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ABSTRACT

The modern scientific enterprise often appears so complex and sophisticated that it may seem unapproachable. This view of science is questioned in this booklet, which looks at science as a human endeavor, one which is within the grasp of all people. This document highlights the personal stories of four young scientists in an effort to provide prospective scientists with some insight into what to expect from the world of science. Background information and summaries of the work of these individuals are intended to provide a broad look into the realm of scientific endeavor. The scientists discussed are: (1) Steven L'Hernault (Cell Biologist); (2) Julie Morris (Geochemist); (3) John Watson (Plant Molecular Biologist); and (4) Wendy Freedman (Astronomer). A final section of the booklet discusses some of the possibilities available in scientific research and post-doctoral experiences. (TW)

Becoming a Scientist: Gateway to Research

An essay about basic research from
The Carnegie Institution
of Washington

Perspectives in Science
Number 3
1987

PREFACE

The modern scientific enterprise is large and sophisticated, and may seem, to the young or noninitiated, to be nearly inapproachable. This is not true. Science is a human endeavor. Its aims and purposes are within grasp of us all. While the process of entering the world of science is long and often difficult, the rewards can be deeply satisfying. For those considering such a journey, it is hoped that this essay—the personal stories of four young scientists—may provide some insight about what to expect along the way.

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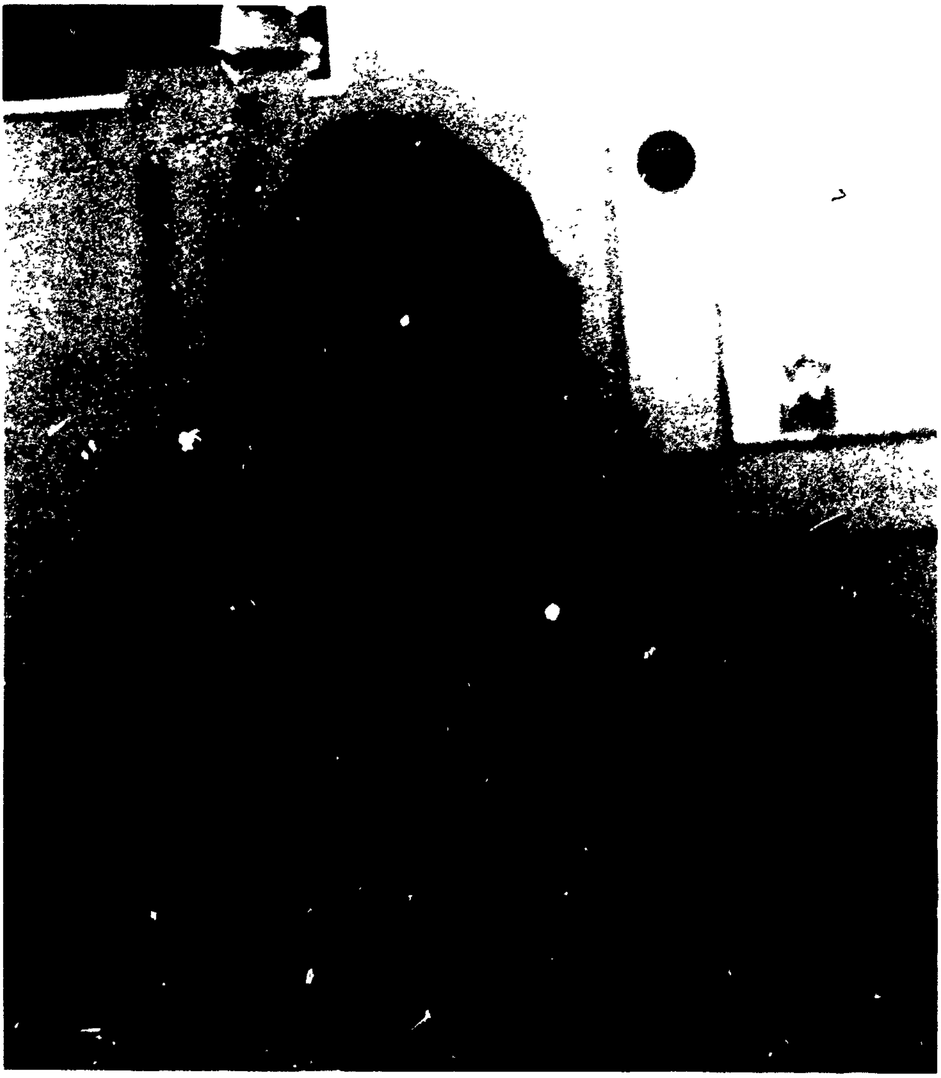


John Watson

> . . . a scientific life is . . . exciting, rather passionate, and—in terms of hours of work—a very demanding and sometimes exhausting occupation . . . . A novice must stick it out until he [or she] discovers whether the rewards and compensations of a scientific life are . . . commensurate with the disappointments and the toil: but if once a scientist experiences the exhilaration of discovery and the satisfaction of carrying through a really tricky experiment . . . then he [or she] is hooked and no other kind of life will do.
>
> Peter B. Medawar
> *Advice to a Young Scientist*
> 1979

John Watson, a tall redhead with a full beard and hearty laugh, has spent the last nine years of his life preparing for a career as a plant molecular biologist. Now, 32 years old and on the final leg of his educational odyssey, he is getting ready to apply for his first professional job. He is looking especially hard toward major universities, for large universities tend to have the greater opportunities for research, and while John wants to teach, he wants even more to do research. He says he goes through withdrawal if he stays away from the laboratory too long.

John spent the first six years of his advanced education at Indiana University, where he earned his Ph.D. in 1982. Since then, he has been a postdoctoral fellow at a small, technically advanced plant biology research laboratory near San Francisco, California, where he studies the genes of the ordinary pea plant. As a postdoctoral fellow, John is not considered a student. He takes no courses and he receives no formal instruction. But neither is he considered a full-fledged professional scientist. His status is somewhere in between, growing more toward the professional as his fellowship proceeds. John's postdoctoral years have been a time of transition, a sort of "rite of passage," connecting student and professional life.

John's experience is not unusual. Very few Ph.D. recipients aspiring to research careers in the physical and biological sciences go straight from graduate school to employment in universities or industry. Most first pass through a period of postdoctoral study that lasts from one to three years or even longer. The postdoctoral interval is an important stage in a scientist's career; it is during this time that an individual becomes an integral part of a professional community. It is when the long years of study—four years of undergraduate school and four or even six or seven years of graduate training—begin to pay off.

A graduate student usually chooses to do postdoctoral work in a research environment away from his or her degree-granting university. It is an exhilarating step into the professional world. Freed from the anxiety of the Ph.D. thesis—that first large venture into data collection and analysis that can take years to complete and which hangs heavily over the graduate student—and under no obligation to teach or take courses, the "postdoc" can devote almost full time to research. Wendy Freedman, an astronomer, says her postdoctoral fellowship is the best opportunity she's ever had. "There's something nice about suddenly being finished with your thesis," she says. "You have everything in front of you."

Most postdoctoral appointments are made for one year but can be extended for as many as three, depending on the policies of the funding and host institutions and the postdoc's performance. Guarantees of renewals, however, are rare. Some postdocs find this insecurity stressful. Others take it all in stride. However one reacts, the challenges of finding support for research are an important part of a scientist's life; research money is often tied to grants or contracts from government, foundation, or other sources. The postdoctoral years provide valuable insight into this "business" side of research.

The postdoctoral years offer more. Running a research laboratory can be time-consuming and expensive; sharing space, instruments, and technicians is often required. Postdocs learn to develop the necessary skills of administration and interpersonal communication. They also learn how to balance their time, between growing professional commitments on the one hand, and independent research on the other.

Despite the experience (and self-confidence) gained during the postdoctoral years, competition for subsequent positions in academia or industry can be intense. Postdoctoral fellow Steven L'Hernault, a cell biologist, says that looking for a job in his field is not easy. "It's a buyer's market," he says. "You don't decide you want to go to university X and write them a letter and tell them you're available. You read the notices in journals, you look at the letters to your department head soliciting applications. For each opening there may be as many as 100 applicants."

Steve's words echo the frustrations of postdocs in other fields. Geochemist Julie Morris, for example, has spent two years as a postdoctoral fellow. She has applied for twelve jobs in her immediate field, interviewed for six, and is in the final running for three. But the geochemistry field is very crowded now, and she is often in competition with from 50 to 100 other applicants. The situation may appear to be discouraging, but she is not one to give up. Her work is too much a part of her to do that.

The four individuals mentioned above—Julie, Steve, Wendy, and John—have never met, but each one is, at the time of this writing, a postdoctoral fellow at the Carnegie Institution of Washington. The stories of these four—chosen from about 75 postdoctoral appointees in residence at the Carnegie departments during 1986—are detailed in the following essay. The reader will see that the process of becoming a scientist requires no one type of personality, approach, or background. In these respects, each of these individuals is unique. What each one shares, however, is a strong spirit of commitment—a spirit that forms the heart of a long, often difficult, but rewarding journey. It is to this spirit, in these and future scientists, that this essay is dedicated.

