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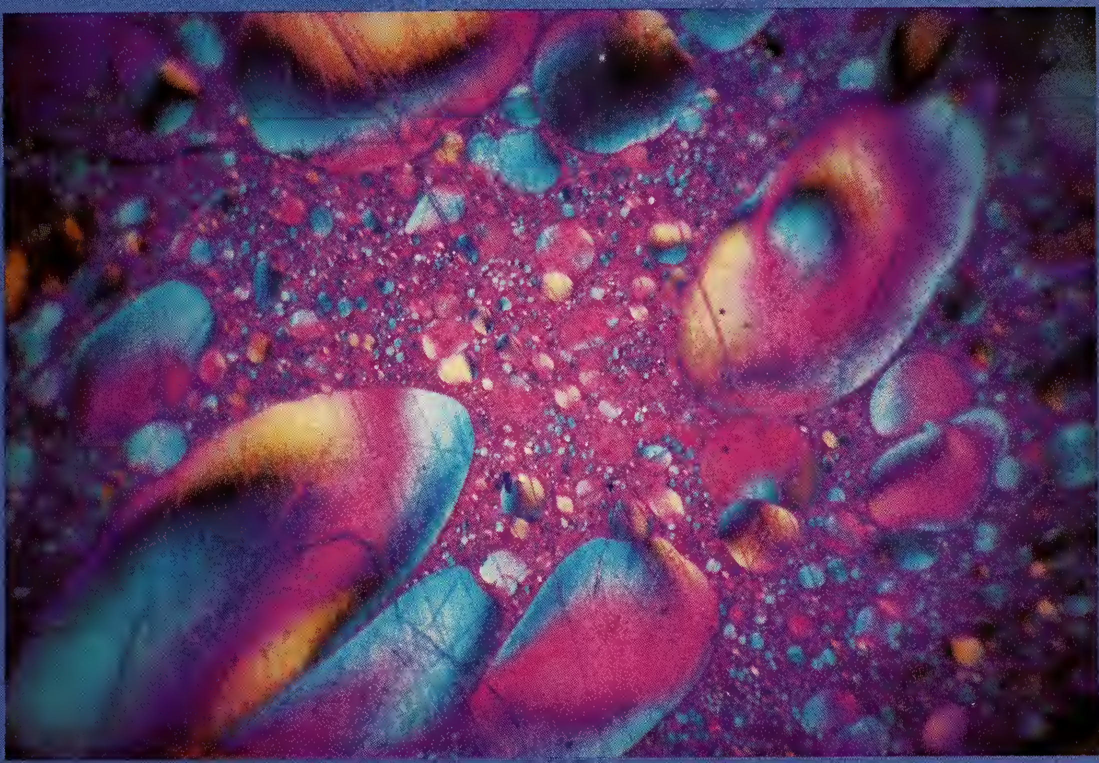

Year Book 83

1983–1984

Cover: Liquid crystals (mesophase) are an intermediate state through which many organic compounds pass in responding to increasing time and temperature. During mesophase, thermally immature, structurally disordered carbon-based compounds become visible as ordered units. Often seen during coke manufacturing, mesophase was not observed in nature until last year, when Geophysical Laboratory postdoctoral fellow Andrew Giże and his colleague Sue Rimmer of Penn State University discovered the first-reported occurrence of thermal mesophase in a geological setting. The microphotograph on the cover is of thermally altered petroleum residues from a lead-zinc mine in Baffin Island, Canada, viewed on the surface of a polished sample with reflected light. The mesophase appears as the rounded globules; the colors are artifactual. (See p. 94.)

Carnegie Institution

OF WASHINGTON

Year Book 83

The President's Report

1983–1984

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President's Commentary

Questions of galaxy interaction and galaxy formation are at the forefront of inquiry in today's astronomy. The spindle-like galaxy MCG 5-7-1 is one of roughly a dozen in the southern skies identified as S0 galaxies with polar rings. The delicate but well-delineated ring lies almost at right angles to the main body of the system. Carnegie staff members Paul Schechter and Jerome Kristian, and Caltech's Jeremy Mould, obtained this deep image of MCG 5-7-1 last year with the Irénée du Pont telescope at Las Campanas, Chile, equipped with a Charge-Coupled Device. Evidence continues to accumulate that such systems result from recent mergers of S0 galaxies with smaller gas-rich galaxies. (See p. 51.)

I find the great thing in this world is not so much where we stand, as in what direction we are moving. . . . We must sail sometimes with the wind and sometimes against it—but we must sail, and not drift, nor lie at anchor.

Oliver Wendell Holmes
The Autocrat of the Breakfast-Table
1858

Recent numbers of *The Chronicle of Higher Education* have dwelt on the plight of today's college and university presidents, who it is said are so preoccupied with form filling and fund raising that they have little time to provide leadership toward academic excellence. Frustrated and overworked, many of these dedicated individuals are experiencing presidential "burnout."

Fortunately, neither form filling nor fund raising occupies most of my time, possibly because the Institution is unique, and small. My attention continues to be focused primarily on the Institution's work in its chosen fields and on ways to build upon its existing strengths. Fund raising is vital of course, and time-consuming, all the more so because it is an activity new to the Institution. But for a unique organization like ours—lacking a large body of alumni, and focused on advanced training and basic research of a pioneering nature—our tradition of scientific excellence must come first. This tradition is indeed our ultimate resource, from which the benefits of philanthropy must spring.

Increasingly, I have been giving attention to the setting of priorities within the Institution. Such matters force themselves on the attention of every president, indeed of every individual scientist.

The year 1984 saw the Institution reach a difficult yet crucial decision. Following a three-year assessment of its priorities in astronomy, the Institution plans to phase out its support of programs on Mount Wilson and to channel the resources thus conserved to the strengthening of the Las Campanas Observatory. It is not our intention to close Mount Wilson Observatory unless it becomes absolutely necessary. It is our hope that the direction and support, either of Mount Wilson as a whole or of individual telescopes and programs, will be assumed by other organizations. To that end, the Institution is prepared to receive expressions of interest, and ultimately proposals, from organizations having the resources, both intellectual and financial, requisite to assume responsibility.

This step is but the first of several that will be required if the Institution is to maintain its position of strength in observational astronomy. The ultimate goal must be for the Institution's astronomers to have, in George Preston's words, "access to one of the new breeds of large telescopes that will dominate ground-based optical astronomy by or before the turn of the century." It is clear that the Institution cannot "go it alone" in developing such an instrument, and thus a major collaboration with at least one other institution appears to be required. Meanwhile, high priority must be given to two short-term goals, namely to provide the best possible instrumentation at our active facilities and to upgrade computational facilities. The cost savings achieved by ending our support of the solar astronomy program and the operation of the Mount Wilson 2.5-meter telescope can be redirected toward these goals, which will surely require the creation of a new group committed to a broadly based program in telescope and auxiliary-instrument technology. Such investment in technology development is a wise strategy, and is absolutely necessary if we are to participate in the design and construction of a large telescope at Las Campanas.

But astronomy is not the only field requiring a hard look at priorities for the next decade. Indeed all of our departments are reviewed periodically by visiting committees, which focus not only on the immediate health of the departments, but on their future needs and opportunities as well. For example, at their most recent meeting, the members of the Visiting Committee to the Department of Plant Biology confirmed (resoundingly) the director's statement of need for new greenhouses and constant-temperature facilities. As a consequence, those improvements should be completed during 1985.

The timing of this report permits me to do little more than identify the most thorny problem now before us, namely that of creating an environment providing both more-functional laboratories and a more stimulating intellectual environment for the Geophysical Laboratory and Department of Terrestrial Magnetism, whose main buildings were completed in 1906 and 1914, respectively. As the needs for new instrumentation grow, especially for large computational facilities, it will not be possible to provide them separately. The sharing of facilities is to a considerable degree already a way of life in the two departments but—and here I express only my personal view—there has been less sharing of ideas. I am happy to say that there has been more intellectual sharing even within the past year. For example, the two departments recently sponsored a workshop on the mantle, bringing together seismologists, mineral physicists, geochemists, and other earth and planetary scientists, for two days of animated discussions.

In an important step well under way, a Committee on the Physical Sciences chaired by George Wetherill and including representatives of both departments, along with Morton Roberts and George Tilton, is examining the future relations between the two departments. Specifically, the group is asking whether the departments should be brought together on one campus in a new building. I have used the phrase "brought together"—the least inflammatory phrase I can think of at this time—for almost every other word I have used on other occasions implies, to one individual or another, that one of the departments may lose its identity. The issue is emotionally charged, though probably no more so than the curtailment of our support at Mount Wilson. It is certainly an understatement that I await the report of the Committee with interest.

The next few years promise to be critical ones in the Institution's history. How shall we order our priorities in the physical sciences? Can we develop the resources necessary to proceed both with a new building for the earth and planetary sciences and, over the next few years, to participate with others in the construction of a large telescope in the Southern Hemisphere? Can we maintain our leadership in observational astronomy and in the earth and planetary sciences? And, can these objectives be accomplished without drawing down the Institution's financial resources, as happened during the 1970's? Clearly, our decisions now will influence the course of the Institution's work well into the next century.

James D. Ebert
December 20, 1984

The Year in Review

Department of Embryology staff, June 1984. Bottom row, left to right: Earl Potts, Donald Brown, Joe Gall, Mike Sepanski, Rahul Warrior, Bill Hoerichs, Jennifer Schwartz. Second row: Suki Parks, Dianne Thompson, Kunio Takeyasu, Kathy French, Eileen Hogan, Naomi Lipsky, Celeste Berg, Diane Shakes, Chris Murphy, Ernestine Flemmings. Third row: Gloria Wilkes, Betty Addison, Paul Uster, Mike Tamkun, Richard Sleight, Bill Taylor, Steve L'Hernault, Fred Moshiri, Lloyd Epstein, Dick Pagano, Joe Vokroy, Ophelia Rogers. Fourth row: Richard Kelley, Sandy Lazarowitz, Doug Fambrough, Thomas Miller, Rick Johns, Kent Vrana, Marty Schwartz, Tom Malooly, Sam Kelly, Bill Duncan, Barry Wolitzky.

The Year in Review

> The compartmenting of subject matter is a constant threat to the unity of science . . .
>
> Caryl P. Haskins
> Report of the President
> *Year Book 56*

A strong trend in the history of modern science is the movement toward specialization among scientists, a development opposite from an earlier tradition of broad-ranging individual scholarship. As knowledge pyramided from decade to decade in our century, scientific disciplines became divided into subdisciplines, and subdisciplines became fragmented into ever-narrower specialties. The resulting arrangement made possible many of the remarkable discoveries of modern times.

Ever more powerful research tools reinforced the trend toward specialization. Observations and experiments became possible at finer and finer levels of detail, and especially in the last decade or so, the ability to record and analyze vast amounts of data drastically improved. Investigators increasingly required mastery of intricate and highly specialized equipment and techniques. As a result, radio astronomers came to be distinguished from optical astronomers, x-ray crystallography became itself a specialty, and revolutionary new techniques for studying the genetic molecule strengthened specialization within the field of developmental biology.

Today, as in recent years, most newcomers to the scientific profession enter as practitioners of some narrow research field. There is so much to learn within each specialty, so many exciting ideas to explore, so much competition among investigators to achieve recognized results, that the surest path to recognition is by remaining within one's chosen field, building knowledge and supplying new ideas within its generally understood bounds. To move into a different subdiscipline requires mastery of a new family of knowledge and techniques, and to launch a major quest for synthesis across disciplinary boundaries carries high risk of failure.

Thus, most investigators spend most of their time in detailed specialized research; their professional contacts typically are with investigators of identical or very closely related specialties, and their professional writings are largely in the form of detailed reports of original, specialized investigations. To cite a familiar example, much of the material in recent Carnegie Year Books is manifestly intended for a limited readership of fellow specialists; lay persons and scientists in unrelated specialties find much of the language beyond comprehension.

The case should not be overstated, however, nor is it necessarily to be deplored. Specialized knowledge and expertise are basic to creativity and leadership in discovery. Specialization has not prevented the emergence of grand syntheses—witness in our century the birth of the expanding universe concept, the plate tectonic revolution in the earth sciences, and the fundamental understanding of the nature of the gene from the discovery of its molecular structure. Such syntheses have properly given direction to the research of many later investigators.

But if the dominant pattern remains that of specialized research, there is also unmistakable indication that the pressures leading to specialization are being moderated by influences leading in an opposite direction. More and more frequently, scientific problems are very difficult and call for the expertise and tools of more than a single discipline; discoveries in one subdiscipline are recognized to be of immediate significance to workers in others. In short, communication—indeed collaboration—across traditional boundaries appears increasingly crucial for assembling the knowledge and ideas needed for further significant advance.

In plant biology, for example, biochemists and ecologists traditionally have had little understanding of, or interest in, one another's problems; it is probably not possible for any one individual to be completely comfortable and well-informed in both realms. A great strength of Carnegie Institution's Department of Plant Biology has come from its attempts to bridge the two—to connect what goes on in the whole organism to what goes on between the molecules of a cell. At the Department in recent decades, studies of the whole organism in the field, in combination with laboratory studies of the cellular components and biochemical processes, have led to far greater understanding than either approach could have yielded separately. Then a few years ago, the extraordinary promise of molecular biology brought yet another dimension; today, there seems to be no problem in basic plant research that cannot be approached profitably by applying this new field. At the Carnegie Department, fundamental questions—how light influences plant development, for example—are now being addressed in all three realms: that of the whole plant, the cell, and the genetic molecule.

Donald Brown, director of the Institution's Department of Embryology, recently identified a comparable, though less fully developed, movement toward vertical integration in his field. Past model systems in developmental biology have centered on single molecules of known, important function, Brown writes, although complex structures such as organelles, tissues, and finally whole organisms are built from the interaction of these molecules. Brown concludes that, however powerful the modern methods of molecular analysis may be, they are not enough; developmental biologists must learn to think and experiment while keeping in mind the implications of their research for understanding the complex functioning of the whole organism.

Meanwhile, we seem to be witnessing a growing-together among the subdisciplines of the earth sciences and astronomy, indeed a growing-together of the earth sciences and astronomy themselves. There is, of course, a gross difference in how we see and touch planet Earth and how we look upon the cosmos from afar; the research tools for studying the Earth are accordingly very different from those of the astronomer, so that the separation of the earth sciences from astronomy has become traditional. It can be argued, however, that the separation has been an artificial one, for the natural world lies before us not in two exclusive spheres but in a grand continuum of distance and time—a continuum encompassing the inner Earth and reaching to the farthest galaxies. No part of the continuum can be long considered in isolation from its neighbors, and the perspectives of all the physical sciences should be brought to bear in studying each part.

Studies of regions beyond our Milky Way Galaxy, for example, tell how populations of many galaxies are distributed in age, shape, size, and location; such information offers crucial but otherwise unattainable perspectives for understanding our own Galaxy. Likewise, studies of populations of neighboring and distant stars expand comprehension of our own Sun and its solar system, while research on the planets, comets, and asteroids of our solar system give insight as to how the Earth's core and mantle may have formed. Discoveries about the deep Earth, then, influence our understanding of processes in the crustal regions we inhabit. Finally, the whole scheme also applies in reverse—the detailed observations possible in

The Department of Plant Biology's seminar room.

studying our own Sun give knowledge valuable for understanding other stars, rocks from meteorites contain isotopic evidence of processes in distant stars, and so on.

If evidence of growing integration across the subdisciplines of science is real, it is a trend for which the Carnegie Institution is well prepared. Although each Carnegie scientist is typically a specialist in some field, there is opportunity—indeed encouragement—to grow as a generalist, to develop research interests transcending conventional disciplines. By creating environments for daily interaction and collaboration across subdisciplines, the Institution's departments have already established traditions in harmony with a vision of integration. Thus in the strengths of its scientists in many disciplines, and in its eagerness to cross disciplinary boundaries, the Institution is well prepared for leadership in developing the syntheses that surely lie ahead.

The Review of the Year's Work. Our tour in the pages that follow is not all-inclusive. Only some of the research in progress—generally those activities nominated by the directors of the departments—is presented. A few ventures have been treated more expansively than others in the hope of expanding the nonspecialist reader's perspective in representative areas; it is to be expected that different topics will receive expanded treatment in future Year Books. In general, there has been an attempt to make the material intelligible to nonscientist readers by including more background information than has formerly been the case and by reducing the extent of technical detail. Readers interested in the kind of detailed information found in previous Year Books are referred to the Bibliography of Published Work on pages 115–136.

The text has been developed from unpublished inputs prepared in July 1984 by the directors and scientists, and most of the direct quotations used here are taken from these sources.

The Biological Sciences

> The Department has long held the philosophy that molecular biologists, biochemists, physiologists, and ecologists do not have to live in isolation, and that a thorough understanding of any facet of plant biology will almost certainly require the combined efforts of people from each group.
>
> Winslow R. Briggs
> Director, Department of Plant Biology
> July 1984

> The future challenges before us can be predicted. Our model systems to date have been one-dimensional in the sense that we center our attention on single molecules that we know have important functions. However, complex structures such as organelles, tissues, and finally whole organisms are built from the interaction of many of these molecules. Therefore we must learn to think and experiment in two dimensions (or more) to understand these complexities.
>
> Donald D. Brown
> Director, Department of Embryology
> July 1984

The mechanisms that plants and animals have devised to create, adapt, maintain, and restore life are each one unique—unique to an environment, unique to a species, unique to a gene. Biological research, too, evidences extraordinary diversity. At the same time that plant ecologist Olle Björkman studies salt stress in mangrove leaves, for example, molecular biologist William Thompson is investigating light regulation in genes of the pea plant in a laboratory down the hall. While geneticist Allan Spradling studies how eggshell protein genes work in the fruit fly, Richard Pagano is exploring lipid metabolism in hamster cells.

What unites these seemingly disparate activities? What common ground do physiological ecologists, biochemists, and molecular biologists share? One answer, simply, is a common search for mechanisms of biological regulation. Plant physiologists ask what controls a plant's photosynthetic capacity in stressful environments. Cell biologists ask what regulates the traffic in a living cell. Molecular biologists are interested in what controls the actions of genes.

Many questions of control, it seems, ultimately come down to the genes. For in the genetic codes of inheritance are many of the answers to the puzzles of how life is maintained and how it has evolved. Perhaps the genes also contain answers to the question of how life arose from nonlife. Today, we are closer to understanding these mysteries. But, as Donald Brown expresses above, an understanding of the larger questions of life requires a new synthesis. We need to know how genes influence and are influenced by other genes; we need to know how genes are controlled by signals from other parts of the chromosome, indeed by signals from the cell membrane and from the organism's external environment. We need to know how genes know when to turn on and off: Where does their time sense come from?

Hence, at Carnegie's Department of Embryology and at the Carnegie-Caltech Developmental Biology Research Group (where Carnegie Senior Research Associate Roy Britten works), one finds a growing emphasis on studies "in situ" (within the organism), where one can begin to determine the range of environmental variables affecting a particular biological system. Correspondingly, at the Institution's Department of Plant Biology, there is a continuing attempt, as director Winslow Briggs says, "to bridge what goes on in nature to what goes on between the molecules of the cell—to cover the entire vertical spectrum from the macro to the micro to the molecular." Investigators there, in fact, have reached the point where they can begin to use molecular techniques as tools in the elucidation of questions posed on the cellular and organismal levels.

How Light Controls Plant Development

The merging of plant molecular biology with other, more established disciplines is one of the most significant developments of recent years at the Department of Plant Biology.

The Department has been far-sighted in preparing the necessary facilities for this synthesis. Still, crossing the boundaries that separate disciplines is a difficult task, one that requires the vision and open-mindedness of the scientists themselves. This year, Department scientists report preliminary, noteworthy achievements in one such discipline-bridging collaboration—that between Winslow Briggs' photobiology group and the molecular biology lab of William Thompson. How, these scientists ask, does light affect plants—at the levels of the whole plant, the cell, and the gene?

The response of a plant to light is mediated by various pigment molecules, called photoreceptors, which absorb different wavelengths, or colors, of the spectrum. The green pigment chlorophyll, which traps energy during photosynthesis, absorbs energy most efficiently from red and from blue light. The pigment phytochrome, which stimulates many chemical changes not involved in photosynthesis, for example, seed germination and flowering events, responds to red and far red light.

Red Light Regulation. Several years ago, Dina Mandoli, a graduate student working in Briggs' laboratory, carefully described the phytochrome growth responses of dark-grown oat seedlings to low and very low levels of red light (*Year Book 79*, pp. 126–131). These responses begin very early in development, as the growing shoot reaches the first light while still below the soil surface, and continue as emergence occurs. Light influences the rate of stem elongation (which slows down after a light stimulus) and triggers events leading to construction of the photosynthetic apparati and the expansion of leaves (thus permitting the plant to become energetically self-supporting at a young age). Some phytochrome responses to red light occur in two stages. The first stage is very sensitive, being stimulated by amounts of light ranging from the equivalent of a single firefly flash to about one minute of full moonlight. The second stage is less sensitive and requires at least one hundred times more light than the first.

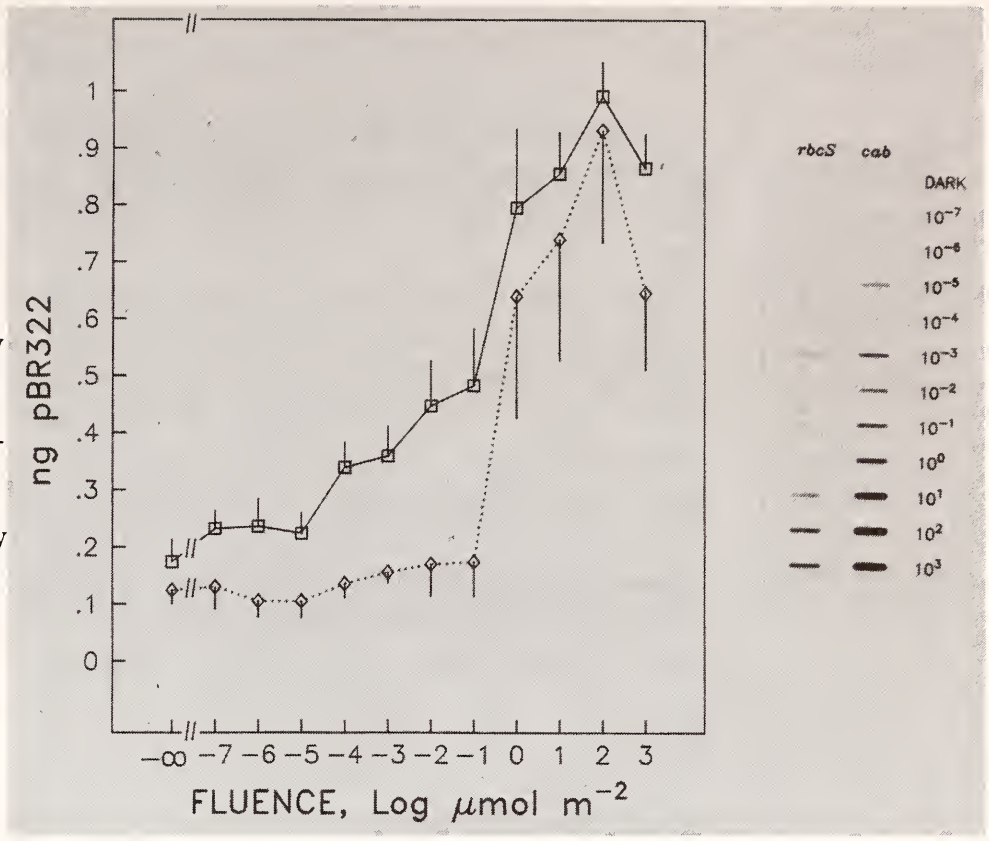
In an extension of this study last year, predoctoral fellow James Shinkle, also in the Briggs lab, discovered that it is the amount of the growth hormone auxin in the plant tissue that determines whether the tissue shows high sensitivity to red light (high levels of auxin), both high and low sensitivity components in a complex response (intermediate levels), or only the lower sensitivity response (low levels).

Last year, using pea plants, Lon Kaufman, in a collaboration between Briggs' and Thompson's laboratories, began examining in detail what effect light has on the amount of messenger RNA (mRNA) transcribed by several different genes. (Messenger RNA is copied from DNA and forms the template for protein production.) Among some thirteen genes studied by Kaufman were two that coded for important proteins in the photosynthetic apparatus. One of the proteins is responsible for binding a major fraction of the chlorophyll in a "light-harvesting" complex; the other is the smaller of the two subunits that make up the enzyme ribulose bisphosphate carboxylase (RuBP carboxylase), which is required for the initial carbon-fixing stages of photosynthesis.

Thompson and his colleagues had shown previously that patterns of light treatment known to produce phytochrome induced growth responses in plants also caused changes in levels of mRNA. As early as 1978, they had begun to develop a library of cloned genes to use as probes for the detection of specific mRNA sequences in tissues exposed to varying regimes of white, red, and far red light. This technique was possible because, when mixed under appropriate laboratory conditions, the cloned gene sequences hybridized with, or to, similar (complementary) mRNA sequences in the sample being assayed. The extent of reaction—indicating the amount of mRNA complementary to a given clone—could be roughly visualized using autoradiography techniques. Over the years, as the sensitivity of the hybridization technique improved, so did the detail of the measurements.

When Kaufman, with Thompson and Briggs, began his experiments last year, he was able to measure mRNA abundance at very precise levels. In the first round of experiments (where he treated individual six-day-old plants with just enough red light to induce the first-stage response), he found a clear increase in the message for the chlorophyll-binding protein after a 24-hour period, but no change in the level of mRNA for the small subunit of RuBP carboxylase. When he treated plants with enough light to stimulate stage two of growth, however, he found an additional response for the chlorophyll-binding protein mRNA as well as a response of the small subunit mRNA.

In further detailed studies of the eleven other genes, Kaufman found that these genes (whose functions in the cell are yet unknown) responded differently to the light treatments. Some of the mRNAs increased immediately and continued to increase for the entire 24 hours of the experiments, while others climbed rapidly for a little over an hour, then reached a plateau. Yet a third group showed a lag of about 16 hours before beginning to climb. And, finally, one group was climbing steadily even in the dark; the light treatment merely increased the rate at which the mRNAs accumulated.



Scientists at the Department of Plant Biology are developing sensitive molecular biology techniques for studying developmental responses to light. Shown here are results from experiments by Lon S. Kaufman, William F. Thompson, and Winslow Briggs, who are investigating the response of pea seedlings to controlled red light irradiations. The upper curve shows production of the mRNA for the chlorophyll-binding protein (as described in text); the lower curve shows production of the mRNA for the small subunit of RuBP carboxylase. At very low red light fluence (at −4 on the horizontal scale), the chlorophyll-binding protein mRNA exhibits accumulation, but the lower curve does not. At higher fluences, both mRNAs exhibit accumulation. The investigators note that inasmuch as light at very low fluence is present deeper in the soil, the chlorophyll-binding protein mRNA may start to accumulate very early in seedling development, possibly before the RuBP carboxylase mRNA and certainly before chlorophyll accumulation. (The slot blots shown at right are the data used to calculate the fluence response curves in connection with the DNA hybridization techniques. The notations *cab* and *rbcS* refer to the respective RNAs; pBR322 refers to the plasmid vector DNA used in the hybridization.) (Adapted from the investigators' report in *Science 226*, p. 1447, 21 December 1984, copyright 1984 AAAS.)

It is known that identical copies of the genes both for the chlorophyll-binding protein and the small subunit of RuBP carboxylase exist in the nuclear DNA. Not all copies would necessarily be expressed (or transcribed into mRNA) under all conditions, and one very interesting possibility is that light regulates only certain copies of the genes. Postdoctoral fellow John Watson, with Thompson, has begun to clone different copies of the genes in an effort to determine what controls their differential expression. Meanwhile, another postdoctoral fellow working in Thompson's lab—Neil Polans—is combining molecular techniques with conventional genetics in an attempt to place these genes on the pea genetic map.

Light is clearly turning on very elaborate—and complex—programs of change at the molecular level. These changes are reflected in the effects of light on the whole plant, and open up a vast array of experiments designed to unravel the threads of developmental change under the influence of light. Without the whole plant studies, writes Briggs, the physiological and molecular studies would not (and indeed could not) have been done.

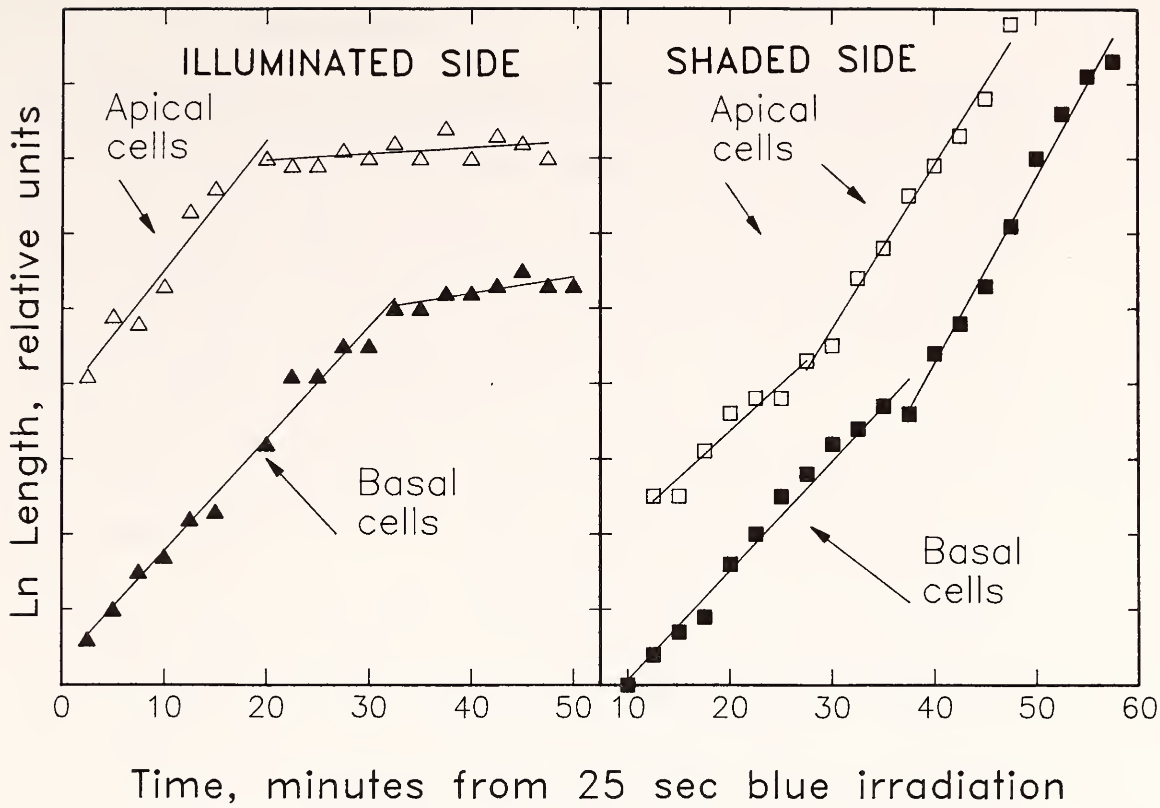
The question of how genes are regulated by light is becoming a common theme at the Department. Much of what is happening in Thompson's laboratory, for example, represents a direct assault on this problem at the molecular level. Evidence in the literature suggests that the degree to which DNA sequences are methylated, or modified by the addition of methyl groups, is often related to whether or not the gene is expressed. Thompson's group is now finding differences in the extent of methylation of the same genes in root and shoot cells. Experiments are in progress to determine if and how light affects the degree of methylation of these and other genes.

In another study in Thompson's lab, graduate student David Stern has initiated an effort to determine whether genes in mitochondria show light regulation. (Mitochondria, in which most plant respiration occurs, contain their own, separate DNA.) Stern's preliminary results suggest that certain mitochondrial genes, like those already studied in the nucleus and the chloroplast, respond to light. The molecular mechanism of this response, and indeed of any of the responses studied so far, is unknown, and will be the focus of research efforts for years in the future.

Blue Light Regulation. Blue light, like red, effects a variety of responses in plants, but the nature of the photoreceptors (or pigments) involved is largely unknown. Some years ago, workers in Briggs' laboratory obtained evidence that a particular flavin-containing pigment complex located in the outermost membranes of photoreceptor cells might play a central role in blue light photoreception in such processes as phototropism, which causes plants to bend toward the Sun (*Year Book 80*, pp. 94–96).

Phototropism has often been described as the consequence of a growth differential induced across the plant axis. But the precise way whereby light influences this response has remained elusive. Dow Woodward, on sabbatical leave from Stanford University, has made substantial progress in isolating and purifying the flavin-containing pigment complex from corn, preparatory to detailed characterization. This work is essential, writes Briggs, if we are to understand the first steps by which the light signal is transformed into a biological response.

Meanwhile, Moritoshi Iino, in the Briggs laboratory, has



Results of an experiment investigating growth responses in corn to illumination from a single direction. The drawing depicts growth pattern on the illuminated and the shaded sides of red light-grown maize coleoptiles following a pulse of blue light. (The apical cells are near the tip and are 4 mm above the basal cells.) Depression of growth rate is seen on the illuminated side, and stimulation of growth on the shaded side, some minutes after irradiation; both changes occur in the apical cells about ten minutes prior to onset in the basal cells. The investigators—Tobias Baskin, Moritoshi Iino, and Winslow Briggs—suggest that net growth in the direction of the source is explained by transport of the growth hormone auxin, induced by blue light irradiation. (Data was obtained by time-lapse photomicrography through a horizontal microscope. Cell edges were isolated for measurement in enlarged images. The natural log of the measured length is plotted vs. minutes after irradiation.)

been carrying out detailed kinetic studies both on phototropism in corn shoots and on another blue light mediated response—the opening of a plant's stomata, or its "gas-exchange" valves. (The latter studies were done in collaboration with Eduardo Zeiger at Stanford.) And in yet another blue light study in the Briggs lab, Iino and former fellow Eberhard Schäfer showed that the phototropic response of a particular fungal reproductive structure to a pulse of blue light was remarkably similar to—though much more sensitive than—the phototropic response of a coleoptile (the sheath that covers the first leaves of a monocot seedling). Briggs notes that the similarities between these two very different systems suggest that the same photoreceptor is probably operating in both, and indeed may be of general importance in light regulation in plants.

In extending phototropic studies to the level of individual cells, Iino and Tobias Baskin last year found that plants responding phototropically to light from a single direction showed a very sharp wave of growth inhibition that migrated down the irradiated side of the stem. An equally sharp wave of growth stimulation migrated down the shaded side. At any given point along the shoot, a new growth rate was established in less than five minutes. Further, these waves moved at just the rate expected for the downward transport of the growth hormone auxin. This suggests that the response is caused by the lateral *redistribution* of growth, and that it is not necessarily accompanied by changes in net growth. Currently, Baskin is doing experiments to determine whether this blue light–induced response to short pulses of light in low doses is confined to seedlings of grasses (such as corn and oats) or if it is more general.

In showing that auxin is growth limiting, Iino and Baskin's experiments lend elegant support to a very old (but recently challenged) theory of phototropism stating that blue light acts on shoots by setting up a lateral movement of auxin from the illuminated to the shaded side. Blue light must be exerting very precise control over this movement.

In other blue light studies, Kaufman and Watson (in Thompson's group) have found preliminary evidence that blue light brings about dramatic changes in the expression of mRNA from several (but not all) of the same genes that they found responded to red light. In addition, they found that auxin itself can bring about changes in the expression of these same mRNAs. Auxin can also effect changes in mRNAs that are *not* affected by blue light, but all blue light–affected mRNAs seem to respond to auxin. Briggs says that all of the blue light studies represent a coordinated attack on the photoregulation of plant processes by blue light, and complement and interact with studies involving red light.

Pigment Structure. In yet another look at light regulation in plants, Arthur Grossman and his colleagues are investigating an important light-harvesting system in red and blue-green algae. Functionally analogous to the light-harvesting chlorophyll-protein complex in higher plants, this system is composed of stacks of varied pigmented polypeptides linked together by colorless proteins (called linkers) in an orderly array and attached to the photosynthetic membrane by a high-molecular-weight pigmented polypeptide called the anchor protein. These unique pigment-protein structures, called phycobilisomes, often absorb light from the middle range of the light spectrum—the range most available to some algae that dwell just beneath the water's surface.

In certain algae, the phycobilisomes have the striking ability to adjust the amount of their individual pigmented proteins according to the color of the light they are receiving (a phenomenon called chromatic adaptation). If the algae are exposed to red light, they maximize the amount of a red-absorbing pigment and minimize a green-absorbing pigment. If they are exposed to green light (for example, if they are shaded by green algae), they maximize the green light absorber and minimize the red. The system shows full photoreversibility, and the question suddenly becomes obvious: How does this reversible photo regulation occur?

Two years ago, Grossman launched a major effort to understand how the phycobilisome system works, how its genes are arranged, and how it has evolved. Already, he and the postdoctoral fellows who work in his lab have isolated and cloned several phycobilisome genes. Peggy Lemaux has cloned four genes encoding the pigmented phycobiliprotein subunits in a eukaryotic alga. Pamela Conley is doing similar work with prokaryotic algae. And Terri Lomax has tackled the difficult job of obtaining the genes for the linker proteins.

Briggs observes that phycobilisome photoregulation resembles the red-sensitive phytochrome system under study in the Briggs and Thompson laboratories, and he suggests that the Grossman and the Briggs-Thompson efforts will soon converge.

Staff member Jeanette Brown is also exploring pigment structural relationships—but from a different viewpoint. This year, in collaboration with Jacques Duranton from the French Atomic Energy Center at Saclay, Brown used special spectral techniques to show the absorption of β-carotene (a major photoprotective pigment) in a chlorophyll-protein complex. As well, she has compared the reaction center complexes (those pigment complexes wherein the primary reactions of photosynthesis occur) and the principal light-gathering (antenna) pigment complexes from a wide range of plants. She finds that the reaction center complexes are conserved in the same spectral form over a number of organisms, while the antenna complexes show a high degree of variation. The molecular approaches of Grossman and his colleagues, says Briggs, will no doubt be of value in learning whether the pigment-binding proteins of the reaction center complexes are likewise conserved.

Gene Engineering—in Nature and in the Laboratory

One of the fascinating aspects of phycobilisome biosynthesis is that the genes that encode them are not all found in the same location in a cell. In red algae, for example, the biliprotein polypeptides are encoded in the chloroplast genome, while the colorless linker proteins are encoded in the nucleus. (In higher plant and eukaryotic algae, DNA is found not just in the nucleus but in two other subcellular organelles, the chloroplast and the mitochondrion.) Many scientists believe that chloroplasts are evolutionary descendants of primitive blue-green algae. Blue-green algae may have become engulfed into unicellular organisms and, in the course of evolution, may have lost much of their genetic potential to the nucleus of the host organism. The nuclear-localized linker genes in red algae may represent just such an evolutionary migration.

There is other evidence that genes inside plants may move from one genome to another over time. For example, graduate student David Stern and former graduate student and research associate Jeffrey Palmer find surprising similarities (homologies) between the chloroplast and mitochondrial genomes, suggesting an ongoing evolutionary process of DNA sequence transfer from one organelle to the other (*Year Book 82*, pp. 17–19).

One important process involved in the evolution and regulation of plant genes concerns the recombination (both "legitimate" and "illegitimate") of DNA. Viruses provide some of the best-studied recombination systems. This year at the Department of Embryology, staff associate Sondra Lazarowitz found evidence that the DNA of a small plant geminivirus called Squash Leaf Curl may consist of more than two components, one of which has distinct regions of partial sequence homology to the others. The structure of the components indicates that they may have evolved as a result of recombination events.

The "legitimate" recombination between homologous DNA sequences is a fairly common event in all organisms. From it, for example, come variations that make offspring different from their parents. Recombination may also occur "illegitimately" between nonhomologous DNA. Barbara McClintock, the 1983 Nobelist in Physiology or Medicine, uncovered the first evidence of this phenomenon forty years ago while working as a staff member at Carnegie's former Department of Genetics in Cold Spring Harbor, New York. She found that, during cell division, pieces of DNA could move about, or transpose, within the maize genome, inserting themselves into places they normally did not belong. If a transposable element happened to move into or near a gene, it could turn that gene off; when the element moved away, during a subsequent cell division, the gene turned back on. These unstable mutations showed up in the corn plant as colorful variegations in the kernels and leaves. Because the variegations appeared to be expressed in regular and highly characteristic patterns, McClintock called the transposable DNA pieces "controlling elements."

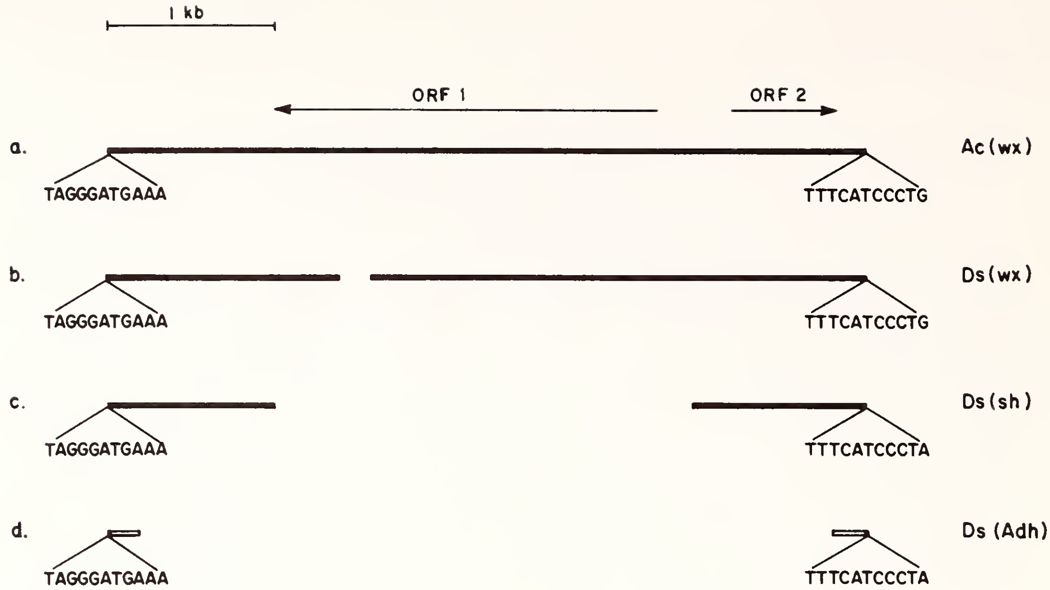
McClintock suggested that transposition was an example of a normal developmental control system gone awry. So far, however, molecular biology techniques have provided no direct evidence that transposable elements are involved in the control of gene expression in maize (or in any other organism in which they have been found). But the possibility has not been ruled out, since transposable elements seem to be responsible for patterned gene expression in a variety of organisms.

