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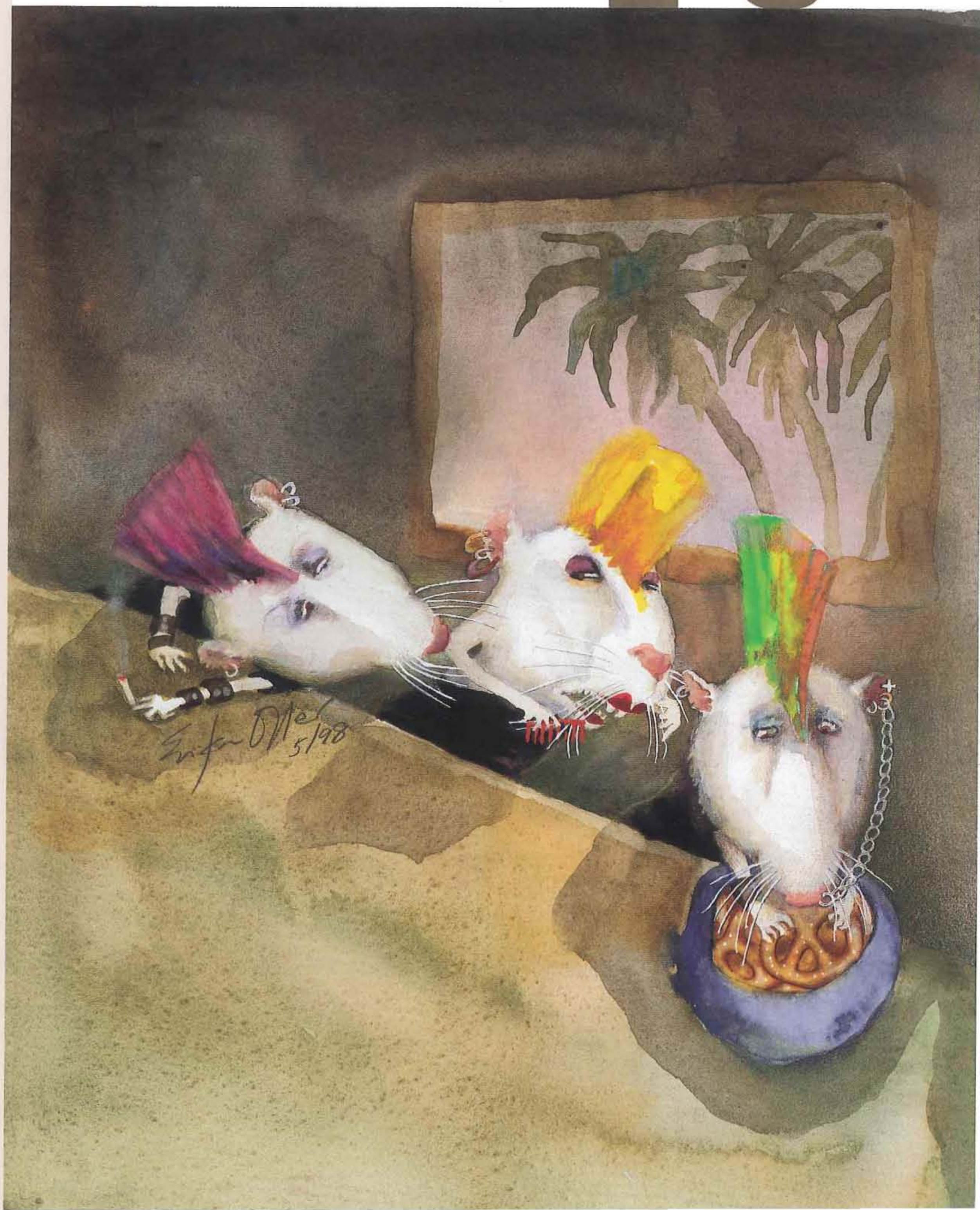
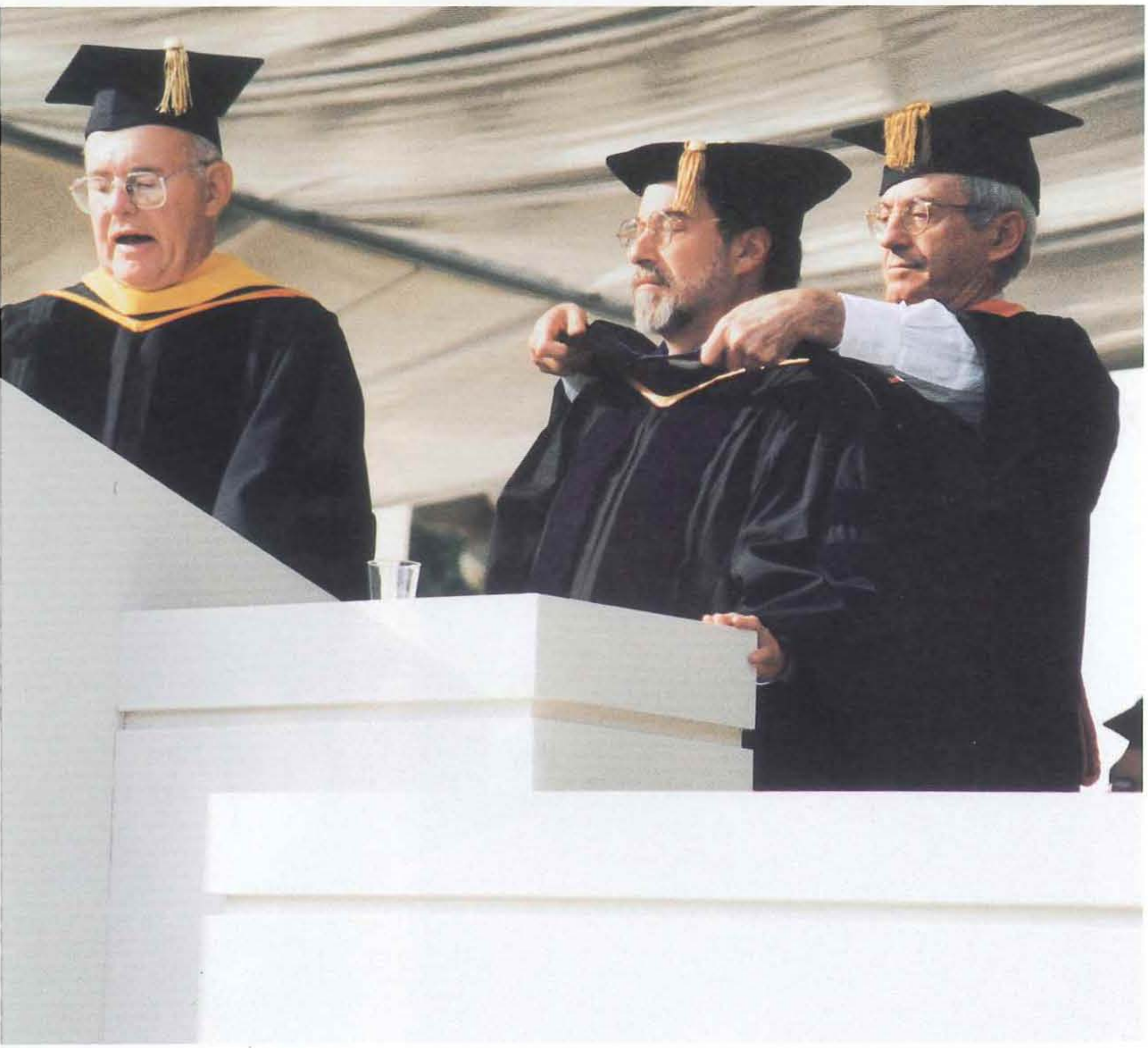
IN THIS ISSUE





Board of Trustees Chair Gordon Moore formally invests David Baltimore as Caltech's new president, as Vice Chair Benjamin Rosen places Robert Millikan's ceremonial hood over Baltimore's shoulders. At the ceremony on March 9, Maxine Singer, president of the Carnegie Institution of Washington, traced Baltimore's career and compared it to that of another of Caltech's founding fathers, George Ellery Hale. An article adapted from her speech begins on page 28.

ENGINEERING AND SCIENCE

California Institute of Technology

Volume LXI, Number 1, 1998

On the cover: Microelectronic technology has reached the point where scientists can record the brain signals of rats happily going about their daily business, leading to the discovery that nuzzling, grooming, and getting face-down into your food are three things that activate a rat's cerebellum. These punked-out lab rats are having a night on the town, but by day, they're stars of rodent MTV as biologists listen to their brain signals while videotaping them doing their thing. Story on page 8.

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Random Walk

When the satellite steam plant was built, it was given a blue tile dome to match the domes of Kerckhoff and North Mudd. In March, a new blue dome suddenly sprouted behind the gate (top). Under this tarp, the Cosmic Background Imager (see *E&S*, 1996, No. 4) is taking shape (right). (That's Steve Padin, chief scientist for the Cosmic Background Imager, on the ladder.) The framework (above) will support 13 one-meter radio telescopes. Assembly and testing will continue through August or so, after which it will be dismantled and rebuilt at its permanent home in northern Chile, where it will search for the seeds of the very first galaxies. "We'll actually make some observations right here while we're doing the final testing," says Anthony Readhead, professor of astronomy. "The first-year graduate students are very excited about that."

Earthquakes Can Generate Enough Heat to Melt Plates

Humans have probably known since the days of loincloths and clubs that the ground sometimes shakes from earthquakes. But only recently has it become clear that at least some earthquakes can also turn up the heat.

In the February 6 issue of *Science*, Hiroo Kanamori, the Smits Professor of Geophysics; Tom Heaton, professor of engineering seismology; and Don Anderson, the McMillan Professor of Geophysics (see page 39) reported that a powerful 1994 earthquake in Bolivia let loose heat at a rate of 35 billion megawatts during the 40 seconds when the rocks slipped about 400 miles under the surface. The earthquake released about as much heat as is generated by the entire United States in two months.

The 8.3 Bolivian earthquake not only sent out some truly prodigious seismic waves, but it also generated enough heat in the region of the plates to at least partially melt them and let them slide together more easily. The 1994 earthquake was the largest deep earthquake ever detected. It was felt as far away as Canada, but caused little or no property damage even at the epicenter because of its depth.

The thermal energy generated by the earthquake is especially interesting because it allowed the plates to turn molten, says Kanamori, the lead author of the paper. And if the plates were molten, they could slide together more easily.

"There are lots of implications," he says, "but mainly it allows us to understand better the basic physics of earthquakes—and more pointedly to better understand the mechanics of the slipping of the surfaces themselves."

The results also help to answer a basic question that has been around for many decades, adds Heaton. "There are some fundamental mysteries of how an earthquake can occur at such depths in the first place," he says. "At a depth of 400 miles, you have truly gigantic pressures that ought to pack the plates together so tightly that they just wouldn't be able to slide. The Bolivian earthquake happened at a depth where the pressure is equivalent to about 200,000 atmospheres. But this frictional melting might have allowed the plates to slide more easily."

A good analogy is an ice skater, Heaton says. While the friction between a steel skate blade and frozen ice would normally be rather high, the frictional energy of the heavy skater allows a thin film of water to greatly reduce the resistance between skate and ice. Therefore, at the depth of the Bolivian earthquake, the plates were solid before the shaking began, even though they were quite hot. The frictional energy of the earthquake then raised the temperature in the vicinity of the plate surfaces from their original ambient temperature of about 1,200 to 1,800 degrees Celsius to a point far above the melting point of the olivine materials.

Kanamori says that it's impossible to tell precisely how hot things got at the frictional points of the plates without knowing precisely how much material was available for the 35 billion megawatts of energy to diffuse through. If there was a comparatively small amount of material, he says, the plate surfaces could have quickly reached 50,000 degrees Celsius, which is much hotter than the surface of the sun. Regardless of the temperature, though, there was more than enough energy to turn the plate surfaces molten, he says.

The scientists reached their conclusions by computing the minimum strain energy change in the materials and then subtracting out the amount of seismic energy detected as ground shaking by surface sensors. Thus, most of the energy that could not be accounted for in the seismic waves could only have been converted to heat energy.

"This was a very good earthquake for computing the minimum strain energy change in this type of problem," Heaton says. "If you know the size of the slip in the earthquake, and you know how stiff the rocks are, then you can estimate the minimum energy necessary to put that much slip into that stiff a rock."

As for practical implications for those living in earthquake country, there may be no clear ones at present, Heaton and Kanamori say. In the case of Southern California, there are no deep earthquakes at all. Such earthquakes typically occur at subduction zones where old ocean floor is being returned into Earth's interior, such as in the plates of South and Central America, Alaska and the Aleutians, the South Pacific, and Japan.

But the results nonetheless underscore a nagging question that has existed for some time, Heaton says. Based on the amount of energy available and the pressures involved, there should be a bit of melting in most earthquakes, even the shallow ones of the San Andreas fault. But fault zones exposed to the surface by erosion show little or no melting.

"Since people don't see much melt, there is probably some other low-friction influence at work," Heaton says. "But we'd like to understand why this is so, and these results could help us better understand the physics of how even Earth's shallow insides move around." □ —*RT*

Wired!

Caltech students have often been noted for their wired appearance (partially due to the massive caffeine intake). But now, Caltech itself is being acknowledged for its digital appeal. In their May 1998 issue, *Yahoo! Internet Magazine*—with more than 400,000 readers nationwide—named Caltech the seventh most wired school in the country. More than 400 schools were surveyed, and Yahoo's results showed that half of all students at Caltech have computers, 75 percent have home pages on university Web space, and 50 percent of classes use the Net to post study aids and other materials. Students can also sign up for high-bandwidth cable modem access to the Net, which means faster and more direct access to campus network resources. □—*RP*

SURF's Offspring Make Waves of Their Own

They tried and tried, but couldn't find a water-related acronym for Caltech's newly named Office of Student-Faculty Programs, formerly the SURF office, which handles Caltech's popular SURF (Summer Undergraduate Research Fellowship) program, in addition to other student-focused research programs. SURF has come a long way since its inception in the summer of 1979, when the first batch of SURFers totaled only 18. Today, on the eve of its 20th anniversary, SURF is stronger than ever, enrolling more than 200 students each summer. In fact, the majority of Caltech undergraduates apply for at least one SURF at some point in their four years at the Institute, drawn by the opportunity to perform independent research under the guidance of a faculty, postdoc, or graduate-student mentor in their field. And, as a testament to its success, SURF has spawned a number of related programs, the most recent of which are Frosh SURF and JPLUS.

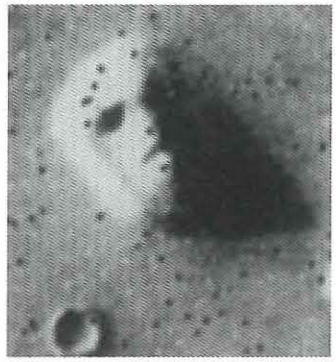
Frosh SURF, as its name implies, offers the chance for students to participate in the SURF program in the summer before they are matriculated. The program is offered as an incentive to the most academically talented students admitted to Caltech, in addition to the traditional merit scholarship. This summer will be Frosh SURF's first offering. On the other hand, the JPLUS (Jet Propulsion Laboratory Undergraduate Scholars) program provides opportunities to the top student at each of the 25 community colleges closest to JPL and Caltech. JPLUS offers a $500 merit scholarship for each of a student's first two years at the community college, and the students are also encouraged to apply for a regular SURF at Caltech or JPL during the summer.

The JPLUS program was founded in May 1997 by JPL's Office of Educational Affairs, with funds provided by Caltech. The funds were part of a NASA bonus that the Institute received as a reward for its stellar administration of JPL. Fred Shair—manager of Educational Affairs at JPL and one of the original architects of SURF—teamed up with Richard Alvidrez (also of JPL's Educational Affairs Office) to come up with the idea for JPLUS. "Many very good students start their education in the community colleges," says Alvidrez, "and this program will recognize them." At the first annual award banquet to honor the 25 awardees (18 of whom were underrepresented minorities), every one of the participating college presidents attended the banquet.

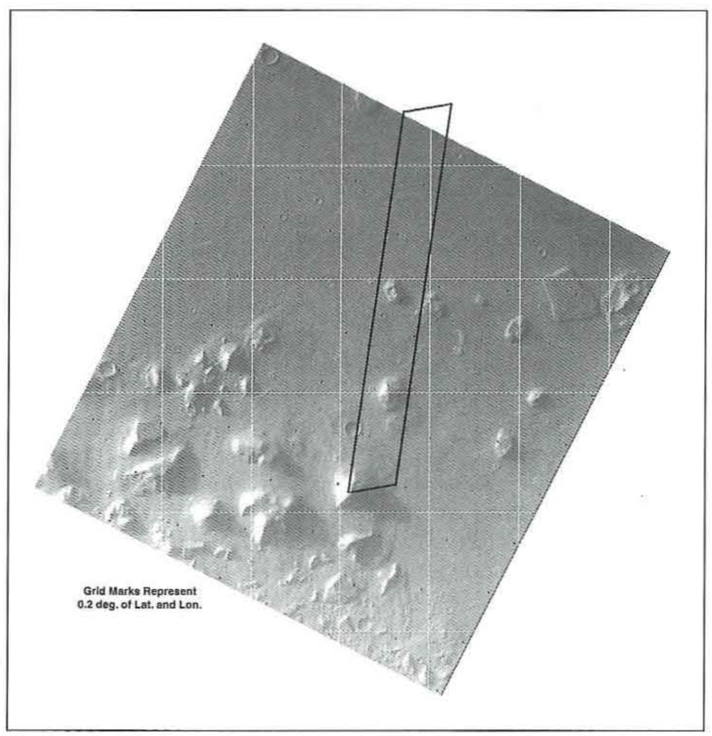
JPLUS is dedicated to the memory of Robert B. Leighton, a renowned physicist and astronomer at Caltech who began his undergraduate career at Los Angeles City College before transferring to the Institute, where he earned his BS in electrical engineering, as well as his MS and PhD in physics. Leighton's many contributions to science include designing and building equipment for imaging the planets in the pre-space-exploration era, serving as team leader at JPL in the mid-'60s for the Mariner 4, 6, and 7 missions to Mars, serving as chair of Caltech's Division of Physics, Mathematics and Astronomy, and editing the famous *Feynman Lectures in Physics*.

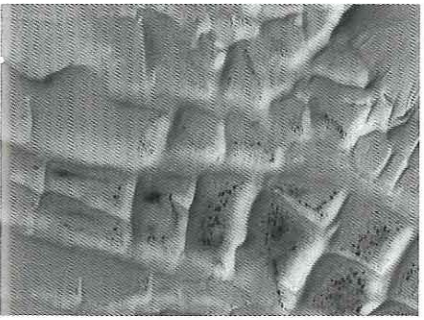
Other programs that the Office of Student-Faculty Programs coordinates include the MURF (Minority Undergraduate Research Fellowship) program, which brings minority students who are not attending Caltech to the campus for the summer; and TIDE (Teaching and Interdisciplinary Education), which provides an opportunity for students who want to work on education-focused (rather than research) projects. □
—*RP*

Mars Global Surveyor Loses Face



Faithful readers of the *Weekly World News* will be disappointed by the photograph of the mile-wide "face" on Cydonia taken by JPL's Mars Global Surveyor (MGS) in April. The Viking 1 orbiter took the above left picture on July 25, 1976. The speckles peppering the image are missing data bits; a fortuitous few became the nostril, dimpled chin, and helmet visor, while shadows formed the other features. The MGS image (above right), taken with the sun at a different angle (and with 10 to 20 times better resolution), shows no monument to ancient astronauts—although, with some imagination, the rock formation looks vaguely like the mask of Greek tragedy. The graphic below shows the MGS mapping swath.



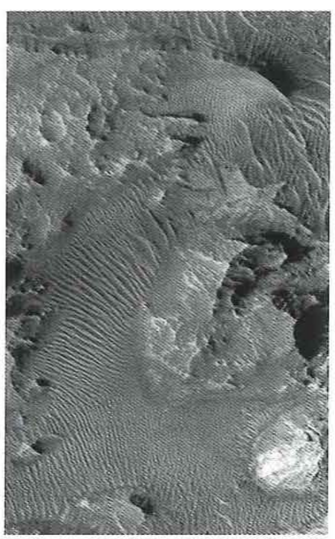


MGS is seeing a lot of other strange and wonderful things, however.

Above, left: This view of the south polar region shows a gridlike system of intersecting ridges, spaced at intervals of a few miles—a giant alien ice-cube tray, perhaps?

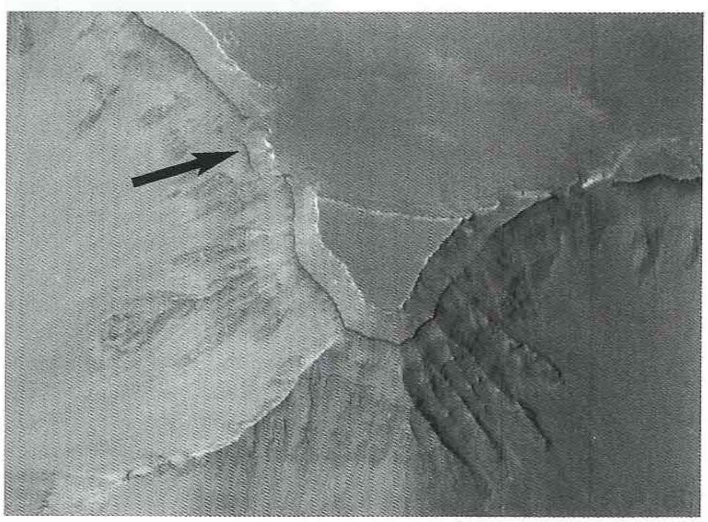
Above, right: This photo of Nanedi Vallis resolves features as small as 12 meters—the length of a boxcar. The terraced walls and the 200-meter-wide channel on the canyon floor, best visible near the top of the frame, may indicate the canyon was cut by running water.

