mass clump has formed and is shown as a tiny dot at about 12 o'clock. (Courtesy Alan Boss.)

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[4] Elias Zerhouni, "The NIH Roadmap," *Science 302*, 63, October 3, 2003.

[5] Howard Hughes Medical Institute, "HHMI Selects Rafael Viñoly Architects PC as Architect for Janelia Farm Research Campus," press release, February 28, 2002.

The high-pressure group at the Geophysical Laboratory, under the leadership of David Mao and Russ Hemley, is perhaps the leading group in the world in this research area. Group members have been able to use diamond-anvil cells to create pressures like those at the core of the Earth; they have used pressure as a variable to measure material properties in the same fashion that other scientists use temperature. These efforts have led not only to an understanding of the property of materials deep within the Earth, but also to a refined understanding of some of the fundamental properties of matter.

The staff at the Department of Embryology remains at the cutting edge of many remarkable advances in molecular and developmental biology. Andy Fire, for example, provided key insights into RNA interference (RNAi)—the process whereby a particular form of RNA serves to suppress the expression of genes. His discoveries are opening up the possibility of a very powerful tool for genetic studies and for disease prevention and control. Marnie Halpern's lab focuses on the genetic regulation of asymmetrical development in the zebrafish nervous system, which sheds light on similar development in other animals, including humans. New staff associate Alex Schreiber is also interested in the signals that control asymmetrical development. He studies the flatfish and the processes involved in the remodeling of the craniofacial system as the flatfish grows (Fig. 5). As the only scientist studying this aspect of the flatfish, he is pioneering new territory.

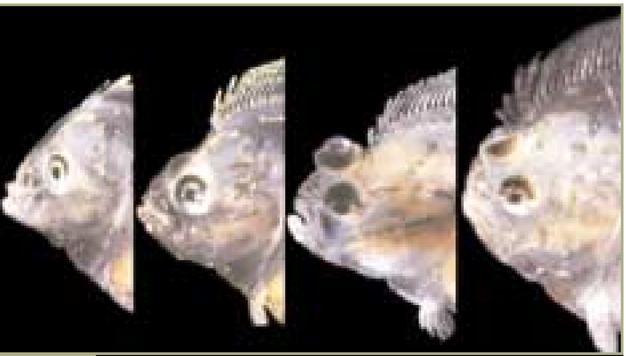


Fig. 5. Alex Schreiber, staff associate at the Department of Embryology, studies flatfish metamorphosis. Four different stages are shown. On the far left is a premetamorphic larva. The two middle panels show metamorphosing fish as the eye moves over the top of the head. On the far right is a post-metamorphic juvenile fish. At this stage, the entire animal is about the size of a dime. (Courtesy Alex Schreiber.)

Fig. 6. From left, Observatories Starr Fellow Paul Martini, instrument scientist David Murphy, and staff astronomer Eric Persson pose next to PANIC (Persson's Auxiliary Nasmyth Infrared Camera) during its deployment.

The skill of the Carnegie astronomers has meant that the two 6.5-meter Magellan telescopes at Las Campanas are among the best performers of the current generation of large telescopes. The skills of the Carnegie astronomers are now on further display with the introduction of a series of remarkable instruments to exploit the telescopes. Steve Shectman, with colleague Rebecca Bernstein, led the effort to build MIKE, a high-resolution spectrograph that can observe faint objects in detail. Alan Dressler is the driving force behind IMACS, an instrument that can view hundreds of galaxies at one time to reveal the structure of the early universe. Eric Persson and his team have developed PANIC, an infrared camera to observe molecular clouds and distant objects (Fig. 6). Each of these ingenious devices is exceeding even the most optimistic projections.

The staff of the Department of Plant Biology is actively engaged in using the tools of molecular biology to understand the behavior of plants. For example, Wolf Frommer, a new staff member, is using fluorescent molecules to unravel the control mechanisms for the movement of nutrients. Dave Ehrhardt, formerly a staff associate and now a staff member, studies poorly understood components of cellular structures using novel imaging techniques. Shauna Somerville is working on the genes and pathways that regulate disease susceptibility and resistance (Fig. 7). Sue Rhee's database on *Arabidopsis* is one of the most heavily used biological databases in the world, providing an important service to the entire biological community in the study of this model organism.

Although the Department of Global Ecology is new, its staff is already making its mark. Department director Chris Field is providing important information on how moisture, soil nitrogen, temperature, and atmospheric carbon dioxide concentration interact to affect uptake by plants. And Greg Asner is using the tools of remote sensing to understand biological processes (Fig. 8), including the impacts of humans on the Amazon rain forest.

Although this summary provides only a sampling of the work that is under way under the aegis of the Carnegie Institution, it shows that Carnegie scientists continue to contribute novel scientific insights in a variety of fields. The vibrant scientific enterprise of the Carnegie Institution continues to advance the goals of our founder. Andrew Carnegie would be proud both of what a century of effort has produced and of the promise of even more startling discoveries in the years ahead.

—Richard A. Meserve
October 2003

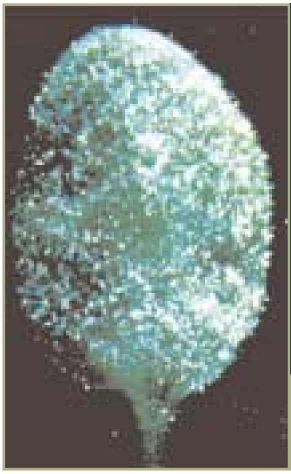


Fig. 7. Powdery mildew fungi infect more then 9,000 plant species worldwide, including agriculturally important ones. Shauna Somerville at the Department of Plant Biology studies the molecular mechanisms of the plant-pathogen interactions of this disease. She uses the model plant *Arabidopsis* in her work. Powdery mildew has spread over this *Arabidopsis* leaf seven days after infection. (Courtesy Shauna Somerville.)

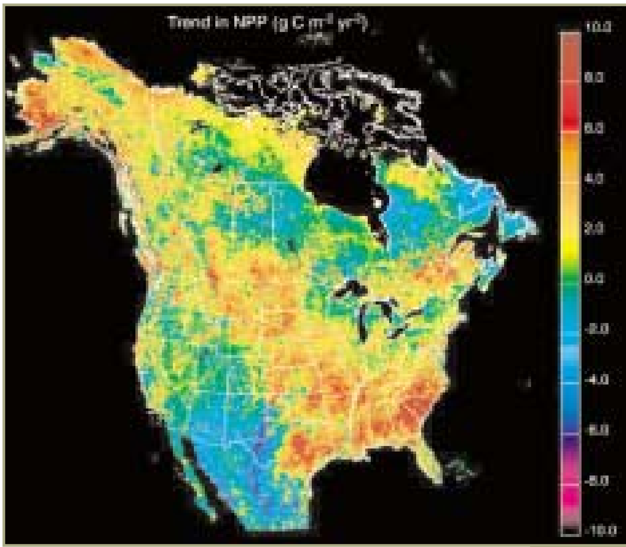


Fig. 8. Remote sensing is one of the many tools Greg Asner of the Department of Global Ecology uses to unravel interactions among the Earth's ecosystems. This map shows the geographic distribution of changes in net primary production—the amount of plant growth—throughout North America from 1982 to 1999. It was created from thousands of satellite images and was analyzed with Carnegie's global ecosystem model. Large increases are evident in the central and southeastern U.S. and Alaska, while decreases appear in the southwestern U.S. and areas of eastern and northern Canada. Measuring plant growth is one useful component to help understand how much of the greenhouse gas carbon dioxide is locked up in plants as they convert it to food during photosynthesis—important data to better comprehend the global carbon cycle. (Image courtesy NASA; analysis and modeling at Carnegie.)

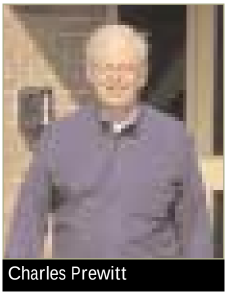
RETIREMENTS

The past year saw three retirements at GL: staff members **John Frantz** in October 2002 and **Neil Irvine** in June 2003, and, also in June, former director **Charles Prewitt**.


Neil Irvine

GAINS

Przemyslaw Dera became a staff associate at the Geophysical Lab in January 2003. Also in January, staff member **Wolf B. Frommer** joined the Department of Plant Biology.


Charles Prewitt

TRANSITIONS

Tom Urban stepped down as chairman of the board of trustees in May 2003 and was succeeded by **Michael Gellert**. Also in May, **William Rutter** became a senior trustee. **John Diebold** became a trustee emeritus in December 2002.

Maxine Singer retired as Carnegie president in December 2002 and became a member of the board of trustees. She was succeeded by former trustee **Richard Meserve** in April 2003. Trustee **Michael Gellert** served as acting president in the interim.

Chris Field, staff member at the Department of Plant Biology since 1984, became the first director of the new Department of Global Ecology on July 1, 2002.


Przemyslaw Dera

Wendy Freedman, Observatories astronomer since 1984, became the Crawford H. Greenewalt Director of the Observatories on March 1, 2003, succeeding **Augustus Oemler, Jr.**, now director emeritus.

HONORS

Trustee **Freeman Hrabowski** was elected to the American Philosophical Society in April 2003.

Carnegie president **Richard Meserve** was elected to the National Academy of Engineering.


Wolf B. Frommer

Embryology

Andrew Fire won numerous awards for his work on RNA interference: the 2002 Meyenberg Prize from the German Cancer Research Center; the 2002 Genetics Society of America Medal; the 2003 Wiley Prize with colleagues Craig Mello, Thomas Tuschl, and David Baulcombe; the 2003 National Academy of Sciences Award in Molecular Biology with Craig Mello; and the 2003 Passano Physician/Scientist Award.

In April 2003 **Marnie Halpern** received the H. W. Mossman Award in Developmental Biology at the annual meeting of the American Association of Anatomists.


Maxine Singer

Director **Allan Spradling** and former Embryology staff member Gerald Rubin received the 2003 George Beadle Award of the Genetics Society of America.

Geophysical Laboratory

Ronald Cohen was elected a fellow of the American Physical Society in fall 2002.

Marilyn Fogel was elected a fellow of the Geochemical Society.

Russell Hemley received the Hillebrand Prize of the American Chemical Society in March 2003.

Senior Fellow **Viktor Struzhkin** was recognized as an outstanding mentor by the Siemens Foundation, sponsor of the Siemens Westinghouse Competition in Math, Science, and Technology.

The Observatories

Director **Wendy Freedman** was elected to the National Academy of Sciences in spring 2003.

Plant Biology

Kathryn Barton was elected a fellow of the American Association for the Advancement of Science in October 2002.

In August 2002 **Arthur Grossman** was awarded the Darbarker Prize by the Botanical Society of America.

Terrestrial Magnetism

Alan Boss was elected a Fellow of the American Academy of Arts and Sciences in May 2003.

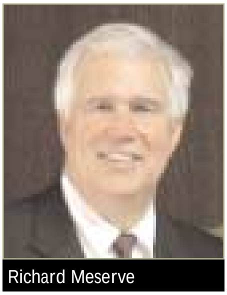
Paul Butler, with colleagues Geoffrey Marcy, Steven Vogt, and Debra Fischer, received the 2002 Carl Sagan Memorial Award, given jointly by the American Astronautical Society and the Planetary Society.

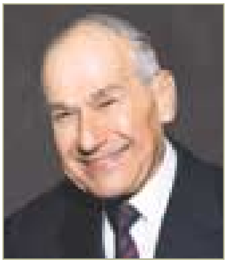
Richard Carlson was elected a fellow of both the American Geophysical Union and the Geochemical Society.

Steven Desch, a Carnegie Fellow and NASA Astrobiology Institute Fellow, won the 2003 Alfred O. Nier Prize of the Meteoritical Society. The prize is given annually to a scientist younger than 35 “for a significant contribution in the field of meteoritics and closely allied fields of research.”

Senior Fellow **Vera Rubin** was awarded the 2002 Cosmology Prize of the Peter Gruber Foundation in November 2002. She was also was awarded the 2003 Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific.

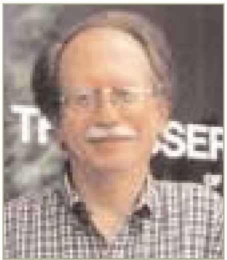
Director Emeritus **George Wetherill** received the 2003 Henry Norris Russell Lectureship of the American Astronomical Society in recognition of a lifetime of preeminence in astrophysical research.


Richard Meserve


Michael Gellert


Christopher Field


Wendy Freedman


Augustus Oemler

The Carnegie Institution received gifts and grants from the following corporations, foundations, individuals, government agencies, and other sources during the period July 1, 2002, to June 30, 2003.

FOUNDATIONS AND CORPORATIONS

$1 Million or More

The David and Lucile Packard Foundation
The Helen Jones Urban and Thomas Nelson Urban, Sr. Foundation
Sidney J. Weinberg, Jr. Foundation

$100,000 to $999,999

The Wallace H. Coulter Foundation
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$1 Million or More

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Over $1 Million

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National Institutes of Health
National Science Foundation
U.S. Department of Energy

$100,000 to $1 Million

Space Telescope Science Institute
U.S. Air Force Office of Scientific Research
U.S. Department of Agriculture
U.S. Office of Naval Research

$10,000 to $99,999

National Institute for Global Environmental Change, Western Regional Center
National Oceanic and Atmospheric Administration

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Institute of Earth Sciences, Academia Sinica
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THE DIRECTOR'S REPORT:

A Year of Firsts for First Light

For the first time in six years, more than 90% of First Light students were new enrollees. And thanks to a group of parents and students from Shepherd Elementary School, one of CASE's 15 DC ACTS schools, First Light saw a marked increase in its female enrollment. "My daughter's teacher told us about the program," said Ralph McMillan, whose daughter, Alexis, joined First Light this year. "She raved about how great the CASE Summer Institute was and said they also had a program for kids. With that type of enthusiastic endorsement, I had to get Alexis into the class." Once Alexis was on board, the rest of her Girl Scout Troop soon followed. The female-to-male student ratio did a complete 180° turn, with the girls outnumbering the boys almost 2 to 1.

While the Carnegie Institution welcomed a new president, First Light strengthened its partnership with the Living Classrooms Foundation (LCF) and formed a new partnership with the Langston Junior Golf Program (LJGP). Founded by Washington, D.C., sports legend Ray Savoy and funded by the United States Golf Association. LJGP's goal is to instill the nine core values connected with the game of golf and to increase its participants' academic success. First Light students focused on the study of golf physics, design technology, mathematics, health, physical education, and values education.

In addition to sponsoring the Schools in Schools: Shad and Herring Raise and Release Project (Figs. 2, 3, and 4), the Living Classrooms Foundation used First Light students to test new hands-on inquiry-based environmental science lessons. In one of the lessons our students learned about the indigenous Native American culture while cruising down the Potomac River aboard the *Half Shell*, LCF's 75-year-old oyster boat turned floating classroom. In late spring they set sail for Mason Neck State Park in Occoquan, Virginia. Along the way, they caught a 3-foot catfish, performed water-quality tests, and learned how to navigate the boat. Once at Mason Neck they set up camp, went on a hike, and slept under the stars, returning to Washington the next day. For many students it was their first time on a boat; for others it was their first time on a camping trip.

Left and above right: Weekly field trips are part of the curriculum at Carnegie's First Light Saturday science school. These First Light students learn about navigation as they cruise the Anacostia River in Washington, D.C.

Figs. 2., 3., and 4. First Light students participate in the Schools in Schools: Shad and Herring Raise and Release Project. Sponsored by the Chesapeake Bay Foundation, the Living Classrooms Foundation, the Interstate Commission on the Potomac River Basin, the U.S. Fish and Wildlife Service, the Anacostia Watershed Society, and the Chesapeake Bay Trust, the project's goal is to help restore shad and herring to local rivers and to raise the public's awareness and appreciation of the fish. These students place the "bio-balls" into the hatch tank's lower reservoir to act as a habitat for beneficial bacteria to break down harmful elements in the water.

During the summer, First Light met at the historic Langston Golf Course, located in Northeast Washington, D.C. In the pre–Civil Rights Act era, Langston was the only place where African Americans could play. Later it became the only golf course in the United States owned and operated by African Americans. Situated along the banks of the Anacostia River, Langston hosts a number of local and regional junior golf tournaments as well as hundreds of elementary, middle, and high school children in its Hook A Kid On Golf program. In addition to First Light extending its reach to students in neighborhoods far from Carnegie's P Street administration building, the partnership with LJGP also allowed the students to apply what they learned in the Schools in Schools: Shad and Herring Raise and Release Project. Last spring, First Light students as well as students from 30 other D.C.-area elementary schools, helped to restock the Anacostia and Potomac rivers with shad and herring they had raised in their classrooms.

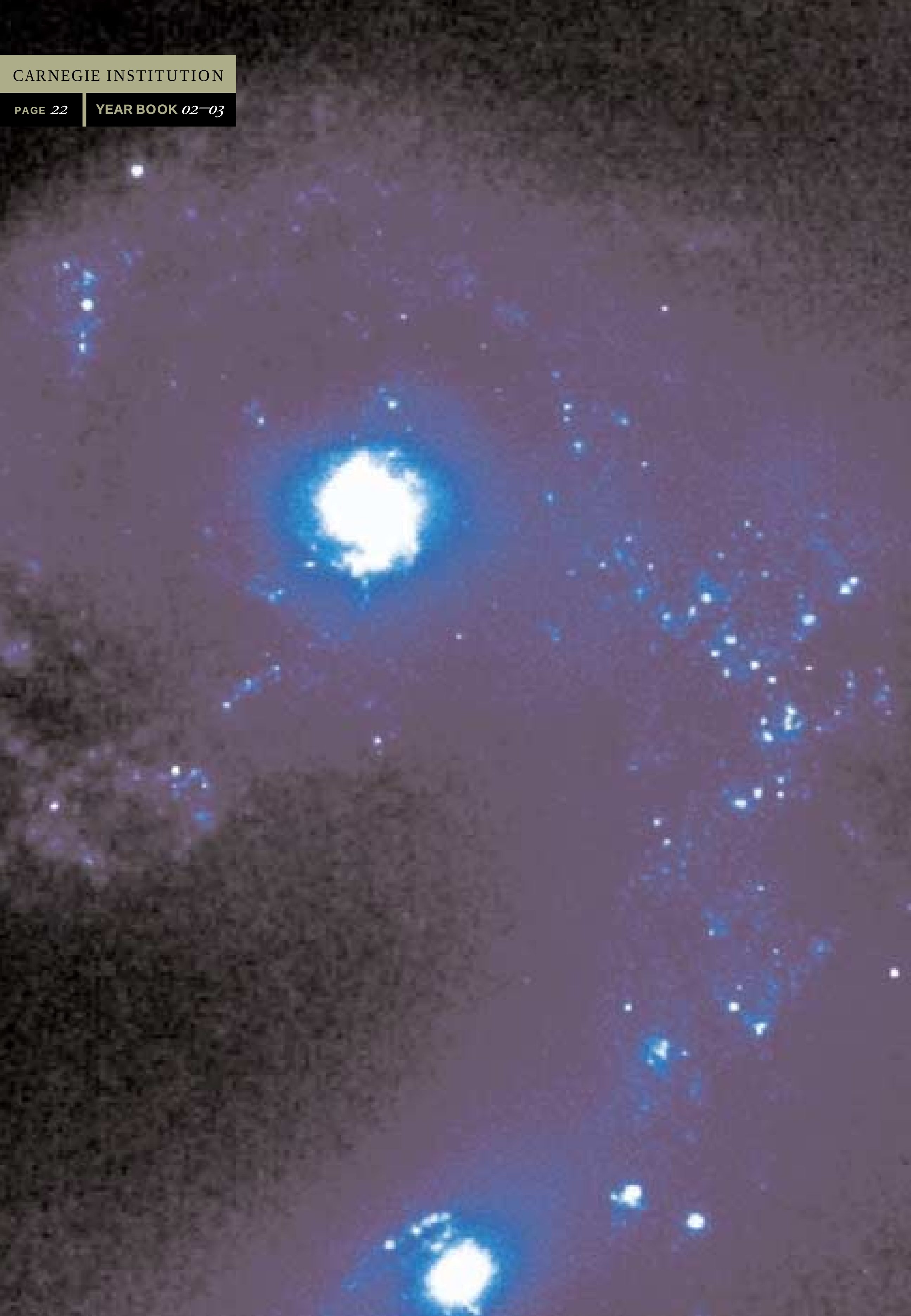
First Light received more great news last spring when several students were accepted into exclusive D.C.-area private schools. Henry and Rocío Valdes, son and daughter of CASE Fellow Rogelio Valdes, were both accepted into the Edmund Burke School. James Greene, Jr., was accepted into Edmund Burke, St. Anselm's Abbey, and the Maret School. After much deliberation, James chose Maret. Both families said that their children's involvement in the First Light program and their strong science background played a prominent role in their being accepted into the schools.

The coming year promises more success stories for our students. The Maret School will host an open house for First Light. In addition to continued participation in the Schools in Schools Project and the Langston Junior Golf Program, First Light students will design, build, and program Lego Dacta robots. These robots are made from Legos that have been fitted with programmable gears and motors.

The future is ripe with many wonderful experiences for our students, but First Light and CASE must both overcome a very serious challenge. The Howard Hughes Medical Institute turned down our proposal to expand First Light to middle school students. We are waiting to hear about a proposal to the National Science Foundation to establish teacher professional communities in D.C. public elementary schools, which have strong principal leadership and several CASE mentor-teachers. This is very much a period of transition for CASE and First Light—time will tell whether we survive in the 21st century.

—Inés Lucía Cífuentes, CASE director,
and Gregory Taylor, First Light lead teacher

Fig. 5. Each summer CASE teachers present their hands-on projects for review. Julie Edmonds, associate director of CASE (right), discusses a project with one of the teachers enrolled in the program.



THE DIRECTOR'S REPORT:

Carnegie Astronomical Telescopes in the 21st Century

> "TELESCOPES HAVE, SINCE OUR BEGINNING,
> BEEN THE SYMBOL OF THE INDEPENDENCE,
> VISION, AND BOLDNESS OF THE INSTITUTION."
>
> ***—Maxine Singer, 1990***[1]

The pace of astronomical discovery over the past century has been remarkable. From the revolutionary discovery of the expansion of the universe; the realization that the universe is filled with giant, evolving galaxies, each filled with the myriad stars whose furnaces churn out the chemical elements from which we are formed; the discovery of exotic black holes; the evidence for a new type of *dark matter*—matter that does not shine but interacts only through gravity; the recent astonishing result implying a mysterious new form of *dark energy*, which fills all of space and is pushing the universe apart at an ever-accelerating rate; to the unambiguous detection of well over a hundred planets circling other suns—these discoveries excite the imaginations, not just of the scientists who have made them, but of people of all ages and interests. And Carnegie astronomers have been, and continue to be, world leaders in this overall endeavor.

As the 21st century dawns, the Observatories face a formidable and exciting challenge. The California Institute of Technology, the University of California, and the National Science Foundation (NSF)-funded National Optical Astronomy Observatory have partnered in proposing to build a 30-meter telescope. This consortium is also discussing the possibility of collaborating with European astronomers on a 60-meter, or perhaps even a 100-meter, telescope. NASA is planning a successor to the Hubble Space Telescope called the James Webb Space Telescope. A giant array of radio telescopes, the Atacama Large Millimeter Array, is planned for construction in Chile in the next decade. Given this scale of activity, is there a continuing role for Carnegie astronomy in the 21st century? Not only do I believe so, I also believe that our role is becoming increasingly important in this new era of giant, multi-institutional, government-funded, and perhaps international partnerships.

On March 1, 2003, after Augustus Oemler's productive six-year term, I became the tenth director

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[1] Maxine Singer, "The President's Commentary," Year Book 90/91 (Washington, D.C.: Carnegie Institution of Washington).