STEVEN L'HERNAULT, CELL BIOLOGIST

I've been told that these [the postdoctoral years] are the best years of my life. But it's not a time without its problems . . . . At every step along the way, there is a series of pressures you have to deal with.

Steven L'Hernault
November 1985

Steven L'Hernault evidenced early the curiosities of a scientist. As a boy, he showed a "diabolical" interest in his chemistry set ("before the age of product liability") and he was a fanatic about dinosaurs. His parents were supportive. When his interests turned to biology, they bought him a microscope and a dissecting kit.

By the time Steve entered New Hyde Park Memorial High School, in New York, he was pretty sure he wanted to pursue a scientific career. His teachers there, he says, were some of the best he has ever had. He particularly liked his chemistry teachers. "They were an inspiration to me," he says. "They made the subject material exciting." They also nearly convinced him to make chemistry his life's career. But after two years of high school chemistry, Steve decided it wasn't for him. "I went into biology by default."

Steve started college at the University of Miami, but soon transferred to Hofstra University in New York. Though he found many of the humanities courses he took there appealing, he concentrated on science. He acquired many more science credits than he needed to graduate.

Steve is now 32 years old. He is an intense individual whose voice betrays his Long Island origins. He was the first member of his family on either side to complete college. His ambition leaves little room for vanity, however. "I'm very goal oriented," he says.

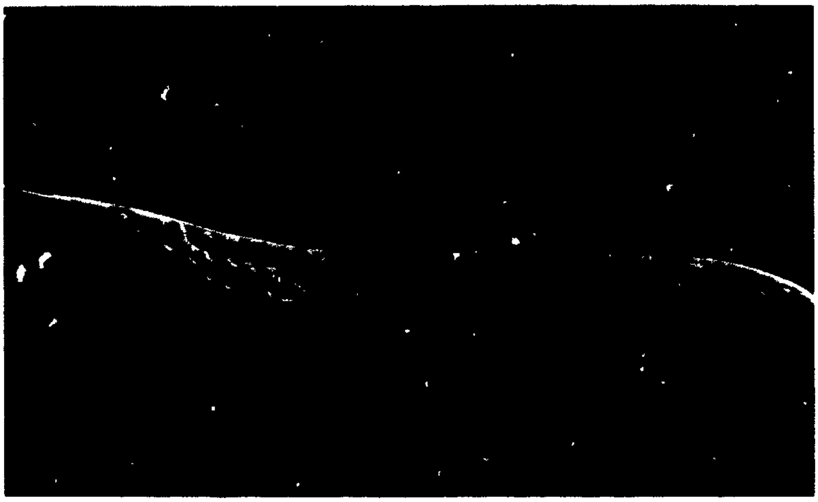
He is sitting in the small, windowless office he shares with one postdoctoral fellow and one graduate student at Carnegie's Department of Embryology in Baltimore, Maryland, one of the world's most advanced centers for the study of biological development. He muses about why he chose the direction he did. He says his parasitology professor at Hofstra, Dr. Eugene Kaplan, was particularly influential. "I remember how he introduced the section on parasitic worms. He held up a jar containing a foot-long worm and said, 'This is an *Ascaris*. It came out of me. I got the infection from eating pigeons in Jerusalem.' " Steve says it was this teacher who tied things together for him. "He was the first person who pushed me, the first one who told me I had a knack."

Thus encouraged, Steve started doing original research in the laboratory of Dr. Gary Grimes in his junior year of college. Two years later, in 1977, he had the unusually early satisfaction of seeing his name in print, as coauthor of a paper on the development of a unicellular protozoan. (Many scientists don't begin to publish until they are well into their graduate work.) Steve stayed at Hofstra until 1978, working toward his master's degree. When finished, he went on to do graduate work in the laboratory of Dr. Joel Rosenbaum at Yale University, all the time delving deeper and deeper into the phenomenon of development. How, he wondered, do developmental patterns form? What signals are responsible for one cell to become part of an arm, another to become part of a leg? How does a fertilized egg, which contains the blueprint for an entire organism, give rise to different tissues?

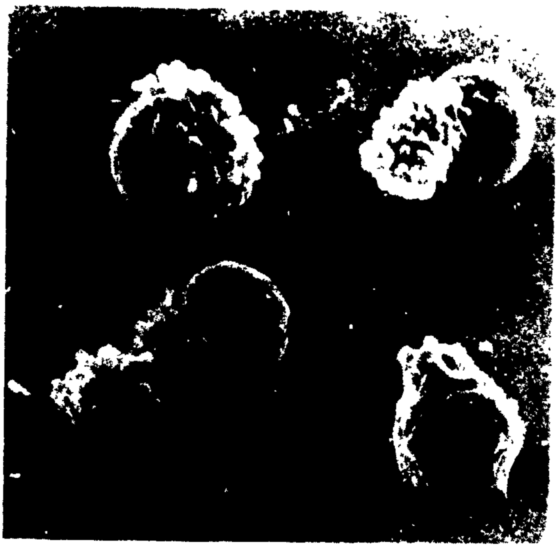
Questions of development are among the most complex of any in biology. The process whereby a single cell becomes a whole organism involves a staggering number of interactions—interactions between cells and tissues, between cells and cells, between genes and proteins. The challenge is to eliminate · many variables, as many of these interactions, as possible—to get to the lowest common denominators. To Steve, this meant getting down to the unit of the individual cell. He became fascinated by the primitive unicellular alga *Chlamydomonas reinhardtii*. For his Ph.D. thesis, he set out to interpret a classic experiment using *Chlamydomonas*. In this experiment, if one of the alga's two flagella (whip-like hairs) is removed, the organism resorbs the other flagellum until it is the same size as the chopped-off stump. Then, the two synchronously grow outward until both reach normal size. "When I read that," says Steve, "it really blew me away."

His work exploring the intracellular control system of *Chlamydomonas* was exciting and satisfying to him, and from it Steve achieved not only his Ph.D. but the publication of three original research articles. But *Chlamydomonas* wasn't just right for what he wanted to do. He wanted to understand the patterns of development. "An organism is laid out like a map," he explains. "The challenge is to figure out ways of disturbing, or mutating, the patterns so you can gain insight into the mechanisms that direct a particular sequence of events." To do this it is essential to understand genetics—to know which genes are responsible for various characteristics of the organism, and to be able to manipulate those genes in experimental ways.

The genetics of *Chlamydomonas*, however, are not particularly easy to manipulate, so Steve began to look around for another model system—an experimental organism that had more accessible genetics. "I said to myself, 'You want to do genetics. What systems are there with good genetics?' The answer is that there are remarkably few. There are bacteria, yeast and other fungi, fruit flies, nematode worms, mice, Indian corn, some algae. But I had a second requirement. I wanted a system that offered me means to look at the function of a single cell—one that had some prospect for doing good biochemistry. While some systems may be superb in one way or another, if you want to do biochemistry on a single cell of an advanced organism, and you want that cell to undergo developmental changes in a fashion independent of other cells, then you're left with very few choices. One of the best is the sperm cell of the nematode *Caenorhabditis elegans*."



The nematode worm *Caenorhabditis elegans*, above, averages one millimeter in length; its sperm cell, which Steve studies, is only 5/1000 of a millimeter long. Steve chose to study the *C. elegans* sperm because it provided a superb system for examining how developmental processes are controlled.



Scanning electron micrograph of a field of *C. elegans* spermatozoa on a glass slide. While sperm cells of most organisms are propelled by flagella, these cells, like amoebas, move by membrane flow in extended pseudopods. Cell at lower right is aberrant. (Specimen prepared by Dr. Tom Roberts.)

Caenorhabditis elegans is a roundworm that is so ubiquitous that any handful of soil might contain thousands. Despite its microscopic size, it contains many organs and tissues and is a complex animal. Its sperm, however, are single-celled, and are capable of setting up developmental patterns all by themselves, that is, without directions from or interactions with other cells of the worm. To Steve this was critical.

At the time, Steve was looking for a laboratory where he could do postdoctoral research. He knew that changing from *Chlamydomonas* to *C. elegans* would be no easy, carefree matter, for the time he would need to become acquainted with the new organism, he felt, would probably make it difficult for him to change again. His postdoctoral years, he hoped, would give him time to do this, "to set something up and get it rolling," so that when he was ready to start a job, he could "hit the ground running."