Below: Like waves in an estuary, dunes lap against rocky outcrops on the floor of Hebes Chasma.



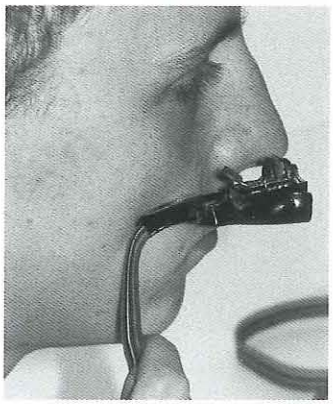
Right: This swath through Coprates Chasma, one of the main canyons that make up the central portion of the 6,000-kilometer-long Valles Marineris system, captures details as small as six meters—the length of a full-sized station wagon. The gray-scale MGS image has been combined with a Viking orbiter color view of the same area. Multiple rock layers, varying from a few meters to a few tens of meters thick, are visible in the steep slopes near the top and bottom of the frame.

Below: In this close-up, you can see where a graben—a depression caused by subsidence between two faults—has offset the strata (arrow).



Olfactory Worker

"This is a high-school science project," a passerby noted to Nathan Lewis, Caltech professor of chemistry, when examining the experimental procedures for Lewis's electronic nose. [See *E&S,* No. 3, 1996] Well, Mark McGrath, a high-school junior in Hilton Head Island, South Carolina, has made good on that assertion.



Mike McGrath shows that Nate Lewis (as he appeared in *E&S*, No. 3, 1996) isn't the only human with two noses.

McGrath, a devoted inventor (and, as it so happens, the grand-nephew of Robert M. McCurdy, who was the assistant city manager of Pasadena, and president of the Rose Parade), read an article about Lewis's electronic nose project in *Ties Magazine,* and contacted Caltech for more information. Using the *E&S* article as one of his references, McGrath set to work on making the nose for his high school science fair.

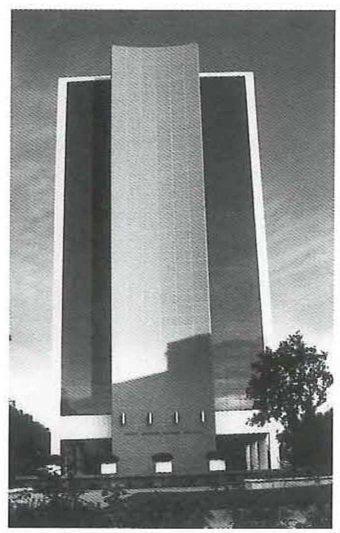
Like Lewis's nose, McGrath's project consists of a number of sensors, each made up of a different type of conducting plastic. Each sensor is exposed to a certain odor-producing agent, while an electrical current is passed through the sensor. By measuring the pattern of resistance for each sensor and odor, the nose can assign a chemical "fingerprint" to the smell.

McGrath's nose is also smelling the first whiffs of victory. At press time, McGrath's electronic nose had already taken first place at both McGrath's high school science fair and the regional science fair, and was on its way to the International Science Fair in Fort Worth, Texas, May 10–16.

McGrath is no stranger to fame. Through such inventions as the K-9 Cooler, a solar-powered pet carrier to keep pets ventilated while in a closed vehicle, and Scram Away, a warning device that puts out vibrations and unpleasant sounds to keep pets and small children away from glass windows (an invention which, incidentally, won fourth place and a $500 savings bond in the Duracell Competition for high school students), McGrath has attracted national attention.

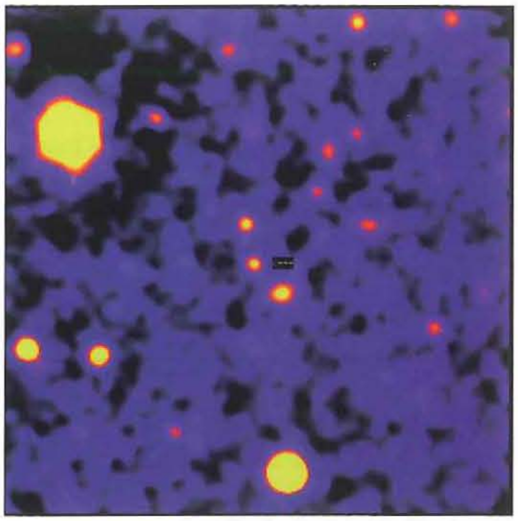
In addition to the numerous awards he's received, McGrath has also appeared on a number of television shows, including an appearance on *The Tonight Show* and a running clip on the Discovery Channel. The producers of *The Oprah Winfrey Show* even featured him in a show on child prodigies.

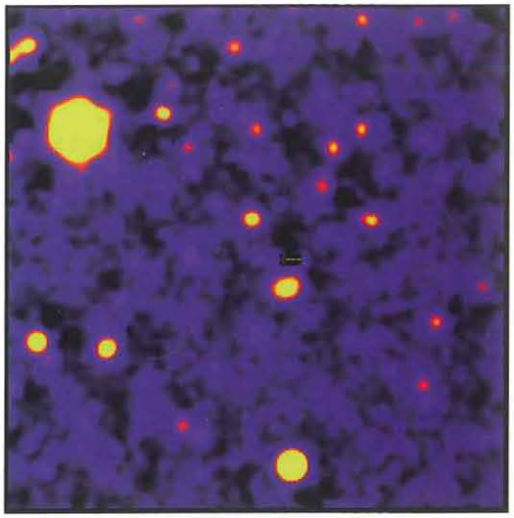
Perhaps his most prodigious accomplishment is the fact that McGrath has been successful in spite of having a learning disability. "Mark recognizes his strengths and weaknesses, but he doesn't allow either one to define him," says Hank Noble, his friend and former principal. Mark doesn't have time to bask in his glories, however. He's too busy sniffing out ideas for new inventions and working toward getting his pilot's license. □—*RP*



Shaking Up the System

Unlike James Bond, southland residents are used to having their beverages (and everything else around them) shaken *and* stirred, when the buildings they are in respond to the massive force of an earthquake. But thanks to the extensive digital earthquake-monitoring system that the USGS (United States Geological Survey) recently installed in Caltech's nine-story Millikan Library, researchers from Caltech, USGS, and elsewhere will now have a first-rate testbed to gain a more comprehensive understanding of what happens to reinforced-concrete buildings during earthquakes. The new 36-channel system—which provides detailed information about the building's movements in real time—replaces a 10-channel system that recorded strong earthquake shaking on film, which then had to be developed before it could be analyzed. □—*RP*





It may be hard for most of us to tell, but these images show evidence of the most energetic event yet observed in the universe—a phenomenon that generated several hundred times more energy than a supernova and for a second or two was as luminous as all the rest of the universe. A gamma-ray burst, named GRB 971214, that had been discovered in December left a faint visible-light afterglow (arrow, far-left image), which was found by a team of astronomers from Columbia and Dartmouth Universities. When the afterglow faded about two months later, a Caltech team (under astronomy professors Shrinivas Kulkarni and George Djorgovski) at the 10-meter W. M. Keck II Telescope in Hawaii discovered a very faint galaxy in its place (right image, above). They measured the distance to this galaxy as 12 billion light-years and, from this distance and the observed brightness of the burst, calculated the amount of energy released—an amount that "staggers the imagination" and that most theoretical models cannot explain, according to Kulkarni.

Proposed Radioactive Dump Site May Be Seismically Active

Recent geodetic measurements using Global Positioning System (GPS) satellites show that the Yucca Mountain area in southern Nevada is straining roughly 10 to 100 times faster than expected on the basis of the geologic history of the area. And for the moment at least, geologists are at a loss to explain the anomaly.

In the March 28 issue of the journal *Science*, Caltech Professor of Geology Brian Wernicke and colleagues at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, reported on Global Positioning System surveys they conducted from 1991 to 1997. Those surveys show that the Yucca Mountain area is stretching apart at about one millimeter per year east-southeastward.

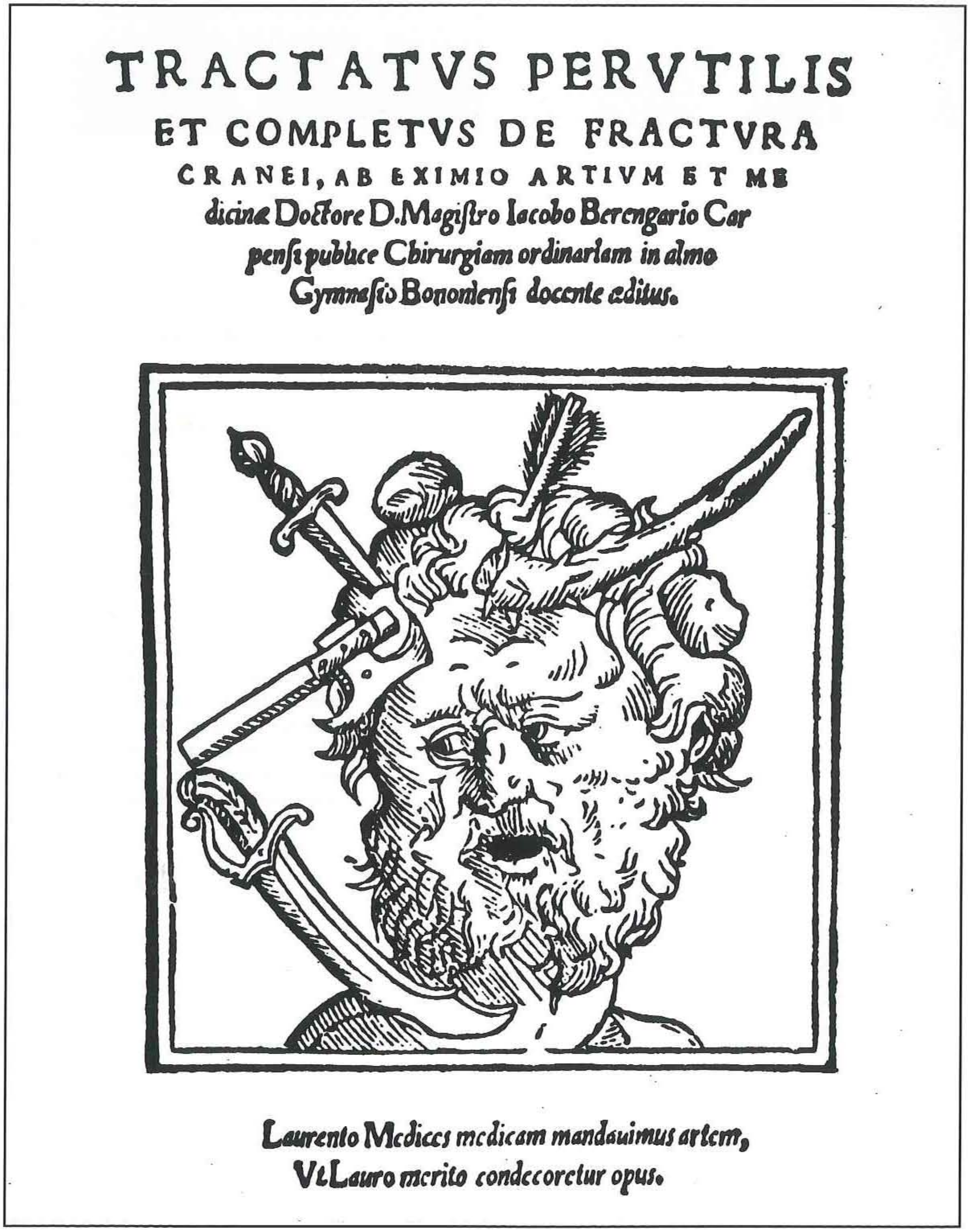
"The question is, why are the predicted geological rates of stretching so much lower than what we are measuring?" asks Wernicke. "That's something we need to think through and understand." The answer is likely to be of interest to quite a few people, because Yucca Mountain has been proposed as a site for the permanent disposal of high-level radioactive waste. Experts believe that the waste-disposal site can accommodate a certain amount of seismic activity, but they nonetheless would like for any site to have a certain amount of stability over the next 10,000 to 100,000 years.

Yucca Mountain was already known to have both seismic and volcanic activity, Wernicke says. An example of the former is the 5.4-magnitude "Little Skull Mountain" earthquake that occurred in 1992. And an example of the latter is the 80,000-year-old volcano to the south of the mountain. The volcano is inactive, but still must be studied according to Department of Energy regulations.

The problem the new study poses is that the strain is building up in the crust at a rate about one-fourth that of the most rapidly straining areas of Earth's crust, such as near the San Andreas fault, Wernicke says. But there could be other factors at work.

"There are three possibilities that we outline in the paper as to why the satellite data doesn't agree with the average predicted by the geological record," he says. "Either the average is wrong, or we are wrong, or there's some kind of pulse of activity going on and we just happened to take our data during the pulse." The latter scenario, Wernicke believes, could turn out to be the case. But if Yucca Mountain is really as seismically active as the current data indicate at face value, the likelihood of magmatic and tectonic events could be 10 times higher than once believed. □—*RT*

The electrodes feed both an oscilloscope and a loudspeaker—like Jodie Foster's character in *Contact*, Hartmann actually listens to her life forms.



TRACTATVS PERVTILIS
ET COMPLETVS DE FRACTVRA
CRANEI, AB EXIMIO ARTIVM ET ME
dicinæ Doctore D. Magistro Iacobo Berengario Car
pensi publice Chirurgiam ordinariam in almo
Gymnasio Bononiensi docente æditus.

Laurento Medices medicam mandauimus artem,
Vt Lauro merito condecoretur opus.

Listening in on the Cerebellum

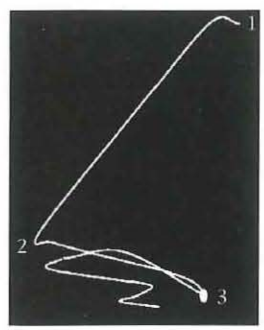
by Douglas L. Smith

The frontispiece of the first known book on the treatment of head injuries, Jacopo Berengario da Carpi's ***Tractatus Perutilis et Completus de Fractura Cranei***, published in 1535. Doctors have been trying to deduce brain functions from brain injuries ever since. (Reprinted from ***Origins of Neuroscience*** by Stanley Finger, Oxford University Press.)

The cerebellum is the part of your brain that lies above the spinal cord and below the cerebrum, which is the seat of higher thought. The cerebellum got its name (which is Latin for "little brain") because, in humans, it looks like a smaller edition of the cerebrum above it—it has two wrinkled hemispheres, left and right, connected by a structure called the vermis, from the Latin word for "worm." It's part of the hindbrain, evolutionarily the oldest part of the brain, so it probably does something pretty basic; and it's pretty big, occupying about one-fifth of the adult human cranium, so it probably does something pretty important. And, at well over 100 billion neurons, or nerve cells, it contains far more cells than the cerebrum. At the beginning of this century, doctors studying patients with cerebellar injuries concluded that it is the organ of motor coordination—regulating (but not initiating) the muscular commands needed for posture, balance, and voluntary movement. This remains the generally accepted view today, but experiments in Professor of Biology James Bower's lab at Caltech are bolstering his theory that the cerebellum plays a fundamentally different role. We'll get to Bower's theory shortly, but first let's see why the mainstream view prevails.

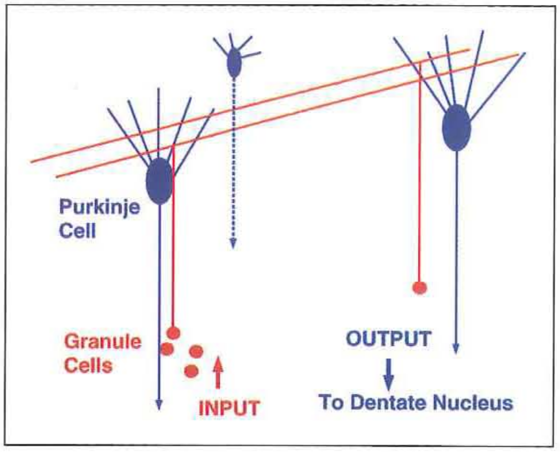
The first rigorous studies of cerebellar injuries were done by Gordon Holmes, a field neurosurgeon attached to the British army during World War I. The Great War was a great boon to researchers mapping the brain's functions—the widespread use of that marvelous new weapon, the machine gun, provided a bountiful selection of patients with neat, localized brain injuries. By observing what each patient could no longer do, one could deduce the function of the region of brain tissue excised by the bullet. Unfortunately for neuroscience, Holmes was unable to follow many of his cases for extended periods, because they were "of necessity evacuated to England." Still, he noticed several characteristics peculiar to cerebellar injuries.

In a classic set of experiments, Holmes attached a small light bulb to the patient's fingertip, and then took long-exposure photographs to map the finger's trajectory when the patient was asked to hold his arm upright over his head and then touch his nose. The patient usually missed the mark, often smacking himself smartly in the face. Then, like a golfer who takes five putts to sink the ball, shooting wide of the cup by inches each time, the hand would flail around the nose in a series of overcorrections. Closer examination of the photos revealed that, whereas an uninjured person would make one smooth, coordinated movement of the shoulder and elbow, Holmes's patients moved each joint separately. They rotated the shoulder to bring the arm down to nose level, then flexed the elbow to bring the fingertip in. His patients also had difficulty with such fine-motor-skill tasks as buttoning their shirts, or striking a designated key on a piano.



The patient started with his arm over his head (1). When asked to touch his nose, he brought his arm down (2), then drew his hand in, smacking himself in the face (3). Adapted from Holmes's *The Cerebellum of Man.*

The patients had muscle-control problems even when standing still. If Holmes pushed or pulled on the patient's arm after telling him to hold it out rigidly, the arm would move through a greater arc than normal. Or if the patient was resting his arm on a bar that Holmes suddenly removed, the arm would drop considerably before readjusting, whereas a normal person's arm would just bob slightly.



A Purkinje cell looks like a menorah might, if Hanukkah lasted 280 days or so.

The essence of the granule-cell/Purkinje-cell circuit. A nerve impulse arrives at a granule cell (red) and is sent up the ascending fiber, which ends in a T whose arms (the parallel fibers) run perpendicularly through rank after rank of Purkinje cells (blue). The Purkinje cells collect information from the parallel fibers and send it out of the cerebellum via the dentate nuclei, which lie deep in the cerebellum's interior.

Holmes also noticed delays in initiating actions. This was most apparent when only one side of the cerebellum was injured, and the patient was asked, for example, to raise both arms at once. The affected limb would consistently lag behind the unaffected one. The delays got worse, Holmes found, if the patient's attention was distracted during the experiment, or if the patient was taken by surprise—a patient told to expect a command reacted faster than did one to whom Holmes gave a command out of the blue.

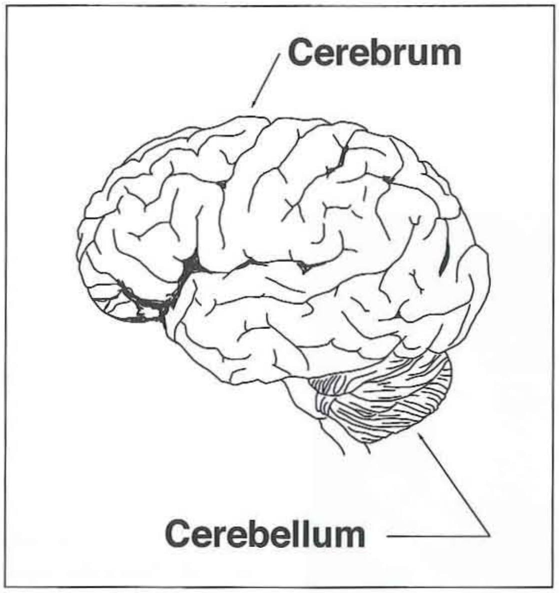
The conclusions seemed clear: the cerebellum is in charge of helping the various muscle groups talk to one another, coordinating movement and body position, and relaying motor commands from the higher brain centers that plan the movements. These functions are normally unconscious, so the patients had to exert conscious control to compensate. As a patient of Holmes with a right-cerebellar-hemisphere injury remarked, "The movements of my left arm are done subconsciously, but I have to think out each movement of the right arm. I come to a dead stop in turning and have to think before I start again."