Scientists know quite a bit about how transposable elements function at the molecular level in such simple organisms as bacteria and yeast. Answers to questions about how they work in maize, however, must wait until scientists have a better idea how these elements are structured and organized within the maize genome. This has been the goal of Nina Fedoroff, staff member at the Department of Embryology, for several years. Continuing McClintock's genetic detective work on the molecular level, Fedoroff and her colleagues last year succeeded in isolating and cloning several transposable elements in maize—three designated *Ds* and one designated *Ac*.

Ds and *Ac* were the first transposable elements that McClintock discovered in maize. *Ds* first manifested itself as a site of chromosome breakage. Hence, she called it *Ds*, for dissociation. Soon it became apparent to her that *Ds* could move. But to do so, it required the presence of another element, which she named *Ac*, for activator. Then, McClintock found that *Ac*, too, could move, but it did not require the presence of another element; it could move on its own.

In collaboration with Joachim Messing at the University of Minnesota, Fedoroff and her colleagues Samuel Kelly and Rick Johns recently determined the entire nucleotide sequence of *Ac*. The element, they found, is 4,563 bases long and has short sequences (11 nucleotides long) that appear as mirror, i.e., inverted, repeats at either end. (Inverted repeats are characteristic of transposable elements and appear to be necessary for the transposition process.) Within the nucleotide sequence of *Ac* they found two genes—a long gene and a short gene. The function of the small gene is not yet known, but Fedoroff and colleagues believe the long gene encodes an enzyme, called transposase, that is required for transposition.

The investigators were able to make this conclusion by analyzing the structure of the subsequently isolated *Ds*'s. The first of the *Ds* elements that they isolated was virtually identical to the *Ac* element, except it lacked a short sequence (194 nucleotides long) from the longer *Ac* gene. Since the genetic effect of this change was to immobilize *Ds* (rendering its transposition dependent on the presence of *Ac*), Fedoroff concluded



Diagrammatic representation of one Activator (*Ac*) and three Dissociation (*Ds*) transposable elements isolated from maize by Nina Fedoroff and her colleagues at the Department of Embryology. (*a*) The *Ac* element isolated from the *wx* locus is 4563 base pairs (bp) in length and terminates in an imperfect 11-bp repetition. It is shown as having two major divergent uninterrupted protein-coding sequences (open reading frames or ORFs), although recent data suggest that ORF 1 has either a short internal intervening sequence or that it comprises two smaller ORFs. (*b,c,d*) Three different *Ds* elements, isolated from the *wx*, *sh*, and *Adh* maize loci all terminate in perfect 11-bp repetitions virtually identical to that of the *Ac* element. The *Ds* element at (*b*) is very similar to, and was derived directly from, the *Ac* element; it differs only by having a 194-bp deletion in one of the protein-coding sequences, represented by the gap in solid line. The smaller *Ds* element (*c*) resembles the ends of the *Ac* element. The gap in the line's center represents the part of the *Ac* element's sequence not represented. The smallest *Ds* element (*d*) has no sequences in common with the *Ac* element except for the terminal inverted repetition; its sequence is thus represented by an open box. *Ds* elements comprise a heterogeneous family of sequences that can be mobilized by the *Ac* element's trans-acting function or functions, which appear to act on the terminal sequences.

that the long gene must be responsible for making the transposase that initiates transposition. Her conclusion was strengthened when they found another *Ds* that lacked almost all of the long gene. Elements called *Ds* thus appear to contain the structural information required for transposition, but they cannot initiate the event.

Fedoroff and her colleagues have made a few preliminary explorations into how maize transposable elements can be used—both for the isolation of certain genes that are marked by insertion mutations, and as transmitting agents, or vectors, for introducing DNA into maize and other plants. In experiments toward the first objective, they were able this year to isolate the *bronze* (*bz*) locus (which encodes an enzyme involved in pigment synthesis), by virtue of its association with an *Ac* element having flanking sequences homologous to *bz*.

They succeeded in isolating the *bz* locus rather readily, suggesting to Fedoroff that the *Ac* element will be useful for the isolation of other genes with similar insertions. In the mean-time, the isolation of the *bz* locus will prove useful in their efforts to isolate another family of transposable elements that McClintock studied in maize—the Suppressor-mutator (Spm) family. Fedoroff and her colleagues recently cloned and are currently analyzing the structure of several members of this family.

In the second set of experiments—those designed to determine how *Ds* and *Ac* elements might be used as vectors—Fedoroff's group (in collaborative experiments with Josef Schell of the Max Planck Institute for Plant Breeding, Cologne, West Germany), are testing the ability of the *Ac* element to transpose in the tobacco genome. (To insert the element into the tobacco plant, they splice it into a bacterial plasmid capable of entering the cells.) They are also attempting to reintroduce *Ac* or *bz* directly into maize plants or cultured maize cells. One importance of these experiments, which Fedoroff says will probably progress slowly, lies in the eventual possibility of introducing agronomically useful genes into crop plants.

Manipulating Genes in the Laboratory. For many years, scientists have been able to isolate genes, splice them into bacterial plasmids, and insert them into the genomes of such simple systems as bacteria and viruses. The ability to transfer genes into the genomes of higher organisms, as Fedoroff is trying to do, has come more slowly, largely because of the lack of appropriate vectors, capable of transmitting genes from one organism to another. With the discovery that the genomes of higher organisms contain transposable elements, however, the situation began to change. Fedoroff's attempts to use transposable elements as the transfer vehicle in maize, in fact, rests on an analogous—and successful—technique developed in the fruit fly (*Drosophila*) by Department of Embryology staff member Allan Spradling and former staff member Gerald Rubin two years ago.

Spradling and Rubin found that they could transfer a gene into a *Drosophila* embryo by inserting the gene into a transposable element (the P element) and then injecting the modified element (or transposon) directly into the embryo. Once inside the embryo, the transposon jumped directly into the genome, where it was stably incorporated. Furthermore, in future generations, the gene continued to be accurately expressed (*Year Book 81*, pp. 181–188).

This technique is a powerful research tool. With it, researchers can transfer into a *Drosophila* line, genes whose control regions have been experimentally modified. The molecular basis for genetic disruptions can be examined, and questions about how control regions activate genes at precise times

Members of the laboratory for study of *Drosophila* development. Left to right, row 1: Allan Spradling, Joe Levine; row 2: Barbara Wakimoto, Laura Kalfayan; row 3: Suki Park, Dianne Thompson; row 4: Pam Fornili, Richard Kelley, Terry Orr-Weaver.

during development can be posed. Many laboratories around the country are using the technique successfully in *Drosophila*, but efforts to use P elements as vectors in other organisms have so far failed. It is not surprising, therefore, that other methods of gene transfer need to be developed in other higher organisms. At the Carnegie-Caltech Developmental Biology Research Group at the Kerckhoff Marine Laboratory, California, for example, Carnegie Senior Research Associate Roy Britten and his colleagues are working on a simple, rapid microinjection method for introducing DNA into sea urchin eggs.

In their experiments, Britten and his colleagues (Constantin Flytzanis, Andrew McMahon, Barbara Hough-Evans, and Eric Davidson) inject cloned DNA sequences into unfertilized sea urchin embryos and then examine the five-week-old larvae (50,000 cells). In some experiments, as many as 85% of the larvae contained the injected sequences, and in over half of these, the sequences were present at an average of more than one copy per cell. Britten's group found that an injected bacterial gene (chloamphenicol acetyl transferase) is expressed under control of a *Drosophila* heat shock promoter region also present on the injected plasmid. The transcription of the bacterial gene is enormously increased under conditions that induce a heat shock response in the sea urchin larvae, indicating that this transcription control DNA must be highly conserved.

When the larvae undergo metamorphosis, much of the replicated DNA is lost. A significant quantity, however, remains in a minority of individuals. Within the DNA of one such individual, Flytzanis found junction regions between genomic and injected DNA. One junction region was sequenced, demonstrating that the injected DNA had indeed been integrated into the sea urchin genome.

Evolutionary Divergence. The gene transfer method described above is important for future studies of gene control mechanisms during sea urchin development. Sea urchins are particularly favorable organisms for the study of gene function, for considerable detailed molecular information exists on sea urchin gene expression. A great deal of information also exists on sea urchin phylogeny, which makes them additionally useful for the study of evolution.

Roy Britten has been fascinated with evolution ever since his discovery—twenty years ago as a member of the former Biophysics Group at Carnegie's Department of Terrestrial Magnetism—that some DNA sequences are copied in the genomes of higher organisms as many as one million times. At the Kerckhoff Laboratory, which Britten joined in 1972, he and his colleagues use recombinant DNA techniques to measure the conservation of repeated and single-copy DNA sequences in different sea urchin species of known phylogenetic relationship. They have found that repeated sequences often show strong similarity between distantly related species. In one case, members of a particular family of repeats show more than 95% homology between two sea urchin species that last shared a common ancestor more than 100 million years ago. Homology between single-copy DNA, in contrast, was very slight.

This year, Britten *et al.* simulated by computer the effect of frequent copying and insertion of DNA sequences to determine if copying was limiting divergence of the repeated segments. They found that copied and control sets drifted at precisely equal rates. Thus, it appeared that copying does not retard the rate of evolutionary drift. According to Britten, two alternative explanations for the lesser evolutionary divergence of repeats remain: repeats either undergo sequence-dependent selection pressure or they are transferred horizontally between species by viral infection or some unknown mechanism.

Individual genes can have tremendous evolutionary significance. The bindin gene, for example, which produces the sperm-binding protein in sea urchins, is likely to be a significant speciation mechanism. This is because bindin, by binding to the receptor on the egg membrane, renders fertilization species-specific. It provides a barrier against the hybridization of two separate species in the wild. Recently, Britten's group began a comparative study of the bindin gene between individuals and closely related species. The first step has been accomplished this year. Boning Gao, a visitor from mainland China, has isolated the gene regions and is now sequencing the gene from the sea urchin *Strongylocentrotus purpuratus*. She finds that the gene exists as single-copy rather than as a gene cluster member, which simplifies the study of its evolution.

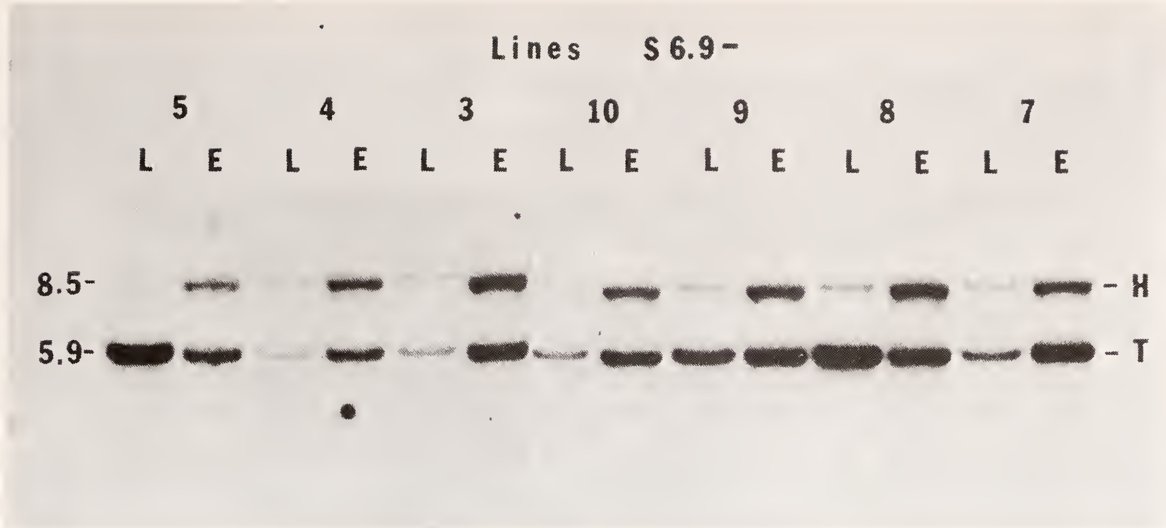
The Functioning Genome: A Vista on Developmental Control

Evolution and development. Two sides of the same coin—one the rearrangement of the genome on timetables of millions of years, the other the expression of that genome on the order of days, minutes, seconds. It is a continuing mystery that each cell of an organism contains the same genes as every other cell of that organism. How does differentiation then occur? What are the factors that turn some genes on and others off, particularly during the early stages of a developing embryo when individual cells and tissues are being shaped? At the Department of Embryology, the question is posed in a variety of ways, with a variety of organisms. Each organism provides a model system with which to explore fine details of gene function.

Allan Spradling and his colleagues focus their attention on a set of genes in *Drosophila* that code for eggshell (or chorion) proteins. These genes, found in every cell of the fruit fly, are expressed only in the ovarian follicle cells, where they are amplified (increased in number) as many as sixty times. These amplified genes produce enormous quantities of messenger RNA but they do so only at a precise time during the development of each egg.

What causes these genes to function at the appropriate time and place during the development of the egg? To help answer this question, Spradling's group uses a combination of classical and molecular techniques sometimes called "in vitro genetics." This involves isolating genetic material, mutating it—i.e., restructuring it in the laboratory by deleting or rearranging nucleotide bases—and then testing its ability to function by inserting it into the germline. (They insert the chorion gene via transposable P elements; see pp. 25–26.)

By progressively deleting DNA sequences from end regions flanking the chorion gene in the chromosome, Spradling and his colleagues have defined the DNA sequences that are sufficient to cause amplification of the chorion gene regions in ovarian follicle cells. The sequence is small, about 3,800 nucleotides long. At the present time, experiments are in progress to obtain further insight into the mechanism by



The effect of chromosome position on amplification. Allan Spradling of the Department of Embryology and his colleagues constructed seven *Drosophila* strains using P-element–mediated gene transfer. Each contained a single insertion of a specific transposon carrying a 3.8-kb DNA segment believed to be responsible for controlling the amplification of chorion genes during stages 9–13 of *Drosophila* oogenesis. The only difference between these strains (termed lines s6.9-3 through s6.9-10) was the chromosomal site at which transposon insertion occurred. The extent to which transposon sequences underwent amplification during oogenesis in these strains was determined by the binding, or hybridization, of DNA from early (*E*) egg chambers (before amplification begins) and from late (*L*) egg chambers (after amplification was complete) to a transposon-specific probe (*T*) and a control probe (*H*). The ratio *T*/*H* in late-stage DNA compared to *T*/*H* in early-stage DNA indicates the extent of transposon amplification. The extent of amplification observed varied between 1-fold and 59-fold among the seven lines, demonstrating that amplification is subject to position effect.

which this control region initiates and regulates local DNA replication.

Spradling's group has also determined the control element responsible for the tissue and time-specific expression of a chorion gene. So far, they have found that sequences lying between a point 510 base pairs upstream of the transcription start site and a point 74 base pairs downstream from it are sufficient to program developmentally specific transcription. Additional experiments are in progress to define the minimum size of this control sequence and to compare it with the control regions of other chorion genes that differ in their time of activation.

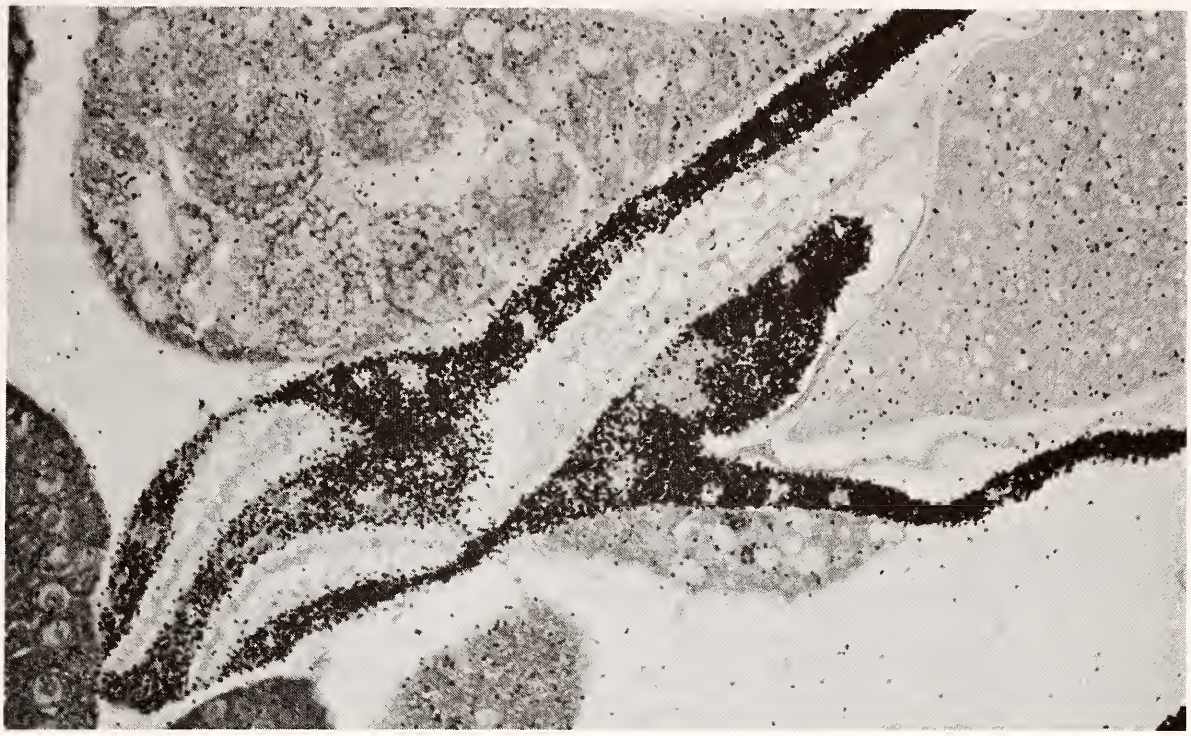
During the course of their experiments, Spradling and his colleagues found that when they introduce genes into *Drosophila,* the genes do not always integrate in the same place. Sometimes, gene action is influenced by the chromosomal location at which it inserts. Such "position effects," in the case of transformed chorion genes, seem to modify only the amount of mRNA produced, not the tissue or temporal specificity. The levels of mRNA produced by identical genes at different sites may vary as much as tenfold. The 3,800-nucleotide-long control sequence for amplification is even more sensitive to these position effects. At about half the sites tested, it failed to induce amplification. At the remaining sites tested, the fragment did cause differential replication but the level of amplification was generally lower than normal.

The existence of position effects indicates that DNA sequences at the site of insertion can significantly influence the expression of the chorion gene. The nature of this influence is yet unknown. Further study of the interactions of genes with their chromosomal environment will no doubt provide additional insight into the ability of the genomes of higher organisms to adjust to changes in gene arrangement.

The interaction of genes with their molecular environments is the major focus of Donald Brown's laboratory. Brown and his colleagues are concerned with the signals that control the differential expression of two closely related genes in a frog-like organism called *Xenopus*. The two genes ("somatic 5S RNA" and "oocyte 5S RNA") are expressed differently: in somatic cells (the body's nonsex cells), the somatic 5S RNA genes are active and the oocyte 5S RNA genes are repressed. A few years ago, Brown's group discovered the DNA signals in and around these genes that direct the accurate initiation and termination of RNA synthesis (*Year Book 78*, pp. 71–84). Their efforts in determining the DNA signals that account for the differences in gene expression, however, have met with only limited success. This is because they lack an assay system that reproduces in vitro (in the test tube) the differential gene expression of somatic cells. Nevertheless, they have identified and purified two of the components needed to activate 5S RNA genes, and, as a result of experiments this year by predoctoral fellow Mark Schlissel, they now have a clearer idea of the molecular environment that represses the oocyte 5S RNA genes in somatic cells.

Schlissel found that the somatic 5S RNA genes in the chromosomes of somatic cells are programmed into normal transcription complexes. The oocyte genes, on the other hand, are repressed by structures containing a protein called histone H1. The two physical states—activation and repression—are very different, but each is stable and not easily converted to the other. Furthermore, both states are maintained in the same cell by the interaction of their respective molecules with genes.

Currently, Brown and his colleagues are attempting to isolate the components of both active and repressed complexes and to study how they interact. It appears that such complexes account for a variety of developmental phenomena, including cell differentiation. It may be, in fact, that developmental control in general will be explained by the affinity of genes for one or more specific protein factors.



A microscopic section of *Drosophila* oocyte (unlaid egg) showing messenger RNA (mRNA) that codes for one of the eggshell proteins. The mRNA (black regions) shows up as silver grains in the autoradiographic emulsion exposed by a radioactive probe molecule. The probe molecule is part of a special in situ nucleic acid hybridization technique developed by Joseph Gall and colleagues to locate specific mRNAs in microscopic cell sections.

Tracking Gene Products. In charting the time at which genes are turned on and off during early embryonic development, it would be helpful to track the synthesis and accumulation of specific gene products (RNAs) within the cells of a given tissue or organ. Recently, staff member Joseph Gall and his colleagues at Embryology have perfected a technique that permits precise localization of RNA molecules in the nuclei and cytoplasm of cells even when these molecules are present at very low concentrations. The technique is a modification of an in situ nucleic acid hybridization technique first worked out by Gall and his student, Mary Lou Pardue, about fifteen years ago. Basically, it involves binding a radioactive probe molecule (either RNA or DNA) to a chromosome or other nucleic acid–containing component of the cell and then detecting the probe by a sensitive photographic method. Originally, the technique worked well in localizing RNA molecules on chromosome preparations, but it was difficult to apply to microscopic sections of whole cells. By combining and modifying a variety of more or less standard methods of cell preparations, Gall's group can now routinely apply the technique to mark RNA molecules in cell sections.

Gall is also intrigued by the complex structure and function of chromosomes in higher organisms. In fact, it is to this area that his major efforts over the years have been directed. In 1963, for example, he helped establish the now generally accepted view that chromosomes of higher organisms, like those of bacteria and viruses, are essentially single DNA molecules. This year, he and his colleagues have paid particular attention to the telomere, or end, of a chromosome. For a long time it has been thought that the telomere must have a special structure. This is chiefly because the ends of chromosomes, in nature, do not adhere to one another, whereas the ends of chromosomes broken by x-rays or other means become "sticky" and readily combine with other broken ends. To understand the chemical structure of the telomere, Gall and his colleagues use a very short chromosome (20,000 nucleotides long) from the protozoan *Tetrahymena*. They have made progress in defining how the composition of a telomere helps maintain a chromosome's linear shape. In future studies they also hope to determine how the telomere replicates when the chromosome as a whole divides.

How do Cells Organize Their Proteins? To answer large questions in the biological sciences, investigators necessarily focus on small problems. Gall could not hope to understand chromosome structure by attacking the multitude of complex chromosomes found in a human cell, for example. He had to choose a single chromosome that was short enough and simple enough to be manipulated by ordinary biochemical methods. So also staff member Samuel Ward, in addressing the broad and difficult questions about how cells differentiate, had to choose a single, simple cell from an organism that can be manipulated easily in the laboratory. The cell he chose is the sperm cell of the roundworm *Caenorhabditis elegans*.

During the development of any organism from a fertilized egg, cells become differentiated by the expression of different genes, which produce different proteins. But cells, to become differentiated, must also arrange these proteins in unique ways. For example, neuron proteins are arranged to form synapses; muscle cell proteins are assembled into parallel filaments. In roundworms, sperm proteins must be shaped to promote the sperm's amoeboid-like movement. What, asks Ward, are the instructions in the roundworm's genome or in the spermatozoa themselves that specify such specific protein arrangements?

Since 1978, Ward and his colleagues have described the development of *C. elegans* sperm and characterized mutations in more than fifteen different genes necessary for development.

This year, in an effort to analyze protein arrangements in spermatozoa, they have characterized several monoclonal antibodies that react with sperm proteins. Because monoclonal antibodies combine only with specific proteins, they can be used to reveal the exact location of a protein in a cell. This is accomplished by labeling the antibody with dyes or metals. Ward's group found that four different antibodies react with the same set of eight sperm proteins, which means that these proteins must share a common antigenic domain. (An antigen is usually a foreign substance that, when introduced into an organism, stimulates antibody production.) Furthermore, in collaboration with former postdoctoral fellow Tom Roberts, now at Florida State University, they found that the locations of the proteins are restricted to sperm membranes. This suggests that the antigenic parts of these proteins might be part of the signal that localizes the proteins to the membrane.

During sperm development, the antigenic proteins are assembled in the outer membrane, forming a transient organelle called the fibrous body. Other cytoplasmic sperm proteins are assembled inside this organelle. The organelle is moved into the developing sperm during development, taking the proteins along within it. At the final stage of development, the fibrous body disassembles, releasing its cytoplasmic proteins and eventually inserting its membrane into the membrane of the mature sperm. Thus, both cytoplasmic and membrane proteins are transported to the sperm in different parts of the same transient organelle.

The Dynamic Membrane

The structure of the cell membrane is critical in allowing proper cell function. This ultrathin sheet of proteins and lipids creates a separate environment within which the biochemical processes of life can take place; it interacts with other cells to form tissues; it attacks foreign viruses; it may even communicate with the nucleus, telling it when to start and stop dividing.

Because of their importance in controlling some of the vital functions of the cell, membranes are arousing great curiosity among biologists. At the Department of Embryology, three staff scientists devote their efforts toward understanding how membranes work. Martin Snider studies cell surface receptors. Douglas Fambrough studies the mechanisms by which the cell surface membrane proteins of nerve and muscle cells are regulated. And Richard Pagano studies the little-understand role of lipids in membrane assembly.

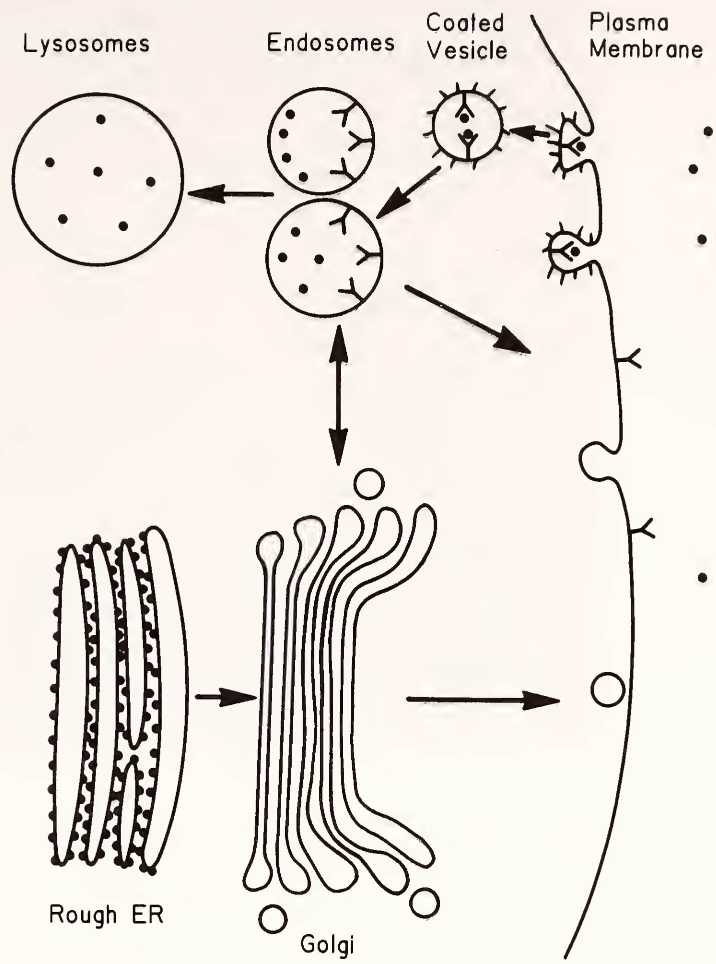
Membranes mediate traffic into and out of a cell. That traffic can be quite heavy. It is known, for example, that extracellular molecules like hormones are bound to the membrane and then moved into the cell's interior. At the same time, components destined for the cell surface are assembled within internal organelles and then carried to the outer membrane in small vesicles. As many as ten different membrane-bound organelles within cells participate in the synthesis, secretion, and internalization of surface components.

Embryology staff associate Martin Snider is interested in the role of internal organelles in the establishment and maintenance of surface properties in mammalian cells. He is particularly interested in the function of cell surface receptors. These receptors comprise a large family of glycoproteins that bind to many different types of molecules, including metal carriers, hormones, lipoproteins (a major source of cholesterol), and molecules involved in cellular nutrition. Typically, each receptor functions by entering the cell along with its bound molecule (or ligand). Once inside, the ligand dissociates from the receptor. It is then either used or destroyed. The receptor, meanwhile, returns to the cell surface to repeat the cycle.

Snider is developing a technique that will enable him to detect the movement of receptors inside the cell. This involves altering receptors on the cell surface, so that they can be acted on by various enzymes found in individual internal organelles. If the altered receptors have been acted on by an enzyme specific to a certain organelle, then transport to that organelle has occurred.

This past year, he developed two assays designed to chart the movement of surface molecules to the Golgi complex, an organelle thought to be very important in cell traffic. Each assay tests for the movement of the receptor for transferrin to a particular Golgi region. (Transferrin is the molecule by which all mammalian cells get iron from blood circulation.) He finds that the receptor moves from the cell surface to the distal region of the Golgi (the one closest to the cell surface), but not to the proximal region. However, it appears that passage through the Golgi does not occur each time the receptor enters the cell, since the rate of receptor internalization is more rapid than the rate of transport to the Golgi complex.

The nature of cell surface receptors also intrigues Doug Fambrough, who in 1968 launched an effort to understand the regulatory mechanisms governing the muscle cell surface receptors that respond to acetylcholine, a neurotransmitter that is released by motor nerve cells at nerve-muscle junctions. The work led to the elucidation of several human neuromuscular disorders, such as myasthenia gravis, which is characterized by an abnormal level of receptors at neuromuscular junctions (*Year Books 72, 74, 80*).

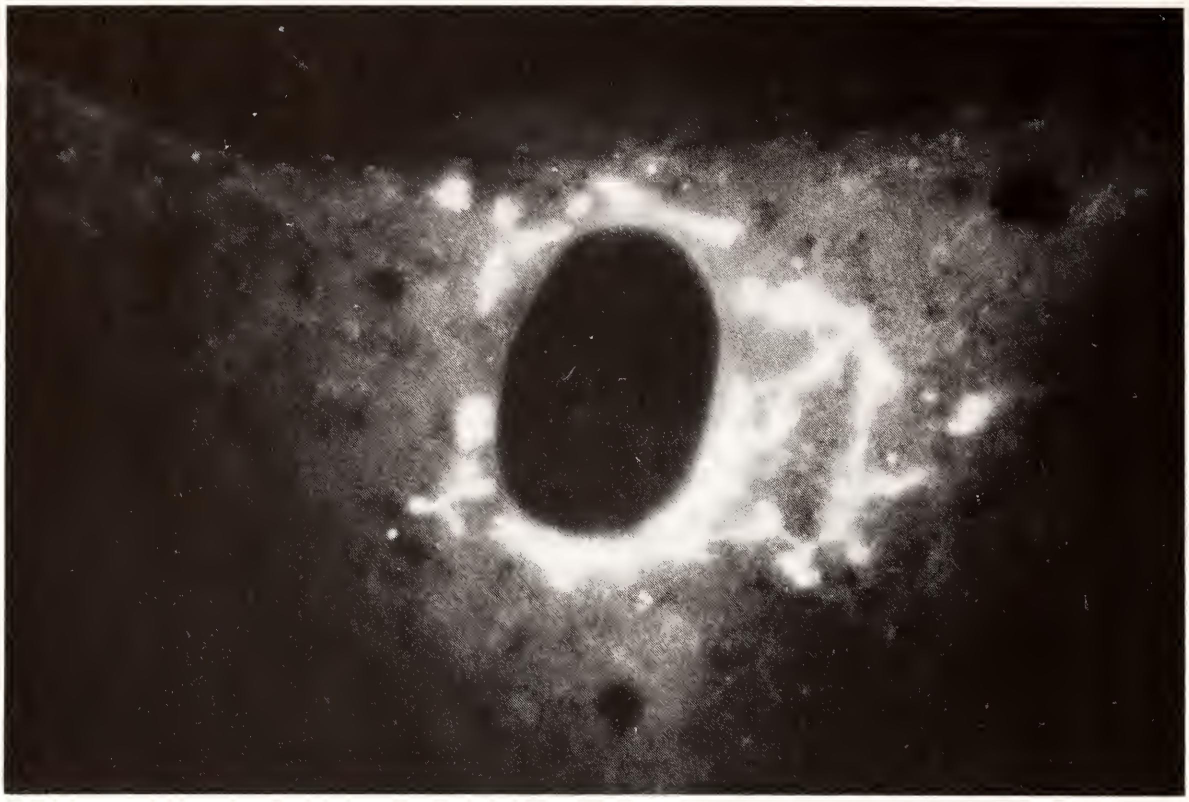


Intracellular organelles involved in secretion and internalization (endocytosis) within mammalian cells. Secreted products originate in the rough endoplasmic reticulum (*Rough ER*), pass through the Golgi complex, and are then released at the cell surface. Extracellular material (shown as solid dots) is internalized by binding to surface receptor glycoproteins (shown as *Y*'s). This bound material is taken into coated vesicles, endosomes, and lysosomes, where it is degraded. Martin Snider's finding that the bound surface receptors can also enter the Golgi complex establishes a connection between the organelles involved in secretion and those involved in endocytosis.

Two years ago, Fambrough and his colleagues changed their focus to the sodium- and potassium-ion stimulated ATPase (known more familiarly as the sodium pump). This molecule, found in the surface membranes of all animal cell types, performs the major work of transporting sodium ions out of, and potassium ions into, cells. The ionic gradients established as a result of this movement are used in generating the large transmembrane voltages characteristic of electrically excitable cells such as neurons and muscle fibers.

Using monoclonal antibodies specific to an antigenic determinant on the outside-facing part of the molecule, Fambrough and his colleagues have mapped the distribution of sodium pumps on several types of cells, and have begun to study the mechanisms regulating the number of sodium pump molecules per cell. They are also determining the sites of insertion of new sodium pumps into the surface membranes of growing neurons. This work may help confirm (or disprove) a major hypothesis of nerve growth—that is, that new surface area is added in the form of new pieces of membrane inserted at the growing tips.

Their data so far suggest that there are several molecular forms of the sodium pump, with different forms occurring on different cells. To analyze the regulatory mechanisms govern-



Fluorescence micrograph of a cultured human skin cell treated with a fluorescent analog of ceramide, a precursor of a type of lipid called a sphingolipid. Richard Pagano and his colleagues find that each type of fluorescent lipid, once introduced inside a cell, labels a different collection of intracellular membranes. Ceramide becomes localized in the Golgi complex (shown in white).

ing sodium pump action, they are currently attempting to clone the genes encoding each subunit of the sodium pump in a variety of cells. According to Fambrough, the results may be relevant in understanding such human diseases as epilepsy and hypertension.

Membrane Lipid Traffic. Meanwhile, in a laboratory down the hall, Richard Pagano and his colleagues are asking questions about the assembly and intracellular transport of lipids. Most scientists studying membranes focus on proteins—their synthesis, metabolism, and transport. Proteins are relatively large, fairly easy to manipulate, and are known to be responsible for many of the major reactions on the cell surface. Lipids, in contrast, have generally been relegated to supporting roles.

Over the last few years, however, Pagano and a handful of other lipid scientists have established that lipids are more than just matrices for proteins. Instead, they are dynamic molecules (some 2,000 different kinds exist) with complicated life cycles of their own. Over the course of several years, Pagano and his colleagues have developed a novel series of lipid analogs that are chemically very similar to their natural counterparts. These artificial molecules, however, carry a fluorescent "tag." Thus, they can be inserted into living cells and their movements visualized by high-resolution fluorescence microscopy. Each fluorescent lipid, as it travels through the cell, labels a different collection of intracellular membranes. Some label only the cell surface membrane, while others label internal membranes such as the endoplasmic reticulum, mitochondria, and Golgi body.

The differential transport of fluorescently tagged lipids is an intriguing phenomenon. But does it reflect the behavior of natural lipids? And, if so, how are the labeling patterns maintained and regulated? This has been the thrust of Pagano's most recent efforts. This year, he and his colleagues found that the metabolism of both fluorescent ceramide and radiolabeled ceramide are virtually identical. (Ceramide is an important precursor to a lipid called sphingolipid, deficiencies in the degradation of which are related to the onset of certain progressive degenerative diseases, such as Tay-Sachs or Niemann-Pick disease.) Their results suggest that the fluorescent tag does not affect the lipid's fate in the normal metabolic pathway.

They have also made progress this year in determining how lipids move across cell membranes. It appears that lipids use different methods to enter a cell. The fluorescent analogs of the lipids phosphatidylcholine and phosphatidylethanolamine, for example, enter in different ways and move to different locations. Phosphatidylcholine moves inward by an endocytic mechanism (i.e., it is engulfed by a fragment of the plasma membrane). Once inside, it accumulates in the Golgi apparatus. Phosphatidylethanolamine, in contrast, goes right through the membrane (i.e., it "flip-flops"), and subsequently labels the mitochondria, nuclear envelope, and endoplasmic reticulum. Yet another lipid, the fluorescently labeled phosphatidic acid, enters cells in an even more remarkable manner. It does not pass through the membrane as a whole molecule, but disassembles, losing its phosphate group (in a process called dephosphorylation) to become diglyceride. In this form, it flip-flops across the membrane so that it faces the interior of the cell, where it can label internal membranes or be rephosphorylated back to phosphatidic acid. In the coming year, Pagano and his colleagues hope to learn more about what controls the intricate patterns of movement of these lipid molecules within the living cell.

Plant Response to Stress: Coping with Extremes

The mechanisms of membrane synthesis and transport that Pagano, Fambrough, and Snider study are examples of the extraordinarily diverse ways that cells have devised to carry out the business of living. Such diversity is also evident in the myriad ways that plants, which are monumental aggregates of cells, have devised to cope with extremes in their environments. At the Department of Plant Biology, a major interdisciplinary effort has been long in progress to study how plants respond to stress. About five years ago, for instance, staff members Olle Björkman and Joseph Berry noted that as the temperature at which certain plants were growing changed dramatically (as they do during the growing season in Death Valley), the capacity of the plants to do photosynthesis at high temperatures increased, while their capacity to photosynthesize at low temperatures declined.

This observation—that the plants have a remarkable capacity to adapt to changing temperatures—might have been sufficient for many ecologists, and the issue dropped. The Carnegie physiologists, however, chose to move into the laboratory. Björkman pursued the question of why a low temperature would decrease photosynthesis. He found that it was related in large part to changes in the level of a particular enzyme in the carbon dioxide fixation pathway (*Year Book 77*, pp. 262–276). Berry asked why higher temperatures increased photosynthetic capacity; he found that the answer was related to complex changes in the chloroplast membranes, which make the membranes more stable at high temperatures (*Year Book 77*, pp. 276–283, and *Year Book 78*, pp. 149–152). The combined study of the whole organism in the field with biochemical and biophysical study of its cellular components yielded far more insight than either of the approaches could have produced alone.

A similar multileveled approach is currently being pursued in a collaborative venture between members of Berry's lab and molecular biologist Arthur Grossman. About eight years ago, Berry and his colleagues discovered that the unicellular algae *Chlamydomonas reinhardtii* could develop the capacity to pump inorganic carbon into its cells against an opposing concentration gradient if carbon dioxide (CO_2) was deficient in its environment (*Year Book 75*, pp. 423–433). In nature, this event can occur in large lakes, where billions of algae plants spread out in large mats just under the water's surface. CO_2 levels may be high at night, but during the day, when the plants are performing photosynthesis, competition for CO_2 may be fierce enough to limit alga function; what *is* present, however, is bicarbonate (HCO_3^-). Bicarbonate normally can not pass through the membrane. But under stressful conditions, this algae (and other algal species, it was later discovered) can quickly transform itself to pump HCO_3^- in past the membrane barrier. Once inside (where it can reach a concentration far beyond that present in the surrounding water), it is converted to carbon dioxide.

Last year, John Coleman, a postdoctoral fellow working in Berry's lab, joined forces with molecular biologist Arthur Grossman to study the nature of the response at the cellular level. Coleman and Grossman artificially induced the response by transferring algae from environments high in HCO_3^- concentration to those low in HCO_3^- concentration. The transfer effected a dramatic biochemical change. Just outside the plasma membrane but inside the cell wall there appeared an enzyme (carbonic anhydrase), which they found facilitated the HCO_3^- exchange reaction. This year, Grossman is investigating—on the molecular level—the precise role this enzyme plays in the bicarbonate-concentrating mechanism.

Grossman is also pursuing similar studies on algae in environments limited in sulfur. His preliminary results show that plant cells exposed to environments lacking sulfur evidence changes comparable to those induced by the HCO_3^- reaction. For instance, he has found that at least one of the enzymes involved in sulfur metabolism—an enzyme that, like carbonic anhydrase, is found just outside the cell membrane—appears to undergo changes much like those he noticed in carbonic anhydrase. Studies like these are important in understanding plant response to stress at the biochemical level. As well, they could lead to a general model explaining how plants respond—at both the cellular and genetic levels—to nutrient deprivation.

Photoinhibition. Olle Björkman has for years been fascinated with the mechanisms plants devise to cope with extremes in their environment, such as extremes of light, temperature, or dryness. Last year, this interest carried him to Australia, where he spent six months studying the mangroves of coastal salt marshes. Mangroves grow under conditions that would kill most other plants. The temperature is high, the light is strong, and the plants often stand in full-strength seawater, which produces abnormally high salt concentrations in the leaves. Not surprisingly, the plants don't survive unscathed. Comparing salt-stressed mangroves with other plants growing in nonstressed sites nearby, Björkman found that stressed mangrove leaves were severely damaged by full sunlight, showing serious photoinhibition (diminished photosynthetic capacity). High salt seemingly predisposes the photosynthetic apparatus to photoinhibition.

To understand this phenomenon more thoroughly, Björkman moved from the field to the laboratory. The greenhouses at the Department of Plant Biology are now filled with mangroves, and together with visiting fellow Barbara Demmig, Björkman is beginning to do mechanistic studies on these plants at the physiological and eventually the biochemical levels.