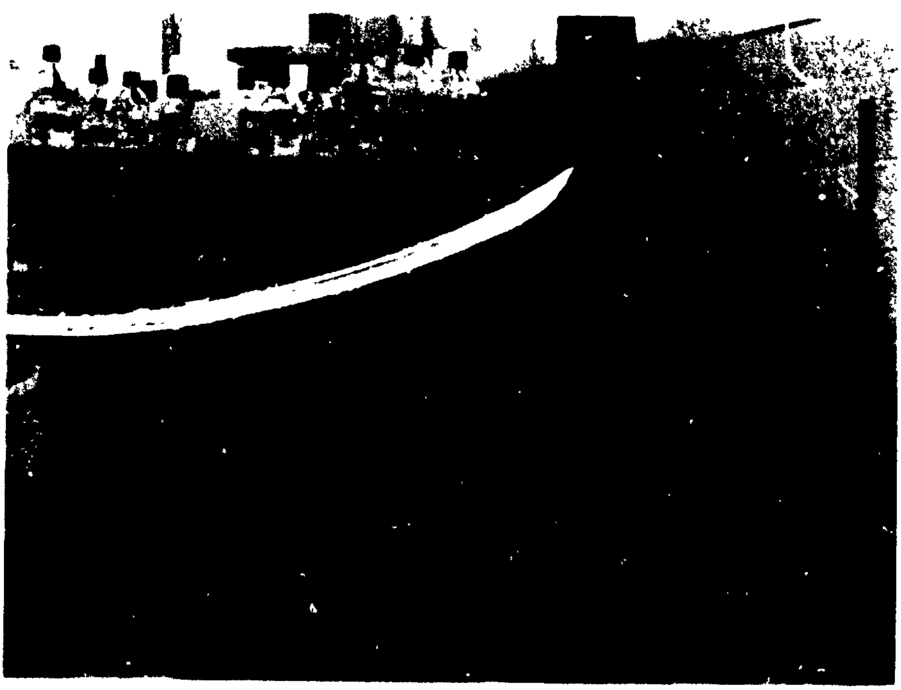
By reading journal articles, Steve learned that the Carnegie laboratory of Dr. Samuel Ward was studying the sperm of *C. elegans*. Fortunately, there happened to be a postdoctoral position available in Ward's lab. Steve applied, was accepted, and started his fellowship—with a grant from the National Institutes of Health (probably the world's largest supporter of postdoctoral education in the biological sciences)—in January 1984. The transition was "pretty hairy," he says. When he found out that he had been accepted at Carnegie, his wife, Nancy, an electron microscopist, applied for and subsequently accepted a position at the nearby Johns Hopkins University. But Hopkins couldn't wait any longer than September 1983, so the two moved to Baltimore in September. Steve says he wasn't even done with the experiments for his thesis then. During the next few months, while finishing up his work at Yale, he drove more than 5,000 miles traveling back and forth between New Haven and Baltimore.

Carnegie's Department of Embryology sits on a corner of the

Johns Hopkins campus. It is home to eight principal investigators, whose work encompasses a wide variety of experimental organisms, ranging from the fruit fly to Indian corn. The eight staff members, who are similar in rank to university professors but without classroom teaching duties, work in independent labs on independent questions. Each postdoc is loosely tied to a particular staff member and shares his or her lab space. For the most part, the postdocs work independently.

Steve concentrates on signals inside the *C. elegans* sperm that control the final stages of its development. To do this, he studies mutations that disturb the process, that is, that cause male sterility. How many genes, he wants to know, are involved? When Steve arrived at Carnegie, Ward and his colleagues had identified only one gene having multiple mutations affecting sterility. Since then, working with graduate student Diane Shakes and postdoctoral fellow Jacob Varvey, Steve has found eight more such genes. In trying to get a handle on the kinds and numbers of mutations within the sperm cell, the work got tedious. "There's no joy picking hundreds of worms off an agar plate and getting bleary-eyed," he says. During this "getting to know you" stage, it was only the conceptual framework, he says, that kept him going.

Steve has identified four genes that he plans to explore on the molecular level. Before he does so, however, he wants to become even more familiar with *C. elegans* genetics. "It's sort of like building a house," he says. "You have to put the foundation in

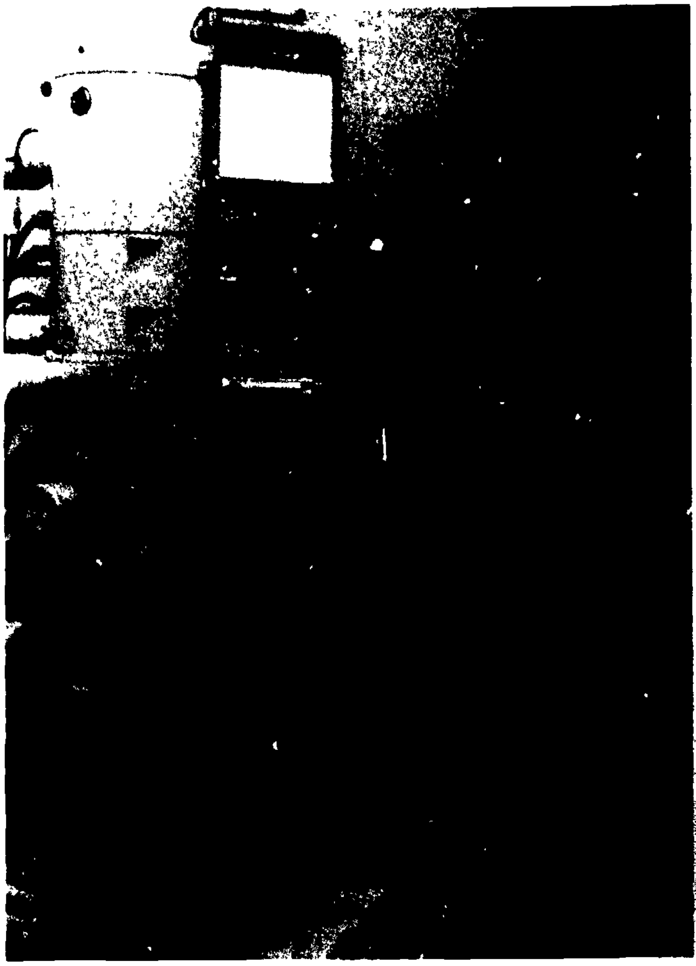


Steve poses with Carnegie staff member Sam Ward and graduate student Diane Shakes.

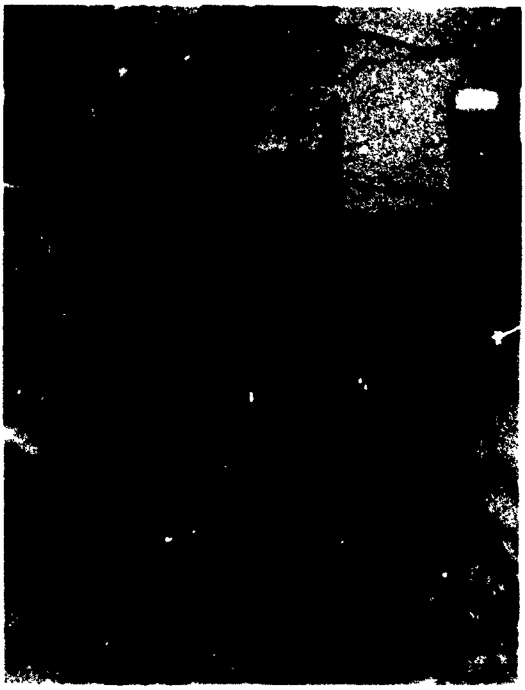
before you put the roof on. When I arrived, only the barest sketches of the foundation were in place."

Steve's day-to-day life is often rather solitary. As at research laboratories all over the world, levels of intensity at the Department of Embryology are high. Steve thrives in this sort of environment. He likes being a research scientist. One thing he doesn't particularly relish, however, is writing. "It's painful," he says. "I think virtually every scientist you talk to would agree." Why? The reason, he says, is that in a scientific paper every sentence has to go together just right. "There has to be a minimum of ambiguity." Also, by being so close to the material (the experimental results), it is easy to lose objectivity.

However difficult it is to achieve, careful writing is a necessary part of a scientist's life, for the communication of new data is extremely important. Without scholarly journals, many investigators would be duplicating the work of others, wasting valuable time and energy. The results of every experiment are part of a vast network of data that must be understood in context with other work. Otherwise, few conclusions could be drawn, no broadly useful theories conceived and tested.



Steve sits at the transmission electron microscope, which he uses to examine the fine structure of the *C. elegans* sperm.



Steve is a member of the Department's softball team. He is also an enthusiastic cross-country skiier. At left, he poses with his wife, Nancy, and friends on a vacation trip in Quebec, Canada.

The journals are not the only means to this end. There are also professional conferences and seminars, and the informal conversations with other investigators. Steve looks forward especially to large conferences and meetings. "I always come back from meetings feeling exhilarated." According to Steve, such an event fills three functions: it exposes the scientist to new material, it provides an intellectually stimulating break from routine, and it provides an opportunity to see old friends. For the postdoc, a conference fills a fourth function: it is a way to make contacts. "In the tight job market," says Steve, "any advertising you can do for yourself helps."

Steve himself hopes to find a position where he can both teach and do research (mostly do research), but another year of fellowship remains before he puts himself "on the market." He both dreads and looks forward to it. Neither he nor Nancy relish the thought of moving, but they are anxious to get their lives settled. He says he will miss the freedom of his postdoctoral years—to call his own hours, to take off occasionally in the middle of the day to play squash (his racquet sits in a corner of his office), and especially the freedom to do uninterrupted research.

What he won't miss is the stress of not knowing his future. What helps him cope, besides physical activity (he runs 14 miles a week), is to consider the process of becoming a scientist as an adventure. Even so, he says it takes a great deal of perseverance and dedication. "If you want to be a research scientist, you have to be highly motivated," he says. "You have to really want it badly. I tell that to anyone considering a career in science. It's unfair not to."

JULIE MORRIS, GEOCHEMIST

Some people know they want to be geologists practically from the day they were born, but not I. I didn't actually become a geologist until my third year in college.