Left: This Magellan infrared image of the pair of colliding galaxies known as the Antennae was taken with PANIC, the Persson's Auxiliary Nasmyth Infrared Camera, built by staff member Eric Persson and infrared instrument specialist David Murphy. On its first commissioning night at the telescope during the spring of 2003, this camera achieved "astronomical seeing" of 0.27 arc second. For reference, this is very near to the resolution obtained with the Hubble Space Telescope orbiting above the Earth's atmosphere. This spectacular seeing is a reflection of both the success of the Magellan telescopes as well as the imaging potential in the near infrared. This camera is being used to study distant supernovae and the assembly of galaxies in the early universe.

"It is not easy to keep alive the tradition of independent private funding in an era of big government and continuing inflation. The Carnegie Institution is the chief sustainer of that tradition; it runs... the Las Campanas Observatory..."

—Freeman Dyson, 1984[2]

"It is impossible to predict the dimensions that reflectors will ultimately attain."

—George Ellery Hale, 1908[3]

of the Carnegie Observatories. I follow in the footsteps of a century of remarkable and dedicated individuals, from George Ellery Hale and his construction of the Mount Wilson telescopes, to our own recent construction of the 6.5-meter telescopes at Las Campanas. The directorship of George Preston ushered in a new era with the Magellan Project, and Ray Weymann, Leonard Searle, and Augustus Oemler all contributed greatly in the huge effort toward completing these telescopes. Both are operating successfully in Chile (Fig. 1).

In his 1981 book, *Cosmic Discovery: the Search, Scope, and Heritage of Astronomy*, Martin Harwit argued convincingly that the rate of astronomical discoveries was directly tied to the development of new technology. Examples include Galileo's discovery of the moons of Jupiter and the phases of Venus, Carnegie astronomer Edwin Hubble's discovery of galaxies outside the Milky Way and the expansion of the universe, the discovery of the remnant radiation from the Big Bang at microwave wavelengths, and so much more.

Earlier in the century, Hale possessed a similar view about new technology. He was convinced that progress in astrophysics would come with the construction of large, reflecting telescopes, and this vision was borne out repeatedly with the construction of the Mount Wilson solar telescopes, the Mount Wilson 60- and 100-inch reflectors, and the Palomar 200-inch telescope. None of those accomplishments came easily. But, remarkably, two years *before* the 60-inch was even completed(!), Hale had found an enthusiastic donor, John D. Hooker, for the planned 100-inch telescope. That tool provided a window on the universe that led to Hubble's revolutionary discoveries. As Carnegie astronomer Frederick Seares commented, Hale would occasionally utter, "The gods bring threads to a web begun."[4]

Fig. 1. The twin Magellan 6.5-meter telescopes, the Baade and the Clay, are located in the Andes Mountains in Chile.

A New Direction

As a fitting mark of our centennial, the Carnegie Observatories, with our Magellan consortium partners, have embarked on an exciting new telescope venture. Named the Giant Magellan Telescope (GMT), the 20-meter (65-foot!) design, the brainchild of Roger Angel of the University of Arizona, consists of seven 8.4-meter mirrors, six in an outer circle around one in the center. One begins to perceive the scale of the GMT when realizing that each of the individual segments has almost twice the area of a single Magellan 6.5-meter telescope (Fig. 2). The overall collecting area of the GMT will be 12 times that of the Magellan telescopes,

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[2] Freeman Dyson, *American Scholar 53*, 2 (Spring 1984).

[3] George Ellery Hale, *The Study of Stellar Evolution: An Account of Some Recent Methods of Astrophysical Research* (Chicago: University of Chicago Press, 1908) p. 242.

[4] F. H. Seares, *ISIS 30*, 240-267, 1939.

with a gain in sensitivity of more than a factor of 100. Moreover, the spatial resolution of the GMT, and consequently its ability to distinguish fine detail, will be 10 times that of the orbiting Hubble Space Telescope—but for a small fraction of the cost. And, if funded and begun now, it could be the first of the next-generation telescopes, which are already being engineered.

The scientific potential of the Giant Magellan Telescope is awe-inspiring. It is capable of achieving much of the science proposed for a 30-meter telescope, and that described by the decadal survey of the National Academy of Sciences, *Astronomy and Astrophysics in the New Millennium*. A novel aspect of its design will make it singularly capable of studying close-in planets around stars other than the Sun. The GMT will be poised to make fundamental discoveries in many areas: the appearance of the first light in the universe; the birth and nature of distant planets; the detection of planets with Earth-like characteristics (perhaps those that could harbor life); the understanding of how stars form within the shrouded regions in which they are hidden; the mysteries of dark matter and dark energy in the universe; the enigma of black holes; and the assembly of galaxies. Of course, as so often occurs with new and powerful capability, some of the most exciting discoveries may emerge in areas where we currently cannot even imagine the questions to ask. I will limit myself in this essay to a discussion of only exoplanets and the genesis of galaxies, two promising areas for study with the GMT.

Observing Extrasolar Planets with the GMT

The first discovery of massive exoplanets orbiting stars outside the solar system occurred in 1995, and already more than a hundred are known. This revolution is in large part due to the collaboration of Department of Terrestrial Magnetism staff member Paul Butler and UC-Berkeley astronomer Geoff Marcy. Prior to these observations, the general view, based on detailed theoretical modeling, was that planets with large, Jupiter-like masses could not form near a star, a theory now completely overturned by the data. As our knowledge of massive exoplanets has grown, fascinating new questions have catapulted into view, all the more exciting in the context of plans for a telescope with the power and high resolution of the GMT. Moreover, the unique design of the GMT, and its expected superb image quality, is such that it will have the capability *to see planets directly*. At present, discoveries of exoplanets are made by observing the motion of a parent star that is perturbed by the gravitational pull of the planet. These discoveries have led to new questions: Do planets like the Earth occur commonly, or is our planet a rare event? How, in general, do planets form? Does the interplay among planets in a system affect the location of a planet and thus, subsequently, whether there are conditions that could be favorable for life? The GMT will be capable of addressing questions about the atmospheric chemistry of exoplanets, what determines their chemical makeup, and ultimately it may ascertain if some planets are conducive to life. Such questions, so long the province only of science fiction, are now ripe for answers.

Fig. 2. The current design of the Giant Magellan Telescope (GMT) is shown side by side with one of the Magellan 6.5-meter telescopes. The two human figures by the GMT are shown for scale. The GMT will revolutionize our knowledge of nearby planets and provide a window on the earliest moments of our universe.

Detecting First Light in Stars and Galaxies

We are in the midst of a revolution in our understanding of the origin and evolution of the universe. Applying models of particle physics to the early universe, it is predicted that infinitesimally small parts of the universe expanded exponentially in an infinitesimally short time after the Big Bang. During this epoch, called the inflationary period, small differences in density were generated. These fluctuations grew gravitationally over cosmic time to produce the galaxies and galaxy clusters that we observe today. Observations of the cosmic microwave background radiation, produced about 300,000 years after the Big Bang, provide evidence of these early fluctuations. And deep observations made at the outer limits of the Hubble Space Telescope's capability have revealed faint smudges of galaxies, which formed about a billion years after the Big Bang. However, at present we know almost nothing about the era in between, the so-called dark ages of the universe. Our ignorance of this period is profound. We don't even know whether the first objects to form were ordinary stars or the more mysterious black holes.

The opportunity to detect this "first light" in the universe is only now coming within our grasp. The light from distant objects is shifted to red wavelengths (redshifted) due to the expansion of the universe. Fortuitously, the visible and ultraviolet light from distant galaxies is shifted to wavelengths of 1 to 2.5 microns, where the GMT will have its highest performance. With a GMT, we will be able to view how galaxies assembled and whether they were built from smaller objects that merged together. We will see directly when the first objects, whatever they were, were formed. The GMT, with its huge sensitivity, resolution, and ability to observe at infrared wavelengths, will literally be able to shine light on the dark ages.

The GMT Project

The GMT consortium (Carnegie, Harvard-Smithsonian, the University of Arizona, the Massachusetts Institute of Technology, and the University of Michigan) has begun a conceptual design study of a 20-meter telescope, and entered into an agreement initiated last year by Augustus Oemler. This year a project scientists' working group with members from each of the consortium institutions—including Carnegie staff scientist Steve Shectman and Arizona's Roger Angel—has actively undertaken detailed studies of the telescope design, mirror fabrication, dome construction, and instrument development. There are plans for a secondary mirror with several thousand actuators responding on very rapid timescales, which will yield higher spatial resolution, using a technique known as adaptive optics. Carnegie engineer Matt Johns, the project manager for the Magellan telescopes (following Al Hiltner and Peter de Jonge), is now the GMT project manager. A science working group, chaired by Carnegie scientist Patrick McCarthy, is exploring the scientific capabilities and instrument needs of the GMT. This group also has members from each consortium partner, as well as DTM staff scientist Alycia Weinberger. Finally, there is a governing GMT board with representatives from each institution, of which I am the elected chair.

The scale of science projects is increasing. Not just for astronomy, but for every branch of science, facilities are growing in size and cost. The major research equipment and instrumentation budgets at the National Science Foundation are severely overstrained; and the ability to begin new large projects is a difficulty for the NSF and an enormous challenge for an institution like Carnegie.

The Magellan telescopes were completed about a decade after other telescopes of comparable or greater size, and we became operational more than a decade after the Hubble Space Telescope was launched. A tremendous and productive synergy occurred as other large ground-based telescopes were able to provide spectra (and therefore redshifts, and other critical quantitative details such as the chemical makeup) of the objects newly studied or discovered by the Hubble. If at all possible, I believe that we should avoid repeating this situation for the GMT. Instead, we should strive to be operating at least at the same time as but preferably even *sooner* than the rest of the next-generation facilities. We should aim to be among the first to answer the questions we are posing, or we may miss the opportunity to reap the benefits of the new discovery capability that will be opened up by the GMT.

What makes us think that we can succeed in such an enterprise? There are numerous reasons why I am highly optimistic:

1. **We have a great track record.** The two Magellan telescopes were budgeted at $72 million. At its conclusion, the total cost of the project amounted to $68 million; that is, *the telescopes came in under budget!* This is no small feat. Many other large telescopes built over the past couple of decades ran over budget at the tens of millions of dollars level, and some overran by 50% of the estimated cost.

2. **The performance of the Magellan telescopes is superb.** The image quality of these telescopes appears to be unsurpassed by any other telescope, even those built at sites where the atmospheric seeing conditions are intrinsically better than at Las Campanas.

3. **We have a talented core group with the required expertise.** It is no accident that the Magellan telescopes came in under budget and have spectacular performance. It is a testament to the people who built them, particularly Steve Shectman, telescope engineer Steve Gunnels, and Matt Johns and his predecessors, Al Hiltner and Peter de Jonge. Many Carnegie Institution scientists and engineers played critical roles. And this same core group is now eager and poised to take on the challenge of the GMT.

4. **We have the necessary expertise in instrumentation.** Within the consortium there is a huge capability in astronomical instrumentation. On the Carnegie side, three major Magellan instruments were commissioned in the past year (Frontispiece, Fig. 3, and Fig. 4).

5. **We have a core group of interested institutions.** For all of the reasons enumerated above, all five of the Magellan consortium partners have contributed to the funding of the conceptual design phase of the GMT project, and they are seeking donors for further funding. We are actively talking to potential partners at other universities.

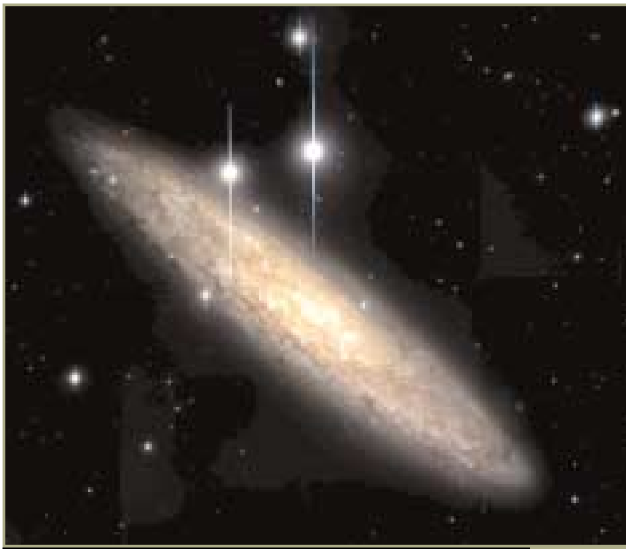

Fig. 3. This image of nearby galaxy NGC 253 was taken during the first commissioning run of the Inamori Magellan Areal Camera and Spectrograph (IMACS) in August 2003. Staff member Alan Dressler is the project scientist for IMACS, and Bruce Bigelow the project engineer. IMACS has a field of view on the sky of 27 arc minutes—comparable to the diameter of the full Moon and corresponding to an area about 100 times greater area than that of the Wide Field Camera of the Hubble Space Telescope. The IMACS spectrograph has the capability of obtaining spectra of many hundreds of objects simultaneously, using individual slit openings in a mask cut with a laser. For some applications, it will be able to take about 1,500 or more spectra at one time.

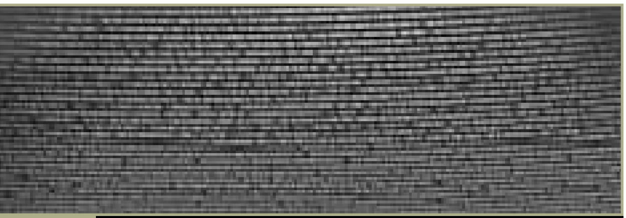

Fig. 4. The Echelle spectrum of the twilight sky was taken with MIKE, the Magellan Inamori Kyocera Echelle. MIKE is a high-resolution spectrograph built by staff member Steve Shectman and former Hubble Fellow Rebecca Bernstein, now an assistant professor at the University of Michigan. This spectrograph is so sensitive that it makes up for the smaller aperture of the Magellan telescopes relative to that of other, larger telescopes in operation. The hundreds of dark vertical bands are a result of absorption of various elements in the atmosphere of the Sun. The twilight sky is simply reflected solar light. This spectrograph is now being used to explore the formation history of our Milky Way galaxy and the most distant quasars in the universe.

I anticipate that the partnership in the GMT will evolve over the next several years as the design of the telescope becomes more concrete, and as institutions pursue various funding avenues. In the case of the Magellan telescope project, we originally began with an 8.4-meter telescope design in collaboration with Carnegie, the Johns Hopkins University, and the University of Arizona. The project eventually transformed into a different, larger partnership with two 6.5-meter telescopes. More institutions will likely wish to join the GMT project as we make more progress. Who knows? Perhaps we will build two 20-meter telescopes! The idea is not as crazy as it first sounds. Roger Angel has a concept that incorporates a second telescope on a movable track and acts as an interferometer with much greater resolution than that of the planned 20-meter or 30-meter telescopes. Such a "20/20" telescope would greatly enhance the potential for studying the atmospheres of Earth-like planets and newly forming stars.

In any case, in an era of giant collaborations, pursuing ideas in "the Carnegie way" becomes even more imperative. The GMT will not be a telescope that can do everything. It will be designed according to what the scientists and engineers agree is feasible within a constrained budget, and built on a heritage of success with the Magellan telescopes. At the same time it will incorporate novel technologies that will provide the greatest science potential for use by Carnegie and its partner-institution scientists. It will necessarily be a much different kind of project than multi-institutional/ government collaborations with budgets of about $1 billion and perhaps thousands of participants. And there will be a major role for creative, individual scientists, as envisaged and incorporated by Andrew Carnegie into the fabric of this institution.

No doubt the task before us is a daunting one. But our current 6.5-meter telescopes have collecting areas 20 to 240 times smaller than those of 30- or 100-meter telescopes. In the future, we will not be able to compete at the forefront of astronomical research with such disparities, and we have no choice but to find a way to succeed.

> *"What we like to do next is what people tell us we can never do."*
>
> *—Kazuo Inamori, Carnegie trustee, 1991*[5]

One hopes that the 21st century will bring many opportunities and stimulating challenges to the Carnegie Institution, in many different fields and in each of our departments. The institution will need to maintain a balance, as it has so successfully done before. For the construction of the Magellan telescopes a creative funding solution was found, and the project was completed with little impact on the institutional endowment. It is likely that the scale of the Giant Magellan Telescope will require, as in Hale's day, that a significant donor become sufficiently excited by this new enterprise to bring it into realization. Hale was fond of the phrase "Make no small plans." I resoundingly agree!

—Wendy L. Freedman
Crawford H. Greenewalt Director

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[5] Maxine Singer, "The President's Commentary," Year Book 90/91 (Washington, D.C.: Carnegie Institution of Washington).

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July 1, 2002 – June 30, 2003

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Patrick McCarthy
Andrew McWilliam
John Mulchaey
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George Preston, *Director Emeritus*
Michael Rauch
Allan Sandage, *Staff Member Emeritus*
François Schweizer
Leonard Searle, *Director Emeritus*
Stephen Shectman
Ian Thompson
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[1] From March 1, 2003
[2] To February 28, 2003
[3] From May 1, 2003
[4] To August 29, 2002
[5] From July 8, 2002
[6] From September 25, 2002
[7] To September 1, 2002
[8] To September 16, 2002`
[9] To August 1, 2002
[10] To July 31, 2002
[11] To August 15, 2002
[12] From October 1, 2002
[13] From January 1, 2003
[14] To December 3, 2002
[15] From June 25, 2003
[16] To November 1, 2002
[17] To October 31, 2002
[18] To August 31, 2002
[19] From September 1, 2002
[20] From October 16, 2002
[21] To August 26, 2002
[22] To August 5, 2002
[23] To November 30, 2002
[24] From March 15, 2003
[25] From January 2, 2003
[26] From July 1, 2002
[27] To September 6, 2002
[28] To December 19, 2002

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THE DIRECTOR'S REPORT

The Geophysical Laboratory (GL) conducts world-class research into the basic physics, geochemistry, and geobiology of Earth and the other planets, including fundamental properties of materials at temperatures and pressures of planetary interiors. This year's report highlights a variety of research areas: prebiotic chemistry, techniques for detecting microbial life on other planets, the understanding of geochemical processes in the interiors of Earth and Mars, the synthesis of superhard diamonds in the laboratory, and the discovery of a new form of graphite harder than diamond.

Prebiotic Chemistry on the Early Earth

Detection of a prebiotic threshold into the RNA world

Life appears to have arisen as a natural geochemical process of the primitive Earth. George Cody's work has shown that transition metal sulfides provide the catalysts necessary to promote key prebiotic carbon fixation reactions. He has also identified a chemical pathway starting with CO_2, H_2, and H_2S that leads to the synthesis of citric acid. This pathway is not similar to any known biological carbon-fixation scheme. Cody is now exploring the incorporation of nitrogen in hydrothermal reactions involving citric acid and various products and intermediates. He has shown that the addition of ammonia has an enormous effect, resulting in numerous new reaction pathways. One hydrothermal reaction was discovered that yields the pyrimidine orotic acid—a precursor to the pyrimidine nucleosides uracil, cytosine, and thymine—key components in the geochemical evolution toward RNA.

Origin of chirality

The discovery of plausible prebiotic mechanisms for the synthesis of biomolecules represents one of the greatest successes of origin-of-life research. The consensus is that Earth's Archean oceans were rich in organic molecules, including most of the basic molecules of life. A key problem remains, however: By what mechanisms did the complex organic soup differentiate and organize into useful biological structures? Bob Hazen has been conducting studies of adsorption on mineral surfaces as one attractive possibility.

Hazen has been examining chiral-selective adsorption on chiral crystal surfaces of quartz (tyrosine and perhaps alanine) and calcite (aspartic acid and glutamic acid). These mineral surfaces differentiate left- and right-handed molecules, with chiral excesses >10% in some experiments. Hazen finds that some other chiral molecules, such as malic acid and tartaric acid (both dicarboxylic acids), are not selectively adsorbed. This behavior points to a fundamental chiral selection requirement: there must be three noncolinear points of bonding between the chiral mineral surface and the chiral molecule. Dicarboxlyic acids are thus less likely to be chirally selected than tricarboxylic acids or amino acids, which contain three charged groups.

Left: This rendering is an artist's conception of the Huygens probe descending through the organic-aerosol-laden atmosphere of Saturn's moon Titan. (Courtesy ESA/NASA.)

Prebiotic Chemistry on Other Worlds

Characterizing the molecular structure of Titan "tholin" compounds

In mid-2004 the *Cassini-Huygens* spacecraft will reach Saturn and in 2005 it will launch the Huygens probe towards Saturn's moon Titan (Frontispiece). Titan is peculiar in that it has a dense atmosphere of N_2 with a few percent CH_4 and abundant organic aerosols. It may provide the solar system's largest abiotic organic reservoir. In preparation for the encounter, laboratory experiments have simulated organic synthesis in Titan's atmosphere. Brown organic solids called tholins form when N_2-CH_4 atmospheres are exposed to ultraviolet (UV) light; however, their molecular structure is complex and poorly characterized. George Cody has been collaborating with Gene McDonald at the Jet Propulsion Laboratory to use solid-state nuclear magnetic resonance (NMR) to gain a better understanding of this enigmatic material. Their data reveal a substance relatively rich in aliphatic carbon and hydrogen including formamides, carboxylic acids, and amidine and urea functional groups. Only a trace of nitrile is detected, and less than 10% of the nitrogen resides as amines. These data indicate that laboratory tholins react to produce numerous oxygen-containing groups when exposed to air. The formation of amide and urea imply that highly reactive nitrogen functional groups, such as carbodiimides, are present in the original tholin, suggesting that Titan's atmosphere can provide clues to ancient prebiotic chemistry on Earth.

Searching for Evidence of Life on the Early Earth

Sulfur isotope geochemistry has the complementary capabilities of identifying the activity of sulfur-metabolizing microbes via $^{34}S/^{32}S$ ratios and of recording the effects of solar UV light photochemistry on Earth's atmosphere via $^{33}S/^{32}S$ and $^{36}S/^{32}S$ ratios. Microbes preferentially metabolize ^{32}S, and consequently may cause large $^{34}S/^{32}S$ isotope fractionations that are easily measured in pyrite-bearing rocks. Solar UV light causes photochemical reactions in the atmosphere, where reaction rates are strongly influenced by isotopic composition. Disparate reaction rates lead to anomalous enrichments in ^{33}S and ^{36}S. The isotope enrichments are transported to the surface in aerosol particles, metabolized by microbes, and precipitated in pyrite. Thus, by measuring the four stable isotopes of sulfur, ^{32}S, ^{33}S, ^{34}S, and ^{36}S, in a single grain of pyrite, the presence of microbial activity and the action of UV atmospheric photolysis can be identified.

Postdoctoral fellow Shuhei Ono completed an investigation of the ratios of three of the four sulfur isotopes, ^{32}S, ^{33}S, and ^{34}S, in drill core samples from the Hamersley Basin, Western Australia. The entire range of presently known natural variations in anomalous fractionations of ^{33}S was found. A comparison of different depositional environments represented by black shale and dolomitized limestone shows that both normal and anomalous fractionation patterns are influenced by local depositional conditions. The observed large changes in isotope ratios are probably caused by a combination of two factors: (1) differential dilution of native sulfur atmospheric aerosols by seawater sulfate, and (2) fractionation of sulfur isotopes by local and different populations of microbes.

Searching for Evidence of Life on Other Planets

A test bed

Andrew Steele and his group of postdoctoral fellows—James Hall, Marc Fries, Jan Toporski, and Jake Maule—are developing miniaturized microbiological instrumental techniques to search for evidence of life on other planets, such as Mars. They have been developing a Modular Assay for Solar System Exploration (MASSE) test bed for applying these techniques on Earth. Steele is working with NASA's Marshall Space Flight Center to incorporate a microfluidic system for wet sample handling. Recently its feasibility has been proven for bacterial cell lysis and DNA extraction. The system will be incorporated into MASSE for protein and biomarker extraction.