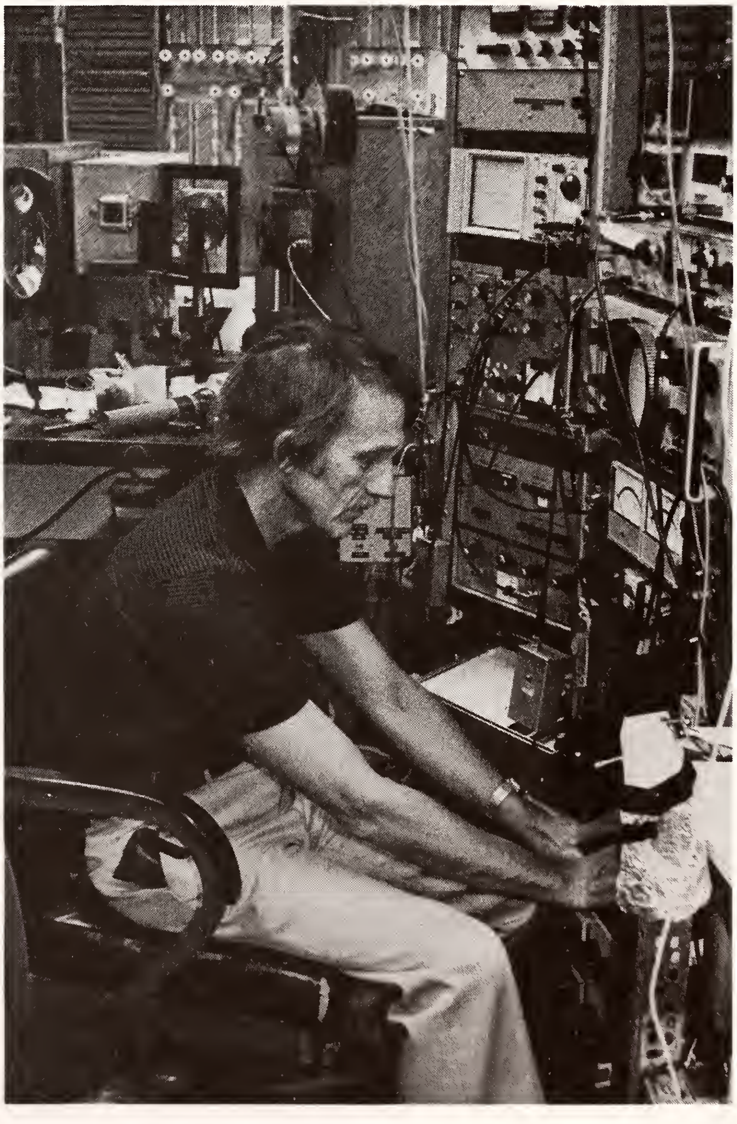
Meanwhile, with Berry and senior fellow Dennis Greer, Björkman is continuing photoinhibition studies on other plants, such as the chilling-sensitive bean. The group has shown that recovery from photoinhibition requires complex processes of protein synthesis. These processes are strongly inhibited at chilling temperatures. And, indeed, bean plants show no recovery from photoinhibition at temperatures less than about 15°C. The failure of the recovery system could well account, at least partially, for the chilling sensitivity of this species.

In related studies, staff member David Fork has continued his detailed explorations into photoinhibition in algae. He is particularly interested in learning how algae adjust their photosynthetic apparatus to stress. How do certain algae, he asks, dissipate excess light energy when the temperature is too low or too high, the salt concentration too high, or in a system depleted in calcium? (Calcium is needed for the normal functioning of one of the two photosystems involved in photosynthesis.) Fork and his colleagues have developed very sensitive probes for heat damage, cold damage, and for the monitoring of energy redistribution during stress. Previously, they demonstrated that the photosynthetic apparatus of the red alga *Porphyra perforata* has at least four ways of coping with light imbalance (*Year Book 81*, pp. 45–58; *Year Book 82*, pp. 55–65). This year they discovered another mechanism that algae use for coping with stress. Some algae, it appears, can dissipate excess energy under stress, be it heat, salt, or calcium depletion, through the fluorescence of a nonchlorophyll light-gathering pigment. (Fluorescence is one of three ways that a molecule or atom expends the excitation energy induced by photons of light. The other two are loss through heat and loss by the initiation of a chemical reaction. Photosynthesis occurs as a result of the latter.)

Fork's studies are of importance in understanding the detailed ways by which plants cope with stress at the biophysical level. Two members of Joseph Berry's laboratory, in contrast, are examining how plants adjust their photosynthetic apparatus (in this case, physiological responses which control gas-exchange) to stressful environmental conditions at the level of the whole plant.

Berry's colleagues—predoctoral fellow J. Timothy Ball and postdoctoral fellow Keith Mott—have used instrumentation developed by Ball for making very precise measurements of gas exchange. When a leaf opens its stomatal pores to take in carbon dioxide from the atmosphere to do photosynthesis, it

Olle Björkman inspects Australian mangrove plants in growth chambers at the Department of Plant Biology. He and Barbara Demmig hope to learn how the high-salt environment of Australian marshes predisposes the plants to photoinhibition.



Plant Biology staff member David Fork collects fluorescence spectra for biophysical studies on stress.

simultaneously creates an opening for water loss. The regulation of this gas exchange process is of critical importance to the plant, for too much water loss can waste a limiting resource. Ball and Mott have succeeded in separating stomata responses to limited water availability from those to limited carbon dioxide. With carbon dioxide held constant, they found that it is the relative humidity gradient from inside the leaf to the outside, rather than the rate of water loss, that is sensed by the mechanism controlling stomatal aperture.

Ball and Mott also examined a standing hypothesis stating that the stomatal aperture is controlled by a constant ratio of carbon dioxide inside the leaf to that outside. This provides a good empirical basis to predict stomatal aperture from knowledge of the biochemical responses of the leaf mesophyll. However, Ball and Mott show that this hypothesis is not correct. If it were, it should be possible to manipulate independently the stomata on separate sides of a leaf by imposing different CO_2 concentrations on each side. The two scientists show that stomatal responses in such experiments are inconsistent with the constant-ratio hypothesis.

Meanwhile, Mott and Jeffrey Seemann, also in Berry's lab, have been studying conditions under which the key enzyme in carbon dioxide fixation—the previously mentioned ribulose bisphosphate carboxylase, or RuBP—is kept active in leaves. In laboratory experiments, it is not possible to keep RuBP of spinach leaves fully active under conditions thought to exist within the photosynthetic organelle (the chloroplast), even though photosynthesis in the intact leaf requires full activation. Mott finds, however, that the enzyme can be kept fully activated in a more-alkaline test-tube medium (high pH). Thus, he is currently reexamining the natural chloroplast environment, particularly the pH.

In related work, Seemann finds that in certain other plants (soybeans, for example), RuBP may be inactive in the dark and will activate only when the leaves have received light. While inactive RuBP extracted from leaves kept in darkness responds like the spinach RuBP to high pH in the test tube, it still does not carry out the CO_2 fixation reaction effectively. Activation, at least in soybeans, must then involve some other components not required in spinach.

The Collection of Human Embryos

> Perhaps we are now ready to heed the challenges of experimental embryologists, albeit on our own terms. They have warned the molecular biologist repeatedly about the complexity of developmental phenomena and the

need to study at least whole cells and tissues, if not the entire organism.

Donald D. Brown
1984

An understanding of how cells work, how they communicate with one another, how the genes generate signals to the cell membranes, and how the membranes, in turn, influence the genes, is the goal of much of the research in biology—both in animals and in plants—at the Carnegie Institution. Such an understanding promises to lead to elucidation of the factors involved in the development and growth of an organism, particularly in the development of the human embryo.

It was to study human embryology that the Department of Embryology was orginally founded in 1914. By mid-century, however, attention at the Department began to shift away from the whole embryo to detailed studies of its component parts—individual cells and genes. In 1973, the Department passed its renowned human embryo collection to the University of California. There, at the Carnegie Laboratories of Embryology, study of these embryos continues under the direction of Department of Embryology research associate Ronan O'Rahilly.

It is perhaps fitting that we close our summary of the biological sciences with a brief description of the year's research in human embryology. As Brown expresses in the above quote, molecular biologists can no longer remain isolated from the complexities of development, for life is a process, and more, a continuum of events. Nowhere is this complexity and continuum more aptly illustrated than in a developing human embryo.

Development of the Nervous System. Ronan O'Rahilly and Fabiola Müller continued their study of the developing nervous system in staged human embryos. Their results on the development of the human brain at stages 8 and 9 have appeared, and they are investigating stage 10 (22 days) in embryos 2.0–3.5 mm in length. Precise graphic reconstructions are being prepared. In collaboration with Grover M. Hutchins and G. William Moore (both of Johns Hopkins Medical School), data relating to the first five prenatal weeks (stages 7–15) have been filed into a computer. The data include 100 key developmental features, and the filing method clarifies the sequence and timing of developmental events, as well as variations.

O'Rahilly and Müller's detailed study of the developing hypoglossal nerve also appeared recently. It included an investigation of the occipital somites—segmental units that become incorporated into the base of the skull, the posterior part of which develops like a vertebra according to Goethe's vertebral theory of the skull. The occipital somites also give rise to the musculature of the tongue, the origin of which was traced by means of graphic reconstructions.

Inquiries concerning the human embryo collection, as well as requests for publication permission, should be addressed to Ronan O'Rahilly, Carnegie Laboratories of Embryology, California Primate Research Center, Davis, California 95616.

The Physical Sciences

Purely observational science would be nothing but data gathering, were it not directed and integrated by a continual striving to understand what it all means. A considerable portion of our scientific effort is therefore theoretical, recognizing that a healthy science is characterized by an active interplay between theory, observation, and experiment.

George W. Wetherill
Director, Department of Terrestrial Magnetism
July 1984

Experimental verification and demonstration of the complex rock-forming processes within the earth deduced primarily from observations on the end products, the rocks themselves, has been the hallmark of the Geophysical Laboratory.

Hatten S. Yoder, Jr.
Director, Geophysical Laboratory
1984

Much has changed in observational astronomy from the times of George Ellery Hale. But the combination of intellectual rigor and curiosity about the universe among practitioners of this lively field remains timeless.

George W. Preston
Director, Mount Wilson and Las Campanas Observatories
1984

The Carnegie Institution's three principal departments in the physical sciences—the Geophysical Laboratory, the Department of Terrestrial Magnetism (DTM), and the Mount Wilson and Las Campanas Observatories (founded as the Mount Wilson Observatory)—have been in continuous existence from the Institution's first decade. Over the years, the three took leadership in separate realms—in experimental geology, in observational astronomy, and in the remarkable range of ventures that has marked the history of DTM.

Today, Carnegie researchers continue to work at the leading edges of various subdisciplines of the physical sciences. But along with this, there is unmistakable evidence of leadership of a different kind. At the front of this essay, we took note of a present-day trend toward synthesis in the earth sciences and astronomy—a growing-together of the various subdisciplines, indeed a growing-together of the earth sciences and astronomy themselves. Carnegie Institution scientists are working—in a number of examples—at the very forefront of this development.

Our review of this year's work in the physical sciences will offer many examples of linkages and crossings-over at the level of the traditional subdiscipline. Distinctions between "stellar" and "galactic" studies are blurring, for example, as capabilities improve for observing individual stars and star clusters in galaxies beyond our own. Similarly, solar and stellar physics are coming together in the form of "solar-stellar physics"—the study of nearby stars in the context of what is known about our Sun, and vice versa—a field being pioneered at Mount Wilson. Meanwhile at DTM and the Geophysical Laboratory, the work of the petrologists, mineralogists, and crystallographers interested in the Earth's upper regions is being increasingly influenced by the work of those seismologists, geochemists, and high-pressure and high-temperature experimentalists who engage in explorations of deep-Earth processes, which may fundamentally affect the crust. Theoreticians at DTM, for example, are building a computer-based model for the structure and behavior of the mantle, one that brings together thermodynamics and fluid mechanics theory, seismological data, and geochemical analyses of material raised rapidly from the mantle.

The earth sciences and astronomy meet most directly in the search to understand the formation of the Earth 4.5 billion years ago within a primordial solar nebula. Our knowledge of this event will come from—and will in turn influence—our understanding of the processes of galaxy and star formation on the one hand and the evolution of earth and planetary interiors on the other. Astronomers and earth scientists alike were interested in the late-1984 observations (at Carnegie's Irénée du Pont telescope on Las Campanas) indicating the existence of an early solar system around the nearby star β Pictoris; further observations may greatly contribute to understanding our own planetary system in its youth. An elegant example of cross-disciplinary inquiry came this year in an experimental investigation at the Geophysical Laboratory. The researchers—earth scientists by training and career—conducted experiments at temperatures and pressures similar to those believed to have existed in the solar nebula during its condensation to form the terrestrial planets.

In one of the quotations opening this section, DTM's director, George Wetherill, writes that a healthy science is characterized by active interplay among theory, observation, and experiment. A major stride in any of these realms must influence, and must be influenced by, continuing work in the other two. All three realms—theory, observation, and experiment—are manifest in the recent strengths of the Carnegie departments: the predominant emphasis is experimental at the Geophysical Laboratory, theoretical and observational at DTM, observational at the Mount Wilson and Las Campanas Observatories. New techniques of research and new targets of investigation have come and gone, but the broadest common goal linking the three—the search for understanding of the Earth and universe—has been unchanging.

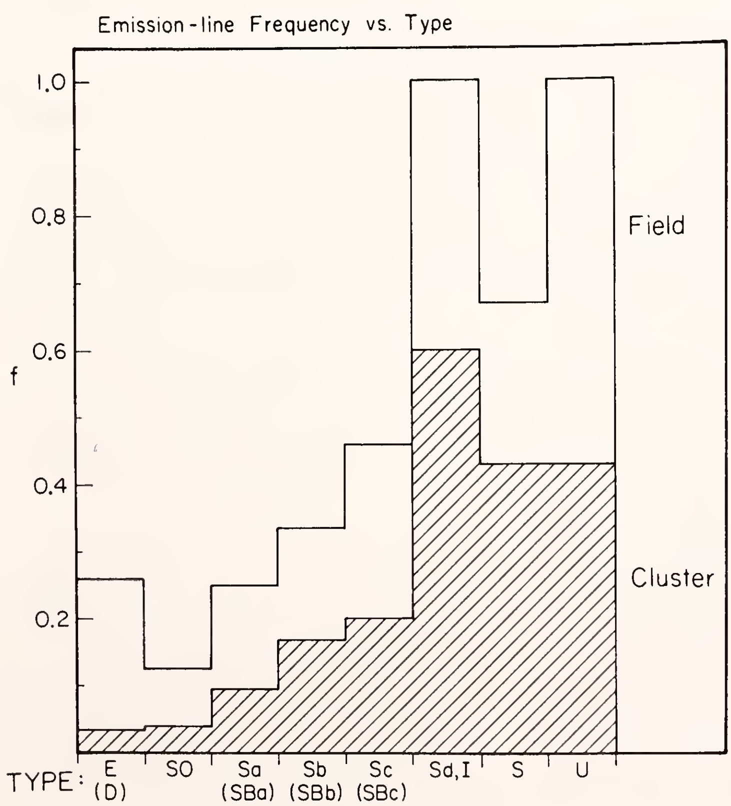
Turning Back the Cosmic Clock

> As the pieces continue to come together, we begin to appreciate that we live in a very dynamic universe, and that the processes of galaxy formation and evolution are still very much in evidence more than ten billion years after the Big Bang.
>
> Alan Dressler
> Mount Wilson and Las Campanas Observatories
> July 1984

Astronomy is unique among the sciences in that much of nature's past is directly observable. Because light travels at a finite speed, the information that arrives on Earth from distant objects has been in transit for millions or even billions of years. Observations of distant galaxies thus provide a view of the universe as it used to be, and give astronomers a valuable means for studying how galaxies have evolved over time. Thanks to enormous gains in the last ten years in the efficiencies of electronic detectors, it is possible, but by no means easy, to obtain spectra of galaxies up to ten billion light years distant—more than halfway back in time to the origin of the present universe.

Staff member Alan Dressler of the Mount Wilson and Las Campanas Observatories, in a long-term continuing project, is obtaining optical spectra of galaxies in distant clusters. By comparing emission-line and absorption-line characteristics of these galaxies—seen as they were about five billion years ago—with those of nearby galaxies, Dressler hopes to determine whether cluster galaxies have changed in their star-formation and nuclear-emission activity. Using an extremely sensitive Charge-Coupled Device (CCD) system built by James E. Gunn of Princeton, Dressler and Gunn have obtained spectra for sixty-odd galaxies in two distant clusters. In both clusters, there is evidence that star formation was taking place and/or that actively emitting galactic nuclei were present to a greater extent than in present-day galaxies. Since the distant galaxies are seen at ages only about 30 percent younger than nearby ones, it seems likely that even greater changes may have occurred over the full age of the universe.

Dressler, Gunn, and Donald P. Schneider of Caltech interpret these observations in relation to changes to the galaxy environments caused by the falling together of galaxies into dense clusters. Similar environmental influences have been further highlighted in a new study by three Observatories' sci-



Emission-line characteristics of galaxies, from an analysis of over a thousand nearby cluster galaxies and noncluster galaxies, from spectra obtained by Carnegie astronomers Alan Dressler and Stephen Shectman at the du Pont telescope. Relatively strong emission is seen in the central regions of 31% of the noncluster (field) galaxies but in only 7% of the cluster galaxies. The above histogram illustrates that differences in morphological types cannot fully explain this effect, as emission-line galaxies are less frequent in cluster galaxies of all morphological types.

entists. Dressler, research associate Ian Thompson, and staff member Stephen Shectman show that strong star formation and nuclear activity are four times less common in nearby cluster galaxies than in nearby noncluster, or field, galaxies. (Accelerated rates of star formation early in a cluster's history will hasten the exhaustion of gas, with the result that galaxies in clusters may reach a dormant state before field galaxies.) Dressler concludes: "With more observations of such nearby galaxies, relatively distant clusters, and when possible, extremely distant clusters, the relative importance of nature versus nurture for galaxy formation will be better understood."

Systematic observations of several hundred very faint, noncluster galaxies have been undertaken by David Koo of the Department of Terrestrial Magnetism and Richard Kron of Yerkes Observatory. Employing the 4-meter telescope at the Kitt Peak National Observatory, Koo and Kron (like Dressler and Gunn) are able to obtain spectroscopic observations of about ten faint objects simultaneously (thereby saving precious telescope time). They are observing objects as faint as about magnitude 22.5—ten times fainter than in any previous survey of field galaxies. Their preliminary analyses indicate that the rate of star formation in noncluster galaxies—as in the cluster galaxies studied by Dressler and Gunn—was greater in the past than now. The Koo-Kron data are also being used to study the evolution of large-scale clustering and regions in space largely void of galaxies.

Further clues to the evolution of galaxies are coming from objects that emit strongly at the radio frequencies. For several years, Rogier Windhorst at Leiden University has been developing deep radio maps, taking advantage of the sensitivity of the Westerbork radio telescope in The Netherlands. Windhorst collaborated in several studies with Koo and Kron, who had been obtaining faint optical observations in areas of the sky also of interest to Windhorst. The collaboration led to the discovery of faint radio sources, many of which when optically identified turned out to be very blue, faint galaxies, whose images look like those of interacting or merging galaxies. These faint blue galaxies appear to represent a new population of objects, quite unlike the giant red ellipticals usually found from bright radio sources.

Windhorst became a Carnegie Fellow at the Observatories in early 1984. He is working to develop a technique for finding clusters of galaxies at great distances by means of surveys with the Westerbork telescope and the Very Large Array (VLA) radio telescope at Socorro, New Mexico. At the faint detection levels now obtainable at the VLA, it is possible to locate extremely distant areas having high density of faint galaxies. When identified at the optical telescopes, these faint galaxies may become useful targets for redshift measurements as a means of determining their distances from us.

Quasar Studies. Another means of probing the early universe is the study of quasars, which are generally (though not universally) believed to be emitters of enormous amounts of energy from the nuclear regions of galaxies. Given their high luminosity, many quasars can be detected beyond even ten billion light years. By studying very faint quasars, Koo and Kron find that quasars were much more luminous in the distant past than they are today; further—contrary to the generally accepted view—their results suggest that quasars were *less* numerous in the early universe than now.

Although slow to yield their secrets, quasars are gradually bowing to the persistence of investigators worldwide. Carnegie and Caltech astronomers, for example, in varied studies often employing observations at Carnegie's 2.5-meter du Pont telescope at Las Campanas, Chile, or at Caltech's 5-meter Hale instrument at Palomar, California, are working to understand quasar emission mechanisms.

Sensitive observations by Alexei Filippenko and collaborators at Caltech have strengthened the idea that the weakly emitting nuclei of certain nearby galaxies are low-luminosity counterparts of more-distant quasars. Related studies suggest that such nuclear activity may be present in a significant fraction of all nearby galaxies, and may be the result of gas accretion by black holes at the galactic centers. Meanwhile, Carnegie's Alan Dressler's kinematical study of M31 and M32—two of the galaxies nearest our own—suggests the presence of black holes (10^6–10^7 solar masses) in both. It thus appears that a crucial element (i.e., black holes) needed for active nuclei may be present in all galaxies and, indeed, that many now-normal galaxies were themselves quasars in the distant past.

Earlier work by Todd Boroson of the Observatories and J. B. Oke of Caltech showed that some quasars are surrounded by a faint fuzz having the spectrum of stars—strong evidence that quasars indeed reside in distant galaxies. Boroson and Oke's expanded sample of 24 objects now reveals a division into two classes. In one group, little or no emission is seen in the fuzz; Boroson and Oke believe that a dense accretion disk is absorbing the radiation emitted by the nuclear source. In the other group, emission is seen, they argue, when the nuclear region is surrounded by less-dense clouds, chaotically distributed and moving at high velocity; radiation from the central source ionizes the surrounding gas.

Just as quasars seem to be declining in luminosity, galaxies, too, in their star-forming activity, may be "running down." Dressler writes that it is tempting to regard both decay processes as results of the ever-decreasing supply of gas available to galaxies—for making stars in one case and for feeding central black holes in the other. A fuller understanding of this connection requires greater knowledge of the gas and galaxy densities of the early universe.

As it happens, the best way to investigate this question is by means of quasar emissions. One group of researchers, primarily from Caltech, has been examining quasar spectra to study absorption lines caused, they believe, by material lying between the quasars and ourselves. They suggest that heavy-element absorption lines arise in the outskirts of intervening galaxies, while the hydrogen absorption lines originate in intervening gas clouds. Both types of absorbers—the galaxies and the clouds—appear to have been more numerous in the past than in recent times.

The sizes of gas clouds at different epochs can be investigated by studying the spectra of close pairs of quasars to see if they have common absorption lines, caused by a single cloud. Several investigators using the Reticon spectrometer at the du Pont telescope at Las Campanas recently uncovered three quasar pairs having separations of less than one arc-minute. These objects should be valuable in future probes of the intervening gas material.

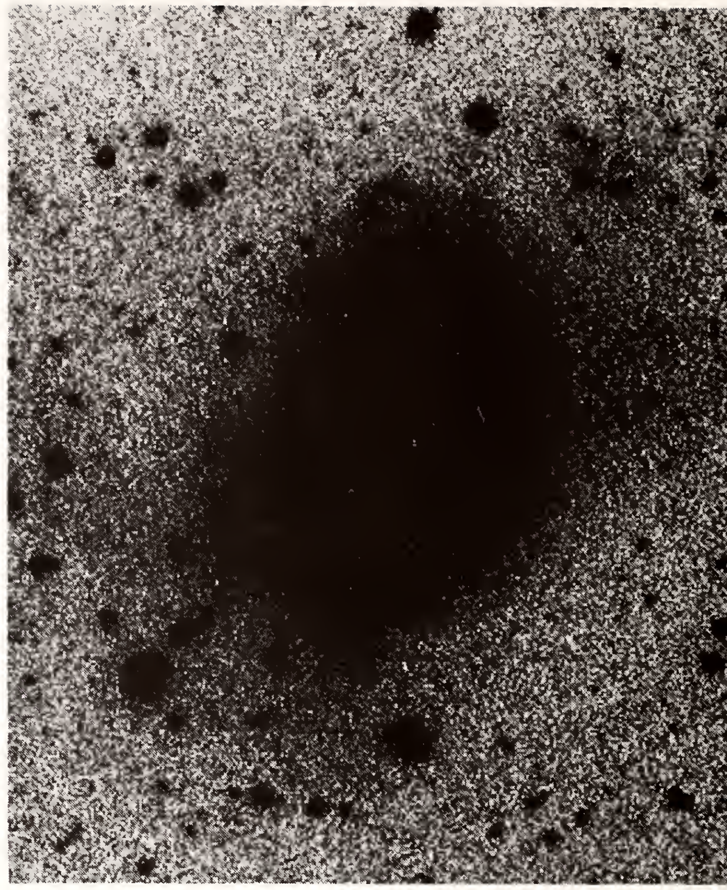
Galaxies in Collision. Until recently, interactions among galaxies were considered to be of little importance in the study of galaxy evolution. The huge distances between galaxies suggested that encounters between them are probably rare; further, since galaxies are mostly empty space, it was thought that even interpenetrating collisions would produce only small changes to the configurations of the original galaxies.

These ideas are changing fast. Astronomers now widely believe that the initial positions and velocities of galaxies were such that encounters have occurred far more frequently than randomly—indeed, that galaxies may have been "born to merge." Computer simulations have shown that the collision and merger of gas-rich "protogalaxies" can result in the formation of new galaxies, and that such collisions are scarcely benign. The gravitational fields of colliding galaxies are so vastly altered as to disorganize completely the original forms of the galaxies, and the compression of impacting gas clouds may trigger huge episodes of star formation which may then dominate the appearance of the product galaxy for a billion years.

Not surprisingly then, galaxies with unusual or disturbed forms—most likely the results of recent galaxy encounters and mergers—have become widespread targets for study. At the Department of Terrestrial Magnetism, François Schweizer and W. Kent Ford are continuing their observational work on colliding and merging galaxies, and on how certain collisions can result in the formation of elliptical galaxies. Their work employs new digital image-enhancement techniques. Complementary numerical work by DTM postdoctoral fellow Kirk Borne on the extensive transfer of kinetic energy of colliding galaxies to disordered motions of the constituent stars, further predicts that galaxy mergers are not rare.

Such insights have been refined as the result of recent work related to merging systems by Carnegie Fellow Thomas Steiman-Cameron at the Observatories. Steiman-Cameron has continued his Ph.D. studies modeling gas disks (representing galaxies) under the influence of irregular gravitational potentials. His theoretical models—the first to treat viscous forces in a rigorous self-contained way—reveal that the settling times for perturbed disks are much longer than those indicated in earlier calculations. Steiman-Cameron concludes that settled-disk (spiral) galaxies seen today must, in general, be very old, and—since only a small percentage of galaxies seen today are unsettled—that occasions where a galaxy encounters or captures a neighbor are less frequent than might otherwise be supposed. Although it is clear that galaxy interactions are far more important than was once believed, it remains difficult to pin down how often mergers occur: the average number of encounters already experienced by presently observable galaxies to date could be anywhere from one to ten.

Galaxies having rings of gas or stars encircling the poles rather than the galactic equator have been a favorite subject of study for Paul Schechter at the Observatories. Schechter believes that many such systems are results of merging galaxies, where the gas has yet to settle into an equatorial disk, as Steiman-Cameron's models predict; no single line of argument provides positive proof, but evidence continues to accumulate in support of Schechter's view. The peculiar galaxy MCG 5-7-1, cataloged by Halton Arp of the Observatories and Barry Madore of the University of Toronto, is one of roughly a dozen identified as S0 galaxies with polar rings (*Year Book 81*, pp. 566–569; *Year Book 82*, pp. 627–630). Schechter and Jerome Kristian of the Observatories and Jeremy Mould of Caltech have obtained deep images of this object with a CCD television-type detector on the du Pont telescope at Las Campanas.



Two photographs produced from a single frame of the polar-ring galaxy MCG 5-7-1. The view at right was produced at twice the contrast of the one at left, which also serves as frontispiece to this book. Low-surface-brightness material is distributed roughly in the shape of the main body but extends much farther from the center. The investigators suggest that this envelope is the stellar debris from a gas-rich galaxy disrupted in a merger with a larger S0 galaxy; gas from the smaller system then settled into the polar ring and formed a new generation of stars.

These pictures provide detailed information about the encircling ring and also reveal a faint, asymmetrical envelope extending well beyond the main body of the galaxy. The investigators offer the hypothesis that this system is the product of a merger between an S0 galaxy and a smaller gas-rich galaxy, that the smaller system was tidally disrupted, and that its stellar debris spread out to form the faint envelope. Gas from the smaller system then settled into the observed ring and formed a new generation of stars.

Schweizer at DTM strongly agrees that the polar ring configuration is a likely consequence of galactic collision. He and Bradley Whitmore—a former fellow at DTM now at the Space Telescope Science Institute—are using a number of such galaxies as dynamical probes of the nonluminous region outside the visible spiral disk. The stars of the polar ring are "test particles"—used by the investigators to measure the gravity field perpendicular to the plane of the disk. The measurements show that the "missing mass" evidenced in earlier DTM studies of spiral-galaxy dynamics is distributed more nearly spherically than flat, and is comparable to the mass of the visible disk itself.

Evidence that galaxy interactions play a major role in star formation has come from the Infrared Astronomical Satellite, IRAS. Because galaxies with very vigorous star formation release at least as much energy in the far infrared as in the optical, IRAS has provided a means to identify galaxies having either unusually vigorous star formation or active nuclei. Various investigators including Eric Persson of the Observatories have made follow-up spectroscopic observations of IRAS sources at the Hale telescope at Palomar. They have detected optical emission lines that, in the vast majority of cases, indicate enormous amounts of star formation, thus ruling out very active galactic nuclei as the cause of the intense emissions. Star-formation rates as high as 400 solar masses per year have been found—about 100 times that of the galaxy M82, which from other evidence is believed to be undergoing a strong episode of star formation, and 400 times that of the Milky Way. Furthermore, Carol J. Lonsdale of Jet Propulsion Laboratory, Keith Matthews of Caltech, and Persson have found that many of the galaxies identified by IRAS are interacting pairs—a result supporting the suspicion that interactions trigger bursts of star formation. Still other infrared observations with the Hale telescope of known interacting galaxies point to the same result.

Today's students of the distant realms live in an exciting time. Their ability to observe very faint, very distant objects, along with the vastly improved capabilities at the radio and infrared wavelengths, are enabling astronomers to assemble a picture of an evolving universe—a universe still very much in the process of change. In this picture, the galaxies are not isolated islands but instead interact with one another, altering their own forms and changing the large-scale structure of the universe. We next turn to a parallel development in astronomy—how new capabilities for studying objects closer to ourselves (nearby galaxies, star clusters, and regions of star formation, for example) are bringing fresh understanding of how stars, and the galaxies which they largely define, are formed and evolve.

How Stars and Galaxies Form: Challenges to Past Views?

More than fifty years have passed since the confirmation by Edwin Hubble at Mount Wilson that many of the "nebulae"—fuzzy patches of light faintly visible with telescopes of moderate power—were in reality systems of stars beyond our own

Milky Way Galaxy. Later, Hubble and colleague Milton Humason showed that these galaxies were moving away from one another at speeds proportional to their distances.

Since Hubble's time, galactic astronomers, favored by ever more powerful telescopes and by superior observing sites like those in Chile, have looked deeper and deeper into the universe, with ever-finer detail. Galaxies have been widely analyzed, and the distance-time relation of Hubble's expanding universe has been thoroughly reevaluated. (Allan Sandage, whose career at Mount Wilson overlapped with Hubble's, now calculates the time since the start of the universe's expansion to be about 18 billion years—about ten times more than the value first calculated by Hubble.)

Meanwhile, stellar astronomers continued along the paths opened late in the 19th century with the invention of the spectrograph. By breaking the light from individual stars of our Galaxy into its component wavelengths and by studying the resulting spectra, these scholars have come to understand the life histories of many typical stars.

The spectrographic methods that were the life's blood of the stellar astronomers, however, were of limited use in observing other galaxies. Although it was possible to obtain spectra across a whole galaxy, the resolution and light-gathering power of telescopes were insufficient to permit spectrographic measurements of individual stars and star clusters in external galaxies. It has been simply impossible to study stars in other galaxies with anything like the detail possible in studying the Milky Way. Partly for this reason, stellar and galactic astronomy have remained largely separate subdisciplines, and basic understanding of how galaxies form and evolve has been slow in coming.

Today, new electronic detectors, like the Reticon and Charge-Coupled Device (CCD) systems designed and built by Carnegie Institution's Stephen Shectman, mounted on the spectrographs of the larger telescopes, permit spectrographic observations of individual stars in the globular clusters of our Galaxy and integrated spectra of globular clusters in nearby galaxies. Varied data can thus be acquired on the chemical compositions, structures, and internal motions of the globulars.

Globular Cluster Studies. The globular clusters are like fossils. Many of these spheroidal collections of stars are as old as (or, perhaps, older than) the galaxies in which they reside. In their spectral lines are records of the proportions of the heavy elements—carbon, nitrogen, oxygen, and iron—present at the time and place of globular (and galaxy) formation. Globular cluster ages can be estimated from the colors and magnitudes of their stars (*Year Book 82*, pp. 619–624). Knowing chemical abundances and ages of a nearby galaxy's globulars, then, astronomers can attempt to trace the chemical-enrichment history of the galaxy and its ancestral material. From observations of globular cluster populations in several galaxies, then, it is possible to explore correlations linking differences in the globular populations with other galactic properties.

An ultimate goal of such investigations is to revise existing models of galaxy formation and evolution. The generally accepted view, now under serious challenge, has been that a typical galaxy was formed from a large cloud of gas and dust which underwent a single gradual collapse under its own weight.

Leonard Searle of the Mount Wilson and Las Campanas Observatories has undertaken a long-term investigation of the chemical-enrichment history of galaxies in our Local Group. Several years ago, Searle and Robert Zinn of Yale University measured "metal abundances"—i.e., composition in elements heavier than helium and hydrogen—in globulars of our Galaxy (*Year Book 76*, pp. 144–145). They found a bimodal distribution, as follows. Metal-poor globulars, a tenfold majority, occupy a vast and relatively thinly populated sphere, or "halo," outside the disk and nuclear bulge of the Galaxy; the rarer, metal-rich globulars reside close to the Galactic center. Searle found little or no evidence, however, that metal abundance varies smoothly as a function of distance from the Galactic center. This result failed to support the old view that when the primordial cloud gradually collapsed, metal abundance in stars gradually increased; instead, it suggested that the collapse may have been episodic or even chaotic, the metal-rich globulars perhaps forming in a separate event.

New measurements by Allan Sandage and volunteer research assistant Paul Roques have now shown that at least one of these metal-rich globulars, NGC 6171, is as old as the metal-poor systems—about 17 billion years—and therefore was not formed in a separate event. Thus, it seems possible that *all* the globular clusters in our Galaxy may have formed very early in the Galaxy's history. Such evolution is to be contrasted with that of a nearby galaxy, the Large Magellanic Cloud (LMC), where Searle and Horace Smith, a former Carnegie Fellow now at Michigan State University, found many globular clusters that formed as recently as a few billion years ago (*Year Book 80*, pp. 608–610).

It seems clear that galaxies can differ greatly in their chemical-enrichment histories. Our Milky Way, a typical galaxy in

Outside the offices of the Mount Wilson and Las Campanas Observatories, Pasadena, 30 April 1984. G. Marcy, H. Crist, H. Arp, R. Georgen, A. Dressler, A. Sandage, E. Persson, H. Snodgrass, D. Duncan, E. Snoddy, T. Steiman-Cameron, G. Preston, S. Heathcote, L. Searle, R. Howard, M. Anderson, O. C. Wilson, J. Gantz, N. Suntzeff, J. Boyden, D. Sahlin, E. Vasquez, J. Adkins, P. Gilman, S. Knapp, N. Breski, J. Todd, L. Woodard, S. Padilla, C. Hartrich, C. Friswold, H. Babcock.

size, mass, and luminosity, appears to have reached a metal abundance near the present (solar) value in the first 1–2 billion years of its 18-billion-year lifetime, while the smaller LMC remained very metal poor until a few billion years ago. This difference may simply reflect the longer time required for collapse and formation of the less-dense LMC system. On the other hand, Searle's data clearly show that old globulars do exist in the LMC, and that some are probably as old as any in our Galaxy. The LMC therefore must have formed at about the same time as our Galaxy, but it experienced a vigorous episode of star formation only five billion years ago.

Applying such methods to the study of other nearby galaxies promises to show how star formation and chemical enrichment proceeded in galaxies of varied mass and size. In *Year Book 82* (pp. 622–624), Searle presented the results of a photometric study of 100 globular clusters in M31, a large nearby spiral galaxy similar to our own. Searle found that nearly all the globulars in M31 are old systems like the globulars of our Galaxy, unlike the many young clusters in the Magellanic Clouds. This result provides further evidence that relatively large galaxies like our own, early in their histories, experienced large amounts of star formation and accompanying synthesis of heavy elements, thereby raising average metal abundance to the present values. The process appears to have been even more pronounced in M31: a third of the globular clusters in M31 are metal rich contrasted with only a tenth in our Galaxy.

This year Searle and colleagues completed a spectroscopic study to determine the motions of these same M31 globulars, in hopes of exploring correlations between motions and chemical composition. The observations were obtained by Searle and Stephen Shectman using Shectman's Reticon detector on the Cassegrain spectrograph of the Palomar 5-meter telescope; the observations have been analyzed by Peter Stetson, a recent Carnegie Fellow, now at the Dominion Astrophysical Observatory.

Again, the data fail to fit the old view of a slow, dissipative collapse. The old model predicts that a collection of collapsing metal-rich clusters will rotate more rapidly about the symmetry axis of the galaxy than will a subset of (noncollapsing) metal-poor clusters, since the spin of a collapsing system increases, as a skater's spin increases upon drawing in his or her outstretched arms. The investigators found, on the contrary, that the rotational properties of the clusters were independent of metal abundance. The mean rotational velocity, the velocity dispersion, and the fraction of clusters in backward motion, are not significantly different for subsets of metal-rich and metal-poor clusters.

The result clearly conflicts with the standard picture, and tends to support an alternative view, urged in recent years, that such clusters were formed in the dense and dynamically stable disks of preexisting "protogalaxies." If so, most of the galaxies we observe today could be secondary structures formed by the collisions and mergers of the protogalaxies. Stars and clusters of the earlier protogalaxies would thus compose the halos of today's systems like M31 and the Milky Way.

Evidence from Observations of Noncluster Stars. Globular clusters are particularly good tools for studying the star-formation histories of galaxies because globulars are bright and can be age-dated. On the other hand, there are relatively few of them in any given galaxy, and it is uncertain exactly how their evolution parallels that of a galaxy's vastly more numerous noncluster stars. Therefore, measurements of motions and metal abundances of single stars are a necessary complement to the globular cluster studies.

In a famous paper in *Astrophysical Journal* in 1963, Allan Sandage, Donald Lynden-Bell, and Olin Eggen presented results of a study of noncluster stars in the halo of our Galaxy. Their data showed that most metal-poor stars have very large velocities perpendicular to the plane of the Galaxy; these motions serve to carry them high into the halo. On the other hand, no metal-rich stars were found with such high velocities—a result indicating that these stars are largely confined to the Galaxy's plane.

Now, Sandage and research assistant Gary Fouts, working with the Reticon spectrometer on the Mount Wilson 2.5-meter Hooker telescope, have obtained 4000 radial velocity measurements of 1000 noncluster stars, thereby quadrupling the size of the 1963 sample. The new data confirm the old result—that no stars with high metal abundance are found in the halo. Although this circumstance was once taken as evidence that the Galaxy collapsed from a large gas cloud with steadily increasing metal abundance and flatness (a view contradicted in Searle's research, described above), the data could fit other scenarios. Halo stars could have been scattered into a spheroidal distribution after forming in a metal-poor disk, for example, or the halo could have resulted from a merger of two or more metal-poor protogalaxies. The more-metallic disk stars would then have followed. The new data of Sandage and Fouts are important constraints for the builders of galaxy models.

R. Michael Rich, a Caltech graduate student, has been measuring the motions and metal abundances of K-giant stars in the densely populated nuclear bulge of our Galaxy, using the

2.5-meter du Pont telescope at Las Campanas. Rich has found that although the integrated spectrum of this central region of the Galaxy appears to be metal rich, a star-by-star investigation reveals that at least a fourth of the 62 stars he studied have metal abundances as low as one-tenth solar. The old concept of a slowly collapsing gas cloud argues that only metal-rich stars should be encountered; thus the new data appear to feed the concept of a more complex history involving at least two generations of stars and/or mergers of distinct subsystems.

Las Campanas Fellow Nicholas Suntzeff has been continuing his investigations into the chemical composition of the nearby satellite galaxies of the Milky Way. Working in collaboration with Robert P. Kraft of Lick Observatory, Marc Aaronson of Steward Observatory, and Edward Olszewski of Dominion Astrophysical Observatory, Suntzeff has obtained spectra of eleven K-giant stars in the Ursa Minor dwarf elliptical galaxy. Analysis of these spectra has shown that the metal abundance is very low in Ursa Minor, at most one-hundredth solar, in keeping with theoretical expectations that lower-mass galaxies are less efficient at making, or are less able to retain, the metal-enriched gas from which new stars will form. In collaboration with Kraft and John Graham, Suntzeff has begun to measure the metal abundances of giant stars in the Magellanic Clouds. The results should provide interesting comparisons with the previously studied abundances of globular clusters in the Clouds.

New Insights from Spectra of Spirals. Galactic astronomers at DTM have applied other tools to questions of star (and galaxy) formation. For several years, Vera Rubin and W. Kent Ford have been obtaining optical spectra for use in determining the rotational velocities and mass distributions of spiral galaxies, and in correlating these properties with galaxy luminosity, galaxy type, and other variables. Now, in collaboration with former postdoctoral fellow Bradley Whitmore, Rubin and Ford have used the identical spectra to study variations in chemical properties within and among spiral galaxies. They find that the nitrogen-to-sulfur ratio increases with galaxy luminosity; in the most luminous galaxies sampled, the ratio is higher by a factor of four than in the least luminous galaxies. This difference is likely to be related to differences in the star-formation histories of the galaxies, since nitrogen and sulfur are produced in very different types of stars.