Julie Morris
October 1985

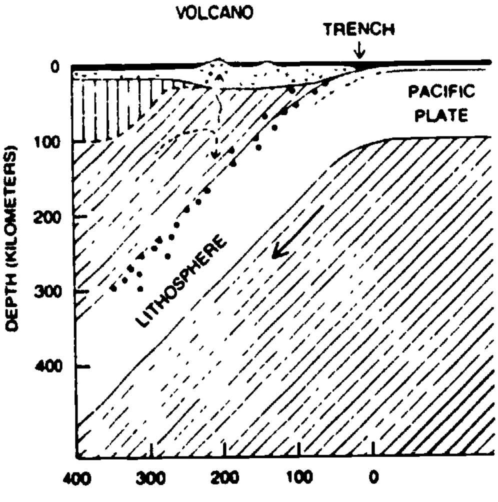
Though Julie Morris grew up in a small town in California's Sierra Nevadas, her interests centered more around people than rocks. When she enrolled at the University of California at Santa Cruz, she chose psychology as a major, but she was interested also in history and Spanish literature. She took science courses only to fulfill mandated requirements. She surprised herself by liking them. Oceanography, especially, intrigued her. She took a geology course at the end of her second year, and liked it so much she began to think about changing her major. "I guess all those years of hiking in the mountains, wondering about the volcanos and roots of volcanos that made up the landscape, began to catch up with me," she says.

Still, it seemed a drastic decision, and partly to think it over, she took a year off from college. "I had to decide if I really wanted to go back and do the physics and calculus that I had to take in order to become a geologist." When she returned, she had made her decision. She was ready to buckle down; her days were long and her head was constantly filled with physics and equations. But she loved it. "I would get so caught up that I'd forget to eat lunch."

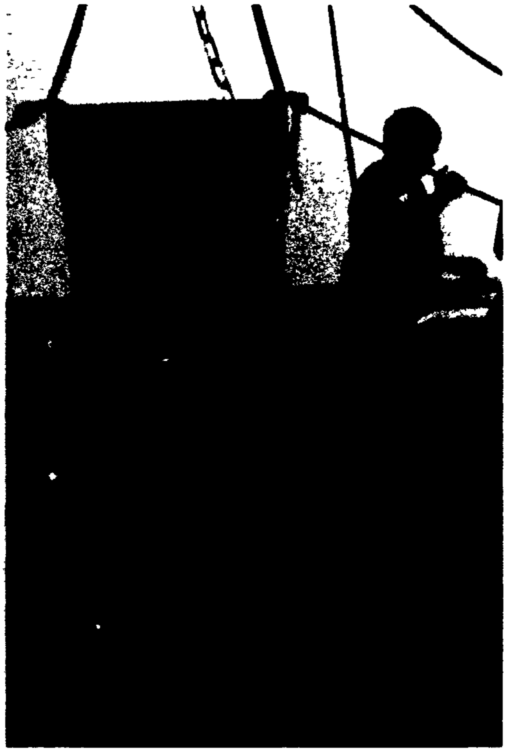
That decision determined the course of her professional life. Today, Julie, 32, is a postdoctoral fellow at the Carnegie Institution's Department of Terrestrial Magnetism (DTM) in Washington, D.C., where she is pursuing a career as an isotope geochemist. As such, she studies the chemistry of volcanic rocks, particularly of magma (molten rock) that erupts as lava in volcanic island arcs of the Pacific Ocean. These magmas act as probes of the Earth's interior, allowing geologists to speculate about the structure, composition, and history of the deep (and remote) Earth.

Island arcs are formed when two of the plates that make up the Earth's crust converge; tectonic forces drive one of the plates downward. Magma, formed on the slab or in the region above it, ascends to the surface, producing a chain of active volcanos. Although such volcanic chains are a major feature of the Earth, no one knows exactly how the magma forms deep in the interior. By studying the isotopes, or chemical signatures, of the lavas, Julie is attempting to understand how and where lava originates as magma, and the mechanisms of its ascent through the crust.

Julie talks about life as a scientist as she negotiates the heavy rush-hour traffic on Washington's beltway. She has just driven another DTM postdoctoral geochemist, Sonia Esperança, to the airport. In return for this favor, Sonia has agreed to lend Julie her car. (Julie has never owned a car; she has never had the money.) Julie and Sonia, who are both single, have become good friends. They go to exercise classes together, they both like movies and good jazz, and they talk a lot about their work, about men, about life.



Volcanic island arcs form where an ocean plate is subducted beneath another plate. In the simplified figure above, dots indicate the location of earthquakes that mark the plate-mantle boundary. Magma rises from depths of from 100 to 200 km to erupt as lava.



Julie spent four weeks in November 1985 on board the research vessel *Thomas G. Thompson* participating in a dredging operation that brought up rocks produced by young volcanos in the Mariana volcanic arc. (The Marianas are in the western Pacific; the island of Guam lies at the southernmost tip.) The dredge assembly, shown above, was lowered overboard and dragged along the sea floor. After a month of rolling and rocking, Julie, right, regains her footing while touring in Japan with fellow crew members.

Like the biology that Steve practices, the science that Julie and Sonia study is experimental; geochemists work with samples of rocks that must be collected and processed with care. Julie herself has been on several collecting trips. She recently spent a month on board a research vessel in the island arcs of the western Pacific Ocean, participating in a dredging operation that brought up rocks produced by very young, very small submarine volcanos. Earlier, as a graduate student, she spent six weeks in Indonesia collecting lava samples. There, she lived in remote village homes, carpentry shops, and timber camps, "fighting off mosquitos and leeches," all in the interest of collecting her own samples. She says this is important: "There's no substitute for knowing instantly and almost intuitively how your samples relate to one another. The only way you can know that is if you see them in the field. No one else can transfer the information you need so that you understand it completely."

Julie's interest in island arc magmas began to form at the University of California at Santa Cruz, but it became focused at the Massachusetts Institute of Technology, where she spent six years doing the course, lab, and field work required to earn her Ph.D. There, encouraged by her advisor, Stanley Hart (a former DTM staff member), she developed a thesis project to study the origin of magma in the Aleutian and Indonesian island arcs. She especially wanted to know if sedimentary material on top of a subducting oceanic plate is carried down into the mantle and later transported back up to the Earth's surface in arc magmas. The answer, she and others believed, lay in isotope analysis.

It was to gather samples for this project that Julie, in her third year of graduate school, traveled to Indonesia. It was, she says, an unforgettable experience. "I'm pretty sure I went to places where I was the first Caucasian woman," she says. "Wherever we stayed, there would be a group of children outside watching me. The brave ones would rub my skin to see if the color would come off." Besides the novelty of being in a different culture, there was the thrill—and the fear—of being on her own. "I felt stretched, like I was really expanding my limits. Being in the field is wonderful. And being on a volcano is tremendously interesting. Walking around, trying to build pictures in your mind, you see something and it makes you think of a process, a way something might have happened. Then you go to another place and ask, 'Is this consistent?' The work is hard—both physically and mentally—but it is very engrossing. You don't have time to think about anything else."

Julie is short (about 5') and often finds her size to be a hindrance—not in terms of her own abilities (she can wield a hammer as well as any one), but in how she is perceived. In Indonesia, she was as tall as most of the people (there, it was her sex that provided the worst barrier—most people assumed she was the foreign wife of her Indonesian field assistant), but elsewhere she says some people are surprised to find she is athletic. Because of this attitude, she feels she must work harder to be accepted.

Julie arrived at DTM in 1984, soon after completing her thesis. She calls DTM a "gracious old anachronism." While it contains modern research facilities, the main building, set on spacious and well-maintained grounds, dates from the early days of this century. Also, the name—Terrestrial Magnetism—no longer describes accurately the research environment. Of about a dozen full-time staff members, no one studies magnetism. They instead study earthquakes, rocks, meteorites, planets, and stars.

At DTM, Julie quickly found a niche within a diverse group of scientists working on the same general question she had explored in

Julie took this picture of a small ash eruption on the volcanic island of Uracas from the deck of the *Thomas G. Thompson*.

her thesis. This group, including chemist Fouad Tera, nuclear physicist Louis Brown, and geophysicist Selwyn Sacks, were using a novel "tracer"—the radioisotope beryllium-10 (^{10}Be)—to explore subduction processes. They were also using a unique measurement tool—the tandem accelerator at the University of Pennsylvania, which Brown and his co-workers at Penn modified for this work. (Julie says this development was necessary because conventional mass spectrometers can not measure the minute levels of ^{10}Be required.) Members of the group alternate accelerator runs, which involve staying awake and functional for up to 36 consecutive hours. Julie travels to Philadelphia once every other month.

Unlike isotopes of strontium, neodymium, lead, and other tracers typically used by geochemists, ^{10}Be is constantly being formed in the Earth's atmosphere. It is carried to the Earth's surface in rain and snow, is quickly adsorbed onto sediment particles, and settles on the ocean floor in a thin layer. It stays there, slowly decaying, with a half-life (time required to reduce its concentration by 50%) of 1.5 million years. But while it decays, it travels with the plate on which it sits—at a speed of about 8 centimeters per year.