A micro PCR lab

One of the stratagems for searching for life is to look for DNA-like molecules. This approach requires amplification of a tiny sample, which is normally done in modern forensic labs using PCR amplification, requiring a very large, complex, and human-intensive wet lab. In the course of developing a miniaturized flight instrument, a field kit for microbial detection and identification was assembled and deployed at the Jug Bay Natural Area in collaboration with Marilyn Fogel. PCR in the field was demonstrated for the first time in the Arctic, and protocols were successfully tested for field identification of 16 and 18s DNA genes, as well as functional metabolic genes including those involved in nitrogen cycling. This field kit will be employed at the Rio Tinto in Spain to support an Ames Research Center drilling project and in the Arctic Mars Analogue Svalbard Expedition to survey the world's northernmost hot-spring deposits (Fig. 1).

Nanometer microscopes

Another important capability required to find biomarkers on other planets is to examine samples with powerful microscopes to find and analyze biological morphologies. Steele has recently conducted concept studies on a new nanometer scale microscope, which combines atomic force microscopy (AFM), confocal light microscopy, confocal Raman and fluorescence spectroscopy, and near-field fluorescence spectroscopy for sub-30nm imaging and spectroscopy. Samples of the Tagish Lake meteorite, the Nakhla Mars meteorite, and some interplanetary dust particles were analyzed with this instrument at submicron resolutions.

Understanding Ecosystems on Earth

For the past three years Marilyn Fogel and Matthew Wooller (now at the University of Alaska Fairbanks) have been traveling to a remote island, Twin Cays, off the coast of Belize to study the biocomplexity of mangrove ecosystems. They have collected and measured carbon and nitrogen isotopic compositions of more than 1,000 red and black mangrove leaves, roots, stems, and wood samples. Early in the study, they found a very unusual and particularly large range in nitrogen isotopic compositions.

Together with John Cheeseman of the University of Illinois and Myrna Jacobson of the University of Southern California, Fogel and Wooller assembled an integrated picture of nitrogen cycling at Twin Cays. They believe that foliar uptake of ammonia may be a critical source of nitrogen for the mangrove ecosystem. Because phosphorus limitation is extreme, dwarf trees have adapted to resolving nitrogen limitation and root dysfunction through their leaves. The researchers conclude that phosphorus-limited dwarf trees growing adjacent to ammonia sources, in addition to lichens on trees in microbial and dwarf zones, obtain a large portion of their nitrogen from atmospheric sources. Although it has been shown that foliar uptake is an important pathway for nutrient uptake for crop plants, the possibility that the nitrogen cycle at Twin Cays has a large atmospheric component supporting mangroves has not been demonstrated previously in natural ecosystems.

Fig. 1. Andrew Steele (black hat) and intern Maia Schweizer (red hood) conducting PCR of bacterial ribosomal and functional genes in situ at Trollolsen Springs, Svalbard, Norway. The two gun-carrying polar bear guards are expedition leader Hans Amundsen (left) and Allan Treiman (LPI).

Earth's Interior

Natural occurrence and synthesis of two postspinel polymorphs of chromite

Rus Hemley and Dave Mao have discovered two new minerals with far-reaching implications. In a single chromite grain in the shock veins of the Suizhou meteorite, they identified three zones of identical composition but with different crystal structures: a new dense polymorph with a type structure of $CaTi_2O_4$ (CT), another with a type of $CaFe_2O_4$ (CF), and the original chromite. Laser-heated diamond-anvil-cell experiments establish that chromite-spinel transforms to the CF phase at 12.5 gigapascals (GPa), then to the CT phase above 20 GPa. With the ubiquitous presence of chromite, the CF and CT phases may be among the most important index minerals for a natural transition sequence in mantle rocks and shock-metamorphosed meteorites.

Forty years ago Ted Ringwood, a prominent GL alumnus, searched for denser polymorphs of the newly discovered silicate spinel (ringwoodite) and modified spinel (wadsleyite) that were stable at the pressure and temperature conditions of the Earth's transition zone. He proposed orthorhombic CF and CT structures as the top candidates for "post-spinel" phases for the lower mantle. Although the dominant ferromagnesian silicate spinels were later found to break down to simple oxides or stishovite plus perovskite, this Hemley-Mao work establishes that oxide spinel actually transforms to postspinel CF and CT polymorphs. The quenchable polymorphic series provides valuable information on the high P-T history of the natural sample. In addition, these postspinel phases behave as hosts for many major and trace elements in the deep Earth, such as Cr, Al, Mg, Fe, Na, Si, and other transition and rare Earth elements, thus playing a major role in element partitioning and geochemical evolution.

Silicate glass at high pressure

The structure of silicate glasses and melts at high pressure plays a key role in many magmatic processes in the crust and mantle and has been a challenging problem in high-pressure/high-temperature geochemistry and condensed-matter physics. Carnegie Fellow Sung Keun Lee, working with staff members Yingwei Fei, George Cody, and Bjørn Mysen, recently explored the nature of high-pressure glasses and melts using two-dimensional ^{17}O 3QMAS NMR (triple quantum magic angle spinning nuclear magnetic resonance) and the multianvil high-pressure apparatus. The two-dimensional NMR technique provides improved resolution over conventional MAS NMR. Figure 2 shows its first spectra for sodium silicate glass quenched from melts at 10 GPa. The spectra reveals new structural details for the melts at high pressure. The atomic structures of glasses at high pressure are significantly different from those at ambient pressure and show evidence of extensive chemical ordering, which affects corresponding thermodynamic and transport properties. These results and methods shed light on studying melt structures at high pressure and provide improved prospects on microscopic origins of melt properties and the geochemical processes in the Earth's interior.

Planetary Interiors

Temperature of the Martian core

Space missions to Mars have provided important constraints on the planet's internal density distribution; however, its thermal structure remains uncertain. Estimating the core temperature is difficult because of the uncertainty in the core's chemical composition and physical state. Several lines of observation may clarify the physical state. These observations include the solar tidal deformation data based on *Mars Global Surveyor* radio tracking, the weak magnetic field on Mars today, and the existence of a strong past magnetic field as discovered by the spacecraft. The solar tidal deformation data suggest a liquid Martian core. Melting experiments conducted in the multianvil high-pressure lab indicated that a minimum temperature of 1400 K at the core-mantle boundary is required to sustain a liquid outer core. A tight constraint on the core temperature requires knowledge of the sulfur content and its effect on the liquidus temperatures between pure iron and the eutectic composition

(15 wt%S). staff member Yingwei Fei and Visiting Investigator Connie Bertka have determined the liquidus temperatures in the Fe-Fe_3S system at high pressure, which define the minimum temperatures for an entirely liquid Martian core. For such a core, the inferred core temperature would be greater than 1800 K at the core-mantle boundary pressure.

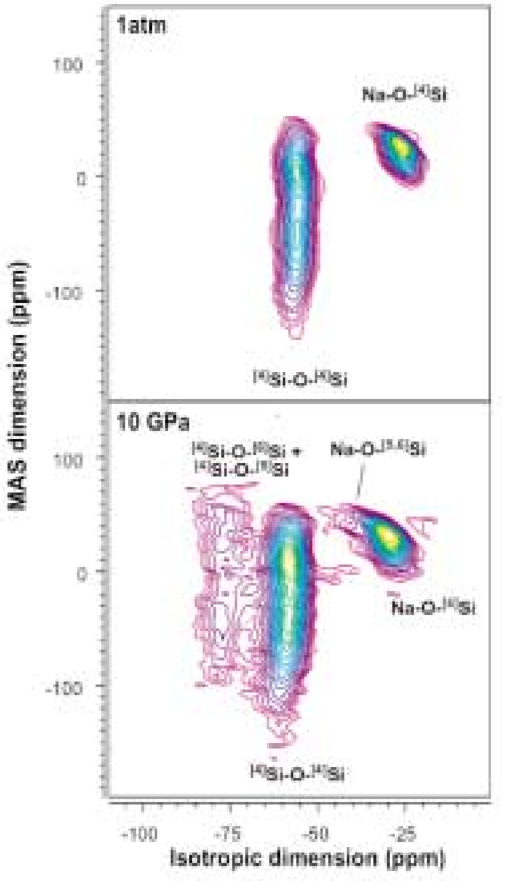

Fig. 2. ^{17}O triple quantum MAS NMR spectra for sodium trisilicate glasses is quenched from melts at ambient pressure and at 10 GPa in a multianvil device. This image reveals new oxygen sites at high pressure, including $^{[5,6]}$Si-O-$^{[4]}$Si and Na-O-$^{[5,6]}$Si. (Reprinted with permission from *Geophys. Res. Lett.*, *30*(16), 1845, 10.1029/2003GL017735, 2003. Copyright 2003 American Geophysical Union.)

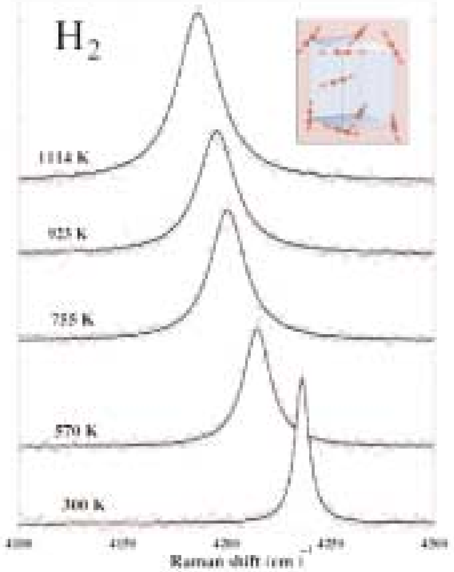

Fig. 3. This is an image of Raman spectra of hot dense hydrogen at 70 GPa.

Spectroscopy of hot dense hydrogen

The behavior of hydrogen at high pressures and temperatures is critical to understanding problems ranging from fundamental physics and the interiors of large planets to processes leading to inertial confinement fusion. Measurements of vibrational spectra of dense hydrogen over an expanded range of pressures and temperatures provide new insight into the nature of the material under extreme conditions. High P-T Raman measurements have been performed for the first time on solid and fluid hydrogen to above 1100 K and to 155 GPa, conditions previously inaccessible by static compression experiments (Fig. 3). The data give a direct measure of the melting curve, extending previous optical investigations by up to a factor of four in pressure. The magnitude of the temperature derivative of the H-H stretching mode frequency increases significantly over the measured pressure range, indicating an increase in anharmonicity and weakening of the molecular bond. Additional information has been obtained from Brillouin, infrared, and optical spectra of hydrogen at variable P-T conditions.

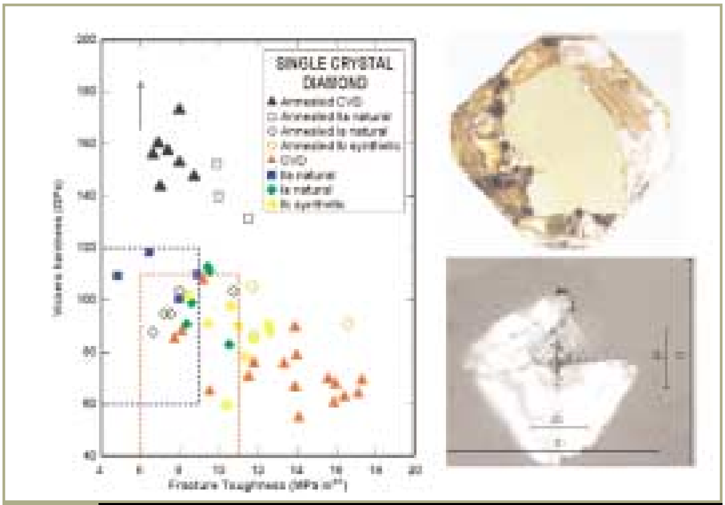

Fig. 4. At left is Vickers hardness and fracture toughness on the {100} faces of various diamonds in the <100> direction. Reported ranges for natural IIa diamond are enclosed by the blue dotted square and for polycrystalline CVD diamond films and conventional polycrystalline diamond by the red dotted square. The arrow indicates a lower bound. At upper right is a 1 mm-thick annealed CVD diamond grown on a 4x4x1.5 mm^3 type Ib seed (residual yellow color from the seed). At lower right is a photomicrograph of the CVD diamond after indentation. Also shown is a sketch of the cracked lines, d_1, d_2, c_1, and c_2, used to determine the hardness (H_v) and toughness (K_c) using standard procedures.

Fundamental Properties of Materials

New high-energy-density materials from high pressure

Recent developments in high-pressure techniques have resulted in significant progress in the creation and characterization of novel high-energy-density materials—substances that could be used as future fuels and propellants. One of the most interesting is pure nitrogen, which has been examined over a broad range of conditions. Exploration of the phase diagram to 900 K and 100 GPa has revealed new classes of polymorphs, including phases in which the diatomic molecules are strongly interacting (e.g., polynitrogen). These investigations also shed light on the polymer of nitrogen produced by the GL group several years ago at higher pressure. High P-T experiments above 100 GPa reveal numerous transformations including one to a phase containing polymeric nitrogen that can be preserved and recovered at ambient pressure. A novel salt, nitrosonium nitrate ($NO^+NO_3^-$), was produced by laser heating of N_2O and N_2O_4 under pressure and characterized by a variety of techniques. At temperatures below 180 K, the $NO^+NO_3^-$ species was found to persist at atmospheric pressure, making it an intriguing high-energy material.

Ultrahard single-crystal diamond

The search for new types of superhard materials continues to be a major focus of materials research. During the past year, GL scientists have successfully combined high growth-rate chemical vapor deposition (CVD) of single-crystal diamond with a high-pressure/high-temperature technique to produce a material that is significantly harder than any other diamond-based substance. The microwave plasma CVD-grown single-crystal diamond (>1 mm thickness) was deposited on type Ib {100} synthetic diamond. High-pressure/high-temperature annealing at 2000° C and 5-7 GPa using a multianvil apparatus transformed the CVD diamonds into a transparent, colorless material (Fig. 4). Surprisingly, the annealed CVD diamond is ultrahard (~160 GPa), of a hardness beyond that of both type IIa natural diamond and polycrystalline diamond. These observations indicate that the annealed CVD single-crystal diamond is in fact harder and tougher than the measured values indicate. This diamond, with its high growth-rate synthesis, should find a variety of applications in technology and basic materials research.

Bonding changes in compressed superhard graphite

Graphite has long been known as a unique example of an opaque metal that transforms reversibly to a transparent insulator by compression. The previous interpretation that the high-pressure phase was hexagonal diamond or a diamondlike material left numerous unsettling questions. Probing the basic bonding and crystal structure of the compressed graphite with newly developed high-pressure X-ray spectroscopic and diffraction techniques, GL researchers have concluded that the high-pressure phase is quite simple yet elegant: under compression along the c-axis, the p bonds of bridging carbon atoms convert into s bonds while the p bonds of nonbridging carbon atoms remain unchanged. This new material essentially has the crystal structure of graphite but the physical properties of diamond. In addition, it was demonstrated that the high-pressure graphite is superhard and capable of indenting diamond (Fig. 5).

—Wesley T. Huntress, Jr.

Fig. 5. This photomicrograph shows a ring crack in the diamond anvil caused by the high-pressure, superhard form of cold-compressed graphite. (Reprinted with permission from *Science 302,* 426. Copyright 2003 American Association for the Advancement of Science.)

Fig. 6. Members of the Geophysical Laboratory staff are shown in November 2003. First row (from left): S. Ono, G. Cody, M. Fogel, J. Scott, A. Steele, D. George, S. Schmidt, P. Esparza, P. Wang, and A. Contreras. Second row: S. Keshav, M. Bacote, J. Shu, Y. Ueno, P. Roa, R. Dingus, P. Dera, S. Hardy, Y. Fei, E. Gregoryanz, and P. Meeder. Third row: B. Key, Z. Gong, O. Degtyareva, C. Hargrove, D. Presnall, M. Wolf, B. Hazen, W. Huntress, J. Toporski, B. Militzer, A. Asthagiri, Z. Wu, R. Hemley, and K. Lipinska-Kalita. Fourth row: J. Straub, D. Presnall, C. Hadidiacos, B. Mysen, S. Gramsch, R. Cohen, L. Ehm, J. Maule, M. Aihaiti, and Y. Chen. Fifth row: T. Okuchi, N. Irvine, G. Gudfinnsson, J. Lin, A. Colman, G. Sághi-Szabó, S. Lee, V. Struzhkin, Y. Song, and J. Hall. Missing from the picture: N. Boctor, G. Bors, B. Brown, Z. Chen, N. Choudhury, S. Coley, B. Collins, M. Fries, M. Furlanetto, M. Imlay, A. Mao, D. Mao, B. Minarik, N. Platts, D. Rumble, M. Santoro, R. Scalco, R. Torres, J. Xu, and C. Yan.

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[1] Retired October 31, 2002
[2] Retired June 30, 2003
[3] Retired June 30, 2003
[4] From January 1, 2003
[5] From July 1, 2002
[6] To December 31, 2002
[7] From January 15, 2003
[8] To June 30, 2003
[9] Joint appointment with DTM
[10] From May 8, 2003
[11] To September 30, 2002
[12] From June 1, 2003
[13] To March 31, 2003
[14] To November 23, 2002
[15] From June 23, 2003
[16] From March 17, 2003
[17] From September 1, 2002
[18] From January 15, 2003
[19] To March 31, 2003
[20] From July 1, 2002
[21] From July 1, 2002
[22] To October 31, 2002
[23] To October 1, 2002
[24] To June 30, 2003; joint appointment with DTM
[25] From June 30, 2003
[26] To March 31, 2003
[27] To December 31, 2002
[28] To June 30, 2003
[29] To August 16, 2002
[30] To August 31, 2002
[31] To August 31, 2002
[32] From June 25, 2003
[33] From September 11, 2002
[34] From July 1, 2002
[35] Joint appointment with DTM
[36] From May 26, 2003; joint appointment with DTM
[37] Joint appointment with DTM
[38] From October 1, 2002, to May 31, 2003
[39] Joint appointment with DTM
[40] Joint appointment with DTM
[41] Joint appointment with DTM
[42] Joint appointment with DTM
[43] Joint appointment with DTM
[44] Joint appointment with DTM
[45] From July 29, 2002
[46] Joint appointment with DTM

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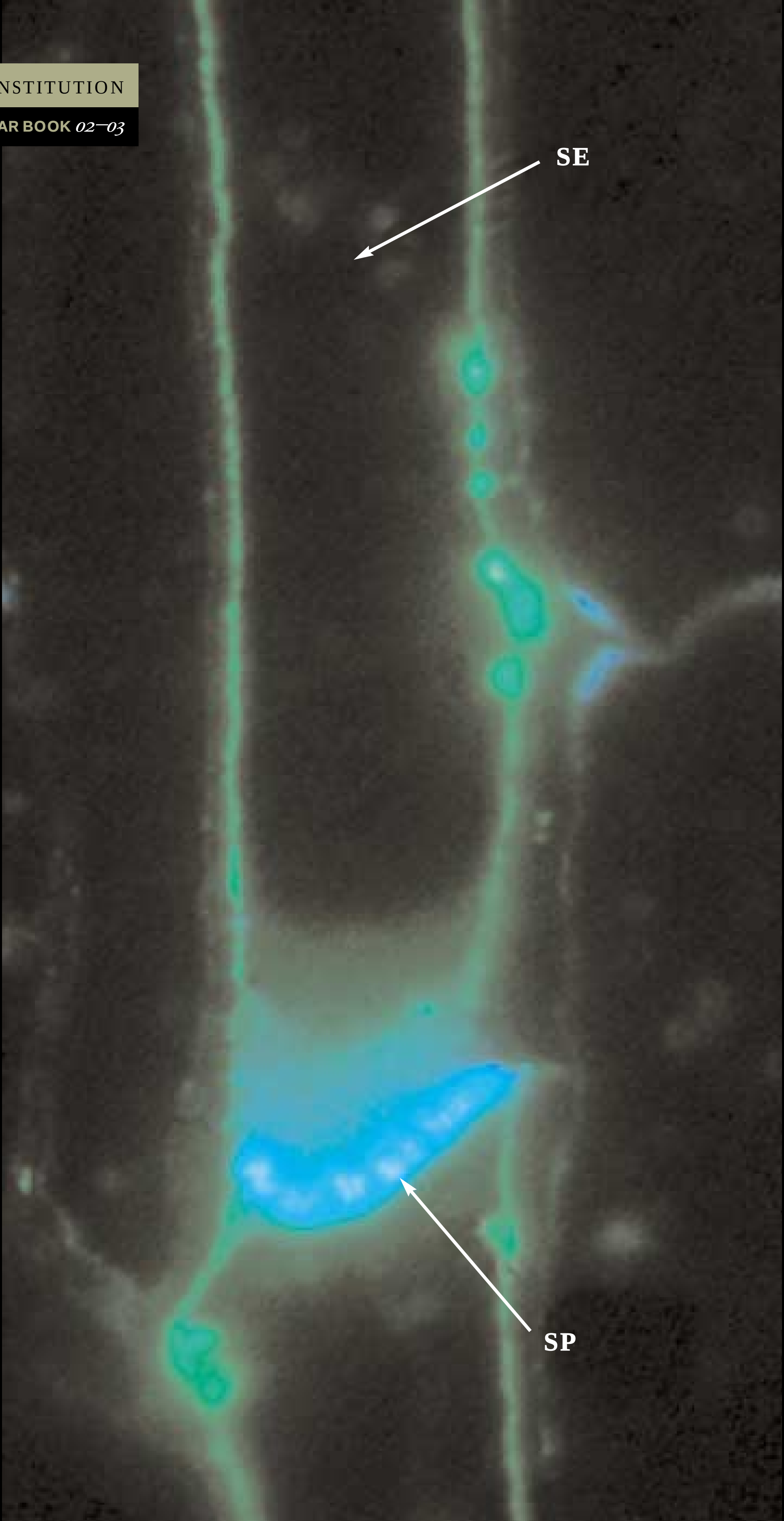
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THE DIRECTOR'S REPORT

To understand plant cell function in the postgenomic era, it will be necessary to know what each gene encodes, how much of each gene product is present, and where the gene products are located. It will also be necessary to discern what other kinds of molecules are present in the cell, where they are located, and how much of each molecule resides in the various cellular compartments. Two new department staff members, David Ehrhardt and Wolf B. Frommer, are pursuing complementary new approaches to these daunting problems.

Dave joined the department as a staff associate six years ago, following postdoctoral studies with Sharon Long at Stanford University. He rapidly integrated into the department. His deep knowledge of cell biology and imaging methods and his collegial approach to research stimulated other members of the department to think about problems in new ways. During his six years at Plant Biology he has collaborated with most of the other research groups, contributing many thoughtful insights and beautiful images that reveal new aspects of biological phenomena.

Wolf came to the department from the University of Tübingen, where he was professor of plant physiology. In that capacity he managed a large group of graduate students, postdocs, technicians, and junior faculty. His technician, Melanie Hilpert, and two postdocs, Marcus Fehr and Sakiko Okumoto, came with him to found his new Carnegie laboratory. Because the members of the new Department of Global Ecology are still housed in the Department of Plant Biology facilities, there was no space for Wolf and his lab in the department. Stanford University generously offered him laboratory space in the Gilbert Biosciences Building during his first year. When the new Global Ecology building is completed in early 2004, we will renovate the space formerly occupied by Chris Field, Joe Berry, and Olle Björkman for Wolf and Dave, and we expect them to occupy the space by the summer of 2004.

The research groups led by Dave and Wolf focus on the development and use of new tools to observe and measure molecules in living cells. Both laboratories use fluorescence-imaging technology based on new methods that permit specific labeling of biological molecules and cellular structures with fluorophores. The relatively noninvasive nature of fluorescent detection allows visualization of these labels in living tissue, such that transient and dynamic events can be seen and measured in three dimensions. The discovery of the green fluorescent protein (GFP) from the jellyfish *Aequorea victoria*, and its many natural and mutated spectral variants, has provided new and powerful opportunities to create fluorescent proteins. GFP can be fused to

Left: Sucrose is transported in a specific conduit inside plant cells named sieve elements (se)—cells that degrade their nuclei after they form. Despite this loss, sieve elements can remain functional. They are tightly associated with their neighboring cells via plasmodesmata, which mediate transport of nucleic acids and proteins. Sucrose-transporter proteins are present in sieve elements. Antibodies directed against the central loop of a sucrose -transporter can be used to localize the cells and membranes in which the transporter protein is present. Here the low-affinity sucrose-transporter SUT4 from tomato is localized. This finding is highly interesting since mature sieve elements have no nuclei and are unable to transcribe genes. Since the gene is expressed in companion cells and the protein is found in sieve elements, either the mRNA or the protein must be transferred from companion cells to sieve elements, probably through plasmodesmata. (Image courtesy Wolf Frommer.)