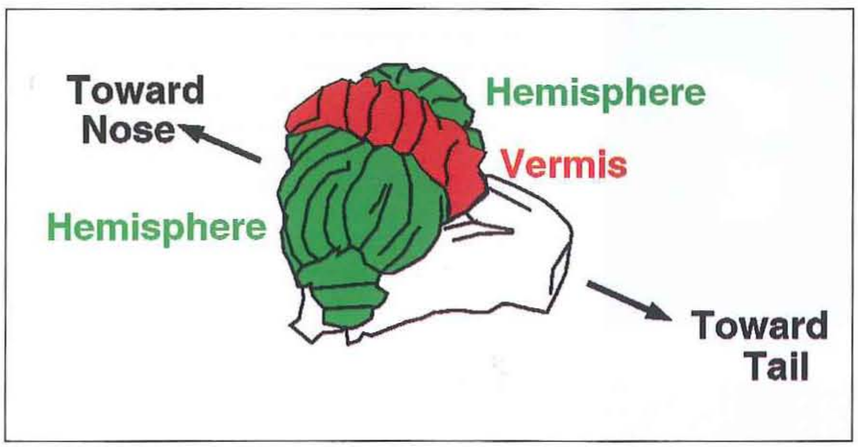
As seen under a microscope, the wiring diagram of the cerebellar cortex is very simple and regular. Only five basic cell types—the basket, granule, Golgi, Purkinje, and stellate cells—live there, and their arrangement repeats over and over and over again in an endless hall of mirrors. And the simplest reduction of the cerebellar circuitry contains only two types of cells, granule and Purkinje cells, which between them make up a complete input-output system. (The Golgi cells feed back to the granule cells, damping their output; the basket and stellate cells are part of another circuit beyond the scope of this article.) Granule cells collect inputs from outside the cerebellum and send them along parallel fibers that are strung like telephone lines between the Purkinje cells. Each granule cell has one parallel fiber, which feeds perhaps seven-score Purkinje cells. The Purkinje cells pick information off the parallel fibers and send it out of the cerebellum—in fact, they are the cerebellar cortex's only output channel. A Purkinje cell looks like a menorah might, if Hanukkah lasted 280 days or so. Up to 300,000 parallel fibers may be strung through a Purkinje cell, although it only makes contact with one-half to two-thirds of them. If we assume that form follows function, then a uniform circuit implies that the cerebellum applies some uniform process to its inputs. So in light of Holmes's and others' studies, it seemed reasonable to believe that the granule-cell/Purkinje-cell circuit sorts and collates motor controls.

Or does it? If, off in the distance, you see a bicyclist weaving erratically through an empty parking lot, you might assume that the bike's handlebars have come loose. But as you approach, you might discover that the cyclist is practicing a stunt, and is in fact blindfolded. Thus either a mechanical output problem or a sensory input problem can have the same outward effect. Might such an analogy apply to the cerebellum? Could the manifestations of cerebellar damage that appear to be deficiencies in motor control actually result from a sensory failure of some kind?

Bower believes that the cerebellum acts to optimize how the nervous system acquires the sensory data on which it depends. "Sensory surfaces are very, very sensitive," he says. "Small changes in the position of, say, your fingertips can have enormous consequences for the sensory data received by the brain. We believe that the cerebellum is involved in coordinating the fine position of the sensory surfaces—making adjustments of a few microns over millisecond time scales—to ensure that the rest of the brain has the best possible data available to it." Thus, when you reach into your pocket to find a penny, your cerebellum ensures that you have the sensory data necessary to distinguish it from a quarter or a nickel by its size, weight, and texture. The motor-control centers, in turn, use this sensory data to generate accurate instructions to send to your muscles. So if the sensory information is messed up, the control of movement would be less precise. In Bower's view, this accounts for Holmes's observations.

It's actually been known for some time that the cerebellum handles sensory information. In the late 1960s, researchers recording the electrical impulses from granule cells in the cerebellar hemispheres of anesthetized rats found that lightly tapping on the rat's lips or whiskers caused a large response, but when the rat's legs or tail were touched, nothing much happened. This was a surprise, because if the cerebellum is really a motor-coordination center, it should be linked to the parts of the anatomy that walk around; rats don't walk on their whiskers. Instead, the whiskers and lips are the rat's chief organs of touch.



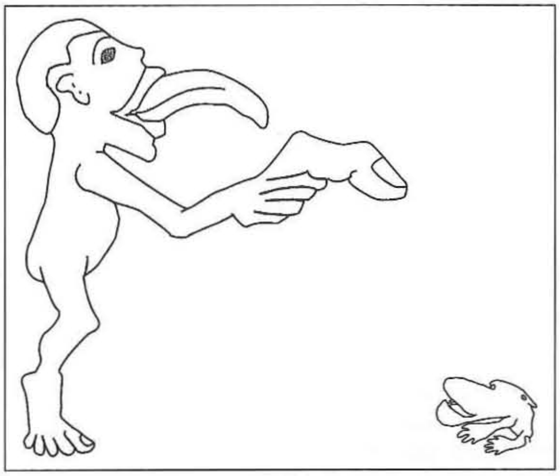


While the human cerebellum nestles under the centers of higher thought (right), the rat's cerebellum rides atop the rest of its brain like the shell on a snail (below).

We now know that, in general, large regions of the cerebellum collect visual, tactile, and auditory information. While some regions of the cerebellum are devoted to sensory information that reflects the positions of the animal's limbs in space and the tension of its muscles (called proprioception—an internal sense of one's self, if you will), the largest part of the cerebellum is devoted to the external senses. Furthermore, the proportion of the cerebellum devoted to each class of sensory input varies from species to species in a way that mirrors how each creature explores its world. Thus, the cat cerebellum draws tactile information from the mouth and forepaws, and has stout conduits from the eyes and ears. Echolocating bats are wired for sound. Electric fish have cerebellar structures that sense disturbances created by prey swimming through the electric field the fish generates. Similarly, the platypus devotes much of its cerebellar wiring to its electrosensitive beak. These electrosensors are astonishingly acute, registering the infinitesimal electric fields generated as the prey's muscles contract—not even the swishing of the gills goes unnoticed. (Picture a berserk platypus starring in *Friday the 13th, Part LXVI*—its victims cowering in the darkness, desperately trying to hold their breath to avoid detection.) In humans and other primates, the tactile inputs to the cerebellum come from the hands and fingers. In addition, the spider monkey has a strong cerebellar connection to a patch of hairless skin, like that on the palm of your hand, on the underside of the tip of its tail. "Spider monkeys frequently use this part of their tail to explore the ground, and objects around them," explains Mitra Hartmann, a grad student in Bower's lab. "And sometimes they carry their tails over the top of their heads to sense the environment in front of them."

So what is the cerebellum doing with all this sensory information? This question is very hard to answer when your subject is anesthetized, or, worse, thinly sliced on a microscope slide. Bower's hypothesis that the cerebellum acts to fine-tune how sensory data is gathered implies that it should

Adapted from *Essentials of Neural Science and Behavior*, Kandel, Schwartz, and Jessell eds, published by Appleton & Lange.



Sit, boy. Speak. Good rat. In the somatosensory cortex, which is where the cerebrum (as opposed to the cerebellum) processes tactile information, the acreage of cortical real estate devoted to input from each part of the body is proportional to the extent to which we use that body part to feel out our surroundings. The human and rat above are drawn in those same proportions, although not to the same scale. Thus, humans tend to explore with the thumb and tongue (as any parent of a one-year-old knows); rats rely on the lips and snout. Furthermore, the cortical regions that handle adjacent parts of the body adjoin one another. But in the rat's cerebellum, the regions that respond to different parts of the body are all jumbled together, as shown in the map of cerebellar region crus IIa at right. The colors correspond to the colors on the rat's face below.

be very busy when the animal is exploring its environment—a time when accurate sensory data are likely to be particularly important. But anesthetized animals don't take much interest in their surroundings, so, in order to explore that hypothesis, you need to record from a wide-awake animal that's poking its nose into things. Literally—the parts of the cerebellum that Bower's lab studies are devoted to the sense of touch.

Until recently, it was quite difficult to tap into the brain of a freely moving animal. The electrical signal from a single cell is minuscule—about two-tenths of a millivolt when recorded right next to the cell. Since the signals are so small, you need a preamplifier near the source, i.e., mounted on the animal's head, to push the signal up the wire to the data-acquisition system. Thanks to silicon technology, we now have multichannel preamps small enough for rodent haberdashery. These preamps inspired Hartmann and Upinder Bhalla (PhD '93) to design and build electrode arrays that could be permanently implanted into a rat's brain. Says Hartmann, "In the last five or ten years, the notion of doing chronic recordings from freely moving animals has really taken off." Researchers can now examine the animal's neural activity as the rat goes about its rat business for weeks or months.

Preparing a rat for a preamp hat is a three- to six-hour surgical procedure in which Hartmann inserts arrays of up to eight electrodes into one or both hemispheres of an anesthetized rat's cerebellum. Each electrode is a wire less than 50 microns in diameter—thinner than a rat's whisker. One end of each electrode is painlessly inserted into the rat's brain, while the other end is attached to a connector about the size of a Pez candy. The electrodes and the connector are glued to the rat's skull with the same acrylic that dentists use to make retainers; what you have after the operation is a punk rat with a plastic Mohawk. The rats don't seem to mind their new hairdos and fancy

The electrodes and the connector are glued to the rat's skull with the same acrylic that dentists use to make retainers; what you have after the operation is a punk rat with a plastic Mohawk. The rats don't seem to mind their new hairdos and fancy hats, and upon recovery from the operation, they behave just like their more conventionally attired cousins.

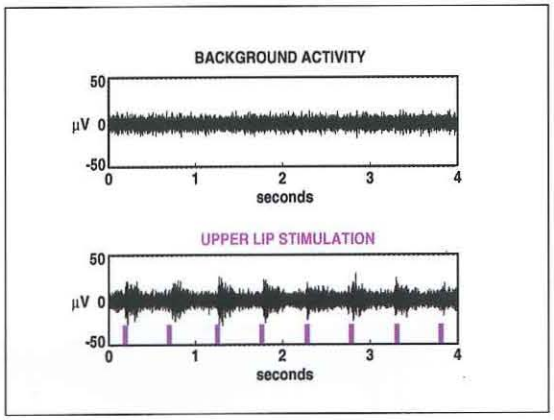
hats, and upon recovery from the operation, they behave just like their more conventionally attired cousins. The matchbook-sized preamp, which plugs into the connector, is moved from rat to rat.

The electrodes feed both an oscilloscope and a loudspeaker—like Jodie Foster's character in *Contact*, Hartmann actually listens to her life forms. "The speaker is very important, because it's much easier to hear a short, sharp burst than it is to watch for it on an oscilloscope. If you blink, you'll miss it. It's very convenient that a lot of the power in neural signals falls within our audible range, which is a feature of our own neural apparatus. I like that idea, because it's kind of recursive." Neural activity sounds like AM radio static.

So Hartmann has been eavesdropping on rats resting, eating, grooming, and just generally being rats, while at the same time videotaping them to correlate their behavior with the recorded neural signals. The particular cells she's wire-tapped live in a region called crus IIa, and respond when the lip and whiskers are touched—in the case of the rat in the accompanying pictures, the upper right lip and its attached whiskers. Because the granule cells are so small—five to six microns in diameter—her best guess is that she's hearing a couple of hundred cells at once. (Purkinje cells are much larger, and could in theory be isolated by an electrode this size, but for several technical reasons we can't yet record from them in rat cerebellums.)

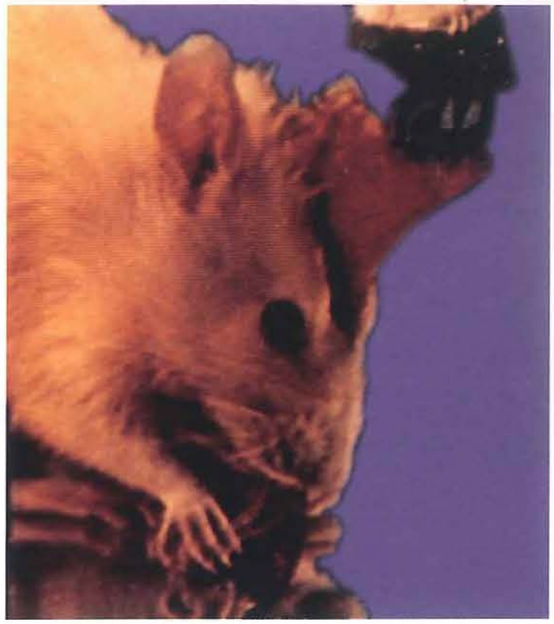
Her studies have confirmed that these granule cells deal only with sensory information, even in an awake, moving animal. Says Hartmann, "That result in and of itself was surprising to many people, because they expected at least some modulation of the response by motor activity. Or maybe even that the response to touch was subsidiary to a motor response." The clearest-cut example of the distinction between motor and sensory activity was furnished by the rats as they dined.

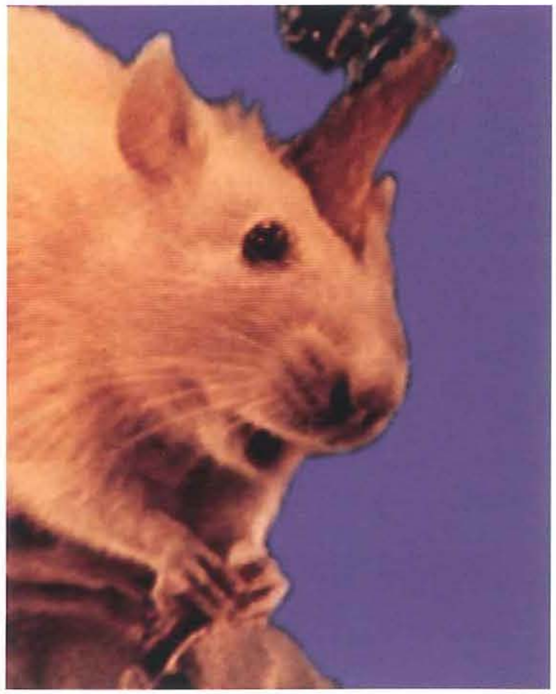
This rat responds to stimulation of the upper right lip and whiskers, as shown in the graph below. The vertical axis is the change in the granule cells' electrical output (plotted in millionths of a volt) rela-tive to a baseline voltage. The purple lines mark when the whiskers were touched with the wooden handle of a Q-tip.

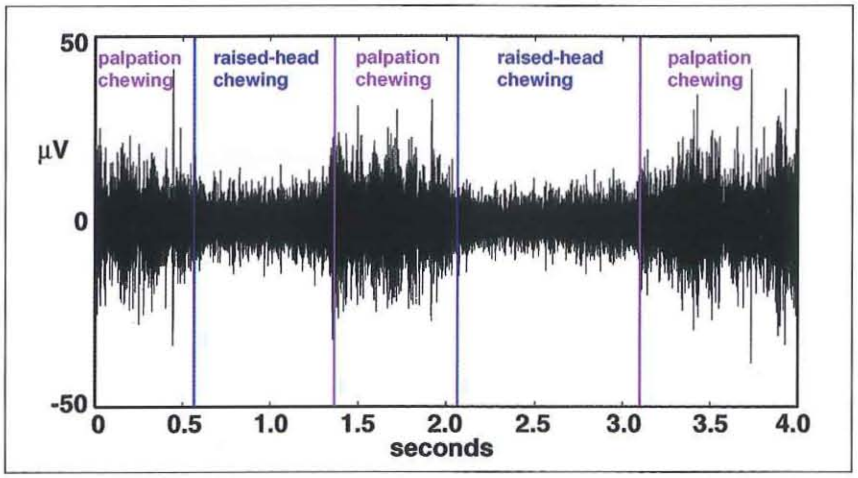


As you may have noticed on a walk through the park, squirrels, rats, and other rodents eat in a multi-step process. First, they hold the food steady with their forepaws and move their lips back and forth across its surface, exploring the food before biting into it. "It's a little bit like holding a whole loaf of bread in your hands and having to figure out how to get a bite out of it," Hartmann explains. Then the animal takes a bite and begins to chew, while at the same time continuing to nuzzle and explore the food with its lips. Hartmann has christened this behavior "palpation chewing." And finally, the rat removes its lips from the food, raises its head, and continues to chew before swallowing. This is called "raised-head chewing," for obvious reasons, and presumably lets the animal look around to avoid becoming a meal itself. In both palpation and raised-head chewing, the motor activity (the chewing) is identical, but the granule cells fired only during palpation chewing—a SH-SH-SH-SH-SH-SH-SH-SH-SH in time with the food touching the rat's lips.

Watching the rats groom themselves confirmed



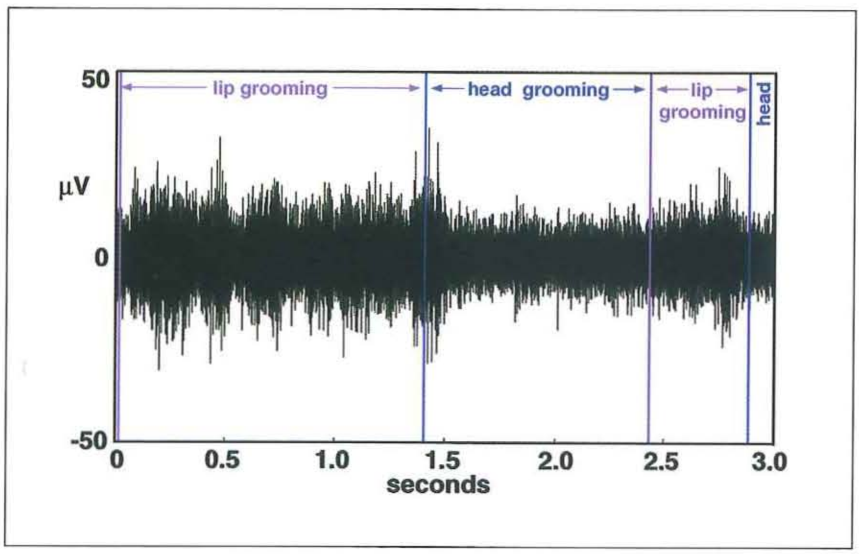




Top: Palpation chewing.
Bottom: Raised-head chewing.
Left: The granule cells pulsed with activity during palpation chewing.

Rats groom the way cats and bachelors do—they moisten a forepaw and slick back their hair.

Again, the granule cells pulsed as the lip was touched.

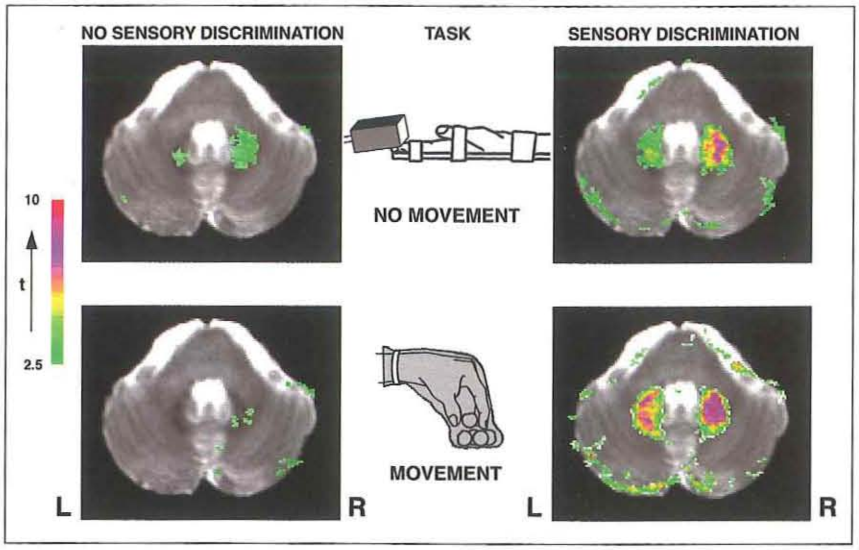


that the bugged cells were dealing only in sensory information from one locale. Rats groom the way cats and bachelors do—they moisten a forepaw and slick back their hair. When the rat groomed its upper right lip, the granule cells responded, but when it was grooming elsewhere, they didn't.

But by far the session that recorded the most sustained bursts was when the rat was trying to get at a chunk of pretzel wrapped in tissue paper. ("Rats prefer pretzels to chocolate," says a bemused Hartmann.) As the rat nuzzled the paper, trying to figure out how to get to the goodie within, the granule cells went nuts every time the lip touched the tissue.

Doggone it, I *know* there's a pretzel in here!

The central, testable nub of Bower's theory is that the cerebellum is going to be busiest when it's choreographing the sensory apparatus to get detailed information about an object the rest of the brain is interested in. Looked at another way, the theory predicts that the cerebellum should be quieter when sensory receptors are being stimulated but the brain is not using the information it's getting from those receptors. This idea is difficult to test, however, with a rat. It's hard to know, for example, when a rat is interested, and when it's ignoring the stimulation. Perhaps rats pay constant attention to all stimuli—as we might, too, if we spent all our time surrounded by organisms a thousand times bigger than ourselves. So in order to test the theory further, it was necessary to study an animal whose mind's workings are



Left: Functional Magnetic Resonance Imaging measures the level of dissolved oxygen in the blood as a proxy for brain activity—busy regions get extra oxygen to fuel their work. The gray background image is an anatomical MRI scan of the cerebellum, on which the functional data have been overlaid in color. The scale labeled *t* shows cerebellar activity compared to baseline levels measured when the subject was lying quietly. In the upper two panels, the fingertips were rubbed with sandpaper; in the right-hand panel, the subject was asked to judge the sandpaper's texture. In the lower two panels, the subject was handling unseen balls; in the right-hand panel, the subject had to judge their shape. The activity is actually greatest in the dentate nuclei (the two dark, crescent-shaped bodies near the midline), which collect the Purkinje cells' output.

more accessible—*Homo sapiens*. But even the most eager grad students don't generally volunteer to have electrodes inserted into their heads, so the Bower lab is collaborating with a group headed by Dr. Peter Fox at the University of Texas Health Science Center in San Antonio. The Fox group uses functional Magnetic Resonance Imaging (fMRI) techniques to watch the activity of human cerebellums as various tasks are performed. People have their pluses as experimental animals—we're much easier to train than rats, which require weeks of coaching. On the minus side, fMRI provides a very indirect measure of brain activity.