If ^{10}Be can be detected in the lavas of the island arcs, it suggests that the sediments atop the subducted plate are actually being carried into the mantle to mix with the magma—only to be spewed out again in lava. This is indeed what the DTM researchers found.

To avoid contamination in the geochemical clean lab, white coats, gloves, and protective footwear must be worn. At right, Julie talks with Paterno Castillo, a postdoc from the Philippines.

Julie introduces former DTM postdoc Robert Stern, now a professor at the University of Texas at Dallas, at a symposium she chaired at a recent meeting of the American Geophysical Union. At left, she grabs a quick cup of coffee during a break. Chatting with her are fellow DTM postdoctoral fellow Sonia Esperança and DTM staff member Fouad Tera.

In fact, because of its atmospheric origin, the signature of ^{10}Be was much easier to distinguish than those isotopes that have origins similar to that of the magma. Indeed, ^{10}Be seemed to be a much better tracer than any other isotope used before. Julie was very excited, for here, she believed, was a way to resolve the question of island arc subduction that had formed the basis of her thesis.

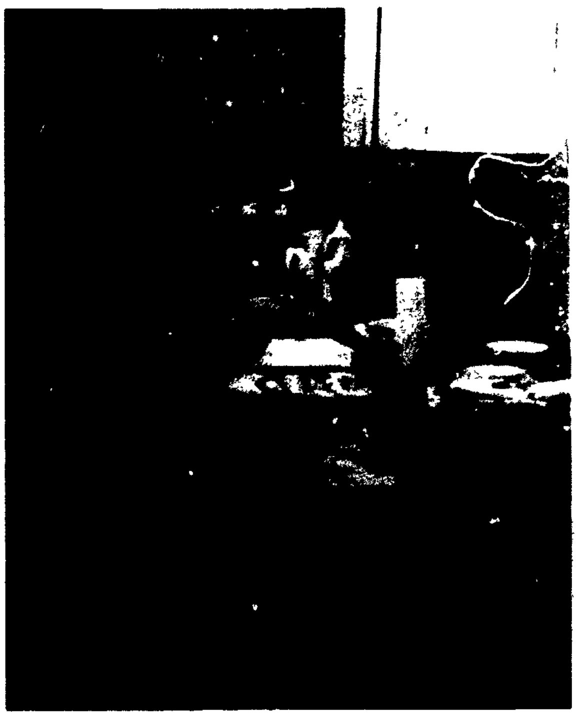
Her geological background brought fresh perspective to the ^{10}Be project at DTM. She immediately began trying to understand why some island arcs contained ^{10}Be, while others did not. One concern was that the ^{10}Be present in the lava samples may be coming not from the magma below, but rather from the interaction of rainwater with the lavas after eruption. She spent nearly a year on this problem. When she had satisfied herself and her colleagues that rainwater contamination was not an issue, she went on to examine other factors associated with ^{10}Be incorporation in island arcs. In the process, she developed a model that she and her colleagues are currently testing. So far, the model has worked well, and she is pleased, although (with typical scientific skepticism) she "waits for the one result that the model just can't accommodate."

As her professional status has grown, Julie has become more and more involved in outside activities. Like other scientists, she routinely reviews manuscripts written by her colleagues for publication in scholarly journals. She has also chaired two sessions of meetings of the American Geophysical Union, and was an invited speaker at three meetings. She was recently nominated for the newly created position of International Secretary of the Geochemical Society. If elected, she will travel frequently to Europe to encourage increased interaction with European geochemists.

One of her most satisfying activities, however, is as an occasional speaker at local elementary and high schools. She considers it important not only for the students but also the teachers to know that science is approachable and fun, for women as well as for men. "I still meet twelve-year-olds who don't realize that girls can become geologists," she says.

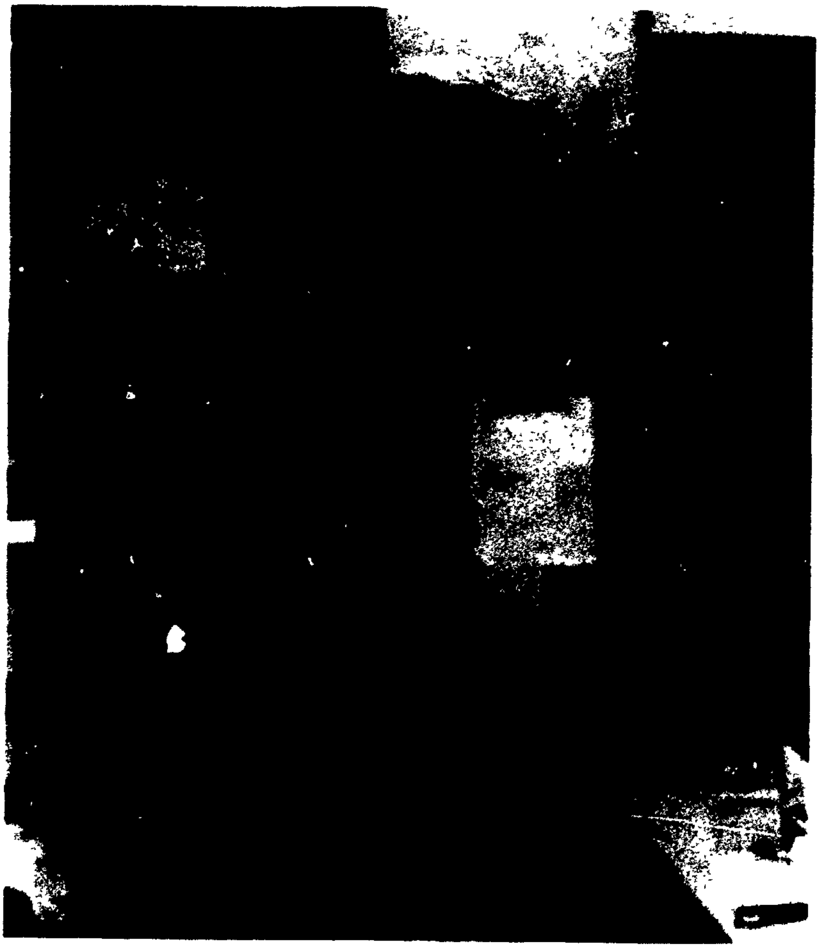
Julie feels she has grown a lot professionally during her postdoctoral fellowship years. Even though the job market is tight in the geochemistry field, she has realized that the direction she chose was the right one. "You need something to give you staying power—to carry you through," she says. "It can be persistence, an easy-going attitude, faith, or pleasure in your work. For me, one of the things I've realized during the last two years is just how much I really love what I do. Even after interviewing for jobs and not getting them, feeling frustrated and sometimes rejected, I still find great pleasure in my work."

Julie says that some day she would like to teach, but right now she wants to be in an environment favoring research. She has several experiments planned to explore the chemistry, structure, and evolution of the deep Earth. She plans to leave no stone unturned in her search for a position that will allow her to carry them out.



"Lunch Club" has been a DTM tradition for over thirty years. Participating scientists alternate weekly cooking duties. Julie, preparing a stew at right, says she cooks about two weeks a year. The only rules at lunch club are (1) hotdogs no more than once a week, and (2) no complaining about the food.

JOHN WATSON, PLANT MOLECULAR BIOLOGIST



Every once in a while I'll grow up some plants and extract some chloroplast DNA. It's sort of an addiction.

John Watson
December 1985

John Watson calls himself a "lab rat." He loves to do the hands-on experimental work that his science requires. He especially loves extracting DNA from plant cells.

At the Department of Plant Biology, in Stanford, California, John studies genes of the pea plant. He follows a tradition first begun in the nineteenth century by the monk Gregor Mendel, who used pea to usher in the science of genetics. But the techniques of modern molecular biology that John uses are significantly different from those of Mendel. Molecular biology is a very powerful combination of genetics and biochemistry that focuses on the nucleic acids (DNA and RNA) and proteins of the chromosomes. The associated techniques have been developed over the course of several decades,

Staff and fellows meet weekly to hear talks about ongoing research in the seminar room at Carnegie's Department of Plant Biology, above. The weather is mild at Stanford; John rides his bike to the lab every day.

mostly using bacteria and animals as experimental systems. Plants are new to the game—so new that when John decided to pursue a career in plant molecular biology, when he was a graduate student at Indiana University, many of his colleagues told him that he'd have difficulty succeeding. Since then, however, the science of plant molecular biology has exploded so much that John claims there are now more than forty positions for which he is qualified to apply. (Of course, as he points out, there is also a rapidly developing supply of qualified candidates.)

John grew up in a small farming community in Indiana. He says his father—a truck driver—encouraged his interest in nature and the outdoors, but he doesn't know exactly where the urge to study science came from. "In high school I loved doing experiments in chemistry class, but I still had outdoor instincts."

When he entered Butler University in Indiana, his future was still uncharted. "My mom never went to college, but she was very interested in writing. She was constantly buying me books. I started college as a literature major." But he ended up taking many science courses in his first year, and liked them. Biology and chemistry were his early loves, but once he discovered orchids, in his sophomore year, he switched to botany. Plants have been a passion for him ever since.