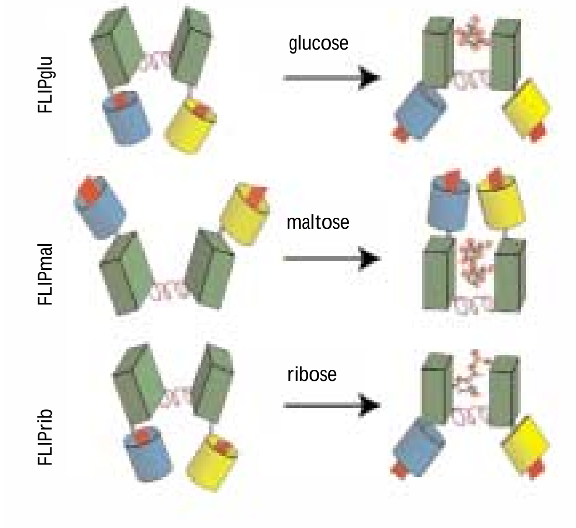

Fig. 1. Nanosensors are used for in vivo metabolite imaging. This diagram illustrates the principle of nanosensors for the detection of sugars. The nanosensors consist of three modules: a blue version of the “green fluorescent protein” (GFP), a sugar-binding protein (green) from bacteria (periplasmic binding protein), and a yellow version of the green fluorescent protein. The binding protein itself is composed of three domains: two globular domains (lobes) involved in binding the sugar and a spring connecting the lobes. When the sugar is recognized by the binding protein, the binding protein closes using a “clam” or “Venus flytrap” mechanism. The movement drives the two GFP versions farther apart for the glucose- and ribose-binding proteins (FLIPglu and FLIPrib), or, in the case of the maltose-binding protein (FLIPmal), closer together. When the blue GFP is irradiated with light that activates fluorescence, it will emit fluorescence and, in addition, it can transfer energy to the yellow GFP by resonance. Thus although the yellow GFP is not irradiated it will emit fluorescent light at a wavelength different from that of the blue GFP. The efficacy of resonance energy transfer depends on the distance between the two GFPs and thus on the binding to the substrate. Thus, more light from yellow GFP relative to blue GFP in case of FLIPglu indicates no bound glucose, whereas a reduction in resonance energy transfer indicates bound glucose. FLIPmal behaves inversely. (Image courtesy Wolf Frommer.)

any protein sequence and expressed in any cell in transgenic plants. This flexibility allows fluorescently tagged proteins to be expressed in cell types that are difficult or impossible to microinject, and on a tissue scale that is not accessible with microinjection. Further, the genetic nature of GFP and its variants promotes novel strategies for generating cellular probes and using fluorescent markers in living tissue.

The Frommer lab has used GFPs of different spectral properties to create a new generation of optical sensors for small molecules such as sugars, allowing measurement of these key metabolites in living cells for the first time (Figs. 1 and 2). Since the

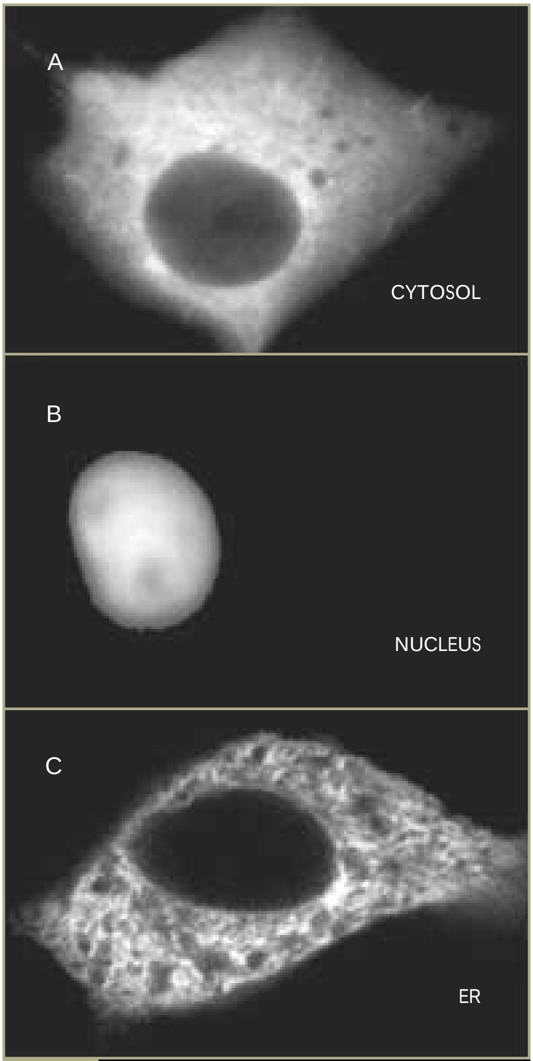

Fig. 2. To image glucose levels in different cellular compartments, FLIPglu can be specifically targeted by adding “ZIP codes.” (A) FLIPglu expressed in the cytosol of a mammalian cell, (B) FLIPglu expressed in the nucleus of a mammalian cell, and (C) FLIPglu expressed in the endoplasmic reticulum of a mammalian cell. It is thus now possible to measure glucose or other metabolites in subcellular compartments of living cells. (Image courtesy Wolf Frommer.)

cellular membranes limit exchange with the environment, cells have a large number of protein pores that control import and export of molecules. These transporters either equilibrate specific solutes with the extracellular medium, or they transport the compounds actively into or out of the cells. Similarly, transporters also control the movement of metabolites between different organelles within cells. Since in most metabolic pathways transport represents the first step, regulation of transport activity is critical for controlling metabolism and development.

Membrane transport proteins are very modular proteins, typically composed of arrayed α-helices that can pass the membrane to form the pore. The modularity facilitates the identification of genes for transport proteins by bioinformatic methods. Analysis of the *Arabidopsis* genome for putative transporters indicates that approximately 8% of all genes encode transporters. (For more information see http://aramemnon.botanik.uni-koeln.de/.) The large number of putative transporters highlights the central importance of controlling transmembrane flux of molecules to the processes that support life.

Membrane proteins are difficult to study because they normally adopt a functional conformation only when solubilized in a membrane. Therefore, during the past decade these proteins have largely been studied by expressing the corresponding genes in a surrogate host such as yeast cells or frog's eggs (*Xenopus* oocytes), or by suppressing the function of the genes by transgenic methods. These methods have resulted in the identification of transporters for sugars and amino acids. Wolf's group was the first to identify sucrose and amino acid transporters in plants. They found that these proteins localize to the plasma membrane of the vascular tissue, suggesting a function in long-distance transport. Sucrose is a primary product of photosynthetic CO_2 fixation and is the carrier of carbon from photosynthetic tissues to nonphotosynthetic tissues such as roots, flowers, and seeds. Interestingly, sucrose transporters were localized in the membranes of sieve elements, very peculiar plant cells that lose their nuclei during development. This raised the question of how sucrose transporters can be constantly supplied to a cell lacking nuclei. The solution seems to be that the mRNA is produced in the neighboring companion cells and moves through plasmodesmata into the sieve elements, where translation and delivery to the plasma membrane must occur. The mechanism by which this movement of RNA happens represents one of the future challenges for the group.

Wolf's work has shown that there are three types of sucrose transporters, all present in sieve elements, which have been shown to interact in com-

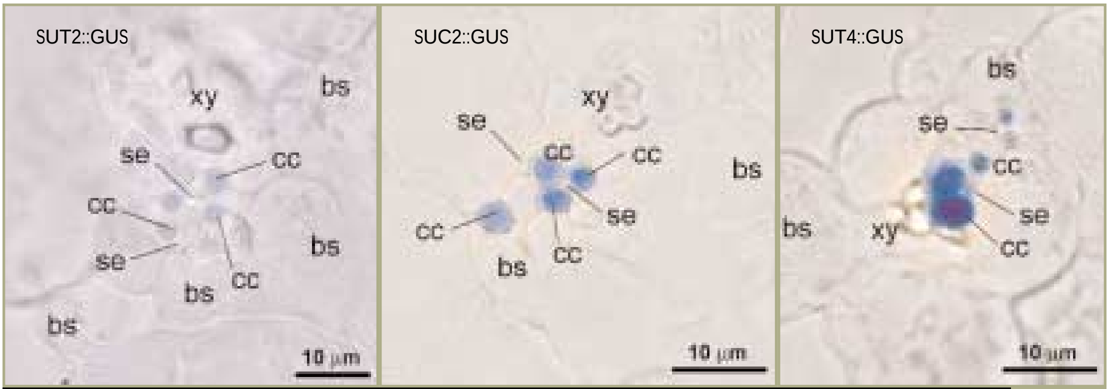

Fig. 3. Localization of the expression of three sucrose transporters from *Arabidopsis* is shown. The promoters of SUC2, SUT2, and SUT4 were fused to the β-glucuronidase reporter gene. Cells turning the gene on are able to convert a colorless precursor X-gluc into indigo blue. All three fusion genes are expressed in the phloem, more specifically in the companion cells that neighbor the actual conduits, the sieve elements. (Image courtesy Wolf Frommer.)

plexes (Fig. 3). Thus, another challenge is to characterize the role of the individual transporters and to understand why they have the potential for oligomerization. Related questions being addressed are how amino acids, the major nitrogen transport form in plants, are ferried throughout the plant and how phytohormones, which control carbon and nitrogen allocation, exert their effects over long distances. Respective carriers have been identified and studied regarding their biochemical functions.

Although at present some carriers have been identified, many of the transporters that are predicted to exist are still unknown. Functions have been assigned to less than 50% of all genes for putative transporters. Proteins that function in export and intracellular transporters are technically more challenging to study than the proteins involved in cellular uptake. Thus, Wolf is developing new methods that may enable monitoring of efflux or vacuolar uptake. Another problem is that metabolic pools within cells can change very rapidly and cannot directly be observed by currently available methods. Therefore, the factors that control compartmentation of sugars or amino acids are still poorly understood. To approach this problem, Wolf developed fluorescent nanosensor proteins that exhibit changes in fluorescence depending on the concentration of a specific ligand in the solution. Thus, by simply measuring the amount of fluorescence emitted from a cell, or part of a cell, it is possible to know precisely how much of the ligand is present. Wolf thinks it likely that a family of such sensors can be developed for the key metabolites and hormones present in plant cells. The new fluorescent sensors will facilitate progress in understanding the factors that control dynamic changes in living cells by allowing direct visualization of metabolite concentrations at a subcellular level.

David Ehrhardt uses imaging technologies to investigate the mechanisms that create plant cell structure, shape, and pattern. Plant cells are different from animal cells in that they have thick cells walls composed mostly of polysaccharides. The cell wall not only protects plant cells and provides them with mechanical support, it also plays a central role in the mechanisms by which plants achieve form and pattern. When a plant cell divides, the daughter cells remain surrounded by the cell wall of their mother and a new cell wall is created to separate them. The new cell walls hold the daughter cells in a fixed position relative to each other so they are not free to migrate and change position. Thus, plant cells typically establish their identity and function by their position—they need to determine who their neighbors are and respond appropriately. The cell wall, however, also limits the means by which plant cells can share such information. It prevents cells from direct contact, so signals must be sent either across the walls, or via special sites where direct channels, or plasmodesmata, form between neighboring cells. Although there is growing evidence that these channels through the cell walls play an important role in plant cell com-

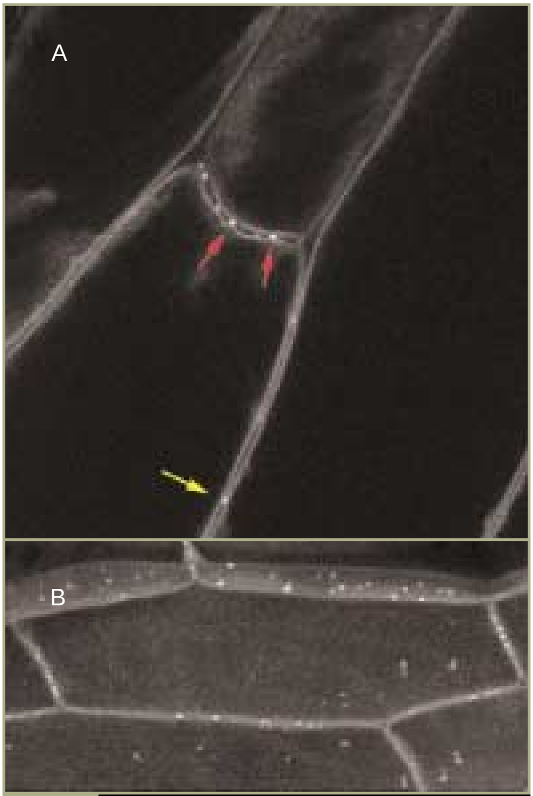

Fig. 4. A GFP fusion to a membrane-protein identifies cell-cell channels, or plasmodesmata (arrows), through which macromolecules are exchanged between neighboring cells. (Image courtesy Dave Ehrhardt.)

munication and development, little is understood of their molecular composition, the mechanism of their formation, or how they are regulated.

To identify and study poorly understood components of cellular structures, such as plasmodesmata, Dave and graduate student Sean Cutler developed a screen for fluorescently tagged protein sequences that localize to discrete subcellular locations. They isolated and fused random fragments of plant genes to a gene-encoding GFP. This library of chimeric genes was introduced into *Arabidopsis*, and the resulting transgenic plants were screened for expression and subcellular localization of the fluorescent protein. This process resulted in the identification of a host of peptide sequences that direct the fluorescent protein to discrete locations within the cell. The probes were made immediately available to the scientific community and have enabled or enhanced a variety of studies at Carnegie and in many other labs around the world. Dave and staff associate Sue Rhee are now engaged in a large-scale, multi-institutional effort to fluorescently tag most or all of the genes of unknown function in *Arabidopsis*. The time and place of expression, and the localization of the chimeric proteins within the cell, will help to generate hypotheses for the function of these unknown genes. A localization pattern can be determined for a chimeric protein even if the native protein is essential for the viability of the organism, a problem often encountered in analysis of protein function by gene inactivation.

The protein:GFP fusions recovered from this project will be useful for exploring structures that are defined morphologically but for which few if any unique component proteins are known, a prominent example being plasmodesmata. Dave identified a fusion protein that localizes to these channels (Fig. 4). He is now using transgenic plants that express this protein in a variety of ways to learn more about these essential but mysterious conduits through the walls of neighboring cells. Because the structures can now be visualized, it has become possible to screen for mutations in genes that are required to specify how many channels are made, how the cell decides where to place them, and in which cells the channels are created. Likewise, it is now possible to screen for chemicals in combinatorial libraries that inhibit or activate these gene products, a useful strategy if the underlying genes are also essential. Because the chimeric probe likely interacts with other proteins to be directed to and retained at cell channels, it may be used as a biochemical hook to pull out proteins that may form a part of plasmodesmata or that may be used to direct protein traffic to these sites. Thus, Ehrhardt's work provides many new openings to comprehend these important but poorly understood components of plants.

Dave and Wolf intend to join their efforts to address micro- and macromolecule movement through plasmodesmata. In addition to finding markers for the plasmodesmata, Ehrhardt and collaborators have identified many other useful markers and have used them to understand a variety of other cellular processes. They recently discovered that the creation of the cell plate, which had previ-

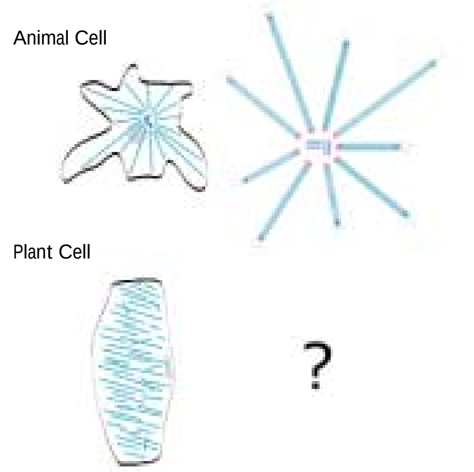

Fig. 5. The microtubule cytoskeleton plays important roles in cell organization and development. The microtubule cytoskeleton of animal cells is arranged in a radial and polarized array by a microtubule organizer called the centrosome. Plant cells lack identifiable centrosomes and create highly organized arrays of microtubules that are not observed in animal cells, such as the helical interphase array around the plant cell cortex. It is not yet understood how these arrays are created and organized. (Image courtesy Dave Ehrhardt.)

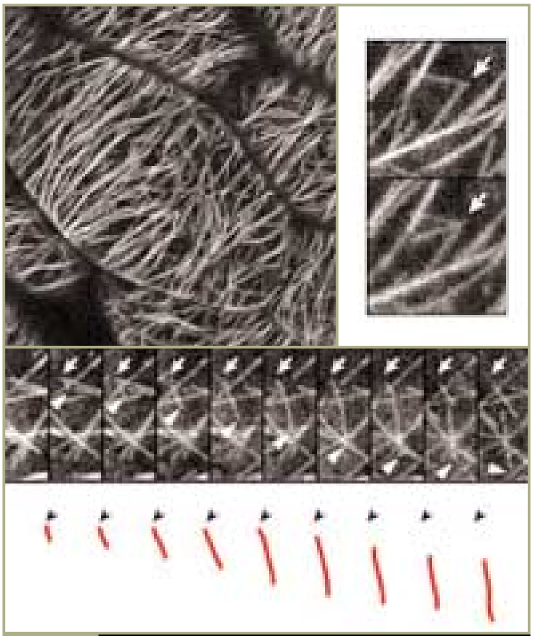

Fig. 6. At top left, individual microtubules can be tracked by confocal imaging of GFP-labeled tubulin protein. At top right, time-lapse imaging of microtubules in living *Arabidopsis* seedlings reveals that microtubules can originate at multiple sites around the cell cortex, suggesting that many organizing centers are not confined to a common and central location in plant cells. At bottom, microtubules are observed to change position by migrating across the cell cortex. Photobleaching experiments revealed that this motility is due to polymer treadmilling—loss of protein at one end coupled with gain at the other. (Image courtesy Dave Ehrhardt.)

ously been thought to initiate in the center of most plant cells, was instead displaced to the edge of the cell in some cell types. This displacement results in a highly polarized mode of development in which the new cell plate grows as an advancing front from one side of the cell to the other, rather than as a radially expanding disk from the cell's center. This mode of development suggests an important role for short-range molecular interactions at the cell cortex to guide the placement and insertion of the new cell wall, an important determinant of cell shape. Because the researchers were able to visualize this process in intact tissue, they could also ask if neighboring cells influenced this intracellular process. They found that the position of peripheral displacement of the cytokinetic apparatus was indeed not randomly chosen but preferentially occurred where the cell was in contact with a neighbor, suggesting that adjacent cells influence the organization of their neighbor's cell cortex.

Ehrhardt and technician Dori Allen also created a series of optimized fluorescent tags for the microtubule cytoskeleton. The cytoskeleton is an organizational engine, forming distinctive arrays that serve to direct cellular processes including secretion, cell division, and cell growth pattern. To understand how plant cells become organized to achieve developmental pattern, we need to determine how the cytoskeleton becomes organized and how an organized cytoskeleton helps direct the machinery of cytokinesis and cell growth. Plants offer unique insight into the mechanisms of cytoskeletal organization because they build novel arrays, such as the helical cortical array and the preprophase band that are not found in animal and fungal cells (Fig. 5). Further, plant cells appear to lack a defined organelle, such as a spindle pole body or centrosome, to act as a centralized organizer of the cytoskeleton as in yeast and animal cells, respectively. Organizational mechanisms that we discover in plant cells may also act in animal cells, but are less accessible or visible.

The new probes allow visualization of individual microtubules in living plant cells and for the first time provide a window onto the dynamic behavior of the plant cytoskeleton at a molecular level. Experiments with Stanford biologist Sid Shaw utilizing these tags with time-lapse confocal imaging and photobleaching analysis have revealed several new insights into the organization and behavior of the plant cytoskeleton. Among the key findings are that new microtubules originate adjacent to the plasma-membrane in the cell cortex, that cortical microtubules migrate across the cortex of the cell by a polymer treadmilling mechanism, and that migrating microtubules can change their orientation by colliding with or tracking along other microtubules (Fig. 6). These findings have implications for the mechanisms that nucleate new microtubules, regulate the stability of the polymer ends, and mediate attachment of microtubules to the plasma membrane and to each other. The researchers hypothesize that treadmilling migration and polymer bundling play roles in organizing the cortical microtubule array. They are now trying to test this hypothesis and thereby extend our understanding of the mechanisms of cytoskeletal organization and the role that this organized array plays in directing cell growth. To this end, they are using a combination of genetic analysis, comparative genomics, the creation of new in vivo markers for cytoskeletal organization, and cellulose synthase. A recently acquired spinning-disk, confocal microscope will extend our ability to observe rapid cellular dynamics into four dimensions (x, y, z, and time).

—Christopher Somerville

Fig. 7. Members of the Plant Biology staff. First row (from left): Nakako Shibigacki, Jennifer Johnson, Michelle Facette, Marc Nishimura, Miguela Osbual, Susan Cortinas. Second row (from left): Nick Moseyko, John Emery, Tanya Berardini, Behzad Mahini, Eva Huala, Iris Xu, Peifen Zhang, Jessie Zhang, Brandon Zoeckler, Chung-Soon Im. Second row (from left, standing): Arthur Grossman, Chris Somerville, Paul Sterbentz. Third row (from left): Pablo Jenik, Erin Osborne, Wirulda Pootakham, Devaki Bhaya, Sue Thayer, Bi-Huei Hou, Radhika Garlapati, Jeffrey Moseley. Fourth row (sitting on end): Monica Stein, Marta Berrocal-Lobo, Rebecca McCabe, Ginger Brininstool. Fourth row (sitting on steps): Meghan Sharp, Sonja Vorwerk, Sakiko Okumoto, Marcus Fehr, Kathi Bump, Rachael Huntley, Matt Humphry. Fourth row (sitting on end): Zhiping Deng, Matt Evans. Fifth row (from left): Steven Pollock, Khar-Wai Lye, Serry Koh, Marcella Pott, Melanie Hilpert, Renata Csihoyne, Patti Poindexter, Jennifer Milne. Sixth row (from left, just before row standing at back): Danny Yoo, Ying Sun, Thorsten Hamman, Wolfgang Lukowitz, Heather Youngs, Suparna Mundodi. Sixth row (standing): Ted Raab, Debbie Alexander. Back row (from left, standing): Dominique Bergmann, Christophe Tissier, Kelly Wetmore, Glenn Ford, Winslow Briggs, Tong-Seung Tseng, Trevor Swartz, Soo-Hwan Kim, Yigong Lou, Wolf Frommer, David Ehrhardt, Nick Kaplinsky, Stefan Bauer, Josh Gendron, Zhiyong Wang, Jun-Xian He.

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July 1, 2002 – June 30, 2003

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THE DIRECTOR'S REPORT:

Moving Biological Studies "in vivo"

Understanding complex and sophisticated biological processes long honed by evolution remains a daunting and seemingly quixotic challenge. Much of what we know about life processes comes from greatly oversimplifying cellular events. Biological molecules, for example, are purified and their properties studied in vitro, or "cell-free systems" are established that recapitulate a particular cellular subprogram using an increasingly defined set of components. Undeniably, the conditions under which purified molecules perform in such experiments differ vastly from the enormously complicated, highly concentrated milieu of living cytoplasm.