The human experiments involved stimulating the subjects' fingertips, which we use for tactile exploration much the same way rats use their lips and whiskers. (Also, unless you know the subject very well, it's best to avoid playing with a Texan's whiskers.) Fox's group started by determining

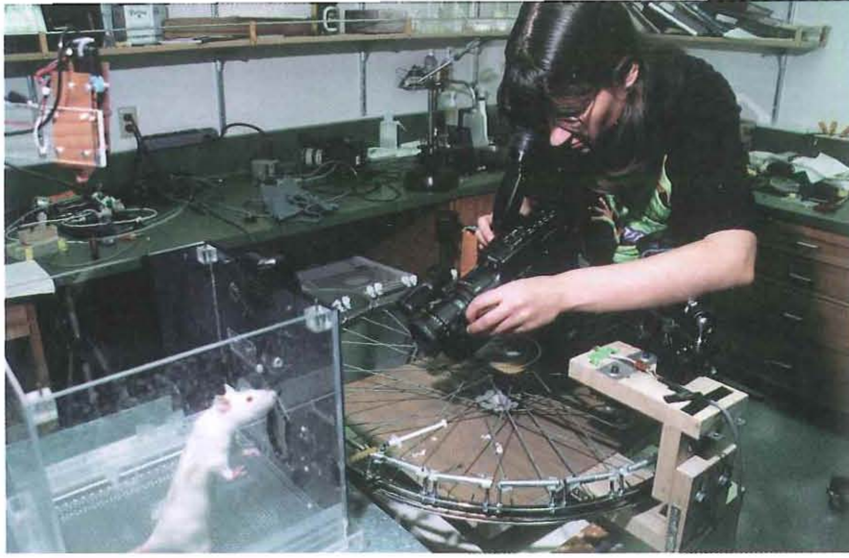
Since people can't be anesthetized just to explore their cerebellums, the volunteers were told to do the next best thing—to lie motionless in the fMRI machine and pretend they were watching C-SPAN coverage of the Department of Labor's budget committee hearings.

how much cerebellar activity resulted from passive stimulation of the fingertips—the equivalent of stroking an anesthetized rat. Since people can't be anesthetized just to explore their cerebellums, the volunteers were told to do the next best thing—to lie motionless in the fMRI machine and pretend they were watching C-SPAN coverage of the Department of Labor's budget committee hearings. Their limp fingers were then lightly rubbed with sandpaper, resulting in a low but discernible cerebellar response. Next, the subjects were told to focus their thoughts on the sandpaper and decide how coarse it was. The cerebellum flared to life—a result consistent with Bower's theory.

But the critical test was still to come—Bower had predicted that simply moving the fingers without making a sensory judgment would produce less activity than if the moving fingers were also being used for sensory discrimination. In this set of experiments, the subjects were first asked to pick up and drop small, unseen balls, then asked to handle them again and identify their shape. The result was quite remarkable—there was no cerebellar response when the balls were grasped and released, but shape discrimination set the cerebellum ablaze.

While the human studies were remarkably consistent with the predicted results, only with implanted electrodes can researchers actually see what small groups of neurons are up to. So Hartmann and Bower returned to their rats for, well, ratification. They decided that having rats use their lips and whiskers to distinguish between different textures would be a good analog to the human fMRI experiments. But as we've seen, getting inside a rat's head isn't so easy. The experiment would have to be designed to exploit behavior one could reasonably expect from a rat in such a way that the experimenters could be sure that the rat was actually interested in the stimulus and was making a discrimination based on it. Designing the task properly, and training the rats to perform it, was going to be a big job—especially since Murphy's Law of Behavioral Biology states, "Under standard experimental conditions, the animal will do as it damn well pleases."

Enter Carolyn Chan and Angela Poole, two Caltech undergrads who not only helped design and build the apparatus, but also trained the rats. The general plan was to have the rats learn that a rough texture pointed the way to a sugar-water reward. This led to the design of the experimental cage: one wall had a central door, big enough to admit the rat's head, and a syringe filled with sugar water in each corner. Both syringes were



The rats are trained for their role in the experiment before the surgery is done. Here Hartmann sets up the video camera while her colleague gets used to the box. The metal door is visible under the rat's chin; black construction paper keeps the rat from seeing the wheel. One of the two syringes can be seen in the foreground.

Harmonica lessons might be more fun, but nuzzling a bolt is a steady job.

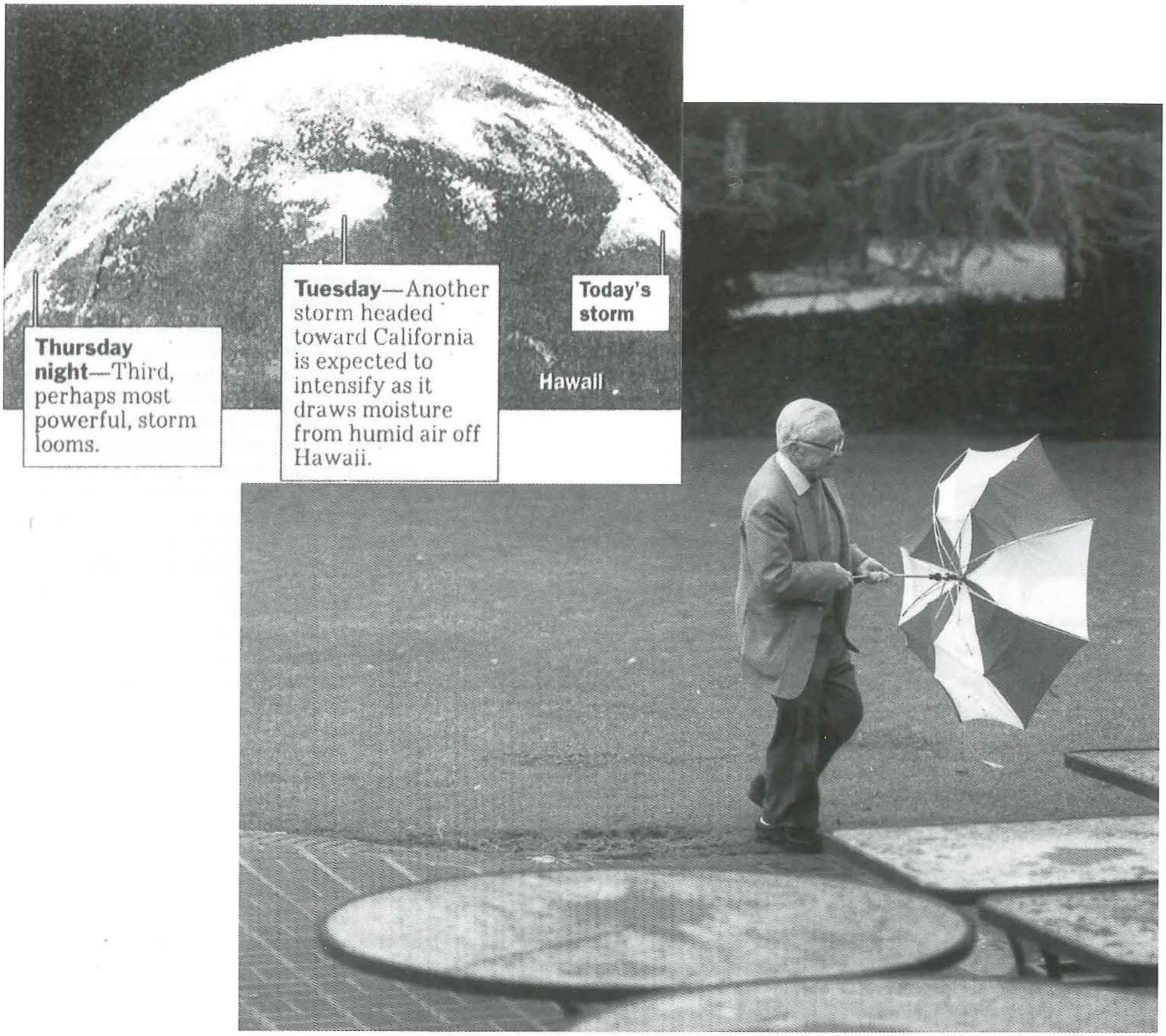
kept full, so that the rat couldn't tell by the smell which one would dispense the reward on any given trial. Behind the door was a lazy Susan (an old bicycle wheel, actually) around whose rim were a series of threaded, horizontal rods—decapitated bolts from Caltech's physical-plant department. The left and right halves of the bolts each had one of three different textures: coarse threading, fine threading, or no threading. During each trial, the door opened, the rat stuck its head out, felt the bolt, and then walked over to the syringe of its choice. If it picked the one closest to the coarser texture, it got a sweet sip. As the rat was drinking (or futilely sucking on the wrong syringe), the door closed and a stepper motor spun the wheel, bringing a new bolt to the door. This way, the rat couldn't see the wheel spin, and there was no scent of a human croupier that might have influenced the rat's decision. Because there were three possible textures, the rat couldn't simply choose the texture that pointed to the reward the previous time. Instead, the rat actually had to evaluate differing degrees of coarseness and pick the coarsest one.

Hartmann, Chan, and Poole were able to train the rats to choose the correct syringe nearly 80 percent of the time—much better than the 50 percent success rate that random chance would bring. So the rats clearly learned to perform the discrimination. But Hartmann, who is now writing up her PhD thesis, is still analyzing the neural data from the experiments.

Bower stresses that he's not proposing that the cerebellum actually interprets the world around us, but that it merely works to ensure that the data arriving at the higher brain centers that *do* do the interpreting is as clean and useful as possible. And although his lab's work to date has revolved around touch, Bower says that similar logic could apply to sight and hearing as well. (Remember, other species, including our own, devote much of their cerebellums to either or both of these senses.) The eyes and ears rely on muscle-tension information to know where they're pointed. Even a couch potato, eyes glued to the TV and inert but for one channel-surfing thumb, makes continuous tiny eye movements from object to object on the screen. Bower compares the cerebellum's role of supporting the rest of the brain's activities to that of your car's cooling system. "The radiator responds to your rate of speed by increasing the coolant flow, and thereby helps your engine run better, but it doesn't itself propel the car. If the radiator springs a leak, a lot of things will happen—the air conditioning will fail, and eventually the car won't run at all. Yet these effects aren't directly related to the radiator's structure or chief function."

Viewed through the prism of Bower's theory, the behavioral effects that cerebellar injuries cause make perfect sense. The muscle-control problems Holmes described would be due to an injured cerebellum being unable to ride herd on the quality of data from the limb-position and muscle-tension sensors, meaning the motor centers would have a fuzzier sense of how the body was poised, and thus movement plans would be less accurate. Similarly, the delay in initiating a movement would be explained by the motor centers taking longer to organize and coordinate movements from the lousy data, throwing the movement's timing off.

Bower's theory might even help to explain some aspects of the most baffling form of mental illness. He explains, "It has often been suggested that at least some forms of autism may be related to the inability of the child to deal with sensory data. Autistic individuals sometimes report that, at different times, the world provides too much or too little sensory data. Cerebellar dysfunction could very well be a contributing factor, especially if the result is inconsistent control over sensory data acquisition. And, indeed, recent MRI studies, performed in Eric Courcesne's lab at UC San Diego, have indicated that cerebellar activity patterns in some autistic children are abnormal." □


Thursday night—Third, perhaps most powerful, storm looms.
Tuesday—Another storm headed toward California is expected to intensify as it draws moisture from humid air off Hawaii.
Today's storm
Hawaii

El Niño and Global Warming: What's Happening to Our Weather?

by Andrew P. Ingersoll

Satellites are the forecaster's best friend. This view of the Pacific Ocean, which ran in the *Los Angeles Times* on Saturday, February 14, shows three storms in procession from Japan (left) to L.A. (right) and their predicted arrival times. Satellite photo courtesy of the National Oceanic and Atmospheric Administration (NOAA), forecast by WeatherData, Inc. But satellites can't see unborn storms—on Monday, February 23rd, a fourth one rolled into town and engaged Ed Lewis (PhD '42), Morgan Professor of Biology, Emeritus, and Nobel laureate, in a tug-of-war for his umbrella.

As you all know, the wet weather we've been having was actually predicted half a year ago. For example, on August 20, 1997, the *Los Angeles Times* ran an article headlined "Southland Prepares for Worst Winter in Decades—Up to 300 percent of normal rainfall is expected from El Niño. Agencies scramble to be ready." Now they weren't predicting that we would have a big storm on any particular day; they were just predicting that we'd have a wet winter. They were quite right about the latter, and they wouldn't have dared to do the former. Since the days of Noah, no one has succeeded in predicting the weather, to the day, six months in advance. There are reasons for that, and I'll tell you what they are. (We can predict Jupiter's day-to-day weather six months in advance, and I'll also talk about that, but it doesn't work here on Earth.) But there are certain kinds of long-term weather predictions that we *can* make, such as El Niño and global warming, and that's my primary subject.

We are getting better at forecasting the weather a few days ahead. Thirty to forty years ago, you could predict tomorrow's weather, and you could make some kind of wild estimate about the day after. Beyond that, you were guessing—you might as well have read the *Farmer's Almanac*. But now we make reasonably reliable six-day forecasts. Again, for example, the *Los Angeles Times* for Saturday, February 14, predicted drenching rain for that day, to be followed by another storm on Tuesday and a third storm Thursday night. The *Times* being a morning paper, the forecast was actually made on the previous day, Friday. And Thursday night the third storm came in, right as expected. This is the kind of thing that makes meteorologists proud. A 90 percent versus an 80 percent chance of rain isn't really what they live for—it's the long-range forecast that shows off who's good.

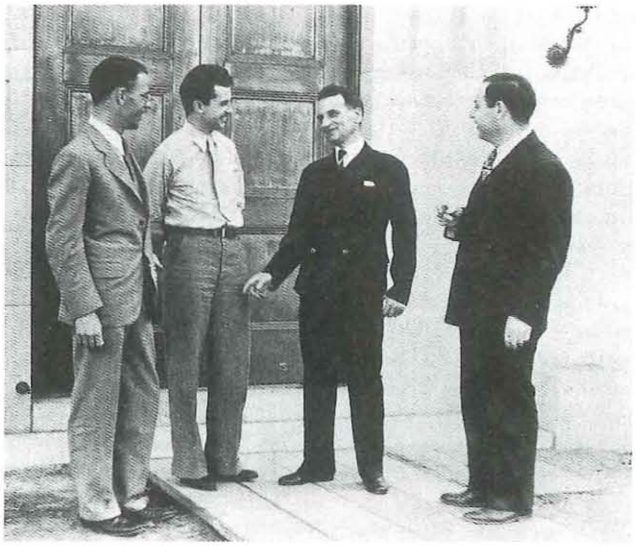
It's not that the IQ of weather forecasters has gone up; it's just that they have better tools nowadays. One important tool is a set of satellites that gives global coverage of the planet and fills in the gaps between the ground stations. In the old days, the only midocean data you had were from wherever a ship or an island happened to be. At our latitude, storms basically move from west to east, so if you see one out in the middle of the Pacific today and you know how fast it's moving, you can extrapolate forward and say when it's going to hit. It's like a merry-go-round going from left to right, and the storms are the horses—if you have a little child on the merry-go-round, you can sit and read your book and, as the child comes around, look up and wave. Weather forecasting is tougher because the horses keep vanishing, and new horses appear

> Is the Kyoto agreement just another rain dance, irrelevant to what's actually driving our climate? Or do we know enough now to say that this is really the right action?

in different places. Thus the theoretical limit to how far ahead you can forecast the weather is set by the lifetime of the storms. It's probably about two weeks at best—we don't yet know exactly where the limit is, because we haven't got the tools to really test it. And because you don't know when and where storms are going to appear and disappear, you can't just put your data into a computer model—another important new tool—and fast-forward the model to print out six months' worth of weather predictions.

At this point, I promised some friends that I would read from the scriptures. But this is Caltech, so the scriptures are *The Feynman Lectures*

Forecasting a gas ball's weather is much simpler because the storms last much longer. Jupiter's Great Red Spot has been there for as long as astronomers have trained telescopes on it; the Earth-sized white oval just below it formed in 1939.



Caltech's first meteorology course, on atmospheric structure, was taught in the geology department by seismologist Beno Gutenberg in 1930. (Gutenberg was interested in acoustic waves in the atmosphere as well as seismic waves.) The meteorology program began in the fall of 1933 under the aegis of the aeronautics department. Besides Gutenberg, the instructors included (from left) Clark Millikan (PhD '28), Irving Krick (MS '33, PhD '34), Theodore von Kármán, and Arthur Klein BS '21, MS '24, PhD '25). The program eventually became a freestanding department with Krick, a grad student of both Gutenberg and von Kármán, as its chair.

on Physics—the bane of Caltech undergrads in the 1960s and '70s. Feynman understood why complicated classical systems, as opposed to quantum-mechanical systems, are basically unpredictable. Let me read from the Book of Feynman, Chapter 38, Page 9: "If we knew the position and the velocity of every particle in the world, or in a box of gas, we could predict exactly what would happen.... Suppose, however, that we have a finite accuracy and do not know *exactly* where just one atom is, say to one part in a billion. Then as it goes along it hits another atom, and because we did not know the position better than to one part in a billion, we find an even larger error in the position after the collision. And that is amplified, of course, in the next collision, so that if we start with only a tiny error it rapidly magnifies to a very great uncertainty." That's it, folks. That's exactly why weather forecasting is so hard. That's why no computer will ever foretell the birth or death of a specific storm. Weather forecasters call this the Butterfly Effect: the flapping of a butterfly's wing in Brazil might eventually cause a blizzard in Helsinki.

Caltech had a meteorology department back in the '30s and '40s, and the faculty bandied about the idea of a theoretical limit to predictability. It was not clear then that there was such a thing. (And there really isn't on Jupiter, as I said.) In fact, the department chair, who maintained that it was possible to predict the weather months in advance by matching observed weather patterns with historical ones, supposedly predicted the weather for D-Day in December 1943. Caltech abolished its meteorology program shortly after the war, partly because President DuBridge, who took office in September 1946, wanted to focus the Institute on basic instead of applied science.

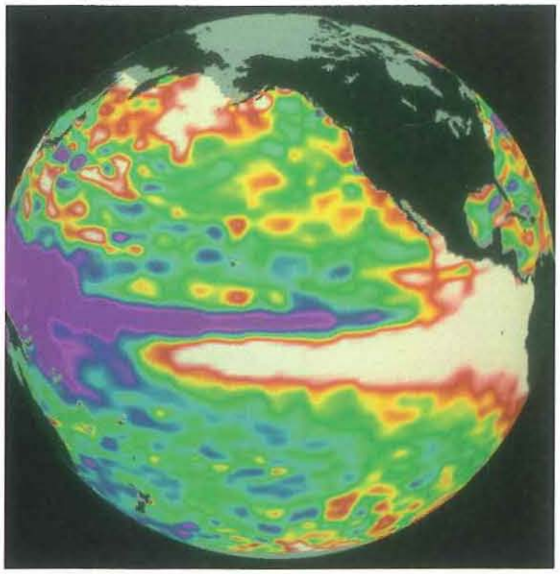
Several decades passed, and Caltech hired a few planetary scientists with some atmospheric-science background, one of whom was me. And a funny thing happened—we started predicting the weather on the giant planets months in advance. I was a member of the Voyager imaging team, and I was in charge of Jupiter's atmosphere. We knew that in the last two days before the spacecraft zoomed past Jupiter, we would get a chance to photograph some of its storms up close. Voyager would be so close that only a small portion of Jupiter would fit in the camera frame, so we had to figure out where the storms were going to be in time to send commands up to the spacecraft saying, at such and such a time, aim the camera at such and such a place, and we promise there will be a storm there. We had to give the engineers the aim points three weeks in advance. That's how long it took the engineers to integrate our aim points into everything else the spacecraft was doing, write up the whole command sequence, test it, and send it to the spacecraft. (Later, for Galileo, we had to provide a rough forecast for Jupiter six months in advance, so that the mission team would know which side of the planet the Great Red Spot would be on.)