The Question of Binary Stars. The near absence of binary, or double, stars in the ancient star population raises the concept that ancient stars may have formed in conditions very different from those of more-recent star formation. (Among younger stars, double stars are the rule rather than the exception.) Theoretical studies of such questions, including work by Alan Boss at the Department of Terrestrial Magnetism, have shown that the formation of single rather than multiple stars is sensitive to the details of how angular momentum is redistributed during the gravitational collapse of the material destined to form the star. It is possible that these details were different early in the history of the Galaxy. However, new work by DTM postdoctoral fellow Linda Stryker and her collaborators at the Dominion Astrophysical Observatory contradicts the view that double stars were rare in the ancient population. The result makes it somewhat less likely that the processes of star formation were significantly different in the ancient Galaxy, and a potentially misleading false constraint on the history of star formation in our Galaxy has been removed.

Infrared Observations of Young Stars in Molecular Clouds

> Such a mass, when it began to shine, would be red and of low surface brightness but of very low density and great surface so that its total light emission would be large. As it contracted it would grow smaller, hotter, whiter, and increase in surface brightness so that its light-emission would not change much.
>
> Henry Norris Russell
> Princeton University
> 1913

Scholars in the 19th century had already recognized that contraction of a self-gravitating mass could produce a star, and in 1913 Henry Norris Russell at Princeton speculated, as in the above quotation, about what might be observed in the early stages of star formation. Russell failed in his attempt to identify such embryonic stars among those in the temperature-luminosity diagram that now bears his name, however, and no one knew how to go about looking for them.

Alfred Joy of Carnegie Institution's Mount Wilson Observatory provided an important clue in 1945, when he called attention to a remarkable group of stars inhabiting the environs of a dark cloud of obscuring material in the constellation Taurus. The spectra of these stars were vaguely solar-like but were overlain by bright emission lines of common elements that could only be produced by large volumes of gas. George Herbig at the Lick Observatory later showed that such stars,

DTM astronomers Vera Rubin and David Koo, with Alan Dressler of the Mount Wilson and Las Campanas Observatories, following Dressler's seminar in the DTM library, May 1984.

called T Tauri stars after the archetype, abound in or near all dark clouds in the Galaxy. Herbig argued persuasively that the T Tauris are very young objects (10^6 years old) in the late stages of gravitational contraction, i.e., new stars. However, the line-emitting regions of these bodies are not the contracting spheres envisioned by Russell. Instead they are expanding—driven by physical forces still the subject for reasoned speculation.

Infrared astronomers, probing the interiors of the dark molecular clouds at longer wavelengths, have discovered hotter, more-massive counterparts of the T Tauri stars. Carnegie astronomer Eric Persson explains that as these "young stellar objects," or YSOs, migrate from their inner-cloud birthplaces, they ionize and energetically illuminate surrounding regions (like the spectacular nebula of Orion), ultimately to explode as Type II supernovae. Many questions are yet unanswered—what fraction of a molecular cloud eventually becomes turned into YSOs, for example, and whether the shock waves produced by them speed up or disrupt further star formation. Answers are slow to come, as the number of such stars in the birth process is small, and they are typically buried in the parent clouds where observations at the optical wavelengths are impossible.

Needed are observations of temperatures, densities, velocities, and other conditions in regions close to the central sources themselves. Infrared photometric and spectroscopic data have been scarce. The advent of CCD cameras and spectrometers that are extremely sensitive in the red, however, sharply changes the situation. During the past year, for example, Persson and Carnegie fellow Peter McGregor obtained high signal-to-noise optical spectra of a dozen YSOs deeply embedded in dust. They employed the Palomar 5-meter telescope with the double spectrograph to cover (1) a broad wavelength band reaching into the infrared at low resolution and (2) a narrow band at high resolution.

Persson notes that the YSOs have provided many surprises. One of the most remarkable (obtained at radio wavelengths) is that surrounding cloud material is pushed away from the YSO in an outflowing wind. The geometry of the outflow is bipolar, as if two back-to-back nozzles were spewing material away from a small region centered on the star. Meanwhile, slowly rotating disks of molecular gas have been detected around a few YSOs; these may serve to confine and direct the mass outflow. As would be expected, the axes of disk rotation line up well with the direction of the outflow. The amount of material in the outflow typically amounts to several solar masses; velocities of several tens of kilometers per second are typical. By stellar standards, the mass flux is extremely energetic and appears to require an extremely powerful driving source at the center. It is intriguing to note that the overall geometry resembles that seen in the expulsion of gas from the nuclei of certain galaxies to form double radio sources, although the size and energy scales differ by many orders of magnitude.

Persson and McGregor's picture of a strong central source, a shielding disk of about 1 Astronomical Unit (1 A.U. = the distance of the Earth's orbit from the Sun), and a massive surrounding envelope lightly emitting in the infrared, is supported by their detailed analysis of YSO spectra. The spectrum of each YSO broadly resembles the others despite wide apparent differences in the evolutionary states of the YSOs; all exhibit strong H I, Ca II, and O I emission lines—a signature similar to that of T Tauri stars. The hydrogen lines provide information on the generation of the outflowing wind at the central source; the line widths indicate outflow velocity, line strengths indicate outflow mass. Together, the velocity and mass measurements represent the expelling force available in the ionized regions of the central sources.

It appears, however, that the outputs of the ionized central region are many times insufficient to drive the molecular outflow. Evidently, the outflow continues to be accelerated in regions beyond the ionized zone. The extent of the acceleration zone and the possible link to the shedding of angular momentum in the emission region and surrounding envelope are the next challenges in the study of these objects. Detailed understanding of the motions will require knowledge of the shapes of the emission lines, interpreted with the aid of computer models that explain the transfer of energy through the system.

Solar-Stellar Research at Mount Wilson

> The attack is along three converging lines, involving the study of the Sun as a typical star; the study of stars and nebulae and of their relationship to the Sun and to one another; and the interpretation of both solar and stellar phenomena by means of carefully chosen laboratory experiments.
>
> George Ellery Hale
> Director, Mount Wilson Observatory
> *Year Book 5*

Strong in the leadership of George Ellery Hale was the idea that the study of the Sun was inextricable from study of the stars. The work of Carnegie astronomer Olin Wilson in the 1950s and early 1960s, in demonstrating that certain stars had long-term magnetic cycles like the Sun's, paved the way for the Institution's present leadership in "solar-stellar" studies. Favored by the availability of excellent observing facilities at Mount Wilson, regular observations of chromospheric activity in 91 selected stars were begun six years ago at the Mount Wilson 60-inch telescope. By observing periodicity in the rise and fall of a star's chromospheric emissions (the H and K lines) as active, or "starspot," regions rotated into and out of an observer's field of view, the investigators expected to see direct evidence of the star's rotation.

Rotational modulation was indeed detected in many stars, and a further relation linking the mean level of HK flux with rate of rotation was developed for more-general application. At present, the investigators—research associate Douglas Duncan and staff associate Arthur Vaughan of the Mount Wilson and Las Campanas Observatories, and colleagues at the Harvard-Smithsonian Center for Astrophysics and the Lowell Observatory—continue to monitor the long-term HK cycles in the selected star population. But in addition, as seen in this year's work, the venture has led to a flow of other results scarcely anticipated at the outset.

George Preston, director of the Mount Wilson and Las Campanas Observatories, attributes the group's successes in part to three circumstances—the broad participation of scientists from several institutions, the capabilities of the chromospheric spectrometer designed by Vaughan for the venture, and the assurance of sustained support. The effort complements the long-range program of observation at the Mount Wilson solar telescopes and provides an excellent example of the coming together of two branches of astronomy.

Rotations in Hyades Dwarf Stars. Since all the stars in the early HK investigations were solar-like, the investigators could neglect differences in stellar convection—the circulation of heat and material in an extensive region beneath the star's visible surface. For extending relationships to other types of stars, however, Duncan and Vaughan in *Year Book 82* (pp. 607–608) suggested that a star's chromospheric activity level (its HK flux) varied not with the star's rotation period alone but rather with the ratio of the rotation period to the star's convective zone turnover time. This year, Duncan and Vaughan, in collaboration with Richard Radick of Sacramento Peak Observatory and Wes Lockwood and others of Lowell Observatory, began a test of this relation. Observing nine Hyades dwarfs (nonsolar-like), the investigators at Lowell determined rotational periods by monitoring changes in optical light from the star's visible surface, or photosphere. These values were compared with predictions of rotational rate made from HK measurements at Mount Wilson. Agreement between the predicted and measured Hyades rotational rates was generally good, but the predicted periods tended to be slightly low.

In accounting for the discrepancy, the investigators noted that Hyades stars are on average more metal rich than are the nearby, solar-type stars studied earlier. The Hyades convection zones thus should be slightly deeper and the turnover times longer, necessitating an adjustment to the simple HK flux-rotation conversion; in short, the discrepancy tended to confirm the relation suggested in *Year Book 82*. (No estimates have been made, however, in assessing the magnitude of the effect.) In addition, both photospheric and chromospheric measurements of flux showed that, as in the case of the Sun, "starspots" reduce a star's luminous output but on a much larger scale; how the missing radiant energy can be stored in stellar envelopes is not known.

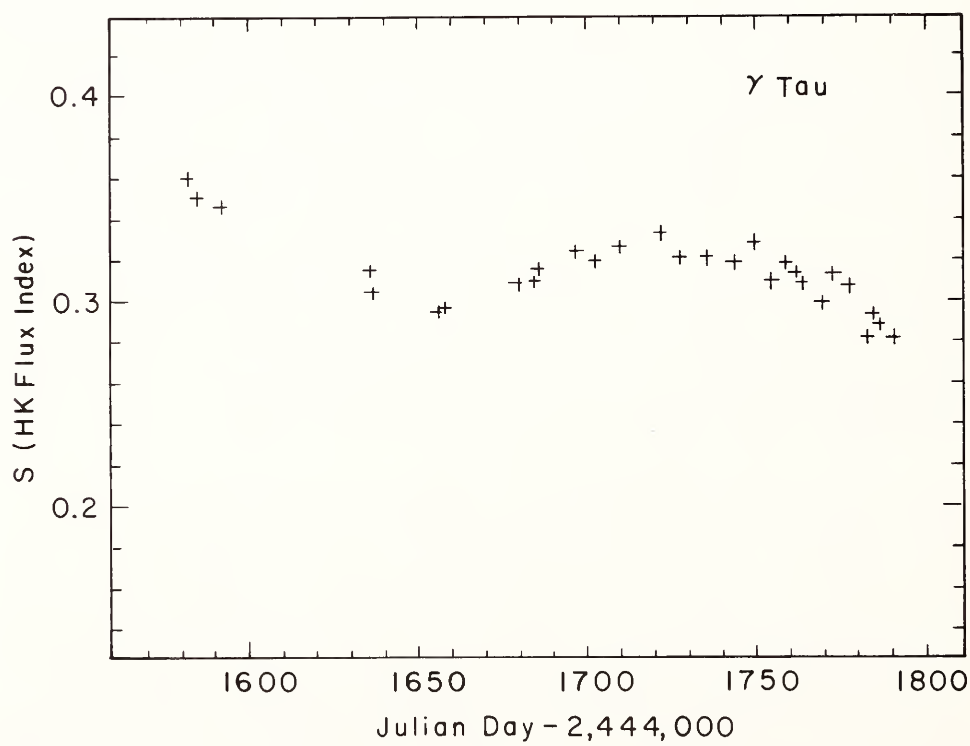
It appears that the broadband photometric method used in the Lowell Hyades observations is the most efficient way of detecting rotational modulation in young, heavily spotted stars, while the HK spectrophotometry used at Mount Wilson is more efficient for stars older than about 10^9 years. To their mutual advantage, the Mount Wilson and Lowell groups have compared mathematical techniques for extracting periodic phenomena from noisy observations. Collaboration will continue through winter 1984–1985, when observations at Lowell—extended to cooler stars than have been heretofore studied—will permit a test of HK prediction in a new regime.

Differential Rotation in Stars. The fact that the Sun rotates faster at its equator than at its poles first led former Observatories' director Horace Babcock to suggest that shear is the dynamical mechanism that amplifies solar magnetic fields and gives rise to the Sun's 11-year "sunspot" cycle of magnetic activity. In *Year Book 81* (p. 611), Vaughan and Duncan reported variations in HK flux for the star HD 149661 that could have arisen from the beating of two slightly different frequencies. It seemed possible that the observers were detecting two strong areas of chromospheric activity, located at two different latitudes having different periods of rotation. Now, HK observations have provided strong evidence of differential rotation in nine additional stars.

In most cases, data from a single season are insufficient to distinguish unambiguously between differential rotation and the evolution of active regions. Observations over several seasons, however, may strengthen evidence favoring the former. Star HD 190406, for example, has an apparent 2.6-year magnetic activity cycle; if, as has been observed in the Sun (*Year Book 81*, pp. 596–599), the sites of magnetic activity gradually move during the activity cycle to a different latitude with a different rotational velocity, then the observer should detect a gradual increase in rotation period. This has indeed been observed in HD 190406. Further, in the third observing season, a fresh period equal to that of the first season was detected, presumably caused by renewed magnetic activity at the original latitude, a phenomenon also seen on the Sun.

Solar-Stellar Seismology. Like seismic waves within the Earth, seismic waves travel through the Sun and are reflected at various boundaries; some oscillations appear to traverse regions as deep as the Sun's center. Duncan, in collaboration with Robert Noyes, Sallie Baliunas, and others at the Harvard-Smithsonian Center for Astrophysics, has begun a search for counterparts of the Sun's "five-minute oscillations" in stars. Observing ϵ Eridini, a K2 dwarf star cooler and less massive than the Sun, the investigators obtained one-minute HK integrations at short intervals over a period of about six hours; several such six-hour sets were obtained. They detected a number of low-amplitude spectral peaks spaced at about 86 and 172 μHz. The 172-μHz spacing, which should approximate the reciprocal of the travel time through the star, agrees well with theoretical predictions for a star of ϵ Eridini's size. The peak power occurs for periods near ten minutes, correcting the predicted duration of about four minutes for a star of this type. The early success of this line of investigation is most encouraging.

Rotation in Red Giants. Preston writes that perhaps the year's most exciting event in solar-stellar physics is the first-ever determination of the rotation period in red giant stars. Duncan and colleagues report evidence for rotational modulation in 20 of the 50 giants under systematic observation. When a sufficient number of periods have been established, statistical comparison of the rotations of giants with those of their main-sequence progenitors will provide the first means for describing how angular momentum is redistributed within stars during post-main-sequence evolution. This knowledge in turn should aid in refining models used to predict subsequent important phases of stellar evolution.



Rotation in the red giant star γ Tau is revealed in this plot of HK flux vs. date. The periodicity of about five months results from rotation of the star, whereby regions of greater and lesser HK activity are carried into and out of the observer's field of view. The detection of rotational modulation in twenty red giant stars this year is the year's most significant result in solar-stellar research at Mount Wilson.

Formation of the Sun and Solar System

A central theoretical question, occupying a middle ground between astronomy and the earth sciences, is how a single star can be formed with a planetary system like our own.

To some extent everything in the universe is rotating. When an interstellar cloud of dust and gas becomes sufficiently dense to begin collapsing under its own weight, its spin increases as it contracts, like the familiar skater. At some rate of rotation, the self-gravity of the cloud will no longer withstand the centrifugal force tending to tear the cloud apart. The cloud will then fragment, leading to a number of subclouds which can continue to collapse until once more their rotation causes fragmentation.

The process must be in some way related to the observation that new stars are usually formed in large groups, for example in the region of the Great Orion Nebula in our Galaxy. There is difficulty, however, in understanding how the continuing fragmentation stops. (If it did not stop, single stars like the Sun could not form.) Somehow, angular momentum must be removed from the contracting star and be transferred to the dust and gas surrounding it.

A fashionable way to explain single-star formation, writes DTM's George Wetherill, is by calling upon turbulent motion in the collapsing cloud to transfer the necessary angular momentum. This may be the way it happens, he continues, but there is no strong theoretical reason to believe that the necessary turbulence actually occurs; indeed, the rapid motions associated with turbulence could preclude the formation and growth of planetesimal bodies like those that formed the planets of our solar system.

Alan Boss at DTM has been carrying out theoretical and numerical studies of star formation, including the first fully three-dimensional study of the collapse and heating of a rotating cloud. His three-dimensional work incorporates the presence of asymmetries—the barlike structures observed in some irregular objects, for example—that are precluded by the artificial symmetry assumed in simpler calculations. His results show that these asymmetries are able to transfer angular momentum by gravitational forces, even in the absence of turbulence. If in fact this was a significant mechanism during the formation of our solar system, then the solar nebula—the flattening disk which rotated about the very early Sun and from which the planets formed—could have been relatively cool and quiescent.

Meteorites as Windows on the Early Solar System. Most meteorites are derived from small asteroidal bodies that have not been altered by the active geological processes of a planet like the Earth. Meteorites, therefore, are believed to be a prime source of detailed evidence about the solar nebula and the early solar system.

Past discussions have been dominated by the concept of a high-temperature solar nebula—one hot enough to have vaporized all preexisting interstellar grains. But even a moderately turbulent solar nebula would be relatively cool and capable of vaporizing only the more volatile components of interstellar grains. Studies of meteorite material in recent years by isotope geochemists provide widespread evidence of isotopic heterogeneity, a result compatible with the concept of a cool solar nebula. The observed isotopic data vary over a wide range, and it seems likely that they will be explained by a complex model of only partly homogenized interstellar material within the solar nebula.

During the past year, James R. Ray, research associate at DTM, has developed theoretical treatments attempting to explain the presence of oxygen isotope anomalies and the complex mixture of isotope variations (the "FUN" anomalies) found only in special inclusions of the Allende carbonaceous meteorite. Meanwhile, DTM staff members Typhoon Lee and Fouad Tera completed a search for a third class of anomaly—one produced by the decay of now-extinct radioactive nuclei, in this case the radioisotope ^{53}Mn (2-million-year half-life). Earlier work on the problem was discussed in *Year Book 82* (pp. 541–544). Lee and Tera have now increased the sensitivity of their search by a factor of 200, but they still have not found evidence for the existence of ^{53}Mn in the early solar system. The result is puzzling in view of the relatively high abundance at that time of the shorter-lived isotope ^{26}Al, and it rules out some astrophysical models for the formation of ^{26}Al because they require quantities of ^{53}Mn greater than those observed.

A difficulty in making full use of meteoritic data has been in identifying the immediate sources of these fragments. In the past few years, it has become clear that a few rare meteorites are fragments of the Moon, while others were probably ejected from Mars by giant impacts. Problems remain, however, in identifying sources of the most abundant class of stony meteorite, the "ordinary chondrites." It has become increasingly clear that the source of these meteorites is somewhere in the asteroid belt between the orbits of Mars and Jupiter. But during the last few years, other evidence has been obtained defining the general orbits of these meteorites when they impact the Earth, and it has not been possible to show how asteroidal sources could produce the required orbital distribution.

The question has been greatly clarified by the recent work of Jack Wisdom at the University of California, Santa Barbara. Wisdom found that asteroidal material entering a narrow range of the asteroid belt 2.5 A.U. from the Sun will be subject to large and chaotic orbital changes. This behavior is the result of resonance with the motion of Jupiter. (An object at 2.5 A.U. will make three revolutions about the Sun in the same time interval required for Jupiter to make one.) This resonance condition has been known for a long time, but not until the work of Wisdom was it known that such extreme orbital changes would result.

During the past year, George Wetherill has pursued in detail the implications of Wisdom's discovery for understanding the source of the ordinary chondrite meteorites. Wetherill found that the chaotic orbits evolve in just the right way to provide asteroidal fragments matching very well the observed distribution of meteorite orbits. The total mass and number of meteorites striking the Earth also agree with the mass and number expected from the 2.5-A.U. source. Moreover, the resonance mechanism explains in a natural way the relationship between the larger (ca. 1-kilometer-diameter) Earth-approaching Apollo Objects and the smaller meteoritic fragments. Wetherill writes: "It now seems very likely that the ordinary chondrites are fragments of a few large asteroids near 2.5 A.U., as well as fragments of their retinue of smaller asteroids produced by mutual asteroidal collisions."

Conditions in the Primitive Solar System. In an innovative new program, termed condensation petrology, workers at the Geophysical Laboratory are subjecting materials representative of the early solar system to laboratory conditions simulating those in the solar nebula during planetary formation.

Meteorites offer evidence of processes occurring during early stages of solar system formation. Some contain chondrules—small (about 1-millimeter) bodies of crystalline material, which may have formed initially as molten droplets by direct condensation in the solar nebula. Other meteorite materials lacking chondrules may have crystallized directly from a gas phase; i.e., they solidified without passing through a liquid state. The possible pressure conditions accompanying these processes have never been investigated experimentally.

The new venture involves study of the triple-point conditions for the major meteoritic minerals (i.e., the pressure above which a mineral will proceed through a molten state, and below which crystallization will occur directly from the gas). Ikuo Kushiro, David Virgo, and Bjørn Mysen built a furnace assembly, which permitted high-temperature experiments at pressures as low as 10^{-9} bars—much lower than pressures previously attained in experimental petrology. The sample is held in a molybdenum crucible with a small orifice in the lid. The triple point for diopside composition ($CaMgSi_2O_6$), a characteristic material in meteorites, was found to be 4×10^{-8} bars at 1553K; that for enstatite composition ($MgSiO_3$), also a meteorite material, was found to be somewhat lower.

Encouraged by the success of these experiments, the investigators are constructing a chamber capable of attaining still lower pressures, and are incorporating facilities for studying the same minerals under controlled hydrogen-gas pressure. In preliminary work with the new chamber, they have reached 10^{-11} bars. A closer approach to conditions in the solar nebula may thereby be achieved. In any case, the early experimental data indicate that certain materials crystallized in the solar nebula at pressures several orders of magnitude lower than has been generally proposed.

A Theoretical Problem in Planet Formation. One of the most fundamental heretofore unresolved theoretical problems of planet formation is that of dynamic tidal instability. (Just as the Earth's ocean tides rise and fall from the gravitational attractions of the Moon and Sun, solid bodies are distorted in shape by the pull of gravitational forces of nearby bodies.) It has been known from the work of the great classical physicists of the 19th century, subject to assumptions such as static equilibrium and the absence of viscosity, that a large satellite orbiting the Earth at a distance closer than the "Roche limit" (about three Earth radii) would fragment into smaller pieces in response to tidal forces. It has not been known whether fragmentation would occur if a body simply flew by the Earth, passing within the Roche limit for approximately one hour. The question is fundamental because in the accumulation of planets from smaller planetesimals, such close encounters will occur eight times as often as actual collisions.

If fragmentation occurs, "survival of the biggest" is the likely result, where tidal forces reduce to rubble all but a few large embryonic planets. Except for the possible late-stage merger of these embryos, planets will therefore be formed by accumulations of many smaller bodies. But if there is not enough time for fragmentation to occur during the flybys, then planets would grow from collisions of large bodies of comparable mass. The alternative possibilities lead to very different models of thermal and chemical evolution of the Earth, and would be related to such questions as the origin of the Moon and the mare basins visible on its surface.

As a result of careful numerical modeling at DTM, Hiroshi Mizuno and Alan Boss have demonstrated that if the body flying by is rocky (as expected) rather than liquid, the encounter time will be too short for tidal fragmentation to occur. Their result thus indicates that planetary formation by large-body collision is the more probable, and that theories of lunar origin based on "disintegrative capture" are untenable, as is the formerly most reasonable explanation of the close time grouping in the formation of the mare basins.

Understanding the Structure of the Inner Earth

> The nodule studies show increasingly that the mantle is more diverse than has heretofore been realized; indeed, the problems of its origin and evolution are equally as complex as those relating to the Earth's crust.
>
> Hatten S. Yoder, Jr.
> July 1984

> The time appears ripe to begin to . . . relate this initial state to the subsequent thermal and chemical history of the Earth, with the goal of matching theory to the observed geological and geochemical record preserved in the most ancient rocks. Discussions of this kind clearly involve many uncertainties, are bound to be in large part speculative, and conclusions must be tentative. Nevertheless, we believe that with sufficient attention to the requirements of consistency and physical and chemical plausibility, first steps can be taken toward understanding these most fundamental geological questions.
>
> George W. Wetherill
> July 1984

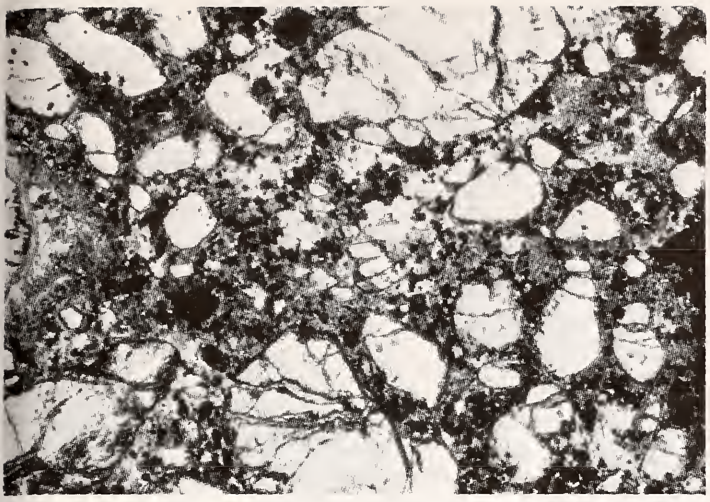
As a result of theoretical work on planet formation during the past decade, Wetherill writes, it has become evident that the Earth formed at a temperature high enough to melt, at least partly, silicate rocks and metallic iron. (Although the solar nebula was likely to have been cool, as we have noted, the Earth was heated during its formation by the kinetic energy of impacting planetesimal bodies.) This view is a reversal of the older theory that the Earth formed at a rather low temperature and slowly reached its present thermal state as it was heated by the decay of the radioactive elements uranium, thorium, and potassium.

One product of the new view is seen in the work of Alan Boss, Charles Angevine, and Selwyn Sacks at DTM on convective transport of heat immediately after Earth formation. They note that melting caused by the impacting planetesimals should have initiated the separation of iron from less-dense silicates. Heat transport driven by chemical density differences (as the iron descended toward the center of the planet) accounted for the initial temperature distribution within the Earth. Numerical modeling by Boss *et al.* indicates that this temperature distribution should produce a large initial burst of solid (or mixed solid-liquid) convection, which will cause hot material from the deep interior to be transported above cooler material previously near the surface. This rapid redistribution of material results in a stable temperature inversion, and this initial convection will halt. It appears that 500 million years or more may be required to erase this condition of stability; the modeling thus suggests that mantle-wide convection in the Earth was re-established four billion years ago, 500 million years after initial Earth formation.

Although the concept is highly speculative, Sacks and Boss suggest that this thermal and convective history may be related to the 500-million-year hiatus between the formation of the Earth and the formation of the oldest continental-type crust known. This view is based on an analogy with the modern Iceland Plateau, where seismological work by workers in Iceland and later at DTM has shown the basaltic crust to be about 25 kilometers thick—much thicker than the oceanic crustal thickness of about 5 kilometers. Iceland lies above a convective mantle "plume," which feeds hot, silicate material to the surface from the deep interior, possibly from the core-mantle boundary, thereby accounting for the thick crust. Deep plumes, however, cannot have formed under the Boss *et al.* model for the early history of the Earth until after the primordial temperature inversion was erased.

Crusts 25 kilometers thick are buoyant enough to resist subduction downward into the mantle, whereas present-day evidence shows that thin crusts (attached to higher-density subcrustal lithosphere) are readily subducted. Thus, the delayed formation, about four billion years ago, of these unsinkable rafts of thick crust may have initiated the formation of continental land-masses, which then grew larger through collisions among these ancient continental nuclei.

Direct Studies of Mantle Rocks. However speculative may be the newest models for explaining the inner Earth, they



Kimberlite in thin section, consisting of colorless fresh olivines in a fine-grained matrix of opaque spinels, serpentine, and calcite. The field of view is about 2.5 mm across; plane polarized light.

Fragments of metasomatized sedimentary material in kimberlite rock raised from the mantle at Ison Creek pipe, Elliott County, Kentucky. The scale in foreground is marked in cm. Investigators at the Geophysical Laboratory study such inclusions as a means of understanding fluid-rock metasomatic reactions in the mantle.

must ultimately stand the test of consistency with known experimental and observational evidence. At the Geophysical Laboratory, several investigators are making direct studies of mantle rocks—the rounded fragments, or "nodules," that were carried to the Earth's surface in ancient eruptions of kimberlite magmas and alkaline basalts. Their results reveal the complexity of mantle structure and composition.

In his studies of mantle nodules, Francis R. Boyd of the Geophysical Laboratory finds that the stable, ancient continental nucleus, or craton, of southern Africa has a root of rigid, relatively cool rocks, which extends to greater depths than the lithosphere of the surrounding mobile belts and oceanic regions. Boyd suggests that this root has existed since early in the Earth's history, i.e., from Archean times. His evidence comes from garnet crystals, isolated and protected as inclusions in diamonds, and dated by the Nd-Sm method at 3.2–3.3 billion years. Boyd has determined that the olivines and garnets in these inclusions formed under conditions of pressure and temperature that plot close to a geotherm consistent with present-day heat flow. He interprets this relationship to indicate that temperatures in the root of the craton 3.2 billion years ago were not appreciably different from those existing today—a different conclusion from the currently common view that the Archean upper regions were exceptionally hot.

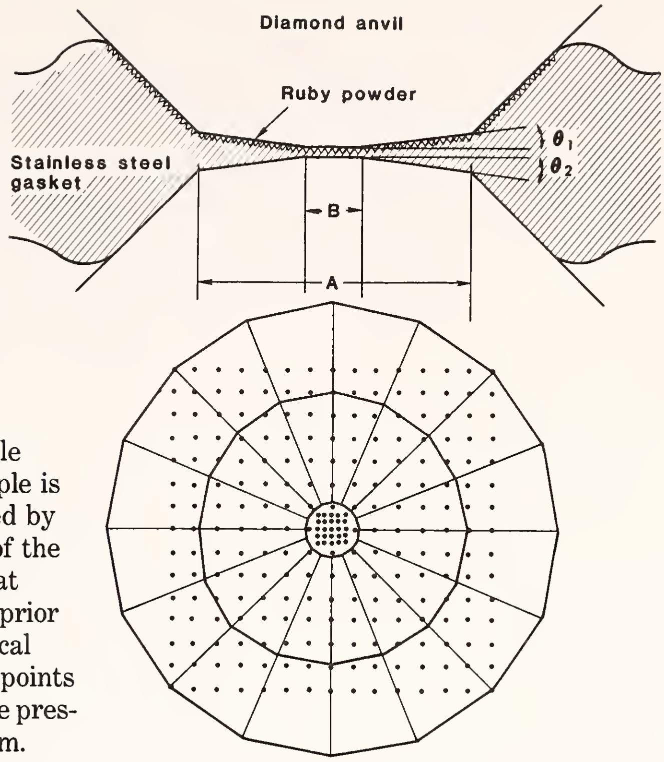
Similarities between mantle and crustal geology can be seen in certain mantle features recently attributed to metasomatic processes—i.e., to mineralogical and chemical changes caused by reaction of rocks with migrating fluids (particularly magmatic liquid and supercritical carbonated aqueous solutions). For example, Daniel Schulze has found that the garnets in ultramafic nodules from Kentucky kimberlites are inhomogeneous, and that clinopyroxene megacrysts from the Ile Bizard in Quebec are zoned; both features suggest incomplete reactions. Schulze also interprets the low Ca content of garnets from some diamond-bearing peridotites as an indication that the peridotite was formed by reconstitution of subducted metaserpentinite, a rock that is a product of near-surface alteration.

Experiments at High Pressure: A Breakthrough in Technology. Mankind's deepest drillings have penetrated only 12 kilometers into the Earth, while natural eruptions have raised unmelted mantle material from at most about 250 kilometers. Experiments with synthetic mantle materials at high pressures and temperatures are thus indispensable for understanding the inner Earth.

During the mid-1960s, workers at the National Bureau of Standards and at the University of Maryland devised a new kind of apparatus for experiments at high pressures, one deceptively simple in principle. In diamond-cell devices, mechanical force was applied to two precisely cut diamonds, which held a tiny sample to be compressed. At the University of Rochester, William Bassett and colleagues developed diamond cells capable of attaining about 300 kilobars, equivalent to a depth in the Earth of 900 kilometers. Assisting Bassett was a graduate student, Ho-kwang Mao, who—Ph.D. in hand—came to the Geophysical Laboratory in 1968, where he began a long association with fellow staff member Peter Bell.

Spurred by the availability of laser technology for heating samples inside the diamond cell, Mao and Bell "really went to work" improving the experimental devices. Many times, the two investigators saw their diamonds shatter as pressure was increased. They gradually discovered better techniques for maintaining exact alignment of the facing diamonds, and at the end of 1975, they attained the then-remarkable static pressure of 1000 kilobars (one megabar)—equivalent to a depth in the mantle more than halfway to the molten core.

Although much of their time went into experiments at upper-mantle pressures, the Geophysical Laboratory team kept working to attain much higher pressures. One day in 1978, upon reaching 1.7 megabars—their highest pressure to that date—the investigators encountered a new phenomenon. Instead of shattering in the usual way at the limit of its strength, one of the diamonds began to deform as if by plastic flow. It was a remarkable event but also a disappointing one, for it appeared that diamond-cell technology may have reached a limit—the ability of diamonds to resist plastic deformation.



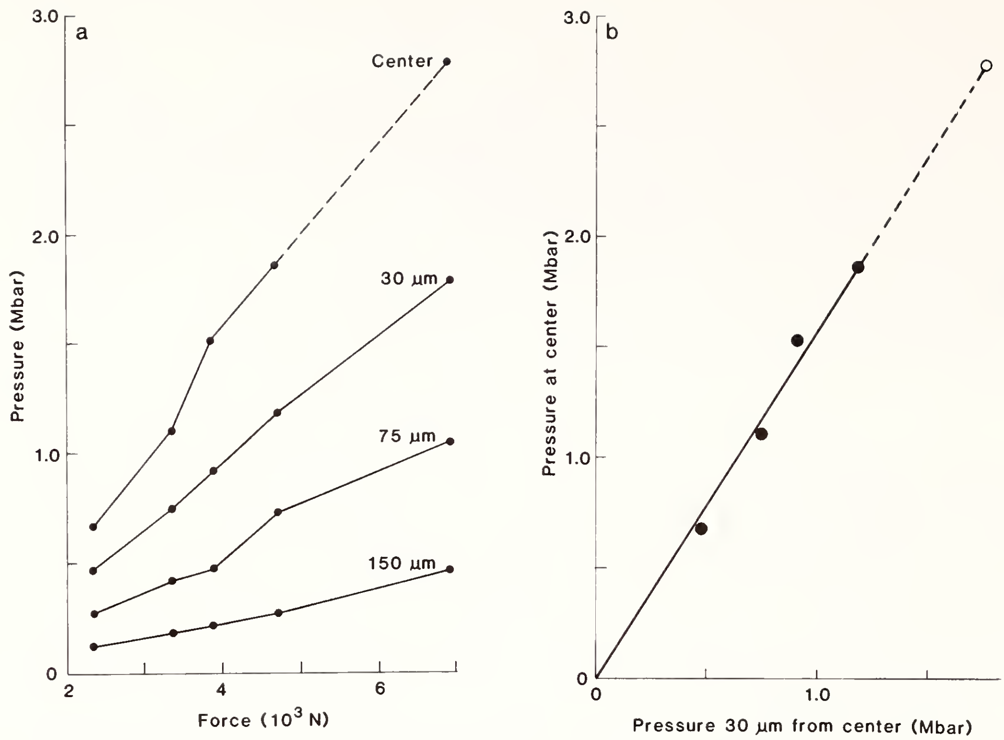
Cross-section and plan views of the sample chamber area of the diamond cell. The sample is held between two facing diamonds separated by a stainless steel gasket. The configuration of the angles of bevel (angles θ) and the central flat area *B* were critical in redesigning the cell prior to the recent 2.8-Mbar run at the Geophysical Laboratory. The dots on the plan view are points of the computer-stored position matrix where pressure was measured. $A = 300\mu m$, $B = 50\mu m$.

The 3.5 megabars of the Earth's center, 6370 kilometers deep, seemed beyond reach.

Seeking clues for overcoming the plastic-flow problem, Mao, Bell, and staff member Kenneth Goettel looked closely at the other diamond—the one that had not failed at 1.7 megabars. This diamond, they learned, had an unusually high concentration of nitrogen platelets; for their subsequent experiments, therefore, the investigators sought out high-nitrogen diamonds. At the same time, they increased the rigidity of the diamond-cell's steel structure. (This improvement reduced bending upon applying force, which interfered with perfect diamond alignment.) Finally, they redistributed force loadings within the diamonds by (1) reducing the flat area where the two diamonds faced and (2) changing the angle of beveling at the sides, where shattering most often occurred. It was clear in the early trials that pressures well above the previous record would be attained.

But in testing the redesigned cell, the investigators faced yet another problem. In past years, pressure within the sample chamber had been obtained by observing fluorescence emitted by ruby crystals inside the chamber. Geophysical Laboratory workers had used the method extensively and had put much effort into its calibration. Unfortunately, ruby fluorescence (R lines) is no longer observed above about 1.85 megabars, so the method cannot be used above that pressure.

Seeking an alternative, Goettel, Mao, and Bell first prepared computer software for measuring ruby fluorescence simultaneously at many points across the sample chamber. The



Determination of 2.8 Mbar static pressure achieved in the recent experiment at the Geophysical Laboratory. (a) Plot of pressure vs. applied force as a function of distance from the center of the sample chamber of the diamond-cell high-pressure apparatus. The dashed line is the linear extrapolation from the 1.8 Mbar measurable by the ruby fluorescence method. (b) Plot of pressure at the center of the sample chamber vs. pressure 30 µm from the center. The line defined by the four lower readings is extended to intercept the 1.8-Mbar value measured 30 µm from the center; this method is independent of applied-force measurements.

ruby readings at various force loadings documented how pressure increases to a maximum at the exact center of the diamond face. The new measuring capability was useful in redesigning the diamond face, and it promises to be an important aid in making further design improvements. Indeed, in surveying the major accomplishments in instrumentation of the group this year, director Hatten S. Yoder, Jr., has written that "the principal contribution is in the development of a technique for mapping the pressure gradient across the diamond anvil."

The investigators kept stepping up the force loadings, well beyond the old limit. For determining the new peak pressures at the center of the diamond face, two methods were available. One method relied on the new pressure-mapping capability, which resulted in the extrapolation of high values of pressure at the center from ruby measurements (up to 1.85 megabars) at the sides. But a more conclusive (though laborious) technique was also available—essentially the method used several years earlier to verify and calibrate the ruby fluorescence scale at lower pressures. After each increase in force loading, the Geophysical Laboratory team made precise mechanical measurements of applied force and microscopic measurements of areas within the cell. Together, the force and area measurements led to calculations of pressures in various regions in the cell.

Reporting measurements in 1984 from both methods, Bell, Mao, and Goettel demonstrated that their group had successfully attained a pressure of 2.8 megabars at the center of the diamond face. At this point, they slowly reduced the pressure (in preference to further increasing the force loading to eventual failure of one of the diamonds). They thereby obtained valuable measurements during the unloading and saved the diamonds for examination.

The 2.8 megabars attained in the laboratory is equivalent to well inside the Earth's inner core and approaches the pressure of 3.5 megabars at the Earth's center. Still higher pressures are possible using the diamond cell; Yoder writes that "conditions like those at the center of the Earth may soon be achieved and sustained under control." An immediate goal is to develop a convenient scale to replace the ruby method at the higher pressures now attainable.

Synthetic Mantle Minerals at High Pressure. The Geophysical Laboratory investigators this year continued experimental work with possible materials of the mantle. Such studies can provide incontrovertible data valuable in developing models of the inner Earth. In x-ray diffraction experiments with the diamond cell, for example, crystal structure can be measured and pressure-density relations (i.e., compressibility) determined at temperatures and pressures of the inner Earth. Any model of the mantle developed from seismological, geochemical, and theoretical evidence must be consistent with what is seen in the laboratory.

This year, Pascal Richet conducted x-ray diffraction measurements on magnesiowüstite $Fe_{0.8}Mg_{0.2}O$ up to 470 kilobars. He finds the compressibility of this and other magnesiowüstites, within experimental error, to be a linear function of composition. Meanwhile, Bell, Mao, and Xu determined the compressibilities of grossularite and andradite at 100–200 kilobars.

Techniques recently developed at the Laboratory for hydrostatic experiments were important in several investigations. (In hydrostatic work, samples under pressure are enveloped in fluid and are thus compressed evenly from all directions; distortions attributable to a single axis of compression are thereby eliminated.) Bell, Mao, and Xu studied periclase MgO; argon, a weak plastic solid under pressure, served as the hydrostatic medium. Under conditions up to 650 kilobars, the periclase was virtually free of nonhydrostatic stress. Meanwhile, predoctoral fellow Andrew Jephcoat studied the compressibility of iron (up to 750 kilobars) and FeS_2 pyrite (up to 450 kilobars)—materials of interest in understanding the possible composition of the Earth's core. Jephcoat's results under hydrostatic conditions show no evidence for the existence of a phase transition, reported from nonhydrostatic shock-wave experiments in pyrite in this pressure range.

The diamond cell is also being used for Mössbauer and infrared studies of minerals at mantle pressures. Martha Schaefer is conducting Mössbauer studies of the geometric and electronic structures of iron-bearing minerals of the type believed to exist in the mantle and core. By making the measurements (up to 600 kilobars) under hydrostatic conditions by means of an argon pressure medium, she avoided hitherto troublesome problems with the Mössbauer spectra.

The infrared spectra are of interest because their longer-wavelength modes can be used to measure values of specific heat. From preliminary results, Anne Hofmeister and Mao expect to be able to do spectroscopy in this region at pressures up to 500 kilobars. The specific heat data are needed to calculate the Grüneisen parameter γ—a fundamental equation relating temperature, pressure, volume, and internal energy of a substance.* All terms in γ except specific heat can be determined from laboratory measurements of pressure, volume, and temperature (equation-of-state data), so that the ability to determine accurate values of specific heat from spectral observations (including both the Raman and infrared modes) at high pressure will lead to a more complete estimate of the parameter and the associated properties of materials in the mantle.