Consequently, it is axiomatic in biology that observations and conclusions derived from purified systems be "validated" by showing that substantially the same steps actually do take place in unbroken cells. For many years, the exquisite specificity of antigen-antibody interaction has been the basis for identifying individual biomolecules in cells and tissues. By preparing antibodies that specifically react with each key component of a process, locations of individual biomolecules under various conditions can be determined (only after fixation, however) and compared with predictions. Not infrequently, two proteins that are predicted to work together to carry out some process are found to actually reside in different cellular compartments, where interaction would be unlikely.

Perhaps the most stringent tests are genetic ones. By constructing mutated organisms lacking a specific component of interest, scientists can learn if the process under study is altered according to prediction. Again, it is commonplace to find in such experiments that removing a protein within the living cell has no detectable effect, or a completely unpredicted effect, compared with the consequence observed under simpler in vitro conditions. Indeed, it is the frequent, unexpected outcomes of such experiments that shape the very different worldviews of experimental biologists compared with those of a more theoretical bent.

In recent years, new methods for determining the location and behavior of proteins and other biomolecules have been greatly enhancing our knowledge of what these molecules actually do in minimally perturbed cells. As with antibodies and mutants, the new techniques are based on high-resolution microscopy and molecular genetics. However, rather than relying on antibody binding, specific proteins are tagged with a small fluorescent protein segment that has been added to their normal gene sequences by genetic manipulation (Frontispiece). Such "tagged" proteins not only can be localized in fixed cells, they also can be followed in real time in living cells undergoing processes of interest. Tags have been constructed that can be detected using different wavelengths, making it possible to simultaneously study two or more specific molecular species. Other tags facilitate one-step purification, and thereby simplify the task of analyzing protein function and of identifying interacting molecules.

Left: This confocal microscopy image of the brain reveals the intricate circuitry already formed in a two-day-old zebrafish embryo. Subsets of neurons (shown in red) are visualized in a transgenic line (kindly provided by Hitoshi Okamoto from Higashijima et al., *J. Neurosci. 20,* 206-218, 2000), while double labeling for acetylated tubulin highlights nerve fibers (shown in green). (Image courtesy Christian Brösamle and Marnie Halpern.)

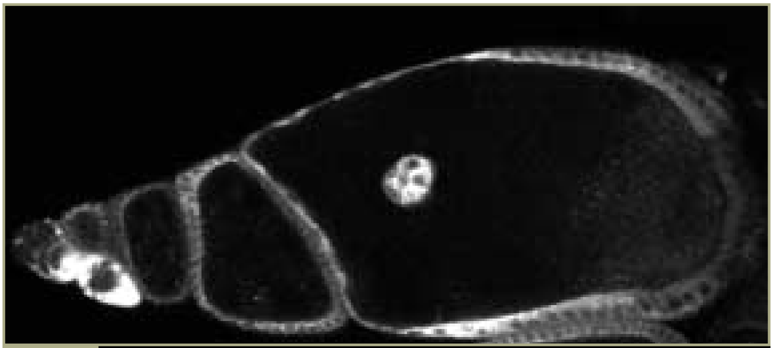

Fig. 1. This *Drosophila* ovariole shows the expression pattern of a gene identified by random tagging. Expression is seen in the vicinity of the stem cells at the left of the picture. In older follicles, seen toward the right, the protein is expressed in a specific group of migrating cells (labeling near center) as well as in a surrounding layer of ovarian follicle cells. Molecular studies revealed that the tagged protein was tropomyosin-I. (Image courtesy Michael Buszczak.)

Of course, like all techniques, fluorescent tagging has a substantial number of potential drawbacks. Producing the tagged protein may perturb the protein's normal concentration or location, the tag may alter the process under study, and the irradiation required to excite the tag may bleach the signal and damage the cell. In practice, however, these problems can usually be recognized and circumvented. Indeed, the common experience is that protein tagging allows more and higher-quality information to be obtained about the location and behavior of specific molecules. It is not surprising, therefore, that these approaches apply to virtually the entire range of research throughout the department.

Studying the action of proteins in living cells has further advantages when combined with our growing knowledge of entire genomes. Rather than just fusing tags onto known genes, it is possible to add tag-encoding sequences at random positions throughout the genomes of easily manipulated organisms, such as yeast or *Drosophila*, and then to identify resulting organisms that express a novel tagged protein. An example of such a *Drosophila* strain taken from such a genome-wide project in my laboratory is shown in Figure 1. In this case, a gene expressed near ovarian stem cells was identified.

Increasingly, the cycle of discovery is being reversed. Now it is becoming routine to first identify a protein because an epitope-tagged version resides in an interesting location or near proteins that are already under study. Only then is the actual identity of the protein determined, and its properties and genetic function studied. As the tagging technology improves further, it will be increasingly possible and commonplace to watch specific processes take place in fine molecular detail without ever disrupting an organism or its cells.

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Support of research in the department comes from a wide variety of sources. Doug Koshland, Yixian Zheng and I, and various members of our laboratories are employees of the Howard Hughes Medical Institute. Others are grateful recipients of individual grants from the National Institutes of Health, the John Merck Fund, the G. Harold and Leila Y. Mathers Charitable Foundation, the American Cancer Society, and the National Science Foundation.

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Milena Vuica, *Department of Pathology, The Johns Hopkins University School of Medicine*

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[1] To September 19, 2002
[2] To July 24, 2002
[3] To June 30, 2003
[4] To April 30, 2003
[5] To January 2, 2003
[6] To August 15, 2002
[7] To November 15, 2002
[8] From June 9, 2003
[9] To May 15, 2003
[10] From May 29, 2003
[11] From May 12, 2003
[12] To October 22, 2002
[13] To August 30, 2002
[14] To August 16, 2002
[15] To June 30, 2003
[16] From September 9, 2002

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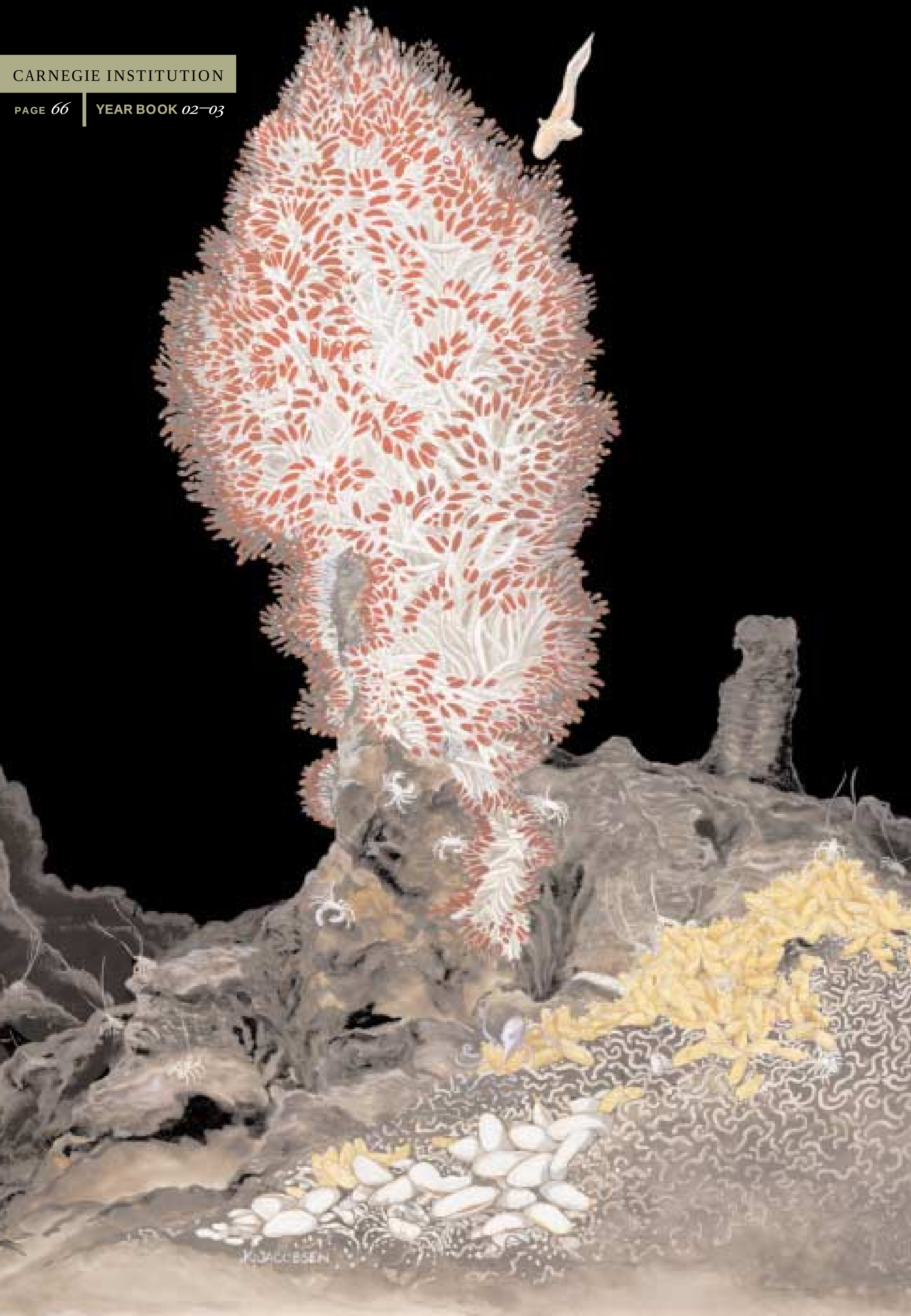

THE DIRECTOR'S REPORT:

Real Promise of New Fruitfulness

"AN AREA FOR RESEARCH THAT GIVES REAL PROMISE OF NEW FRUITFULNESS IS A COMBINED PHYSICAL, CHEMICAL, AND BIOLOGICAL APPROACH TO THE STUDY OF LIVING MATTER. TOO OFTEN IN THE PAST, COMPARTMENTATION IN SCIENCE HAS INTERFERED WITH PROGRESS IN THIS IMPORTANT FIELD."

—Merle A. Tuve (1948)*

Immediately following World War II, a small group of physicists at the Department of Terrestrial Magnetism (DTM) embarked on a concerted effort to tackle problems in biophysics. Building on the earlier development of the department's cyclotron, intended from its outset as a factory for radioisotopes to be used in experiments in biology and medicine, the group—consisting initially of Philip Abelson, Dean Cowie, and Richard Roberts and later joined by Ellis Bolton, Roy Britten, and others—began by forging collaborations with local biologists and taking advantage of laboratory visits to immerse themselves in the language and thinking of biological research. Perhaps the team's best-known work was an elucidation, from the late 1940s through the 1950s, of pathways for the assembly of key organic molecules by the *Escherichia coli* bacterium. By means of radiochemical tracers and chromatographic analysis, the group determined quantitatively the chains of reactions leading to the synthesis by *E. coli* of amino acids, nucleic acids, and proteins. More generally they demonstrated—as DTM director Merle Tuve had predicted—that opportunities for fresh scientific insight are opened when a research group leaps the boundary between traditionally distinct scientific disciplines.

Six years ago DTM joined forces with the Geophysical Laboratory and collaborators at several other institutions to pursue a parallel initiative in the emerging field of astrobiology. Fostered (and named) by the National Aeronautics and Space Administration (NASA), the science of astrobiology encompasses the origin, distribution, and evolution of life on Earth and in the cosmos. Its practitioners span the disciplines of astronomy, Earth and planetary science, chemistry, physics, and biology, and the distinct languages and modes of thinking in these disparate fields pose challenges to interdisciplinary progress at least as formidable as those faced by the biophysicists of the postwar era. To stimulate the growth and visibility of astrobiology, and to experiment with new methods for encouraging interdisciplinary research, NASA in

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*M. A. Tuve, Year Book No. 47 (Washington, D.C.: Carnegie Institution of Washington, 1948), p. 77.

Left: This artistic rendering of some of the species of megafauna found at hydrothermal vents along midocean ridges in the deep ocean formed the focus of an educational poster entitled "Astrobiology: Discovering New Worlds of Life." As part of the contribution of the Carnegie Institution team to the education and public outreach mission of the NASA Astrobiology Institute, 22,000 copies of the poster and associated educational materials were published in the November-December 2001 issue of *Science Scope,* the journal of the National Science Teachers Association, and distributed at science education meetings. (Image copyright Karen Jacobsen, In Situ Science Illustration, 2001, issik@aol.com; no use without permission.)

1998 solicited proposals from teams of investigators to participate in the NASA Astrobiology Institute (NAI). Envisioned as a "virtual institute" in which geographically far-flung teams would interact primarily through electronic means, NAI was managed from its start by an administrative headquarters sited at the NASA Ames Research Center. The Carnegie Institution team was one of 11 selected, on the basis of peer review of the proposals submitted, to receive five years of research support as a founding member of the new institute.

The initial scientific focus of the Carnegie NAI team was the physical, chemical, and biological evolution of hydrothermal systems. The motivation for this focus was to explore an alternative to the traditional view that life's origin on Earth was rooted in processes near the photic zone at the ocean-atmosphere interface, where ionizing radiation provided energy for prebiotic organic synthesis. In the context of astrobiology, the traditional origin paradigm restricts the initial "habitable zone" around stars to planets and satellites with surface water, although adaptations on Earth and possibly elsewhere subsequently led to an expansion of the biosphere into subsurface habitats. The alternative hypothesis is that life-forming processes may also occur by means of oxidation-reduction reactions in submarine or subsurface hydrothermal environments at water-mineral interfaces. Several lines of evidence lend credibility to this second hypothesis. Numerous recent discoveries of high-pressure life suggest that hydrothermal environments support abundant life. The record of large impacts on the Moon and elsewhere in the inner solar system indicates that the Earth likely experienced large, surface-sterilizing impacts as recently as 3.8 billion years ago, but deep hydrothermal zones may have insulated life from these traumas. Studies of molecular phylogeny hint that microbes suited to high-temperature environments may be the closest living relatives of the last universal common ancestor. If a subsurface origin of life is possible, then the initial habitable zone around stars is greatly expanded to objects capable of hosting aqueous environments where redox reactions can be driven along thermal and chemical gradients.

The initial proposal to participate in NAI included 15 investigators, nine from the Carnegie Institution and six from collaborating institutions. During the ensuing five years, nine additional Carnegie investigators were recruited from current and new research staff members at DTM and the Geophysical Laboratory. In 2003, NAI held a new competition for institute membership, open both to original teams and to new groups. The Carnegie Institution team was one of six original teams, and one of 12 teams overall, selected for research support during the second five years of the institute. By the time of the second proposal our team consisted of 27 investigators, nine from collaborating institutions, with 18 Carnegie Institution investigators evenly split between DTM and the Geophysical Laboratory. The scientific focus of the team's efforts had broadened as well. The unifying theme of the team's efforts is now the evolution of organic compounds from prebiotic molecular synthesis and organization to cellular evolution and diversification. The research agenda to address this theme involves multiple complementary approaches. Some team members are studying processes related to chemical and physical evolution in plausible prebiotic environments—the interstellar medium, circumstellar disks, extrasolar planetary systems, the primitive Earth, and other solar system bodies. In parallel, other team members are carrying out field and experimental studies to document the nature of microbial life at extreme conditions, to characterize organic matter in ancient fossils, and to develop biotechnological approaches to life detection on other worlds.

By several metrics, the institution's participation in the NASA Astrobiology Institute has fueled important elements of the scientific and educational activities on the campus. That 18 research staff members from DTM and the Geophysical Laboratory are working together on a single project presents an unprecedented opportunity to explore collaborative research initiatives between the two departments. One of the principal areas of support provided by our NAI award has been for postdoctoral fellows, and during the first five years of the program 18 fellows worked at DTM or the Geophysical Laboratory, supported in part by

NAI funds. Two of those fellows are now on the Carnegie Institution staff—Larry Nittler at DTM and James Scott at the Geophysical Laboratory. And during the first five years of NAI membership, Carnegie Institution team members and their collaborators at partner institutions published or had accepted for publication more than 220 journal articles or book chapters reporting work supported at least in part by NAI.

Life on Earth is based on carbon, and although one could postulate that living systems on other worlds may have a different chemical basis, the principal focus of research by the Carnegie NAI team is on the evolution of carbon from the interstellar medium to terrestrial organisms. Organic compounds are composed predominantly of carbon and hydrogen, but also oxygen, nitrogen, and sulfur. These five elements, forged in stellar interiors, provide the most basic chemical prerequisites for known forms of life. Carbon compounds have been identified spectroscopically within interstellar clouds, and it is the manner by which materials are processed during the collapse of such clouds to form young stars and the circumstellar disks of gas and dust from which planets eventually coalesce that determines the inventory of organic compounds on young planets. A variety of planetary processes in turn lead to further organic synthesis reactions, and where life originates biological processes act to modify planetary environments. A few examples of ongoing work by DTM participants in the Carnegie NAI team illustrate both the range of questions being addressed within this broad framework and some of the new collaborations that have been stimulated by the institution's embrace of astrobiological research.

Larry Nittler and Conel Alexander are collaborating with Geophysical Laboratory staff members George Cody and Andrew Steele as well as NAI team member Rhonda Stroud (U.S. Naval Research Laboratory) on the nature of organic matter in interplanetary dust particles (IDPs). Collected by aircraft from the Earth's stratosphere, IDPs are thought to be among the most primitive extraterrestrial materials currently available for laboratory study. These particles are small (typically less than 20 µm) and are generally aggregates of much smaller grains of silicates, metal, sulfides, and carbonaceous

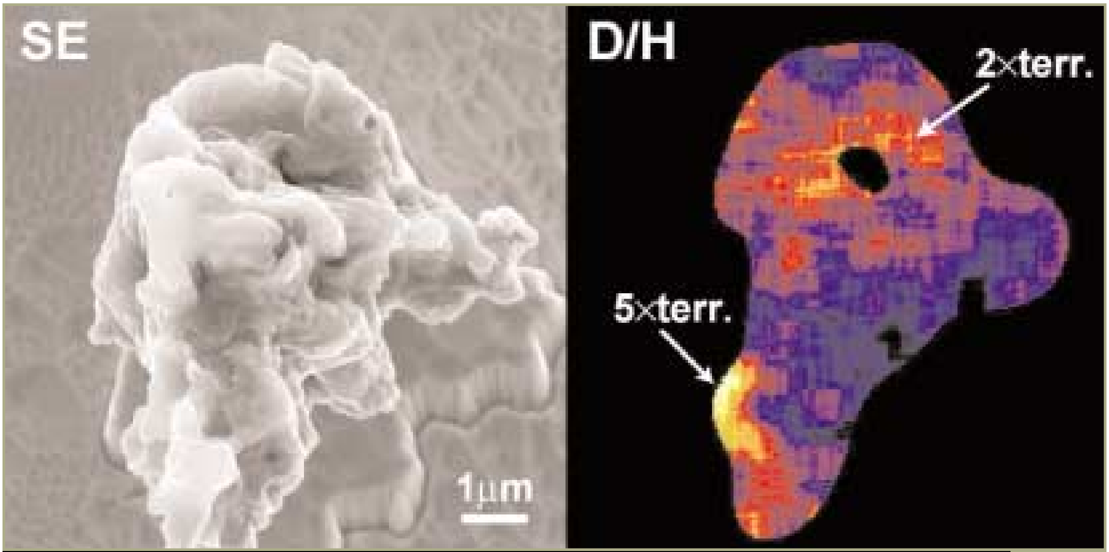

Fig. 1. An interplanetary dust particle (IDP) displays a highly variable D/H ratio on a µm scale. At left is a secondary electron image of the particle, which consists of carbonaceous material intermixed with fine-grained silicate and sulfide minerals. At right is an image of the D/H ratio obtained with the DTM ion microprobe. D/H ratios as much as five times the terrestrial value indicate the partial preservation of presolar interstellar organic material. (Images courtesy former DTM Fellow Sujoy Mukhopadhyay, now at Harvard University, and Larry Nittler.)

material. The carbonaceous material is largely organic, and the suggestion has been made that IDPs may have been an important source of organic matter delivered to the early Earth.

Organic matter in IDPs displays large and variable enrichments in the ratio of deuterium (D) to hydrogen (H) and in $^{15}N/^{14}N$ relative to terrestrial values (Fig. 1). These strong isotopic enrichments are signatures of the preservation of organic material from the interstellar molecular cloud from which the Sun and the solar system formed more than four and a half billion years ago. Nittler, Alexander, and their collaborators are attempting to characterize the presolar material preserved in IDPs, trace the alteration processes that affected the organic compounds, and compare organic matter in IDPs with that in primitive carbonaceous meteorites. They plan a multi-technique approach. Isotopic imaging with the DTM ion microprobe permits the mapping of D/H, C/H, and $^{15}N/^{14}N$ ratios at approximately 1 μm spatial resolution (Fig. 1). Chemical and mineralogical characterization is being carried out with the field-emission scanning electron microscope recently purchased jointly by DTM and the Geophysical Laboratory, as well as with fluorescence microscopy (in Steele's laboratory), transmission electron microscopy (in Stroud's laboratory), and scanning transmission X-ray microscopy.

Alexander and Nittler are also collaborating with Fouad Tera and Geophysical Laboratory staff members Cody and Marilyn Fogel on the nature of organic matter in carbonaceous chondritic meteorites. The asteroidal parent bodies of these meteorites are the last vestiges of the swarm of planetesimals from which the terrestrial planets ultimately formed. Many chondritic meteorites experienced a period of hydrothermal activity that modified the mineral species present, adding sulfides and hydrated silicates, minerals that may have played important roles in facilitating prebiotic organic synthesis on the early Earth. The duration of such hydrothermal activity was limited in meteorite parent bodies, however, and the pressures were low by comparison with submarine and subter-

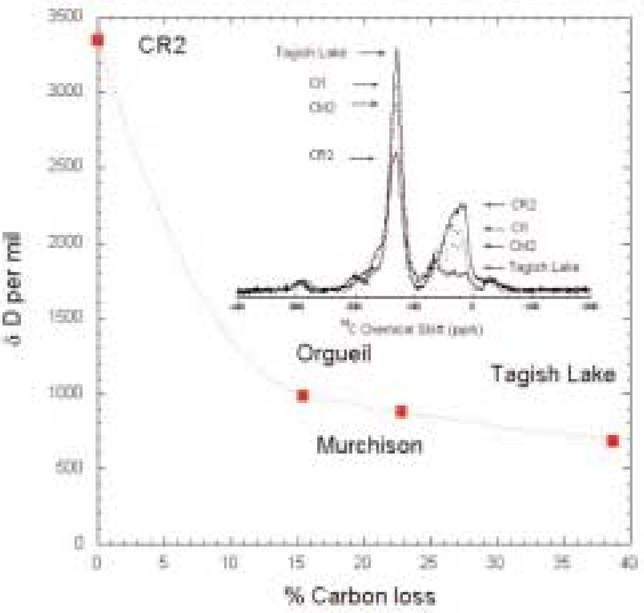

Fig. 2. A combination of solid-state nuclear magnetic resonance (NMR) spectroscopy and stable isotope analyses of organic matter in carbonaceous chondritic meteorites by Conel Alexander, Fouad Tera, and Geophysical Laboratory colleagues George Cody and Marilyn Fogel points to variations in hydrothermal processing of organic matter among meteorite parent bodies. The inset, an overlay of four ^{13}C NMR spectra obtained from organic residues isolated from several carbonaceous chondrites, indicates a progressive oxidative loss of organic carbon among the samples. The main figure plots the hydrogen isotopic abundance of each organic residue (given as the ratio of deuterium to hydrogen relative to a standard in parts per thousand) versus the apparent loss of carbon derived from parent-body processing. Combining these isotopic data with NMR spectra suggests that the high D/H ratios are correlated with specific chemical components and that the trend from high to low D/H is the result of progressive destruction of extraterrestrial organic carbon early in the history of the solar system.

ranean settings on Earth. The source bodies of meteorites, therefore, provided a natural system capable of promoting organic chemical reactions, but they were probably incapable of bridging from chemistry to life.