John went off to graduate school thinking he was going to study the biochemistry and mechanics of photosynthesis—that primary process by which plants convert sunlight to food energy. "I was convinced that by studying photosynthesis somebody some day might be able to increase plant productivity. Having come from an agricultural community, I thought, gee, this is important. All of this was before gene cloning. I'd never heard of recombinant DNA or gene engineering. All I knew was that I wanted to go into some area of plant physiology and that I wanted to be a professional biologist."

John did his graduate work at Indiana University in Bloomington. It was close to home, had a good plant biology program, and offered him a scholarship. On the first day of his first molecular biology class the students extracted DNA from the leaves of the bean plant. "I loved it," John remembers. "It soon became apparent to me that an interesting way to study chloroplasts [structures within leaf cells where all photosynthetic reactions occur] was not through the enzymes and proteins involved in photosynthesis but through the genetic machinery behind all that."

At that time, the chloroplast was a mystery—"a big black box," says John. It was known that chloroplasts contained a set of genes distinct from those in the nucleus, but no one knew what chloroplast DNA was or what function it served. Why should there be separate pockets of DNA inside the cell?

John began an effort to extract DNA from bean chloroplasts. But he found he wasn't good at isolating chloroplast DNA from bean, so he switched labs—and organisms. He stepped backward evolutionarily to the single-celled alga *Chlamydomonas*, the same organism that originally appealed to Steve L'Hernault.

Before he began his new research program, however, John took some time out to study for the graduate qualifying exams, which graduate students at most universities must pass before continuing study beyond the master's degree. To most graduate students, the qualifying exams are much more scary than their final thesis defense exams. "By the time you are ready to defend your thesis," John explains, "your professors would have told you if you were not destined to get the Ph.D. They wouldn't have let you get that far." To pass the qualifying exams, John studied everything from plant taxonomy to plant physiology to biochemistry. The test itself involved eight hours of writing and one and one-half hours of oral interrogations.

Once he finished, John was ready to tackle his new experimental system. He was also ready to get down to a program of research that would provide data for his graduate thesis. For this purpose, John devised a new technique for finding chloroplast genes that encode proteins in *Chlamydomonas*—by using similar genes of the bacterium *E. coli* as probes. To his knowledge, he was the first person to do so.*

*Today, many scientists believe that chloroplasts are evolutionary remnants of primitive, single-celled organisms (like bacteria) that became incorporated into other organisms. Because of this evolutionary relationship, the use of well-known bacterial genes to find lesser-known but similar genes in plant cell chloroplasts is now quite common.

John talks with Carnegie staff member Bill Thompson. John says he has learned a lot from Thompson, who designed one of the most sophisticated labs in the world for exploring genes of the pea plant. Thompson has since left Carnegie for a position at North Carolina State University.

As his graduate research continued, John says he had a sort of revelation, a change in interests. "Once I started studying genes, I began to be interested in them for their own sake, and not because they coded chloroplast components. I became more interested in the mechanisms of gene expression, particularly in plants, where there is a real lack of knowledge about gene expression."

This change of interest was reflected in the laboratories to which John applied for postdoctoral fellowships. He knew he wanted to continue doing research, but he wanted to change the focus of that research. He wanted to study actual gene function in plants—pioneering work that only a few laboratories in the world performed. He found an ideal environment at the Carnegie Institution's Department of Plant Biology, located in a cluster of buildings and greenhouses on the Stanford University campus, near Palo Alto, California. There, scientists study photosynthesis and other plant processes on organisms that "aren't considered second-class citizens." There, also, a scientist by the name of William Thompson was doing some of the first gene-function experiments on photosynthetic-related genes of the pea plant. Because of Thompson's work, pea genes were, at the time, some of the best-understood genes in the plant kingdom. John applied for a postdoctoral fellowship in Thompson's lab and was accepted. He and his wife, Charlotte, whom he had met several years before while both were summer camp counselors, arrived in Stanford in 1982. Charlotte quickly found a job as an office manager for a cable television organization.

John, meanwhile, was settling into his new research environs. It didn't take long. He and Thompson hit it off instantly. They still joke about the first time they met. "I planned to meet Bill at a scientific meeting," says John, "but I didn't know what he looked like. A friend of mine had met Bill and described him to me. After a minute I realized I was listening to a description of myself! Both of us are tall, thin, redheaded, and bearded."

John had never worked with the pea plant but he had worked with bean, a similar higher plant, and so the switch from *Chlamydomonas* was not particularly difficult for him. With Thompson and the other postdocs in the group, John began exploring mechanisms of gene expression in pea. Their major tool was light—simple, ordinary sunlight.

Light is critical to the proper expression of genes that code for photosynthesis-related proteins. If a pea seedling (indeed, any seedling) is deprived of light while it grows, it will become a nongreen, nonphotosynthesizing plant, which soon dies. If, however, a dark-grown seedling receives a single pulse of light early in its development, then it will begin to manufacture components of its photosynthetic system.

Light is, therefore, a valuable tool. "Light is an inductive agent," John explains. "You can give it and then take it away. This is very practical in terms of designing experiments." To determine how

Seven-day-old pea seedlings that John grew under different regimes of light show variations in responses. From left to right, the treatments were: (1) continuous (absolute) darkness, (2) darkness for five days, with a pulse of red light on day 6, then back into darkness, (3) same as 2, but red pulse followed by a far-red pulse, (4) darkness then transfer to continuous white light on day 6, (5) continuous white light for the entire seven days, (6) continuous dim. red light for entire seven days, and (7) same as 6, but with a pulse of blue light on day 6.

John checks the results of some of his experiments for an article he is co-authoring with a Plant Biology colleague. The first paper that bore John's name was published in the *Proceedings of the National Academy of Sciences* when John was still in graduate school; it was submitted to the journal by the eminent geneticist Marcus Rhoades: "a dream come true," says John.

genes respond to light, John and his colleagues measure levels of RNA in cells that have received various regimes of light treatment. (RNA, copied from the DNA, serves as a template for protein manufacture.) Over the last few years, using a set of twelve closely related photosynthetic genes of the nucleus, Thompson, Watson, and the rest of the group have found that light influences RNA levels in highly diverse ways. Some genes seem to require only a tiny flash of light in order to become fully functional; others need much more light at various phases of development.

To John, the challenge in understanding how these twelve genes are coordinated at the molecular level is acute. What makes them respond to light in such diverse ways, he wonders? Does the way a gene responds to light depend only on the gene itself, or are there factors in the nucleus, other than the genes, that are involved?

John hopes someday to develop an *in vitro* (test tube) system— one in which a gene works much as it does within the plant itself. In so trying, however, he feels as if he is "stepping off into a black hole." As far as he knows, while such systems have been designed for certain animal genes, no biochemical system has yet been designed to study gene expression *in vitro* in any plant for any gene.

As a postdoctoral fellow, John has the freedom to pursue this goal, and others, whenever he finds the time. He is virtually on his own. But there are aspects of his postdoctoral career that he finds very stressful. "When you are working on your thesis," he says, "there's a certain amount of pressure on you to get that degree. But after a point, if you have a conscientious Ph.D. committee, you begin to relax a little. A postdoctoral fellowship, though, is much more stressful. You don't get the same kind of feedback. You're not quite sure if you're jumping through the right hoops."

John says his postdoctoral experience has also given him a glimpse into things he was never taught in graduate school. For example, he is learning about what he calls "grantsmanship." "Big-time science involves big-time grants from big-time funding agencies," he says. "It is frustrating to have to take time away from science and divert it into funding." As a result, he has become much more realistic about research. "It's not easy to be successful at this game."

John's postdoctoral fellowship is nearly at an end, and he is beginning to do some soul searching. "I'm at a point where I'm supposed to get a job, and most jobs will probably take me out of the lab. I'm trying to sort it out—how happy will I be out of the lab?" He sees a university system as his best option, especially a large university that has access to sophisticated instruments. The university system also provides more options. "If you tire of doing research at a research institution," he says, "you leave. But if you tire of research at a university, you teach more, or you move to administration." He approaches his future with confidence. Even though the realities of "big-time" science have tempered his enthusiasm, he would willingly go through again the long process of becoming a scientist. Science, to him, is not only work—it's fun.

WENDY FREEDMAN, ASTRONOMER

Everyone wants to know where we fit in this Universe—but it's not only that sense of where do we fit in, but what *is* this Universe? What is it made of? How does it tick?

Wendy Freedman
December 1985

Once, when she was seven years old, Wendy Freedman and her father were looking upward at the stars. Her father told her that the light they were seeing had left the stars millions of years ago, that they were seeing those stars not as they are at the present time but as they were at a far-distant time. Wendy was awed. "If I were to point to one event in my early life when I can remember that feeling of awe, that fascination," she says, "that was it."

Wendy, now 29 and a professional astronomer, is still awed by the stars. Today, however, her fascination is directed toward understanding some of the most basic questions about the Universe.

Recently, she has become particularly interested in Cepheid stars—those pulsating stars long used to calculate distances of objects in the Universe. Astronomers are taking a new look at Cepheids, and Wendy, a postdoctoral fellow at Carnegie's Mount Wilson and Las Campanas Observatories in Pasadena, California, is one of them.