Anyway, during Voyager's long approach to Jupiter, the spacecraft was snapping pictures every day, as were telescopes on Earth. And we knew that the storms on Jupiter rode the merry-go-round for a long, long time—the Great Red Spot, for example, is at least 300 years old. The storms

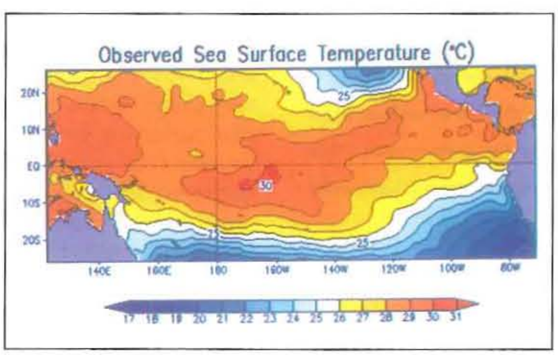
Neptune is too far away for its storms to be easily visible from Earth, but it had ample time to establish a track record during Voyager's leisurely approach. The Great Dark Spot is at center; Scooter is the white cloud halfway between the dark spots.

are all moving relative to one another, and of course the planet is rotating, so we took the data from the pictures, plotted the storms' positions as a function of time, laid a ruler on the graph, and extrapolated where the storms were going to be. The storms do change—they churn and boil, they fade and brighten; their appearance changes daily. And smaller storms come and go. But we hit just about every target, and that's not because we were brilliant people. It's just that Jupiter is very different from Earth. Predicting the weather on the giant planets is simpler—probably because they have no solid surfaces, no topography, and no oceans to complicate the circulation patterns.

Ten years later, Voyager 2 was at Neptune. Neptune is a little more complicated because, while Jupiter's storms move at relative velocities of tens of meters per second, Neptune's storms zip past one another at velocities of up to several hundred meters per second. For example, the two dark spots north and south of a storm we nicknamed Scooter lap each other every five days. (Neptune's storms may also be shorter-lived—the Great Dark Spot seems to have disappeared from Hubble Space Telescope images taken in 1991.) But we could still make our three-week forecasts with junior-high-school mathematics. We didn't have any supercomputers or fancy stuff, but it worked. We got wonderful photos. By contrast, at the same time, August 1989, Hurricane Hugo was threatening the Carolina coast like a prize-fighter—dancing around, faking left, faking right. The meteorologists on the East Coast were issuing 12-hour forecasts, trying to predict where Hugo would come ashore. But the hurricane kept stopping dead and veering off in another direction, leaving them flat-footed.

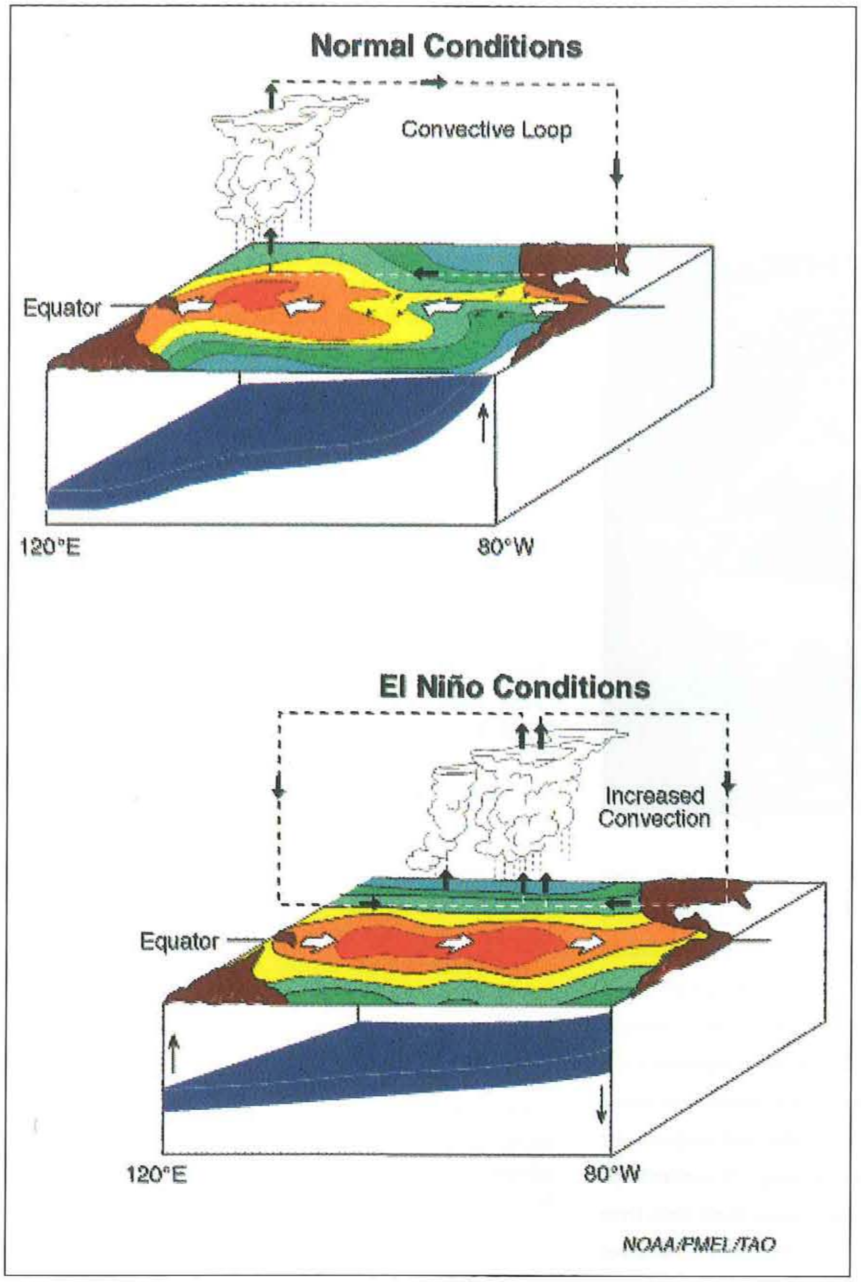


Above: A portrait of El Niño from October 23, 1997. This data is from JPL's TOPEX/Poseidon satellite, which doesn't actually measure ocean temperature, but instead measures the expansion of the ocean—a good proxy for temperature, because warm water bulges the ocean's surface upward. (See *E&S*, Spring 1995.) Yellow-green represents the ocean's normal height. Yellow is five centimeters above normal, red is 10, and white is 15; blue and magenta are below normal, with magenta being -15 centimeters. Below: NOAA seven-day average temperature data from October 26 – November 1, 1997. This data is compiled from buoys, ships, and satellites that measure the infrared radiation from the topmost millimeter of seawater (which, unfortunately, is sensitive to winds, clouds, sunlight, and evaporation).



Enough about day-to-day forecasting—let's move on to predicting El Niño six months in advance. El Niño is a sloshing of warm water from the western side of the Pacific Ocean eastward toward the American side. There's a lot of mass involved, and the ocean currents move slowly, and it's this ponderousness that makes long-range predictions possible—people know that once the warm water piles up on our side, it's going to stay here for a while. This affects our weather because warm water evaporates faster, and more water vapor in the atmosphere means more rainfall and more storms. Meanwhile, in the western Pacific, the water is colder than normal, which causes droughts and fires—you may remember that Indonesia had terrible problems with both.

The upper figure at left is a picture of this year's El Niño—I'm sure you've seen pictures like this. The angry, highly colored region is five or more degrees centigrade above normal. But this isn't really the way the ocean temperatures look—the actual sea-surface temperatures are shown in the map at left. The warmest water is south of Hawaii in the central Pacific, near the equator, where the



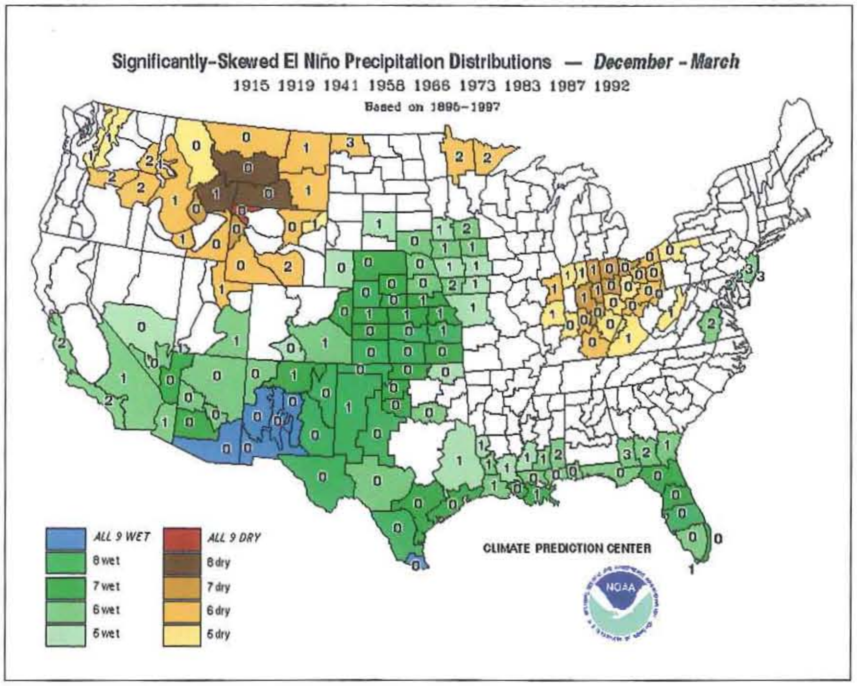
The sloshing thermocline. Under normal conditions (top), the trade winds (white arrows) blow from east to west. The warm surface water (orange and red contours) piles up in the western Pacific, pushing the thermocline (the blue layer) down there, while allowing it to rise in the eastern Pacific. In an El Niño year (bottom), the wind slackens or even reverses direction, and the warm surface water remains evenly distributed across the entire ocean. Then the thermocline becomes almost horizontal.

most sunlight falls. Well, so what—wouldn't you expect that? This is actually abnormal because, during normal years, the warm water is all piled up in the western Pacific. The trade winds, which blow from east to west at the equator, drive the warm water westward. So if we take the abnormal pattern and subtract from it the normal pattern, you get the picture we're used to seeing. The American coast looks warm, because the water there is normally much colder. In fact, the American coast is the warmest anomaly of all—the largest departure from normal.

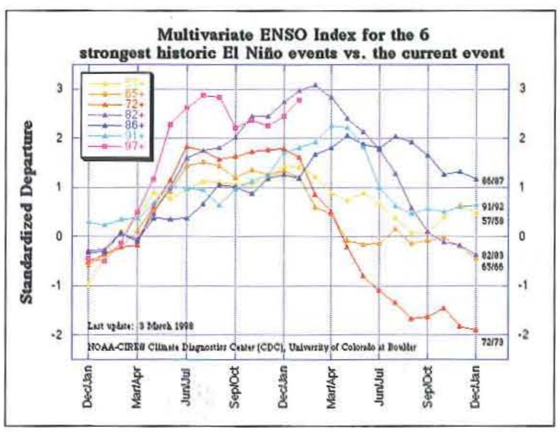
It's not really the ocean's surface that's sloshing, but something called the thermocline, which lies about a hundred meters deep. The thermocline is the interface between the upper ocean, which is relatively warm (up to 30° C), and the cold water below. Most of the ocean is barely above the freezing point. Normally, the trade winds blow the warm surface water toward the west, depressing the thermocline in the western Pacific. Pushing the warm water westward means the thermocline rises to the surface in the east, so that there's cold water off the coast of Peru. But for some reason, the trade winds periodically slacken or even reverse, blowing the warm water the other way. The thermocline gets shoved down in the east, and there's warm water all the way across.

So the thermocline sloshes back and forth, like water in a kid's bathtub, and the frequency of the sloshing depends on the density difference above and below the thermocline. This difference is not very great, so the frequency is very slow. It's like that parlor toy you may have seen that's supposed to relax you—the long, horizontal container filled with two different-colored fluids of almost the same density. You tip the container, and waves slosh back and forth very slowly.

But there are several mysteries connected with El Niño. The natural period of the bathtub mode is a little less than a year, which is too short to explain the observed frequency of El Niño. El



Above: The colored areas in this map of the United States show regions that have been particularly wet or particularly dry in the nine El Niño years of this century. (The white areas got normal precipitation.) The number in each colored area shows how often an El Niño year bucked the trend—a dry year in a region that usually gets extra rainfall during El Niño, for example.

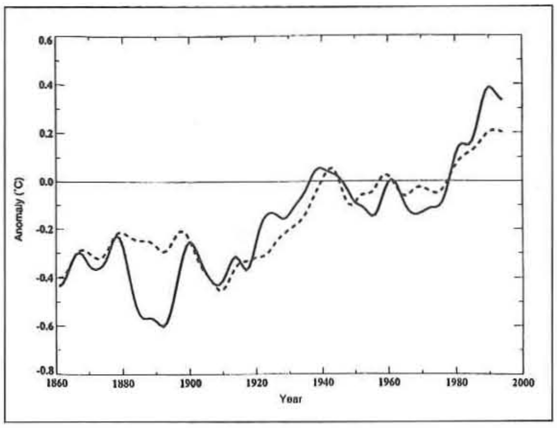


Above: Although El Niño's arrival was predicted successfully, predicting its strength is still dicey. Early indications were that it would be very strong indeed—the fierceness of its onset outstripped the one of the winter of 1982, which did tremendous damage. Fortunately, the current El Niño has not lived up to its advance billing. The "multivariate index" is a composite of such variables as air pressure and temperature, wind speeds, ocean temperature, etc.

Niños come, on average, every four years, but they can be as few as two or as many as seven years apart. Also, the bathtub mode doesn't take into account the trade wind's changing direction, which obviously has something to do with El Niño. This leads to another problem—when water vapor condenses into rain, the vapor gives up heat and warms the air. The warm air rises, causing a convective motion that draws in more air down at the surface. So when the trade winds slacken and the convection centers drift eastward toward Peru, they augment the eastward-blowing winds along the surface. The ocean should get stuck in the El Niño mode, with all the winds blowing east, and never get out. Or it should get stuck in the opposite, normal position, with all the winds blowing west, and the air rising near Australia. So we're at a loss to understand why the trade winds weaken and allow the water to slosh back. We have lots of empirical theories, but no grand understanding behind them.

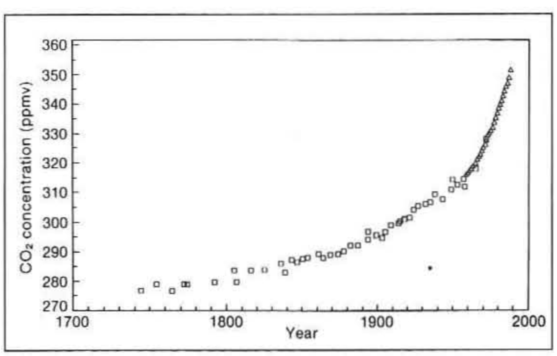
I started to get a little tired of the media hype last fall, and I decided to see what past El Niños had really done to the weather. So I checked the Web site of the National Oceanic and Atmospheric Administration (NOAA), and I found the map at left. Researchers divided the United States into geographical areas, and for each area they took a hundred years of weather data for December through March, which they divided into thirds. So, by definition, one-third of the years were wet years, one-third were dry, and the rest were medium. Now, what wet means in Arizona is different from what it means in Florida, but still, each geographic area has its definition of wet, dry, and medium. And then the researchers asked, of these nine El Niño years, how many were wet? how many were dry? how many were medium? You can see from the colors that the southern part of the U.S. typically had wet El Niño years, but notice that Southern California only had six wet years out of nine, which is not overwhelming odds. And the figures on the map tell you the number of El Niño years that went the opposite way—in our case, dry years. Southern California had six wet years, two dry, and one in-between. That's hardly a slam-dunk for El Ninõ. So all we can say, based on past experience, is that we've got six out of nine chances that this year will be in the wettest one-third. I went around saying that, and I offered to bet one of my colleagues that this winter would be a dry one, if he would give me 4:1 odds—his $4 to my $1. He didn't take me up on it, which is good, because I clearly would have lost.

Let's move on to global warming. It has been predicted that if we add carbon dioxide, methane, freon, and some other gases to our atmosphere, which we are doing—no question about that!—then Earth will warm up, and in 50 to 100 years we'll have some very costly changes in our climate. These gases are called greenhouse gases, because a



Above: The global mean annual temperature from 1861 to 1994, as compared to an arbitrary "normal" temperature of about 15° C, shown as 0.0 on the graph. Thus, for example, -0.4 is really 0.4° C below normal. The solid line is air temperatures averaged over the land masses, and the dashed line is average sea-surface temperatures. Data after the 1995 Intergovernmental Panel on Climate Change (IPCC) report.

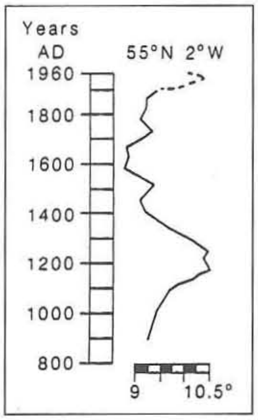
Below: Atmospheric carbon dioxide levels in parts per million, measured at Mauna Loa, Hawaii (triangles) and from air bubbles trapped in the ice near Siple Station, Antarctica (squares). Data from the 1990 IPCC report.



greenhouse stays warm even in the winter; its windows trap the heat inside it. These gases do the same for planet Earth. But cutting down on carbon dioxide production means burning less oil and coal—our civilization's basic energy source. That's going to hurt the world economy, so there are sacrifices involved—we're playing for real stakes here. And last December, delegates from all over the world met in Kyoto, Japan, to hammer out an agreement about who should sacrifice how much. You might ask, have we finally gotten to the point where we're having such an impact on the weather that we have to make these great sacrifices? There have been rain dances for as long as there have been people growing crops. There were, on occasion, serious sacrifices—people were killed; cattle were slaughtered. Is the Kyoto agreement just another rain dance, irrelevant to what's actually driving our climate? Or do we know enough now to say that this is really the right action?

Let's look at the evidence. For one thing, 1997 ranks as the warmest year of the century. And why not? There's got to be a warmest year, so why not 1997? But this is really quite unusual, because five of the century's warmest years have been in this last decade. Clearly, it's getting warmer. Is the buildup of greenhouse gases, mainly carbon dioxide, responsible? The mean annual temperature for the planet, compiled from daily temperature data from several hundred stations around the world, is shown at top left. You can see lots of bumps and wiggles—for example, it went up to a maximum around 1940, and then back down again. But for the last few decades, it's been going up steadily.

The amount of atmospheric carbon dioxide in parts per million, as measured directly at Mauna Loa and from air bubbles trapped in the Greenland and Antarctic ice sheets, is shown at left. The level was pretty constant until nearly our century, when combustion took off—carbon dioxide is now

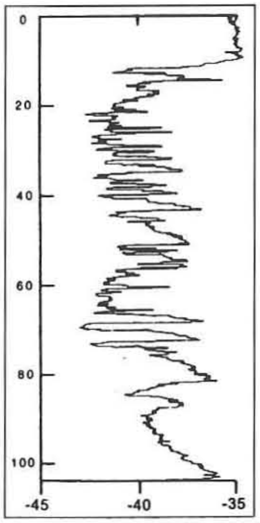


Left: The mean annual temperature, in degrees Centigrade, in the vicinity of Newcastle-Upon-Tyne in northern England. Data after H. H. Lamb.

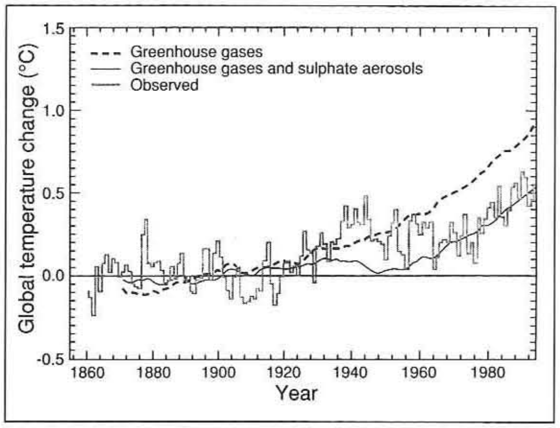
Left: Europe's glaciers have been retreating for more than 100 years. The engraving (top), circa 1850–1860 by an unknown artist, shows the front of the Argentière glacier lying close to the church in the village of the same name, near the Swiss–Italian border. In the photograph (bottom), taken from the same vantage point in 1966, the glacier has receded to the mountain's shoulder. From *Times of Feast, Times of Famine* by Emmanuel Le Roy Ladurie.

at 370 parts per million, and rising. So it's tempting to associate the two curves, especially when we know that carbon dioxide traps heat. It's a fairly easy calculation to say how much heat it traps, but what's difficult is calculating all the other elements of the climate system. If you warm Earth up a little bit, you might get more clouds—clouds are bright and reflect sunlight, and might cool Earth back down. Or there might be more thunderstorms—thunderheads condense at relatively high altitudes and would carry heat up into the atmosphere, cooling the surface. Clouds, thunderstorms, and turbulence in general are basically unsolved problems, so associating the carbon dioxide buildup with the temperature rise is a tough business.

Another reason it's a tough business is that the climate varies naturally. There are changes of several degrees going on over hundred- and thousand-year timescales. In the temperature data above, you can see that the period from about A.D. 1400 to 1850 was approximately a degree and a half colder than the periods before or since. That's true in Michigan and England, in Canada and California. This period is known as the Little Ice Age, and it really was a little ice age. There are old pictures of Swiss glaciers reaching way down into the valleys, and if you go to the same spots today the glaciers are gone. They've retreated up into the mountains. There were great midwinter parties in London, where they rolled big logs out onto the ice in the middle of the River Thames and roasted oxen. The Thames never freezes now. But the Little Ice Age had nothing to do with human impact—in fact, no one quite knows what caused it. Maybe the sun dimmed a little; maybe the Gulf Stream stopped carrying warm, equatorial water northward. A lot of things might have happened. And if you look farther back into time, there are even bigger changes—20,000 to 40,000 years ago, there was ice a mile thick covering Chicago, with lots of rapid changes in between.