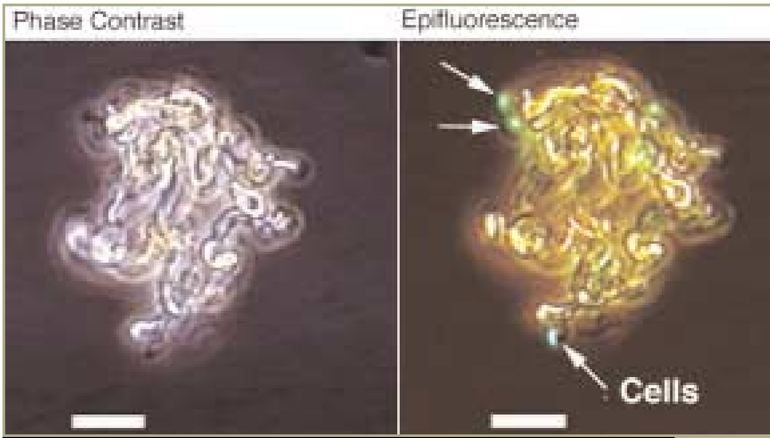

Fig. 3. Iron-oxidizing bacteria living in the water column above the submarine Loihi volcano south of the island of Hawaii appear to fractionate iron isotopes, according to work by Erik Hauri, former DTM fellow Karl Kehm, and collaborator David Emerson (American Type Culture Collection, George Mason University). Shown are phase contrast and epifluorescence images of biogenic iron oxide filaments precipitated by these bacteria (the scale bars denote 10 µm); several bacterial cells are highlighted in green in the epifluorescence image. (Images courtesy David Emerson.)

As with the analysis of IDPs, the characterization of organic matter in meteorites is being studied with a variety of approaches. Solid-state nuclear magnetic resonance (NMR) spectroscopy (in Cody's laboratory) is being used to characterize the carbon chemistry in meteoritic macromolecular material. Stable isotope analysis (in Fogel's laboratory) reveals variations among meteorite types that correlate with carbon chemistry and suggests that variations in hydrothermal alteration among meteorite parent bodies led to systematic differences in the degree of modification and destruction of extraterrestrial organic carbon (Fig. 2). Additional tools to be applied in the group's ongoing characterization efforts include high-resolution X-ray absorption near-edge spectroscopy and scanning transmission X-ray microscopy, both to be carried out at the Advanced Light Source at the Lawrence Berkeley National Laboratory.

In the search for life on other solar system bodies, and in the recognition of the earliest signatures of life on Earth, the identification of clear markers of biological processes is an important goal. One route being explored by Erik Hauri, former DTM fellow Karl Kehm, now at Washington College, and collaborator David Emerson of the American Type Culture Collection, George Mason University, involves the use of isotopes of iron. Kehm and Hauri developed a new method for iron isotope analysis using one of DTM's multicollector inductively coupled plasma mass spectrometers. In a first application of the technique, Kehm, Hauri, Alexander, and DTM's Richard Carlson demonstrated that for a range of meteorite types there is no significant isotopic fractionation of iron from terrestrial values, indicating that chemical differentiation processes in the planetesimals that accreted to form the inner planets did not significantly alter the isotopic composition of iron.

Emerson, Hauri, and Kehm have found that iron isotopes in iron oxides precipitated by bacteria near hydrothermal vents on the Loihi volcano south of the island of Hawaii (Fig. 3) display a significant fractionation toward heavier isotopes. As the oxides age, however, the degree of iron isotope fractionation relative to surrounding volcanic rocks is gradually reduced. The team is pursuing the hypothesis that the bacteria catalyze biological iron oxidation that fractionates iron isotopes in the precipitating oxides, but that as the organic-oxide mix ages precipitation of additional iron oxides by purely chemical processes drives the ratio of biotic to abiotic oxidation products and the iron isotopic anomaly of the mix toward zero. This scenario, if common to other biogenic iron fractionation processes, raises the question of the longevity of this potential isotopic biosignature. Hauri, Emerson, and Kehm plan to pursue this question through several parallel experiments. They will carry out measurements similar to those made on Loihi at another field site, one with iron-rich groundwater flowing through a

Fig. 4. John Chambers is DTM's newest staff member in astronomy.

small wetland and active Fe-oxidizing bacteria, and they will conduct aging experiments by killing the microbes in samples placed in situ to permit continued abiotic oxidation. Parallel experiments will be conducted under controlled conditions in the laboratory, and iron isotope fractionation will be followed for each set of experiments.

DTM's contributions to astrobiology in the areas of circumstellar disks and extrasolar planets and planetary systems were treated in last year's director's report (Year Book 01/02, pp. 66-73). Our newest appointment to the research staff, John Chambers (Fig. 4), will strengthen further the expertise of the astronomy group in planetary system science. A former postdoctoral associate at DTM (1994-1996), Chambers subsequently held positions on the research staff at Armagh Observatory in Northern Ireland, NASA Ames Research Center, and the SETI Institute. A planetary dynamicist, Chambers works on problems ranging from the stability of Earth-like planets in extrasolar planetary systems to the process that led to the heavy impact bombardment on the Moon and throughout the inner solar system. Although his appointment was approved in the spring of 2003, Chambers will not join the DTM staff on a permanent basis until April 2004.

Recent simulations by Chambers of the growth of the inner planets by the accretion of rocky planetesimals give one illustration for how his work will impact questions in astrobiology. Water, thought to be a necessary ingredient for life, most likely was present as a solid phase in the nebula of gas and dust from which these planetesimals formed only outside of the eventual orbit of the Earth. The Earth and other inner planets therefore must have gained most of their inventories of water by the accretion of objects driven toward the inner solar system as a result of gravitational perturbations by the gas-giant planets Jupiter and Saturn. The predicted water budgets of the inner planets, Chambers has shown, are very sensitive to the time of formation, masses, and orbital characteristics of the gas-giant planets (Fig. 5). His calculations will help us to understand not only the original water invento-

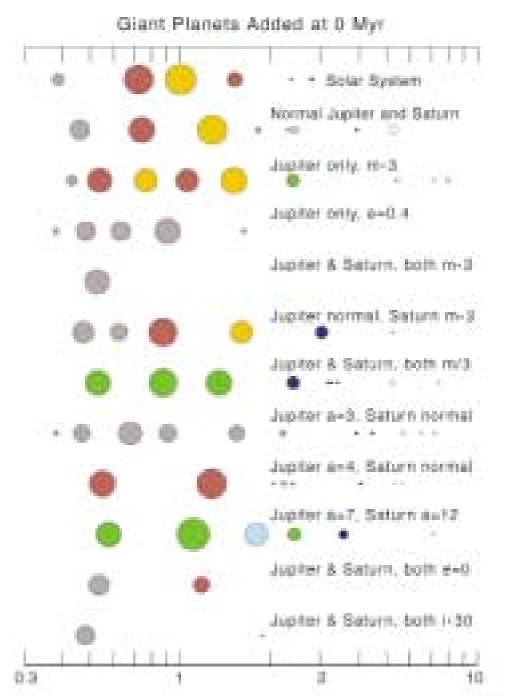

Fig. 5. Simulations of inner planet formation by John Chambers show the water contents of terrestrial planets that accrete in systems with early-formed gas-giant planets. The outcomes of each simulation are represented by the relative dimension and radial distance of the final set of rocky inner planets and by the water content of each body. Each progressive color from gray through red, yellow, green, light blue, and dark blue denotes five times more water per planet mass. The distance from the central star is shown in Astronomical Units (1 AU equals the Sun-Earth distance) on a logarithmic scale. The semimajor axes *a* (in AU), orbital eccentricities *e*, orbital inclinations *i*, and masses *m* (in multiples) of the Jupiter and Saturn analogues are indicated.

Fig. 6. Members of the Department of Terrestrial Magnetism staff are shown on October 16, 2003. First row (from left): Lucy Flesch, Linda Warren, Katherine Kelley, Adelio Contrera, Pablo Esparza, Janice Dunlap, George Wetherill, Vera Rubin, and Ben Pandit. Second row: Alison Shaw, Steven Shirey, Fouad Tera, Richard Carlson, Erik Hauri, Mark Schmitz, Mark Behn, Paul Silver, Kathleen Flint, Sean Solomon, Alexis Clements, Maceo Bacote, and Brian Schleigh. Third row: Michael Smoliar, Jianhua Wang, Alan Linde, Kevin Wang, James Cho, Selwyn Sacks, David James, Brooke Hunter, Alycia Weinberger, William Minarik, Shaun Hardy, and Paul Butler. Fourth row: Jay Bartlett, Conel Alexander, Roy Dingus, Nader Haghighipour, Sara Seager, Sandra Keiser, Georg Bartels, Saavik Ford, Nelson McWhorter, Roy Scalco, and Charles Hargrove. Fifth row: Terry Stahl, Gary Bors, Timothy Mock, Mary Horan, Larry Nittler, Kevin Burke, John Graham, and Louis Brown.

ries of Earth's neighbor planets but also the range of possible water budgets in Earth-like planets in other planetary systems.

These illustrations touch on only a small fraction of the sweep of astrobiological research questions now being pursued at DTM, the Geophysical Laboratory, and our partner institutions in the NASA Astrobiology Institute. It is still too early to tell whether these activities will, at some point, achieve a scientific impact equal to that made by DTM's biophysics group in the 1950s. Nonetheless, it is the sense of many on this campus that the "real promise of new fruitfulness" that Tuve envisioned would be achievable by combining the approaches of physics, chemistry, and biology may yet be fulfilled through progress on such basic questions as the conditions that led to the origin of life on Earth and the extent to which those conditions are duplicated elsewhere in the cosmos.

—Sean C. Solomon

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July 1, 2002 – June 30, 2003

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[9] To June 30, 2003
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[11] From September 1, 2002
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[13] To July 31, 2002
[14] From July 1, 2002
[15] To February 15, 2003
[16] From September 11, 2002
[17] From July 1, 2002
[18] To June 30, 2003
[19] From September 9, 2002
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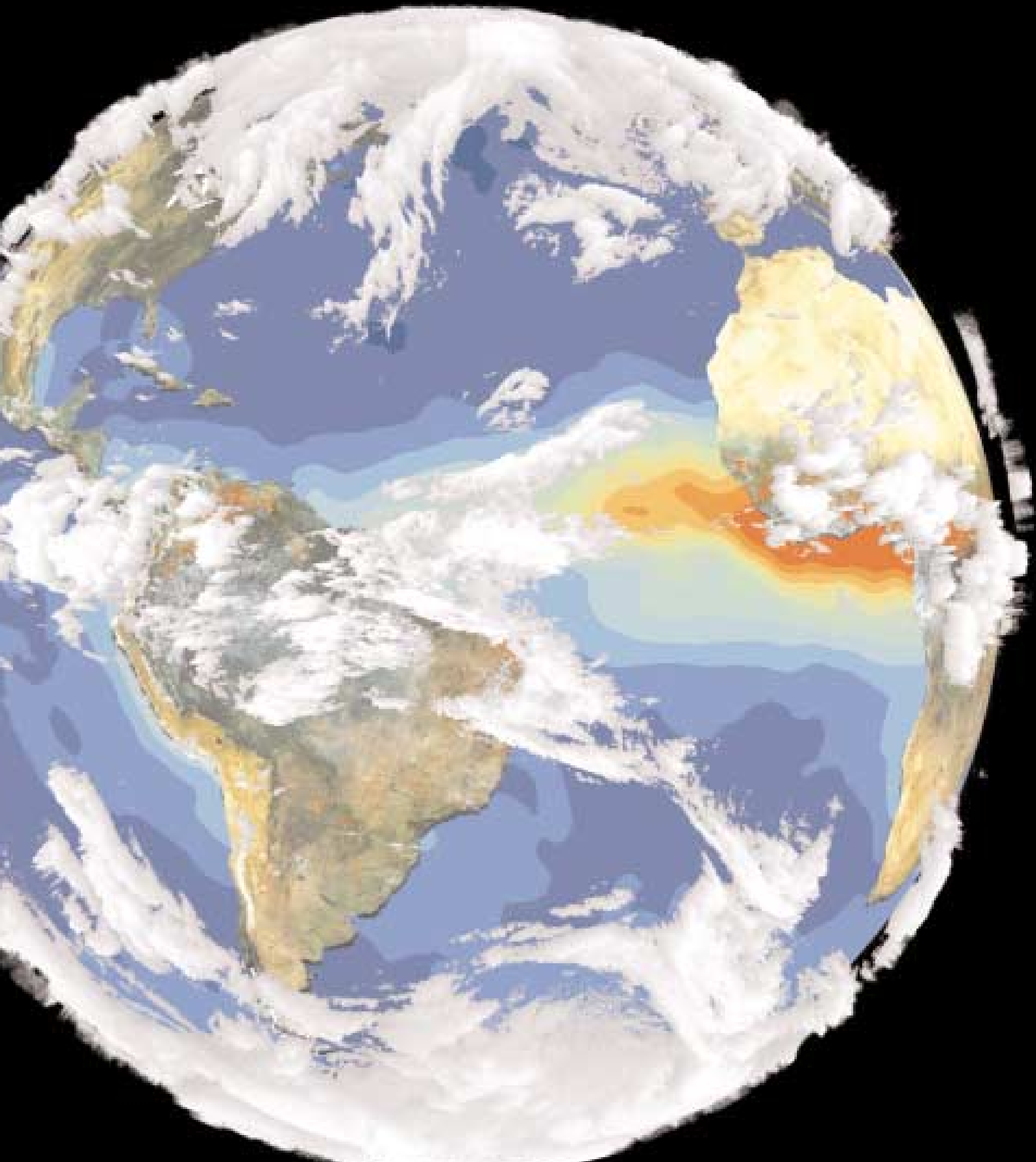

THE DIRECTOR'S REPORT

On July 1, 2002, Global Ecology became the first new department of the Carnegie Institution in more than 80 years. By the time we unveiled the new sign outside the front entrance and popped the cork on the champagne, the scientific adventure was already under way (Fig. 1). In its first year, Global Ecology sustained the momentum of the active research programs that transitioned from the Department of Plant Biology in addition to building the foundations for a range of new activities.

When it opened its doors for business, Global Ecology had three active labs, led by Greg Asner, Joe Berry, and me. During the first year, we initiated a search for a fourth faculty member, an oceanographer who we hope will join the department in the next year. Other major activities during Global Ecology's first year included refining the philosophy that underlies the department's activities, planning and beginning construction of the buildings that will be home to the new department, and completing a number of exciting scientific studies, which have attracted substantial scientific and public attention.

Refining the Philosophy

With every passing year, the importance of connections between diverse aspects of the Earth and its inhabitants becomes clearer and clearer. As we learn more about specific processes and organisms, the strongest message is often the value of integrating, of understanding the organism in its environment and the process in its context. Integration is central to the mission of the Department of Global Ecology, with the focus on understanding the ways that biological, physical, and human factors interact to shape the Earth's ecosystems.


Fig. 1. Department director Christopher Field opens champagne to launch Carnegie's Department of Global Ecology on July 1, 2002.

Some of the work in the department is integrative in an additive sense. It explores large-scale consequences of processes, for example timber harvesting, that are relatively straightforward to quantify locally but tend to drift behind a veil of uncertainty at the scales that make the most difference for national policy or global climate. Other projects are integrative in linking perspectives from several disciplines or processes. For example, Joe Berry's work on regional carbon balance draws heavily on concepts and data from both ecology and atmospheric science. Both of these kinds of integration focus, at their core, on understanding "emergent properties," fundamentally new kinds of structures, types of response, or modes of behavior that appear only above a certain scale and are the consequence of interactions among processes at smaller scales.

Left: Scientists at the Department of Global Ecology explore the planet as an integrated system. Their research focuses on the interactions among the Earth's ecosystems, including living organisms and their relationships to the land, atmosphere, oceans, and human activity. Several different satellites were used to produce this composite image of Earth's interrelated systems. (Image courtesy NASA/Goddard Space Flight Center, GPN-2002-000121.)

The tradition at Carnegie is that faculty members explore the topics that they determine to be most promising scientifically. The Department of Global Ecology continues this tradition. By assembling a group of faculty members interested in broad questions and providing them with the tools to adopt novel approaches, the department makes integrative science an opportunity rather than a mandate. Our experience to date is that the combination of experience and perspective creates an atmosphere that vigorously stirs the intellect and opens doors to explore a vast array of questions that are deep and fundamental, but also critical for the sustainability of our planet.

Global Ecology's New Home

The Department of Global Ecology will continue to share the Stanford University campus site, which has been occupied by the Department of Plant Biology since 1928. This 7.4-acre campus within a campus, provided by Stanford through a long-term lease, positions both Carnegie departments as major contributors to and beneficiaries of the intellectual life of the university. On the border between the university's core campus and less-developed areas, the Carnegie site is within walking distance of libraries and seminars, but still rural enough to allow us to maintain extensive greenhouses and several acres for experimental plantings. Co-locating Global Ecology with Plant Biology provides critical intellectual advantages, facilitating interactions with the potential to lead to fundamental breakthroughs in coming years. Sharing a single campus also creates efficiencies from sharing key support staff, administrative expertise, and research facilities, especially the new greenhouse complex completed this year.

The new facilities for Global Ecology include four different kinds of spaces, each designed to take advantage of and contribute to unique aspects of the way global ecology research is conducted. Some of the key spaces are outdoors where new courtyards and work areas are designed to take advantage of the climate. These can be used for discussions and research that do not require a roof. The new buildings are diverse and include a large complex of research greenhouses, a barn for supporting activities that do not require expensive or intensively conditioned space, and an 11,000-square-foot research building with offices and sophisticated labs (Fig. 2). The greenhouses were completed in June 2003, and the other buildings will be ready for occupancy in the first quarter of 2004.

All of the buildings were designed and constructed with high-performance features—designs and materials that enhance the safety and comfort of the occupants while minimizing the use of nonrecyclable materials and energy required for heating, cooling, and lighting. The new greenhouses approximately double the capacity of the old greenhouses, with 12 individually controlled rooms. Rolling benches maximize the fraction of each room that can be used for plants. The greenhouses' double-wall construction and multistage heating and cooling keeps energy consumption to a minimum, while providing research-grade control of temperature, light, and the composition of the atmosphere.

Fig. 2. The new research building for the Department of Global Ecology is scheduled for completion in spring 2004. It was designed with many high-performance features to maximize energy efficiency, minimize waste, and enhance occupant comfort. This photo was taken in January 2004.

At the May 22, 2003, groundbreaking for the main research building, Carnegie president Dick Meserve expertly dipped the bucket of a backhoe into a former transplant garden and started construction on a building that will contain approximately 5,000 square feet of offices and 5,000 square feet of labs. Designed by EHDD Architecture, the structure will employ a diverse array of high-performance features. Some of these, such as high-efficiency air filtration, low-VOC paints, and the strict avoidance of vinyl, enhance the safety of the working environment. Other features minimize the environmental impacts of the construction materials. The redwood siding, for example, is recycled from used wine barrels, while the gravel in the concrete is crumbled concrete from other buildings. The biggest emphasis on high performance is found in features that make the building a miserly user of water and energy. All of the landscaping will consist of California native plants that do not need irrigation. Taking advantage of daylight, heat-reflecting glass, heat-reflecting paint, and superefficient cooling and heating systems, we calculate that operating the new building will, on a per-occupant basis, release only one-fourth as much carbon to the atmosphere as a typical new laboratory in California. The entire Global Ecology community is looking forward to kicking the tires on this high-performance machine.

Broad Communication

The Department of Global Ecology was productive, with four dozen new papers in its first year. It was also increasingly recognized by the scientific community, entering the top 1% of institutions for the number of recent citations in Ecology/Environment, based on analysis from the Institute for Scientific Information. Several papers garnered attention beyond the scientific community. One of these was a study exploring the factors responsible for recent trends in crop yields in the midwestern United States. Graduate student David Lobell and staff member Greg Asner, writing in *Science*, concluded that approximately 20% of the increases in the average yields of wheat and soybeans over the past 20 years appear to be caused by a cooling trend, rather than being a result of improved management or improved crop varieties. This conclusion urges tempered expectations about future crop yields, especially in a warming climate.

Fig. 3. The Jasper Ridge Global Change Experiment explores the potential effects of global climate change in a California grassland. The study is conducted at Stanford University's Jasper Ridge Biological Preserve. The project includes scientists at Stanford University and Carnegie's Department of Global Ecology, and researchers from other institutions. This is the first study to examine the interaction of four environmental components of global change in a natural ecosystem—warming, elevated CO_2, increased precipitation, and increased nitrogen deposition. The researchers shown here—Lisa Moore, Elsa Cleland, and Thuriane Mahe—sample plant material from one of the 32 circular plots. (Image courtesy Chris Field.)

Two papers from the Jasper Ridge Global Change Experiment (Fig. 3) had a public impact. Graduate student Erika Zavaleta, writing with Chris Field and a number of others, found that plant responses to simulated warming led to unexpected changes in soil moisture. Her paper in the *Proceedings of the National Academy of Sciences* demonstrated that a warmer environment caused plants to mature earlier, leading to decreased water consumption and, consequently, increased soil moisture in warmed plots. This result adds to the conclusions of a growing number of studies demonstrating the fundamental importance of ecosystem responses in modulating effects of climate change. Former postdoc in the Field lab M. Rebecca Shaw was the lead author on a paper in *Science* demonstrating that elevated atmospheric carbon dioxide, the main heat-trapping gas emitted from fossil-fuel combustion, does not always make plants grow faster, especially when the elevated carbon dioxide occurs in combination with other global changes. Her paper, written with Chris Field and several others, adds weight to the accumulating evidence that ecosystem responses have a limited ability to offset emissions of carbon dioxide caused by fossil-fuel combustion.

Broad communication of scientific results is a priority in Global Ecology. As one example, Greg Asner and his lab will be featured in a forthcoming TV documentary on ecological impacts of non-native plants and animals. In addition, all of the faculty speak regularly to civic and school groups about issues in global ecology.

Ongoing Research

Fig. 4. Global Ecology staff scientist Joe Berry.

Ongoing research activities were diverse, spanning nearly all terrestrial ecosystems from the tropics to the Arctic. The main research theme in Joe Berry's lab was quantifying and understanding ecosystem carbon balance at regional scales (Fig. 4). Carbon balance, the sum of carbon uptake by plants through photosynthesis and carbon release through respiration and combustion, can be measured at the scale of up to about 1 square kilometer, using a meteorological technique called eddy flux. Eddy flux essentially quantifies the upward or downward transport of atmospheric carbon dioxide in every passing turbulent puff of air. At the continental scale, estimates of carbon balance can be derived from the spatial pattern of atmospheric carbon dioxide concentration, using an atmospheric transport model run to solve for the locations responsible for the excesses and deficits of carbon dioxide.

While both the eddy flux and continental scale approaches are powerful, they fail to address processes at a broad range of intermediate spatial scales. Many ecological and human processes occur at these intermediate scales, including governmental units (counties, states, and countries), agricultural regions, and major ecosystem types. Understanding new processes that emerge at these scales is a central goal of Global Ecology. Joe Berry and his colleagues, especially postdoc Brent Helliker, have been exploring new ways to extract information about carbon balance at the Earth's surface from measurements in the atmosphere. They have developed an approach based on the fact that the atmosphere near the ground typically mixes only slowly with higher levels in the atmosphere. As a consequence, the atmosphere at heights of less than a couple of kilometers carries a signature of the upwind carbon fluxes over an area of 10,000 to 100,000 square kilometers. The challenge is reading this signature. Joe and colleagues, especially atmospheric researcher Alan Betts, looked first at the exceedingly complex problem of understanding the complete motion and energy exchange of the atmosphere near the ground. This problem can be solved under some conditions, but not under others. It turns out, however, that it is possible to use a gas with known sources and sinks, such as water or radon, as a tracer for the movements of the atmosphere, and then use these movements as the basis for calculating the flux of carbon dioxide. Tests of this approach based on measurements of water vapor and carbon dioxide from the 400-meter level of a television transmission tower in Wisconsin verify its robustness, and provide the first-ever measurements of annual carbon balance for an area the size of Wisconsin. In the future, this technique is likely to play an important role in understanding regional carbon balance and evaluating carbon management strategies.