Slight and dark, with an engaging smile, Wendy grew up in Toronto, Canada. Her father, a psychiatrist, and her mother, a concert pianist turned writer, encouraged her to be independent and intellectually curious. Wendy took this attitude to heart. Educated in the Canadian public schools, she soon decided not to limit her career options by dropping science and math—as did many of her girlfriends. She did well in these subjects and enjoyed them, but she also enjoyed history, literature, French, archaeology, and philosophy. Throughout high school she didn't know what she wanted to do with her life. Though she found the subject of astronomy interesting, the possibility of becoming an astronomer never entered her head. "In high school I just didn't realize there were professional astronomers who could spend their lives doing what they enjoyed," she says. It wasn't until her first year at the University of Toronto that Wendy began seriously to consider pursuing astronomy.

As she talks, the early morning mist lifts, and the mountains become visible from her office. "One of those is Mount Wilson," she says. The name conjures up visions of a shivering astronomer peering through the eyepiece of a telescope. "Actually, astronomers don't look directly through telescopes any more," Wendy explains. "They now sit in warm viewing rooms, watching the data come in at computer terminals." Though that particular romance is gone from astronomy, what is left, to those who pursue it, is a fascinating mixture of precise measurement and speculative conjecture, for astronomy is one of the most abstract of sciences. There is nothing as concrete as a cell or a rock to study; the closest objects are millions of miles away.

Wendy's first experience with a telescope came during her first year of graduate school (at the University of Toronto). Scheduled to use a small telescope in Quebec, she got a bitter taste of the vagaries of weather. "I had nine nights reserved on the telescope," she says, "and it snowed for eight. I had only one hour for observing and I took one [photographic] plate."

Wendy is philosophic about the experience. She says that astronomy is a field that, because of the weather, requires a lot of patience. "If the weather is bad, you have to reapply for time on the telescope. And you have to wait a whole year before the stars are aligned again the way you want them." (Competition for observing time on the big telescopes is intense. An astronomer must submit a proposal to the allocations committee of the telescope he or she wishes to use, and then wait to hear if the proposal has been accepted.)

In choosing astronomy as a career, Wendy became a member of a select group: only about 7% of all professional astronomers are women. But while Wendy says that many people still have the attitude that astronomy is not for women, for her, in deciding to

Carnegie's Las Campanas Observatory is built on a remote ridge of Chile's Sierra del Condor Mountains. At top is the 2.5-meter du Pont telescope. At bottom left is the 1-meter Swope telescope, and at far right is the University of Toronto's 24-inch telescope, which Wendy used several times while in graduate school. Wendy looks forward to her visits. She enjoys the peacefulness of her surroundings as much as the opportunity to observe with one of the world's most sophisticated telescopes.

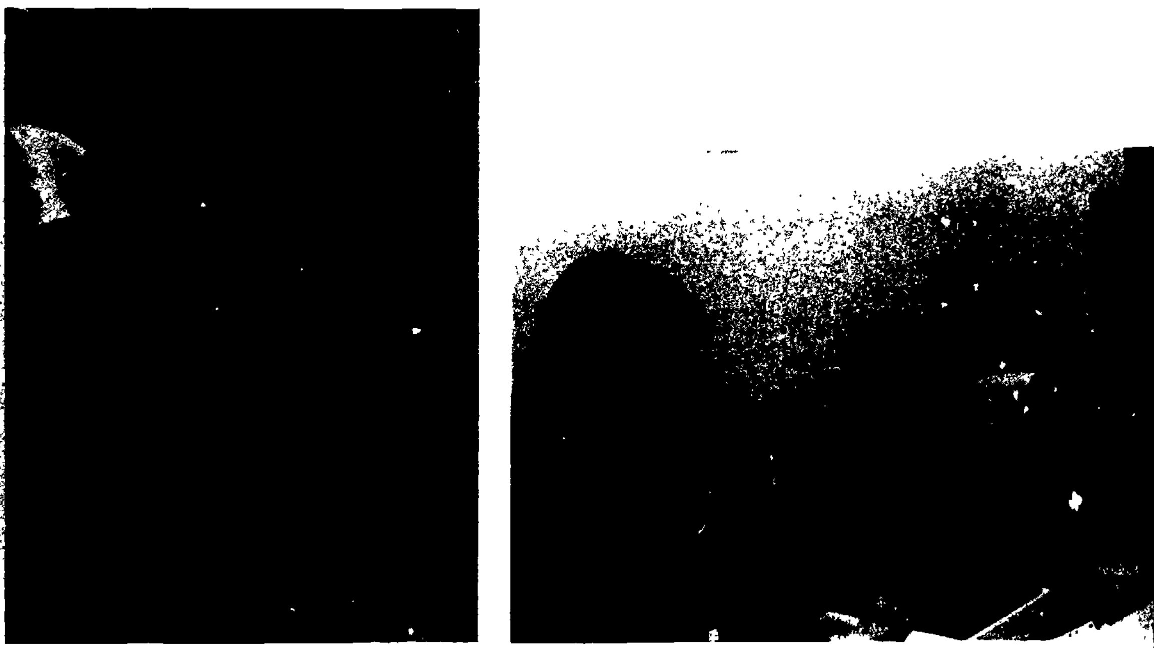
become an astronomer, sex was not a major barrier. She was fortunate enough to be surrounded by supportive people who encouraged her to pursue her goals. She does, however, acknowledge her debt to the pioneers. "As recently as ten years ago, women astronomers had to fight harder, and I think it's easier for people like me because they did."

Of deeper concern for Wendy was the knowledge that, once she finished her studies, a position in astronomy might be hard to find. It is not uncommon for the astronomy department of a university, for example, to receive 100 or more applications for a single opening. But throughout her undergraduate and graduate years, Wendy put aside that nagging worry. She immersed herself in her work, and enjoyed it. This, to her, was most important.

Wendy joined the Mount Wilson and Las Campanas Observatories as a postdoc in 1984, shortly after finishing her thesis at the University of Toronto. For her thesis, she had examined star formation, showing that stars formed in different types of galaxies in very similar ways. It was a large-scale project requiring the painstaking analysis of hundreds of photographic plates, which she obtained in observations over several years at the Canada-France-Hawaii telescope on Mauna Kea, Hawaii. ("At 14,000 feet," she says, "Mauna Kea is a totally unique environment. It's hard to breathe, move, even think.") She came to the Pasadena-based Observatories well versed in computers and telescope technology. She also came with an idea for an even larger-scale project, one involving Cepheid stars, and she welcomed the promised freedom of up to three years of uninterrupted research.

Some of Wendy's colleagues had warned her that she might find the atmosphere at the Observatories' headquarters intimidating. While it had excellent research facilities, she was told, the astronomers there tended to be intense and competitive, and other postdocs had complained of being ignored. But Wendy, independent by nature, has had few problems adjusting. She likes to choose her own hours, coming in very early ("when the computer is very fast"), and working on weekends. Her schedule is flexible enough so she can take time out in the day to swim laps in a nearby pool. She says it's the best work environment she has ever had—a far cry from her days in high school, when she had a part-time job shelving books in the library. "Then, I spent all of my time looking at the clock," she says. "Now, I never have that feeling."

The only crinkle in the fabric—and it's a big one—is Wendy's marriage. In June 1985, she married her former thesis advisor at Toronto, Barry Madore. They now live some 3,000 miles apart. Though the two often collaborate professionally, and Barry has



Some astronomers don't particularly like to reduce their data—but Wendy does. "I feel as if I came along at the right time," she says. "A lot of what you did in the past by hand you can now do with computers and CCD's, and I love to play with computers." Above (left) she loads a CCD tape onto a computer. Back in her office (right), she calls up a CCD galaxy image onto a small viewing screen. CCD images, which consist of digitally displayed, individually counted photons, are much more detailed and accurate than images formed by photographic plates.

spent time in Pasadena recently while on a Canadian fellowship, Wendy says the separations haven't been easy. Madore is a tenured professor at Toronto, and, as Wendy says, tenure is not something you give up lightly. Wendy herself would never consider giving up her career: "I wouldn't be happy if I couldn't work." Long-distance commuting is a serious problem for many married postdocs, especially those who marry professionals like themselves. Often, one member of a couple sacrifices time in his or her career, and this can cause bitterness. More usually, loneliness is the price paid, something to endure, with hope of eventual reunion.