Left: Temperature variations over the last 100,000 years, as deduced from the ratio of oxygen isotopes in a core from the Greenland ice cap. The vertical scale is marked in thousands of years before the present; an increase of five units on the horizontal scale is equivalent to a temperature increase of 6° C. Note the frequent variations of several degrees over time periods of 1000 years or less. As moist air cools on its poleward journey, water molecules containing the heavier ^{18}O tend to fall out faster than those containing the lighter ^{16}O. The colder it gets, the less ^{18}O is left aloft. Comparing the ancient ice's $^{18}O/^{16}O$ ratios to ratios measured around the planet today gives a measure of how cold the ice was when it froze—a technique invented by Caltech's Sam Epstein in the 1950s. Data after Dansgaard et al.



Left: If your computer model only includes greenhouse gases, its predictions (dashed line) don't match the real-world data (gray line). But if you add a soupçon of smog (solid line), the fit is much better. Data from the Hadley Center, UK Meteorological Office's climate model, published in the 1995 IPCC report.

Then, about 12,000 years ago, the ice suddenly melted, and it's been relatively warm for the last 10,000 years. Earth was about 7° C colder during the depths of the last Ice Age. By contrast, the warming in our own century has been about 0.7° C.

So how did we come to predict global warming? We used computer models of Earth's climate. (The three main models in the U.S. are at the National Center for Atmospheric Research, the Goddard Space Flight Center, and the NOAA labs at Princeton. There are other models that don't have as much funding but have some very smart people working on them, including a model developed at UCLA.) These models all divide the globe up into a grid, and put pressure and temperature and moisture content and whatnot into each box in the grid. There are equations for how these parameters interact, and how air moves from one box to the next, and how land and sea and the passing of the seasons affect the air. There are even equations for how plants suck carbon dioxide out of the air as they photosynthesize. We set the model in motion, gradually add carbon dioxide, and watch what happens.

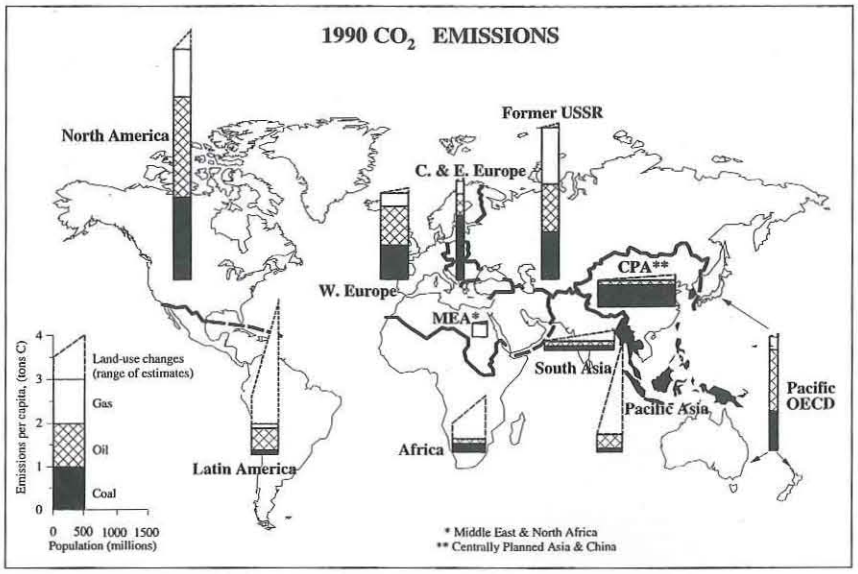
Global warming may or may not account for the little upturn of the last few decades, but I'm quite confident that we'll see its effect in the next century. The effect is just beginning to rise above the noise of natural planetary variability.

But if we just model the rising levels of greenhouse gases, we overpredict the warming—if we start the model at, say, 100 years ago, it tells us that the planet should be hotter today than it actually is. But if we add in some aerosols—shiny particles, smog basically—that reflect sunlight, we don't get as much warming, and the model tracks the historical data pretty well. So it seems we might be pulling the weather in one direction with heat-trapping greenhouse gases, and pushing it the other way with sunlight-reflecting aerosols. The average of the models' predictions, if carbon dioxide doubles in the next 75 years, is a global mean temperature increase of 2.5° C. That's about a third of the warming that occurred from the end of the last Ice Age to the present. The human race survived that, so we should be able to survive another 2.5 degrees. Some models say 1.5 degrees; others say 4.5 degrees. There's a lot of uncertainty, and just about every element in the models is under debate. They make different assumptions about turbulence, for example, and the effects of clouds. But in the end, we have to use the models—they're all we've got. We just don't trust them to the last decimal point. We always quote an uncertainty.

There's currently a lot of debate about whether we've already seen the signature of global warming. I would say that debate is not a terribly productive one. Global warming may or may not account for the little upturn of the last few decades, but I'm quite confident that we'll see its effect in the next century. The effect is just beginning to rise above the noise of natural planetary variability. If it turns out that the current upturn was because the ocean hiccuped, it doesn't mean that global warming is going to go away.

Of course, things can happen. For example, a good-sized volcano such as Mount Pinatubo can fill the stratosphere with shiny, highly reflective particles that could cool Earth and stave off global warming for a time. However, while the aerosols stay up for a few years, the carbon dioxide lasts for centuries.

So now we come to politics. The economists, meteorologists, and everyone in between are all trying to say what the world should do. The report by the Intergovernmental Panel on Climate



Above: Global output of carbon dioxide from fossil fuels and from deforestation (labeled as "land-use changes" on the legend; note the large range of uncertainties in the tropical estimates). Since the number of tons of carbon emitted per capita is plotted vertically and each region's population is plotted horizontally, the area of each bar gives the total amount of carbon dioxide emitted by each region. Pacific OECD stands for Pacific Organization for Economic Cooperation and Development. Data from the 1995 IPCC report.

Change formed most of the basis for the debate in Kyoto. The meteorologists predicted that if we warm the planet by 2.5° C, the world's desert areas will expand. Louisiana might become a desert, and Montana might become a lush agricultural area. (Of course, the rainfall predictions are just as uncertain as the temperature predictions.) The economists took that data and said, well, how much would those changes cost the world? There'll be losses to agriculture, and the increased use of water for irrigation may drive up its cost for all users. As the deserts expand, trees and other vegetation will die. There'll be some 30 centimeters of sea-level rise, which will affect ports, beachfront property owners, and coastal wildlife. There'll even be the cost of extra air-conditioning. Typical estimates for the U.S. alone were that it might cost us $50–100 billion a year. That's not a lot—it's one or two percent of our economy. But India and China, for example, would be much more vulnerable, because their economies are weaker and they're more dependent on hand-to-mouth agriculture. Their losses could be 10 percent of their economy. Taken overall, the losses will be a few percent of the world economy.

Then you have the question of who should pay. Well, who's doing the damage? North America, Western Europe, the former Soviet Union, and China are the big players, as you can see from the graph above. So you might say we should pay according to how much carbon dioxide we produce. The Chinese say that's baloney—that they've got many times more people than we do, that they have the right to pollute as much as we do on a per capita basis, that they want to build up their economy to be on a par with ours. And if you look at how much carbon dioxide each country produces per capita, China looks very good and we look very bad. In fact, we're a lot worse than Western Europe and the former Soviet Union.

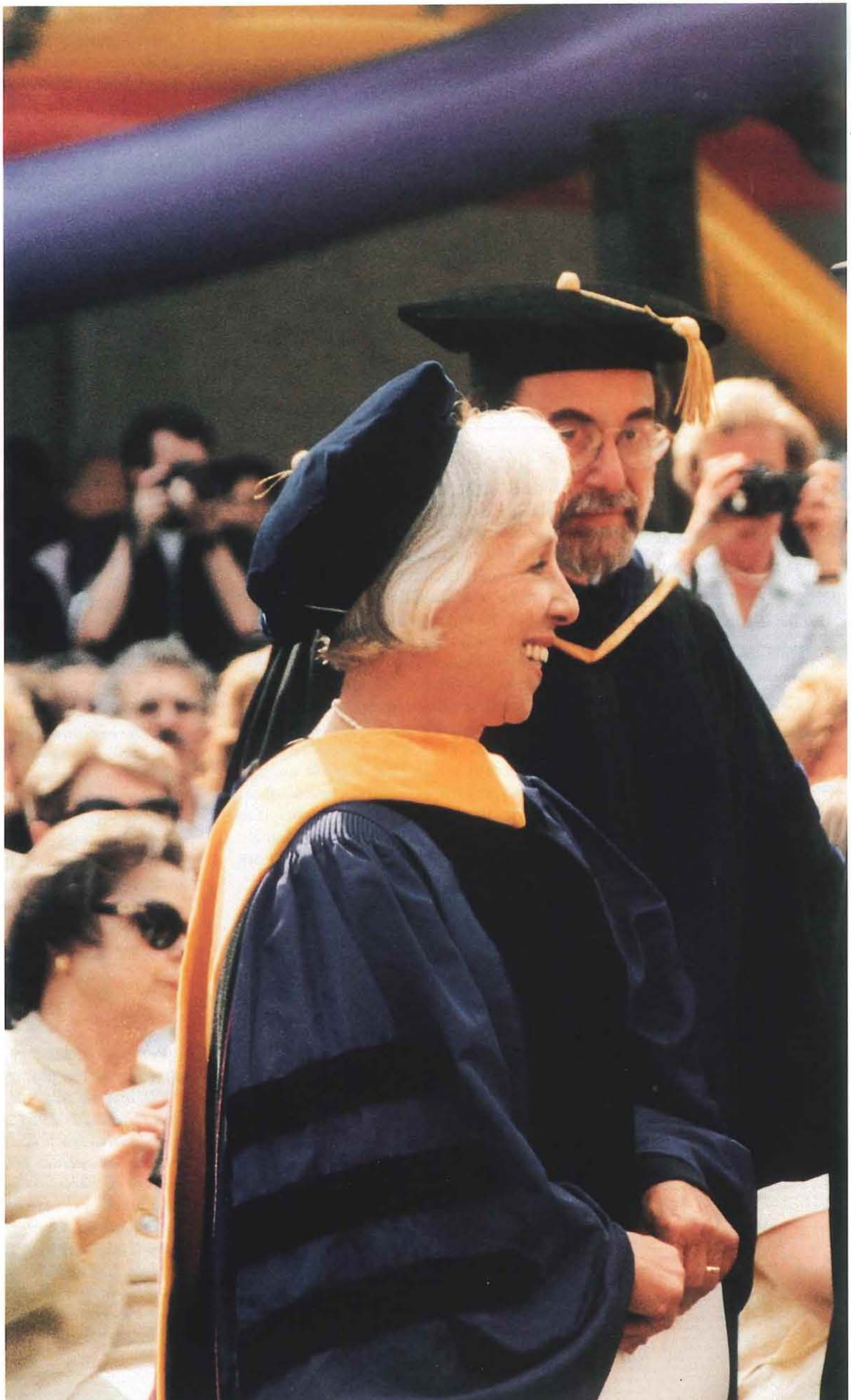
The decision was finally made to reduce the United States' emissions to 7 percent below their 1990 levels over the next 10 years. (The treaty hasn't been ratified by Congress.) If we do ratify it, the cost to the U.S. economy to achieve these reductions will be about 1 or 2 percent—the same as the cost of global warming. The European Union is to reduce their emissions by 8 percent; Canada and Japan by 6 percent. India and China carried their point, and are not required to make any reductions under the treaty.

I don't think that the scientific issues are as uncertain as the economic and political ones. It's quite possible that in 75 years, we will have developed solar energy, clean nuclear fuel, wind power, or who knows what. [See *E&S*, 1997, No. 3] Then the debate will disappear, because we won't burn coal and oil any longer. In which case, why worry now? Let's just wait for that wonderful future. The other possibility is that we'll be so overrun with wars, famines, and plagues, that we'll have much worse problems to worry about. There, too, we don't have to do anything, if we're waiting for the end of the world. It's only as long as we believe in something in between that we have to do something. I'm serious, and I do believe in something in between—my children and grandchildren. But on the other hand, I like to defer my taxes. I especially don't pay taxes today that I won't owe until 10 years from now—that would be foolish.

So I think we should start stimulating our economies to develop those wonderful technologies the optimists think might happen. We have to work on conservation and stimulate the marketplace to prepare for limits on combustion by developing those other power sources. We could stimulate the marketplace by imposing a tax on people who exceed some emissions quota, or allowing people to sell credits to produce carbon dioxide. Let's not clamp down on the economy and send it into a depression—let's push it a little bit instead, so that this wonderful world of cheap, clean energy will actually come to pass. □

Professor of Planetary Science Andrew P. Ingersoll earned his BA in physics from Amherst College in 1960, and his AM and PhD in atmospheric physics from Harvard in 1961 and 1966, respectively. He immediately came to Caltech as an assistant professor, becoming an associate professor in 1971 and a full professor in 1976. At one time or another, Ingersoll has worked on the atmospheres of Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune as part of the Mars Global Surveyor, Cassini, Galileo, VEGA, Voyager, Nimbus, Viking, and Pioneer teams. He has five children and six grandchildren and is optimistic about the future.

This article was adapted from a recent Watson lecture.



The Inauguration of David Baltimore

by Maxine F. Singer

David Baltimore was inaugurated as Caltech's sixth president on March 9, 1998, a warm, sunny day unthreatened by El Niño. Beckman Mall (aka the Court of Man), festively decorated for the occasion, hosted an audience of friends, students, staff—and the faculty, who, also festively decorated, processed through the crowd to a march played by the Convocations Brass and Percussion Ensemble.

Baltimore was welcomed to the Institute in brief remarks by Maria Throop Smith, great-granddaughter of Caltech founder Amos Throop; by Faculty Chair David Stevenson, the Van Osdol Professor of Planetary Science; by Kohl Gill for the undergraduates and Geneviève Sauvé for the graduate students; by Thomas Tyson, '54, PhD '67, president of the Alumni Association; and by Caltech presidents emeriti Marvin Goldberger and Thomas Everhart. The Caltech Glee Clubs performed an arrangement by Robert A. M. Ross, '98 of the traditional college song "Gaudeamus Igitur" before Baltimore was invested as president by Gordon Moore, chair of the Board of Trustees. Kip Thorne, the Feynman Professor of Theoretical Physics and chair of the search committee that chose Baltimore, introduced the new president, who then delivered his inaugural address (see the current issue of Caltech News*).*

Before the actual investiture, Maxine Singer, president of the Carnegie Institution of Washington, who had been chosen to be the "invited speaker," also spoke to the inaugural audience. Her remarks follow.

Left: Before the ceremony, Maxine Singer and David Baltimore bring up the rear of the academic procession to the podium.

Good afternoon Gordon Moore, members of the Caltech Board of Trustees, David Baltimore, Alice Huang, Teak Baltimore, and all of you gathered here. I am honored by your invitation to speak to the Caltech community on this extraordinary day.

It is especially wonderful to tell all of you, on behalf of David's family, friends, and longtime colleagues, of our pride and pleasure as we join you to celebrate the gifts that he brings to this university. His are the kinds of talents that have allowed individuals to shape and sustain institutions and, through them, our society.

Caltech would not collapse if it had no president; most of you would keep right on doing the things that make this place a source of new knowledge and talent. And, in fact, these days the chief executives of many important American institutions—universities, corporations, and foundations—are faceless and nameless, inner-directed caretakers and fixers. They turn outward not to provide leadership, but to pursue special interests. Theirs is a meager success.

But universities should do more than just carry on; they should give shape to the evolution of our society. Such a *grand* success depends on bold leadership by exceptional people who can recognize and define the changing currents. The stewardship of a great private university bestows an environment for the exercise of such leadership. And that is why the inauguration of a new president at a place like Caltech is an event of national, even international, consequence.

Your own institution took shape from the mind of one great scientist, George Ellery Hale. Unlike many other private institutions, Caltech's roots lie not in some religious or philanthropic motivation or, as has happened in recent times, the nature of the tax laws, but in Hale's imagination. He envisaged, in a place then far removed from the intellectual center of the nation, an institution where science and the education of young scientists would flourish.

Hale came to Pasadena from Chicago 95 years ago to establish, on behalf of the Carnegie Institution of Washington, my institution, an astronomical observatory on Mount Wilson. By the time he was 33 years of age, his research had revealed so much new about the sun (and thus other stars) that he had already been elected to the National Academy of Sciences. He found here a town scarcely begun. A horse-drawn bus took him

In 1909 Andrew Carnegie (left) visited George Ellery Hale at Mount Wilson's 60-inch telescope, which Hale's imagination and Carnegie's money had built. And when Hale wanted an even bigger telescope, with a 100-inch mirror, Carnegie helped fund that too.

"Murph" Goldberger (left), Caltech's president from 1978 to 1987, and Tom Everhart, who succeeded him from 1987 to 1997, joined in welcoming the newest president.

through muddy, unpaved streets to the start of the burro trail that led to the peak of Mount Wilson.

There he built solar telescopes and the huge 60-inch and 100-inch reflectors, the largest in the world, and Carnegie astronomers changed forever our view of the universe. "Never do a small thing when you can carry out a big one," Hale said (quoted in Helen Wright's book *Explorer of the Universe*). And Hale's definition of "big" kept on getting bigger and bigger. Eventually he dreamt of a 200-inch telescope, and though he didn't live to see it, he died knowing it would one day gather light on Palomar Mountain.

The universe itself was insufficient challenge for Hale's tumultuous brain. Undaunted by the distance between Pasadena and the East, he became a driving force for the modernization of the National Academy of Sciences and the establishment of the National Research Council Fellowships, which were to a large extent responsible for the growth of American science between the two world wars. He set the precedent for the unceasing travels of contemporary academics and *he* did it by train.

At home, Hale imagined Pasadena as a civilizing center for education, the arts, and the good life. As early as 1906 he began scheming to convince Henry E. Huntington to establish with his collections, not just a museum, but a research library, in Pasadena. It took more than 20 years, but just a few months before Huntington's death in 1927, Hale succeeded.

Foremost among Hale's dreams for Pasadena was the metamorphosis of the small, provincial Throop Polytechnic Institute, of which he was a trustee, into this great California Institute of Technology. So much of what the Institute is was set down by Hale's boundless enthusiasms, his persistence, his scheming, his skill at inspiring national foundations and wealthy local citizens with his plans, and his unyielding tactics with the great scientists he convinced to come to Pasadena. It is a source of great pride to my own institution that its support of Hale and his plans made much of this possible. The common roots of Caltech and the Carnegie Observatories here in Pasadena remain a strong mutual tie.

David Baltimore was born on March 7 (happy birthday, David), exactly two weeks after Hale passed away, in 1938. Together their lives span the astounding scientific years from the last decades of the 19th century to the present. And like Hale, David contributed in seminal ways to these scientific revolutions and to the place of science in our society.

In 1970, only 10 years after he had received a bachelor's degree, David made a discovery that toppled longstanding assumptions about the flow of biological information. Simultaneously with another biologist, Howard Temin, a Caltech PhD, he demonstrated a mechanism for copying RNA molecules into DNA. At the time, this startling reverse flow of genetic information appeared to be restricted to a certain kind of virus. But in the intervening years, the significance of the discovery was magnified many times over. The enzyme they described became a central tool of contemporary molecular biology, as basic as telescopes are to astronomy. We now know that similar enzymes are encoded in the genomes of most if not all living organisms, not just those of certain viruses. And, most surprisingly, we have recently learned that one essential process, the construction of the ends of new DNA molecules, actually depends on the kind of enzyme that they discovered almost 30 years ago.

David recognizes, as did Hale, that great scientific accomplishment privileges a broad scope, an opportunity, even an obligation, to champion the place of science in the larger society. But the contemporary challenges to the exercise of that privilege would surprise Hale and frustrate him.

In Hale's day, the larger society almost universally viewed science with awe and great expectation. Today, the awe and expectation are tarnished for significant segments of the public for reasons both understandable and inexplicable. How then can the obligation to champion the place of science in society be exercised?