Greg Asner's lab had a far-flung year, with major projects in Brazil, Hawaii, Argentina, Mexico, and the American Southwest. The common element linking all these projects was the application of remote sensing, from satellites and aircraft, to phenomena that are too subtle or occur on a scale too fine to be quantified with traditional remote sensing. The science questions have also been diverse, ranging from assessing biological invasions and the way they alter nutrient cycling and patterns of wildfire to quantifying illegal logging.

One of the major efforts in the Asner lab concerns the increasing abundance of shrubs in many grassland and desert areas, especially in the southwestern United States. Using a combination of historical and remote-sensing data, Greg and his colleagues, especially Steve Archer at the University of Arizona, have quantified changes in shrub dominance over much of the Southwest. They have shown that the increase in shrub abundance is real, that it is strongly connected with historical patterns of land management, and that it leads to changes in carbon accumulation and nutrient cycling.

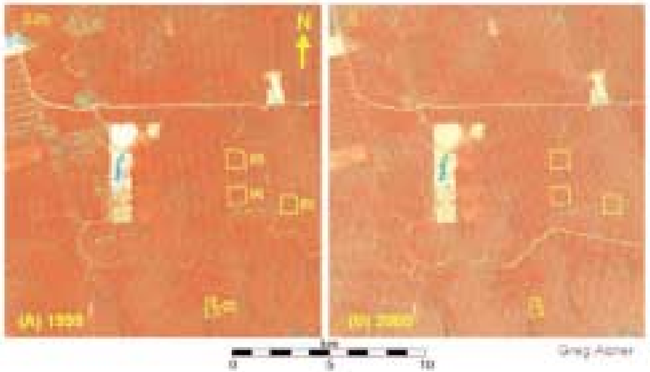

Fig. 5. Greg Asner’s lab is determining how data from existing satellites can be used to locate and determine the intensity of logging in the Amazon Basin. The data for these images of Fazenda Cauaxi came from the Landsat Enhanced Thematic Mapper Plus. The left image was taken on July 13, 1999, and the right image on July 31, 2000. The plots were between 25 and 100 hectares and were used to see if image band analysis could be used to detect and quantify the damage to the forest canopy years after selective logging. The yellow boxes show the following information: (1) 1998 conventional logging; (2) 1998 reduced–impact logging; (3) 1996 conventional logging; (4) 1996 reduced-impact logging; and (5) forest that had not been logged. (Image courtesy NASA.)

In Brazil, the Asner lab is using advanced remote-sensing techniques to address two very different problems. One concerns the water stress in tropical forests. Using data from the EO-1 satellite, launched in November 2000, Asner and colleagues tested algorithms for quantifying water stress and compared the results with those from ground-based studies. The ground-based studies further allow them to explore the ecosystem impacts of the water stress and to build these impacts into models.

Also in Brazil, the Asner lab is using a combination of satellite and aircraft remote sensing to quantify a broad range of logging activities that have been invisible to other techniques (Fig. 5). Selective logging, which removes individual trees while leaving much of the canopy intact, can have large impacts on biological diversity and ecosystem function while not completely disrupting forest canopies. Selective logging can also create a major law-enforcement problem for a country like Brazil, where much of the forest is legally protected but ground-based enforcement is insufficient to effectively cover the vast areas involved. Greg and his colleagues use satellite data to assess the relative abundance of leaves and stems. Subtle changes in these relative abundances can, when calibrated against ground observations, pinpoint areas where selective logging is occurring. In addition to implications for law enforcement, this technique has provided a new assessment of the importance of selective logging in Brazil, demonstrating that it is the dominant form of human impact over vast areas of the Amazon Basin. This study also demonstrates that logging and fire are not always tightly connected, with little fire in some of the areas with selective logging.

Deforestation was also a major theme in the Field lab. Ruth DeFries, from the University of Maryland, took the lead in a project to use the 20-year history of data from the NOAA weather satellites to quantify changes in global forest cover. Since the spatial scale of the finest information from the NOAA satellites is very coarse (the smallest areas they can resolve are several kilometers across), DeFries, Field, and colleagues needed an index of deforestation based on something other than direct observation of the edges of the deforested zone. Using techniques similar to those the Asner lab employs to quantify selective logging, DeFries and colleagues extracted information about the amount of forest within each satellite pixel (the smallest area resolved by the satellite) from the spectral and temporal information. While this inference does not extend to the very fine scale of deforestation addressed in the Asner lab, it allows the exploration of a global data set extending over 20 years. The rates of tropical deforestation estimated through this approach are smaller than those from land-based observations of the forestry services of individual countries. Even after correcting for the selective logging studied in the Asner lab, this study suggests that tropical deforestation may have been overestimated in the past. Although this is good news for the forests, it implies that past estimates of forest growth offsetting the deforestation were also too large.

Concluding Thoughts

As the Department of Global Ecology moves into its second year, it is clearly building momentum. The continuing research is diverse and vibrant. It addresses topics that are important in themselves and that lay the foundations for a much broader understanding of the full suite of mechanisms that drive ecosystem processes at the global scale. In the department's second year, ongoing projects will augment new ventures, in which labs join forces and techniques. Integrative science is the cornerstone of Global Ecology. The faculty has a tradition of broad collaboration, and we are increasingly taking advantage of the unique resources of a Carnegie department to link our interests and skills to explore new horizons for science.

—Christopher Field

Department of Global Ecology Personnel

July 1, 2002 — June 30, 2003

Research Staff Members

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Christopher B. Field, *Director*

Visiting Investigator

Rebecca Shaw, *Nature Conservancy*

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Brent Helliker, *NSF Research Associate*[2]
Jeffrey Hicke, *NASA Research Associate*[3]
Robin Martin, *NASA Research Associate*[4]
Florent Mouillot, *NASA Research Associate*
Lydia Olander, *NSF Research Fellow*[5]

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Laura Hoffman, *Stanford University*
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Halton Peters, *Stanford University*
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Susan Gere, *Laboratory/Field Assistant*[11]
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[1] From January 1, 2003
[2] From August 15, 2002
[3] To March 31, 2003
[4] From June 1, 2003
[5] From January 1, 2003
[6] From October 1, 2002
[7] From October 20, 2002
[8] From October 28, 2002
[9] From October 1, 2002, to May 31, 2003
[10] From April 16, 2003
[11] From October 9, 2002
[12] From February 1, 2003
[13] To January 31, 2003
[14] From October 26, 2002, to December 31, 2002
[15] From June 16, 2003
[16] To June 15, 2003
[17] From November 1, 2002, to May 31, 2003
[18] From October 1, 2002, to December 31, 2002
[19] From October 31, 2002, to December 31, 2002
[20] From October 1, 2002, to November 15, 2002

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Carnegie administration staff and visitors pose on the steps of the administration building on June 5, 2003. Top row (from left): John Lively, Charles Fonville, Charles Kim, Ann Keyes, Michael Pimenov, Sharon Bassin, Richard Meserve, Tina McDowell, Trong Nguyen, Claire Hardy, and Arnold Pryor. Middle row: Don Brooks, Andrea Bremer, Kerry Kemp, Cady Canapp, Vickie Tucker, Kris Sundback, Jeffrey Lightfield, unidentified, Darla Keefer, Susanne Garvey, Ellen Carpenter, and Jacquelyn Hicks. Linda Feinberg and Rhoda Mathias are between the front and middle rows on the right. Bottom row: Lloyd Allen, Norma Torres, Jacqueline Williams, Alma Morales, Pamela Rivera, Julie Edmonds, Marta Oyola, and John Strom. (Image courtesy John Strom.)

Carnegie Administrative Personnel

Lloyd Allen, *Building Maintenance Specialist*
Sharon Bassin, *Assistant to the President/Assistant Secretary to the Board*
Andrea Bremer, *Business Coordinator*
Gloria Brienza, *Budget and Management Analysis Manager*
Don Brooks, *Building Maintenance Specialist*
Marjorie Burger, *Financial Accountant*
Cady Canapp, *Human Resources and Insurance Manager*
Ellen Carpenter, *Public Events and Publications Coordinator*
Sonja DeCarlo, *Business Officer*
Diana Dougherty, *Database Implementor*[1]
Linda Feinberg, *Manager of External Affairs*
Charles Fonville, *Lobby Attendant*
Susanne Garvey, *Director of External Affairs*
Michael Gellert, *Acting President*[2]
Claire Hardy, *Database and Communications Coordinator*
Bambi Hauptman, *Database Implementor*[3]
Margaret Hazen, *Staff Director, Centennial Committee*[4]
Jacquelyn Hicks, *Database Implementor*[5]
Susan Humphreys, *Secretary to the President*[6]
Darla Keefer, *Administrative Secretary*
Kerry Kemp, *Database Implementor*[7]
Ann Keyes, *Payroll Coordinator*
Charles Kim, *Systems Administrator*
Jeffrey Lightfield, *Deputy to the Financial Manager*
John Lively, *Director of Administration and Finance*
Rhoda Mathias, *Secretary to the President*[8]
Tina McDowell, *Editor and Publications Officer*
Richard Meserve, *President*[9]
Trong Nguyen, *Financial Accountant*
Michael Pimenov, *Endowment Manager*
Arnold Pryor, *Facilities Coordinator for the Centennial*
Maxine Singer, *President*[10]
John Strom, *Web Manager*
Kris Sundback, *Financial Manager*
Vickie Tucker, *Administrative Coordinator/Accounts Payable*
Yulonda White, *Human Resources and Insurance Records Coordinator*
Jacqueline Williams, *Assistant to Manager, Human Resources and Insurance*

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[1] From February 20, 2003, to May 7, 2003
[2] From December 31, 2002, to April 1, 2003
[3] From February 20, 2003, to March 7, 2003
[4] To December 31, 2002
[5] From May 20, 2003
[6] To August 2, 2002
[7] From March 31, 2003
[8] From September 3, 2002
[9] From April 1, 2003
[10] To January 31, 2003

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Addae Akinsheye, *Intern*[1,2]
Dayo Akinsheye, *Mentor Teacher*[1,2]
Inés Cifuentes, *CASE Director*[1,2]
Naamal De Silva, *Intern*[2]
Asonja Dorsey, *Mentor Teacher*[1,2]
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Laurie Young, *Mentor Teacher*[1]

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[1] Summer Institute 2002
[2] Summer Institute 2003
[3] To February 28, 2003
[4] From January 31, 2003

The 2002-2003 lecture series was sponsored by the Carnegie Institution with substantial support from Johnson & Johnson Family of Companies. The lectures are free and open to the public and are held in the Root Auditorium at Carnegie's headquarters at 16th and P Streets, NW, in Washington, D.C. Speakers meet informally with groups of high school students. During the 2002-2003 season, the following lectures were given:

CAPITAL SCIENCE LECTURES AND OTHER EVENTS—THIRTEENTH SEASON 2002-2003

Persisting Problems in Tuberculosis, John McKinney
(Laboratory of Infection Biology, The Rockefeller University) October 22, 2002.

Untangling a Complex Ecosystem: Energy Flow in Tropical Mangroves, Marilyn Fogel
(Geophysical Laboratory, Carnegie Institution) November 19, 2002.

The Weather's Face: How Meteorology Became a Science
(Washington film premiere of Norwegian documentary on Vilhelm Bjerknes) December 9, 2002.

Cosmic Africa
(Washington film premiere of South African documentary) January 16, 2003.

The Human Genome and Beyond, Eric Lander
(Director, Center for Genome Research, Whitehead Institute and MIT) February 11, 2003.

Probing the Universe with Gravitational Waves, Kip Thorne
(Department of Physics, California Institute of Technology) March 25, 2003.

Overcoming Dyslexia, Sally and Bennett Shaywitz
(Department of Pediatrics, Yale University) April 8, 2003.

Evolution of Darwin's Finches, Peter and Rosemary Grant
(Department of Ecology and Evolutionary Biology, Princeton University) April 22, 2003.

The Twisted World of RNA: One Molecule, Many Functions, Jennifer Doudna
(Department of Molecular and Cell Biology, University of California, Berkeley,
Howard Hughes Medical Institute Investigator) May 27, 2003.

Financial Profile

Reader's Note: In this section, any discussion of spending levels or endowment amounts are on a cash or cash-equivalent basis. Therefore, the funding amounts presented do not reflect the impact of capitalization, depreciation, or other non-cash items.

The primary source of support for Carnegie Institution of Washington's activities continues to be its endowment. This reliance has led to an important degree of independence in the research program of the institution. This independence is anticipated to continue as a mainstay of Carnegie's approach to science in the future.

At June 30, 2003, the endowment was valued at approximately $525.7 million and had a total return (net of management fees) of 7.0%. The annualized five-year return for the endowment was 8.5%.

For a number of years, Carnegie's endowment has been allocated among a broad spectrum of asset classes. This includes fixed-income instruments (bonds), equities (stocks), absolute return investments, real estate partnerships, private equity, an oil and gas partnership, and a hedge fund. The goal of diversifying the endowment into alternative assets is to reduce the volatility inherent in an undiversified portfolio while generating attractive overall performance.

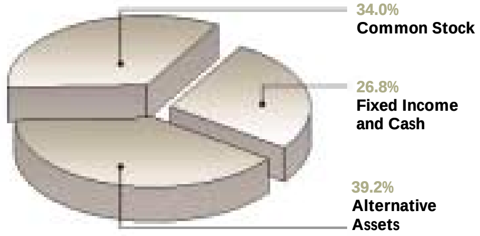
In its private equity allocation, the institution accepts a higher level of risk in exchange for a higher expected return. By entering into real estate partnerships, the institution holds part of its endowment in high-quality commercial real estate, deriving both the possibility of capital appreciation and income in the form of rent from tenants. Along with the oil and gas partnership, this asset class provides an effective hedge against inflation. Finally, through its investments in an absolute return partnership and a hedge fund, the institution seeks to achieve long-term returns similar to those of traditional U.S. equities with reduced volatility and risk.

The finance committee of the board regularly examines the asset allocation of the endowment and readjusts the allocation, as appropriate. The institution relies upon external managers and partnerships to conduct the investment activities, and it employs a commercial bank to maintain custody.

The following chart shows the allocation of the institution's endowment among the asset classes it uses as of June 30, 2003:

	Target Allocation	Actual Allocation
Common Stock	35.0%	34.0%
Alternative Assets	45.0%	39.2%
Fixed Income and Cash	20.0%	26.8%

Actual Asset Allocation



Carnegie's investment goals are to provide high levels of current support to the institution and to maintain the long-term spending power of its endowment. To achieve this objective, it employs a budgeting methodology that provides for:

- averaging the total market value of the endowment for the three most recent fiscal years, and
- developing a budget that spends at a set percentage (spending rate) of this three-year market average.

Since the early 1990s, this budgeted spending rate has been declining in a phased reduction, moving towards an informal goal of a spending rate of 4.5%. For the 2002-2003 fiscal year, the rate was budgeted at 5.20%. While Carnegie has been reducing this budgeted rate by between 5 and 10 basis points a year, there has also been continuing, significant growth in the size of the endowment. The result has been that, for the 2002-2003 fiscal year, the actual spending rate (the ratio of annual spending from the endowment to actual endowment value at the conclusion of the fiscal year in which the spending took place) was 4.76%.

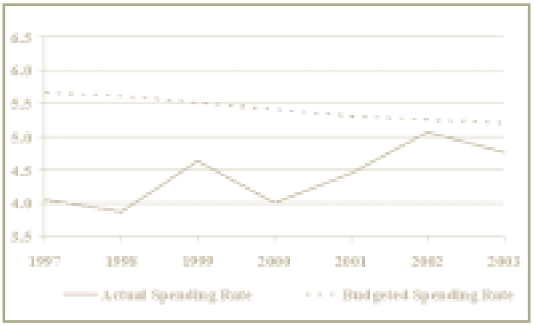
Financial Statements For the year ending June 30, 2003

Carnegie Funds Spending Over Seven Years (Dollars in Millions)

FY	96-97	97-98	98-99	99-00	00-01	01-02	02-03
Carnegie Funds Spending	$ 15.5	$ 16.4	$ 20.9	$ 20.0	$ 22.8	$ 25.5	$ 25.0
Actual Market Value at June 30	$382.9	$423.3	$451.6	$477.9	$512.0	$501.8	$525.7
Actual Spending as % of Market Value	4.05%	3.87%	4.63%	4.18%	4.45%	5.07%	4.76%
Planned Spending Rate in Budget	5.66%	5.61%	5.50%	5.40%	5.30%	5.25%	5.20%

The table above compares the planned versus the actual spending rates, as well as the market value of the endowment from 1996-1997 to the most recently concluded fiscal year, 2002-2003.

Budget and Actual Spending Rates



Within Carnegie's endowment, there are a number of "Funds" that provide support either in a general way or in a targeted way, with a specific, defined purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of $10 million. Mr. Carnegie later made additional gifts totaling another $12 million during his lifetime. Together these gifts are now valued at over $464 million.

UNAUDITED

The following table shows the amount in the principal funds within the institution's endowment as of June, 2003.

Market value of the Principal Funds Within Carnegie's Endowment

Andrew Carnegie	$464,398,852
Mellon Matching	12,023,756
Capital Campaign	9,979,731
Astronomy Funds	9,593,196
Anonymous	7,951,088
Anonymous Matching	7,430,380
Wood	5,824,679
Golden	3,984,214
Science Education Fund	2,397,321
Colburn	2,094,091
McClintock Fund	1,710,903
Bush Bequest	1,210,569
Endowed Fellowships	1,066,380
Starr Fellowship	806,675
Roberts	450,687
Lundmark	336,909
Hollaender	274,230
Forbush	147,996
Green Fellowship	116,494
Hale	114,694
Harkavy	110,568
Total	532,023,413

Independent Auditors' Report

To the Audit Committee of the
Carnegie Institution of Washington:

We have audited the accompanying statements of financial position of the Carnegie Institution of Washington (Carnegie) as of June 30, 2003 and 2002, and the related statements of activities and cash flows for the years then ended. These financial statements are the responsibility of Carnegie's management. Our responsibility is to express an opinion on these financial statements based on our audits.

We conducted our audits in accordance with auditing standards generally accepted in the United States of America. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audits provide a reasonable basis for our opinion.

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of the Carnegie Institution of Washington as of June 30, 2003 and 2002, and its changes in net assets and its cash flows for the years then ended, in conformity with accounting principles generally accepted in the United States of America.

Our audits were made for the purpose of forming an opinion on the basic financial statements taken as a whole. The supplementary information included in the schedule of expenses is presented for purposes of additional analysis and is not a required part of the basic financial statements. Such information has been subjected to the auditing procedures applied in the audits of the basic financial statements and, in our opinion, is fairly presented in all material respects in relation to the basic financial statements taken as a whole.

KPMG LLP

October 24, 2003

Statements of Financial Position

June 30, 2003 and 2002

	2003	2002
Assets		
Cash and cash equivalents	$631,216	177,964
Accrued investment income	98,668	76,768
Contributions receivable, net (note 2)	6,561,772	6,877,761
Accounts receivable and other assets	8,877,030	6,122,068
Bond proceeds held by trustee (note 6)	29,536,629	83
Investments (note 3)	532,023,413	507,443,374
Property and equipment, net (notes 4 and 5)	133,195,832	126,980,631
Total assets	$710,924,560	647,678,649
Liabilities and Net Assets		
Liabilities:		
Accounts payable and accrued expenses	$5,083,899	3,975,669
Deferred revenue (note 5)	35,523,865	34,810,393
Bonds payable (note 6)	64,715,672	34,953,919
Accrued postretirement benefits (note 8)	11,359,000	10,636,000
Total liabilities	116,682,436	84,375,981
Net assets (note 9):		
Unrestricted:		
Board designated:		
Invested in property and equipment, net	62,492,924	57,216,319
Designated for managed investments	462,571,402	440,440,733
Undesignated	6,049,088	4,398,917
	531,113,414	502,055,969
Temporarily restricted	24,207,950	23,453,842
Permanently restricted	38,920,760	37,792,857
Total net assets	594,242,124	563,302,668
Commitments and contingencies (notes 10, 11 and 12)		
Total liabilities and net assets	**$ 710,924,560**	**647,678,649**

See accompanying notes to financial statements.

Statements of Activities

Years ended June 30, 2003 and 2002

	2003				2002			
	Unrestricted	**Temporarily restricted**	**Permanently restricted**	**Total**	**Unrestricted**	**Temporarily restricted**	**Permanently restricted**	**Total**
Revenues and support:								
External revenue:								
Grants and contracts	$24,705,588	—	—	24,705,588	20,514,020	—	—	20,514,020
Contributions and gifts (note 13)	18,130,285	5,149,505	1,090,549	24,370,339	1,137,470	2,469,655	11,688	3,618,813
Net losses on disposals of property	(18,012)	—	—	(18,012)	(61,147)	—	—	(61,147)
Other income	1,683,264	—	—	1,683,264	2,117,228	—	—	2,117,228
Net external revenue	44,501,125	5,149,505	1,090,549	50,741,179	23,707,571	2,469,655	11,688	26,188,914
Investment income, net (note 3)	32,665,818	1,926,187	37,354	34,629,359	14,451,779	781,810	17,836	15,251,425
Net assets released from restrictions and clarification of donor intent (note 9)	6,321,584	(6,321,584)	—	—	1,452,841	(1,452,841)	—	—
Total revenues and other support	83,488,527	754,108	1,127,903	85,370,538	39,612,191	1,798,624	29,524	41,440,339
Expenses:								
Program expenses:								
Terrestrial Magnetism	8,299,433	—	—	8,299,433	7,467,442	—	—	7,467,442
Observatories	9,528,962	—	—	9,528,962	8,562,433	—	—	8,562,433
Geophysical Laboratory	11,665,517	—	—	11,665,517	9,463,055	—	—	9,463,055
Embryology	6,984,748	—	—	6,984,748	6,195,323	—	—	6,195,323
Plant Biology	8,551,064	—	—	8,551,064	9,592,810	—	—	9,592,810
Global Ecology	2,516,856	—	—	2,516,856	—	—	—	—
Other programs	1,422,287	—	—	1,422,287	1,763,724	—	—	1,763,724
Administrative and general expenses	5,462,215	—	—	5,462,215	5,177,065	—	—	5,177,065
Total expenses	54,431,082	—	—	54,431,082	48,221,852	—	—	48,221,852
Increase (decrease) in net assets	29,057,445	754,108	1,127,903	30,939,456	(8,609,661)	1,798,624	29,524	(6,781,513)
Net assets at beginning of year	502,055,969	23,453,842	37,792,857	563,302,668	510,665,630	21,655,218	37,763,333	570,084,181
Net assets at end of year	$531,113,414	24,207,950	38,920,760	594,242,124	502,055,969	23,453,842	37,792,857	563,302,668

See accompanying notes to financial statements.

Statements of Cash Flows

Years ended June 30, 2003 and 2002

	2003	2002
Cash flows from operating activities:		
Increase (decrease) in net assets	$ 30,939,456	(6,781,513)
Adjustments to reconcile increase (decrease) in net assets to net cash provided by (used in) operating activities:		
Depreciation	6,009,836	4,700,801
Net gains on investments	(29,639,941)	(6,760,930)
Contributions of stock	(79,675)	(2,467,969)
Losses on disposals of property	18,012	61,147
Amortization of bond issuance costs and discount	57,347	36,865
Contributions and investment income restricted for long-term investment	(2,662,965)	(1,891,271)
(Increase) decrease in assets:		
Receivables	(2,438,973)	1,230,991
Accrued investment income	(21,900)	47,021
Increase (decrease) in liabilities:		
Accounts payable and accrued expenses	1,108,230	(1,701,135)
Deferred revenue	713,472	1,761,857
Accrued postretirement benefits	723,000	139,000
Net cash provided by (used in) operating activities	4,725,899	(11,625,136)
Cash flows from investing activities:		
Acquisition of property and equipment	(4,550,914)	(4,304,605)
Construction of telescope, facilities, and equipment	(7,692,135)	(6,255,047)
Proceeds from sales of property and equipment	—	9,396
Investments purchased	(241,085,299)	(234,823,334)
Proceeds from investments sold or matured	246,224,876	253,914,272
Purchases of investments by bond trustee	(29,536,546)	—
Net cash provided by (used in) investing activities	(36,640,018)	8,540,682
Cash flows from financing activities:		
Proceeds from bond issuance	30,000,000	309
Bond issuance costs capitalized	(295,594)	—
Proceeds from contributions and investment income restricted for:		
Investment in endowment	410,100	1,576,148
Investment in property and equipment	2,252,865	315,123
Net cash provided by financing activities	32,367,371	1,891,580
Net increase (decrease) in cash and cash equivalents	453,252	(1,192,874)
Cash and cash equivalents at beginning of year	177,964	1,370,838
Cash and cash equivalents at end of year	$ 631,216	177,964
Supplementary cash flow information:		
Cash paid for interest	$ 1,165,587	1,404,797
Noncash activity – contributions of stock	79,675	2,467,969

See accompanying notes to financial statements.