Characterization of the Mantle's Transition Zone. It is conceivable that the absence of samples from deeper than 250 kilometers in the mantle is attributable to mineral transitions seen in laboratory experiments at pressures equivalent to slightly greater depths. In experiments at pressures of the "transition zone" (depth of 300–670 kilometers), Geophysical Laboratory researchers have shown that most known mantle silicates change to the perovskite structure. Looking toward the eventual correlation of seismic observations with mineral structures, researchers at the Laboratory have undertaken a major new initiative to characterize the minerals believed to exist in the transition zone by defining their properties at con-

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*
$$\gamma = \frac{\alpha_v K_T}{C_v \rho},$$

where α_v is the volume coefficient of thermal expansion; K_T, the isothermal bulk modulus; C_v, the specific heat at constant volume; and ρ, the density.

ditions in the Earth.

Toward this end, Bell and Mao have begun experiments using a diamond cell fitted with a laser-heating system. The temperature will be measured indirectly by means of the thermal-emission spectrum of an area 5 μm in diameter within the 40-μm, laser-heated focal spot. The pressure measurement is to be carried out simultaneously from the fluorescence emission of Eu-doped YAG crystals in the heated zone and ruby in the unheated zones of the sample chamber. Raman spectra, obtained in 0.1-second pulses and by continuous scan, will be used to detect phase transitions. Brillouin spectra, used for a direct measure of plastic and thermodynamic properties, may also be obtained on the same sample. The first experiments are being conducted on samples of garnet.

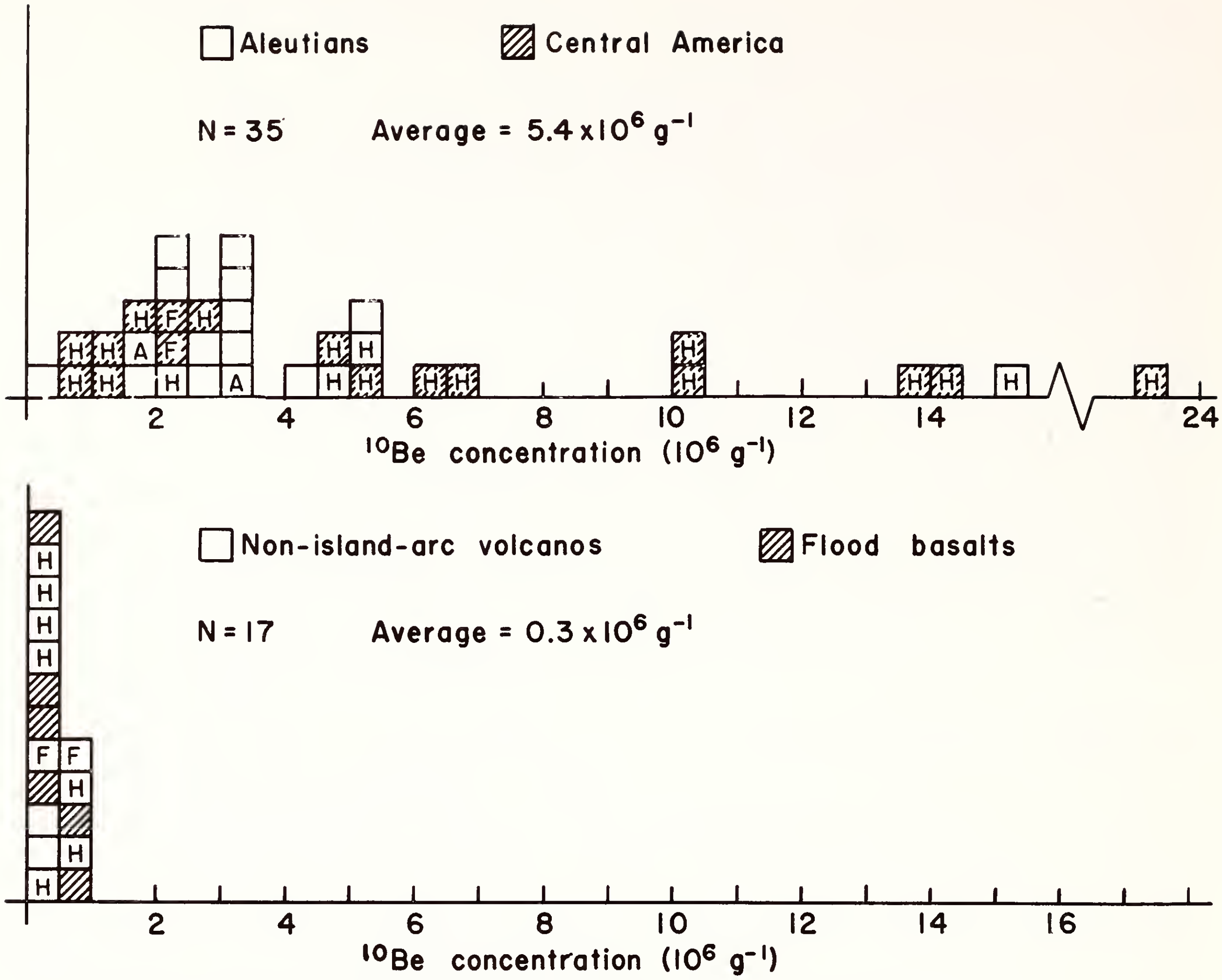
Processes of the Crust and Upper Mantle

The Earth's crust is a changing region—a shell whose varied, often slow processes are largely driven by the flow of heat and material from below. Within the solid crust are subsurface chambers of magma—liquid intrusions that may lead to volcanic eruptions or may slowly solidify in complex chemical pathways to form layers of igneous rocks. Meanwhile, various elements dissolved in intergranular fluids are slowly transported through the crust, sometimes resulting in deposits of useful minerals. New crust is constantly forming out of heated mantle material at the midocean ridges, while oceanic plates are pushed against continental margins, leading to subduction, volcanism, and surface mountain-building.

Earth scientists at the Geophysical Laboratory and the Department of Terrestrial Magnetism, employing the most advanced techniques and instruments to obtain data at the finest possible level of detail, seek basic understanding of these phenomena.

The Generation of Continental Material: Isotopic Studies. Louis Brown and colleagues at DTM, in collaboration with scientists at the University of Pennsylvania, in recent years have developed a technique to measure the ^{10}Be content in samples by using the University's tandem Van de Graaff accelerator as a mass spectrometer. The method has proven to be extremely sensitive, and it has been successfully used for the research purpose originally envisioned—to trace the journey of oceanic crust (whose sediment carries ^{10}Be from rainfall) to its eruption in island arc and continental volcanos.

This year, Brown and Fouad Tera of DTM, with Roy Middleton and Jeffrey Klein of Penn, have increased considerably



Histograms showing ^{10}Be measurements in various samples, obtained by DTM's Louis Brown and colleagues at the University of Pennsylvania in their effort to trace the journey of oceanic crustal material to its eruption in volcanos.

Each square designates a measurement; measurements are placed along the horizontal axis in bins of 0.5×10^6 atoms of ^{10}Be per gram. *F*, the flow was fresh at the time of collection; *A*, the flow was from an active volcano; *H*, the flow was historical; no letter, the sample was from a dormant volcano, and the age of the lava is uncertain. (Values from the fresher samples are less likely to be affected by any ^{10}Be deposited from rainfall after eruption.)

The upper histogram shows measurements from Central America and the Aleutians—two arcs where concentrations significantly above the instrumental noise are consistently found. The lower histogram shows lavas from volcanos unrelated to subducting plates and from flood basalts too old to evidence initial ^{10}Be. Three other island arcs examined in similar detail (Java, Halmahera, and the Marianas) have not shown ^{10}Be at levels greater than the non-island-arc group. Other arcs are being studied, but the data are still too few to allow conclusions.

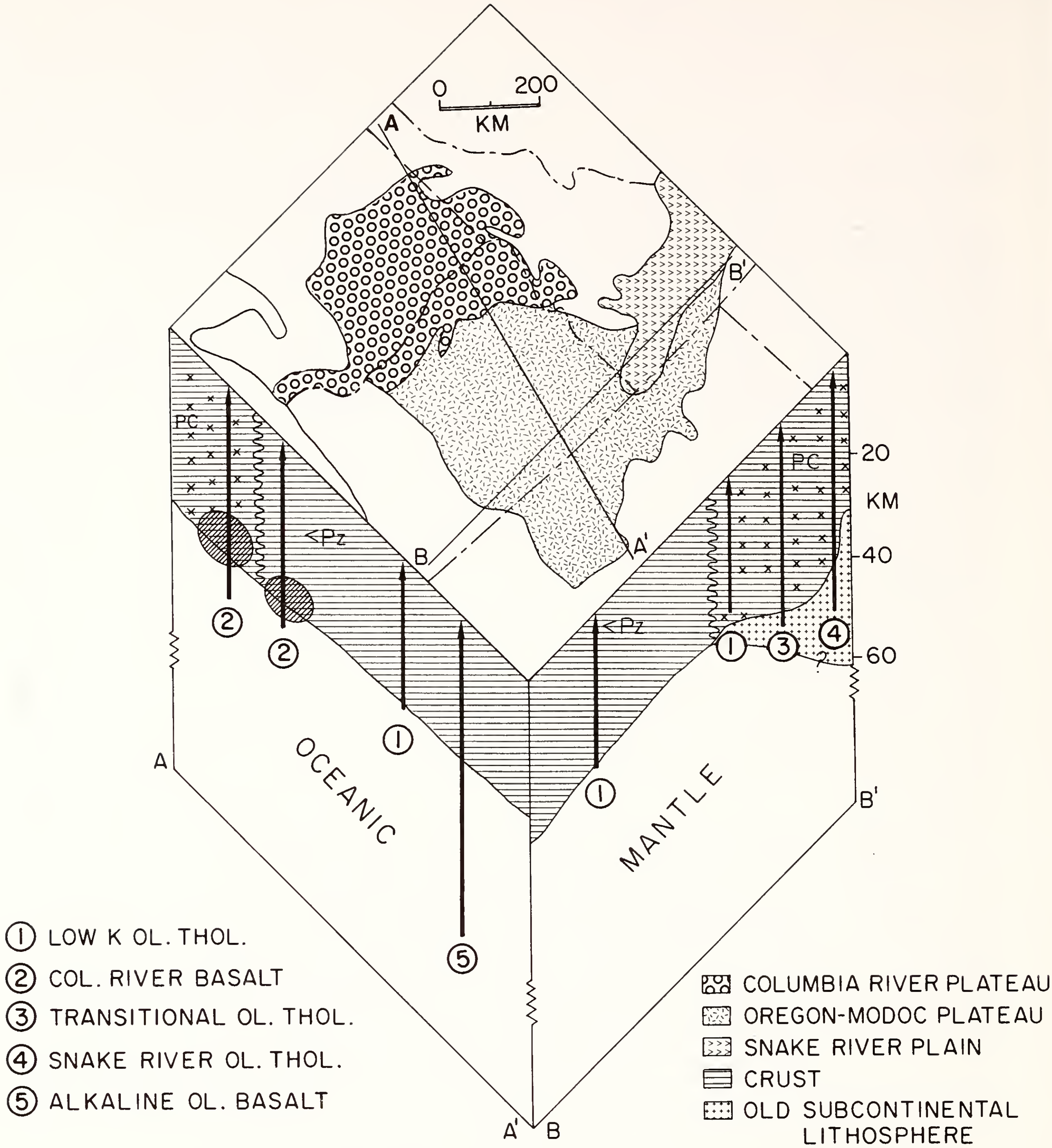
the number of volcanic samples analyzed. The patterns previously seen have been largely confirmed: in general, volcanic rocks not associated with subduction zones are, within measurement errors, devoid of ^{10}Be, while those from magma originating from the heating of subducted material exhibit large ^{10}Be concentrations. It seems clear that in the latter case, the observed ^{10}Be comes from oceanic sediment carried downward with subduction of the oceanic plate and later incorporated in subduction-zone magma. The result is a convincing demonstration of plate tectonic theory.

It is clear, however, that the extent of ^{10}Be transport is markedly regionally dependent. The concentration of 2×10^6 atoms per gram is exceeded in 91% of volcanic samples from the Aleutians and from Central America, but in only 22% of rocks from other subduction zones, primarily in the western Pacific. In fact, within present limits of accuracy, about half the rocks from these other subduction zones contain no more ^{10}Be than samples from volcanos unrelated to subduction. The reason is not well understood, though it is probably related to differences in how the particular subduction zones work. In order to investigate the phenomenon, additional measurements are being made, and data are being obtained from other isotope systems.

Other types of isotope studies provide other important insights into subduction processes. DTM workers, for example, are trying to learn what percentage of crustal material is raised to the surface in subduction-related volcanos, and what percentage is pushed downward, to be "recycled" into the mantle.

The Cascade Mountains of the northwestern United States are volcanos caused by the heating in subduction of the oceanic plate beneath the lighter North American continent. In addition, some 200–300 kilometers farther to the east, extremely voluminous basalts were erupted about 15 million years ago. In a study completed recently by DTM's Richard W. Carlson, these mantle-derived basalts of the Columbia River Plateau were found to contain strontium, neodymium, lead, and oxygen isotopic signatures attributable to the presence of subducted sediments in their source region. The involvement of sedimentary materials in the genesis of these basalts implies that at least some fraction of the subducted crustal material survived its passage through the source region of the Cascade volcanism. This implication is significant, because the recycled material carries with it into the mantle high concentrations of the "incompatible" (in the mantle) radioactive heat-producing elements (U, Th, and K) and volatile compounds such as H_2O and CO_2. Both of these components enhance the ability of the mantle to produce melts that will eventually be erupted as volcanic rocks. Thus, Wetherill comments, extensive recycling of crustal materials into the mantle through subduction processes may, in part, explain why the Earth remains volcanologically and tectonically active, while other terrestial planets like Mercury and the Moon have long been dead.

In contrast, studies of large-volume basalt eruptions just to the south of the Columbia Plateau by DTM postdoctoral fellow



The proposed crust and mantle structure of the northwestern United States, developed by DTM's Richard Carlson and William Hart from their geochemical study of basaltic volcanic rocks in the area. The upper part of the drawing is a surface map of the northwestern United States (state boundaries shown) depicting the Columbia River Plateau, the Oregon-Modoc Plateau, and the Snake River Plain. The cross-sections show subsurface structure beneath the lines *A–A′* and *B–B′*.

Low-K olivine tholeiites (*1*) of the Oregon-Modoc Plateau were generated by melting at shallow depth of incompatible-element-depleted "oceanic-type" mantle existing beneath the newly formed (younger than Paleozoic, <*Pz*) crust of the plateau. Basalts of the Columbia River Plateau (*2*) were generated in much the same manner, but compared to the Oregon-Modoc Plateau the lack of severe crustal extension led to ponding of the primary magmas near the base of the crust (cross-hatched regions). This ponding resulted in cooling and differentiation of the Columbia magmas prior to eruption, and allowed some of them to interact with the old (Precambrian, *PC*) crustal section existing beneath parts of the Plateau. Snake River basalts (*4*), the easternmost low-K basalts, and basalts with transitional chemical characteristics between these two (*3*) were generated by melting of an ancient (2.5-billion-year-old) incompatible-element-enriched subcontinental mantle region confined to an area underlying the Precambrian crust of the eastern margins of the study area.

William Hart, and by Carlson and Hart, fail to show isotopic evidence for the presence of recycled sediment in the volcanic source. However, there is a strong suggestion, especially in the data for the basalts studied by Hart, that an ancient (2.0–2.6 billion years) subcontinental mantle region enriched in the incompatible elements (Rb, Nd, and U, for example)—similar to that proposed by Boyd to exist beneath the African craton—is involved in the genesis of these basalts. On the basis of a very good correlation between geographic position of eruption and the isotopic compositions of the basalts, Hart concludes that this ancient enriched mantle is confined to an area roughly beneath the Archean continental boundary (approximated by the Oregon-Idaho state border). To the west, the crust may represent a very recent (less than 100 million years) addition to the North American continent. Further evidence of subcontinental mantle regions enriched in the elements generally concentrated in the crust comes from a study by Xinhua Zhou (a former visiting investigator to DTM from the State Seismological Bureau of Beijing) and Carlson on the Pb isotopic systematics of young basalts from eastern China.

Wetherill notes that the existence of enriched mantle regions beneath continents requires that more incompatible elements have been extracted from the mantle than has been supposed. If the enriched mantle exists in sufficient volume, then, much more than the often accepted one-third of the remaining mantle would have been correspondingly depleted in incompatible elements. It therefore becomes less likely that the 670-kilometer discontinuity known from seismology represents the boundary between depleted upper mantle and undepleted lower mantle.

Sulfur Isotope Geochemistry. The stable isotopes of the five elements sulfur, carbon, hydrogen, oxygen, and nitrogen (the SCHÖN, or "beautiful," system) present a unique set of tools to learn about both organic and inorganic processes under geological conditions. During the past decade, the Geophysical Laboratory has developed the capacity to measure the isotopes of C, H, O, and N. This year, a new mass spectrometer is being fitted with four detectors to measure simultaneously the ion beams of the four stable sulfur isotopes (^{32}S, ^{33}S, ^{34}S, and ^{36}S). Thomas Hoering has developed a method using BrF_3 as a fluorinating agent to produce SF_6 from sulfide minerals for the measurements.

The new capability will be used in various geological investigations. For example, in collaboration with John M. Ferry of Johns Hopkins University, Douglas Rumble and Hoering plan to measure sulfur isotopes in pyrite (FeS_2) and pyrrhotite

($Fe_{1-x}S$) from metamorphic rocks of the Waterville-Augusta, Maine, area. It appears that as fluid from nearby igneous rocks moved through this area, sulfur-bearing minerals slowly broke down, releasing sulfur and altering pyrite to pyrrhotite (a process called desulfurization). The investigators suspect that measurement of the S isotopes will provide evidence of this reaction. The study offers a unique opportunity to relate the pyrite-to-pyrrhotite transition and its accompanying isotope exchanges to understanding of fluid flow through rock during metamorphism.

Element Concentration in Magma Intrusions. Academic and exploration geologists alike are interested in understanding how a given element or mineral can be concentrated at a particular site within the Earth, sometimes to concentrations many times greater than the material's overall abundance in the crust. One mechanism for the formation of such concentrations is in the solidification of subsurface magma bodies, or intrusions, into successive layers of rock, each with distinctive chemical compositions. Important insights into the nature of the layering process in intrusions have emerged from studies in recent years by T. Neil Irvine, a petrologist at the Geophysical Laboratory.

In a recent paper in *Economic Geology* (November 1983), Irvine, D. W. Keith of Stillwater PGM Resources in Montana, and S. G. Todd of the same firm summarize their concepts explaining the formation of certain layered intrusions and how ore deposits have been concentrated therein. Their analysis is based on studies of the Stillwater Complex in Montana and the Bushveld Complex in South Africa. Fundamental to their view is a concept—previously offered by Irvine in studies of the Muskox Intrusion in northwestern Canada—whereby solid layers are formed not by the accumulation of settling crystals (as has traditionally been assumed) but rather by the crystallization of each layer from distinct, matching liquid layers. The theory rests heavily on experimental studies conducted at the Geophysical Laboratory and elsewhere; applying the theory to data from field observations (at places where intrusions have been exposed at the surface by erosion) provides a limited test of its validity.

The formation of zones enriched in the platinum-group elements (PGE) at Stillwater and the Bushveld is related to the incompatibility of PGE in the structures of most magmatic silicate and oxide minerals, and the enormous affinity of PGE for sulfide liquid. Irvine, Keith, and Todd note that intrusions that are open both to additions of fresh magmatic liquid and to removal of fractionated residual melt should be subject to enrichment in PGE provided that the magma has not reached saturation in sulfide liquid. (They believe that the Stillwater and Bushveld intrusions formed from the mixing of two parent magmas; the PGE were derived from the first parent, most of the sulfur from the second.)

The investigators then postulate that the Stillwater and Bushveld magmas underwent stratified convection. Numerous liquid layers crystallized into separate cumulate (rock) layers, while residual liquid was passed successively from level to level. In these circumstances, each liquid layer was itself effectively an open fractionating magma body, and enrichment effects may be amplified from layer to layer, possibly upgrading PGE concentrations by 1–2 orders of magnitude. Irvine *et al.* suggest that this effect is essential to the production of the extremely high PGE concentrations in the ore-zone sulfides when sulfide liquid eventually precipitated.

Opposite circumstances appear to have occurred at the Muskox, where Irvine has found PGE widespread in amounts of 5–300 ppb but no indication of enrichment to ore grades (20,000–30,000 ppb). Although sulfides form only small, local deposits in Muskox, they are on the whole much more conspicuous in small amounts than in either Stillwater or Bushveld. Thus it may be that ore formation failed to occur because the parent silicate magma became saturated with sulfide liquid early, so that sulfide precipitation occurred *before* the PGE could be substantially enriched by fractional crystallization.

Element Concentration in Aqueous Transport. Crustal rocks contain intergranular fluid consisting primarily of water but also dissolved compounds, such as NaCl, HF, CO_2, and KOH. This intergranular fluid is an important medium in processes of mineral dissolution, transport, and precipitation which result in element concentrations in the crust. The structural and thermodynamical properties of supercritical (high-temperature, high-pressure) aqueous fluids strongly affect these processes.

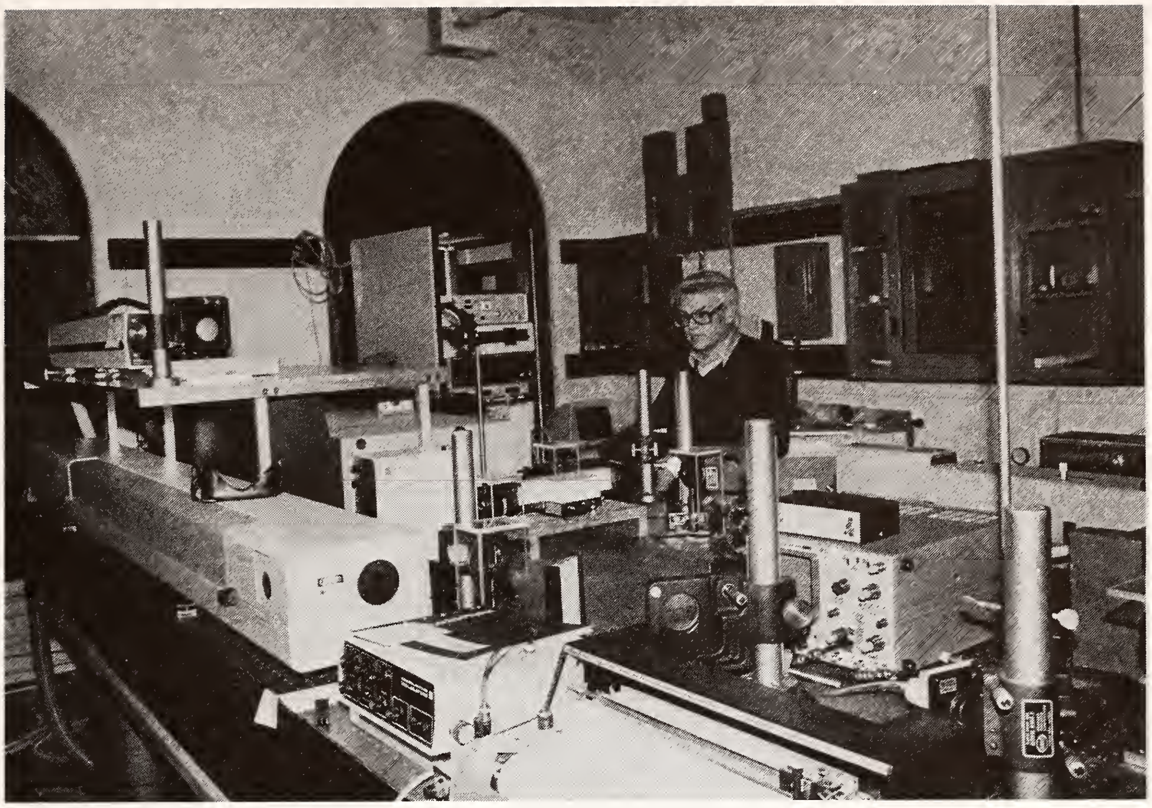
In developing structural models of aqueous intergranular fluids, John Frantz and William Marshall (Oak Ridge National Laboratory) pay particular attention to the ionization behavior of aqueous compounds. This study includes the measurement of a compound's ionization constant, which is the ratio of molecules to free-standing ions (for example, the ratio of NaCl to its constituent ions Na^+ and Cl^-), as well as determination of the numbers of solvation, which are the numbers of water molecules (from the host medium) that bind electrostatically to the charged ions. Frantz and Marshall this year examined solutions of potassium chloride, sodium carbonate, and sodium hydroxide at pressures up to 4 kilobars and at temperatures between 25° and 575°C. In the case of sodium hydroxide, they overcame previous difficulties by using zirconia rather than alumina as an electrical insulator. They find that as temperature increases and density decreases, ionization behavior changes dramatically. Ion pairing increases (i.e., more molecules are formed, fewer ions), the numbers of solvation decrease (i.e., fewer water molecules bond to ions), and mineral solubility increases.

From computations with these data, it is possible to calculate the hydrolysis constant for NaCl. At elevated temperatures and pressures, NaCl hydrolyzes (reacts with water) to produce molecular NaOH and HCl. This work is important not only in developing theoretical models related to element concentration but also in analyzing steam-generated corrosion in nuclear power plants.

Fluoride ions are common in aqueous fluids, and fluoride-bearing solutions play a significant role in the transport of ore-forming elements, especially in the formation of porphyry copper deposits. Frantz and postdoctoral fellow Mark Barton calculated thermodynamic properties of dissolved KF and NaF. One of these properties, the free energy of formation, is used to calculate equilibrium constants and hence relative stabilities of minerals in a fluid solution. These data are essential in modeling ore-forming fluids because gangue mineral assemblages (the worthless minerals associated with an ore) commonly buffer the fluid composition, and thus control transport and deposition of ore minerals.

Structure of Liquids and Glasses. Researchers at the Geophysical Laboratory have for several years been investigating the structures of molten silicates. Knowledge of the structures (i.e., the unit arrangements of atoms and their bondings) is needed for understanding the important role of molten rock, or magma, in heat- and mass-transfer processes within the Earth and terrestrial planets. Once known, the structures of a melt can be used to calculate liquid properties and liquid-crystal equilibria under infinite combinations of composition, pressure, and temperature. Thus, by means of experiments at the structural level—a level of detail rarely studied in liquids until recently—the researchers are developing fundamental insights into such questions as how melts are generated, how igneous rocks are formed from melts in nature, and how melts are transported by infiltration through the largely solid material of the Earth's crust.

Until several years ago, most scientists believed the atoms of silicate liquids (molten rocks) to be in random configuration,



David Virgo in the Raman spectroscopy lab at the Geophysical Laboratory.

having no discernable systematics in structural arrangement. The existence of systematic structural features in liquids, with similarities to those in crystals, was not appreciated, and until the application of recent spectral methods to such questions, liquid structures were not profitably studied.

In about 1977, the research interests of two Geophysical Laboratory scientists converged. David Virgo, who worked with iron-bearing minerals, and Bjørn Mysen, interested in the chemistry and physics of crystal-liquid interaction, began collaborating in systematic investigations of the structures and properties of silicate melts, and in applying these properties to igneous processes. In experiments with liquids or with their quenched "equivalent" glasses, Mysen, Virgo, and various colleagues employed the array of modern spectral equipment assembled in recent years at the Laboratory to obtain detailed structural information.

They soon confirmed that liquid structures have some of the same building blocks found in crystals, though without the latter's extensive repeating configurations and long-range order. Like their crystalline counterparts, silicate liquid structures typically contain many tetrahedral (pyramid-shaped) entities of four oxygen atoms equidistant from a central cation such as Si, Al, or Fe^{3+} (i.e., the SiO_4 configuration). Each oxygen atom may "bridge" to, and thus be a part of, an adjoining tetrahedron, thereby forming a link in a network of tetrahedra. Such combinations of tetrahedra form a structural unit. Or an oxygen may be "nonbridging," by bonding to a network-modifying cation in a different type of unit—octahedral perhaps. The nonbridging oxygens thus form the boundaries of structural units. Mysen and Virgo explored the proportions of different types of units in liquids, the lengths and angles of the bondings, and relations between structure and properties.

Observing that the structural roles of iron appeared to be important in defining properties of liquids, Virgo and Mysen began to look closely at this little-understood phenomenon. In Raman, Mössbauer, and other spectral investigations on critical iron-bearing systems, they succeeded in observing how ferric iron (Fe^{3+}) and ferrous iron (Fe^{2+}) function as network formers and network modifiers under various conditions, and in measuring the presence of ferric and ferrous iron as a proportion of total iron in the liquid. They sought correlations between measured values of the ratio Fe^{2+}/Fe^{3+} and what was previously known about the rest of the liquid structure; especially, they explored how temperature, pressure, oxygen activity, and overall chemical composition (the essential parameters in igneous petrology) are related to this seeming crucial ratio. They now offer a general model of the structure of magmatic liquids, one that also explains the structural state of iron in silicate and aluminosilicate liquids.

From their varied spectral data, they show that in oxidized glasses (where Fe^{3+} predominates over Fe^{2+}) the Fe^{3+} is tetrahedrally coordinated. Under the same oxidizing conditions, the spectra indicate that the Fe^{2+} ions are all in octahedral coordination. In contrast, in reduced glasses (where Fe^{2+} predominates) the Mössbauer results are consistent with varying proportions of tetrahedrally and octahedrally coordinated Fe^{3+}, whereas the Fe^{2+} remains octahedrally coordinated. A significant proportion of the iron occurs as amorphous iron-rich clusters with certain properties resembling those of inverse spinels (e.g., Fe_3O_4), and as isolated Fe^{2+} and Fe^{3+} ions. At dilute Fe^{3+} concentration, the ferric iron is wholly octahedrally coordinated.

Virgo and Mysen found Fe^{2+}/Fe^{3+} to be a simple function of $Al/(Al + Si)$ and to decrease linearly with increasing $Al/(Al + Si)$ at fixed temperature, oxygen activity, and proportion of nonbridging oxygens. The Fe^{2+}/Fe^{3+} also decreases systematically with increasing melt basicity, and depends on the types of network-modifying cations. (The ratio is comparatively low in Na^{+} systems, intermediate in Ca^{2+} systems, and high in Mg^{2+} systems.) Interpreting the structural implications of these now-established empirical relationships, Mysen and Virgo then demonstrated how to calculate Fe^{2+}/Fe^{3+} over the known compositional range of igneous rocks. As a result of these calculations, Mysen and Virgo illustrated the sensitivity of the paths of fractional crystallization in a magma to Fe^{2+}/Fe^{3+}. The work also provides an experimental basis for interpreting the dependence of melt viscosity on Fe^{2+}/Fe^{3+}. In addition, having observed an increase in Fe^{3+} in plagioclase with increasing oxygen activity, Virgo and Mysen suggested that the partitioning of iron has potential as an oxygen barometer in igneous processes.

The coordination shift of Fe^{3+} from tetrahedral to octahedral with reduction of a magma may result in changes of the crystal-liquid partition coefficients of some geochemically important trace elements. In several experiments this year, Virgo and Mysen measured the crystal-liquid partition coefficients of Ba and Sr in the system diopside-anorthite; they detected essentially no change over a wide range of Fe^{3+} as a proportion of total iron, within the sensitivity of their proposed melt-structure model. On the other hand, they found indications of significant effects in experiments with transition metals Ni and Ti. The difference may be related to the suggestion that transition metals like Ti and Ni can complex with the iron-bearing structural units; thus, their activity in the silicate melts depends systematically on the proportion of iron-bearing units. These results also lead toward understanding why many petrologically important major, minor, and trace element mineral-melt partition coefficients are sensitive functions of the chemical composition of the melt.

Numerical Modeling of Transfer Processes. Thermal and chemical diffusion are important mechanisms for the transfer of heat and mass in earth processes. Diffusive heat flow, for example, which requires no movement of material, is an important mechanism in a cooling liquid intrusion or in the transfer of heat through the Earth's crust. Chemical diffusion can be the rate-controlling process during the growth of crystals in a solidifying magma or during the alteration of rocks in contact metamorphism. Modeling of such transport phenomena requires experimental data concerning rates and the theoretical solution of the governing transport equations.

Postdoctoral fellow Gregory Muncill has been working at the Geophysical Laboratory to solve the linear equation for diffusive heat transfer with no sources or sinks of heat. Applying results from heat-transfer experiments by Hatten S. Yoder, Jr., Muncill has inserted geological boundary conditions (such as where a magma intrusion contacts cooler surrounding rock) more reasonable than those used in previous models. Staff member Larry Finger has helped with the theoretical analysis and has developed the computer programs needed to estimate the variable parameters of the experimental data and test the validity of the models generated. One of the principal advances has been in the characterization of the temperature rise through a boundary, for example at the contact of an intrusion.

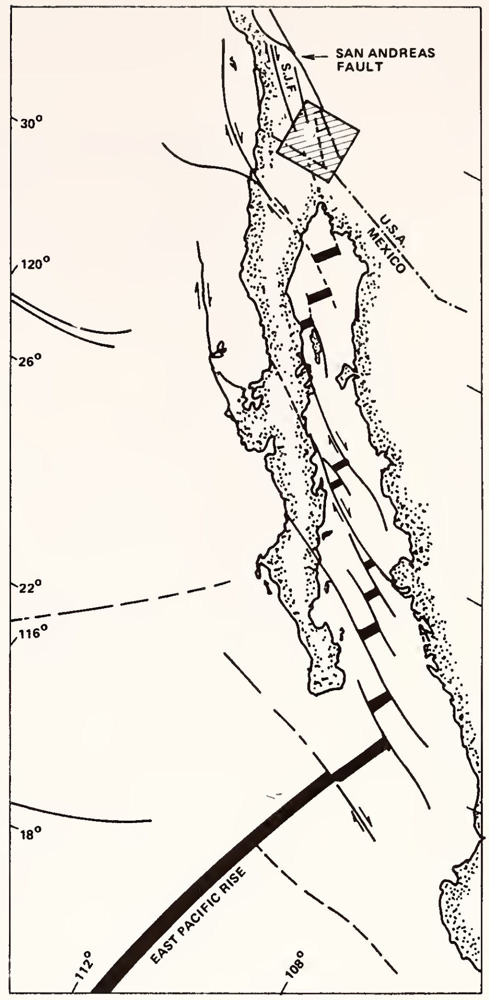
Another of Muncill's goals is to develop, through various numerical techniques, a model for coupled multicomponent diffusion in silicate melts. By integrating experimental diffusion data with such mathematical models, it may become possible to describe mass transport across boundary layers in igneous systems. These boundary layers can be at the micrometer scale during crystal growth or at the meter scale across boundaries in a convecting magma chamber. The ultimate goal will be to model *simultaneous* heat and mass transfer within large-scale boundary layers in melts.

Seismological Investigations. From early in the Institution's history, Carnegie scientists have been leaders in studying earth structure by means of the seismic signals produced by earthquakes or explosions, and in studying the earthquake process itself. In recent years, the seismology group at DTM has made scientific contributions ranging from studies of the Earth's core and mantle to analyses of the rupture characteristics of earthquakes and localized earth deformation. The latter work, which promises to aid in earthquake prediction, employs data collected over extended periods by subsurface strainmeters—sensitive instruments designed and developed at DTM.

Paul Silver of DTM has proposed a new method for extracting information from seismic data. Although it has been known for some time that seismograms contain information on the physical dimensions of earthquakes—the length, width, and duration of faulting, and the rupture-propagation characteristics—even a simple description of such properties of a given earthquake has been surprisingly difficult to obtain. Silver's method is based on a statistical measurement of the duration of the body-wave signal generated by the earthquake and recorded at dispersed stations.

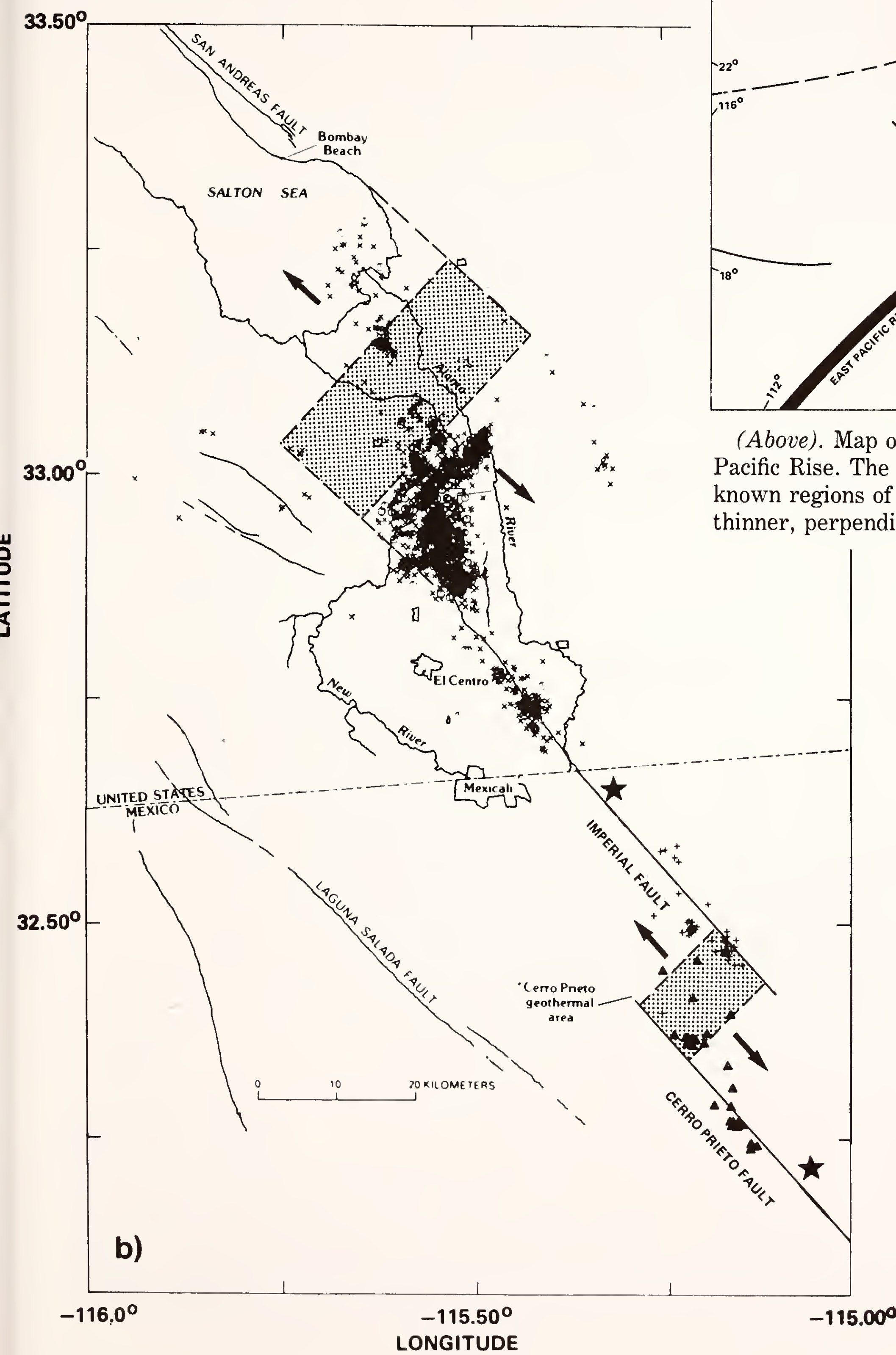
This year, Silver and DTM postdoctoral fellow Tetsu Masuda set out to test the method. They applied it to two shallow (6-kilometer-deep), moderate-sized earthquakes occurring at the southern end of the San Andreas fault system—the 1979 Imperial Valley earthquake on the Imperial Fault, California (magnitude 6.9), and the 1980 Victoria earthquake on the Cerro Trieto Fault, Baja California (magnitude 6.5), which occurred eight months later and 50 kilometers to the south.

The Imperial Valley earthquake has been thoroughly studied by other investigators and thus represents an interesting



(Above). Map of the northern end of the East Pacific Rise. The thick line segments represent known regions of sea-floor spreading, and the thinner, perpendicular lines are transform faults.

(Below). Expanded map of the box region of adjacent map. The two stars show the locations of the Imperial Valley earthquake of 15 October 1979 on the Imperial Fault, and the Victoria Earthquake of 9 June 1980 on the Cerro Prieto Fault. The smaller symbols are epicenter locations of seismic events. Analysis of these events by Paul Silver of DTM leads him to propose that spreading events took place in the stippled regions, in the directions of spreading shown by the arrows. Silver's evidence suggests that the Imperial, Cerro Prieto, and San Andreas Faults are on-land transform faults associated with the East Pacific Rise.

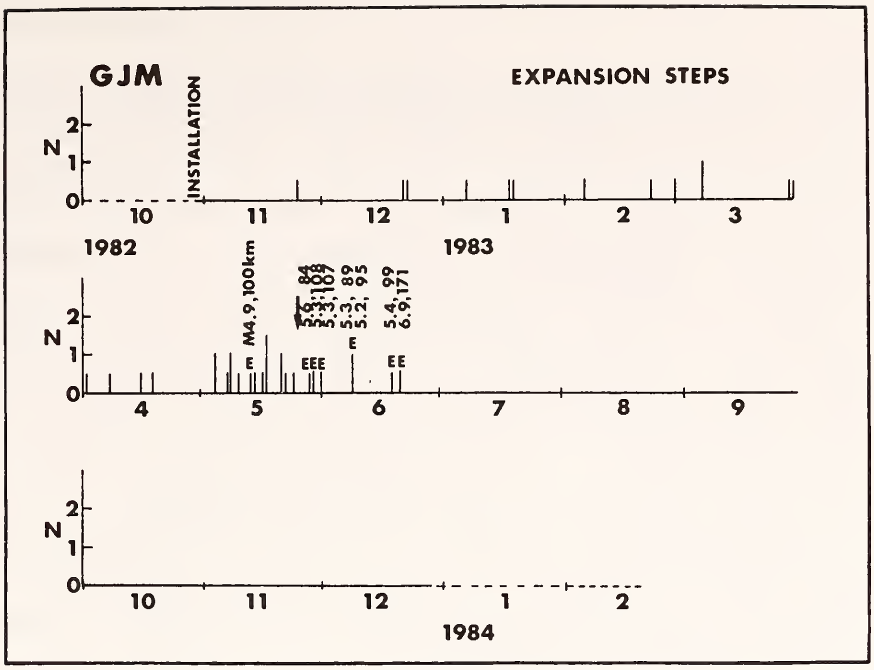


test of the new method's potential. Surprisingly, Silver's results differed significantly from those of earlier investigators. His analysis confirmed the well-documented faulting that extended from the Mexican border northward into the Imperial Valley; but in addition, Silver found evidence of previously unknown faulting southward into Baja California, very close to the region of the second earthquake. This finding has now been confirmed by previously unconsidered seismic data collected close to the southern component of faulting. Silver's discovery of a first-order feature that had previously been overlooked indicates that his technique is a powerful tool, one applicable not only to other shallow earthquakes but also to deep earthquakes (deeper than 100 kilometers), about which very little is known.