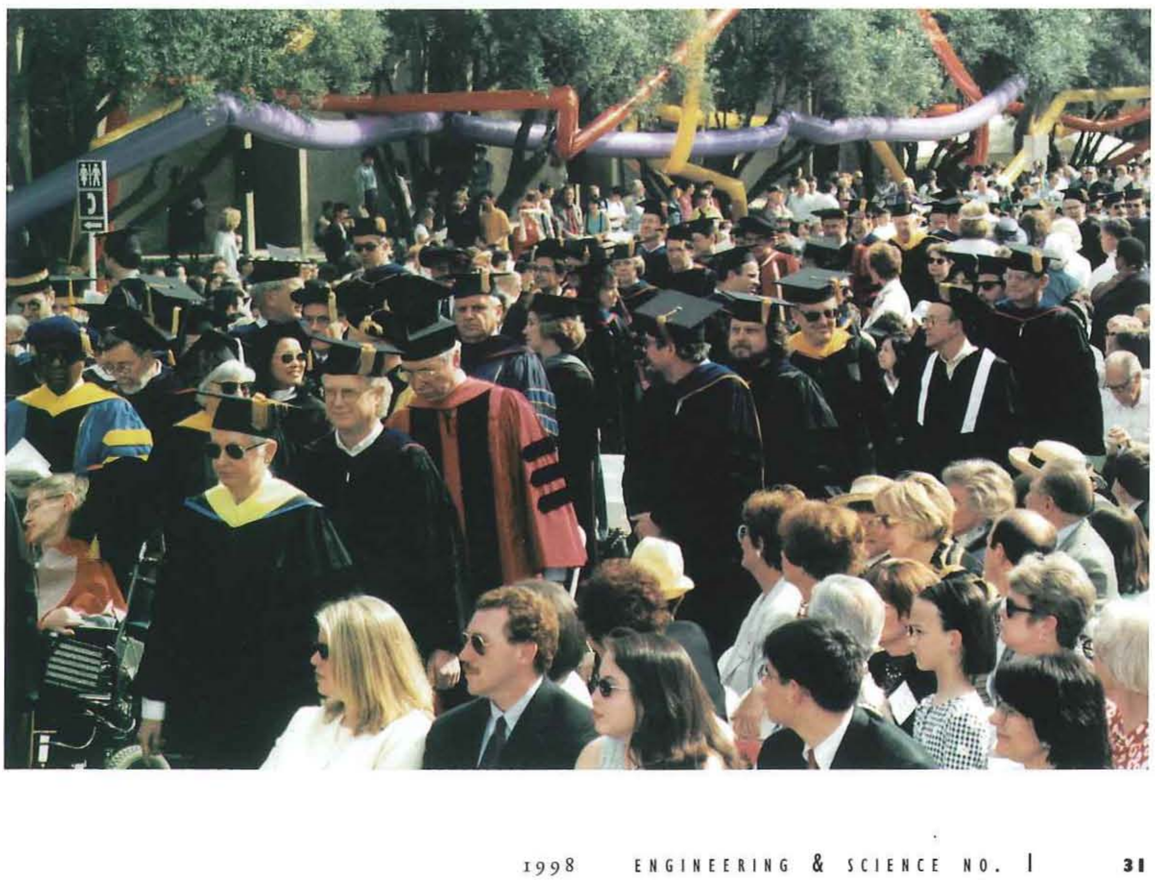
Now we are at a point where traditional disciplines define methodologies, not innovative scientific questions, the questions that inspire both scientists and the public.

A. Bartlett Giamatti, a nonscientist who was president of Yale and a uniquely eloquent spokesman for universities, gave an answer to this question when he said (in *The University and the Public Interest*, 1981): "From the scientists . . . we learn what we should never forget, that to view nature justly, nature human and material, we must eschew parochialism and casual labels and bureaucratic boundaries, and seek to see the truth from as many vantage points as humankind can summon."

That is a wonderful vision, but Giamatti was not naive. He knew well enough from his own faculty that parochialism, casual labels, and bureaucratic boundaries are alive and well in academic institutions. To be credible champions for science, then, requires that the university's own house be in order.

Boundaries between disciplines are even less pertinent today than they were when David learned, as an undergraduate, about the tensions between chemists and biologists. Now we are at a point where traditional disciplines define methodologies, not innovative scientific questions, the questions that inspire both scientists and the public. Consider, for example, the relation between physics and cosmology. Or between chemistry, biology, and earth science. Some on this campus are already working to bridge these boundaries. But parochial ideas are still afloat. I have even heard some people express surprise that a biologist is Caltech's new president.

Hale would not be surprised. In 1928, the same year he finally succeeded with Huntington and was cooking up ways to get the 200-inch telescope built, he and Millikan and Noyes were busy completing the scope of Caltech's programs by extracting Thomas Hunt Morgan, an extraordinary biologist, out of an eastern institution. Morgan and his colleagues had, by then, transformed rudimentary and quite abstract Mendelian notions into the chromosomal theory of heredity. Parenthetically, Morgan learned the hard way that Hale, so attentive while Morgan was being recruited, was not much concerned about mundane matters.



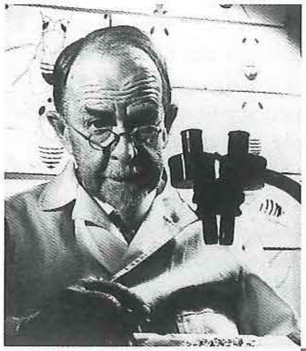
Already at their seats, delegates from more than 60 academic institutions and learned societies, led by Honorary Marshal Stephen Hawking (left), watch as the Caltech faculty and the rest of the academic procession file past.

During the six months he was preparing to leave Columbia to come to Caltech, a frustrated Morgan was driven to write directly to Arthur Fleming, president of the Board of Trustees (August 3, 1928, Caltech Archives, Morgan files): "Kindly order thru Western Scientific Company 2500 half pint milk bottles and three gross culture tubes." Dr. Moore, what would you do with such a note from a newly recruited faculty member?

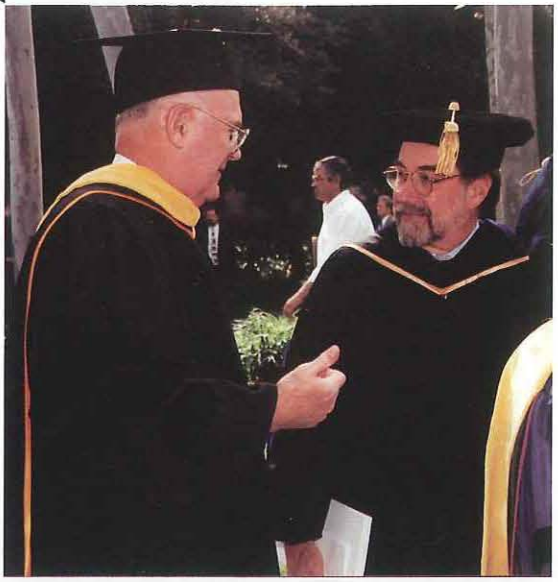
Besides modern biology, the Morgan group brought to Caltech its own then peculiar research habits. As described by Robert Kohler in his book *The Lords of the Fly*, these "elite drosophilists were the oddballs in a social system. . . . they were highly ambitious and aggressive, and more devoted to a fast-paced, highly productive style of experimental work than was the norm." Sound familiar? They brought this style to Pasadena; by now it is the highly productive norm here and elsewhere.

But that style, for all its advantages, has a down side. Unlike Hale, Morgan, however brilliant, was not an institution builder. When he finally retired, in his mid-70s, some of the most extraordinary of the younger generation of biologists had passed through his department. Passed through, and gone on to other places. The intense pursuit of great science by single individuals is not enough. It takes an institution to sustain greatness. If all of us had to pursue our research while holding down a job in a patent office, like Einstein, most of 20th-century science would never have happened.

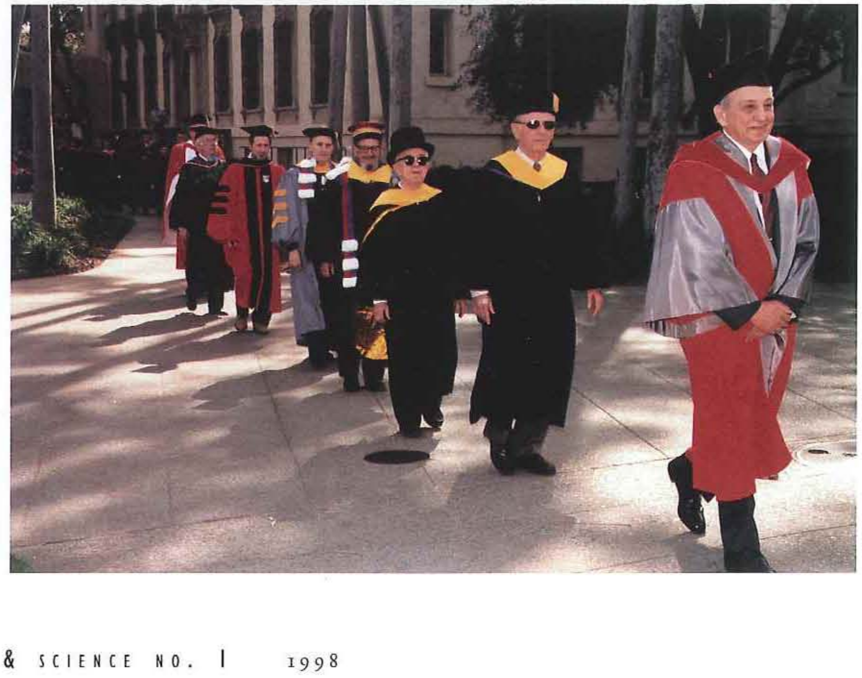
An institutional perspective urges us to make room and provide for young scientists. We must help students, postdocs, and young faculty to develop their own bold visions and independence. And yet the specialized demands of contemporary science leave little time, and sometimes even less motivation, to provide gifted young people with the requisite *liberal* education. Currently, too

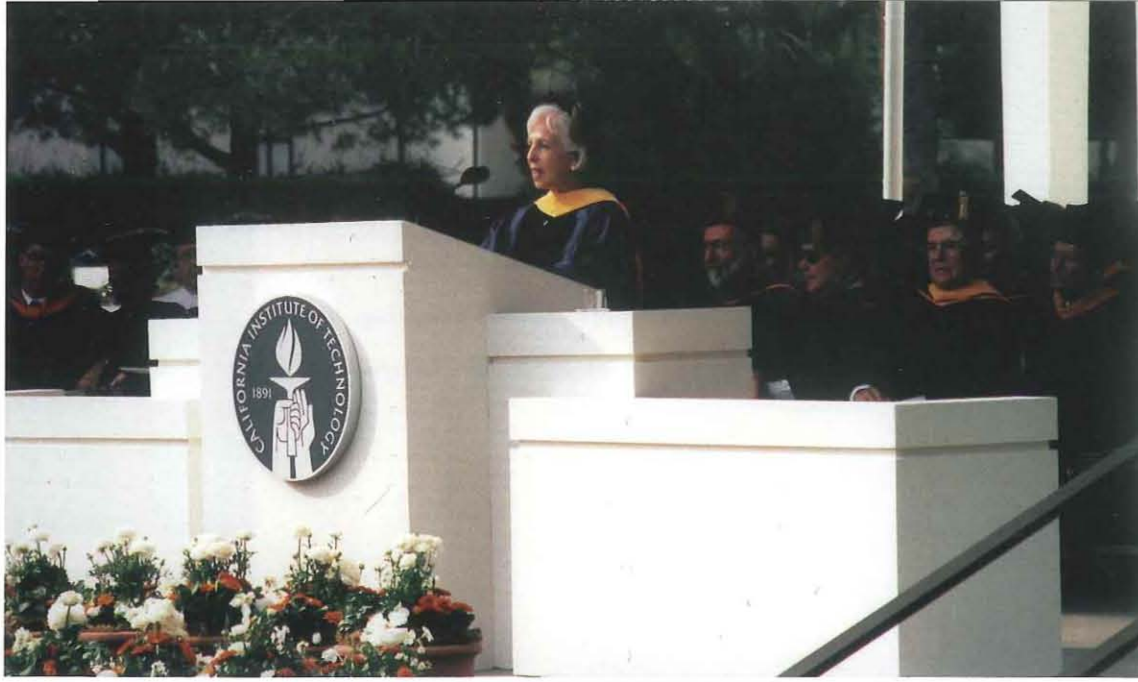


Below: Gordon Moore (left) and David Baltimore chat during the procession. Has Baltimore perhaps just asked the Board of Trustees chair for lab supplies, as Thomas Hunt Morgan (photo, left) did in 1928?



Below: The laureates lead off the academic procession. From front to back: Nobel laureates Rudy Marcus (Noyes Professor of Chemistry), Paul Berg (Cahill Professor in Cancer Research, Stanford), and Ed Lewis, PhD '42 (Morgan Professor of Biology, Emeritus); Crafoord laureates Gerald Wasserburg (MacArthur Professor of Geology and Geophysics) and Seymour Benzer (Boswell Professor of Neuroscience, Emeritus); and Nobel laureates Doug Osheroff '67 (Jackson and Wood Professor of Physics, Stanford) and Renato Dulbecco (president emeritus, Salk Institute).





From the steps of Beckman Auditorium, Maxine Singer addresses the assembled inauguration guests.

many young scientists have no concept of the history of their own fields, let alone the history and literature of the nation and the world or of the fact that the "liberal" in liberal education has nothing whatever to do with politics. Too many of them still glean from their mentors a narrow view of the roles that they, as scientists, can play in our society.

Hale would have objected to this constricted outlook. In 1907, writing for his former teachers at MIT (from which he graduated in 1890), Hale

In our contemporary world, preserving the special freedom of private institutions requires the exercise of public responsiblities.

said, speaking of a boy entranced by machines and their design: "He does not yet know that to become a great engineer he should cultivate not merely his acquaintance with the details of construction, but in no less degree his breadth of view and the highest powers of his imagination."

David too understands the need for breadth. His own liberal education and his experience gave him a keen appreciation of the world and its complexities. No doubt he also already knows the local galleries, concert halls, and jazz joints better thnn most of you.

But Hale's and David's worlds are very different. Hale could, without blinking an eye, assume that the scientist or engineer was a "he." But David's liberal education occurred in a place that was founded in the middle of the 19th century specifically to advance the equal and coeducation of men and women. He was exposed there to women who were his intellectual equals. and he is at ease in such a world, as we see from his wonderful marriage to a brilliant scientist, from the way they have raised the marvelous young woman who is their daughter, and from the female students and colleagues he has encouraged. He knows that neither science nor Caltech should be limited by irrelevant ideas about the packaging of scientific talent.

There's another difference. Hale could concern himself with boys whose upbringing was, like his own, privileged by wealth and an educated family. But in our time, the challenge is to bring the unprivileged boys and girls, growing up without such advantages, into science. Caltech has already engaged this challenge; its programs in the Pasadena schools are a model for many of us all over the country. Caltech's new president will likely want to enhance these efforts.

There are other challenges unique to our time. One is building institutional commitment in an academic world increasingly dominated by a spirit of independent entrepreneurship. We all understand the reasons for this: the structure of a wonderfully productive federal support system for science; the increasing cost of research; the highly competitive nature of scientific work; the speed with which new knowledge is turned into economically rewarding new technology. None of us wants to lose the stimulus of these aspects of our world. But neither do we want our enterprise to fail intellectually by compromising its purpose and character.

In our contemporary world, preserving the special freedom of private institutions requires the exercise of public responsibilities. One essential responsibility is to help the larger society understand the choices and dilemmas posed by science and technology. For this, you can count on your new president. In the early 1970s, faced with the sudden conversion of biology from a descriptive to a manipulative science, he and a few others, were brave enough to ask their colleagues to pause, to think about what they were doing, to construct a

The accession of new leadership is a time of promise. But for all the excitement, there is a wariness in the air, a sense of the unknown unfolding. The future seems both secure and indeterminate.

New president David Baltimore with his wife, Alice Huang (right), and daughter, Teak Baltimore.

responsible framework for research, and to do it in public. Again, in the mid-1980s, when the growing AIDS epidemic was still viewed by some as a problem restricted to an unpopular sector of our society, even as a divine punishment, David led a group that would study and define the threat to all and call for a large, targeted research effort. This serious scientific endeavor helped to change the mind of our nation and the world. And all this was going on while he was founding a new institution for biomedical research, one which, after only 15 years, is a major source of new knowledge. Eventually he devoted a substantial part of his own research program to AIDS and the virus responsible for it. Currently he is also committed to lead a national effort to develop an AIDS vaccine.

Your new president also knows that in our society there is a huge price to be paid for bold leadership. The more celebrated an individual, the more likely he or she will be publicly dissected.

We turn heroes into punching bags. No one ever thought in the past that heroes were perfect. But they chose to ignore the warts in order to savour the inspiration. Hale was a national hero, a media success, particularly when he undertook the Palomar project. Would Hale, with his periodic confinements for severe depression, have been allowed today to build Caltech or realize Palomar? Would our society reject Hale's dreams because the dreamer was, as we all are, a flawed human? It might.

The accession of new leadership is a time of promise. But for all the excitement, there is a wariness in the air, a sense of the unknown unfolding. The future seems both secure and indeterminate. In a way, it's like the typical Californian's wariness about this winter's weather. Is it a temporary aberration, or a sign of fundamental change in paradise?

The only response a scientist can make to such uncertainty is optimism. You have, in your new president, an optimistic person with the spirit and nature of a leader, who, *with* you, will give shape to the future. He will not be a caretaker. And he will espouse your dreams as well as his own; the grand successes of his presidency will be *mutual* accomplishments; for that is the way of *our* time. Together, all of you can show the world how to "view nature justly."

You have chosen well. I congratulate you all. □

Currently president of the Carnegie Institution of Washington, Maxine Singer is an eminent biochemist whose wide-ranging research on RNA and DNA has greatly advanced scientific understanding of how nucleic acids behave in viral and human genes. She received her bachelor's degree from Swarthmore (also David Baltimore's alma mater) in 1952 and her PhD from Yale in 1957. She worked as a research scientist at the National Institutes of Health in the Institute of Arthritis and Metabolic Diseases until 1975, when she moved to the National Cancer Institute. In 1988 Singer was named president of the Carnegie Institution, but holds the title of scientist emeritus at NIH and continues to work in her NIH lab. A member of the National Academy of Sciences and its Institute of Medicine, Singer served on the governing board of Yale (1975–90) and continues to serve on that of Israel's Weizmann Institute of Science. She received the Distinguished Presidential Rank Award, the highest honor given to a civil servant, in 1988, and in 1992 she was awarded the National Medal of Science for her "outstanding scientific accomplishments and her deep concern for the societal responsibility of the scientist."

A drop of ferrofluid (part liquid, part magnet) on glass flows into a unique shape determined by magnets placed underneath. Photo by Felice Frankel in *On the Surface of Things.*

On the Surface of Things: Images of the Extraordinary in Science

by Felice Frankel and George M. Whitesides
Chronicle Books, 1997, 160 pages

This project stems from a collaboration between an artist—MIT photographer Felice Frankel—and a scientist—Harvard chemist George Whitesides (PhD '64)—who agreed on two basic principles. First, visually striking images are an excellent way to draw attention to science. And second, left to their own devices, scientists do a generally lousy job of producing effective images. So Frankel and Whitesides decided to see what might be done, and the result is this handsome and entertaining book.

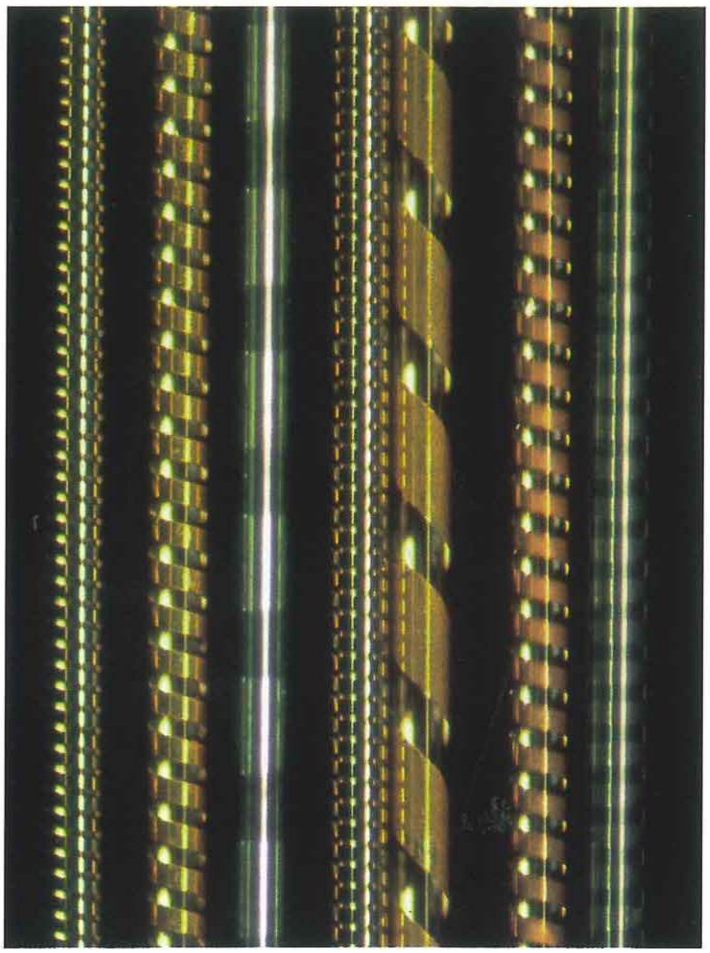
The contents consist of about 65 entries, pairing Frankel's photographs with Whitesides's interpretations of the underlying science. Many of them are based on state-of-the-art research in surface science, carried out in Whitesides's group as well as those of colleagues. Some of the images would be extraordinary even without considering their connection to science. One of the most striking is a photograph of a drop of ferrofluid in a complex magnetic field. The combination of unusual symmetry and weird shapes obtained by deploying magnets, with the colors and composition that a skilled photographer knows how to produce, make this a stunning art object in any context.