(1) Organization and Summary of Significant Accounting Policies

Organization

The Carnegie Institution of Washington (Carnegie) conducts advanced research and training in the sciences. It carries out its scientific work in six research centers located throughout the United States and at an observatory in Chile. The centers are the Departments of Embryology, Plant Biology, Global Ecology, and Terrestrial Magnetism, the Geophysical Laboratory, and the Observatories. Income from investments represents approximately 40% and 37% of Carnegie's total revenues for the years ended June 30, 2003 and 2002, respectively. Carnegie's other income is primarily from gifts and federal grants and contracts.

Basis of Accounting and Presentation

The financial statements are prepared on the accrual basis of accounting. Contributions and gifts revenues are classified according to the existence or absence of donor-imposed restrictions. Also, satisfaction of donor-imposed restrictions are reported as releases of restrictions in the statements of activities.

Investments and Cash Equivalents

Carnegie's debt and equity investments are reported at their fair values based on quoted market prices. Carnegie reports investments in limited partnerships at fair value as determined and reported by the general partners. All changes in fair value are recognized in the statements of activities. Carnegie considers all highly liquid debt instruments purchased with remaining maturities of 90 days or less to be cash equivalents. Money market and other highly liquid instruments held by investment managers are reported as investments.

Income Taxes

Carnegie has been recognized by the Internal Revenue Service as exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code (the Code) except for amounts from unrelated business income. Carnegie is also an educational institution within the meaning of Section 170(b)(1)(A)(ii) of the Code. The Internal Revenue Service has classified Carnegie as other than a private foundation, as defined in Section 509(a) of the Code.

Fair Value of Financial Instruments

Financial instruments of Carnegie include cash equivalents, receivables, investments, bond proceeds held by trustee, accounts and broker payables, and bonds payable. The fair value of investments in debt and equity securities is based on quoted market prices. The fair value of investments in limited partnerships is based on information provided by the general partners.

The fair value of the 1993 Series A bonds payable is based on quoted market prices. The fair value of the 1993 Series B and 2002 revenue bonds payable is estimated to be the carrying value, since these bonds bear adjustable market rates (see note 6).

The fair values of cash equivalents, receivables, bond proceeds held by trustee, and accounts and broker payables approximate their carrying values based on their short maturities.

Use of Estimates

The preparation of financial statements in conformity with accounting principles generally accepted in the United States of America requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and disclosure of contingent assets and liabilities at the date of the financial statements. They also affect the reported amounts of revenues and expenses during the reporting period. Actual results could differ from those estimates.

Property and Equipment

Carnegie capitalizes expenditures for land, buildings and leasehold improvements, telescopes, scientific and administrative equipment, and projects in progress. Routine replacement, maintenance, and repairs are charged to expense.

Depreciation is computed on a straight-line basis, generally over the following estimated useful lives:

Buildings and telescopes – 50 years
Leasehold improvements – lesser of 25 years or the remaining term of the lease
Scientific and administrative equipment – 2-10 years, based on scientific life of equipment

Contributions

Contributions are classified based on the existence or absence of donor-imposed restrictions. Contributions and net assets are classified as follows:

Unrestricted – includes all contributions received without donor-imposed restrictions on use or time.
Temporarily restricted – includes contributions with donor-imposed restrictions as to purpose of gift and/or time period expended.
Permanently restricted – generally includes endowment gifts in which donors stipulated that the corpus be invested in perpetuity. Only the investment income generated from endowments may be spent. Certain endowments require that a portion of the investment income be reinvested in perpetuity.

Contributions to be received after one year are discounted at an appropriate discount rate commensurate with the risks involved. Amortization of the discount is recorded as additional revenue and used in accordance with donor-imposed restrictions, if any.

Gifts of long-lived assets, such as buildings or equipment, are considered unrestricted when placed in service. Cash gifts restricted for investment in long-lived assets are released from restriction when the asset is acquired or as costs are incurred for asset construction.

Grants

Carnegie records revenues on grants from federal agencies only to the extent that reimbursable expenses are incurred. Accordingly, funds received in excess of reimbursable expenses are recorded as deferred revenue, and expenses in excess of reimbursements are recorded as accounts receivable. Reimbursement of indirect costs is based upon provisional rates, which are subject to subsequent audit by Carnegie's federal cognizant agency, the National Science Foundation.

Allocation of Costs

The costs of providing programs and supporting services have been summarized in the statements of activities. Accordingly, certain costs have been allocated among the programs and supporting services benefited. Fundraising expenses of $464,854 and $583,951 for the years ended June 30, 2003 and 2002, respectively, have been included in administrative and general expenses in the accompanying statements of activities.

Reclassifications

Certain reclassifications have been made to the 2002 amounts to conform to the 2003 presentation.

(2) Contributions Receivable

Contributions receivable are summarized as follows at June 30, 2003:

Unconditional promises	
expected to be collected in:	
Less than one year	$ 3,745,846
One year to five years	2,917,834
	6,663,680
Less:	
Allowance for uncollectible amounts	(9,500)
Discount to present value	(92,408)
	$ 6,561,772

Pledges receivable as of June 30, 2003 and 2002, were discounted using the 3-year U.S. Treasury rate, which was approximately 2% and 3.4%, respectively.

(3) Investments

Investments at fair value consisted of the following at June 30, 2003 and 2002:

	2003	2002
Time deposits and money market funds	$43,208,095	16,406,227
Debt mutual funds	9,817	248,511
Debt securities	105,656,891	123,090,148
Equity securities	156,746,457	146,148,319
Limited real estate partnerships	44,576,914	55,951,123
Limited partnerships	181,825,239	165,599,046
	$ 532,023,413	507,443,374

Investment income, net consisted of the following for the years ended June 30, 2003 and 2002:

	2003	2002
Interest and dividends	$ 6,103,313	9,622,175
Net realized gains	45,333,103	17,131,992
Net unrealized losses	(15,693,162)	(10,371,062)
Less investment management expenses	(1,113,895)	(1,131,680)
	$ 34,629,359	15,251,425

As of June 30, 2003, the fair value for approximately $88.2 million of Carnegie's $226.4 million of limited real estate partnership and limited partnership investments has been estimated by the general partners in the absence of readily ascertainable values as of that date. As of June 30, 2002, the fair value for approximately $92.3 million of Carnegie's $221.6 million of limited real estate partnership and limited partnership investments has been estimated by the general partners in the absence of readily ascertainable values as of that date. However, these estimated fair values may differ from the values that would have been used had a ready market existed.

(4) Property and Equipment

Property and equipment placed in service consisted of the following at June 30, 2003 and 2002:

	2003	2002
Buildings and improvements	$ 45,435,945	44,926,389
Scientific equipment	26,901,472	23,645,798
Telescopes	80,888,440	50,434,811
Construction in progress	17,537,973	40,281,812
Administrative equipment	2,433,184	2,859,168
Land	787,896	787,896
Art	38,105	40,192
	174,023,015	162,976,066
Less accumulated depreciation	(40,827,183)	(35,995,435)
	$ 133,195,832	126,980,631

Construction in progress consisted of the following at June 30, 2003 and 2002:

	2003	2002
Buildings	$ 4,184,529	1,009,249
Scientific equipment	13,353,444	10,482,894
Telescope	—	28,789,669
	$ 17,537,973	40,281,812

At June 30, 2003 and 2002, approximately $83.5 million and $82 million, respectively, of construction in progress and other property, net of accumulated depreciation, was located in Las Campanas, Chile. During construction in 2002, Carnegie capitalized interest costs of approximately $1,344,000 as construction in progress.

(5) Magellan Consortium

During the year ended June 30, 1998, Carnegie entered into an agreement (Magellan Agreement) with four universities establishing a consortium to build and operate the Magellan telescopes. The two Magellan telescopes are located on Manqui Peak, Las Campanas in Chile. The first telescope, with a cost of approximately $41,708,000, was placed in service during 2001. The other, with a cost of approximately $30,148,000, was placed in service in 2003.

The university members of the consortium, by contribution to the construction and operating costs of Magellan, acquire rights of access and oversight as described in the Magellan Agreement. Total contributions by the university members for construction are expected to cover 50% of the total expected costs. As of June 30, 2003, $36,152,642 has been received. These monies are being used by Carnegie to finance part of the Magellan Telescopes' construction costs. As of June 30, 2003 and 2002, the excess of university member's contributions over operating costs totaled $32,075,946 and $32,235,751, respectively, and is included in deferred revenue in the accompanying statements of financial position. The deferred revenue is being recognized ratably as income over the remaining estimated useful lives of the telescopes.

(6) Bonds Payable

1993 California Educational Facilities Authority Revenue Bonds

On November 1, 1993, Carnegie issued $17.5 million each of Series A and Series B California Educational Facilities Authority Revenue tax-exempt bonds. Bond proceeds were used to finance the Magellan telescope project and the renovation of the facilities of the Observatories at Pasadena. The balances outstanding at June 30, 2003 and 2002, on the Series A issue totaled $17,494,289 and $17,471,444, respectively, and on the Series B issue totaled $17,496,495 and $17,482,475, respectively. The balances outstanding are net of unamortized bond issue costs and bond discount. Bond proceeds held by the trustee and unexpended at June 30, 2003 and 2002 totaled $112 and $83, respectively.

Series A bonds bear interest at 5.6% payable in arrears semiannually on each April 1 and October 1 and upon maturity on October 1, 2023. Series B bonds bear interest at variable money market rates (ranging from 1% to 1.6% during the year, and 1.1% at June 30, 2003) in effect from time to time, up to a maximum of 12% over the applicable money market rate period of between 1 and 270 days and have a stated maturity of October 1, 2023. At the end of each money market rate period, Series B bondholders are required to offer the bonds for repurchase at the applicable money market rate. When repurchased, the Series B bonds are resold at the current applicable money market rate and for a new rate period.

Carnegie is not required to repay the Series A and B bonds until the October 1, 2023, maturity date. Sinking fund redemptions begin in 2019 in installments for both series. The fair value of Series A bonds payable at June 30, 2003 and 2002, based on quoted market prices is estimated at $20,051,000 and $18,325,000, respectively. The fair value of Series B bonds payable at June 30, 2003 and 2002 is estimated to approximate carrying value as the mandatory tender dates on which the bonds are repriced are generally within three months of year end.

2002 Maryland Health and Higher Education Facilities Authority Revenue Bond

On October 23, 2002, the Maryland Health and Higher Education Facilities Authority (MHHEFA) issued $30 million of its Revenue Bonds on behalf of Carnegie. Bond proceeds are being used to construct and equip a new facility for Carnegie's Department of Embryology on the Johns Hopkins Homewood Campus in Baltimore, Maryland. Construction began in April 2003, and the facility is expected to be ready for occupancy in February 2005.

The balance outstanding at June 30, 2003, on the Carnegie 2002 Series totaled $29,724,888. The balance outstanding is net of unamortized bond issue costs. Bond proceeds held by the trustee and unexpended at June 30, 2003, totaled $29,536,517.

The bonds were issued in the weekly mode and bear interest at a variable rate determined by the remarketing agent, Lehman Brothers. The rates fluctuated between 0.50% and 1.80% during the year ended June 30, 2003 (see note 7). The rate at June 30, 2003, was 1.05%. Rates on remarketed bonds are selected in such a manner that the selling price will closely approximate the face value, but under no circumstances will the rate exceed 12% per annum. Interest is payable on the first business day of each month. Bonds in the weekly mode are subject to redemption at the request of Carnegie on any interest payment date. Bonds in weekly mode can be changed to daily, commercial paper, term rate or fixed rate mode at the request of Carnegie. Bonds are subject to mandatory tender for purchase prior to any change in the interest rate mode.

Scheduled maturities and sinking fund requirements are as follows:

Due:	
October 1, 2033	$ 6,000,000
October 1, 2034	6,000,000
October 1, 2035	6,000,000
October 1, 2036	6,000,000
October 1, 2037	6,000,000
	$ 30,000,000

Standby credit facilities have been established with SunTrust Bank in the aggregate amount of $30,000,000 as of June 30, 2003, for a period of 364 days. Carnegie pays 0.08% per annum on the amount of the available commitment, payable quarterly in arrears. SunTrust Bank may extend the agreement, but Carnegie is not required to maintain a liquidity facility for any bonds. The standby credit facility has not been used as of June 30, 2003.

(7) Interest Rate Swap Agreement

Carnegie entered into a swap agreement with an effective date of October 23, 2002. This swap agreement relates to $15 million face amount of its Series 2002 Maryland Health and Higher Education Facilities Authority Revenue Bonds (see note 6). The agreement provides for Lehman Brothers Special Financing Inc. to receive 3.717% in interest on a notional amount of $15 million and to pay interest at a floating rate of 68% of the three-month LIBOR rate, reducing on the dates and in the amounts as follows:

October 1, 2033	$ 3,000,000
October 1, 2034	3,000,000
October 1, 2035	3,000,000
October 1, 2036	3,000,000

The interest rate swap agreement was entered into by Carnegie to mitigate the risk of changes in interest rates associated with variable interest rate indebtedness. Carnegie applies the provisions of FASB Statement No. 133, *Accounting for Derivative Instruments and Hedging Activities*. This standard requires certain derivative financial instruments to be recorded at fair value. The interest rate swap agreement described above is a derivative instrument that is required to be recorded at fair value and is included in accounts payable and accrued expenses on the accompanying statements of financial position. The change in fair value for the year ended June 30, 2003, was a loss of $1,246,619 and is included as a reduction of other income.

(8) Employee Benefit Plans

Retirement Plan

Carnegie has a noncontributory, defined contribution, money-purchase retirement plan in which all U.S. personnel are eligible to participate. After one year of participation, an individual's benefits are fully vested. The Plan has been funded through individually owned annuities issued by Teachers' Insurance and Annuity Association (TIAA) and College Retirement Equities Fund (CREF). Contributions made by Carnegie totaled approximately $2,783,000 and $2,800,000 for the years ended June 30, 2003 and 2002, respectively.

Postretirement Benefits Plan

Carnegie provides postretirement medical benefits to all employees who retire after age 55 and have at least 10 years of service. Cash payments made by Carnegie for these benefits totaled approximately $587,000 and $635,000 for the years ended June 30, 2003 and 2002, respectively.

The expense for postretirement benefits for the years ended June 30, 2003 and 2002 consists of the following:

	2003	**2002**
Service cost – benefits earned during the year	$ 576,000	340,000
Interest cost on projected benefit obligation	734,000	554,000
Amortization of gain	—	(120,000)
Postretirement benefit cost	$1,310,000	774,000

The 2003 postretirement benefits expense was approximately $723,000 more than the cash expense of $587,000, and the 2002 postretirement benefits expense was approximately $139,000 more than the cash expense of $635,000. The postretirement benefits expense was allocated among program and supporting services expenses in the accompanying statements of activities.

The reconciliation of the plan's funded status to amounts recognized in the financial statements at June 30, 2003 and 2002 follows:

	2003	2002
Change in benefit obligation:		
Benefit obligation at beginning of year	$ 10,300,000	7,572,000
Service cost	576,000	340,000
Interest cost	734,000	554,000
Actuarial loss	9,508,000	2,469,000
Benefits paid	(587,000)	(635,000)
Benefit obligation at end of year	20,531,000	10,300,000
Change in plan assets:		
Fair value of plan assets at beginning of year	—	—
Actual return on plan assets	—	—
Contribution to plan	587,000	635,000
Benefits paid	(587,000)	(635,000)
Fair value of plan assets at end of year	—	—
Funded status	(20,531,000)	(10,300,000)
Unrecognized net actuarial loss (gain)	9,172,000	(336,000)
Accrued benefit cost	$ (11,359,000)	(10,636,000)

The present value of the benefit obligation as of June 30, 2003, was determined using an assumed discount rate of 6%. The present value of the benefit obligation as of June 30, 2002, was determined using an assumed discount rate of 7.3%. Carnegie's policy is to fund postretirement benefits as claims and administrative fees are paid.

For measurement purposes, an 11% annual rate of increase in the per capita cost of pre-Medicare covered healthcare benefits and a 13% annual rate of increase in the per capita cost of post-Medicare covered healthcare benefits was assumed for 2003; the rate for both types of benefits was assumed to decrease gradually to 5.5% in 2016 and remain at that level thereafter. The healthcare cost trend rate assumption has a significant effect on the amounts reported. A one-percentage point change in assumed annual healthcare cost trend rate would have the following effects:

	One-percentage point increase	One-percentage point decrease
Effect on total of service and interest cost components	$ 279,000	(215,000)
Effect on postretirement benefit obligation	3,872,000	(3,042,000)

(9) Net Assets

Temporarily Restricted Net Assets

Temporarily restricted net assets were available to support the following donor-restricted purposes at June 30, 2003 and 2002:

	2003	2002
Specific research programs	$ 14,384,361	14,195,484
Equipment acquisition and construction	3,638,444	3,452,955
Passage of time	6,185,145	5,805,403
	$ 24,207,950	23,453,842

Permanently Restricted Net Assets

Permanently restricted net assets consisted of permanent endowments, the income from which is available to support the following donor-restricted purposes at June 30, 2003 and 2002:

	2003	2002
Specific research programs	$ 15,716,041	14,588,138
Equipment acquisition and construction	1,204,719	1,204,719
General support (Carnegie endowment)	22,000,000	22,000,000
	$ 38,920,760	37,792,857

Net Assets Released from Restrictions and Clarification of Donor Intent

During 2003 and 2002, Carnegie met donor-imposed requirements on certain gifts and received clarifications from donors about the intention of their gifts and, therefore, released temporarily restricted net assets as follows:

	2003	2002
Specific research programs	$ 2,984,309	3,737,082
Equipment acquisition and construction	962,034	2,639,406
Passage of time	2,375,241	2,682,126
Clarification of donor intent	—	(7,605,773)
	$ 6,321,584	1,452,841

(10) Commitments

Carnegie entered into a contract with the University of Arizona for the construction of a secondary mirror and support system for the second telescope in the Magellan project. The amount of the contract is approximately $590,000, none of which had been incurred at June 30, 2003.

Carnegie has outstanding commitments to invest approximately $71 million in limited partnerships at June 30, 2003.

(11) Lease Arrangements

Carnegie leases a portion of the land it owns in Las Campanas, Chile, to other organizations. These organizations have built and operate telescopes on the land. Most of the lease arrangements are not specific and some are at no cost to the other organizations. One of the lease arrangements is noncancelable and had annual rent of approximately $160,000 for each of the fiscal years 2003 and 2002. For the no-cost leases, the value of the leases could not be determined and is not considered significant and, accordingly, contributions have not been recorded in the financial statements.

Carnegie also leases a portion of one of its laboratories to another organization for an indefinite term. Rents to be received under the agreement are approximately $509,000 annually, adjusted for CPI increases.

Carnegie leases land and buildings. The monetary terms of the leases are considerably below fair value; however, these terms were developed considering other nonmonetary transactions between Carnegie and the lessors. The substance of the transactions indicates arms-length terms between Carnegie and the lessors. The monetary value of the leases could not be determined and has not been recorded in the financial statements.

(12) Contingencies

Costs charged to the federal government under cost-reimbursement grants and contracts are subject to government audit. Therefore, all such costs are subject to adjustment. Management believes that adjustments, if any, would not have a significant effect on the financial statements.

In 1999, Carnegie notified the National Science Foundation (NSF) of its discovery of inappropriate expenditures made under one of its grants to Carnegie. In 2002, NSF began an investigation of these expenditures. The investigation is ongoing, and its results are unknown, however the NSF estimates the potential amount to be repaid by Carnegie will not exceed $300,000. Management believes that the result of the investigation will not have a material adverse effect on the financial statements.

(13) Related Party Transactions

Carnegie recorded contributions from its trustees, officers and directors of $21,440,335 and $1,228,195, for the years ended June 30, 2003 and 2002, respectively.

Schedule of Expenses

Years ended June 30, 2003 and 2002

	2003			2002		
	Carnegie funds	**Federal and private grants**	**Total expenses**	**Carnegie funds**	**Federal and private grants**	**Total expenses**
Personnel costs:						
Salaries	$ 16,608,700	4,636,962	21,245,662	14,957,846	4,938,335	19,896,181
Fringe benefits and payroll taxes	4,494,032	2,200,589	6,694,621	4,818,312	1,392,338	6,210,650
Total personnel costs	21,102,732	6,837,551	27,940,283	19,776,158	6,330,673	26,106,831
Fellowship grants and awards	1,674,086	648,011	2,322,097	1,486,946	760,633	2,247,579
Depreciation	6,009,836	—	6,009,836	4,700,801	—	4,700,801
General expenses:						
Educational and research supplies	2,161,910	5,565,549	7,727,459	1,670,969	4,041,028	5,711,997
Building maintenance and operation	2,716,592	693,621	3,410,213	2,336,183	575,179	2,911,362
Travel and meetings	1,250,038	680,267	1,930,305	1,119,553	413,802	1,533,355
Publications	40,842	39,231	80,073	43,937	95,801	139,738
Shop	63,573	—	63,573	160,851	2	160,853
Telephone	187,470	10,363	197,833	187,242	10,360	197,602
Books and subscriptions	310,759	—	310,759	295,298	390	295,688
Administrative and general	3,104,188	186,887	3,291,075	1,479,605	253,462	1,733,067
Interest	1,364,369	—	1,364,369	—	—	—
Printing and copying	80,780	—	80,780	60,807	—	60,807
Shipping and postage	161,121	27,582	188,703	189,010	13,479	202,489
Insurance, taxes, and professional fees	2,080,254	130,192	2,210,446	1,698,210	108,970	1,807,180
Equipment	2,485,875	3,390,935	5,876,810	2,282,630	2,552,393	4,835,023
Fundraising expense	637,295	—	637,295	516,855	—	516,855
Total general expenses	16,645,066	10,724,627	27,369,693	12,041,150	8,064,866	20,106,016
Total direct costs	45,431,720	18,210,189	63,641,909	38,005,055	15,156,172	53,161,227
Indirect costs – grants and contracts	(6,495,399)	6,495,399	—	(5,357,848)	5,357,848	—
Total costs	38,936,321	24,705,588	63,641,909	32,647,207	20,514,020	53,161,227
Capitalized scientific equipment	(5,871,899)	(3,338,928)	(9,210,827)	(2,813,180)	(2,126,195)	(4,939,375)
Total expenses	$ 33,064,422	21,366,660	54,431,082	29,834,027	18,387,825	48,221,852

On the cover: **Above:** Sucrose is transported in a specific conduit inside plant cells named sieve elements (se)—cells that degrade their nuclei after they form. Despite this loss, sieve elements can remain functional. They are tightly associated with their neighboring cells via plasmodesmata, which mediate transport of nucleic acids and proteins. Sucrose-transporter proteins are present in sieve elements. Antibodies directed against the central loop of a sucrose -transporter can be used to localize the cells and membranes in which the transporter protein is present (see page 50). (Image courtesy Wolf Frommer.)

Below: Remote sensing is one of the many tools Greg Asner of the Department of Global Ecology uses to unravel interactions among the Earth's ecosystems. This map shows the geographic distribution of changes in net primary production—the amount of plant growth—throughout North America from 1982 to 1999 (see page 13). (Image courtesy NASA; analysis and modeling at Carnegie.)

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