The discovery of the southern component of faulting suggests that a much closer and perhaps causal relationship links the two earthquakes. The region is thought to represent an on-land extension of the East Pacific Rise, an oceanic spreading center where the North American and Pacific plates are being generated. The two earthquakes then can be viewed as the failures of two adjacent faults associated with spreading on the East Pacific Rise. Currently being examined is the possibility that a spreading event has occurred in the region between the two earthquakes and/or farther north, between the Imperial and San Andreas Faults. If verified, the area would become only the third place on Earth where active on-land spreading has been observed. (The others are in Iceland and Afar, Africa.)

Meanwhile, Alan Linde and I. Selwyn Sacks of DTM, with Shigeji Suyehiro of the Japan Meteorological Agency, have made a new analysis of strainmeter and surface-uplift data for the interval between the 1978 and 1980 Izu peninsula earthquakes in southeastern Honshu. The strain changes were recorded in the regional network of strainmeter instruments monitored by the Japan Meteorological Agency. The new analysis significantly alters earlier views of the events, and illustrates that erroneous conclusions can result when analysis is based only on uplift data with partial areal coverage. (Often, such information is all that geophysicists have, since many earthquake-related events occur offshore.)

From the coherence of the strain signals over a large area and the correlation of these changes with the substantial increase in seismic activity, it is apparent that a major readjustment of stress has occurred in the Earth over the two-year period under study. Three possibilities are now being considered to explain the observed data: (1) upward motion of nearby vertical sheets of magma originating beneath Oshima island, an active volcano near the Izu peninsula (a dyke se-



Incidence of expansion strain signals recorded at station GJM in northern Honshu, from the date of installation in October 1982 to the start of 1984. The strain events increased slightly in frequency of occurrence during the first six months of recording. A dramatic increase took place in the month preceding the large, 7.7-magnitude earthquake of 26 May 1983 (marked by arrow), 80 km away under the Japan Sea. The strain events continued, at lower frequency, for another month during the large aftershocks. After June 1983, no more strain events were recorded. K. Suyehiro of Tohoku University and DTM's Selwyn Sacks and Alan Linde note that the signals appear to have been precursors to the earthquake.

quence), (2) a large, slow earthquake on the Philippine Sea plate–Eurasian plate boundary, which lies beneath the region, and (3) a rebound episode associated with subduction of the Philippine Sea plate near Izu.

Probably equally important but presently less well understood are "bumps" seen in the strainmeter output obtained at the coastal station in northern Honshu in 1982. The rate of occurrence of these unusual strain signals increased dramatically just before the 7.7-magnitude earthquake in the Japan Sea about 80 kilometers away. The unusual strain signals became less frequent after the earthquake, and none have been seen since the last large aftershocks. They appear to have been precursors to the earthquake.

Somewhat similar signals are now being recorded in southern Iceland at strainmeter stations near a transform fault on the Mid-Atlantic Ridge. (The Ridge lies above sea level in this region, which is very active tectonically.) From comparison of recent seismic and volcanic activity with the historical record, the DTM seismologists believe that a significant episode of tectonic activity (with seismicity and volcanism) may occur in the region instrumented. Indeed, a volcanic eruption occurred in the area since installation of the strainmeter net in 1979, and the associated strain changes were recorded on all instruments. The recorded data led to a model confirming the view that the region is undergoing an increase in stress. More-recent strain signals are much larger than the similar signals recorded in Honshu, possibly because the instruments are closer to the region undergoing tectonic changes. Although at present it is not possible to determine the source of the signals, all of the data together are consistent with the original view that southern Iceland is now undergoing major readjustment to the forces driving seafloor spreading.

The strain signals recorded in Iceland and Honshu represent new and clear observations of stress redistribution, and they may provide important clues to seismologists in their quest to understand the earthquake generation process.

Biogeochemistry

> The opening of this field has been preceded by a long period of pioneering studies, many of which were undertaken by the staff of the Geophysical Laboratory. Recognition of the potential of the new tools and methods has been followed by the demand for investigators trained not only in geology but also in the more advanced specialties of the biological sciences. Biogeochemists may soon become commonplace in university rosters.
>
> Hatten S. Yoder, Jr.
> July 1984

The physical and biological sciences come together in the fast-growing field of biogeochemistry, where scientists are interested in the influence of living organisms and organic material on the physical Earth. Present-day biogeochemical techniques open to investigation a number of fundamental questions in the earth sciences.

Organic matter present in sedimentary rocks can offer "fingerprints" for tracing ore sources and various processes in these rocks. Such associations are being exploited by postdoctoral fellow Andrew Giże, who has adapted techniques commonly used in the petroleum, coal, and coking industries. Giże has observed changes in organic matter found in ore deposits—increased compositional homogenization, greater thermal maturity, and greater structural order. Recently, he compared textures in bitumens (organic materials found in rocks) from Nanisivik, Canada, and Kongsberg, Norway. Results provide further measures of the thermal history of such rocks and give evidence of migration patterns during ore formation. His experiments are among the first using petrographic techniques (those normally associated with hard, crystalline rock), coupled with spectroscopy and analytical chemistry, to investigate organic material in ore deposits.

While Giże views such questions petrographically, Thomas Hoering has used an approach from organic chemistry. There are reasons to believe that certain materials in low-temperature ore deposits migrate in the form of metallic ions combined as complexes with organic matter. Some such metallo-organic compounds are known from sediments—the vanadium and nickel porphyrins found in petroleum are classic examples. (Porphyrins are the end products of the transformation of chlorophyll, the green pigment in leaves responsible for their light-gathering function. In a living leaf, chlorophyll binds with the magnesium ion, but after deposition in a sediment, chemical transformations take place, and magnesium is leached out and replaced by vanadium and nickel.) It is reasonable to inquire if porphyrin complexes of other metals could be involved in deposition of low-temperature ore deposits in sediments.

Using the "hydrous pyrolysis" method that he developed last year, Hoering attempted to prepare porphyrin complexes of divalent metal ions (such as Co, Cu, Be, Pb, and Zn ions) under simulated geological conditions. But even though sediments were heated with large excesses of these ions, only Ni and V porphyrins were found in the products. Apparently the complexes of the other ions are not stable enough to persist under the experimental conditions, and are therefore unlikely candidates as carriers in low-temperature ore solutions. Currently, Hoering is studying the metallo-binding, or chelating,

A key stage in the thermal transformation of organic compounds to structured and compositionally homogeneous forms is the formation of a mesophase. Last year, Geophysical Laboratory postdoctoral fellow Andrew Giże and his colleague Sue Rimmer of Penn State University recorded the first discovery of mesophase in a geological setting. The microphotograph, above, is of thermally altered petroleum residues from a lead-zinc mine in Baffin Island, Canada, viewed on the surface of a polished sample with reflected light. The mesophase appears as the rounded globules.

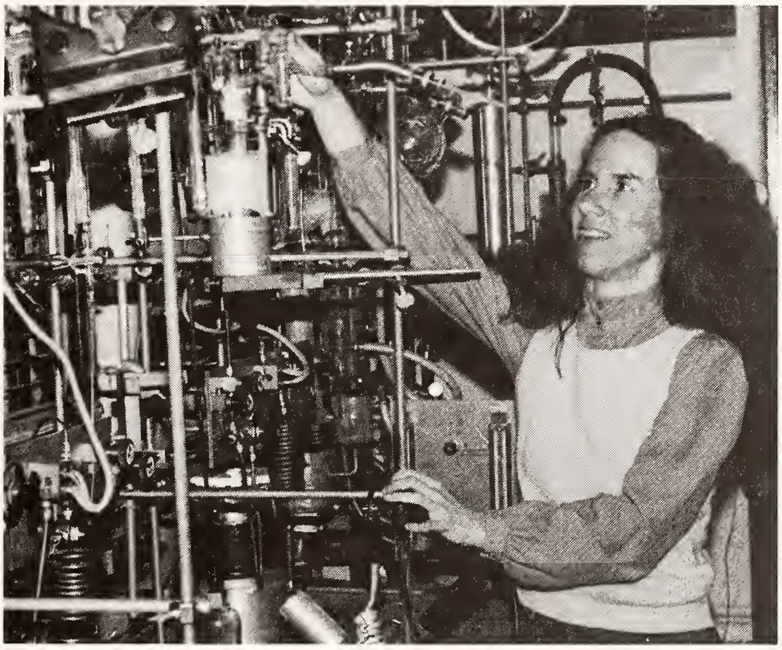
potential of other kinds of sedimentary organic matter—the naphthenic acids, for example.

Hoering has collaborated with the DTM-Penn group (see p. 79) in investigating a surprising recent report on the presence of cosmic-ray-produced ^{10}Be in ancient petroleums. Because the half-life of this radionuclide is 1.5 million years, it should have decayed away and become undetectable in material older than 15 million years. Examination of sixteen crude oils produced from Miocene-aged reservoirs (older than 20 million years) disclosed three samples from the Lake Maracaibo region of Venezuela with high and easily detectable concentrations of ^{10}Be. By measuring the molecular constitution of the saturated hydrocarbons in these three petroleums, Hoering found that they had been severely biodegraded. The linear and slightly branched molecules had been consumed by aerobic microorganisms. These crude oils from Venezuela are also well known for their high concentration of Ni and V porphyrin compounds, for their high asphalt content, and for the exceptionally high ash content upon combustion of the asphalt.

It is tempting to speculate that the ^{10}Be, the aerobic bacteria, and the metallic constituents found in the ash were added late in the history of these crude oils, presumably by a flux of surface water during migration of the oil from the primary source beds into the reservoir. It is known, however, that the ^{10}Be brought to the Earth's surface in rain is rapidly and strongly sorbed by mineral surfaces in soils and sediments and would not be readily transported by fresh water. The origin of ^{10}Be in crude oils remains unknown.

The organic material preserved in sediments is only that small fraction of organic matter (about 0.01%) escaping the dynamic biological cycle. This small percentage ends up as inert, high-molecular-weight material—humic acid and kerogen, which are very complex and little understood. The complicated process whereby organic material degrades and chemically transforms into kerogen and humic acid is called diagenesis. This year, Geophysical Laboratory guest investigator E. Kent Sprague, with Giże and staff member Marilyn Estep, examined the early diagenesis of organic matter in the very productive ecosystems of coastal salt marshes. By isotopic analysis, pyrolysis–gas chromatography, and optical microscopic methods, they deduced the relative contribution of terrestrial plants and phytoplankton to the muds. They found that the organic matter of plants, except the persistent long-chain waxes, had been quickly degraded, whereas the organic material of the phytoplankton had been polymerized to form biologically resistant humic acids. Eventually, it may be possible to determine quantitatively the proportion of recycled and preserved material in such organic deposits.

(Right) Mats of the sulfur-oxidizing bacterium *Thermoproteus*, growing at a temperature of 85°C in Big Creek Hot Springs, Idaho.



Biogeochemist Marilyn Estep preparing a sample of a thermophilic microorganism from Yellowstone for isotope analysis. In her studies of algae and bacteria that thrive in water at near-boiling temperatures and high acidity, Estep is gaining understanding of the nature of the microorganisms that first populated the Earth.

Estep is also engaged in a long-term study of the thermophilic microorganisms that thrive in the hot springs of Yellowstone National Park. These algae and bacteria present a unique opportunity for inferring the nature of the microorganisms that first populated the Earth.

In their natural environments, thermophilic microorganisms can withstand water temperatures up to 95°C and high, corrosive acid levels (pH = 1). Estep and her colleagues at the Laboratory are investigating the subtle differences in protein structure that result in this strong resistance. They find that high concentrations of hydrophobic amino acids and strong peptide bonds formed by valine, leucine, and isoleucine probably caused the resistance.

In much of her research, Estep uses measurements of the stable isotopes of carbon, hydrogen, and nitrogen. Because various enzymatic reactions (such as nitrogen fixation, photosynthesis, and sulfate reduction) produce distinctive isotopic compositions in organic material, these isotopes can serve as tracers in delineating the physiology and biochemistry of organisms. Estep plans to make early use of the sulfur-isotope techniques being developed at the Laboratory (see p. 83). Among the microorganisms growing in the Yellowstone springs are the S-oxidizing and S-reducing bacterium *Thermoproteus*, which grows in boiling water at neutral acidity, and the aerobe *Sulfolobus*, which grows in boiling water at high concentrations of sulfuric acid. Some of the microorganisms in the Earth's early history were S-oxidizing and S-reducing species. It will be interesting to learn if pyrite in ancient sediments retains the sulfur isotopic signature of these modern Yellowstone species.

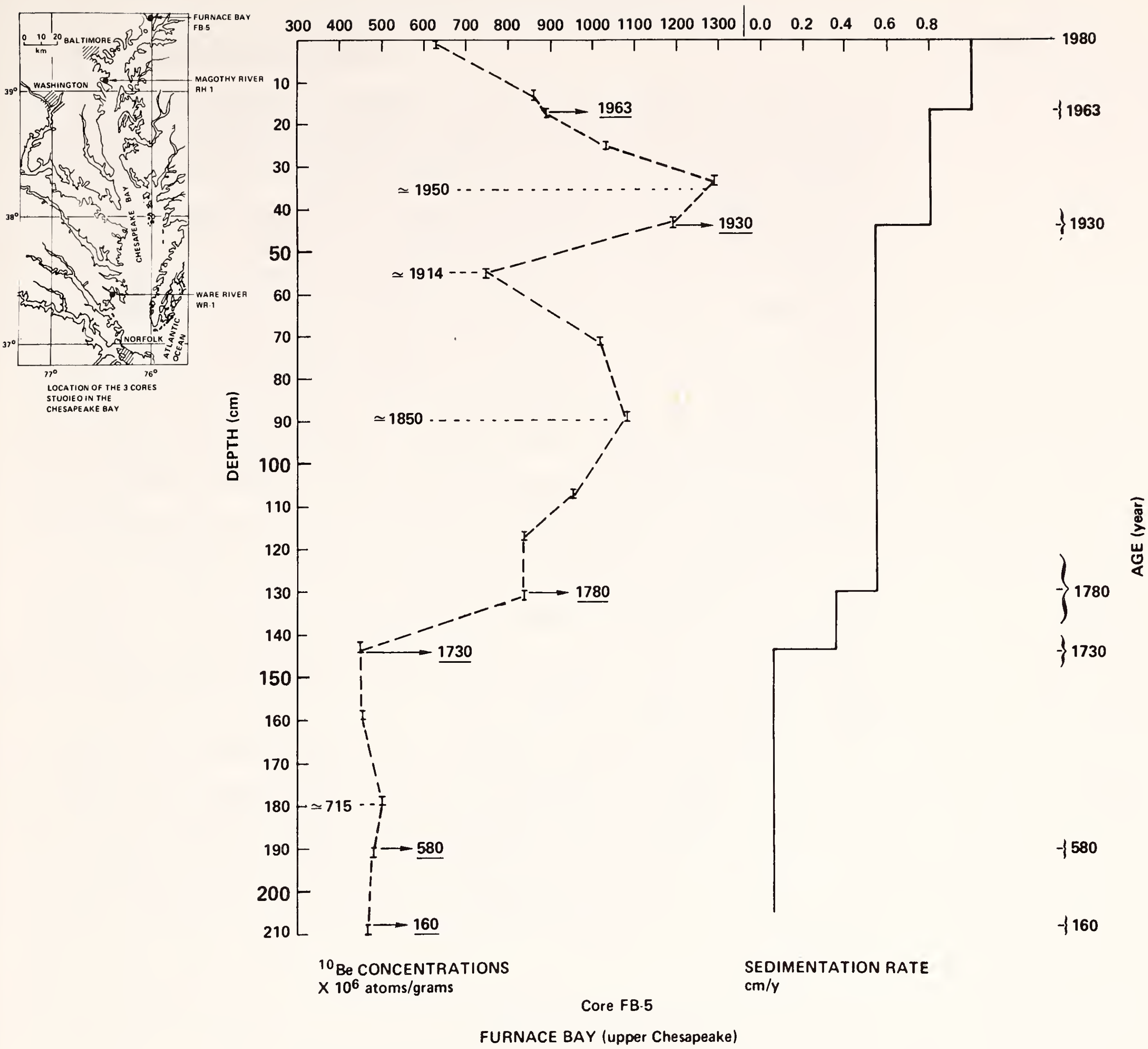
^{10}*Be Studies of Surface Erosion*

Scientists have made an important beginning in studying the building of the continental land masses by inner-Earth processes. Better understood has been the opposite phenomenon—the continual removal of surface crust by weathering and erosion. By themselves, these destructive processes would reduce the continents to sea level within a few hundred million years.

Quantitative measurement of erosion has been difficult, however, particularly the determination of the rate of erosion at a given location. Nathalie Valette-Silver, Louis Brown, and Fouad Tera of DTM, in collaboration with Milan Pavich of the U.S. Geological Survey and Roy Middleton and Jeffrey Klein at the University of Pennsylvania, have carried out a number of studies where erosion rates are obtained by measuring ^{10}Be concentrations in soils and sediments. Their method is based on the principle that most soil formations are old enough to have reached a steady-state balance between the rates of ^{10}Be deposition in rainfall and its removal by erosion and radioactive decay. The radioactive decay constant is known, and the deposition rate is becoming more accurately known from measurements of ^{10}Be in rain; measurement of the steady-state concentration thus permits calculation of the erosion rate.

The investigators have applied the method to determine rates of erosion at three localities in the Maryland piedmont. Their results agree with presumably cruder estimates based on the present elevations of the sites.

In another study, the same workers, in collaboration with Grace Brush of Johns Hopkins, have combined various techniques to investigate the history of erosion during the past 2500 years in the Chesapeake Bay. Using measurements of ^{14}C, ^{137}Cs, and ^{10}Be concentrations and pollen analyses in



^{10}Be measurements and the historical erosion of surface soils in the Chesapeake Bay area. DTM's Nathalie Valette-Silver and colleagues are detecting evidence of events that increased erosion over the last 300 years by measuring ^{10}Be concentrations as a function of depth in the sediments of bay tributaries.

The small map at left shows the location of the cores recently analyzed by the group.

Shown at the left of the diagram are values of ^{10}Be concentration (in millions of atoms per g) vs. depth for a core collected at the mouth of the Furnace Bay tributary. The underlined numbers are the historical dates, from measured ages; the dates not underlined were obtained by extrapolation. At the right are plotted the derived sedimentation rates vs. depth and historical date.

three cores of sedimentary material taken from rivers feeding the bay, the investigators calculated sedimentation rate and changes in local vegetation over time. The pollen analyses of the sediments reveal an increase of herbaceous pollen (e.g., ragweed) over tree pollen during the last 300 years; associated with these changes are sharp increases both in ^{10}Be concentration and sedimentation rate.

The pollen changes correspond to two agricultural horizons, interpreted by Brush to be the introduction of European farming techniques and forest clearing at the time of (1) initial settlement and (2) the start of intensive cultivation—the years 1650 and 1840 in the southern region, 1730 and 1780 in the northern. The higher sedimentation rates at these times indicate strong increases in sediment transport and presumably soil erosion, and, since previous work shows that ^{10}Be is enriched in top soil, the increases in ^{10}Be apparently result from increased erosion and transport of ^{10}Be-rich soils previously formed under forest cover. After about 1860—represented in the upper parts of the three cores—a generally decreasing trend is seen in ^{10}Be concentration, while the sedimentation rate increases. A simple explanation is that ^{10}Be-poor soils, presumably located lower in the column, are being eroded. Some increases in ^{10}Be concentration are evident prior to the European settlements; these are difficult to interpret because of the low sedimentation rate registered at that time, but they could be associated with the loss of forest cover because of fires or other natural phenomena.

The work demonstrates the potential usefulness of ^{10}Be profiles, along with sedimentation rate data and pollen analyses, for understanding the erosion process. It also reveals the effect of human activities on erosion, thus permitting evaluation of natural rates during geological history prior to human intervention.

Leadership in Collective Ventures

Every subdiscipline consists of a worldwide community of scholars who both cooperate and compete in research. The arrangement assures the advancement of knowledge while allowing scope for personal achievement and reward. Occasionally, the customary individualistic patterns of research are set aside, when a group of investigators organize themselves and their resources to attain some research purpose likely to benefit all. This year, Carnegie Institution earth scientists are providing leadership in organizing three such endeavors.

An Inverted Telescope. Older discussions of the continents often involved reconstructions based on surface geology and were expressed in terms of recognizable surface features such as collisional and accreted terranes, suture zones, and transform faults. There has been in the last two decades an astonishing revolution in understanding how continents evolve. In plate tectonic terms, the structures and compositions of continents are described as results of dynamical and chemical processes taking place over billions of years within the Earth. Further advances in understanding of the continents require an ability to "see" downward into the crust and upper mantle at much greater resolution than has been yet achieved.

A major new initiative has been taken this year at DTM. The idea is to build a capability to obtain seismological "images" of the Earth's interior by means of an array of seismic instruments. The instrument array will be mobile, and is to be positioned at locales and in layouts specific for viewing particular subsurface earth regions. The "inverted telescope" will record seismic waves from earthquakes or explosions. The system will include considerable data-recording and data-processing equipment, for operation in both field and laboratory.

David James and Selwyn Sacks have used Carnegie seed money to convene initial organizational meetings, looking toward establishing the new venture on a national scale. Carnegie is also temporarily acting as lead institution for implementing this program in "lithospheric seismology."

Initial emphasis lies in developing a new generation of versatile, portable seismograph systems, featuring microprocessor-based "intelligence." When used in large numbers (1000 or more) in densely packed arrays, the instruments will improve the "seeing" of subsurface structure by a factor of ten or more. That critical increase in resolution will provide the technical means for unlocking major geologic puzzles. Meanwhile, the versatility of the instruments, particularly their ability to examine signals and determine whether or not they should be recorded, and over what frequency band and dynamic range, will open a wide range of studies not now readily possible. Development of the new seismograph is being carried out by an instrument design team chaired jointly by Sacks and R. P. Meyer of the University of Wisconsin, with representatives from the academic community and seismograph-manufacturing companies.

As the coordinator of the national program, James has been working to prepare a long-range scientific plan. In addition, he is developing at DTM a capability for the computer analysis needed to convert the seismic observations to high-resolution imaging and tomography of the Earth's interior.

The initiative is expected to develop into a major national effort, primarily supported by federal funds, to rival national facilities in other areas like optical and radio astronomy. George Wetherill writes that the Institution's scientists expect to participate in the future scientific program, whose start was assured in large measure by the seed funds made available by the Institution. The effort, he concludes, represents a potentially highly rewarding scientific venture.

Mineral Energetics: A Systematic Approach. Earth scientists have not yet succeeded in integrating the complex interrelationships among mineral structure, bonding, physical properties, and thermochemical parameters. Traditionally, an investigation of a mineral has exploited a single method—determination of crystal structure, calorimetry, or study of spectral response to a given radiation. Yet all the approaches can contribute to understanding why a specific structure exhibits certain observed physical and thermochemical properties. Forging a new style of approach, scientists at the Geophysical Laboratory have instituted a venture in cooperative and interdisciplinary research—one that will exploit the wide array of talent and experimental equipment at the Laboratory and will enlist the collaboration of workers and institutions elsewhere.

Robert Hazen at the Laboratory has taken the initiative in organizing a consortium, one also involving UCLA, Virginia Polytechnic Institute and State University, and SUNY Stony Brook. The planned program of investigation is both tightly focused (in specifying the materials and conditions to be studied) and wide-ranging (in its use of many research methodologies). The collaborators plan to study a well-characterized suite of related minerals in the system BeO-Al_2O_3-SiO_2. This suite consists of ordered, stoichiometric compounds that occur in large, single crystals with elements of low atomic number.

Each of the phases in the system will be examined with at least five different techniques. Crystal structures will be measured by x-ray crystallography at cryogenic temperatures, as well as at simultaneously high temperatures and pressures. The resulting equation-of-state information will be augmented by elastic-constant measurements with ultrasonic and Brillouin-scattering techniques. Raman and infrared vibrational spectroscopy will be performed on all samples. The heat capacities thus derived will be compared with calorimetrically determined thermochemical properties. Computational quantum chemistry will be used to derive bond-force constants, which in turn will be used to calculate from first principles vibrational frequencies, elastic moduli, and thermochemical properties.

Hatten S. Yoder, Jr., director of the Laboratory, comments that this broad-based approach to the properties of a targeted minerals group—the first of its kind—should result in valuable, internally consistent data sets on a chemically related suite. The project should lead to more-precise prediction of mineral behavior within the Earth; perhaps of equal importance, Yoder notes, the effort should provide an example for similar approaches in the future to mineralogical (and materials science) investigations.

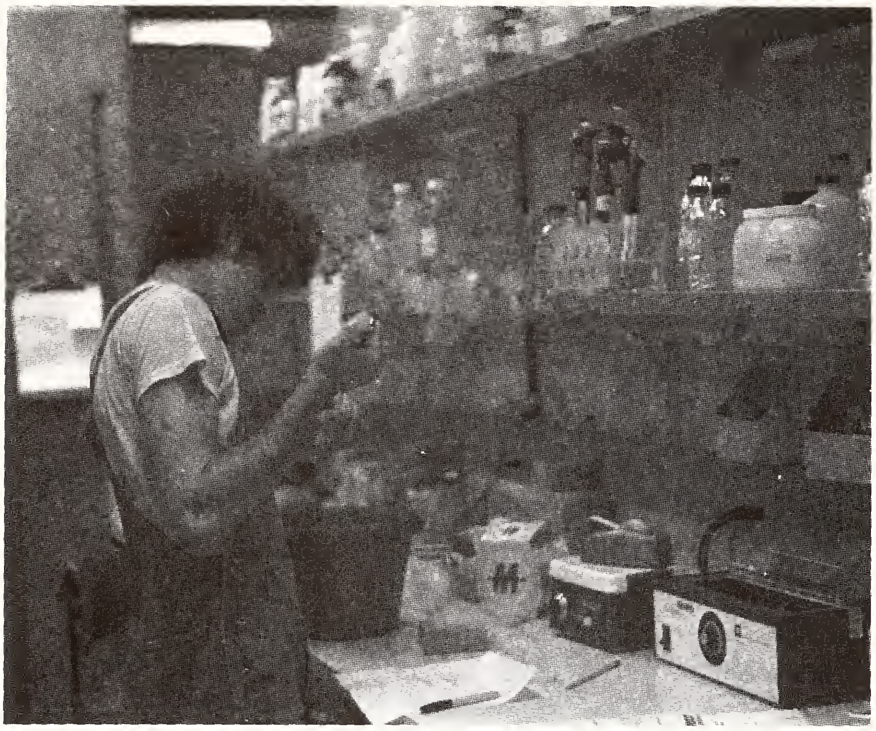
A Data Base for Igneous Petrology. The data explosion in descriptive petrography that began after World War II continues at an accelerating rate. Petrologists worldwide are collecting more and more information, including information of more and more different kinds, such that the accumulation defies effective organization by traditional scholarly procedures. Yet, little systematic advantage has been taken of the remarkable developments in electronic data storage and retrieval. In recent years, much of the work of Felix Chayes of the Geophysical Laboratory has been in developing means whereby petrographers can systematically use modern computational techniques, not only for storage and retrieval but also for extracting and using pertinent chemical, petrographic, and mineralogical information.

The International Geological Correlation Project, chaired by Chayes, is pioneering in the design and development of a world data base for igneous petrology. This year, the group made its first major deposit of information for public use at the world data center in Boulder, Colorado. Chayes, in order to strengthen the public's ability to exploit this large and heterogeneous data base, has been refining a method for improving the efficiency of matching operations used in data extraction. He has also developed methods for working with samplings of large data arrays, including techniques of particular interest to petrologists.

Professional Activities

The Educational Roles

The training of young scientists for productive careers in research is a foremost function of each department. Generally speaking, postdoctoral fellows and students work on their own research studies under the guidance and supervision of the Institution's staff scientists. Topics are within the general range of the staff's interests, so that significant opportunities for collaboration and exchange develop readily. At any time during the report year, a total of about eighty postdoctoral fellows,



David Stern, graduate student at the Department of Plant Biology, has found surprising homology between mitochondrial and chloroplast DNA. His experiments, conducted with former research associate Jeffrey Palmer, have important implications in understanding the relationships between these two plant organelles—both functionally and in an evolutionary sense.

predoctoral fellows, and undergraduate students served at the Institution's departments.

Each fellow and student brings to his or her tour at Carnegie a special set of curiosities, drives, and imaginations; most individuals have superb previous educational backgrounds, along with firm ideas as to personal direction and goals. Each is expected to grow not only in research but also in communicating results—in local seminars, in published work, and in presentations at scholarly gatherings elsewhere.

Fellows and students make valuable contributions to the overall missions of the departments, and their research brings acknowledgement within the profession. A striking example was seen in the work of graduate student David Stern at the Department of Plant Biology. Stern's published results this year comparing plant mitochondrial and chloroplast DNA, in collaboration with the Department's former graduate student and research associate Jeffrey D. Palmer (see p. 22), received prompt and widespread professional note.

Many come from other countries. This year, Plant Biology hosted fellows from Japan, New Zealand, West Germany, and India. Serving at Embryology were Diane de Cicco (fellow of the European Molecular Biology Organization), Fritz Müller (fellow of the Swiss National Fund), and Daniel Burke (a graduate student from the National Research Council of Canada).

At the Geophysical Laboratory, postdoctoral fellow Pascal Richet of the University of Paris and Andrew Jephcoat, a graduate student at Johns Hopkins from the United Kingdom, worked in the group engaged in studying materials at high pressures. Tetsu Masuda and Hiroshi Mizuno from Japan worked with scientists at DTM. Postdoctoral fellows at the Observatories were Peter J. McGregor of Australia and Rogier A. Windhorst of The Netherlands. In graduate study at Caltech was Chilean Fernando Selman, supported by the Institution under its Carnegie-Chile fellowship program.

Financial support for the fellowship and student programs comes from the Institution's own resources as well as from the Carnegie Corporation and other outside foundations. In the past year, for example, the McKnight Foundation of Minneapolis awarded a three-year, $750,000 grant to the Carnegie Department of Plant Biology and the Stanford University Department of Biological Sciences, primarily to support graduate students and postdoctoral fellows working in the Carnegie-Stanford plant biology program.

The McKnight grant builds upon a long tradition of cooperation between Carnegie Institution and Stanford University in research and education; for many decades, Carnegie staff members have held appointments in the Stanford Department, and Stanford graduate students have conducted their doctoral research at Carnegie. In making the grant, the McKnight Foundation envisioned that an interdisciplinary approach—involving molecular biologists, plant physiologists, and physiological plant ecologists—is necessary for understanding the genetic mechanisms that enable plants to adapt under environmental stresses. Winslow Briggs, director of the Carnegie Department, reports that the effort has gotten off to a vigorous start; a general meeting of plant scientists held in Asilomar, California, in April, attracted over fifty people. Briggs notes that the award will strengthen the Carnegie-Stanford complex as a magnet for top-quality postdoctoral and graduate applicants.

After completing postdoctoral training at Carnegie, individuals typically move to research careers elsewhere. As their professional careers develop in later years, many former fellows and students lead strong research programs at their own institutions, and may engage in frequent communication, collaboration, and friendly competition with their former mentors at Carnegie. Thus, through its informal body of alumni, the Institution fertilizes growing fields of investigation; its impact is to be measured not only in the research of its present staff but also in the achievements of its former fellows and students.

A Reach to Future Scientists. As part of the Institution's educational and informational venture, Perspectives in Science, staff members at the Geophysical Laboratory and DTM recorded short discussions on the general subject of research on the Earth's core. The recordings were sent without charge to several hundred educational and public radio stations (including over a hundred stations reporting past use of the series). In addition, Perspectives in Science was expanded to include publication of an essay-booklet "The Earth's Core: How Does It Work?" The booklet was designed for use by classroom teachers and outstanding students, and copies have been made available to members of the National Science Teachers Association and were sent free to all members of the National Association of Geology Teachers.

Leadership in Professional Groups

Every scientist, over and beyond his or her immediate institutional affiliation, has an identity as part of a national and worldwide community of scholars. This community is organized amorphously into many diverse and overlapping entities, including professional associations, learned societies, review panels, advisory boards, foundations, and the like. As an individual's stature in research grows, the opportunities to contribute in positions of leadership beyond the principal workplace tend to increase. Each individual must acknowledge such obligations and must determine how such roles may enrich his or her primary career in research. The examples below are intended to suggest how Carnegie scientists, as active members of this community, share in its day-to-day functioning.

Among the founders of the Life Sciences Research Foundation in 1981 and its only president to date is Donald Brown, director of Carnegie's Department of Embryology. The Foundation provides a mechanism for the sponsorship of three-year postdoctoral fellowships by industrial corporations; the Foundation's Peer Review Committee chooses the fellowship recipients, who work at institutions of their own choice. Brown announced the first nine recipients and their corporate sponsors in spring 1983.

Public service aspects are also strong in the outside activities of many other individuals. Douglas Fambrough of the Department of Embryology serves as member of the Scientific Advisory Committee of the Muscular Dystrophy Association; Nina Fedoroff is a member, Recombinant DNA Advisory Committee, National Institutes of Health; Olle Björkman of the Department of Plant Biology served on a committee of the National Academy of Sciences evaluating the current status of bioscience research in the U. S. Department of Agriculture; Joseph Berry helped organize and served on a panel considering the possible effects of nuclear war on primary photosynthetic productivity; Robert Hazen of the Geophysical Laboratory was secretary of the History and Teaching Commission, International Mineralogical Society.

The outside activities of Hatten S. Yoder, Jr., director of the Geophysical Laboratory, exemplify how senior scientists contribute in the making of the nation's science policy. Yoder serves on the National Research Council's Commission on Physical Sciences, Mathematics, and Resources, its Board of Minerals and Energy Resources, and its Continental Scientific Drilling Committee. He is a member of the Nominating, the Report Review, and the Day Prize and Lectureship Committees of the National Academy of Sciences, and is on the Advisory Committee on Experimental Petrology of the U. S. Geological Survey. He also serves on the Council of the American Philosophical Society.

The wide range of research at DTM is reflected in the diverse outside roles of its scientists. During the past year, George Wetherill served as president of the Meteoritical Society and continued as editor of *Annual Review of Earth and Planetary Sciences*. Vera Rubin served as president of Commission 28 (Galaxies) of the International Astronomical Union and as member of the editorial board of *Science*. David James was editor-in-chief for the U. S. National Report, consisting of over a hundred articles by U. S. scientists, submitted to the International Union of Geodesy and Geophysics. DTM scientists served on panels on explosive volcanism and on earthquake prediction, on advisory committees to the U. S. Ocean Drilling program, the Space Science Board, and the International Council of Scientific Unions, and on the steering committee for the International Halley Watch.

Observatories' director George Preston served on the Visiting Committee for The Association of Universities for Research in Astronomy, Inc., and on the National Academy of Sciences Nominating Committee for Astronomy. Allan Sandage served on the Council of the Astronomical Society of the Pacific and on the Scientific Advisory Committee for the National New Technology Telescope.

Joseph G. Gall of the Department of Embryology is president of the Society for Developmental Biology. Richard Pagano of the Department of Embryology is serving as chairman-elect for the 1985 Gordon Conference on Lipid Metabolism.

Carnegie vice president Margaret MacVicar is a member of the National Policy and Higher Education advisory panel of the Carnegie Foundation for the Advancement of Teaching. She is also working closely with the Alfred P. Sloan Foundation in a major program to infuse technology into the liberal arts curriculum.

Seminars and Symposia

A full listing of the outside presentations by the Institution's scientists would be as varied and wide-ranging as the research interests of the scientists themselves. While a majority of such activity takes place at meetings in this country, there are frequent occasions for contributions at gatherings abroad. Here, as a means of suggesting the dimensions of such activity in all the departments, we review the speaking presentations in other countries this year by staff members of the Department of Embryology. The enumeration also serves to convey the international flavor that characterizes all branches of science today.

Donald Brown gave the Tanner Lecture on Human Values, Brasenose College, Oxford; his topic was "Genetic Engineering: Promises and Problems." He also spoke at the Symposium on Gene Expression at the Royal Society, London, and at the Meeting on Life Sciences and Mankind, Tokyo.

Douglas Fambrough lectured at the International Congress of Physiological Sciences in Sydney, Australia, and at the 38th Annual Meeting of the Society of General Physiologists at the University of Otago Medical School, Dunedin, New Zealand.

Among nearly a dozen talks and lectures in Europe by Nina Fedoroff were presentations at the 16th Meeting of the Federation of European Biochemical Societies, at the Max Planck Institute for Plant Breeding, Cologne, and at the Swiss Institute for Experimental Cancer Research, Lausanne.

Joseph Gall served as session chairman on "Aspects of Gene Expression and Its Control" at the Royal Society of London, and on "Programs for Development" at the British Society for Developmental Biology.

Local Seminars. Each of the departments conducts seminars, roughly weekly, where current research directions are presented and discussed. Presentations are made by outside and visiting scholars, as well as by staff members, fellows, and advanced students working in the department. All resident scientists typically attend, along with visitors from local institutions interested in the given topic. The seminars provide a formal means for interaction across disciplines and research groups, and are viewed as an ideal training ground for fellows and students. This year, the seminars offered several examples of interaction among the Carnegie departments—Nina Fedoroff of Embryology and Marilyn Estep of the Geophysical Laboratory gave presentations at Plant Biology; David Koo and Vera Rubin of DTM held forth at the Observatories; Marilyn Estep and Anne Hofmeister of Geophysical and Alan Dressler and Rogier Windhorst of the Observatories gave seminars at DTM; and David James, Richard Carlson, Alan Boss, and Louis Brown of DTM spoke at the Geophysical Laboratory.

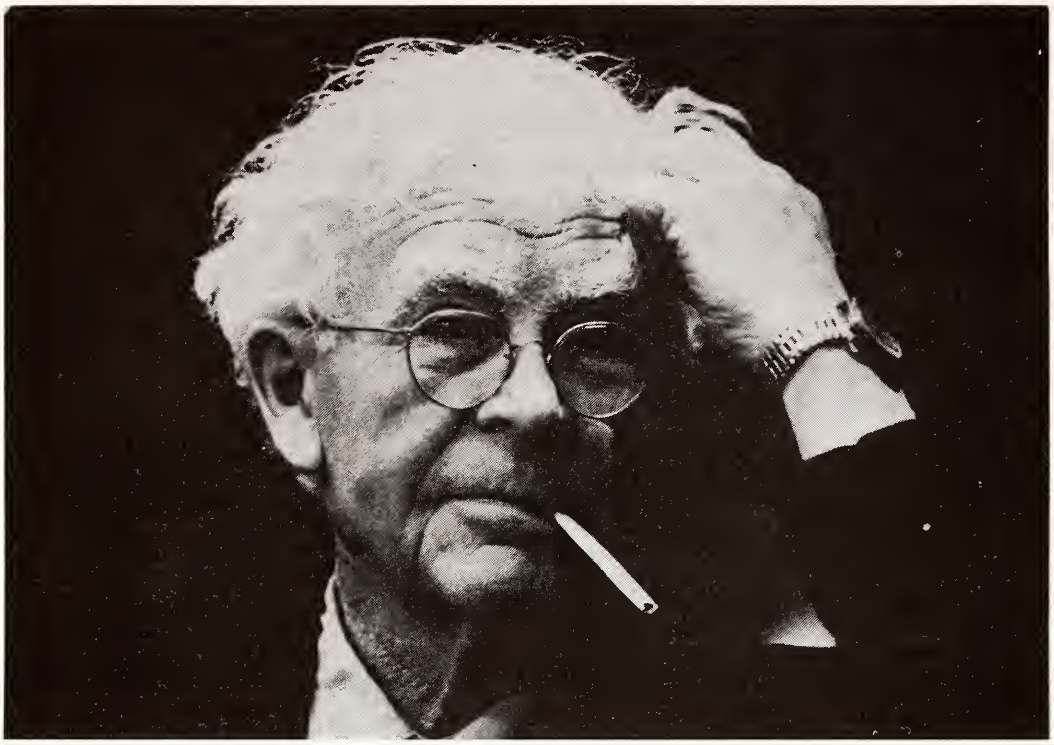
In other seminar activities, the Geophysical Laboratory continued its past role hosting meetings of the Washington Organic Geochemistry Colloquium, the Washington Crystal Colloquium, and the Petrologists' Club. The Department of Embryology hosted the monthly meetings of the Baltimore-Washington Membrane Club and the evening Disease of the Month Club; the Department's annual one-day minisymposium was on "Molecular and Genetic Approaches to the Study of the Nervous System."

The lecturer at Carnegie Evening, May 3, 1984, at Root Hall in the Administration Building, was I. Selwyn Sacks of the Department of Terrestrial Magnetism. Sacks' illustrated lecture, "The Mobile Earth," was attended primarily by members of the East Coast Departments, their families, and invited friends from the Washington-Baltimore area.

Losses, Gains, Honors....

With deep sorrow, we report the death this year of Scott E. Forbush, a former staff member at the Department of Terrestrial Magnetism. An expert in cosmic rays and other solar-terrestrial relationships, Forbush was known for his discovery in 1937 that a sharp decrease in cosmic ray intensity occurs one or two days after a major solar flare. This phenomenon became widely known as the Forbush effect. Forbush's 42-year official career with the Institution included service on the vessel *Carnegie* at the time of its destruction in 1929; after his retirement in 1969, he remained active at DTM and in his chosen field. Forbush moved to Charlottesville in 1982, where he died after a short illness on April 4, 1984.

Theodore Dunham, Jr., a staff member at Mount Wilson from 1930 until 1947, also died in April 1984. Dunham's interests centered around planetary atmospheres, element abundances in stars, and spectrophotometry of biological cells. His most important discovery, made in 1932 with colleague Walter



Former DTM staff member Scott E. Forbush, an expert in the study of solar-terrestrial relationships, died in April 1984.

Adams, was that the atmosphere of Venus contains a large amount of carbon dioxide, disproving years of speculation that the Venusian atmosphere is similar to Earth's.

Other former Carnegie employees who passed away this year include George Streisinger, an associate geneticist at Carnegie's Department of Genetics at Cold Spring Harbor from 1956 to 1960, and two former workers at Terrestrial Magnetism—fellow Jacob Duerksen (1959–1960) and research associate Alois Purgathofer (1964–1965). Streisinger, a well-known expert on molecular mechanisms of mutation in the phage virus, early in his career participated critically in the discovery of the important process of transduction, where genetic material is transferred from one bacterium to another by phage.