Most of the photographs, though, derive their interest jointly from artistic and scientific aspects. A picture of alternating blue and green squares seems, at first glance, to be an array of abnormally colored Chiclets; but it is actually a dramatic demonstration of how surface properties can be tailored to produce square drops of water. A display of glass fibers wound with spiral metallic bands shows us the surface scientist's amazing ability to fabricate intricate patterns—and then the amazement is magnified manyfold as the scale of the objects sinks in, and one realizes that each fiber is about as thick as a single hair. (The scale of each photo is effectively communicated by apposing a circle that represents the size of a pinhead under the same magnification.) Other examples are photos of more commonplace objects, viewed in a new light: ice crystals forming on a window, backlit by the setting sun; lichen attacking old stone columns; brilliant patterns of color and light in an opal.

Whitesides's scientific explications are far from cold technical accounts. Written for the general reader, they are verbally picturesque and make frequent use of analogy and metaphor to help the reader relate abstruse concepts to the more everyday world. Sometimes this may go a bit *too* far for some readers. The imagery of electrons or molecules as conscious beings is overused, for my taste. Examples: "Molecules —like ants, lemmings, herring, people—are happiest when surrounded by their own kind"; "The quantum dots are boxes just small enough to give electrons claustrophobia"; and, perhaps the topper, "Then there are the adolescents [of molecular society]—liquid crystals."

Similarly, frequent reference to sound vibration is used to help convey the less familiar concept of electromagnetic vibrations in light. In one case—comparing the appearance of a red surface under white illumination with the resonant vibration of a tuning fork—the analogy may be more misleading than helpful, seemingly conflating reflection with adsorption/reemission. Is this really necessary? For instance, the formation of "tears" on a glass of wine (illustrated by an unusual shadowgram) is explained with complete clarity and readibility, without any reliance on analogy.

Patterns of gold, silver, and copper are etched on optical fibers the size of a human hair, constructing a ladder of mirrors to conduct a message of light through the fiber. Photograph by Felice Frankel from *On the Surface of Things.*



Nonetheless, the majority of the explanations seem to be on the right level for the intended audience; and if some degree of rigor has been sacrificed in favor of a lyrical style, that's perhaps a justifiable choice. In any case, for those who want more detail, an appendix provides brief technical descriptions of both the photography and the science (and references, where appropriate) for each entry.

I hope it is clear from the above that I greatly enjoyed this book. And yet . . . from a scientist's point of view, I couldn't help feeling a small degree of unease. In the introduction, there is the statement: "A single image organizes a deluge of information in a form that is easy to understand. An image that is rich in composition and color always catches the eye. And what catches the eye, catches the mind." Is "catching the mind" being equated with making something "easy to understand?" I suppose the former must precede the latter (like the old joke about getting a mule to obey: first you hit it over the head with a two-by-four to get its attention); but few of the images seem to evince nearly as much concern with their potential ability to help explain as with their power to capture attention. Indeed, in some cases I had trouble figuring out just what I *was* looking at—a much more prosaic diagram, while unquestionably less visually attractive, might have made things much clearer—and all too often, the information content of an entry derives *entirely* from the explanation, and not at all from the photo.

Probably it is unfair to dwell much on this aspect, since it was not meant to be a focus of the book—the authors explicitly announce their intention to exhibit the beauty of science while suppressing some of the difficulties (more precisely, comparing science to a rose bush, "we try to display some of the flowers and avoid the thorns"). Perhaps in their future collaborations, the authors will explore new ways to go beyond the generation of arresting images and exploit those images for probing more deeply into the science itself. *On the Surface of Things* is a significant accomplishment, which I recommend strongly to scientists and laymen alike; but in a certain sense, its title is just a little *too* appropriate. □

Jay A. Labinger

Jay Labinger, a chemist and a member of the professional staff, has lately written widely on the "science wars." He is administrator of the Beckman Institute.

David S. Wood 1920–1998

In the Caltech Stock Company's 1959 production, *The Importance of Being Earnest* (Watson), a serape-clad David Wood tried to lure Earnest Watson away from Caltech to sunny Mexico.

David Shotwell Wood (BS '41, MS '46, PhD '49), professor of materials science, emeritus, died March 12 of cancer. Born in Akron, Ohio, he attended Pasadena City College before transferring to Caltech.

He chaired or served on innumerable campus committees, was Associate Dean of Students, and was variously mayor, city councilman, and planning commission member for the city of Sierra Madre, director of the San Gabriel Valley Municipal Water District, and director of the Pasadena Symphony Association.

These remarks are adapted from the memorial service held in Dabney Lounge on April 16.

I have had the good fortune to have been associated with David for half a century. First he was my mentor, then a fellow faculty member and a close personal friend.

It started when I was hired as an undergraduate research assistant, working with David on the design of a system to initate yielding in metals. My contributions were minimal, but it was a great opportunity to learn. David had already built several unique facilities, including one for the fast propagation of compressive waves—basically a slingshot powered by giant rubber bands that fired one metal rod into another. These devices led to his invitation to join the Manhattan Project's mechanical-design group at Los Alamos. There he met and married Constance, better known to us as Connie. After the war, he returned to Caltech and materials research. Along with rapid loading, he was especially interested in the strain waves produced by impact and explosive loading. He also studied how metals fracture, and the behavior of the crystal dislocations that lead up to it. In 1950, he and Don Clark won the American Society for Testing Materials's Templin Award for their work on plastic deformation. His interest in the dynamic properties of materials was contagious—so contagious that I caught it. Later, he was on my thesis committee, and we've since coauthored a number of experimental and theoretical papers.

This association naturally led to close ties between the Vreelands and the Woods—after all, our family initials are next to each other in the alphabet. We shared in the joy of the births of our children, and in their growth into adulthood. Our banjo-playing son was warmly welcomed into the Caltech Stock Company by the Woods, who introduced him to the talented staff (or should I say characters?) and made him feel he belonged.

I will always remember David for his mentoring, for our friendship, as well as for his remarkable spirit and bravery in the fight against his terminal disease.

Thad Vreeland Jr. (BS '49, MS '50, PhD '52), professor of materials science, emeritus

Our mother was a professional singer and a pianist. Our father, besides being a mechanical engineer, played the fiddle. A family friend, a local bank teller, played the cello. Every Thursday night was trio night at our house. As little kids we were allowed to stay up until the cellist arrived and did some rumbles on his low strings for us. We went to sleep blissfully listening to a Mendelssohn, Arensky, or Beethoven trio.

In 1937, my father bought a 1936 Ford V-8 deluxe four-door sedan, with a chrome-wire steering wheel, a pink plastic gearshift knob, and a radio. We spent so much time in the garage listening to that radio that it was decided to have one in the house. We got a Zenith AM/short-wave tabletop, and listened to the NBC Symphony with Toscanini, the New York Philharmonic, the Firestone Hour with Richard Crooks, the Metropolitan Opera, and, of course, KFAC's old Gas Company programs.

As teenagers, we went to the Hollywood Bowl, where we could hear great music without today's airplane noise and freeway traffic. And we sang in the Ascension Church choir in Sierra Madre. Dave's singing was not pretty, but he was accurate—and loud. Later, when my mother, Dave, Connie, and I sang in the Pasadena Community Chorus, I remember sitting between Hans Lehman, a German house painter, and Dave. I couldn't hear myself. Loud was fine for Beethoven's Ninth, but not good for the requiems of Fauré and Mozart. I remember Dr. Lert, the Pasadena Symphony conductor, telling us to stop bellowing.

But it was a great experience for us, and I'm sure contributed to Dave's stirring performances in Kent Clark's musicals.

Alan Wood
JPL public information specialist, retired

Anyone who knows Dave Wood knows that he was a joy to be around. Aside from all his technical accomplishments and his with-it grasp of the world we inhabit, he had a calm unthreatened optimism, a taste for exploration and adventure, and a great sense of fun. His laugh will echo in the memory of his friends like a favorite song. In the past few years we have all learned, the hard way, that Dave also had the courage of a lion—a cheerful resilience that would make Stoics like Marcus Aurelius sound like sniveling children.

"Nineteen hundred thirty-three and Long Beach rocked and rumbled." From left: Oliver, Knowles, Wood, and Corcoran brought down the house at the DuBridge farewell in a way no earthquake ever could.

But to me, the first images of Dave that leap to mind are of Dave the performer—the singer, actor, and invaluable member of the now-legendary Caltech Stock Company. Scenes from shows, rehearsals, cast parties, and special events will charm and comfort us for as long as we remember anything.

To understand this odd state of affairs it is necessary to understand two facts about Caltech. The first is that the Caltech faculty and staff and their spouses constitute a family. (It is not true, incidentally, that we are a family because no one else can stand us. We are a family because no one else can *understand* us in the depth that our fellow members do.) The second fact is that the Stock Company was a special subset of the Caltech family devoted to musical comedy, to honoring our great friends, and to explaining the family to itself.

Now the Caltech family takes a lot of explaining. It is, shall we say, different, if not systematically deranged, and the Stock Company over 20 years and some 10 shows never could explain it all, or exploit all the rich comedy intrinsic in it. But we tried. And for this—for performing musical comedy and understanding Caltech—Dave Wood had several great advantages.

First off, Dave could actually sing. After he and Connie joined us, we would never have dreamed of staging a show without them. Dave had some other virtues that he shared with his Stock Company friends. He had a fine sense of humor and great enthusiasm; he was reliable as a Swiss watch; and he was a quick study. (I should add that the Stock Company had the highest per-capita IQs in the history of show business).

Finally, and perhaps most important, was the fact that Dave was the genuine Caltech article. He had taken all three degrees here (which should get him a purple heart with two oak-leaf clusters), and he knew the Caltech faculty like a book. (I almost said "comic book.") When we recruited him, he had already earned his way into the Caltech family and become a connoisseur of Caltech characters. So when he sang about the Caltech scene, he sang as an authority.

I can't overemphasize this point—you don't become a *real* member of the Caltech family simply by showing up. You become a member by attrition and by years of shared experience. You know you have arrived when you quit saying "those flakes" and start saying "our flakes."

Anyway, the Caltech Stock Company existed for the purpose of reminding us that we *are* a family, that we're all in this weird enterprise together, and that we really wouldn't want to be anywhere else. For this reason, it was absolutely essential that key parts should be played by genuine Techers—the faculty and the marvelously talented students and staff we have co-opted over the years. I like to believe that the scripts are funny and the songs at least droll. But they would lose a whole dimension of comedy if they were not delivered by great family members like Ward Whaling, Dick Jahns, Ed Hutchings, Mu Harvey, Bill Corcoran, and Virginia Kotkin—to name a few.

Perhaps the most famous number that Dave and his cronies—this time Jim Knowles, Bill Corcoran, and Bob Oliver—ever performed was their 1969 rendition of "The Richter Scale" in a farewell show for Lee Dubridge. Dave's solo begins, "Nineteen hundred thirty-three and Long Beach rocked and rumbled." The show was recorded and that song has been played for years on records and tapes, even getting national airplay on *The Dr. Demento Show*. But unless you actually saw the performance on the Beckman stage and watched those clowns collapse you can never get the full effect. And, of course, you will never be truly happy.

The last formal full-length production of the Company was *Beautiful Beckman* in 1975, but ensembles and individuals gave many performances afterward for special occasions—even a couple of half-hour shows. One such occasion was the Athenaeum retirement party for Robert P. Sharp—a marvelous guy and deservedly a Caltech Icon. The song was called "C-Sharp." Dave and Connie sang it as a duet. They delivered it, of course, like the real pros that they are. Long after I have forgotten my own name, I will still hear them singing "C-Sharp."

The final episode I will indulge in was suggested to me the other day when Connie, with a pleased laugh, reminded me that Dave and Cynthia Corngold danced together in the Beckman show. The words were hardly out of her mouth when the whole scene came back in 3-D. I was standing in the wings, left front, where I could look across and see Elliott Davis and his musical group (which included Thad Vreeland's son, Mike, on the banjo and my son, Don, on the guitar). The number was called "A Nice Place Like This"—a reprise of "A Nice Girl Like You." The nice place referred, of course, to Beckman Auditorium—and by extension to Caltech. The ensemble had already sung the first chorus and was going into a dance that Fritzi Culick had choreographed. The dancers—Fritzi, Cynthia, Virginia, Jackie Knowles, and Betty Hanson; Dave, Dan Erickson, Gary Lorden, Dick Dean, and Jim—were a distillate of the Stock Company. The movements were elegant, to a melody line carried by the electric guitar. I was giddy with admiration.

With Connie's permission, that is where I will leave Dave: safe with his subfamily and his extended family, hearing and probably humming "A Nice Place Like This" (and it *is* a nice place), and dancing with Cynthia Corngold.

J. Kent Clark
professor of literature, emeritus
(delivered in absentia *by Robert Oliver, professor of economics, emeritus)*

Geophysicist Anderson Wins Crafoord

The Royal Swedish Academy of Sciences is to award the 1998 Crafoord Prize in geosciences, with special emphasis upon "the dynamics of the deeper parts of the Earth," to Don L. Anderson, the McMillan Professor of Geophysics, and Adam M. Dziewonski of Harvard University for their fundamental contributions to our knowledge of the structures and processes in Earth's interior. The prize, valued at $500,000, will be presented at a ceremony on September 16 in Sweden.

On hearing that he had been awarded the prize, Anderson said, "I think it's very significant that deep-Earth geophysics is being honored by this award. It is rare for our field to be acknowledged in this way. I am really delighted that Adam Dziewonski, a close colleague of mine, is also being honored for his work. Most people, when they think of geophysics, think of earthquakes, but seismologists do other things, such as x-raying Earth using seismic tomography to see what is going on in the deep Earth."

Caltech president David Baltimore congratulated Professor Anderson and noted that "the Institute is very proud and pleased that Don will be receiving the Crafoord. It is exciting news. Don's work is truly deserving of this great prize. He is one of the world's most prominent scientists in the area."

According to the Royal Academy, Anderson and Dziewonski have together developed a generally accepted standard model of how Earth is organized and of the dynamics of the processes at its core and in its mantle that govern continental drift, volcanism, and earthquakes.

Anderson and his team have investigated changes arising from the pressure deep down in Earth's mantle. Sudden changes in the rock types at depths of 400 kilometers and 660 kilometers are explained by conversions undergone by the rock types, so that they contain minerals entirely unknown at Earth's surface. At 400 kilometers, the mineral olivine, common in lava, changes to spinel, a high-pressure mineral. At 660 kilometers, the mineral perovskite is formed, a mineral otherwise only produced in the laboratory at very high pressures and temperatures. Anderson's research has shown that such changes in composition of the mantle may explain the occurrence of tensions in Earth's crust that can lead to earthquakes.

Anderson and his research team have also used seismic data to study convection currents in the mantle, important for understanding continental drift and volcanism. Recently, Anderson has also used geochemical and chemical-isotope methods not only for mapping Earth's development, but also for understanding the development of the moon, Mars, and Venus.

Anderson was born in 1933 in Maryland and received his doctorate in geophysics from Caltech in 1962. He has been a leading figure in "deep-Earth" research since the 1960s. He was director of the Seismological Laboratory at Caltech from 1967 to 1989. In 1989 he published his *Theory of the Earth*, a remarkable synthesis of his broad and provocative research and a guide for geo-researchers from different fields for future exploration of the dynamics of the deep parts of Earth.

The Crafoord Prize is awarded at a ceremony held on September 16, Crafoord Day. On this occasion, the prizewinner gives a public lecture and the Royal Academy organizes an international scientific symposium on a subject from the chosen discipline of the year.

The Anna-Greta and Holger Crafoord Fund was established in 1980 to promote basic research in mathematics, astronomy, the biosciences (particularly ecology), the geosciences, and polyarthritis. Both an international prize and research grants to Swedish scientists are awarded among the scientific fields mentioned above. □—*RT*

Honors and Awards

Michael Alvarez, associate professor of political science, has, along with coauthor Jonathan Nagler, been selected by the Midwest Political Science Association to receive the 1998 Robert H. Durr Award for their paper, "A New Approach for Modeling Strategic Voting in Multiparty Systems." The award is for the best paper applying quantitative methods to a substantive problem in political science.

Michael Brown, assistant professor of planetary astronomy, has been awarded an Alfred P. Sloan Research Fellowship. Sloan recipients are selected on an extraordinarily competitive basis from a group of nominees representing the very best of young scientists.

Peter Dervan, the Bren Professor of Chemistry, and chair of the Division of Chemistry and Chemical Engineering, and Caltech Trustee David Ho (BS '74), director of the Aaron Diamond AIDS Research Center in New York City, have been elected to membership in the Institute of Medicine of the National Academy of Sciences. The Institute is a unit of the National Academy but with separate membership; it is based in the biomedical sciences and health professions.

Richard Flagan, professor of and executive officer for chemical engineering, has been awarded the Thomas Baron Award in Fluid-Particle Systems by the American Institute of Chemical Engineers.

Daniel Kevles, the J.O. and Juliette Koepfli Professor of the Humanities, has been elected a fellow of the Society of American Historians, in recognition of the literary and scholarly distinction of his historical work.

Rod Kiewiet, professor of political science, has been awarded a 1998 Haynes Foundation Faculty Fellowship for his proposal, "Educational Finance in California in Comparative Perspective."

Wolfgang Knauss (BS '58, MS '59, PhD '63), professor of aeronautics and applied mechanics, has been awarded the Kapitsa Medal by the Russian Academy of Natural Sciences. He was honored for his contribution to understanding the time-dependent mechanical behavior of polymers and composites.

Michael Ortiz, professor of aeronautics and applied mechanics, has been elected a fellow of the U.S. Association of Computational Mechanics for his contributions to the field of computational mechanics.

Anatol Roshko (MS '47, PhD '52), the Theodore von Kármán Professor of Aeronautics, Emeritus, is the recipient of the 1998 AIAA Fluid Dynamics Award, presented by the American Institute of Aeronautics and Astronautics "for outstanding contributions to the understanding of the behavior of liquids and gases in motion as related to needs in aeronautics and astronautics." Roshko is internationally known for his research in areas vital to aerospace engineering, vehicle aerodynamics, and wind and ocean engineering.

Thayer Scudder, professor of anthropology, has been appointed to the World Commission on Dams, which is being organized by the World Conservation Union and the World Bank to review the costs and benefits of large dams throughout the world. Scudder is an authority on resettlement and social issues related to river-basin infrastructure development.

Thomas Tombrello, the William R. Kenan, Jr., Professor and professor of physics, and a graduate of Rice University, has been selected by the Association of Rice Alumni to receive one of its 1998 Distinguished Alumni Awards, awarded on May 9 in Houston. The award is the highest honor bestowed by the association for "excellence in one's chosen field."

Alexander Varshavsky, the Smits Professor of Cell Biology, has received the 1998 Novartis-Drew Award in Biomedical Science, for his work on "the ubiquitin system and intracellular protein degradation."

Gerald Wasserburg, Crafoord laureate and the John D. MacArthur Professor of Geology and Geophysics, will receive the title of Docteur Honoris Causa from Rennes 1 University, France, at an official ceremony on June 30.

Professor of Aeronautics and Applied Mechanics Wolfgang Knauss (BS '58, MS '59, PhD '63) and Robert McEliece (BS '64, PhD '67), the Puckett Professor and professor of electrical engineering, have been elected to the National Academy of Engineering.

Ahmed Zewail, Pauling Professor of Chemical Physics and professor of physics, is the recipient of the Southern California section of the American Chemical Society's 1997 Richard C. Tolman Medal for his pioneering work in femtochemistry. □

Structural Support

As one of the pioneers in earthquake engineering, George Housner, Caltech's Carl F Braun Professor of Engineering, Emeritus, spent almost his entire career at the Institute conducting research that had an enormous impact in advancing earthquake safety. Housner says that his successful career, which began in 1945 at Caltech—from which he received his MS and PhD degrees—would not have been possible anywhere else because of the Institute's commitment to research.

After Housner became an emeritus professor in 1982, he began considering ways to repay the Institute. In December 1992, he established a charitable remainder trust with Caltech that will provide the Institute with a sizable gift once he dies.

"I'm essentially repaying Caltech for the many years it provided a base for my research," says Housner, who received the National Medal of Science, the nation's highest scientific honor, from President Reagan in 1988. "I have a great loyalty to Caltech, beginning when I was a student in the 1930s."

Housner's charitable trust was established with stock that he had acquired over the years and that had greatly appreciated. The trust enabled him to avoid the capital gains taxes that would have resulted had he sold the stock, and thus allowed him to make a bigger gift to the Institute. By establishing the charitable trust, Housner received a large charitable deduction on his income taxes, and also gets quarterly payments, which, over the course of a year, total 5 percent of the net fair market value of the assets in the trust.

But Housner, who is single, says that the real reason he established the trust was to benefit Caltech and its earthquake engineering group. Housner has stipulated that when he dies, income from the trust will be used to fund Caltech's Earthquake Engineering Research Laboratory for seven years, after which time the gift becomes unrestricted.

"It's appropriate that the Institute and the Division of Engineering and Applied Science, which appointed me professor, should benefit from this gift," says Housner, frequently referred to as the father of earthquake engineering for his contribution to the design of earthquake-resistant structures. "I owe a lot to the school for my education, which had an important influence on my development. From the beginning, Caltech was a very good environment for doing research, and I appreciate that very much."

Housner also showed his appreciation last December, when he gave a substantial amount of stock to Caltech that will fund the George W. Housner Earthquake Engineering Research Fund to assist and supplement the research activities of the earthquake engineering group at Caltech.

"In the future, Caltech has a special role to play in science and engineering," Housner says. "I want to help that continue."

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