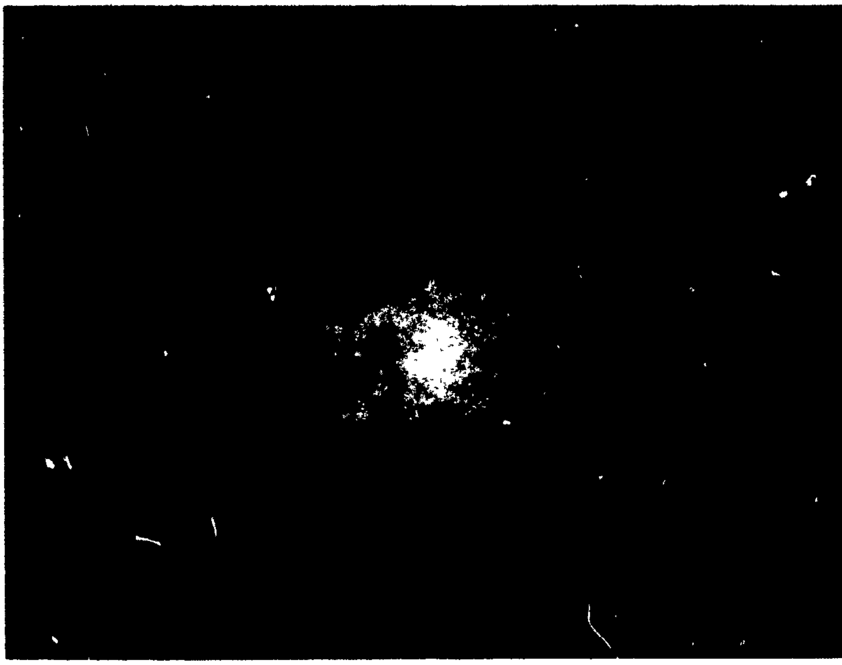
Wendy, though, feels lucky. Barry has been very supportive of her career, and both feel committed to making their marriage and careers work. She also keeps her schedule so packed with work, seminars, and travel that she barely has time for loneliness. She spends several weeks each year observing, mostly at the Las Campanas mountain site in Chile, where Carnegie's premier telescope—the 100-inch du Pont instrument—is located.

Wendy finds observing with the du Pont telescope an exhilarating experience. Las Campanas tends to be more isolated than most observatories, not just because of its remote site in the mountain desert, but because it is staffed by very few people. (Each telescope is overseen by a single night assistant, for example.) Though she says she is not a night person (unusual for an astronomer), she likes to use the instruments, to watch the data coming in. She finds Las Campanas quiet and peaceful, and the views spectacular. When she is not observing or sleeping, she writes papers for publication in journals, or she reads, or takes long walks and thinks.

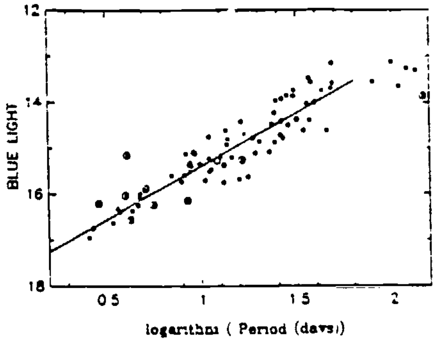
A lot of the time, those thoughts turn to Cepheids. Cepheids are pulsating stars whose light appears to brighten and dim at regular intervals. Early in this century, the Harvard astronomer Henrietta Leavitt discovered that the periods of these pulsations—the time between each cycle—closely indicated the absolute, or intrinsic, brightness of the star. Those stars with the longest cycles, she found, were intrinsically the brightest.

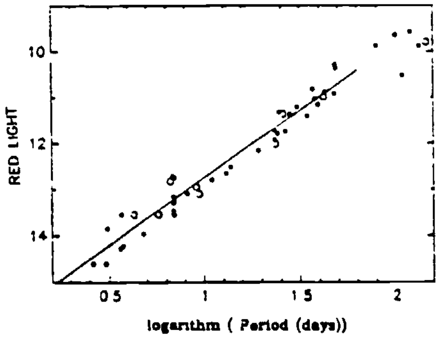
Later, other astronomers saw that by comparing a Cepheid's absolute brightness with its apparent brightness, as seen by us on Earth, these stars could be used to measure distances. Today, Cepheids are common "yardsticks" in determining distances to nearby galaxies. They are, in fact, at the base of most distance scales. To those attempting to understand the age of the Universe, it is very important that the Cepheid scale be correct. If it is not, and objects are found to be closer or farther away than originally thought, then the age of the Universe, now believed by many astronomers to be between 10 and 20 billion years, must be reassessed. As Wendy says, "Cepheids set the zero point. If the Cepheid data are faulty, then the whole thing collapses."

Soon after her arrival in Pasadena, Wendy started the ambitious project she had been planning in the back of her mind: to reexamine the old Cepheid data—the measurements of brightnesses originally obtained over many decades using photographic plates—and compare those data with newer data of the same Cepheids obtained with



Using a CCD detector at Caltech's 5-meter (200-inch) Hale telescope at Palomar, California, as well as the Canada-France-Hawaii telescope in Hawaii, Wendy obtained data on the Cepheid stars of the nearby spiral galaxy M33, above, in an effort to reassess M33's distance from us. The CCD detector enabled her to work at fairly long, red wavelengths, where light is less dimmed by dust than it is in the shorter, blue wavelengths where Cepheid distance-calculating studies have traditionally been carried out. Her CCD data indicated that M33 is significantly closer to us than former measurements showed it to be, suggesting to her that astronomers should pay more attention to the effect of reddening—dimming by dust—when calculating distances.





Reddening effects are evident in plots at left, which show the period-luminosity relation for Cepheids in the nearby galaxy IC 1613 at both blue and red wavelengths. Plotted are the blue and red magnitudes versus the logarithm of the period—the standard so-called Cepheid period-luminosity (P-L) relation. As seen, the intrinsic width (or scatter) of the PL relation is over a factor of 2 less in the red than it is in the blue. This allows a more precise estimate of distance.

Wendy, shown with her husband and occasional collaborator, Barry Madore, adjusts the CCD dewar (containing the CCD chip and filled with liquid nitrogen to keep it cool) at Las Campanas.

modern light detectors called Charge-Coupled Devices, or CCD's. Would she find differences? If so, would these differences be great enough to have to reassess the distance scale?

A CCD, unlike the old-fashioned photographic plate which it is slowly replacing, captures units, or photons, of light individually, counts them, and records the resulting image digitally. The CCD image is much more accurate and easier to read than a photographic image. CCD's also allow astronomers to observe not only in the blue but also in the longer, red wavelengths, which are not usable in work with traditional plates.

To Wendy, this is critical. At red wavelengths, she says, light is less dimmed by the presence of dust than it is at blue wavelengths. Thus, in measuring intrinsic distances of Cepheids, the older data, taken in the blue, may be slightly distorted. They might show the stars to be dimmer and thus apparently farther away than they actually are.

Wendy's results so far are preliminary. She has found no drastic differences between the red CCD data and the older, blue data from the photographic plates. But according to her calculations, made by extrapolating her red data to infinite wavelength, she found that the distance of one nearby galaxy, M33, is significantly closer to us than older measurements indicated. This part of her work has received a fair amount of attention from her fellow astronomers.

Wendy intends to continue her study of known Cepheids. She also is involved in a project to look for more. She is, for example, a member of a group of astronomers currently writing a proposal to the Space Telescope Science Institute, asking for time to use the future planned orbiting observatory, the Hubble Space Telescope, in this effort. But, she adds, "Cepheids are not forever." There is too much else out there she wants to understand.

A LIFETIME OF DISCOVERY

Wendy has not yet applied for an astronomy research position. When she does, she hopes to find one affording her the sort of freedom she has enjoyed at the Observatories. She poignantly realizes she might not find such a position near her husband, but she is far too committed to her work to harbor a lesser dream.

Becoming a research scientist in any field requires courage, commitment, and a long, hard struggle. Why do these individuals do it? What is it that drives Wendy, John, Julie, Steve, and others to spend nearly a dozen years preparing for such a career? Neither money nor fame seems to be a prime consideration; salaries of scientists are modest, and few scientists aspire to become television celebrities.

Of all possible motivations, foremost is the hope to become respected members of a community of individuals who care deeply about the same ideas they themselves do. Curiosity—intense curiosity to get at the root of things, to get at the truth of the natural world—is a powerful drive. In today's sophisticated world, it is hardly possible to satisfy this curiosity without the tools of science. These include not only the physical tools—the microscopes, telescopes, and measuring instruments—but intellectual tools as well—the methodology, knowledge, and understanding of what has gone before, what may lie ahead. Access to these tools is generally available only to those willing to follow the rituals—who complete each step of learning as it comes: college, graduate school, the postdoctoral experience.

Every step in this journey has its own rewards. The postdoctoral interval is the final stage, where there are no courses to take, no tutorials to teach, no theses to write. The postdoc can devote nearly full time to research. Further, it is a time when confidence grows, when an individual becomes ever more committed to science. During these years the young scientist begins to be considered as an equal in a select group of like-minded professionals. The resulting intellectual stimulations—the collaborations, the debates, the syntheses, the responses to one's work—are satisfying vindications of the long years of preparation.

EPILOGUE

As this essay went to press, three of its four subjects—Julie, Wendy, and John—had accepted offers for research positions. John is now an assistant professor at the University of Maryland's Department of Botany. In this capacity, he will teach one course a semester; most of his time will be devoted to research. Wendy, who recently announced that she and Barry are expecting a child, will become a staff member of Carnegie's Observatories in July 1987. Julie will become a staff member at DTM, also in July. To celebrate, she went out and bought a shiny red car. Steve, meanwhile, is in the process of interviewing.

Acknowledgements

The author wishes to thank the four principal subjects of this essay, without whose good humor and kindness the stories wouldn't have been so fun to write. She also thanks Mr. Gordon Peterson (San Marino, CA), Mr. Christie Drago (Rochester, NH), Dr. William Zumeta (Seattle, WA), Dr. Ernest Riggsby (Columbus, GA), and Dr. George Wetherill (Washington, DC), for their helpful comments and advice.

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Patricia Parratt
February 1987

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