The untimely and tragic death of Hiroyuki Fukuyama, a senior postdoctoral fellow at DTM, was a great shock to his friends and colleagues. Fukuyama was an assistant professor at Tokyo University and a former student of Geophysical Laboratory staff member Ikuo Kushiro. Fukuyama and two Japanese colleagues were on a field trip in Iceland during August 1984 when all three drowned while fording a swollen river.

Leroy Dabney, custodian of the Administration Building from 1942 to 1976, died on March 15 at the age of 74. Everett Shipley, who worked in the Geophysical Laboratory shop for 25 years (1948–1973), died on September 24, 1984.

One trustee and several staff members stepped down from active service this year. Crawford Greenewalt resigned from the Board of Trustees after 32 years of active and loyal service. Designated a trustee emeritus, Mr. Greenewalt says he will not hold appointments on standing committees, but will take on other assignments as special opportunities arise. As the Institution explores new areas in the earth sciences and astronomy—a special interest of Mr. Greenewalt, who with his wife Margaretta generously supplied funds to construct the 2.5-meter du Pont telescope at Las Campanas—such opportunities may not be long in coming.

L. Thomas Aldrich retired this year after serving as a staff member at DTM for 34 years. In collaboration with A. O. C. Nier, Aldrich was the co-discoverer of radiogenic ^{40}Ar, the basis of one of the most widely used methods of radiometric dating. He also made pioneering studies on the abundance of the helium isotope in natural materials, and, in collaboration with George Tilton, Gordon Davis, George Wetherill, and Louis Nicolaysen, established the Rb-Sr method of geological age determination. Tom Aldrich cooperated in much of the Department's early seismology program. With Merle Tuve and others, he studied the Earth's crust and mantle by means of earthquakes and manmade explosions. Much of this work took place in the Andes of Peru, Chile, and Bolivia, where Aldrich was also responsible for operating a net of magnetic variograph stations for studying electrical conductivity. For a time, Aldrich served as DTM's associate director (1966–1974) and then as acting director (1974–1975).

James Boise joined the Institution's bursar's office in 1952, becoming bursar in 1960. Boise co-authored the Institution's retirement plan and was the first bursar to attend meetings of the Finance Committee of the Board of Trustees. He retired on June 30, 1984. Kenneth Henard resigned as business manager in early 1984.

Also retiring this year were Observatories archivist Helen Czaplicki and Department of Embryology senior technician William Duncan. Helen Czaplicki came to Santa Barbara Street in 1946 as secretary to then director Ira Bowen. In 1981, she became archivist and began the task, since completed, of organizing the papers of Walter S. Adams, Bowen's predecessor.

William Duncan joined Embryology in 1947. There, he learned the techniques for fixing, embedding, sectioning, and staining human embryos and placentas, working closely with staff member Elizabeth Ramsey in her pioneering studies of the placenta. Later, he helped advance techniques for the preparation of cells for study with the electron microscope.

Two staff members have left the Institution this year for positions elsewhere. Robert Howard, an astronomer at Mount

Wilson and Las Campanas Observatories since 1961 and assistant director of Mount Wilson since 1982, assumed the directorship of the National Solar Observatory in Tucson, Arizona, in September 1984. DTM astronomer Norbert Thonnard has left the Institution and now works at Atom Science, Inc., in Oak Ridge, Tennessee.

Gains

The Board of Trustees gained a new member with the election this year of Mr. Gunnar Wessman. Wessman is president and chief executive officer of the Swedish chemical and pharmaceutical company Pharmacia AB, which manufactures products for the separation and purification of biological substances and for the diagnosis and treatment of diseases. Before joining Pharmacia in 1980, Mr. Wessman was president of the Swedish companies Scholten-Honig (1964–1969), Perstorp AB (1970–1975), and Uddeholm AB (1975–1980). He holds an M.Sc. degree from the Royal Institute of Technology, Stockholm.

With the retirement this year of James Boise, assistant bursar John Lawrence assumed the role of bursar. Lawrence joined the Institution in 1982. He holds the M.B.A. from Columbia University and is a certified public accountant.

Honors

A report year that began with the announcements of Barbara McClintock's Nobel Prize and the naming of the Edwin P. Hubble Space Telescope (both reported in *Year Book 82*) bid well to be unusually rich in honors. This expectation was more than amply fulfilled.

Allan Spradling, staff member at the Department of Embryology, and former Embryology staff member Gerald Rubin won the Newcomb Cleveland Prize for 1982–1983 from the American Association for the Advancement of Science. The Prize is awarded each year to the authors of original work published in *Science.* Spradling and Rubin's paper describing details of their gene transfer technique appeared in the October 22, 1982, issue.

Observatories astronomer Stephen Shectman was selected to receive a Sloan Research Fellowship from the Alfred P. Sloan Foundation, beginning in mid-September 1984 and lasting for two years. Sloan fellowships, which provide financial support for basic research, are awarded annually to gifted young scientists who show promise of making original contributions.

Halton Arp, also of the Observatories, received a Senior

Observatories staff member emeritus Olin C. Wilson received the Catherine Wolfe Bruce Medal of the Astronomical Society of the Pacific in recognition of lifetime achievement in astronomical research.

United States Scientists Award from the Alexander von Humboldt Foundation for a year of study at the Max Planck Institute for Physics and Astrophysics in Munich. The Award recognizes Arp's accomplishments in research and teaching. Last year, Department of Plant Biology director Winslow Briggs also received a Humboldt Award, for study in Germany.

Former Observatories staff member Olin C. Wilson received the Catherine Wolfe Bruce Medal of the Astronomical Society of the Pacific for 1984. The Bruce Medal, a distinguished international award that was first bestowed in 1898, was given to Wilson in recognition of his lifetime achievements in astronomical research, especially for his work on stellar chromospheres.

Nina Fedoroff, staff member at Embryology, was appointed a Phi Beta Kappa Visiting Scholar for 1984–1985. In this role, she will visit various college campuses to take part in classroom and seminar discussions and to meet informally with students and faculty.

Joseph Gall, also of Embryology, was honored by the Catholic University of America with their 1984 Director's Scholarship.

Geophysical Laboratory staff member Marilyn Estep received the Bradley Prize for the best technical paper presented to the Geological Society of Washington during 1983.

Peter Bell, also of the Geophysical Laboratory, received a 1984 NASA Special Scientific Award for a study of extraterrestrial materials.

Barbara McClintock, Distinguished Service Member of the Institution, and trustees Lewis Branscomb and Edward E. David received honorary degrees from Rutgers University in May 1984.

Lise Caron and Edmond Giraud, both recent Ph.D. recipients from France, were awarded Carnegie–del Duca Fellowships for postdoctoral work at the Department of Plant Biology and the Mount Wilson and Las Campanas Observatories, respectively.

Mark Schlissel, a predoctoral fellow at Embryology, received the 1984 Michael A. Shanoff Award from the Johns Hopkins University School of Medicine in recognition of his essay, "Molecules Involved in the Developmental Regulation of *Xenopus* 5S RNA Gene Transcription."

A new mineral, fingerite, was named this year in honor of Larry W. Finger, a staff member at the Geophysical Laboratory. Also, asteroids were named this year after former Mount Wilson Observatory staff members Edwin Hubble, Milton Humason, and Henrietta Swope.

Gunnar Kullerud, former staff member at the Geophysical Laboratory now at Purdue University, was elected to the National Academy of Science in Norway. Three former fellows at the Laboratory—Michael Engel, E. Bruce Watson, and Raymond Jeanloz—received Presidential Young Investigator Awards through the National Science Foundation's Division of Earth Sciences.

Vice president Margaret MacVicar presented the Phi Beta Kappa Oration at the 1984 Literary Exercises during Harvard University's Commencement Week in June.

Trustee emeritus Crawford Greenewalt was elected president of the American Philosophical Society in April 1984.

William Golden was elected a member of the American Academy of Arts and Sciences.

Philip Abelson was corecipient of the National Science Foundation Distinguished Public Service Award.

The Johns Hopkins University School of Advanced International Studies established an international finance and economics chair in honor of William McChesney Martin, Jr. In March, Harvard College officially established the Frank Stanton Professorship of the First Amendment at the John F. Kennedy School of Government.

Richard E. Heckert was awarded an honorary Doctor of Science degree from Miami University in May 1984.

Charles H. Townes received the Centennial Medal of the Institute of Electrical and Electronics Engineers in May 1984.

William Greenough received a Gold Medal Founders Award in June from the Board of Directors of International Insurance Seminars Inc.

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The seismologist I. Selwyn Sacks delivered the annual lecture at Carnegie Evening, May 3, 1984, in Root Hall of the Administration Building. Shown here with Sacks after his lecture, "The Living Earth," is retired research assistant Liselotte Beach, who worked with Sacks at the Department of Terrestrial Magnetism. Behind them is Mrs. Hatten S. Yoder, Jr.

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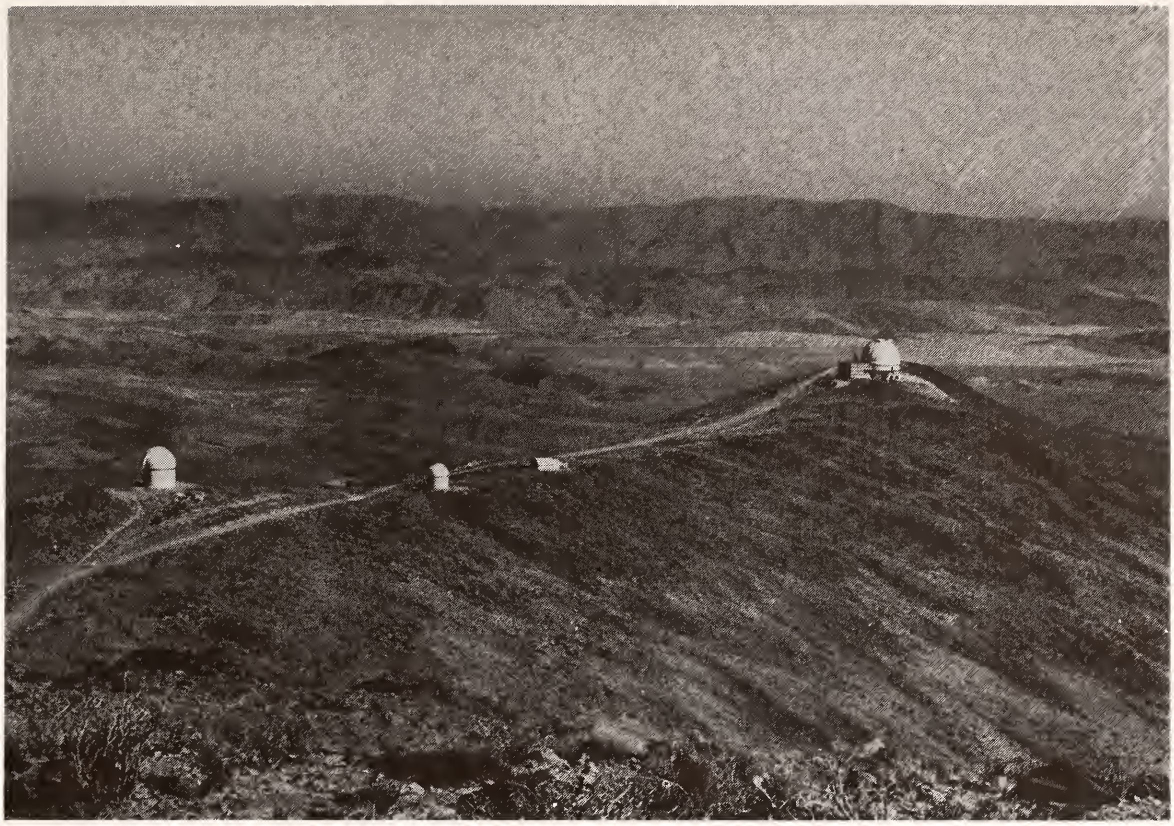

Las Campanas, photographed shortly before dedication of the Irénée du Pont telescope in 1976. From left to right: the dome of the 40-inch wide-angle Swope reflector, the dome of the University of Toronto 24-inch reflector, the housing of the 10-inch Ross refractor, and the du Pont telescope dome.

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Allan Sandage

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Paul L. Schechter

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Leonard Searle

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Stephen A. Shectman

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Horace A. Smith

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Herschel B. Snodgrass

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Thomas Y. Steiman-Cameron

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Arthur H. Vaughan

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Rogier A. Windhorst

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PUBLICATIONS OF THE INSTITUTION

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[1]From September 1, 1983
[2]To September 30, 1983
[3]To February 29, 1984
[4]To February 29, 1984
[5]To September 30, 1983
[6]To February 29, 1984
[7]From January 15, 1984
[8]From September 1, 1983
[9]From April 16, 1984
[10]To September 30, 1983
[11]From April 1, 1984
[12]From November 1, 1983
[13]From October 1, 1983
[14]To September 30, 1983
[15]From January 1, 1984
[16]To February 29, 1984
[17]To October 15, 1983
[18]From January 1, 1984
[19]From November 15, 1983
[20]From November 1, 1983
[21]From July 1, 1983
[22]From September 1, 1983
[23]To August 1, 1983
[24]From May 30, 1984
[25]From January 20, 1984
[26]From May 15, 1984
[27]From September 1, 1983
[28]To September 1, 1983
[29]To September 1, 1983
[30]To June 30, 1984
[31]From January 1, 1984
[32]From August 29, 1983
[33]To September 30, 1983
[34]To November 30, 1983
[35]To February 29, 1984
[36]To October 1, 1983
[37]From October 10, 1983
[38]From June 1, 1984

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Department of Embryology staff member Joseph Gall (seated) and his colleagues (from left) Christine Murphy, Lloyd Epstein, and Celeste Berg study the structure and function of chromosomes using a variety of cytological and molecular techniques.

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Rudolph Warren, Technician
Aida E. Wells, Department Secretary
Brian M. Walsh, Mechanical Engineer

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[1]To August 31, 1983
[2]To October 31, 1983
[3]To August 31, 1983
[4]To January 20, 1984
[5]To February 24, 1984
[6]To February 29, 1984
[7]To August 31, 1983
[8]To August 15, 1983
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[12]To December 7, 1983
[13]To November 30, 1983

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Terry L. Stahl, Fiscal Officer

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[1]Retired, June 30, 1984
[2]Holds additional appointment as Adjunct Staff Member, Mount Wilson and Las Campanas Observatories
[3]On leave of absence at Academia Sinica, Taipei
[4]Resigned March 15, 1984
[5]To April 20, 1984
[6]To May 31, 1984
[7]From March 5, 1984
[8]From April 6, 1984
[9]Died August 10, 1984
[10]To May 15, 1984
[11]From June 14, 1984
[12]Visiting Investigator to November 15, 1984
[13]From September 19, 1983
[14]From February 28, 1984
[15]To March 15, 1984
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[19]To June 15, 1984
[20]To December 31, 1983
[21]Temporary employee

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[1]In residence at Geophysical Laboratory, March 13–April 13, 1984; leave of absence at University of Tokyo, remainder of report year
[2]From October 16, 1983
[3]From September 1, 1983
[4]From June 1, 1984
[5]To December 31, 1983; to Assistant Professor, Department of Earth and Space Sciences, UCLA
[6]From March 1, 1984, to June 30, 1984
[7]From November 1, 1983
[8]Temporary appointment from October 17, 1983, to February 29, 1984
[9]To September 15, 1983
[10]Retired, June 30, 1984
[11]From March 19, 1984

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Peter B. Stetson, Carnegie Fellow[5]
Thomas Y. Steiman-Cameron, Carnegie Fellow
Nicholas B. Suntzeff, Carnegie Las Campanas Observatory Fellow
Rogier A. Windhorst, Carnegie Fellow

Carnegie-Chile Fellow

Fernando J. Selman

Sabbatical Visitor

Eduardo Hardy, University Laval, Canada[6]

The Las Campanas Mountain Crew. Seated (left to right): Mauricio Villalobos, Fernando Peralta, Bill Robinson, Ljubomir Papič, Angel Guerra, Oscar Duhalde. Standing: Hernán Solis, Mario Taquías, Honorio Rojas, Drago Papič, Héctor Balbontín, Pedro Rojas, Victorino Riquelme, Herman Olivares, Alfredo Parades, Leonel Lillo.

Visiting Associates

Gerard Gilmore, Royal Observatory, Edinburgh
Rita E. M. Griffin, University of Cambridge
Roger F. Griffin, University of Cambridge
Joseph L. Snider, Oberlin College
Gustav A. Tammann, University of Basel, Switzerland

Supporting Staff, Pasadena

John M. Adkins, Senior Research Assistant, Solar Physics
Maria Anderson, Manuscript Typist and Editor
John R. Bedke, Photographer
Nicolette Breski, Purchasing Agent[7]
Richard T. Black, Business Manager
John E. Boyden, Systems Programmer, Solar Physics
Ken D. Clardy, Data Systems Manager
Maynard K. Clark, Electronics Engineer, Solar Physics
Harvey W. Crist, Machinist
Douglas C. Cunningham, Assistant Photographer[8]
Helen S. Czaplicki, Archivist[9]
Gary Fouts, Research Assistant/Observer
Carroll L. Friswold, Head, Design Group
Joan Gantz, Librarian
Robert T. Georgen, Machinist (Foreman)
Pamela I. Gilman, Research Assistant, Solar Physics
Rhea M. Goodwin, Assistant to the Director
Charles E. Hartrick, Draftsperson
Basil N. Katem, Senior Research Assistant
Stephen L. Knapp, Electronics Engineer
Stephen P. Padilla, Research Assistant, Solar Physics
Christopher K. Price, Electronics Engineer
Alexander Pogo, Honorary Curator, Historical Collection
William D. Qualls, Driver
Delores B. Sahlin, Receptionist
Edward H. Snoddy, Designer, Coordinator for Las Campanas Support Office
Jeannie B. Todd, Bookkeeper
Nancy Tomer, Technical Illustrator[10]
Arturo Urquieta, Technical Assistant to the Director[11]
Estuardo Vasquez, Machinist
Stephen Wilson, Carpenter
Laura A. Woodard, Research Assistant/Observer

Supporting Personnel, Mount Wilson

David M. Carr, Electronics Technician
James Frazer, Night Assistant/Observer
Howard H. Lanning, Night Assistant/Observer
Jean Mueller, Night Assistant/Observer
Anthony Misch, Observatory Technician
Frank Perez, Mountain Superintendant[12]
Eric Rawe, Observatory Technician
Tevfik Soyumer, Night Assistant/Observer[13]
Michael Thornberry, Steward
Larry Webster, Resident Solar Observer
Ricardo de Leon, Steward

Supporting Personnel, Las Campanas

Héctor Balbontín I., Chef
Angel Cortés, L.
Oscar Duhalde C., Night Assistant
Angel Guerra F., Night Assistant
Leonel Lillo A., Carpenter
Mario Mondaca O., El Pino Guard
Herman Olivares G., Warehouse Attendant
Ljubomir Papič P., Mountain Superintendant
Alfredo Paredes Z., Equipment Operator
Fernando Peralta B., Night Assistant
Leonardo Peralta B., Driver and Purchaser
Victorino Riquelme P., Janitor
Honorio Rojas P., Pump Operator
Pedro Rojas T., Mason
William Robinson W., Electronic Technician
Luis H. Solis P., Electronic Technician
Mario Taquias L., Plumber
Gabriel Tolmo V., El Pino Guard
Jorge Tolmo V., El Pino Guard
Mauricio Villalobos H., Cook
Patricia Villar B., Administrative Assistant

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[1]Resident Scientist/Administrator to December 1, 1983
[2]From December 1, 1983
[3]To December 20, 1983
[4]To April 1, 1984
[5]To August 31, 1983
[6]From January 1984
[7]From October 25, 1983
[8]To April 15, 1984
[9]Retired June 30, 1984
[10]To December 31, 1983
[11]To September 30, 1983
[12]To June 30, 1984
[13]To February 29, 1984

APPOINTMENTS IN SPECIAL SUBJECT AREAS

Roy J. Britten, Staff Member of the Institution[1]
Barbara McClintock, Distinguished Service Member of the Institution[2]

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[1]Distinguished Carnegie Senior Research Associate, Developmental Biology Research Group, California Institute of Technology
[2]Cold Spring Harbor, New York

OFFICE OF ADMINISTRATION

Cheryl Allen, Editorial Assistant (part-time)[1]
Lloyd H. Allen, Custodian
James W. Boise, Bursar[2]
Ray Bowers, Editor, Publications Officer
Don A. Brooks, Custodian
Carolyn J. Davis, Secretary
Barbara F. Deal, Administrative Assistant[3]
D'Ann L. DeBruyn, Secretary[4]
James D. Ebert, President
Joseph M. S. Haraburda, Accounting Manager
Kenneth R. Henard, Business Manager[5]

Susan E. Henderson, Junior Accountant
Antoinette M. Jackson, Facilities and Support Services Manager[6]
Sherman L. E. Johnson, Payroll Supervisor
Jacqueline L. King, Administrative Assistant[7]
Richard S. Kuzmyak, Senior Accountant
John C. Lawrence, Assistant Bursar[8]
Margaret L. Loflin, Secretary to the Vice President[9]
Raymond G. Ludwig, Junior Accountant[10]
Margaret L. A. MacVicar, Vice President
Diep T. Nguyen, Administrative Assistant[10]
John B. Osolnick, Junior Accountant[11]
Patricia Parratt, Assistant Editor
Adrienne Powell, Administrative Assistant[12]
Arnold T. Pryor, Equal Opportunity Officer
Anthony Sherman, Custodian (part-time)[13]
Susan Y. Vasquez, Assistant to the President

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[1]To August 26, 1983
[2]Retired June 30, 1984
[3]Secretary to March 27, 1984
[4]From June 25, 1984
[5]To February 29, 1984
[6]Administrative Assistant to February 1, 1984
[7]From January 16, 1984
[8]Bursar from July 1, 1984
[9]From August 22, 1983
[10]To April 13, 1984
[11]From March 5, 1984
[12]To August 5, 1983
[13]From March 19, 1984, to June 22, 1984

Visiting Investigators

DEPARTMENT OF EMBRYOLOGY

Kenneth Longmuir, University of California, Irvine
Gerhard Meissner, University of North Carolina, Chapel Hill,
Martin Schwartz, University of Maryland, Baltimore

DEPARTMENT OF PLANT BIOLOGY

Jacob Levitt, Senior Fellow, University of Minnesota, Minneapolis
Patrick Williams, Senior Lecturer, Biophysics Department, Chelsea College, University of London
Dow Woodward, Senior Fellow, Stanford University

DEPARTMENT OF TERRESTRIAL MAGNETISM

Barbara Barreiro, Darmouth College
William K. Hart, Miami University, Oxford, Ohio
Emi Ito, University of Minnesota, Minneapolis
Milan J. Pavich, U. S. Geological Survey, Reston, Virginia
J. Arthur Snoke, Virginia Polytechnic Institute and State University, Blacksburg
Ragnar Stefansson, Iceland Meteorological Office, Reykjavik
Richard T. Williams, University of South Carolina, Columbia

GEOPHYSICAL LABORATORY

Mary Jo Baedecker, U.S. Geological Survey
Nonna Bakun-Czubarow, Polish Academy of Sciences
Joy Beier, Indiana University
Nabil Z. Boctor, Purdue University
Barbara Brassat, University of Maryland
James Brophy, Johns Hopkins University
Lynn Caporale, Georgetown University
Luis A. Cifuentes, University of Delaware
Howard Feldman, Indiana University
John M. Ferry, Arizona State University
Katherine H. Freeman, Wellesley College
S. Guha, Howard University
Bjørn Gunnarson, Johns Hopkins University
James T. Gutmann, Wesleyan University
Joseph Hailer, Indiana Geological Survey
Emi Ito, University of Minnesota
Kay Kaneda, Johns Hopkins University
Douglas W. Keith, Manville Corporation
K. Kobayashi, University of Maryland
Julie Kokis, George Washington University
Linda Kovach, Johns Hopkins University
Ian D. MacGregor, National Science Foundation
Brooks McKinney, Johns Hopkins University
Tsutomu Murase, Institute of Vocational Training, Kanagawa, Japan
Virek Navale, University of Maryland
Linda Nunnermacker, University of Maryland
Norma K. Pannell, George Washington University
Henry Polack, Australian National University
Pascal Richet, University of Paris
Meyer Rubin, U.S. Geological Survey
Andrei Serban, Weizmann Institute, Israel
Patrick Shanks, U. S. Geological Survey
Hiroyasu Shimizu, Gifu University, Japan
Douglas Smith, University of Texas at Austin
E. Kent Sprague, University of Georgia
Danielle Velde, University of Paris
Luis Vierma, Indiana University
Bernard Waitzenegger, George Washington University
Ke-Nan Weng, Institute of Geochemistry, Academia Sinica, People's Republic of China
Jianguo Xu, Institute of Geochemistry, Academia Sinica, People's Republic of China
Takehiko Yagi, Tokyo University

MOUNT WILSON AND LAS CAMPANAS OBSERVATORIES

Sallie L. Baliunas, Harvard-Smithsonian Center for Astrophysics
Pierre Bergeron, University of Montreal
Graham Berriman, University of Cambridge
Bruno A. Binggeli, University of Basel
Benjamin Bishoff, Oberlin College
Jacques Blamont, National Center of Scientific Research, France
Douglas Brown, University of Washington
Alessandro Cacciani, Astronomical Observatory of Rome
Luis E. Campusano, University of Chile
Mark Colavita, Massachusetts Institute of Technology
Robert Dicke, Princeton University
Steven Federman, Jet Propulsion Laboratory
Gilles Fontaine, University of Montreal
Peter A. Gilman, High Altitude Observatory, National Center for Atmospheric Research
Keith Horne, University of Cambridge
Stephen Knowles, Naval Research Laboratory
Richard Kron, Yerkes Observatory, University of Chicago
Jeffrey R. Kuhn, Princeton University
Daniel Kunth, Institute of Astrophysics, Paris
John Landstreet, University of Western Ontario
Kenneth Libbrecht, Princeton University
Bruno Liebundgut, University of Basel
Victoria Lindsay, University of California, Berkeley
Barry F. Madore, David Dunlap Observatory, University of Toronto
Matthew Malkan, University of Arizona
Jorge Melnick, University of Chile
Mariano Moles, Astrophysical Institute, Andalucia
Robert W. Noyes, Harvard-Smithsonian Center for Astrophysics
John Ottusch, University of California, Berkeley
Carol Lonsdale Persson, Jet Propulsion Laboratory
Hernán Quintana, Catholic University of Chile
Neill Reid, University of Sussex
Edward J. Rhodes, Jr., University of Southern California

Réné Rutten, Astronomical Institute, University of Utrecht, The Netherlands
William Sebok, Princeton University
Michael Shao, Naval Research Laboratory
Bradford A. Smith, University of Arizona
Horace A. Smith, Michigan State University
Verne Smith, McDonald Observatory, University of Texas
David Staelin, Massachusetts Institute of Technology
Rae Stiening, Stanford University
Linda Stryker, Department of Terrestrial Magnetism, Carnegie Institution of Washington
Jean Surdej, European Southern Observatory
Jean-Pierre Swings, University of Liège
Santiago Tapia, University of Arizona
Richard J. Terrile, Jet Propulsion Laboratory
Roberto Terlevich, Royal Greenwich Observatory
Carlos Torres, University of Chile
J. Anthony Tyson, Bell Laboratories
Roger K. Ulrich, University of California, Los Angeles
Douglas L. Welch, University of Toronto
Rosemary F. C. Wyse, University of California, Berkeley

California Institute of Technology Observers[1]

Mary Barsony
Timothy Beers
Gregory Bothun
Judith Cohen
G. Edward Danielson
Richard Edelson
Alexei Filippenko
James Gibson[2]
Alain Porter
Steven Pravdo[2]
James McCarthy
Jeremy Mould
James Nemec
R. Michael Rich
Wallace L. W. Sargent
B. Thomas Soifer
Edward Tedesco[2]
John Tonry
John Trauger
David Tytler

[1]Faculty, professional staff, research fellows, and graduate students observing at Mount Wilson, Las Campanas, and the 1.5-meter telescope at Palomar

[2]Jet Propulsion Laboratory

The staff at La Serena, Chile. From left: Leonardo Peralta, Jorge Tolmo, Gabriel Tolmo, Rosa Gomez, W. A. Krzeminski, Patricia Villar, Angel Cortés, William Kunkel, Mario Mondaca.

Report of the Executive Committee

To the Trustees of the Carnegie Institution of Washington

In accordance with the provisions of the By-Laws, the Executive Committee submits this report to the Annual Meeting of the Board of Trustees.

During the fiscal year ending June 30, 1984, the Executive Committee held four meetings. Accounts of these meetings have been or will be mailed to each Trustee.

A full statement of the finances and work of the Institution for the fiscal year ended June 30, 1983, appears in the Institution's *Year Book 82*, a copy of which has been sent to each Trustee. An estimate of the Institution's expenditures in the fiscal year ending June 30, 1985, appears in the budget recommended by the Committee for approval by the Board of Trustees.

The terms of the following members of the Board expire on May 11, 1984:

Lewis M. Branscomb
John Diebold
Gerald M. Edelman
Crawford H. Greenewalt
William C. Greenough
William R. Hewlett
Richard S. Perkins
Frank Stanton

In addition, the terms of all Committee Chairmen and the following members of Committees expire on May 11, 1984:

Executive Committee
Edward E. David, Jr.
Crawford H. Greenewalt
Robert C. Seamans, Jr.
Frank Stanton

Finance Committee
Robert G. Goelet
John D. Macomber
Richard S. Perkins

Nominating Committee
Gerald M. Edelman

Auditing Committee
Antonia Ax:son Johnson
Frank Stanton

May 11, 1984

William C. Greenough, *Chairman*

Abstract of Minutes

of the Eighty-Seventh Meeting of the Board of Trustees

The annual meeting of the Board of Trustees was held in the Staff Lounge of the Department of Embryology, Baltimore, Maryland, on Friday, May 11, 1984. The meeting was called to order by Chairman William R. Hewlett.

The following Trustees were present: Philip H. Abelson, Edward E. David, Jr., John Diebold, Gerald M. Edelman, Robert G. Goelet, William T. Golden, William C. Greenough, Caryl P. Haskins, William R. Hewlett, George F. Jewett, Jr., Antonia Ax:son Johnson, John D. Macomber, Robert M. Pennoyer, Richard S. Perkins, Charles H. Townes, and Sidney J. Weinberg, Jr. Garrison Norton, Trustee Emeritus, James D. Ebert, President, Margaret L. A. MacVicar, Vice President, James W. Boise, Bursar, and John D. Lawrence, Assistant Bursar, were also in attendance.

The minutes of the Eighty-Sixth Meeting were approved.

The Chairman notified the Trustees of the deaths of Carl J. Gilbert and Charles P. Taft, Trustees Emeriti. Dr. Haskins read a memorial statement in tribute to Mr. Gilbert, and the following resolution was unanimously adopted:

> *Be It Therefore Resolved*, That we, the Board of Trustees of the Carnegie Institution of Washington, hereby record our sorrow at the death of Carl J. Gilbert.
>
> *And Be It Further Resolved*, That this resolution be entered on the minutes of the Board of Trustees, and that copies be sent to Mrs. Gilbert.

He then read a memorial statement in tribute to Mr. Taft, and the following resolution was unanimously adopted:

> *Be It Therefore Resolved*, That we, the Trustees of Carnegie Institution of Washington, record our deep sense of loss at the death of Charles P. Taft.
>
> *And Be It Further Resolved*, That this resolution be entered on the minutes of the Board of Trustees, and that copies be sent to the family of Mr. Taft.

The reports of the Executive Committee, the Finance Committee, the Employee Benefits Committee, and the Auditing Committee were accepted. On the recommendation of the latter, it was resolved that Price Waterhouse & Co. be appointed as public accountants for the fiscal year ending June 30, 1985.

On the recommendation of the Nominating Committee, Gunnar Wessman was elected a member of the Board of Trustees, and the following were reelected all for terms ending in 1987: Lewis M. Branscomb, John Diebold, Gerald M. Edelman, William C. Greenough, William R. Hewlett, Richard S. Perkins, and Frank Stanton.

The following were elected for one-year terms: Robert C. Seamans, Jr., as Chairman of the Executive Committee; Sidney J. Weinberg, Jr., as Chairman of the Finance Committee; Frank Stanton, as Chairman of the Auditing Committee; Robert G. Goelet, as Chairman of the Nominating Committee; and William T. Coleman, Jr., as Chairman of the Employee Benefits Committee.

Vacancies in the Standing Committees, with terms ending in 1987, were filled as follows: Edward E. David, Jr., John D. Macomber, Robert C. Seamans, Jr., and Frank Stanton were elected members of the Executive Committee; Robert G. Goelet, John D. Macomber, and Richard S. Perkins were elected members of the Finance Committee; William T. Golden was elected a member of the Nominating Committee; and Antonia Ax:son Johnson and Frank Stanton were elected members of the Auditing Committee. In addition, William C. Greenough was elected a member of the Finance Committee for the unexpired term ending in 1986.

The Chairman pointed out that Crawford H. Greenewalt, who has been an active member of the Board for many years, had chosen not to stand for re-election. His resignation was noted with regret, and in accordance with Article 1.6 of the By-laws, Mr. Greenewalt was designated Trustee Emeritus.

The annual report of the President was accepted.

To provide for the operation of the Institution for the fiscal year ending June 30, 1985, and upon recommendation of the Executive Committee, the sum of $15,271,000 was appropriated.

Financial Statements

for the year ended June 30, 1984

Carnegie Institution of Washington
Ten-Year Financial Summary, 1975 – 1984

(All figures are thousands of dollars; fiscal years ended June 30)

	1984	1983	1982	1981	1980	1979	1978	1977	1976	1975
Income										
Interest and dividends	$10,224	$ 8,983	$ 9,100	$ 6,976	$ 6,486	$ 5,256	$ 5,019	$ 4,675	$ 3,958	$ 3,295
Other	187	241	314	197	156	306	80	338	126	83
Restricted grants, expended	4,308	4,476	4,587	3,912	2,613	1,805	1,544	1,077	772	447
Total income	14,719	13,700	14,001	11,085	9,255	7,367	6,643	6,090	4,856	3,825
Expenses										
Terrestrial Magnetism	1,563	1,513	1,478	1,212	1,030	1,000	1,106	1,209	1,046	1,188
Mount Wilson Observatory	1,851	1,563	1,437	1,002	1,170	1,191	1,168	1,204	1,085	1,027
Las Campanas Observatory	980	910	1,211	958	831	792	700	1,056	1,753	2,138
Geophysical Laboratory	1,506	1,412	1,745	1,168	1,269	1,284	1,202	1,162	1,032	1,136
Embryology	864	810	343	77	483	815	818	900	816	851
Plant Biology	1,078	820	703	614	602	537	530	636	620	1,270
Research projects, etc.	58	67	96	76	118	190	107	115	111	75
Office of Administration	1,196	1,099	1,073	941	791	710	602	577	500	571
General publications	80	67	76	91	66	62	78	59	66	78
Professional fees, insurance, taxes	327	311	264	231	199	175	216	226	158	134
Retiree and special benefits	203	156	190	192	139	143	145	117	102	81
Investment services	411	395	385	342	278	308	265	238	205	213
Restricted grants, expended	4,308	4,476	4,587	3,912	2,613	1,805	1,544	1,077	772	447
Total expenses	14,425	13,599	13,588	10,816	9,589	9,012	8,481	8,576	8,266	9,209
Excess (deficiency) of income over expenses before capital changes	$ 294	$ 101	$ 413	$ 269	$ (334)	$ (1,645)	$ (1,838)	$ (2,486)	$ (3,410)	$(5,384)
Realized net gain (loss) on investments	$11,707	$16,157	$ 6,774	$ 5,350	$ 4,581	$ 1,752	$ (102)	$ 2,803	$ 4,365	$ (1,369)
Gifts — endowment and special funds	809	1,097	1,028	364	157	998	637	241	41	146
Market value of investments	130,805	137,859	95,759	101,464	94,359	86,425	84,136	89,287	92,215	93,719

Contributions, Gifts, and Grants for the Year Ended June 30, 1984

Yvonne Aitken
Joseph F. Albright
American Cancer Society
Anonymous
George Assousa
Henry and Claudine Ator
BARD (United States–Israel Binational Agricultural Research and Development Fund)
Ailene J. and G. Philip Bauer
The Charles Ulrick & Josephine Bay Foundation
Liselotte Beach
Giuseppe Bertani
Lars Olof Björn
John J. Bonica
Fern Borgen
Bent G. Böving
Montgomery S. Bradley
The Bristol-Myers Fund, Inc.
Donald Brown
Donald M. Burt
William Buscombe
California Institute of Technology
Carnegie Corporation of New York
James F. Case
Ernst W. Caspari
Roland Caubergs
Celanese Corporation
The Jane Coffin Childs Memorial Fund for Medical Research
John and Annette Coleman
Hayden G. Coon
Charles E. Culpeper Foundation, Inc.
H. Clark Dalton
The Charles A. Dana Foundation, Inc.
Edwin A. Davis
Louis E. DeLanney
John P. de Neufville
John Diebold
The William H. Donner Foundation, Inc.
James and Alma Ebert
W. Gary Ernst
Exxon Education Foundation
Sandra M. Faber
Michael Fleischer
Louis B. Flexner
Stacy and Margaret French
Robert G. Goelet
Sibyl and William T. Golden Foundation
Richard H. Goodwin
Crawford and Margaretta Greenewalt
John B. Gurdon
William G. Hagar, III
Richard Hallberg
Per Halldal
Pembroke J. Hart
Stanley R. Hart
Caryl and Edna Haskins
Robert J. Hay
Ulrich Heber
Richard Heckert
Mary G. Hedger
Lawrence Helfer
Edward P. Henderson
Alfred D. Hershey
Richard E. Hewitt
William R. Hewlett
William M. Hiesey
High Pressure Diamond Optics, Inc.
E. Kathleen Hill
Robert Hill
International Business Machines Corp.
Earl Ingerson
Kyoichi Ishizaka
George F. Jewett, Jr.
Antonia Ax:son Johnson
Paul A. Johnson
David D. Keck
W.M. Keck Foundation
Elizabeth M. Ramsey and Hans A. Klagsbrun
Robert N. Kreidler
Harold H. Lee
Howard M. Lenhoff
Ta-Yan Leong
Edna and Harry Lichtenstein
Melvyn Lieberman
Charles A. Little
Eckhard Loos
Richard A. Lux
John D. & Catherine T. MacArthur Foundation
John D. Macomber
William McChesney Martin, Jr.
Sheila McGough
The McKnight Foundation
The Andrew W. Mellon Foundation
Günter H. Moh
The Ambrose Monell Foundation
Monsanto Company
Francis L. Moseley
Muscular Dystrophy Association
National Aeronautics and Space Administration
National Geographic Society
National Science Foundation
Office of Naval Research
Malcolm Nobs
Garrison Norton
Jessie Smith Noyes Foundation, Inc.
Seigo Ohi
Tokindo S. Okada
Gunnar Öqvist
Elburt F. Osborn

(continued)

Contributions, Gifts, and Grants for the Year Ended June 30, 1984 (continued)

Eijiro Ozawa
Jill D. Pasteris
Robert M. Pennoyer
Penta Corporation
The Pew Memorial Trust
Pioneer Hi-Bred International
Alexander Pogo
Harold T. Prothro
Public Health Service
Rambabu P. Ranganayaki
John E. Rash
Robert G. Roeder
Glenn C. Rosenquist
Vera C. Rubin
Dorothea Rudnick
Ruth N. Schairer
Paul H. and Margaret Hale Scherer
Maarten Schmidt
Robert C. Seamans, Jr.
Shell Companies Foundation, Inc.
Alfred P. Sloan Foundation
A. Ledyard Smith
The Smithsonian Institution
Harold Speert
Frank Stanton
Christer Sundqvist
Ziro Suzuki
Henrietta Swope
Lawrence A. Taylor
The Teagle Foundation, Inc.
Heinz Tiedemann
George R. Tilton
Elwood O. Titus
George Tunell
United States Agency for International Development
United States Department of Agriculture
United States Department of Commerce
United States Department of Energy
United States Department of the Interior
University of California
A. Unsöld
William B. Upholt
Hemming Virgin
Ken-Ichi Wakamatsu
The Sidney J. Weinberg, Jr. Foundation
James Weinman
Richard E. White
Helen Hay Whitney Foundation
D.G. Whittingham
Susanne Widell
Damon Runyon–Walter Winchell Cancer Fund
Frederick T. Wolf

Price Waterhouse

1801 K STREET, N.W.
WASHINGTON, DC 20006
202 296-0800

September 4, 1984

To the Auditing Committee of
Carnegie Institution of Washington

In our opinion, the accompanying statements of assets, liabilities and fund balances and the related statements of income, expenses, and changes in fund balances present fairly the financial position of the Carnegie Institution of Washington at June 30, 1984 and 1983, and the results of its operations and the changes in its fund balances for the years then ended, in conformity with generally accepted accounting principles consistently applied. Our examinations of these statements were made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Our examinations were made for the purpose of forming an opinion on the basic financial statements taken as a whole. The supporting schedules 1 through 5 are presented for purposes of additional analysis and are not a required part of the basic financial statements. Such information has been subjected to the auditing procedures applied in the examination of the basic financial statements and, in our opinion, is fairly stated in all material respects in relation to the basic financial statements taken as a whole.

Price Waterhouse

Statements of Assets, Liabilities, and Fund Balances
June 30, 1984 and 1983

	1984	1983
Assets		
Current Assets		
Cash and cash equivalents	$ 519,851	$ 112,303
Accounts receivable and advances	116,942	53,770
Grants receivable	339,209	526,948
Accrued interest and dividends	910,906	801,202
Due from brokers	...	1,201,164
Total current assets	1,886,908	2,695,387
Investments*		
Fixed income—short term	51,223,621	9,765,000
Fixed income—bonds	12,034,596	6,730,420
Fixed income—mortgages	22,969,328	35,899,756
Corporate stocks—common	44,668,237	61,817,178
Other	451,875	393,191
Adjustment to lower of cost or market	(542,276)	...
Total investments	130,805,381	114,605,545
Plant		
Land	1,027,524	1,010,529
Buildings	4,051,744	4,087,968
Equipment	10,211,819	10,182,648
Total plant	15,291,087	15,281,145
Total assets	$147,983,376	$132,582,077
Liabilities and Fund Balances		
Current liabilities		
Due to brokers	2,692,583	...
Accounts payable and accrued expenses	965,319	828,429
Deferred grant income	1,610,448	1,316,753
Total current liabilities	5,268,350	2,145,182
Fund balances	142,715,026	130,436,895
Total liabilities and fund balances	$147,983,376	$132,582,077

* Approximate market value on June 30, 1984: $130,805,381; June 30, 1983: $137,858,753.

The accompanying notes are an integral part of these statements.

Statements of Income, Expenses, and Changes in Fund Balances for the Years Ended June 30, 1984 and 1983

	Year Ended June 30	
	1984	1983
Income		
Investment income	$ 10,224,014	$ 8,982,808
Grants		
Federal	3,370,722	3,114,168
Private	936,811	1,362,665
Other income	187,423	241,292
Total income	14,718,970	13,700,933
Expenses		
Personnel and related	8,745,860	7,967,624
Equipment	1,290,621	1,496,072
General	4,388,688	4,136,028
Total expenses	14,425,169	13,599,724
Excess of income over expenses before capital changes	293,801	101,209
Capital changes		
Realized net gain on investments	11,707,307	16,156,663
Unrealized gain (loss) on investments	(542,276)	1,942,166
Gifts—endowment and special funds	809,357	1,097,074
Land, buildings, and equipment capitalized	9,942	63,981
Total capital changes	11,984,330	19,259,884
Excess of income and capital changes over expenses	12,278,131	19,361,093
Funds balance, beginning of year	130,436,895	111,075,802
Funds balance, end of year	$142,715,026	$130,436,895

The accompanying notes are an integral part of these statements.

Notes to the Financial Statements
June 30, 1984

Note 1. Significant Accounting Policies

The financial statements of the Institution are prepared on the accrual basis of accounting.

Investments are carried on the balance sheet in the aggregate at the lower of cost or market value. A detailed listing of all securities held by the Institution as of June 30, 1984, has been included as Schedule 5 of this report.

The Institution capitalizes expenditures for land, buildings, telescopes and other significant equipment, and construction projects in progress. Expenditures for other equipment are charged to current operations as incurred, and the cost of such other equipment is not capitalized. The Institution follows the policy of not depreciating its buildings, telescopes, and other significant equipment.

Note 2. Retirement Plan

The Institution has a noncontributory money-purchase retirement plan in which all United States employees are eligible to participate. Voluntary contributions may also be made by employees. Actuarially determined contributions are funded currently by the Institution, and there are no unfunded past service costs. The total contributions made by the Institution were $845,671 in 1984 and $766,410 in 1983. Benefits under the plan upon retirement depend upon the investment performance of the Institution's Retirement Trust. After four years' participation (participation for one year after July 1, 1984), an individual's benefits are fully vested.

Note 3. Restricted Grants

Restricted grants are funds received from foundations, individuals, and federal agencies in support of scientific research and educational programs. The Institution follows the policy of reporting revenues only to the extent that reimbursable expenditures are incurred. The Restricted Grants Statement (Schedule 3) shows all of the current grants.

Note 4. Income Taxes

The Institution is exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code. Accordingly, no provision for income taxes is reflected in the accompanying financial statements. The Institution is also an educational institution within the meaning of Section 170(b)(1)(A)(ii) of the Code. The Internal Revenue Service has classified the Institution as other than a private foundation, as defined in Section 509(a) of the Code.

Schedule 1

Schedule of Expenses by Department for the Years Ended June 30, 1984 and 1983

	1984				1983
	Endowment and Special	Restricted Grants		Total Expenses	Total Expenses
		Federal	Private		
Education and scientific research expenses					
Terrestrial Magnetism	$ 1,562,452	$ 698,812	$ 80,670	$ 2,341,934	$ 2,156,252
Mount Wilson Observatory	1,851,414	672,710	158,955	2,683,079	2,446,348
Las Campanas Observatory	979,738	...	...	979,738	909,667
Geophysical Laboratory	1,505,938	506,330	191,313	2,203,581	2,096,347
Embryology	863,806	1,347,478	305,494	2,516,778	2,373,535
Plant Biology	1,078,165	145,392	178,235	1,401,792	1,467,011
Research projects, etc.	58,001	...	22,144	80,145	123,110
Total	7,899,514	3,370,722	936,811	12,207,047	11,572,270
Administrative and general expenses					
Office of Administration	1,196,697	...	...	1,196,697	1,098,817
General publications	80,207	...	...	80,207	66,710
Professional fees, insurance, and taxes	326,647	...	...	326,647	311,047
Retiree and special employee benefits	203,456	...	...	203,456	155,865
Investment services	411,115	...	...	411,115	395,015
Total	2,218,122	...	...	2,218,122	2,027,454
Total expenses	$10,117,636	$3,370,722	$936,811	$14,425,169	$13,599,724

The accompanying notes are an integral part of these schedules.

Schedule 2

Changes in Fund Balances for the Year Ended June 30, 1984

	Balance July 1, 1984	Investment, Grants, and Other Income	Endowment and Special Gifts	Realized Net Capital Gains	Expenses	Other	Balance June 30, 1984
Endowment funds							
Andrew Carnegie	$ 22,000,000	...	...	...	...	...	$ 22,000,000
Sybil and William T. Golden	25,000	...	...	...	...	...	25,000
Anonymous gifts	1,390,175	...	$250,000	...	...	...	1,640,175
Mellon Matching	709,194	...	477,353	...	...	...	1,186,547
Astronomy Matching	778,715	...	120,185	...	...	...	898,900
Realized capital gains	63,082,408	...	...	$ 8,895,628	...	...	71,978,036
Unrestricted capital funds							
Carnegie Corporation	10,000,000	...	...	...	...	...	10,000,000
Carnegie Futures	276,117	...	...	...	...	...	276,117
Vannevar Bush	100,000	...	...	...	...	...	100,000
Realized capital gains	12,766,344	...	...	2,445,347	...	...	15,211,691
Working Capital Fund	202,702	$10,089,917	(40,000)	...	$10,018,607	...	234,012
Restricted Grants	...	4,307,533	...	...	4,307,533	...	...
Special funds							
Astronomy	958,601	82,980	584	94,272	...	...	1,136,437
Ira S. and Mary Bowen	459,088	39,627	...	45,256	17,972	...	525,999
Bush gift	62,350	6,852	...	7,784	...	...	76,986
Colburn	395,645	36,185	...	41,472	17,000	...	456,302
Hale Relief	15,049	1,484	...	1,686	...	...	18,219
Harkavy	18,676	1,559	...	1,781	1,000	...	21,016
Lundmark	72,327	5,785	...	6,606	3,000	...	81,718
Morganroth	57,925	4,186	...	4,778	2,000	...	64,889
Moseley Astronomy	171,760	14,158	...	16,225	7,684	...	194,459
Francis L. Moseley gift	91,300	7,757	...	8,812	...	...	107,869
Roberts Memorial	56,468	5,100	1,235	5,777	...	...	68,580
Special Instrumentation	223,311	17,698	...	20,107	...	...	261,116
Special Opportunities	120,636	10,723	...	12,183	...	...	143,542
Wood	1,121,959	87,426	...	99,593	50,373	...	1,258,605
Plant Fund	15,281,145	...	...	...	...	$9,942	15,291,087
Fund balances	$130,436,895	$14,718,970	$809,357	$11,707,307	$14,425,169	$9,942	$143,257,302
Adjustment to lower of cost or market							(542,276)
Adjusted balance							$142,715,026

The accompanying notes are an integral part of these schedules.

Schedule 3

Restricted Grants
for the Year Ended June 30, 1984

	Balance July 1, 1983	New Grants	Expenses	Balance June 30, 1984
Federal grants				
BARD (U.S.-Israel Agriculture Fund)	$ 8,127	...	$ 572	$ 7,555
National Aeronautics and Space Administration	373,460	$ 494,040	483,424	384,076
National Science Foundation	928,697	1,264,926	1,187,298	1,006,325
Office of Naval Research	67,425	87,722	112,631	42,516
Public Health Service	596,763	1,582,822	1,179,740	999,845
The Smithsonian Institution	439	10,000	10,439	...
U.S. Agency for International Development	261,082	229,400	89,957	400,525
U.S. Department of Agriculture	110,936	55,000	131,729	34,207
U.S. Department of Commerce	4,061	21,100	15,041	10,120
U.S. Department of Energy	91,714	60,000	124,689	27,025
U.S. Department of Interior	16,118	141,721	35,202	122,637
Total federal grants	2,458,822	3,946,731	3,370,722	3,034,831
Private grants				
American Cancer Society	...	700,142	83,045	617,097
Anonymous	339,801	...	84,829	254,972
California Institute of Technology	...	35,100	9,816	25,284
University of California	...	42,035	38,624	3,411
Carnegie Corporation of New York	500,642	...	125,642	375,000
Charles E. Culpeper Foundation, Inc.	200,000	...	100,000	100,000
The Jane Coffin Childs Memorial Fund for Medical Research	2,250	86,083	25,969	62,364
The Charles A. Dana Foundation, Inc.	42,202	...	37,034	5,168
The William H. Donner Foundation, Inc.	7,144	...	7,144	...
Exxon Education Foundation	75,000	(25,000)	...	50,000
Max C. Fleischmann Foundation	50,000	...	50,000	...
William R. Hewlett Lead Trust	...	1,000,000	11,224	988,776
Pioneer Hi-Bred International	...	58,000	6,802	51,198
W.M. Keck Foundation	...	225,000	886	224,114
John D. & Catherine T. MacArthur Foundation	15,000	...	15,000	...
The McKnight Foundation	78,677	(72,558)	6,119	...
The Andrew W. Mellon Foundation	500,000	250,000	7,443	742,557
The Ambrose Monell Foundation	50,000	...	50,000	...
Monsanto Company	...	30,000	...	30,000
Francis L. Moseley	...	160,000	5,402	154,598
Muscular Dystrophy Association	17,675	52,484	42,409	27,750
National Geographic Society	23,103	42,770	30,095	35,778
Jessie Smith Noyes Foundation, Inc.	33,605	...	31,709	1,896
The Pew Memorial Trust	175,000	...	100,000	75,000
Richard B. T. Roberts	2,000	...	694	1,306
Vera C. Rubin	3,500	...	...	3,500
Damon Runyon-Walter Winchell Cancer Fund	4,124	...	4,124	...
Aflred P. Sloan Foundation	21,705	5,345	2,050	25,000
The Teagle Foundation, Inc.	17,000	30,000	36,000	11,000
The Charles Ulrick & Josephine Bay Foundation	...	10,250	10,250	...
Helen Hay Whitney Foundation	14,501	51,000	14,501	51,000
Total private grants	2,172,929	2,680,651	936,811	3,916,769
Total restricted grants	4,631,751	$6,627,382	$4,307,533	6,951,600
Less cash not yet received from grants	3,314,998			5,341,152
Deferred income	$1,316,753			$1,610,448

The accompanying notes are an integral part of these schedules.

Schedule 4

Schedule of Expenses for the Years Ended June 30, 1984 and 1983

	1984			1983
	Endowment and Special	Restricted Grants	Total Expenses	Total Expenses
Salaries, fringe benefits, and payroll taxes				
Salaries	$ 5,202,451	$1,153,887	$ 6,356,338	$ 5,788,865
Fringe benefits	943,578	216,081	1,159,659	1,018,305
Payroll taxes	310,683	69,315	379,998	375,850
Total	6,456,712	1,439,283	7,895,995	7,183,020
Fellowship grants	447,392	350,279	797,671	731,254
Awards, grants, and honoraria	28,248	23,946	52,194	53,350
Equipment				
Educational and research	298,270	687,272	985,542	1,132,375
Administrative and operating	129,397	9,000	138,397	194,602
Library	92,284	10,000	102,284	104,188
Land (improvement)	16,995	...	16,995	11,361
Building (improvement)	18,232	...	18,232	47,397
Telescopes (improvement)	29,171	...	29,171	6,149
Total	584,349	706,272	1,290,621	1,496,072
General expenses				
Educational and research supplies	487,575	719,912	1,207,487	1,268,694
Building maintenance	1,006,463	...	1,006,463	832,806
Investment services	411,115	...	411,115	395,015
Administrative	578,107	694	578,801	532,431
Travel	254,243	99,995	354,238	346,093
Retiree and special employee benefits	195,222	...	195,222	155,865
General insurance	184,887	...	184,887	205,610
Publications	136,762	30,158	166,920	129,539
Professional and consulting fees	159,408	...	159,408	163,349
Commissary	56,812	...	56,812	41,923
Shop	33,026	...	33,026	28,813
Real estate taxes	8,930	...	8,930	9,192
Rent	10,379	15,000	25,379	26,698
Total	3,522,929	865,759	4,388,688	4,136,028
Indirect costs	(921,994)	921,994	...	...
Total expenses	$10,117,636	$4,307,533	$14,425,169	$13,599,724

The accompanying notes are an integral part of these schedules.

Schedule 5
1 of 3

Schedule of Investments
June 30, 1984

Description	Par/Shares	Cost	Approximate Market
Fixed income—short term			
Barclays Americancorp., PN, 11.15%, 1984	700,000	$ 692,446	$ 692,446
Barclays Americancorp., PN, 11.05%, 1984	1,035,000	1,025,469	1,025,469
Export Development Corp., PN, 10.75%, 1984	7,000,000	6,929,976	6,929,976
General Electric Corp., PN, 10.75%, 1984	800,000	800,000	800,000
General Motors Acceptance Corp., PN, 11.05%, 1984	3,100,000	3,100,000	3,100,000
Hibernia National Bank, VR, CD, 10.725%, 1984	2,000,000	2,000,000	2,000,000
Houston Natural Gas, PN, 11.05%, 1984	3,500,000	3,462,399	3,462,399
Mercantile National Bank, Dallas, PN, 10.685%, 1984	2,500,000	2,500,000	2,500,000
Mellon Bank Pittsburg, VR, CD, 10.960%, 1985	3,500,000	3,500,000	3,500,000
Merrill Lynch & Co., PN, 10.80%, 1984	2,000,000	2,000,000	2,000,000
Merrill Lynch & Co., PN, 11.15%, 1984	2,200,000	2,179,558	2,179,558
Mitsubishi International Corp., PN, 10.40%, 1984	3,500,000	3,466,750	3,466,750
Mitsubishi International Corp., PN, 11.30%, 1984	3,000,000	2,972,692	2,972,692
Morgan Bank of Delaware Co., 11.00%, 1984	3,000,000	3,000,000	3,000,000
Southern Bell Telephone & Telegraph Co., 11.05%, 1984	3,000,000	2,972,375	2,972,375
Texaco Inc., PN, 11.05%, 1984	3,200,000	3,167,587	3,167,587
Texas Commerce Bank Houston, VR, CD, 10.915%, 1985	3,000,000	3,000,000	3,000,000
United Technologies Corp., PN, 10.75%, 1984	1,500,000	1,483,875	1,483,875
Wells Fargo & Co., PN, 11.10%, 1984	2,000,000	1,979,650	1,979,650
Whirlpool Acceptance Corp., PN, 10.30%, 1984	1,000,000	990,844	990,844
Total fixed income—short term		51,223,621	51,223,621
Fixed income—bonds			
Boeing Co., Sub Conv., L/T, 8.875%, 2006	593,000	657,404	705,670
Ford Motor Credit Co., VR, 11.563%, 1987	2,500,000	2,500,000	2,500,000
Ford Motor Credit Co., VR, 11.187%, 1993	700,000	700,000	700,000
Service Merchandise Co., Conv., Sub Deb, 11%, 2002	355,000	709,752	550,250
United States Treasury Note, 13.125%, 1994	1,675,000	1,604,859	1,610,094
United States Treasury Note, 10.875%, 1989	5,800,000	5,862,581	5,821,750
Total fixed income—bonds		12,034,596	11,887,764
Fixed income—mortgages			
FHLMC, Group #18738, 7%, 2011	2,089,622	1,253,773	1,366,091
FHLMC, Group #18349, 8%, 2005	882,380	545,973	612,152
FHLMC, Group #180783, 7%, 2008	262,383	193,180	170,877
FHLMC, Group #180893, 8%, 2008	1,923,806	1,368,837	1,334,640
FHLMC, Group #181062, 6%, 2008	2,923,712	1,622,655	1,878,485
FNMA, Group #278, 8.5%, 2009	4,291,399	2,843,052	3,079,079
FNMA, Group #280, 8.5%, 2012	6,840,652	4,583,237	4,942,371

The accompanying notes are an integral part of these schedules. *(continued)*

Schedule 5
2 of 3

Schedule of Investments, June 30, 1984 (continued)

Description	Par/Shares	Cost	Approximate Market
Fixed income—mortgages (continued)			
FNMA, Group #282, 8.5%, 2011	5,311,198	$ 3,664,726	$ 3,810,784
FNMA, Group #1149, 8%, 2012	4,678,333	3,508,750	3,315,768
FNMA, Group #1150, 8.5%, 2012	3,251,868	2,499,874	2,381,993
FNMA, Group #1490, 8%, 2008	450,794	361,199	315,556
FNMA, Group #2133, 8%, 2008	473,845	355,384	330,507
FNMA, Group #2579, 7%, 2007	228,344	168,688	150,136
Total fixed income—mortgages		22,969,328	23,688,439
Corporate stocks—common			
Allied Corp.	6,000	194,780	189,750
Amerada-Hess	10,500	336,630	295,312
American Information Technologies Co.	20,100	1,324,354	1,306,500
American Telephone & Telegraph Co.	171	2,855	2,950
AMR Corp.	6,500	202,188	198,250
Arizona Bancwest Corp.	27,500	477,812	495,000
Atlantic Richfield Co.	4,500	215,982	204,750
Avco Corp.	7,500	211,253	223,125
Bank of Boston Corp.	4,300	165,981	132,225
Bankers Trust New York Corp.	3,800	172,345	146,300
Bell Atlantic Corp.	20,100	1,351,897	1,364,288
Beneficial Corp.	8,000	215,512	202,000
Burlington Industries, Inc.	7,000	261,310	184,625
Central & South West Corp.	9,200	161,900	163,300
Cigna Corporation	15,081	624,923	473,166
Citicorp	4,600	200,280	140,875
El Paso Electric Co.	71,300	855,600	739,737
Exxon Corp.	5,500	210,182	224,125
Farmers Group Inc.	16,600	553,850	639,100
Financial Corporation of America	12,000	207,135	126,000
First Alabama Bancshares, Inc.	40,000	710,000	720,000
First Bank System Co.	24,800	704,150	573,500
First Union Corp.	13,800	324,300	358,800
Ford Motor Co.	23,500	917,482	848,936
General Motors Corp.	21,500	1,458,755	1,405,562
Golden West Financial Corp.	12,500	213,544	145,312
Goodyear Tire & Rubber Co.	22,000	640,197	566,500
Gulf States Utilities Co.	12,000	173,151	130,500
Hewlett-Packard Co.	20,150	352,636	735,475
Illinois Power Co.	7,000	134,365	129,500
International Business Machines Corp.	29,976	2,860,728	3,169,962
International Paper Company	19,500	1,001,227	948,187
Irving Bank Corp.	3,500	181,915	175,000
IU International Corp.	17,900	419,970	317,725
Jim Walter Corp.	7,500	204,680	184,688
Kansas City Power & Light Co.	8,250	155,877	122,719
Kerr-McGee Corp.	10,000	334,432	312,500
Leaseway Transportation Corp.	8,000	314,800	213,000
McCormick & Co.	29,000	609,941	953,375
Marine Midland Banks Inc.	7,000	169,057	138,250
Marsh & McLennan Companies, Inc.	17,300	777,040	752,550
Maryland National Bank	18,000	537,750	567,000

(continued)

The accompanying notes are an integral part of these schedules.

Schedule 5
3 of 3

Schedule of Investments, June 30, 1984 (continued)

Description	Par/Shares	Cost	Approximate Market
Corporate stocks—common (continued)			
Medtronic Inc.	9,000	$ 502,212	$ 228,375
Mercantile Texas Corp.	5,700	172,499	115,425
Monsanto Co.	36,400	1,678,270	1,574,300
J.P. Morgan & Co. Inc.	2,300	167,384	142,888
NCNB Corp.	50,000	1,203,000	1,200,000
National City Corp.	5,850	171,600	166,725
Niagara Mohawk Power Corp.	10,000	169,544	140,000
Northeast Utilities	13,500	167,985	153,563
Northwest Corp.	12,400	347,200	311,550
Nynex Corp.	25,800	1,590,151	1,560,900
Occidental Petroleum Corp.	22,000	675,900	629,750
Ohio Casualty Corp.	8,000	353,000	319,000
Orbanco Financial Services	23,500	676,175	293,750
Pacific Telesis Group	23,800	1,341,874	1,294,125
J.C. Penney Co.	9,500	525,950	482,125
Pfizer Inc.	17,500	643,461	573,125
Philip Morris Inc.	26,500	963,249	1,835,125
Republicbank Corp.	4,700	157,913	124,550
Rochester Gas & Electric Corp.	9,400	175,109	130,425
Royal Dutch Petroleum Co.	4,000	152,842	191,500
Safeway Stores, Inc.	8,500	210,760	195,500
Shawmut Corporation	8,200	334,150	348,500
Sonat Inc.	6,000	171,352	194,250
Southeast Banking Corp.	35,000	698,687	774,375
Southwestern Bell Corp.	23,000	1,357,737	1,285,125
Standard Oil Co. (Ohio)	4,500	209,700	196,313
Tenneco Inc.	68,000	2,622,524	2,541,500
Texaco Inc.	20,700	814,256	698,625
Tucson Electric Power Co.	28	1,029	1,061
Union Electric Co.	11,700	175,458	149,175
United Illuminating Co.	6,500	176,743	82,063
U.S. Life Corp.	8,000	215,036	202,000
U.S. West	26,500	1,587,197	1,530,375
United Technologies Corp.	49,600	1,643,668	1,612,000
Westinghouse Electric Corp.	61,600	1,471,836	1,355,200
Total corporate stocks—common		$44,668,237	$43,553,682
Other			
Alan Dressler, Second trust, variable interest rate	...	60,137	60,137
James D. & Alma C. Ebert (non-interest-bearing loan to president secured by real estate)	...	200,000	200,000
Arthur Grossman, 9.0%, 2114	...	93,792	93,792
François Schweizer, First trust, 10.5%, 2007	...	97,946	97,946
Total other		451,875	451,875
Adjustment to lower of cost or market		(542,276)	...
Total investments		$130,805,381	$130,805,381

The accompanying notes are an integral part of these schedules.

Articles of Incorporation

Fifty-eighth Congress of the United States of America;

At the Second Session,

Begun and held at the City of Washington on Monday, the seventh day of December, one thousand nine hundred and three.

AN ACT

To incorporate the Carnegie Institution of Washington.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the persons following, being persons who are now trustees of the Carnegie Institution, namely, Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, their associates and successors, duly chosen, are hereby incorporated and declared to be a body corporate by the name of the Carnegie Institution of Washington and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions herein contained.

Sec. 2. That the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind; and in particular—

(a) To conduct, endow, and assist investigation in any department of science, literature, or art, and to this end to cooperate with governments, universities, colleges, technical schools, learned societies, and individuals.

(b) To appoint committees of experts to direct special lines of research.

(c) To publish and distribute documents.

(d) To conduct lectures, hold meetings, and acquire and maintain a library.

(e) To purchase such property, real or personal, and construct such building or buildings as may be necessary to carry on the work of the corporation.

(*f*) In general, to do and perform all things necessary to promote the objects of the institution, with full power, however, to the trustees hereinafter appointed and their successors from time to time to modify the conditions and regulations under which the work shall be carried on, so as to secure the application of the funds in the manner best adapted to the conditions of the time, provided that the objects of the corporation shall at all times be among the foregoing or kindred thereto.

Sec. 3. That the direction and management of the affairs of the corporation and the control and disposal of its property and funds shall be vested in a board of trustees, twenty-two in number, to be composed of the following individuals: Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, who shall constitute the first board of trustees. The board of trustees shall have power from time to time to increase its membership to not more than twenty-seven members. Vacancies occasioned by death, resignation, or otherwise shall be filled by the remaining trustees in such manner as the by-laws shall prescribe; and the persons so elected shall thereupon become trustees and also members of the said corporation. The principal place of business of the said corporation shall be the city of Washington, in the District of Columbia.

Sec. 4. That such board of trustees shall be entitled to take, hold and administer the securities, funds, and property so transferred by said Andrew Carnegie to the trustees of the Carnegie Institution and such other funds or property as may at any time be given, devised, or bequeathed to them, or to such corporation, for the purposes of the trust; and with full power from time to time to adopt a common seal, to appoint such officers, members of the board of trustees or otherwise, and such employees as may be deemed necessary in carrying on the business of the corporation, at such salaries or with such remuneration as they may deem proper; and with full power to adopt by-laws from time to time and such rules or regulations as may be necessary to secure the safe and convenient transaction of the business of the corporation; and with full power and discretion to deal with and expend the income of the corporation in such manner as in their judgment will best promote the objects herein set forth and in general to have and use all powers and authority necessary to promote such objects and carry out the purposes of the donor. The said trustees shall have further power from time to time to hold as investments the securities hereinabove referred to so transferred by Andrew Carnegie, and any property which has been or may be transferred to them or such corporation by Andrew Carnegie or by any other person, persons, or corporation, and to invest any sums or amounts from time to time in such securities and in such form and manner as are permitted to trustees or to charitable or literary corporations for investment, according to the laws of the States of New York, Pennsylvania, or Massachusetts, or in such securities as are authorized for investment by the said deed of trust so executed by Andrew Carnegie, or by any deed of gift or last will and testament to be hereafter made or executed.

SEC. 5. That the said corporation may take and hold any additional donations, grants, devises, or bequests which may be made in further support of the purposes of the said corporation, and may include in the expenses thereof the personal expenses which the trustees may incur in attending meetings or otherwise in carrying out the business of the trust, but the services of the trustees as such shall be gratuitous.

SEC. 6. That as soon as may be possible after the passage of this Act a meeting of the trustees hereinbefore named shall be called by Daniel C. Gilman, John S. Billings, Charles D. Walcott, S. Weir Mitchell, John Hay, Elihu Root, and Carroll D. Wright, or any four of them, at the city of Washington, in the District of Columbia, by notice served in person or by mail addressed to each trustee at his place of residence; and the said trustees, or a majority thereof, being assembled, shall organize and proceed to adopt by-laws, to elect officers and appoint committees, and generally to organize the said corporation; and said trustees herein named, on behalf of the corporation hereby incorporated, shall thereupon receive, take over, and enter into possession, custody, and management of all property, real or personal, of the corporation heretofore known as the Carnegie Institution, incorporated, as hereinbefore set forth under "An Act to establish a Code of Law for the District of Columbia, January fourth, nineteen hundred and two," and to all its rights, contracts, claims, and property of any kind or nature; and the several officers of such corporation, or any other person having charge of any of the securities, funds, real or personal, books or property thereof, shall, on demand, deliver the same to the said trustees appointed by this Act or to the persons appointed by them to receive the same; and the trustees of the existing corporation and the trustees herein named shall and may take such other steps as shall be necessary to carry out the purposes of this Act.

SEC. 7. That the rights of the creditors of the said existing corporation known as the Carnegie Institution shall not in any manner be impaired by the passage of this Act, or the transfer of the property hereinbefore mentioned, nor shall any liability or obligation for the payment of any sums due or to become due, or any claim or demand, in any manner or for any cause existing against the said existing corporation, be released or impaired; but such corporation hereby incorporated is declared to succeed to the obligations and liabilities and to be held liable to pay and discharge all of the debts, liabilities, and contracts of the said corporation so existing to the same effect as if such new corporation had itself incurred the obligation or liability to pay such debt or damages, and no such action or proceeding before any court or tribunal shall be deemed to have abated or been discontinued by reason of the passage of this Act.

Sec. 8. That Congress may from time to time alter, repeal, or modify this Act of incorporation, but no contract or individual right made or acquired shall thereby be divested or impaired.

Sec. 9. That this Act shall take effect immediately.

J G Cannon

Speaker of the House of Representatives.

Wm P Frye

President of the Senate pro tempore.

Approved.
April 28. 1904.
Theodore Roosevelt

By-Laws of the Institution

Adopted December 13, 1904. Amended December 13, 1910, December 13, 1912, December 10, 1937, December 15, 1939, December 13, 1940, December 18, 1942, December 12, 1947, December 10, 1954, October 24, 1957, May 8, 1959, May 13, 1960, May 10, 1963, May 15, 1964, March 6, 1967, May 3, 1968, May 14, 1971, August 31, 1972, May 9, 1974, April 30, 1976, May 1, 1981, and May 7, 1982.

ARTICLE I

The Trustees

1.1. The Board of Trustees shall consist of twenty-four members with power to increase its membership to not more than twenty-seven members.

1.2. The Board of Trustees shall be divided into three classes each having eight or nine members. The terms of the Trustees shall be such that those of the members of one class expire at the conclusion of each annual meeting of the Board. At each annual meeting of the Board vacancies resulting from the expiration of Trustees' terms shall be filled by their re-election or election of their successors. Trustees so re-elected or elected shall serve for terms of three years expiring at the conclusion of the annual meeting of the Board in the third year after their election. A vacancy resulting from the resignation, death, or incapacity of a Trustee before the expiration of his term may be filled by election of a successor at or between annual meetings. A person elected to succeed a Trustee before the expiration of his term shall serve for the remainder of that term. There shall be no limit on the number of terms for which a Trustee may serve, and a Trustee shall be eligible for immediate reelection upon expiration of his term.

1.3. No Trustee shall receive any compensation for his services as such.

1.4. Trustees shall be elected by vote of two-thirds of the Trustees present at a meeting of the Board of Trustees at which a quorum is present or without a meeting by written action of all of the Trustees pursuant to Section 4.6.

1.5 If, at any time during an emergency period, there be no surviving Trustee capable of acting, the President, the Director of each existing Department, and the Executive Officer, or such of them as shall then be surviving and capable of acting, shall constitute a Board of Trustees *pro tem*, with full powers under the provisions of the Articles of Incorporation and these By-Laws. Should neither the President, nor any such Director, nor the Executive Officer be capable of acting, the senior surviving Staff Member of each existing Department shall be a Trustee *pro tem* with full powers of a Trustee under the Articles of Incorporation and these By-Laws. It shall be incumbent on the Trustees *pro tem* to reconstitute the Board with permanent members within a reasonable time after the emergency has passed, at which time the Trustees *pro tem* shall cease to hold office. A list of Staff Member seniority, as designated annually by the President, shall be kept in the Institution's records.

1.6. A Trustee who resigns after having served at least six years and having reached age seventy shall be eligible for designation by the Board of Trustees as a Trustee Emeritus. A Trustee Emeritus shall be entitled to attend meetings of the Board but shall have no vote and shall not be counted for purposes of ascertaining the presence of a quorum. A Trustee Emeritus may be invited to serve in an advisory capacity on any committee of the Board except the Executive Committee.

ARTICLE II

Officers of the Board

2.1. The officers of the Board shall be a Chairman of the Board, a Vice-Chairman, and a Secretary, who shall be elected by the Trustees, from the members of the Board, by ballot to serve for a term of three years. All vacancies shall be filled by the Board for the unexpired term; provided, however, that the Executive Committee shall have power to fill a vacancy in the office of Secretary to serve until the next meeting of the Board of Trustees.

2.2. The Chairman shall preside at all meetings and shall have the usual powers of a presiding officer.

2.3. The Vice-Chairman, in the absence or disability of the Chairman, shall perform the duties of the Chairman.

2.4. The Secretary shall issue notices of meetings of the Board, record its transactions, and conduct that part of the correspondence relating to the Board and to his duties.

ARTICLE III

Executive Administration

The President

3.1. There shall be a President who shall be elected by ballot by, and hold office during the pleasure of, the Board, who shall be the chief executive officer of the Institution. The President, subject to the control of the Board and the Executive Committee, shall have general charge of all matters of administration and supervision of all arrangements for research and other work undertaken by the Institution or with its funds. He shall prepare and submit to the Board of Trustees and to the Executive Committee plans and suggestions for the work of the Institution, shall conduct its general correspondence and the correspondence with applicants for grants and with the special advisors of the Committee, and shall present his recommendations in each case to the Executive Committee for decision. All proposals and requests for grants shall be referred to the President for consideration and report. He shall have power to remove, appoint, and, within the scope of funds made available by the Trustees, provide for compensation of subordinate employees and to fix the compensation of such employees within the limits of a maximum rate of compensation to be established from time to time by the Executive Committee. He shall be *ex officio* a member of the Executive Committee.

3.2. He shall be the legal custodian of the seal and of all property of the Institution whose custody is not otherwise provided for. He shall sign and execute on behalf of the corporation all contracts and instruments necessary in authorized administrative and research matters and affix the corporate seal thereto when necessary, and may delegate the performance of such acts and other administrative duties in his absence to the Executive Officer. He may execute all other contracts, deeds, and instruments on behalf of the corporation and affix the seal thereto when expressly authorized by the Board of Trustees or Executive Committee. He may, within the limits of his own authorization, delegate to the Executive Officer authority to act as custodian of and affix the corporate seal. He shall be responsible for the expenditure and disbursement of all funds of the Institution in accordance with the directions of the Board and of the Executive Committee, and shall keep accurate accounts of all receipts and disbursements. Following approval by the Executive Committee he shall transmit to the Board of Trustees before its annual meeting a written report of the operations and business of the Institution for the preceding fiscal year with his recommendations for work and appropriations for the succeeding fiscal year.

3.3. He shall attend all meetings of the Board of Trustees.

3.4. There shall be an officer designated Executive Officer who shall be appointed by and hold office at the pleasure of the President, subject to the approval of the Executive Committee. His duties shall be to assist and act for the President as the latter may duly authorize and direct.

3.5. The President shall retire from office at the end of the fiscal year in which he becomes sixty-five years of age.

ARTICLE IV

Meetings and Voting

4.1. The annual meeting of the Board of Trustees shall be held in the City of Washington, in the District of Columbia, in May of each year on a date fixed by the Executive Committee, or at such other time or such other place as may be designated by the Executive Committee, or if not so designated prior to May 1 of such year, by the Chairman of the Board of Trustees, or if he is absent or is unable or refuses to act, by any Trustee with the written consent of the majority of the Trustees then holding office.

4.2. Special meetings of the Board of Trustees may be called, and the time and place of meeting designated, by the Chairman, or by the Executive Committee, or by any Trustee with the written consent of the majority of the Trustees then holding office. Upon the written request of seven members of the Board, the Chairman shall call a special meeting.

4.3. Notices of meetings shall be given ten days prior to the date thereof. Notice may be given to any Trustee personally, or by mail or by telegram sent to the usual address of such Trustee. Notices of adjourned meetings need not be given except when the adjournment is for ten days or more.

4.4. The presence of a majority of the Trustees holding office shall constitute a quorum for the transaction of business at any meeting. An act of the majority of the Trustees present at a meeting at which a quorum is present shall be the act of the Board except as otherwise provided in these By-Laws. If, at a duly called meeting, less than a quorum is present, a majority of those present may adjourn the meeting from time to time until a quorum is present. Trustees present at a duly called or held meeting at which a quorum is present may continue to do business until adjournment notwithstanding the withdrawal of enough Trustees to leave less than a quorum.

4.5. The transactions of any meeting, however called and noticed, shall be as valid as though carried out at a meeting duly held after regular call and notice, if a quorum is present and if, either before or after the meeting, each of the Trustees not present in person signs a written waiver of notice, or consent to the holding of such meeting, or approval of the minutes thereof. All such waivers, consents, or approvals shall be filed with the corporate records or made a part of the minutes of the meeting.

4.6. Any action which, under law or these By-Laws, is authorized to be taken at a meeting of the Board of Trustees or any of the Standing Committees may be taken without a meeting if authorized in a document or documents in writing signed by all the Trustees, or all the members of the Committee, as the case may be, then holding office and filed with the Secretary.

4.7. During an emergency period the term "Trustees holding office" shall, for purposes of this Article, mean the surviving members of the Board who have not been rendered incapable of acting for any reason including difficulty of transportation to a place of meeting or of communication with other surviving members of the Board.

ARTICLE V

Committees

5.1. There shall be the following Standing Committees, *viz.* an Executive Committee, a Finance Committee, an Auditing Committee, a Nominating Committee, and an Employee Benefits Committee.

5.2. All vacancies in the Standing Committees shall be filled by the Board of Trustees at the next annual meeting of the Board and may be filled at a special meeting of the Board. A vacancy in the Executive Committee and, upon request of the remaining members of any other Standing Committee, a vacancy in such other Committee may be filled by the Executive Committee by temporary appointment to serve until the next meeting of the Board.

5.3. The terms of all officers and of all members of Committees, as provided for herein, shall continue until their successors are elected or appointed. The term of any member of a Committee shall terminate upon termination of his service as a Trustee.

Executive Committee

5.4. The Executive Committee shall consist of the Chairman, Vice-Chairman, and Secretary of the Board of Trustees, the President of the Institution *ex officio*, and, in addition, not less than five or more than eight Trustees to be elected by the Board by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term. The presence of four members of the Committee shall constitute a quorum for the transaction of business at any meeting.

5.5. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution. It shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication.

5.6. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

Finance Committee

5.7. The Finance Committee shall consist of not less than five and not more than six members to be elected by the Board of Trustees by ballot for a term of three years, who shall be eligible for re-election. The presence of three members of the Committee shall constitute a quorum for the transaction of business at any meeting.

5.8. The Finance Committee shall have custody of the securities of the Institution and general charge of its investments and invested funds and shall care for and dispose of the same subject to the directions of the Board of Trustees. It shall have power to authorize the purchase, sale, exchange, or transfer of securities and to delegate this power. So long as the Institution is the trustee under any retirement or other benefit plan for the staff members and employees of the Institution, it shall be responsible for supervision of matters relating to investments thereunder and for the appointment or removal of any investment manager or advisor. It shall also be responsible for reviewing the financial status and arrangements of any employee benefit plan for which the Institution is not the trustee and for appointment or removal of any plan trustee or insurance carrier. It shall consider and recommend to the Board from time to time such measures as in its opinion will promote the financial interests of the Institution and improve the management of investments under any retirement or other benefit plan. The Committee shall make a report at the annual meeting of the Board.

Auditing Committee

5.9. The Auditing Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years.

5.10. Before each annual meeting of the Board of Trustees, the Auditing Committee shall cause the accounts of the Institution for the preceding fiscal year to be audited by public accountants. The accountants shall report to the Committee, and the Committee shall present said report at the ensuing annual meeting of the Board with such recommendations as the Committee may deem appropriate.

Nominating Committee

5.11. The Nominating Committee shall consist of the Chairman of the Board of Trustees *ex officio* and, in addition, three Trustees to be elected by the Board by ballot for a term of three years, who shall not be eligible for re-election until after the lapse of one year. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term, provided that of the Nominating Committee first elected after adoption of this By-Law one member shall serve for one year, one member shall serve for two years, and one member shall serve for three years, the Committee to determine the respective terms by lot.

5.12. Sixty days prior to an annual meeting of the Board the Nominating Committee shall notify the Trustees by mail of the vacancies to be filled in membership of the Board. Each Trustee may submit nominations for such vacancies. Nominations so submitted shall be considered by the Nominating Committee, and ten days prior to the annual meeting the Nominating Committee shall submit to members of the Board by mail a list of the persons so nominated, with its recommendations for filling existing vacancies on the Board and its Standing Committees. No other nominations shall be received by the Board at the annual meeting except with the unanimous consent of the Trustees present.

Employee Benefits Committee

5.13. The Employee Benefits Committee shall consist of not less than three and not more than four members to be elected by the Board of Trustees by ballot for a term of three years, who shall be eligible for re-election, and the Chairman of the Finance Committee *ex officio*. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term.

5.14. The Employee Benefits Committee shall, subject to the directions of the Board of Trustees, be responsible for supervision of the activities of the administrator or administrators of any retirement or other benefit plan for staff members and employees of the Institution, except that any matter relating to investments or to the appointment or removal of any trustee or insurance carrier under any such plan shall be the responsibility of the Finance Committee. It shall receive reports from the administrator or administrators of the employee benefit plans with respect to administration, benefit structure, operation, and funding. It shall consider and recommend to the Board from time to time such measures as in its opinion will improve such plans and the administration thereof. The Committee shall submit a report to the Board at the annual meeting of the Board.

ARTICLE VI

Financial Administration

6.1. No expenditure shall be authorized or made except in pursuance of a previous appropriation by the Board of Trustees, or as provided in Section 5.8 of these By-Laws.

6.2. The fiscal year of the Institution shall commence on the first day of July in each year.

6.3. The Executive Committee shall submit to the annual meeting of the Board a full statement of the finances and work of the Institution for the preceding fiscal year and a detailed estimate of the expenditures of the succeeding fiscal year.

6.4. The Board of Trustees, at the annual meeting in each year, shall make general appropriations for the ensuing fiscal year; but nothing contained herein shall prevent the Board of Trustees from making special appropriations at any meeting.

6.5. The Executive Committee shall have general charge and control of all appropriations made by the Board. Following the annual meeting, the Executive Committee may allocate these appropriations for the succeeding fiscal year. The Committee shall have full authority to reallocate available funds, as needed, and to transfer balances.

6.6. The securities of the Institution and evidences of property, and funds invested and to be invested, shall be deposited in such safe depository or in the custody of such trust company and under such safeguards as the Finance Committee shall designate, subject to directions of the Board of Trustees. Income of the Institution available for expenditure shall be deposited in such banks or depositories as may from time to time be designated by the Executive Committee.

6.7. Any trust company entrusted with the custody of securities by the Finance Committee may, by resolution of the Board of Trustees, be made Fiscal Agent of the Institution, upon an agreed compensation, for the transaction of the business coming within the authority of the Finance Committee.

6.8. The property of the Institution is irrevocably dedicated to charitable purposes, and in the event of dissolution its property shall be used for and distributed to those charitable purposes as are specified by the Congress of the United States in the Articles of Incorporation, Public Law No. 260, approved April 28, 1904, as the same may be amended from time to time.

ARTICLE VII

Amendment of By-Laws

7.1. These By-Laws may be amended at any annual or special meeting of the Board of Trustees by a two-thirds vote of the members present, provided written notice of the proposed amendment shall have been served personally upon, or mailed to the usual address of, each member of the Board twenty days prior to the meeting.

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